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Observations On Dissolved Oxygen Conditions In Three Virginia Estuaries After Tropical Storm Agnes (Summer 1972)

R.A. Jordan

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 Chesapeake Research Consortium, Inc. is indebted to the following groups for their logistic and/or financial aid to one or more of the consortium institutions in support of investigations into the effects of Tropical Storm Agnes.

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- -- Transportation Corps, Fort Eustis, Virginia

U. S. Navy
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- -- Coastal River Squadron Two, Little Creek, Virginia
- -- Assault Creek Unit Two, Little Creek, Virginia
- -- Explosive Ordnance Disposal Unit Two, Fort Story, Virginia
- -- Naval Ordnance Laboratory, White Oak, Maryland

U. S. Coast Guard
- -- Reserve Training Center
- -- Coast Guard Station, Little Creek, Virginia
- -- Portsmouth Supply Depot
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National Oceanic and Atmospheric Administration
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The National Science Foundation

Food and Drug Administration

Environmental Protection Agency

U. S. Office of Emergency Preparedness

State of Maryland, Department of Natural Resources

Commonwealth of Virginia, Office of Emergency Preparedness

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OBSERVATIONS ON DISSOLVED OXYGEN CONDITIONS IN THREE VIRGINIA ESTUARIES AFTER TROPICAL STORM AGNES (SUMMER 1972)[1]

Robert A. Jordan [2]

ABSTRACT

Dissolved oxygen (DO) and salinity levels in the James, York, and Rappahannock estuaries were monitored for approximately two months (June 24-August 31, 1972) following Tropical Storm Agnes. DO depressions developed more rapidly and were more severe in the deep waters of the York and Rappahannock than in the James. Depressions that developed immediately after the storm were followed by recoveries and subsequent, more severe depressions. In late July, bottom water DO concentrations below 1 mg/1 were found at stations covering 15 miles of the York and 25 miles of the Rappahannock. Comparison of river data with Chesapeake Bay data suggests that the rivers contributed oxygen poor water to the Bay during the post-Agnes period. Comparison of 1972 river data with data from other years suggests that the post-Agnes oxygen depressions were more severe than those that occur in normal years.

INTRODUCTION

Among the environmental disturbances that occurred in Virginia waters in the aftermath of Agnes were episodes of depressed DO concentrations. This account consists of descriptions of DO fluctuations that were observed in the estuarine reaches of the James, York, and Rappahannock Rivers during the two months (June 24-August 31, 1972) following the storm.

METHODS

In the immediate post-Agnes period, VIMS personnel engaged in an intensive effort to monitor the major hydrographic parameters in these rivers as well as in portions of lower Chesapeake Bay and at certain stations off the Bay mouth. Anchor stations were manned continually from June 24 through the first week of July for measurement of DO and salinity levels at one or two hour intervals. Slack water sampling runs, covering the same parameters at a longitudinal series of stations in each river, were conducted frequently beginning June 24 and extending into August.

Salinities were measured in terms of electrolytic conductivity on a Beckman model RS-7B Induction Salinometer. DO concentrations were measured by the standard Winkler iodometric method (American Public Health Association 1971).

RESULTS

James River Anchor Station

One of the anchor stations occupied in the James River was located at 36° 59.5'N latitude and 76°27.1'W longitude, approximately 10 nautical miles upstream

[1]Contribution No.775, Virginia Institute of Marine Science
[2]Virginia Institute of Marine Science, Gloucester Point, Va. 23062

from the river mouth. Maximum water depth was 12 m.

Fig. 1 shows the temporal distributions of surface and bottom salinity and DO at this station from June 24 to July 6, 1972. Salinity stratification was initially strong, with surface levels of approximately 1 ppt and bottom levels of 14-16 ppt. Bottom salinity declined and surface salinity remained relatively stable until June 30, when salinity at both depths began to rise. By July 6 salinity stratification had been reduced to a difference of 5 ppt between surface and bottom.

DO concentrations at both the surface and the bottom varied diurnally in relation to the solar cycle, but showed little day to day change during the 13 day period. Bottom concentrations rarely dropped below 4.5 mg/1, and were usually within 3 mg/1 of the surface concentrations.

James River Slack Water Stations

Slack water stations were located at approximate three mile intervals, starting at the river mouth (Mile 0). Fig. 2 shows the temporal patterns of surface and bottom salinity and DO measured at Mile 0 and Mile 12. Maximum depth was 14 m at both stations.

The salinity distribution at Mile 12 closely follows the pattern observed at the anchor station through July 6. At Mile 0 salinities at both depths were higher and varied more widely than at Mile 12 during this initial period. At both stations there was a period in mid-July (11-14) of reduced salinity stratification, followed by an abrupt rise in bottom salinity, which peaked on July 21. Salinity stratification remained strong at Mile 0 into August, while it weakened at Mile 12 as surface salinity rose.

The DO patterns observed at both stations were similar. Concentrations ranged for the most part between 4 and 9 mg/1. A major decline in bottom DO concentrations, to levels below 4 mg/1, occurred in conjunction with the salinity rise in the latter part of July. Subsequent recovery was rapid.

Figs. 3 and 4 show the spatial distributions of DO for selected slack water runs. The June 1971 run, included for reference in Fig. 3, shows essentially no variation with depth, but a tendency for DO to decline with distance upstream from the mouth. The June 24 and July 5, 1972 runs show the latter trend, but also some decline with depth at deeper stations. The July 24 run (Fig. 4) shows that the DO depression during the July peak in bottom salinity affected most of the river below Mile 24, while the August 25 run shows that the August recovery was equally widespread.

York River Anchor Station

The temporal salinity and DO distributions presented in Fig. 5 were observed at an anchor station located at $37^{o}14.7'$N latitude and $76^{o}31.1'$W longitude, approximately 6 nautical miles upstream from the York River mouth. Maximum water depth was 18 m.

Surface salinity dropped sharply between June 24 and June 27, while bottom salinity declined gradually until July 2. Salinity at both depths then began increasing. Surface and bottom DO concentrations fluctuated diurnally more strongly than they did day to day. Bottom concentrations frequently fell below 3 mg/1.

York River Slack Water Stations

The salinity patterns at two slack water stations (Fig. 6) are similar to the anchor station patterns for the June 24-July 6 period. Maximum depth at both stations was 18 m. Both stations show subsequent sharp declines in salinity stratification (July 7-15) followed by sharp rises in bottom salinity similar to those observed in the James River slack water runs.

The surface DO distributions show large short-term fluctuations, but no long-term trends. Bottom DO declined initially to minima at both stations in early July. Concentrations subsequently increased, peaking July 13, before plunging rapidly to levels below 1 mg/l in late July, in conjunction with the maximum in salinity stratification. Bottom DO concentrations fluctuated between 1 and 3 mg/l at both stations for the remainder of July and August.

Fig. 7, 8, and 9 present slack water spatial distributions of DO for selected dates. The three plots in Fig. 7 cover the initial period of bottom DO decline and recovery. Concentrations were between 2 and 3 mg/l in the bottom water at all stations below mile 20 on June 29. Fig. 8 shows the distribution of DO during the second period of declining bottom concentrations. Levels below 1 mg/l occurred over much of the bottom between Mile 20 and Mile 5 on July 24. The August 29 distribution (Fig. 9) was similar to the one observed two months earlier (Fig. 7), and bottom water concentrations were similar to those observed in August 1973 (Fig. 9). The July 1973 plot shows bottom concentrations much above those found in August 1973, and similar to those observed on July 13, 1972 at the end of the initial post-Agnes recovery.

Rappahannock River Anchor Station

An anchor station located at 37°40.0'N latitude and 76°33.2'W longitude, approximately 15 nautical miles upstream from the Rappahannock River mouth, was sampled hourly on a 24 hour basis from June 24 to June 30, and hourly during the day from July 1 through July 7, 1972. Maximum water depth was 15 m.

The salinity time distribution (Fig. 10) shows initially strong vertical stratification which weakened gradually during the observation period. Surface and bottom DO fluctuated diurnally, while bottom concentrations declined, on the average, from June 27 through July 4, to a minimum of 2 mg/l.

Rappahannock River Slack Water Stations

Fig. 11 shows the temporal distributions of salinity and DO at two slack water stations, Mile 0 (maximum depth 12 m) and Mile 10 (maximum depth 20 m). Salinity stratification was strong at the outset, reduced in early July, then became stronger and was relatively stable from mid-July to early August. Bottom DO at Mile 10 recovered briefly after its initial decline in June, then declined below 3 mg/l in early July and below 1 mg/l in late July. At the shallower Mile 0 station bottom DO remained above 4 mg/l until mid-July, when it dropped below 3 mg/l. Concentrations at this station did not fall below 1 mg/l during the period of observations.

The spatial distributions of DO for six selected slack water runs are shown in Figs. 12 and 13. The June 24 and July 3, 1972 plots illustrate the development of vertical DO stratification immediately following the storm. The July 11, 1973 distribution indicates that stratified DO conditions develop in more normal summers as well. The July 24 plot shows the intense vertical concentration gradient observed during late July, with levels below 1 mg/1 in deeper layers at all stations below Mile 25. Slight recovery had occurred by August 14. The August 1973 plot also shows strongly stratified conditions, with concentrations below 3 mg/1 in the deeper layers.

Chesapeake Bay Slack Water Stations

Selected Chesapeake Bay slack water data are included for comparison with river data. Fig. 14 presents time series plots of salinity and DO measurements made at a station located at 37°15.8'N latitude and 76°8.6'W longitude, approximately 19 miles above the Bay mouth and 12 miles east of the York River mouth. Maximum water depth was 12 m.

Surface salinity varied between 10 and 14 ppt. Bottom salinity fluctuated in a manner similar to the patterns observed for the James and York Rivers, with an initial decline followed by a sharp increase to a peak in late July. Bottom DO dropped from 5 mg/1 to 2 mg/1 during the period of rising bottom salinity.

The plots in Fig. 15 show the spatial distributions of salinity and DO in the Bay during three slack water runs conducted during the period of rising bottom water salinity. Pronounced vertical stratification of both parameters was evident on both July 20 and July 25, with bottom water DO concentrations below 2 mg/1 at four of the upper stations.

DISCUSSION

Following Agnes, bottom water DO fluctuations in the three Virginia estuaries, as well as in lower Chesapeake Bay, were closely related to fluctuations in vertical salinity gradients. The James River experienced less severe DO depressions than did the other two rivers. There was no marked depression immediately after the storm in this river, but one occurred in late July in conjunction with an influx of highly saline water from the Bay. Bottom concentrations during the depression remained above 3 mg/1, and recovery was rapid.

In both the York and Rappahannock Rivers, bottom DO declined immediately after Agnes, recovered briefly, then dropped again to levels lower than those reached in the initial decline. In the York River the major depression occurred in conjunction with the influx of highly saline Bay water in late July, while in the Rappahannock no massive salinity peak occurred. In late July, DO concentrations below 1 mg/1 were observed in bottom waters at stations covering 15 miles of the York River and 25 miles of the Rappahannock. Recovery was much slower in these rivers than in the James.

Bottom water DO concentrations at Chesapeake Bay slack water stations were similar to concentrations found at the mouths of adjacent rivers. On July 20, for example, at Mile 37 in the Bay the bottom DO was 1.3 mg/1, while on July 24 at the mouth of the Rappahannock River, eight miles to the west, the concentration was 1.1 mg/1. At Mile 19 in the Bay on July 20 the bottom DO was 2.5 mg/1, while at the York River mouth on July 24 the bottom level was 2.8 mg/1. These similarities suggest that the DO decline that was observed in the lower Bay during July was due in part to contributions of oxygen-poor water from the tributaries.

Low bottom water DO concentrations are known to occur in the deeper sections of Virginia's estuaries during normal summers. Comparisons of post-Agnes slack water data with data from other years suggest that for the York and Rappahannock Rivers, Agnes was followed by abnormally severe DO depressions.

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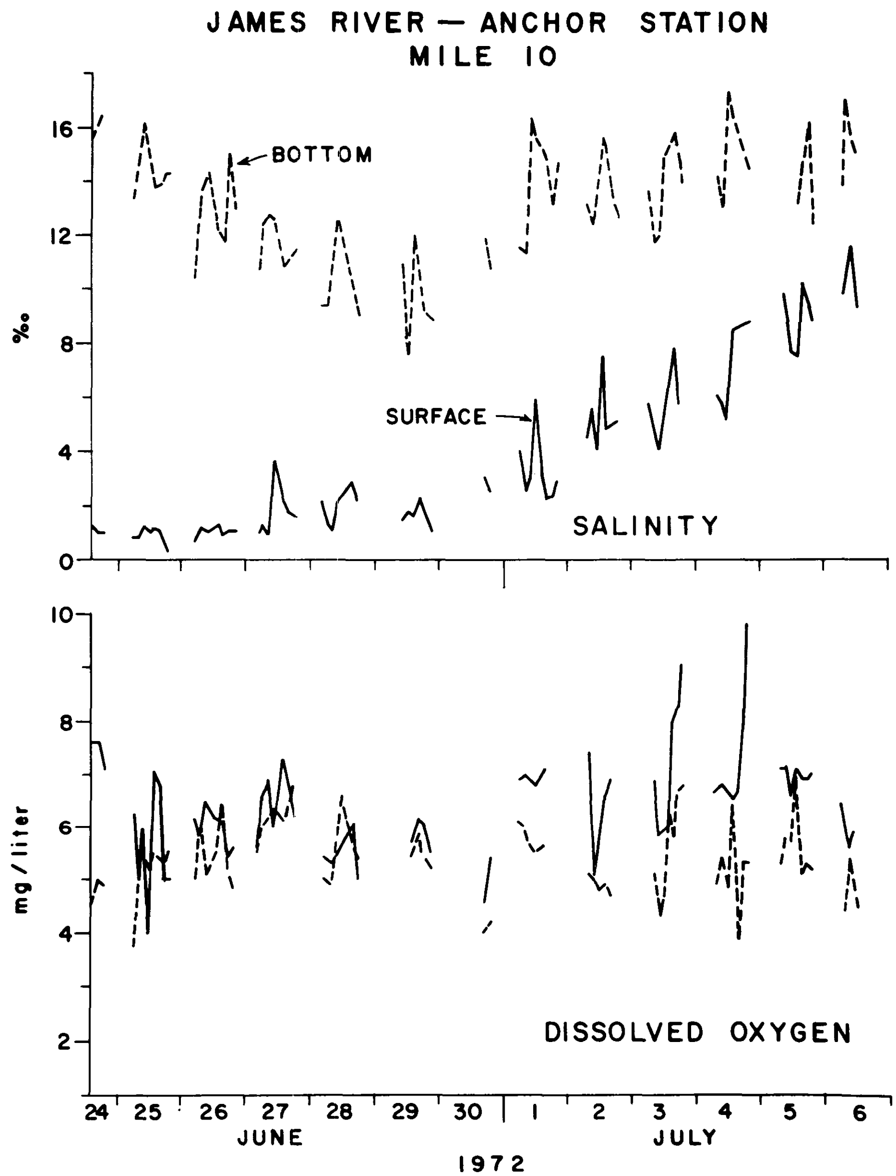

Figure 1. James River anchor station salinity and dissolved oxygen temporal distributions.

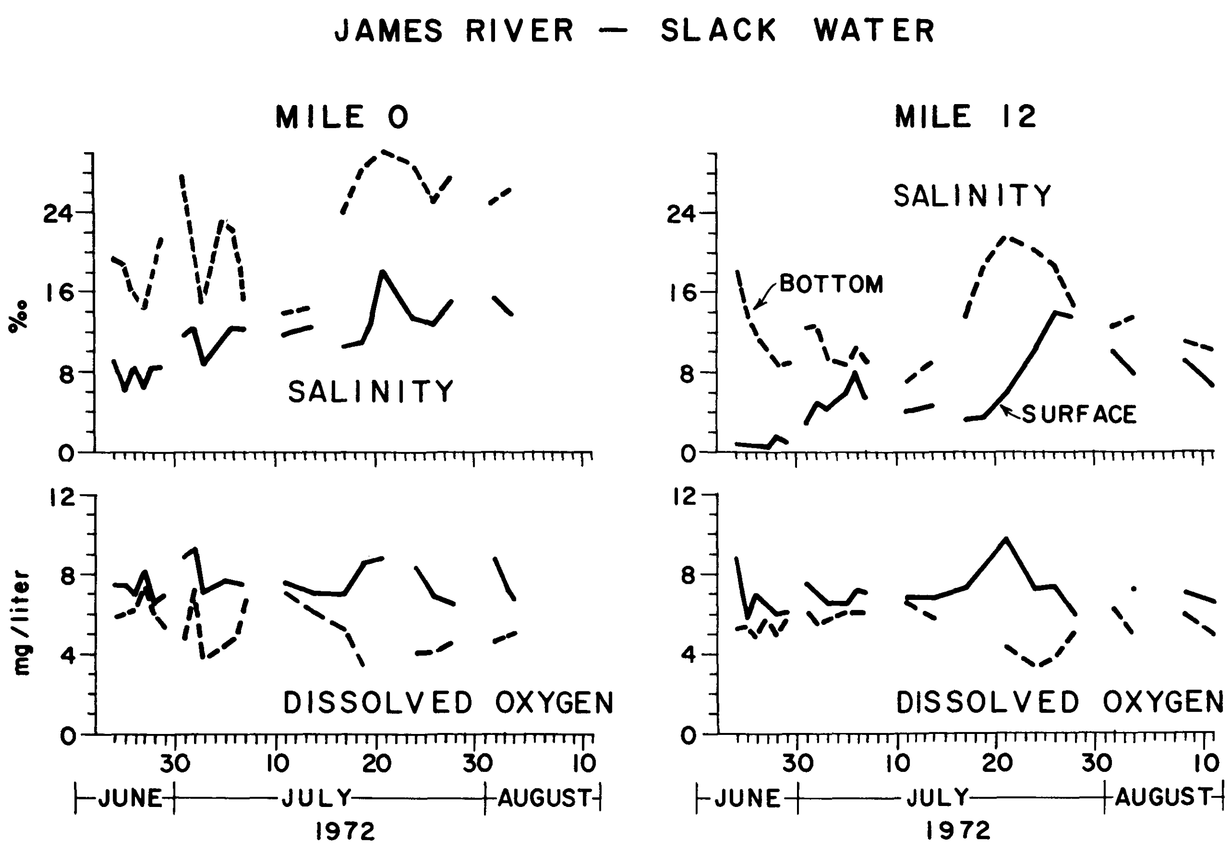

Figure 2. James River slack water salinity and dissolved oxygen temporal distributions.

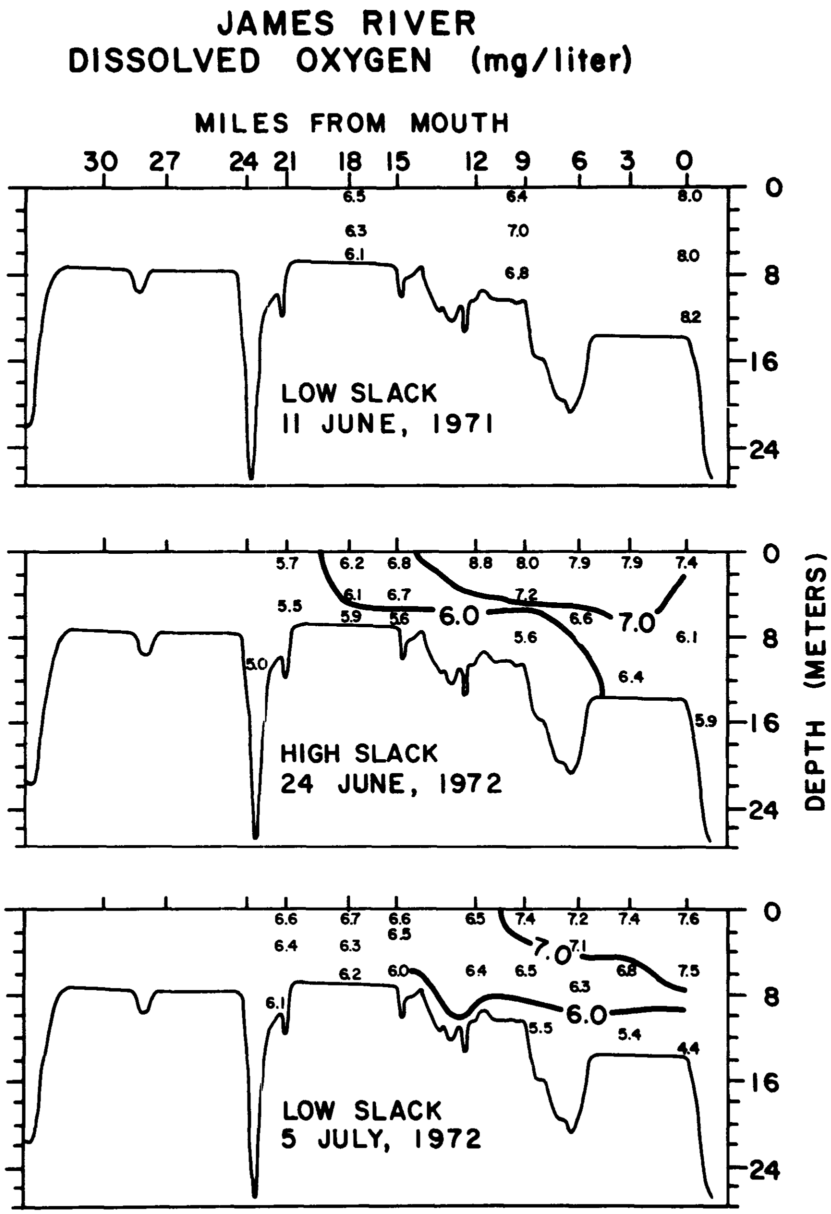

Figure 3. James River slack water dissolved oxygen spatial distributions I.

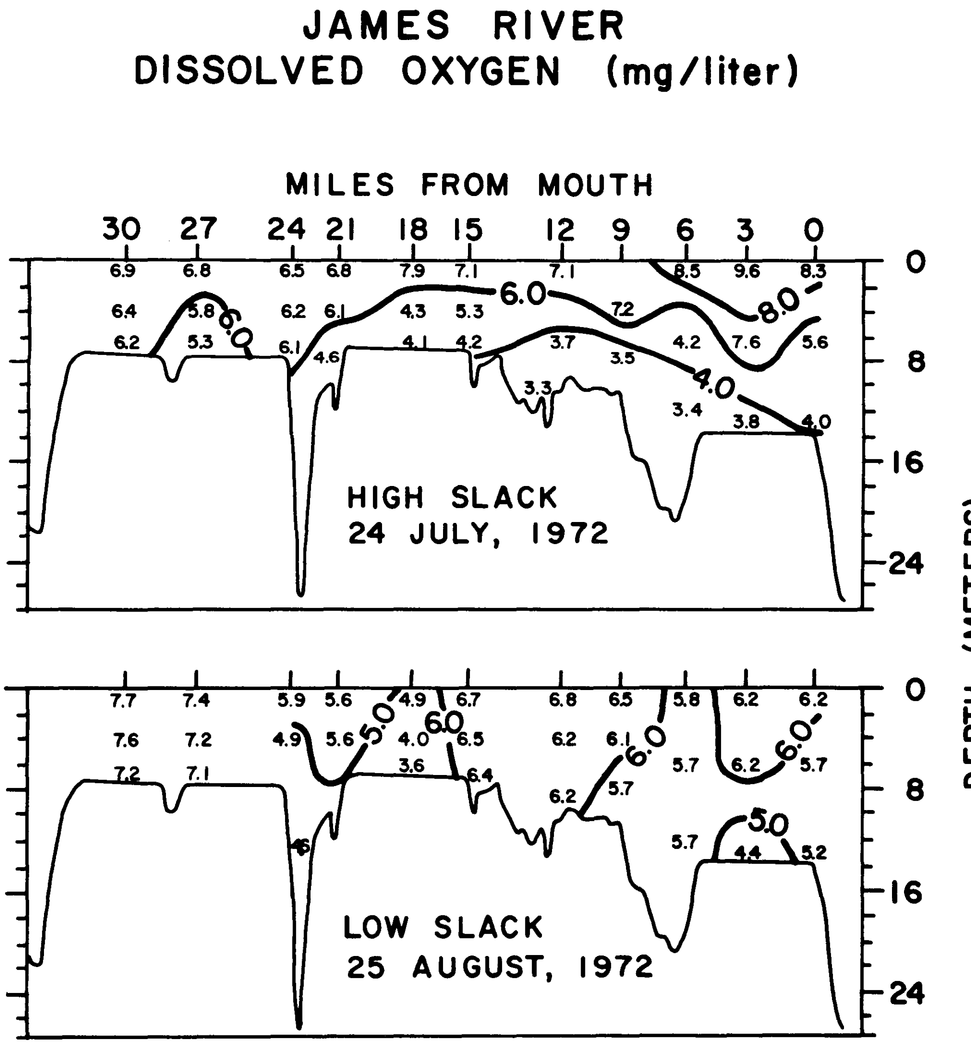

Figure 4. James River slack water dissolved oxygen spatial distributions II.

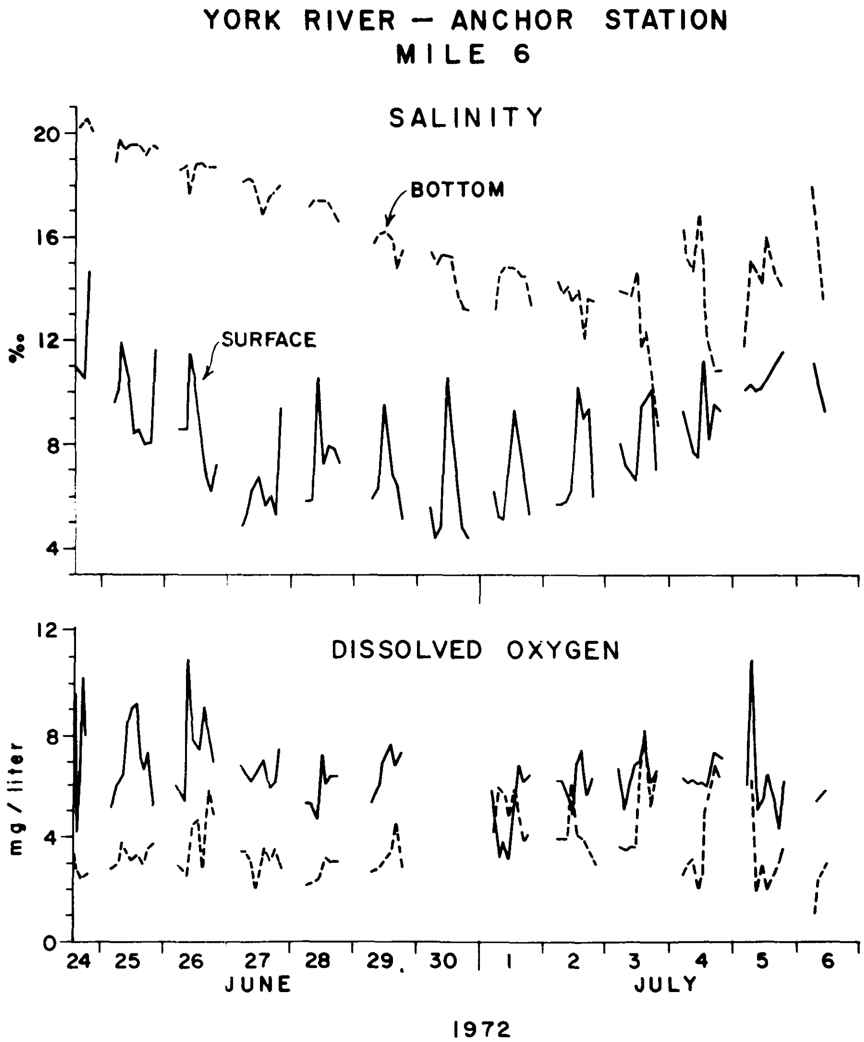

Figure 5. York River anchor station salinity and dissolved oxygen temporal distributions.

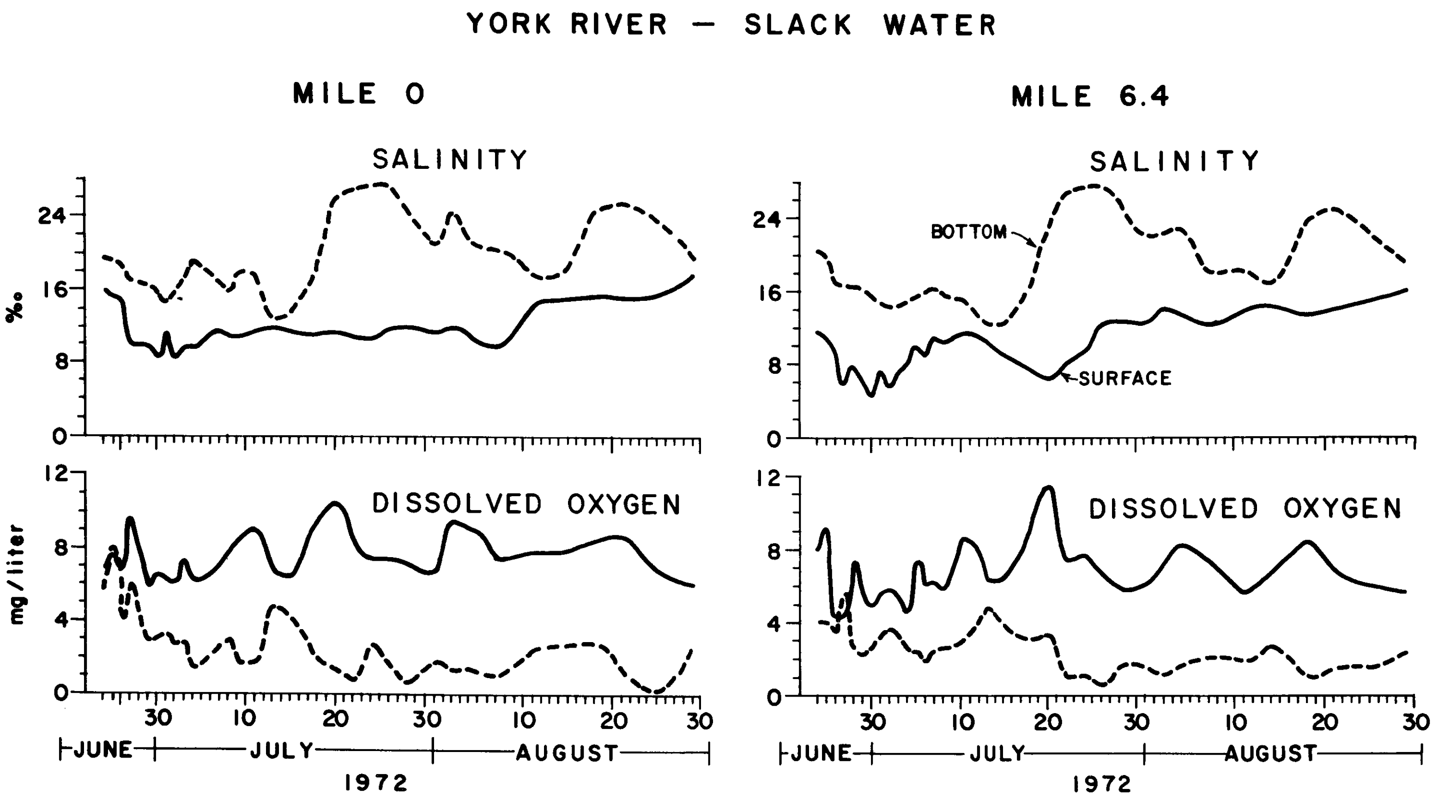

Figure 6. York River slack water salinity and dissolved oxygen temporal distributions.

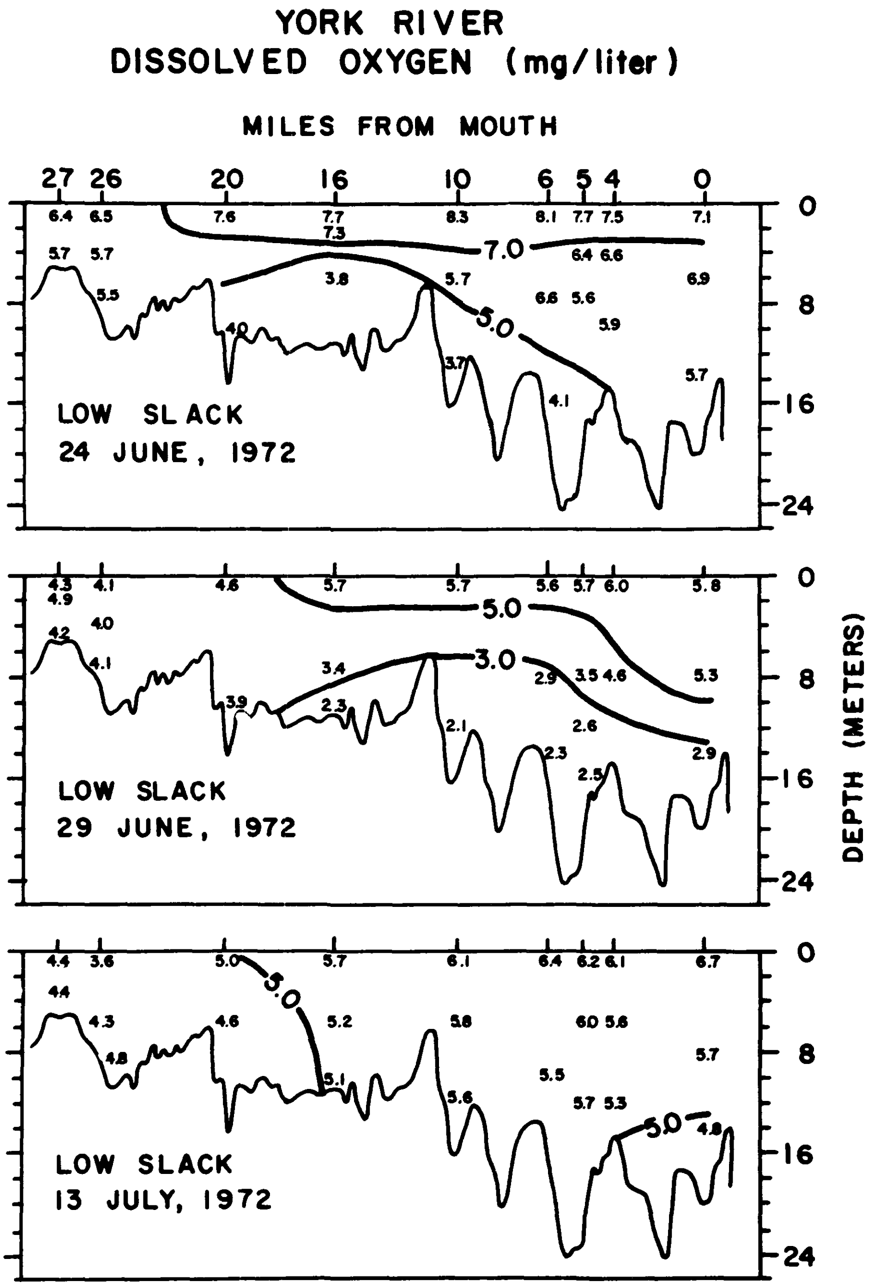

Figure 7. York River slack water dissolved oxygen spatial distributions I.

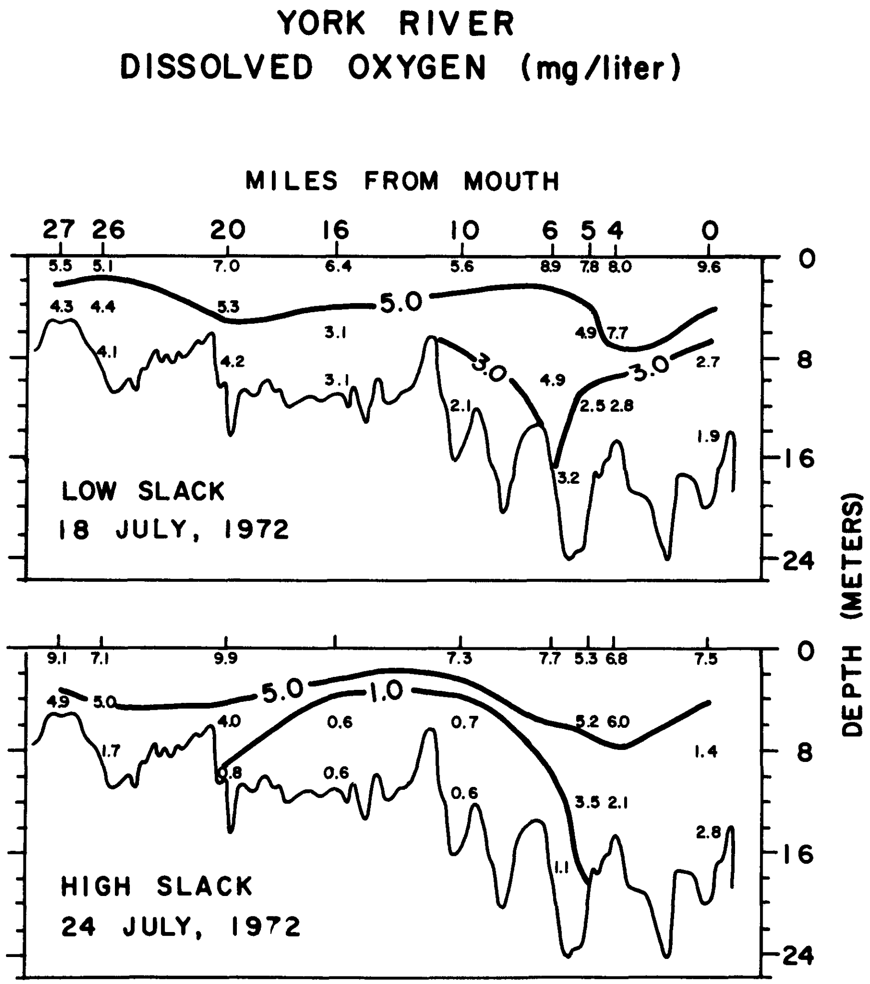

Figure 8. York River slack water dissolved oxygen spatial distributions II.

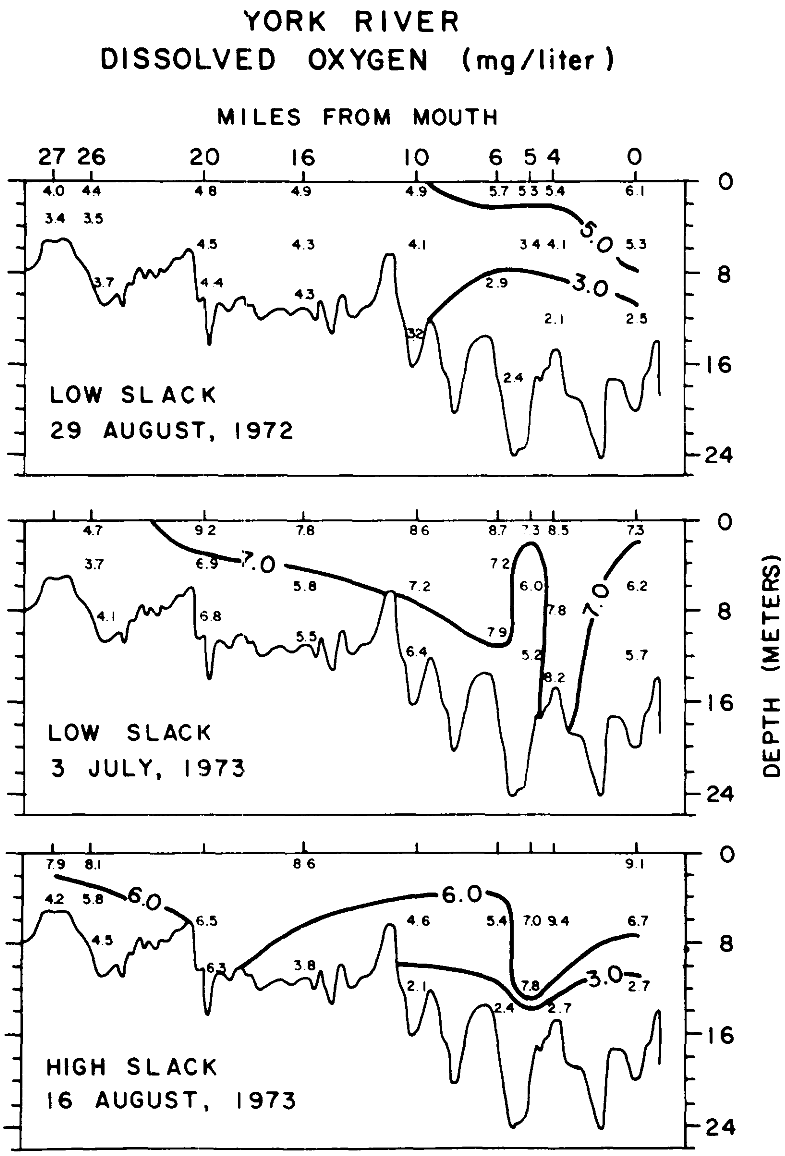

Figure 9. York River slack water dissolved oxygen spatial distributions III.

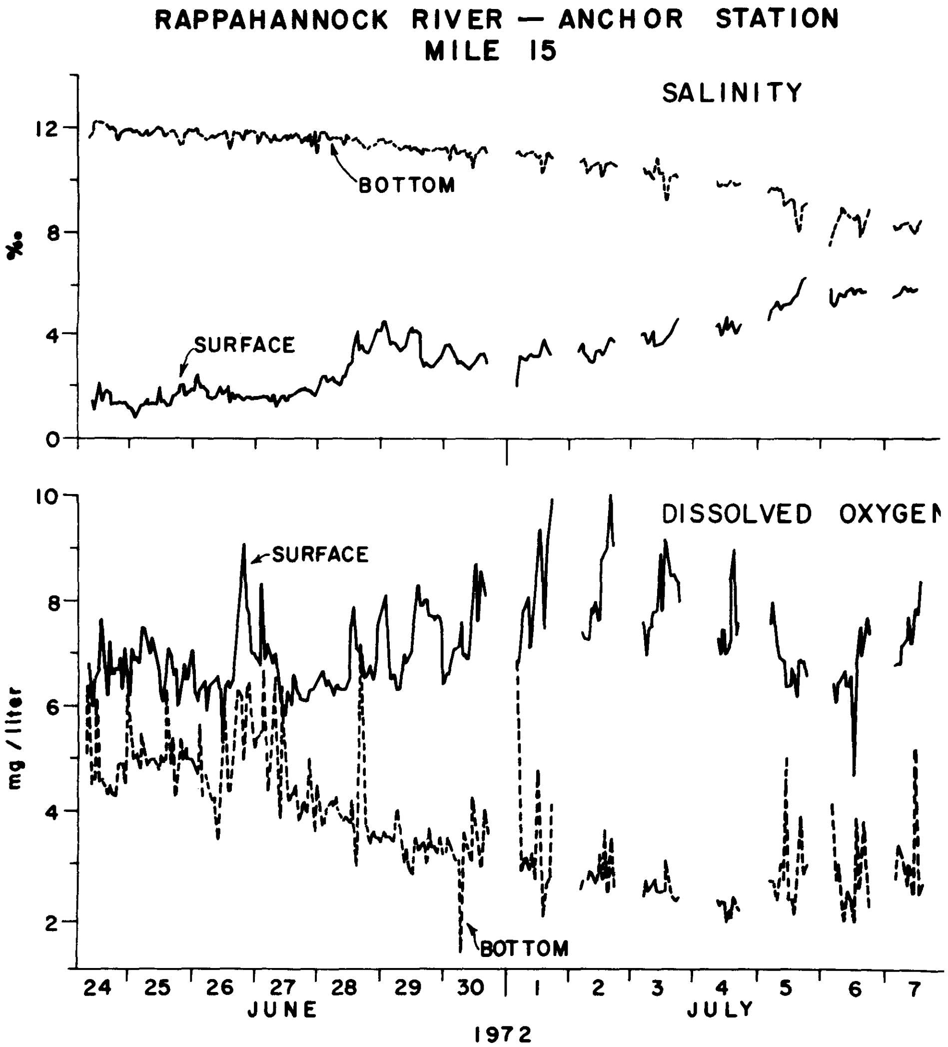

Figure 10. Rappahannock River anchor station salinity and dissolved oxygen temporal distributions.

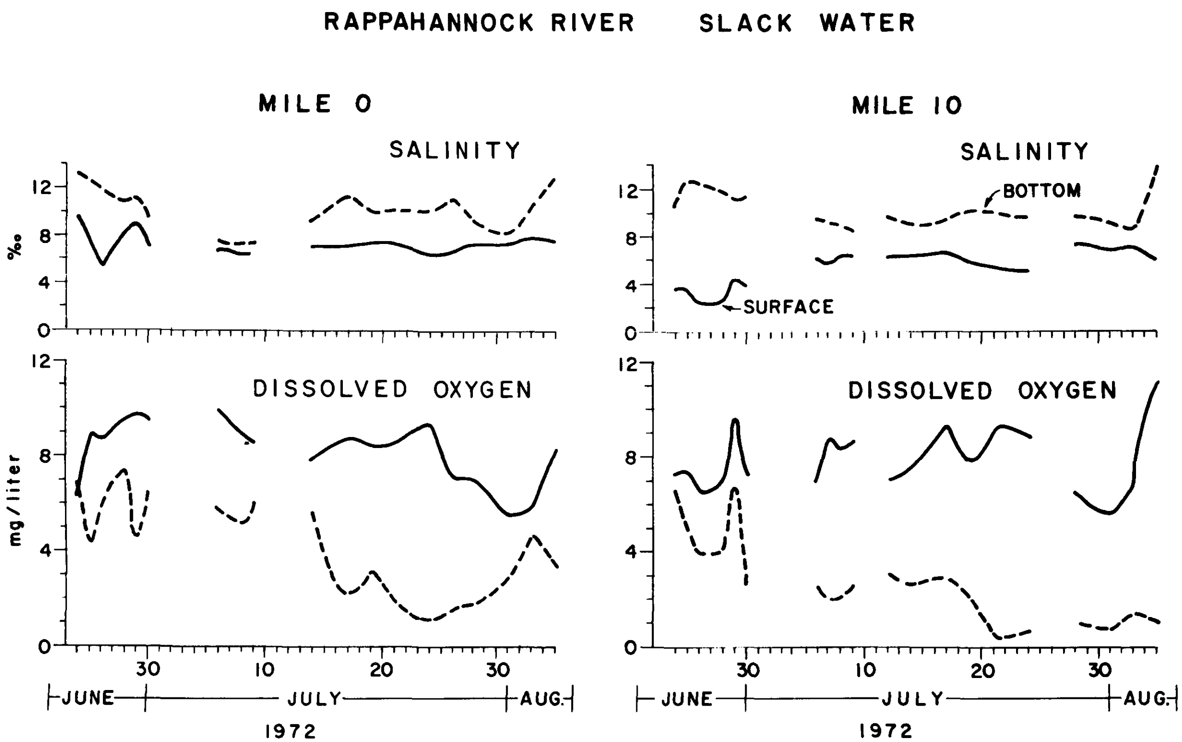

Figure 11. Rappahannock River slack water salinity and dissolved oxygen temporal distributions.

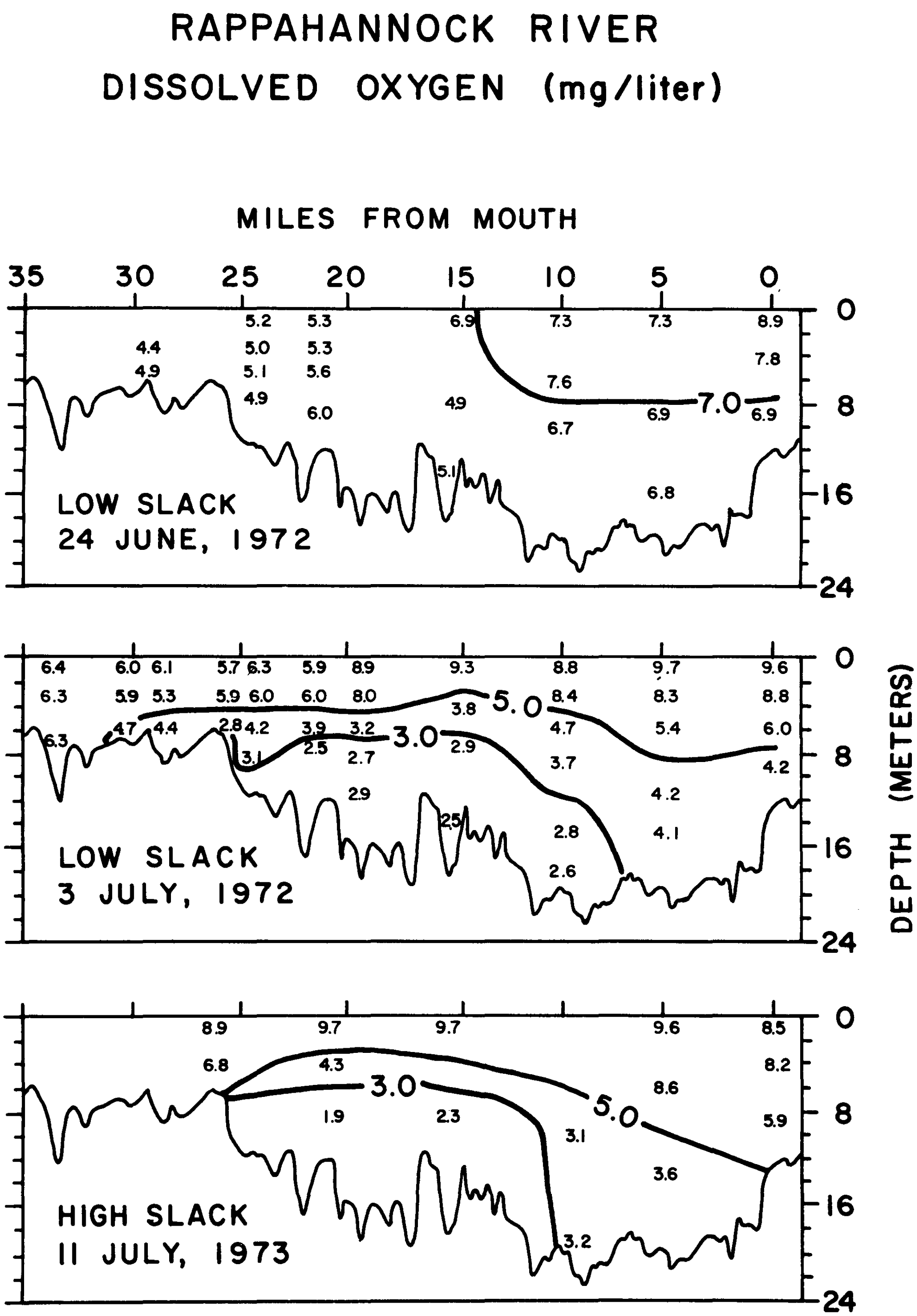

Figure 12. Rappahannock River slack water dissolved oxygen spatial distributions I.

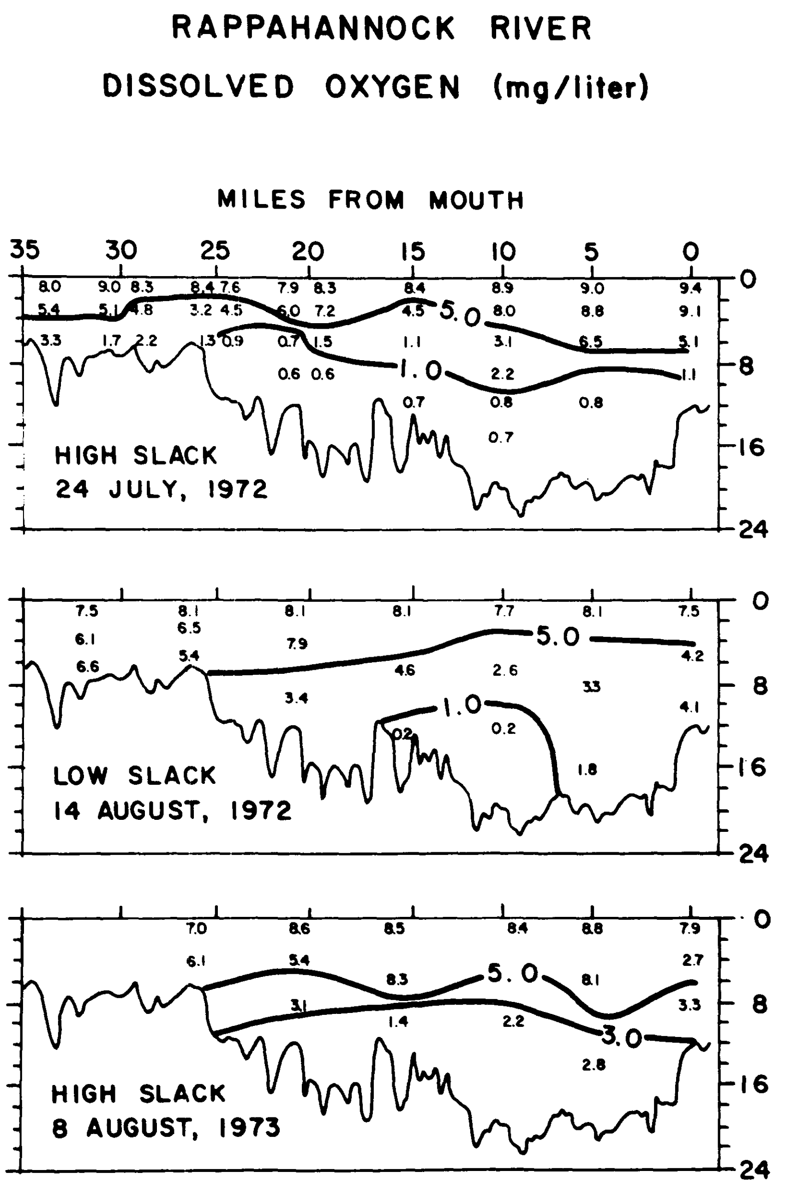

Figure 13. Rappahannock River slack water dissolved oxygen spatial distributions II.

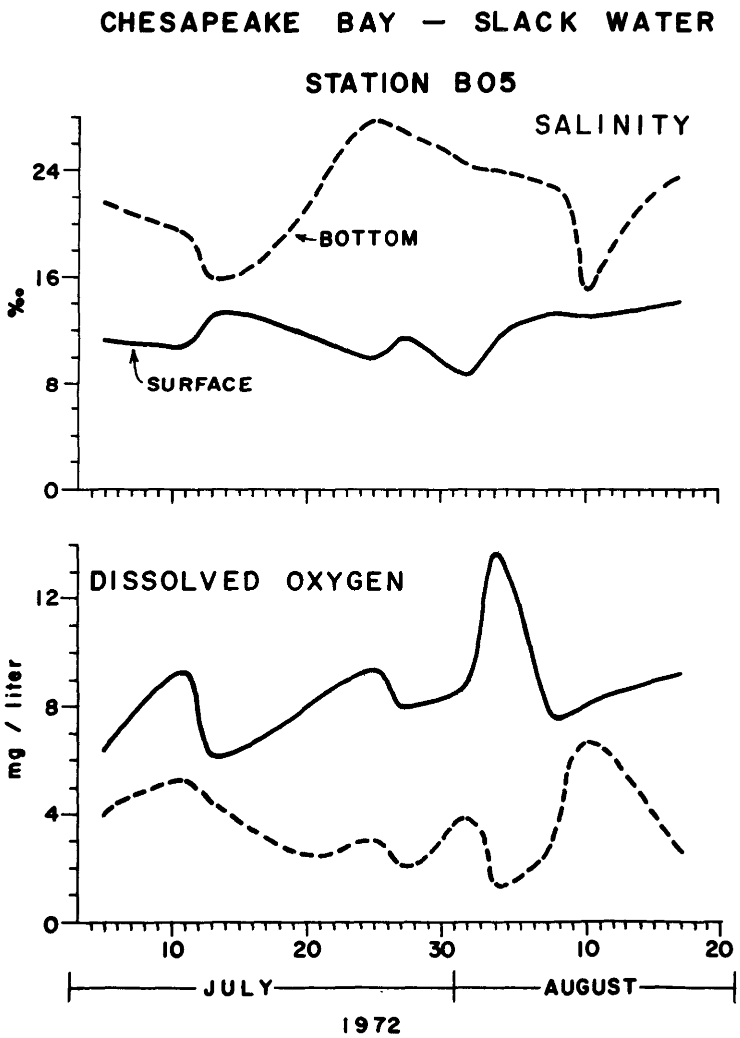

Figure 14. Chesapeake Bay slack water salinity and dissolved oxygen temporal distributions.

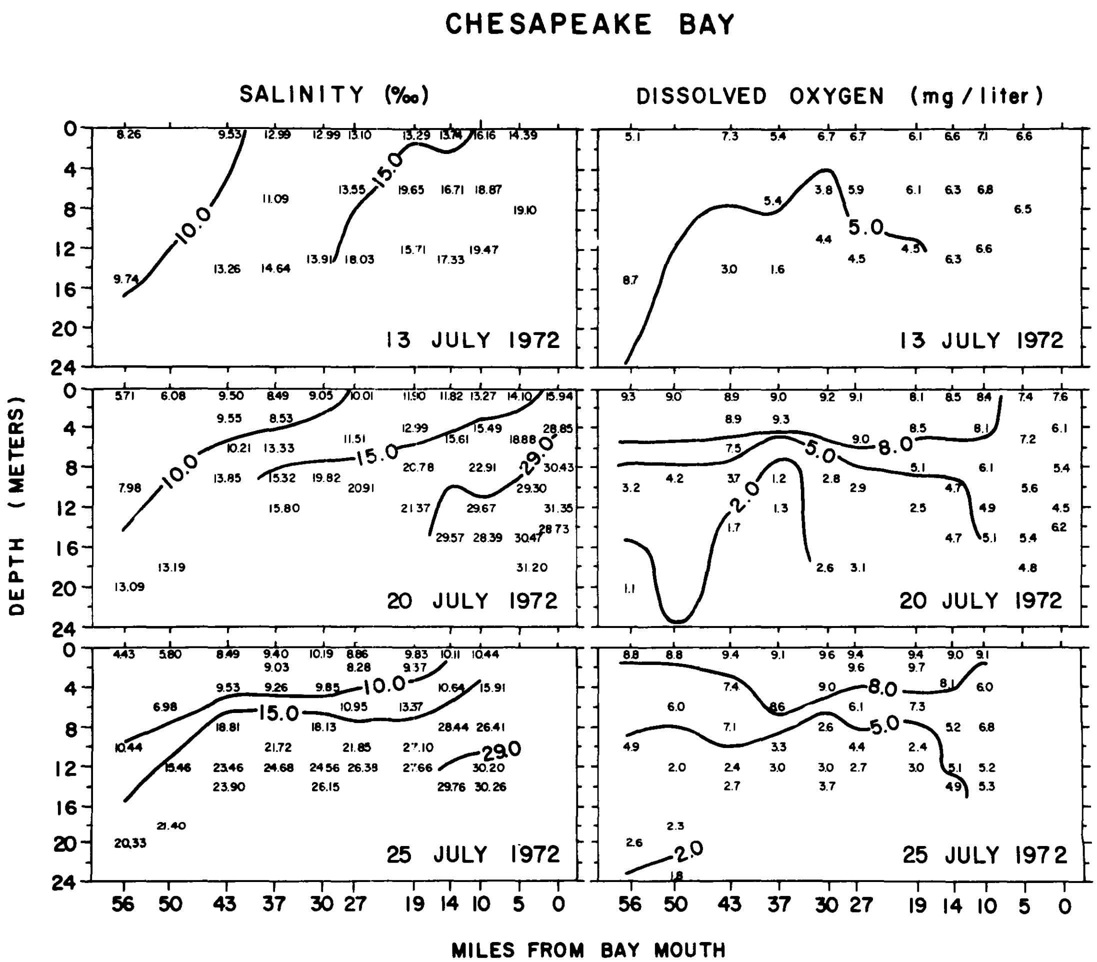

Figure 15. Chesapeake Bay slack water salinity and dissolved oxygen spatial distributions.