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The Effect of Tropical Storm Agnes as Reflected in Chlorophyll A and Heterotrophic Potential of the Lower Chesapeake Bay

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The Effects of Tropical Storm Agnes on the Chesapeake Bay Estuarine System

The Chesapeake Research Consortium, Inc.

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THE CHESAPEAKE RESEARCH CONSORTIUM, INC.

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Preface

During June 1972 Tropical Storm Agnes released record amounts of rainfall on the watersheds of most of the major tributaries of Chesapeake Bay. The resulting floods, categorized as a once-in-100-to-200-year occurrence, caused perturbations of the environment in Chesapeake Bay, the nation's greatest estuary.

This volume is an attempt to bring together analyses of the effects of this exceptional natural event on the hydrology, geology, water quality, and biology of Chesapeake Bay and to consider the impact of these effects on the economy of the Tidewater Region and on public health.

It is to be hoped that these analyses of the event will usefully serve government agencies and private sectors of society in their planning and evaluation of measures to cope with and ameliorate damage from estuarine flooding. It is also to be hoped that the scientific and technical sectors of society will gain a better understanding of the fundamental nature of the myriad and interrelated phenomena that is the Chesapeake Bay ecosystem. Presumably much of what was learned about Chesapeake Bay will be applicable to estuarine systems elsewhere in the world. Most of the papers comprising this volume were presented at a symposium held May 6-7, 1974, at College Park, Maryland, under the sponsorship of the Chesapeake Research Consortium,Inc., with support from the Baltimore District, U.S. Army Corps of Engineers (Contract No. DACW 31-73-C-0189). An early and necessarily incomplete assessment, *The Effects of Hurricane Agnes on the Environment and Organisms of Chesapeake Bay* was prepared by personnel from the Chesapeake Bay Institute (CBI), the Chesapeake Biological Laboratory (CBL), and the Virginia Institute of Marine Science (VIMS) for the Philadelphia District, U.S. Army Corps of Engineers. Most of the scientists who contributed to the early report conducted further analyses and wrote papers forming a part of this report on the effects of Agnes. Additional contributions have been prepared by other scientists, most notably in the fields of biological effects and economics.

The report represents an attempt to bring together all data, no matter how fragmentary, relating to the topic. The authors are to be congratulated for the generally high quality of their work. Those who might question, in parts of the purse, the fineness of the silk must keep in mind the nature of the sow's ears from which it was spun. This is not to disparage the effort, but only to recognize that the data were collected under circumstances which at best were less than ideal. When the flood waters surged into the Bay there was no time for painstaking experimental design. There were not enough instruments to take as many measurements as the investigators would have desired. There were not enough containers to obtain the needed samples or enough reagents to analyze them. There were not enough technicians and clerks to collect and tabulate the data. While the days seemed far too short to accomplish the job at hand, they undoubtedly seemed far too long to the beleaguered field parties, vessel crews, laboratory technicians, and scientists who worked double shifts regularly and around the clock on many occasions. To these dedicated men and women, whose quality of performance and perseverance under trying circumstances were outstanding, society owes an especial debt of gratitude.

It should be noted that the Chesapeake Bay Institute, the Chesapeake Biological Laboratory, and the Virginia Institute of Marine Science, the three major laboratories doing research on Chesapeake Bay, undertook extensive data-gathering programs, requiring sizable commitments of personnel and equipment, without assurance that financial support would be provided. The emergency existed, and the scientists recognized both an obligation to assist in ameliorating its destructive effects and a rare scientific opportunity to better understand the ecosystem. They proceeded to organize a coordinated program in the hope that financial arrangements could be worked out later. Fortunately, their hopes proved well founded. Financial and logistic assistance was provided by a large number of agencies that recognized the seriousness and uniqueness of the Agnes phenomenon. A list of those who aided is appended. Their support is gratefully acknowledged.

This document consists of a series of detailed technical reports preceded by a summary. The summary emphasizes effects having social or economic impact. The authors of each of the technical reports are indicated. To these scientists, the editors extend thanks and commendations for their painstaking work.

Several members of the staff of the Baltimore District, U.S. Army Corps of Engineers, worked with the editors on this contract. We gratefully acknowledge the helpful assistance of Mr. Noel E. Beegle, Chief, Study Coordination and Evaluation Section, who served as Study Manager; Dr. James H. McKay, Chief, Technical Studies and Data Development Section; and Mr. Alfred E. Robinson, Jr., Chief of the Chesapeake Bay Study Group.

The editors are also grateful to Vickie Krahn for typing the Technical Reports and to Alice Lee Tillage and Barbara Crewe for typing the Summary.

The Summary was compiled from summaries of each section prepared by the section editors. I fear that it is too much to hope that, in my attempts to distill the voluminous, detailed, and well-prepared papers and section summaries, I have not distorted meanings, excluded useful information or overextended conclusions. For whatever shortcomings and inaccuracies that exist in the Summary, I offer my apologies.

Jackson Davis
Project Coordinator

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THE EFFECT OF TROPICAL STORM AGNES AS REFLECTED IN CHLOROPHYLL A AND HETEROTROPHIC POTENTIAL OF THE LOWER CHESAPEAKE BAY[1]

Paul L. Zubkoff[2]
J. Ernest Warinner, III[2]

ABSTRACT

A hydrographic station (Station Y) at the mouth of the York River (37°14.6'N, 76°23.4'W) was under biological surveillance for one year prior to the arrival of Tropical Storm Agnes. For one full year following this storm, these measurements were continued. In addition, the chlorophyll a and heterotrophic potential measurements were incorporated into an ongoing zooplankton sampling program of the lower Chesapeake Bay below 37°40'N latitude.

In the sub-surface waters (0.5-1.0 meter below the surface) at Station Y, chlorophyll a distributions for the year (June 1971 to June 1972) varied seasonally between 4 and 20 μg chlorophyll a l^{-1}. Within 4 weeks following Agnes, a maximum of 22 μg chlorophyll a l^{-1} was reached, which dropped to a minimum of 6 μg chlorophyll a l^{-1}in November 1972. In lower Chesapeake Bay, post-Agnes chlorophyll a distributions were greater than 6-8 μg^{-1} at the lower limit; the upper limit for the post-Agnes summers (1972 and 1973) was considerably greater than 20 μg l^{-1} pre-Agnes maximum at Station Y.

The heterotrophic potential (μg glucose $l^{-1}h^{-1}$) reflects the activity of microorganisms capable of growth and reproduction when dissolved organic matter is available. In the two-year Station Y study, the heterotrophic potentials fell into 4 ranges: low 0.04-0.25; moderate 0.26-0.82; high 0.83-1.70; and very high 1.70-3.00. In the immediate post-Agnes period (July-August 1972) the heterotrophic potential for approximately one-half of the Lower Bay stations was moderate (0.26-0.82), whereas the other half was very high (1.7-3.0).

INTRODUCTION

The York River, a mesohaline estuary in southeastern Virginia with a sizeable fishing industry, has, until recent times, been little influenced by industrial and municipal development. Because populations in the immediate vicinity are increasing rapidly, the York River will undoubtedly become impacted by human endeavors. In order to provide a stronger reference base for helping management agencies to make informed judgements with respect to the lower York River ecosystem, an investigation into the producer trophic levels was initiated in the summer of 1971. Specific objectives of this project included the development of techniques for the measurement of the autotrophic (photosynthesizing) and heterotrophic (microbial) communities and the testing of these techniques at a hydrographic station at the mouth of the York River (Station Y, 37°14.6'N, 76°23.4'W; Fig. 1). In addition, the selected techniques were to be amenable to the processing of large numbers of samples with a time for analysis less than that more commonly employed in ecological studies (Patten, Mulford, & Warinner 1963; Mackiernan 1968; Manzi 1973; Stofan 1973).

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When Agnes passed through the Chesapeake Bay drainage basin, a zooplankton investigation using a stratified sampling regime for the entire lower Chesapeake Bay was underway (Grant, et al. this volume). Subsequently, these projects were coordinated in order to better assess the effects of the massive freshwater input on the distributions of plankton in the lower Chesapeake Bay and more effectively utilize limited personnel and vessel availability. There were no published synoptic measurements for chlorophyll a and heterotrophic potential for the lower Chesapeake Bay; therefore these measurements were continued for one full year after the occurrence of the tropical storm in order to assess the aftermath of the perturbation.

Nineteen Station Y and 276 lower Chesapeake Bay (Lower Bay) hydrographic stations were sampled in the year following the passage of Agnes. Although several hydrographic and biological observations were made, this report summarizes only the chlorophyll a and heterotrophic potential in the surface waters.

SAMPLING AND METHODS

Six sub-strata, A-F, in lower Chesapeake Bay were selected according to morphometry of the region, predominating salinity regimes, and major circulation patterns (Grant 1972). Sub-strata A and D are predominantly shallow areas of lower salinity waters; sub-strata C and E are deep channel areas of intermediate salinities; and sub-strata B and F are higher salinity waters (Stroup & Lynn 1963). Station Y, located in the channel of the York River, is approximately 20 meters deep. Stations for the Lower Bay were sampled at monthly intervals before and after Agnes, with three additional sampling cruises during the weeks following the storm (Grant, et al. this vol.). Although samples were routinely obtained by either a Van Dorn bottle or submersible pump for sub-surface (0.5-1.0 meter), intermediate, and bottom depths, only the measurements obtained for the sub-surface waters are reported herein.

Chlorophyll a, determined either spectrophotometrically or fluorimetrically (Biological Methods Panel on Oceanography 1969) serves as a first order approximation of the standing crop of phytoplankton. As with any single chemical measurement of biomass, chlorophyll a does not reveal species identification, enumeration, nor does it reflect the state of viability of the organisms. However, chlorophyll a is a useful approximation, within limits, of algal biomass.

The heterotrophic potential (V_{max}) is a kinetic parameter which estimates the potential activity of the microbial populations (heterotrophic microorganisms) and is useful for spatial and temporal comparisons of the relative microbial populations of an aquatic ecosystem (Wright & Hobbie 1966; Williams 1973).

The heterotrophic potential of the estuarine plankton community is measured by the uptake of simple ^{14}C-labeled dissolved organic substrates added to natural water samples. When varying concentrations of substrate are employed, the response to an increase in substrate concentration resembles that of an enzyme-catalyzed reaction. As the concentration of a substrate such as glucose is increased, there is initially a linear increase in the rate of uptake by the heterotrophic organisms at low substrate concentration; at higher substrate concentrations, the rate of uptake reaches a maximum.

The rate of uptake of the substrate at any given concentration is calculated using the pseudo-first order equation of enzyme kinetics (Parsons & Strickland 1962):

$$v = \frac{c(Sn + Sa)}{C\mu t}$$

where

v = velocity of uptake of the substrate ($\mu g\ l^{-1}h^{-1}$)
c = counts taken up by heterotrophic population
Sn = natural substrate concentration
Sa = added substrate concentration
C = number of counts per µCi of substrate
μ = number of µCi added to incubation medium
t = time of incubation (hours)

When this equation is combined with a modified form of the Michaelis-Menten equation:

$$\frac{(Sn + Sa)}{v} = \frac{K_t}{V_{max}} + \frac{(Sn + Sa)}{V_{max}}$$, where

K_t = transport constant
V_{max} = maximum velocity of uptake at substrate saturation

the resulting equation is:

$$\frac{C\mu t}{c} \text{ or } \frac{(Sn + Sa)}{v} = \frac{(K_t + Sn)}{V_{max}} + \frac{1}{V_{max}}(Sa)$$

When $C\mu t/c$ is plotted against Sa, the result is a straight line with slope equal to $1/V_{max}$. The value of V_{max} has the units of µg glucose $l^{-1}h^{-1}$. Although several kinetic parameters may be calculated, V_{max} is the most useful one for describing the relative functional microbial activity in this study.

The kinetic data obtained are undoubtedly the result of heterogeneous assemblages of organisms which have active transport systems (Williams 1973). V_{max} is the rate of uptake observed at a substrate concentration high enough to completely saturate the transport mechanisms of the natural microbial populations under the experimental conditions (Vaccaro & Jannasch 1966). In these studies, V_{max}, *glucose* is interpreted as an indicator which reflects the activity of the viable natural population of microbial organisms at the time of sampling; it is an experimentally measured number which is a resultant of the endemic community's cell size, number, and state of viability as a function of temperature.

The V_{max}, *glucose* was determined by incubating 10 ml aliquots of an estuarine water sample with labeled ^{14}C-glucose and carrier at final concentrations of 37.5, 75.0, 187.5 and 375 µg l^{-1} in the dark at ambient temperature for two hours. Approximately 0.1 ml of 2% neutralized formalin was added for the inactivated control sample and to terminate the reaction. The ^{14}C-labeled particulate fraction was then collected on cellulose-acetate filters (Millipore^R EH, 0.5µ), treated with NCS^R tissue solubilizer, and dissolved in a toluene-based scintillation fluid containing 2,5-diphenyloxazole. Counting was completed at 87-95% efficiency using a liquid scintillation counter with external standardization. The calculation of V_{max}, *glucose* using linear regression analysis has an r value of 0.85 or greater for at least three of the four concentrations of substrate used.

Since no provision was made to trap and measure the respired CO_2 from the assimilated ^{14}C-glucose, the calculated V_{max}, *glucose* values represent only that portion of labeled substrate transformed into particulate form, and is therefore, a minimum estimate of the functional microbial community (Wright 1973).

RESULTS

Hydrography

After the passage of Agnes, the measured sub-surface salinity at the mouth of the York River ranged from 10.28-21.82 ppt (Table 1, Fig. 2). The seasonably low salinity of the sub-surface waters of May-June 1972 were below those of 1971, a result of the unusually high freshwater discharge into the York River from its drainage basin during the spring of 1972 (Fig. 3). Discharge was estimated by summing the discharge data obtained from the U. S. Geological Survey for the Mattaponi and Pamunkey Rivers and adjusting for drainage area below the gauging stations.

Chlorophyll a

In the year prior to the passage of Agnes, chlorophyll a at the mouth of the York River ranged from 4.3-20.0 µg l^{-1} (mean = 8.80, s.d. = 3.71, n= 27, Table 1), with isolated low values in the winter. Highest values occurred in late spring and summer, periods of high insolation and temperature. In 1972, prior to Agnes, all values measured were generally low, between 5.0 and 13.0 $µg^{-1}$, including the commonly recognized "spring pulse" (maximum) in May. However, three to four weeks following Agnes, a maximum at 24.5 $µg^{-1}$ chlorophyll a was observed, with a peak of 27.9 µg l^{-1} in August (Fig. 4A).

For the year following Agnes, chlorophyll a at the mouth of the York River ranged from 5.7-24.6 µg l^{-1} (mean = 14.26,s.d. = 5.60, n = 18). Chlorophyll a reached a low observed value of 6 µg l^{-1} during the late fall (November), with generally higher values throughout winter and spring of 1973 in comparison to 1972. The chlorophyll a concentrations for the summer of 1973 were approximately the same as those for the post-Agnes period of 1972. It appears that for a period after Agnes, the values were generally higher than for the year before. It should be noted, however, that climatological parameters of 1971, 1972, and 1973 were quite different, springs of 1971 and 1972 being relatively "wet" and the summers of 1971 and 1973 being relatively "dry".

The chlorophyll a measurements for the lower Chesapeake Bay sub-strata A-F (Tables 2A, 2B, and 2C) are plotted according to monthly sampling periods and are presented in Fig. 4B. Most values are greater than 6-8 µg l^{-1} at the lower limit (in comparison to 4-6 µg l^{-1} for the York River Mouth prior to Agnes). The upper limits for the post-Agnes summers of 1972 (A = 19.67, B = 30.13, C = 15.43, D = 38.23, E = 24.53 and F = 23.80) and 1973 (A = 16.87, B = 11.23, C = 7.97, D = 28.63, E = 18.73, and F = 14.20) are considerably greater than the 20.0 µg l^{-1} 1971 maximum for the mouth of the York River.

In Fig. 4C, the approximate range of values (within 2 standard deviations of the mean), obtained by grouping the entire Lower Bay values for a sampling period, is superimposed on those values for the mouth of the York River reported for the same sampling period. It should be noted that most of the values, both for the Lower Bay and Station Y, are in the same range.

When the post-Agnes chlorophyll a measurements are compared with those of the previous year (Fig. 4D), it is noted that the 1972 values far exceed those for the pre-Agnes period (cross-hatched area) whereas the summer values for 1972 and 1973 (both post-Agnes) are quite similar.

Table 1. Selected parameters for the surface waters at the York River Mouth (August 1971 - August 1973).

Date	Salinity (ppt)	Temperature (^oC)	Chlorophyll <u>a</u> $\mu g\ l^{-1}$	V_{max} $\mu g\ G\ l^{-1} h^{-1}$
5 May 1971	17.34	16.0	7.1	-
19	17.67	20.3	7.8	-
4 June	14.68	23.5	20.0	-
12	15.27	24.5	14.8	-
18	16.77	23.5	8.6	-
23	15.74	25.5	9.5	-
2 July	16.47	26.5	11.9	-
9	17.27	27.0	10.5	-
20	19.21	27.0	-	-
4 Aug	-	28.0	5.1	2.90
10	21.30	26.2	11.0	1.39
17	-	26.0	7.1	-
25	20.79	25.5	10.0	0.54
1 Sept	19.70	25.0	9.2	0.48
8	19.72	27.0	5.1	0.97
17	20.29	26.0	11.7	1.00
23	20.82	24.0	13.2	0.21
8 Oct	19.24	20.7	7.0	0.30
13	18.84	-	7.3	0.35
22	19.13	20.5	3.9	0.38
13 Nov	17.62	15.0	4.4	0.28
7 Dec	18.31	10.0	5.2	0.10
24 Jan 1972	18.84	11.5	7.5	0.08
16 Feb	19.64	6.0	10.0	0.21
10 Mar	15.57	7.0	6.7	0.41
4 Apr	16.07	11.0	12.9	0.46
2 May	15.14	18.0	5.9	1.03
6 June	13.83	18.5	4.3	1.69
15	15.81	20.4	-	-
21-22		TROPICAL STORM AGNES		
26	-	23.0	7.0	0.67
27	10.28	22.9	-	-
28	-	24.5	15.8	1.38
6 July	11.67	23.0	7.9	0.68
13	11.93	24.5	11.8	0.81
27	-	26.7	21.6	2.44
8 Aug	11.83	27.9	21.6	2.30
21	15.17	26.5	16.8	2.46
14 Sept	17.20	24.2	12.9	0.75
13 Oct	17.43	18.4	9.3	0.38
16 Nov	-	12.5	5.7	0.15
11 Dec	17.75	9.4	-	-
12 Jan 1973	-	-	9.5	0.04
13 Feb	12.62	-	13.8	-
19 Mar	17.69	8.3	13.8	0.63
16 Apr	14.77	11.0	17.0	0.69
14 May	15.90	18.9	14.3	0.89
25 June	16.69	24.9	10.8	0.63
23 July	19.66	26.1	24.6	1.87
13 Aug	21.82	26.7	22.5	-

Table 2A. Selected hydrographic parameters for the western sub-surface waters (Lower Chesapeake Bay). Cruise mean values and standard deviation.

	Sub-Stratum A					Sub-Stratum D				
1972	S ppt	T °C	Chl. a µg G l^{-1}	*Vmax* µg G $l^{-1}h^{-1}$	n	S ppt	T °C	Chl. a µg l^{-1}	*Vmax* µg G $l^{-1}h^{-1}$	n
June	13.50	22.37	15.60[3]	0.75	3	12.87	22.70	12.60[1]	1.01	2
29-30	1.35	0.21	1.97	0.06		0.26	0.14	0.85	0.06	
July	16.11	21.40	10.37	0.52	3	10.59	23.05	14.25[2]	0.86	2
6-7	0.89	0.44	0.40	0.10		0.50	0.35	3.61	0.03	
July	14.24	23.67	9.30[2]	0.73	3	12.11	23.25	11.05[1]	1.13	2
13-14	0.81	0.35	0.14	0.16		0.01	0.07	0.07	0.13	
July	16.77	27.07	14.60[2]	1.37	3	9.28	28.73	17.00[3]	2.02	3
24-27	1.51	0.46	10.83	0.27		1.33	0.06	2.19	0.19	
Aug.	18.43	24.60	9.70	0.27	2	14.82	25.87	38.23[3]	1.27	3
15-21	1.75	1.40	*	*		0.74	0.06	13.61	0.31	
Sept.	17.34	23.10	19.67[2]	0.71	3	17.15	23.37	14.03[1]	0.61	3
12-14	0.29	0.10	2.19	0.51		0.84	0.81	2.11	0.10	
Oct.	21.92	17.23	9.13	0.69	3	19.47	17.20	8.63	0.28	3
16-24	1.00	0.21	0.90	0.22		0.15	0.30	1.37	0.23	
Nov.	21.75	14.43	9.27	0.20	3	19.16	12.60	6.73	0.65	3
13-16	0.50	0.25	4.97	0.05		0.36	1.18	1.01	0.41	
Dec.	19.35	9.53	8.67	0.19	3	17.98	8.65	10.20	0.43	2
11-13	0.25	0.35	2.48	0.09		0.06	0.07	2.12	0.13	
1973										
Jan.	19.42	7.27	5.50	0.63	3	15.25	6.53	7.20	-	3
3-4	4.59	0.31	0.36	0.05		0.28	0.23	1.20		
Feb.	14.80	3.20	9.27	0.33	3	13.97	2.97	10.90	-	3
13-14	0.93	0.40	2.11	*		0.66	0.23	1.39		
March	20.58	8.13	10.80	0.67	3	17.65	7.77	10.83	-	3
19-20	1.36	0.21	2.31	*		0.89	0.25	5.47		
April	17.48	11.20	9.50	0.80	3	16.49	11.40	13.53	-	3
16-17	0.91	0.56	3.21	*		0.15	0.44	7.09		
May	19.58	17.40	10.00	0.75	3	15.85	18.40	12.93	1.12	3
14-16	2.14	0.36	1.56	*		0.31	0.36	0.85	*	
June	17.01	25.07	8.33	0.66	3	15.54	25.17	10.93	0.80	3
25-27	1.13	0.25	0.64	*		0.25	0.38	3.54	*	
July	23.58	23.83	7.75	0.32	3	18.50	25.80	28.63[2]	1.59	3
23-24	0.96	0.49	0.49	*		2.26	0.20	8.29	*	
Aug.	23.60	26.97	16.87[1]	1.14	3	21.01	26.60	25.53[3]	1.56	3
13-14	1.25	1.93	10.21	*		1.22	0.14	2.17	*	

Lower number in each pair is standard deviation

- = no data taken

* = single value used

[1] [2] [3] = number of plankton blooms observed at stations.

Table 2B. Selected hydrographic parameters for the mid-channel sub-surface waters (Lower Chesapeake Bay). Cruise mean values and standard deviation.

	Sub-Stratum C					Sub-Stratum E				
1972	S ppt	T ^oC	Chl. a µg l^{-1}	V_{max} µg G $l^{-1}h^{-1}$	n	S ppt	T ^oC	Chl. a µg l^{-1}	V_{max} µg G $l^{-1}h^{-1}$	n
June	15.51	22.45	12.15	0.58	2	11.92	22.7	6.4	0.68	1
29-30	1.89	1.34	2.19	0.11		*	*	*	*	
July	13.85	21.10	9.30	1.00	1	11.10	22.1	16.3^1	0.63	1
6-7	*	*	*	*		*	*	*	*	
July	16.84	23.40	9.30	0.80	2	11.88	24.40	13.65	0.99	2
13-14	4.20	0.85	0.42	0.21		0.07	1.27	0.78	0.06	
July	16.07	26.53	12.43	1.64	3	8.46	29.23	15.97^2	3.30	3
24-27	1.14	1.31	2.15	0.80		1.95	2.01	4.27	2.84	
Aug.	19.34	24.23	15.43^1	0.98	3	14.87	25.53	24.53^3	2.50	3
15-21	2.43	1.55	15.12	0.81		0.66	0.40	4.51	*	
Sept.	17.79	22.90	14.90	2.26	3	16.17	23.87	14.20^3	1.09	3
12-14	0.94	0.00	3.24	2.52		0.51	1.01	1.22	1.00	
Oct.	21.10	17.15	7.15	0.49	2	18.42	16.60	9.80	0.50	3
16-24	0.12	0.07	2.19	0.01		1.92	0.95	0.69	0.12	
Nov.	23.82	14.47	7.50	0.20	3	20.09	12.73	7.33	0.26	3
13-16	2.28	0.15	0.95	0.03		0.70	0.42	0.42	0.12	
Dec.	19.48	8.70	9.20	0.17	3	17.95	9.07	8.30	0.21	3
11-13	0.81	0.35	1.87	0.04		0.76	0.29	1.08	0.00	
1973										
Jan.	23.97	7.65	4.40	-	2	17.12	6.57	5.60	-	3
3-4	0.87	0.07	0.42			2.21	0.25	0.53	-	
Feb.	15.98	2.97	9.37	-	3	13.97	3.60	9.00	-	3
13-14	1.35	0.15	1.55			1.00	0.56	4.46	-	
March	24.09	7.67	14.80	0.18	3	16.35	7.80	8.43	0.36	3
19-20	0.80	0.06	6.85	*		0.78	0.17	1.30	*	
April	21.15	11.40	3.33	-	3	16.36	11.00	13.13	0.63	3
16-17	2.98	0.72	0.45			1.27	0.46	6.01	*	
May	20.77	17.33	7.90	0.68	3	16.67	17.90	12.30	0.91	3
14-16	2.12	0.25	1.01	*		0.62	0.17	2.19	*	
June	18.98	24.10	4.90	-	3	15.42	25.37	9.03	0.61	3
25-27	1.85	0.98	0.60			0.47	0.31	2.30	*	
July	25.97	23.47	6.87	0.16	3	19.09	25.80	18.73	1.56	3
23-24	1.19	0.83	3.17	*		1.55	0.36	0.42	*	
Aug.	27.92	24.03	7.97	0.66	3	21.54	26.70	17.40	1.43	3
13-14	5.20	1.19	3.41	*		2.57	0.28	0.52	*	

Lower number in each pair is standard deviation

\- = no data taken

* = single value used

$^{1\ 2\ 3}$ = number of plankton blooms observed at stations

Table 2C. Selected hydrographic parameters for the eastern sub-surface waters (Lower Chesapeake Bay). Cruise mean values and standard deviation.

	Sub-Stratum B					Sub-Stratum F				
1972	S ppt	T °C	Chl. a µg l^{-1}	V_{max} µg G $l^{-1}h^{-1}$	n	S ppt	T °C	chl. a µg l^{-1}	V_{max} µg G $l^{-1}h^{-1}$	n
June	15.90	22.30	10.60	1.08	2	13.17	22.85	8.70	1.05	2
29-30	1.54	0.28	2.40	0.21		1.87	0.92	1.13	0.78	
July	15.43	21.35	8.35^1	2.91	2	12.92	21.85	23.80^1	1.03	2
6-7	4.42	0.35	3.61	2.46		1.17	0.21	4.10	0.10	
July	17.58	24.03	12.73^3	0.87	3	14.92	23.20	8.75	1.00	2
13-14	5.11	1.86	5.78	0.22		2.54	0.14	2.05	0.04	
July	14.80	25.60	11.90	-	1	9.31	28.80	12.00	2.16	3
24-27	*	*	*	-		1.73	1.06	1.56	1.05	
Aug.	19.40	23.77	30.13^2	0.90	3	14.25	24.17	16.60	1.45	3
15-21	3.00	0.21	31.09	0.15		0.39	0.98	2.01	0.33	
Sept.	19.74	23.20	13.43^3	0.67	3	16.60	24.03	12.17	1.44	3
12-14	1.28	0.10	0.47	0.25		0.49	0.21	1.76	*	
Oct.	-	-	-	-	0	18.33	15.90	9.5	0.67	1
16-24	-	-	-	-		*	*	*	*	
Nov.	22.83	13.53	8.07^1	0.22	3	21.20	12.40	6.50	0.20	3
13-16	2.78	0.95	1.44	0.04		0.64	0.20	0.00	0.13	
Dec.	20.05	9.40	8.40	0.18	3	17.71	9.60	9.33	0.24	3
11-13	1.18	0.46	0.95	0.05		0.33	0.26	0.81	0.04	
1973										
Jan.	21.60	7.33	7.10	-	3	16.69	7.27	10.93	-	3
3-4	2.05	0.38	1.04			0.18	0.12	3.07		
Feb.	18.30	3.60	8.30	-	3	17.18	3.27	12.17	-	3
13-14	3.16	0.78	2.69			2.24	0.12	1.42		
March	20.37	7.87	11.20	-	3	17.19	7.67	14.97	-	3
19-20	0.86	0.21	0.89			1.33	0.12	2.75		
April	21.92	11.37	5.03	-	3	17.27	11.30	7.47	0.67	3
16-17	1.68	0.25	2.41			0.54	0.26	2.18	*	
May	21.71	17.33	11.23	0.98	3	18.41	17.47	11.50	0.46	3
14-16	6.49	0.60	7.44	*		1.38	0.32	1.25	*	
June	18.34	24.83	6.50	1.01	3	16.29	24.63	11.07	0.98	3
25-27	0.90	0.21	4.59	*		4.58	0.51	3.42	*	
July	26.67	23.33	8.80	0.50	3	21.02	25.25	14.10	0.23	2
23-24	0.90	0.57	1.15	*		0.04	0.07	*	*	
Aug.	23.43	23.10	8.77	0.48	3	24.06	-	14.20	-	2
13-14	1.63	5.09	2.56	*		2.18	-	1.41	-	

Lower number in each pair is standard deviation
- = no data taken
* = single value used
$^{1\ 2\ 3}$ = number of plankton blooms observed at stations.

It is apparent that approximately 68% of the Lower Bay stations sampled had very high chlorophyll *a* values in both the period immediately after Agnes and the year following. *It* should be emphasized that although there is only a single reference location for comparison (Station Y), this conclusion is a conservative interpretation.

Heterotrophic Potential (V_{max}, *glucose*)

The heterotrophic potential is a kinetic parameter which reflects the activity of a population of microorganisms. For the two-year study at the mouth of the York River (Table 1), the heterotrophic potentials may be divided into 4 ranges: low, moderate, high, and very high (Table 3). The highest values were observed in summer months and the lowest values in the winter.

Table 3. Frequency of Heterotrophic Potential ranges for the sub-surface waters (mouth of the York River and Lower Chesapeake Bay).

	Low 0.04-0.25 $\mu g\ G\ l^{-1}h^{-1}$	Moderate 0.26-0.82 $\mu g\ G\ l^{-1}h^{-1}$	High 0.83-1.50 $\mu g\ G\ l^{-1}h^{-1}$	Very High >1.50 $\mu g\ G\ l^{-1}h^{-1}$	n
York River Mouth		All Months			
Pre-Agnes 1971-1972	4	8	4	2	18
Post-Agnes 1972-1973	2	8	2	4	14
		June- August			
Pre-Agnes					
1971	0	1	1	1	3
1972	0	0	0	1	1
Post-Agnes					
1972	0	2	1	3	6
1973	0	0	1	1	2
Lower Chesapeake Bay					
Sub-Stratum		June-August (1972)			
A	0	9	3	0	12
B	0	6	2	0	8
C	0	2	6	3	11
D	0	0	9	3	12
E	0	2	2	4	8
F	0	7	3	0	10

In the immediate post-Agnes period (July-August 1972) the heterotrophic potential for approximately one-half of the Lower Bay stations was moderate (0.26-0.82) and the other half was very high (1.7-3.0) (Fig. 5B). In other words, the activity of the microbial flora of the Lower Bay waters was abundant. These abundant populations continued throughout the autumn and low populations occurred in the winter (Figs. 5A and 5B).

Although there is a paucity of data, it can be seen that, for the most part, the microbial populations of the York River Mouth and approximately 68% of those of the Lower Bay stations were quite similar during the post-Agnes period (1972-1973) (Fig. 5C).

When the 68% range of Lower Bay heterotrophic potentials of 1972-1973 is superimposed on that of the Station Y for 1971-1972, it appears that these population densities are quite similar (Fig. 5D). It may be inferred that the 1972 York River microbial population was near its maximum just prior to Agnes, that Agnes disrupted it, and that the population recovered rapidly and approached its greatest value. Furthermore, this population underwent its normal decline to the minimum in the winter. The exception is the response of the York River Mouth station following Agnes which more nearly follows the higher values shown in Fig. 5B for June and July 1972. Examination of these data reveals that the high V_{max}, *glucose* values obtained in the Lower Bay on the July 24-27 cruise and the August 15-21 cruise were from stations in sub-strata D and E, adjacent to the York River Mouth.

With respect to spatial distribution, the major observation on heterotrophic populations present in the Lower Bay was the extreme abundance that occurred in sub-strata D, E, and F when sub-surface waters reached their maximum temperature four to six weeks following the passage of Agnes. Some increased abundance was also observed in the deep channel sub-strata of the Lower Bay and in sub-stratum A which may represent discharge from the James River.

An illustration of the variability in the processed data is presented in Table 4. Although variations in the salinity and temperature are evident in July and August, the great disparity between the mean and standard deviation for chlorophyll a is evident because the concentrations measured do not follow a statistically normal distribution due to the occurrence of phytoplankton blooms which were noted at the time of sampling (Table 4). More consistent data are reported for the 4 parameters in October, November, and December, whereas greater variation in the heterotrophic potential is seen for September. This detailed presentation of the original data is provided for making a judgement on the similarity or dissimilarity of the producer communities. Identifying a finer gradient of planktonic communities on the basis of these few parameters is still premature.

DISCUSSION

Several earlier studies have reported a seasonal trimodal distribution of phytoplankton populations in the relatively higher salinity waters of the lower Chesapeake Bay (Patten, Mulford, & Warinner 1963; Mackiernan 1968; Taylor 1972; Manzi 1973). There is a prominent abundance of phytoplankton seasonally in the spring, early summer and fall. This may in part be related to the grazing patterns of the zooplankton (Burrell 1968; Grant, et al. this volume).

This trimodal abundance of phytoplankton is also indicated by chlorophyll a distributions for the York River Mouth (Fig. 4A). It should be noted that the range of chlorophyll a values for the York River was rather small (4-20 $\mu g\ l^{-1}$) for the year prior to Agnes. However, there was a prolonged peak in the late

Table 4. Selected hydrographic parameters for Lower Chesapeake Bay sub-surface waters.

Date	Sub-Strata	S ppt	T °C	Chl. a $\mu g\ l^{-1}$	V_{max} $\mu g\ G\ l^{-1} h^{-1}$	n
26 July 1972	A90	15.03	27.6	2.1	1.61	
	A46	17.55	26.8	20.6*	1.42	
	A09	17.73	26.8	21.1*	1.07	3
	Mean	16.77	27.07	14.60[2]	1.37	
	S. D.	1.51	0.46	10.83	0.27	
17 Aug. 1972	B13	16.13	23.6	65.6*	0.84	
	B73	22.01	23.7	7.6	0.78	
	B44	20.06	24.0	17.2*	1.07	3
	Mean	19.40	23.77	30.13[2]	0.90	
	S. D.	3.00	0.21	31.09	0.15	
12 Sept. 1972	A05	17.38	23.0	17.2*	0.62	
	A22	17.03	23.1	21.4*	0.25	
	A39	17.61	23.2	20.4	1.26	3
	Mean	17.34	23.10	19.67[2]	0.71	
	S. D.	0.29	0.10	2.19	0.51	
18 Oct.	C08	21.18	17.2	8.7	0.50	
	C12	21.01	17.1	5.6	0.48	2
	Mean	21.10	17.15	7.15	0.49	
	S. D.	0.12	0.07	2.19	0.01	
13 Nov. 1972	A13	21.26	14.2	6.3	0.25	
	A74	21.75	14.4	15.0	0.17	
	A83	22.28	14.7	6.5	0.17	3
	Mean	21.75	14.43	9.27	0.20	
	S. D.	0.50	0.25	4.97	0.05	
12 Dec. 1972	07	19.24	8.9	7.2	0.18	
	08	18.81	8.9	10.9	0.13	
	16	20.38	8.3	9.5	0.20	3
	Mean	19.48	8.70	9.20	0.17	
	S. D.	0.81	0.35	1.87	0.04	

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*phytoplankton bloom observed at station

[2] number of plankton blooms observed at stations.

summer after Agnes. The range of chlorophyll a values we report for the Lower Chesapeake Bay is quite similar to that reported by Taylor (1972). For comparison, chlorophyll a values for other mid-Atlantic estuaries are listed in Table 5.

Table 5. Annual ranges of Chlorophyll a values for the mid-Atlantic Region (values in μg liter $^{-1}$).

Location	Annual Range	Blooms	Citation
Long Island Sound (N. Y.)	3-25	-	Horne 1969
Patuxent River (Md.)	1-120	-	Flemer et al. 1970
Severn River (Md.)	13-30	386	Loftus et al. 1972
Pamlico River (N.C.)	1-40	250	Hobbie et al. 1972
Potomac River (Md.)	20-30	-	Jaworski et al. 1972
Chesapeake Bay (Md.)	6-59	-	Taylor 1972

The V_{max}, *glucose* for the York River Mouth varied between 0.04 μg $l^{-1}h^{-1}$ in the winter to as high as 2.9 μg $l^{-1}h^{-1}$ in the late summer. These values are lower than those reported for the Pamlico Sound estuary, one of the most microbially active aquatic environments where, V_{max}, *glucose* was reported to be 0.15-24.10 μg glucose $^{-1}h^{-1}$ during 1966, 1967 and 1968 (Crawford, Hobbie, & Webb 1973).

It should be noted that for most of the sub-surface waters of the Lower Bay (204 stations) that the V_{max}, *glucose* values fell within the range for that of the York River (0.04-3.0), whereas 72 stations exceeded the upper limit, particularly during the summer months of 1972. These values reached a maximum in late July, which coincided with maximum water temperatures for the Lower Bay. However, this peak of heterotrophic potential preceded that for primary productivity potential which occurred in mid-August (Zubkoff & Warinner, unpublished).

The reasons for the increases in heterotrophic potential may be several:

1) Responses of the phytoplankton and heterotrophic communities to freshwater runoff and associated enrichment by inorganic nutrients (Loftus, SubbaRao, & Seliger 1972).

2) Increase in suspended sediment with its associated microbial flora.

3) Infestation of the regions of normally higher salinity water by a microbial flora which is adapted to lower salinity waters.

4) Shift from the usual heterotrophic population to another population which is resistant to grazers.

5) Relatively high water temperatures (24-27^{o}C) with prolonged sunlight which would favor both microbial and phytoplankton growth and reproduction.

CONCLUSION

From the chlorophyll a and heterotrophic potential data of the Lower Chesapeake Bay, and with respect to a single hydrographic station (Station Y) followed on a seasonal basis, it may be concluded that Agnes produced:

1) An enriching effect on the phytoplankton populations of the Lower Bay waters during the period immediately following the storm.

2) The enrichment persisted throughout the year (in the fall and winter) and continued into the summer of 1973.

3) An enriching and stimulatory effect on heterotrophic activity (York River Mouth and Lower Bay) which subsequently declined to their probable winter levels.

4) Activities of the Lower Bay heterotrophic populations of 1973 spring and summer were probably similar to those populations which occurred prior to Agnes.

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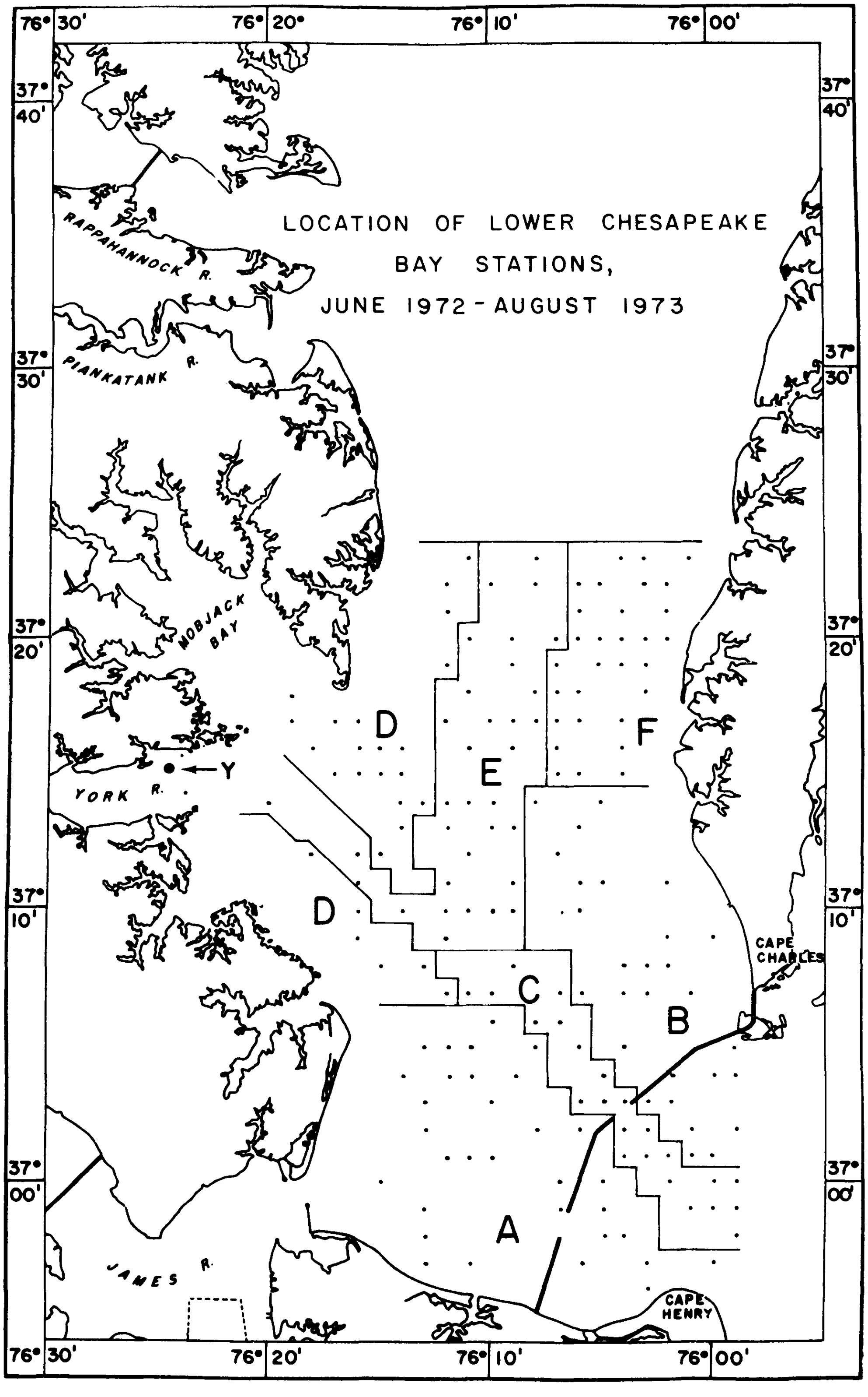

Figure 1. Area of study during one year study of lower Chesapeake Bay following Agnes. Y designates station at the mouth of the York River.

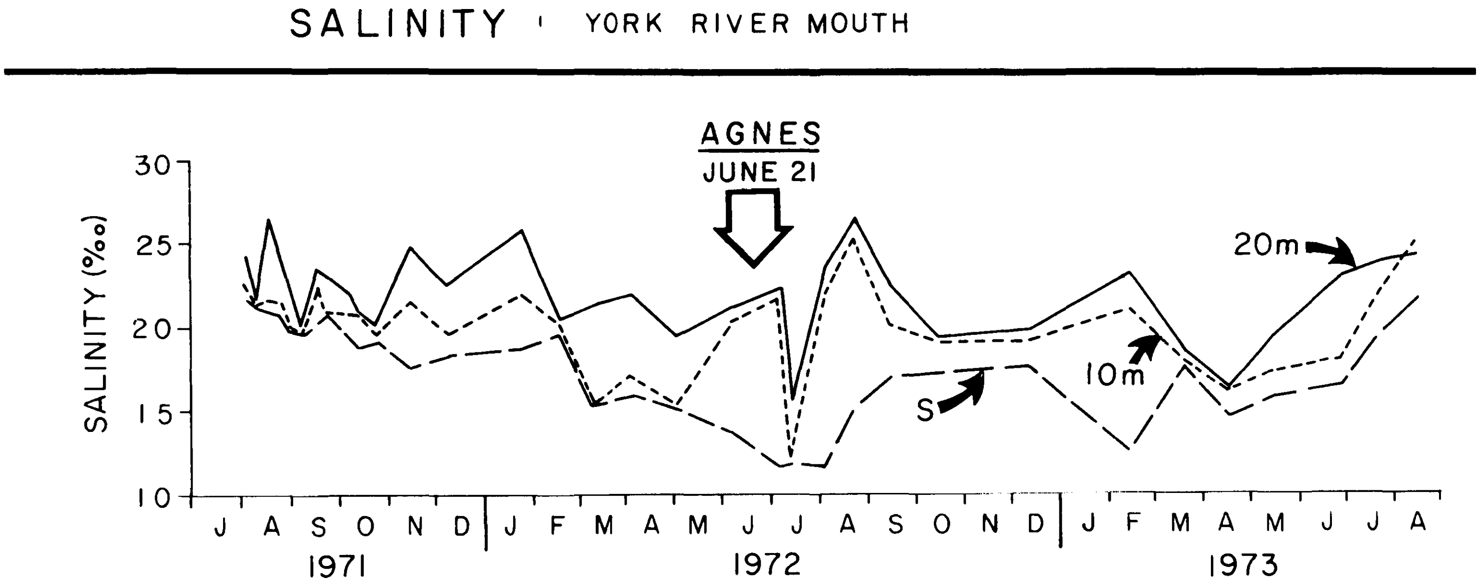

Figure 2. Salinity at the mouth of the York River (June 1971-August 1973) S = waters within 1 meter of the surface; 10 m = water at 10 meters below surface; 20 m = bottom waters.

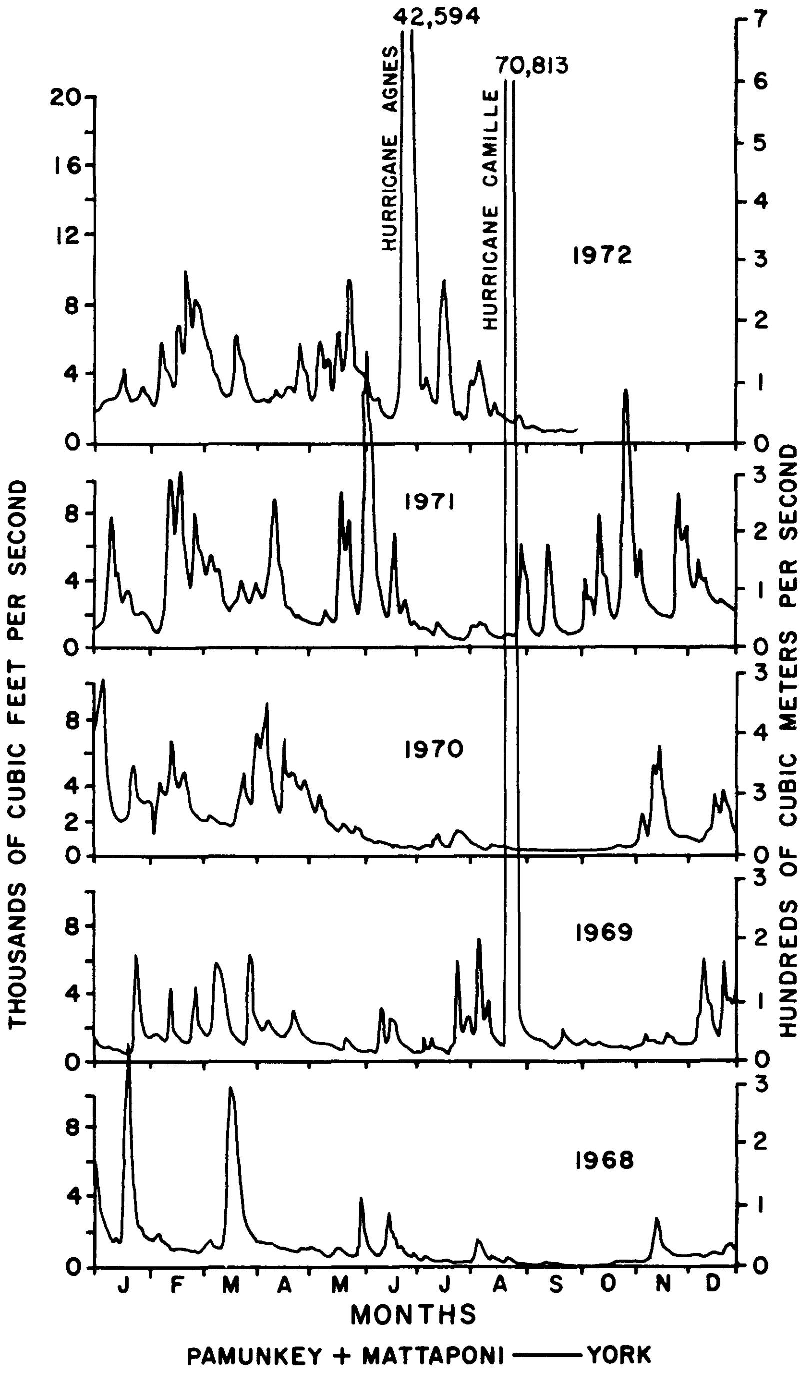

Figure 3. Freshwater discharge into the York River (1968-1972).

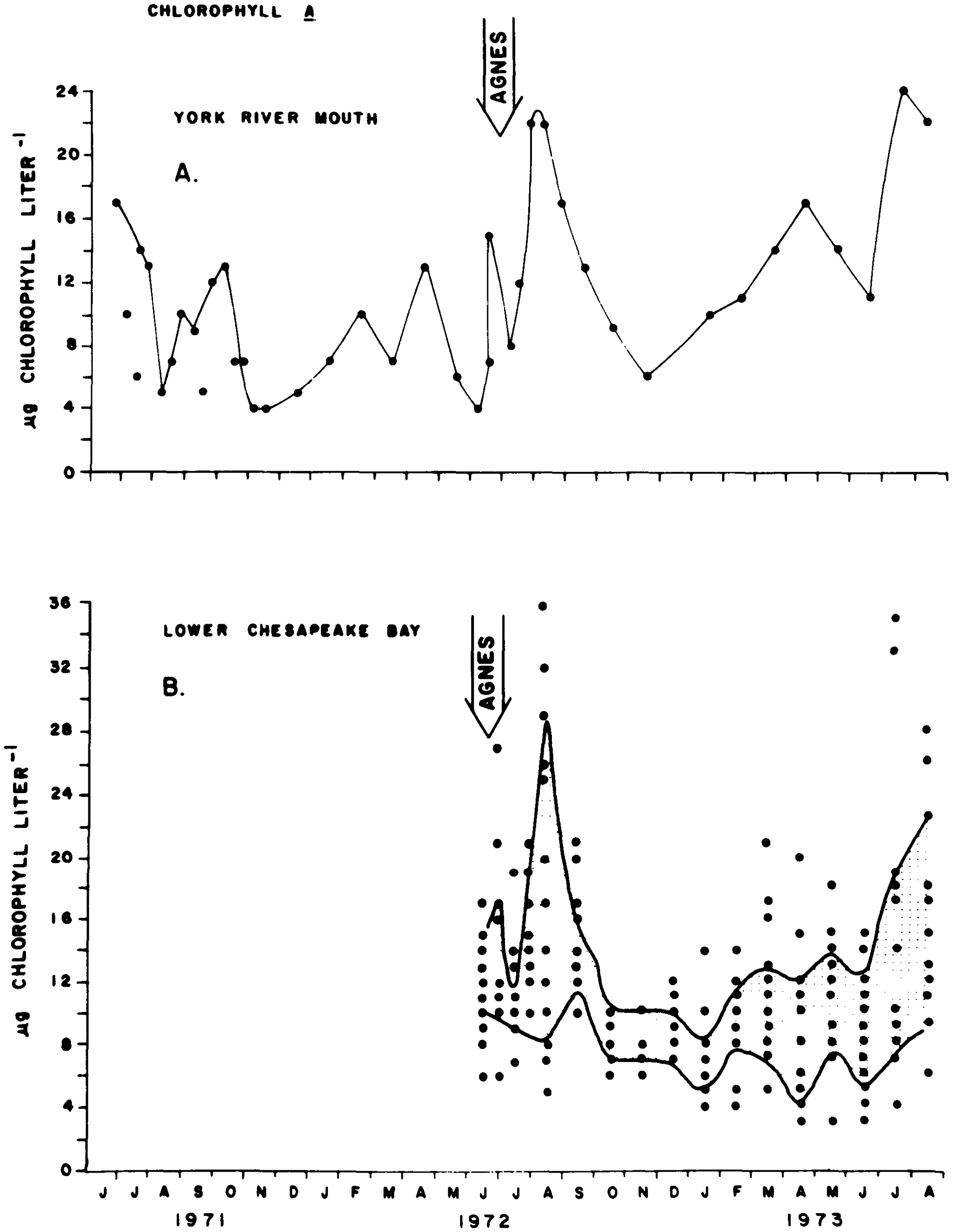

Figure 4A&B. Concentrations of chlorophyll a in the sub-surface waters. The shaded area bounded by heavy lines indicates the range in which 68% (2 standard deviations) of the observed values occur.

A. York River Mouth (June 1971-August 1973)

B. Lower Chesapeake Bay (June 1972-August 1973).

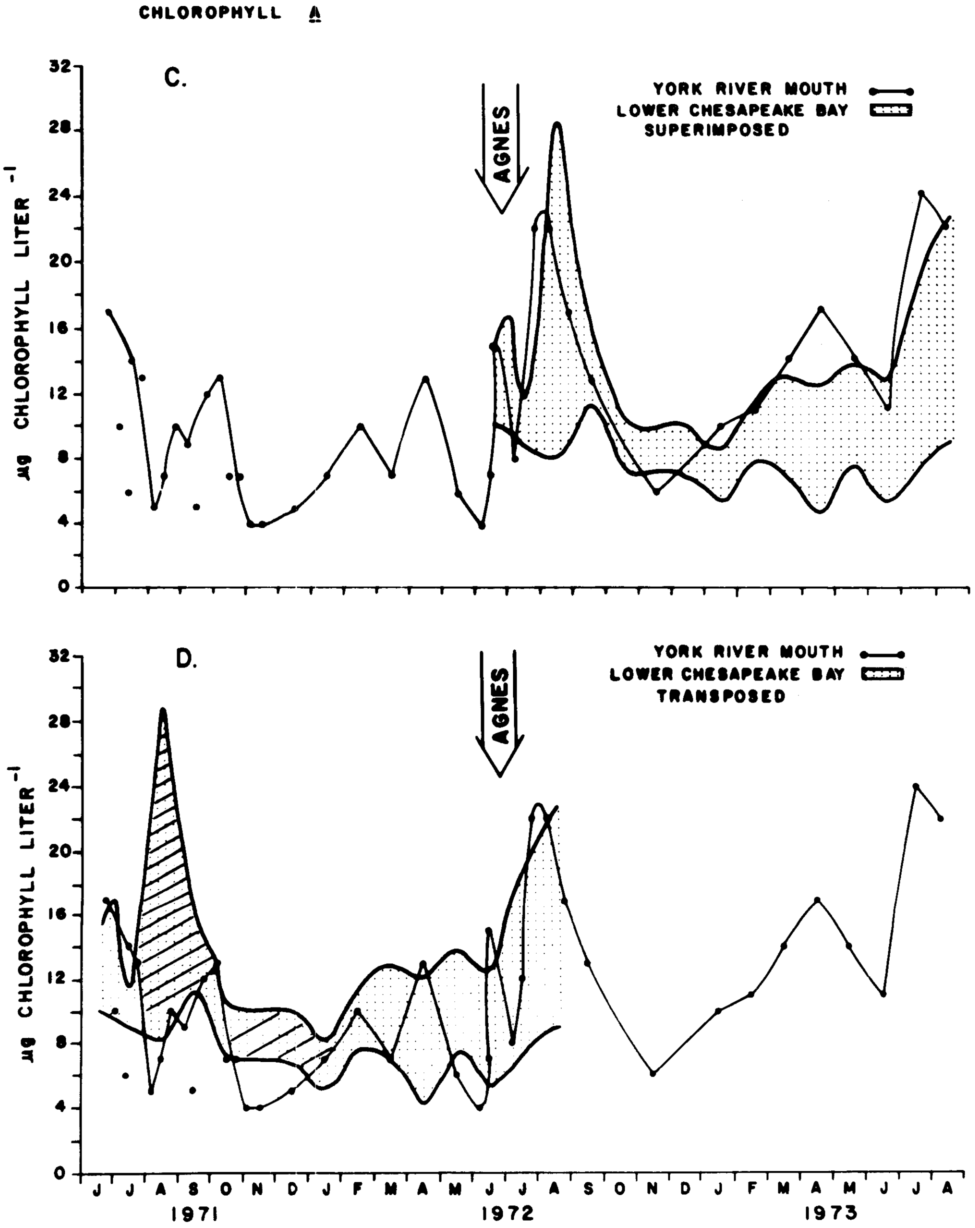

Figure 4C&D. Concentrations of chlorophyll *a* in the sub-surface waters. The shaded area bounded by heavy lines indicates the range in which 68% (2 standard deviations) of the observed values occur.

C. Lower Chesapeake Bay (1972-1973) superimposed on York River Mouth (1972-1973).

D. Lower Chesapeake Bay (1972-1973) transposed on York River Mouth (1971-1972).

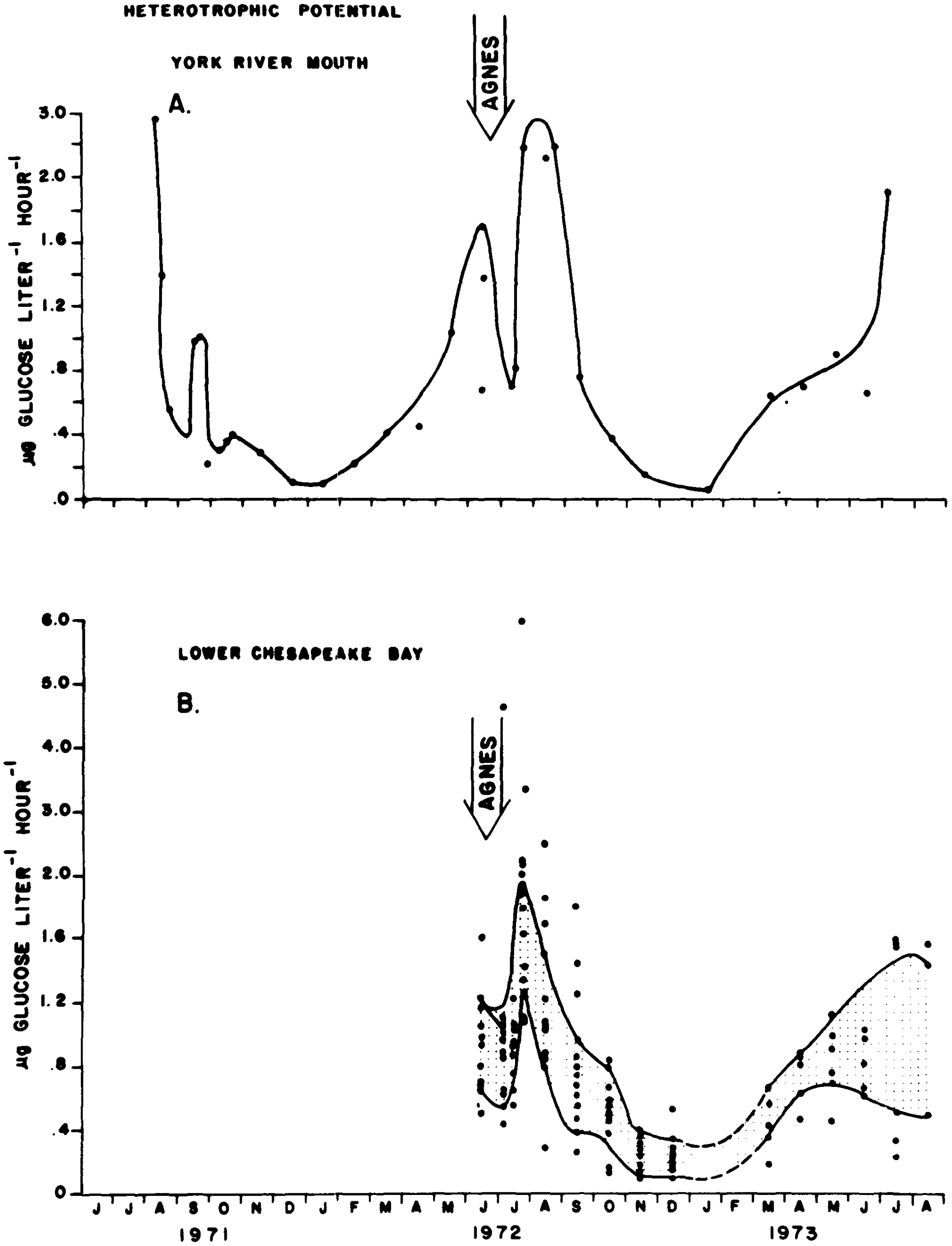

Figure 5A&B. Heterotrophic potential (*Vmax, glucose*) in the sub-surface waters. The shaded area bounded by heavy lines indicates the range in which 68% (2 standard deviations) of the observed values occur.
A. York River Mouth (June 1971-August 1973)
B. Lower Chesapeake Bay (June 1972-August 1973).

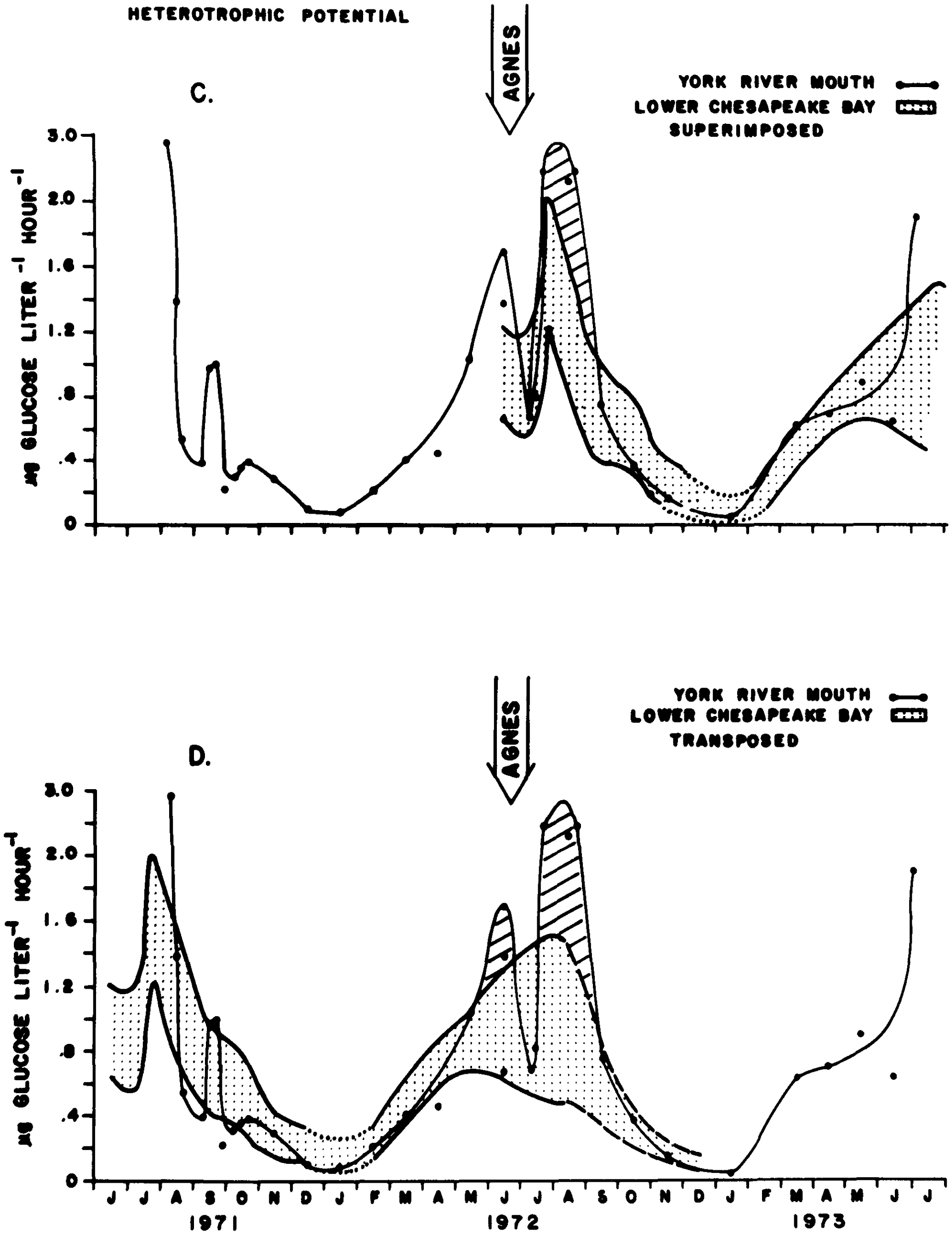

Figure 5C&D. Heterotrophic potential (V_{max}, *glucose*) in the sub-surface waters. The shaded area bounded by heavy lines indicates the range in which 68% (2 standard deviations) of the observed values occur.

C. Lower Chesapeake Bay (1972-1973) superimposed on York River Mouth (1972-1973).

D. Lower Chesapeake Bay (1972-1973) transposed on York River Mouth (1971-1972).