1976

Effects Of Tropical Storm Agnes On Zooplankton In The Lower Chesapeake Bay

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

The Chesapeake Research Consortium, Inc.

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TROPICAL STORM AGNES
ON THE
CHESAPEAKE BAY ESTUARINE SYSTEM

THE CHESAPEAKE RESEARCH CONSORTIUM, INC.

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November 1976

CRC Publication No. 54

Published for The Chesapeake Research Consortium, Inc., by The Johns Hopkins University Press, Baltimore and London

Manufactured in the United States of America

The Johns Hopkins University Press, Baltimore, Maryland 21218
The Johns Hopkins Press Ltd., London

Library of Congress Catalog Card Number 76-47392
ISBN 0-8018-1945-8

Library of Congress Cataloging in Publication data
will be found on the last printed page of this book.

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

Acknowledgements

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.

U. S. Army
- Corps of Engineers, Baltimore District
- Corps of Engineers, Norfolk District
- Corps of Engineers, Philadelphia District
- Transportation Corps, Fort Eustis, Virginia

U. S. Navy
- Naval Ordnance Laboratory
- 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
- Light Towers (Diamond Shoal, Five Fathom Bank, and Chesapeake)

National Oceanic and Atmospheric Administration
- National Marine Fisheries Service (Woods Hole, Massachusetts and Sandy Hook, New Jersey)

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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ABSTRACT

Sampling techniques in use since August 1971 were employed to study effects of Tropical Storm Agnes on lower Chesapeake Bay zooplankton following the storm's passage on June 21, 1972. Mean catches of copepods, cladocerans, barnacle larvae, decapod larvae, chaetognaths, and fish eggs and larvae were calculated for the entire study area and six subareas from 8" bongo net collections. A single subarea was selected for specific identifications within major taxa of zooplankton.

Biomass, as estimated from settled volume and dry weight, was reduced following flooding in 1972. The average dry weight in August 1972 was 89 mg/m^3 compared with 269 mg/m^3 in 1971, a year of more nearly normal rainfall. Copepods, dominated by the euryhaline *Acartia tonsa*, were least affected by flooding, although the seasonal maximum may have been delayed one month. Cladocerans, however, were decimated following the flood; *Evadne* and *Penilia* were eliminated from most of the lower Bay. Most of the observed reduction in biomass is attributed to severe effects of freshwater runoff on polyhaline cladoceran populations, which had not fully recovered by the summer of 1973.

Other groups of zooplankton were more or less reduced in numbers, but within the extremes observed for copepods and cladocerans.

INTRODUCTION

Agnes reached Norfolk, Virginia on the night of June 21, 1972. Record rainfall over most of the Chesapeake drainage basin followed closely on the heels of heavy rain from frontal activity the preceding week. Preceding months of 1972 were also unusually wet, especially in late winter and early spring. Freshwater discharge from the Potomac and Susquehanna rivers, principal tributaries to the Chesapeake, exceeded by 50% mean flows for the 10-month period preceding Agnes. Salinities in Chesapeake Bay, therefore, were already well below normal (CBRC 1973), and intensified the ecological stress induced by Agnes.

Literature contains little information on effects of floods and hurricanes on zooplankton populations. Numerous authors have reported alterations in fish populations (Baughman 1949, Breder 1962, Robins 1957, Simmons & Hoese 1960, Tabb & Jones 1962). Effects on oysters and other benthic invertebrates include reports by CBRC 1973, Andrews 1973, Burbanck 1961, Butler 1949, 1952, Lunz 1956, May 1972, and Stone and Reish 1965.

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[1]This research was supported, in part, by the Chesapeake Research Consortium, Inc., through funds supplied by the RANN program of the National Science Foundation. Contribution No. 760 from the Virginia Institute of Marine Science, Gloucester Pt., Va. 23062
[2]Virginia Institute of Marine Science, Gloucester Point, Va. 23062

Agnes interrupted the eleventh monthly survey in a 2-year investigation of zooplankton in lower Chesapeake Bay, begun in August 1971. We were therefore able to adapt an ongoing survey program to an impromptu study of flood effects and to compare flood data with before-and-after survey results. Quantitative zooplankton collections obtained with bongo samplers were analyzed by plankton groups. Summer surveys in 1971 and 1973 are compared with the flood period of 1972.

METHODS AND MATERIALS

Stations sampled monthly from August 1971 through July 1973 were randomly selected prior to each cruise from within each of eight subareas (A-H in Fig. 1). This technique was altered following Agnes for three weekly cruises beginning June 29-30, 1972, when those stations completed on June 19-20 (subareas A-F) were revisited. Random selection of stations was reinstituted with the July 24-27 regular monthly cruise. Data collected in subareas G and H are omitted from consideration in this paper, so that flood and non-flood periods are directly comparable, and are not included in any area means.

Hydrographic data reported herein were collected by means of a submersible pump, lowered to an even number of meters from the surface, but safely off the bottom. Temperatures were recorded and water samples collected for salinity and dissolved oxygen (DO) determinations at each 2-meter interval to the surface. Surface samples were taken within the upper half meter. A fuller description of sampling techniques may be found in Grant (1972).

Zooplankton was collected (Fig. 2) with 8-inch bongo samplers, fitted with 202μ mesh nets (Biological Methods Panel Committee on Oceanography 1969; McGowan & Brown 1966). General Oceanics, Inc. flowmeters were attached to the gear and used for volumetric estimates of water sampled. Tows were made from near the bottom to the surface in a stepped oblique technique, usually one minute per 2-meter interval.

Each tow yielded replicate samples, one from each of the bongo nets. The first was rinsed in distilled water and frozen over dry ice. After initial concentration in a 110μ sieve. The second was preserved in 5% formalin. Frozen samples were lyophilized in the laboratory for dry weights; preserved samples were settled for 24 hours in Imhoff cones for determination of settled volume, then split into successively smaller aliquots for counts and identification, first of the larger and rarer taxa, then of the smaller and numerically dominant zooplankters.

RESULTS

Hydrography of Lower Chesapeake Bay

Surface salinity in the lower Chesapeake Bay (below 37°23'N) fluctuates around mean values of from 19 ppt in the northwest portion to 25 ppt at Cape Charles during summer months (Stroup & Lynn 1963). This is the polyhaline region of the Bay. Mean summer temperatures at the surface over the years included in Stroup and Lynn (1963) range between 26 and 27.5°C, decreasing from west to east and toward the Bay mouth.

Mean surface temperatures and salinities within subareas A-F are shown in Fig. 3 for the period June 19-20 to September 1972. Grand means for comparable months in other years of our survey are also included. An initial rapid drop in salinity from June 19-20 to June 29-30 probably reflects local runoff and discharges from lower Chesapeake rivers such as the James, York, and Rappahannock. Surface salinity fluctuated during the next two weeks at abnormally low levels, before dropping to record lows in late July, one month after the passage of Agnes. Surface temperatures varied inversely with salinity, increasing rapidly from early to late July. Temperatures also elevated rapidly in this period at depth, increasing 2-5^{o}C at 2 and 4 meters. At 6 meters, increases were from 1-3^{o}C except in subareas C and E, where higher salinity water was encountered. The appearance of warm, low salinity surface waters in late July indicates a lag period of one month before full effects of flood waters from the Susquehanna were felt in the lowermost, normally polyhaline, region of Chesapeake Bay. Salinities were still below normal in September, but had recovered by October 1972. Except for the peak in late July, surface temperatures during summer 1972 were considerably below long-term averages.

Depletion of DO at deeper levels of the lower Chesapeake Bay, especially in deep holes found in the lower York and Rappahannock rivers, is a frequently observed summer phenomenon (VIMS, unpublished data). In the lower Bay proper in non-flood years, occasional measurements in the range of 3.4-4.3 mg/liter were taken from depths of 4-12 meters, from July through September. In the summer of 1972 DO was more severely reduced and over a greater area of the lower Bay (Table 1), especially after the arrival of flood waters from northern Chesapeake Bay. Low oxygen also was observed closer to the surface than in non-flood years, at depths of 4 meters.

Table 1. Occurrence of low dissolved oxygen measurements in lower Chesapeake Bay, June-September 1972.

Dates (1972)	Subarea*	Depth (m)	DO_2(mg/liter)
June 19-20	E (2)	6-10	3.9-4.4
	F (1)	8-10	3.5-4.3
June 29-30 - no notably low values			
July 6-7	E (1)	10-11	3.5-3.7
July 13-14	E (1)	6-12	3.2-3.6
July 24-27	A (1)	6	1.6
	D (2)	6-8	1.1-2.1
	E (3)	4-12	1.0-3.1
	F (3)	4-16	2.1-4.9
Aug 15-21	A (1)	4-6	2.6-3.6
	D (3)	4-8	0.2-3.9
	E (2)	6-12	1.4-3.4
	F (1)	8-10	3.6-3.7
Sept 12-14	D (1)	6-8	4.0

*number of stations in parentheses

Zooplankton Biomass in Lower Chesapeake Bay

Two basic estimates of plankton biomass were routinely derived from bongo net samples: 24 hour settled volume of preserved samples in ml/m^3 and dry weight of frozen samples in mg/m^3. Agreement between the two estimates is generally good, except in periods of ctenophore abundance. *Mnemiopsis leidyi*, fully incorporated in dry weight estimates, disintegrates in formalin. Remaining tissues tend to float in preserved samples, so are not included in settled volume measurements. *Beroe ovata* presents similar difficulties, but of lesser magnitude. The resulting disagreement between estimates when *Mnemiopsis* is abundant is evident in June 1973 data shown on Fig. 4. Apparent agreement between estimates in June 1972 is deceptive since in that month most ctenophores were counted and discarded before freezing of samples. A slight divergence in estimates in late July 1972 may be due to the presence of *Beroe*.

The high biomass found in August 1971 was not attained in the flood year of 1972. Instead, biomass decreased to relatively low levels after the surge of *Mnemiopsis* in June and remained low (ca. 100 mg/m^3) throughout the summer (Fig. 4).

General Composition of Zooplankton

Data presented in Tables 2 and 3 were obtained from counts of major taxa separated in initial sorting of preserved bongo collections. Certain minor groups, such as mollusk larvae, polychaete larvae, amphipods, isopods and mysids are excluded from the tables.

Density of copepods, cladocerans, barnacle larvae, decapod larvae, chaetognaths, and fish eggs and larvae are given for the study area in Table 2 and for individual subareas in Table 3. Cruises included are those from immediately prior to Agnes through the summer of 1972 and, for comparison, August and September 1971 and June and July 1973. Copepods increased rapidly from an annual June low to a maximum in September 1972, when counts corresponded to those observed in August 1971. Cladocerans decreased drastically following Agnes and, except for a slight recovery in August, remained in very low numbers throughout the summer of 1972. In August 1971, cladocerans were dominant over copepods, accounting for a large part of the biomass peak. Their scarcity in 1972 may conversely account for the absence of a normal August peak in biomass. One year after the flood, June 25-27, 1973, the few cladocerans seen were taken in subareas B and C, near the mouth of the Bay.

Barnacle larvae decreased steadily from June through September 1972; counts in June and July 1973 were even lower. The peak in decapod larvae numbers occurred in August 1972, but at an order of magnitude lower than that of 1971. Chaetognaths normally peak in September, so escaped much of the flood's effect. Numbers of fish eggs and larvae, on the average, were not notably reduced in 1972.

Species Composition of Selected Groups in Subarea D

Subarea D, located in the shallower portions of the western side of lower Chesapeake Bay from Wolf Trap to Back Bay, was subjected to the greatest reduction in salinity among the six subareas considered here, and is selected for a detailed examination of zooplankton changes. The deviation from normal T-S relationships in this subarea produced by flooding from Agnes is evident in Fig. 5.

Diversity among copepods is naturally low in Subarea D during summer because of the overwhelming dominance by *Acartia tonsa*. However, after Agnes the diversity was decreased even further (e.g. H' in August 1971 was approximately 0.037, but only 0.008 in August 1972). Reappearance of certain species occurred in September 1972 (Table 4). Low diversity among summer copepods was repeated in 1973, with the nearly complete absence of species other than *A. tonsa* in June and July.

Table 5 gives catches within species of both cladocerans and chaetognaths. Three species of cladocerans are normally present in this subarea during summer.

Table 2. Density of major zooplankton taxa in the lower Chesapeake Bay, before and after Tropical Storm Agnes. Mean number per cubic meter for subareas A-F combined; based on stepped oblique tows with 8" bongo nets, mesh size 202μ.

	Number per Cubic Meter						
	Primary Consumers			Secondary Consumers			
			Barnacle			Fish	
Dates	Copepods	Cladocera	Larvae	Decapods	Chaetognaths	Eggs	Larvae
PRE-FLOOD							
Aug 16-19, 1971	19,750	77,570	24	1,429	17	49	25
Sept 21-23, 1971	12,800	1,078	11	51	226	<1	<1
June 19-20, 1972	175	1,062	225	38	<1	69	1
FLOOD (1972)							
June 29-30	260	41	85	19	<1	27	4
July 6-7	1,510	78	48	11	<1	48	2
July 13-14	12,740	87	43	22	<1	83	9
July 24-27	13,720	8	9	12	2	72	24
Aug 15-21	12,690	2,015	4	101	15	32	13
Sept 12-14	20,400	1	4	26	102	0	<1
POST-FLOOD (1973)							
June 25-27	638	260*	3	22	<1	36	<1
July 23-24	2,542	1,655	34	63	1	115	12

*all at a few seaward stations

Table 3. Density of major zooplankton taxa within individual subareas A-F during flood period of 1972 and comparable months in 1971 and 1973.

Dates	Numbers/m^3						
	Copepods	Cladocerans	Chaetognaths	Barnacle Larvae	Decapod Larvae	Fish Eggs	Fish Larvae
			SUBAREA A				
16-19 Aug 71	13,180	5,734	18	0	3,357	13	4.7
21-23 Sept 71	4,670	311	315	21	25	0	1.2
19-20 June 72	117	448	<1	139	64	74	0.6
29-30 June 72	791	51	<1	111	43	29	13.9
6-7 July 72	1,459	143	<1	77	6	68	2.5
13-14 July 72	12,000	8	<1	52	28	63	12.6
24-27 July 72	5,655	<1	<1	10	38	76	16.6
15-21 Aug 72	15,340	1,215	10	3	27	50	8.2
12-14 Sept 72	12,030	3	14	3	20	0	0.3
25-27 June 73	378	0	<1	1	6	17	0.4
23-24 July 73	4,381	838	1	13	70	174	7.6
			SUBAREA B				
Aug 71	13,040	153,500	20	81	1,558	52	13.0
Sept 71	2,913	3,221	238	13	46	<1	0.1
19-20 June 72	191	2,622	0	78	75	99	1.3
29-30 June 72	114	<1	<1	169	7	3	0.03
6-7 July 72	1,431	69	<1	19	13	15	2.3
13-14 July 72	16,560	110	<1	55	37	86	17.6
24-27 July 72	no samples						
15-21 Aug 72	9,886	757	3	9	91	40	19.0
12-14 Sept 72	32,780	<1	405	6	42	0	0.5
June 73	480	3	<1	0	19	40	0.7
July 73	2,065	1,091	4	30	80	290	35.1
			SUBAREA C				
Aug 71	5,734	53,090	5	0	2,937	116	46.4
Sept 71	3,764	431	358	12	34	<1	0.2
19-20 June 72	134	1,111	0	64	18	58	0.9
29-30 June 72	117	3	<1	31	11	13	1.7
6-7 July 72	1,410	255	0	15	4	115	4.3
13-14 July 72	19,920	340	1	27	22	125	10.2

Table 3. (Continued)

Dates			Copepods	Cladocerans	Chaetognaths	Barnacle Larvae	Decapod Larvae	Fish Eggs	Fish Larvae
			Numbers/m^3						
					SUBAREA C (Continued)				
24-27	July	72	6,872	30	2	2	12	82	20.2
15-21	Aug	72	4,500	8,168	15	1	206	22	12.3
12-14	Sept	72	25,560	<1	102	3	23	0	1.1
	June	73	1,204	1,225	1	10	61	62	0.3
	July	73	3,385	4,042	3	21	166	136	24.8
					SUBAREA D				
	Aug	71	38,120	16,960	8	35	467	5	42.7
	Sept	71	57,530	2	113	7	74	0	0.8
19-20	June	72	131	20	0	1,256	17	16	0.5
29-30	June	72	74	10	0	65	11	48	0.2
6-7	July	72	3,453	1	0	43	31	47	1.2
13-14	July	72	8,203	0	0	17	10	19	2.9
24-27	July	72	15,290	0	<1	18	5	77	11.5
15-21	Aug	72	18,900	<1	<1	7	21	50	7.8
12-14	Sept	72	15,640	6	16	10	20	0	0.2
	June	73	468	0	0	5	10	22	0.6
	July	73	1,712	1,210	<1	51	16	89	4.9
					SUBAREA E				
	Aug	71	18,880	42,890	15	1	512	61	30.0
	Sept	71	19,320	615	50	12	58	0	0
19-20	June	72	185	967	0	163	12	90	2.0
29-30	June	72	40	255	0	14	21	16	0.7
6-7	July	72	119	0	0	11	7	11	0.4
13-14	July	72	10,900	<1	<1	54	13	44	4.0
24-27	July	72	17,140	2	3	9	4	92	27.7
15-21	Aug	72	12,090	79	21	3	54	33	16.2
12-14	Sept	72	14,920	<1	28	1	16	0	0
	June	73	332	0	0	<1	15	15	0.2
	July	73	1,471	1,503	<1	36	25	50	6.3

Table 3. (Continued)

Dates	Numbers/m³						
	Copepods	Cladocerans	Chaetognaths	Barnacle Larvae	Decapod Larvae	Fish Eggs	Fish Larvae
			SUBAREA F				
Aug 71	35,130	114,000	30	0	384	27	18.1
Sept 71	8,518	417	181	2	71	<1	0.2
19-20 June 72	265	531	0	123	16	57	1.6
29-30 June 72	53	0	0	100	7	47	1.3
6-7 July 72	803	8	0	88	4	39	1.7
13-14 July 72	4,577	29	<1	44	16	152	4.1
24-27 July 72	22,400	<1	1	10	5	37	36.9
15-21 Aug 72	18,310	176	26	4	136	17	12.9
12-14 Sept 72	18,990	<1	49	1	32	0	0.3
June 73	683	0	<1	<1	7	39	0.1
July 73	1,823	783	1	52	17	46	2.8

Table 4. Species composition of copepod collections in Subarea D, summer months of 1972 and comparable months in non-flood years.

Dates	Numbers Per Cubic Meter								
	Acartia tonsa	*Labidocera aestiva*	*Pseudodiaptomus coronatus*	*Temora turbinata*	*Paracalanus crassirostris*	*Oithona* sp.	Unidentified harpacticoid	*Centropages hamatus*	*Eurytemora* sp.
PRE-FLOOD									
Aug 1971	36,740	35	29	24	16	--	8	--	--
Sept 1971	55,730	37	1,517	--	--	--	-	--	--
June 19-20, 1972	131	--	--	--	--	--	-	<1	--
FLOOD (1972)									
June 29-30	72	--	--	--	--	2	-	--	--
July 6-7	3,451	--	--	--	--	--	-	--	--
July 13-14	8,203	--	--	--	--	--	-	--	--
July 24-27	15,216	--	--	--	--	25	37	--	--
Aug 15-21	18,879	<1	--	--	--	--	--	--	11
Sept 12-14	6,607	10	13	--	82	10	--	--	--
POST-FLOOD (1973)									
June 25-27	534	--	--	--	--	--	2	--	--
July 23-24	1,803	--	--	--	--	--	--	--	--

Table 5. Species composition of cladoceran collections and abundance of the chaetognath *Sagitta tenuis* in Subarea D, summer months of 1972 and comparable months in non-flood years.

	Numbers Per Cubic Meter Cladocera			Chaetognatha
Dates	*Podon polyphemoides*	*Evadne tergestina*	*Penilia avirostris*	*Sagitta tenuis*
PRE-FLOOD				
Aug 1971	399	14,580	2,193	6
Sept 1971	<1	2	0	110
June 19-20, 1972	20	0	0	0
FLOOD (1972)				
June 29-30	10	0	0	0
July 6-7	1	0	0	0
July 13-14	0	0	0	0
July 24-27	0	0	0	0
Aug 15-21	<<1	<1	0	<1
Sept 12-14	6	<<1	0	16
POST-FLOOD (1973)				
June 25-27	0	0	0	0
July 23-24	1,210	0	0	<<1
Aug (cladoceran cruise)	183	646	53	--

Podon polyphemoides decreased rapidly after Agnes to complete absence in mid- and late July; a slight recovery occurred in September. None were taken in June 1973; sizable catches occurred in July. *Evadne tergestina*, very abundant in August, 1971, was absent in June and July 1972, very rare in August and September, absent again in June and July 1973. *Penilia avirostris* was present in Subarea D only in August 1971. A post-survey cruise in August 1973, for the sole purpose of assessing cladoceran abundance, revealed the presence of all three species.

The single species of warm-water chaetognath taken in this subarea, *Sagitta tenuis*, was considerably reduced in numbers during August and September of 1972 compared with catches in the previous year.

Fish larvae were also considerably reduced in 1972, although this subarea is not normally very productive. Anchovies, most likely *Anchoa mitchilli*, were the most abundant larvae, reduced from $35/m^3$ in August 1971 to $6/m^3$ in August 1972. Two as yet unidentified species, one a goby and the other a blenny, were also present in low numbers both years. Several species, although rare, were present in August 1971, but absent in August 1972. They were *Cynoscion regalis*, *Gobiesox strumosus*, *Sphaeroides maculatus*, *Symphurus plagiusa*, *Trinectes maculatus* and *Syngnathus fuscus*.

Other zooplankton groups not incorporated in Tables 3-5 include gastropod larvae, polychaete larvae, amphipods, isopods, phoronid larvae and mysids. Among these, only gastropod larvae were numerically important. They were fairly abundant just prior to Agnes ($110/m^3$), then declined during flooding until the late July cruise. Numbers remained low thereafter. The following year, June and July 1973, found gastropod larvae very abundant and occasionally dominant over copepods (to $750/m^3$).

DISCUSSION

In attempting to evaluate effects of the flood on zooplankton populations, catastrophic changes induced by Agnes must be distinguished from normal annual and seasonal variations. The present exercise in evaluating a catastrophic perturbation on a particular segment of the biota has demonstrated to us the need for long-term monitoring of seasonal and annual changes in abundance. With data from only one complete and two partial summer periods, a description of normal zooplankton composition must be highly speculative. However, the data reveal distinct trends in zooplankton abundance and the storm significantly altered existing distributional and numerical zooplankton patterns during and directly following the flood period.

Normally, intensive predation by the ctenophore *Mnemiopsis leidyi* on crustacean populations results in very low numbers of copepods in May and June in the lower Bay (Burrell 1968). This occurred in both 1972 and 1973. As *Mnemiopsis* is reduced in July through predation by another ctenophore, *Beroe ovata*, the crustacean zooplankton, dominated by *Acartia tonsa*, builds to an August maximum. Our data indicate that the copepod maximum in 1972 was delayed until September (Table 2), even though the dominant *A. tonsa* is a widely distributed copepod occupying salinities as low as those encountered during the flood (Heinle 1972, Joseph & Van Engel 1968, Burrell 1972), and *Beroe* appeared throughout the lower Bay, as usual, in July 1972. However, no lasting effect on this euryhaline copepod was evident. Copepod abundance in September 1972 compared closely with that observed in August 1971, and we conclude that Agnes had little effect on total copepod population size.

Barnacle larvae and gastropod larvae were reduced in numbers following the flood, as were decapod larvae, chaetognaths, and to a lesser extent, fish eggs and larvae. The greatest effect by far was on the Cladocera. In August 1972, the mean number of cladocerans per cubic meter in the lower Bay was 2×10^3 as compared with 77×10^3 in August 1971. Collections from Subarea B in August 1971 showed counts of 153×10^3, compared with 0.8×10^3 in August 1972; other subareas were similar in reduction of cladoceran counts. *Evadne tergestina* and *Penilia avirostris*, two high salinity species, comprised the bulk of the cladoceran population in Subarea D in summer 1971 (Table 5). Bosch and Taylor (1968) found that the lowest salinities inhabited by these two species in Chesapeake Bay were 15.75 ppt and 18.12 ppt, respectively. In view of this, it is not surprising that *Evadne* and *Penilia* were almost completely eliminated from the lower Bay following Agnes.

The reduction in Cladocera may have been a relatively long-term one, extending through the summer of 1973. In June 1973, cladocerans were found only at a few seaward stations, and these consisted of *Podon polyphemoides* and *Evadne nordmanni*, remnants of a May peak. *Evadne tergestina* and *Penilia avirostris* did not reoccur in the lower Bay until July 1973 or in Subarea D until August 1973. It is quite likely that overwintering resting eggs deposited in the lower Bay were destroyed by the flood, so that repopulation had to await the influx of individuals from coastal water populations. Andrews (1973) has stated that recovery was slower among benthic organisms having crawling or sedentary larvae than among species with pelagic larvae. Planktonic organisms such as cladocerans, with a part of their life cycle tied to the bottom, might also be expected to recover slowly.

Cladocerans were the dominant zooplankton organisms in the lower Chesapeake Bay in August 1971. By August 1972, after flooding from Agnes, they were essentially absent. The severe reduction in cladocerans probably accounts for most of the observed loss in plankton biomass, down from 269 mg/m^3 dry weight in August 1971 to 89 mg/m^3 in August 1972.

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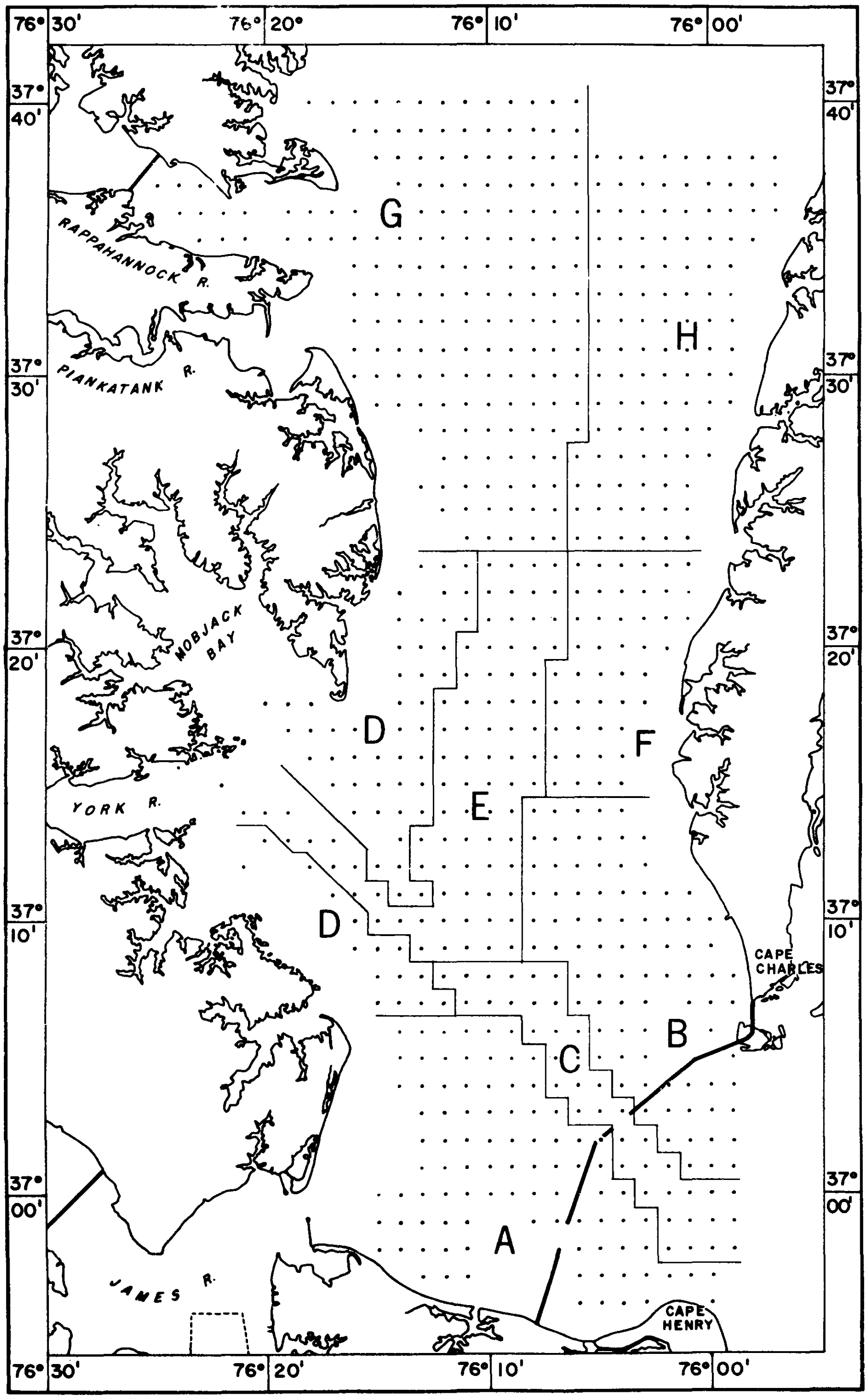

Figure 1. Area of study during two-year zooplankton survey of lower Chesapeake Bay where stations were chosen at random from within each of the eight subareas A-H each month. Flood studies consider only subareas A-F.

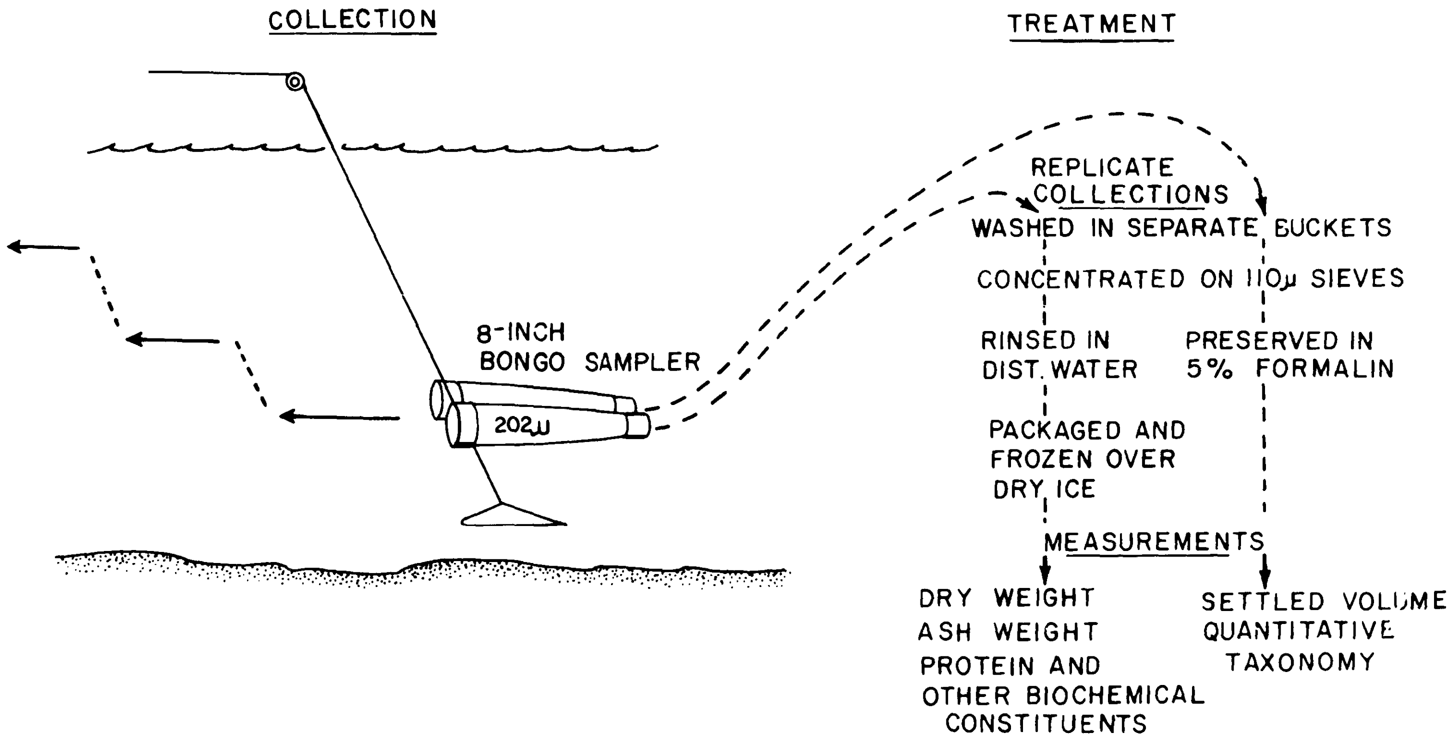

Figure 2. Diagram of zooplankton collection method and subsequent treatment of samples.

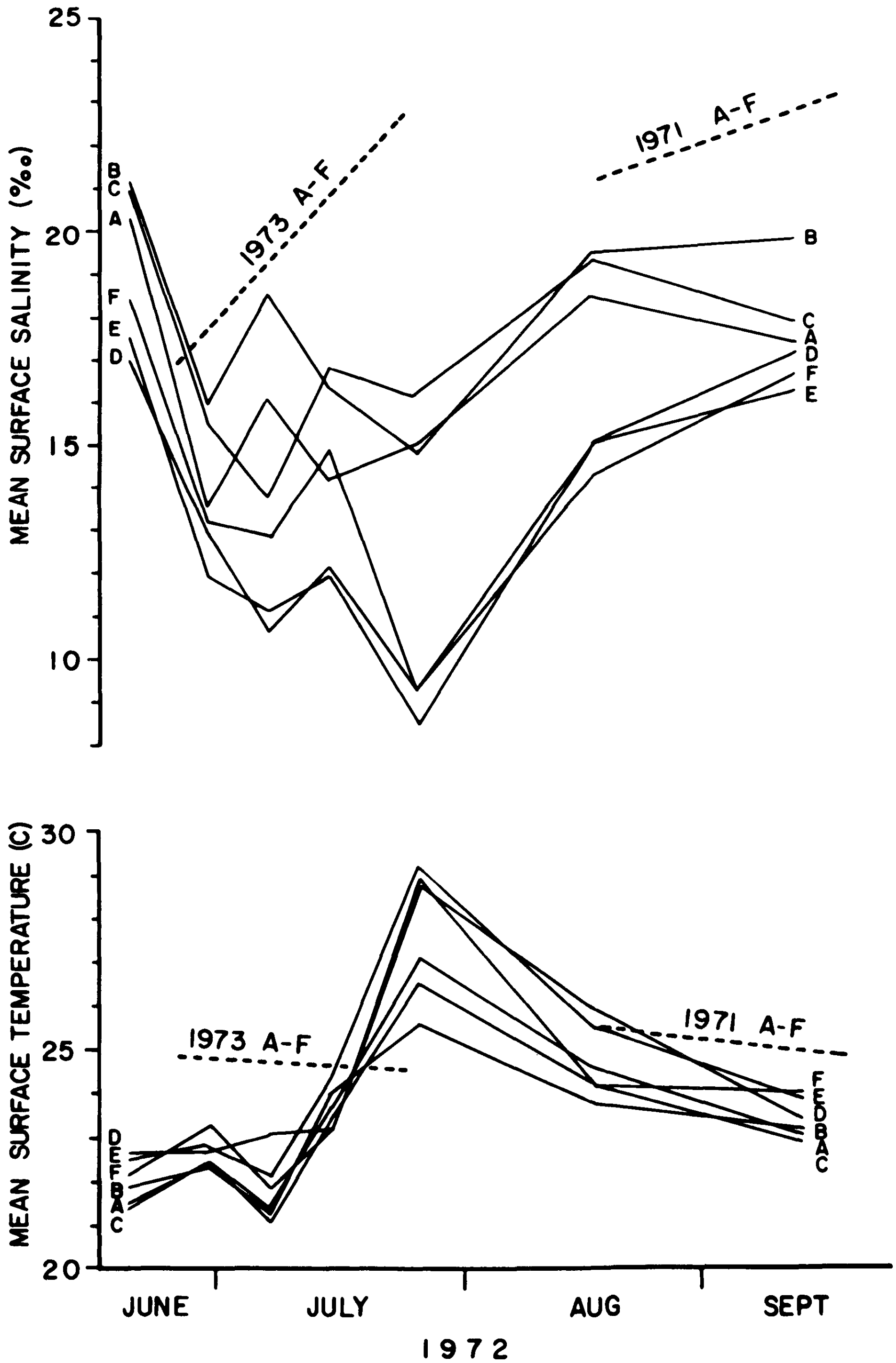

Figure 3. Mean surface salinity (top) and temperature (bottom) within subareas A-F, June 19-20 - September 12-14, 1972 (solid lines); total area means for comparable months in non-flood years connected by dashed lines.

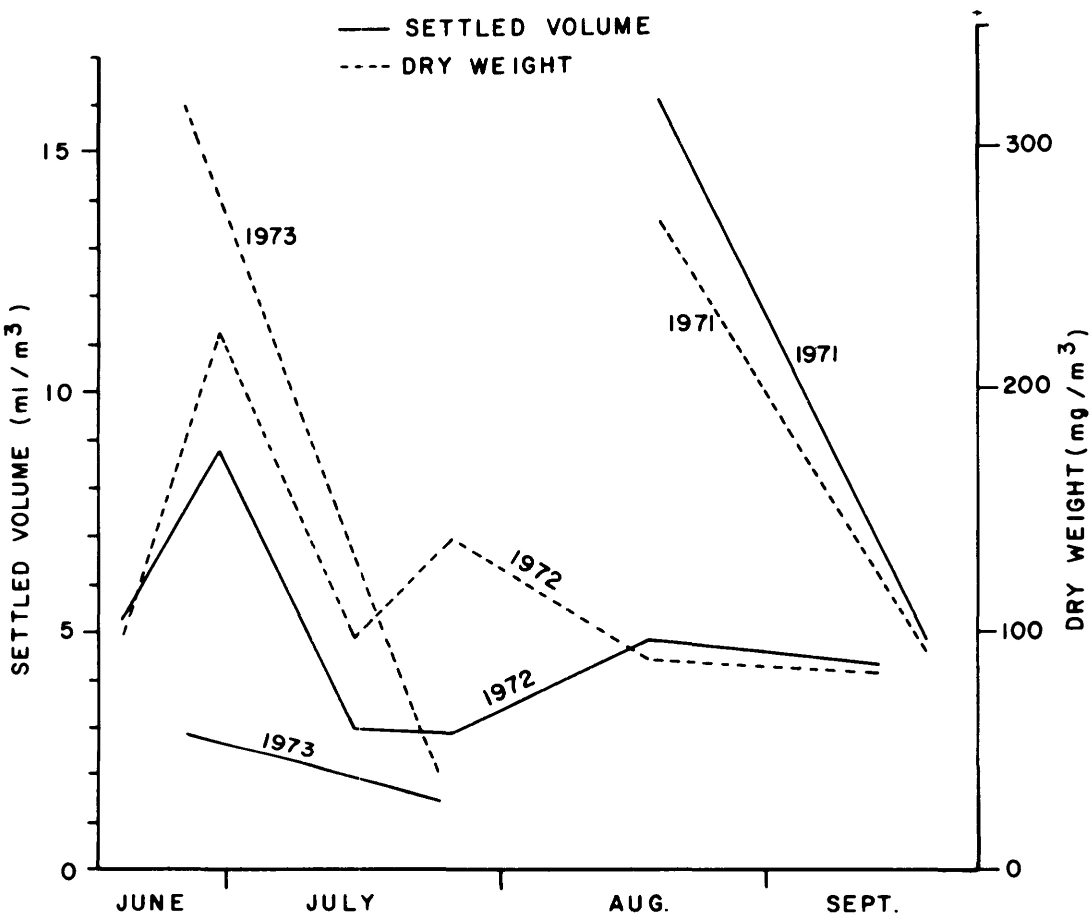

Figure 4. Estimates of zooplankton biomass in the lower Chesapeake Bay, dry weight in mg/m^3 and settled volume in ml/m^3, June 19-20 - September 12-14, 1972, and comparable months in 1971 and 1973; mean values for the entire study area (subareas A-F).

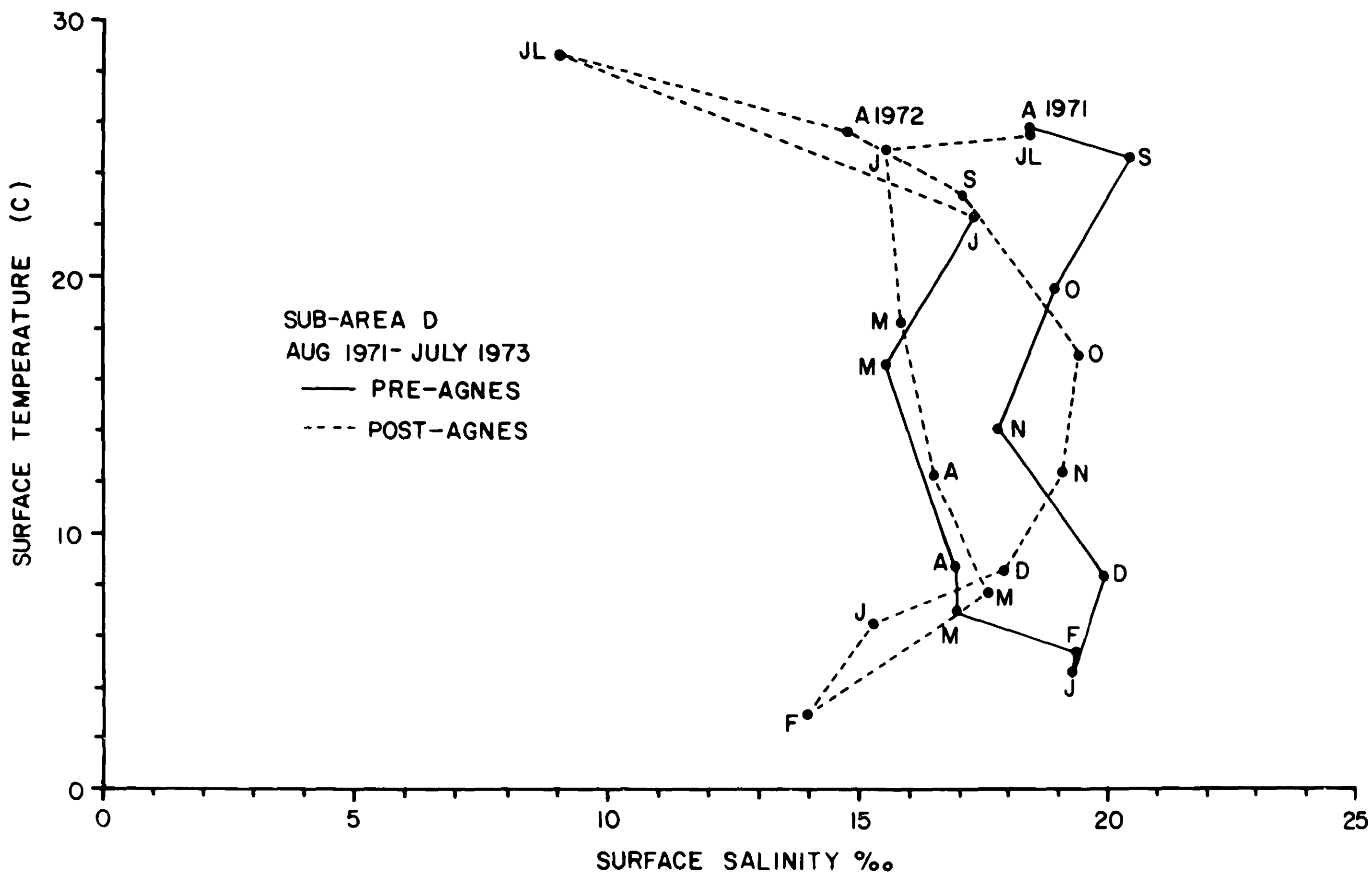

Figure 5. Mean surface temperature-salinity relationship in subarea D, August 1971-July 1973.