ASSESSMENT OF SUPERFLUX RELATIVE TO FISHERIES RESEARCH AND MONITORING

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INTRODUCTION

The National Marine Fisheries Service (NMFS) mission is to "achieve a continued optimum utilization of living marine resources for the benefit of the nation". These resources include oceanic, coastal, estuarine, and anadromous fisheries, their forage species, and habitats. An essential aspect of this mission is to promote the conservation, restoration, and enhancement of the productivity of these resources and the habitats upon which they depend, through scientific research, monitoring, analysis and application of findings.

The purposes of Superflux were to: 1) advance the development and transfer of improved remote sensing systems and techniques for monitoring environmental quality and effects on living marine resources; 2) increase our understanding of the influence of estuarine "outwellings" (plumes) on contiguous shelf ecosystems; and 3) provide a synoptic, integrated, and timely data base for application to problems of marine resources and environmental quality.

In terms of fishery research and monitoring we would like to know where the Chesapeake Bay plume goes offshore, how it behaves, what it carries, what it deposits, and what its effects are on the biota. We would like to know what area of the shelf the plume influences through time and what the influences are. Such information is necessary to more effectively direct our research and monitoring programs.

We have believed that new methods and approaches are needed for the resolution of these and other matters of interest to the NMFS. Synoptic sampling of dynamic systems with relatively short-lived events has been a problem with the use of conventional techniques. Therefore, Superflux was conceived to respond to the need for new methods and approaches to better carry out our various missions.

ASSESSMENT OF ACTIVITIES

This paper reviews some of the findings of the Superflux program relative to fishery research and monitoring. My plan is to 1) demonstrate that there is a relatively well-defined area over the continental shelf that is influenced by the Chesapeake Bay plume, 2) describe some of the actual and potential influences of the plume on the shelf ecosystem contiguous to the mouth of

Chesapeake Bay, 3) present new insights derived from the combined use of *in situ* and remotely sensed data, and 4) say something about all of this in terms of fishery research and monitoring.

Definition of the Chesapeake Bay Plume

We have, through Superflux, demonstrated that a definable area exists over the continental shelf that is influenced by the Chesapeake Bay plume. We have been interested in defining such an area in relation to long-term monitoring and for planning an initial strategy for combatting catastrophic spills of toxic substances or other such occurrences. Boicourt (ref. 1) examined the plume area from February 1971 to August 1972, and determined that the major influence of the Chesapeake Bay plume was southward from the mouth of the Bay along the Virginia coast.

Munday and Fedosh (ref. 2) examined the historical data from Landsat available since 1972 to define an area influenced by the Chesapeake Bay plume over the contiguous shelf. From the 81 images they examined, covering all seasons of the year, they defined areas of influence based on various wind and tidal conditions (see ref. 2, Figures 7 and 8). In general, they found that the plume frequented a relatively well-defined area east and south of the Bay mouth, along the Virginia coast.

A similar pattern is exhibited in terms of the *in situ* data as indicated by σ_t (ref. 3, Figure 2(a)); total suspended material (ref. 4, Figure 2); biostimulants such as the phytoplankton nutrient orthophosphate (ref. 5, Figure 3); biomass such as bacterial numbers (ref. 6, Figure 1), chlorophyll *a* (ref. 3, Figure 2(b)), and phytoplankton cell counts (ref. 7, Figure 6); community structure in terms of phytoplankton assemblages (ref. 7, Table 8); and ecosystem function such as heterotrophic potential ((ref. 6, Figure 1) and total plankton respiration (ref. 3, Figure 2(d)). Contaminants such as hydrocarbons (ref. 8, Figure 2) and heavy metals (Figure 1) associated with total suspended matter, had similar distributions.

Likewise, remotely sensed data, as evidenced by salinity derived from the L-band microwave radiometer in conjunction with the PRT-5 infrared radiometer (ref. 9, Figure 5), turbidity based on the Ocean Color Scanner (OCS) (ref. 10, Figure 9), chlorophyll (relative fluorescense) based on the Airborne Oceanographic Lidar (AOL) (ref. 11, Figure 8) and the Testbed Airborne Multispectral Scanner (TBAMS) (ref. 12, Figure 9), and phytoplankton community composition derived from an Airborne Lidar Oceanographic Probing Experiment (ALOPE) fluorosensor (ref. 13, Figure 5) confirmed a very similar distribution of variables. Thus a rather well-defined plume or outwelling area from Chesapeake Bay extends over the continental shelf.

The area of influence, however, may contract or expand depending on freshwater discharge from the Bay mouth. During the latter half of 1980, a severe drought caused the plume to contract (Figure 2). Eight years previous, Boicourt (ref. 1) found a greatly expanded plume caused by excessive rainfall and freshwater runoff following hurricane Agnes (Figure 2).

Influence of Chesapeake Bay Plume on Contiguous Shelf Ecosystem

The waters emanating from the mouth of Chesapeake Bay exert an influence on the contiguous shelf ecosystem. Some examples of the kinds of influence that the Chesapeake Bay plume has or could have on the shelf system, based on information obtained during the Superflux experiments, are presented here. We are interested in defining the actual and potential influences of the plume so that with increased understanding our ability to assess and manage the system might be improved.

Flowing out of the Bay with the estuarine water (ref. 3, Figure 2(a)) are higher concentrations of total suspended matter (ref. 4, Figure 2) which not only affect light penetration for primary production, but also provide a source of both food and contaminants for particulate feeders, both in the water column and on the seabed. Evidence suggests that particulate material outwelling from the Bay settles to the seabed down the length of the plume (Figure 3 and ref. 3, Figures 4, 5, and 6). See reference 14, Figure 8 for station locations.

The Bay also is a source of nutrients for primary producers (ref. 5, Figure 3). These nutrients stimulate primary production, resulting in increased biomass and higher concentrations of phytoplankton and chlorophyll over the area influenced (ref. 7, Figure 6, and ref. 3, Figure 2(b)). This increased biomass, plus particulate and dissolved organic material from the estuary, acts as a food source to stimulate and support other trophic levels (ref. 6, Figure 1). Functionally, the response is a biologically more active system in the plume than in adjacent shelf waters. We see this with heterotrophic potential (ref. 6, Figure 1) and total plankton respiration (ref. 3, Figure 2(d)), both indicators of rates of utilization and decomposition of organic matter.

In terms of community structure the phytoplankton assemblage of the Chesapeake Bay plume is different from surrounding shelf waters (ref. 7, Table 8, and ref. 13, Figure 5). Thus not only do quantitative and functional differences arise between the plume and surrounding shelf waters, but there are also qualitative differences which would affect higher trophic levels through their feeding habits.

Oertel and Wade (ref. 8) reported on the characteristics of total suspended matter and associated hydrocarbon concentrations in shelf waters adjacent to Chesapeake Bay. Of particular interest was the fact that there was no congruence in the plumes of total suspended matter, hydrocarbons, and salinity (ref. 8, Figures 3 and 4). Each was characteristic of a separate, definable subplume emanating from the Bay mouth. During the June 1980 experiment the total suspended matter subplume was closest to the beach, the hydrocarbon subplume was furthest away, and the salinity subplume was in the middle (ref. 8, Figures 3 and 4). Such a distribution, with all flowing from one single Bay mouth, suggests different primary sources from within the estuary and the maintenance of the continuity with each of these sources as the materials are carried from the Bay to the shelf. Thus, not only is there stratification or vertical layering and partitioning (between the plume surface waters and the benthos) as suggested earlier in the paper, but also separation of the various stimulating and contaminating influences on a horizontal basis, as demonstrated by Oertel and Wade. This means that the potential exists for different biological responses to occur in different parts of the outwelled water as well as on the seabed beneath the several subplumes emanating from the Bay mouth. Oertel and Dunstan (ref. 15) describe a similar phenomenon for the Georgia estuaries with foam-line fronts forming between the various sources within the estuary and subsequent "uncoupling" at the seaward ends of the plumes offshore. Therefore, this phenomenon is not unique to Chesapeake Bay, but probably is found with most dendritic-patterned estuaries and their offshore plumes.

Distance or length of the outwelling plume from the Bay mouth is related to time, and depends on the volume of water discharged and the interaction of the meteorological and physical factors affecting the shelf. With time, organic materials are oxidized (hydrocarbons weathered) and inorganic materials are reduced. Nutrients are incorporated into phytoplankton during photosynthesis and released during respiration and decomposition. Contaminants may be inactivated or detoxified by binding or destructive mineralization. However, they may also be concentrated on suspended particulates which then may be fed upon by plankton and nekton or sink to the seabed, to be consumed by benthos. Thus distance down the outwelling allows time for physical, chemical, and biological processes to function to modify the dissolved and particulate materials emanating from the Bay mouth. Such modification leads to further fractionation and partitioning of the various constituents which in turn affect the biota of the contiguous shelf ecosystem.

Combined Use of in situ and Remotely Sensed Data

The combined use of in situ and remotely sensed data and comparisons between the two provide insight into the potential use of remote sensing in fishery research and monitoring programs such as those described by Pearce (ref. 16). During the June 1980 experiment a salinity plume was defined east and south of the Chesapeake Bay mouth along the Virginia coast based on data collected from a research ship over a period of several days and a number of tidal cycles (Figure 4). The result was a smoothly contoured plume which gave the impression of a discrete tongue of water with a central core emanating from the Bay mouth.

During this same experiment, but lasting for periods of two hours instead of several days, an L-band microwave radiometer was flown over the Chesapeake Bay plume area on several different days to map the distribution of surface salinity (ref. 9, Figures 5 and 6). These data are nearly synoptic compared with the in situ data collected over several days. The contouring is not as smooth and regular, even though the same general pattern is seen in both the in situ and remotely sensed data. Notice the change in salinity distribution between 23 June and 25 June (ref. 9, Figures 5 and 6). The low salinity water still ranges from the Bay mouth south along the Virginia shore. However, what is particularly interesting is the presence of high-salinity water between two tongues of low-salinity water exiting southeastward from the Bay mouth (ref. 9, Figure 6). Isolated pockets of lower or higher salinity water are present. This so-called "pocketing", added detail in contouring, and the rather large change in salinity distribution over a period of several days were not in evidence in the more generalized in situ data (Figure 4). This is new information in terms of understanding the dynamics of an estuarine plume; we are unable to obtain this kind of synoptic, repeated, and detailed information using a single surface ship.

Similar detail is seen in the Ocean Color Scanner (OCS) data (ref. 10, Figures 7, 8 and 9). The outline of the plume is not regular, nor is the plume of uniform density. The satellite imagery of sea surface temperature presented by Vukovich (ref. 17, Figures 1, 2 and 10) has less resolution, but covers a very much larger area. The shelf/slope front is jagged in appearance and the continental shelf surface waters are highly heterogeneous. This kind of imagery is changing our perspective of the oceans by allowing us to see and understand some of their structural and dynamic complexity.

Additionally, remote sensors have the capability of providing real-time or near-real-time output of data sufficiently reduced to be useful in directing operations during the course of an experiment. The Ocean Color Scanner data collected by Ohlhorst during June 1980 (ref. 10, Figures 7, 8, and 9) were transmitted in real time from the aircraft to a ground station and used to direct operations. The Airborne Oceanographic Lidar, the L-band microwave radiometer, the PRT-5 infrared radiometer, and the Multichannel Ocean Color Scanner all produced data capable of being reduced in near-real-time for purposes of directing operations.

A particularly graphic example illustrating the usefulness of airborne remote sensing for defining major regions of the shelf and then directing surface ship sampling was presented by Grew (ref. 18, Figure 14). He used real-time output from a Multichannel Ocean Color Scanner (MOCS) to define the shelf regions and then direct a surface ship to each of the key areas. Approximately 8 to 9 hours prior to the aircraft-directed sampling, the NOAA Ship Kelez was requested to collect and process surface bucket samples (one every 10 to 15 minutes) for chlorophyll and phaeopigment (for Fo/Fa ratio) from the mouth of Chesapeake Bay east across the shelf to the continental rise (ref. 14, Figure 13). Data from the in situ samples were to be compared with the MOCS remotely sensed data. Although processed immediately, the data from these samples were not graphed until after the cruise. Consequently, the shape of the cross-shelf profile was unknown to those of us on the surface ship until much later. Thus no guidance was provided to aircraft personnel for directing in situ sampling. Once offshore over the continental rise we were asked to proceed back toward the mouth of the Bay along the same line we had just sampled (ref. 14, Figure 14). The difference, however, was that we took many fewer samples and those we did take were at locations selected by airborne MOCS operators on the basis of the real-time output they observed from MOCS.

In our charted data, notice that the cross-shelf profiles, as defined by both the remotely sensed and the in situ data, are similar (Figure 5), and that the in situ data derived from the aircraft-directed sampling (Figure 5b) do describe the basic features of the chlorophyll a cross-shelf profile. Thus a degree of confidence can be had in the remotely sensed data to 1) characterize in real time the major features of the shelf and slope surface waters and 2) direct in situ sampling of these waters. This is particularly relevant to fishery research and monitoring in that the ability to define major type areas in real time enhances our ability to effectively utilize our ships and personnel.

CONCLUDING REMARKS

In terms of fishery research and monitoring, the combined use of in situ and remotely sensed data has enabled us to define, for each experiment as well as over time, the area of the continental shelf that is influenced by the Chesapeake Bay plume. Based on historical as well as present information we know that this area contracts and expands based on freshwater discharge from the Bay mouth and meteorological and physical factors affecting the shelf. From Superflux we know that the waters emanating from Chesapeake Bay contain biostimulants, contaminants and other materials as well as increased biomass and biological activity and structurally different assemblages of organisms. These waters emanating from the Bay are not homogeneous, but rather appear to be a series of discrete subplumes each with its own set of characteristics. We also see evidence to suggest that particulate materials settle from plume waters to the seabed down the length of the plume. Thus by way of expansion, contraction, changes in direction, and the fractionation or partitioning of materials, the Chesapeake Bay plume exerts greater or lesser positive and negative influences on the living marine resources of the contiguous shelf.

From remote sensing we have learned something of the complexity of the Chesapeake Bay plume and adjacent shelf surface waters. Remote sensing of the plume and neighboring shelf waters provided us with more synoptic and more detailed information concerning the distributions of temperature, salinity, turbidity, chlorophyll a, and phytoplankton assemblages in these surface waters than was obtainable using a single surface ship. In certain cases, repeated coverage by remote sensors informed us of some of the dynamic changes that took place over a period of several days. Additionally, sufficiently reduced real-time output from the remote sensors enabled definition of surface water masses over the continental shelf. Such ability to define the various water masses was used to direct in situ sampling of surface waters in near real time. Thus remote sensing adds to our ability to understand complex and dynamic areas by 1) providing synoptic and detailed information for the surface field in which in situ measurements at isolated locations are being made, and 2) directing surface ships to key areas to maximize their sampling ability.

Surface ships, however, not only provide sea truth for the remote sensors, but also examine the vertical structure of the water column and investigate variables not directly relatable to those measured by remote sensors. Thus it is the flow of information back and forth between remote sensing and in situ sampling that provides the real power to 1) overcome the temporal-spatial problems of in situ sampling and 2) expand the interpretability of the remotely sensed data to variables not measured directly by the remote sensors.

Johnson (ref. 19) has stated, "The exciting prospect is that remote sensing will be [is] a logical bridge between intensive ecological research on small areas and the application of principles thus revealed to planning and management of large political units such as townships, counties or states or whole natural units such as watersheds, tropical rain forests, or ocean basins." In future years remote sensing will be used more heavily in research. It will be used to monitor environmental quality and to assist in managing resources (e.g. directing fishing operations) and habitats (e.g. ecological zoning for development or waste disposal). Finally, because of its perspective vantage point and ability to describe surface flow and transport of materials, remote sensing will be utilized increasingly to respond to catastrophic events and major spills of toxic substances.

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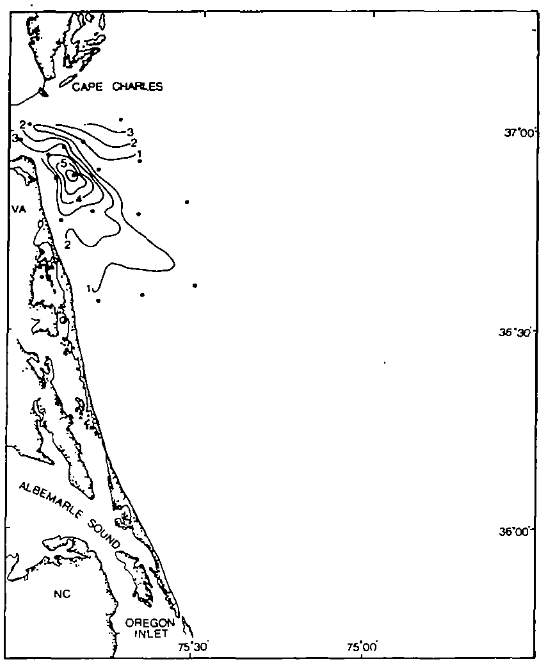
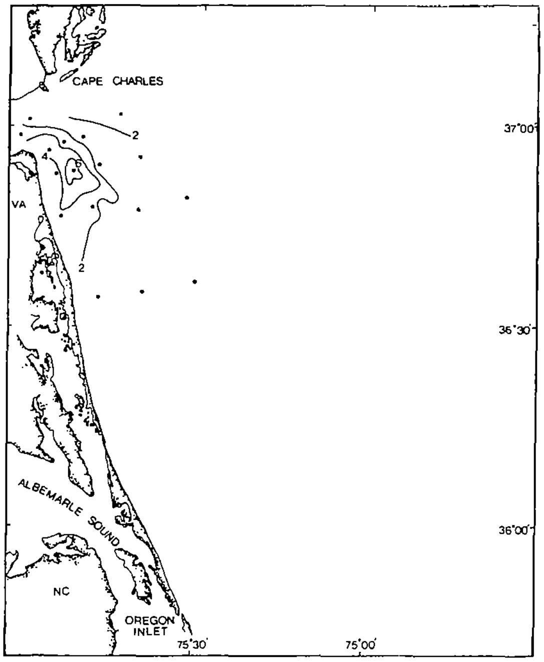
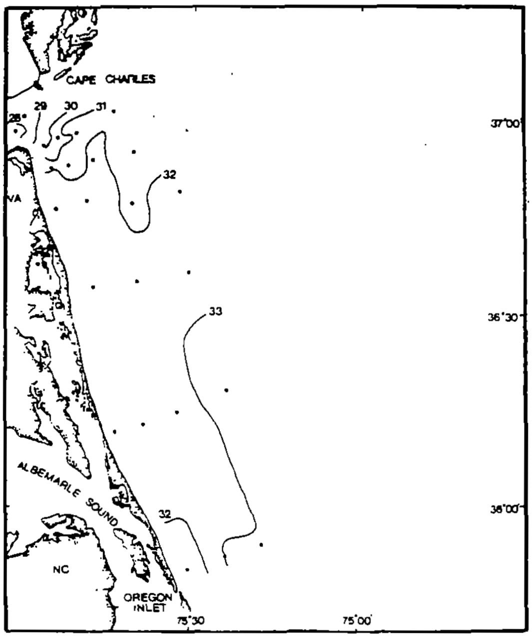


(a) Particulate manganese (mg Mn/g dry wt. sus. sed.) at 1 m depth for June 1980.

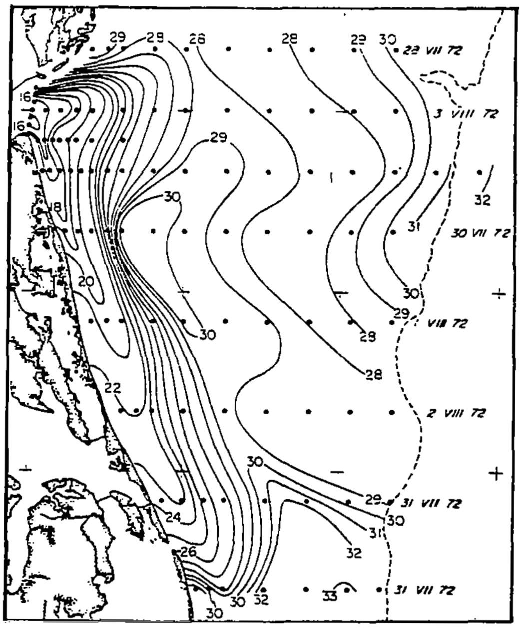


(b) Particulate iron (Fe in % dry wt. sus. sed.) at 1 m depth for June 1980.

Figure 1.- Heavy metals associated with total suspended matter (from ref. 20).



(a) October 1980.



(b) July-August 1972.

Figure 2.- Surface (1 m) salinity distributions ($^{0}/oo$) for October 1980 and July-August 1972 (from ref. 1).

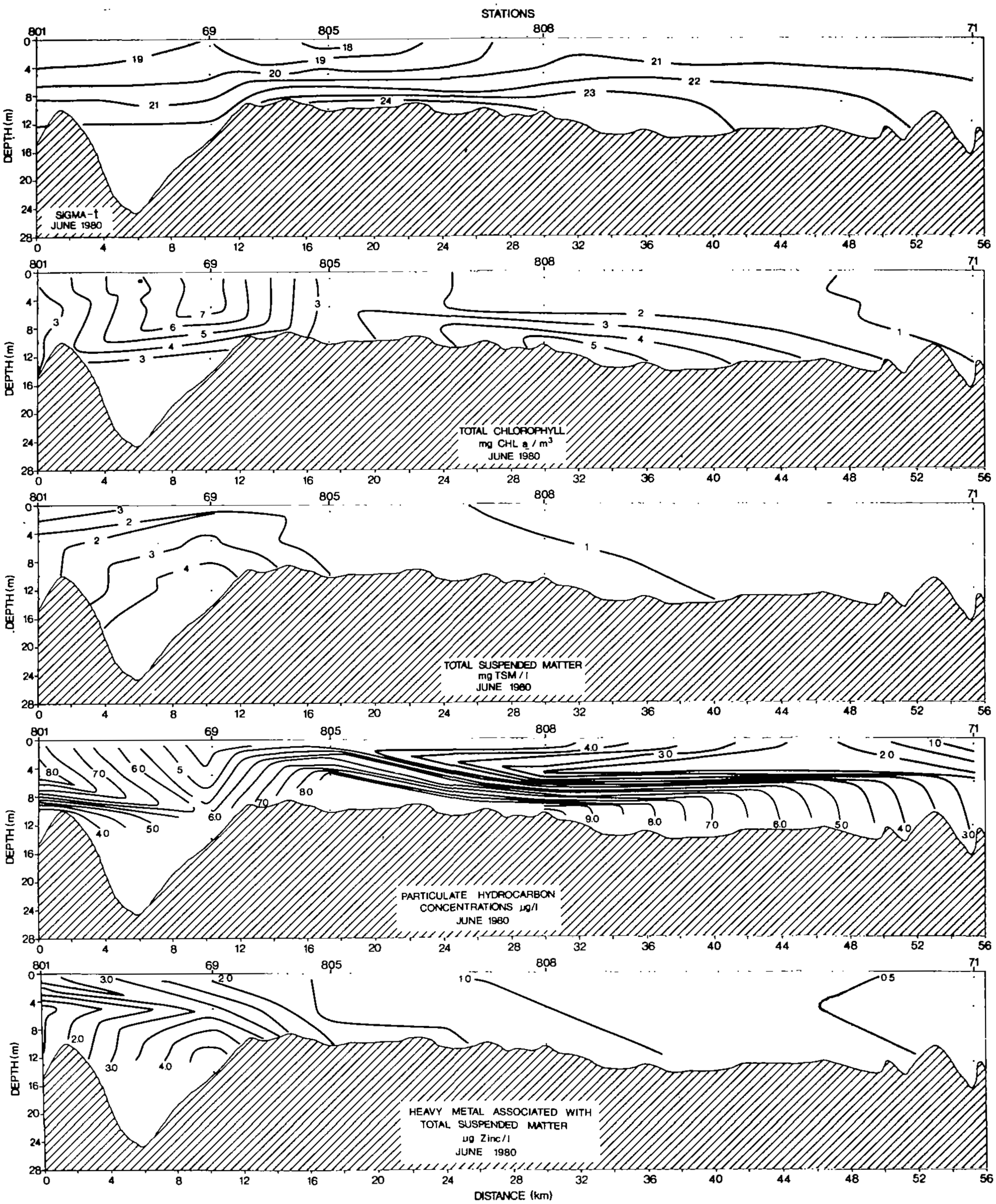


Figure 3.- Lengthwise section of the Chesapeake Bay plume for σ_t, total chlorophyll a, total suspended matter, particulate hydrocarbons (data from ref. 21), and heavy metal concentrations (ref. 20). See reference 14, Figure 8 for station locations.

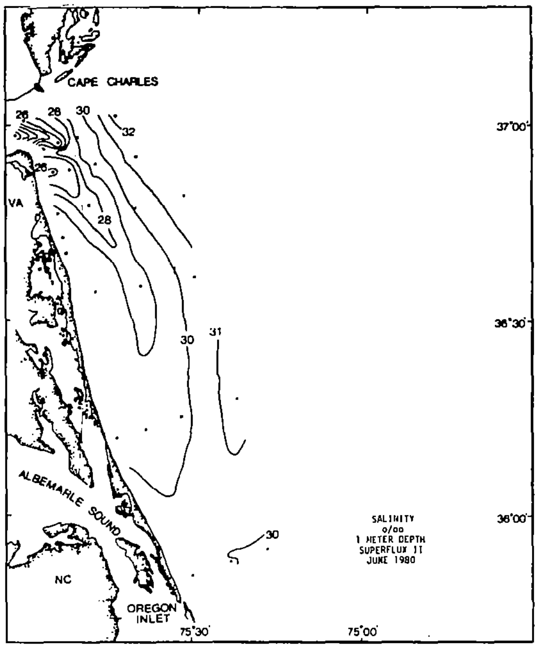


Figure 4.- Surface (1 m) salinity distribution (°/oo) for period 17-22 June 1980.

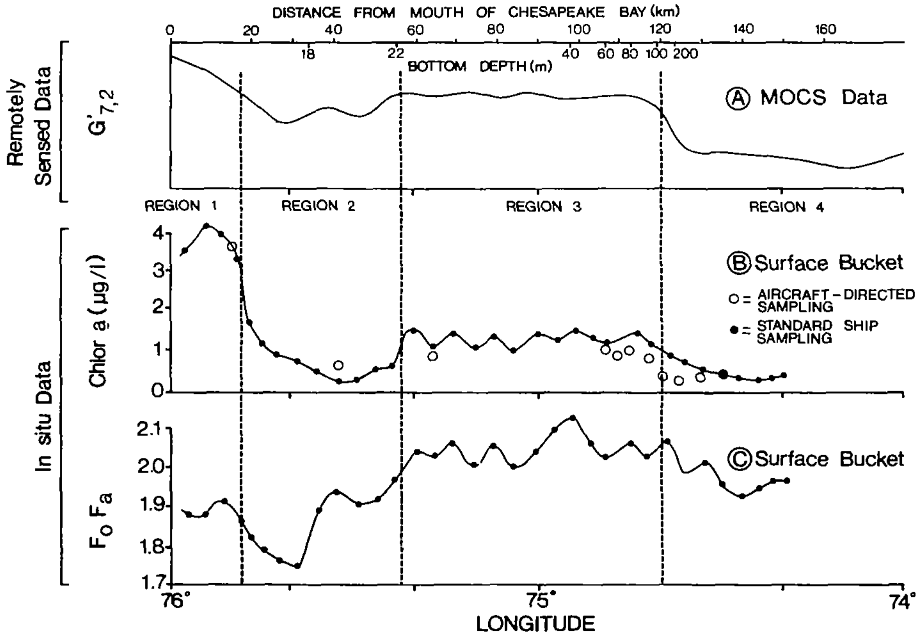


Figure 5.- Multichannel Ocean Color Scanner (MOCS) data, in situ surface chlorophyll a, and Fo/Fa ratios along transect from the mouth of Chesapeake Bay across shelf to continental rise and return on 21 October 1980 (after ref. 18).

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