OCEANOGRAPHY FIELD PRACTICUM

Spring Half-Term, 1972

The practicum is offered through the cooperation of the Marine Biological Laboratory and the Woods Hole Oceanographic Institution, Woods Hole, Massachusetts, with the support of the University of Michigan Sea Grant Program.

Compiled by

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and

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THE UNIVERSITY OF MICHIGAN SEA GRANT PROGRAM

The University of Michigan Sea Grant Program is a part of the National Sea Grant Program, which is maintained by the National Oceanic and Atmospheric Administration of the US Department of Commerce.

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PREFACE

For the second consecutive year, The University of Michigan conducted its "Oceanography Field Practicum" at Woods Hole, Massachusetts, during May and June 1972. This report provides a comprehensive description of the 1972 practicum. As in the previous report on the practicums, the present report is intended for a varied readership, including

- administrative officers of the institutions involved in this venture;
- University of Michigan faculty members teaching in related disciplines whose students may wish to participate in subsequent offerings of this course;
- staff members of other universities which are contemplating the inauguration of oceanography field courses;
- the many members of the research staff of the Woods Hole Oceanographic Institution who worked actively to make this venture a success;
- the future student participants in this course, many of whom will choose to build upon the studies conducted during this and the previous year; and
- the students who participated in The University of Michigan's M&O 560 course during 1972, and to whom the eventual existence of this report represented an incentive to prepare, in the time allotted, the most complete reports on their individual research projects.

ACKNOWLEDGMENTS

We wish to thank all the people on the staff of the Woods Hole Oceanographic Institution (WHOI) whose aid made this program possible. We also wish to acknowledge the cooperation of the administrative officers of the WHOI, and the encouragement of Dean H. Burr Steinbach. The opportunity afforded the majority of this year's practicum students to join the R/V *Knorr* on leg five of Cruise 25 is gratefully acknowledged. The assistance of Mr. W. Gary Metcalf and Mr. Marvel C. Stalcup in this regard is recognized with thanks. The use of the R/V *Asterias* for several days each week during the Woods Hole interval of the course was an essential ingredient in our program, and the interest and understanding shown by Mr. Dick Colburn when he operated the R/V *Asterias* during our practicum exercises is greatly appreciated.

The cooperation of Dr. Redwood Wright, who was conducting a UNESCO-sponsored program for oceanographers from developing nations in Woods Hole during a portion of the interval when our Ocean Practicum was underway, is acknowledged with thanks. Both our programs benefited from the several shared activities.

We wish to thank Dr. Gilbert T. Rowe, Dr. Bruce P. Luyendyk, and Mr. Marvel C. Stalcup for the central roles they occupied in the conduct of our course.

We are grateful to the additional fifteen WHOI scientists listed elsewhere in this report, all of whom gave one or more lectures, and many of whom advised students on their individual research projects.

The assistance of Mr. Homer P. Smith, General Manager of the Marine Biological Laboratory, and of his staff is gratefully acknowledged.

We wish to thank Professor Harold E. Edgerton of Massachusetts Institute of Technology for meeting with our students in Cambridge, the EG&G Environmental Equipment Division for providing a tour of its Waltham plant, and Mr. Paul Ferris Smith of EG&G for giving a lecture to our group in Woods Hole.

We wish to acknowledge the support given this course by the Department of Meteorology and Oceanography, the College of Engineering, and the Sea Grant Program of The University of Michigan. Our thanks to the University of Michigan's School of Natural Resources and Department of Civil Engineering for the loan of instruments needed in the conduct of this course.

INTRODUCTION

The University of Michigan's Oceanography Field Practicum (M&O 560) was initiated in 1971 to make available to the University's significant number of graduate students in oceanography and related fields the opportunity at the beginning of their graduate education to carry out experimental observations on the ocean, and in this and similar ways to become acquainted with the practical techniques currently used in marine research. This motive has continued to govern the operation of this program.

The catalog description of this eight-credit course is as follows:

> Design and implementation of oceanographic observational programs; marine data-gathering capabilities: research vessels, buoys, etc.; shipboard data processing. Current techniques in physical, chemical, geological and biological oceanography, marine geophysics and marine meteorology.

The course was taught in Woods Hole, Massachusetts, utilizing the facilities of the Marine Biological Laboratory (MBL) and the facilities and staff of the Woods Hole Oceanographic Institution (WHOI). The course was offered during The University of Michigan's spring half-term (IIIA), and was divided into two time periods. The initial six weeks were spent at Woods Hole (4 May-14 June 1972), followed by a 12-day period (ending on 26 June 1972) for the completion of the student reports.

The course was supervised by Dr. Edward C. Monahan of The University of Michigan's Department of Meteorology and Oceanography with Mr. G. Thomas Kaye serving as the teaching assistant.

There were 19 student participants in the 1972 Ocean Practicum: eight graduate students and 11 seniors. Ten of the students were from the Department of Meteorology and Oceanography, College of Engineering; seven were from the School of Natural Resources; one was from the Department of Civil Engineering, College of Engineering; and one was from the Biology Department, College of Literature, Science, and the Arts. All of the 1972 student participants were regularly enrolled students at The University of Michigan.

Woods Hole Interval

During the six-week interval in Woods Hole, there were three distinct aspects of the course. These were the practicum exercises, the lectures (series and individual), and the individual research projects.

Practicum Exercises

The practicum exercises were based on a series of day and half-day cruises aboard WHOI's 40-ft R/V *Asterias.* A total of ten days, spread over the six-week Woods Hole interval, were devoted to these exercises during the 1972 Ocean Practicum. This aspect of the course was under the immediate direction of Mr. Marvel C. Stalcup, research associate in the Physical Oceanography Department of the Woods Hole Oceanographic Institution. The shipboard work was supplemented by sample analyses and data handling ashore. The dates and details of the 1972 R/V *Asterias* cruises are included in the course log section of this report.

As an adjunct to the 1972 Ocean Practicum, ten of the 19 students in the course were able to participate in a ten-day pre-course cruise aboard the 245-ft R/V *Knorr,* sailing from San Juan, Puerto Rico, on 30 April and arriving in Woods Hole early on 9 May. Mr. Stalcup supervised the students aboard the R/V *Knorr.* A summary of the nightly seminars provided for the students aboard the R/V *Knorr,* a summary of the shipboard activities participated

Figure 1. U-M Students Aboard R/V *Asterias* as It Heads into Vineyard Sound for a Series of Hydrographic Stations

in by these students, and profiles of hydrographic station data prepared by this group are included in the appendix to this report. Among the people who presented seminars aboard the R/V *Knorr* were Mr. Rich Johnson, a University of Michigan PhD candidate and a teaching assistant for the 1971 Ocean Practicum, and Mr. Randy Borys, a student participant in the 1971 Ocean Practicum.

One student, Miss Evans, participated in a two-day cruise (1-2 June) on the 99-ft R/V *Gosnold*. This cruise was part of the UNESCO-NODC training program for oceanographers, and was directed by Dr. Redwood Wright of WHOI.

Lectures

The lecture portion of the course was divided into two components. The first component was made up of the two lecture series or "short courses," each consisting of 12 hours of classroom instruction, and each ending in a written examination. The second component of this portion of the course consisted of numerous individual lectures.

One of the 1972 lecture series, entitled "Current Problems in Marine Geophysics," was given by Dr. Bruce P. Luyendyk, assistant scientist in the Geology and Geophysics Department of WHOI. The other 1972 lecture series, "Topics in Biological Oceanography," was given by Dr. Gilbert T. Rowe, assistant scientist in the Biology Department of WHOI.

While the "short courses" given as part of the 1972 Ocean Practicum were the same as those given in the previous year, the program of individual lectures was expanded, partly to accommodate the more diverse backgrounds and interests of the student participants of 1972.

A total of 24 individual lectures, spread throughout the six-week interval, were given at Woods Hole by

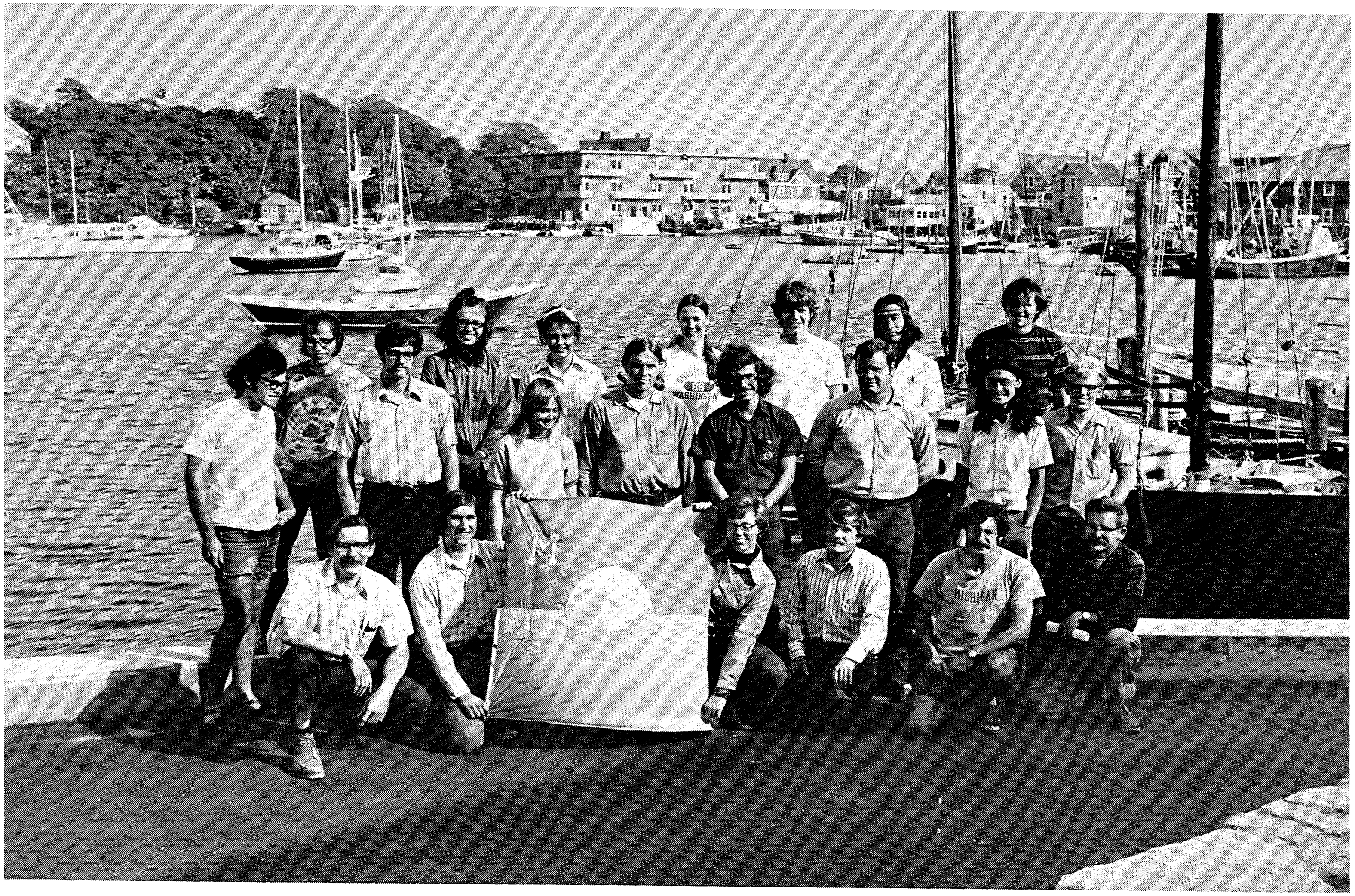

Figure 2. U-M Ocean Practicum 1972 Participants: Back Row, L to R: M. Senneff, V. Evans, S. Williams, C. Kramer, R. Grove, N. Takeuchi, E. Chesney; Middle Row, L to R: R. Kettner, J. Allender, J. Alexander, D. Ryker, R. Moore, J. McPeak, G. Sugihara, B. Higgins; Front Row, L to R: Prof. E. Monahan, R. Patchen, M. Vanderlaan, P. Perschbacher, J. Maresca, Mr. M. Stalcup. Not Shown: Mr. T. Kaye. (In background: Eel Pond and WHOI's Redfield Building)

Mr. Dean F. Bumpus	Phys. Oceano., WHOI
Dr. William Dunstan	Biology, WHOI
Dr. Richard L. Haedrick	Biology, WHOI
Dr. George R. Harvey	Chemistry, WHOI
Dr. Charles D. Hollister	Geology & Geophys., WHOI
Mr. G. Thomas Kaye	M&O, University of Michigan
Dr. Peter Kilham	Biology, WHOI
Dr. James R. Luyten	Phys. Oceano., WHOI
Mr. W. Gary Metcalf	Phys. Oceano., WHOI
Mr. Eduardo D. Michelena	M&O, University of Michigan
Dr. Edward C. Monahan	M&O, University of Michigan
Dr. Fred L. Offensend	Marine Policy, WHOI
Dr. Charles C. Remsen III	Biology, WHOI (2 lectures)
Dr. David A. Ross	Geology & Geophys., WHOI
Dr. Kenneth R. Tenore	Biology, WHOI
Dr. Thomas Sanford	Phys. Oceano, WHOI
Dr. Peter M. Saunders	Phys. Oceano, WHOI
Dr. Kenneth L. Smith	Biology, WHOI
Mr. Paul F. Smith	Environ. Equip. Div., EG&G, Inc.
Mr. Marvel C. Stalcup	Phys. Oceano., WHOI

The titles of the lectures, most of which were given in the Loeb Building of the MBL, are included in the course log section of this report, as are notices of tours, work sessions, and other course activities. Also listed in the course log are the numerous lectures, sponsored by other groups in the Woods Hole scientific community, which were open to, and often attended by, the Ocean Practicum students. The presence of Dr. Wright's UNESCO training program and Dr. Ketchum's Coastal Zone Workshop during portions of the 1972 Woods Hole interval gave rise to additional pertinent lectures available to the Michigan students.

Individual Research Projects

Each student carried out a research project under the direction of one of the participating scientists. An attempt was made to identify research topics related to each student's stated interest. During the 1972 Ocean Practicum, individual students were advised not only by Dr. G. Rowe, Dr. B. Luyendyk, Mr. M. Stalcup, and Professor E. Monahan but also by Dr. K. Smith, Dr. F. Offensend, Dr. K. Tenore, Dr. W. Dunstan, Dr. R. Haedrick, Dr. P. Kilham, and Dr. C. Remsen. The abstracts of the student research papers and complete texts of selected papers are contained in a separate section of this report.

Facilities

During the Woods Hole interval, the students lived and ate in the new dormitory-dining hall of the Marine Biological Laboratory. This structure is close to the Loeb Building, where most of the M&O 560 activities were centered. The Lillie Building of the MBL, which houses the combined library holdings of the MBL and WHOI, is also close by. Within short walking distance are most of the other buildings of the WHOI and the facilities of the Woods Hole Laboratory of the National Marine Fisheries Service.

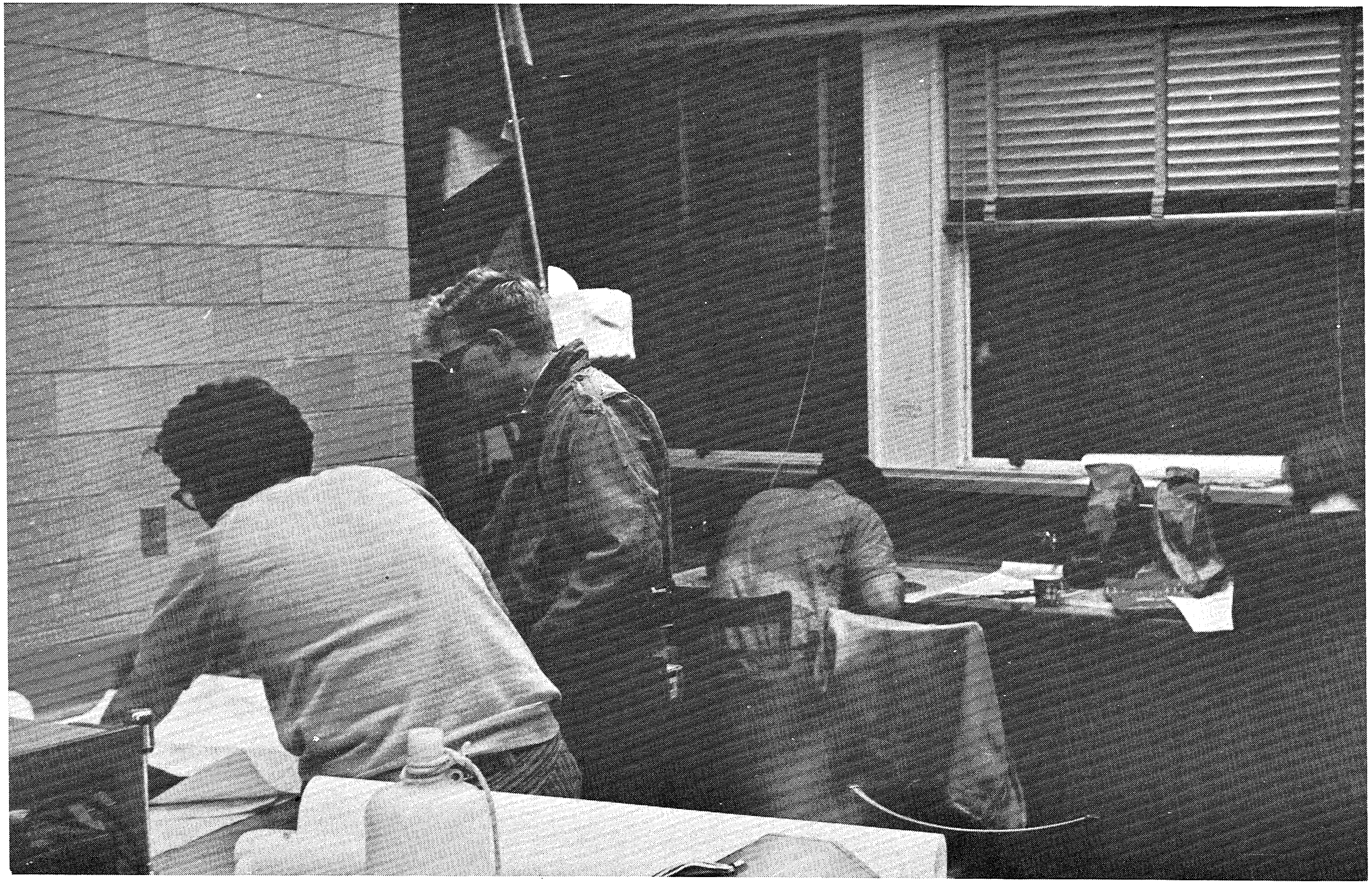

Figure 3. Evening Preparations for the Next Morning's Field Work (Room 126, Loeb Teaching Building, Marine Biological Laboratory)

COURSE LOG

The lectures, cruises, and other activities listed on the following pages which do not have a specific notation as to sponsorship were the integral components of The University of Michigan Oceanography Field Practicum of 1972. The numerous other lectures, seminars, etc. listed in this log which have a notation as to sponsorship are included in this report to convey the scope of the other activities in Woods Hole which were available to, and frequently attended by, the M&O 560 students. The public functions sponsored by the various resident groups in the Woods Hole academic institutions played a significant role in the overall student experience during the Woods Hole interval.

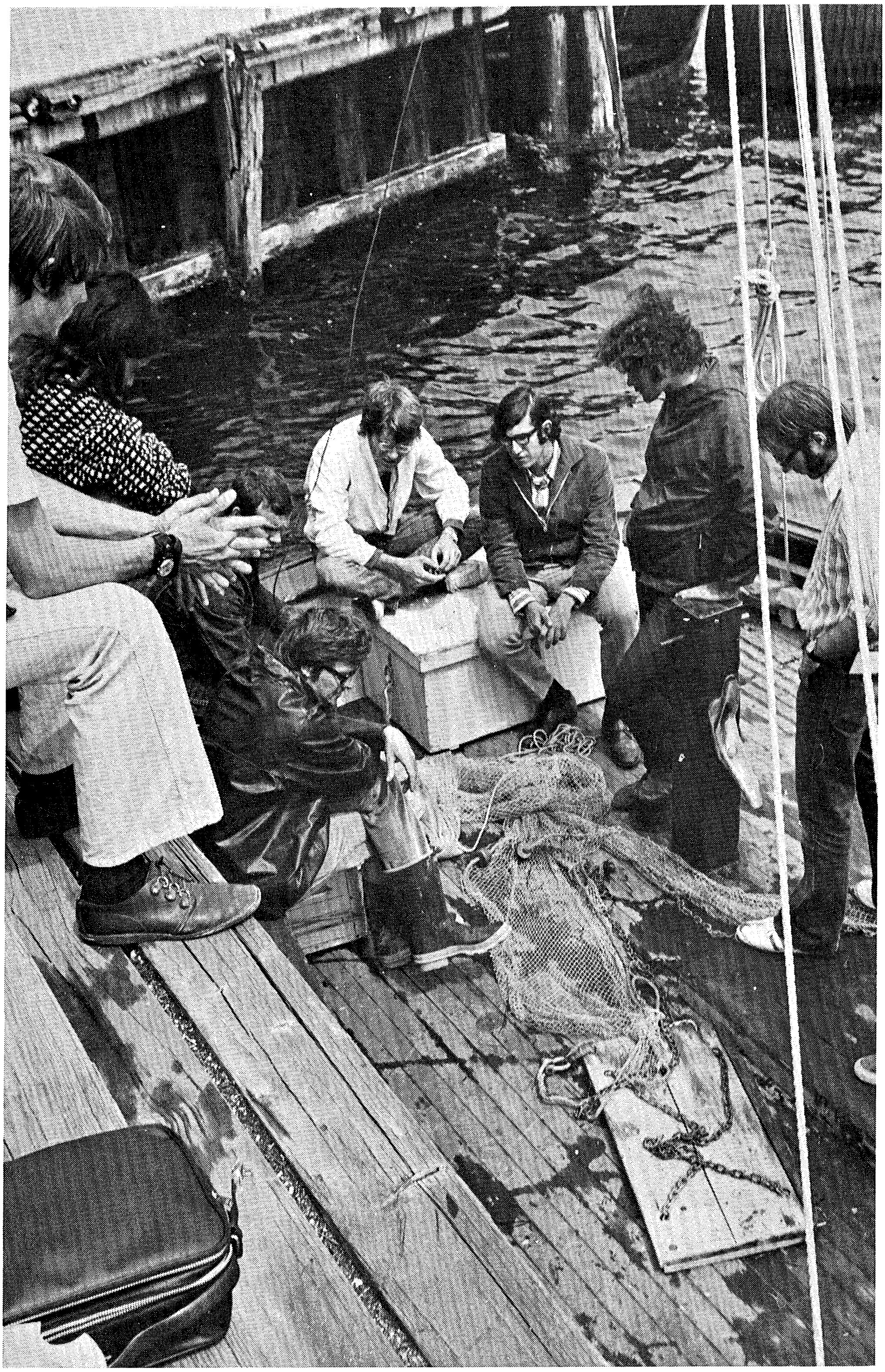

Figure 4. A Moment for Thought at the WHOI Pier Before Rigging an Otter Board Trawl Aboard the R/V *Asterias*.

4 May 1972 (Thursday)

9:00 am	Ocean Practicum Orientation Meeting Rm. 126 Loeb Building (MBL) Professor E. C. Monahan, Univ. of Michigan Brief Walking Tour of Scientific Facilities in the Village of Woods Hole Professor E. C. Monahan, Univ. of Michigan
10:15 am	Departure via U-M Stationwagen and Car for Cambridge, Mass.
12:30 pm	Box Lunch on MIT Campus
1:00 pm	"Underwater Photography, Sonar, etc." Rm. 4-405 MIT Dr. Harold E. Edgerton, MIT
3:00 pm	Departure for Woods Hole
*8:00 pm	"A New International Order in Ocean Space" 2nd J. Seward Johnson Lecture in Marine Policy Redfield Auditorium, Redfield Building (WHOI) Ambassador Arvid Pardo

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* Recommended Lecture

5 May 1972 (Friday)

9:00 am Introductory Lecture in Biological Oceanography
201 Loeb Building (MBL)

Dr. Gilbert T. Rowe, WHOI

10:30 am "Open Ocean Current Meter Moorings: A Buoy Cruise Aboard the R/V *Knorr*"
201 Loeb Building (MBL)

Professor E. C. Monahan, Univ. of Michigan

**12:00 pm "Science and the Reality of Politics" (movie)
AAAS (MBL Club)

Sponsored by WHOI Peanut Butter Club

1:30 pm Introduction to the MBL Library

Aboard R/V *Asterias* (WHOI)

Dr. Gilbert T. Rowe, WHOI
1 student

2:00 pm Individual Meetings of Students with WHOI Staff Members Supervising Student Research Projects

6 May 1972 (Saturday)

**1:30 pm "Seaweed" Surface Drifter Assembly Session
126 Loeb Building (MBL)

Mr. G. Thomas Kaye, Univ. of Michigan

(Need to assemble 200 of these drifters)

** Optional Activity

8 May 1972 (Monday)

8:30 am Aboard R/V *Asterias* (WHOI) 72 Mich 2
(Drogue Study)

Professor E. C. Monahan, Univ. of Michigan
5 students
(4 students ashore manning theodolites)

1:30 pm Aboard R/V *Asterias* (WHOI) 72 Mich 3
(Drogue Study)

Mr. G. Thomas Kaye, Univ. of Michigan
4 students
(4 students ashore manning theodolites)

8:00 pm "Assessment of Oceanic Rainfall and Related Heat Budget Parameters Through Enhanced Satellite Photographs"
Redfield Building (WHOI)

Dr. Joanne Simpson, NOAA, Univ. of Miami

Sponsored by WHOI Journal Club

9 May 1972 (Tuesday)

10:30 am	"Decision Model for Fishery Planning" 201 Loeb Building (MBL) Dr. Fred L. Offensend, WHOI
**12:00 pm	"Enzymes and Metabolism in Marine Invertebrates" 22 Loeb Building (MBL) Dr. Carl S. Hamman, Univ. of Rhode Island Sponsored by MBL Systematics-Ecology Program
**12:15 pm	"Propagation Loss as Predicted by Modified Ray Theory" Conference Room, Smith Building (WHOI) Dr. James Davis, WHOI Sponsored by WHOI Geology & Geophysics Group
1:30 pm	Meeting of All M&O 560 Students, Including Those Arriving Aboard the R/V *Knorr* 201 Loeb Building (MBL) Professor E. C. Monahan, Univ. of Michigan
*2:30 pm	"The Circulation on the Continental Shelf: A Brief Summary, and Thoughts for Future Work" Conference Room, Smith Building (WHOI) Mr. Dean F. Bumpus, WHOI Sponsored by WHOI Physical Oceanography Group

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[*] Recommended Lecture

[**] Alternate Optional Activi

10 May 1972 (Wednesday)

9:00 am "Airborne Oceanography"
201 Loeb Building (MBL)

Dr. Peter M. Saunders, WHOI

10:30 am "Radio (Omega) Drogue Tracking"
201 Loeb Building (MBL)

Mr. Eduardo D. Michelena, Univ. of Michigan

1:30 pm Meeting on Practicum Exercises and Projects
201 Loeb Building (MBL)

Professor E. C. Monahan, Univ. of Michigan
Dr. Gilbert T. Rowe, WHOI
Mr. Marvel C. Stalcup, WHOI

*2:30 pm "Oceanic Finestructure Experiments"
Conference Room, Smith Building (WHOI)

Dr. Albert J. Williams, III, WHOI

Sponsored by WHOI Ocean Engineering Group

**8:00 pm Drift Bottle Filling Session
Swift House (WHOI)

Professor Monahan et al.

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*Recommended Lecture

**Optional Activity

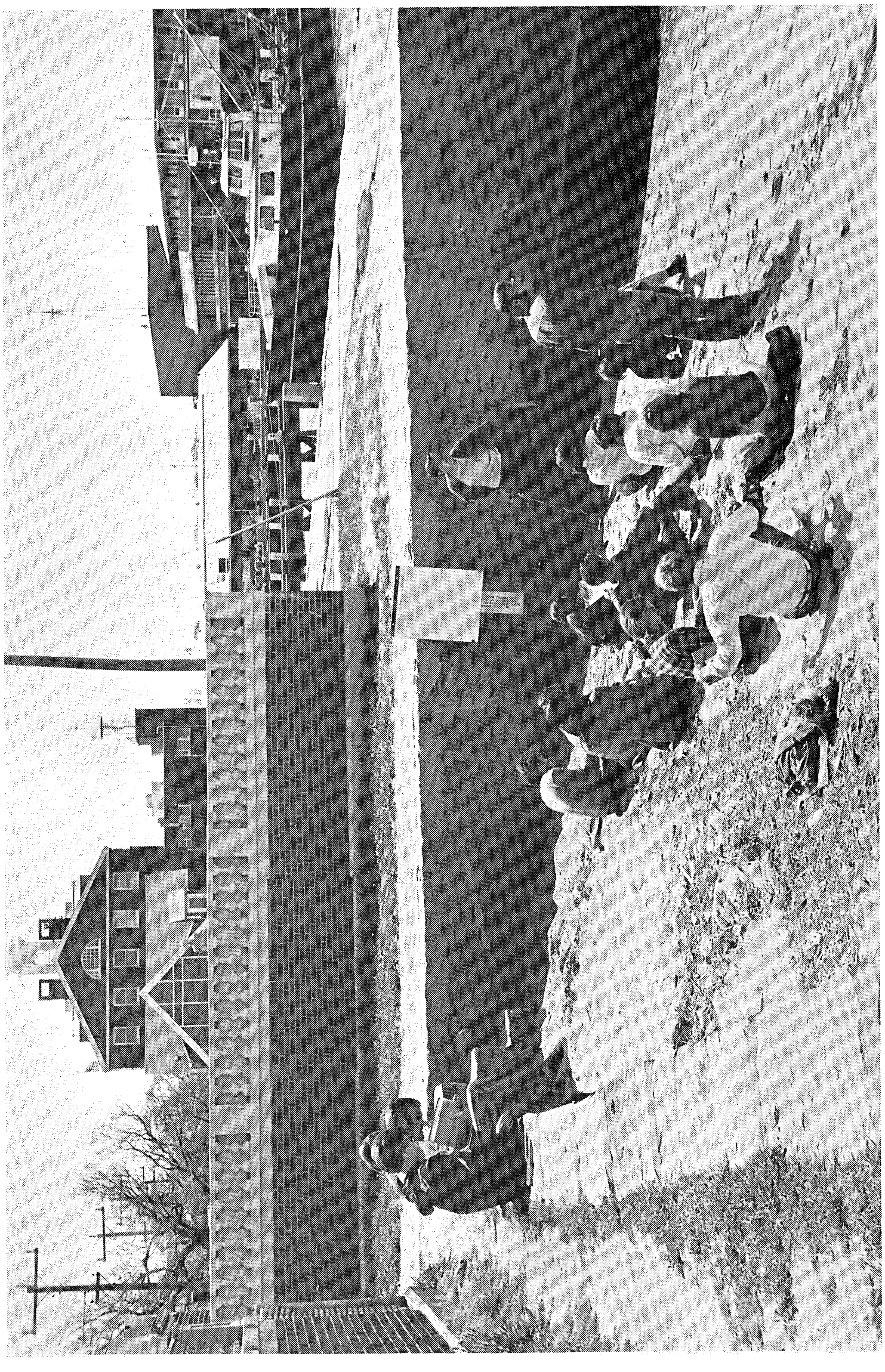

Figure 5. A Lecture on Ocean Currents Conducted on the Beach on a Rare Warm Spring Morning (In the Background: WHOI's Bigelow, Smith, and Iselin Buildings)

11 May 1972 (Thursday)

8:30 am	Aboard R/V *Asterias* (WHOI) 72 Mich 4 (Drift Bottle Study) (am and pm) Mr. G. Thomas Kaye, Univ. of Michigan Mr. Eduardo Michelena, Univ. of Michigan 5 students Students Ashore Work on Individual Research Projects
8:00 pm - 10:00 pm	"Current Problems in Marine Geophysics" Lecture 1 Conference Room, Smith Building (WHOI) Dr. Bruce P. Luyendyk, WHOI

12 May 1972 (Friday)

9:00 am	"Topics in Biological Oceanography" Lecture 2 201 Loeb Building (MBL) Dr. Gilbert T. Rowe, WHOI
10:30 am	"Role of Bacteria in the Marine Environment" 201 Loeb Building (MBL) Dr. Charles C. Remsen, III, WHOI
**12:00 pm	"The Biologist and the Boy" (movie) NOAA (MBL Club) Sponsored by WHOI Peanut Butter Club
1:00 pm -	Students Work on Individual Research Projects

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[*] Optional Activity

15 May 1972 (Monday)

[#]8:30 am Aboard R/V *Asterias* (WHOI) 72 Mich 5
(Hydrographic Stations, Drogues) (am into pm)

Mr. Marvel C. Stalcup, WHOI
Mr. G. Thomas Kaye, Univ. of Michigan
5 students

Students Ashore Work on Individual Research Projects

[**]12:00 pm Subject to Be Announced
304 Redfield Building (WHOI)

Dr. Hugh Livingston

Sponsored by WHOI Chemistry Club

4:00 pm Dockside Tour of R/V *Knorr* (AGOR 15) (WHOI)

Professor E. C. Monahan, Univ. of Michigan

(For students not on R/V *Knorr* Cruise 25)

8:00 pm "The Effect of 'Hot Spots' on Ocean Floors?"
Redfield Building (WHOI)

Dr. Peter Vogt, US Naval Oceanographic Office

Sponsored by WHOI Journal Club

[#] Canceled Due to High Winds and Rain

[**] Optional Activity

16 May 1972 (Tuesday)

9:00 am	"Topics in Biological Oceanography" Lecture 3 201 Loeb Building (MBL) Dr. Gilbert T. Rowe, WHOI
10:30 am	"Ecological Approaches in Studying Aquaculture Food-Chains Enriched with Treated Sewage Effluent" Invertebrates 201 Loeb Building (MBL) Dr. Kenneth R. Tenore, WHOI
**12:15 pm	"Heat Flow Near Orlando, Florida, and Uvalde, Texas" Conference Room, Smith Building (WHOI) Mr. Warren King, WHOI/MIT Sponsored by WHOI Geology & Geophysics Group
**1:30 pm	Tour of Dr. Tenore's Laboratory Meet in Loeb Building Lobby Dr. Kenneth R. Tenore, WHOI
*2:30 pm	"Some Inferences on Ocean Circulation from GEOSECS Test Cruises" Conference Room, Smith Building (WHOI) Dr. Derek Spencer, WHOI Sponsored by WHOI Physical Oceanography Group

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*Recommended Lecture

**Optional Activity

17 May 1972 (Wednesday)

9:00 am "Topics in Biological Oceanography" Lecture 4
201 Loeb Building (MBL)

Dr. Gilbert T. Rowe, WHOI

10:30 am "Distribution of Mesopelagic Fishes"
201 Loeb Building (MBL)

Dr. Richard L. Haedrich, WHOI

1:30 pm "Deep Sea Drilling in the Red Sea"
Conference Room, Smith Building (WHOI)

Dr. David A. Ross, WHOI

3:00 pm "Coastal Circulation (Drift Bottle Studies)"
Conference Room, Smith Building (WHOI)

Mr. Dean F. Bumpus, WHOI

4:30 pm "Two Weeks Down, Four to Go: Where Do We Stand?"
201 Loeb Building (MBL)

Professor E. C. Monahan, Univ. of Michigan

(Each student will briefly describe his/her individual research project.)

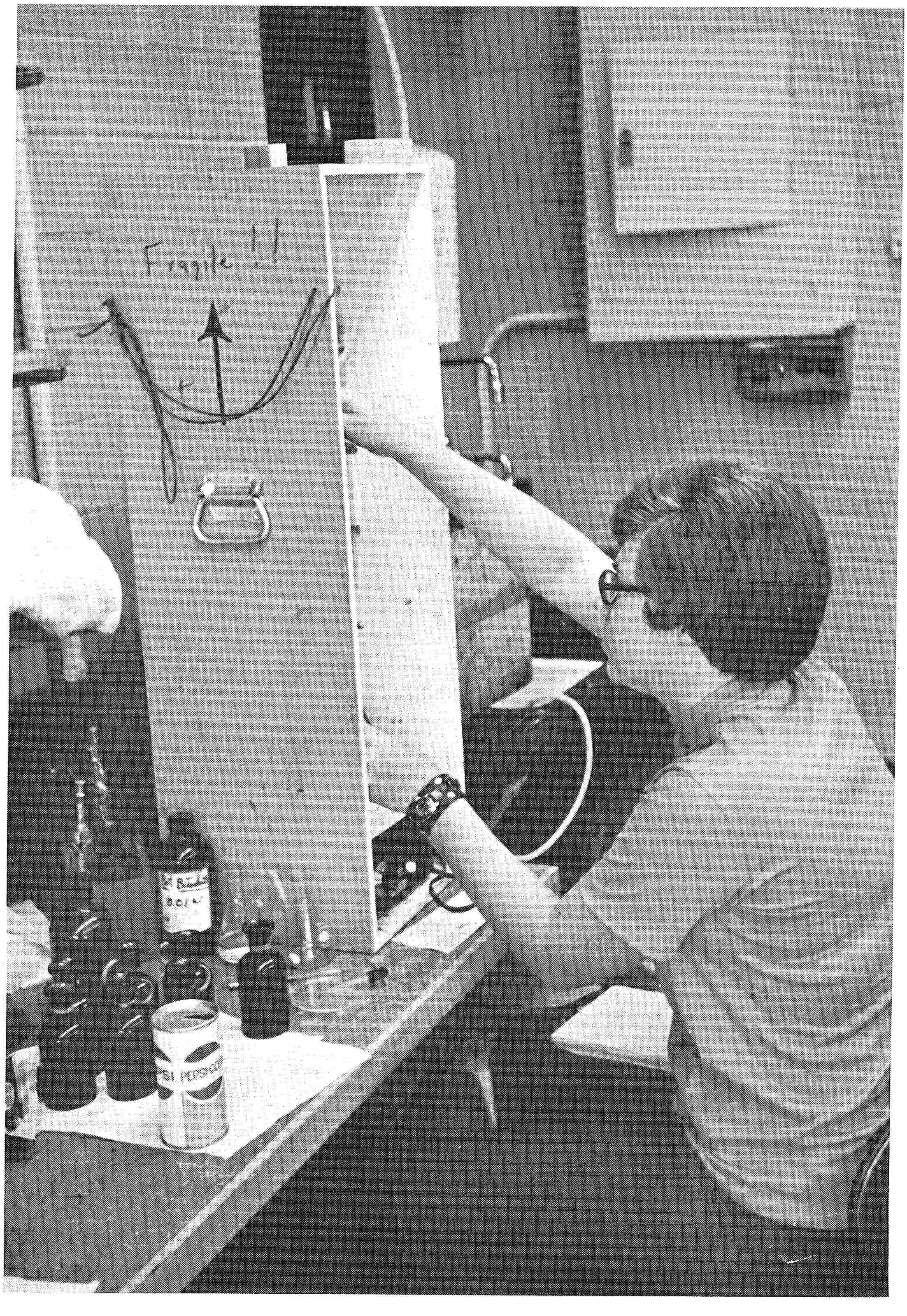

Figure 6. An M&O 560 Student Determining Seawater Dissolved Oxygen Concentration Using a Standard Shipboard Winkler Titration Apparatus

18 May 1972 (Thursday)

8:30 am Aboard R/V *Asterias* (WHOI) 72 Mich 6
(Hydrographic Stations, Drogues) (am and pm)

Students Ashore Work on Practicum Data or
Individual Research Projects

*9:00 am "Antilles Ridge"
Conference Room, Smith Building (WHOI)

Dr. W. Redwood Wright, WHOI

Sponsored by WHOI/UNESCO Program

**12:00 pm "Plastic Particles in the Sea"
MBL Club

Dr. Ed Carpenter, WHOI

Sponsored by WHOI Biology Luncheon Group

8:20 pm - "Current Problems in Marine Geophysics" Lecture 2
10:20 pm Conference Room, Smith Building (WHOI)

Dr. Bruce P. Luyendyk, WHOI

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[*] Recommended Lecture for Those Ashore

[**] Optional Activity

19 May 1972 (Friday)

9:00 am "Topics in Biological Oceanography" Lecture 5
201 Loeb Building (MBL)

Dr. Gilbert T. Rowe, WHOI

10:30 am "Intercomparison of Surface Drifters: A Laboratory Study"
201 Loeb Building (MBL)

Mr. G. Thomas Kaye, Univ. of Michigan

**12:00 pm "Sailing" and "Viking Ships of Roskilde" (movies)
MBL Club

Sponsored by WHOI Peanut Butter Club

1:30 pm "Marine Meteorology"
Conference Room, Smith Building (WHOI)

Mr. Joseph Chase, WHOI

Sponsored by WHOI/UNESCO Program

**3:30 pm Open House
GEOSECS Building, Quissett Campus, WHOI

[**] Optional Activity

22 May 1972 (Monday)

8:30 am Aboard R/V *Asterias* (WHOI) 72 Mich 7
(Hydrographic Stations, Surface Drifters, Vineyard Sound & Nantucket Sound)

Mr. Marvel C. Stalcup, WHOI
Mr. G. Thomas Kaye, Univ. of Michigan
6 students

Students Ashore Work on Practicum Data or on Individual Research Projects

**12:00 pm "Determination of Marine Levels of Americum-241 and Neptumium-237"
304 Redfield Building (WHOI)

Dr. Hugh Livingston

Sponsored by WHOI Chemistry Club

8:00 pm "Sex and Philosophy on Cannery Row" or "Ricketts and Steinbeck Reconsidered"
Redfield Building (WHOI)

Dr. Joel Hedgpeth, Univ. of Oregon

Sponsored by WHOI Journal Club

** Optional Activity

23 May 1972 (Tuesday)

9:00 am "Topics in Biological Oceanography" Lecture 6
201 Loeb Building (MBL)

Dr. Gilbert T. Rowe (WHOI)

10:30 am "Ecological Approaches in Studying Aquaculture Food-Chains Enriched with Treated Sewage Effluent" Phytoplankton
201 Loeb Building (MBL)

Dr. William M. Dunstan, WHOI

**12:00 pm "The Sulfur Cycle in Oyster Pond"
Lecture Hall, Loeb Building (MBL)

Dr. Galen Jones, Univ. of New Hampshire

Sponsored by MBL Systematics-Ecology Program

*12:15 pm "Signal Processing on the IDOE Eastern Atlantic Continental Margin Cruise"
Conference Room, Smith Building (WHOI)

Dr. Arthur Baggeroer, MIT

Sponsored by WHOI Geology & Geophysics Group

1:30 pm "Proposed Sewer Outfall in Vineyard Sound"
22 Loeb Building (MBL)

Dr. Robert Long, WHOI

Sponsored by WHOI/UNESCO Program

*2:30 pm "Scattering of Surface Waves by an Irregular Bottom"
Conference Room, Smith Building (WHOI)

Dr. Robert Long, WHOI

Sponsored by WHOI Physical Oceanography Group

*8:00 pm "Energy Flows, Impact Diagrams"
Redfield Auditorium, Redfield Building (WHOI)

Dr. H. T. Odum, Univ. of Flordia

Sponsored by Institute of Ecology (IOE)-
WHOI Coastal Zone Workshop

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[*] Recommended Lecture

[**] Optional Activity

24 May 1972 (Wednesday)

8:00 am Tour of Factory of Environmental Equipment Division, EG&G
151 Bear Hill Road, Waltham, Mass.

Visit to New England Aquarium (Admission: $1.50)
Boston, Mass.

Bus from MBL

Joint Activity with WHOI/UNESCO Program

*2:30 pm "A New Concept in Ocean Transport, SEABEE Class Ship"
Conference Room, Smith Building (WHOI)

Lt. Jay M. Cohen, WHOI/MIT

*4:00 pm To Be Announced
Redfield Auditorium, Redfield Building (WHOI)

Dr. Eugene Cronin, Nat. Res. Inst.

Sponsored by IOE-WHOI Coastal Zone Workshop

*8:00 pm "Power Plant Siting" (Panel Discussion)
Redfield Auditorium, Redfield Building (WHOI)

Mr. Paul Ferris Smith, EG&G

Sponsored by IOE-WHOI Coastal Zone Workshop

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*Recommended Lecture

25 May 1972 (Thursday)

6:00 am Trip to Oyster Experimental Farm (NMFS)
Milxford, Conn.

Dr. Kenneth R. Tenore, WHOI
Dr. William M. Dunstan, WHOI
3 students

8:30 am Aboard R/V *Asterias* (WHOI) 72 Mich 8
(Drogues, Surface Drifters) (am and pm)

Mr. G. Thomas Kaye, Univ. of Michigan
5 students

Students Ashore Work on Practicum Data or on Individual Research Projects

**12:00 pm "Salps"
MBL Club

Dr. Rich Harbison

Sponsored by WHOI Biology Luncheon Group

4:00 pm "Topics in Biological Oceanography" Lecture 7
201 Loeb Building (MBL)

Dr. Gilbert T. Rowe, WHOI

8:20 pm - 10:20 pm "Current Problems in Marine Geophysics" Lecture 3
Conference Room, Smith Building (WHOI)

Dr. Bruce P. Luyendyk, WHOI

** Optional Activity for Those Ashore

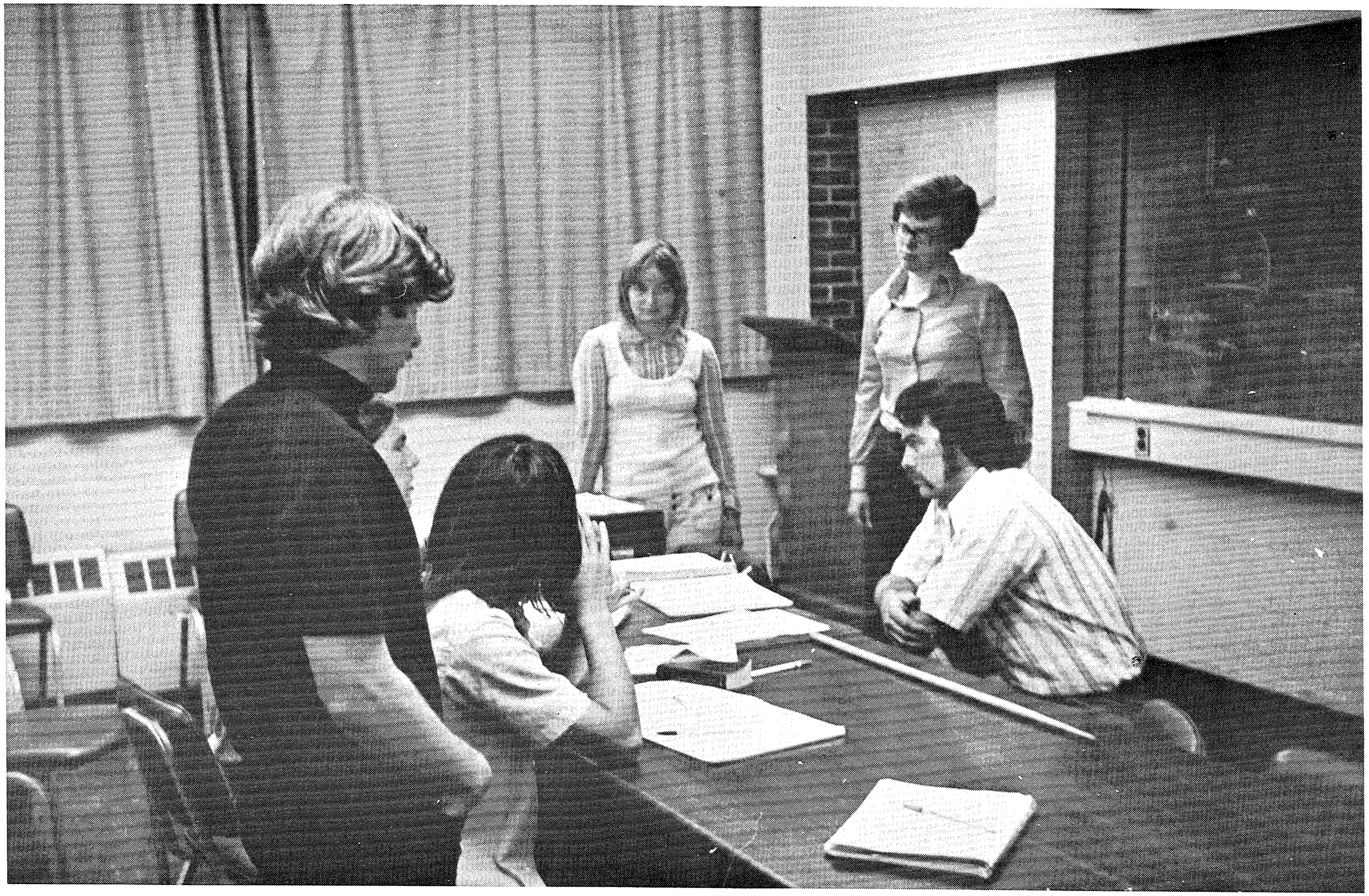

Figure 7. A Few Questions on Plate Tectonics Being Directed at Dr. Bruce Luyenyk During a Break in One of His Evening Lectures

26 May 1972 (Friday)

9:00 am "Geomagnetic Electro-Kinetograph (GEK), Nobska Point Across Vineyard Sound"
201 Loeb Building (MBL)

Mr. Marvel C. Stalcup, WHOI

10:30 am "A Physical Explanation of the 'Coriolis Effect'"
201 Loeb Building (MBL)

Professor E. C. Monahan, Univ. of Michigan

1:30 pm "Topics in Biological Oceanography" Lecture 8 (Identification of Benthic Organisms)
201 Loeb Building (MBL)

Dr. Gilbert T. Rowe, WHOI

2:30 pm "Benthic Community Analysis"
Laboratory Session for All Students
126 Loeb Building (MBL)

Dr. Gilbert T. Rowe, WHOI

*8:00 pm "Unity and Diversity in the Coastal Zone Regions of the US"
Whitman Auditorium (MBL)

Dr. Lewis Alexander, Univ. of Rhode Island

Sponsored by IOE-WHOI Coastal Zone Workshop

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*Recommended Lecture

29 May 1972 (Monday)

MEMORIAL DAY

*8:00 pm "Circulation of Coastal and Shelf Water and What We Don't Know About It"
Redfield Auditorium, Redfield Building (WHOI)

Dr. Erik Mollo-Christensen, MIT

Sponsored by IOE-WHOI Coastal Zone Workshop

30 May 1972 (Tuesday)

9:00 am "Whitecaps vs Wind Speed: Ships of Opportunity in Oceanographic Research"
201 Loeb Building (MBL)

Professor E. C. Monahan, Univ. of Michigan

10:30 am "Some Attempts at Coastal Zone Circulation Measuring and Modeling"
201 Loeb Building (MBL)

Mr. Paul Ferris Smith, EG&G

*8:00 pm "Technological Problems for Municipal Waste Disposal"
Redfield Auditorium, Redfield Building (WHOI)

Dr. Norman Brooks, CIT

Sponsored by IOE-WHOI Coastal Zone Workshop

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*Recommended Lecture

31 May 1972 (Wednesday)

8:30 am Aboard R/V *Asterias* (WHOI) 72 Mich 9
(Vineyard Sound, Drogues & Dye, BT) (am and pm)

Mr. Marvel C. Stalcup, WHOI
Mr. G. Thomas Kaye, Univ. of Michigan
5 students

Students Ashore Work on Practicum Data or on Individual Research Projects

4:00 pm "A Third of the Way to Go--Some Comments on Student Reports, etc."
Group Photo
201 Loeb Building (MBL)

Professor E. C. Monahan, Univ. of Michigan

*8:00 pm "Coastal Zone Management--The California Experience"
Redfield Auditorium, Redfield Building (WHOI)

Dr. Robert Krueger, Calif. Advisory Commission for Marine and Coastal Resources

Sponsored by IOE-WHOI Coastal Zone Workshop

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*Recommended Lecture

1 June 1972 (Thursday)

8:00 am Aboard R/V *Gosnold* (WHOI) (2-day cruise)

Dr. Wright
UNESCO students, 1 U-M student

8:30 am Aboard R/V *Asterias* (WHOI) 72 Mich 10
(Diffusion Study in Great Harbor) (am and pm)

Mr. Marvel C. Stalcup, WHOI
5 students

Students Ashore Work on Practicum Data or on Individual Research Projects

**12:00 pm "Brain Patterns in Some Deep Sea Fishes"
(MBL Club)

Tracy McLellen, WHOI

Sponsored by WHOI Biology Luncheon Group

*4:00 pm "Mathematical Models of Water Quality Systems"
Redfield Auditorium, Redfield Building (WHOI)

Dr. Donald O'Connor, Manhattan College

Sponsored by IOE-WHOI Coastal Zone Workshop

8:20 pm - 10:20 pm "Current Problems in Marine Geophysics" Lecture 4
Conference Room, Smith Building (WHOI)

Dr. Bruce P. Luyendyk, WHOI

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[*] Recommended Lecture

[**] Optional Activity

2 June 1972 (Friday)

9:00 am	"Chlorinated Hydrocarbons: Some Observations on Distribution in Atlantic Ocean Organisms" 201 Loeb Building (MBL) Dr. George R. Harvey, WHOI
10:30 am	"Gulf Stream Meanders" 201 Loeb Building (MBL) Dr. James R. Luyten, WHOI
1:30 pm	"Uses of Motionally Induced Electric and Magnetic Fields in Oceanography" 201 Loeb Building (MBL) Dr. Thomas Sanford, WHOI

5 June 1972 (Monday)

9:00 am "Marine Community Energetics"
201 Loeb Building (MBL)

Dr. Kenneth L. Smith, WHOI

10:30 am "Nutrient Uptake Kinetics of Phytoplankton"
201 Loeb Building (MBL)

Dr. Peter Kilham, WHOI

**12:00 pm "Observations of the Operational Aspects of the Deep Sea Drilling Project"
304 Redfield Building (WHOI)

Lee Waterman, WHOI

Sponsored by WHOI Chemistry Club

**4:00 pm "Marine Affairs Program"
201 Loeb Building (MBL)

Mr. George Cadwalader, WHOI
Mr. Lawson Hunter, WHOI

Sponsored by WHOI/UNESCO Program

**8:00 pm "Ecological Approaches to Aquaculture Food Chains Based on Treated Sewage Effluent Enrichment"
Redfield Building (WHOI)

Dr. William M. Dunstan, WHOI
Dr. Kenneth R. Tenore, WHOI

Sponsored by WHOI Journal Club

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[*] Optional Activity

6 June 1972 (Tuesday)

8:30 am Aboard R/V *Asterias* (WHOI) 72 Mich 11
(Hydrographic Section, etc.)

Mr. Marvel C. Stalcup, WHOI
5 students

Students Ashore Work on Individual Research Projects

**12:15 pm "Magneto-Telluric Measurements near Hawaii"
Conference Room, Smith Building (WHOI)

Dr. James Larsen, Univ. of Hawaii

Sponsored by WHOI Geology & Geophysics Group

*2:30 pm "A World Ocean Model"
Conference Room, Smith Building (WHOI)

Dr. Kirk Bryan, NOAA, Princeton

Sponsored by WHOI Physical Oceanography Group

8:00 pm Marine Geophysics Laboratory Session
DESC (WHOI)

Dr. Bruce P. Luyendyk, WHOI

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* Recommended Lecture

** Optional Activity

7 June 1972 (Wednesday)

9:00 am "Topics in Biological Oceanography" Lecture 9
201 Loeb Building (MBL)

Dr. Gilbert T. Rowe, WHOI

10:30 am "Equatorial Current/Countercurrent System"
201 Loeb Building (MBL)

Mr. W. Gary Metcalf, WHOI

8:00 pm Individual Student Research Project Presentations
Session 1

Presentation 1	Mr. N. Takeuchi
Presentation 2	Miss S. Williams
Presentation 3	Mr. J. Allender

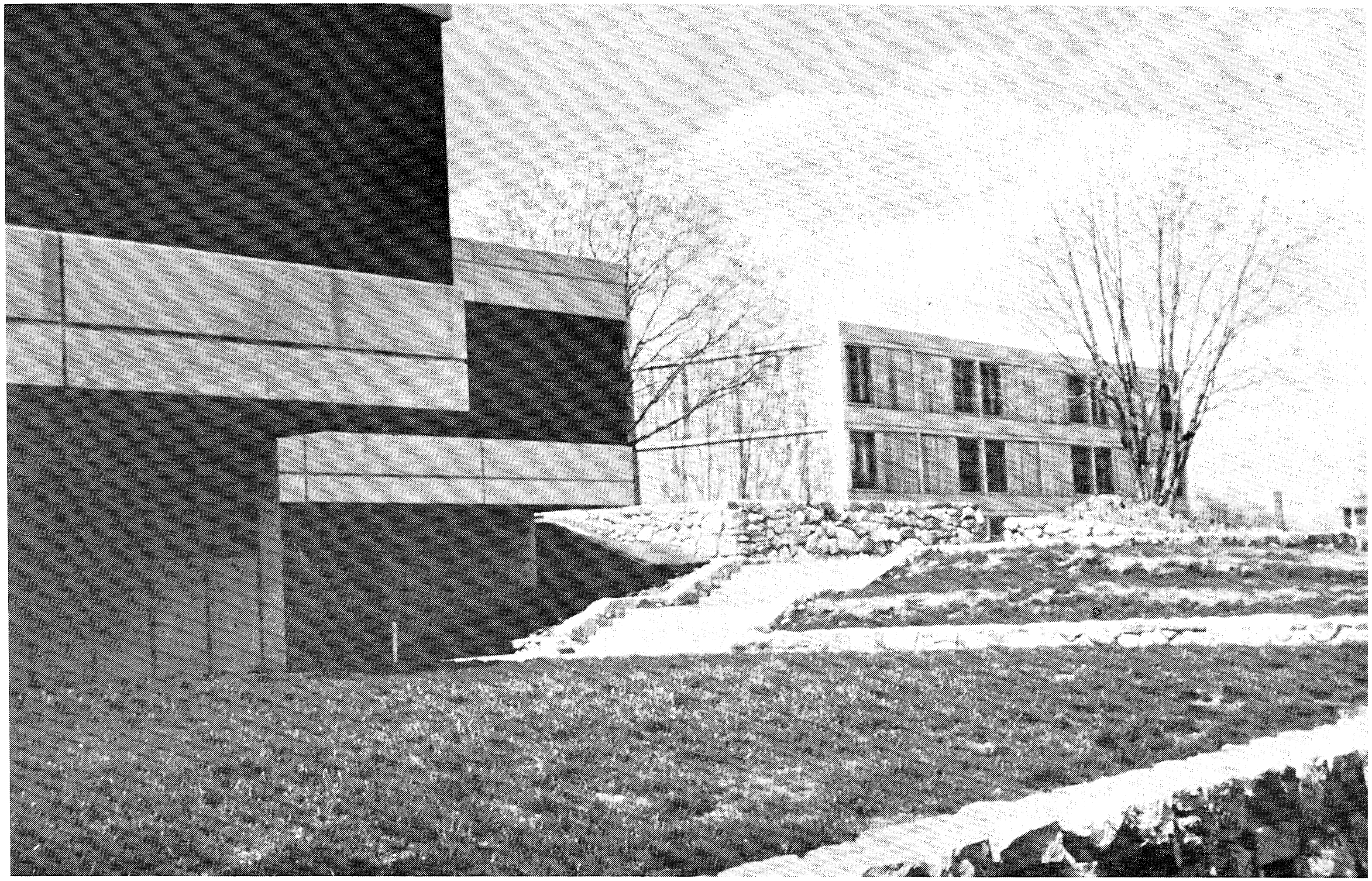

Figure 8. The New MBL Dormitory-Dining Hall, Where the Participants in M&O 560 Resided

8 June 1972 (Thursday)

8:30 am Aboard R/V *Asterias* (WHOI) 72 Mich 12
(Biological Sampling Techniques)

Dr. Gilbert T. Rowe, WHOI
6 students

10:30 am Aboard R/V *Asterias* (WHOI) 72 Mich 13
(Biological Sampling Techniques)

Dr. Gilbert T. Rowe, WHOI
6 students

Students Ashore Work on Individual Research Projects

**12:00 pm "Some Aspects of the Microbial Sulphur Cycle in the Sea"
MBL Club

Dr. John Tuttle, WHOI

Sponsored by WHOI Biology Luncheon Group

1:30 pm Aboard R/V *Asterias* (WHOI) 72 Mich 14
(Biological Sampling Techniques)

Dr. Gilbert T. Rowe, WHOI
Dr. Richard L. Haedrich, WHOI
7 students

*2:30 pm "Deep Stepped Structure in the Mediterranean"
Conference Room, Smith Building (WHOI)

Dr. Ola M. Johannessen, Saclant ASW Research Center

Sponsored by WHOI Physical Oceanography Group

4:00 pm Individual Student Research Project Presentations
Session 2

Presentation 4	Mr. B. Higgins
Presentation 5	Miss J. Alexander

8:20 pm - 10:20 pm "Current Problems in Marine Geophysics" Lecture 5
Conference Room, Smith Building (WHOI)

Dr. Bruce P. Luyendyk, WHOI

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*Recommended Lecture

**Optional Activity

9 June 1972 (Friday)

9:00 am "Topics in Biological Oceanography" Lecture 10
201 Loeb Building (MBL)

Dr. Gilbert T. Rowe, WHOI

10:30 am "Interactions Among Marine Micro-Organisms"
201 Loeb Building (MBL)

Dr. Charles C. Remsen, WHOI

8:00 pm Individual Student Research Project Presentations
Session 3

Presentation 6	Mr. R. Grove
Presentation 7	Mr. E. Chesney
	Mr. R. Moore
	Mr. M. Senneff
	Miss M. Vanderlaan

10 June 1972 (Saturday)

3:30 pm Picnic for M&O 560 Participants and UNESCO Program Participants
Dr. Wright's Beach

12 June 1972 (Monday)

9:00 am "Topics in Biological Oceanography" Lecture 11
(Examination)
201 Loeb Building (MBL)

Dr. Gilbert T. Rowe, WHOI

**12:00 pm "Chemistry of the Cariaco Trench"
304 Redfield Building (WHOI)

Dr. Peter Brewer

Sponsored by WHOI Chemistry Group

1:30 pm Individual Student Research Project Presentations
Session 4

Presentation 8	Mr. J. McPeak
Presentation 9	Mr. G. Sugihara
Presentation 10	Mr. J. Maresca

8:00 pm "Launching the *Challenger* Expedition"
Redfield Auditorium, Redfield Building (WHOI)

Dr. Harold L. Burstyn, Carnegie-Mellon Univ.

Sponsored by WHOI Journal Club

**Optional Activity

13 June 1972 (Tuesday)

9:00 am "Sampling the Deep Sea Floor"
Conference Room, DESC (WHOI)

Dr. Charles D. Hollister, WHOI

10:30 am "Diving in Submarine Canyons"
Conference Room, Smith Building (WHOI)

Dr. David A. Ross, WHOI

**12:15 pm "Geomorphological Evolution of the Allegheny Front in Pennsylvania"
Conference Room, Smith Building (WHOI)

Mr. Dennis O'Leary, USGS

Sponsored by WHOI Geology & Geophysics Group

1:30 pm Individual Student Research Project Presentations Session 5

Presentation 11	Mr. D. Ryker
Presentation 12	Mr. R. Patchen
Presentation 13	Mr. R. Kettner

*2:30 pm "Interactions Between Internal Gravity Waves and Geostrophic Flows"
Conference Room, Smith Building (WHOI)

Dr. Peter Muller, WHOI

Sponsored by WHOI Physical Oceanography Group

8:20 pm - 10:20 pm "Current Problems in Marine Geophysics" Lecture 6
Conference Room, Smith Building (WHOI)

Dr. Bruce P. Luyendyk, WHOI

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[*] Recommended Lecture

[**] Optional Activity

14 June 1972 (Wednesday)

9:00 am "Topics in Biological Oceanography" Lecture 12
201 Loeb Building (MBL)

Dr. Gilbert T. Rowe, WHOI

10:30 am Individual Student Research Project Presentations
Session 6

Presentation 14	Miss V. Evans
Presentation 15	Miss C. Kramer
Presentation 16	Mr. P. Perschbacher

**12:00 pm "The Radula of the Chaetodermatidae" or
"What You Eat with If Your Cousin Is a Snail
but You Have Decided to Turn into a Worm"
MBL Club

Amelie H. Scheltema, WHOI

Sponsored by WHOI Biology Luncheon Group

*2:30 pm "Harvard-WHOI Digital Cassette Recorder System/
11 Million Bits in a Little Bitty Can"
Conference Room, Smith Building (WHOI)

Winfield Hill, Harvard Electronics Design Center

Sponsored by WHOI Ocean Engineering Group

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[*] Recommended Lecture

[**] Optional Activity

STUDENT RESEARCH REPORTS

In this section are the abstracts or papers which the students prepared on the basis of their individual research projects. The papers are presented here in the form in which they were submitted, with only minor editing where necessary. The results, conclusions, and suggestions contained in the following papers are therefore those of the respective authors. Also included in this section are several closely related student papers prepared as part of previous courses, i.e., M&O 560 (spring 1971)* and M&O 559 (Measurements in Physical Oceanography) (winter 1972), also supervised by Professor E. C. Monahan.

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*The paper referred to was not available for inclusion in the previous report "Oceanography Field Practicum 1971."

COMPARISON OF IN SITU RESPIRATION OF BENTHIC COMMUNITIES WITHIN A SALT MARSH

Jennifer L. Alexander

In situ respiration studies were performed on two creekbeds within a salt marsh in Falmouth, Massachusetts. Experiments were done with an oxygen electrode recording system connected to an opaque bell jar. The areas examined were a control creek and a highly fertilized creek to which K. M. Turf and Tree fertilizer had been added. The study was conducted in May, and values for total community respiration ranged from 30.8 ml $O_2/m^2/hr$ to 81.8 ml $O_2/m^2/hr$ in the control creek and from 66.0 ml $O_2/m^2/hr$ to 99.7 ml $O_2/m^2/hr$ in the creek of high fertility. Temperature during the study ranged from 12.2° C to 22.5° C, and a linear regression analysis showed a correlation between the log transformations of temperature and total community oxygen consumption. A slope of 1.70 was obtained.

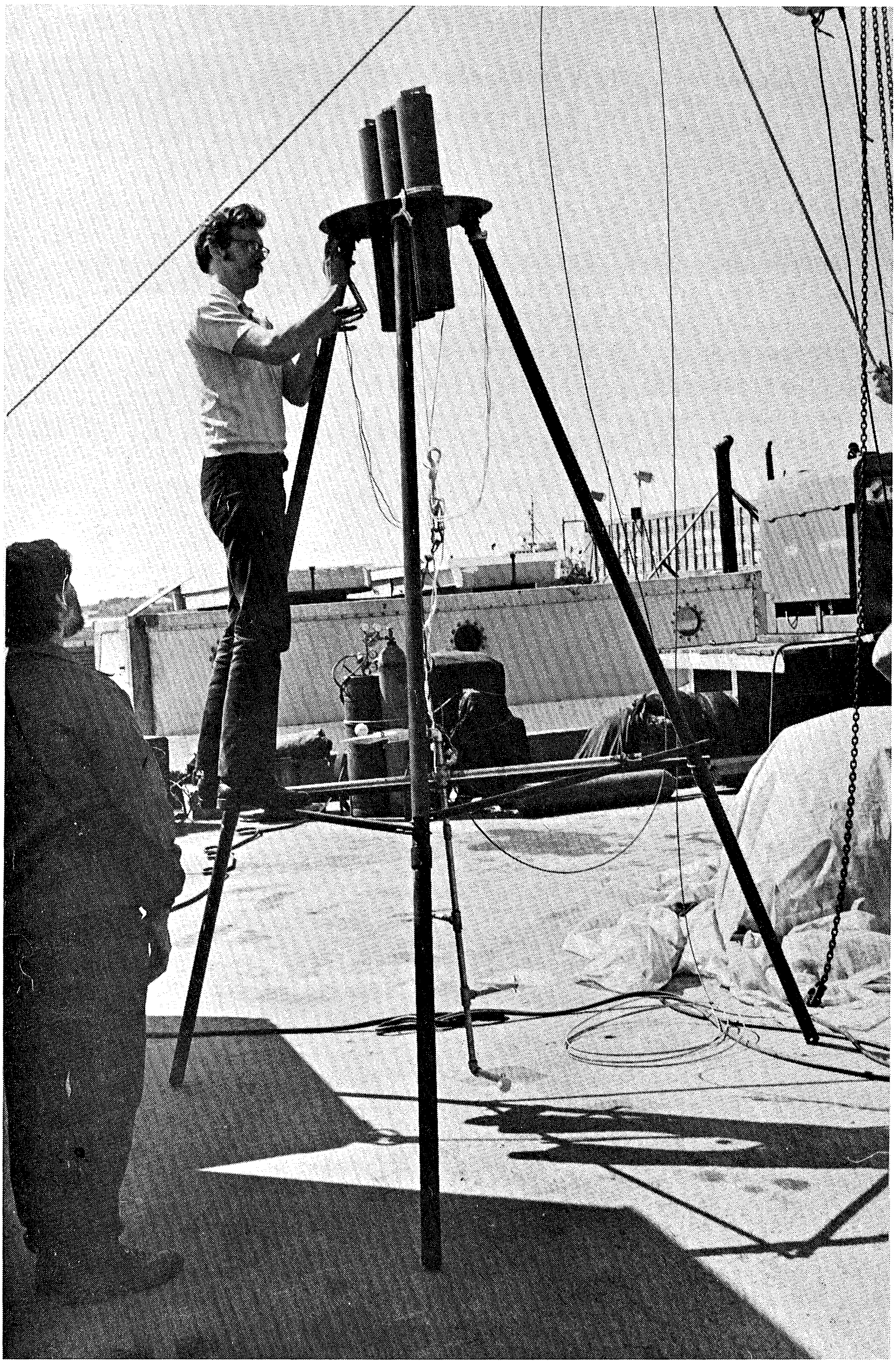
Total respiration of the benthic communities was broken down into its component parts (infauna, bacteria, and chemical demand of the sediment) by injecting antibiotics and formalin in separate treatments. This removed bacteria and infauna respiration so that values could be obtained for each component. An average value of 62.0 ml $O_2/m^2/hr$ was found for total respiration in the control creek and a value of 84.5 ml $O_2/m^2/hr$ for the highly fertilized creek. In the control creek, the infauna represented the largest component of the community oxygen consumption, 50.6 percent. Bacteria respiration represented the largest fraction of the metabolism of the highly fertilized creekbed, with 52.7 percent.

Despite this difference, a statistical F-test showed no significant difference in the community respiration of the two areas. This agreed with a Hargrave report which showed that temperature is the most important factor affecting community respiration in benthic communities. Grab samples were taken and, although sample size was inadequate for an estimation of diversity, the samples did indicate very patchy distribution of both species and total number of individuals present.

THE DESCRIPTION AND USE OF AN INSTRUMENT TO MEASURE FLOW NEAR THE SEABED

James H. Allender

The purpose of this paper is to describe an instrument designed to measure flow in the bottom boundary layer, and to present data taken using this measurement scheme during the 1972 Ocean Practicum. The objective of data analysis was to assess the reliability of this device by comparing measured velocity profiles with existing theoretical predictions. Preliminary results indicate that this instrument may provide a viable, inexpensive means of defining flow in the bottom boundary layer.



Allender with His Instrument Used to Measure Flow Near Seabed

CARBON FLUX AT WOODS HOLE OUTFALL

Edward Chesney

Carbon exists in the ocean as inorganic, dissolved organic, and particulate organic carbon. If we examine the different forms and the flow of carbon through a system such as the Woods Hole outfall system, we find that it can give us a qualitative picture of the ecological interactions taking place in the system. This qualitative picture can be represented in the form of a flow diagram.

By measuring these rates and deriving differential equations for each of the flow rates, an even more precise description of the carbon flux can be obtained. After deriving the flux rates it is possible to program the data into the computer in the form of a simulation model. This can be used as a predictive tool.

Upon examination of these flow rates, we find that large amounts of particulate organic carbon, in the form of benthic algae and effluent from the outfall, are being fluxed into the Woods Hole system at a rate greater than the rate that it can be used by the heterotrophs (filter feeders and detrital feeders). This is causing an unusually high rate of burial of carbon as compared to the surrounding areas that are not subjected to such a stress. Therefore, these flow rates, such as rate of burial of carbon in the sediments, might be useful as indicators of the condition of the ecosystem.

COASTAL ZONE MANAGEMENT: ALTERNATIVE SOLUTIONS FOR THE NANTUCKET SOUND ISLANDS

Victoria Evans

For more effective use of the coastal zone's finite resources, a management solution is needed. This management system should permit informed choices among development alternatives, provide for proper comprehensive planning, and encourage recognition of the long-term importance of coastal zone resources. An ongoing controversy over the management of the Nantucket Sound Islands was studied. An objective analysis of alternative institutional arrangements, proposed and existing, was made. These arrangements included: the Nantucket Sound Islands Trust Bill (S 3485), Federal Coastal Zone Management Bill (S 3507), and existing state and local laws. The provisions, implications, and political forces in legislative process were looked at in each.

A MODEL OF THE WIND-DRIVEN CIRCULATION OF THE ATLANTIC OCEAN

Ron Kettner

A simple computer model is developed of the water circulations in the Atlantic Ocean basin. This basin is taken to be of a constant depth equal to the average depth of the main thermocline, so that one gets a good idea of only the surface circulation. The box is assumed to be rectangular in shape and no flow is allowed through the sides of the box. The basic equation was originally derived by Henry Stommel and is a simplified version of the vertically integrated vorticity equation. Inertial terms are omitted, the wind stress is assumed to be sinusoidal, and a simple relation is used to account for any frictional effects.

As one would expect, a clockwise gyre with a westward intensification of stream lines is observed. The westward bunching of the stream lines corresponds to the Gulf Stream current.

The boundary value problem is solved by first scaling the equation and then by casting it into finite difference form. This final system is then solved using Liebmann's method. Convergence was accelerated by overrelaxation. Some instability was encountered which was probably due to either truncation or round-off errors, or possibly was due to a poor placement of the grid points.

THE FOOD VALUE OF PHYTOPLANKTON TO INVERTEBRATES

Carolyn Kramer

The means of detecting nutrient value differences in potential aquaculture food sources for invertebrates were studied as an alga moves along the growth curve. The alga *Skelletonema* was used and grown in cultures of limited volume under controlled conditions of light and temperature. The F/2 media suggested by Ryther and Guillard was used.

The results regarding food potential which could be drawn were based largely on (1) percentage ash, (2) micrograms of ash-free dry weight per cell, (3) micrograms of carbon per cell, and (4) the C/N ratio. Cell size, obtained by direct measurements, and carbon levels, determined by C-N-O analysis and direct measurements, were used as the indicator of the food value of the cell. By determining how these values changed as the alga moved through the different phases of the growth curve, it could be predicted at what point the alga would be most profitable to harvest. The results seem to indicate that cell size changes insignificantly along the growth curve, and this particular aspect would have no effect on *Skelletonema*'s value as a potential aquaculture food source. The food value, based on the four parameters, appears to be greater in the young cells, therefore indicating them as a better food source for invertebrates than the older cells.

OUTFALL EFFECTS ON GREAT HARBOR, WOODS HOLE, MASSACHUSETTS

John D. McPeak

The characteristics and effects of the Woods Hole sewer outfall which discharges into Great Harbor are investigated. Data acquisition methods such as ocean stations, Nansen casts, current meters and literature search are described. All of the resulting information is used to produce results relating to dilution and dispersion of the effluent and bacterial concentrations. By means of current measurement, ocean station profiles and volume calculations, dilution estimates are computed and results are summarized. Conclusions are drawn as to the ecological and environmental impact of the sewage discharge on the oceanic ecosystem. The Woods Hole sewer outfall is not detrimental to the general receiving waters.

A MODEL OF THE WOODS HOLE OUTFALL

Ralph Moore

In studying a biological system such as that of the Woods Hole outfall, related chemical and physical parameters must be considered in order to gain a sense of the dynamic picture of the flow of carbon there. A mathematical model or simulation can also be used to gain insight into what's happening in such a system, although often the model deviates markedly from the physical reality. This paper discusses the preliminaries for modeling and then describes the attempt made by the four investigators to relate the information in the flow diagram to observations in the field. Linear relationships were assigned for the functions relating the state variables of resident carbon, carbon in the benthic biota, particulate organic carbon (POC) emanating from the outfall plume, buried carbon in the sediments, carbon in phytoplankton, carbon in heterotrophs, carbon in benthic algae, particulate organic carbon that is transported essentially out of the system and lost, and carbon in the outside world. Errors in the mathematical logic behind the model itself are presented, the most obvious being that a linear model such as this one is a poor approximation of basically nonlinear biological phenomena.

A SUBSURFACE CURRENT METER MOORING IN GREAT HARBOR, WOODS HOLE, MASSACHUSETTS

Richard Patchen

A subsurface current mooring, to record the direction and speed of the current for a period of about seven days, was placed in Great Harbor, Woods Hole, Massachusetts, approximately 6 ft above a sewer outfall pipe. The purpose of the mooring was to determine both the short-term and long-term velocity fluctuations. The results were used in conjunction with the physical and biological parameters to determine the effect of the sewer outfall.

The current meter record indicates a variable current, which responds to tidal currents, winds, and forcing conditions from adjacent bodies of water. The wind regime has the most pronounced effect on the circulation in Great Harbor. The tidal currents seem to determine the speed cycle, which is definitely tidal, but has little effect on direction of flow. The flow through Vineyard Sound appears to play an important role in determining the total circulation in Great Harbor.

SEASONAL CHANGES OF TEMPERATURE, SALINITY, AND OXYGEN ON VINEYARD SOUND DURING MAY 1971 AND JUNE 1972

Norishige Takeuchi

A series of hydrographic cruises were conducted aboard the R/V *Asterias* by students from The University of Michigan and by Marvel Stalcup between May 1971 and June 1972. Seasonal temperature, salinity, and oxygen were measured. Silicate was measured in May and June 1972. Stations were divided into five sectors, A to E, corresponding with points from Nobska Point to Martha's Vineyard. There was not a significant difference in depths at the stations.

The surface factors were taken for construction of seasonal sequence. Temperature showed the highest points in August or September and the lowest points in February and March. Oxygen showed the highest contents in May and the lowest contents in August or September. Salinity showed the highest contents in January and the lowest contents in May or June. Salinity gradients between sectors were seen during the lowest salinity season. The lowest salinity was found on the Nobska Point side. This phenomenon was caused by the effect of Buzzard's Bay fresh water accumulated from the New England land mass during the spring. Oxygen corresponded well with salinity in cases where there were gradients between sectors.

THE STUDY OF CARBON BREAKDOWN THROUGH THE USE OF BOD, COD, AND CARBON COMBUSTION ON BOTTOM SEDIMENTS OF WOODS HOLE, MASSACHUSETTS

Mary F. Vanderlaan

The village of Woods Hole, Massachusetts, has been putting mascerated and chlorinated sewage into the harbor since 1949. This has resulted in an increase in the concentration of organic material. This organic material can be divided into three classes: (1) carbonaceous material--used as food for aerobic organisms, (2) oxidizable nitrogen--serves as food for specific bacteria, (3) chemical-reducing compounds--react with dissolved oxygen.

Over 99.9 percent of this organic material is mineralized in the sea by marine aerobic microorganisms, and especially bacteria. The principal food source for these organisms is the carbon in the form of carbohydrates. This carbon is a very important mineral to the ecosystem.

Several researchers have studied respiration rates and sediment oxygen demands of the sediment. In this study the concept of sediment oxygen demand was used on a 70-cm core taken from the harbor of Woods Hole. It was used to determine the rate at which carbon is broken down and returned to the system. Three techniques were used to evaluate the core sections: (1) biochemical oxygen demand (BOD)--the amount of oxygen consumed by bacteria during carbon breakdown, which is a measure of the amount of carbonaceous material present; (2) chemical oxygen demand (COD)--the oxygen demand of nonbiological oxidation of chemical compounds; (3) carbon combustion--yields weight in percentage of carbon found in each core section.

Many researchers have found that in the top 10-20 cm of a core, the predominate oxygen demand is BOD, inferring that carbon is being returned to the system through breakdown by bacteria. Below 10-20 cm, the BOD decreases and COD tends to increase, indicating slow anaerobic breakdown and carbon being essentially lost to the system through burial. The carbon combustion data fluctuates widely and hence indicates very little. This fluctuation may be due to changes in the rate of deposition.

This experiment points up many errors involved in an investigation of this type, and in the techniques employed.

UREA DECOMPOSITION AT THE WOODS HOLE OUTFALL

Susan Lynn Williams

Urea decomposition among microorganisms at the Woods Hole sewer outfall is too complex to delineate primary urea decomposers from the data obtained. Phytoplankton concentrations, especially of species with large cross-sectional areas like *Rhizosolenia delicatula* and *Leptocylindrus minimus* were significantly lowered by filtering with a 35-μ mesh filter. The 10-μ mesh filter also significantly lowered phytoplankton concentrations, especially pennates and centrics. Water samples from each filter often showed a decrease in urea decomposition rates higher than would be expected from the decrease in phytoplankton counts, possibly indicating that the phytoplankters filtered out were the ones responsible for most of the urea decomposition.

Data deviated from the expected results that filtration would decrease urea decomposition and phytoplankton concentrations in three ways. These deviations were: increased urea decomposition and increased phytoplankton concentrations after filtering, increased urea decomposition and decreased phytoplankton concentrations after filtering, and decreased urea decomposition and increased phytoplankton concentrations after filtering.

Bacterial concentrations were significantly altered by filtering in all stations except one, even though the filter sizes were large enough to pass bacteria through. The changes could be attributed to bacteria adhering to particulate matter.

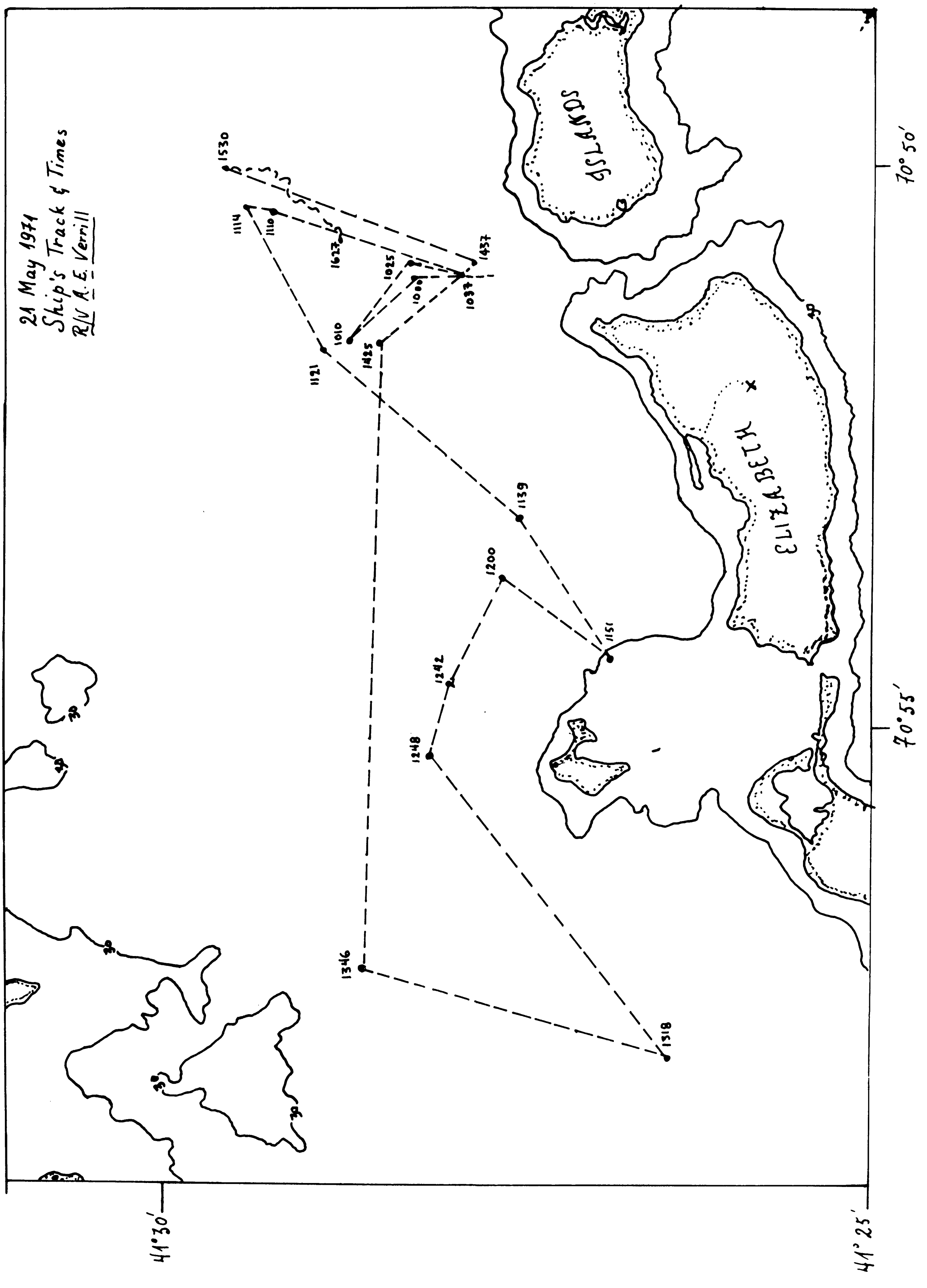
CONTINUOUS SEISMIC REFLECTION AND SEDIMENT STUDIES IN PARTS OF BUZZARDS BAY

Irene Barinoff and Andy Schaedel

A study of seismic wave penetration in varying types of sediment was conducted in Buzzards Bay in May 1971. Bottom samples were taken and compared with wave penetration. Results indicate that penetration of the transmitted wave decreases with increasing sediment size, due to rapid attenuation of energy through gravels, shells, etc. Navigation difficulties prevented point-to-point correlations of sediment samples with depths of penetration. Sediment deposition patterns are related to Pleistocene placiation.

A study of the problem of relating types of sediments to depth of penetration of seismic waves was conducted on Buzzards Bay in December 1969 on a student cruise of the R/V *Albatross*. The results of this cruise, compiled into a chart of the surveyed area, showed a definite relation between the two parameters. It was found that the depth of penetration of the seismic wave was inversely proportional to the size of the sediments; that is, as the size of the sediments increased from clay to gravel, the depth of penetration decreased. This is due to the higher reflectivity of the gravel size grains, and compaction and porosity of the various sediments.

This study was further extended by a student cruise aboard the R/V *A. E. Verrill* in May 1971. The primary purpose of the cruise was to perform various field tests on two Ocean Research Equipment Inc. seismic penetration transducers, one transmitting at 1.4 kHz, and the other transmitting at 3.5 kHz. The transect covered by the ship was essentially parallel to that of the *Albatross* cruise. The observational program consisted of continuously recording the seismic reflections of the various sediment boundaries, visually monitoring these results, and taking grab samples at points where it was felt that the depth of penetration had changed.


21 May 1971
Ship's Track & Times
R/V A.E. Verrill
ISLANDS
ELIZABETH
1530
1114
1110
1627
1025
1008
1037
1457
1010
1425
1121
1139
1200
1151
1242
1248
1346
1318
30
30
30
30
30
30
70°50'
70°55'
41°30'
41°25'

The analysis of this collected data involved plotting ship positions, conducting an analysis of the grain size of the collected sediments, studying the topography and current and tidal information of Buzzards Bay, and determining the maximum depth of penetration of the seismic waves into the sediments. Ship positions were plotted from information contained in the ship's log, and dead-reckoning between fixes was used. Whenever possible, intermediate points between stations were plotted using a range and bearing or two ranges to well-known navigational buoys.

At each station at least one bottom sample was taken by a Smith-McIntyre grab sampler. The samples were briefly described in the field, then stored for later analysis (see Appendix*). The analysis primarily involved the separation of the sediments into various grain sizes. A representative portion of each sample was wet-sieved through a 62-μ (.062-mm) mesh sieve. Those sediments of size greater than 62 μ were collected in a beaker and allowed to dry. The finer sediments (less than 62 μ) were put into solution in 1 liter of distilled water and a pipette analysis was conducted to determine the silt and clay portions of the sample (Krumbein, 1939). After the fine sediment samples dried, they were weighed. The coarse sediment samples were combusted at 500° C, to remove any organic material. They also were weighed, then dry-sieved through 2000-, 1000-, 500-, 250-, 125-, and 62-μ mesh sieves, respectively. These fractional samples were weighed, and the combined data yielded the percentage composition by weight of the total sample. These results are shown in Figures 4-18.* The various samples are plotted on the chart to show the position of the larger percentage sediment grains of the sample.

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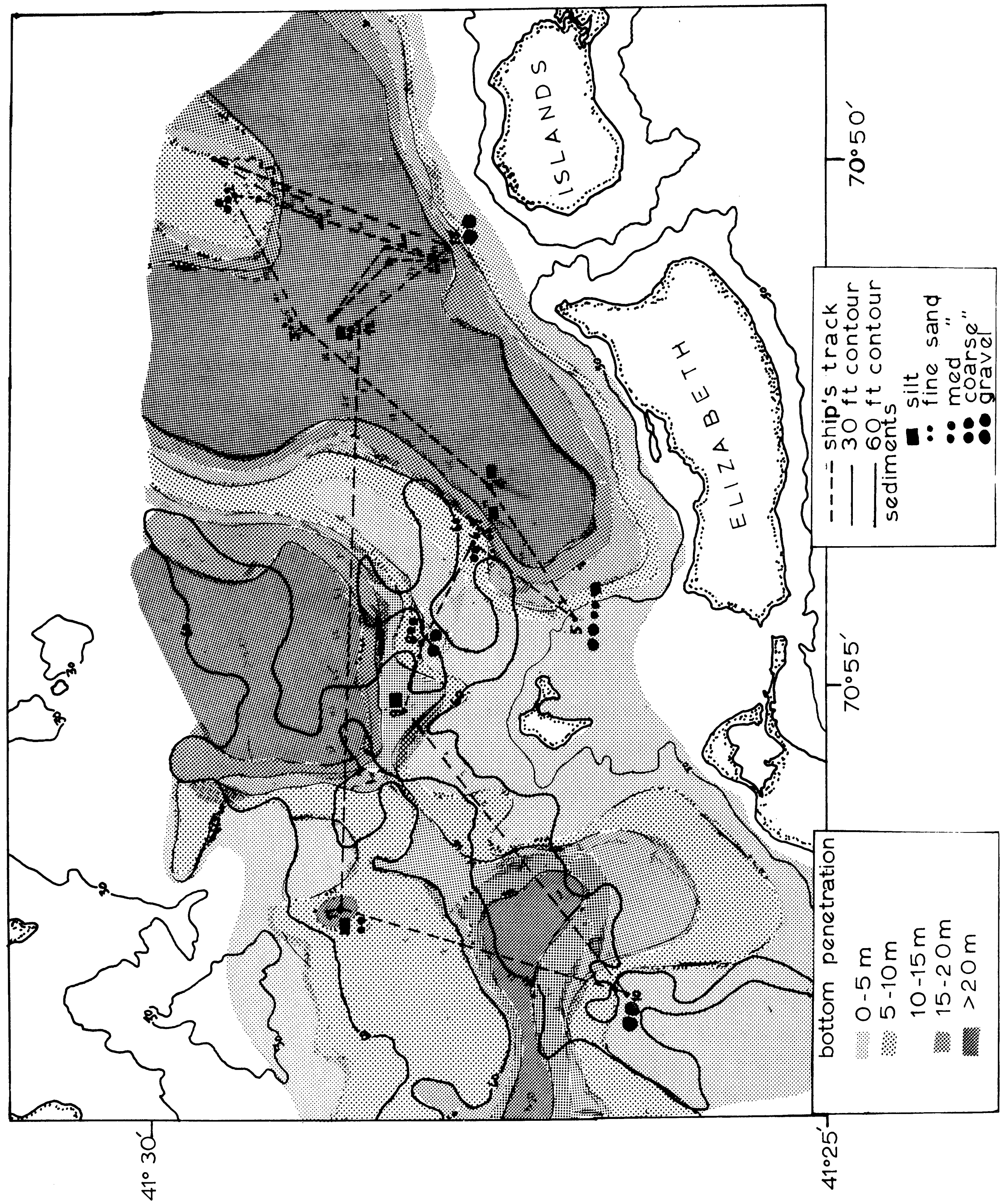
*On file at the Department of Meteorology and Oceanography, The University of Michigan.


bottom penetration
0-5 m
5-10 m
10-15 m
15-20 m
>20 m
ship's track
30 ft contour
60 ft contour
sediments
silt
fine sand
med "
coarse "
gravel
ELIZABETH
ISLANDS
70°50′
70°55′
41° 30′
41°25′

Seismic analysis of the profile chart involved interpreting the graphical record for depth of penetration and sharpness of the reflection. Each leg of the transect was divided into equal intervals between two stations. The distance between the same two stations was divided into the same number of intervals on the profile. Each point thus obtained yielded a topographic depth and depth of penetration, assuming a seismic velocity of 2 km/sec for the sediments. A brief description of the individual stations is found in the Appendix.*

Topographic analysis was done by using the recording scale on the seismic profile paper and adding 12 ft for the fish depth. The results agree quite well with the 21st edition (30 VI 1969) ESSA chart of the area. It was noted that the 60-ft contour on the chart prepared by the R/V *Albatross* investigators did not agree with either the ESSA chart or the R/V *Verrill* cruise record.

The results indicate, within some fairly wide generalization of the seismic data, that penetration of the transmitted wave does decrease with increasing sediment size, due to the rapid attenuation of the down-going energy through gravels, shells, etc. In the case of the bottom penetration, the true bottom surface may not be indicated very sharply on the output of the graphic recorder if the sediments are quite unconsolidated (Ewing and Nafe, 1963). That is, the density difference between the water and the unconsolidated sediments is so slight that it is not recorded. Also, if rock of high reflectivity is fairly near the surface and is covered by silt, the profile will indicate low penetration, while a sediment analysis will imply a very deep penetration.

Although porosity was not specifically investigated, the assumption that the larger sediment grain sizes are denser than the finer sediment grains, combined with the relation that as porosity increases, density linearly decreases (after Nafe and Drake, 1963), yields that sediments with low porosity exhibit a higher reflectivity and consequently less depth of penetration.

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*On file in the Department of Meteorology and Oceanography, The University of Michigan.

Compaction effects of sediments are primarily observed in the sharpness of the record for the various layers. If the sediments are very compact, a clear boundary is recorded, while loose sediments yield a fuzzy graph which may interfere with and distort the subbottom boundary.

The above conclusions must be regarded in a most general sense. The data was not precisely collected in any portion of the analysis, except perhaps the recorded seismic reflections (provided the instrument was correctly functioning) and the analysis of the sediments. The fault lies more in the sampling techniques rather than with the investigators.

There was considerable ship drift; therefore, the dead reckoning positioning of the ship is questionable. It is suggested that the bearings and ship speed be recorded at frequent intervals to correct for this. Since the record of the seismic data is dependent on the path of the ship, this same error was continued into the analysis of the seismic profiles. Also, the technicians often stopped, restarted, and changed various parts of the instruments as part of the field test. The use of two fish caused some interference on the profile records, and in some spots made penetration reading difficult. Marks on the record indicating where the samples were taken and the ship's course, speed, and and time were not precise. This was due in part to the inexperience of the student crew and in part to the priority of the field testing over the scientific work. Consequently, point-to-point correlation of the sediment samples with the depths of penetration could not be conducted. However, if a suitable data point substantiating the general hypothesis was found within a fairly limited time period (i.e., position) on the seismic profile, this was accepted as good correlation. It is suggested by Hersey (1963) that core samples are useful for obtaining a fairly good idea of sediment structure to compare to the recorded profiles. In areas where the local geology is well known, these correlations are more easily discovered.

The grab samples initially were not taken with good sampling technique. When R. Borys pointed out that the grab should be slowly lowered the last few meters on the fall, then carefully raised to the surface, his suggestion was applied and better results were obtained. In the analysis of the sediments, although care was taken to obtain a representative sample, the amount of sample used in the actual analysis was very small and a sizeable error in the final percentages is conceivable. The errors induced through the techniques themselves are adequately described by Krumbein and Pettijohn (1938). In the analysis of the fine sediments, only the boundary values for the silt and clay sizes were determined. Therefore, in the graphical presentations, the height of the histogram rather than the area under the curve should be considered.

The patterns of sediment deposition are related to both past geology of the area and present features of the tides and local geography. According to Strahler (1966), Cape Cod, Buzzards Bay, the Elizabeth Islands, etc. were formed in the Wisconsin Stage of the Pleistocene Epoch (50,000-70,000 years ago) by the unidirectional deposition of sand, gravel, clay, and boulders by the Laurentide Ice Sheet. After remaining stationary for some thousands of years, the ice partially melted and again reached equilibrium. During this second standstill of the ice sheet, the area was formed. The position of the area is the result of three ice lobes; Buzzards Bay, Cape Cod Bay, and South Channel. As the ice receded, deposits of basal till (glacial till with clays, highly compacted) and residual till (glacial till with high sand content) were exposed, forming the Buzzards Bay moraine, which extends from Elizabeth Islands to the Cape Cod Canal.

Sedimentation began about 12,000 years ago. Using a maximum value of 100 m penetration from the profile, a sedimentation rate of 100 m/12,000 yr or 0.83 cm/yr is obtained. River deposition and tidal currents are the primary factors controlling sedimentation in Buzzards Bay, although in its central portion, currents are weak and variable (Tidal Currents Tables, 1971). The patterns of sedimentation illustrate the result of these factors. On the chart (assume for simplicity that the top of the chart is North), as area of heavy sedimentation, just north of 41° 25', is bounded by two areas of coarse sediments. These two boundaries, Mishaum Ledge to the north and Coxens Ledge to the south, provide a type of channel for the sediments to settle in. To the northeast, is located another area of sedimentation. Through its orientation, it is deduced that deposition from the Apponagansett River and Acushnet River was instrumental in its formation. The third area of heavy deposition parallels the curve of the Elizabeth Islands. The accumulation of sediments is probably due to their slow transport from the mouths of other rivers into Buzzards Bay and southwest.

The area of low sedimentation on 70° 55' meridian just north of the Elizabeth Islands is due to a tidal channel. As mentioned before, the two areas of low deposition east of the tidal channel are ledges. The small area in the northeast section of the chart is noted as "rocky" on the C&GS navigation charts and exhibits low penetration (display of an outcrop on the profile), but no apparent explanation can be made as to its origin other than a remnant of the glacial age.

ACKNOWLEDGMENTS

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OBSERVATIONS ABOUT THE PROPAGATION OF *BOTRYLLUS SCHLOSSERI* AND ITS SPECIFIC ROLE IN A FOOD CHAIN IN REFERENCE TO AN OYSTER AQUACULTURE SYSTEM

Bob Grove

The purpose of this experiment is to study the propagation of *Botryllus*, since their fouling tendencies have created problems in an oyster aquaculture system. Preferred growing conditions are tested with respect to temperature and growing surface. Also, observations of natural populations and aquaculture growth are compared and their role in a marine food chain is analyzed.

During May 1972, continuing *Botryllus* populations were found in abundance in Eel Pond and to a lesser extent on buoys and pilings in other inlets near Woods Hole, Massachusetts. The experimental oyster aquaculture system at Woods Hole also supported large *Botryllus* populations.

Growth experiments on *Botryllus* revealed: (1) a distinct asexual growth retardation temperature at 17.5° C compared to 20.0° C; an inhibition of growing activities except colony fission at 14.0° C and 17.5° C, dependent upon growing surface; (3) in this low temperature zone, the smooth, clean surface of glass slides stimulated a continuation of high colony fission, while on rough, aged surfaces of oyster shells fission was inhibited; (4) above the suspended activity range (20.0° C) growing easily doubled *Botryllus'* surface area coverage and increased the colony number equally well on glass and shell.

During a 17-day period, beginning 13 May, *Botryllus*-free surfaces were monitored in the existing aquaculture system and in Eel Pond. Completely scrubbed oyster shells and aged shells picked of any *Botryllus* were monitored in each system. No larval attachment or growth was found in either case on the Eel Pond shells. In contrast, *Botryllus* attachment in the aquaculture system revealed three colonies on the cleaned surfaces and 21 colonies on the uncleaned shells that already supported an organic film over their surfaces.

Analysis of *Botryllus'* role in a marine food chain, observed within an aquaculture system, showed that (1) predation by the sand worm *Nereis* occurred and (2) the food utilization efficiency, characterized by a deposition examination, showed *Botryllus* removed nitrogen from the water as effectively as oysters.

INTRODUCTION

Background

Botryllus schlosseri is a colonial sea squirt and its ability to form leathery sheets of colonies that can totally encrust adequate growing surfaces classifies it as a fouling organism. In an experimental oyster aquaculture system at Woods Hole Oceanographic Institution, *Botryllus* have flourished. (A description of *Botryllus*, its versatile reproduction patterns, and sketches of the organism appear in Appendices 1, 2, and 3.) *Botryllus* have not been studied extensively up to now because

(1) colonies are small, 3-10 mm long, and other sea squirts are easier to study morphologically;

(2) range of distribution is not as universal as some sea squirts;

(3) they are not as well recognized as other fouling organisms such as *Balanus;*

(4) they usually pose no serious threat to surfaces they foul, unlike barnacles, and are easy to remove;

(5) they have not been an important species to man, as either a food source or in any other economically significant venture.

Purpose

Undesirable fouling tendencies in the Woods Hole aquaculture system inspired the need for new studies of *Botryllus* with the hope that eventually *Botryllus* can be controlled using ecologically sound principles. The new significance placed on *Botryllus* has necessitated this study of their growing habits and specific role in food chains. Briefly, the involved aquaculture system is designed to study the utilization of eutrophication for the intensive cultivation of marine organisms, and has successfully grown bivalves on algae that were nutrient-fed with treated sewage (Tenore and Dunstan, 1972a). *Botryllus* persistently grew on the oysters and sides of the culture tanks in last summer's outdoor system. In fact, the free-swimming larva (150-µ head dia.) or the small initial colonies even made their way into the carefully regulated, indoor, winter version of the aquaculture system, possibly through (1) the food intake system, (2) the aerated water passing through, (3) newly introduced groups of oysters, or (4) the transfer of submerged equipment.

The most important aspects of *Botryllus* growth in this system are its interference with system efficiency measurements and direct competition with oysters. The consumption of food by any hidden member of the same trophic level will appear as a loss in efficiency (Ryther, 1970). In oyster aquaculture *Botryllus* are also members of the herbivore trophic level. This in turn creates two problems. First, accurate measurements of the efficiency of the utilization of food by the oysters would be affected, resulting in inaccurate energetic flow descriptions (Tenore and Dunstan, 1972b). Second, this fouling species is a competitor of oysters and reduces the percentages of the total food available for ingestion by oysters, thus hindering oyster production. (See Appendix 4 for other general oyster aquaculture problems created by *Botryllus'* presence.*)

Specifically, the purpose of this experiment is to study a few of the aspects of the seldom considered organism *Botryllus schlosseri*. Natural environments (Woods Hole, Massachusetts; May 1972) versus controlled conditions will be compared, running growth comparisons, natural occurrence observations, and performing temperature and growing surface performance tests within the laboratory. Its role in a marine food chain will be considered: observing feeding habits, analysis of deposition rate--nitrogen uptake, and noting any predation upon by other organisms.

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*Appendix 4 is on file in the Department of Meteorology and Oceanography, The University of Michigan.

MATERIALS AND METHODS

Botryllus schlosseri colonies were carefully removed from the oysters and sides of a laboratory aquaculture tank. The tank's parameters included: 20.0° C circulating sea water filtered with 25-μ Ultipor filter units and a constant input of diatoms supplementing the water to 500 μg-at/liter carbon. Intact colonies were placed on microscope slides and oyster shells and allowed to settle from 10 May to 15 May. Firmly attached colonies were then measured as to zooids per colony, dimensions of colonies (in millimeters), and number of colonies per slide or shell. These oval colonies were assumed to be uniformly elliptical so the two diameters (a and b) were measured and surface area calculated using $\pi(ab)/4$. Sets of five shells and five colonies, each surface supporting one to five colonies, were placed in three trays (32 x 28 x 12.5 cm) containing 9 liters of sea water. Each tray received an average flow of 300 ml/min of water. In these three trays, treatments were: one with ambient sea water (14.0 ± 1° C, 143 ± 31 μg-at/liter carbon); one with similar ambient water heated to 17.5 ± 0.5° C; and the last treatment consisting of aquaculture conditions with a regulated food source to equal ambient conditions (20.0 ± 0.5° C, 140 ± 10 μg-at/liter carbon). These trays were maintained from 15 May to 27 May, and final growth measurements taken. The particulate carbon content of the water in each tray was monitored throughout by filtering 500-ml water samples onto Millipore combustible filters and analyzing the sample after drying in an oven at 50° C for one hour. To prepare the phytoplankton supplement for the aquaculture tray, mixed phytoplankton cultures were pumped into the system at a calculated rate to equal ambient conditions (Tenore and Dunstan, 1972b).

In addition, the oysters in an ongoing experiment were monitored for *Botryllus* growth and compared to growth rates of *Botryllus* on oysters suspended in Eel Pond, Woods Hole (13-29 May). In each instance, two groups of oysters were used, one set thoroughly cleaned with a wire brush and the other set voided of *Botryllus* only, leaving the microscopic organic film over the rest of the shells undisturbed. In the aquaculture tank (20.0° C), 170 cleaned and 143 uncleaned oysters were placed on a flat rack in 0.25 m of water. Eel Pond received 91 cleaned and 81 uncleaned oysters suspended in 40-cm trays in 0.75 m of water (11.0° to 14.9° C). At the end of the interval, *Botryllus* growth was recorded, dry weight carbon of *Botryllus* analyzed, and carbon-nitrogen ratios found.

Natural occurrence patterns of *Botryllus* for May-June were established by a random survey in the area. Oysters suspended 0.5 m in Eel Pond on strings since June 1971 were surveyed. Further, data was obtained from the Marine Biological Laboratory showing where that group found their *Botryllus* specimens in the Woods Hole area during this period.

The role of *Botryllus* in marine food chains was partially analyzed with respect to food consumption and predation upon. Fecal pellets were collected, using a micropipet, from the colony's atrial opening of the *Botryllus* lving on the sides of an aquaculture tank. Particulate carbon and C-N ratios were calculated for a resulting 25-ml sample of feces and surrounding water. Similar calculations were made for the tank water alone. These results were to be compared later to similar calculations made on oyster deposition (Tenore and Dunstan, personal communication) to compare one aspect of efficiencies of these competing species. The particulate carbon and C-N ratio analyses were done using the Perkin Elmer 240 Elemental Analyzer.

RESULTS

After examining the research done on *Botryllus* (see references), it became clear that in all of the studies, one of the main questions left unanswered in this fouling organism's existence was: What dominant factors allow them to mass populate certain areas at certain times? *Botryllus* have been known to dominate areas one year and the next year be practically void, for no outwardly apparent reasons (Stubbings and Houghton, 1964; Graves, 1933). It seems that the controlled aquaculture system has been able to simulate only the optimal growing conditions, letting *Botryllus* grow quite uninhibited. Obviously, one of the hardest questions to analyze in ecology is: What are the factors or combination of factors controlling and regulating specific populations? But, in trying to analyze *Botryllus* in an aquaculture system, the task is simpler since the "isolated" case of study is the applicable environment that scientists are concerned about anyway. So, with the problems *Botryllus* growth has created in aquaculture, solutions to help curb their propagation come only after many factors are diligently investigated. This project begins by trying to find out why *Botryllus* are doing so well in the man-made environment, compared to natural populations, by checking the differences in physical parameters. Then a few of the more obvious growth regulation factors are analyzed in an attempt to find controls that can most efficiently eliminate *Botryllus* where undesired in aquaculture.

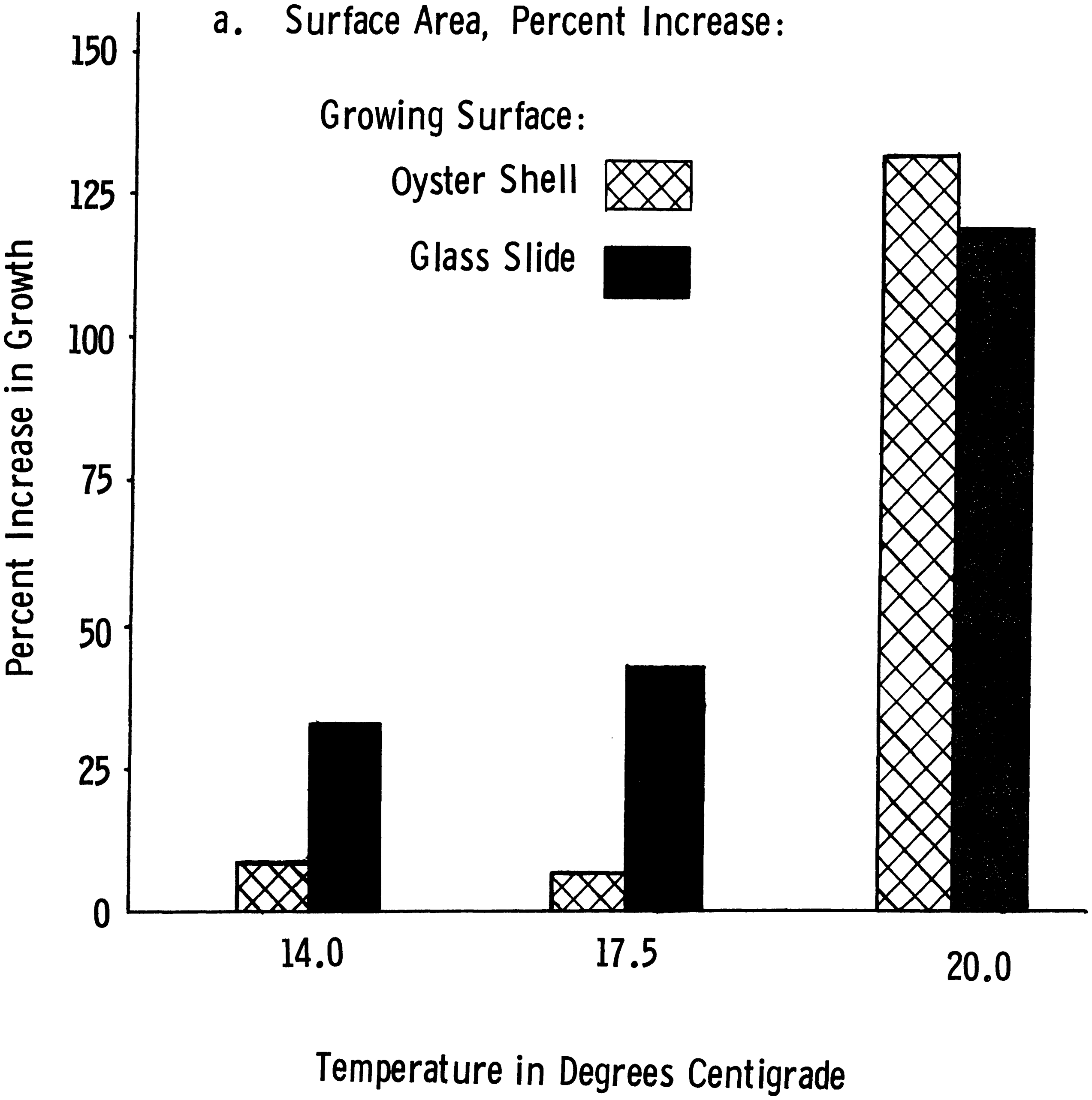
The first important observation was that *Botryllus* do not propagate sexually in May in the natural environment, but do in aquaculture tanks. Stubbings and Houghton (1964) and R. H. Millar (1971) confirm that larva are normally not produced until warm weather in mid-summer. This means larva attachment has started early (April-May) in the aquaculture system, and could extend the sexual continuance period (Appendix 2) into the greater part of the year with its constant food and temperature. However, this fact takes on less significance once the asexual spread of *Botryllus* has begun, since, once established in an area, *Botryllus'* fission and budding become the dominant means of surface fouling.

At the same time, a general survey of the Woods Hole area confirmed that *Botryllus* can easily survive the winter, since many continuing populations were present. Although the budding process was most likely retarded (Milkman, 1967) in the winter's low temperatures, colonies throughout May were functioning healthily. On strings of oysters in

Eel Pond since June 1971, *Botryllus* ranged from 4 to 70 colonies per shell and in some cases completely smothered the oyster shells. *Botryllus* were also found growing on pilings and buoys in the area, meaning they, too, survived the winter months on these, just below tidal zone surfaces.

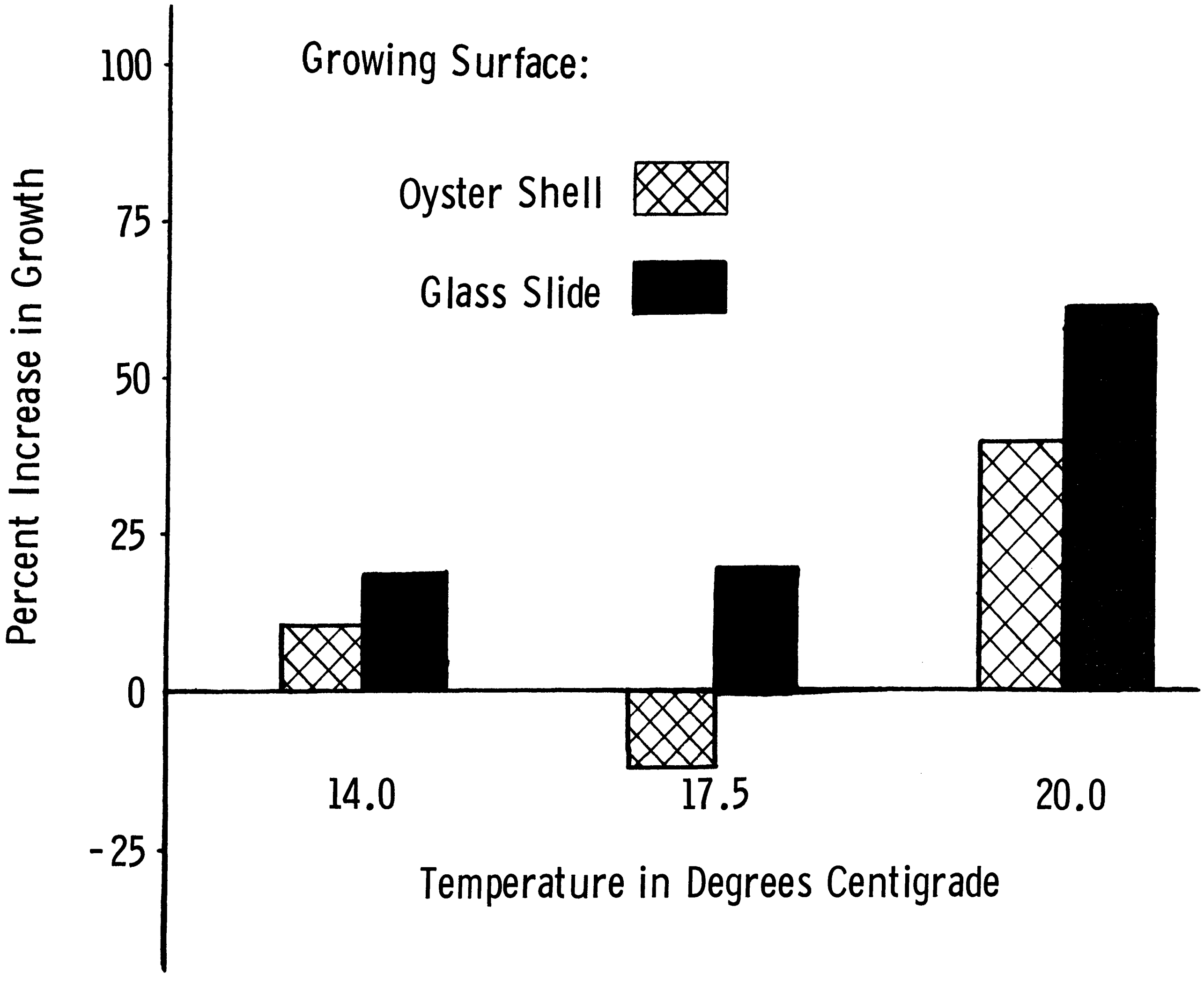
Extensive testing of growing surfaces was done, in trying to find on which surface *Botryllus* grew most efficiently. The preferred larva attachment test showed that completely clean surfaces are less desirable than older surfaces already supporting some organic accumulation (Table 1a). Milkman (1967) stated certain surface growth such as filamentous algae and encrusting ectoprocts can inhibit *Botryllus* cultures completely, yet at the same time this last test confirms R. H. Millar's theory (1971) that certain sessile species require partially fouled surfaces for larval attachment. So, again, the aquaculture system is confirmed as an ideal environment for *Botryllus* with aged surfaces for attachment and with little sessile competition because of 100-μ filters keeping most settling larva out of the system.

Temperature variation tests coupled with growing surface tests provided interesting results for already established colonies. Figure 1 (a-c) shows that there is a definite growth retardation temperature between 17.5° and 20.0° C. This makes temperature a major factor in controlling *Botryllus* propagation and confirms why colony activity differs so much between the natural and aquaculture environments at this time of year. These results also fit into Milkman's (1967) conclusion that growth out of the 18° and 28° C range is slow at best. From the graphs (Figure 1, a-c) it is also evident that the growing surface plays a unique role in *Botryllus* asexual growth. During favorable conditions (20.0° C), both the smooth glass and the roughened, aged shell colonies showed similar growing results. At the lower temperatures neither slide nor shell colonies grew in surface area or number of individuals to any great extent, although the glass colonies did a little better than the shelled. But, when looking at colony number (growth by fission), it is plain that the glass provided a better surface for division and colony

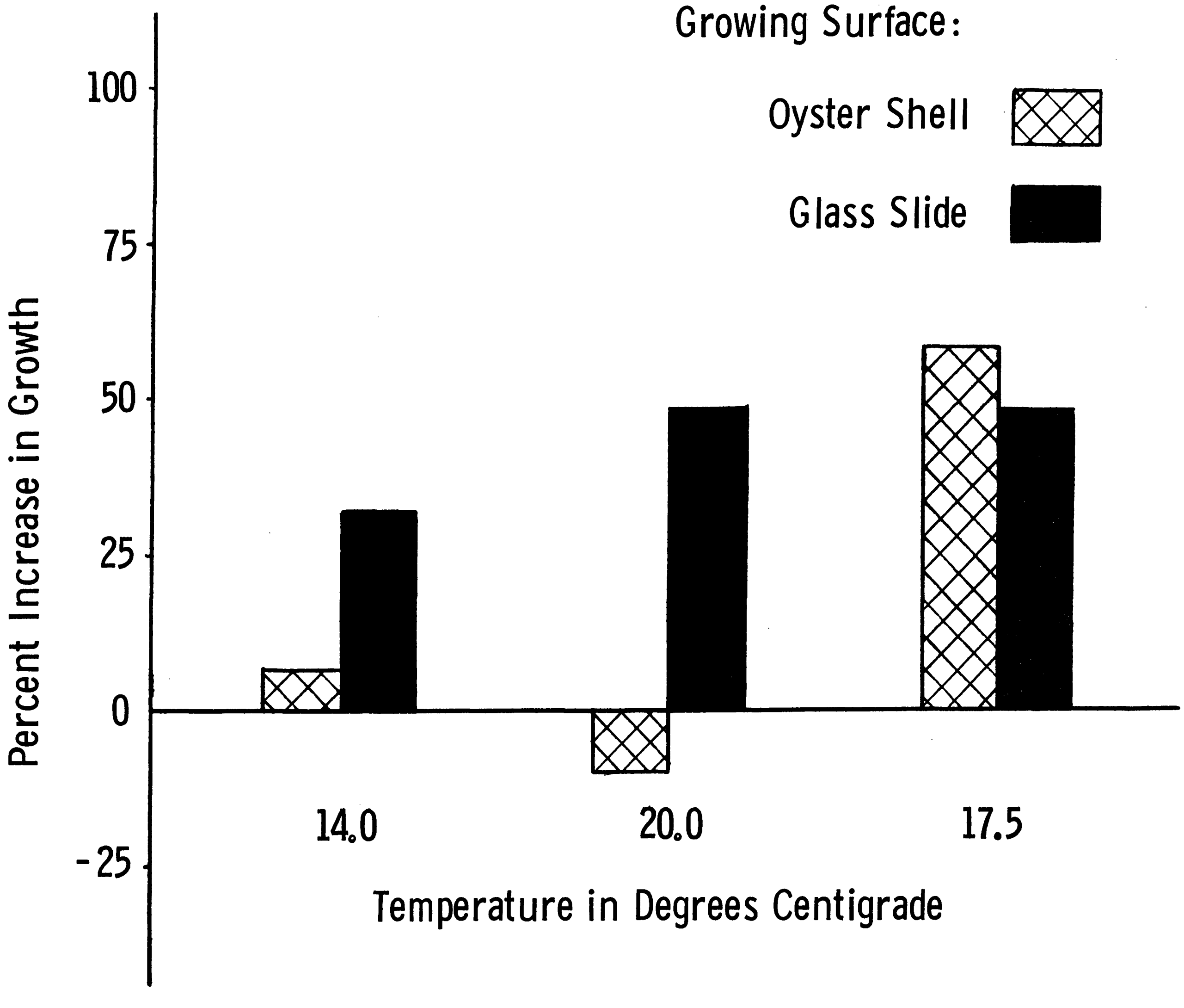


Graph 1. Effect of Temperature and Growing Surface on Three Species of *Botryllus* Growth over a 13-Day Period: (a) Surface Area, Percent Increase; (b) Individual Zooids, Percent Increase; (c) Colony Number, Percent Increase

b. Individual Zooids, Percent Increase;



c. Colony Number, Percent Increase:



migration (Figures 1c and 2*). This could be an evolutionary trend *Botryllus* has adopted, living on ship bottoms and in temperate zones, being able to move into the best position (many small colonies) in unfavorable conditions so as to maximize growth once conditions get better. Applying this to aquaculture systems, even if temperatures are temporally dropped, *Botryllus* control their colonization, with the smoothness of surfaces of the system components becoming a definite limiting factor.

An analysis of a fecal sample revealed that *Botryllus* removed 75 percent of the nitrogen being filtered through their system. Oysters remove 67-83 percent nitrogen (Tenore, personal communication), which means that besides being on the same trophic level as oysters, *Botryllus* are important fouling organisms because their total volume and surface area are high in relation to the tissue weight, and large spaces are covered, and because they are efficient filter feeders, outpacing many of their competitors. Although just one aspect of efficiency, this test has shown that *Botryllus* are at least pacing their filter-feeding competitors in aquaculture, the oysters.

In looking at another area of their role in a marine food chain--predation upon--it was observed that *Nereis* will eat *Botryllus*. This was observed in a relatively flat tank, where a test group of 12 *Botryllus* colonies were devoured within six days by the *Nereis*. The larger the colonies, the harder it was for the sand worms to scrape them off.

CONCLUSIONS

The more testing and observations done on *Botryllus* in this experiment, the clearer it became why *Botryllus* had become a pest in the oyster aquaculture system. Their versatile spread and growth patterns, their tolerance to low temperatures, and their similar growing requirements and abilities as compared to oysters all add up to mean that *Botryllus* are a serious problem in aquaculture. Modifying any of the

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[*] Figures not included in this report are on file in the Department of Meteorology and Oceanography, The University of Michigan.

parameters of the aquaculture system to lessen the good *Botryllus* growing conditions, it appears, would also result in losses to the oysters.

In trying to find an ecologically sound way to rid the system of *Botryllus*, more work has to be done. Seeing that *Nereis* prey on the colonies in a small system is an encouraging lead. Also, an important consideration not tested here is the possibility of a combination of factors limiting *Botryllus* growth without limiting oyster growth in an aquaculture system. Combinations of temperature, salinity, food type and concentration, particle concentration in water, turbidity, and growing surfaces should be considered together in more intricate future experiments.

ACKNOWLEDGMENTS

I wish to acknowledge my indebtedness to Dr. Kenneth R. Tenore for assistance and for facilities furnished during the course of the investigation.

APPENDIX 1

Description of *Botryllus schlosseri*

Botryllus schlosseri (Pallas) is a colonial sea squirt (subphylum Tunicata, class Ascidiacea). Distribution of these organisms ranges from the east coast of the United States and the west coast of Florida to all of the seas of Europe (Berrill, 1950). The colonies are found in waters less than 10 fathoms, normally in very shallow areas, and are especially abundant in harbors. Specifically, *Botryllus* grow on submerged vegetation, rock, and other solid substrates such as shell. Each colony appears as a flat oval disc, a few millimeters in diameter, composed of 2 to 18 zooids averaging 1.5 mm in length. These zooids resemble solitary ascidians in structure and habit. Furthermore, the zooids are radially arranged in a colony around a common atrial (excurrent) opening that connects each individual atrial siphon from within the communal test. In contrast, the oral (incurrent) siphons are peripheral and open directly into the water. Special light-reflecting pigment cells are located randomly in intersiphonal pigment bands between the oral and atrial siphons (Watterman, 1945). Such variation in structure, together with color variations of black, purple, green, and yellow, even within the same group of colonies, has resulted in unjustified subclassification on the basis of appearance in this single species (Herdman, 1924). Colonies are surrounded by gelatinous tests, consisting of numerous amoeboid cells, which maintain the system in a dynamic state (Milkman, 1967). The vascular system is embedded in the test, extending from the zooids and consisting of ampulla and blood vessels (Figure 2).

APPENDIX 2

Botryllus Propagation

Flexibility in reproduction patterns has adaptive value for colony establishment and growth. *Botryllus* reproduce both sexually (hermaphroditic cross- and self-fertilization) and asexually (budding and fission). Thus, *Botryllus* can establish new colonies in various locations with respect to parent colonies during favorable conditions by means of free-swimming larva attaching to suitable surfaces followed by rapid asexual colonization (Graves, 1933; Watterson, 1945). Continual asexual growth during all other months of the year account for the rest of the growth pattern, with retardation of budding only under extreme stress conditions (R. H. Millar, 1971). Carlisle (1961) has even observed colonial fusion in *Botryllus* in an effort to survive through severe conditions. A prolific example of asexual growth, observed by Graves (1933), was where one colonial group developed from a single larva into 3000 individuals within 30 days of larval settlement.

APPENDIX 3

Observed *Botryllus* Growth, Contrasting 14.0° C and 20.0° C Environments

Figure scale: bar in each diagram = 5 mm.

a. Glass slide at 20.0° C on 16 May.

Labeled parts of one colony:

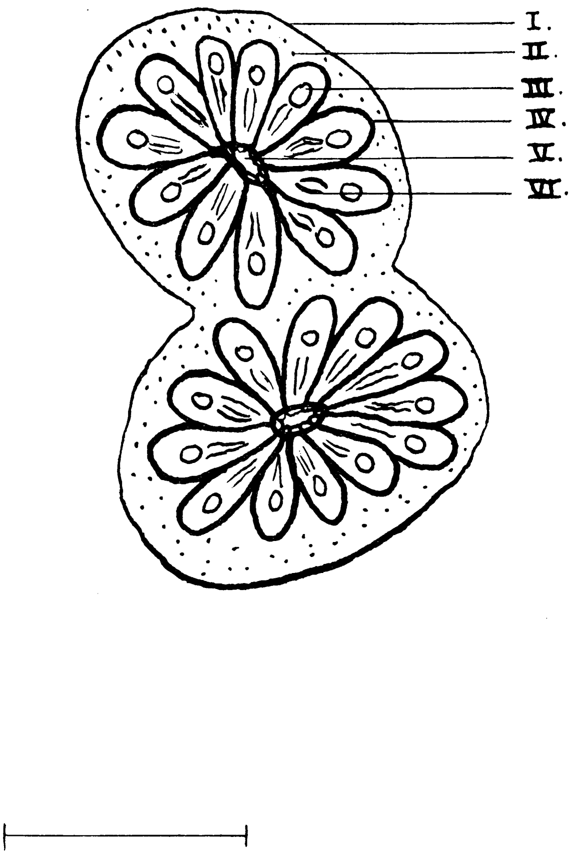
I	communal test
II	vascular system
III	oral siphon
IV	individual zooid
V	atrial siphon
VI	intersiphonal pigment bands

b. Glass slide at 20.0° C after 10 days growth, 27 May.

c. Glass slide at 14.0° C on 16 May.

d. Glass slide at 14.0° C after 10 days growth, 27 May.

a.



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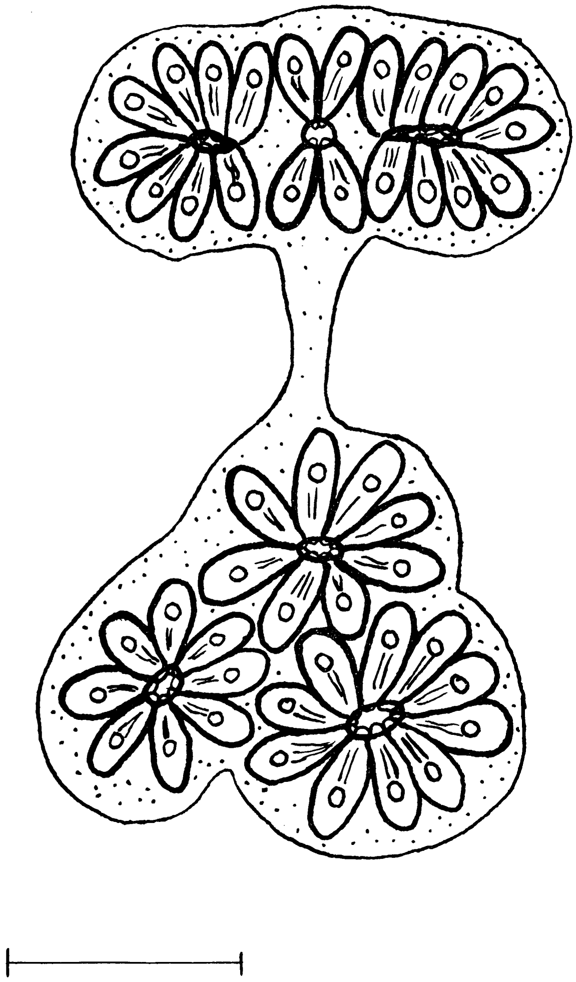

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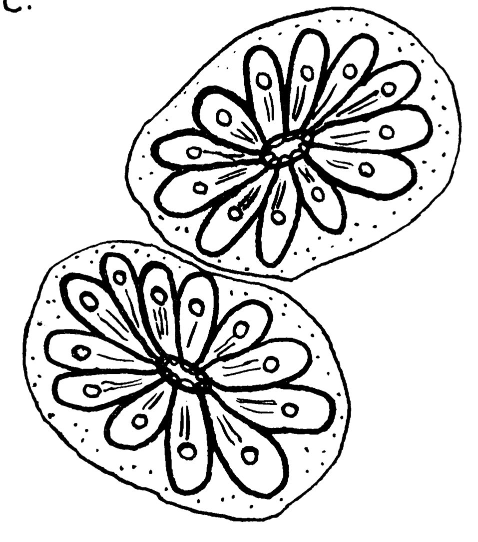

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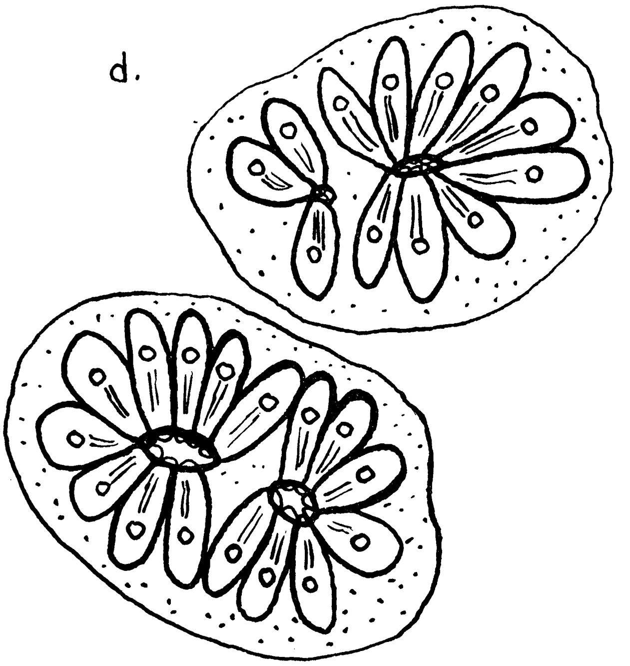

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SURFACE CIRCULATION OF NANTUCKET SOUND AS DETERMINED BY DRIFTERS

Bruce J. Higgins

On 11 and 25 May 1972, surface drifters were released in three patterns across Nantucket Sound. The drifters were of four types to compare the responses of various types to the wind and currents. Of the 891 released, 289 (32.5 percent) were recovered and plotted.

In summary, it appears that: (1) drift bottles released near shore generally follow tidal flow and are not influenced by winds, (2) surface flow is influenced by the wind in locations of weak tidal action, (3) drifters of the type made by forming waterproof envelopes are influenced to such a degree by the wind that it is doubtful that they indicate the true movement of the surface flow, and (4) surface flow in the sound is not easterly if the winds are over 20 mph and from the northeast or northwest.

INTRODUCTION

Nantucket Sound is bounded by three bodies of land: Cape Cod to the north, Martha's Vineyard to the southwest, and Nantucket Island to the southeast. These land masses produce three natural channels for water to enter and leave under the influence of the tides. There is, however, considerable question as to the movement of the surface flow (the top 1 m of water).

According to a previous report (Bumpus et al., 1969), there is a net easterly flow of the sound water. Cayan (1971) attempted to verify this with a study in Vineyard Sound and the western part of Nantucket Sound. He utilized drift bottles, but did not recover a sufficient number to establish defined patterns. He completely disregarded wind effects.

The object of this study was to observe the surface water flow in Nantucket Sound proper. In this body of water, with a long fetch to the south and east, coupled with days when the water can be warmer than the air, it is possible that the wind could play a more important role than the tides. Surface wind drift is generally accepted to be 2 percent of the wind speed (Tolbert and Salsman, 1964).

At the present time, several types of drifters have been suggested for such studies. Very little information, however, is available as to the recovery rate, or the influence of weather and currents on the different types. It was, therefore, decided to use the standard drift bottle and three plastic envelope types of drifters to gain this information.

DESCRIPTION OF EQUIPMENT

To evaluate the relative influences of tidal current and wind, four types of drifters were employed.

(1) Type DB was assembled by using a heavy-duty, 10-oz flint glass bottle. The weight of the bottle was adjusted by the addition of sand so it would float vertically, with its top approximately flush with the water surface. (348 were used.)

(2) Type VDC was a commercially available product, consisting of a polyethylene sleeve (8 x 5 1/2 in.). At one end, a foam sponge float was sealed, and at the other end was sealed an iron weight. The iron ballast was adjusted so that it would remain vertical in the water. As it turned out, these drifters were lightly ballasted and floated with a 1-in. high and 5 1/2-in. long sail. (186 were used.)

(3) Type DC was made by a plastic envelope and a piece of styrofoam. The envelope was heat sealed. The drifter was designed to float flush with the surface of the water. Its dimensions were only slightly larger than those of a post card. (189 were used.)

(4) Type SD consisted of a plastic envelope with a steel washer for ballast. To suspend the envelope below the surface, it was attached to a 10-in. streamer buoyed by a cork float. This type was designed to increase drag. (160 were used.)

Types DC and SD were designed and built by G. T. Kaye.

Each drifter contained a prepaid post card asking the finder for his location and promising to send him the location of release if it were returned. The post cards were a fluorescent orange on one side so that they could be easily seen.

EXPERIMENTAL PROCEDURE

On 11 May 1972, while the tide was running to the east, the R/V *Asterias* was used to deploy 341 drifters. The ship utilized radar to arrive at predetermined locations, where members of the class threw the drifters into the water. The locations of the releases are shown on Chart 1.* The locations were chosen to examine the interactions at the west entrance to Nantucket Sound. Stations 1-4 were located between Nobska Point and West Chop, which roughly defines a line between Vineyard Sound and Nantucket Sound. Station 4 was located between Middle Ground and West Chop, where the currents are reported to act differently than in other water in the area. Stations 5-8 were located along a line connecting West Chop and Cape Poge. The tidal action along this line is strong and bounded by shoals, which might channel the flow. The releases of stations 9-13 were along a line joining Coast Guard buoys. These were to check the motion of the surface water away from shore and between the major shoals of the western sound. The last two stations, 14 and 15, were along the north shore near Falmouth Harbor.

On 25 May 1972, with the tide flowing to the west, the R/V *Asterias* was used again to revisit the original stations; however, the wind picked up and the station locations had to be altered. The first six stations

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*Figures, charts, wind roses, and appendixes not included are on file at the Department of Meteorology and Oceanography, The University of Michigan.

were at the same locations and were labeled with a B to distinguish them from the original stations. Due to poor weather, the last nine stations were abandoned and four new stations were substituted. At the last station, 158 drifters were set free to evaluate the dispersion in the system. The returns were expected to pile up along the beaches of Falmouth and permit an excellent comparison of the different types.

Also on 25 May, the ship *Menemsha* (Nantucket Boat, Inc.) was used to release drifters during its normal service between Hyannis and Nantucket. The ship has a radar, but it was not used to locate the various stations since visibility was good and the captain was able to get good fixes on the buoys. The drops of drifters were made so that the intervals between drops would be approximately 3 miles. On the trip to Nantucket, the tide was running to the west and the north-northeast wind was 25-55 mph. The return trip was rough, with a 40 mph wind from the north-northeast and a tide to the east. These stations were numbered 56 to 60.

DISCUSSION OF RESULTS

The returns began to be received within one week of their release. Tables 1, 2, and 3 were prepared to present a listing of number of each type released from each station along with the number returned. It can be noted that essentially the same number of returns were received from the duplicate drops made at the west end of the sound. In order to determine if one type had a greater percentage rate of returns, a summary was prepared for each transect, listing recovery by type. (See Table 4.) Weather data is contained in Table 5.

To better visualize what happened on each transect, the returns were plotted on a chart along with an indication of their point of release (Appendix I). Each return was shown connected to its point of release by a straight line along a possible water course. These lines are not an attempt to show the actual paths taken by the drifters, but are simply a presentation to aid in analysis of trends.

Table 1

NUMBER OF DRIFTERS RELEASED AND RECOVERED BY STATION

11 May 1972

Station Number	Type DB Released	Type DB Recovered	Type SD Released	Type SD Recovered	Type VDC Released	Type VDC Recovered	Type DC Released	Type DC Recovered
1	10	3	1	0	5	1	1	1
2	10	2	1	0	5	1	1	0
3	10	3	1	1	5	0	1	0
4	10	5	1	0	5	4	1	0
5	10	2	1	0	5	2	1	0
6	10	4	1	0	5	3	1	0
7	10	6	1	0	5	5	1	1
8	10	2	1	0	5	2	1	1
9	15	3	15	2	15	5	15	3
10	10	5	1	0	5	4	1	0
11	15	8	15	0	15	10	15	0
12	10	2	1	0	5	3	1	0
13	10	3	1	0	5	2	1	1
14	10	3	1	0	5	3	1	0
15	10	3	1	0	5	1	1	0
Totals*	160	54	43	3	95	46	43	7

*Total Released: 341; Total Recovered: 110

Table 2

NUMBER OF DRIFTERS RELEASED AND RECOVERED BY STATION

25 May 1972

Station Number	Type DB Released	Type DB Recovered	Type SD Released	Type SD Recovered	Type VDC Released	Type VDC Recovered	Type DC Released	Type DC Recovered
1B	5	1	3	1	2	0	4	1
2B	5	2	3	1	2	1	4	0
3B	5	3	3	1	2	0	4	1
4B	5	0	3	0	2	0	4	1
5B	5	3	3	0	2	0	4	0
6B	5	1	3	2	2	1	4	3
17B	10	1	6	3	4	2	8	2
18B	24	13	11	0	8	3	13	4
19B	25	12	11	3	8	5	11	6
20B	39	13	40	7	39	14	40	16
Total*	128	49	86	18	71	26	96	34

*Total Released: 381; Total Recovered: 127

Table 3

NUMBER OF DRIFTERS RELEASED AND RECOVERED BY STATION

25 May 1972

Station Number	Type DB		Type SD		Type VDC		Type DC	
	Released	Recovered	Released	Recovered	Released	Recovered	Released	Recovered
51	6	3	4	0	2	1	5	1
52	6	2	4	1	2	1	5	2
53	6	3	4	0	2	1	5	0
54	6	4	4	0	2	1	5	0
55	6	3	4	0	2	0	5	0
56	6	0	4	0	2	2	5	1
57	6	0	4	0	2	0	5	1
58	6	4	4	0	2	2	5	2
59	6	6	4	1	2	1	5	0
60	6	6	3	2	2	0	5	2
Total*	60	31	39	4	20	9	50	9

*Total Released: 169; Total Recovered: 53

Table 4

SUMMARY OF RECOVERY BY DRIFTER TYPES

	May 11*	May 25*	May 25**
Type DB	33.8%	38.3%	51.5%
Type SD	7.0%	20.9%	10.2%
Type VDC	48.5%	36.7%	45.0%
Type DC	11.6%	33.4%	22.0%
Total	32.0%	33.4%	31.2%

*Western Transect

**Central Transect

Table 5

WEATHER DATA

Date: May	Air Temperature	Sea Temperature	Wind Direction**
10*	43.0	48.8	M-NNW
11	56.0	49.0	M-SW
12	57.0	49.8	M-W
13	60.0	50.5	L-SW
14	63.0	51.5	L-SW
15	58.0	51.0	L-SSE
16	59.0	52.8	L-S
17	58.0	52.5	L-E
18	59.0	53.0	L-S
19	61.0	53.5	L-NE
20*	53.0	53.3	L-NE
21	62.0	53.5	M-NNW
22	64.0	54.0	M-NE
23	67.0	53.8	L-E
24	64.0	54.8	M-NNW
25	58.0	55.0	M-NNE
26*	53.0	55.0	M-NNE
27	61.0	55.5	M-ENE
28	58.0	55.8	M-SSW
29*	55.0	56.5	M-SW
30	60.0	56.8	M-S
31	67.0	57.8	M-SE

*Water temperature exceeds air temperature, temperature °F.

**L -- 5-10 mph; M -- 10-20 mph; H -- 20-35 mph

Analysis of the results plotted on Chart I points up two general observation: (1) the majority of returns were from the north shore of the sound and (2) the majority of drift-card types were found to the east of the drift bottles. Since the wind was blowing from the southwest during most of the time the drifters were at sea, it would appear that the separation was due to this fact. The drift envelopes tended to be closer to the surface and reflected wind effects to a greater degree.

Chart II, which is a plot of the deployment of another group of drifters in the same general location as in Chart I, in the western end of the sound, does not show the same pattern as the first. However, the exact opposite conditions existed for this drop in as much as there was a northeast wind and a westerly tide. In this case, there is a distinct pattern to the northeast and the southwest. The bottles traveled to the northeast, while the envelopes moved to the southwest along Vineyard Sound, out of Nantucket Sound. It is theorized that the wind was the controlling factor. Moving under the influence of both a westerly tide and a 20 mph wind, the drift envelopes moved far enough into Vineyard Sound so that the slight easterly tidal flow did not return them to Nantucket Sound. In the case of the bottles, they were probably carried back into Nantucket Sound, returning with the tide, and finally ending up on the north shore.

Chart III is a detailed plot of the returns from station 20B. At this station, 158 drifters were released. The conditions at the time of release were: 20 mph winds with the tide to the southwest.

In general, the returns can be grouped into four regions: Nobska Point, east shore of Buzzards Bay, Naushon Island, and Falmouth estuaries. The returns found on Nobska Point were found within one or two days and were the results of the northeastern wind, since the release was only 1000 yd from shore. This accounted for 24 percent of the total found.

Those returned from the east shore of Buzzards Bay drifted past Nobska Point and were apparently caught in the currents of Woods Hole passage, and once through the passage moved with the currents of the bay. Thirty percent of those found took this course.

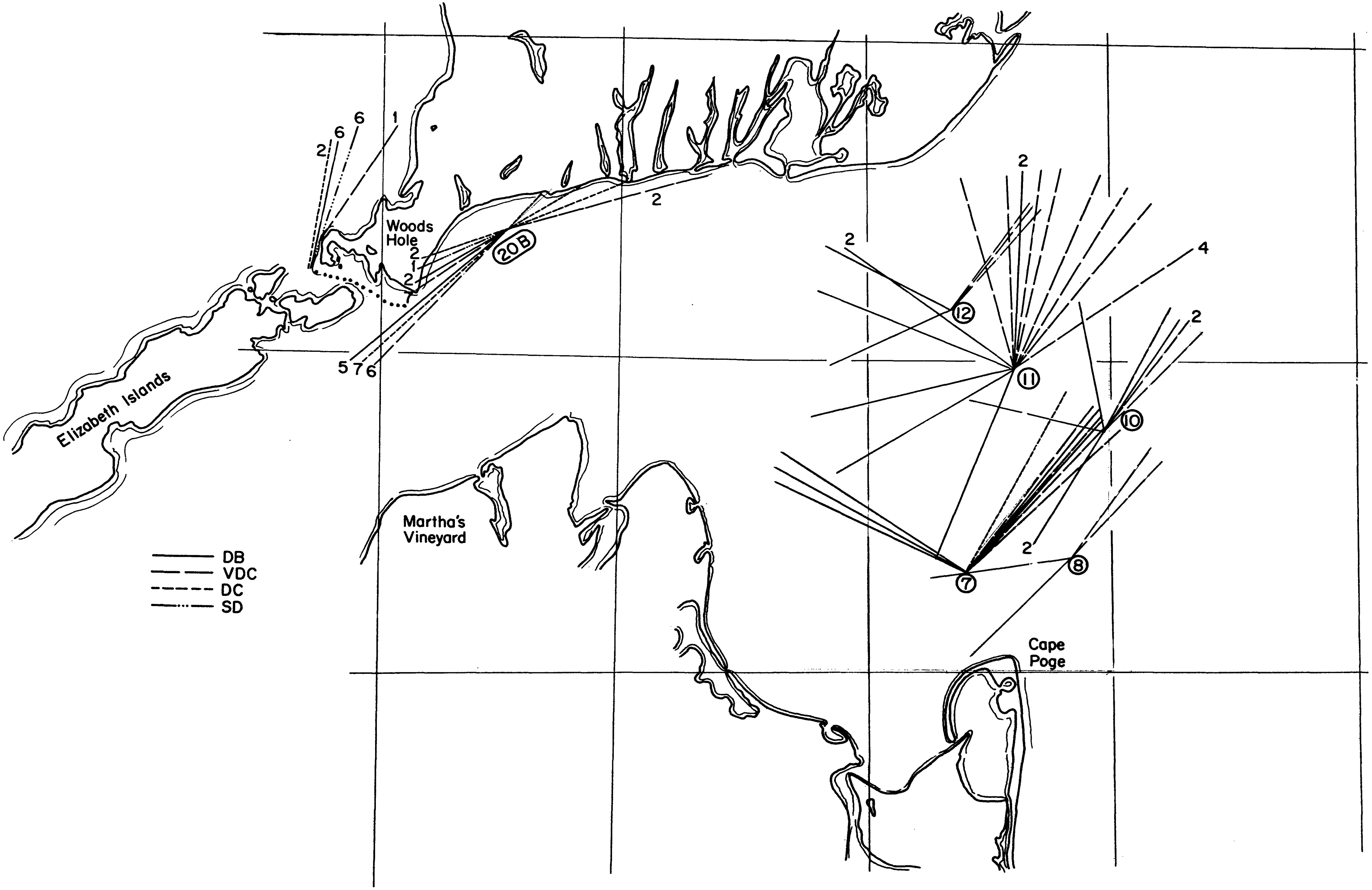
Approximately 34 percent of those recovered were blown past the entrance to Woods Hole passage and entered Vineyard Sound, finally ending up at Naushon Island. The wind probably carried the vertical drifters and drift envelopes past the entrance to Woods Hole; however, there does not appear to be any reason for the bottles to have progressed past the entrance to this passage.

It is difficult to explain how the remaining 10 percent reached Falmouth estuaries to the northeast with the initial tide and wind both producing a current ot the west. Also no returns were received from Oyster Pond, the nearest shore.

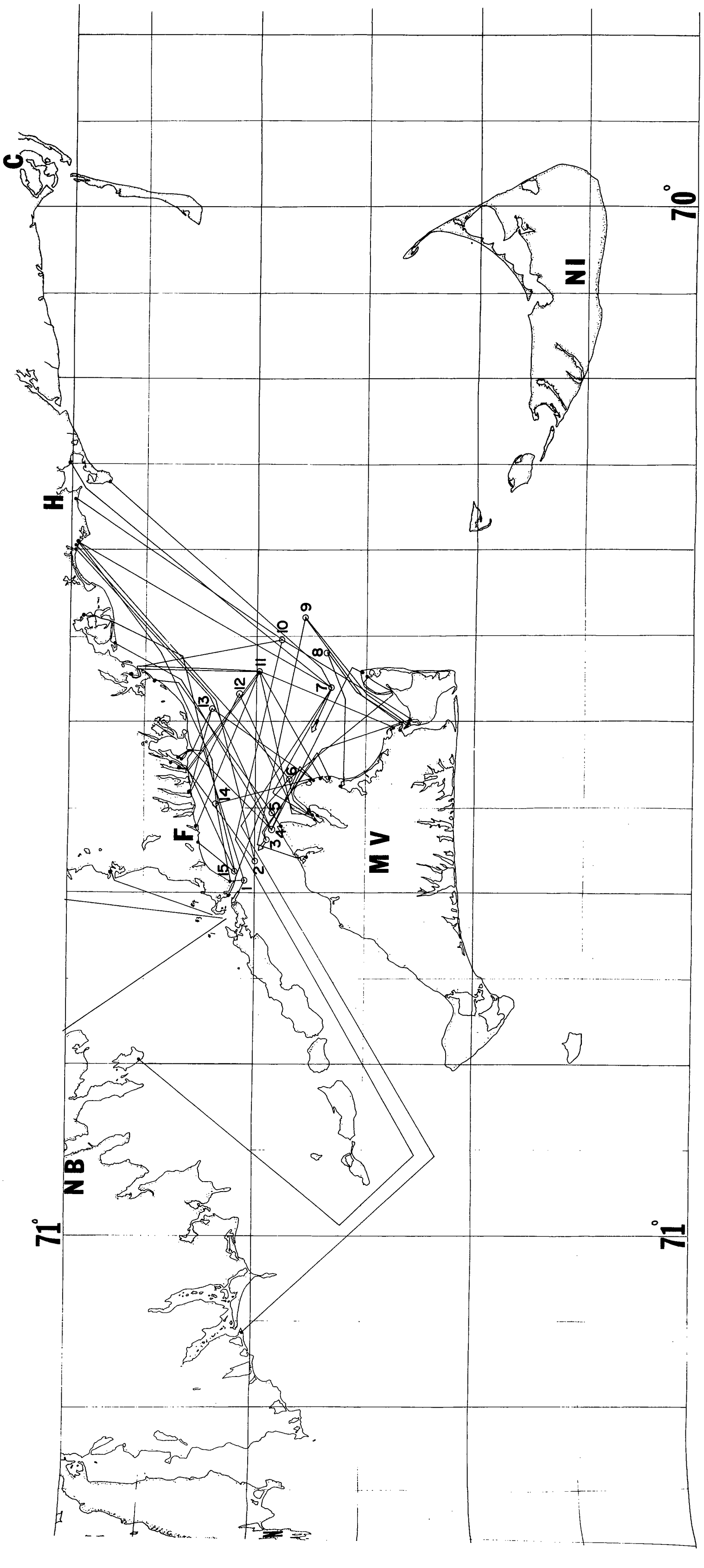
Examination of Chart IV, which plots the returns and releases from the central transect, again confirms that the general direction of surface currents is to the north. In this case, both bottles and drift envelopes tend to follow the same general path toward the north. However, for those within 5 miles from the north shore, the time at which the drops were made was important. Those dropped during a westerly tide ended up northwest of the point of deployment. Those which ended up to the northeast were dropped when the tide was to the east. The wind was probably the most dominant factor, but the tide also played a significant role.

CONCLUSIONS

From the scattering of returns from all stations, it is apparent that the different types of drifters react in a different manner to the tides and winds. The drift envelopes used in this study were judged to be influenced to a significant degree by the wind. The surface flow in the sound is not easterly if the winds are over 20 mph from a northerly direction, as occurred during this study. The role of the wind upon drift bottles was minor if they were released near shore. The surface flow was influenced by the wind in regions of weak tidal action. The central region of the sound demonstrated less mixing of returns than did the western region of the sound.



Drifter Recoveries from 11 May 1972 Release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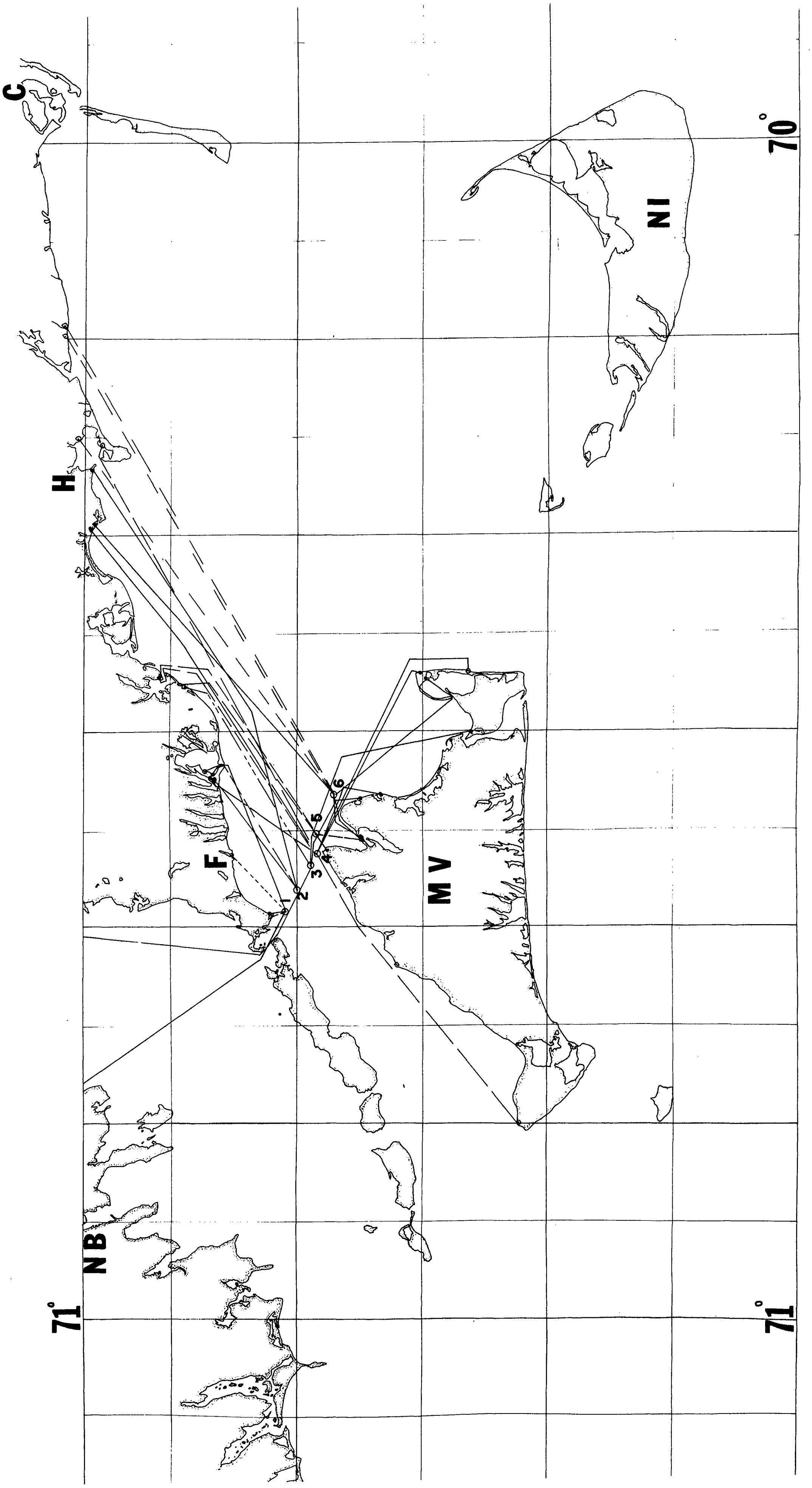
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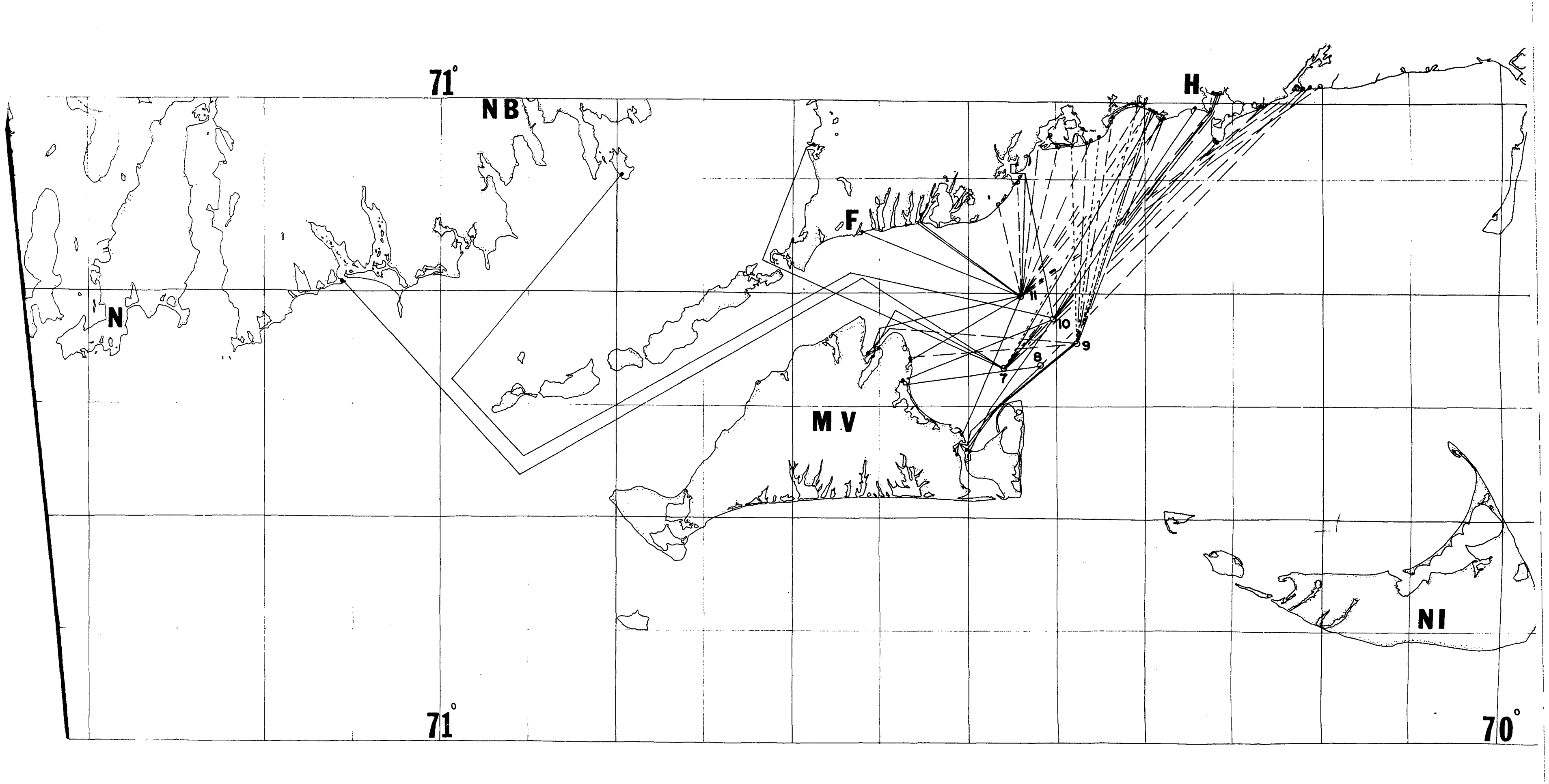
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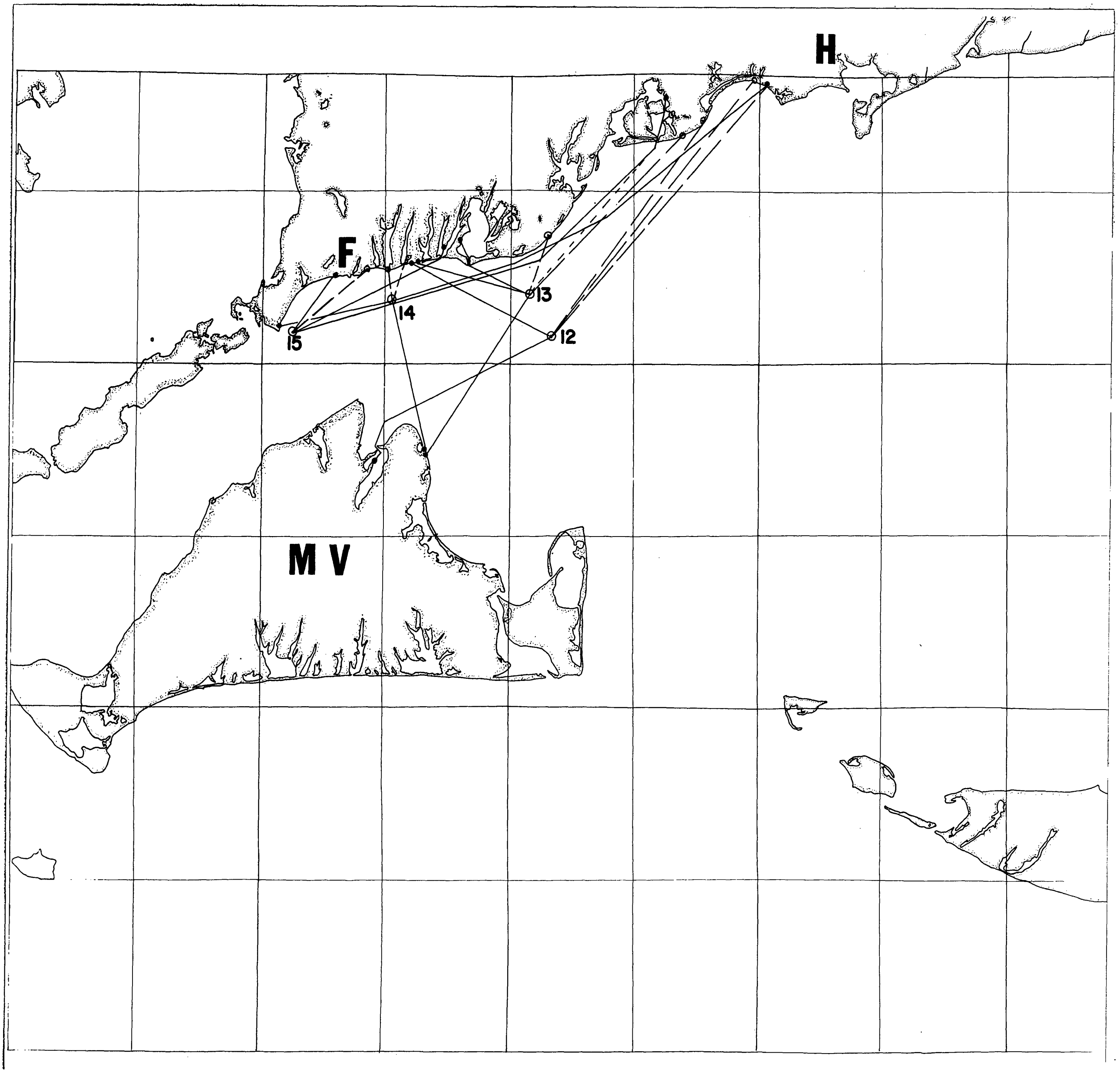
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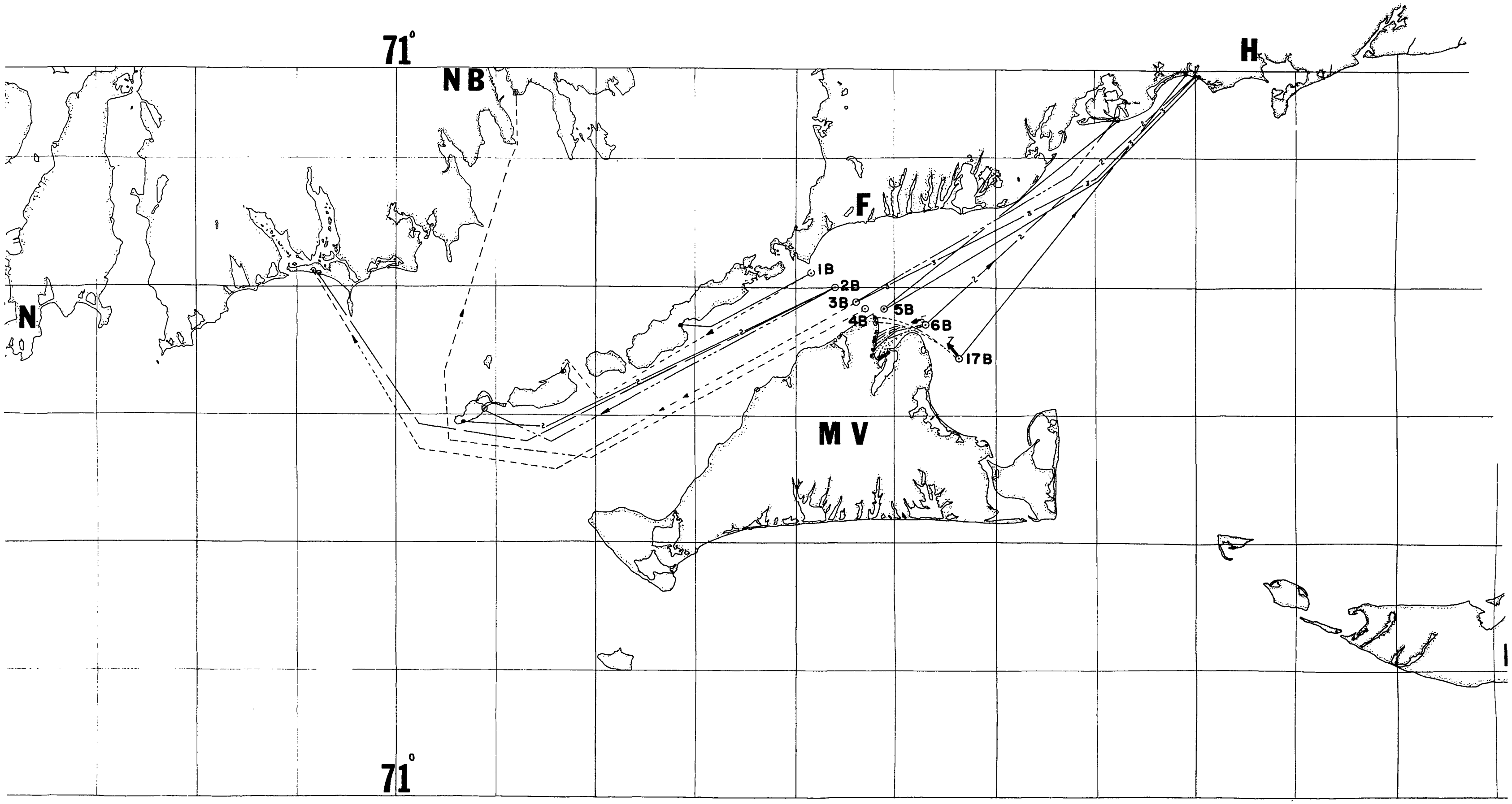
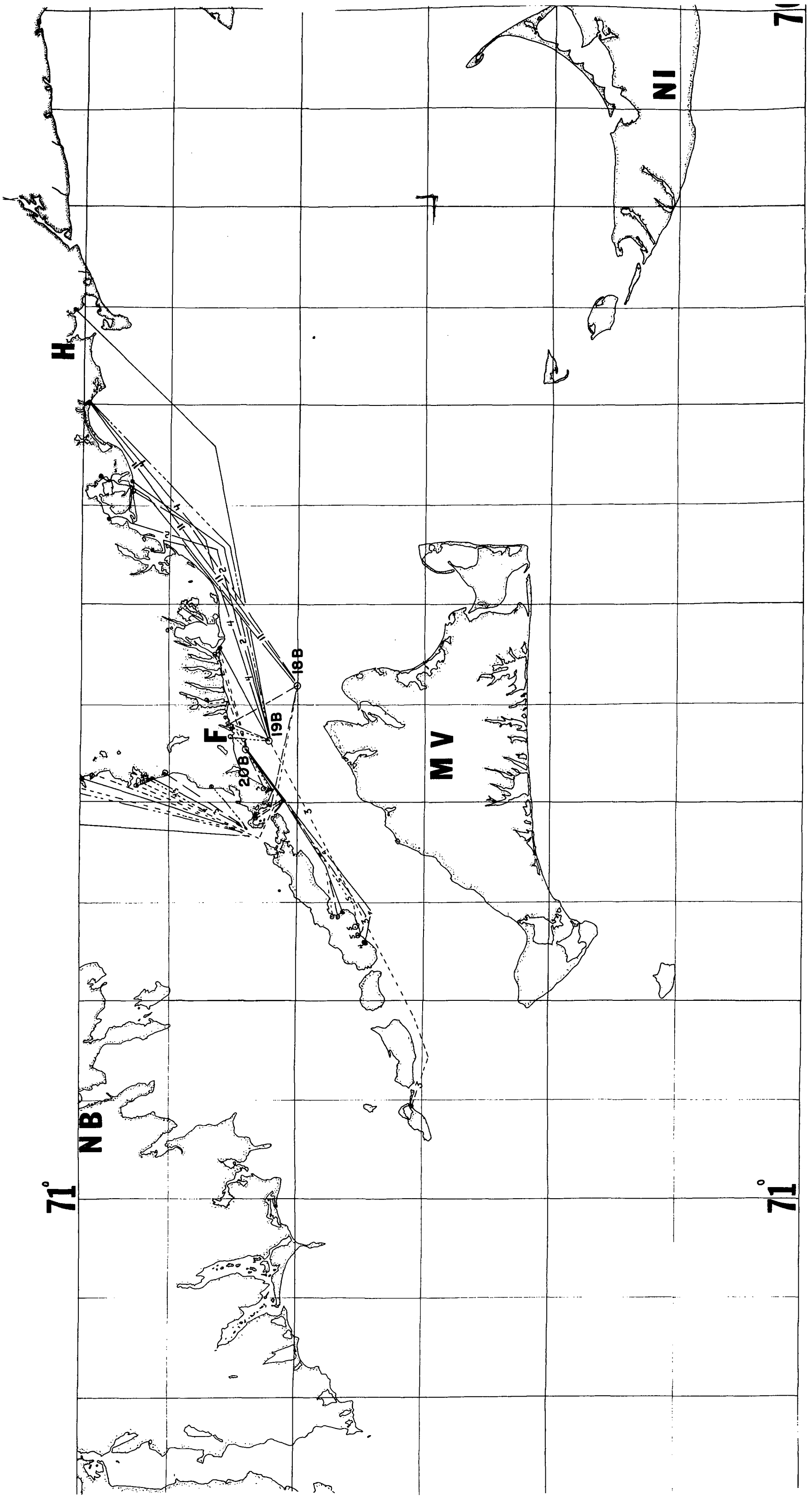


Drifter Recoveries from 25 May 1972 Release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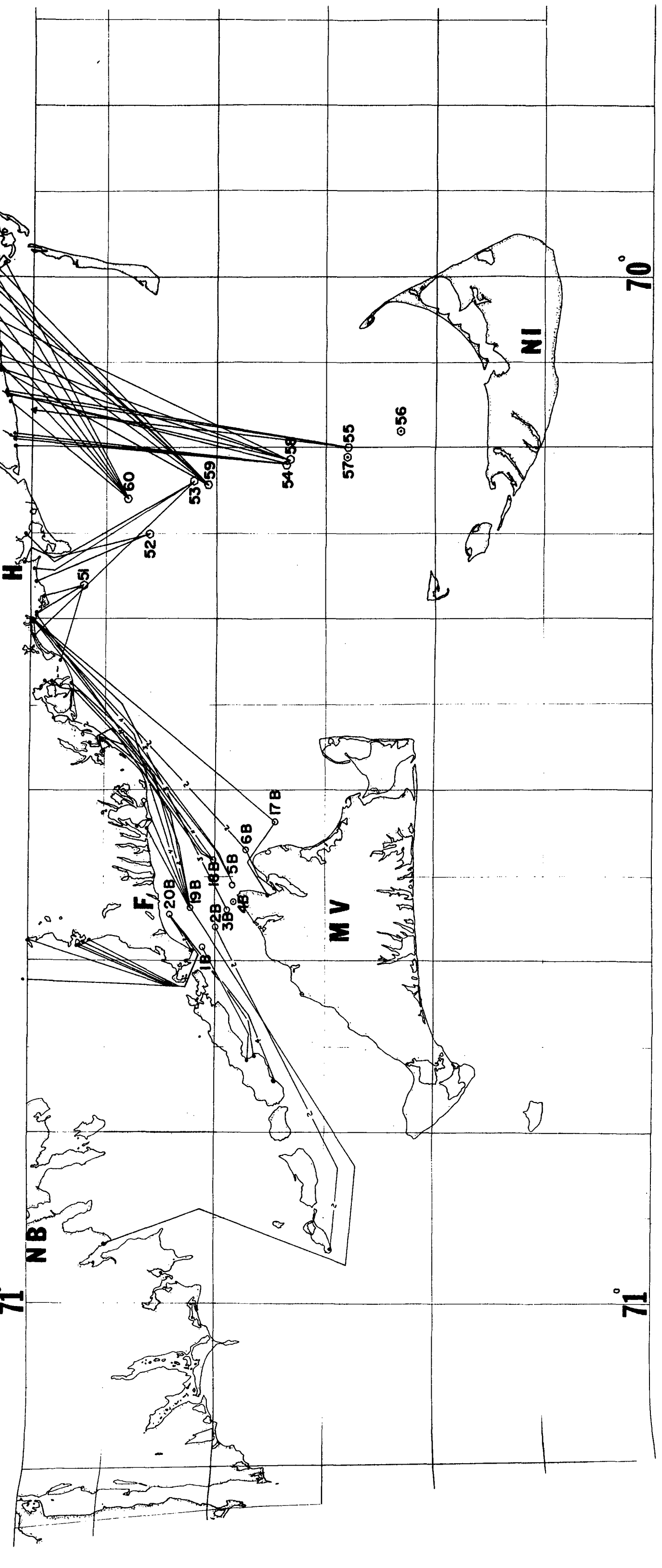
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5B
18B
19B
20B
2B
3B
4B
1B

Drift Bottle Releases from R/V Asteria<u>s</u> on 11 May 1972

Sta.No.	Time EDT	Lat. N	Long. W	Numbers
1	0905	41 30.5	70 49.5	DB 0461-0470 SD 0001 VDC 0201-0205 DC 0101
2	0913	41 30.0	70 38.0	DB 0471-0480 SD 0003 VDC 0206-0210 DC 0102
3	0920	41 29.5	70 37.0	DB 0481-0490 SD 0002 VDC 0211-0215 DC 0103
4	0926	41 29.0	70 36.5	DB 0491-0500 SD 0004 VDC 0216-0220 DC 0104
5	0931	41 29.0	70 35.5	DB 0501-0510 SD 0005 VDC 0221-0225 DC 0105
6	0944	41 28.5	70 33.5	DB 0511-0520 SD 0006- VDC 0226-0230 DC 0106
7	1017	41 26.5	70 28.0	DB 0401-0410 SD 0007 VDC 0231-0235 DC 0107
8	1030	41 27.0	70 26.0	DB 0411-0420 SD 0008 VDC 0236-0240 DC 0108
9	1045	41 27.5	70 23.5	DB 0421-0435 SD 0009-0023 VDC 0241-0255 DC 0109-0123
10	1201	41 29.0	70 25.0	DB 0436-0445 SD 0024 VDC 0256-0260 DC 0124

Drift Bottle Releases from R/V *Asterias* on 11 May 1972

Sta.No.	Time EDT	Lat. N	Long. W	Numbers
11	1213	41 30.0	70 27.0	DB 0446-0460 SD 0025-0039 VDC 0261-0275 DC 0125-0139
12	1224	41 31.0	70 28.0	DB 0641-0650 SD 0041 VDC 0276-0280 DC 0141
13	1235	41 32.0	70 29.0	DB 0651-0660 SD 0041 VDC 0281-0285 DC 0141
14	1304	41 32.0	70 34.5	DB 0661-0670 SD 0042 VDC 0286-0290 DC 0142
15	1326	41 31.0	70 38.5	DB 0671-0680 SD 0043 VDC 0291-0295 DC 0143

Drift Bottle Releases from R/V Asterias on 25 May 1972

Sta.No.	Time EDT	Lat. N	Long. W	Numbers
1B	1310	41 30.5	70 39.5	DB 0732-0736 SD 0044-0046 VDC 0299-0300 DC 0144-0147
2B	1320	41 30.0	70 38.0	DB 0737-0741 SD 0047-0049 VDC 0301-0302 DC 0148-0151
3B	1334	41 29.5	70 37.0	DB 0742-0746 SD 0050-0052 VDC 0303-0304 DC 0152-0155
4B	1339	41 29.0	70 36.5	DB 0747-0751 SD 0053-0055 VDC 0305-0306 DC 0156-0159
5B	1408	41 29.0	70 35.5	DB 0752-0756 SD 0056-0058 VDC 0307-0308 DC 0160-0163
6B	1416	41 28.5	70 33.5	DB 0757-0760 SD 0059-0061 VDC 0309-0310 DC 0164-0167
17B	1424	41 27.2	70 31.9	DB 0521-0530 SD 0062-0067 VDC 0311-0314 DC 0168-0175
18B	1447	41 30.0	70 34.1	DB 0531-0532 & 0534-0555 SD 0068-0078 VDC 0315-0322 DC 0176-0188
19B	1503	41 31.1	70 36.9	DB 0556-0580 SD 0079-0089 VDC 0323-0330 DC 0189-0200
20B	1513	41 32.0	70 37.2	DB 0681-0699 & 0701-0721 SD 0900-0939 VDC 0296-0298 & 0361-0397 DC 0821-0860

Drift Bottle Releases from M/V <u>Menemsha</u> on 25 May 1972

Sta. No.	Time EDT	Lat. N	Long. W	Numbers
51	1030	41 36	70 18	DB 0581-0586 SD 0090-0093 VDC 0331-0332 DC 0761-0765
52	1045	41 33	70 15	DB 0587-0592 SD 0094-0097 VDC 0333-0334 DC 0766-0770
53	1100	41 31	70 10	DB 0593-0598 SD 0098-0099 & 0861-0862 VDC 0335-0336 DC 0771-0775
54	1115	41 26	70 11	DB 0599-0604 SD 0863-0866 VDC 0337-0338 DC 0776-0780
55	1130	41 24	70 10	DB 0605-0610 SD 0867-0870 VDC 0339-0340 DC 0781-0785
56	1600	41 23	70 09	DB 0611-0616 SD 0871-0874 VDC 0341-0342 DC 0786-0790
57	1615	41 24	70 11	DB 0617-0622 SD 0875-0878 VDC 0343-0344 DC 0791-0795
58	1630	41 26	70 11	DB 0623-0628 SD 0879-0882 VDC 0345-0346 DC 0796-0800
59	1645	41 31	70 14	DB 0629-0634 SD 0883-0886 VDC 0347-0348 DC 0801-0805
60	1700	41 34	70 13	DB 0635-0640 SD 0887-0889 VDC 0349-0350 DC 0806-0810

Recovery Information 11 May 1972 Releases

Sta.No.	Drifter No.	Type	Date	Lat. N	Long. W	Bearing	Speed
1	0101	DC	13 05 72	41 33	70 36	044	1.5
2	0205	VDC	12 05 72	41 32	70 39	337	1.5
9	0242	VDC	15 05 72	41 38	70 19	021	2.8
11	0252	VDC	15 05 72	41 38	70 19	035	2.5
13	0651	DB	16 05 72	41 39	70 16	040	1.0
15	0674	DB	16 05 72	41 33	70 33	063	1.0
11	0454	DB	16 05 72	41 33	70 33	306	1.2
14	0287	VDC	13 05 72	41 33	70 34	014	0.5
1	0467	DB	15 05 72	41 31	70 39	340	0.2
7	0233	VDC	16 05 72	41 39	70 16	035	3.0
10	0259	VDC	16 05 72	41 39	70 16	035	2.4
12	0644	DB	15 05 72	41 33	70 34	300	1.2
14	0668	DB	15 05 72	41 36	70 27	073	2.0
11	0263	VDC	15 05 72	41 36	70 25	010	1.8
11	0262	VDC	16 05 72	41 29	70 27	346	0.8
11	0272	VDC	16 05 72	41 38	70 20	051	2.0
2	0479	DB	17 05 72	41 34	70 32	042	0.8
9	0114	DC	15 05 72	41 37	70 22	004	2.2
4	0219	VDC	17 05 72	41 38	70 15	060	3.0
6	0226	VDC	18 05 72	41 40	70 11	058	3.0
11	0270	VDC	15 05 72	41 39	70 12	052	3.8
11	0458	DB	17 05 72	41 34	70 32	305	1.0

Recovery Information 11 May 1972 Releases

Sta.No.	Drifter No.	Type	Date	Lat. N	Long.W	Bearing	Speed
4	0494	DB	17 05 72	41 33	70 32	043	1.0
15	0676	DB	18 05 72	41 38	70 24	075	2.1
3	0002	SD	16 05 72	41 34	70 28	056	1.8
9	0117	DC	18 05 72	41 38	70 24	058	1.4
9	0119	DC	17 05 72	41 38	70 20	013	1.8
10	0260	VDC	16 05 72	41 38	70 13	043	2.6
9	0247	VDC	19 05 72	41 37	70 34	003	1.4
11	0261	VDC	19 05 72	41 37	70 23	023	0.9
13	0283	VDC	19 05 72	41 37	70 23	042	0.7
13	0654	DB	18 05 72	41 33	70 32	291	0.4
7	0231	VDC	20 05 72	41 39	70 16	040	1.7
9	0249	VDC	21 05 72	41 27	70 36	275	0.9
11	0264	VDC	18 05 72	41 35	70 27	357	0.7
11	0271	VDC	21 05 72	41 39	70 10	053	1.6
11	0273	VDC	21 05 72	41 39	70 10	053	1.6
12	0279	VDC	20 05 72	41 38	70 20	040	1.1
12	0280	VDC	21 05 72	41 38	70 22	035	0.9
10	0445	DB	20 05 72	41 36	70 27	350	0.8
11	0446	DB	16 05 72	41 36	70 27	000	1.2
6	0519	DB	21 05 72	41 31	70 40	255	0.6
13	0141	DC	17 05 72	41 37	70 27	040	1.2
4	0216	VDC	20 05 72	41 23	70 27	118	1.1

Recovery Information 11May 1972 Releases

Sta.No.	Drifter No.	Type	Date	Lat. N	Long. W	Bearing	Speed
14	0669	DB	25 05 72	41 27	70 33	166	0.3
15	0294	VDC	17 05 72	41 33	70 36	045	0.5
15	0672	DB	24 05 72	41 33	70 37	040	0.2
1	0465	DB	20 05 72	41 32	70 33	067	0.8
2	0471	DB	02 06 72	41 38	70 17	075	0.8
4	0497	DB	02 06 72	41 38	70 20	064	0.7
6	0518	DB	01 06 72	41 38	70 20	046	0.7
7	0410	DB	01 06 72	41 38	70 20	035	0.6
9	0013	SD	01 06 72	41 38	70 20	016	0.5
9	0021	SD	01 06 72	41 38	70 20	016	0.5
13	0651	DB	01 06 72	41 33	70 34	285	0.2
14	0661	DB	01 06 72	41 28	70 20	072	0.7
3	0485	DB	03 06 72	41 44	70 39	295	0.8
4	0493	DB	29 05 72	41 25	70 26	118	0.5
4	0498	DB	02 06 72	41 27	70 33	118	0.6
7	0401	DB	01 06 72	41 30	71 05	305	1.7
7	0234	VDC	26 05 72	41 37	70 16	040	0.9
10	0438	DB	02 06 72	41 38	70 18	031	0.5
11	0447	DB	16 05 72	41 33	70 36	300	1.6
13	0656	DB	03 06 72	41 27	70 33	213	0.3
7	0407	DB	25 05 72	41 27	70 35	300	0.5

Recovery Information 11 May 1972 Releases

Sta.No.	Drifter No.	Type	Date	Lat. N	Long.W	Bearing	Speed
2	0209	VDC	17 05 72	41 34	70 32	060	1.2
3	0487	DB	29 05 72	41 23	70 31	120	0.5
3	0490	DB	27 05 72	41 27	70 33	120	0.2
5	0223	VDC	25 05 72	41 34	70 27	050	0.5
5	0505	DB	25 05 72	41 29	70 36	235	0.7
5	0508	DB	28 05 72	41 35	70 38	050	0.5
6	0520	DB	21 05 72	41 28	70 35	260	0.2
7	0107	DC	21 05 72	41 38	70 20	030	1.3
7	0232	VDC	01 06 72	41 16	70 37	040	0.6
8	0411	DB	29 05 72	41 23	70 31	220	0.3
9	0250	VDC	25 05 72	41 27	70 33	264	0.5
9	0251	VDC	28 05 72	41 38	70 22	009	0.6
9	0428	DB	28 05 72	41 23	70 30	229	0.4
10	0436	DB	26 05 72	41 23	70 30	211	0.5
11	0275	VDC	21 05 72	41 39	70 12	052	1.5
11	0449	DB	21 05 72	41 27	70 33	240	0.6
11	0451	DB	28 05 72	41 36	70 37	000	0.4
11	0453	DB	26 05 72	41 27	70 36	254	0.5
11	0456	DB	25 05 72	41 24	70 30	201	0.4
12	0647	DB	26 05 72	41 27	70 26	243	0.4

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Sta.No.	Drifter No.	Type	Date	Lat. N	Long. W	Bearing	Speed
4	0217	VDC	20 05 72	41 21	70 50	236	1.5
4	0218	VDC	21 05 72	41 37	70 26	055	1.1
5	0222	VDC	21 05 72	41 27	50 36	185	0.2
6	0227	VDC	17 05 72	41 39	70 13	058	1.2
6	0228	VDC	21 05 72	41 39	70 15	053	1.7
8	0237	VDC	22 05 72	41 39	70 10	040	1.5
8	0240	VDC	21 05 72	41 37	70 16	036	1.2
11	0267	VDC	22 05 72	41 37	70 26	007	0.6
12	0276	VDC	18 05 72	41 37	70 22	035	1.1
13	0282	VDC	13 05 72	41 34	70 28	015	1.0
14	0286	VDC	21 05 72	41 38	70 35	350	0.1
7	0403	DB	16 05 72	41 39	70 16	040	3.0
8	0418	DB	21 05 72	41 26	70 34	264	0.6
1	0469	DB	21 05 72	41 39	70 46	240	1.1
6	0516	DB	14 05 72	41 25	70 28	143	2.3
7	0236	VDC	10 06 72	41 39	70 11	043	0.6
10	0257	VDC	10 06 72	41 38	70 16	036	0.4
14	0290	VDC	11 06 75	41 34	70 35	018	0.0
7	0402	DB	09 06 72	41 37	70 39	295	0.6
7	0409	DB	11 06 72	41 37	70 16	039	0.5
9	0434	DB	11 06 72	41 28	70 37	280	0.4
10	0443	DB	07 06 72	41 35	70 50	284	1.6
4	0491	DB	03 06 72	41 36	70 25	056	0.8

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Sta.No.	Drifter No.	Type	Date	Lat. N	Long.W	Bearing	Speed
2B	0048	SD	27 05 72	41 25	70 56	245	7.5
3B	0152	DC	27 05 72	41 30	71 03	240	13.0
6B	0164	DC	27 05 72	41 28	70 35	250	1.0
6B	0166	DC	27 05 72	41 28	70 35	250	1.0
6B	0167	DC	27 05 72	41 28	70 35	250	1.0
2B	0302	VDC	28 05 72	41 30	71 03	245	8.3
6B	0309	VDC	29 05 72	41 28	70 36	265	0.5
6B	0759	DB	27 05 72	41 28	70 35	265	1.0
17B	0062	SD	26 05 72	41 28	70 36	310	4.0
17B	0172	DC	27 05 72	41 29	70 36	310	2.0
17B	0173	DC	28 05 72	41 27	70 36	310	1.6
17B	0175	DC	27 05 72	41 29	70 36	310	2.0
18B	0188	DC	29 05 72	41 36	70 39	280	2.8
19B	0193	DC	28 05 72	41 25	70 56	240	5.3
17B	0301	VDC	27 05 72	41 28	70 36	310	2.0
17B	0314	VDC	27 05 72	41 28	70 36	310	2.0
18B	0316	VDC	29 05 72	41 33	70 36	330	0.8
18B	0321	VDC	28 05 72	41 31	70 40	283	1.6
17B	0529	DB	26 05 72	41 28	70 36	310	4.0
1B	0734	DB	27 05 72	41 28	70 46	238	3.0
2B	0737	DB	28 05 72	41 25	70 57	240	5.0
2B	0740	DB	28 05 72	41 25	70 57	240	5.0

Recovery Information 25 May 1972 Releases

Sta.No.	Drifter No.	Type	Date	Lat. N	Long. W	Bearing	Speed
3B	0745	DB	01 06 72	41 38	70 20	062	2.3
18B	0531	DB	01 06 72	41 38	70 20	050	2.0
18B	0532	DB	01 06 72	41 38	70 20	050	2.0
18B	0535	DB	01 06 72	41 38	70 20	050	2.0
18B	0540	DB	01 06 72	41 38	70 20	050	2.0
18B	0541	DB	01 06 72	41 38	70 20	050	2.0
18B	0551	DB	01 06 72	41 38	70 20	050	2.0
18B	0552	DB	01 06 72	41 38	70 20	050	2.0
18B	0319	VDC	02 06 72	41 36	70 24	050	1.2
19B	0196	DC	27 05 72	41 25	70 55	240	8.0
19B	0197	DC	27 05 72	41 25	70 55	240	8.0
19B	0200	DC	28 05 72	41 36	70 38	240	5.0
19B	0080	SD	01 06 72	41 38	70 20	070	2.1
19B	0577	DB	01 06 72	41 38	70 20	070	2.1
19B	0565	DB	01 06 72	41 38	70 20	070	2.1
19B	0558	DB	01 06 72	41 38	70 20	070	2.1
20B	0904	SD	03 06 72	41 36	70 39	230	1.0
20B	0683	DB	27 05 72	41 31	70 39	245	1.0
3B	0742	DB	01 06 72	41 38	70 20	065	2.1
3B	0743	DB	02 06 72	41 38	70 20	065	2.1

Recovery Information   25 May 1972 Releases

Sta.No.	Drifter No.	Type	Date	Lat. N	Long. W	Bearing	Speed
20B	0361	VDC	27 05 72	41 32	70 41	230	2.0
20B	0366	VDC	28 05 72	41 31	70 39	240	0.7
20B	0375	VDC	27 05 72	41 32	70 41	230	2.0
20B	0384	VDC	28 05 72	41 31	70 39	240	0.7
20B	0387	VDC	29 05 72	41 28	70 46	230	1.8
20B	0394	VDC	29 05 72	41 31	70 39	235	0.5
20B	0689	DB	28 05 72	41 36	70 39	230	3.0
20B	0697	DB	28 05 72	41 36	70 39	230	3.0
20B	0698	DB	28 05 72	41 36	70 39	230	3.0
20B	0706	DB	28 05 72	41 36	70 39	230	3.0
20B	0839	DC	28 05 72	41 36	70 39	230	3.0
20B	0840	DC	29 05 72	41 33	70 33	072	1.0
20B	0841	DC	26 05 72	41 31	70 29	240	2.0
20B	0842	DC	26 05 72	41 31	70 29	240	2.0
20B	0843	DC	27 05 72	41 33	70 32	071	2.0
20B	0848	DC	29 05 72	41 28	70 46	230	1.8
20B	0850	DC	29 05 72	41 28	70 46	230	1.8
20B	0902	SD	28 05 72	41 36	70 39	230	3.0
20B	0912	SD	28 05 72	41 36	70 39	230	3.0
20B	0934	SD	27 05 72	41 33	70 39	230	3.5
20B	0936	SD	29 05 72	41 36	70 39	230	1.2
20B	0695	DB	27 05 72	41 31	70 39	240	1.0
20B	0913	SD	27 05 72	41 31	70 39	240	1.0

Recovery Information 25 May 1972 Releases

Sta.No.	Drifter No.	Type	Date	Lat. N	Long. W	Bearing	Speed
51	0582	DB	06 06 72	41 37	70 23	290	0.2
51	0585	DB	31 05 72	41 38	70 20	330	0.3
51	0586	DB	02 06 72	41 38	70 18	345	0.2
52	0334	VDC	02 06 72	41 33	70 33	265	1.8
52	0590	DB	03 06 72	41 37	70 18	337	0.5
53	0335	VDC	01 06 72	41 39	70 15	330	1.3
53	0593	DB	02 06 72	41 39	70 15	330	1.1
53	0598	DB	02 06 72	41 38	70 21	315	1.2
54	0601	DB	01 06 72	41 39	70 09	006	1.9
54	0603	DB	01 06 72	41 39	70 10	005	1.9
54	0604	DB	01 06 72	41 39	70 07	012	1.9
55	0607	DB	01 06 72	41 39	70 10	007	2.3
55	0608	DB	02 06 72	41 39	70 10	007	2.0
57	0795	DC	30 05 72	41 40	70 05	013	3.2
58	0624	DB	01 06 72	41 39	70 07	013	1.9
58	0625	DB	01 06 72	41 40	70 03	023	2.1
58	0628	DB	01 06 72	41 40	70 05	020	2.0
58	0797	DC	29 05 72	41 39	70 09	005	1.9
59	0347	VDC	30 05 72	41 38	70 13	358	1.6
59	0632	DB	31 05 72	41 40	70 00	043	2.3
59	0633	DB	30 05 72	41 40	70 00	043	2.8
59	0637	DB	30 05 72	41 40	70 00	058	2.6

Recovery Information 25 May 1972 Releases

Sta.No.	Drifter No.	Type	Date	Lat. N	Long. W	Bearing	Speed
51	0331	VDC	29 05 72	41 34	70 39	250	5.5
54	0337	VDC	30 05 72	41 21	70 27	240	2.6
58	0345	VDC	28 05 72	41 33	70 14	338	2.3 *
60	0636	DB	31 05 72	41 40	70 01	053	1.7
51	0764	DC	27 05 72	41 42	70 39	250	8.0
52	0766	DC	27 05 72	41 41	70 39	265	9.0
57	0794	DC	27 05 72	41 21	70 27	256	6.5
58	0799	DC	29 05 72	41 39	70 10	003	3.3
60	0806	DC	28 05 72	41 35	70 27	279	3.3
59	0883	SD	31 05 72	41 40	70 05	029	1.8
52	0094	SD	31 05 72	41 38	70 18	334	1.0
53	0596	DB	31 05 72	41 38	70 17	328	1.3
57	0793	DC	31 05 72	41 40	70 05	012	2.7
58	0626	DB	31 05 72	41 40	70 05	015	2.3
58	0346	VDC	31 05 72	41 40	70 06	015	2.6
59	0631	DB	31 05 72	41 40	70 01	040	2.2
59	0629	DB	31 05 72	41 40	70 00	043	2.3
59	0634	DB	31 05 72	41 40	70 05	028	1.8
60	0640	DB	30 05 72	41 40	70 05	045	1.8

Recovery Information 25 May 1972 Releases

Sta.No.	Drifter No.	Type	Date	Lat. N	Long. W	Bearing	Speed
60	0638	DB	30 05 72	41 40	70 04	050	1.8
60	0639	DB	31 05 72	41 39	70 08	040	1.2
60	0807	DC	01 06 72	41 38	70 27	278	1.1
52	0589	DB	01 06 72	41 39	70 17	340	1.0
52	0769	DC	28 05 72	41	70		
55	0610	DB	01 06 72	41 38	70 07	006	1.1
56	0341	VDC	07 06 72	41 39	70 07	004	0.7
56	0342	VDC	02 06 72	41 40	70 04	009	2.1
56	0787	DC	30 05 72	41 38	70 21	330	3.8
60	0635	DB	02 06 72	41 40	69 59	062	1.5
54	0599	DB	02 06 72	41 39	70 09	006	1.6
59	0630	DB	30 05 72	41 40	70 02	036	2.6

Recovery Information   25 May 1972 Releases

Sta.No.	Drifter No.	Type	Date	Lat.N	Long.W	Bearing	Speed
19B	0569	DB	02 06 72	41 38	70 20	072	1.9
19B	0564	DB	02 06 72	41 37	70 26	072	1.3
19B	0573	DB	03 06 72	41 37	70 26	072	1.3
19B	0576	DB	03 06 72	41 38	70 21	072	1.6
1B	0144	DC	26 05 72	41 27	70 52	238	13.0
3B	0052	DB	02 06 72	41 38	70 24	061	1.6
4B	0157	DB	28 05 72	41 38	70 54	300	8.3
5B	0752	DB	03 06 72	41 38	70 20	055	1.4
5B	0753	DB	04 06 72	41 37	70 26	050	1.2
6B	0757	DB	02 06 72	41 38	70 20	046	1.9
18B	0543	DB	03 06 72	41 36	70 27	050	1.1
19B	0081	SD	05 06 72	41 38	70 15	075	1.8
19B	0328	VDC	28 05 72	41 32	70 36	020	0.7
19B	0566	DB	31 05 72	41 33	70 32	061	0.7
1B	0044	SD	29 05 72	41 29	70 45	247	1.0
18B	0181	DC	29 05 72	41 27	70 47	255	2.5
18B	0182	DC	29 05 72	41 27	70 47	255	2.5
18B	0185	DC	29 05 72	41 27	70 47	255	2.5
19B	0190	DC	29 05 72	41 27	70 47	242	2.0
19B	0198	DC	29 05 72	41 27	70 47	242	2.0
20B	0297	VDC	29 05 72	41 27	70 47	232	2.2
20B	0298	VDC	29 05 72	41 27	70 47	232	2.2
19B	0323	VDC	29 05 72	41 27	70 47	242	2.0

Recovery Information 25 May 1972 Recoveries

Sta.No.	Drifter No.	Type	Date	Lat.N	Long.W	Bearing	Speed
19B	0325	VDC	29 05 72	41 27	70 47	242	2.0
19B	0330	VDC	29 05 72	41 27	70 47	242	2.0
20B	0286	VDC	29 05 72	41 27	70 47	232	2.0
20B	0388	VDC	29 05 72	41 27	70 47	232	2.0
20B	0392	VDC	29 05 72	41 27	70 47	232	2.0
20B	0690	DB	29 05 72	41 27	70 47	232	2.2
20B	0703	DB	27 05 72	41 29	70 45	232	3.5
20B	0712	DB	29 05 72	41 27	70 47	232	2.2
20B	0717	DB	29 05 72	41 27	70 47	232	2.2
20B	0719	DB	29 05 72	41 27	70 47	232	2.2
20B	0832	DC	29 05 72	41 27	70 47	232	2.2
20B	0826	DC	29 05 72	41 27	70 47	232	2.2
20B	0833	DC	29 05 72	41 27	70 47	232	2.2
20B	0836	DC	29 05 72	41 27	70 47	232	2.2
20B	0853	DC	29 05 72	41 27	70 47	232	2.2

Recovery Information 25 May 1972 Releases

Sta.No.	Drifter No.	Type	Date	Lat.N	Long.W	Bearing	Speed
20B	0367	VDC	28 05 72	41 39	70 39	234	0.7
20B	0268	VDC	04 06 72	41 39	70 39	234	0.2
20B	0397	VDC	27 05 72	41 32	70 39	230	4.5
20B	0695	DB	27 05 72	41 31	70 39	234	1.0
20B	0705	DB	30 05 72	41 38	70 38	234	2.2
20B	0721	DB	04 06 72	41 45	70 38	230	1.7
20B	0831	DC	31 05 72	41 33	70 32	075	0.7
20B	0832	DC	29 05 72	41 33	70 36	050	0.5
20B	0837	DC	27 05 72	41 37	70 39	230	5.5
20B	0839	DC	28 05 72	41 39	70 39	230	4.1
20B	0859	DC	03 06 72	41 33	70 35	070	0.2
20B	0913	SD	27 05 72	41 31	70 39	234	0.2
20B	0932	SD	04 06 72	41 39	70 38	230	1.2
19B	0556	DB	09 06 72	41 35	70 28	069	0.7
19B	0559	DB	05 06 72	41 38	70 22	069	1.3
19B	0572	DB	04 06 72	41 34	70 32	067	0.5
19B	0329	VDC	03 06 72	41 28	70 48	240	1.1
19B	0567	DB	08 06 72	41 38	70 24	069	1.2
5B	0756	DB	03 06 72	41 35	70 57	234	3.2
6B	0059	SD	26 05 72	41 27	70 36	250	3.0
17B	0527	DB	02 06 72	41 38	70 21	040	1.8
18B	0539	DB	03 06 72	41 38	70 20	050	1.6
18B	0542	DB	02 06 72	41 38	70 20	050	1.8
18B	0549	DB	02 06 72	41 38	70 23	048	1.4
18B	0550	DB	02 06 72	41 38	70 20	050	1.8
18B	0555	DB	31 05 72	41 38	70 20	050	2.3
19B	0089	SD	04 06 72	41 32	70 37	002	0.2

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LONGSHORE TRANSPORT OF SAND: FIELD MEASUREMENTS

Joseph W. Maresca, Jr.

A preliminary study of the coastal processes at work along the beach 0.8 km north of Nobska Point, Woods Hole, Massachusetts, was conducted between 18 May 1972 and 4 June 1972. The preliminary objective of the study was to measure the rate of sand transport along the beach on a moderately windy day to obtain a typical rate. The secondary objective of this study was to determine the effect of the independent groin intercepting the littoral drift.

The immersed weight rate of sand transport measured was 0.49 ft^3/min with a predominant direction of transport from south to north along this stretch of beach. Immediately south of the groin, the beach showed a 15-ft build-up seaward. The transport occurred in a narrow zone along shore in the breaker and swash-backwash zones with no observable transport offshore. Transport was independent of grain size for the sample ranging in size from 0.5 mm to 2.0 mm.

INTRODUCTION

"The most important factor affecting the stability of a shoreline is the relationship between the supply and loss of littoral sands" (Herron and Harris, 1966). Not only the scientific and engineering study but also the social, political, and economic impact of the littoral drift is of primary concern to the coastal engineer, the geologist, the property owner, and the beach goer. Accurate quantitative predictions of the littoral drift are difficult, and more reliable field measurements are required in the effort to achieve a complete understanding of the sand movement alongshore.

The primary objective of this paper is the determination of the rate of littoral drift for a given longshore component of wave energy flux for different grain sizes. The secondary objective is the description of the effects of an independent groin intercepting the littoral drift.

The littoral drift is the transport of material alongshore caused by the effects of wind-generated waves (Figure I-1).* The surf region can be divided into three zones: a zone offshore characterized by the dynamics of shoaling waves, a zone characterized by turbulence and breaking waves, and a zone characterized by sheet flow (Figure I-2). These zones will be referred to in this paper are the shoaling zone, the breaker zone, and the swash-backwash zone, respectively. Most transport is believed to occur in the breaker and swash-backwash zones (Savage, 1962), but evidence for large transport offshore is available. Usually no transport occurs in water deeper than 30-60 ft. The limit of landward movement, or "null point," by sand offshore has been measured and modeled by Miller and Zeigler (1958) at Falmouth (Figure 1-3a).

Previous laboratory studies (Krumbein, 1944; Saville, 1950; Shay and Johnson, 1951; Johnson, 1952; Sauvage and Vincent, 1954; and Savage, 1959) and field studies (Watts, 1953; Caldwell, 1956; Moore and Cole, 1960; and Komar, 1969) of sand transport are summarized by Das (1971). Figure I-5 or Figure IV-0 summarizes the existing data in graphs of the immersed transport rate versus the longshore component of wave energy flux. Komar's (1969) field measurements quantitatively verified two models of sand transport. One model related energy flux to transport and the other model stated that the waves provide the power to move the material while the longshore current resulted in the transport.

Figure I-6 qualitatively describes the erosion and deposition of sand around an independent groin. Detailed quantitative and qualitative descriptions of the interception of the littoral drift by groins are described by Horikawa and Sonu (1966), Shimano et al. (1955), and Savage (1959). Design and construction of groins can be found in "Shore Protection Planning and Design," by the US Army Corps of Engineers (1966).

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*Figures, tables, pictures, and appendixes not appearing are on file in the Department of Meteorology and Oceanography, The University of Michigan. Whether or not any of these are mentioned in text has no bearing on whether they are in the paper or on file. Figures, tables, pictures, and appendixes are not mentioned in order within the text.

STUDY LOCATION

This study was conducted on Redwood Wright's beach, located 0.8 km north-northeast of Nobska Point (Figure 7). The beach is characterized by a large rock groin extending 130 ft seaward from a steep 50-ft bluff (Picture IX-1). Beginning at the low waterline, a cobble bottom extends 20-30 ft seaward (Figure I-8) and (Picture IX-3).

On 18 May 1972, an initial beach survey was made by taking profiles at 50-ft intervals for a distance of 150 ft north and south of the groin (Figure I-10). The profiles are labeled alphabetically, A through I, and will be referred to in the text in this manner. The profiles are shown in Figure V-1-10 and the plan views are shown in Figure V-11-13. The beach slope between the high and low waterline is steeper than 1:10, indicative of the coarse material comprising the beach. Sand samples were taken in the shoaling, breaker, and swash-backwash zones, and the backshore along profiles A, D, F, and I for grain size analysis. The sampling locations are shown in Figure I-11 and the results are presented in Table II-1-4 as gradation curves.

Wind-generated waves from Vineyard Sound, developed by southwest winds, approach the beach after considerable refraction and diffraction around Nobska Point. Wind-generated waves from Nantucket Sound, developed by east winds, approach the beach directly. Local wind-generated waves approaching the beach from Vineyard Sound are usually more powerful than those approaching from Nantucket Sound because of the longer fetch length in Vineyard Sound--50 miles compared to 30 miles. However, swells entering Nantucket Sound from the Atlantic will produce the largest and most powerful waves (Figure I-12). In the absence of wave records, the magnitude and direction of the winds are assumed proportional to the magnitude and direction of the wind-generated waves in order to determine the predominant direction of sand transport with time. A record of moderate, heavy, and gale-force winds are presented in wind rose form in Figures I-13, 14. Strong tidal currents are present in Vineyard Sound with a net easterly movement of water mass (Bumpus et al., 1969). Large glacial boulders located up to 50 ft shoreward of the low waterline complicate the flow approaching the beach.

This site was chosen for the study because of the limited sources of material for transport south of the beach and the offer to put the beach at our disposal. With deep water immediately offshore of Nobska Point, it seemed reasonable to assume that Nobska Point was acting as a sink for sand, with only sand being generated north coming from the beach material, the material located in offshore bars, and the material located in the bluff. The water level and the wave energy would dictate the exact source. For normal events, the material is found on the foreshore.

EXPERIMENTAL METHOD AND DATA ANALYSIS

A complete description of the experimental method and the method used to analyze the data can be found in Komar (1969). The major differences in technique between Komar's and the ones used in this study are ones of resources: time, money, and equipment. Only a brief description of the method and data analysis will follow.

A sample grid, 80 ft by 6 ft, was located by stakes placed at 10-ft intervals alongshore (Figures I-15, 16; Picture IX-7). The grid points L, M, and H were located in the field by aligning with the stakes and moving shoreward from the "step," which was distinctly visible during the entire experiment, and by taking one or two 3-ft paces. Grab samples of 225 cm^3 were taken at the L, M, and H grid points using a 25-mm diameter glass tube cut in 10- to 15-cm lengths (Pictures IX-11, 12). In an area with a larger breaker zone, more precise grid point locations would be required.

Approximately 50 lb of local beach material was sprayed with fluorescent red point after sieving into three uniform grain sizes: 0.5-1.0 mm, 1.0-2.0 mm, and 2.0-8.0 mm. The results of tests using this "dying technique" are shown in Appendix VIII. Other methods of dying the tracer material are also described in Appendix VIII. Radioactive tracers were not considered because of availability, environmental considerations, and expense. The red tracer material, similar to the existing median grain sizes on the beach, was assumed to be hydraulically identical to this material.

Five 8-lb plastic bags of tracer material, equally representing the three grain sizes, were placed in the breaker zone, perpendicular to shore and extending seaward of the breaker zone (Figure 16). An additional 8-lb sample was placed offshore in 2-3 ft of water. Care was taken to carefully wet the sample before releasing it so it would act in a similar manner to the existing material. The material was released by ripping the bottom of the plastic bag away while applying pressure from above, being careful not to place any of the sample in suspension. Grab and core samples were taken at 5, 10, 20, 40, 60, and 190 min from the release of the tracer material.

Measurements of the longshore current outside the breaker zone were taken using a ping-pong ball drogue, consisting of a weighted ball attached to an unfilled marker ball by fishline (Picture IX-9) (Sato and Tanaka, 1966). Two shore transits were used to follow the drogue. No attempt was made to measure the longshore current in the breaker zone using dye techniques.

Wave measurements were made using a calibrated staff to measure wave height, a string to measure the wave length, and a stopwatch to measure the period. Only the larger and most distinct swells were measured before, during, and at the completion of the experiment. The angle the waves made with the shoreline was measured with a protractor and string and was checked by a transit placed along the shoreline.

Wind measurements in the field were made using a hand-held anemometer and transit compass, and were checked by the wind magnitude and direction recorded at the Woods Hole Oceanographic Institution. No significant changes in the wave or wind variables were observed until the end of the experiment.

Appendix VI contains the time of the collection, Table 1; the drogue data, Table 2; the wind data, Table 3; the wave data, Table 4; and the survey data, Tables 5 and 6. Appendix III contains the grab sample data, Tables 1-7, and the core sample data, Tables 8-14. The equations used to analyze the grab and core sample data are listed in Appendix III. Reference to Komar (1969) is suggested for complete analysis.

GROIN PROFILES

The beach profiles were taken using a transit as a level, a survey rod, and a 50-ft tape. All distances seaward were measured from a baseline through a stake located at the bluff along Profile B. All elevations refer to an assumed 100.00-ft elevation on a bench mark located on the groin. No tie-in was made to an existing bench mark since only relative differences in elevation were needed. With limited manpower resources, most distances along the profiles were determined by plotting the horizontal angles measured with the transit to find the intersection with the profile lines at a scale of 1 in = 5 ft. Distances are accurate to ± 0.2 ft. Three beach surveys were taken: 18 May 1972, 24 May 1972, and 3 June 1972. The 24 May 1972 survey was intended for ascertaining the extent of material buildup around the groin. The survey notes are included in Tables VII-1-3.

The annual rate of bluff erosion was determined by measuring the distance from the house to the bluff using two sets of aerial photographs, 13 December 1938 and 31 August 1948, and the present measurement. The owner's observations over the last seven years were used to check the estimate.

RESULTS OF THE SAND TRANSPORT EXPERIMENT

The results of the sand transport experiment are given in Table IV-1, in Figure IV-0 as a plot of I_ℓ versus P_ℓ, in Figure IV-1-14 as

Table 1. Rate of Sand Transport Results

TIME FROM $t = 0$ Min	$\overline{Y}$ Ft	$\overline{V}$ Ft/Min	S_ℓ Ft^3/Min
0			
5	12.4	2.48	0.49
10	17.6	1.76	0.68
20	19.8	0.99	0.44
40	29.2	0.73	0.42
60	34.3	0.57	0.37
90	34.8	0.39	0.27
190	45.5	0.24	

$S_\ell = 0.48$ Ft^3/Min $= 0.0080$ Ft^3/Sec

$I_\ell = 0.85$ (Ft - lb)/(Ft - Sec)

$P_\ell = 49.6$ (Ft - lb)/(Ft - Sec) where $\alpha = 20°$, $H = 0.67$ Ft
$L = 13.5$ Ft, $T = 2.5$ Sec

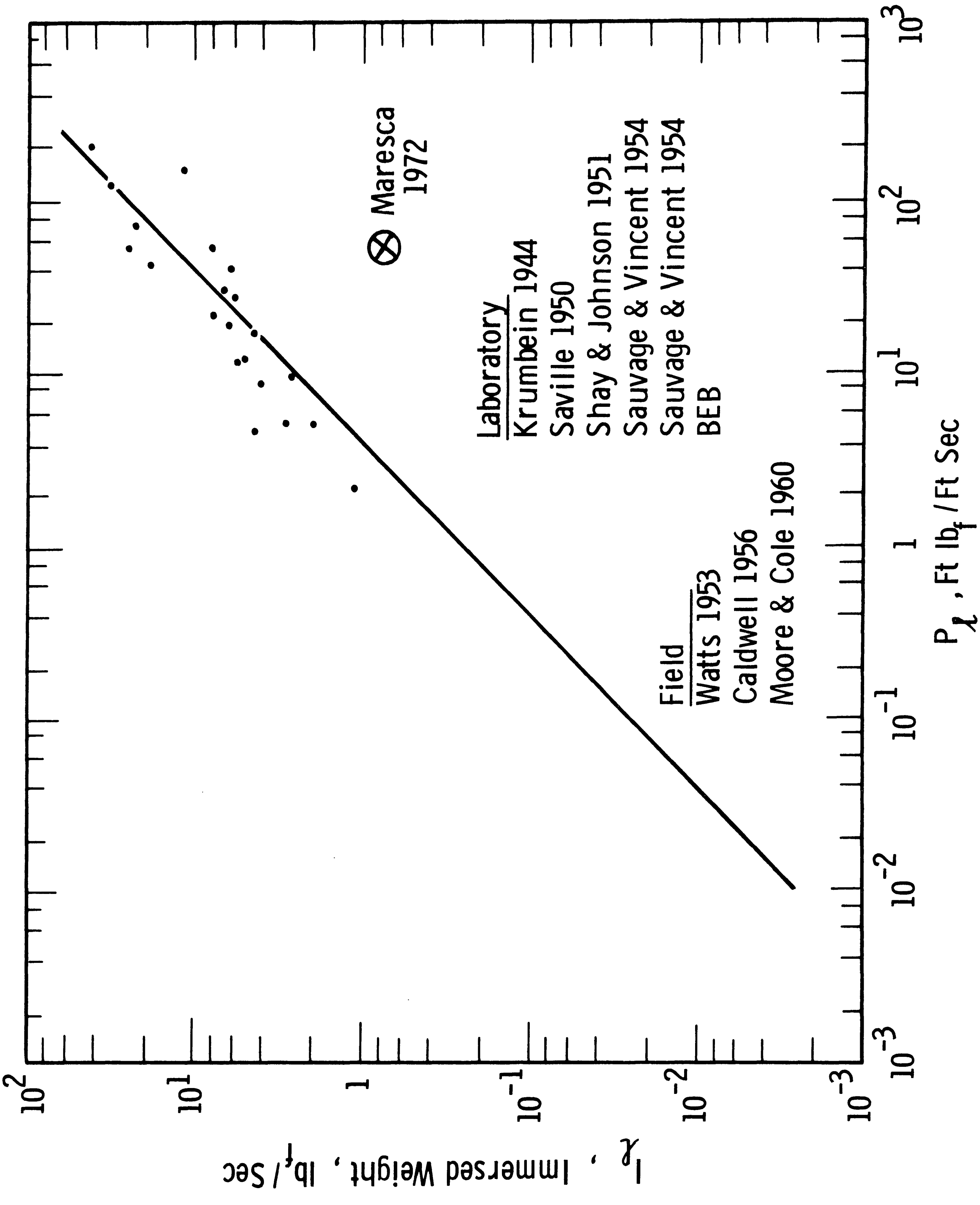
Maresca
1972
Laboratory
Krumbein 1944
Saville 1950
Shay & Johnson 1951
Sauvage & Vincent 1954
Sauvage & Vincent 1954
BEB
Field
Watts 1953
Caldwell 1956
Moore & Cole 1960
10^{-3}
10^{-2}
10^{-1}
1
10^{1}
10^{2}
10^{3}
P_{ℓ}, Ft lb$_f$/Ft Sec
10^{2}
10^{1}
1
10^{-1}
10^{-2}
10^{-3}
I_{ℓ}, Immersed Weight, lb$_f$/Sec

Figure 0

concentration diagrams of the tracer material and sand groin profiles for each material size and run.

A transport rate of 0.49 ft^3/min for a wave energy flux of 49.6 ft-lb/ft-sec was determined. The transport to the north-northeast was confined to a narrow zone bounded by the breaker zone and the swash-backwash zone. No transport was observed immediately seaward of the breaker zone, or in the offshore sample. Transport for this wave energy flux was independent of grain size although the material was sorted and traveled alongshore with the coarsest material found in the breaker zone and the finer material further shoreward.

RESULTS OF THE GROIN PROFILES

The results of the profiling are shown in Figure I-1-10 as typical survey profiles and in Figure I-11-13 as plan views drawn from the survey notes. Table II-1 and Figure II-1-4 show the results of the gradation analysis

The groin effectively intercepted the littoral drift during the 18-day interval extending the beach at Profile F 15 ft seaward with an accompanying 1-ft rise in elevation relative to Profile D. Predominant direction of transport during this time was from south to north. Erosion was observed along Profile D with no net movement seaward during the time interval. The beach 50 ft north and south of the groin was not affected by the groin, indicating the groin was acting independently of the next groin, located over 500 ft to the north. The primary source of sand for transport came from the beaches south of the groin. A preliminary calculation indicated an annual bluff erosion rate of 1.0 ft/yr ± 0.5 ft.

DISCUSSION OF SAND TRANSPORT RESULTS

The tracer concentration diagrams/profiles give a qualitative description of the longshore transport of the tracer material. The profiles, a plot of number of tracer grains versus distance alongshore, indicates a wave face progressing alongshore with the back of the wave attached to the initial sample (Figure IV-1-4) until the sample is depleted and the wave progresses through the sample area (Figure IV-5-7). Comparing the sand groin profiles, the velocity of transport appeared the same qualitatively for the 0.5- to 1.0-mm and 1.0- to 2.0-mm tracer samples. However, sorting shoreward from the breaker zone, coarse to fine, was evident from both the concentration and profile graphs. The 0.5- to 1.0-mm sample traveled closest to H grid points, the 1.0- to 2.0-mm sample traveled through the M grid points, and the 2.0- to 8.0-mm tracer grains traveled between L and M. No measure was made of the suspended load.

Inconsistencies in the tracer concentration diagrams/profiles were noted at station "C" during the 20-, 40-, and 90-min runs (Figures IV-3, 4, 7), where a depression in the wave front was found. The grab samples collected at this station were observed to be coarser and of smaller volume compared to the other grab samples. The sample was probably taken outside the breaker zone, where smaller amounts of material were being transported, and combined with the small sample volume, accounting for the decrease in the number of tracer grains.

The 5-min run (Figure IV-1) indicated that the initial sample did not go into suspension, but behaved as the existing material since stations D through H indicated no portion of the sample had reached that area in the grid. Thus no "quick transport" was observed. The 190-min run (Figure IV-7) indicated that most of the sample had passed through the grid and further measurements would have been fruitless.

Errors in the concentration diagrams/profiles are a function of the collection and analysis of the grab samples. Common sources of error are improper location of the grid points in the field, varying volumes of sample of each grab sample, and counting errors. The results of not returning to the precise grid point and not taking equal volumes of sample at each grid point were discussed previously. In order to count the tracer grains in each sample, the samples were split into halves, quarters, or eighths. Limited time made this procedure necessary. In each sample that was split, it was assumed that a large random distribution

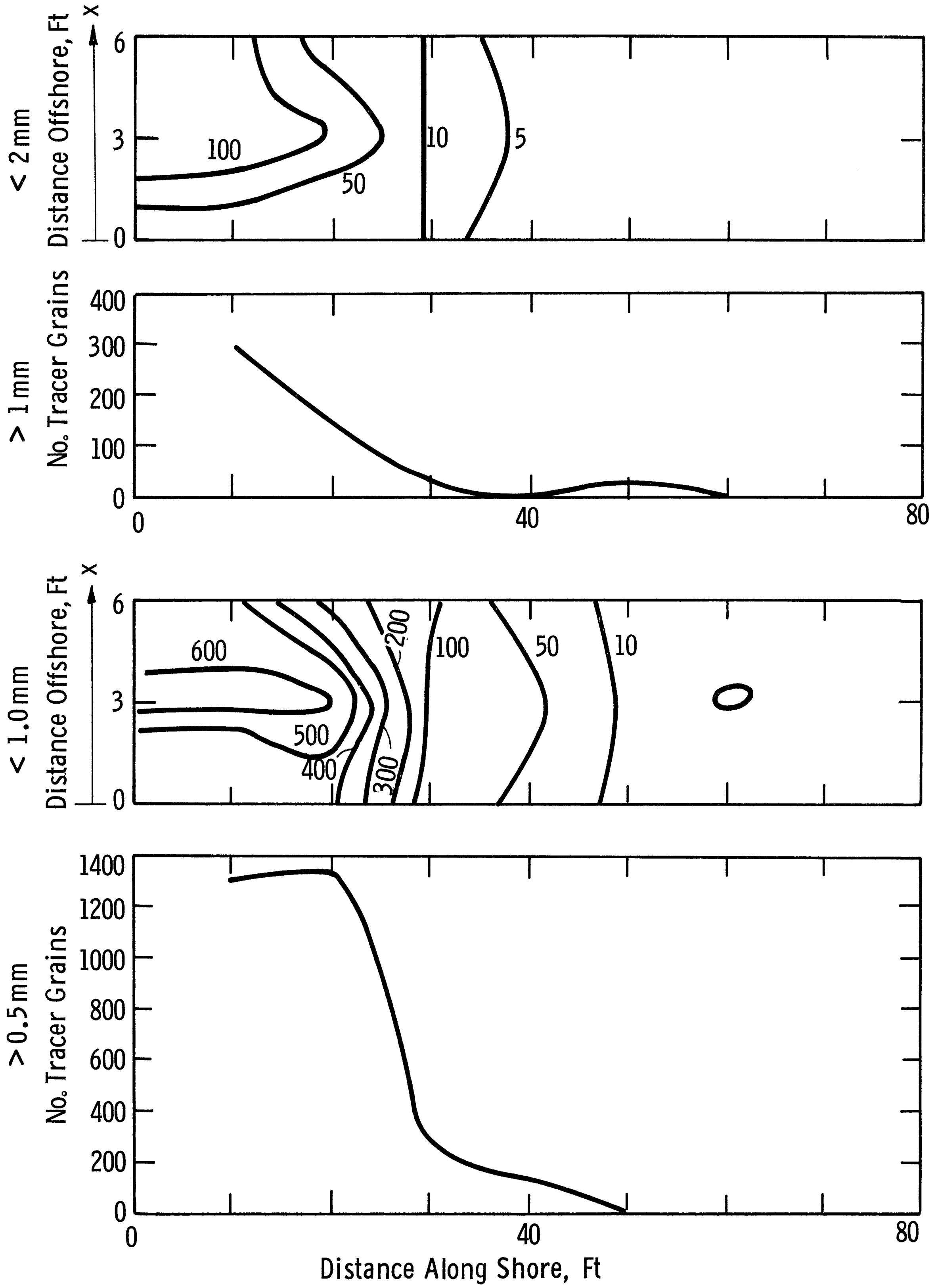

Figure 2. Tracer Concentration Diagram/Profile Time = 10 min

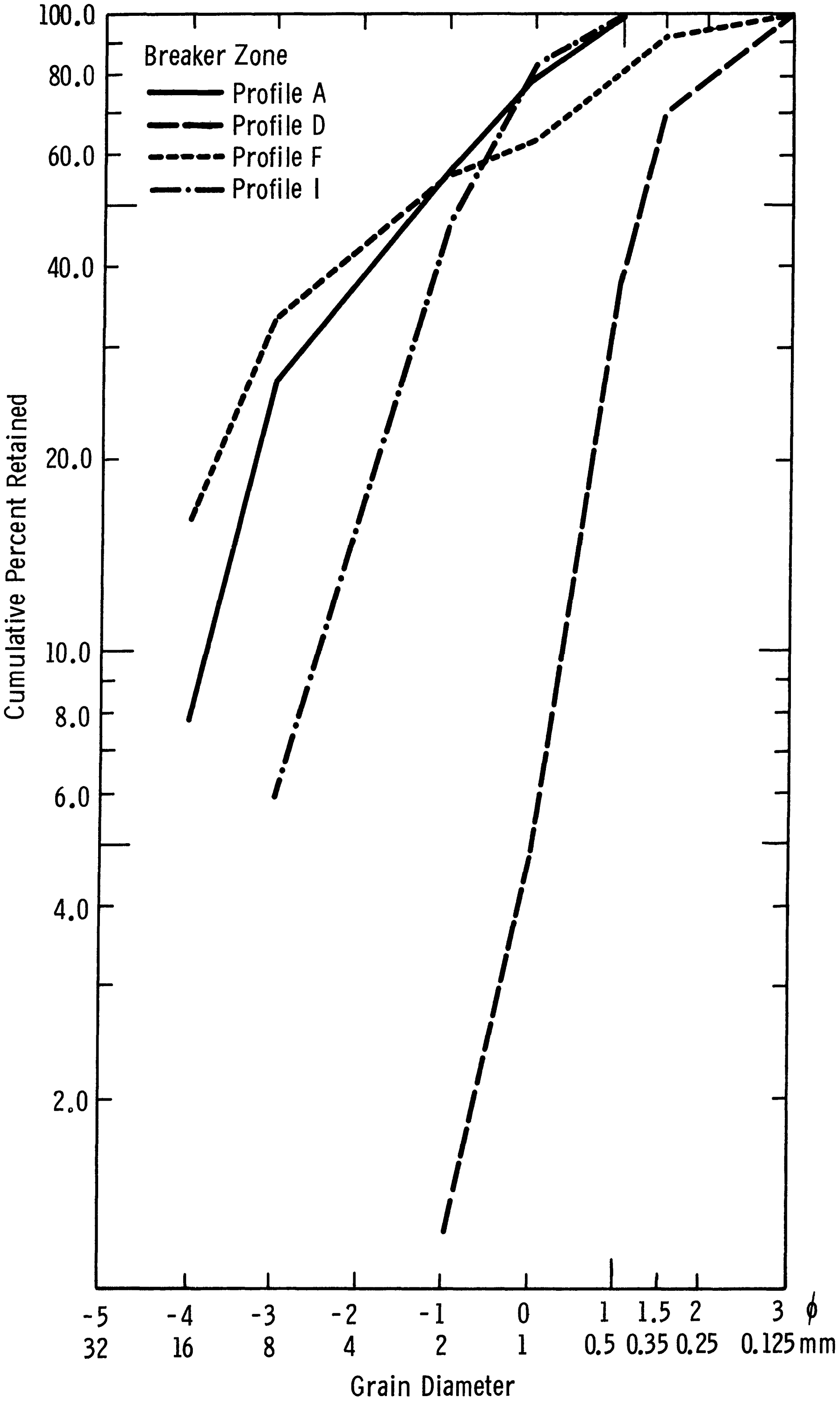

Figure 3. Sand Gradation Curve

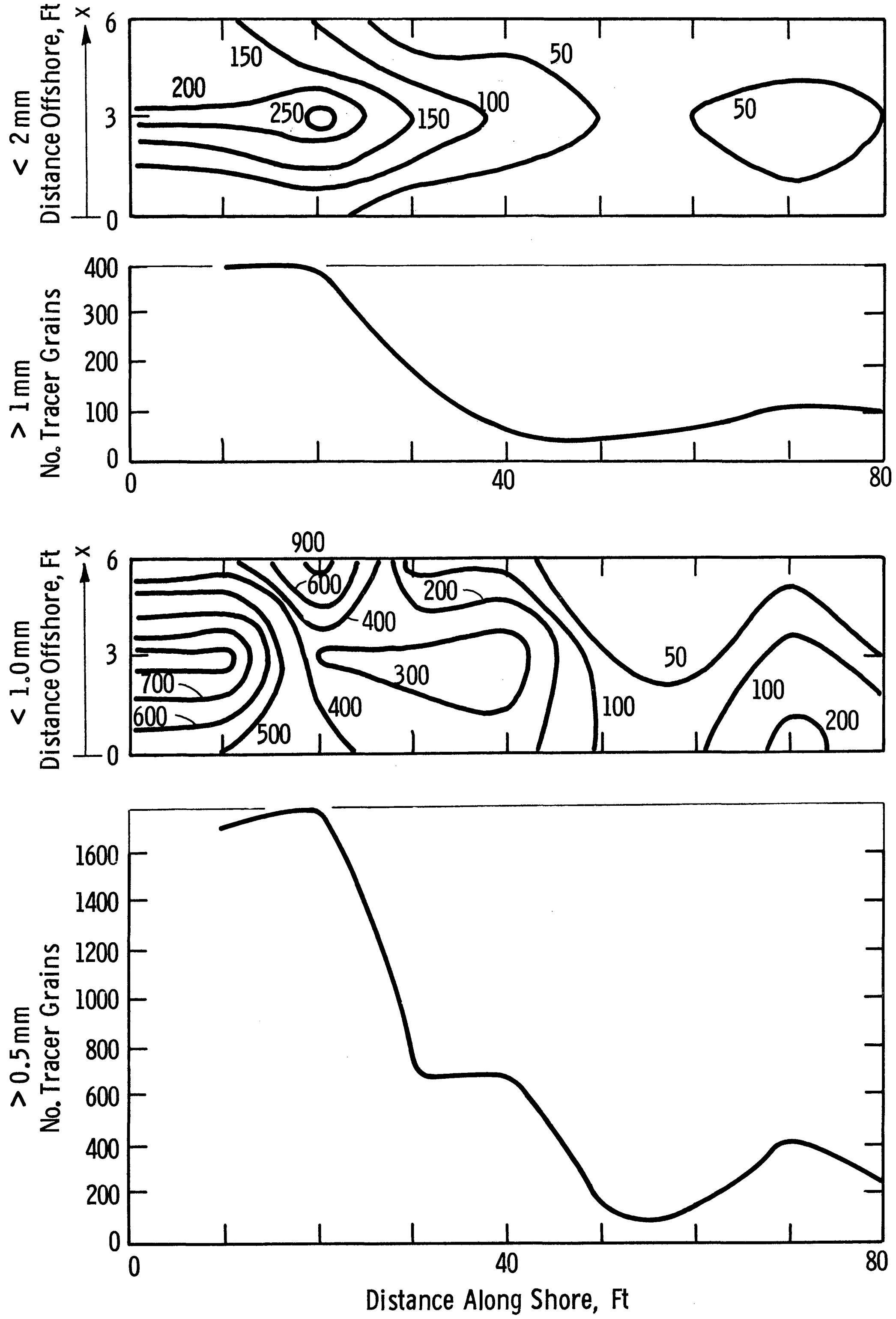

Figure 4. Concentration Diagram/Profile Time = 40 min

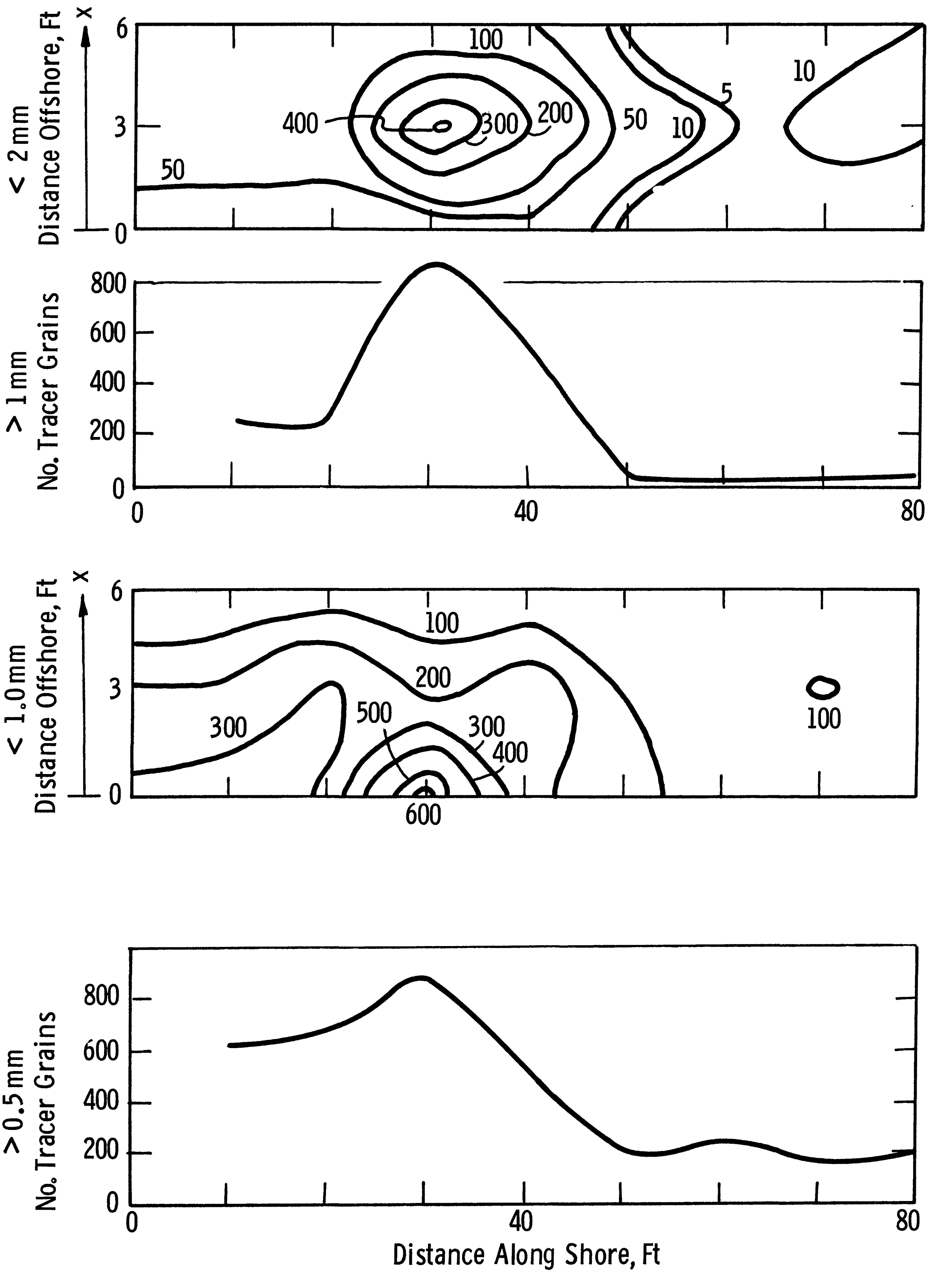

Figure 5. Tracer Concentration Diagram/Profile Time = 60 min

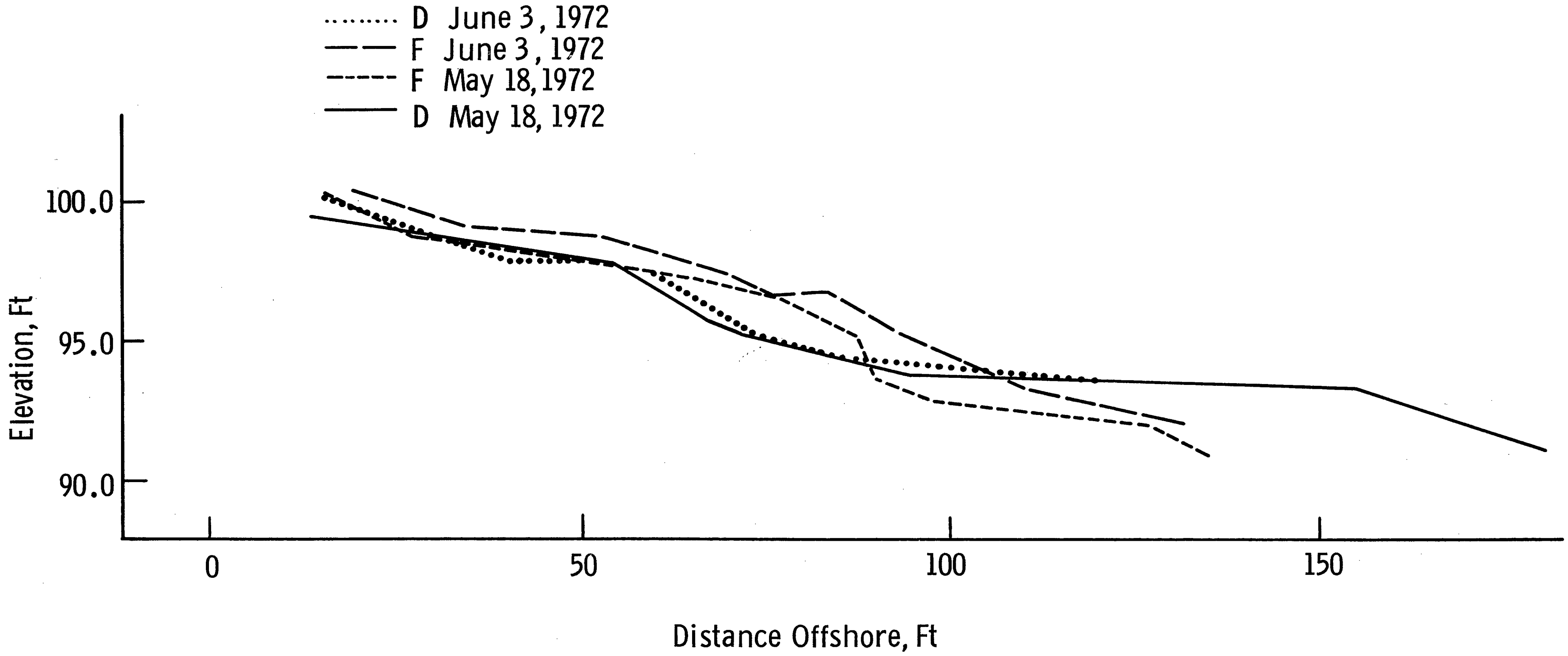

Figure 10. Profile D and F, 18 May 1972 and 13 June 1972, Red Wright Beach

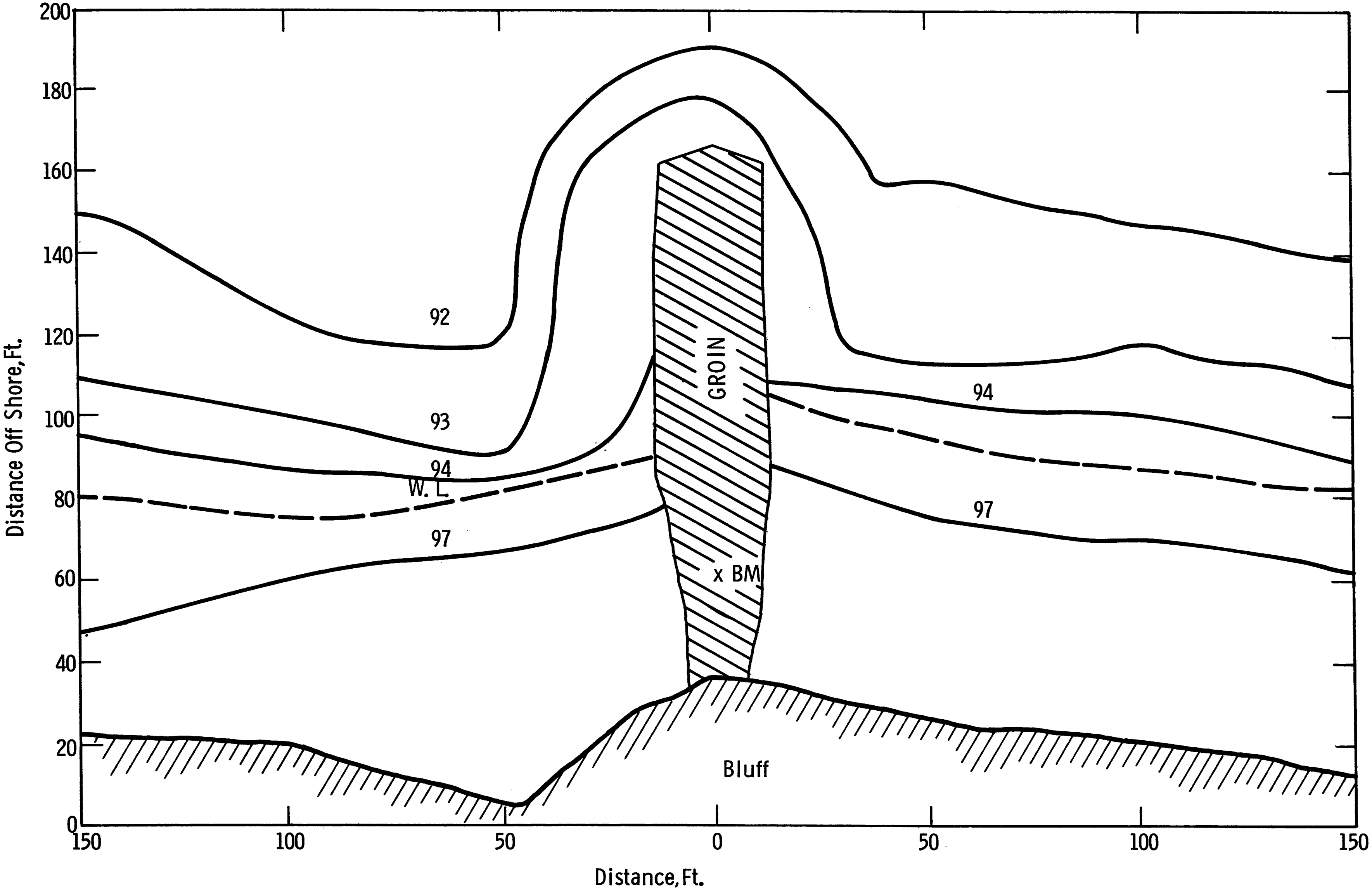

Figure 11. Red Wright Beach, 18 May 1972 Contours--ft; Assumed Elevation: 100.0 ft at BM

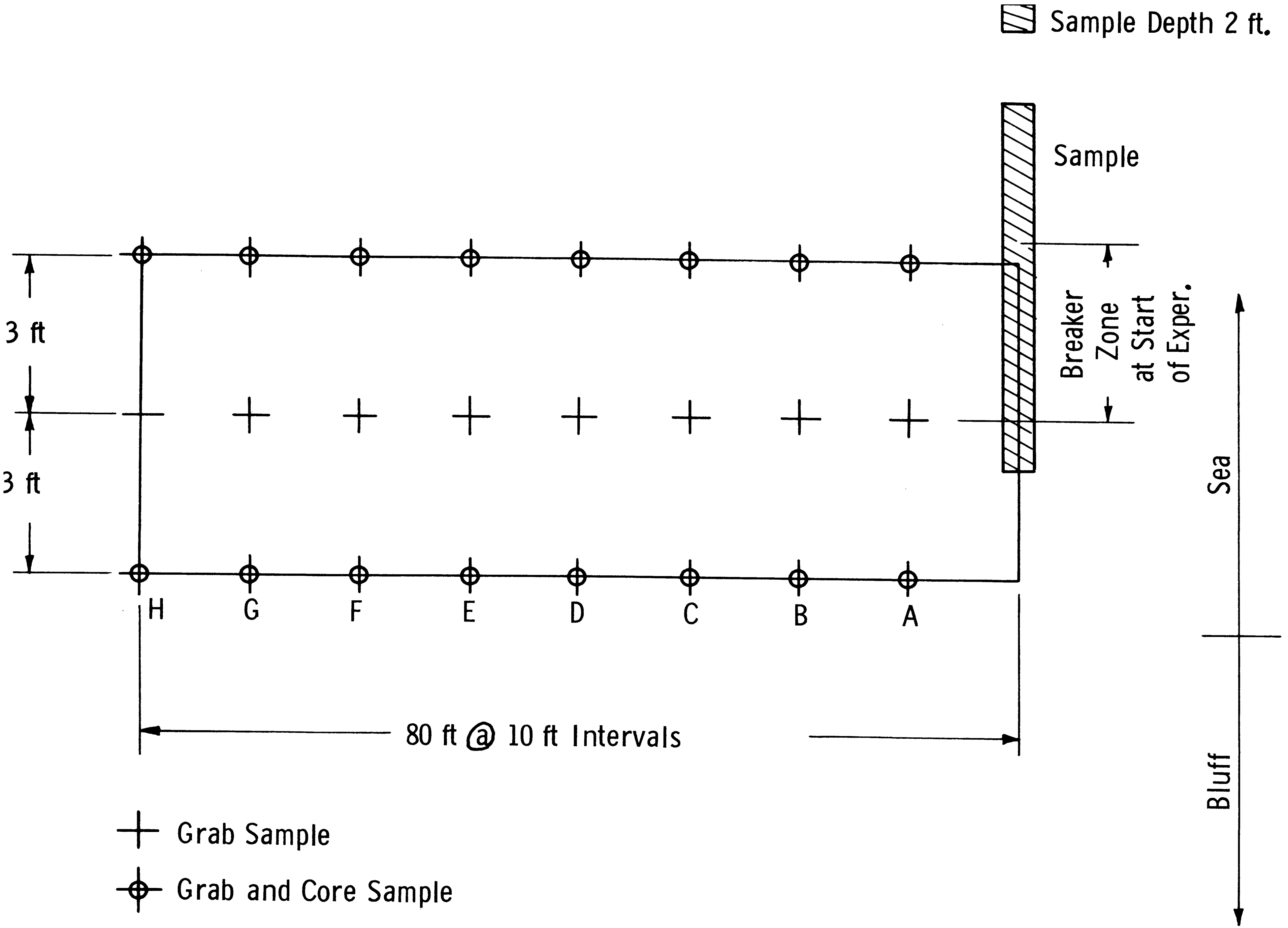

Figure 16. Sampling Grid

of tracer grains would be found in the sample. If a sample was split and this assumption was not valid, a larger portion of the sample was then counted. Using good judgment, splitting the sample did not appear to induce any large errors in the analysis. With more time for analysis, the whole sample could have been counted and this error eliminated.

The core samples were used to determine burial depth of the tracer material. The presence of tracer grains was recorded in the cores at 1-cm intervals. From preliminary tests, the accuracy of taking a core sample in coarse sand was ± 0.5 cm due to the side friction errors. During the analysis, large rocks blocking the core made the core suspect. Some cores were too short because a rock bottom prevented us from obtaining a full sample. Fortunately, a majority of the cores were not adversely affected and the burial depths were determined using an averaging technique. Future experiments should consider using a core of larger diameter. The validity of the burial depth was checked the following day at low tide. In the grid area, burial depths of tracer material measured 3.5-5.0 cm, which checked with the core data. During the night the winds abated, the wave heights decreased to 0.1 ft, and the direction of approach reversed to the southwest, so this check seems reliable.

The immersed rate of sand transport versus longshore component of wave energy flux, shown in Figure IV-0, appears to be within the normal scatter of data points. Without additional repeats of this experiment, it is difficult to evaluate the reliability of this result. One group of errors has been discussed previously, since the data used to plot the tracer diagrams was used to calculate the immersed transfer rate, I_ℓ. The measurement of the wave parameters is also a source of error. For reliable results, a time series analysis must be made on a continuous wave record. The measurement of the wave height, length, and period at discrete intervals of time with cruide equipment makes the calculation of P_ℓ suspect.

The longshore current was measured outside the breaker zone and the results are shown in Figure I-15. The velocities of the longshore current were not high enough to erode and transport the bottom material (Figure I-3b). This explains why the sample placed offshore did not move.

The tracer sample placed through the breaker zone showed a distinct line of demarcation during the experiment. The sample shoreward of the breaker zone was depleted by the end of the experiment, but the sample immediately seaward of the breaker zone did not move. This indicated transport only in the breaker and swash-backwash zones in a narrow zone that moved in with the flooding tide.

The day selected for the experiment was typical of a moderately windy day, with the waves being generated from the southwest up Vineyard Sound, and the results can also be assumed typical of the area.

DISCUSSION OF GROIN PROFILES

Studying the profiles taken 18 May 1972, a net build-up of material was present on the south side of the groin along Profile F. The beach at Profile F extended seaward further than the beach at Profile D. However, seaward of the low waterline, the bottom elevation along Profile D was greater than in the same vicinity at F. This build-up was the material that was being eroded at the shore and being dropped offshore. The predominant wave attack was from the southwest and only the waves highly refracted and diffracted would reach this area, leaving a shadow zone in this area. Material offshore traveling shoreward also was being transported into this shadow zone, where it settled out. The result was a net build-up of the bottom. Fine-grained material found in the shoaling area and the backshore, where the erosion was taking place, was being supplied. The gradation analysis verified this. The material found in the shoaling zone, the breaker zone, and the swash-backwash zone was significantly finer (Profile D) than the other samples taken at Profiles A, F, and I.

Comparing the profiles of 18 May 1972 and 3 June 1972, a net seaward movement of 15 ft had occurred along Profile F relative to Profile

D, indicating a predominant direction of transport from south to north. In general, no net change was made in the other profiles over the 18 days. Since the area of build-up and erosion was limited to the groin, it appears that this groin is acting independently of the next groin, over 500 ft to the north.

This paper represents only a preliminary study of the coastal processes at work in this area. Final conclusions cannot be made until further studies are made. First, more points are needed on the graph of immersed weight of transport versus the longshore component of wave energy flux so a curve can be fitted to the data. Second, profiles over 18 days are not over a period long enough to make long-term conclusions. The profiles should be taken over a year so that the seasonal and storm events can be observed. Third, the sources of sand should be measured quantitatively to ascertain the contributions from the offshore shoals, the beach, and the bluff. Fourth, in conjunction with the source study, an accurate determination of annual bluff erosion should be made using aerial photographs, old land surveys, old topographic maps, and discussions with previous owners.

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PRELIMINARY EXAMINATION OF TWO ENVIRONMENTAL CONTROL METHODS, REDUCED SALINITY AND LIGHT DEPRIVATION, FOR THE TUNICATE *BOTRYLLUS SCHLOSSERI* IN AQUACULTURE SYSTEMS

Peter W. Perschbacher

A study of environmental controls for *Botryllus schlosseri* (Pallas) in aquaculture systems was undertaken in conjunction with an aquaculture project underway at Woods Hole Oceanographic Institution.

Reduced salinities and light deprivation have been examined. Flushing with reduced salinity is indicated. The lethal level for single colonies of *B. schlosseri* at 22° C is 60 min immersion in 5 percent, or 30 min immersion in fresh water. These exposures are well within the tolerance limits of oysters and most bivalves. However, lethal levels appear to be correlated with temperature. At 16.5° C, 30 min immersion in fresh water was necessary to effect 100 percent mortality. No mortality occurred after 6 min immersion in fresh water at 6.5° C.

Light deprivation did not significantly affect the growth of adult colonies. Where filamentous algae interfered with colony growth, reduced light resulted in an increase in colony growth.

B. schlosseri reacts to lowered salinities in a manner similar to that of bivalues. In steadily reduced salinities, a reduction in contact of the colony occurs at 22-23 percent. After a short period of adjustment, a further reduction of 5-10 percent is tolerated before reduction in contact again occurs.

INTRODUCTION

An aquaculture study at Woods Hole Oceanographic Institution has successfully cultured algae utilizing secondary treated sewage as a nutrient source (Dunstan and Menzel, 1971). The algae are used as a food source for bivalve culture in a companion project. Fouling organisms, with the exception of the colonial tunicate, *Botryllus schlosseri*, are eliminated from the system by means of a 100-μ filter for incoming sea water (Kenneth Tenore, personal communication). The present study was undertaken to examine several environmental control methods for this organism in aquaculture systems.

B. schlosseri has appeared in the literature in reference to fouling oyster culture and harbors, with little mention of control techniques. Its undesirability derives from the preference of the larvae for protruding objects as settling sites in the subtidal to 15-20 fathom zone, and the rapid summer growth (Berrill, 1936) by asexual budding, which may result in a doubling of zooids per colony every 2-3 days (Millar, 1971) and a mat of contiguous colonies over a foot in diameter (Milkman, 1967). Adverse effects upon coastal oyster culture and aquaculture systems include overgrowth and suffocation of oysters, food competition, rendering of cultch--settling sites for oyster larvae--unfavorable for settling, and silting due to fecal deposits (Millar, 1971). Cleaning of cultch and oysters in raft cultures has been accomplished by dipping in Victoria Blue, copper sulphate, di-nitro-ortho-creosol, or saturated salt solution (Loosonoff, 1960). Flushing with Victoria Blue has been indicated as a control method in aquaculture systems; however, mortality may occur if the oyster opens and receives a lethal dose (Loosonoff, 1960). Environmental controls for aquaculture systems have not been reported.

Areas of research into environmental control methods which should be considered are predators, light deprivation, and reduced salinities. The predators of *B. schlosseri* are numerous and include crabs, two gastropods, several members of the super families Lamellariacea and Cypraeacea, a number of nudibranchs and turbellarian flatworms (Millar, 1971). Light deprivation repeatedly induced degeneration and death in a species of the genus *Botrylloides* (Pizon, 1899). However, Millar (1971) notes that the effect of light on adult colonies of *B. schlosseri* is little known. In darkness the larvae of *Botryllus niger* will not settle and the larvae of *Symplegma viride* will die after two days (Thorsen, 1964). Reduced salinities of Cheasapeake Bay and the Louisiana coast have been correlated with high oyster production due to pest reduction (Menzel, 1969). Utilization of this effect of low salinities is the basis for a proposal to locate raft cultures in estuarine tributaries (Davis, 1969). The limited osmoregulatory ability of *B. schlosseri* has also been reported (Potts and Parry, 1964; Millar, 1971). In this study light deprivation and reduced salinities have been used to determine lethal levels for *B. schlosseri*. The significance and limitations of the results will be discussed in terms of applications to bivalve aquaculture systems.

MATERIALS AND METHODS

Colonies of *B. schlosseri* were obtained from the sides of a large oyster rearing tank which is part of the ongoing aquaculture project at Woods Hole Oceanographic Institution. The temperature had been maintained at a constant 20° C. The colonies were subdivided into groups of two colonies and five colonies. The group of five was allowed to settle on slides. The group of two colonies was allowed to settle and attach to slides and unclean oyster shells in a tray with flowing sea water of slightly higher than the ambient sea water temperature. Turbulence was reduced to facilitate settling.

Salinity Experiments

The method used for determining the lethal level, or point at which 100 percent mortality occurs, was to place the animal in the lethal environment and note the time of death.

As 23 percent is the lowest reported salinity for *B. schlosseri* (Dybern, 1967; Milkman, 1967), sea water was diluted with fresh water to obtain 1-liter volumes of salinities 20 percent, 15 percent, 10 percent, 5 percent, and fresh water. The salinities were determined by use of a refractometer corrected and checked by a salinometer standardized with Copenhagen water. Two fingerbowls were filled with each salinity on the same day. One fingerbowl was used in the immersion test. Five slides with five colonies attached were counted by zooid number and placed in each of the varying salinities. At intervals of 5, 15, 30, 60, and 90 min a slide was removed, marked, and returned to the initial container of normal salinity, which for Woods Hole is about 31 percent. The salinity of the fingerbowls was again measured to check for change during the test period by refractometer-salinometer. A count to determine mortality was made several days later. Mortality was determined by evidence of decomposition, which results in a red-orange appearance of the zooids.

An initial group of 25 slides was acclimated to room temperature of 22° C, tested at varying salinities and returned to the original container at this temperature to outline the lethal level. Further tests were run with seven slides each, at ambient sea water to 16.5° C and refrigerated sea water of 6.5° C in an identical manner (the slides being immersed in and returned to the noted temperature). Five slides tested the lethal level, as described; one slide was used to test the salinity level; and one slide was used to test the reduced time interval adjacent to the lethal level to detect changes in response with temperature. Similarly, seven slides from the light-deprived tray were tested at 22° C following completion of the preceding experiment. Also, one slide of five colonies was maintained in each of the salinities above the lethal level, 10 percent, 15 percent, and 20 percent, for a prolonged period until 100 percent mortality had occurred, as evidenced by a uniform red-orange color.

A dissecting microscope was used to observe reactions to gradual dilution at 22° C. One to two milliliters of fresh water was added to a fingerbowl of normal salinity with one slide of five colonies until a reaction was noted. After a short interval to allow for accommodation of the colonies, dilution was continued. This process was repeated until no further reaction was noted. The entire cycle was repeated. Utilizing the refractometer-salinometer, measurements were taken of the salinity required to produce the reactions.

Light-Deprivation Experiment

Slides and shells with two colonies attached were counted by zooid number per slide-shell following the growth measurements of Sabbadin (1964). Size increments prove less reliable as colonies often divide during growth. Seven slides and seven shells were arranged, alternately, in three rows in each of three, 4-liter, plastic trays. One tray was left uncovered as a control and, from light-meter readings, received 3000 ft candles illumination. Another tray was covered with double plastic screening and received 800 ft candles illumination. The final tray was covered with aluminum foil and received no illumination. Running sea water with an average temperature of 17.5° C and carbon content of 140 μg C/liter was maintained. The stream was deflected to reduce turbulence. After 21 days, 18 May-8 June, the slide and shell colonies were again counted by zooid number per slide or shell. T-test comparisons were used to detect significant differences in growth.

RESULTS

Reduced Salinities

The mean number of zooids per slide was 52.0 ± 13.6. The initial test at 22° C indicates the lethal level is 30 min in fresh water, 60 min in 5 percent salinity. (The dashed line in Table 1 delimits this area.) At 16.5° C no mortality was observed at 5 percent salinity. (The dashed line in Table 2 delimits this area.) No mortality was observed in fresh water at 6.5° C. The prolonged time periods in 10 percent, 15 percent, and 20 percent salinity produced 10 percent mortality, or a lethal level, at 36 hr, and no mortality after one week, 3 June-10 June, in 15 percent and 20 percent salinity. The lethal levels for the dark adapted colonies were not significantly different from the initial test.

TABLE 1. Comparison of Percent Mortality Versus Immersion Period with Varying Salinities at 22°C

	Immersion Period (min.)				
	5	15	30	60	90
SALINITY (parts per thousand)					
20 % mortality	0%	0%	0%	0%	0%
15 % mortality	0%	0%	0%	0%	0%
10 % mortality	0%	0%	0%	0%	0%
5 % mortality	0%	0%	0%	93%	95%
0 % mortality	0%	0%	100%	100%	100%

TABLE 2. Comparison of Percent Mortality Versus Immersion Period with Varying Salinities at 16.5°C

	Immersion Period (min.)				
	5	15	30	60	90
SALINITY (parts per thousand)					
20 % mortality	0%	0%	0%	0%	0%
15 % mortality	0%	0%	0%	0%	0%
10 % mortality	0%	0%	0%	0%	0%
5 % mortality	0%	0%	0%	0%	0%
0 % mortality	0%	0%	100%	100%	100%

The dilution observations indicate dilution to 22-23 percent will be tolerated by the zooids before a reduction in contact by closing of siphons and contraction of the body wall occurs. After a period of hours, the zooids in the colony return to the normal state and will tolerate a further reduction of 5-10 percent before a reduction in contact again occurs.

Light Deprivation

The mean initial number of zooids per slide-shell was 20.7 ± 3.6. Quantitatively, no mortality occurred as a result of light deprivation. Filamentous algae rather reduced colony growth on shells grown in full illumination or shells at reduced illumination. T-test comparisons of slide versus shell growth show significant differences in growth at 3000 ft candles illumination and 800 ft candles illumination. Slide versus shell growth with no illumination did not show significant differences (Table 3). T-test values of growth differences between slides in no illumination and 800 ft candles, and between 800 ft candles and 3000 ft candles are 1.56 and .238, respectively. These do not indicate significant differences. In general the increase in colony number was as expected with suboptimal spring temperatures. Several slides and shells in each tray were adversely affected, by dislodgment or degeneration, in the immediate area of the water stream deflection. This indicates too severe a turbulence, which, as Milkman (1967) has noted, results in the stated effects. These were not used in computing percent increase or T-test comparisons.

DISCUSSION

Reduced Salinities

The lethal levels for *B. schlosseri*, 22° C and 16.5° C, are well within the tolerance limits of oysters and most bivalves. Oysters may

TABLE 3. Comparison of Percent Increase in Zooid Number per Slide-Shell of Slides Versus Shells at Various Light Intensities

	Slide	Shell	Student's "T" Value
3000 ft. candles Percent increase in zooid number	84.6±14.7 (3)[1]	-51.1±15.7 (3)	8.7*
800 ft. candles Percent increase in zooid number	108.0±17.1 (4)	16.5±18.8 (4)	7.8*
0 ft. candles Percent increase in zooid number	84.9±14.7 (4)	90.3±32.4 (4)	.5

[1] Values given as the mean±standard deviation; the number of slides or shells is given in parenthesis.

*Significant at the .05 probability level.

survive for three days in fresh water with zero mortality (Loosonoff, 1969). Flushing of the system with fresh water thus appears to be an effective environmental control method. The time interval necessary to effect 100 percent mortality will vary with the temperature of the system, in general, lower temperatures requiring longer immersion periods. A 1- to 2-hr flushing period should be adequate for the aquaculture system with which this project is allied, as temperatures will be maintained at 20° C or more. This method would also be applicable to bivalve culture in coastal impoundments. Draining and refilling with fresh water would constitute the flushing process.

Presumably, with application these preliminary immersion periods may be better defined for varying temperatures and other factors not considered in this study, as the effect of colony size, genetic variations in colony, tolerances of the cultured species, etc. Observation of the reaction of the colony to steadily reduced salinities indicates a reduction in contact response, similar to that of bivalves. The prolonged immersions of 15 percent and 20 percent without adverse effects and with the colony maintaining a normal appearance would argue, however, if not for a greater degree of osmoregulation than normally accorded the Tunicates, then certainly for further studies in this area.

Light-Deprivation Experiment

Light does not appear necessary for the normal growth of *B. schlosseri*. A degree of reduced light may, in fact, be necessary to eliminate the adverse effects of filamentous algae. These may include reduction of water flow and food over the colony, and an increase in silting. This accords with the preference of larvae for settling on the underside or shaded side of protruding objects (Woodbridge, 1924). Thus, light deprivation of adult colonies is not to be considered as a control method. Although the discrepancies with Pizon's (1899) conclusions cannot be accounted for, it should be noted that he observed a red-orange coloration of the colonies after three days in the light-deprived environment, which here has been used to establish the onset of colony decomposition. The effect of continued darkness on the larvae of *B. schlosseri* bears investigation as well as predator studies.

ACKNOWLEDGMENTS

I wish to thank Dr. Kenneth Tenore for his advice, assistance, and toleration in this project. I would also like to thank Helen Nearing for typing this report. The cooperation of Dr. Edward C. Monahan is also appeciated.

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A BRIEF LOOK AT FOUR SPECIES OF DEEP SEA FISH

Don Ryker

This paper examines four species of fishes. The fish were caught in three different bottom trawls at depths of 400, 500, and 700 fathoms on the continental slope. The fish examined were *Synaphobranchus kaupi*, *Alepocephalus agassizi*, *Macrourus bairdii*, and *Dicrolene intronigra*. These four fish made up the majority of fish caught in each trawl. The length of each *Alepocephalus agassizi* was measured (head to beginning of caudal fin). For the other three species, the total length of each fish was measured (head to end of caudal fin). Each fish was then weighed to the nearest tenth of a gram. This information was fed into a computer and plots of length versus weight, the length frequencies, and weight frequencies were obtained. The results show that *Synaphobranchus kaupi* and *Dicrolene intropigra* show strong tendencies to increase in age (size) with depth. *Macrourus bairdii* is much more homogeneous. Attempts to find age groups using length and weight frequencies were not reliable. Weight frequencies seem to be sex biased. *Macrourus bairdii* and *Dicrolene intronigra* show age distribution. Growth curves seem to show linear growth patterns for *Synaphobranchus kaupi* and *Macrourus bairdii*. *Alepocephalus agassizi* and *Dicrolene intronigra* show exponential growth curves.

INTRODUCTION

Bigelow and Schroeder (1953) first examined macrourids (Figure 1)* and concluded that these fish were the most abundant fish of the continental slope below 100 fathoms. Their range is from 80-1224 fathoms. Macrourid larvae live near the surface of the open ocean, but adults live much deeper, along the slope and rise.

Marshal (1965) studied the systematics and biology of macrourids, and agreed with Bigelow and Schroeder as to the abundance of the fish. He further concluded that there are at least 300 species of macrourids, each with a limited range. There also is evidence that these fish lay buoyant eggs close to the bottom, that the eggs are fertilized externally, and that they then float upward and develop at about 33.3 fathoms.

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[*] Figures not included in the text are on file in the Department of Meteorology and Oceanography, The University of Michigan.

McLellan (personal communication) has examined *Macrourus bairdii* brains and believes that this species has a sensitive lateral line and a good sense of taste.

Synaphobranchus kaupi (Figure 2) is found at depths greater than 200 fathoms (Schroeder, 1955). The documented locations of areas where this fish has been caught by US fisherman are shown in Figure 3. Bigelow and Schroeder (1953) have found the genus *Synaphobranchus* from depths of 129 fathoms to depths greater than 2000 fathoms. The temperature range of the fish is 1.4°-11.5° C.

Like macrourids, *Synaphobranchus* larvae develop in the surface waters, specifically in the Sargasso Sea. It is believed that this genus lays buoyant eggs near the bottom. The exact species of the larvae are not known although it is believed that those caught to date are not one, but several species, including *S. kaupi*. *Synaphobranchus* larvae go through several stages, which are much unlike the adult, spending several years developing before they finally become an adult (Brun, 1937).

McLellan (personal communication) believes *Synaphobranchus kaupi* use the sense of smell in locating food. Stomach contents contain shrimp.

Alepocephalus agassizi (Figure 4) have been found as shallow as 200 fathoms (Goode and Bean, 1895). McLellan concludes that this species is visually oriented, with a sensitive lateral and a good sense of taste. There is no light at depths below 700 fathoms; therefore, the eyes must be used to see the bioluminescent shrimps. Stomach contents have been examined and support this hypothesis.

Dicrolene intronigra (Figure 5) have a range of 185.5-983 fathoms (Goode and Bean, 1895). Schroeder (1955) mentions that they were caught at 450-730 fathoms. McLellan (personal communication) believes that no sense is particularly well developed, but that if they use any sense, it would be the sense of sight.

The locations of the catches examined in this paper are shown in Figure 6.

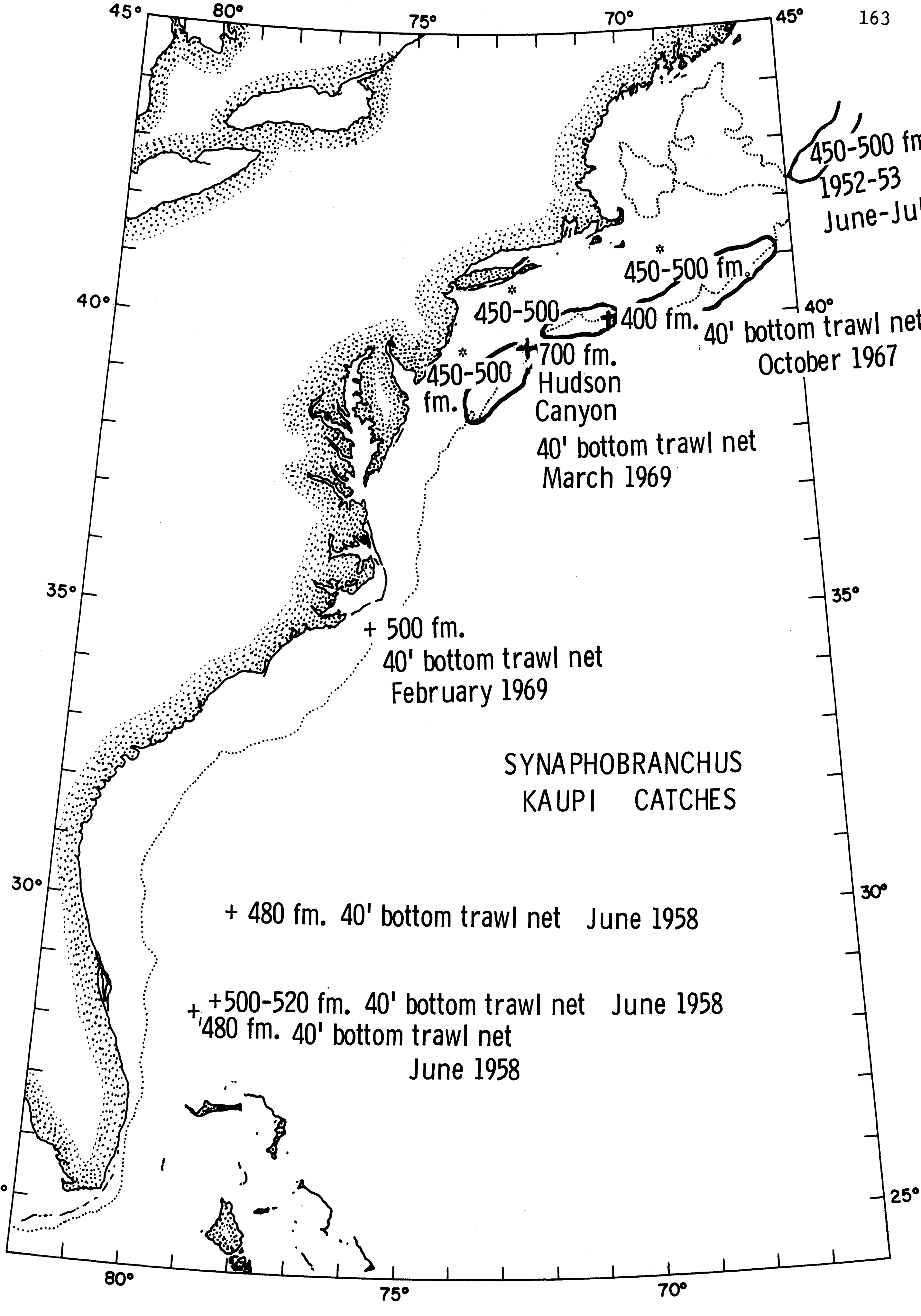

Figure 3. Locations of Catches of *Synaphobranchus kaupi*

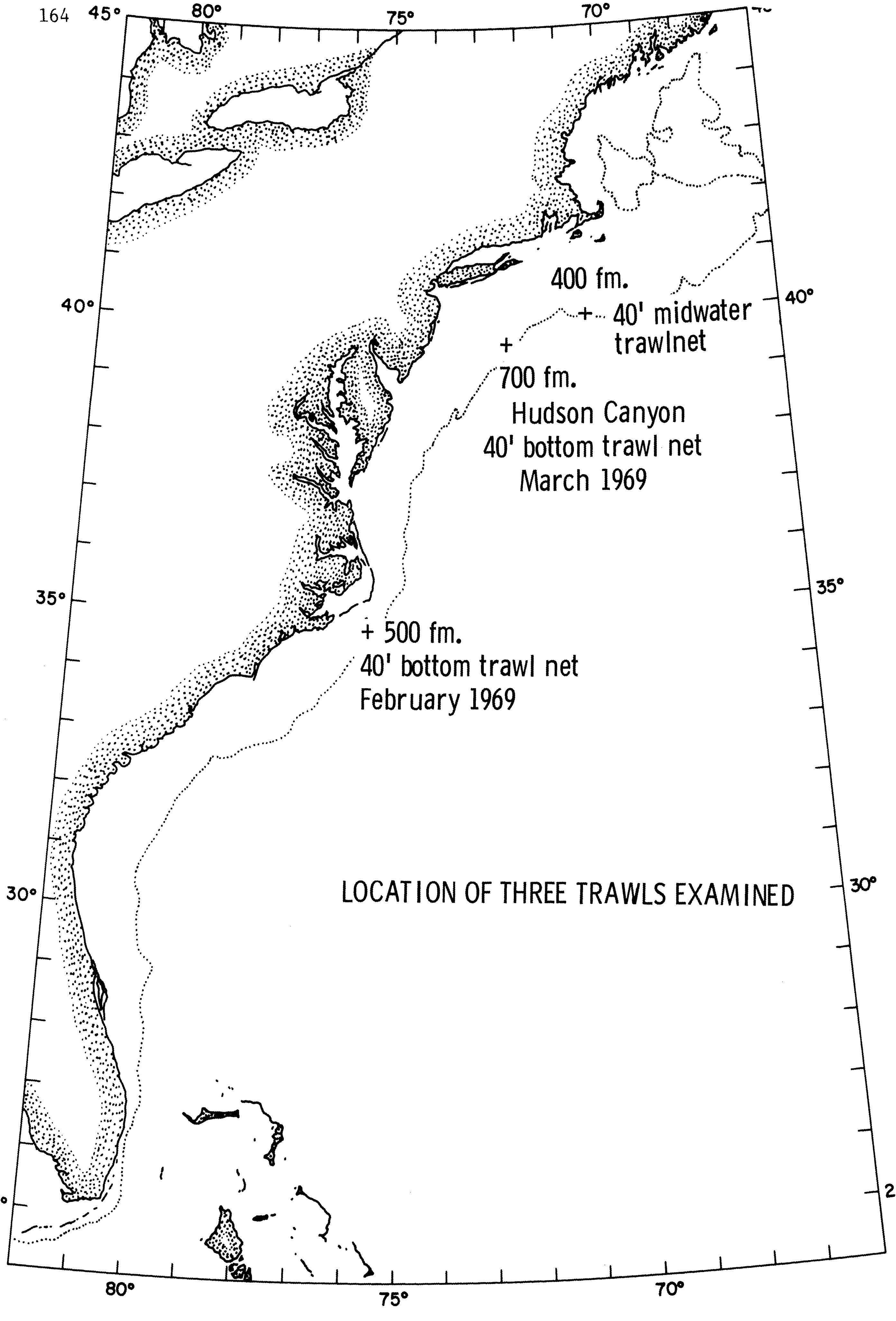

Figure 6. Location of the Three Trawls Examined

MATERIAL

Log of Chain 88, 28 February 1969. Total catch = 96.
500 fathoms

12	*Synaphobranchus kaupi*
74	*Macrourus bairdii*
10	*Dicrolene intronigra*

Log of Chain 88, 6 March 1969. Total catch - 226. (Haedrich, 1970)
700 fathoms

67	*Synaphobranchus kaupi*
47	*Macrourus bairdii*
45	*Dicrolene intronigra*
67	*Alepocephalus agassizi*

Log of Gosnold RHB 1602, 5 October 1967. Total catch = 108.
400 fathoms

100	*Synaphobranchus kaupi*
8	*Macrourus bairdii*

This experiment involved measuring the lengths of the fishes. Standard length was measured for *Alepocephalus agassizi*; total length was used for the rest of the fish. Standard length is the length from the head to the beginning of the caudal fin; total length is the length from the head to the end of the caudal fin. Measurements were made to the nearest millimeter. The weight of each fish was taken to the nearest tenth of a gram on an analytic balance.

This information was put on computer cards and fed into a Sigma 7 computer. Two programs were used. The first program produced plots of length versus weight. For each species, four plots were obtained; one for each of the three catches and a total. These total plots appear in graph form in Figures 7, 10, 13, and 16.* The second program calculated

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*The figures are not presented in order.

the length frequencies and the weight frequencies. From this, eight plots were obtained for each species: length and weight frequencies for each of the three catches and one for the total species caught. The graphs of the totals for three of the species appear in Figures 9, 11, 12, 14, 15, 17, and 18. For *Macrourus bairdii* (Figure 8), the 400 fathoms catch was almost entirely omitted because it would have obscured the results by making means closer.

RESULTS

Alepocephalus agassizi was not caught above 700 fathoms. Schroeder (1955) made many trawls at depths above this and does not mention catching this species of fish. Therefore, this might be an upper boundary for this fish, which would contradict Goode and Bean (1895).

The rest of the results appear in tabular form. For *Macrourus bairdii,* the length versus weight plot (Figure 7) shows that age distribution with depth is not clearly defined. Length frequencies for *Macrourus bairdii* show a distribution that may indicate two different age groups (Figure 8). This first peak is at 32.0 cm and the second is at 38.0 cm. In this graph, the 400-fathom catch was almost entirely omitted because there were too few specimens. The weight frequencies (Figure 9) show a peak at 60 gm; lesser peaks, at 100 gm and 200 gm. Sex of the fish has much to do with the weight of a fish and tends to make the graph, although interesting, unreliable.

Synaphobranchus kaupi so far have been caught in many trawls (Figure 3). The distribution of age with depth is well defined (Figure 10). The largest occur at the deepest depths. Like the macrourids, a linear regression best fits the points on the plot (see the Appendix).

From the length frequencies (Figure 11), two quite distinct peaks can be seen. The first is at 32 cm and the second is at 56 cm. It is believed that this is due to bias in the sampling mechanisms. The weight frequencies also show two peaks, the first at 30 gm and the second at 150 gm.

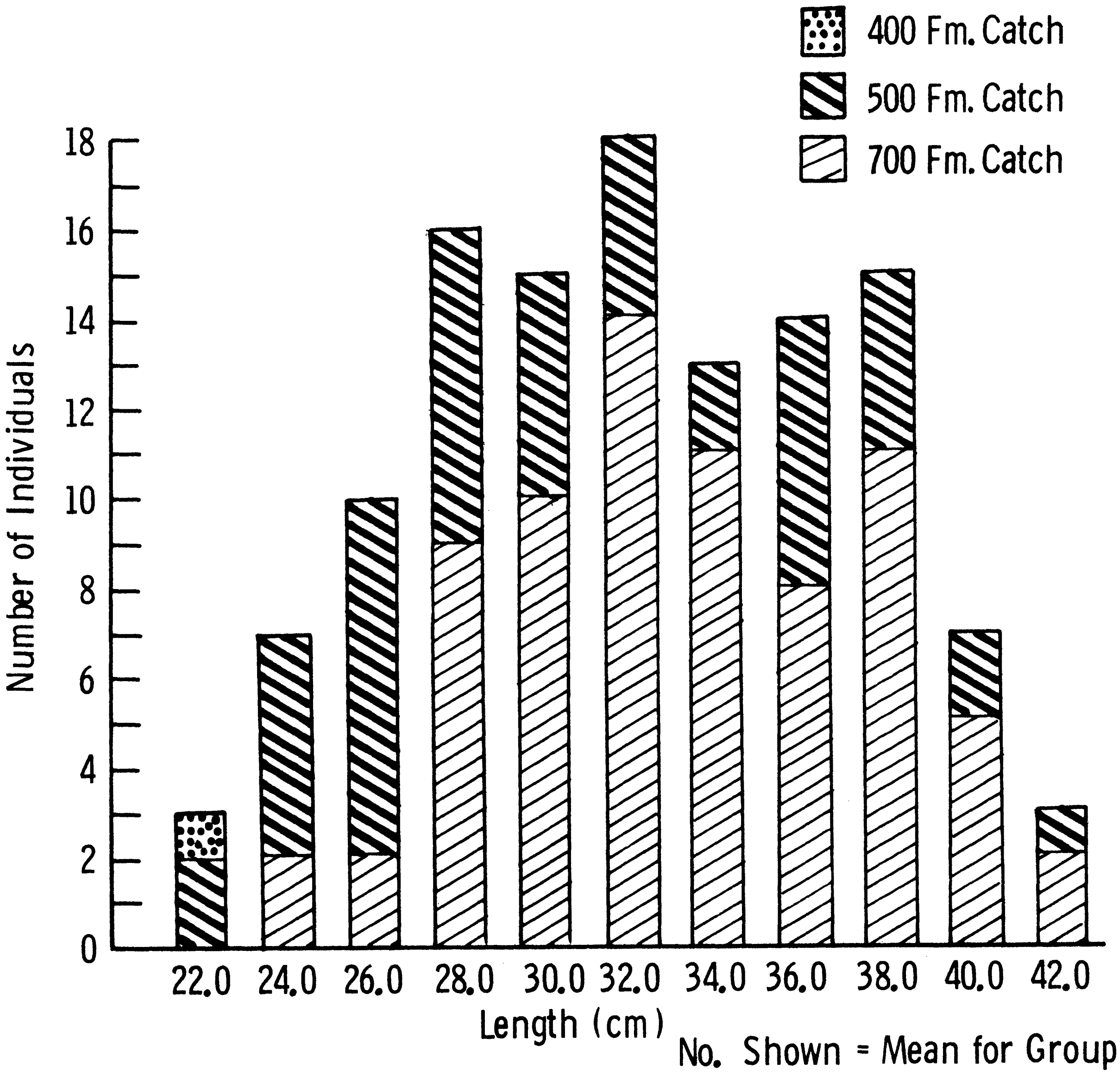


Figure 8. Length Frequencies, *Macrourus bairdii*

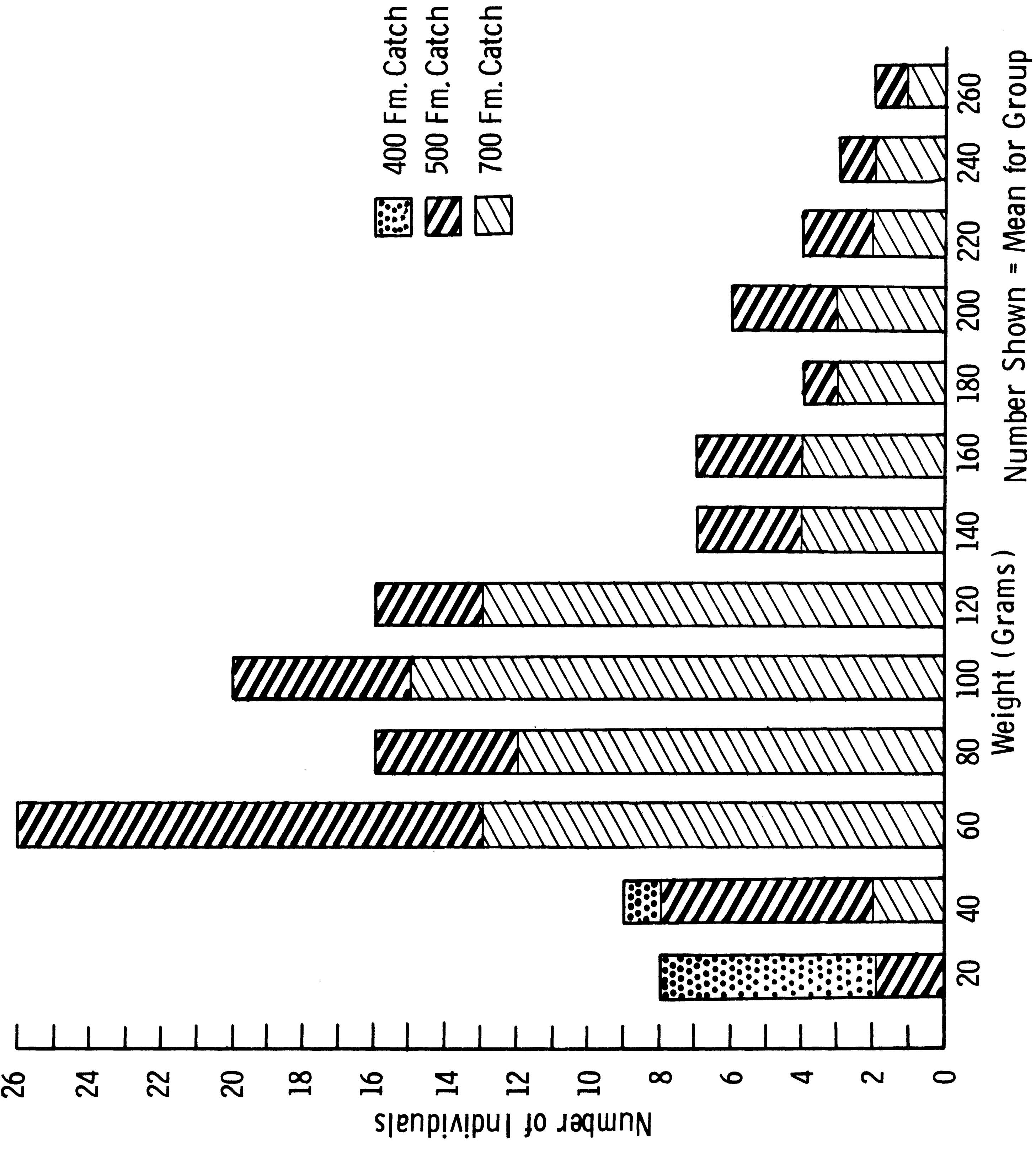
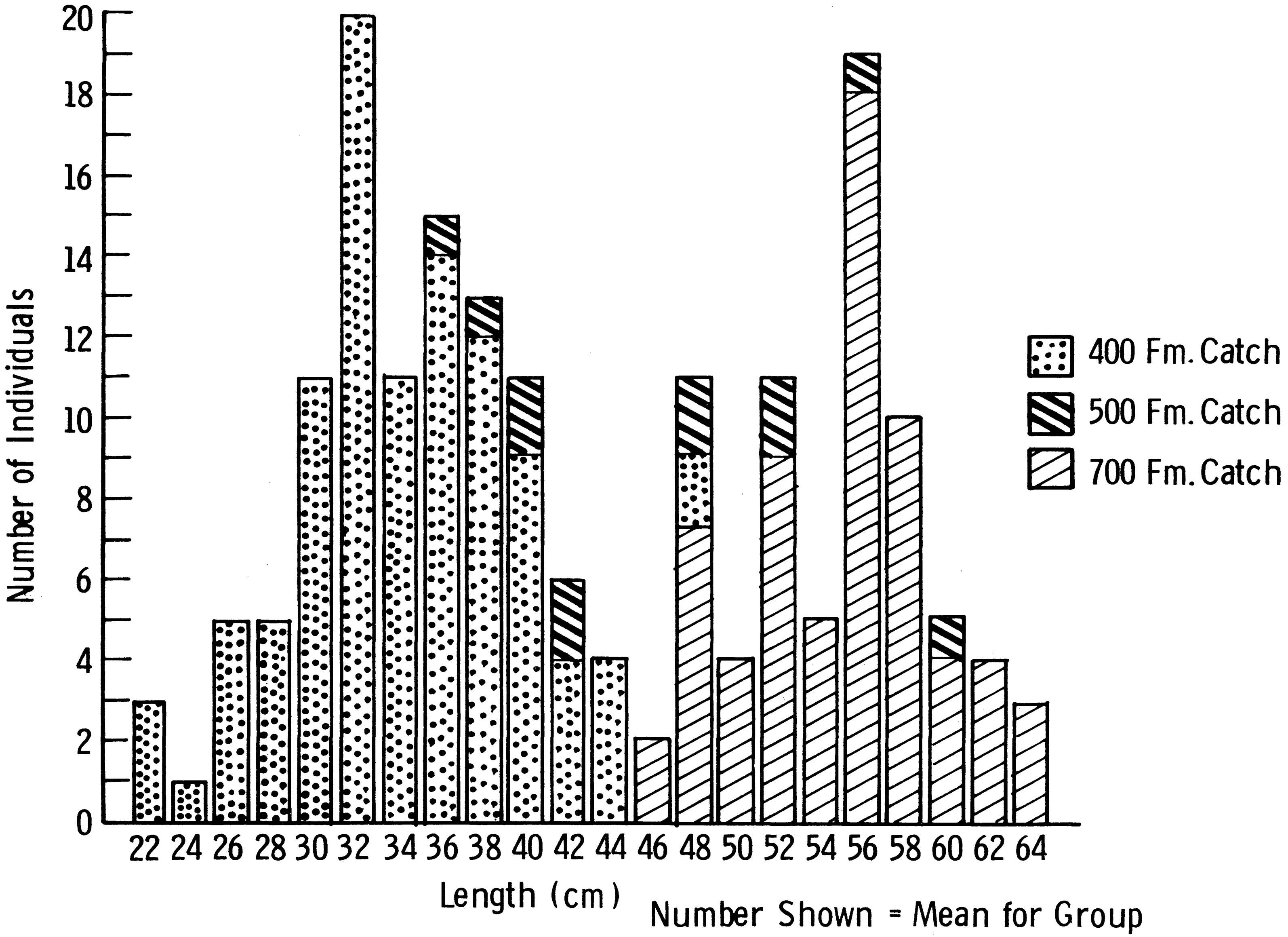


Figure 9. Weight Frequencies: *Macrourus bairdii*



Number Shown = Mean for Group

Figure 11. Length Frequencies: *Synaphobranchus kaupi*

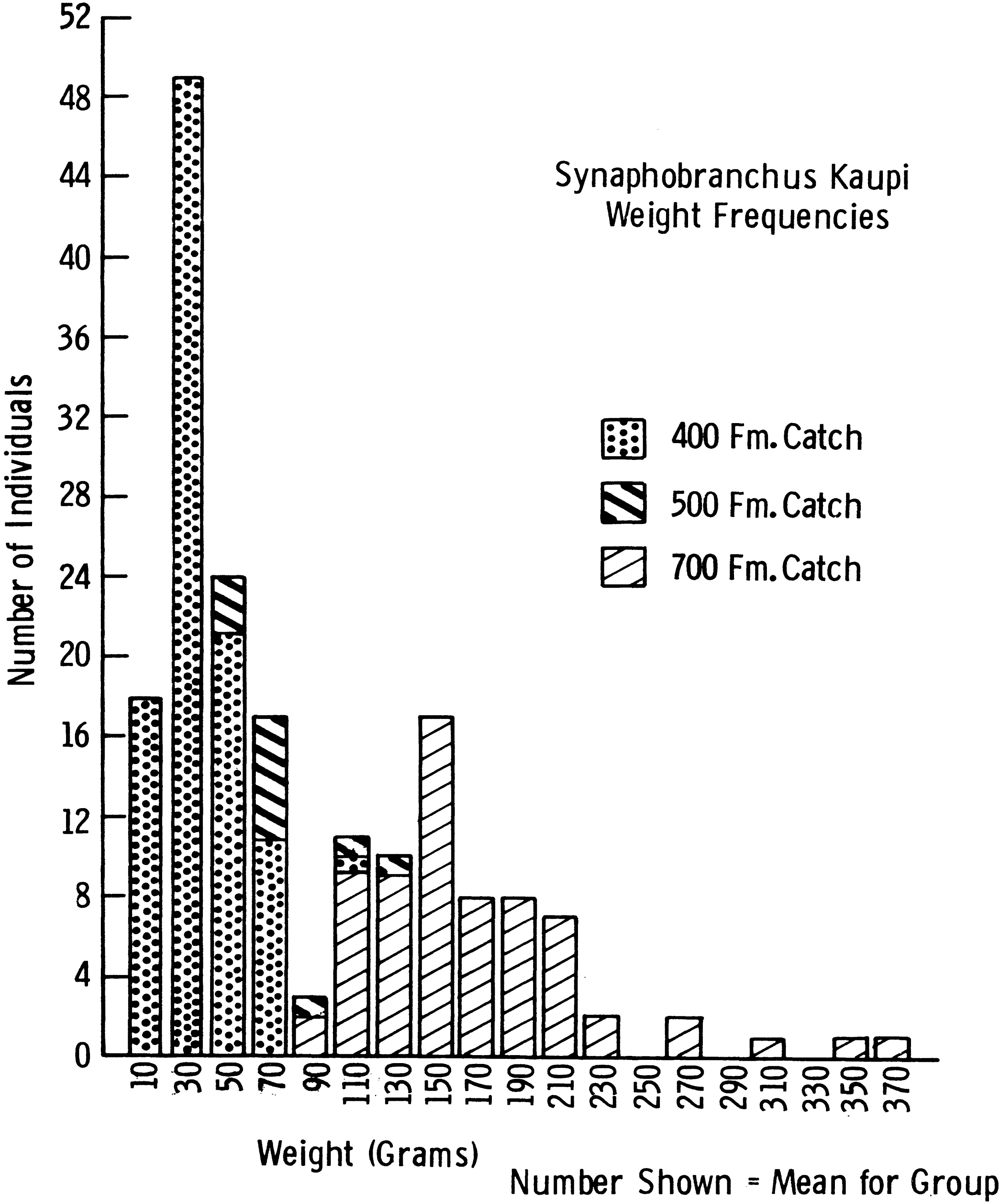


Figure 12. Weight Frequencies: *Synaphobranchus kaupi*

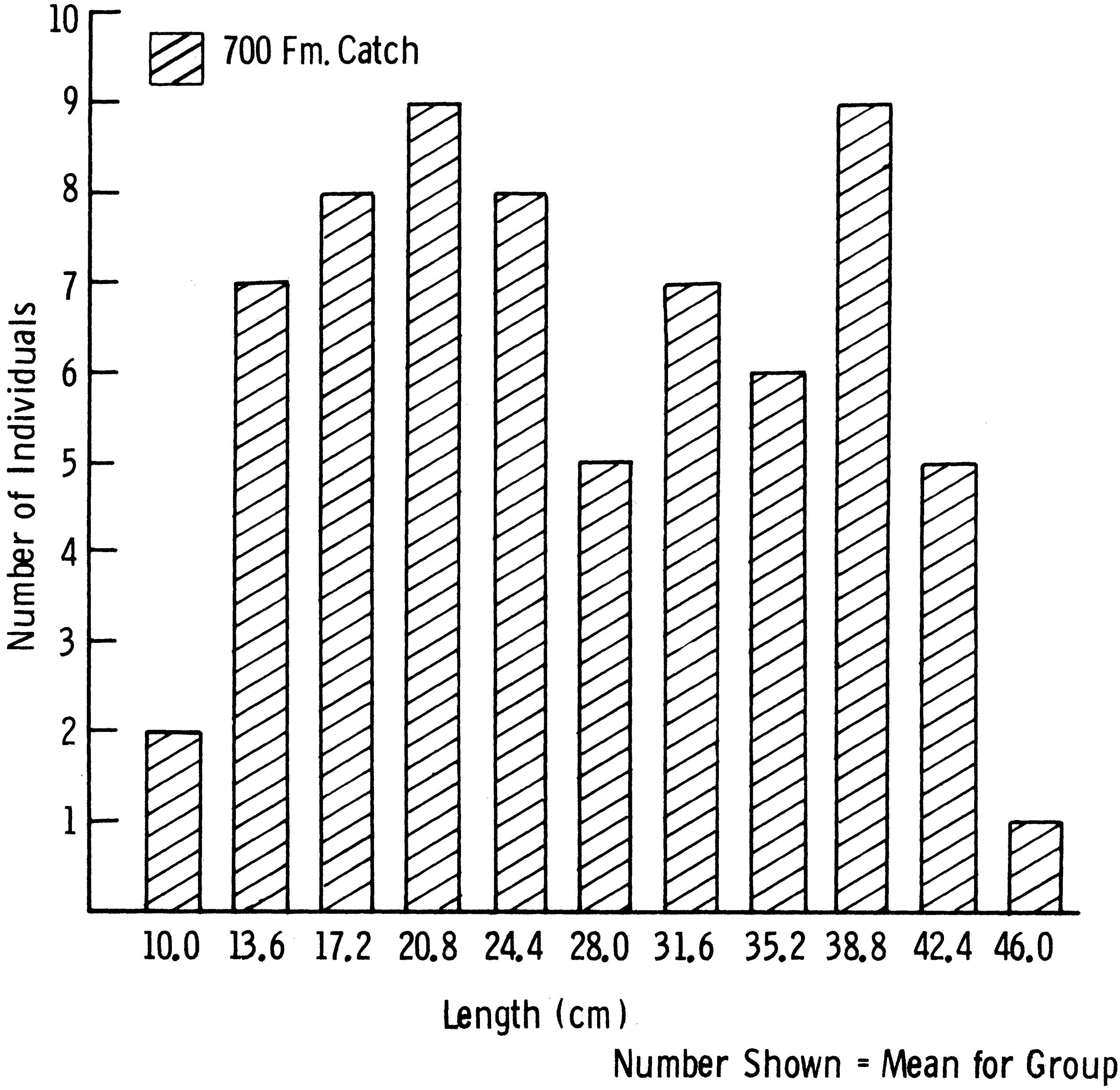


Figure 14. Length Frequencies: *Alepocephalus agassizi*

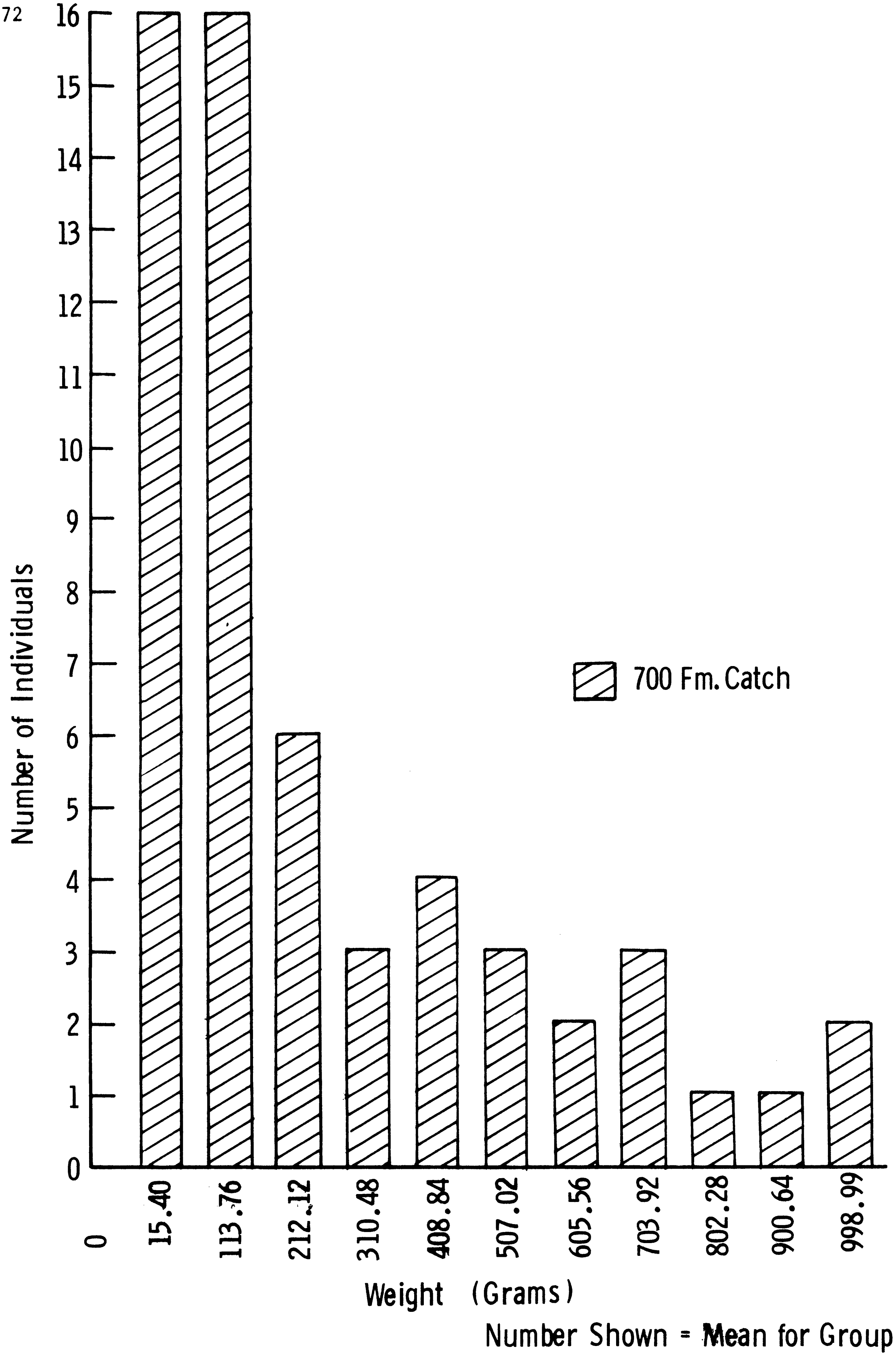


Figure 15. **Weight Frequencies:** *Alephocephalus agassizi*

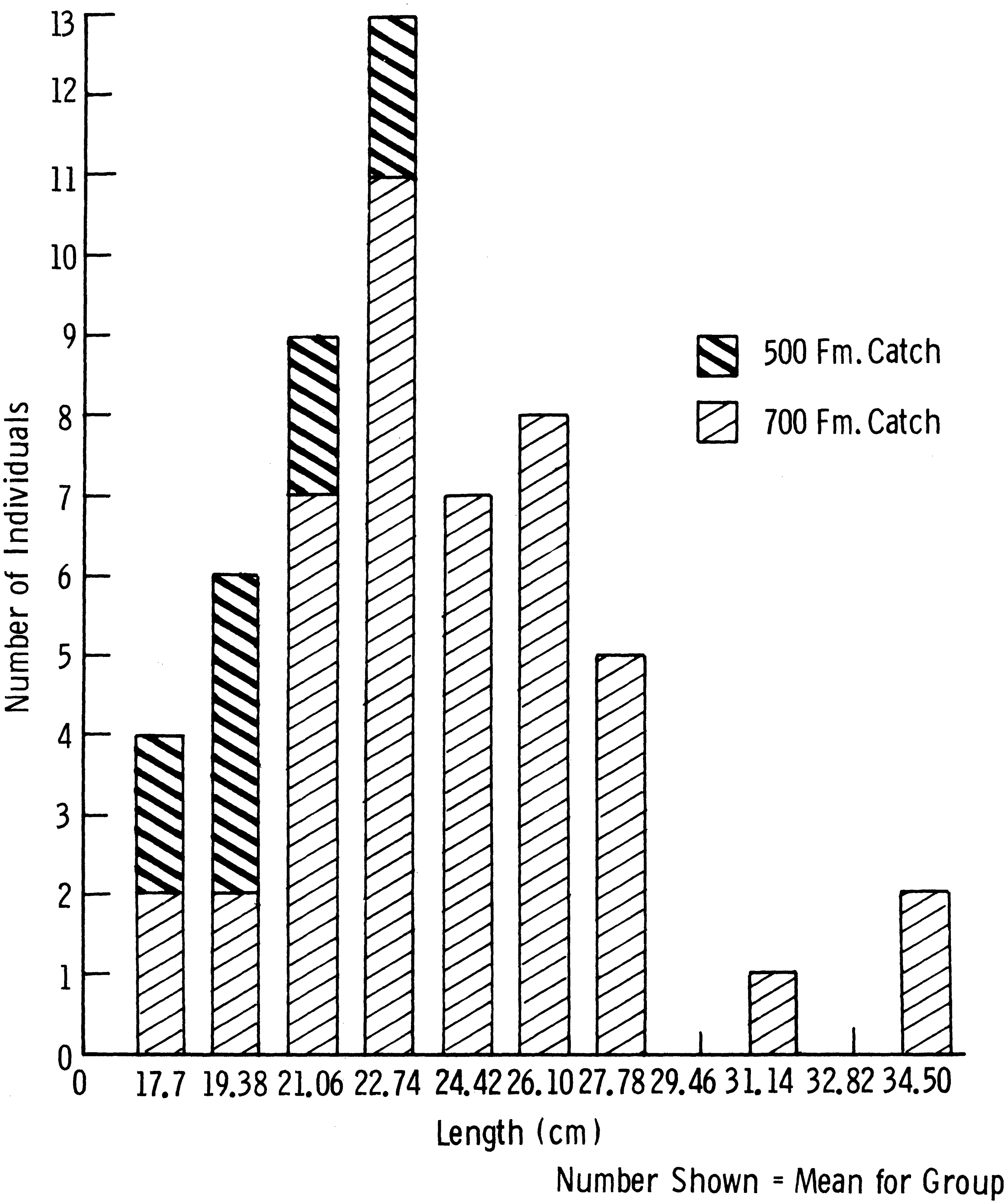


Figure 17. Length Frequencies: *Dicrolene intronigra*

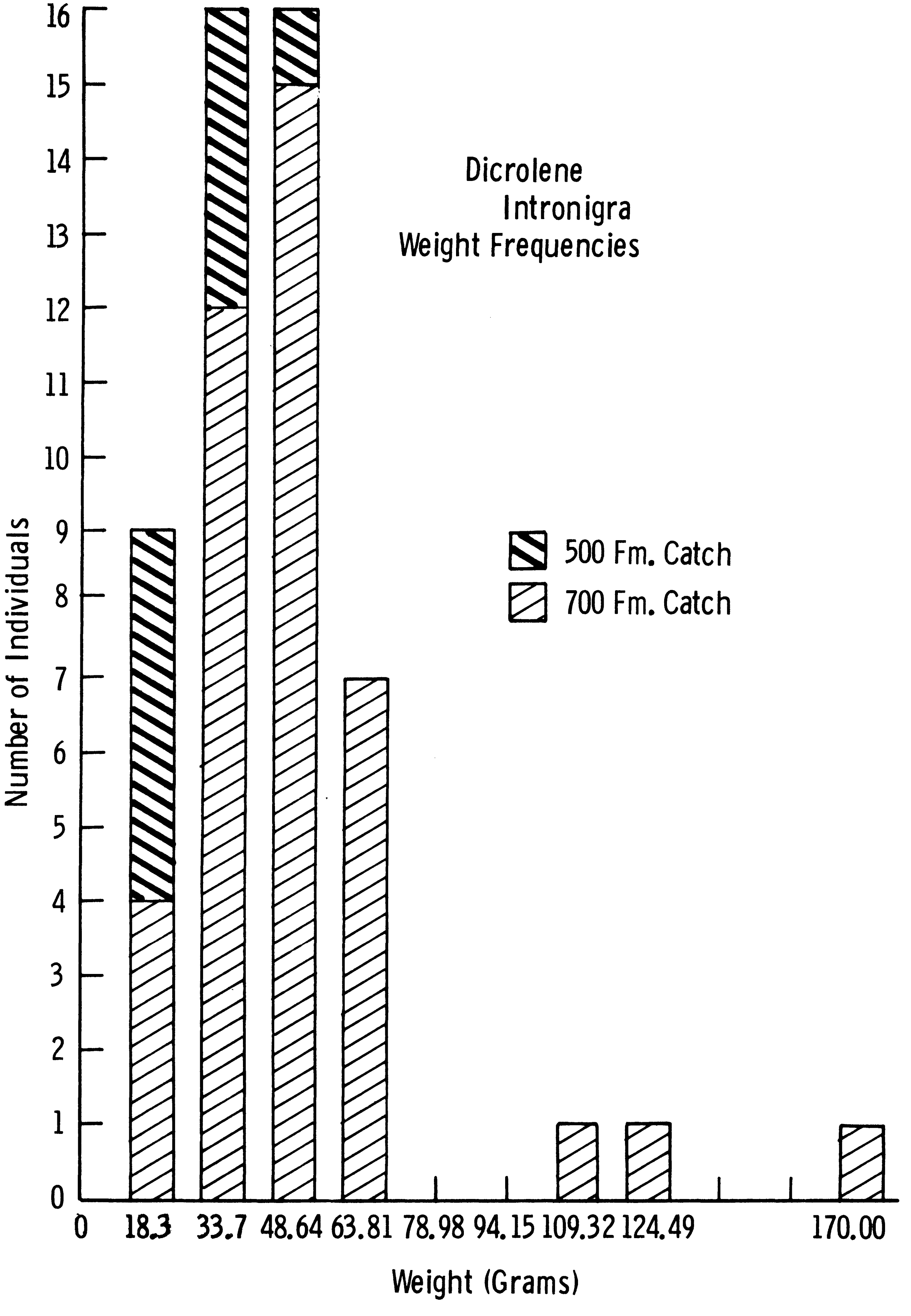


Figure 18. Weight Frequencies: *Dicrolene intronigra*

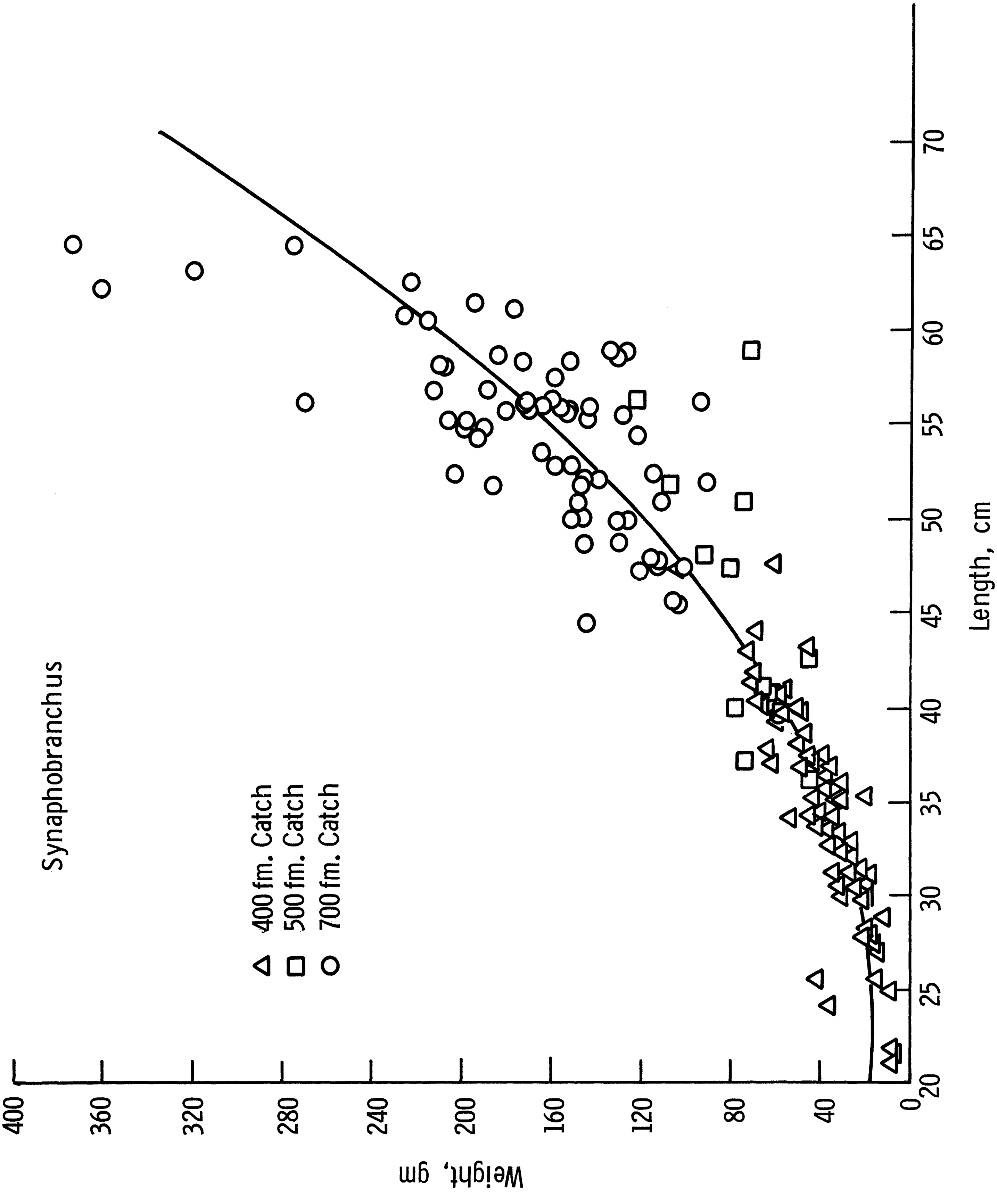
Alepocephalus agassizi was found only at 700 fathoms. From the length versus weight plot (Figure 13), the growth pattern is best fit by a quadratic curve (see Appendix). Length frequencies (Figure 14) show fairly even distribution and no real suggestion of different age groups. Weight frequencies (Figure 15) show distinct peaks at 113.76, 408.89, 709.92, and 998.99 gm.

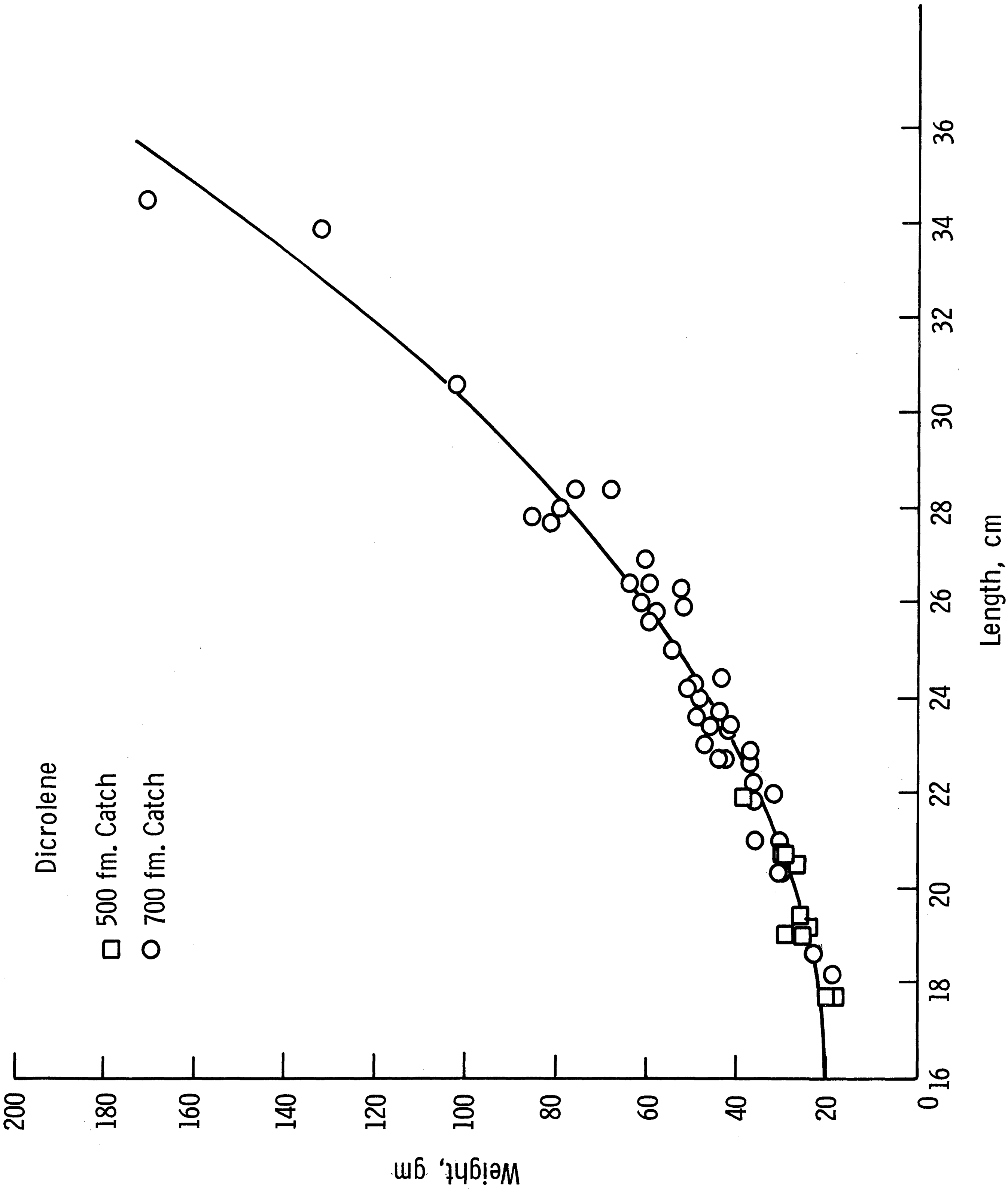
Dicrolene intronigra was found only in the 500- and 700-fathom catches. From its length versus weight plot (Figure 16), it indicates age increases with depth. The best line to fit these points is a quadratic curve (see Appendix). Length frequencies (Figure 17) indicate at least two populations, the first located around 22.74 cm. The weight frequencies (Figure 18) also support this division with two peaks at 41.27 gm and 116.89 gm.

CONCLUSIONS

More sampling must be done before any true conclusions can be reached. What has been observed here is a start and a guideline for further experimentation.

Four general conclusions have been found. First, *Synaphobranchus kaupi* and *Dicrolene intronigra* do show increase with age (size) with depth caught. Second, the growth curves for *Macrourus bairdii* and *Synaphobranchus kaupi* show linear tendencies, while *Dicrolene intronigra* and *Alipocephalus agassizi* do not. Third, as seen in the graphs of frequencies, *Macrourus bairdii* seems to have a growth rate of 6 cm/yr. *Dicrolene intronigra* has a growth rate of 11.86 cm/yr. Fourth, it is believed that weight frequencies do not show age groups as much, but can be used in conjunction with length frequencies to show different age populations of a given fish. *Dicrolene intronigra* is the best example of this.


Synaphobranchus
△ 400 fm. Catch
□ 500 fm. Catch
○ 700 fm. Catch
Weight, gm
0
40
80
120
160
200
240
280
320
360
400
Length, cm
20
25
30
35
40
45
50
55
60
65
70


Dicrolene
□ 500 fm. Catch
○ 700 fm. Catch
Weight, gm
0
20
40
60
80
100
120
140
160
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Length, cm
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18
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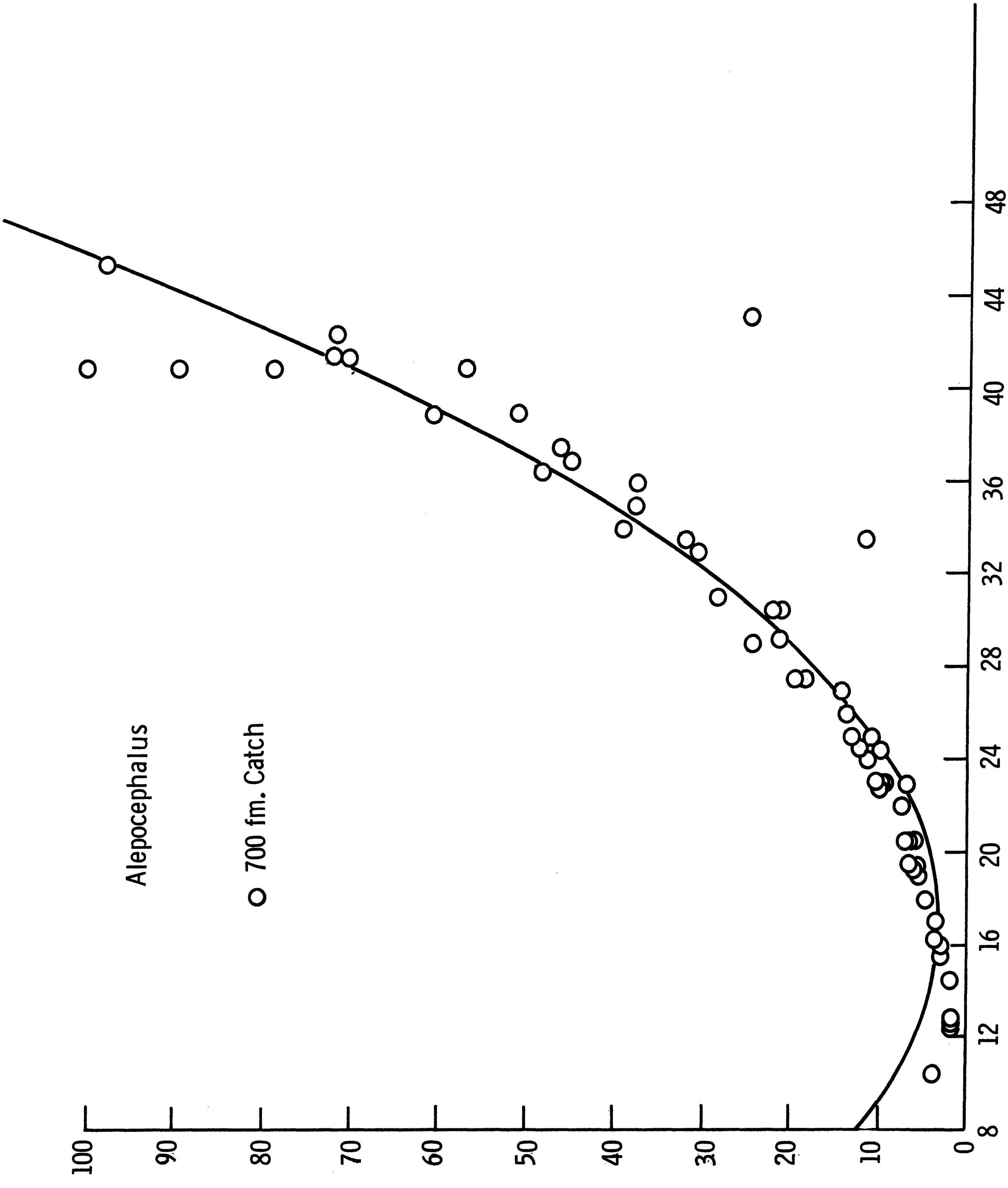
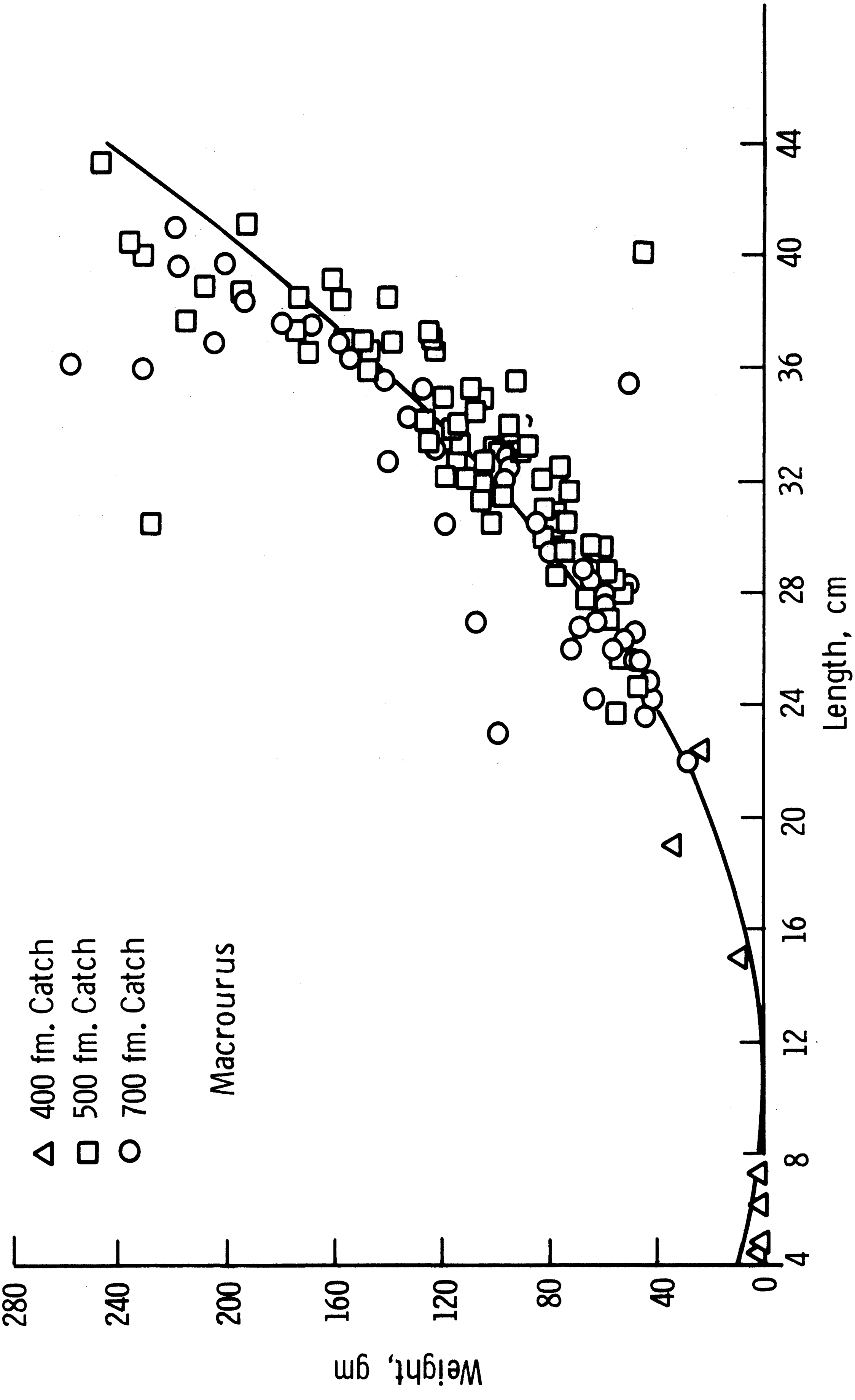
22
24
26
28
30
32
34
36


Alepocephalus
○ 700 fm. Catch
Weight, gm x 10
0
10
20
30
40
50
60
70
80
90
100
Length, cm
8
12
16
20
24
28
32
36
40
44
48


△ 400 fm. Catch
□ 500 fm. Catch
○ 700 fm. Catch
Macrourus
Weight, gm
0
40
80
120
160
200
240
280
Length, cm
4
8
12
16
20
24
28
32
36
40
44

SOURCES OF ERROR

These four conclusions are as general as possible because of the numerous areas of error encountered in the examinations. The first error is in the sampling methods--two different methods were used. The trawl at 400 fathoms used a smaller net (Isiacs Kidd mid-water trawl net) with very small mesh. This would result in the 400 fathoms having smaller fishes. The other two trawls, 500 fathoms and 700 fathoms, were with a 40-ft Gulf of Mexico shrimp trawl net (Kristjonsson, 1959). These allow small fish to slip through the mesh. This problem is best emphasized by the *Synaphobranchus* length frequencies graph (Figure 11), where one could conclude that *S. kaupi* has no mortality from one year to the next. Second, the lengths measured were not always correct because the specimens had broken tails and were no longer perfectly straight. Finally, the ability to weigh fish that are preserved in alcohol is far from accurate, since the alcohol evaporates and the fishes' weights drop.

ACKNOWLEDGMENTS

I wish to thank Dr. Richard L. Haedrich and Tracy McLellan for their assistance.

APPENDIX

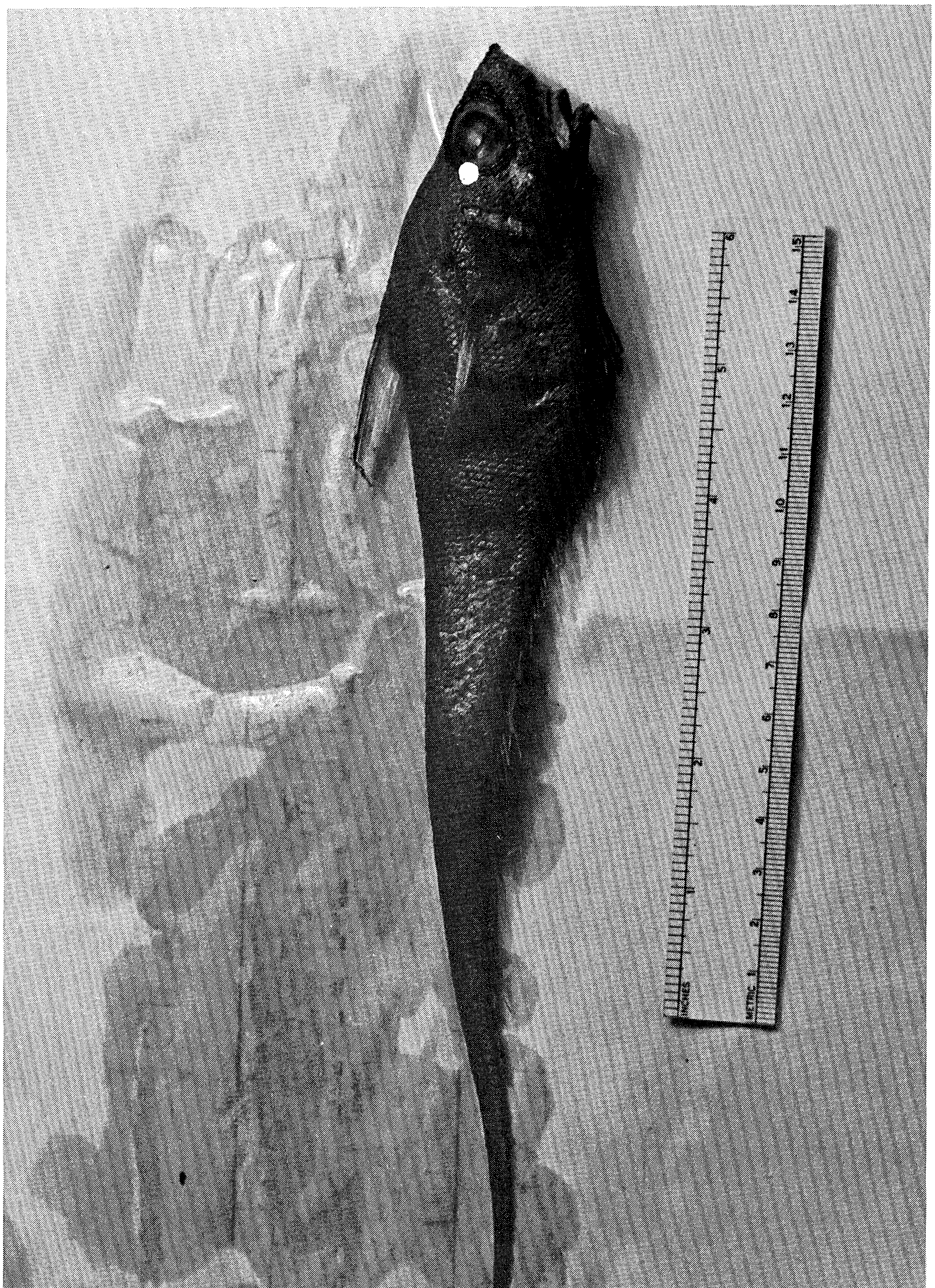
	Best Fit	Equation
Macrourus bairdii		
linear	216.04	$W = 105.4992 + 6.7240L$
quadratic	178.74	
cubic	119.69	
Synapobranchus kaupi		
linear	778.46	$W = 161.9850 + 5.8662L$
quadratic	538.59	
cubic	333.49	
Alepocephalus agassizi		
linear	248.09	$W = 351.9236 - 38.3459L + 1.1437L^2$
quadratic	398.87	
cubic	286.18	
Dicrolene intronigra		
linear	422.32	$W = 115.4563 - 12.0131L + 0.3799L^2$
quadratic	743.58	
cubic	596.95	

Dicrolene intronigra
Sample size = 55
Median weight = 47.57 gm
Median length = 23.38 cm

Macrourus bairdii
Sample size = 121
Median weight = 108.74 gm
Median length = 32.22 cm

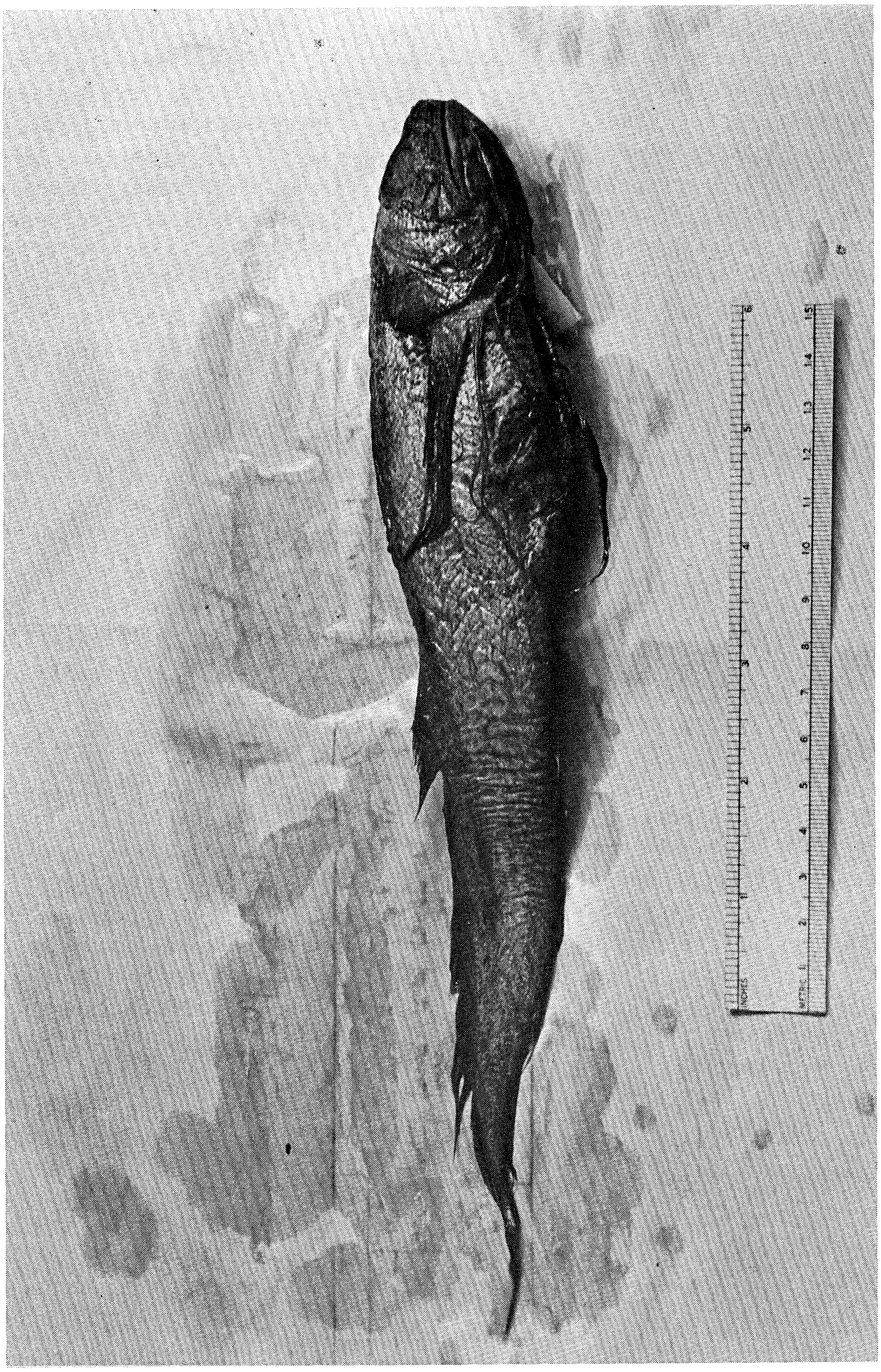
Synaphobranchus kaupi
Sample size = 179
Median weight = 87.75 gm
Median length = 42.59 cm

Alepocephalus agassizi
Sample size = 57
Median weight = 254.4 gm
Median length = 27.0 cm

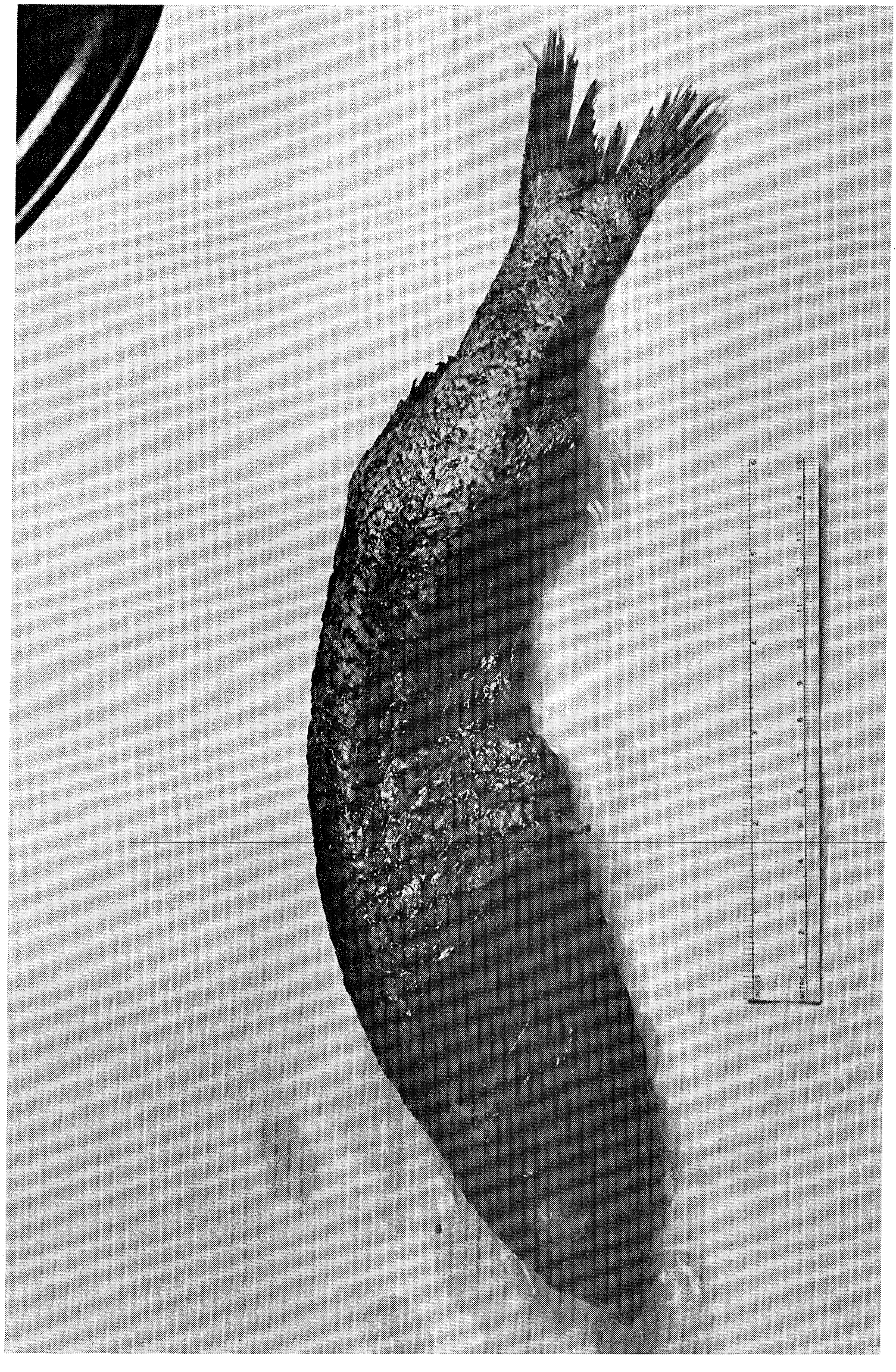


Macrourus bairdii

Synaphobranchus kaupi



Alepocephalus agassizi



Dricolene intronigra

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ANION RESPONSES FOR *CYCLOTELLA NANA*, *NAVICULA ELKAB*, AND *COSCINODISCUS RUDOLPHI*

George Sugihara

The problem posed in this paper is one of physiological ecology. Specifically, what are the effects of the anions $\mathrm{C\bar{O}_3}$, $\mathrm{S\bar{O}_4}$, and $\mathrm{C\bar{l}}$, on three species of diatoms: *Cyclotella nana* (clone 3-H), *Navicula elkab*, and *Coscinodiscus rudolphi*. Further, osmotic effects were tested for *C. nana* (3-H), an estuarine form isolated from Forge River at Moriches Bay, Long Island, New York. *N. elkab* and *C. rudolphi* were both isolated from carbonate lakes in Africa. The anion hypothesis, that a particular diatom species will be favored if grown in medium enriched with the anion that characterizes the water from which it was isolated, seems to be supported by the data for the three species tested. 3-H grew best with chloride enrichment, whereas *N. elkab* and *C. rudolphi* grew best in the carbonate solutions. This indicates that the presence or absence of a particular anion can be a limiting factor in determining dominance and species distribution. The osmotic investigation of 3-H indicated that osmotic pressure might not be a critical physiological factor, as might be expected for this euryhaline clone. The growth rate in solutions of higher osmotic pressure (.3333M and .6667M, where molarity of total dissociated ions in solution is some expression of osmotic potential), which characterize the environment from which *C. nana* (clone 3-H) was isolated, was lower than growth in the solution of lower osmotic value (.1669M). If the osmotic requirement was a sensitive and critical factor, then one would expect the reverse effect. The apparent effect of using an inert osmoticum to boost the osmotic pressure of a stock nutrient solution (WC medium) is to dilute the basic nutrients on a particle level, thus reducing the mass activity of nutrients in solution. At a constant osmotic pressure (.3333M) a higher ratio of nutrients to osmoticum yielded higher growth rates for *C. nana* (clone 3-H).

INTRODUCTION

The primary purpose here was to use differential growth responses to anions to categorize ecologically three species of diatoms: *Cyclotella nana* (clone 3-H), *Navicula elkab*, and *Coscinodiscus rudolphi*. This categorization of species by favored anion types can have important implications for paleolimnology and the geochemical evaluation of closed-basin lakes. In addition to the anion study, a study of the osmotic response of *C. nana* (clone 3-H) was made.

Kilham (1971) discussed the geochemical evolution of closed-basin lakes and arrived at a classification of these lakes by prevalent anion types: $C\overset{=}{O}_3$, $S\overset{=}{O}_4$, and $C\bar{l}$. Hecky and Kilhan (in press) found a parallel between the species succession of diatoms and the geochemical evolution of a closed basin as characterized by the major anion. The field evidence, then, seemed to point to anions as being important factors in determining what species of diatoms attained dominance. Other attempts at the ecological categorization of algae have been made: Droop (1958) thinks that sodium tolerance might be the most important factor in distinguishing between neritic and supra littoral estuarine species; Provasoli (1958) suggested that the optimal monovalent/divalent ion or Ca/Mg ratios might be important; Droop (1958), and McLachlan (1960) suggest that potassium is important.

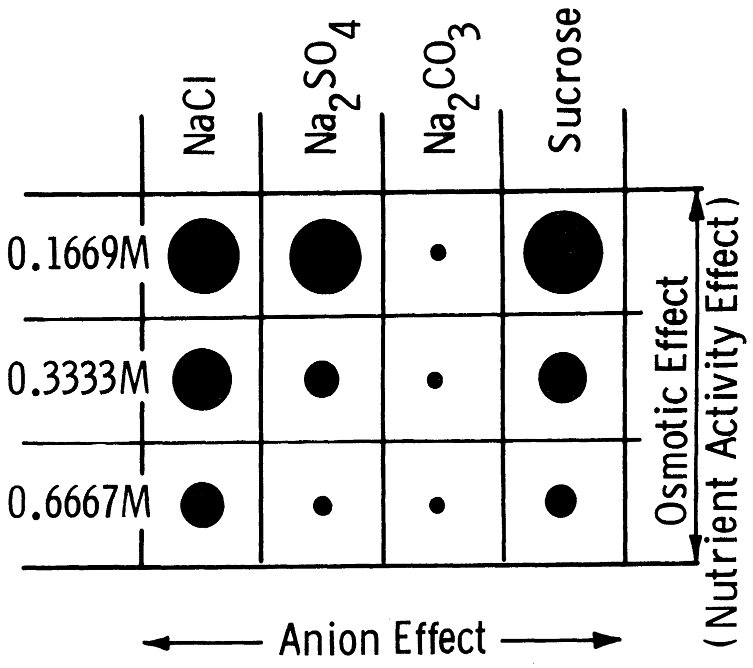
C. nana (clone 3-H) was isolated from the Forge River, Moriches Bay, Long Island, New York, and has been part of the Woods Hole Oceanographic Institution's culture collection for more than 14 years. Much study has been made of this species; however, no anion or osmotic information was available for this clone. *N. elkab* and *C. rudolphi* were recently isolated from African carbonate lakes, but no literature aside from an ecological field study (Hecky and Kilham [in press]) was available.

METHODS

Experiment 1: Anion Effects at 3 Osmotic Pressures for C. nana *(3-H)*

Preparation of Growth Mediums

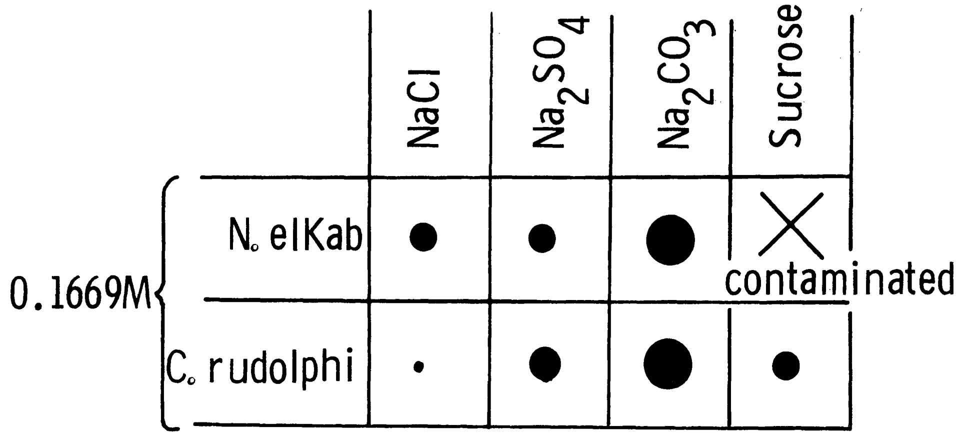
Twelve growth mediums were prepared in concentrations of 0.1669M, 0.3333M, and 0.6667M by adding NaCl, Na_2CO_3, Na_2SO_4, and sucrose, as osmoticums, to a stock growth medium of 0.0079M (see Figure 1A for experimental design). Molarity in this paper is taken as the molarity of total associated ions and is a direct expression of osmotic potential.



Anion Effects are Read Horizontally and Osmotic Effects are Read Vertically.

Note: Osmotic Effects Were Found to be More Probably Nutrient (see figure 1c.)

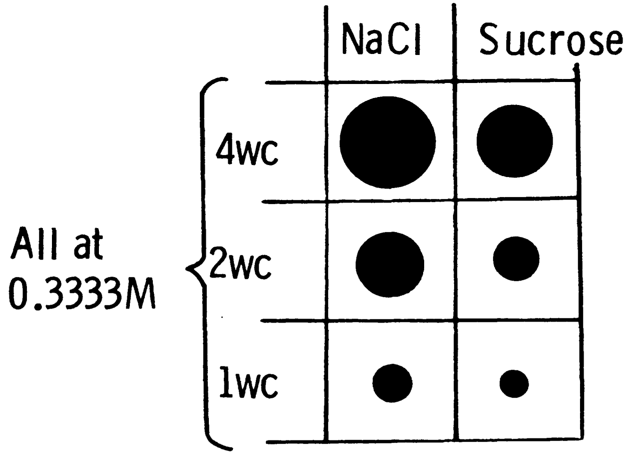
(a)



(b)

Figure 1. (a) Experiment 1: Anion Effects at Three Osmotic Pressures for 3-H, Diagrammatic Representation of Experimental Design and Growth Responses for *C. nana* (clone 3-H); (b) Experiment 2: Anion Effects for *N. elkab* and *C. rudolphi*, Diagrammatic Representation of Experimental Design and Growth Responses for *N. elkab* and *C. rudolphi*

NOTE: The size of the dots is a diagrammatic representation of growth rate (d). This technique was employed to compare three variables two-dimensionally.



(c)

Figure 1 continued. (c) Experiment 3: Nutrient Activity Effect, 3-H

The three molarities chosen were one-sixth, one-third, and two-thirds that of 32 percent sea water (Harvey, 1966). A freshwater stock medium (WC) was used at double strength and was chosen over an enriched seawater medium (f-2) to prevent complexing and the formation of precipitates. One hundred-milliliter portions of each solution were poured into 250-ml Erlenmeyer flasks, stoppered with cotton and gauze plugs, and autoclaved. The carbonate was added, under sterile conditions, to the double-strength medium (2 WC) after autoclaving to prevent the formation of precipitates (Kilham, personal communication).

Preparation of Inoculum and Incubation

C. nana (clone 3-H) was in sterile culture at Woods Hole Oceanographic Institution in a 32 percent enriched seawater medium (f-2). To avoid the effects of osmotic shock, which would ensue if one were to inoculate directly into less concentrated solutions, transfer solutions were prepared (Guillard, personal communication). These consisted of f-2 media diluted to 0.1669M, 0.333M, and 0.6667M. Serial inoculations were made as follows: The 0.6667M solution was inoculated first and allowed to grow; then the diatoms from this flask were transferred to the next lower concentration and so on. One-milliliter, sterile inoculations were made from the transfer flasks to the experimental flasks. The cultures were kept at about 20° C under a light intensity of 4000-5000 lux and with a day/night cycle of 14/10 hr.

Observation of Growth

The Coulter particle counter was used daily to observe growth in this experiment. It was necessary to add acid (HCl) to the portion being counted to dissolve any precipitate that might otherwise be counted. Three counts were taken for each portion and averaged. Any anomalous values were checked by counting cells in a haemocytometer. At the end of the experiment the pH of the solutions was determined by an electronic pH meter.

Data Treatment

The numbers obtained from the Coulter counter and haemocytometer were multiplied by the dilution factors to find the cell numbers per 0.5 cc of culture. These numbers were then plotted against time on semilog paper, and straight-line Michaelis-Menton relationships were interpreted. The values found on the line in the region of active growth were then used to calculate divisions per day (d) using the formula

$$d = \ln \frac{C_t}{C_o} \frac{1}{t \ln 2} ,$$

where C_t and C_o are cell concentrations at times t and o, respectively.

Experiment 2: Anion Effects on Navicula elkab *and* Coscinodiscus rudolphi *at 0.1669M*

In this experiment I prepared four growth mediums, each containing an osmoticum (NaCl, Na_2SO_4, Na_2CO_3, and sucrose) added to double-strength WC medium, to obtain an osmotic value of 0.1669M (see Figure 1B for experimental design). The methods discussed for experiment 1 all apply here. In addition, because *N. elkab* was not isolated in sterile culture standard antibiotic, agar-plate techniques were used. Further, *N. elkab* was grown also in polycarbonate flasks to prevent these silica glutens from sticking to the glass. *C. rudolphi* was isolated in sterile culture at Woods Hole Oceanographic Institution.

Experiment 3: Osmotic Effect vs. Nutrient Activity Effect for C. nana *(3-H)*

Here, three different concentrations of WC medium (4 WC, 2 WC, and 1 WC) were prepared and used NaCl and sucrose as the osmoticums to boost the osmotic value to 0.3333M for all the solutions (see Figure 1C for the experimental design). The methods discussed for experiment 1 were all applicable here except that the inoculum was taken from the growth flasks of experiment 1 one week after that experiment was completed, eliminating the need for transfer solutions.

RESULTS AND DISCUSSION

To better understand the interpretation of the data, a brief description of the physiological implications of anions and osmotic pressure is in order. Also, the concept of stress will be elucidated. Dissolved salts have two kinds of effects on organisms: the osmotic effect and the effects characteristic of the particular ions in solution (Guillard, 1962). Both of these effects are at work on the level of the membrane. A plant cell membrane acts as a selective barrier defining the sap from the surrounding liquid. Osmosis represents a passive transport of solvent across this membrane due to a concentration gradient. This concentration gradient can be maintained by an ion transport mechanism which by active expenditures of energy transports ions into and out of the cell. Further, the ions in solution control membrane permeability, supposedly by a pH effect (Stadelmann, 1962). Thus, the most obvious ways that changing the ionic medium can influence diatom growth is by influencing ion transport and permeability (Guillard, 1962). Further, a high osmotic pressure causing an unbalanced amount of material to "leak" into the cell can cause interference in enzymatic pathways and thus growth inhibition (Sunda, personal communication). Thus, deviation of types of ions and of osmotic values of growth mediums can represent physiological stresses.

Here, stress is defined as the resiliency requirement of an organism, in light of its physiological capacity, to respond to an environmental factor which is not at its optimum value. So, as an organism's capacity to handle a particular stress changes, the magnitude of that stress changes. Of concern then, is the effect that increasing one particular stress has on lowering the cell's resistance and increasing its susceptibility to other stresses, thus magnifying the effects of the other stresses.

Diagrammatically,

$$\sum S = aS_1^{\alpha} + S_1^{\beta}S_2^{\gamma} + cS_2^{\delta} ,$$

where the total stress (ΣS) is the cross product sum of two stresses S_1 and S_2. By increasing S_1, the sensitivity of S_2 is increased.

Osmotic Effect on C. nana *(3-H)*

At first review of the osmotic data for experiment 1 (see Graphs 1, 2, 3, and Figure 1A), it appeared that there was a definite correlation between growth rate (d) and osmotic pressure. The more physiologically inert sucrose was perhaps the best indication of the osmotic requirement. It "appeared" that growth rate (d) for *C. nana* (3-H) was inhibited at the higher osmotic values. This apparence, however, seemed in error for two reasons: First, on the basis of osmotic pressure, one would expect a higher growth rate at the two high osmotic values if osmotic stress were critical. These higher values are close to the average osmotic value of the waters from which the clone 3-H was isolated and so would exert the smallest osmotic stress. Second, because the clone 3-H is euryhaline and thus must be euryosmotic, one would not expect osmotic requirements for this clone to be very critical. Hence, it was concluded that the effects that were witnessed were not osmotic effects, but were perhaps due to competition by the osmoticum with the nutrients for sites on the membrane. The mass activity, then, of the nutrients may have been reduced by the addition of an osmoticum.

To test this hypothesis, another experiment was set up at a constant osmotic pressure and with different concentrations of nutrients, giving different proportions of nutrients to osmoticum (experiment 3).

The data seem to fit the hypothesis (see Graphs 6 and 7,* and Figure 1C); at a constant osmotic value (0.3333M) a higher ratio of nutrients to osmoticum yielded higher growth rates (d).. The stress witnessed in experiment 1, then, was not an osmotic response but was probably due to the competition by the osmoticum with the nutrients for sites on the membrane--"nutrient mass activity effect."

Hence, the osmotic requirement for the estuarine 3-H does not appear to be a critical stress since it is not surprising for this euryhaline clone. Guillard and Myklstad (1971) have made a study of the osmotic requirement of a *C. nana* taken from a Sargasso Sea (clone 13-1). They found osmotic pressure to be a sensitive factor for this marine centric diatom.

An interesting side study was made of the possibility that the apparent osmotic response might have been a response to pH (see Graph 8). However, the pH readings were made at the end of the experiments and therefore are probably not very valid. Also, the correlations found look rather nebulous. This is an area which could be pursued.

Another interesting study could be to grow 3-H in a medium with a particular osmotic and ionic composition, then lyse the cells to find out the differences between the composition of the sap and the growth medium. Doing this for different osmotic pressures and different anions could provide valuable data that would clarify what is actually going on in the cell when it is responding to these stresses.

Anion Effect

In experiment 1, a tendency is seen for the effects of the individual anions tested to become more pronounced for higher molar concentrations (see Graphs 1, 2, and 3); preferential growth for the different anions becomes more pronounced. This is consistent with the concept of

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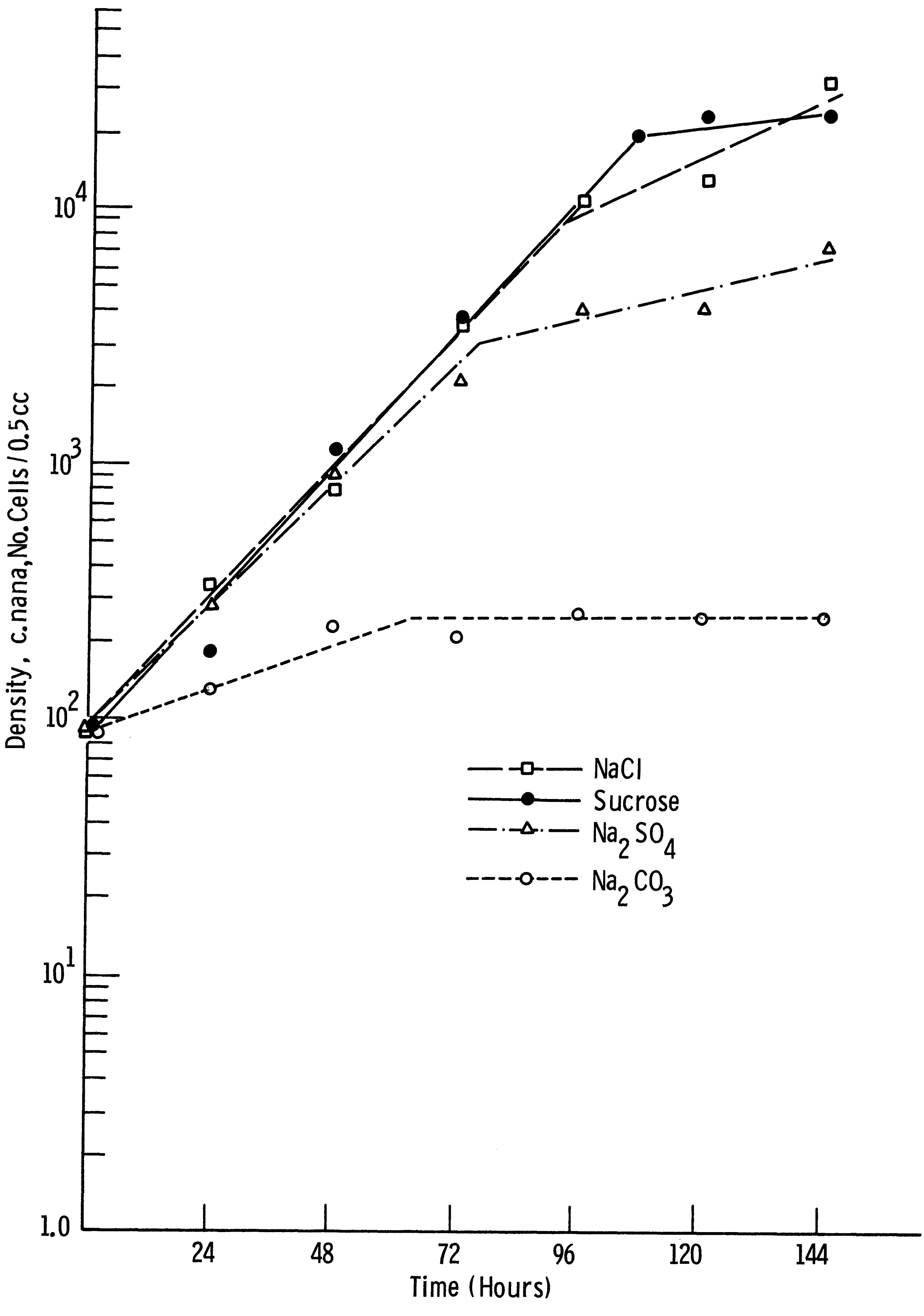
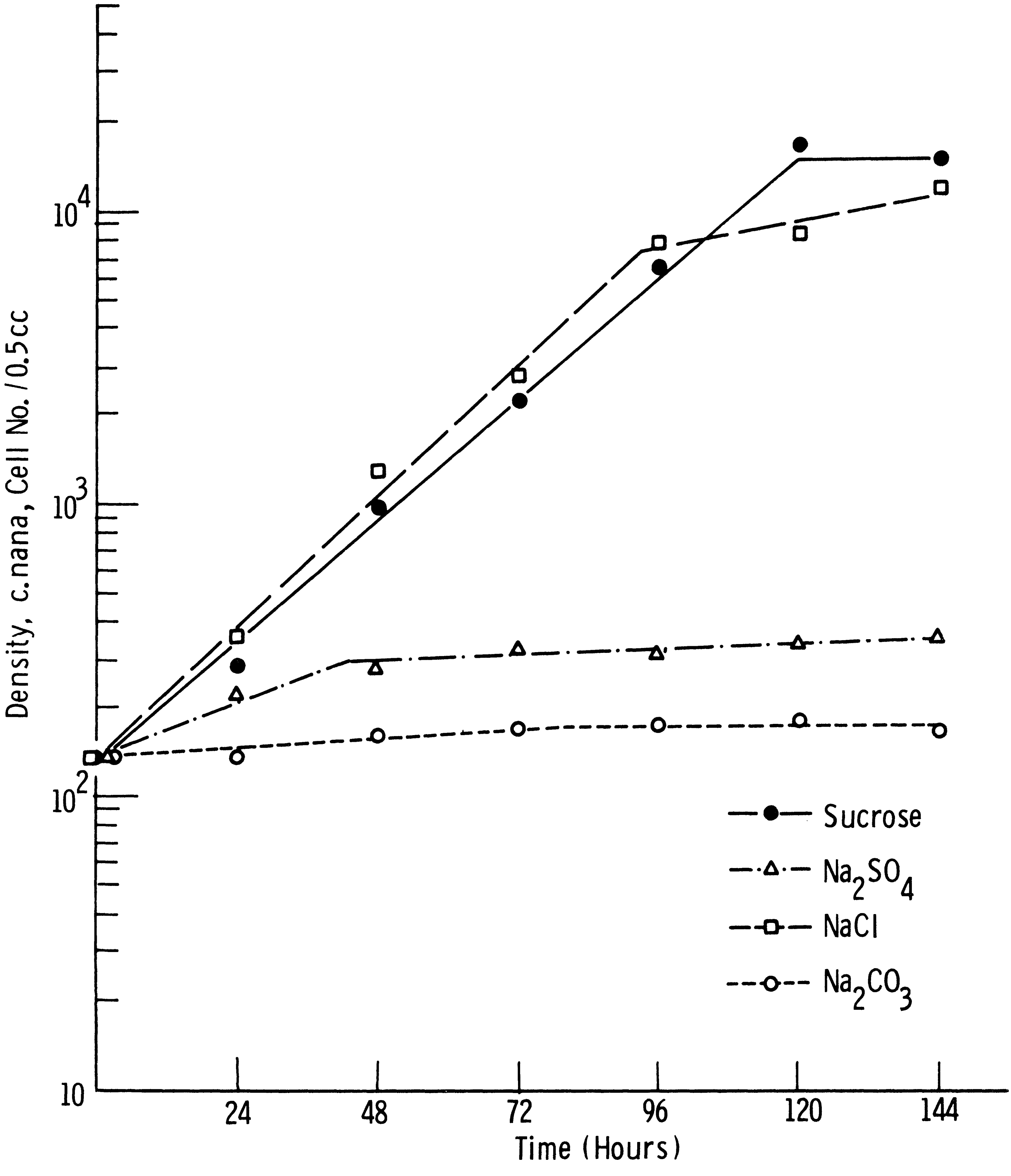
*The graphs are not presented in order.



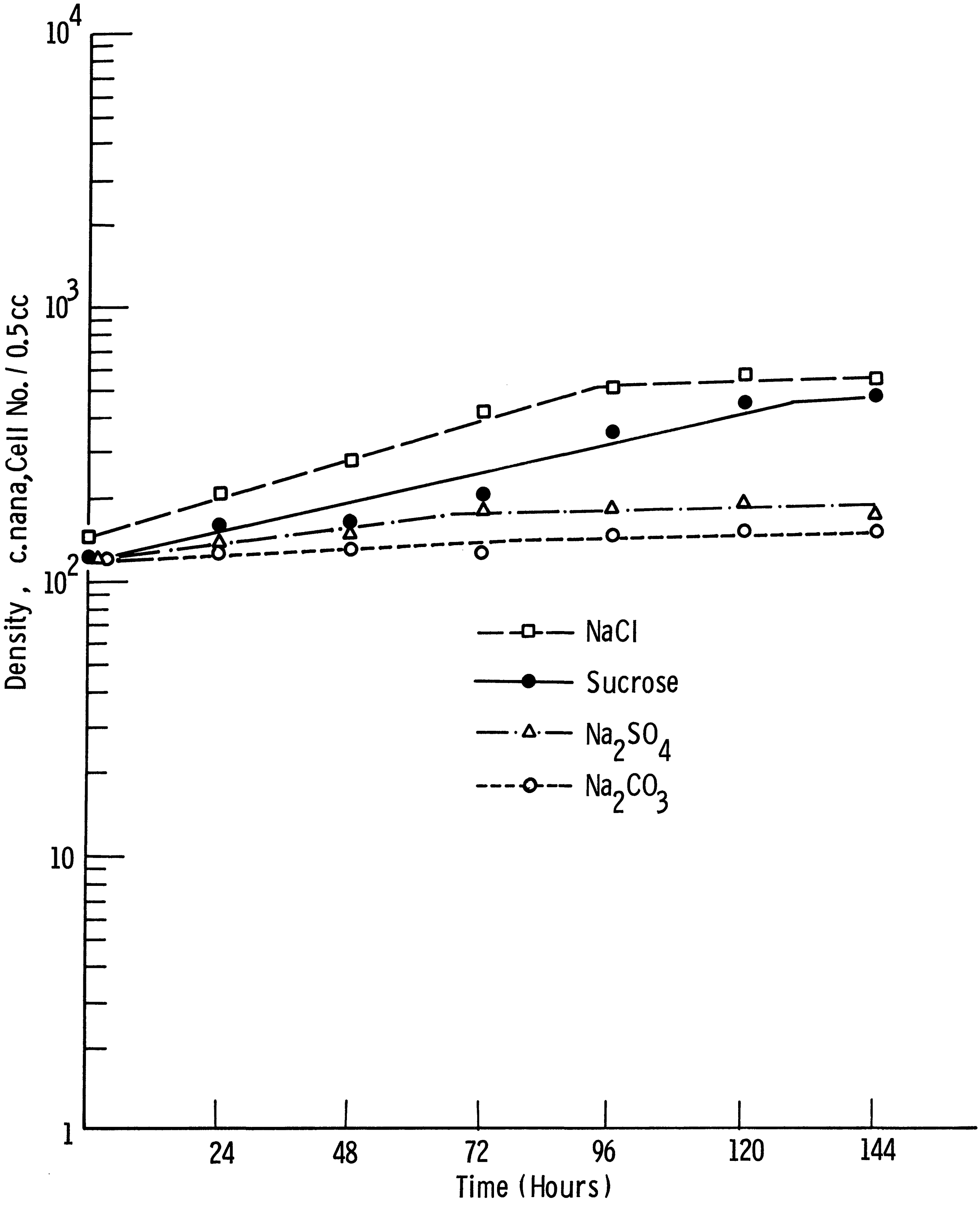
Graph 1. Growth Response to Anions (Experiment 1): Concentration of *C. nana* Cells/0.5 cc vs. Time (Hours)

Growth medium = 0.1669M



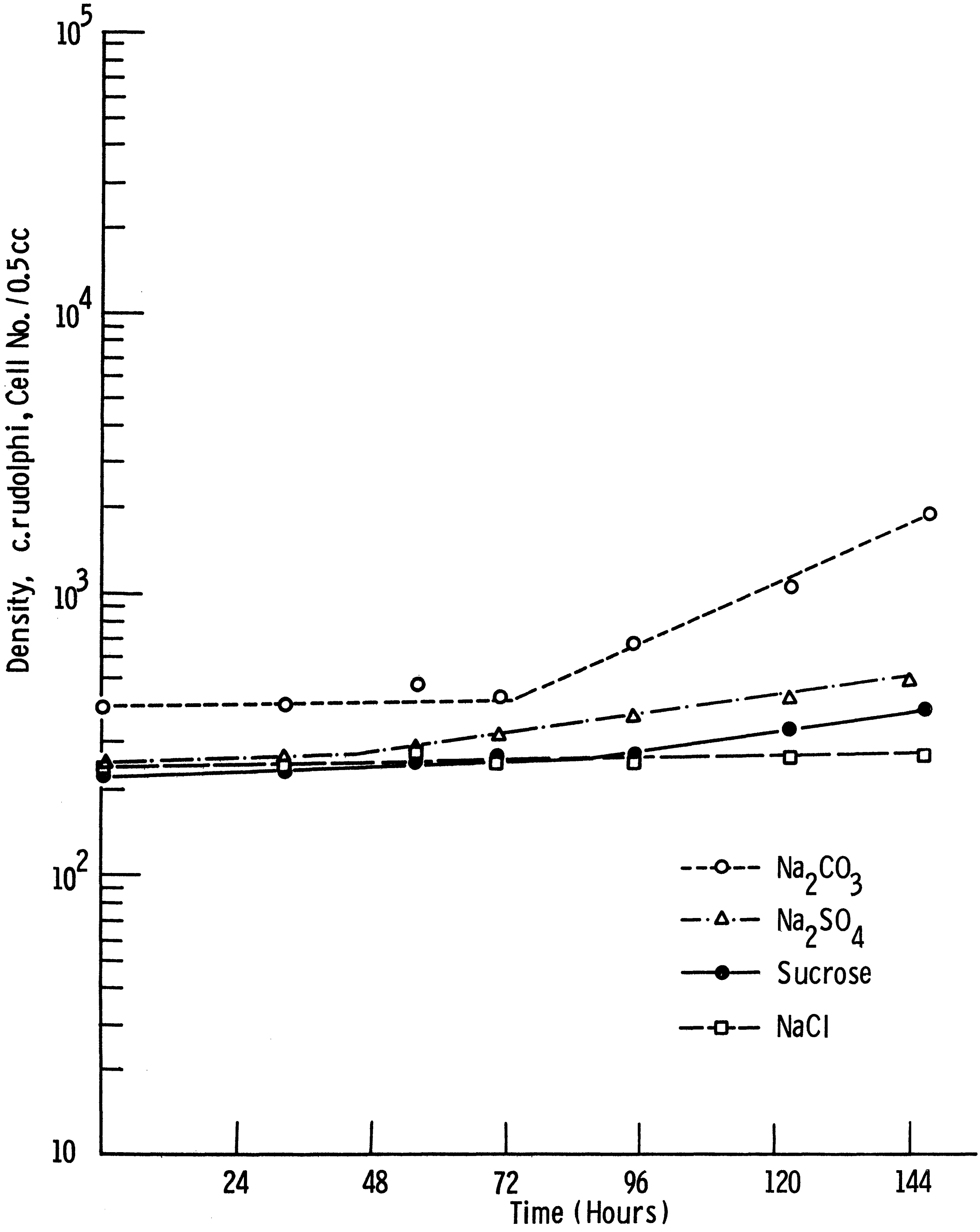
Graph 2. Growth Response to Anions (Experiment 1): Concentration of *C. nana* Cells/0.5 cc vs. Time (Hours)

Growth medium = 0.3333M



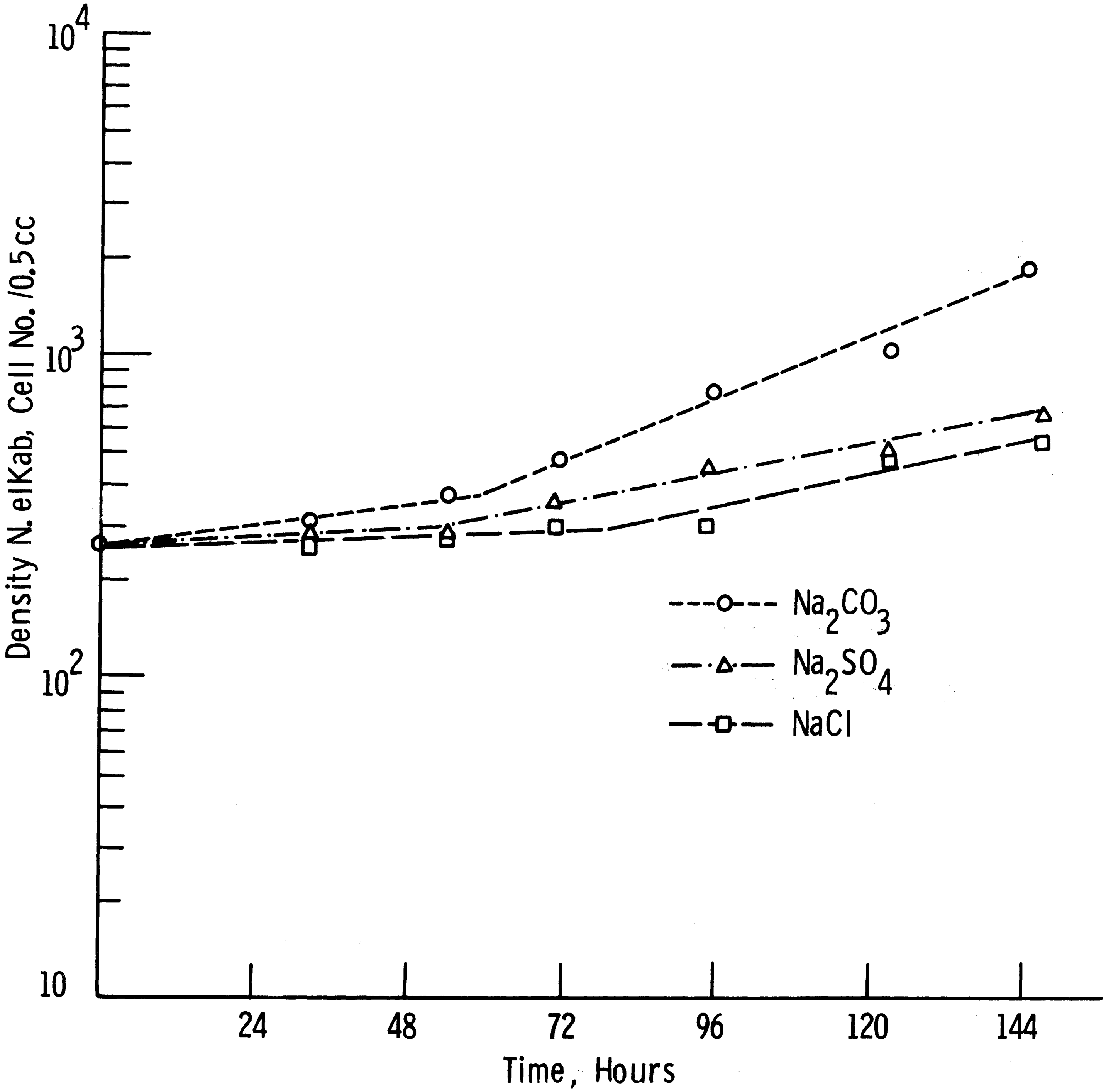
Graph 3. Growth Response to Anions (Experiment 1): Concentrations of *C. nana* Cells/0.5 cc vs. Time (Hours)

Growth medium = 0.6667M



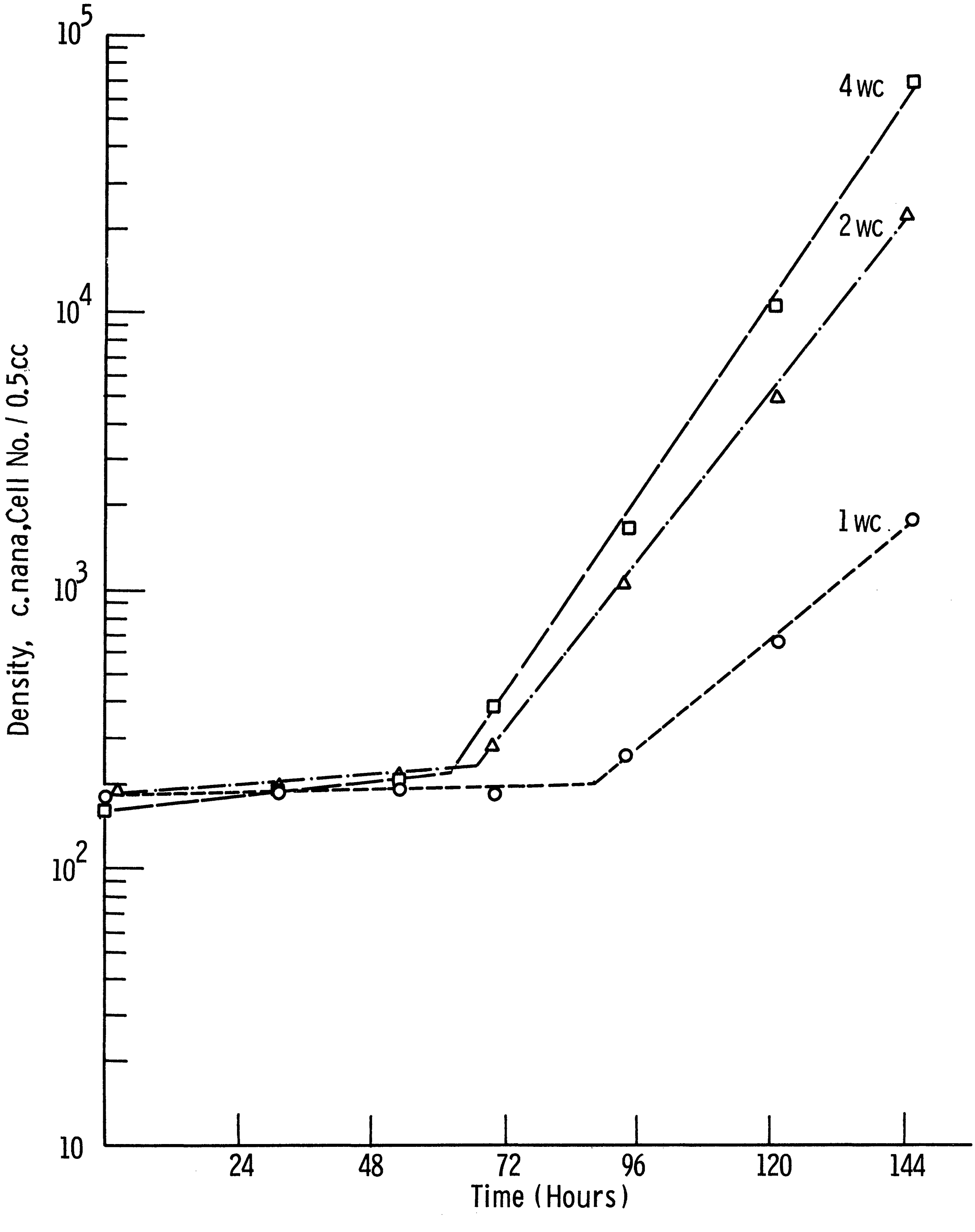
Graph 4. Growth Response to Anions (Experiment 2): Concentration of *C. rudolphi* Cells/0.5 cc vs. Time (Hours)

Growth medium = 0.1669M



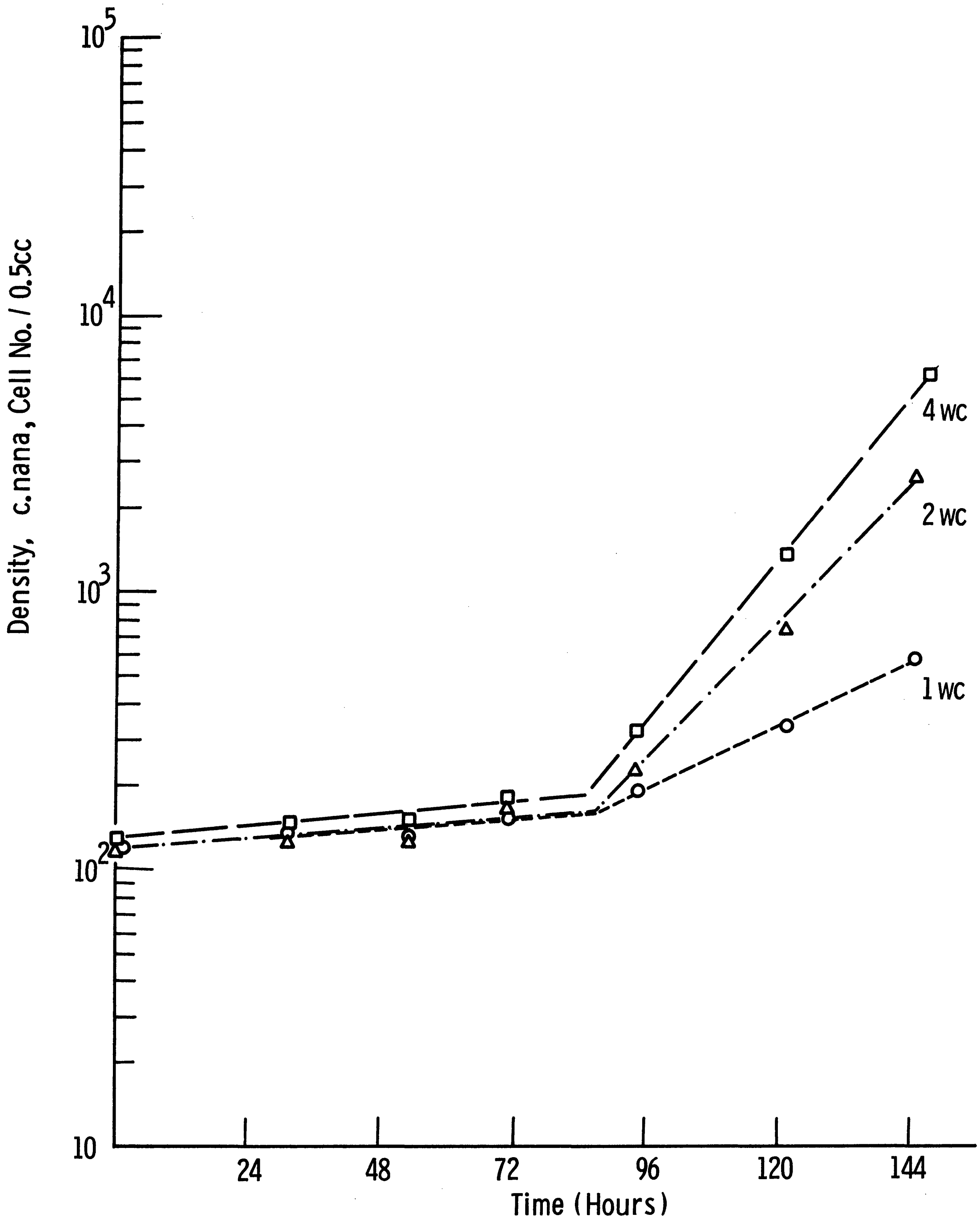
Graph 5. Growth Response to Anions (Experiment 2): Concentration of *N. elkab* Cells/0.5 cc vs. Time (Hours)

Growth medium = 0.1669M



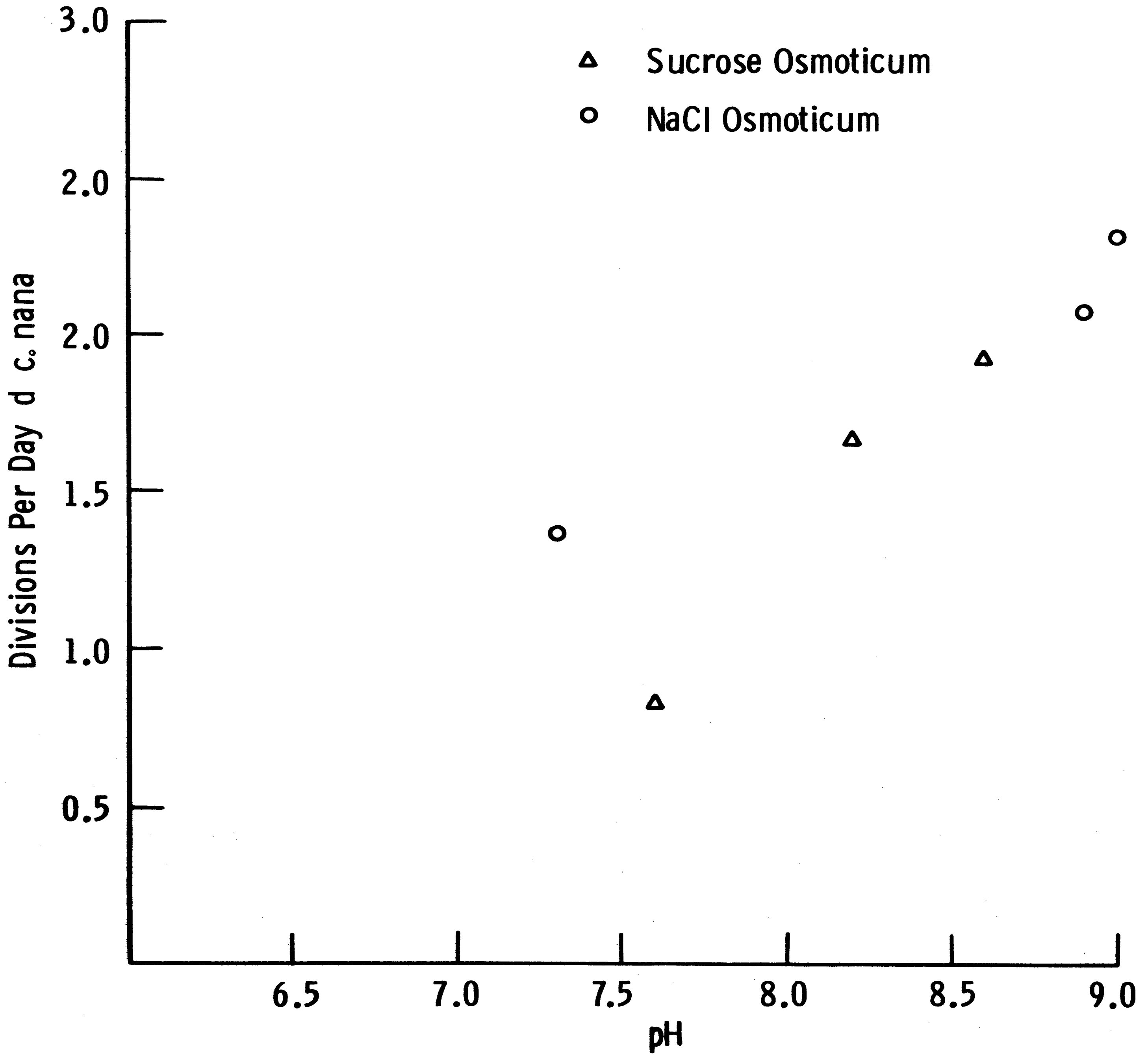
Graph 6. Growth Response to Different Concentrations of Basic Growth Medium (WC) at Constant Osmotic Pressure (0.3333M) (Experiment 3): Concentration of *C. nana* Cells/0.5 cc vs. Time (Hours)

Osmoticum = NaCl



Graph 7. Growth Response to Different Concentrations of Basic Growth Medium (WC) at Constant Osmotic Pressure (0.3333M) (Experiment 3): Concentration of *C. nana* Cells/0.5 cc vs. Time (Hours)

Osmoticum = Sucrose



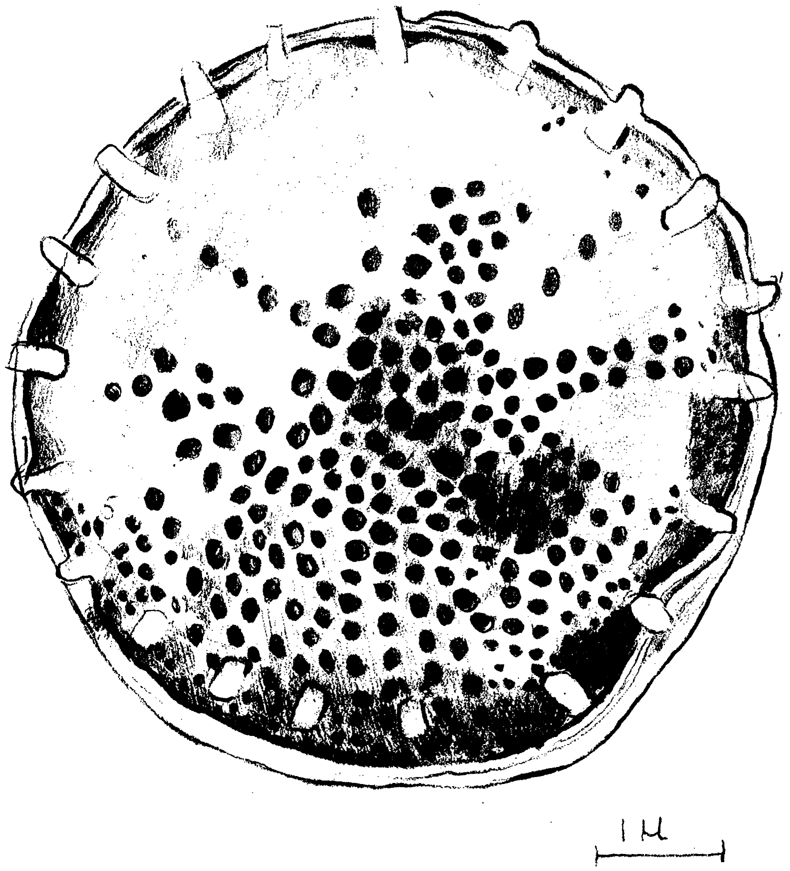
Graph 8. Possible pH Effect on Growth (d) for *C. nana*: Divisions/Day (d) vs. pH

stress, where at higher molar concentrations there is increased stress due to decreased nutrient activity. This increase in stress, then, tends to magnify the effect of the different anions. The anionic affects are most clearly witnessed in the 0. 6667M solution (see Graph 3 and Figure 1A). The curves in Graph 3 show that chloride is preferred, as would be predicted ecologically for *C. nana*. The fact that SO_4 and CO_3 produce growth rates below that attained for inert sucrose indicates that they perhaps exert an inhibitory effect on growth for *C. nana* (3-H). The early leveling-off of the curves might be due to complexing of nutrients by the anions (Kilham, personal communication). Calcium and magnesium, both important nutrients (Droop, 1968; Provasoli, 1958), can be complexed out by these anions.

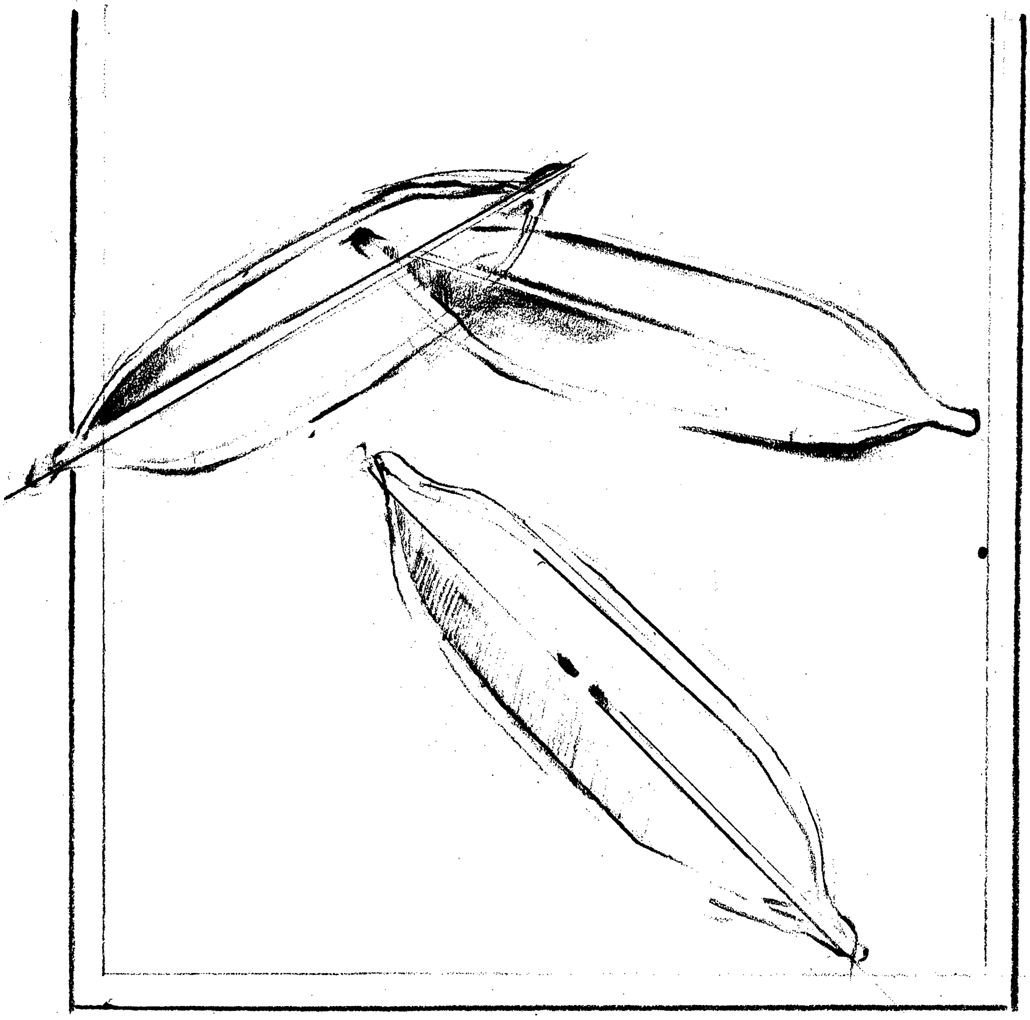
In experiment 2, both *N. elkab* and *C. rudolphi* show a preference to carbonate enrichment at an osmotic pressure of 0.1669M (see Graphs 4 and 5, and Figure 1). This finding is in agreement with ecological considerations for these diatoms. Both *N. elkab* and *C. rudolphi* were isolated from carbonate lakes.

ACKNOWLEDGMENTS

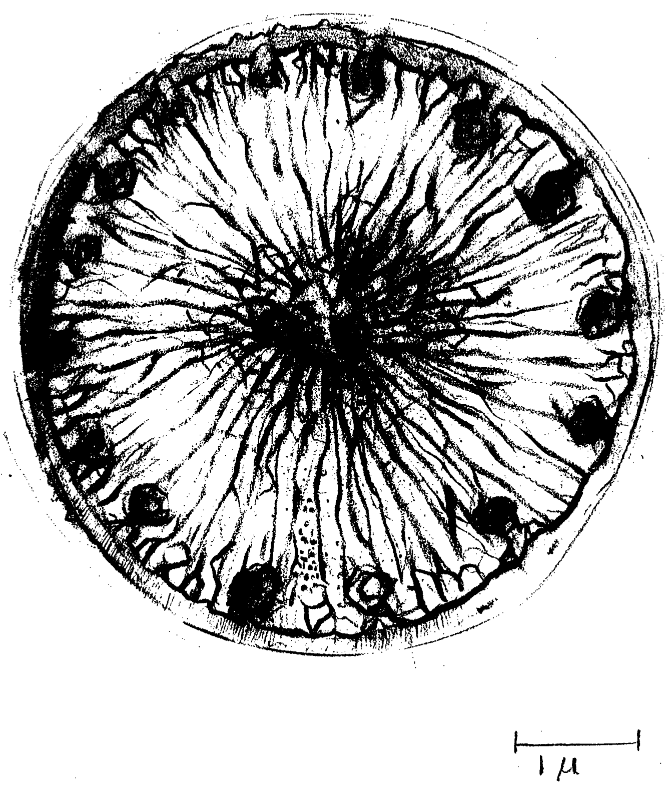
I would like to thank Dr. P. Kilham for his undaunted encouragement, assistance, and advice on this project. Also, I would like to thank Dr. S. Kilham, Dr. Guillard, and the members of Dr. Guillard's laboratory for their advice and assistance.

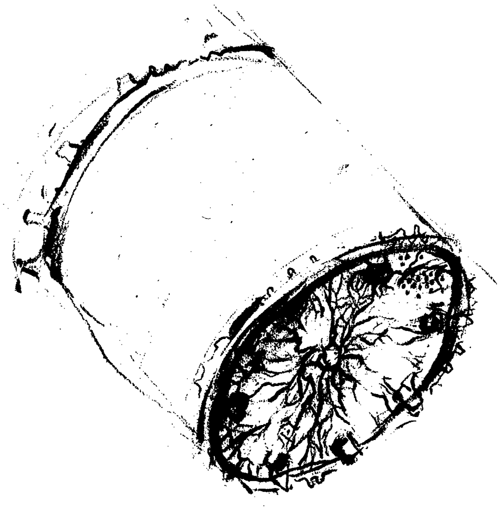


COSCINODISCUS RUDOLFI



NAVICULA ELKAB





CYCLOTELLA NANA

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R/V *KNORR* CRUISE #25 V

As part of The University of Michigan's M&O 560 course, ten students joined the R/V *Knorr* for leg V of cruise #25. This leg began on 30 April 1972 in San Juan, Puerto Rico, and ended in Woods Hole, Massachusetts, on 9 May 1972. During the cruise, six deep hydrographic stations and one large-volume station were occupied, 13 Neuston tows and eight oblique plankton tows were made, and 153 bathythermographs were taken. Three subsurface, anchored, current-meter moorings were recovered and a continuous watch was kept on the echo sounder.

The University of Michigan students were assigned regular four-hour watches, during which they were responsible for the echo sounder log and the bathythermograph lowerings and were required to assist during station operations. The following summaries of activities were written by the various watches: the summary of activities, 4-8 watch; the nightly seminars, 8-12 watch; and the profiles of the hydrographic station data, 12-4 watch.

SUMMARY OF ACTIVITIES ABOARD R/V *KNORR* CRUISE #25 V

Upon joining the research vessel (R/V) *Knorr* in San Juan, Puerto Rico, the students of the M&O 560 course were allowed a period of time to familiarize themselves with the ship. During this time a reading list of books in the ship's library was assigned by Mr. Marvel Stalcup to acquaint the students with the equipment and principles they would be using while on board. These readings were designed to supplement the instruction that the students received in handling instruments and equipment, and methods for interpreting instrument readings and recording data and samples obtained.

The students learned to use instruments such as the bathythermograph (BT), an instrument designed to give water temperature as a function of depth. Taking a BT consisted of lowering and retrieving the instrument and, in addition, interpreting the tracing made by the BT on the smoked-glass BT slides, plotting the information graphically, while keeping a log of the time, position, and environmental conditions when the BT was taken. The BT slides were then labeled and preserved with shellac.

A precision graphic recorder (PGR) was used to display the depth and record sea floor profiles determined by high-frequency echo sounding. Records obtained from the PGR had to be labeled frequently for easy interpretation, and an extensive log was kept of the depths recorded and any changes in the operating mode of the machine or any special remarks.

With this basic information, the students were split into three groups and each group was assigned to one of the three watches (12-4, 4-8, and 8-12 am and pm) under the direction of one of the experienced scientists on board. Watch duties included taking BTs every hour, monitoring the PGR, keeping all log books up to date, plotting data from previous hydrographic stations, and assisting in any of the experiments conducted on any oceanographic stations that occurred during their watch.

In addition to the BT and PGR logs, a geophysical log was kept. This was used to record any occurrence while underway that could be potentially useful information to anyone, along with the time and position of the event. All types of information were recorded, from sighting marine life to passing ships, as well as operations on board the ship.

Most of the biological sampling required little assistance by those on watch, but on the second day of standing watch, hydrographic sampling began. Hydrographic stations consisted of taking water samples and in situ temperatures at depth using Nansen bottles with reversing thermometers. Students learned to set up hydrographic stations; prepare the Nansen bottles; place them on the winch line and retrieve them; draw and preserve water samples from the bottles for dissolved oxygen, silicate, and salinity measurements; and to read the in situ temperatures recorded by the reversing thermometers. Sonar pingers on the end of the winch line were used to determine how far down the winch line extended, and students learned to tell the distance from the pinger to the bottom from PGR tracings and oscilloscope displays. Students also learned to analyze the water samples obtained and the procedures for correcting the in situ temperatures recorded by the reversing thermometers. Bowen bottles were used to occasionally take large-volume samples, which were then stored in labeled barrels on deck. Extensive hydrographic station logs were kept, as well as individual logs, recording the data from water sample analyses.

Watches occasionally helped the biologists aboard with Neuston and plankton tows, usually performed at low speeds. In addition, sargassum was gathered by long-handled nets for studies on the energetics of the sargassum community. An aquarium maintained on deck generally was populated with sargassum, crabs, shrimp, copepods, file and trigger fish, and other planktonic and larval organisms.

On the fourth day of watch, the ship retrieved several subsurface buoys supporting current meters that had been set out several months before. These were released from the bottom by sonar signals and had to be located by radio fixes because rough seas made them difficult to see. Night pickup was facilitated by a flashing strobe light on the buoy, but this could not be seen in daylight.

In addition to the regular duties of the watch, students kept a narrative log describing the unique events and feelings of the students on watch. A brief summary of the highlight events of this log follows.

1-V-72	12-4 am	A fire drill was conducted.
2-V-72	12-4 am	The first large-volume sample was taken.
	12-4 pm	13 Nansen bottles, 4 Niskin bottles, a sonar pinger and bottom camera assembly, and about 1200 m of wire rope were lost in about 5000 m of water when the winch line kinked and parted during a hydrographic station.
	4-8 pm	1-m core taken in 5000 m of water on the end of a winch line with 14 Nansen bottles. Core was a calcareous brown ooze.
	8-12 pm	A very spectacular thunderstorm took place.
3-V-72	8-12 am	Neuston and plankton tows were conducted.
4-V-72	12-4 am	The first subsurface buoy was retrieved.
	4-8 am	The last wraps of the BT wire were painted in an effort to prevent too much line from being let out, but the paint didn't hold.
	4-8 pm	The last subsurface buoy was picked up after a 2-hr search for it in moderate seas.
5-V-72	1925 GMT	A Lyle gun test (a rocket-propelled line-throwing device) was conducted to meet Coast Guard regulations.
	12-4 pm	Two oceanographic movies (Gulf Stream, Sargasso Sea) made aboard the R/V *Knorr* were shown. The water temperature was getting colder.
6-V-72		The ship began to pitch as well as roll.
	8-12 am	The seas began to calm and the sun came out. A Portuguese Man-o-War was captured in a Neuston tow and placed in a tank on deck.
	12-4 pm	A Navy plane circled the R/V *Knorr* a number of times. A school of porpoises was sighted and purple copepods began to replace the blue copepods of the Sargasso Sea.

8-V-72	12-4 am	BTs were taken every half hour as the ship crossed the Gulf Stream due to the unusual temperature distribution across the Stream.
	4-8 am	Half-hour BTs continued to be taken. The color of the sea changed from blue to grey and it was hazy all day long. A larger herd of porpoises was sighted and herring gulls began to follow the ship.
	4-8 pm	Thick fog set in and didn't lift until morning.
9-V-72	8 am	Arrival at Woods Hole, Massachusetts.

READING LIST
UNIVERSITY OF MICHIGAN M & O 560
R/V KNORR CRUISE #25
SAN JUAN - WOODS HOLE

THE FOLLOWING LIST OF SELECTED READING MATERIAL HAS BEEN RATHER ARBITRARILY DIVIDED INTO TWO SECTIONS. THE REFERENCES IN SECTION I DEAL PRIMARILY WITH THE TECHNIQUES AND INSTRUMENTS USED TO COLLECT HYDROGRAPHIC DATA AT SEA. MANY OF THESE INSTRUMENTS HAVE BEEN IN USE FOR DECADES AND, IN THE HANDS OF SKILLED OBSERVERS, HAVE PROVIDED MOST OF THE DATA UPON WHICH OUR KNOWLEDGE OF THE WATER MASSES AND CURRENTS ARE BASED. NEW INSTRUMENTS ARE CONTINUALLY BEING DEVELOPED AND TESTED, BUT ONLY A VERY FEW EVER GAIN WIDE ACCEPTANCE.

IT IS IMPOSSIBLE TO OVER-EMPHASIZE THE IMPORTANCE OF OBTAINING ACCURATE DATA. THE PRECISION OF THE INSTRUMENTS PLACES AN UPPER LIMIT ON THE ACCURACY AND, IN GENERAL, THE INTEREST AND CAPABILITY OF THE OBSERVER DETERMINES THE LOWER LIMIT. ON MOST OF OUR CRUISES, WE MEASURE TEMPERATURE TO +/- 0.01 DEG. C.; DEPTH TO +/- 0.5 PERCENT; SALINITY TO +/- 0.003 PPT; OXYGEN TO +/- 0.1 ML/L; AND SILICATE TO BETTER THAN 0.5 MICROGRAM ATOMS/L.

SECTION II CONTAINS REFERENCES WHICH DESCRIBE THE MANNER IN WHICH THE HYDROGRAPHIC DATA ARE USED TO DESCRIBE THE VARIOUS WATER MASSES AND DEDUCE THE CIRCULATION PATTERNS IN THE ATLANTIC OCEAN. WORTHINGTON'S PAPER DESCRIBES A PORTION OF THE PROBLEM WE HAVE BEEN STUDYING DURING KNORR CRUISE #25.

WE WILL CROSS THE GULF STREAM ON OUR WAY TO WOODS HOLE. STOMMEL AND FUGLISTER'S STUDIES OF THE GULF STREAM HAVE BEEN INCLUDED TO PROPARE YOU FOR OUR CROSSING OF THE "STREAM". IF WE ARE FORTUNATE, YOU WILL SEE MANY OF THE SURFACE FEATURES THESE AUTHORS DESCRIBE.

PLEASE DO NOT REMOVE THESE REFERENCES FROM THE LIBRARY!

M. C. STALCUP
1 MAY, 1972

SECTION I

THE OCEANS - SVERDRUP, JOHNSON, & FLEMING

CHAPTER X OBSERVATION AND COLLECTION AT SEA

INTRODUCTION TO PHYSICAL OCEANOGRAPHY - VON ARX

CHAPTER I EARLY EXPLORATION AND IDEAS
CHAPTER 8 CURRENT MEASUREMENTS BY DIRECT METHOD
CHAPTER 9 CURRENT MEASUREMENTS BY INDIRECT METHODS

A PRACTICAL HANDBOOK OF SEAWATER ANALYSIS - STRICKLAND & PARSONS

PP11-26 SALINITY AND DISSOLVED OXYGEN DETERMINATION
PP65-70 DETERMINATION OF REACTIVE SILICATE

H.O. PUBLICATION #607

CHAPTERS A,C,D,E,R

SECTION II

THE OCEANS - SVERDRUP, JOHNSON, & FLEMING

CHAPTER XV PP604-686, 740-741, 745-755

INTRODUCTION TO PHYSICAL OCEANOGRAPHY - VON ARX

CHAPTER 11

GENERAL OCEANOGRAPHY - DIETRICH
PP 487-500, 529-537 WATER MASSES IN THE WARM WATER SPHERE
PP 135-146 CURRENT MEASUREMENTS

ATLANTIC OCEAN ATLAS - FUGLISTER

THE GULF STREAM - STOMMEL

CHAPTERS 1,2,3,4,5

COLLECTED REPRINTS

1963 #1246 GULF STREAM '60 - FUGLISTER
1966 PART I, #1744 RECENT OCEANOGRAPHIC MEASUREMENTS IN THE CARIBBEAN SEA - WORTHINGTON

SEMINAR SUMMARIES

Each night aboard the R/V *Knorr*, we heard seminars about various aspects of the cruise. Several dealt with projects that individual scientists were doing on the ship, but most dealt with topics that we would be directly involved in during the cruise. In many cases, these seminars served to clarify the motives behind the "field work" of the day.

On the first night, Dick Flegenheimer, the ship's second mate, gave a talk entitled "Operation of the *Knorr*--A View from the Bridge," designed to acquaint us with the "driving of the boat," so to speak. A unique feature of the *Knorr*, a research vessel owned by the Navy and operated by the Woods Hole Oceanographic Institution, is that it is propelled by cycloids which give greater maneuverability for oceanographic sampling. (We were most impressed when the ship pulled into the dock at WHOI *sideways!*) Steering and change of speed are accomplished by changing the pitch of the cycloid blades. Another unique feature is the autopilot, which eliminates manual steering and thus gives the crew greater freedom to answer calls like "Bridge, this is Fantail; permission to do a BT," the hourly source of adrenalin stimulation for all of us. The R/V *Knorr* uses the satellite system (same one the Navy uses) for navigation; when this is not functional, the navigational systems Loran and Omega are employed. (During watch, we were responsible for getting hourly navigational fixes from the bridge.)

The next night, the topic of deep-sea mooring was broached by Bob Heinmiller, whom some of us knew as "Big Bob." This seminar was to acquaint us with types of moorings used in oceanographic information gathering. Surface, subsurface, and deep-sea moorings were described, since we would be retrieving three National Science Foundation moorings equipped with current meters. Such moorings are brought up from the bottom by an acoustically operated anchor release system. Problems with mooring systems were discussed, such as mechanical failures, fishbite, and vandalism.

Randy Borys spoke the next night on hydrographic stations, since we would be making quite a few stations on this leg of the cruise. A hydrographic cast is one of the basic oceanographic tools used in sampling the water column. A cast consists of hanging Nansen bottles at metered intervals on a cable which is lowered to a predetermined depth. Hopefully, the bottles will be triggered by a messenger sent down the cable, causing the bottles to reverse and collect a water sample. However, as we found out, this doesn't always happen. The water samples we collected were analyzed for silicates, salinity, and dissolved oxygen.

Brian Tucholke spoke on deep-sea sediments and on the use of everyone's friend, the precision graphic recorder (PGR), and its use in giving a bottom profile. The PGR can be used to tell how far the deep-sea camera is from the ocean floor.

And what about the biological oceanographers? Well, they weren't to be forgotten. Consider the seminar Dr. Edward Carpenter gave on nitrogen fixation. Nitrogen may be the limiting nutrient in the open ocean, but it is uncertain what is limiting in the Sargasso Sea. Few organisms can fix atmospheric nitrogen, but recently oceanographers have found that a blue-green algae, *Trichodesmium,* has the ability to fix nitrogen, the extent of fixation determined by Ed via acetylene reduction.

Dr. Ken Smith's seminar was on availability and utilization of carbon in the deep ocean. Ken gave what he considered five sources of organic carbon in the deep sea: fecal pellets (carbon concentrators), molts (collection surfaces for dissolved organics), turbidity currents (transport), mortality of large marine animals, and the so-called "ladder effect." Ken's technique for determining utilization of carbon in the deep sea involved a series of Bell jar experiments to test for BOD and COD (biological and chemical oxygen demand).

Dr. Ivan Valiela talked about salt marshes and discussed his project--an attempt to determine if the process of filter feeding in copepods was selective rather than random. This was done by using colored glass beads of various diameters in a salt water medium containing copepods and noting which size classes were ingested. The mortality of "feeding" copepods glass beads was not discussed at this seminar.

Rich Johnson wrapped up the seminar series with a rousing rendition of "Circulation at the Surface of the World Ocean." Rich also summarized the research he did during the past month aboard the *Knorr* in trying to determine the flow regime over the sill separating the Caribbean Sea from the Atlantic Ocean.

All seminars were conducted in an informal fashion in the ship's library. Other "seminar" sessions were even more informal and were designated as "happy hours," but the material discussed in these has been omitted for the purposes of this paper.

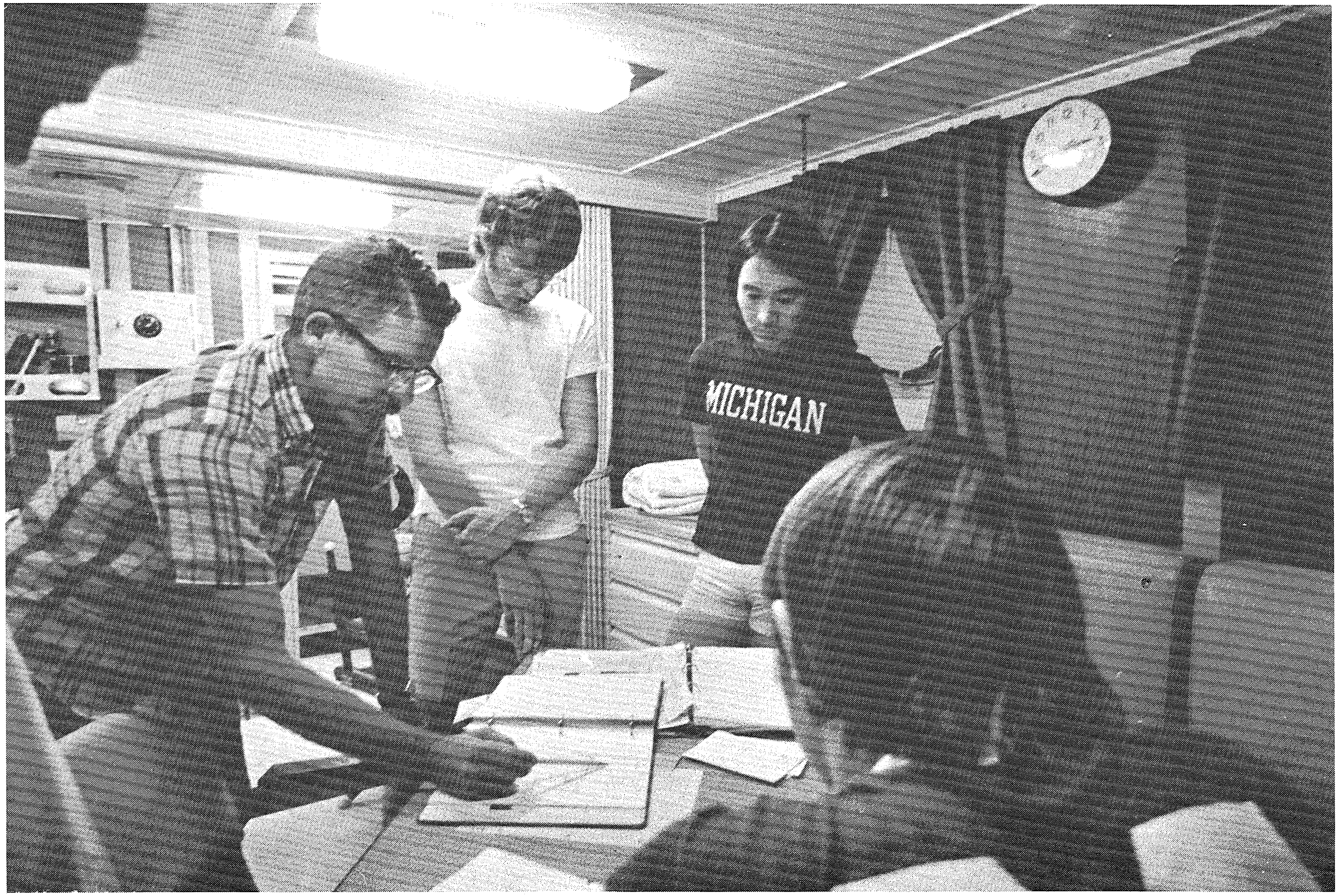


Figure 9. Student Instruction Aboard R/V *Knorr* by Marv Stalcup

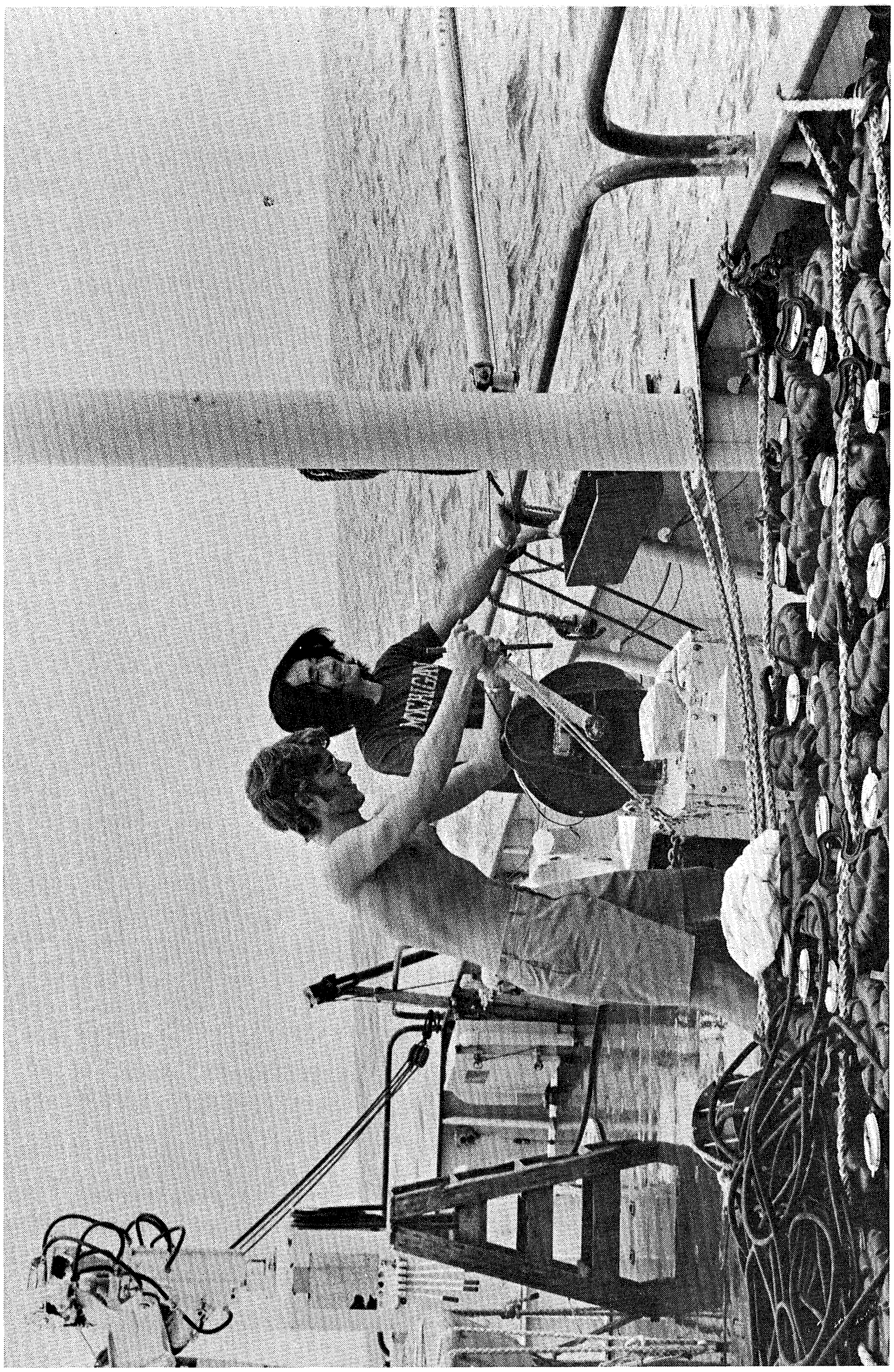
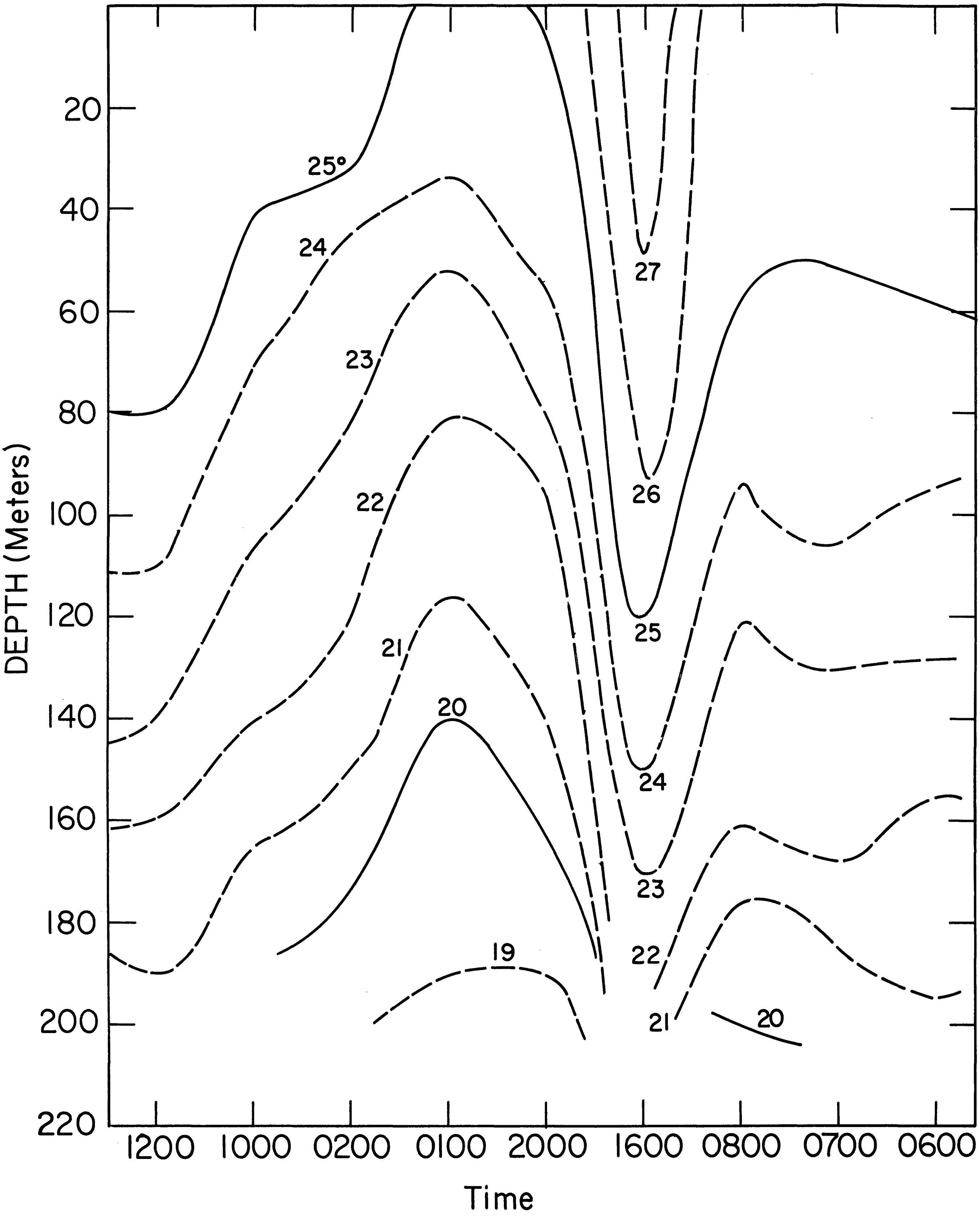
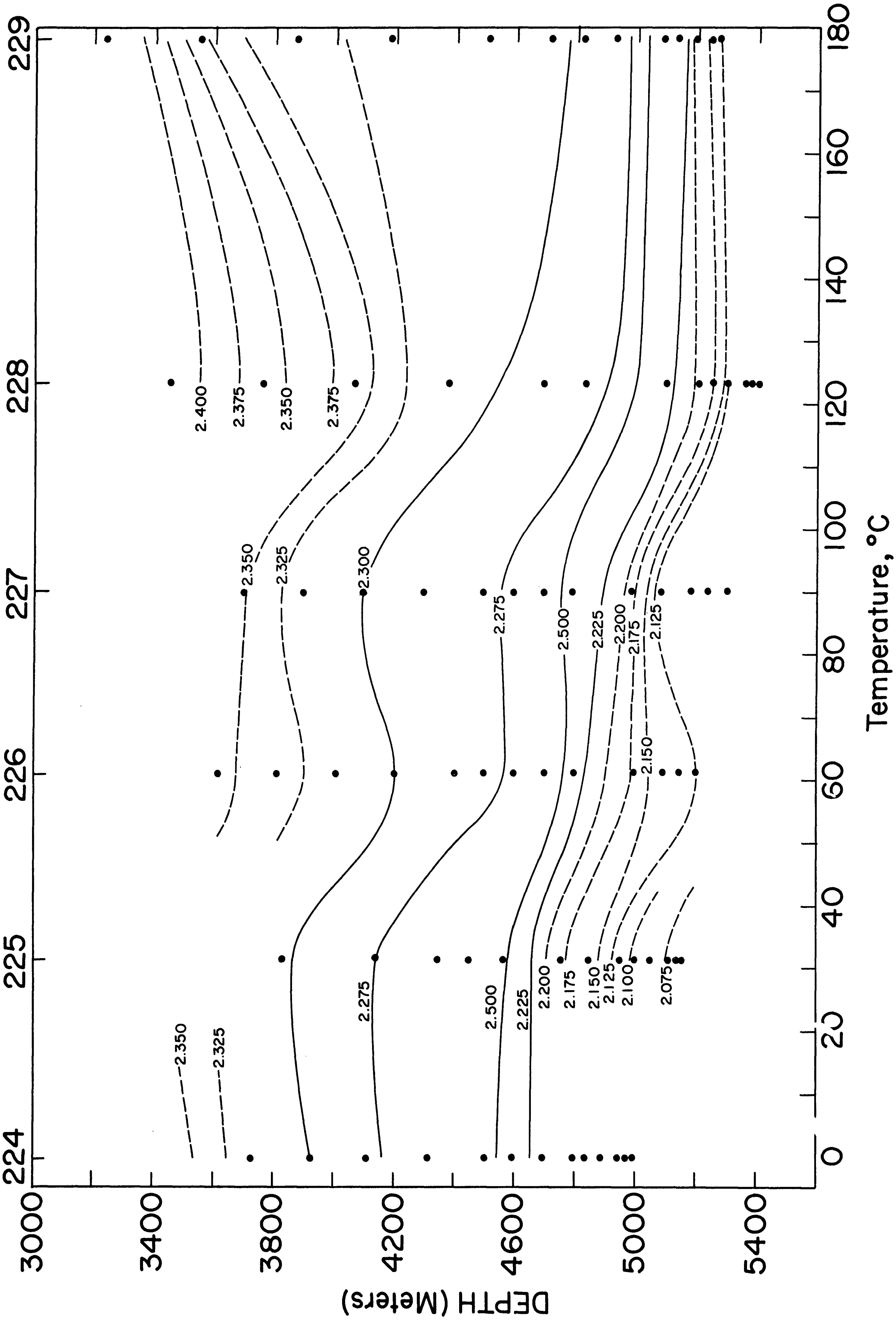


Figure 10. Practicum Students Taking a BT

PROFILES OF THE HYDROGRAPHIC STATION DATA



Temperature (° C)


DEPTH (Meters)
3000
3400
3800
4200
4600
5000
5400
Temperature, °C
0
20
40
60
80
100
120
140
160
180
224
225
226
227
228
229
2.400
2.375
2.350
2.375
2.350
2.325
2.300
2.275
2.500
2.225
2.200
2.175
2.150
2.125
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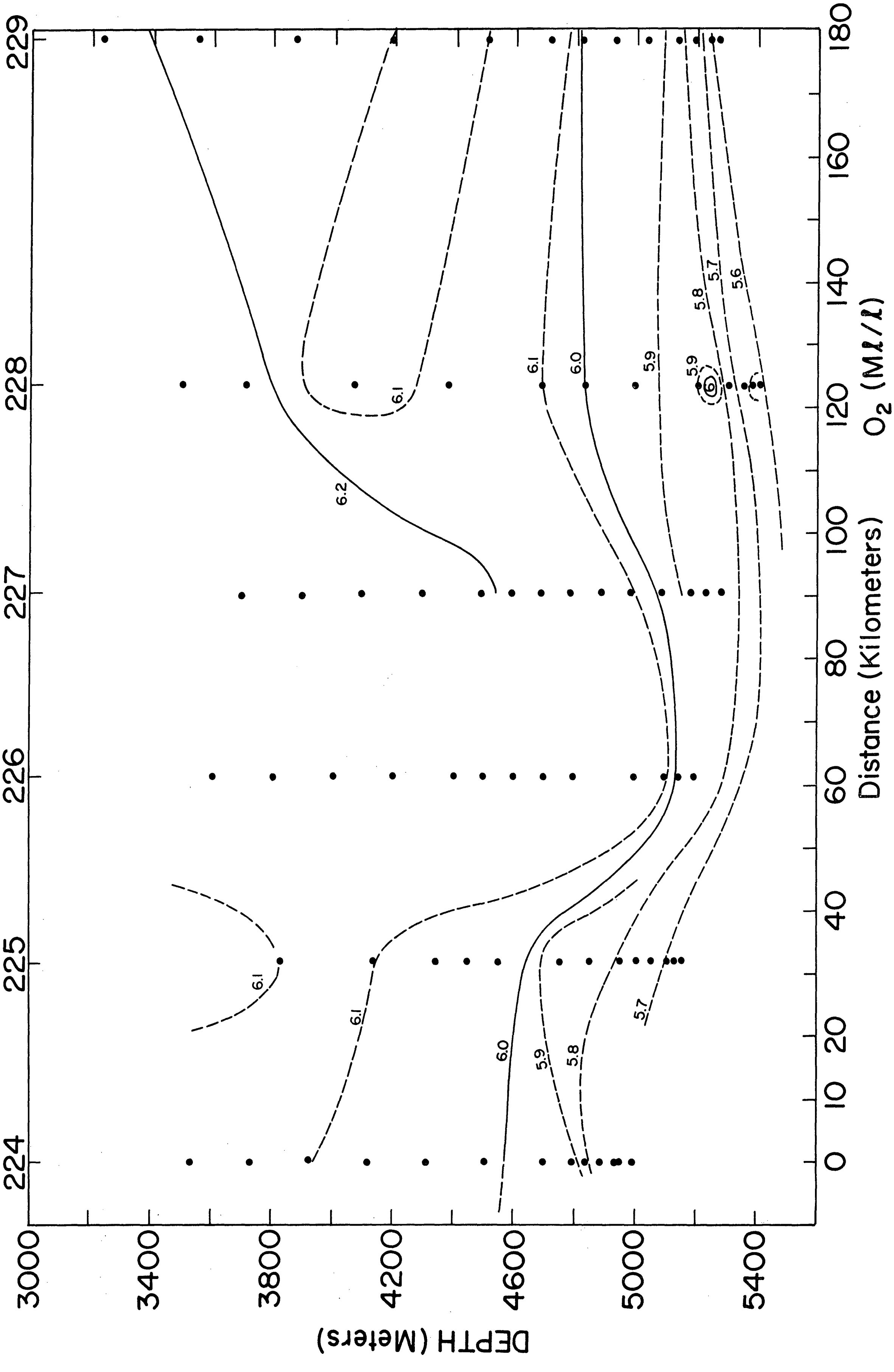
2.200
2.175
2.150
2.125
2.100
2.075


224
225
226
227
228
229
DEPTH (Meters)
3000
3400
3800
4200
4600
5000
5400
0
10
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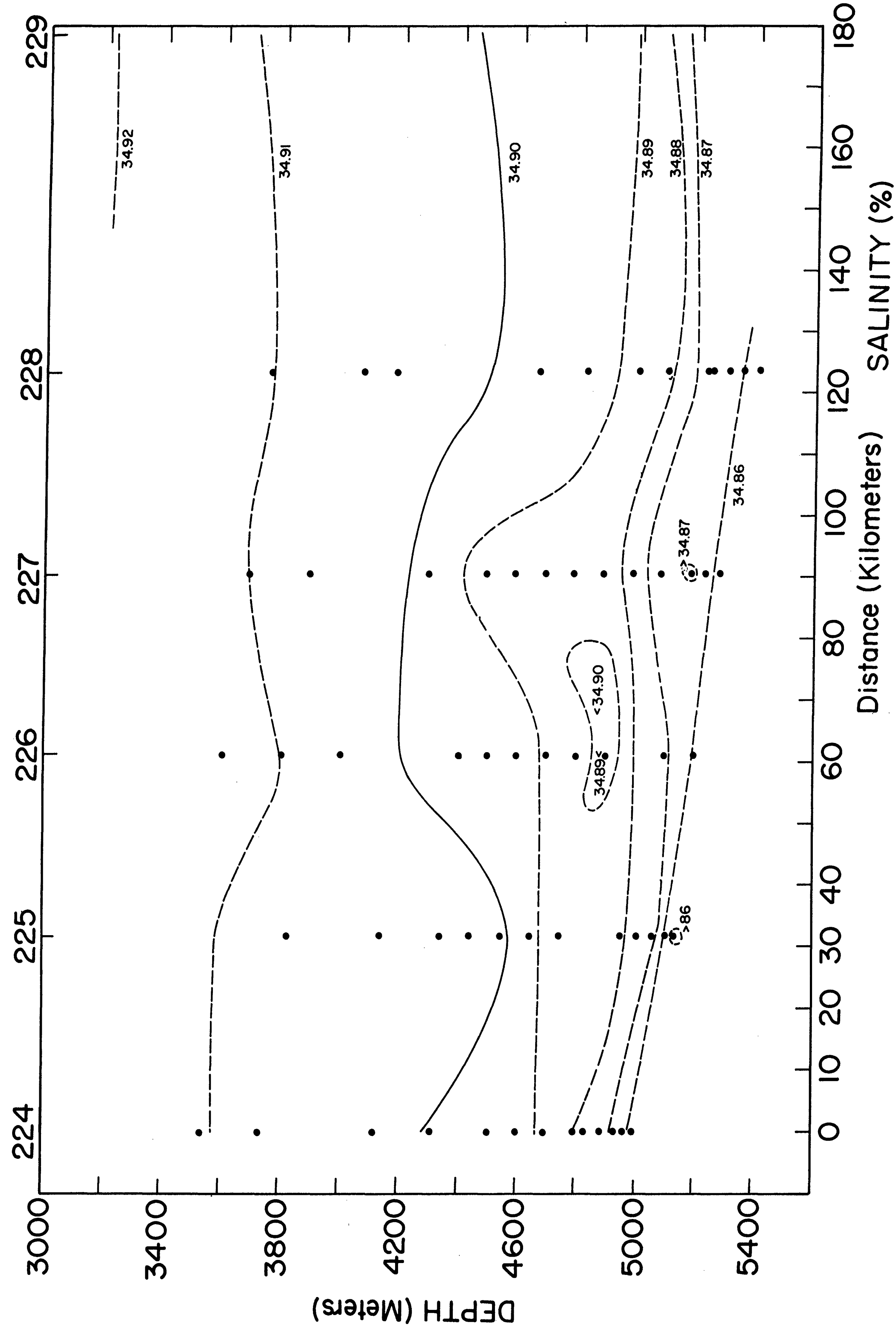
40
60
80
100
120
140
160
180
Distance (Kilometers)
O_2 (Mℓ/ℓ)
6.2
6.1
6.1
6.1
6.1
6.0
6.0
5.9
5.9
5.9
5.8
5.8
5.7
5.7
5.6
6


224
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3000
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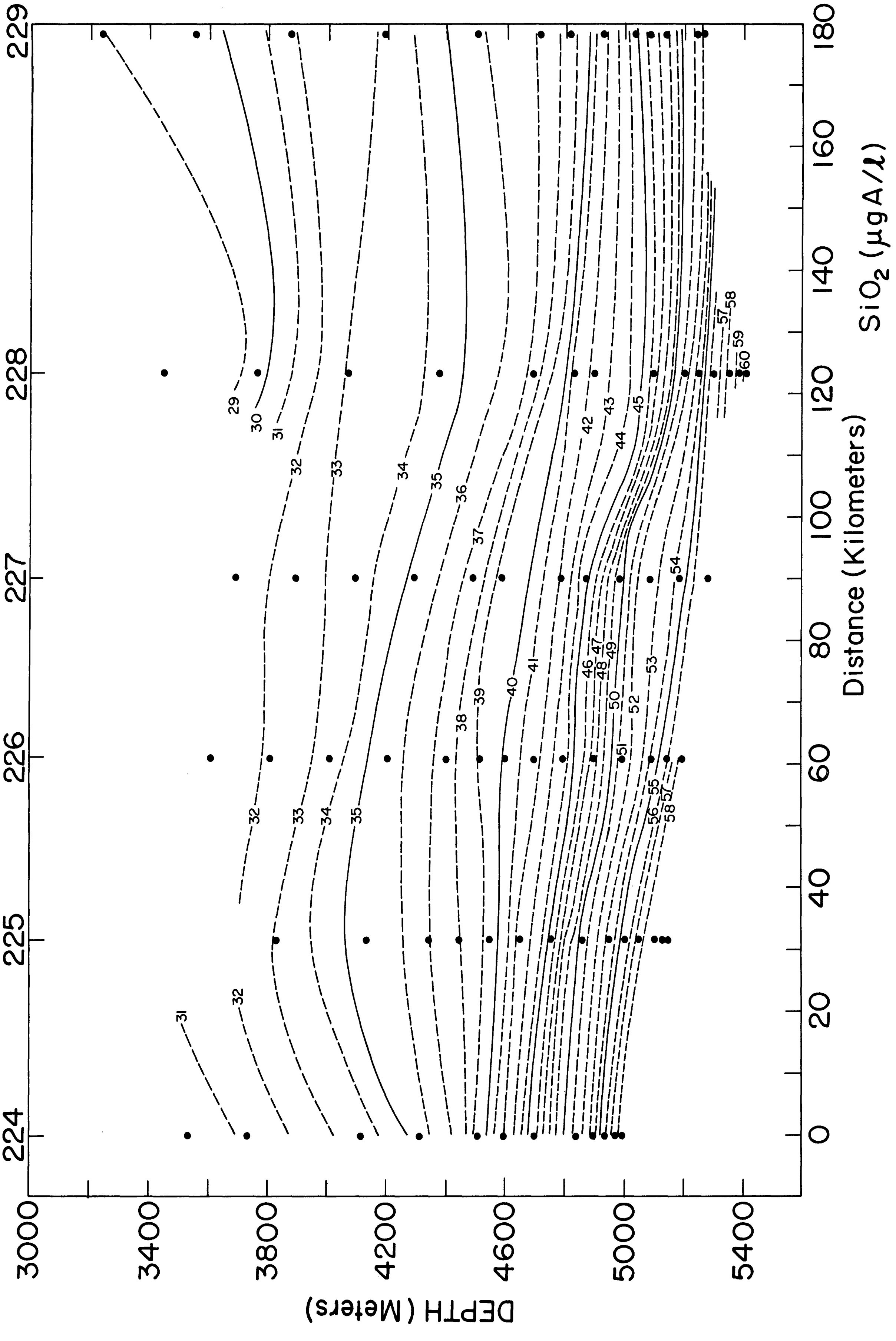
4600
5000
5400
DEPTH (Meters)
0
10
20
30
40
60
80
100
120
140
160
180
Distance (Kilometers)
SALINITY (%)
34.92
34.91
34.90
34.89
34.88
34.87
34.86
<34.90
34.89<
>34.87
>86


224
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3000
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4200
4600
5000
5400
DEPTH (Meters)
0
20
40
60
80
100
120
140
160
180
Distance (Kilometers)
SiO_2 (μgA/ℓ)
29
30
31
32
33
34
35
36
37
38
39
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41
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