SOME EFFECTS OF HURRICANE AGNES ON WATER QUALITY IN THE PATUXENT RIVER ESTUARY

by

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Abstract

A post-Agnes study that emphasized environmental factors was carried out on the Patuxent River estuary with weekly sampling at eight stations from 28 June to 30 August 1972. Spatial and temporal changes in the distribution of many factors, e.g., salinity, dissolved oxygen, seston, particulate carbon and nitrogen, inorganic and organic fractions of dissolved nitrogen and phosphorus, and chlorophyll a were studied and compared to extensive earlier records. Patterns shown by the present data were compared especially with a local heavy storm that occurred in the Patuxent drainage basin during July 1969. Estimates were made of the amounts of material contributed via upland drainage. A first approximation indicated that 14.8×10^3 metric tons of seston were contributed to the head of the estuary between 21 and 24 June. We estimated that 5.6×10^3 metric tons of seston were delivered to the upper estuary between 28 June and 30 August. Particulate carbon was 5% of the seston during the latter period. The particulate carbon:nitrogen ratio (wt/wt) of the material contributed for the 10-week interval, exclusive of the four-day peak flow, was about 4.7:1. From 28 June to 30 August we estimated that about 135 metric tons of total dissolved nitrogen and 10.8 metric tons of total dissolved phosphorus were added to the estuary. These amounts of nitrogen and phosphorus greatly exceeded the requirement for plant primary production, especially during July. Some interesting correlations were observed in the data. Particulate nitrogen and active chlorophyll a were usually correlated with a correlation coefficient of ≥ 0.80 (9 d.f.) in the lower study area. In the tidal freshwater area (Nottingham), NH_3-N and NO_3-N and total dissolved phosphorus were negatively correlated with chlorphyll a. These correlations were not strong in the lower river. The atomic ratio of dissolved inorganic nitrogen to dissolved inorganic phosphate-phosphorus was usually greater than 15 and often above 30, especially at the most seaward station (near Solomons) and in the tidal freshwaters. During August some of the above ratios were less than 2.0 in the middle portion of the estuary; this suggested that nitrogen would potentially become more limiting to phytoplankton growth than phosphorus. At this time the concentration of active chlorophyll a often approximated 30 to 60 mg m^{-3}. The minimum surface salinity at Sandy Point, the most seaward station near Solomons, was 1 ‰ and occurred on 5 July. Strong vertical differences in salinity were noted in the middle portion of the river. In this region, bottom dissolved oxygen values were frequently <1.0 mg $liter^{-1}$.

Introduction

Aside from the obvious destruction that large cyclonic storms incur, there is an opportunity to learn much about the response of coastal estuarine ecosystems from such perturbations. Hurricane Agnes entered the Chesapeake Bay area on 21 June 1972 and provided a unique opportunity to study the environmental impact of an event which usually is unavailable to estuarine scientists. Logistically, we were conveniently located on the Patuxent River estuary to engage in a field reconnaissance of several environmental factors, e.g., salinity, dissolved oxygen, nutrients, chlorophyll *a*, and seston. It was fortunate to have recently completed a field analysis of the above and other factors in the upper estuary between August 1968 and August 1970 (Flemer et al., 1970, much of this information will be published later). Thus our present efforts have considerable comparative value.

Though not as unique or as formidable as Hurricane Agnes, an unusually heavy rainfall in the Patuxent drainage area occurred during late July 1969, and we compared the 1969 data with the present data. Our field studies in this investigation began on 28 June 1972, about one week after Agnes unleashed her fury in the Patuxent, and they were continued at weekly intervals until 30 August 1972. This report provides a summary and interpretations of the environmental data.

Extreme conditions imposed by Agnes were believed of general interest in the area of eutrophication. This study was planned to help characterize the relationship between phytoplankton and nitrogen and phosphorus. Questions regarding nutrient removal at wastewater treatment plants is still an unresolved problem in Maryland, and an active research program in Chesapeake Bay is focusing on the effects of sewage on the estuarine ecosystem (Chesapeake Research Consortium, Inc., proposal under development).

Detritus is considered an important source of energy for many deposit- and filter-feeding organisms. In the oligohaline area of the

Patuxent, we have provided further evidence that the dominant spring copepod, Eurytemora affinis, feeds extensively on detritus (Heinle et al., 1974). We have attempted to characterize the input of detritus to the head of the estuary following the large runoff caused by Agnes. The elemental composition of the suspended material in the estuary complements work reported in a recent symposium (Melchiorri-Santolini and Hopton, 1972), though relatively little information was presented for estuarine conditions.

Description of the Study Area

The drainage basin of about 963 sq. miles (2,494 km^2) lies wholly within the State of Maryland on the western shore of the Bay and forms the next major tributary upstream from the Potomac River (Nash, 1947). The basin lies in both the Piedmont Plateau and the Coastal Plain physiographic provinces. Urbanization is occurring, especially in the upper drainage basin near the Fall Line, which runs approximately between Washington, D. C. and Baltimore. Extensive tidal brackish water marshes are located within the upper two-thirds of the study area with the seaward extension of the marsh complex ending just upstream to Trueman Pt. (Fig. 1).

The present study area included eight channel stations from tidal freshwater (Nottingham) to a location adjacent to Solomons (Sandy Pt.).

Tidal amplitude is small. Cory and Nauman (1967) report a difference of 0.55 m between mean high and mean low tides near Benedict Br. and Mansueti (1961) gave a tidal range of 0.76 m near Nottingham. The estuary is typically a two-layered system (type B of Pritchard, 1955) and occasionally changes to a three-layered system near the mouth.

Methods and Procedures

Field Sampling Procedures

Field samples were obtianed with a 13-ft. Boston Whaler. Sampling began at Sandy Pt. and proceded upstream following the node of the same slack current that preceded flood current. Water samples were pumped with

a battery-powered submersible pump (Teel Manuf. Co., Model 1P811). Dissolved oxygen and temperature were measured with a YSI Model 54 oxygen meter by placing the probe near the end of the sampling hose in a plastic bucket. Salinity was measured with an American Optical Co. refractometer prior to 19 July, and a Beckman Model RS-5 salinometer was used after this date. Samples were brought back to the laboratory and processed. Filtrates and unfiltered samples were frozen in polyethylene bottles. Filter pads were desiccated over silica gel and frozen. Chlorophyll a samples collected on filters were directly frozen without desiccation.

Analytical Methods

Samples for chlorophyll a were collected on Whatman GF/C filters and the chlorophyll a was estimated fluorometrically with a Turner fluorometer (Yentsch and Menzel, 1963; Holm-Hansen et al., 1965). Our adaptation of these two methods is described in detail (Flemer et al., 1970).

Seston, or total suspended material, was determined on tared GF/C filters after drying to constant weight over silica gel.

Particulate carbon was determined by the method of Menzel and Vaccaro (1964) using a Beckman Model 1R215 Infrared Analyzer and a Coleman CHO Analyzer. Particulate nitrogen was determined with a Coleman Model 29A Nitrogen Analyzer equipped with a Model 29 combustion tube and syringe.

Total phosphorus was determined with the oxidation method of Menzel and Corwin (1965). The same method was used to oxidize dissolved organic phosphorus materials after passing the sample through a GF/C filter. Dissolved inorganic reactive phosphorus was determined with the composite reagent method (Strickland and Parsons, 1968).

Ammonia nitrogen analysis followed the procedure of Solorzano (1969). Nitrate and nitrite nitrogen were analyzed by the method of Strickland and Parsons (1965). Soluble organic nitrogen analysis employs a modification of the uv light oxidation (Strickland and Parsons, 1968). A half-strength seawater solution is used for the solvent, for the blanks, ammonium sulfate, and pyridine standards. The seawater solution is made

up according to Strickland's and Parsons' (1968) nitrate method, then diluted by one-half with double distilled, deionized water. This solution is to dilute river water samples and to add salts to facilitate the uv oxidation (unpublished observations). We dilute, if necessary, 20 ml of river water sample to 100 ml with half-strength seawater. Two drops of 30% hydrogen peroxide are added to the sample in a quartz tube, and the sample is capped and irradiated 7 cm from a 1,200-watt Hanovia-Englehardt 189A lamp for 3 hrs. Strickland's and Parsons' (1968) procedure is followed for the remainder of the analysis.

Freshwater Discharge to the Head of the Estuary

Discharge values were calculated for the contribution of freshwater from the drainage basin of the upper Patuxent River above the confluence with Western Branch and for the Western Branch drainage basin. Gaging stations were near the headwaters of the tributaries; thus, the estimates of discharge were based on the ratio of area gaged to the area downstream of the gaging stations. The formulation employed was based on the work of Charles Hall, Maryland Department of Water Resources, where:

$$Q_T = Q_L + 5.9\ Q_W + 1.42\ Q_U + 4.2\ Q_G$$

and

Q_t = total freshwater to head of estuary (main stem of Patuxent, plus Western Branch)

Q_L = discharge at Laurel gaging station

Q_W = discharge at Western Branch gaging station near Largo

Q_U = discharge near Unity gaging station

Q_G = discharge near Guilford gaging station

The unpublished gaging station data were provided by the Geological Survey, Water Resources Division, U. S. Department of Interior, College Park, Maryland.

We determined the total discharge over Δt where the sampling date was near the mid-point. For example, the first sampling date of 28 June with three days before and three days after this date were used to estimate the weekly discharge. The same approach was employed for each

succeeding sampling date. The concentration of a factor at Nottingham, e.g., seston, was multiplied by the total weekly discharge to estimate a flux for the interval. The 10 intervals were summed to provide an estimate of total flux.

Results and Discussion

All data taken in this study are listed in Table 1 and appendix.

Temperature, Salinity, and Dissolved Oxygen

Water temperatures measured in this study were characteristic for the summer (Table 1; Flemer et al., 1970). Maximum values occurred upstream in the general vicinity of the Chalk Point Power Plant. Exceptionally high values, some approximating 36°C, were noted in the upper study area on 26 July. Bottom values were sometimes slightly higher than surface values. These data supplement the extensive records of temperature in the upper river (Herman et al., 1968, and Cory and Nauman, 1967).

Salinities reflected the large rainfall in the drainage basin, and our data record the recovery of the low salinities back to the more normal regime (Table 1). Surface salinities were 0.0 o/oo as far seaward as Benedict Br. during most of July. Strong vertical differences in salinity were noted at Sheridan Pt. and seaward. The minimum surface salinity at Sandy Pt. was about 1.0 o/oo and occurred on 5 July. Bottom salinities on two occasions at Sandy Pt. (28 June and 2 August) were about 1.5 o/oo less than surface values. We point out these differences as possibly accurate observations since Nash (1947) made similar kinds of observations near Sandy Pt.

Some perspective is gained by comparing surface salinities at Sandy Point with those taken nearby at the Chesapeake Biological Laboratory pier. Daily salinities at the pier from 1 June to 20 June 1972 ranged between 7.9 and 10.8 o/oo. These data are not continuous as observations are usually not made on weekends; however, on 28 June the salinity was 2.5 o/oo and agreed closely with our data at Sandy Point. The monthly mean values at the pier during the period 1938 to 1957 for June, July,

and August were 11.0, 12.5, and 13.5 o/oo, respectively (Beaven, 1960). Hurricane Agnes resulted in very low salinities at a time when salinities normally proceed toward maximum values in the River.

Salinity data obtained during July 1969 reflect the aftermath of a heavy rainfall that occurred in the drainage basin. In the lower River, 11.85 inches of rain fell at Solomons on 23 July 1969, over a period of a few hours (NOAA, Ashland, N. C., central records for Solomons area). In the upper River, the surface salinity at Nottingham on 8 July 1969 was 2.7 o/oo and on 30 July 1969, this salinity level was displaced seaward to a point near Trueman Pt. (Flemer et al., 1970).

Information is presented on dissolved oxygen that generally characterizes the oxygen resources of the River (Table 1). Only large changes can be evaluated for the summer since the same slack sampling required some cruises to be initiated at night. Very low concentrations of dissolved oxygen, e.g., 1.0 mg liter^{-1}, were measured in bottom waters between Sheridan Pt. and Broome Is.

Particulate Material

Seston. Highest concentrations of seston occurred upstream of Benedict Br. (Fig. 2). A maximum value of 170 mg liter^{-1} was measured at Lower Marlboro in the bottom sample on 5 July. Seaward to Benedict Br. the concentration of seston seldom was greater than 50 mg liter^{-1}. On 2 August, 168 mg liter^{-1} of seston were recorded at Nottingham, and 68 mg liter^{-1} of seston were measured as far seaward as Broome Is. The above pattern of seston in the River suggests that the maximum discharge of suspended solids associated with Agnes occurred before 28 June. The rapid washout of chlorophyll a, as discussed later, confirms this conclusion.

High sestonic levels were often encountered during earlier work in the River (Flemer et al., 1970). The upper tidal Patuxent received very high amounts of seston during late July 1969. Several values approached 200 mg liter^{-1}. We have no quantitative data on seston for this event at

Solomons, but comparative data for the upper tidal River taken on 8 July and 30 July 1969 documented the impact of this unusually large freshwater discharge to the estuary. These data indicated that the Patuxent River has received large concentrations of seston in the past but Hurricane Agnes was a significant event in the history of the Patuxent system. Normally the so-called "sediment trap," which is well described for the main stem of Chesapeake Bay (Schubel, 1968b; Schubel and Biggs, 1969), extends seaward in the Patuxent estuary to about Chalk Pt. Hurricane Agnes briefly extended the seaward boundary of the sediment trap downstream to, at least, the mouth of the Patuxent River. The system returned quickly to steady-state conditions, and the seaward extension of the sediment trap moved upstream between Benedict Br. and Sheridan Pt.

Chlorophyll a. The concentration of active chlorophyll a, which is an index of the standing crop of phytoplankton (here possibly some mud-dwelling algae) showed a sharp decline between Nottingham and Sheridan Pt. (Figs. 3a and 3b) during the first two sampling periods. Surface values at this time were 5 to 8 mg m^{-3}. Seaward, between Broome Is. and Sandy Pt., the surface concentration of chlorophyll a ranged between 40 to 50 mg m^{-3}. This pattern probably resulted from the seaward displacement of normally high upstream concentrations. Earlier work indicated that the high values observed during this study between Nottingham and Trueman Pt. from 19 July to 30 August are typical for the upper study area (Flemer et al., 1970). Maximum surface concentrations of chlorophyll a observed during the present study were 127 and 105 mg m^{-3}, which occurred at Nottingham and Broome Is. on 9 August and 23 August, respectively. Most moderately deep temperate East Coast estuaries show a single sustained maximum concentration of chlorophyll a during the late summer, especially in the sediment trap area (Ryther, 1963; Flemer, 1970).

Seaward of Lower Marlboro there was a stronger temporal pattern in the distribution of surface chlorophyll a in the present study than that observed for the bottom waters. The low values measured at Queen Tree

and Broome Is. were associated with the low concentration of dissolved oxygen that was present in the bottom waters. In general, the concentration of chlorophyll a observed in the present study compares well with earlier studies on the River (Flemer and Olmon, 1971; Flemer et al., 1970). A feature characteristic of Hurricane Agnes was for more variations over time to occur in the surface waters at higher salinities.

For perspective, we are able to compare the present distribution of chlorophyll a in the river with that for the summer of 1969. The large amount of rain that occurred in late July 1969 was strongly associated with the low chlorophyll a values measured at that time. For example, values at Lower Marlboro rapidly decreased from 46 to 7 mg m^{-3}. This correlates well with the increased sestonic load received by the River during the July 1969 period and illustrates that the upper Patuxent has experienced an important washout of the phytoplankton at other times.

Particulate carbon. The concentration of particulate carbon showed a surprising uniformity in the surface waters through most of the River until early August (Fig. 4a). Most values ranged between 100 and 200 μ moles $liter^{-1}$ (1.2 - 2.4 mg $liter^{-1}$). Highest concentrations of particulate carbon in the surface and bottom waters (Fig. 4b) occurred during late August when chlorophyll a values were maximal.

We observed that the average values of the percent of carbon relative to seston in the surface waters ranged between 6 and 8% from Nottingham seaward to Queen Tree (Table 2). Exclusive of two unusually high concentrations of particulate carbon noted at Broome Is. and Sandy Pt., the values averaged 8.6 and 10.7% at these stations. The average values discussed above compare favorably to earlier work on the River (Flemer et al., 1970).

Seaward of Benedict Br. the percent of carbon relative to seston in bottom samples was about one-half less than the surface average values. Several reasons may help explain these observations. Possibly a differential settling of inorganic material occurred, or the role of decomposition

was greater than that of carbon input from upland drainage, and marsh drainage, and plant production in the River. Also, dilution of the bottom suspended material from the sediments could influence the above pattern (Schubel and Biggs, 1969). If we assume that the carbon values represent about 50% of the organic matter on a dry weight basis, then our values agree more closely with the winter and spring data on organic matter in the upper Chesapeake Bay (Schubel, 1968a).

Particulate nitrogen. In contrast to the distribution of particulate carbon, particulate nitrogen in the surface waters varied more with time than it did position in the river. Most maximum values approximated 40 to 50 μ moles liter^{-1} or 600 to 750 μg liter^{-1} (Fig. 5a). The fairly high correlation between nitrogen and chlorophyll a is obvious from the contour diagrams. Conversely, the pattern of particulate nitrogen in the bottom waters was characterized more by position than time in the river; in fact, a relatively sharp decrease occurred throughout the study in the concentration of particulate nitrogen at Sheridan Pt. (Fig. 5b). A similar trend was noted for chlorophyll a. The concentration of particulate nitrogen measured during this study approximated that measured previously (Flemer et al., 1970).

Nutrients

Phosphorus. Data on several fractions of phosphorus, e.g., total phosphorus, total dissolved phosphorus, and dissolved inorganic reactive phosphate-phosphorus are illustrated in Fig. 6 for four stations along the River. Total phosphorus approximated 6.0 μg at liter^{-1} at Nottingham and showed a gradual decrease seaward to Sandy Pt. where the concentration ranged between 2 and 4 μg at liter^{-1}. Inadvertent filtration of samples from 5 July through 19 July prevented analysis for total phosphorus. Total dissolved phosphorus usually ranged between 20 and 50% of the total phosphorus. Thus, by difference, particulate phosphorus constituted a substantial portion of the phosphorus in the river. Dissolved inorganic phosphate usually accounted

for most of the total dissolved phosphorus. Therefore, relatively little dissolved organic phosphorus was present. On a few occasions the dissolved inorganic values were analytically greater than values for total dissolved phosphorus. We believe that the total dissolved values should be considered only approximate. Work is under way in an attempt to resolve this problem.

Compared to data obtained during the summer of 1969, we conclude that the general pattern of phosphorus distribution and concentrations in the River did not differ in any important way (see Fig.6).

We should mention that the inorganic phosphate concentration is largely controlled in turbid estuaries through sorption reactions with suspended sediments (Pomeroy, Smith, and Grant, 1965). We expect that such reactions strongly influenced the level of phosphate observed in the present study as the Patuxent qualifies as a turbid estuary. The exchange is apparently near-equilibrium when the water has a phosphorus content about 0.7 to 1.5 µg at liter^{-1} (Butler and Tibbitts, 1972). In the Tamar estuary, near the Plymouth Laboratory, England, in contrast to our findings, the total dissolved phosphorus was relatively constant before and after a heavy rain throughout the estuary. The concentration of total dissolved phosphorus in the Patuxent showed a substantial decrease from Nottingham seaward but relatively less change over time during the present study.

Nitrogen. Nitrogen determinations presented in Fig. 7 show the total nitrogen as represented by several fractions. The dissolved organic and inorganic fractions (NH_4^+, NO_2^-, and NO_3^-) are added to the particulate nitrogen. Some comparative data taken during the summer of 1969 are included on the figure (Flemer et al., 1970).

Maximum total nitrogen occurred at Nottingham and during the first six weeks many values ranged between 80 and 100 µg at liter^{-1}. Most values of total nitrogen during the first six weeks at Benedict Br. and Queen Tree ranged between 60 and 80 µg at liter^{-1}. At Sandy Pt. during this period there was a slight increase in the total nitrogen. A maximum

value for the entire study of 146 µg at liter^{-1} occurred at Sandy Pt. on 28 June which presumably was related to the displaced upstream material. Total nitrogen decreased about 50% at all stations during the latter half of the study with few exceptions. One notable exception occurred at Nottingham on 30 August where a concentration of 140 µg at liter^{-1} was measured.

The limited data available from the summer of 1969 suggest that total nitrogen was more highly concentrated during the recovery period of Agnes than noted during the summer of 1969. By comparison, the concentration of total phosphorus failed to show a consistent increase over that of the summer of 1969.

We examined the relative proportion of NH_3-N, NO_2-N, and NO_3-N to the total inorganic nitrogen (see Appendix). The concentration of NH_3-N decreased more rapidly than the concentration of NO_3-N at Nottingham and Benedict Br. from 28 June to 19 July. The pattern was not as clearly discernible at Queen Tree as noted at the upstream stations. At Sandy Pt. the concentrations of NH_3-N and NO_3-N decreased together proportionally for most of the study with the pronounced exception on 30 August. It is tempting to ascribe the more rapid decrease in NH_3-N relative to NO_3-N to differential uptake by phytoplankton (Harvey, 1960). The analysis is complicated by a rapid increase in primary production, unknown changes in the relative rate of supply of the two nutrients and nitrification. Nitrite-nitrogen was quantitatively unimportant compared to the other inorganic nitrogen sources throughout the study.

The concentration of dissolved organic nitrogen often approximated or exceeded the concentration of dissolved inorganic nitrogen (Fig. 7). Most of the dissolved nitrogen was in the form of dissolved organic nitrogen at Benedict Br. and Queen Tree on 9, 16, and 23 August (Appendix 1). At this time the significance of dissolved organic nitrogen to the biological system is not apparent but presumably contributes to the available nitrogen pool in the long-term.

Ratios and Correlations

Data on C:N ratios (atomic) for surface and bottom waters are given in Figs. 8a and 8b. Surface ratios showed more variation with time than position along the axis of the estuary. Both surface and bottom ratios usually were within the range of 3-10. Living phytoplankton typically have a C:N (atomic) ratio of about 7 (Strickland, 1960). The relative constancy of the ratios is dissimilar to the data reported for the upper Chesapeake Bay (Flemer and Biggs, 1971). However, maximum values in the upper Chesapeake Bay usually followed the maximum discharge related to snow melt in the Susquehanna River basin. Possibly the small range in values over the summer in the Patuxent resulted from averaging the high C:N ratios associated with higher plant material with the lower ratios associated with phytoplankton (Gucluer and Gross, 1964).

Particulate carbon (PC) was highly correlated, $r \geq 0.80$, with PN at Trueman Pt. (bottom), Broome Is. (surface and bottom), and Sandy Pt. (surface and bottom; Table 3). At Sheridan Pt. and seaward, except Queen Tree, we observed that PC with chlorophyll *a* and PN with chlorophyll *a* were significantly correlated (Table 3). These correlations are more likely in the more seaward region of the estuary where phytoplanktonic material is relatively more abundant than upstream where considerable material is derived from upland drainage. In earlier work we observed that PN x chlorophyll *a* were highly correlated at the more seaward stations, (e.g., Trueman Pt. and seaward to Queen Tree). Brooks (1970) reported for the Brazos River, Texas, that the particulate organic carbon was directly related to river discharge. In the Patuxent autochthonous sources of particulate organic carbon probably mask the relationship between river flow and the concentration of particulate carbon, especially at the more seaward stations.

The measured ratio of PC:chlorophyll *a* is another way to view the relationship between living algal material and the total suspended particulate carbon (Figs. 9a and 9b). High ratios indicate a relatively low contribution of living plant material. Throughout most of the study the

ratio was less than 100:1, and frequently values between 35 and 50:1 were observed. These ratios are consistently less than those observed during earlier summer work on the River (Flemer et al., 1970) and these low ratios are believed to be atypical of temperate coastal waters. As discussed in the preceding paragraph, these ratios suggest a high percentage of living algal carbon relative to the total measured particulate carbon. Many laboratory algal cultures under good growth conditions will have C:chl a ratios between 30:1 and 50:1 (Parsons et al., 1961). Ratios greater than 150:1 were associated with the early washout of the phytoplankton, and high ratios followed the sudden decline from relatively high concentrations of chlorophyll a, especially at Benedict Br. and seaward during the latter part of this study. We attempted to use the ratio of 50:1 of PC:chlorophyll a to partition the measured surface PC into that related to living phytoplankton and a residual (Fig. 10). The residual would presumably contain material from such sources as detritus and small heterotrophs. Some inconsistent results were noted, especially at the most upstream station, Nottingham; however, the use of a reasonable but still lower ratio of 30:1 eliminated most inconsistencies, except at Nottingham. Average values by station, exclusive of Nottingham, of the percent living carbon ranged between 52 and 79%. No clear axial trend along the estuary was noted in this analysis.

An effort was made to assess the impact of Agnes in terms of the ratio dissolved inorganic nitrogen (DIN) to dissolved inorganic phosphate-phosphorus (DIP) (Table 4). Typically, during the summer in many temperate coastal waters, the ratios of DIN:DIP are less than 15-10:1 (Ryther and Dunstan, 1971) which is interpreted that nitrogen would probably become limiting to phytoplanktonic growth before phosphorus. Frequently, the ratio of DIN:DIP was less than 5:1 during the summer studies of 1969 and 1970 (Flemer et al., 1970). The ratios in the River following Agnes were usually very high, often between 15 and 50:1, except at Benedict Br. and Queen Tree from 9 August to 23 August where several values approximated 1 to 2. These low ratios were generally consistent with high concentrations

of chlorophyll a. The rapid decline of this bloom following the very low DIN:DIP ratio is some evidence that nitrogen may have controlled maximum plant biomass. At Sandy Pt. the ratio of DIN:DIP remained fairly high, a fact which we would not have predicted based on the present and previous work in the River. It is possible that the nutrient regime in the main stem of the Bay influenced the pattern noted at Sandy Pt.

Many other correlations are given in Table 3. At Nottingham many of the nutrient fractions were correlated, e.g., NO_3-N x total dissolved nitrogen (TDN), and TDN x DIP, and nutrients were negatively correlated wtih several particulate fractions, e.g., NO_3-N x ACL (active chlorophyll a). Nutrients would be expected to decrease as particulate material is formed via photosynthesis. The lack of many of these high correlations seaward to Nottingham is evidence that recycling probably dominated the nutrient uptake kinetics, especially from 9 to 23 August.

The C:N:P ratio gives some insight into the relative abundance of elements in the particulate material. Though somewhat variable, living phytoplankton usually are characterized by a C:N:P ratio of 106:10-15:1 (Redfield et al., 1963, and Ryther and Dunstan, 1971). In this study N:P ratios were 10:1 to 15:1 about half of the time (Table 5) with the remaining comparisons above or below the ratio of 10:1 to 15:1. C to P was more variable than N to P. In 13 out of 25 comparisons, the C:P ratio was less than 84:1, six times the ratio was between 85-126:1 and six times the ratio was greater than 127:1. These ratios indicate that often the particulate material is richer in P relative to C. Below the euphotic zone in the ocean the particulate material usually is phosphorus poor relative to carbon and nitrogen (Menzel and Ryther, 1964). The question is still open regarding the relative proportion of dissolved phosphorus that is associated with inorganic material between the open sea and coastal waters.

Flux of Material to the Head of the Estuary

We estimated that about 5.6 x 10^3 metric tons of seston, 262 metric tons of PC, 46 metric tons of PN, 135 metric tons of TDN, and 11 metric

tons of TDP passed Nottingham between 25 June and 2 September 1972 (Table 6). During the peak flow from Agnes between 21 and 24 June, we estimated that 14.8 x 10^3 metric tons of seston were transported to the head of the estuary. This estimate was based on an assumed concentration of 100 mg $liter^{-1}$ since no data on concentrations were available at this time. The estimate is probably conservative when compared to other observations during high flows (Flemer et al., 1970). Further estimates are possible if we assume that the ratio of the various fractions, e.g., PC and TDN, relative to seston contributed between 25 June and 2 September would apply during peak flows of Agnes. This crude approach yielded the following estimates of flux between 21 and 24 June: PC = 696, PN = 121, TDN = 352, and TDP = 28 metric tons, respectively.

It is only possible to give a semiquantitative comparison of the flux of material between Agnes and July 1969 since only three samples were taken between the end of June and the end of August 1969. However, for simplicity, the relative flows are instructive. We estimated that for 28 July 1969 and 22 June 1972, times of peak flows, that 3,104 and 42,554 cfs of water, respectively, were delivered to the head of the estuary. As a minimum, the impact of Agnes was 14 times that of the rainfall of July 1969 in terms of water transported to the upper estuarine area.

In the Patuxent upland drainage is a significant source of nutrients. In the Ythan estuary, just north of Aberdeen, Scotland, marine water contributed about 70% of the phosphate, and freshwater supplied about 70% of the nitrate (Leach, 1971). This author presents interesting comparative data on the contribution of nutrients via freshwater. Based on a semidiurnal tidal cycle (like that of the Chesapeake Bay), the Ythan estuary received about 16.8 kg of inorganic phosphate during the summer. By comparison, we estimated that about 360 kg of total dissolved phosphorus per tidal cycle on the average entered the Patuxent estuary from upstream between 25 June and 2 September. We should emphasize that most of the dissolved phosphorus in the Patuxent is apparently inorganic phosphate, thus the comparison has validity.

General Discussion

Earlier work in the Patuxent River estuary showed that the upper tidal system probably borders on hypertrophication (Stross and Stottlemyer, 1965; Herman et al., 1968; and Flemer et al., 1970). Important increases in recent years have occurred in primary productivity, the concentration of chlorophyll a, nitrogen and phosphorus. The increase in available nitrogen seems especially striking. In view of this information, we were especially interested in the impact of Hurricane Agnes as a possible stimulant to further overenrichment. It is surprising that the Patuxent is still free of the massive bluegreen algal growths so characteristic of the upper Potomac estuary (Jaworski et al., 1972). The dilutions of the wastewaters received by the Patuxent and Potomac Rivers are quite similar (Brush, 1972). Other factors surely play important roles. For example, the extensive tidal marshes characteristic of the Patuxent, but not abundant in the upper Potomac, may play the role of a tertiary treatment system. Salt marsh plots near Woods Hole, Mass., have been shown to retain a large fraction of the nitrogen and phosphorus that were experimentally added as sewage sludge (Valiela et al., 1973). We are currently studying the flux of nutrients between a marsh and its dominant tidal creek in the upper Patuxent; however, results are unavailable for this paper (Heinle et al., 1974). Partial information is available for the Patuxent River on the rate of grazing as an important controlling mechanism to excessive algal biomass (Heinle, in press). If an additional trophic level occurs between phytoplankton and copepods, then it is suspected that grazing will be an important regulator to the standing crop of phytoplankton. Unfortunately, we were unable to obtain data on zooplankton during this study to aid in interpretation of their rate of grazing during the extreme hydrographic conditions imposed by Hurricane Agnes. It must be emphasized that conditions that lead to massive bluegreen algal growths are a problem in ecological succession and not simply one of uptake kinetics or development of algal biomass.

The fact that moderately high concentrations of phytoplanktonic biomass occurred during this study compared to previous studies in the Patuxent probably is strongly linked to washout. The

apparent displacement of high chlorophyll levels typical of the sediment trap area to the mouth of the River substantiates this conclusion of the initial phase following Agnes. The sustained high levels of chlorophyll a at the two upper stations after 26 July suggest that washout was of much less significance at this time. The periods of low and high chlorophyll a concentrations seaward to lower Marlboro after about 26 July reflect the dominance of other factors that are known to control phytoplankton biomass. Though other nutrients were not measured, we would suspect from the N:P ratios that nitrogen played an important role. Welch et al. (1972) have shown that phytoplankton blooms in the Duwamish estuary (Seattle, Washington) are strongly influenced by hydrographic conditions.

Comparative information obtained in our post-Agnes study shows that factors measured in the Patuxent are high relative to most temperate estuaries; Thayer (1971) has summarized much of the pertinent data for these systems. Little information is published on the effects of large floods on water quality in temperate estuarine systems. A phenomenon of comparative interest are the monsoon rains that occur in some tropical areas. These disturbances are a partial natural analog to Hurricane Agnes in the Patuxent. In the Cochin Backwater, S. W. India, the depth profile of nutrients, e.g. nitrogen and phosphorus, showed a marked seasonal change induced by land runoff (Sankaranarayanan and Qasim, 1969). The system changes annually from a marine estuary during the premonsoon period to a freshwater system during the monsoon period. At times of maximum discharge and turbidity, the quantity of settled detritus was comparatively low. This resulted from the strong stratification or halocline that developed in the estuary (Qasim and Sankaranarayanan, 1972). In S. E. India the nutrients were increased with monsoon season in the Vellar estuary (Krishnamurthy, 1967). For example, total phosphorus ranged between 1.01 and 5.05 µg at liter^{-1} near the mouth of the Vellar estuary. We would not like to overdraw the above comparison, but the partial environmental parallel seemed worthy of mention.

Ratios of C:N:P and C:chl a and N:chl a used to characterize the particulate material suggest that some important effects resulted from

Hurricane Agnes. Generally, the emergent picture shows that much of the suspended material found in coastal waters, exclusive of temporary algal blooms, is in the form of organic detritus. Compared to previous data for summer conditions in the Patuxent, the relative amount of living algal carbon to total particulate carbon seemed quite high. Some speculations might prove useful, and they may be tested as hypotheses under experimental conditions. It is surmised that the large-scale flushing of the estuary following Agnes reduced the number of many grazers and, consequently, the abundant fecal pellets usually observed in water samples from the Patuxent (Heinle, pers. com.). Also, the detrital carbon derived from upland drainage apparently was diluted. It should be noted that we did not observe exceptionally high levels of particulate carbon. Consequences of a high percent of living carbon in a system usually dominated by detrital carbon would be interesting to examine in terms of food web dynamics.

In the wake of an event such as Agnes we were interested to learn if the flux of particulate carbon that entered the tidal freshwaters above Nottingham was a significant fraction compared to primary production in the estuary. Cronin (1971) gives the mean low water area of the Patuxent from the mouth to approximately Nottingham as $137 \times 10^6 m^2$. As a first approximation, we can assume that net primary production averaged about 1 gCm^{-2} day^{-1} (Stross and Stottlemyer, 1965). Turbidity caused the rate to become somewhat higher downriver and less in the upper portion of the estuary. Thus, 10.1×10^9 gC were estimated to be fixed photosythetically in the estuary from 21 June to 2 September 1972. Thus, 10.1×10^3 metric tons of fixed carbon from phytoplankton activity far exceed the estimated 958 metric tons of PC derived from upland drainage above Nottingham. It is reasonable to assume that Hurricane Agnes contributed much organic material to the head of the estuary where photosynthesis was minimal on an areal basis, but over the 10-week period following the storm, the allochthonous sources of PC were quantitatively minor for the whole estuary.

Compare this result with that obtained from the upper Chesapeake Bay, where on an annual basis the PC derived from upland drainage constituted about 90% of the PC pool (Biggs and Flemer, 1972). In the Strait of

Georgia, British Columbia, the allochthonous organic material contributed per year by upland drainage approximated the natural primary production of the area (Seki, Stephens, and Parsons, 1969). Thus, for coastal bodies of water, there is a broad range in the relative amount of PC derived from land sources compared to natural primary production.

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Table 1. Temperature (C), salinity (°/oo), and dissolved oxygen (mg liter -1), and top (T) and bottom (B), observed during the Patuxent River Post-Agnes Study, summer 1972.

Table 1. Temperature (C), salinity (°/oo), and dissolved oxygen (mg liter $^{-1}$), and top (T) and bottom (B), observed during the Patuxent River Post-Agnes Study, summer 1972.

Station		6/28			7/5			7/12			7/19			7/26		
		Temp.	Sal.	DO	Temp.	Sal.	DO	Temp.	Sal.	DO	Temp.	Sal.	DO	Temp.	Sal.	DO
Hours		14:15			08:15			13:35			07:05			13:45		
Nottingham	T	24.7	0.0	7.7	-	0.0	-	23.6	0.0	6.6	27.0	0.0	4.8	29.5	0.0	7.7
	B	24.0	0.1	7.2	-	0.0	-	23.3	0.0	5.7	26.5	0.0	4.7	34.5*	0.0	6.5
L. Marlboro	T	25.3	0.1	5.2	-	0.0	-	23.9	0.0	7.1	29.0	0.0	6.4	30.0	0.0	9.8
	B	25.0	0.1	5.3	-	0.0	-	23.5	0.0	6.6	30.0	0.0	6.0	36.0*	0.0	6.6
Trueman Pt.	T	27.2	1.4	5.3	-	0.0	-	25.0	0.0	7.0	29.9	0.0	7.0	30.0	0.5	6.5
	B	27.0	1.9	5.6	-	0.0	-	24.5	0.0	6.6	30.0	0.0	6.3	33.3	1.6	6.1
Benedict Br.	T	26.0	2.5	5.3	24.0	0.0	5.4	25.4	0.0	7.2	28.0	0.0	7.2	29.7	2.3	6.7
	B	25.8	2.6	5.0	23.9	0.3	4.1	25.2	1.1	6.5	27.0	2.4	6.5	32.0	2.6	6.0
Sheridan Pt.	T	25.5	3.1	5.3	23.5	0.5	6.1	24.7	2.3	7.6	26.0	1.4	8.2	27.9	3.1	6.6
	B	24.1	4.1	2.8	21.0	2.3	2.9	24.0	2.5	3.3	24.0	4.5	2.0	27.6	4.0	4.0
Queen Tree	T	25.5	3.6	7.0	23.0	1.5	7.8	24.5	2.8	9.1	27.8	2.3	8.5	27.4	3.4	6.9
	B	25.0	4.4	2.6	21.2	4.0	2.5	23.9	3.4	3.5	23.5	5.0	1.5	26.7	4.4	1.9
Broome Is.	T	26.0	4.2	7.4	22.5	1.3	7.0	24.2	2.3	9.2	26.0	2.3	8.6	27.0	3.4	6.3
	B	25.5	4.7	2.7	21.0	4.5	3.0	22.9	4.5	4.0	24.5	5.6	2.2	27.2	4.4	1.6
Sandy Pt.	T	26.0	4.7*	6.8	22.0	1.3	8.6	23.9	4.5	9.1	25.5	4.5	7.9	27.0	5.0	6.3
	B	24.5	3.1	2.3	21.0	4.5	4.2	22.9	5.6	5.4	24.5	5.6	4.6	27.2	5.0	4.3
Hours		10:35			05:30			10:45			04:15			10:10		

Notes: * asterisk mark unusual results. Time in hours of initiation of sampling is given at bottom of each column and time of conclusion of sampling at the upstream station is given at the top of each column.

Table 1 Continued. Temperature (C), salinity (^{o}/oo), and dissolved oxygen (mg liter^{-1}), and top (T) and bottom (B), observed during the Patuxent River Post-Agnes Study, summer 1972.

Station		8/2			8/9			8/16			8/23			8/30		
		Temp.	Sal.	DO	Temp.	Sal.	DO	Temp.	Sal.	DO	Temp.	Sal.	DO	Temp.	Sal.	DO
Hours			07:10			12:20			07:46			10:43			16:35	
Nottingham	T	24.7	0.0	7.7	26.5	0.1	8.2	24.2	0.2	7.3	-	-	-	26.5	0.1	9.1
	B	24.0	0.1	7.2	25.0	0.2	8.4	23.8	0.2	7.1	-	-	-	26.5	0.1	8.9
L. Marlboro	T	25.3	0.0	5.2	27.0	0.0	6.8	25.0	0.8	6.4	-	-	-	27.5	0.3	7.5
	B	25.0	0.1	5.3	26.0	0.1	6.2	24.3	0.7	6.5	-	-	-	27.5	0.3	7.0
Trueman Pt.	T	27.2	1.4	5.3	27.5	0.9	7.8	25.1	2.2	6.7	27.2	2.8	6.8	28.5	2.5	6.4
	B	27.5	1.9	5.6	28.0	1.0	6.8	24.5	2.4	6.7	27.3	4.0	7.0	29.5	3.1	6.7
Benedict Br.	T	26.0	2.5	5.3	27.0	2.7	7.8	24.1	5.4	5.5	27.0	5.3	6.5	29.0	5.7	7.2
	B	25.8	2.6	5.0	27.0	2.9	6.5	24.1	6.2	3.7	26.5	5.6	5.3	28.0	6.3	4.3
Sheridan Pt.	T	25.5	3.1	5.3	26.5	3.4	9.8	24.5	5.2	5.7	27.9	6.2	7.9	25.5	6.9	7.3
	B	24.1	4.1	2.8	26.0	6.1	1.1	24.0	7.6	0.3	25.3	7.3	1.6	26.0	9.7	0.1
Queen Tree	T	25.5	3.6	7.0	26.0	3.8	9.4	24.8	5.4	6.9	26.9	6.4	7.8	25.5	7.6	7.1
	B	25.0	4.4	2.6	25.0	6.8	0.9	24.0	7.9	0.4	25.0	8.0	0.9	26.5	10.4	0.3
Broome Is.	T	26.0	4.2	7.4	25.5	3.9	10.3	24.2	5.9	6.5	27.0	7.2	9.5	27.0	7.8	5.2
	B	24.5	4.7	2.7	20.3	9.3	0.4	24.0	9.3	0.4	24.5	7.3	0.2	26.5	10.4	0.4
Sandy Pt.	T	26.0	4.7*	6.8	25.1	6.0	8.6	24.0	7.7	6.5	24.5	8.6	7.5	26.0	9.3	2.3
	B	24.5	3.0	2.3	20.3	9.8	1.4	24.0	9.3	5.3	24.5	9.5	3.8	24.5	10.4	2.6
Hours			03:55			09:30			03:35			08:52			13:16	

Notes: *asterisk mark unusual results. Time in hours of initiation of sampling is given at bottom of each column and time of conclusion of sampling at the upstream station is given at top of each column.

the surface (S) and bottom (B) waters. Post-

Table 2. The percent particulate carbon of seston in the surface (S) and bottom (B) waters, Post-Agnes Study, Patuxent River Estuary, summer 1972.

	STATIONS															
	Nottingham		Lower Marlboro		Trueman Pt.		Benedict Br.		Sheridan Pt.		Queen Tree		Broome Is.		Sandy Pt.	
Date	S	B	S	B	S	B	S	B	S	B	S	B	S	B	S	B
6/28	4.8	4.0	-	3.3	2.6	2.8	2.6	2.2	2.7	2.3	4.5	1.4	7.4	2.2	8.2	2.2
7/5	3.7	3.5	4.0	3.9	2.1	3.8	3.8	4.3	1.4	5.0	8.1	4.0	6.9	2.9	8.3	3.5
7/13	5.0	4.0	4.4	4.0	3.5	4.2	2.7	2.9	4.3	2.1	2.9	5.0	7.5	2.9	11.5	2.5
7/19	0.9	3.1	5.0	5.0	4.2	5.0	4.7	7.6	3.9	2.8	7.9	2.8	7.9	3.6	12.0	11.2
7/26	4.8	5.6	4.4	3.0	3.0	5.1	4.0	6.0	3.6	5.6	2.8	5.0	4.5	3.6	9.0	7.1
8/2	4.7	3.8	3.6	3.1	3.4	3.0	2.1	2.8	5.6	3.2	5.0	2.7	8.0	3.7	10.8	6.7
8/9	8.7	10.0	7.5	6.7	6.2	2.0	8.1	5.5	17.9	4.6	13.0	5.8	20.0	2.5	13.1	4.2
8/16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8/23	-	-	-	-	7.5	6.9	8.9	6.6	10.4	5.7	7.5	5.4	60.4	3.0	12.5	6.8
8/30	17.1	16.7	10.8	6.5	6.9	4.6	21.1	13.5	22.5	2.9	11.4	2.5	6.4	2.9	-	4.4
x	6.2	6.3	5.7	4.4	4.4	4.2	6.4	5.7	8.0	3.8	7.0	3.8	8.6	3.0	10.7	5.4

✓ Average exclusive of high value observed on 8/23.

Table 3. Correlation coefficents equal to or greater than + 0.80 or - 0.70, Post Agnes Study, Patuxent River Estuary, 28 June to 30 August 1972.

Station	Factors	Correlation Coefficent	d.f.	P.
Nottingham Surface				
		POSITIVE		
	NO_2 X TDN	0.87	7	0.998
	NO_3 X TDN	0.97	7	1.000
	NO_3 X TDN	0.87	7	0.998
	TDN X DIP	0.95	7	1.990
	TDN X TDP	0.87	7	0.998
	DIP X TDP	0.90	7	0.999
	TCL X ACL	0.996	8	1.000
		NEGATIVE		
	NO_3 X PC	-0.86	8	0.999
	NO_3 X TCL	-0.86	8	.999
	NO_3 X ACL	-0.82	8	.997
	NH_3 X TCL	-0.85	6	.992
	NH_3 X ACL	-0.82	6	.988
	TDN X PN	- .75	7	.983
	TDN x PC	- .83	7	.994
	TDN X TCL	- .81	7	.992
	TDN X ACL	- .76	7	.985
	TDN X SAL	- .77	7	.987
	TDP X PC	- .91	7	.999
	TDP X ACL	- .74	7	.982
	TP X SAL	- .78	5	.968
Bottom		POSITIVE		
	PN X TCL	.92	7	1.000
	PN X ACL	.92	7	.994
	TCL X ACL	.99	8	1.000
		NEGATIVE (NONE)		
Lower Marlboro Surface		POSITIVE		
	TCL X ACL	0.99	8	1.000
		NEGATIVE (NONE)		
Bottom		POSITIVE		
	PC X SES	.95	7	1.000
	TCL X ACL	.99	8	1.000
		NEGATIVE (NONE)		
Trueman Pt. Surface		POSTIVE		
	TCL X ACL	.99	9	1.000
		NEGATIVE (NONE)		

Table 3. Continued.

Station	Factors	Correlation Coefficent	d.f	P.
		POSITIVE		
Bottom	PN X PC	.84	9	.999
	PN X SES	.83	8	.999
	TCL X ACL	1.00	9	1.000
		NEGATIVE		
		(NONE)		
Benedict Bridge				
Surface		POSITIVE		
	NO_2 x NO_3	.99	9	1.000
	NO_2 x TDN	.88	8	.999
	NO_3 x TDN	.88	8	.999
	NO_3 x DIP	.82	9	.998
	TCL x ACL	.99	9	1.000
		NEGATIVE		
	NO_2 x SAL	-.78	9	.996
	NO_3 x TCL	-.74	9	.993
	NO_3 x ACL	-.76	9	.995
	NO_3 x SAL	-.76	9	.995
	TDN x PC	-.71	8	.984
	TDN x SAL	-.78	8	.993
	DIP x SAL	-.70	9	.987
Bottom		POSITIVE		
	TCL X ACL	1.00	9	1.000
		NEGATIVE		
	PC X SES	-.71	8	.984
Sheridan Pt.				
Surface		POSITIVE		
	PN X TCL	.96	9	1.000
	PN X ACL	.96	9	1.000
	TCL X ACL	.98	9	1.000
		NEGATIVE		
		(NONE)		
Sheridan Pt.		POSITIVE		
Surface	TCL X ACL	0.96	9	1.000
		NEGATIVE		
		(NONE)		
Queen Tree				
Surface		POSITIVE		
	NO_2 X TDN	.85	9	.999
	TDP X SAL	.84	9	.999
	TCL X ACL	.99	9	1.000
		NEGATIVE		
		(NONE)		
Bottom		POSITIVE		
	TCL X ACL	.97	9	1.000
		NEGATIVE		
		(NONE)		

Table 3. Continued.

Location	Factors	Correlation Coefficent	d.f.	P.
Broome Is. Surface		POSITIVE		
	PN X PC	.97	9	1.000
	PN X TCL	.94	9	1.000
	PN X ACL	.93	9	1.000
	PN X SES	.90	8	1.000
	PC X TCL	.90	9	1.000
	PC X ACL	.89	9	1.000
	PC X SES	.89	8	.994
	TCL X ACL	1.00	9	1.000
		NEGATIVE (NONE)		
Bottom		POSITIVE		
	PN X PC	.80	9	.998
	PN X SES	.82	8	.999
	PC X SES	.95	8	1.000
	TCL X ACL	.87	9	.999
		NEGATIVE (NONE)		
Sandy Pt. Surface		POSITIVE		
	NO_3 X NH_3	.82	9	.998
	NO_3 X TDN	.94	9	1.000
	NH_3 X TDN	.85	9	.999
	PN X TP	.91	6	.998
	PN X PC	.84	9	.999
	PN X TCL	.87	9	.999
	PN X ACL	.86	9	.999
	TP X TCL	.93	6	.999
	TP X ACL	.94	6	.999
	TCL X ACL	1.00	9	1.000
		NEGATIVE		
	NO_3 X TDP	-.73	8	.988
	NO_3 X SAL	-.70	9	.980
	TDN X SAL	-.74	9	.992
	DON X TP	-.78	6	.980
Bottom		POSITIVE		
	PN X PC	.94	9	1.000
	PN X TCL	.86	9	.999
	PN X ACL	.87	9	.999
	PC X TCL	.94	9	1.000
	PC X ACL	.95	9	1.000
	TCL X ACL	1,00	9	1.000
		NEGATIVE (NONE)		

Table 4. The ratio of dissolved inorganic nitrogen to dissolved inorganic phosphate-phosphorus, Patuxent River Post-Agnes Study, summer 1972.

Date	STATIONS Nottingham	Benedict Br.	Queen Tree	Sandy Pt.
28 June	31	-	33	179
5 July	28	24	13	95
12 July	25	17	46	74
19 July	22	8	15	86
26 July	17	15	276	66
2 Aug.	28	22	54	60
9 Aug.	-	0.7	1.6	48
16 Aug.	17	1.6	2.0	15
23 Aug.	-	1.1	2.2	37
30 Aug.	73	13	50	34

Table 5. The atomic ratio of C:N:P in particulate material, Patuxent River Post-Agnes Study, summer 1972.

Date	STATIONS Nottingham C:N:P	Benedict Br. C:N:P	Queen Tree C:N:P	Sandy Pt. C:N:P
28 June	39:6:1	-	99:23:1	80:12:1
7 July	-	-	-	-
12 July	-	-	-	-
19 July	-	-	-	-
26 July	42:8:1	48:7:1	49:10:1	78:11:1
2 Aug.	55:7:1	21:6:1	63:11:1	96:17:1
9 Aug.	-	73:10:1	135:16:1	89:10:1
16 Aug.	68:8:1	118:9:1	49:11:1	129:21:1
23 Aug.	-	107:10:1	160:20:1	108:13:1
30 Aug.	69:37:1	218:11:1	132:12:1	434:21:1

Table 6. Flux of materials to the head of the Patuxent River Estuary, Post-Agnes Study, summer 1972.

DATE	Q_T	SESTON		PC		PN		TDN		TDP	
	$m^3/At \times 10^6$	$\bar{x}$ conc. mgl^{-1}	Flux $g \times 10^9$	$\bar{x}$ conc. mgl^{-1}	Flux $g \times 10^6$	$\bar{x}$ conc. mgl^{-1}	Flux $g \times 10^6$	conc. $\mu g\ atl^{-1}$	Flux $g \times 10^6$	conc. $\mu g\ atl^{-1}$	Flux $g \times 10^6$
28 June	42.6	33	1.4	1.4	59.6	0.257	10.9	73.8	44.0	2.87	3.8
5 July	21.1	54	1.1	2.0	42.2	0.257	5.4	84.6	25.0	2.38	1.6
12 July	16.8	32	0.5	1.4	23.5	0.355	6.0	81.2	19.1	2.62	1.4
19 July	18.1	32	0.5	0.6	10.9	0.138	2.5	91.4	23.2	2.99	1.7
26 July	7.9	48	0.4	2.5	19.8	0.548	4.3	56.3	6.2	2.18	0.54
2 Aug.	8.1	120	1.0	4.9	39.7	0.600	4.9	64.0	7.3	1.45	0.36
9 Aug.	6.9	40	0.3	3.8	26.2	0.400	2.8	40.0[1]	3.9	4.00[2]	0.86
16 Aug.	6.0	35[1]	0.2	1.8	10.8	0.433	2.6	38.5	3.2	1.09	0.20
23 Aug.	3.8	20[1]	0.08	3.0[1]	11.4	0.6[1]	2.3	20.0[1]	1.1	1.17[1]	0.14
30 Aug.	4.4	24	0.1	4.0	17.6	1.030	4.5	33.1	2.0	1.21	0.17
TOTAL			5.6		261.7		46.2		135		10.8

[1] estimates based on flow and values preceding and following missing data.
[2] based on DIP.
Note - Q_T is an estimate of total freshwater discharge to the head of the estuary.

Appendix. Patuxent River Post-Agnes Data Summary, summer of 1972.

Seston (mg liter^{-1})

Station		DATE 6/28	7/5	7/12	7/19	7/26	8/2	8/9	8/16	8/23	8/30
Sandy Pt.	T	33	12	20	20	20	12	16	-	24	12
	B	45	20	28	32	28	24	24	-	25	16
Broome Is.	T	27	16	16	24	20	20	16	-	48	28
	B	45	24	28	28	15	68	24	-	70	24
Queen Tree	T	40	16	28	24	25	20	20	-	20	28
	B	35	20	36	32	20	56	24	-	24	24
Sheridan Pt.	T	40	64	35	28	25	16	24	-	24	32
	B	35	36	48	36	25	25	28	-	28	28
Benedict Br.	T	50	24	56	36	45	24	36	-	35	36
	B	55	44	48	25	35	64	40	-	35	20
Trueman Pt.	T	87	67	48	50	64	35	32	-	48	32
	B	80	120	48	40	35	64	64	-	48	48
L. Marlboro	T	40	47	32	32	48	56	24	-	-	24
	B	60	170	40	40	40	136	24	-	-	40
Nottingham	T	27	54	24	32	48	72	32	-	-	24
	B	40	54	40	32	48	168	48	-	-	24

T= Top
B= Bottom

Active Chlorophyll a continued on next page.

Active Chlorophyll a ($mg\ m^{-3}$)

Station		6/28	7/5	7/12	7/19	7/26	8/2	8/9	8/16	8/23	8/30
Sandy Pt.	T	46.0	13.2	33.5	35.9	31.2	19.2	38.3	9.3	44.9	54.5
	B	2.0	5.7	3.6	38.3	18.0	26.3	10.2	55.1	9.9	6.3
Broome Is.	T	44.0	18.0	18.0	22.4	9.8	31.2	74.2	16.2	127.2	18.0
	B	1.5	2.2	5.6	7.3	6.9	7.2	5.7	4.6	4.3	4.5
Queen Tree	T	24.0	21.6	25.2	34.7	10.7	14.4	55.1	19.2	15.0	36.5
	B	1.5	6.9	3.2	6.8	14.4	6.5	18.0	3.6	7.3	1.1
Sheridan Pt.	T	9.5	11.0	14.7	29.9	10.8	19.2	53.8	26.3	31.5	43.1
	B	3.5	4.2	5.2	7.2	20.3	7.3	12.0	5.2	11.6	1.6
Benedict Br.	T	3.0	8.7	15.6	29.9	35.3	13.2	49.4	19.2	29.2	38.3
	B	2.0	6.8	9.6	39.0	49.1	10.8	40.4	27.5	15.5	18.0
Trueman Pt.	T	6.0	8.6	16.3	29.9	28.7	10.8	46.4	31.1	23.9	18.9
	B	4.0	8.7	14.9	28.7	38.3	8.2	34.4	28.7	27.5	19.2
L. Marlboro	T	6.0	5.0	17.8	43.1	69.4	20.3	33.4	35.9	--	33.5
		5.0	6.6	19.7	38.3	20.3	26.4	23.9	31.1	--	35.5
Nottingham	T	4.0	5.5	15.5	7.0	81.4	71.8	105.3	45.4	--	74.2
	B	4.0	6.0	10.2	6.6	103.0	105.3	35.9	52.6	--	75.3

Total Chlorophyll a ($mg\ m^{-3}$)

Sandy Pt	T	52.7	17.6	38.5	40.3	36.6	23.4	44.6	11.9	54.4	66.6
	B	3.5	8.7	5.7	43.9	22.0	31.5	13.0	64.4	13.2	8.0
Broome Is.	T	51.3	21.2	21.2	28.2	14.2	38.8	83.4	19.0	149.7	22.0
	B	2.5	4.9	8.9	11.9	11.0	7.8	11.4	6.0	5.6	6.6
Queen Tree	T	29.5	25.6	30.8	43.2	14.7	19.8	64.4	23.4	18.7	39.9
	B	2.5	11.7	7.0	11.4	19.0	13.2	23.4	5.2	9.1	1.1

Total Chlorophyll a continued on next page

Total Chlorophyll a continued

Station		6/28	7/5	7/12	7/19	7/26	8/2	8/9	8/16	8/23	8/30
Sheridan Pt.	T	11.0	14.4	20.5	36.6	16.8	24.2	71.7	34.4	36.1	46.4
	B	4.5	7.9	10.2	14.3	26.4	11.7	16.1	8.0	12.6	2.6
Benedict Br.	T	4.0	11.6	20.5	38.5	44.6	17.6	58.6	23.4	35.2	41.2
	B	3.5	10.4	14.6	48.5	60.0	17.6	51.2	32.9	19.5	19.3
Trueman Pt.	T	9.0	11.2	22.5	38.5	37.3	14.6	57.6	42.5	30.7	24.4
	B	6.0	12.8	20.7	36.6	46.8	13.5	45.8	36.6	35.1	24.9
L. Marlboro	T	7.0	7.5	21.6	51.3	82.0	27.8	42.5	51.2	-	46.8
	B	6.0	9.5	24.9	46.9	27.1	39.5	32.0	41.0	-	46.8
Nottingham	T	5.0	8.3	19.5	9.9	92.2	84.9	120.1	61.5	-	95.2
	B	5.0	8.2	13.7	9.5	115.6	115.6	45.4	70.3	-	96.6

Particulate Carbon (mg liter^{-1})

Station											
Sandy Pt.	T	2.7	1.0	2.3	2.4	1.8	1.3	2.1	1.1	3.0	14.6
	B	1.0	0.7	0.7	3.6	2.0	1.6	1.0	4.0	1.7	0.7
Broome Is.	T	2.0	1.1	1.2	1.9	0.9	1.6	3.2	1.3	29.0	1.8
	B	1.0	0.7	0.8	1.0	0.9	2.5	0.6	0.8	2.1	0.7
Queen Tree	T	1.8	1.3	0.8	1.9	0.7	1.0	2.6	1.1	1.5	3.2
	B	0.5	0.8	1.8	0.9	1.0	1.5	1.4	1.1	1.3	0.6
Sheridan Pt.	T	1.1	0.9	1.5	1.1	0.9	0.9	4.3	3.1	2.5	7.2
	B	0.8	1.8	1.0	1.0	1.4	0.8	1.3	1.5	1.6	0.8
Benedict Br.	T	1.3	0.9	1.5	1.7	1.8	0.5	2.9	2.3	3.1	7.6
	B	1.2	1.9	1.4	1.9	2.1	1.8	2.2	2.5	2.3	2.7
Trueman Pt.	T	2.3	1.4	1.7	2.1	1.9	1.2	2.0	3.0	3.6	2.2
	B	2.2	4.6	2.0	2.0	1.8	1.9	1.3	3.8	3.3	2.2

Particulate Carbon continued on next page.

Particulate Carbon continued

Station		6/28	7/5	7/12	7/19	7/26	8/2	8/9	8/16	8/23	8/30
L. Marlboro	T	-	1.9	1.4	1.6	2.1	2.0	1.8	1.1	--	2.6
	B	2.0	6.6	1.6	2.0	1.2	4.2	1.6	2.0	--	2.6
Nottingham	T	1.3	2.0	1.2	0.3	2.3	3.4	2.8	2.7		4.1
	B	1.6	1.9	1.6	1.0	2.7	6.4	4.8	0.9	--	4.0

Particulate Nitrogen (mg liter $^{-1}$)

Sandy Pt.	T	0.567	0.157	0.436	0.497	0.281	0.265	0.285	0.209	0.441	0.823
	B	0.131	0.193	0.181	0.628	0.369	0.287	0.156	0.484	0.250	0.162
Broome Is,	T	0.521	0.251	0.275	0.487	0.135	0.328	0.486	0.200	1.584	0.316
	B	0.506	0.215	0.140	0.323	0.157	0.387	0.148	0.121	0.346	0.166
Queen Tree	T	0.484	0.215	0.328	0.437	0.157	0.202	0.368	0.284	0.231	0.356
	B	0.083	0.189	0.216	0.225	0.207	0.271	0.230	0.135	0.144	0.100
Sheridan Pt.	T	0.111	0.179	0.282	0.407	0.163	0.189	0.595	0.284	0.352	0.465
	B	0.354	0.428	0.299	0.183	0.224	0.047	0.203	0.138	0.202	0.164
Benedict Br.	T	0.196	0.193	0.501	0.407	0.327	0.174	0.474	0.210	0.342	0.458
	B	0.128	0.280	0.483	0.467	0.409	0.448	0.342	0.378	0.258	0.295
Trueman Pt.	T	0.345	0.362	0.520	0.329	0.326	0.285	0.373	0.382	0.170	0.511
	B	0.367	0.778	0.375	0.363	0.327	0.278	0.408	0.535	0.385	0.317
L. Marlboro	T	0.422	0.448	0.620	0.608	0.638	0.189	0.319	0.296	-	0.370
	B	0.455	0.642	0.378	0.454	0.090	0.546	0.195	0.445	-	0.396
Nottingham	T	0.259	0.257	0.387	0.098	0.503	0.502	0.266	0.394	-	1.504
	B	0.254	--	0.323	0.179	0.593	0.698	0.534	0.472	-	0.555

Dissolved inorganic phosphate-phosphorus (DIP), total dissolved phosphorus (TDP) and total phosphorus (TP) at the surface -- (µg at liter^{-1})

	DATE									
	6/28	7/5	7/12	7/19	7/26	8/2	8/9	8/16	8/23	8/30
					Sandy Pt.					
DIP	0.56	0.66	0.56	0.41	-	0.56	0.41	0.76	0.20	0.71
TDP	-	0.26	0.58	0.34	-	0.57	0.55	0.82	0.58	1.25
TP	3.79	-	-	-	-	1.64	2.51	1.54	2.91	4.04
					Queen Tree					
DIP	0.81	1.83	0.36	0.41	-	0.25	0.56	0.61	0.40	0.60
TDP	0.63	.35	0.46	0.63	-	0.58	0.40	0.59	0.87	1.22
TP	2.15	-	-	-	-	1.88	2.03	2.39	1.69	3.20
					Benedict Br.					
DIP	1.42	1.83	1.98	1.68	-	1.02	0.76	0.81	1.21	1.01
TDP	-	1.70	1.68	1.11	-	1.44	0.88	0.93	1.84	1.53
TP	4.31	-	-	-	-	3.44	4.22	2.49	4.21	4.41
					Nottingham					
DIP	1.88	2.19	2.34	2.85	-	1.17	3.97	0.92	-	0.71
TDP	2.87	2.38	2.62	2.99	-	1.45	-	1.09	-	1.21
TP	5.68	-	-	-	-	6.55	4.76	4.36	-	6.09

Ammonia (NH_3), nitrite (NO_2), nitrate (NO_3), dissolved organic nitrogen (DON) and total dissolved nitrogen (TDN) at the surface (µg at liter $^{-1}$).

	DATE									
	6/28	7/5	7/12	7/19	7/26	8/2	8/9	8/16	8/23	8/30
					Sandy Pt.					
NH_3	48.1	29.6	16.7	16.0	-	9.8	7.7	3.1	2.7	21.5
NO_2	1.1	0.9	1.4	1.3	-	1.8	1.0	0.7	0.2	0.4
NO_3	51.1	32.1	23.4	18.1	-	22.2	11.0	7.6	4.6	2.6
DON	5.0	13.4	20.3	12.6	-	25.8	25.6	22.4	12.1	6.3
TDN	105.3	76.0	61.8	48.0	-	59.6	45.2	33.8	19.6	30.8
					Queen Tree					
NH_3	7.7	3.0	6.6	4.2	-	5.5	0.4	0.7	0.6	-
NO_2	0.7	1.0	0.7	0.1	-	0.8	0.0	0.0	0.1	0.0
NO_3	18.2	20.7	9.2	1.8	-	7.3	0.5	0.5	0.2	0.1
DON	15.6	11.9	23.7	29.2	-	25.4	11.0	19.6	22.2	-
TDN	42.2	36.6	40.2	35.4	-	39.0	11.9	20.8	23.1	22.8
					Benedit Br.					
NH_3	-	12.5	2.9	1.5	-	10.8	0.4	1.1	0.0	-
NO_2	0.8	1.5	1.0	0.4	-	0.6	0.0	0.0	0.0	0.1
NO_3	23.1	30.3	29.4	12.8	-	10.9	0.1	0.2	0.0	0.0
DON	--	11.6	27.4	11.5	-	28.1	26.4	14.9	20.6	-
TDN	-	55.9	60.7	26.2	-	50.4	26.9	16.2	20.6	11.1
					Nottingham					
NH_3	16.0	13.9	6.9	9.3	-	3.1	-	0.6	-	-
NO_2	1.4	2.0	2.3	2.3	-	2.1	1.9	1.0	-	0.9
NO_3	41.7	45.0	49.7	50.8	-	27.6	19.2	14.4	-	7.2
DON	13.9	23.8	22.3	29.0	-	31.3	-	22.6	-	-
TDN	73.0	84.9	81.2	91.4	-	64.1	-	38.6	-	33.1

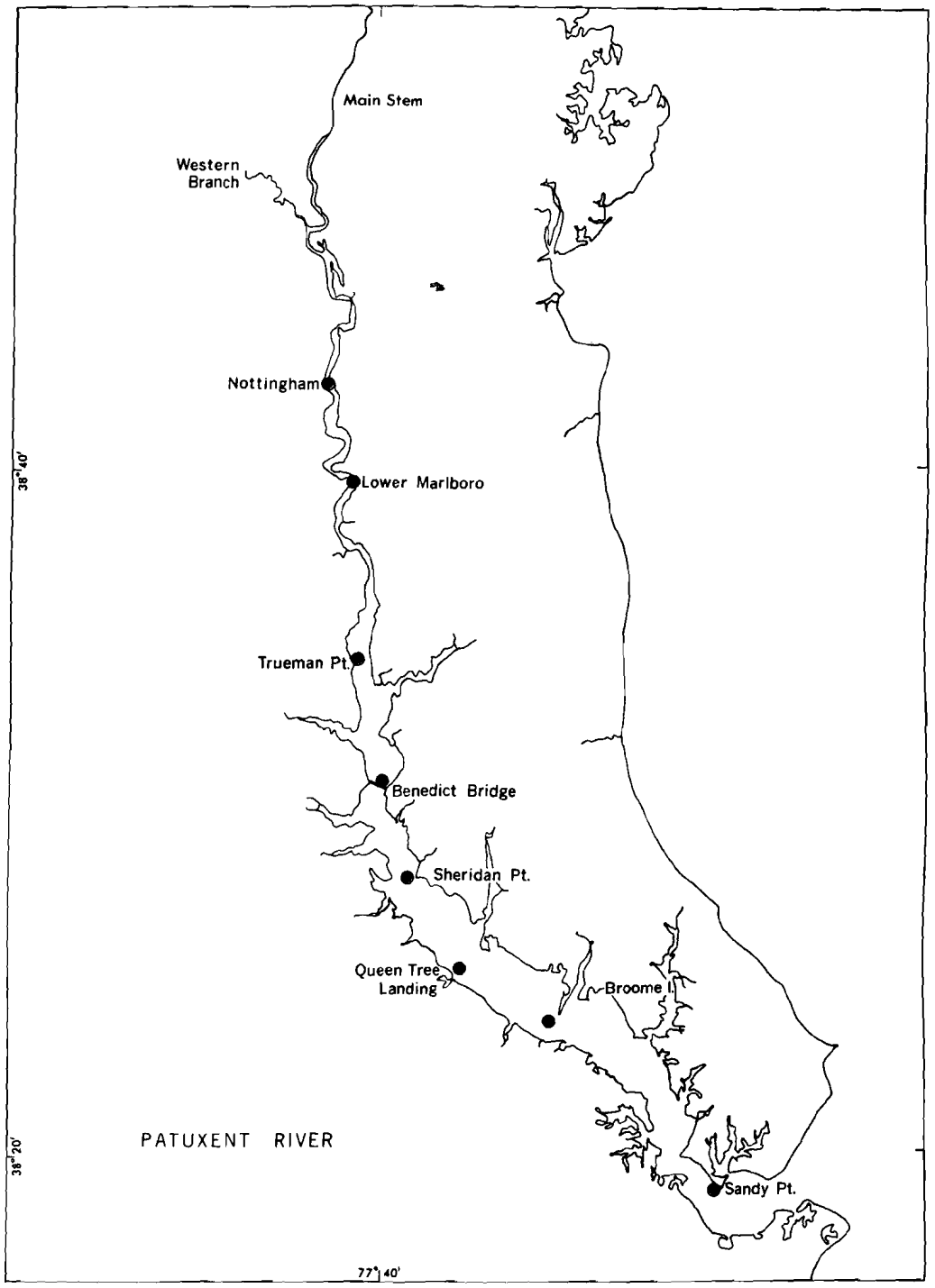

Fig. 1. Map of the Patuxent River estuary showing station locations.

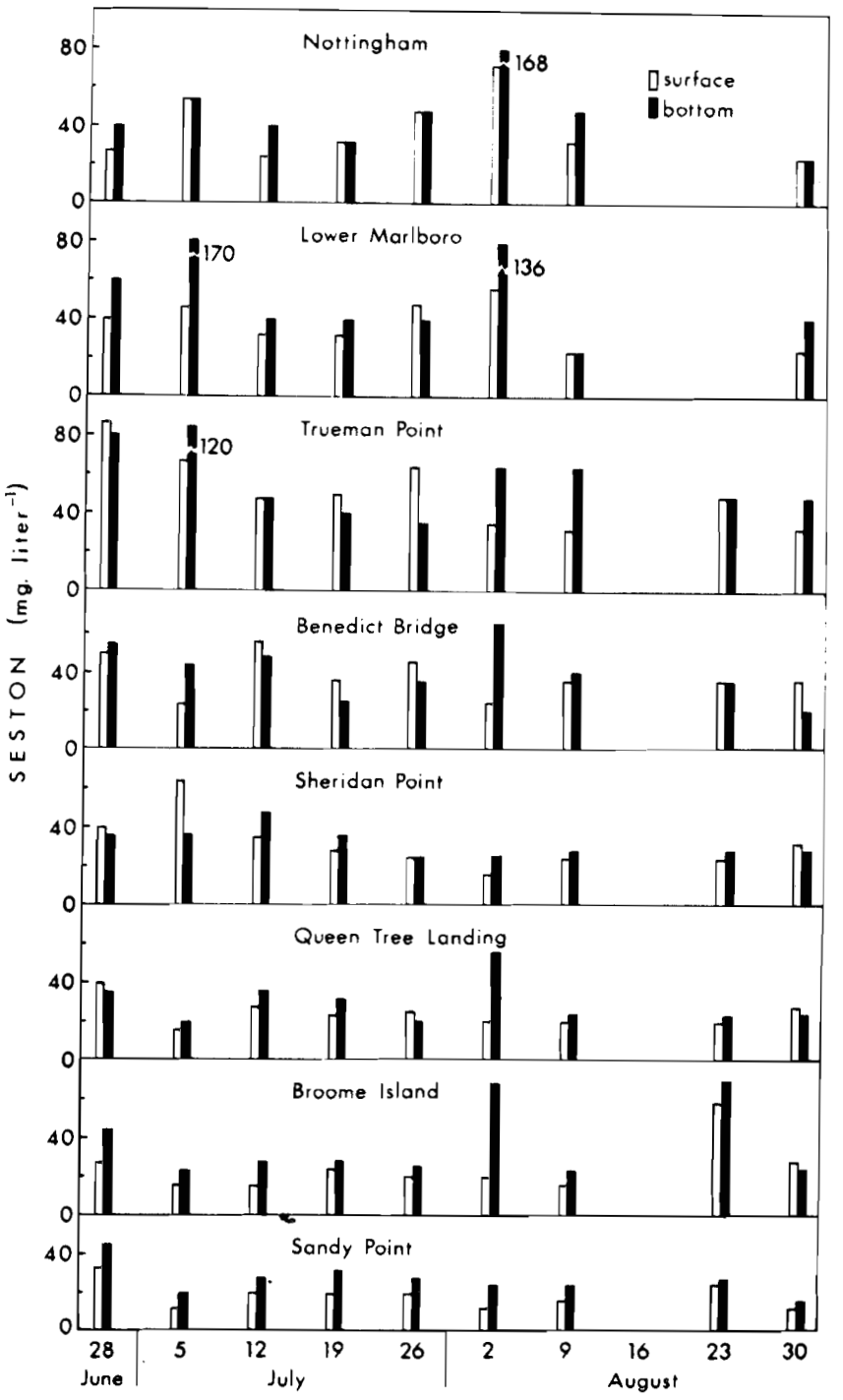

Fig. 2. Surface and bottom seston concentrations (mg liter^{-1}) observed in the Patuxent River estuary during the Post-Agnes Study, summer 1972.

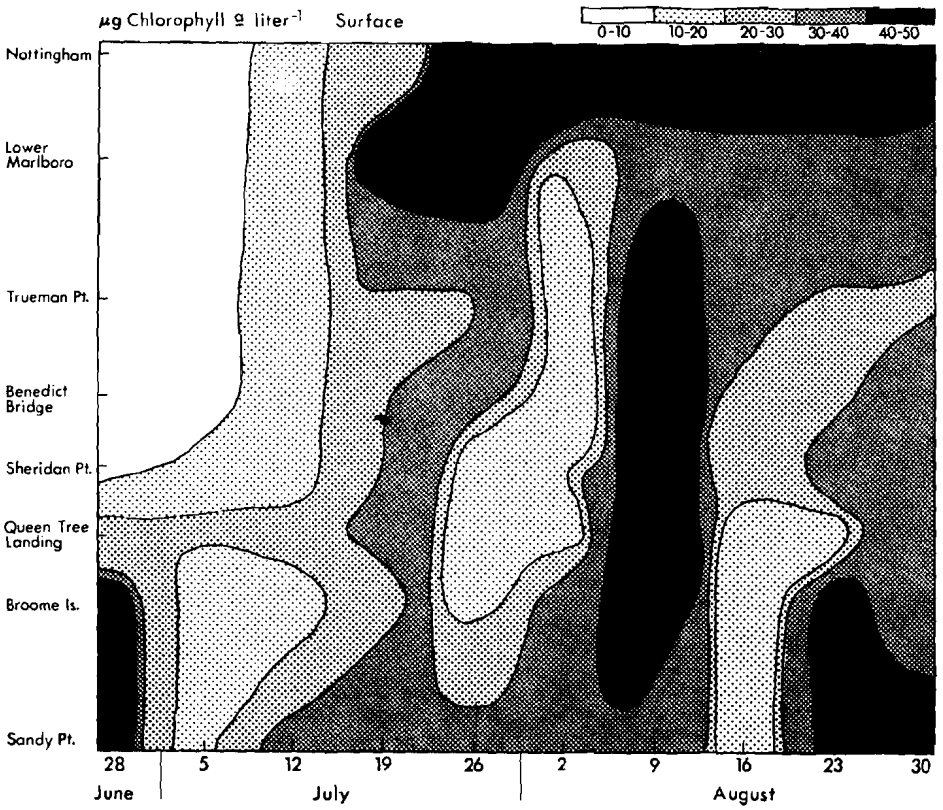

Fig. 3a. Surface concentration of active chlorophyll a (mg m^{-3}) observed in the Patuxent River estuary during the Post-Agnes Study, summer 1972.

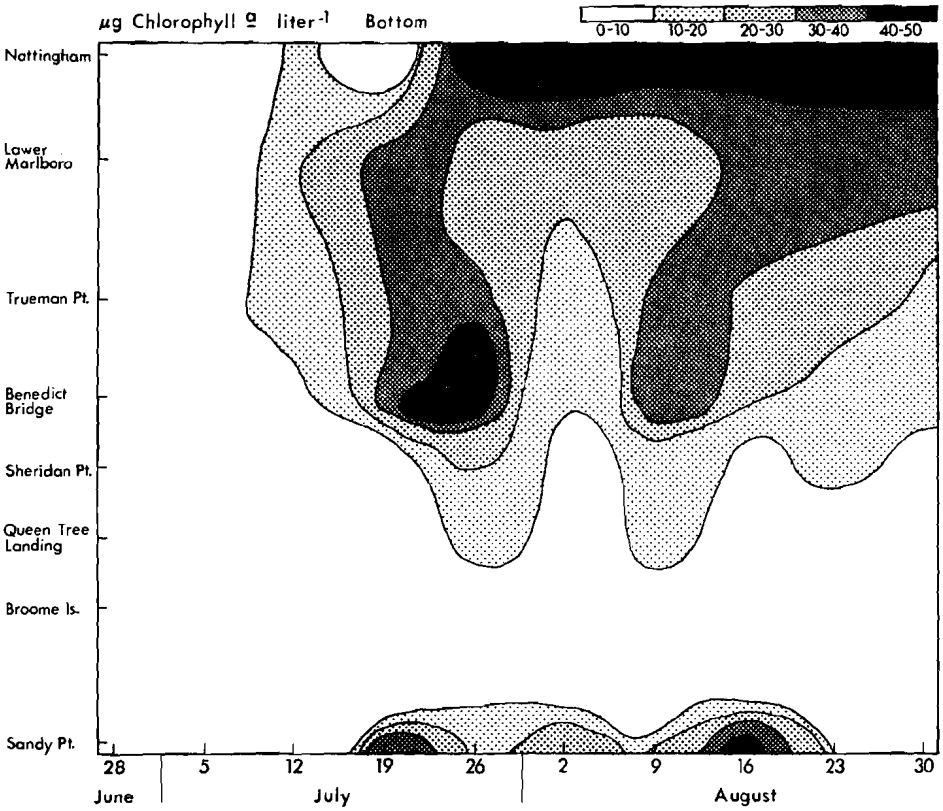

Fig. 3b. Bottom concentration of active chlorophyll a (mg m^{-3}) observed in the Patuxent River estuary during the Post-Agnes Study, summer, 1972.

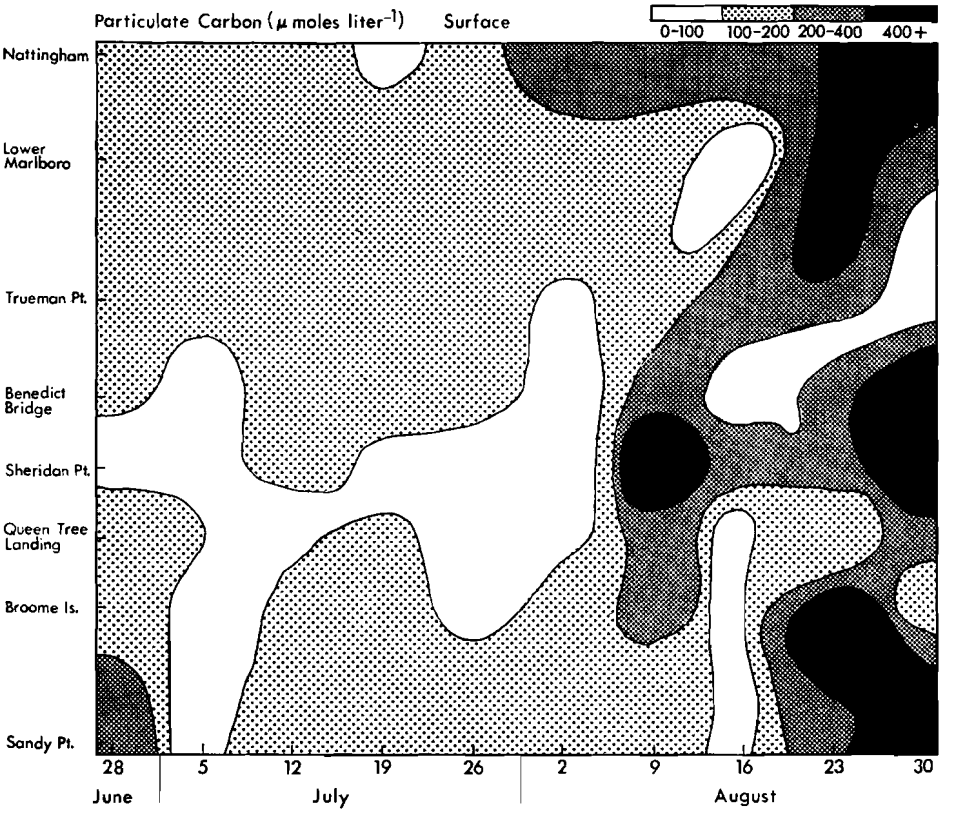

Fig. 4a. Surface concentration of particulate carbon (μ moles liter^{-1}) observed in the Patuxent River estuary during the Post-Agnes Study, summer 1972.

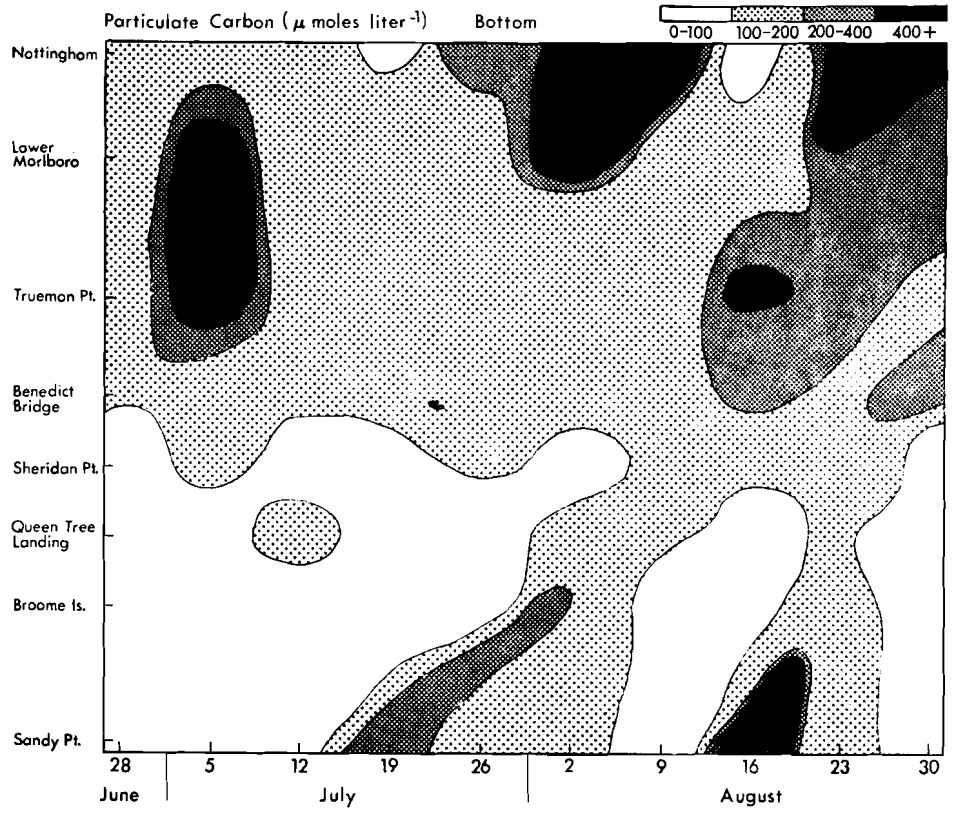

Fig. 4b. Bottom concentration of particulate nitrogen (μ moles liter^{-1}) observed in the Patuxent River extuary during the Post-Agnes Study, summer 1972.

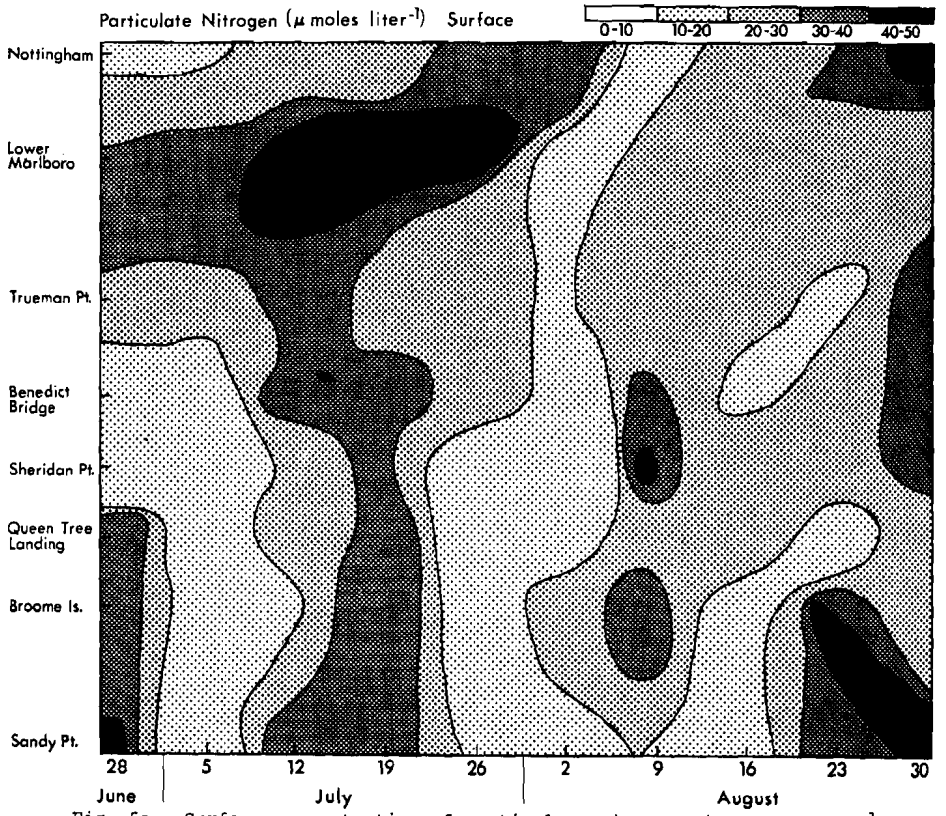

Fig. 5a. Surface concentration of particulate nitrogen (μ moles liter^{-1}) observed in the Patuxent River estuary during the Post-Agnes Study, summer 1972.

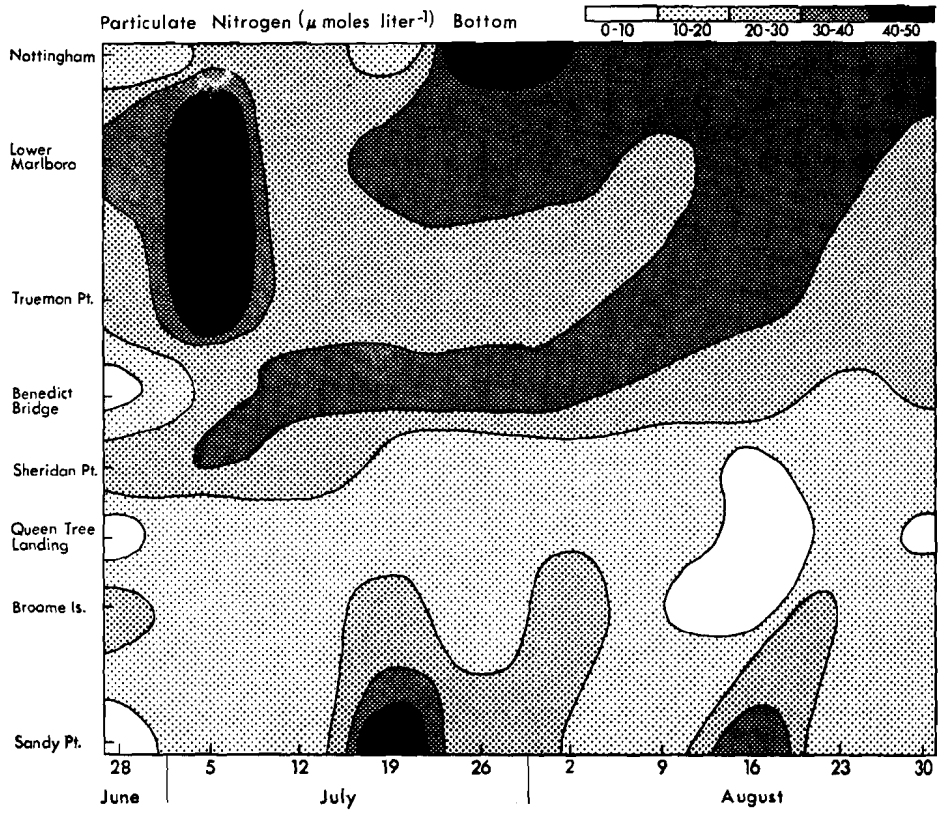

Fig. 5b. Bottom concentration of particulate nitrogen (μ moles liter^{-1}) observed in the Patuxent River estuary during the Post-Agnes Study, summer 1972.

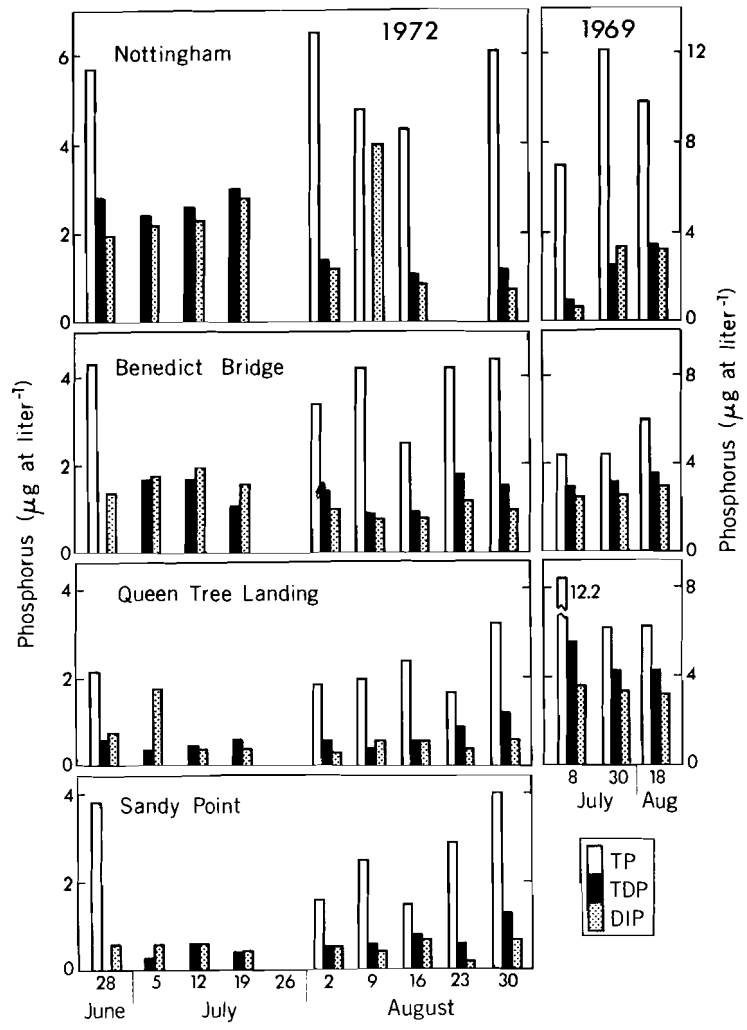

Fig. 6. The concentration (μg at liter^{-1}) of total phosphorus (TP), total dissolved phosphorus (TDP), and dissolved inorganic phosphorus (DIP) at selected stations, Patuxent River Post-Agnes Study, summer 1972. Shown on the figures are comparative data for July and August 1969 (from Flemer et al., 1970).

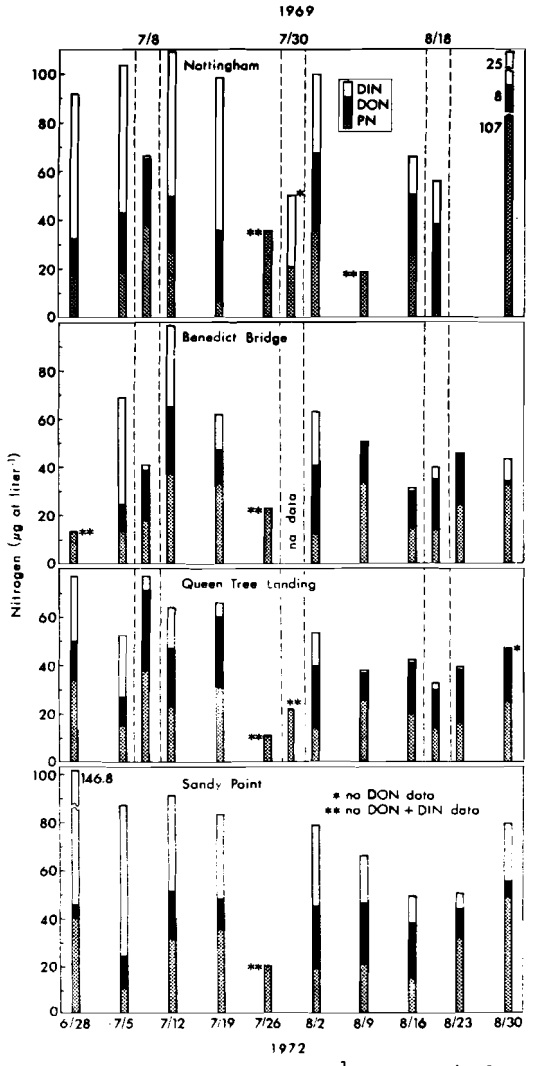

Fig. 7. The concentration (μg at liter^{-1}) of particulate nitrogen (PN), dissolved inorganic nitrogen (DIN), and dissolved organic nitrogen (DON) at selected stations, Patuxent River Post-Agnes Study, summer 1972. Shown in the figures are comparative data for July and August 1969 (from Flemer et al., 1970).

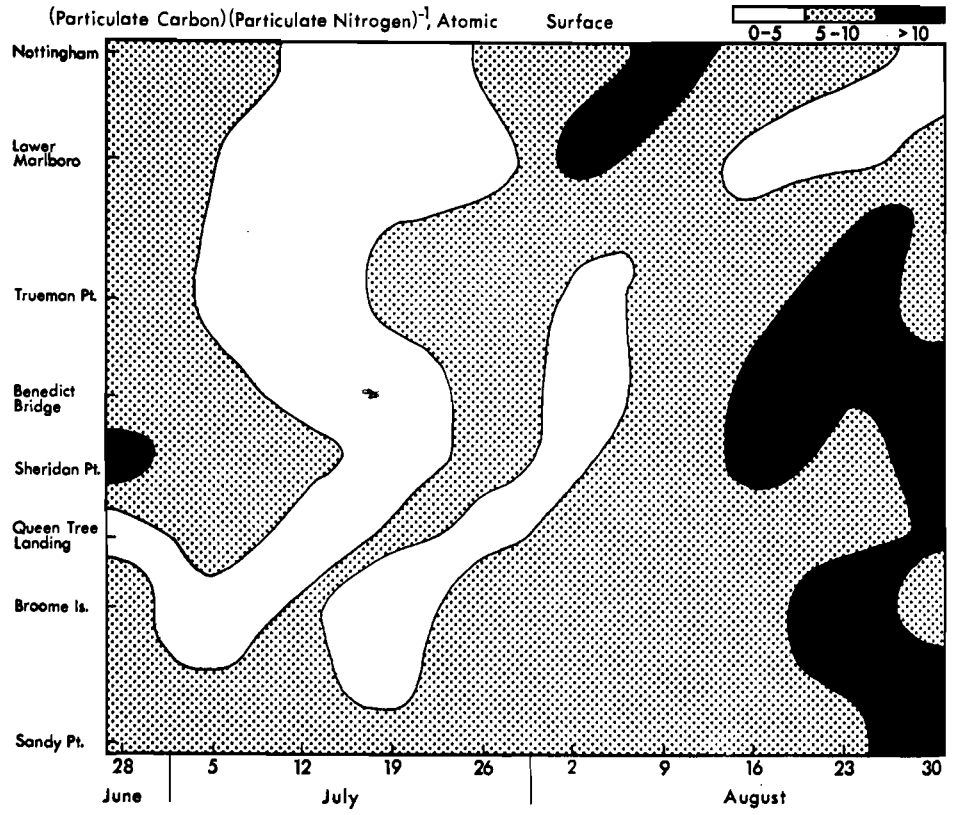

Fig. 8a. The particulate carbon:particulate nitrogen ratio (atomic) for the surface waters, Patuxent River Post-Agnes Study, summer 1972.

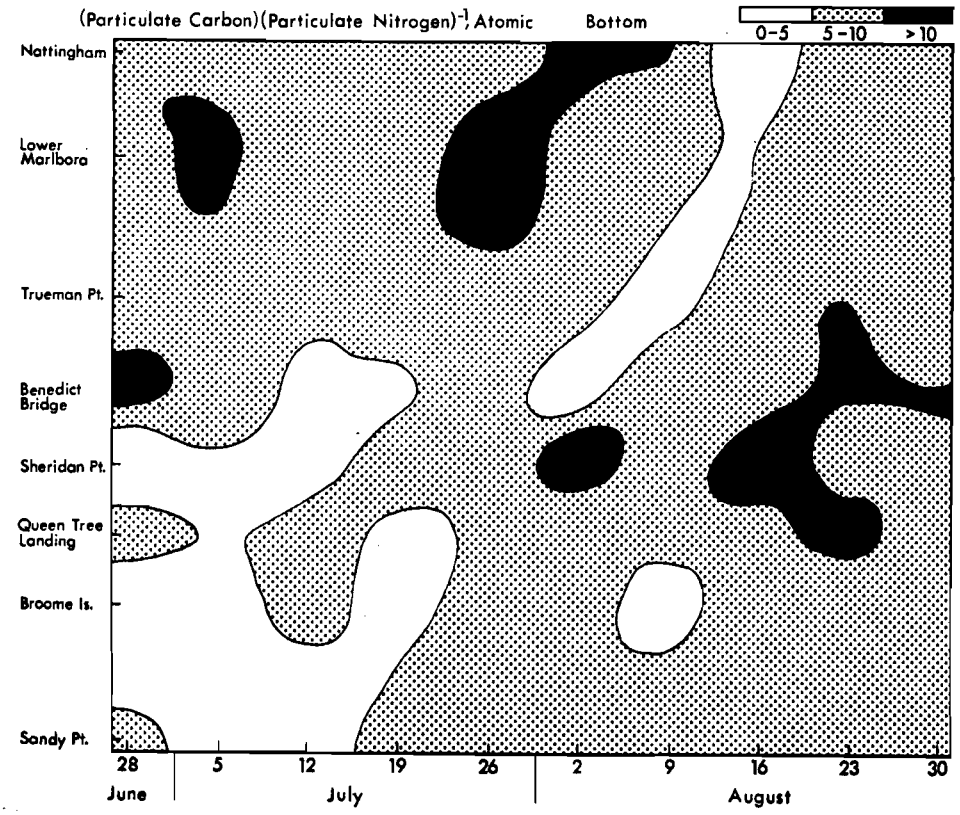

Fig. 8b. The particulate carbon particulate nitrogen ratio (atomic) for the bottom waters, Patuxent River Post-Agnes Study, summer 1972.

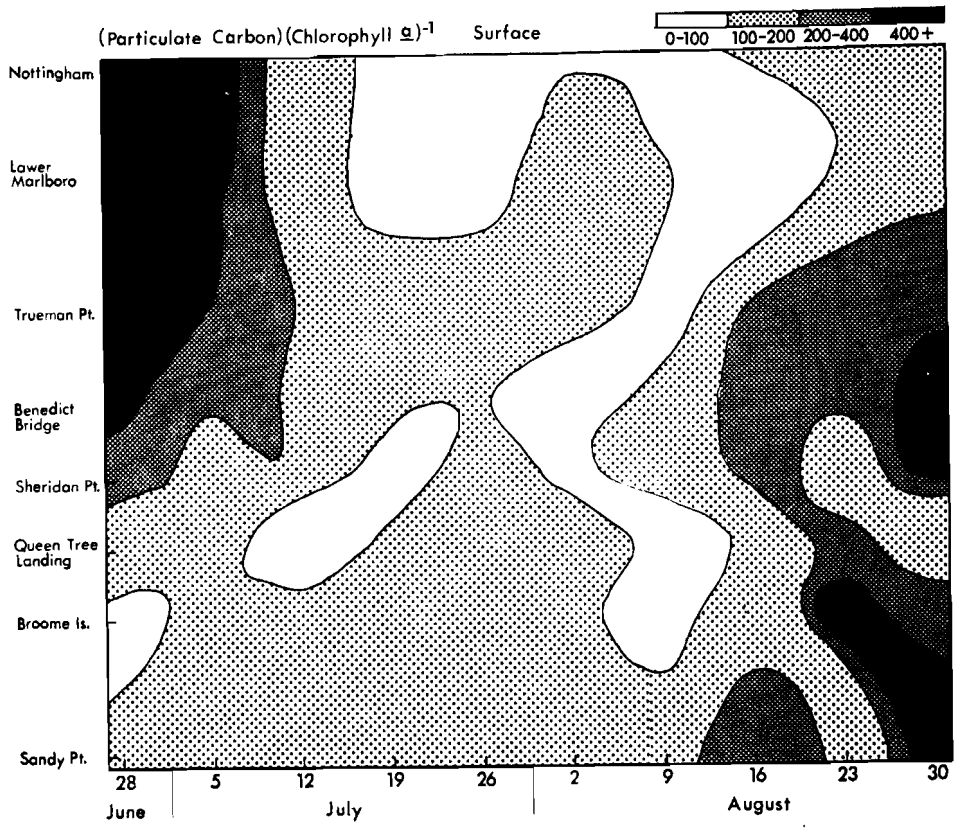

Fig. 9a. The particulate carbon:chlorophyll a ratio for the surface waters, Patuxent River Post-Agnes Study, summer 1972.

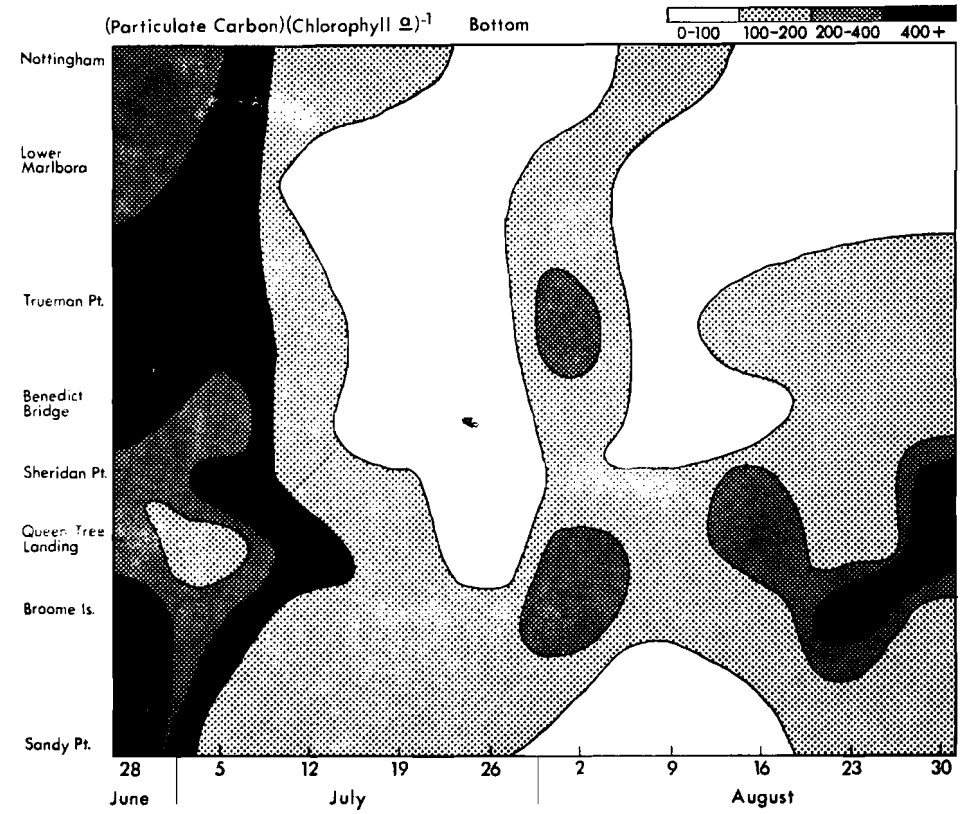

Fig. 9b. The particulate carbon:chlorophyll a ratio for the bottom waters, Patuxent River Post-Agnes Study, summer 1972.

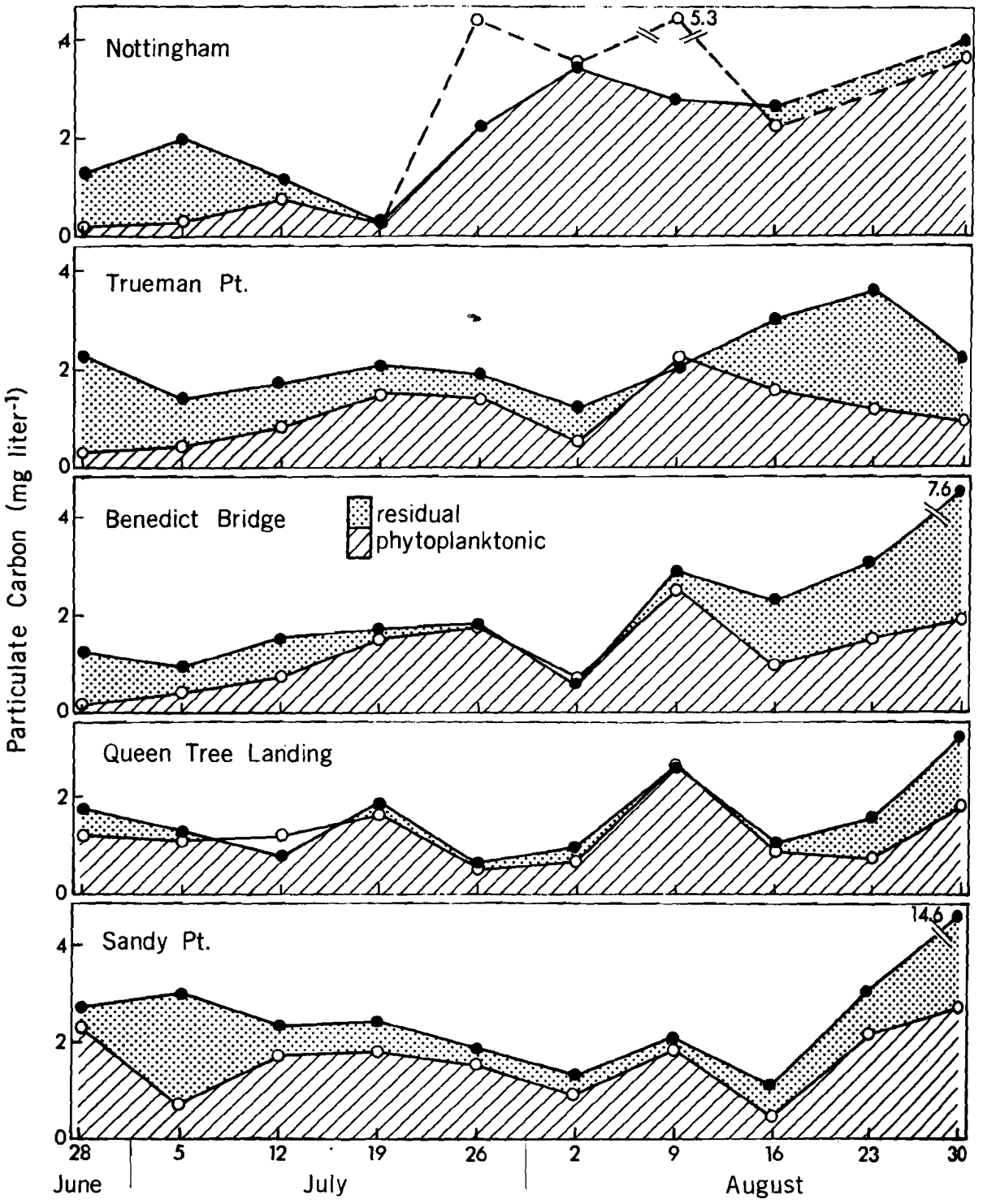

Fig. 10. The distribution of particulate carbon (PC) (top line) and the estimated living phytoplanktonic carbon (bottom line) for selected stations, Patuxent River Post-Agnes Study, summer 1972. The residual PC is indicated.