AN ANALYSIS OF THE PHYSICAL EFFECTS OF THE DISCHARGE OF COOLING WATER INTO CARD SOUND BY THE TURKEY POINT PLANT OF FLORIDA POWER AND LIGHT COMPANY

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1. INTRODUCTION

THE FLORIDA POWER AND LIGHT COMPANY CURRENTLY HAS IN OPERATION A FOSSIL FUEL POWER PLANT LOCATED AT TURKEY POINT ON THE WEST SHORE OF BISCAYNE BAY APPROXIMATELY TWO (2) MILES SOUTH OF HOMESTEAD BAYFRONT PARK. AT THE PLANT THEY ARE CONSTRUCTING TWO (2) ADDITIONAL NUCLEAR UNITS. THE EXTRACTION OF LARGE QUANTITIES OF WATER FROM THE BAY FOR COOLING THE PLANT'S CONDENSERS AND ITS SUBSEQUENT RETURN AT AN ELEVATED TEMPERATURE HAS CAUSED CONSIDERABLE CONSTERNATION AMONG CONSERVATION INTERESTS AND SOME GOVERNMENT AGENCIES. OF PRIMARY CONCERN IS THE EFFECT OF SUCH LARGE QUANTITIES OF HEATED WATER ON THE ECOLOGY AND CIRCULATION OF THE AREA. THIS CONCERN IS HEIGHTENED BY THE EXISTENCE OF THE BISCAYNE NATIONAL MONUMENT NEARBY. SEE FIGURE 1. THIS STUDY WAS PERFORMED FOR THE PURPOSE OF ANALYZING THE PHYSICAL EFFECTS OF THE PLANNED DISCHARGE TO DETERMINE IF THEY MAY BE HARMFUL TO THE ENVIRONMENT OF THE AREA IN GENERAL AND PARTICULARLY TO THE NATIONAL MONUMENT.

2. DESCRIPTION OF THE AREA

THE AREA UNDER CONSIDERATION HERE IS BISCAYNE BAY SOUTH OF HOMESTEAD BAYFRONT PARK AND CARD SOUND. THIS PORTION OF BISCAYNE BAY IS APPROXIMATELY SEVEN (7) NAUTICAL MILES WIDE AND EIGHT (8) NAUTICAL MILES LONG. ON THE WEST SIDE NEAR THE MAINLAND EXTENSIVE SHOALS EXIST. AN AREA OF RELATIVELY DEEP WATER OF 7 TO 8 FEET EXISTS IN THE EASTERLY HALF OF THE BAY FOLLOWED BY A SHOAL AREA ADJACENT TO OLD RHODES KEY. THIS PORTION OF THE BAY IS SEPARATED from Card Sound to the south by a shoal area encompassing the Arsenicker Keys and Cutter Bank. A small navigation channel has been dredged through Cutter Bank to Card Sound. Card Sound is approximately 2.50 nautical miles wide and 5.50 nautical miles long. It is bounded on the west by the Florida mainland and on the east by northern Key Largo and adjacent keys. It is separated on the south from Little Card Sound by Card Bank through which a small navigation channel has been dredged. The depth of Card Sound is quite uniform averaging about 10 feet with deep water prevailing nearly to the shores.

South Biscayne Bay and Card Sound are underlain by shallow bedrock depressions having a deep axis of 13 to 24 feet in depth and extending along the eastern side. The bedrock on the mainland shore rises to approximately mean low water and on the keys to the east to about 6 feet above mean low water(1). Sediments consisting of carbonate sands and muds form a shallow cover over the bedrock. In these areas a moderate to dense cover of Thalassia and calcareous green algae exist.

Fresh water inflow to the area is mainly ground water from the mainland with some contribution of surface flow from a few canals and the swampy fringes. The south Biscayne Bay area is connected to the Atlantic by Caesar Creek, a fairly deep but narrow inlet. Card Sound is connected to the ocean by Broad Creek, Angelfish Creek and several smaller channels

BETWEEN MANGROVE ISLANDS.

TIDES IN THE AREA ARE CHIEFLY SEMIDIURNAL. THE OCEAN TIDE HAS A MEAN RANGES OF 2.44 FEET. THE TIDE IN SOUTH BISCAYNE BAY, AS MEASURED BY SCHNEIDER (2) HAS A MEAN RANGE OF APPROXIMATELY 1.6 FEET. HIGH TIDE LAGS THE OCEAN TIDE BY APPROXIMATELY 2 HOURS AND 15 MINUTES AND LOW TIDE BY APPROXIMATELY 2 HOURS AND 45 MINUTES. CARD SOUND HAS A MEAN TIDAL RANGE OF 0.74 FEET WITH HIGH TIDE LAGGING THE OCEAN TIDE BY 3 HOURS AND LOW TIDE BY 3 HOURS AND 20 MINUTES. CIRCULATION IS RELATIVELY LIMITED AS EVIDENCED BY RATHER HIGH SALINITIES RECORDED DURING THE SUMMER MONTHS.

PREVAILING WINDS ARE EAST AND SOUTHEAST WITH 23 PERCENT FROM THE EAST AND 28 PERCENT FROM THE SOUTHEAST. WINDS FROM THESE DIRECTIONS DO NOT NORMALLY EXCEED 10 TO 12 KNOTS. THE STRONGER WINDS ARE FROM THE NORTHEAST 17 PERCENT OF THE TIME. THESE WINDS ARE NORMALLY ASSOCIATED WITH NORTHEASTERLY STORMS AND FREQUENTLY EXCEED 20 KNOTS (3). ALTHOUGH NO DETAILLED STUDIES HAVE BEEN MADE IN THE AREA, IT IS HIGHLY PROBABLE THAT THESE WINDS, PARTICULARLY THOSE OF HIGHER VELOCITY HAVE A CONSIDERABLE AFFECT ON THE CIRCULATION IN THE AREA.

3. THE PROPOSED PROJECT

THE FLORIDA POWER AND LIGHT COMPANY PROPOSES TO DISCHARGE A MAXIMUM OF 10,625 CUBIC FEET PER SECOND OF CONDENSER COOLING WATER FROM ITS TURKEY POINT PLANT INTO CARD SOUND IN THE VICINITY OF THE MODEL LAND CO

CANAL.(4) SEE FIGURE 1. THIS WATER IS TO BE TAKEN FROM SOUTH BISCAYNE BAY. 4,250 CUBIC FEET PER SECOND WILL PASS THROUGH THE CONDENSERS WITH A MAXIMUM RISE IN TEMPERATURE OF 15°F. NEAR THE DISCHARGE FROM THE CONDENSERS 6,375 CUBIC FEET PER SECOND OF BAY WATER WILL BE ADDED THUS REDUCING THE TEMPERATURE TO 6°F. ABOVE THAT OF THE INTAKE. THIS WATER WILL THEN FLOW SOUTH IN A CANAL FOR APPROXIMATELY SIX MILES TO THE OUTLET IN CARD SOUND. AT THIS POINT, IT IS ESTIMATED THAT THE TEMPERATURE WILL EXCEED THAT OF THE BAY BY 5.8°F.(5).

THE INTAKE WATER PASSING THROUGH THE CONDENSER WILL BE TAKEN FROM THE EXISTING NAVIGATION CHANNEL AT TURKEY POINT. SEE FIGURE 1. THIS CHANNEL EXTENDS IN A NORTHEASTERLY DIRECTION FROM THE PLANT. IT IS 100 FEET WIDE AND 10 FEET DEEP AT MEAN LOW WATER. THE WATER FOR DILUTION WILL BE TAKEN FROM A CHANNEL TO BE CONSTRUCTED ALONG THE NORTH SHORELINE OF TURKEY POINT. THIS CHANNEL IS TO BE 3,200 FEET LONG, 100 FEET WIDE AND 20 FEET DEEP. SEE FIGURE 2.

THE CANAL LEADING FROM TURKEY POINT TO CARD SOUND WILL CARRY A TOTAL OF 10,625 CUBIC FEET PER SECOND OF THE DILUTED COOLING WATER. IT WILL HAVE A BOTTOM WIDTH OF 200 FEET, A TOP WIDTH OF 227 FEET 9 INCHES AND A DEPTH OF 20 FEET.

THE IMMEDIATE OUTLET TO CARD SOUND WILL HAVE A DEPTH OF 20 FEET, A BOTTOM WIDTH OF 200 FEET AND SIDE SLOPES OF 1 ON 3 (1 VERTICAL TO 3 HORIZONTAL). APPROXIMATELY 400 FEET INTO THE SOUND, THE BOTTOM OF CHANNEL WILL BE WIDENED

TO APPROXIMATELY 330 FEET AND THE SIDE SLOPES DECREASED TO 1 ON 5. AT THE POINT WHERE THE NATURAL DEPTH OF THE SOUND REACHES 8 FEET AT MEAN LOW WATER, THE BOTTOM OF THE CHANNEL WILL BE SLOPED FROM A DEPTH OF 20 FEET TO MEET THE NATURAL BOTTOM TO PROVIDE A SMOOTH TRANSITION.

4. The Scope of the Study

This study was authorized by verbal authority of the Florida Power and Light Company on 10 March 1970 confirmed by letter dated 6 April 1970(6). Particular emphasis was placed on requirements of the Department of Natural Resources, State of Florida(7) which stated:

> "Because of the very large volume of water to be discharged into Card Sound through the proposed Florida Power and Light Company Canal, referenced above, we are concerned that tidal flows and current patterns may be altered to such an extent that shoreline and bottom stability will be affected. Therefore, certain hydrographic determinations must be made.
>
> Normally, our consultants, the Department of Coastal and Oceanographic Engineering of the University of Florida, would make determinations regarding hydrographic effects of projects such as this. However, since they have been involved with Florida Power and Light Company on other phases of this plan, it will be necessary that such determinations be made by someone else. The Institute of Marine Sciences of the University of Miami would be qualified to review this matter and make the necessary determinations. Such determinations would derive from a review of available data and from additional field studies if found to be necessary. We would accept their findings and recommendations."

A considerable amount of general data for the area is available. Significant information on the physical aspects in addition to references cited above is contained in reports by Bader(8), Bader and Tabb(9), Pritchard(10), Haeussner(11) and others.

Specifically applicable to the proposed project is the work accomplished by the Department of Coastal and Oceanographic Engineering of the University of Florida during 1969 and 1970. This work consisted of the evaluation of temperature and circulation fields caused by the proposed installation under various conditions of discharge. Most of the determinations were based on numerical modelling techniques as explained by Verma and Dean(12). The model used was of a rather small scale based on a series of one nautical mile grid squares. Field data was used to calibrate the model(13). The results of this analysis are reported by the Department of Coastal and Oceanographic Engineering(14)(15). In addition to the numerical model a small scale hydraulic model was calibrated and operated for a series of tests aimed primarily at determining travel time and recirculation of the heated effluent. Results of these tests are reported by the Department (16).

This study is concerned primarily with the analysis of the available data. Field work for this specific project was limited to a general reconnaissance of the area. In this connection it should be emphasized that the investigator has done a considerable amount of work in the area for more than 10 years.

In view of the fact that hydrographic and topographic survey information taken between 1852 and 1890(17) corresponds very closely to conditions as they presently exist, it can be assumed that the regime of currents and

SEDIMENTS HAS REACHED A STATE OF STABILITY. THEREFORE THIS STUDY IS CONCENTRATED ON THE CHANGES WHICH MAY BE CAUSED BY THE CIRCULATION OF THE COOLING WATER AS PROPOSED.

5. RESULTS OF THE ANALYSIS

A GENERAL UNDERSTANDING OF THE RELATIVE EFFECT OF THE EXTRACTION AND DISCHARGE OF THE COOLING WATER CAN BE GLEANED FROM THE AREAS AND VOLUMES INVOLVED. FOR THIS PURPOSE, MAXIMUM CONDITIONS CORRESPONDING TO A MOVEMENT OF 10,625 CUBIC FEET PER SECOND ARE ASSUMED. DURING ONE-HALF TIDAL CYCLE (6.2 HOURS) THIS AMOUNTS TO 2.38×10^8 CUBIC FEET.

HYDRODYNAMICALLY THE AREA IS CONVENIENTLY DIVIDED INTO TWO BASINS: BISCAYNE BAY SOUTH OF FEATHERBED BANKS (SOUTH BISCAYNE BAY), AND CARD SOUND. WITHIN EACH OF THESE THE TIDAL AMPLITUDES ARE NEARLY CONSTANT ALTHOUGH THEY VARY CONSIDERABLY FROM THOSE OF THE OCEAN AND ADJACENT BASINS.

SOUTH BISCAYNE BAY HAS A SURFACE AREA OF 3.1×10^9 SQUARE FEET AND A VOLUME AT MEAN TIDE OF 19.8×10^9 CUBIC FEET. ITS MEAN TIDAL RANGE IS 1.0 FEET SO THAT A VOLUME OR TIDAL PRISM OF 5.0×10^9 CUBIC FEET WILL ENTER OR LEAVE THE BASIN DURING EACH HALF-TIDAL CYCLE. THE INTAKE OF WATER BY THE PLANT REPRESENTS SLIGHTLY LESS THAN 5 PERCENT OF THIS VOLUME. IF THE BASIN WERE ENTIRELY CLOSED THE INTAKE WOULD REDUCE THE WATER LEVEL BY LESS THAN 1 INCH. ACTUALLY THE WATER LOST WILL BE REPLENISHED CONSTANTLY FROM THE

OCEAN AND CONNECTED BASINS.

Card Sound has a surface area of $.62 \times 10^9$ square feet and a volume at mean tide of 6.2×10^9 cubic feet. Although its mean tidal range is only 0.74 feet, the University of Florida model study indicates a total exchange of 2.145×10^9 cubic feet of water with other bodies during each half tidal cycle. The plant discharge represents a little less than one-ninth of this amount and a little over 7 percent of the volume of the basin at mean tide level. In considering plant discharge in relation to the normal tidal flow, consideration should be given to the fact that the warm effluent is less dense than the normal water. It therefore remains near the surface where better tidal circulation exists.

The effects of the intake and discharge from a point of view of erosion would be concentrated in the vicinity of the intake and outfall channels and in the relatively restricted areas connecting Card Sound with the Ocean and with Biscayne Bay.

In nearly all areas of south Biscayne Bay and Card Sound the greatest effects on bottom sediments and flora can presently be attributed to wave action. Therefore a comparison of velocities at the intake and discharge with normal wave particle velocities is helpful. The particle motion from waves is orbital in character and has only a very slight vertical velocity near the bottom.

Recognizing the infrequency of hurricanes, the comparison can be based on the waves generated by a 30-knot northeasterly wind as a condition exceeded on several occasions each year. For prediction on the basis of methods used by the U. S. Army Corps of Engineers (18) a fetch of 60,000 feet was used. All of the shallow water south of Turkey Point would be exposed to waves developed in a fetch exceeding this value. Under these conditions waves having a height of 2 feet and a period of 3.8 seconds would develop. Water particles in these waves upon reaching a depth of 3 feet just prior to breaking would have a maximum horizontal velocity of 2.2 feet per second at the bottom.

On the basis of his work in the Bahamas, Hay (19) found that strong tidal currents of 1 (1.7 ft/sec) to 2 (3.4 ft/sec) knots promote dense growths of Thalassia. This corresponds to the experience of the present investigator who measured normal tidal currents of 3.3 ft/sec over dense growths of Thalassia in the Virgin Islands. Inasmuch as such growths hold the bottom sediment, it is doubtful that erosion will occur at velocities of 2 feet per second or less. Near the intake and outfall, the bed rock is covered by less than 6 inches of sediment (3). Channels excavated into this material would not erode even with much higher velocities.

The intake to the plant for condenser cooling will be by way of the existing navigation channel and basin a maximum flow of 4,250 cubic feet

PER SECOND WILL OCCUR AT THIS INTAKE. VELOCITIES OCCURRING AS A RESULT OF THIS INTAKE CANNOT BE ACCURATELY DETERMINED UNTIL THE DESIGN DETAIL HAS BEEN WORKED OUT AND STUDIED TO DETERMINE NOT ONLY THE EFFECTS OF THE COOLING WATER INTAKE BUT ALSO THOSE OF THE DILUTION WATER INTAKE WHICH IS CLOSELY ASSOCIATED. NO PROBLEM IS FORESEEN IN KEEPING MAXIMUM VELOCITIES BELOW 2 FEET PER SECOND BY PROPER DESIGN. FURTHER ANALYSIS OF THIS PROBLEM IS NECESSARY PRIOR TO CONSTRUCTION.

DILUTION WATER INTAKE WILL BE FROM A CHANNEL TO BE DUG ALONG THE NORTH SHORE OF TURKEY POINT. SEE FIGURE 2. THIS CHANNEL WILL BE 3200 FEET LONG, 100 FEET WIDE AND 20 FEET DEEP. ITS MAXIMUM FLOW WILL BE 6375 CUBIC FEET PER SECOND. THE CHANNEL IS BOUNDED ON THE NORTH BY SHALLOW GRASS FLATS HAVING A MINIMUM LOW WATER DEPTH OF ONE FOOT. FLOW ACROSS THESE FLATS INTO THE CHANNEL WILL HAVE A VELOCITY OF ABOUT 2 FEET PER SECOND. THE DILUTION WATER WILL FLOW INTO A BASIN DUBBED LOCALLY AS LOCH ROSETTA FROM WHICH IT WILL BE PUMPED INTO A CANAL AND MIXED WITH THE CONDENSER WATER DISCHARGE. THE BASINS AND CHANNELS INVOLVED IN THIS PROCESS ARE CUT FROM ROCK, SO THEY WILL PRESENT NO PROBLEM OF EROSION. FURTHER STUDY IS NECESSARY TO DETERMINE THE INTERRELATION OF FLOW BETWEEN THIS CHANNEL AND THE COOLING WATER INTAKE AS NOTED ABOVE.

THE MAIN CANAL TO CARD SOUND WILL HAVE A BOTTOM WIDTH OF 200 FEET, A TOP WIDTH OF 227 FEET 9 INCHES AND A DEPTH OF 20 FEET. ON THE BASIS OF A

TOTAL MAXIMUM FLOW OF 10,625 CUBIC FEET PER SECOND, THE MAXIMUM VELOCITY AT THE DOWNSTREAM END WILL BE 2.50 FEET PER SECOND. AS THIS CANAL WILL BE DUG IN ROCK, NO EROSION IS EXPECTED.

INITIALLY THE DISCHARGE CHANNEL INTO CARD SOUND HAS A BOTTOM WIDTH OF 200 FEET AND A DEPTH OF 20 FEET WITH SIDE SLOPES OF 1 ON 3. THIS GIVES AN EFFECTED AREA OF 5200 SQUARE FEET FOR A MAXIMUM VELOCITY OF SLIGHTLY OVER 2 FEET PER SECOND. AS THE CHANNEL EMERGES INTO THE SOUND, THE AREA IS INCREASED TO 11,000 SQUARE FEET WHICH WILL REDUCE THE VELOCITY TO LESS THAN ONE FOOT PER SECOND.

FOR A STUDY OF THE EFFECTS ON THE CHANNELS CONNECTING CARD SOUND WITH OTHER BASINS, RESULTS OF THE NUMERICAL MODELLING CONDUCTED BY THE UNIVERSITY OF FLORIDA WERE USED. THESE FLOWS ARE SHOWN ON FIGURE 3 TO 6 INCLUSIVE.

UNDER PRESENT CONDITIONS, MOST OF THE EXCHANGE FOR CARD SOUND OCCURS THROUGH BROAD AND ANGELFISH CREEKS TO THE ATLANTIC OCEAN. FIGURE 3 SHOWS THE RATE OF THIS EXCHANGE AND ALSO FORECASTS THE RATE WHEN THE PLANT DISCHARGE IS ADDED. IT SHOULD BE NOTED THAT UNDER EXISTING CONDITIONS THE MAXIMUM FLOW RATE OF 68,000 CUBIC FEET PER SECOND OCCURS ON THE INCOMING TIDE. ON THE OUTGOING TIDE, THE RATE IS 52,300* CUBIC FEET PER SECOND. THE ADDITION OF THE PLANT DISCHARGE DECREASES THE MAXIMUM INFLOW TO 66,000 CUBIC FEET PER SECOND AND INCREASES THE MAXIMUM OUTFLOW TO 54,750 CUBIC FEET PER

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*FLOW FIGURES ARE ROUNDED FROM THE ORIGINAL DATA.

SECOND WHICH IS STILL FAR BELOW THE MAXIMUM EXISTING FLOW. THEREFORE, THE MAXIMUM FLOW RATE AND CONSEQUENTLY THE MAXIMUM VELOCITY WILL BE DECREASED WHEN THE PLANT EFFLUENT IS ADDED. THE NUMERICAL ANALYSIS SHOWS A TOTAL DIFFERENCE IN FLOW THROUGH THE INLETS FROM THE OCEAN DUE TO THE PLANT EFFLUENT TO BE 1.40×10^8 CUBIC FEET PER TIDE OR ABOUT 29 PERCENT OF THE TOTAL PLANT DISCHARGE.

THE NEXT MOST IMPORTANT EXCHANGE OCCURS WITH SOUTH BISCAYNE BAY AT THE RATES SHOWN ON FIGURE 4. AGAIN, THE MAXIMUM FLOW RATE OCCURS ON THE INCOMING TIDE AND IS REDUCED BY THE ADDITION OF PLANT EFFLUENT. ON THE INCOMING TIDE, A MAXIMUM FLOW OF 72,000 CUBIC FEET PER SECOND INTO CARD SOUND OCCURS WITHOUT THE PLANT DISCHARGE. THE ADDITION OF THE PLANT DISCHARGE REDUCES THIS TO 66,000 CUBIC FEET PER SECOND. ON THE OUTGOING TIDE, THE NORMAL DISCHARGE OF 25,500 CUBIC FEET PER SECOND INTO SOUTH BISCAYNE BAY IS INCREASED TO 31,800 BY THE PLANT DISCHARGE. AS THIS IS LESS THAN HALF OF THE MAXIMUM FLOW UNDER PRESENTLY EXISTING CONDITIONS, MAXIMUM VELOCITIES CONSIDERING THE PLANT DISCHARGE WILL ALSO BE LESS THAN HALF OF THOSE PRESENTLY OCCURRING ON THE INCOMING TIDE. THE PLANT EFFLUENT CONTRIBUTION TO THE EXCHANGE TO BISCAYNE BAY IS ESTIMATED TO BE 3.35×10^8 CUBIC FEET PER TIDE OR 71 PERCENT OF THE TOTAL PLANT EFFLUENT. THIS MEANS THAT ONLY 29 PERCENT OF THE PLANT INTAKE FROM SOUTH BISCAYNE BAY WILL HAVE TO BE MADE UP BY FLOW FROM OTHER AREAS INTO SOUTH BISCAYNE BAY. THIS WILL COME FROM THE ATLANTIC OCEAN AND BISCAYNE BAY NORTH OF THE FEATHERBED BANKS. THIS AMOUNT OF 1.40×10^8 CUBIC

FEET PER TIDE REPRESENTS LESS THAN 1.5 PERCENT OF THE NET TIDAL EXCHANGE FOR SOUTH BISCAYNE BAY DURING A FULL TIDAL CYCLE.

THE EXCHANGE BETWEEN CARD SOUND HAS A MAXIMUM ON THE OUTGOING TIDE OF 38,650 CUBIC FEET PER SECOND. THE PLANT DISCHARGE INCREASES THIS TO 38,800 OR BY LESS THAN ONE-HALF PERCENT.

6. CONCLUSIONS

THESE STUDIES INDICATE THAT THE ALTERATIONS IN TIDAL FLOWS AND CURRENT PATTERNS BY THE INTAKE AND DISCHARGE OF THE LARGE VOLUME OF COOLING AND DILUTION WATER ARE EXTREMELY SLIGHT AND ARE OF SUCH A NATURE AS TO ACTUALLY REDUCE MAXIMUM VELOCITIES IN THE INLETS FROM THE OCEAN AND OVER CUTTER BANK. THIS OCCURS BY VIRTUE OF THE FACT THAT MAXIMUM VELOCITIES OCCUR ON THE INFLOW TO CARD SOUND. THESE VELOCITIES ARE ACTUALLY REDUCED BY THE PLANT DISCHARGE. VELOCITIES IN LOCAL AREAS AT THE INTAKE AND DISCHARGE CAN BE MAINTAINED AT LESS THAN 2 FEET PER SECOND WHICH CORRESPONDS TO WAVE-INDUCED CURRENTS WHICH OCCUR FREQUENTLY. WE THEREFORE CONCLUDE THAT IT WILL HAVE LITTLE EFFECT ON SHORELINE OR BOTTOM STABILITY.

A COMPLETE ANALYSIS OF THE INTAKE CHANNELS COULD NOT BE MADE AT THIS TIME. NO PROBLEM IS FORESEEN IN KEEPING VELOCITIES IN THESE CHANNELS BELOW 2 FEET PER SECOND BUT ADDITIONAL NUMERICAL ANALYSES AND POSSIBLY A MODEL STUDY SHOULD BE MADE TO ELIMINATE THE POSSIBILITY OF LOCALIZED EROSION.

IN ADDITION TO DETAIL DESIGN STUDIES, THE PROJECT SHOULD BE CAREFULLY

ANALYZED DURING THE PERIOD THAT IT IS OPERATING UNDER PARTIAL LOAD SO AS TO ASSURE THE ADEQUACY OF THE DESIGN.

FURTHER STUDIES ARE NEEDED BEFORE THE PROJECT IS COMPLETED AND WHILE IT IS BEING OPERATED UNDER PARTIAL LOAD. THIS WOULD PERMIT MEASURES TO BE TAKEN TO COUNTERACT ANY POSSIBLE CONSEQUENCES THAT MIGHT NOT BE FORESEEN AT THIS TIME.

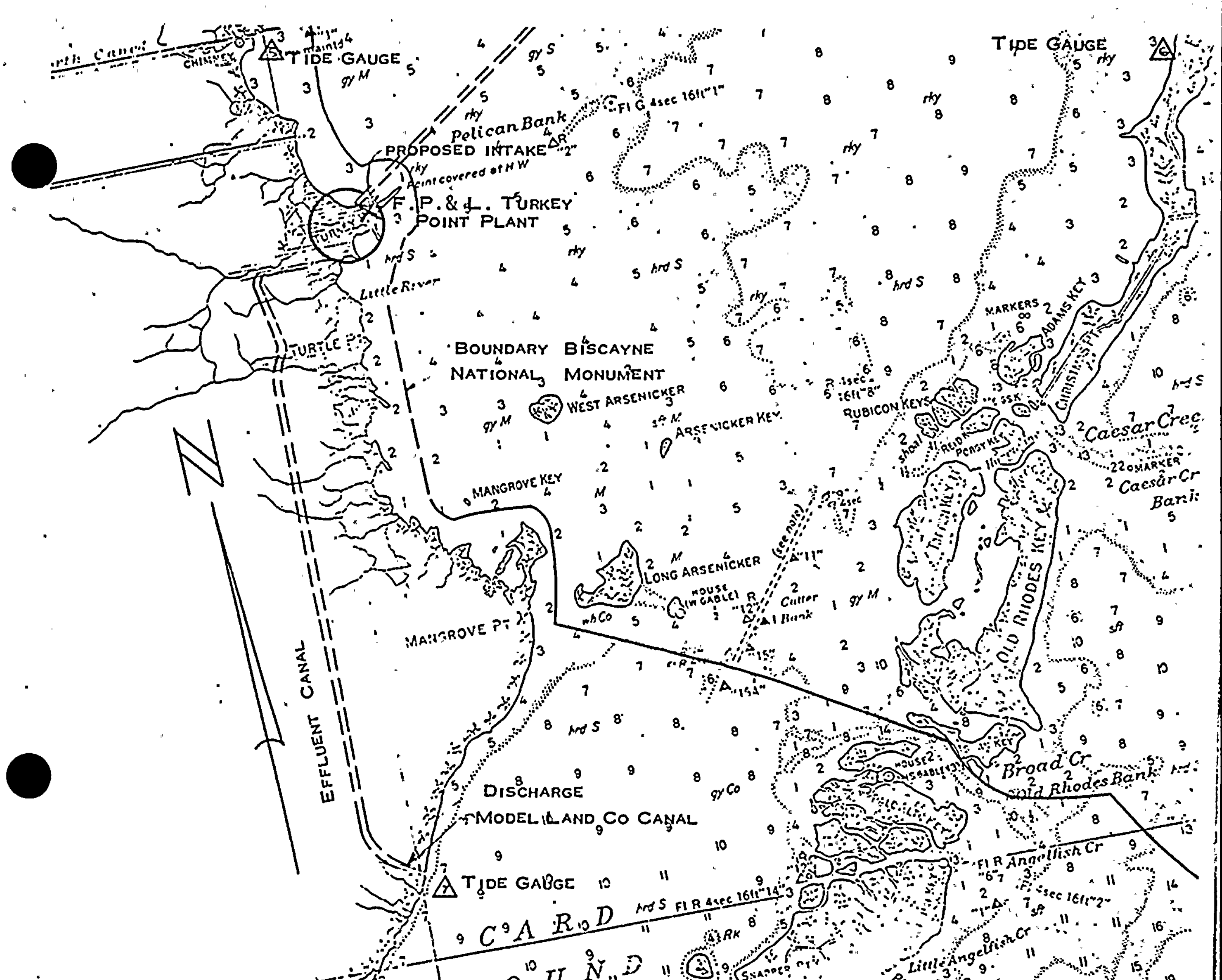


FIGURE 1

LOCATION MAP

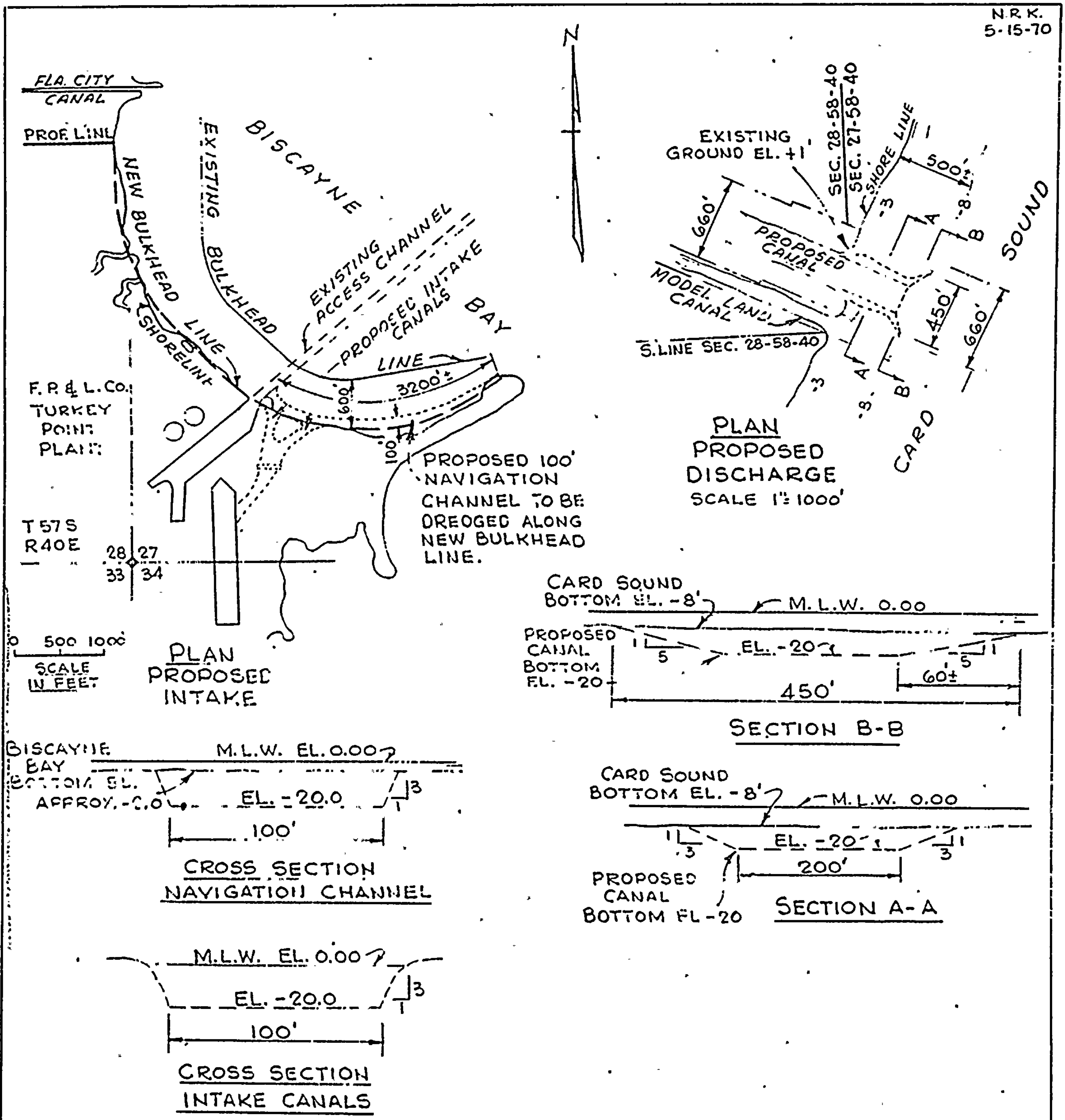
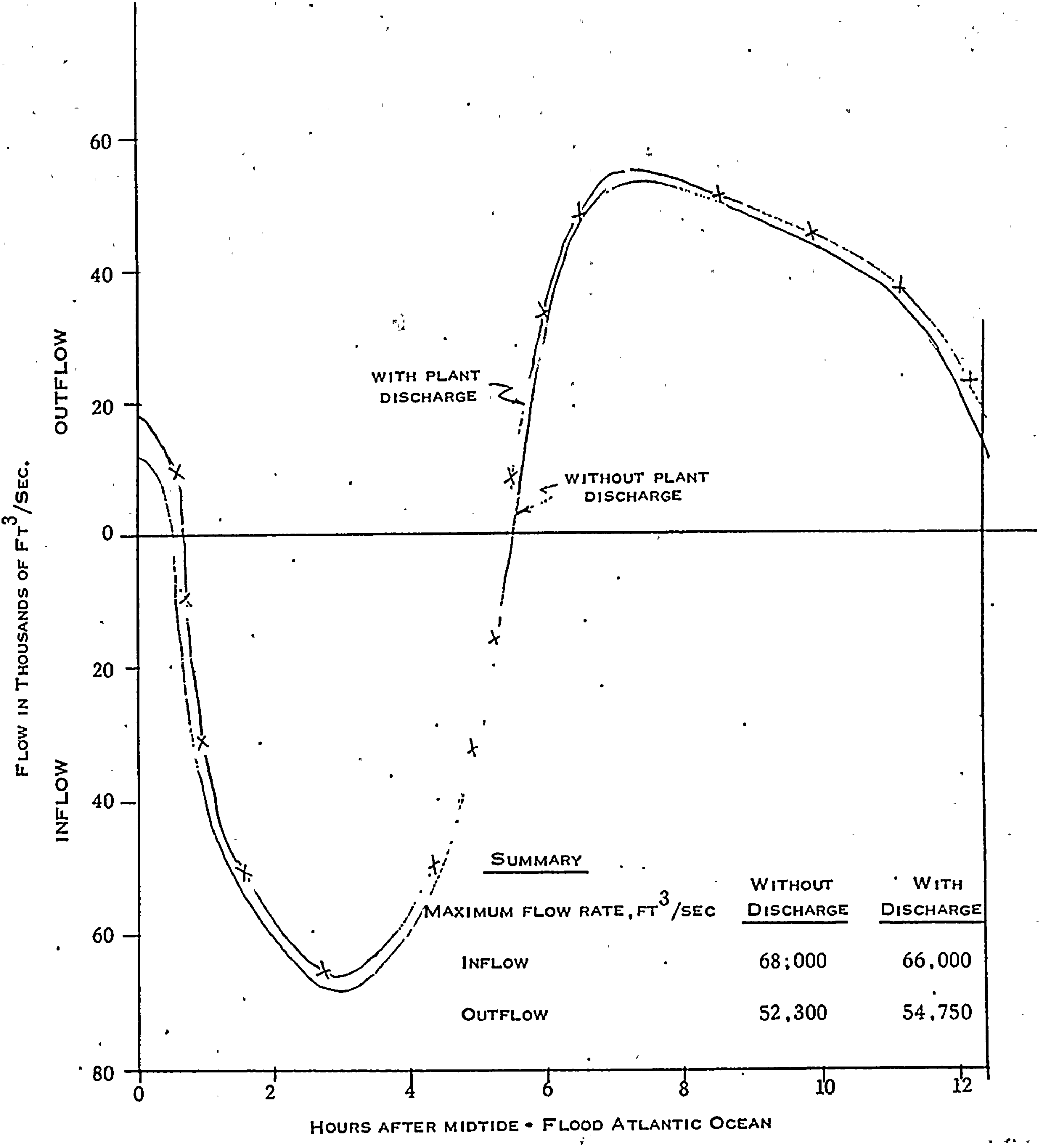


FIGURE 2

CONSTRUCTION DETAILS

THIS IS AN EXCERPT FROM FLORIDA POWER & LIGHT COMPANY'S
APPLICATION FOR PERMIT TO DREDGE INTAKE & DISCHARGE, DECEMBER 18, 1969

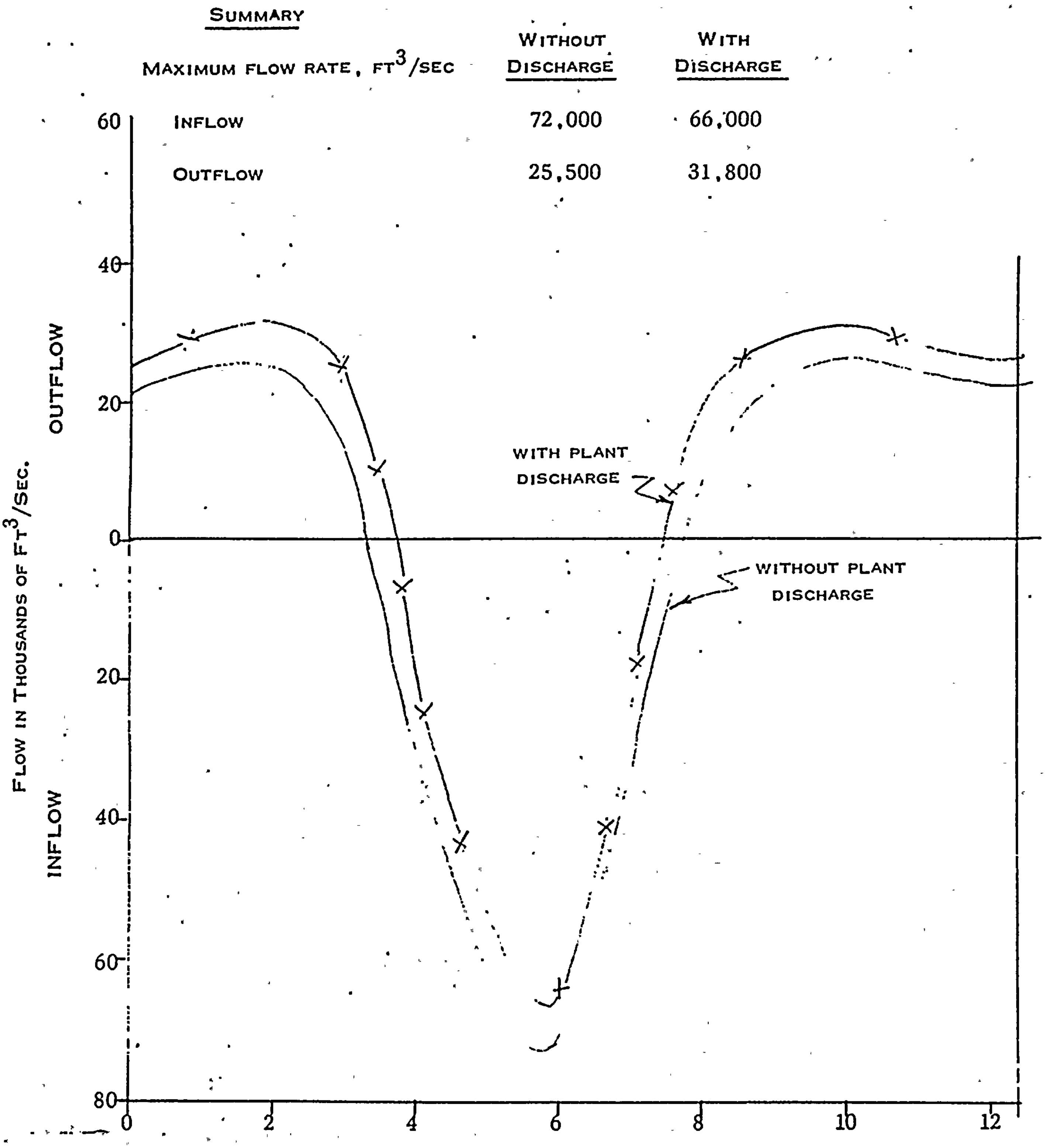


Summary

Maximum flow rate, ft^3/sec	Without Discharge	With Discharge
Inflow	68;000	66,000
Outflow	52,300	54,750

Figure 3
Exchange between Card Sound and Atlantic Ocean

This is a tracing of material furnished by the Department of Coastal and Oceanographic Engineering, University of Florida. 20 March 1970.

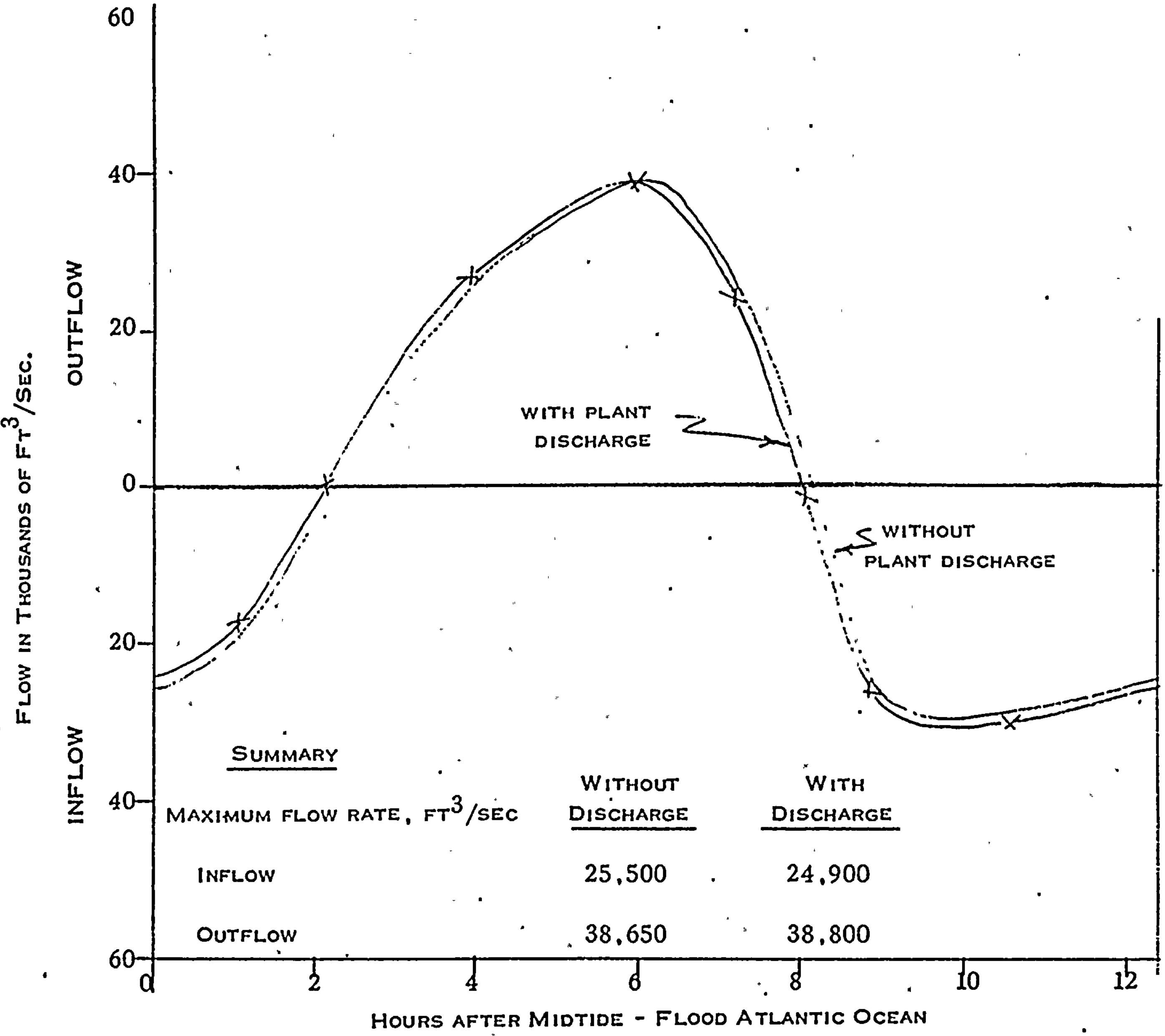


SUMMARY

MAXIMUM FLOW RATE, FT^3/SEC	WITHOUT DISCHARGE	WITH DISCHARGE
INFLOW	72,000	66,000
OUTFLOW	25,500	31,800

FIGURE 4
EXCHANGE BETWEEN CARD SOUND AND BISCAYNE BAY

THIS IS A TRACING OF MATERIAL FURNISHED BY THE DEPARTMENT OF COASTAL AND OCEANOGRAPHIC ENGINEERING, UNIVERSITY OF FLORIDA. 20 MARCH 1970.



SUMMARY

MAXIMUM FLOW RATE, FT^3/SEC	WITHOUT DISCHARGE	WITH DISCHARGE
INFLOW	25,500	24,900
OUTFLOW	38,650	38,800

FIGURE 5
EXCHANGE BETWEEN CARD SOUND AND BARNES SOUND

THIS IS A TRACING OF MATERIAL FURNISHED BY THE DEPARTMENT OF COASTAL AND OCEANOGRAPHIC ENGINEERING, UNIVERSITY OF FLORIDA. 20 MARCH 1970.

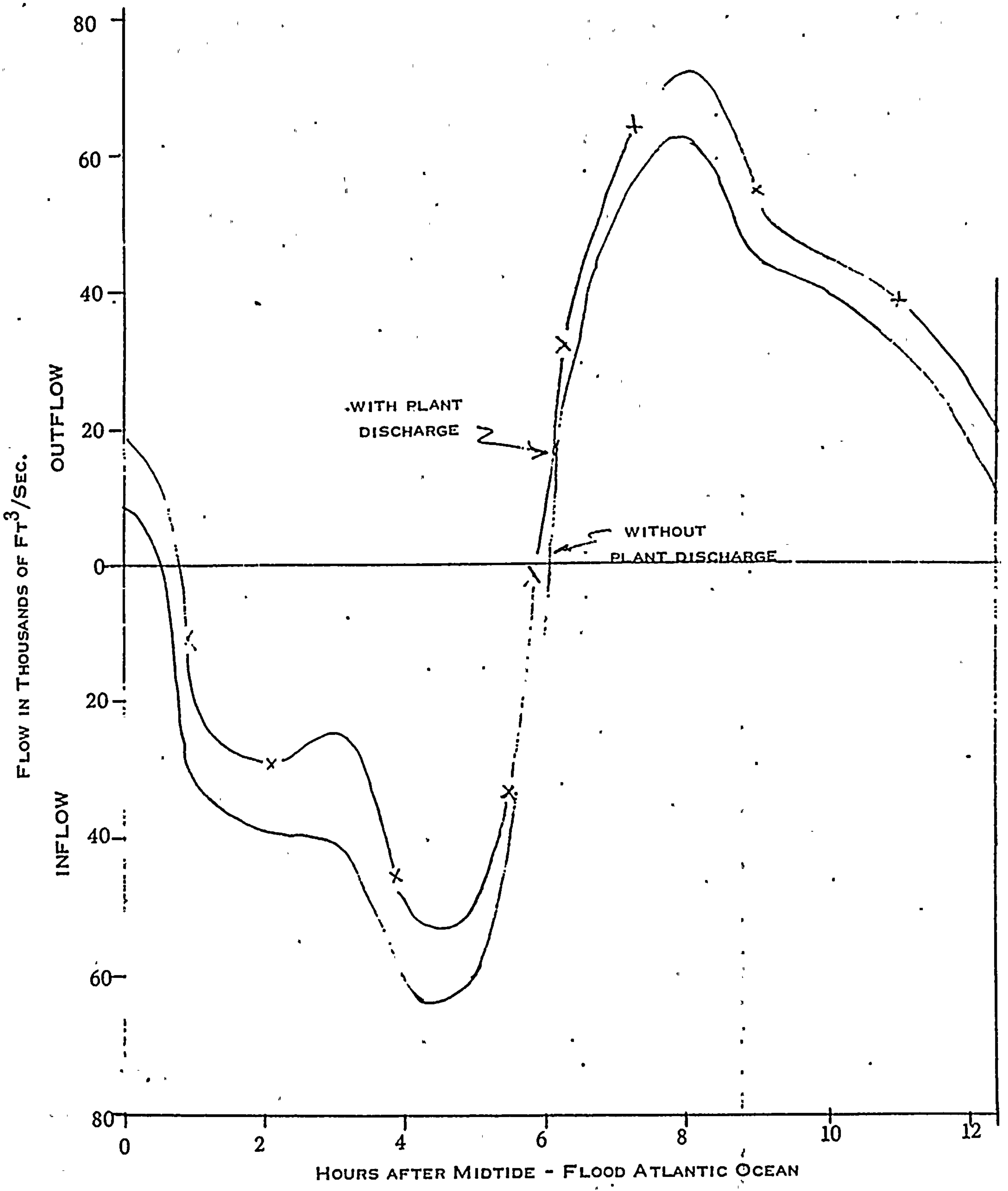


Figure 6.

Net exchange into and out of Card Sound

This is a tracing of material furnished by the Department of Coastal and Oceanographic Engineering, University of Florida. 20 March 1970.

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ROSENSTIEL SCHOOL OF MARINE AND ATMOSPHERIC SCIENCES
UNIVERSITY OF MIAMI

ADDENDUM TO
TECHNICAL REPORT
DATED
MAY 1970

ANALYSIS OF THE PHYSICAL EFFECTS OF THE DISCHARGE OF COOLING WATER INTO CARD SOUND BY THE TURKEY POINT PLANT OF FLORIDA POWER AND LIGHT COMPANY

BY

JOHN F MICHEL

OCTOBER 1970

RICKENBACKER CAUSEWAY
MIAMI, FLORIDA 33149

F. G. WALTON SMITH
DEAN

ADDENDUM TO
TECHNICAL REPORT
MAY 1970
ANALYSIS OF THE PHYSICAL EFFECTS OF THE DISCHARGE OF COOLING WATER INTO CARD SOUND BY THE TURKEY POINT PLANT OF FLORIDA POWER AND LIGHT COMPANY

THIS ADDENDUM IS PREPARED ON THE BASIS OF ADDITIONAL STUDY AUTHORIZED BY THE FLORIDA POWER AND LIGHT COMPANY CONCERNING THE CONCLUSION OF THE SUBJECT REPORT AS STATED ON PAGE 13 OF THE TECHNICAL REPORT DATED MAY 1970 ON THE ABOVE SUBJECT,

> "A COMPLETE ANALYSIS OF THE INTAKE CHANNELS COULD NOT BE MADE AT THIS TIME. NO PROBLEM IS FORESEEN IN KEEPING VELOCITIES IN THESE CHANNELS BELOW 2 FEET PER SECOND BUT ADDITIONAL NUMERICAL ANALYSES AND POSSIBLY A MODEL STUDY SHOULD BE MADE TO ELIMINATE THE POSSIBILITY OF LOCALIZED EROSION."

A PRELIMINARY NUMERICAL ANALYSIS WAS MADE IN DETAIL OF THE INTAKE CHANNELS WITH THE VIEW OF KEEPING VELOCITIES IN THEM AND OVER THE ADJACENT SHOALS WITHIN THE 2 FEET PER SECOND CRITERIA AS ORIGINALLY ESTABLISHED. THIS ANALYSIS SHOWED THAT CERTAIN MODIFICATIONS OF THE ORIGINAL PLAN AS SHOWN ON FIGURE 2 OF THE REPORT WOULD BE DESIRABLE. THE REVISED PLAN IS SHOWN ON FIGURE 1 OF THIS ADDENDUM. CHANGES INCLUDE INCREASING THE CHANNEL DEPTHS IN LOCATIONS WHERE HIGH FLOW IS INDICATED AND PROVIDING GRADUAL SIDE SLOPES IN TRANSITIONAL AREAS. THIS SHOULD PREVENT THE OCCURRENCE OF EROSION. RESULTS OF THE NUMERICAL ANALYSIS ARE REPORTED IN TABLE 1 OF THIS ADDENDUM.

AT THE TIME OF THE ORIGINAL REPORT THE POSSIBILITY OF A HYDRAULIC MODEL WAS STRONGLY CONSIDERED, BUT FROM THE RESULTS OF THE NUMERICAL ANALYSIS ALREADY PERFORMED IT WOULD APPEAR TO BE PREFERABLE TO PERFORM A SERIES OF TESTS

ON THE FACILITY AFTER ITS CONSTRUCTION AND PRIOR TO SUBJECTING IT TO FULL LOAD CONDITIONS.

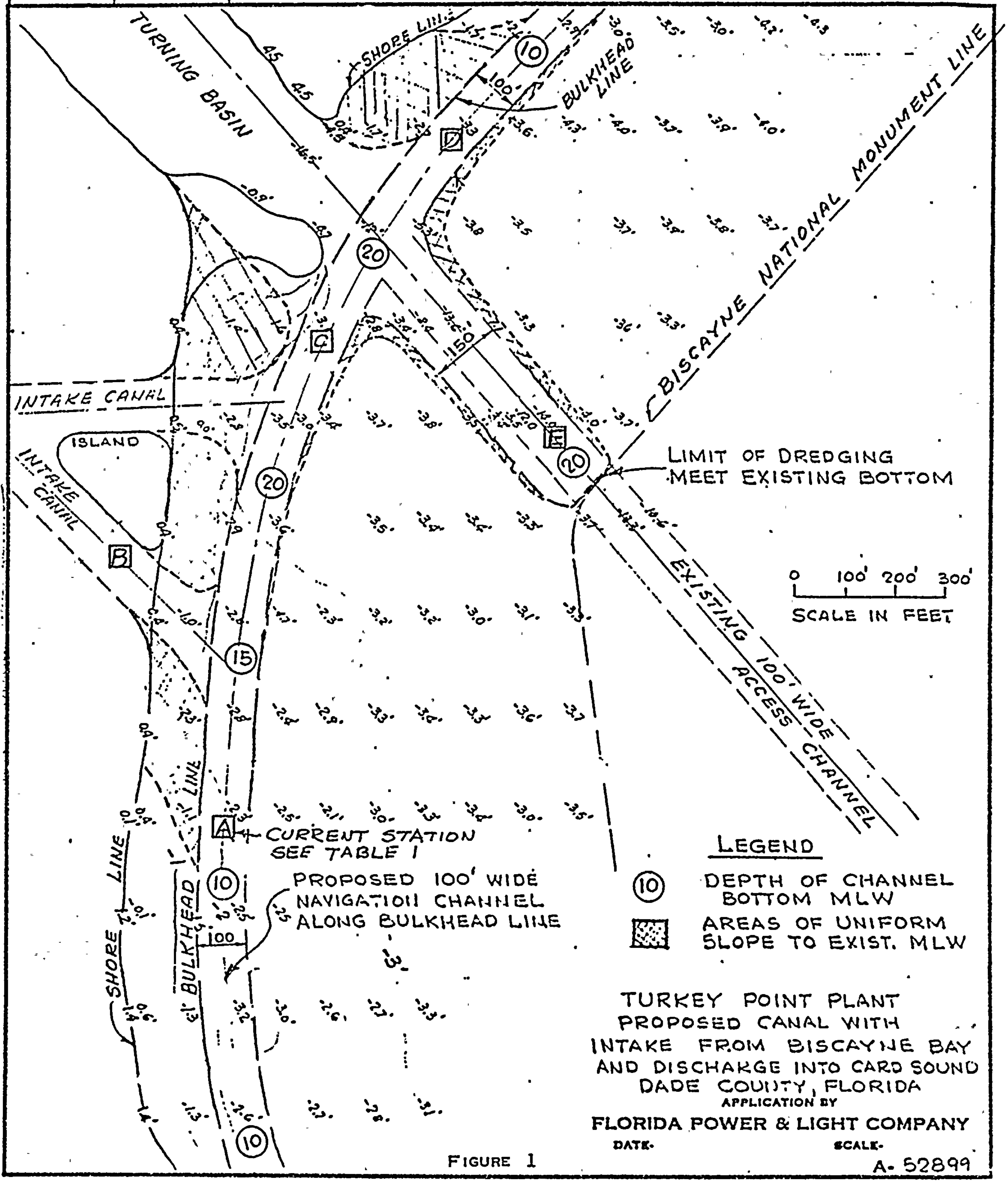
THESE TESTS WOULD BE CONDUCTED UNDER LOADING CONDITIONS AS SHOWN ON TABLE 1. ACTUAL CURRENT AND FLOW MEASUREMENT WOULD BE MADE IN THE CHANNEL. BY COMPARING THEM WITH THOSE SHOWN ON TABLE 1, AN IMMEDIATE EVALUATION OF THE ACCURACY OF THE NUMERICAL ANALYSIS WOULD BE OBTAINED. ANY FLOW ASSUMPTION AND BOUNDARY CONDITIONS FOUND TO BE UNREALISTIC COULD BE MODIFIED TO MAKE THE ANALYSIS MORE PRECISE.

IN VIEW OF THE CONSERVATIVE RESULTS OF THE ANALYSIS UPON WHICH THIS ADDENDUM IS BASED, IT IS UNLIKELY THAT ANY CHANGES IN THE CONSTRUCTION WOULD BE NECESSARY. HOWEVER, IF NECESSARY, THEY COULD BE MADE PRIOR TO LOADING CONDITIONS THAT MIGHT EXCEED THE DESIGN CRITERIA.

THIS WOULD HAVE THE EFFECT OF TESTING A MODEL AT A SCALE OF 1 ON 1 WHICH WILL YIELD MUCH MORE PRECISION THAN A SMALLER SCALE MODEL TESTED UNDER LABORATORY CONDITIONS.

DRAWN BY	KGJ
CHECKED	
CORRECT	

APPROVED:



LEGEND

⑩	DEPTH OF CHANNEL BOTTOM MLW
▨	AREAS OF UNIFORM SLOPE TO EXIST. MLW

TURKEY POINT PLANT
PROPOSED CANAL WITH
INTAKE FROM BISCAYNE BAY
AND DISCHARGE INTO CARD SOUND
DADE COUNTY, FLORIDA
APPLICATION BY
FLORIDA POWER & LIGHT COMPANY
DATE-
SCALE-
A- 52899

FIGURE 1

FORM 839 7-58 PO;05836

TABLE 1

ANTICIPATED FLOR VELOCITIES UNDER VARIOUS LOAD CONDITIONS

1.	LOAD CONDITION	UNITS 1, 2, 3 & 4(1)	UNITS 1, 2 & 3	UNITS 1 & 2(2)
2.	TOTAL FLOW (FT^3/SEC)	10,600	6,600	4,000
3.	MAXIMUM VELOCITY (FT/SEC) AT(3)			
	A	1.8	1.1	0.7
	B	1.5	0.9	0.6
	C	1.5	0.9	0.6
	D	1.5	0.9	0.6
	E	1.4	0.9	0.5
	OVER SHOALS	0.5	0.3	0.2

NOTES:

(1) UNITS 1 & 2 ARE EXISTING FOSSIL FUEL UNITS, UNITS 3 & 4 ARE NUCLEAR UNITS PRESENTLY UNDER CONSTRUCTION.

(2) INCLUDES DILUTION WATER.

(3) SEE FIGURE 1 FOR STAIONS AT WHICH VELOCITY IS COMPUTED.

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CONSULTING ENGINEERS IN THE APPLIED EARTH SCIENCES

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CABLE: DAMEMORE
TELEX: 5-42611

July 23, 1971

Brown & Root, Inc.
Post Office Box 3
Houston, Texas 77001

Attention: Mr. Carl L. Fick

Gentlemen:

We are pleased to submit herewith our report, "Geohydrologic Conditions Related to the Construction of Cooling Ponds, Florida Power & Light Company Steam Generating Station, Turkey Point, Florida, for Brown & Root, Inc."

The scope of work undertaken was as outlined in our initial proposal with extensions and modifications planned in discussions with representatives of Brown & Root, Inc., Florida Power & Light Company, Central and Southern Florida Flood Control District, United States Geological Survey and the Dade County Water Control. During the course of the study, meetings were held with the above mentioned agencies and organizations at the Central and Southern Florida Flood Control District offices in West Palm Beach, Florida. These meetings served to review and discuss preliminary information and results prepared by Dames & Moore concerning the geohydrologic conditions related to the proposed Turkey Point cooling pond.

At this time, some additional analyses of the available data have been requested. These supplementary studies will be presented on completion as an Addendum to this report.

We appreciate the cooperation and assistance provided us during the progress of this study by all of the above mentioned agencies and all other participants. It has been a pleasure performing this investigation for you. Should you have any questions concerning the contents of this report, please feel free to contact us.

Very truly yours,

DAMES & MOORE

Benjamin S. Persons

Leo M. Page

Leo M. Page

Porter C. Knowles

Porter C. Knowles

BSP/LMP/PCK:ds

BENJAMIN S. PERSONS
CERTIFICATE
No. 5754
STATE OF FLORIDA
REGISTERED ENGINEER

GEOHYDROLOGIC CONDITIONS RELATED TO THE CONSTRUCTION OF COOLING PONDS
FLORIDA POWER & LIGHT COMPANY
STEAM GENERATING STATION
TURKEY POINT, FLORIDA
FOR BROWN & ROOT

4598-012-09

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RELATED TO THE CONSTRUCTION OF COOLING PONDS
FLORIDA POWER & LIGHT COMPANY
STEAM GENERATING STATION
TURKEY POINT, FLORIDA
FOR BROWN & ROOT

INTRODUCTION

This report presents the results of our study of ground water conditions related to the construction of cooling ponds at the Florida Power and Light Company Steam Generating Station at Turkey Point, Florida. The study involved a testing program to obtain data on the three dimensional aspect of the aquifer system in the area and included the obtaining of information on lithology, permeability, transmissibility, storage coefficient and geophysical properties. Based on the results obtained from the testing program and using published reports for additional background information to define the aquifer system, a mathematical model was used which was applicable to the conditions at Turkey Point. A digital computer program was developed and used to determine the validity of the mathematical model for the 30 square mile study area under the natural ground water conditions which existed during the recent drought and under conditions of the imposed cooling pond reservoir.

Detailed analyses were made on the ground and surface water regimes near Levee 31 and the proposed cooling pond with its associated interceptor ditch. An electric analog model was constructed and tested simulating the various alternative methods of constructing the cooling pond and interceptor ditch with relation to Levee 31 Borrow Canal.

Findings and Conclusions

Based on the recent investigation and previous work done by Dames and Moore in this area, it appears that by proper construction of the

cooling pond interceptor ditch and by maintaining appropriate head relationships between the Levee 31 Borrow Canal and the ditch, the proposed cooling facility can be operated without causing sea water intrusion to the west of Levee 31. The details of the proposed construction and operation are included in the main part of the report.

Recommendations

The above conclusion is based on field investigation and geohydrologic analyses both detailed and regional in extent. The results of the testing program and the engineering analyses indicate that although there is some variation in the quantitative aspects of the aquifer characteristics in the study area there is regional uniformity of lithologic and geohydrologic conditions.

It is recommended that a monitor system be established to compare the actual and predicted effects of the proposed facility on the geohydrologic regime, with particular attention to the areas where geohydrologic control was not obtained.

Many of the wells that were installed during this investigation can be used as part of the monitor system. It is advisable to begin making periodic measurements in the near future on these wells including the obtaining of information on ground water levels, chloride content and temperature measurements at various depths. These data will provide background information necessary to determine the regime of the aquifer system prior to the construction of the proposed facility. Before final construction of the cooling pond and interceptor ditch additional monitoring devices should be installed in the critical area between the proposed ditch and Levee 31 Borrow Canal.

Special attention should be given to observe for possible piping effects near the proposed cooling pond levee - particularly during the first several months of the operation of the cooling pond. A program should be established to periodically inspect the reservoir perimeter for excessive seepage, turbid water or other evidence of piping.

PURPOSE AND SCOPE

The purpose of this study was threefold:

1. Determine by detailed study what would be the effects of the proposed cooling pond facility on Levee 31 from the standpoint of salt water intrusion and loss of water from Levee 31 Borrow Canal.
2. Determine the effects of the proposed cooling pond on regional geohydrologic conditions.
3. Determine optimum methods of construction and operation of the proposed cooling pond facility.

Plate 1, Map of Area, shows the location of the study area (about 30 square miles) with relation to the surrounding environment and Plate 2, Plot Plan, shows the locations where field testing was done for this investigation. The vertical relationship of geohydrologic conditions is shown on Plate 4, Geohydrologic Cross Section A-A^1, where the most complete information was available. The detailed analyses of the ground water flow pattern near Levee 31 Borrow Canal and the proposed cooling pond were made at section B-B^1 (See Plates 9&10) where the greatest decline in ground water levels was recorded in the study area for the period of study.

Project Staff

The following staff members within the firm provided principal contributions to the information, conclusions, and recommendations presented herein:

S.K. Djou	Senior Projects Engineer (2)
V. Edwards	Field Geologist
C. Farrell	Field Geologist
D. Gibeaut	Senior Engineer (4)
S. Kozlowski	Staff Meteorologist (5)
P. Knowles	Staff Geologist (3)
S. Kupelian	Assistant Engineer
C. Logie	Project Engineer (4)
J. Markham	Field Geologist
W. Moore	Advisory Partner

Project Staff - Cont'd

L. Page	Senior Geologist (1)
B. Persons	Responsible Partner
J. Stogner	Staff Meteorologist (5)
S. Wampler	Field Geologist

(1) Responsible for developing and executing this effort.

(2) Responsible for adapting digital program for use in ground water model study of Turkey Point.

(3) Responsible for technical calculations and supervision of report preparation.

(4) Responsible for construction and calculations involved in electric analog model studies.

(5) Responsible for all programming work related to ground water model.

FIELD INVESTIGATION

The field work was begun on April 19, 1971 and completed on June 26, 1971. Forty-two test holes were drilled at twenty-two separate locations with a total footage drilled of over 2200 feet. Cores were recovered from 14 holes and are stored in core boxes on Florida Power and Light Company property at Turkey Point, Florida. The locations of the test borings are shown on Plate 2, Plot Plan, and the logs are included in Appendix F (Plates 13 to 54). Data obtained during the test drilling included information on geologic conditions, inflow test rates, percent core recovery, drilling rates, E-logs, chloride contents of water obtained from different depths in the wells, and ground water levels obtained from wells of different depths at the same location. All field work was done under the supervision of a ground water geologist or engineer.

Two methods, pump tests and inflow tests, were used to obtain data used in making quantitative evaluations of the aquifer parameters of permeability transmissibility. A description of the procedures used in making the pump and inflow tests is included in Appendices A-3 and A-4.

PUMP TESTS - Three pump tests were performed in the study area - two at GH-14 (GH-14A and GH-14B) and one at GH-11 (GH-11B). The pump tests were run from two to four hours, during which time the effects of pumping on the water levels in the wells essentially reached equilibrium. The values of transmissibility determined from the pump tests at GH-14 and GH-11 were of the same order of magnitude with higher Transmissibility values obtained at GH-11.

INFLOW TESTS - These tests were made on most of the test borings that were cored and on some of the uncored holes. The results of the inflow tests were generally the same as the pump tests - the transmissibility values, particularly in the depth range from 10 feet to 40 feet, were higher in the southerly portion of the study area. At location GH-11 the transmissibility values were obtained using both pump test and inflow test methods, and were of the same order of magnitude.

ENGINEERING ANALYSIS

The engineering analysis was separated into two categories:

1. Regional verification of the aquifer system over a large area (30 square miles) and covering relatively long time periods - October 1970 to April 1971.
2. Detailed analysis of ground water flow patterns as affected by the proposed cooling pond near Levee 31 Borrow Canal.

Regional Verification - The first analysis done was the regional verification of the aquifer system. It was considered that if the quantitative values of aquifer parameters determined from the field investigations could be used to predict ground water levels over large areas it would allow for a higher confidence level to be placed on the extrapolation of subsequent detailed analyses to the larger areas. Details of the ground water model which was used in the regional verification are included in Appendix B of this report.

Detailed Analysis - The detailed analysis of the ground water flow patterns in the area near the proposed cooling pond facility and Levee 31 Borrow Canal was made using the information on transmissibility that was obtained during the field investigation.

An electric analog model was used to study the effects on the aquifer system for various methods of constructing and operating the proposed cooling pond facility. A detailed description of the electric analog model is included in Appendix C of this report.

RESULTS OF INVESTIGATION

REGIONAL GEOHYDROLOGY

The regional geohydrology has been fully described in previous reports on the area. Essentially there are two principal aquifers in the area - the Biscayne Aquifer which is a highly permeable limestone, water table aquifer extending from the ground surface to depths of about 70 feet; and the Floridan Aquifer which underlies the Biscayne Aquifer at considerable depth. It is the shallow Biscayne Aquifer which has been considered in this report.

The Biscayne Aquifer has been subdivided into two principal formations - the Miami Oolite and the Fort Thompson. In the study area the aquifer is capped by a muck layer which varies in thickness from about 1 foot near Tallahassee Road to 4 or 5 feet near Biscayne Bay. The vertical relationship of the formations is shown on Plate 4.

The ground water flow regime in the study area varies throughout the year. During times of high ground water level (end of rainy season, about October) the ground water basin is nearly full, the general slope of the ground water surface is toward Biscayne Bay and there is considerable discharge of fresh ground water into the Bay causing a decrease of salinity content of waters in the Bay..

During times of low ground water levels (generally near the end of May) the ground water levels inland can be drawn below sea level due to the high natural rates of evapotranspiration, and sea water intrusion occurs. During the drought conditions which existed between January and June 1971 the wedge of saline water had moved inland a considerable distance. On Plate 4 are shown the chloride contents of wells which had been drilled and sampled during this investigation - the 16,000 part per million isochlor was found at a depth of 40 feet at a distance of more than one half mile west of Levee 31. During the drought the high evaporation rate from Biscayne Bay

and the lack of fresh water recharge caused an increase of chloride content of Bay water to over 28,000 parts per million, which is more than 1.4 times that of natural sea water. It can be expected that normal rainfall conditions in the rainy season will cause the wedge of highly saline water to be moved seaward and the discharge of surface and ground waters into Biscayne Bay will cause the chloride content to decrease to less than 20,000 parts per million.

All the local water that recharges the Biscayne Aquifer is derived from local rainfall which averages about 60 inches per year. Of the 60 inches, it is estimated that about 22 inches is discharged by evaporation and surface runoff without reaching the water table, and 38 inches reaches the water table. Of this 38 inches, about 20 inches is discharged as ground water flow towards and into Biscayne Bay, and 18 inches is discharged by evaporation of ground water and by pumping from wells.

In the study area there is no ground water pumpage for irrigation and all outflow is from evapotransporation and effluent flow to canals and the Bay. The inflow to the aquifer system is from rainfall, influent flow from canals during certain conditions, sea water intrusion, and since the area is a ground water discharge area, there is a component of ground water inflow from depth in the Biscayne Aquifer.

Samples of water were obtained from most of the test wells drilled, generally at depth intervals of 10 feet for the entire depth of the hole. Samples of water were also obtained periodically of surface water at select locations in the study area as shown on Plate 2, Plot Plan. The samples of water from wells and the surface water sampling locations were tested for chloride content using a conductivity measuring cell. The tabulation of data for chloride content of waters is shown on Table 3 with details on the sampling procedure included in Appendix A-5.

DETAILED GEOHYDROLOGY

The following geohydrologic conditions were observed during the recent investigation:

1. There is regional uniformity of geologic conditions in the area. The sequence and depth range of formations that were generally encountered included:

0-5'	Muck
5-12'	Miami Oolite
12-40'	Fort Thompson - Void Zone - low core recovery, high permeability
40-50'	Fort Thompson - high core recovery, lower permeability
50-70'	Fort Thompson - zones of low to moderate core recovery, moderate to high permeability

2. In northerly portion of study area the upper void zone (depth range 12 feet to 40 feet) is not as well developed as in the southerly portion and the transmissibility of the zone is lower.

3. Zone of extremely high chlorides (>20000 parts per million) of ground water - equal to or greater than chloride content of normal sea water - extends more than 1 mile west of Biscayne Bay.

3 (a) Wedge of saline ground water (in excess of 16000 parts per million chlorides) encountered in test borings over one half mile west of the Levee 31 Borrow Canal (See Plate 3, Geohydrology Section).

3 (b) None of the ground water or surface water which was tested in the study area contained less than one thousand parts per million chloride ion. This water would be unsuitable for use on most crops, and is well above the U.S. Public Health Drinking Water Standard of 250 parts per million.

3 (c) The soil profile in the upper 5 to 10 feet depth range throughout most of the study area consists of several feet

of muck and peat overlying solutionized limestone. With this soil profile there would be a potential for piping to develop under the conditions of abnormally high hydraulic gradients on muck and peat overlying solutionized limestone. With this soil profile there would be a potential for piping to develop under the conditions of abnormally high hydraulic gradients which would exist with a raised cooling pond. Piping, which is the removal of fine particles by erosion from a soil mass, would be most apt to develop near the edges of the proposed cooling pond embankment levees. The adverse effects of piping would be: excessive shallow seepage from the reservoir, difficulty in maintaining water levels in the reservoir, and in extreme conditions - embankment failure. The condition can be prevented from becoming a serious problem by maintaining a surveillance program to detect evidence of incipient piping. If the condition is detected in the early stages, it can be corrected by:

1. Constructing an impermeable membrane such as a bentonite blanket on the reservoir side of the levee.
2. Construction of filter blankets and relief ditches or wells on the downstream side of the levee.

Based on the results of the investigation the Biscayne Aquifer has been subdivided into the following geohydrologic zones:

Depth	Formation	Transmissibility GPD/FT	Storage Coefficient
0-12'	Muck, Miami Oolite	20,000.	0.35
12-40'	Fort Thompson(void Zone)	3,000,000.	0.35
40-70'	Fort Thompson(Less Permeable Zone)	1,000,000.	0.20

GROUND WATER MODEL - REGIONAL VERIFICATION

The above data on transmissibility and storage coefficient were used as part of the basic input to the computer program that was used to verify the mathematical model of the study area. The study area was subdivided into 35 separate nodes as shown on Plate 5, Plan of Nodal Layout. The long narrow nodes represent canals and the larger squares and polygons represent the adjacent land areas. Ground water contour maps were obtained from Dade County Water Control for the periods October 1970, January 1971 and April 1971 (Plates 6, 7 and 8.)

The computer was given a starting set of historic ground water elevations for each node for the time January 1971 (Plate 7). Using the values of transmissibility and storage coefficient previously listed and the estimated amount of surface flow into or out of each node for the period January to April 1971 the computer generates a set of values of ground water levels for each node for time April 1971. If the computed set of ground water levels for April 1971 is in close agreement with the measured historic ground water levels as shown on Plate 8, then the model can be considered to be verified.

Table 4 is a computer printout sheet showing a list of generated water levels (designated as H) for April 1971, and the historic measured ground water levels for each node which are designated as HH. A comparison of H and HH values on Table 4 shows that most of the generated values are within 0.1 feet or 0.2 feet of the measured historic water levels. Considering that the total range in fluctuation of ground water levels at the nodes in the study area averaged about 0.8 feet between January and April 1971 it appears that the values of the parameters and other input used in the computer run were of the right order of magnitude.

GROUND WATER MODEL - EFFECTS OF COOLING POND WITHOUT INTERCEPTOR DITCH CONTROL

With proper design of the cooling pond facility, the seepage from the pond would be picked up by the interceptor ditch as shown by the results of the electric analog model studies. However, it was considered advisable to evaluate the effects on the regional ground water regime if a small portion of the cooling pond seepage was not intercepted. The digital program was used to model the effects of this condition.

In order to impose this condition on the ground water model, nodes #14 and #9 were considered to be the area of the cooling pond. It was assumed that a subsurface flow of 2 gallons per minute per linear foot of pond levee went past the interceptor ditch for the ground water conditions which existed from January to April 1971.

The regional effects of the cooling pond at nodes #14 and #9, and the seepage past the interceptor ditch, are shown in Table 5, Computer Printout Sheet. The significant effects were:

1. Effluent flow (QS) which developed in nodes adjacent to nodes #14 and #9.
2. Rise in ground water level of the nodes in the study area.

The effluent flow amounted to about 80 cubic feet per second, mostly occurring in canal nodes 4, 8, 13 and 19; and the rise in ground water level of the nodes in the study area was more than one half foot.

The results of the ground water model study with the cooling pond imposed on the system are indicative of what the qualitative effects on the regional ground water regime would be if proper interceptor ditch control was not attained. The quantitative information if probably of the right order of magnitude.

ELECTRIC ANALOG MODEL

Based on previous studies and the present field investigation, it appears that it would be possible to construct the proposed cooling pond and associated interceptor ditch, and operate it in such a way that there would not be an adverse effect on the Levee 31 Borrow Canal and/or the regional geohydrologic conditions. The electric analog model provided a method of making detailed studies of the effects on the ambient ground water flow regime of various alternative methods of constructing and operating the proposed cooling pond facility.

Essentially the analog model is a scaled geohydrologic cross section corresponding to the aquifer system in the critical area between the Levee 31 Borrow Canal and the proposed interceptor ditch. The model was used to generate the approximate configuration of equipotential lines from which it

was possible to determine if salt water intrusion would develop from cooling pond seepage -- or if there would be excessive loss of fresh water recharge from the Levee 31 Borrow Canal.

The following conditions have been simulated in the electric analog study of the proposed cooling pond, interceptor ditch and Levee 31 Borrow Canal:

Distance from L31 Canal to Ditch	Water Elevation L31 Canal (MSL)	Water Elevation Ditch (MSL)	Water Elevation West of L31 (MSL)
500'	-0.3	-5.0	-0.5*
500'	-0.3	-3.0	-0.5 (Plate 9-I)*
500'	-0.3	-2.0	-0.5*
500'	-0.3	-1.0	-0.5**
500'	+1.3	0.0	+1.5*
1000'	-0.3	0.0	-0.5 (Plate 9-II)**
1000'	-0.3	-4.0	-0.5 (Plate 9-III)*
1000'	+1.3	-0.3	-0.5 (Plate 10-I)*
500'	+1.3	-3.0	+1.5 (Plate 10-II)*

* No salt water intrusion

** Salt water intrusion occurs

Plates 9 and 10 show the equipotential lines that would develop for various conditions listed above. On Plate 9-II is shown the condition when salt water intrusion would occur - the equipotential lines from the cooling pond extend to the west under Levee 31. Plates 9-I, 9-III, 10-I and 10-II show the equipotential lines when no salt water intrusion occurs. Under these conditions a subsurface divide occurs where the equipotential lines from the west meet the equipotential lines from the cooling pond and no horizontal ground water flow would occur in either direction at this location.

On Plate 10-I are shown the equipotential lines that would develop if recharge water was used to raise the water level in the Levee 31 Borrow Canal to Elevation +1.3 (MSL). Based on a flow net analysis for this condition it can be seen that the outflow of fresh water from the Borrow Canal to the interceptor ditch would be negligible. The flow lines from the Borrow Canal to the east possibly would discharge to some extent at the ground surface through the upper impermeable zone. Under the recharge condition shown on Plate 10-I

the shallow seepage from the Levee 31 Borrow Canal to the ground surface would develop even if the cooling and interceptor ditch were not constructed.

Based on the results of the electric analog analyses it appears that salt water intrusion could be controlled by using any one of the several alternatives listed above, where salt water intrusion would not occur. The natural ground water levels used in the electric analog model study occurred during the drought of 1971 and from this standpoint, the analyses can be considered to be conservative. However, the values of permeability used were average values in each of the three layers used in the model, and in view of the fact that there are large variations between maximum and average values of permeability of the formations in the Biscayne Aquifer, the results of the analog model study should be used conservatively.

SUMMARY

I It is possible to construct and operate a raised cooling pond within 500 feet of the Levee 31 Borrow Canal without causing serious salt water intrusion by maintaining certain head differentials between the water levels in the Canal and in the ditch. For the extreme ground water conditions which existed in May 1971 one favorable scheme would be to construct an interceptor ditch 19 feet deep and operate at a pumping water level elevation of -3.0 feet, Mean Sea Level, as shown on Plate 9-I.

II It may be difficult to insure that the conditions for maintaining the required pumping level in the ditch can be attained during adverse conditions such as hurricanes and power shortage. If this critical head relationship is disrupted for long periods of time such as several weeks -- serious salt water intrusion could occur.

III A monitor system should be established to make it possible to detect excessive seepage conditions which could develop. The monitor system would include wells installed in critical areas. The wells would be checked periodically for ground water levels, ground water quality and temperature.

IV In view of the potential for a condition of piping to develop, special precautions should be taken to observe for the development of this condition. Remedial measures such as use of bentonite membrane of the water side of the cooling pond near the dike; relief ditches and/or wells with filter blanket on the discharge side of the Levee, should be considered.

The attached Appendices are indexed on the following page and complete this report.

Respectfully submitted,

DAMES & MOORE

Benjamin S. Persons

Leo M. Page

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APPENDICES INDEX

APPENDIX A

FIELD INVESTIGATION

1. GENERAL

The field ivestigation was performed in order to obtain qualitative and quantitative information on the three dimensional aspect of geohydrologic conditions in the study area. The work includes test drilling, pump tests, inflow tests, water quality sampling of surface and ground waters, and obtaining E-logs of the test borings.

The field program was conducted under the technical direction and supervision of Dames & Moore Engineering Geologists, Hydrologists and Soil Mechanics Engineers. The investigation was coordinated with and reviewed by representatives of Brown and Root, Central and Southern Florida Flood Control District, Dade County Water Control and the United States Geological Survey, as the work progressed.

Many of the test borings drilled during the recent and previous investigations by Dames & Moore can be used as part of the permanent monitor system which will be established. The monitor system will be used to obtain detailed information of the natural variations of the geohydrologic regime and to determine the effects of the proposed cooling pond facility after it is in operation.

2. DRILLING

The subsurface conditions in the study area were explored by drilling forty-two borings at twenty-two locations. Bore hole depths ranged from fifteen to eighty feet with a total footage of two thousand two hundred thirty seven feet (2,237). Information was obtained at each boring on subsurface materials and rock, by utilizing one or more of the following techniques:

Visual logging of rock and soil cuttings, examination of core recovery, recording of drilling rates, inflow tests to determine transmissibility of specific strata during drilling, electric logs, chlorinity determinations and three pump tests at two locations to further define aquifer transmissibility.

Nine drilling locations were on fill material composed of limestone and coral rubble. The remaining twelve locations were on muck under semi-dry mangrove swamp conditions. Some borings in specific well clusters were utilized as point piezometers, generally at a depth of sixty feet.

All borings were drilled by Geotechnical, Inc., of Lakeland and Miami, Florida under the supervision of one of our ground water geologists or engineers. Boring locations on fill material were drilled with a trailer mounted, rotary rigs. Drilling in the swamp areas was accomplished by mounting rotary rigs on Pochets, a mobile, pontoon mounted platform designed for rig mobility in swampy areas.

The logs of borings are listed in Appendix F, Plates 13-54.

3. PUMP TESTS

The main objective of the pump test program was to obtain information on the transmissibility of the aquifer to a depth of 70 feet. The original plan was to drill two pumping wells at each location - one to a depth of 70 feet and the other to a depth of 40 feet. The wells were to be cased to a depth of about 15 feet with 8 inch diameter casing, and drilled open hole, 6 inch diameter, to the bottom. Separate pump tests were to be made at the two wells of different depth at both pump sites and the transmissibility values of the 40 foot wells could be subtracted from the transmissibility values of the 70 foot wells. Because of the drilling conditions - material caving into the hole - it was not possible to maintain open hole to a depth of 70 feet at any of the pump test sites.

The three sites developed for pumping tests GH-11, GH-14 and GH-16, are shown on Plate 2, Plot Plan. Pump tests were made at two locations GH-11 and GH-14 and based on the results of these tests it was not considered necessary to run the pump test at GH-16.

The locations of the pumping wells and observation wells at GH-11 and GH-14 are shown on Plates 3-A and 3-B. The procedure for conducting the tests was similar at both locations. Automatic water level recorders were installed on observation wells at both locations prior to the start of the pumping tests, and left in place after the completion of the test. This was done in order to screen out the fluctuations in ground water level caused by natural conditions such as tide and rainfall. Water levels were measured periodically in all the observation wells and the pumping wells by tape, electric sounder, or automatic water level recorder. The manual measurements were continued throughout the pumping phase for several hours and during the recovery phase. Pertinent data obtained during the pump tests are tabulated in the Appendix (Tables 1-A, 1-B and 1-C). At GH-14 the chloride content of water from the wells was measured before, during and after the pump test (See Table 2).

At GH-14 two pump tests were run - one at GH-14 A for 4 hours and the other at GH-14 B for 2 hours. The drawdown in the pumping wells for both tests was about 3 feet while pumping at a rate of about 1380 gallons per minute. The ground water levels at this location were definitely affected by tidal fluctuation which was shown on the hydrograph from the automatic water level recorder.

At GH-11 one pump test was made on well GH-11 B for a period of 4 hours. The maximum drawdown in the pumping well was about 1 foot while pumping at a rate of 1380 gallons per minute. There was no observable tidal effect at site GH-11.

The pump tests were useful as a source of information on the transmissibility values of the portions of the aquifer that were tested - from about 15 feet to 50 feet in depth. The values of transmissibility that were obtained from the pump tests were about 3,000,000 gallons per day per foot at GH-11 and about 1,000,000 to 1,500,000 gallons per day per foot at GH-14. The estimates of transmissibility for the aquifer from 50 feet to 70 feet depth are based on inflow tests in the various test borings.

4. INFLOW TESTS

Inflow tests were performed on most of the test holes that were cored and on some of the uncored holes. The data on transmissibility based on inflow tests are indicated on the logs of borings in Appendix F of this report.

The general procedure for making an inflow test was as follows:

1. The test hole of known diameter was drilled to a depth of 5 feet to 10 feet, without casing if this was possible.
2. The static ground water level in the test hole was measured.
3. The drill rods were inserted in the test hole so that the bottom of the rods was about one foot above the bottom of the hole.
4. Water was put into the test hole through the drill rods at a measured rate of flow for a period of 10 minutes or more - when the rate of change of water level was very slow. The water level in the test boring was measured with an electric sounder during the period of inflow.
5. The inflow of water to the test hole was shut off and the static water level was again measured.

The casing was then installed in the depth interval where the inflow test had been performed and the hole was drilled to a depth of 5 feet or more below the casing. Observations were made of drilling water return after the casing was installed to determine if the casing had formed an effective seal. The uncased portion of the test boring was then tested using measured quantities of inflow and obtaining static and inflow water levels as described above. Plate 11 shows a typical setup for an inflow test including casing, open hole static and inflow water levels.

The entire depth of the cored test borings was tested in this manner, by alternately driving casing and testing the uncased portion of the hole below the casing. The casing was driven in stages, generally to depths of about 40 feet. In the uncored borings the casing was installed in the upper 10 feet to 15 feet of the hole and the inflow tests were generally made at 10 feet to 20 feet depth intervals below the casing - to the bottom of the hole.

By measuring the rise in water level for the known rate of inflow it is possible to determine the specific capacity for the depth interval tested. This value of specific capacity was used together with the length of time of the test, to determine transmissibility data for the various zones. The

information obtained on transmissibility based on inflow tests is of limited accuracy but it is very useful in determining major changes of transmissibility with depth.. It is probable that the transmissibility values which were based on inflow tests are of the right order of magnitude.

5. WATER QUALITY SAMPLING

One of the more important aspects of the geohydrologic regime is the natural variation in quality of surface and ground waters. Based on previous studies of geologic and hydrologic conditions in the Biscayne Aquifer of southeast Florida a considerable amount of information is available concerning the general relationship between fresh water and salt water. During the recent investigation a sampling program was carried out that made it possible to delineate the extent of sea water intrusion in portions of the study area, and to determine the chlorinity of surface waters which existed during the extreme drought conditions of 1971.

The sampling of ground waters to determine chloride content was done on most of the test borings drilled. Two types of casing were installed, perforated and unperforated, in order to obtain information on the variation of ground water quality with depth at various locations in the study area. The perforated casings were installed to depths of about 40 feet with the perforations extending the entire length. The ground water levels in the unperforated casings is generally within a foot of the ground surface. Ground water samples were obtained from both perforated and unperforated casings at 10 foot depth intervals using the Foerst Water Sampler.

Surface water samples were periodically taken at the intake structure on Biscayne Bay, the Grand Canal, Card Sound Canal and the Levee 31 Borrow Canal during the investigation. The samples were taken at the surface and at several intervening depths to the bottom of the channel using the Foerst Sampler.

Conductivity measurements of the water samples were made in the field to determine salinity and chloride contents. Some of the water samples were also tested for chloride content using the Mercuric Nitrate method to determine the accuracy of the field determinations.

A tabulation of the chlorinity data for surface and ground waters as determined during the recent investigation is shown on Table 3. The chloride content of surface waters from the intake structure, the Grand Canal, and Card Sound Canal was considerably in excess of normal sea water which contains about 20,000 parts per million. The zone of sea water intrusion in the ground water basin had reached a point more than one half mile inland from the Levee 31 Borrow Canal as shown by the 16,000 part per million isochlor on Plate 3, Geohydrologic Section. The chloride content of ground water was equal to, or greater than, the normal chloride content of sea water at test borings GH-8, GH-10 and GH-14, which are at distances of more than a mile inland from Biscayne Bay.

The program of monitoring surface and ground water quality which was begun during the recent investigation should be continued in the coming months in order to determine the effects of various climatic conditions on the natural variation of water quality in the study area.

6. ELECTRIC LOGS

Spontaneous potential and resistivity logs were performed in many borings under the supervision of one of our ground water geologist or engineers. These logs were made with a Widco Portalogger utilizing standard geophysical techniques to obtain spontaneous potential and resistivity readings on a continuous recorder. The electric logs were analyzed in the field and in our Atlanta Office for correlation pruposes in determining physical parameters of the materials encountered. The resistivity logs have been presented on the Log of Borings, Plates 13 to 54.

Prior to the running of an electric log, the borings were sounded to determine the depth of open hole in the boring and to determine the general condition of the open hole. Continuous recording of the spontaneous potential and resistivity utilizing appropriate scales, were made from the bottom of the open hole to the ground surface or bottom of casing. In come cases, borings were cased for ten to fifteen feet to prevent caving of the soft upper soils which prevents electric log recording in this zone. In other cases, loose and/or soft materials from the highly transmissible void zones caused caving problems in the boring and prevented electric logging of the original drilled depth.

The spontaneous potential and resistivity curves were utilized to provide another correlative tool in the determination of the physical parameters of the aquifer system. Electric curves performed on cored and uncored borings were analyzed to provide an indication of rock characteristics and changes in lithology.

APPENDIX B

GROUND WATER MODEL

INTRODUCTION

A thirty square mile area near Turkey Point, Florida was studied from a geohydrologic standpoint using a mathematical model programmed on a digital computer. The digital computer application used at Turkey Point is patterned after a proven model from the State of California, Department of Water Resources developed for the Chino Ground Water Basin in Orange County, California and modified by Santa Clara County Flood Control and Water District. The program was revised by Dames & Moore to make it applicable for the conditions which exist at Turkey Point, Florida.

MATHEMATICAL BASIS

The formulation of a mathematical model requires simplicication of the elements of the ground water basin, yet it must correspond to the basic hudraulic properties of the aquifer system. The reliability of the model is also dependent on the geologic and hydrologic input data to the mathematical model.

The continuity equation and Darcy's equation were used to establish a generalized ground water equation which defines storage and ground water movement of any unit area in the saturated zone.

Continuity equation: Net subsurface flow + net surface flow = change in storage

Darcy's equation: Quantity of subsurface flow equals transmissibility times width of flow path times hydraulic gradient

$$Q=TJI = Y\Delta H$$

For a branch connecting node "n" to node "i", the subsurface flow in direction from "i" to "n" will be equal to $Y_{n,i}\ (H_i - H_n)$. The net subsurface flow from all the branches surrounding the node "n" will be equal to $\sum iY_{n,i}\ (H_i - H_n)$. A typical layout showing the arrangement of nodes can be seen in Plate 12-I.

If the water levels at node "n" changed from HO_n at the beginning to H_n at the end of time interval (Delta), the rate of storage change will be

equal to $AS_n(H_n-HO_n)/Delta$, where AS_n is the nodal capacitance. The continuity equation can be written as $\sum iY_{n,i}(H_i-H_n) + AQ_n=AS_n(H_n-HO_n)/Delta$, for which the water level elevations H, are to be solved. This relationship is presented in schematic form in Plate 12-II.

A definition of the terms used above is as follows:

Q = Quantity of flow in gallons per day

T = Transmissibility in gallons per day per foot

J = Width of flow path

I = Gradient along flow path

$Y_{n,i}$ = Conductance factor at midpoint in flow path in acre-feet per year per foot width of aquifer between nodes "n" and "i".

ΔH = Difference in elevation between midpoints of nodes on flow path

H_i = Water elevation in feet (MSL) at node "i"

H_n = Water elevation in feet (MSL) at node "n"

AQ_n = Net external flow rate in node "n"

PROCEDURE FOR MODELING

The general approach to modeling is as follows:

1. Set up a nodal pattern for the study area considering geology, hydrology and topography. The distance between two adjacent nodes represents the length of the flow path, and the polygon side common to the two nodes represents width of flow path.

2. Establish storage factors (area in acres times storage coefficient) for each nodal polygon, and conductance factors (transmissibility times width of flow path divided by length) of each flow path.

3. Establish a time period for verification (October 1970 to April 1971) and also a unit duration (three month period) for the study.

4. Establish historical surface inflow and outflow data and estimate subsurface inflows and outflows for each unit time duration.

5. Establish changes in ground water storage in each unit duration, check hydrologic balance.

6. Using the above data as input to the computer program the computer generates water level elevations for each node for a given time period. The generated water level elevations are compared with historic measured water level elevations for each node for the given time period as a measure of verification.

MECHANICS OF PROGRAM

The period of study is divided into intervals called "TIME", and each TIME interval is further divided into subintervals called "DELTA", the time integration step.

The Turkey Point study area is divided into 35 nodes and there will be 35 equations and 35 H's as unknowns. These equations are solved simultaneously for each integration time step DELTA. Using estimated values of storage factor, conductance factor, source flow rates and historical water elevations (HH), together with the physical characteristics of the basin as input data, all the node to node subsurface flows and the change of storage flow are calculated. Then the subsurface flows, source flow rates and change of storage flows are balanced at each node by setting their sum equal to the residual term. Water level elevation at the node is then adjusted using a relaxation technique.

All nodes have a limiting water elevation above which the water level will cease to rise. If a node has its water level fixed at the limiting elevation because of this condition it is said to be clamped. If a node is clamped there will be no storage change at the node and the excess of net inflow over net outflow will appear as surface flow. At such a node the residual flow is converted to surface flow and the residue is set to zero.

PROGRAM FOR TURKEY POINT

For the Turkey Point study there were two conditions that made the modeling effort more difficult than usual:

1. The lack of data on surface inflow and outflow of the study area.
2. The lack of detailed information on ground water levels throughout the study area. The information obtained from Dade County

Water Control was the basis for the ground water contour maps but in a considerable portion of the area there were no data available and the ground water contours were based on estimates.

The effect of the lack of information on surface inflow and outflow was decreased by selecting a period of study during the drought conditions of 1971 when inflow and outflow were at a minimum. The observation wells installed during the recent investigations can be used as a source of ground water level information to determine more accurately the shape of the ground water surface for past and future ground water studies of the area.

Based on the field investigations at Turkey Point the aquifer system was divided vertically into three main layers:

0 - 12 feet, Much & Miami Oolite, relatively impermeable

12 - 40 feet, Ft. Thompson (void zone), very high permeability

40 - 70 feet, Ft. Thompson, high permeability

The digital program was designed so that the aquifer system could be tested as a three layer model. The values of transmissibility were based on inflow and pump test data obtained during the recent field work. Storage coefficients that were used in the first computer runs were obtained from previous studies of the Biscayne Aquifer and were subsequently changed based on the results of the computer runs.

Another feature of the digital program that was useful in the Turkey Point study was the capability of the program to be used to obtain information on effluent ground water flow. This feature was particularly useful when the model was used to test the effects of the proposed cooling pond reservoir on the regional geohydrologic conditions.

The main objective in using the ground water model was to test on a regional basis, for long periods of time, the accuracy of the values used for the major parameters of the aquifer system including transmissibility, storage coefficient, surface flow in and out of study area, and water balance. Based on the results obtained from the modeling study it is concluded that the values used are of the right order of magnitude. With additional work it would be possible to use the model to determine the effects of various schemes of recharge and withdrawal on the regional geohydrologic regime.

APPENDIX C

ELECTRIC ANALOG MODEL

The electric analog model consists essentially of thin sheets of electrical conducting paper in which an electrical current flow pattern is set up by means of suitably attached and energized electrodes. The resultant potential drop pattern established by the current flow is detected and marked directly on the paper by means of a searching stylus used in conjunction with a highly sensitive detecting instrument.

The model permits the direct visual plotting of an approximation of the two dimensional pattern of the equipotential lines in the ground water flow regime near Levee 31 Borrow Canal and the proposed cooling pond facility. The definition of ground water equipotential lines makes it possible to obtain information of the effects of the proposed cooling pond on the aquifer system.

The model used at Turkey Point was prepared as follows:

1. A geohydrologic cross section, similar to Plate 3, was drawn to scale. The section was transformed to allow for a ratio of horizontal to vertical permeability of 9 to 1.
2. Layers of electrical paper of different conductivities were used to simulate the three zones of varying permeabilities shown on Plate 3. The least conductive paper was used for the top and bottom layers of the aquifer system, and the most conductive paper was used to correspond to the highly permeable middle zone. The ratio of the least conductive paper to the most conductive paper for most of the modeling was 1 to 4.5 and several tests were made with a ratio of 1 to 18 and 1 to 36.
3. Four main control points were used on the section to apply voltage differentials to the model:
    - (a) Cooling pond, at Elevation +7.1 feet (MSL)
    - (b) Interceptor ditch, at Elevations +0.3 to -5.0 feet (MSL)
    - (c) L-31 Borrow Canal, at Elevations -0.3 to 1.3 feet (MSL)
    - (d) Area west of L-31, at Elevations -0.5 to 1.5 feet (MSL)

4. The ground water surface between the main control points was simulated by painting in sections with silver conducting paint.

The model was tested using a spacing of 40 feet between the toe of the cooling pond levee and the interceptor ditch, and distances of 500 feet and 1000 feet between cooling pond and Levee 31 Borrow Canal. The water levels used in stressing the model correspond to historic water levels in Levee 31 Borrow Canal and the area to the west, and various proposed pumping levels in the interceptor ditch. A tabulation of various conditions for which the model was tested is shown on page 12 of the text. On Plates 9 and 10 are shown cross sections of various conditions that were studied with the electric analog model.

The results of the electric analog model studies were useful in determining the general configuration of the equipotential lines and the subsurface hydraulic divides of the ground water basin in the study area. The monitor well system which will be installed in the area can be used to accurately determine the geohydrologic conditions.

APPENDIX D

PARTICIPANTS

Agencies Contacted	Location	Persons Contacted
United States Geological Survey	Miami, Florida	Mr. Klein Mr. Meyer Mr. Appel
Central and Southern Florida Flood Control District	West Palm Beach, Florida	Mr. Storch Mr. Taylor Mr. Walker
Dade County Water Control	Miami, Florida	Mr. Parks Mr. Brooks
University of Miami School of Marine and Atmospheric Sciences	Miami, Florida	Dr. I. Tabb Dr. M. Roessler
United States Department of Agriculture, Soil Conservation Service	Homestead, Florida	Dr. Dalton

APPENDIX E

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APPENDIX F

TABLES 1 - 5

PLATES 1 - 54

TABLE 1a

Drawdown on Pumped Well GH 11B

(not subject to tidal influence)

Date - 6/17/71

Pump Capacity - 1386 gpm

TIME	ELAPSED TIME (MIN)	DRAWDOWN (FT)
1013:20	0	0.00
	1.0	0.50
	1.5	0.92
	2.0	1.00
	2.5	0.83
	3.0	0.88
	3.5	0.90
	4.0	0.85
	4.5	0.90
	5.0	0.88
	6.0	0.92
	7.0	0.94
	8.0	0.92
	9.0	0.94
	15.0	0.94
	20.0	1.02
	30.0	0.81
	35.0	0.83
	40.0	0.92
	45.0	0.92
	50.0	0.98
	55.0	0.96
	60.0	0.92
	80.0	0.92
	100.0	0.96
	120.0	0.96
	180.0	0.96
	240.0	0.96
1412:20	RECOVERY	-
	0.5	-0.04
	1.0	-0.04
	1.5	-0.04
	3.0	-0.08
	3.5	-0.08
	4.0	-0.08
	7.0	-0.04
	9.0	-0.04
	11.0	-0.02
	12.5	-0.04
	13.0	-0.04
	14.5	-0.02
	16.0	-0.02
	23.5	-0.02

TABLE 1b

Drawdown on Pumped Well 14A

(subject to tidal influence)

Date - 6/18/71

Pump Capacity - 1386 gpm

TIME	ELAPSED TIME (MIN)	DRAWDOWN (FT)
0959:00	0	0.00
	0.5	3.00
	1.5	2.96
	2.0	2.92
	2.5	3.04
	3.0	3.08
	3.5	3.14
	4.0	3.06
	4.5	3.00
	5.0	3.00
	10.0	3.14
	15.0	3.14
	20.0	3.16
	30.0	3.18
	35.0	3.16
	40.0	3.23
	45.0	3.13
	50.0	3.19
	55.0	3.21
	60.0	3.16
	80.0	3.16
	100.0	3.16
	120.0	3.16
	150.0	3.25
	180.0	3.29
	240.0	3.33
1404:45	RECOVERY	-
	0.5	0.46
	1.5	0.37
	2.0	0.44
	3.0	0.27
	3.5	0.25
	4.0	0.25
	4.5	0.25
	5.5	0.25
	10.0	0.21
	15.0	0.21
	20.0	0.21

TABLE 1c

Drawdown on Pumped Well 14B

(subject to tidal influence)

Date - 6/18/71

Pump Capacity - 1386 gpm

TIME	ELAPSED TIME (MIN)	DRAWDOWN (FT)
1500:50	0.0	0.00
	1.0	3.21
	2.0	3.31
	3.0	3.33
	4.0	3.29
	5.0	3.33
	10.0	3.18
	15.0	3.21
	20.0	3.25
	25.0	3.25
	30.0	3.26
	35.0	3.23
	40.0	3.25
	45.0	3.23
	50.0	3.21
	55.0	3.21
	60.0	3.21
	80.0	3.21
	100.0	3.29
	120.0	3.17
1705:20	RECOVERY	
	1.0	0.07
	1.5	0.05
	2.0	0.05
	2.5	-0.04
	3.0	-0.02
	4.0	-0.02
	5.0	-0.08
	10.0	-0.05
	15.0	-0.12
	20.0	-0.08
	25.0	-0.12
	30.0	-0.12

TABLE 2

WATER QUALITY ANALYSES

Pump Test Chlorinity Data (ppm)

Before Pump Test | During Pump Test

Boring	Sample Depths (ft)							Time	Chlorinity (ppm)
	5	10	20	30	40	50	Bottom depth/		
GH 14A	5160	5400	8000				23 ft./ 10,800	1010 1040 1200 1400	10800 11600 12800 13200
14B	6400	6320	9000	14400	19800	20200		1510 1600 1650	15600 15600 15600
14C	16200	16800	18400	19600	19800	20000	58 ft/ 20,200		
11C	1120	1120	2600	11600			37 ft/ 16200		

TABLE 3
WATER QUALITY ANALYSES
Chlorinity Data (ppm)

BORING	DATE (1971)	TIME	5	10	15	20	25	30	40	50		60	
			Sample Depths (ft)										
L-1	6-25	1100	3,210	3,280	--	4,080	--	11,800	16,000	19,000	56*/19,200		
L-3	6-25	1100	1,800	1,800	--	2,600	--	6,730	17,400	19,000	55*/18,800		
L-5	6-26	1030	1,980	2,000	--	2,280	--	10,600	12,200*				
L-6	6-26	0900	1,240	1,400	1,400	4,300	9,600	8,400	9,200	11,200*			
GH-1	6-14		7,400	7,080	--	9,800	--	12,000	18,800	18,800	--	18,000	
GH-2	6-14		13,600	14,000	--	14,600	--	17,000	19,600	20,000	--	20,200	
GH-3	6-23	1510	20,000	20,600	--	23,200	--	25,600	26,800	25,200	59*/28,000		
GH-4	6-25	1230	13,200	18,400	--	20,400	--	22,400	22,800	24,000	57*/25,200		
GH-5	6-25	1200	14,000	14,000	--	15,400	--				32*/17,000		
GH-6A	6-14		2,360	2,380	--	2,400	--	3,120	13,200	16,200	--	16,400	68*/16,600
GH-6B	6-14		2,240	2,240	--	2,400	--	3,880	16,200*				
GH-7	6-14		1,620	1,800	--	3,120	--	14,000	14,000	16,000	--	16,000	67*/16,000
GH-8	6-14		16,000	16,000	--	16,000	--	17,000	20,800	20,800			
GH-9	6-15	1700	17,600	17,200	--	19,200	--	19,200	19,200	19,200			
GH-10A	6-16	1800	10,600	11,600	--	18,000	--	18,800*					
GH-10B	6-16	1800	19,600	19,600	--	19,600	--	19,800	20,000	19,800	52*/19,800		
GH-11C	6-12		1,120	1,120	--	2,600	--	11,600			37*/16,200		
GH-12A	6-9		1,080	1,080	--	1,080	--	1,240	2,080	6,720	--	11,600	65*/12,800
GH-12B	6-9		760	960	--	2,160	--	7,600					
GH-14A	6-18		5,160	5,400	--	8,000	--				23*/10,800		
GH-14B	6-18	1410	6,400	6,320	--	9,000	--	14,400	19,800	20,200			
GH-14C	6-18	0900	16,200	16,800	--	18,400	--	19,600	19,800	20,000	58*/20,200		

*bottom of hole in feet.

Table continued

TABLE 3 (Continued)

SURFACE SAMPLING STATION CHLORINITY (ppm)

Sampling Station	Remarks	6-1-71	6-11-71	6-22-71	6-23-71	6-25-71	6-26-71
1	Grand Canal At Boy Scout Camp	29,600	29,600	31,600	31,200	32,400	28,800
2	Grand Canal At Card Sound Canal	27,600	30,000	31,200	31,200	33,200	28,800
3	Card Sound Canal Tidal Station	20,800	20,200	23,600	23,000	24,400	21,700
4	Intake Canal Tidal Station	27,200	28,000	30,000	29,200	29,600	27,200
S - 20 Landward	Depth = 1'			1480	1900		1800
	Depth = 8'			1500	1800		1760
S - 20 Seaward	Depth = 1'			8600	9400		8000
	Depth = 8'			9530	10,600		10,400
S - 20A Landward	Depth = 1'			3400	3320	3360	3180
	Depth = 7'			3700	3960	3600	3340
S - 20A Seaward	Depth = 1'			3400	3040	3100	2900
	Depth = 7'			3560	4120	4080	3920

TABLE 5

REGIONAL GROUNDWATER MODEL
COMPUTER OUTPUT
PROPOSED COOLING POND SUPERIMPOSED
ON NODES 9 AND 14 WITHOUT INTERCEPTOR DITCH CONTROL

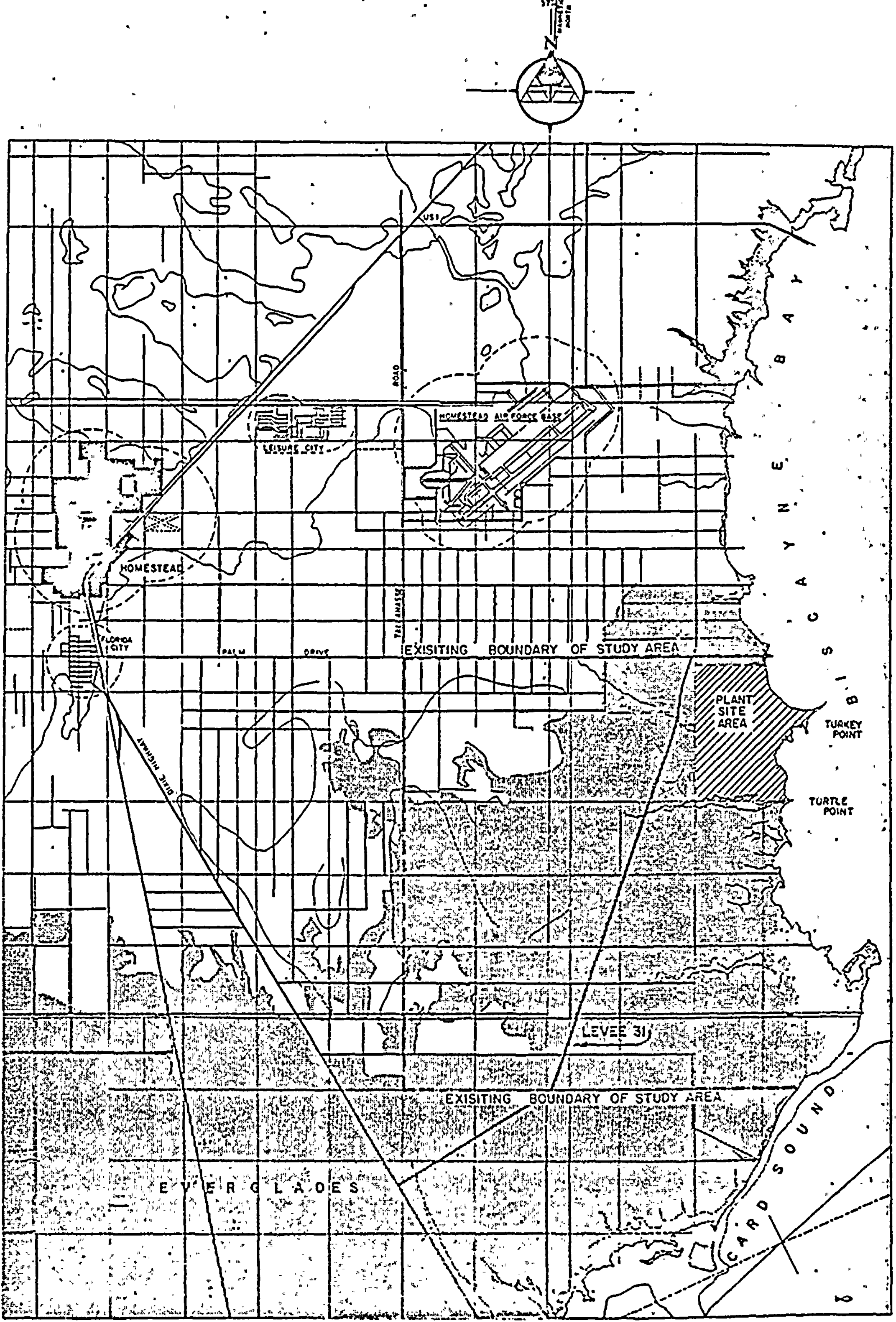
LEGEND
(see TABLE 4)

```
T =    .2500   NO. OF  ITERATIONS =     2   IN THE CURRENT DELTA STEP

NODE    SUMSQ      AQ       AS        S       RES        QS        H        HH       DIFF

  1   1753.1-1866.7   21.5   -27.8   -85.8      0.        .3       .2        .1
  2   2070.3-2126.7   20.1   -16.4   -40.0      0.        .6       .2        .4
  3      -.5     0.       .1     -.0     -.5      0.        .8       .4        .4
  4    666.7 -666.7   11.2     0.       0.   9557.2       .8       .5        .3
  5   1210.5-1321.3   21.5   -26.8   -84.0      0.        .4       .2        .1
  6  -1318.6 -546.7  896.0-1620.3 -245.0      0.        .5       .2        .3
  7     75.4 -733.3  748.3 -551.6 -106.4      0.        .8       .2        .5
  8   1057.3-1057.3   23.1     0.       0.  19047.7     1.1       .4        .7
  9 -31064.540226.7 1470.0 8688.0   474.1      0.       3.1       .4       2.6
 10   2158.1-2266.7   26.6   -27.6   -81.0      0.        .4       .1        .3
 11  -1001.2 -706.7 1120.0-1503.8 -204.0      0.        .6       .2        .4
 12   -147.9 -146.7  516.6 -189.9 -104.6      0.       1.0       .2        .8
 13   1200.0-1200.0   27.6     0.       0.  22548.5     1.2       .3       1.0
 14 -46207.980840.0 3324.033926.5   705.7      0.       3.7       .4       3.3
 15      -.9     0.       .1     -.1     -.8      0.        .4       .1        .3
 16   2750.6-2921.3   21.5   -18.7 -152.0      0.        .4       .1        .3
 17    688.4 -732.0    4.0    -1.3   -42.4      0.        .9     0.          .9
 18     -1.2     0.       .1     -.0    -1.2      0.        .9     0.          .9
 19   1060.0-1060.0   15.1     0.       0.   6229.8      1.0       .3        .8
 20       0.     0.       .1     0.       0.     16.1       .8       .4        .4
 21    -53.3   53.3  336.0     0.       0.   6222.9       .6       .5        .1
 22   -491.0 -293.3  448.0 -509.8 -274.5      0.        .4       .1        .4
 23    -91.4  -60.0   89.3   -45.5 -105.9      0.        .7     0.          .7
 24    -90.0    4.0   11.2    -4.1   -81.8      0.        .7       .2        .5
 25    -59.4  -80.0  362.3   -91.1   -48.3      0.        .8       .3        .5
 26    518.7 -529.3   11.0    -1.4    -9.2      0.        .6       .5        .1
 27    503.6 -792.0   21.5   -15.1 -273.4      0.        .4       .1        .3
 28    384.2 -400.0    3.0    -2.1   -13.7      0.        .5       .4        .1
 29     -3.9     0.       .1     -.1    -3.9      0.        .6       .4        .2
 30    723.6 -796.0   19.1    -4.6   -67.8      0.        .7       .3        .4
 31      -.7     0.       .1     -.0     -.7      0.        .6       .5        .1
 32   -218.5 -240.0  247.1 -271.6 -186.9      0.        .5       .0        .4
 33    -21.9    2.7    6.1    -3.0   -16.3      0.        .6      -.5       1.1
 34    151.2 -293.3  209.0   -86.5   -55.7      0.        .7       .2        .4
 35    258.1 -265.3    6.1    -1.2    -6.0      0.        .5       .5        .0

      TOTAL SURFACE FLOW =     63622.2   FOR CURRENT DELTA STEP
      TOTAL SURFACE FLOW =     31686.8   FOR CURRENT LIST STEP
```



MAP OF AREA

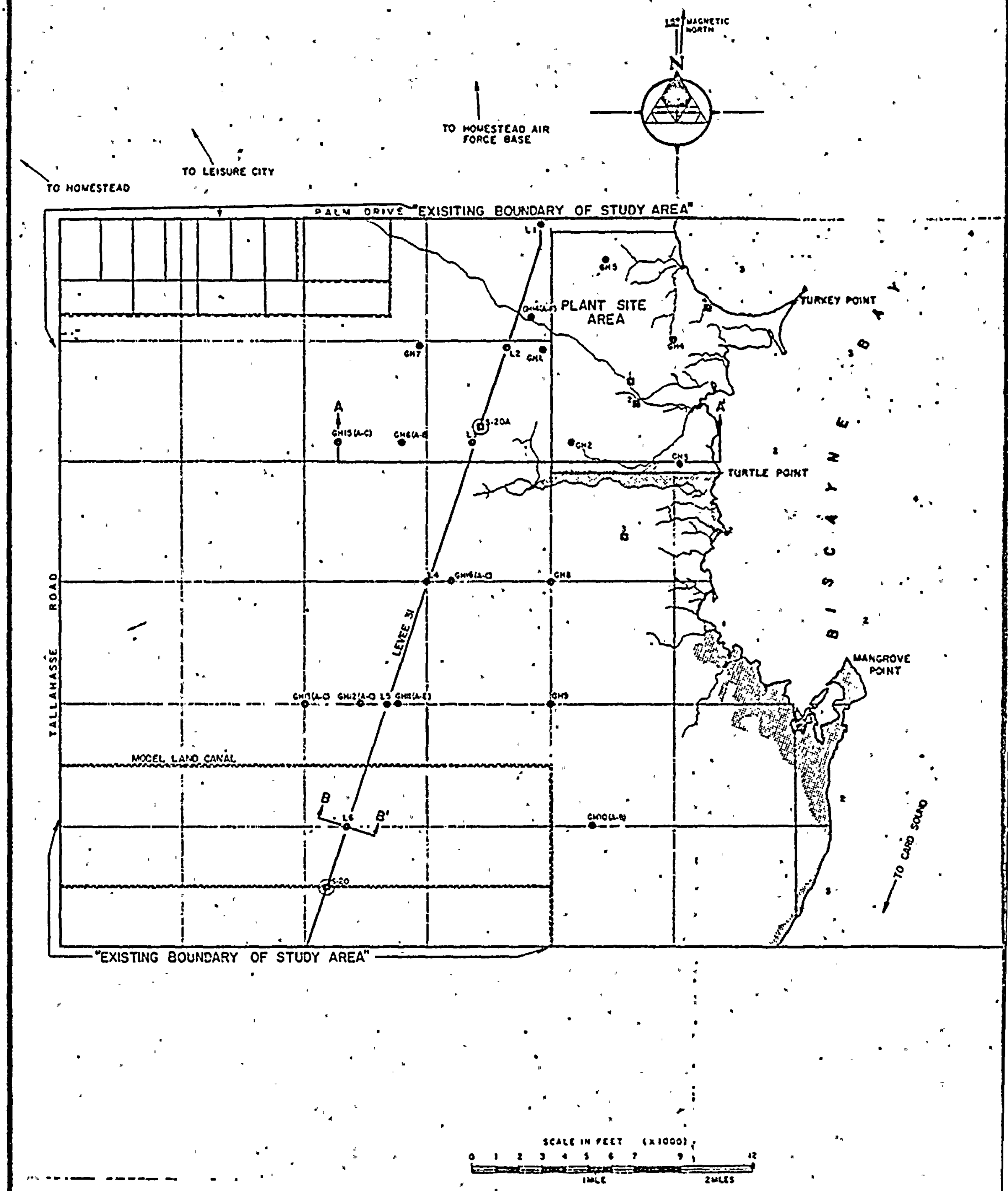
SCALE IN FEET (X1000)

0 1 2 3 4 5 10 15 20

1 MILE 2 MILES 3 MILES 4 MILES

DAMES & MOORE

PLATE I



PLOT PLAN

LEGEND:

- ▪ SURFACE SAMPLE SITES
- ● BORING LOCATIONS

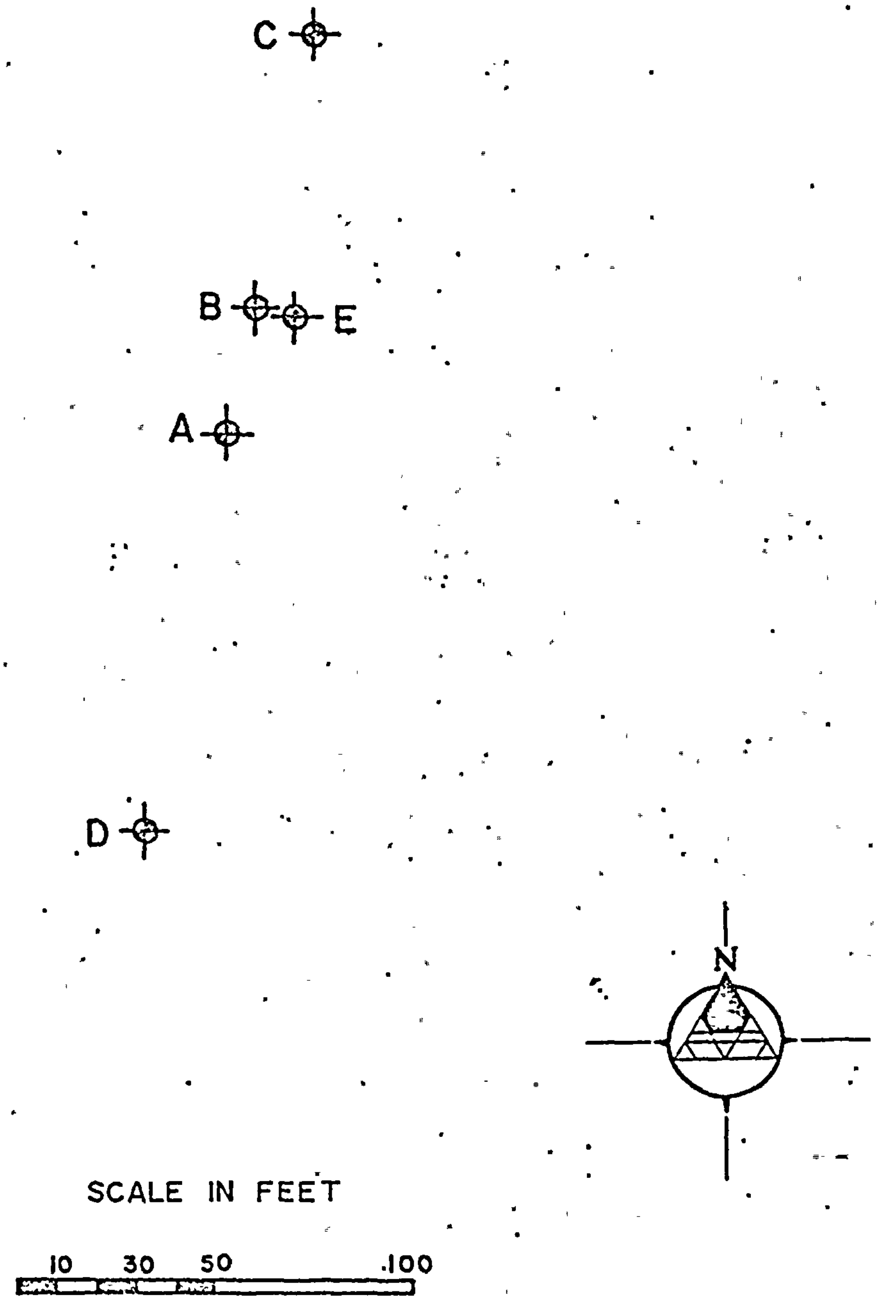
DAMES & MOORE

PLATE 2

PLOT PLAN

PUMP AND OBSERVATION WELL CONFIGURATION

GH 11 (A-E)



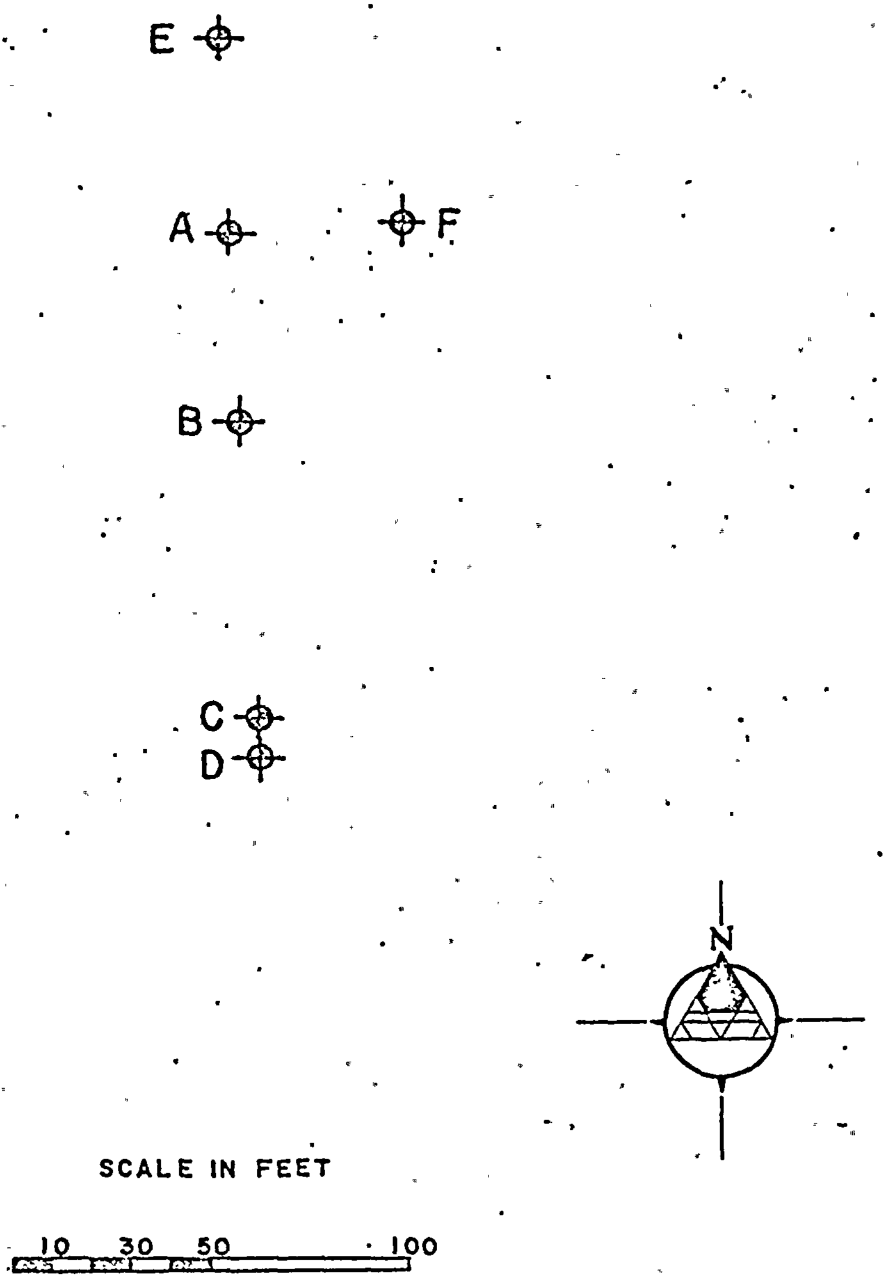
DAMES & MOORE

PLATE 3 A

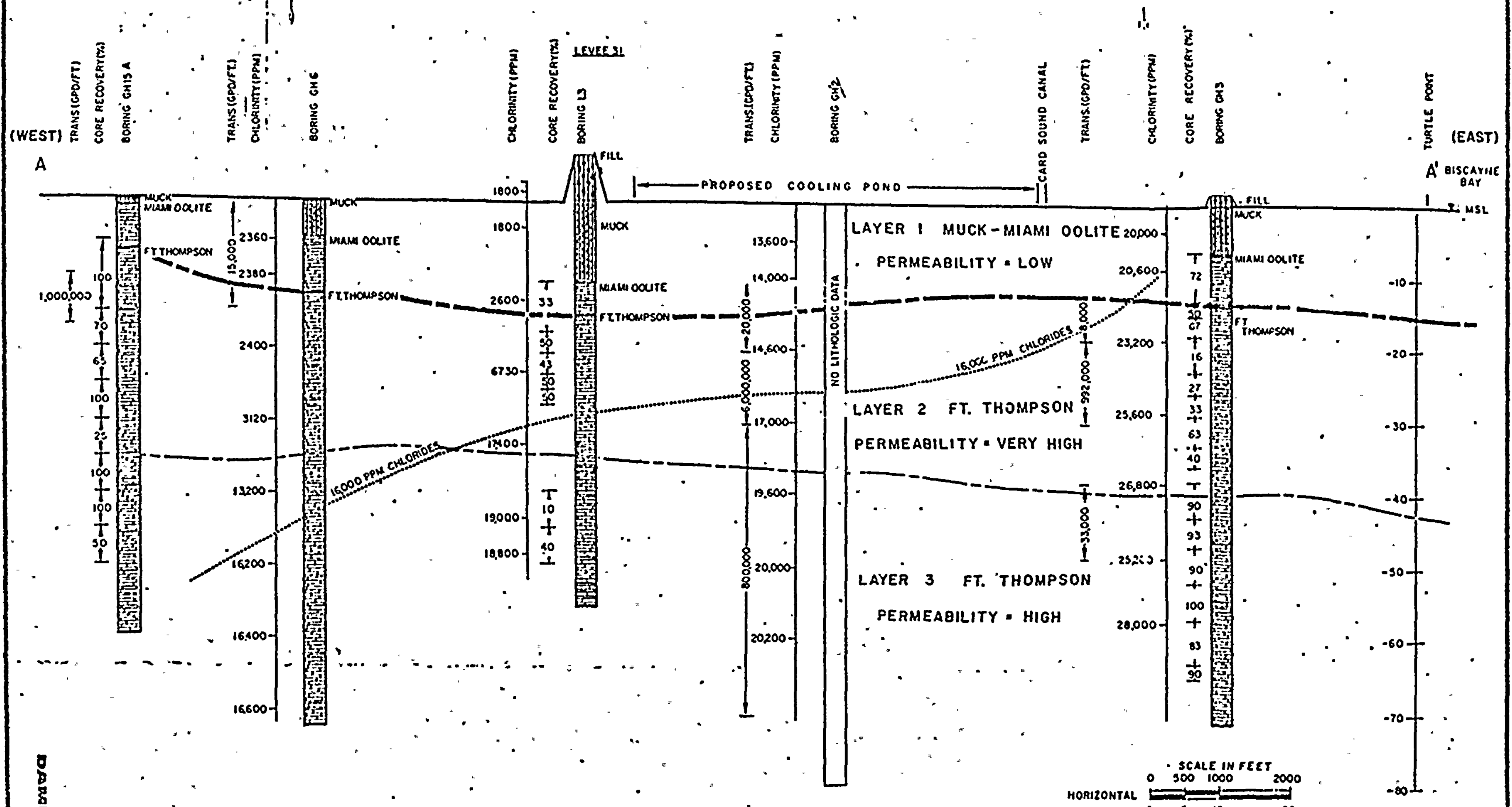
PLOT PLAN

PUMP AND OBSERVATION WELL CONFIGURATION

GH 14 (A-F)



DAMES & MOORE



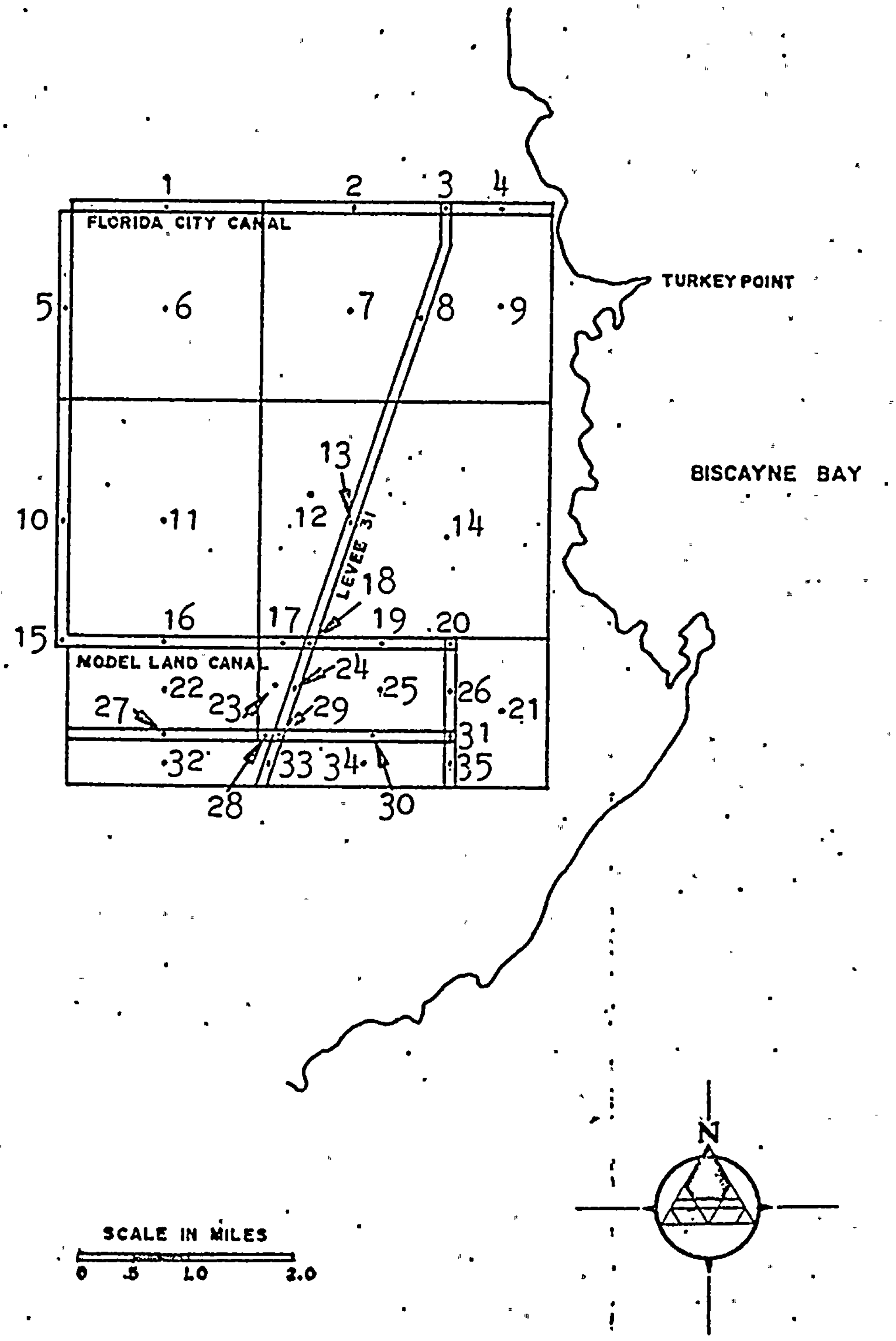
CROSS SECTION & CHLORINITY PROFILE

TURKEY POINT, FLORIDA

DAMES & MOORE

PLATE 4

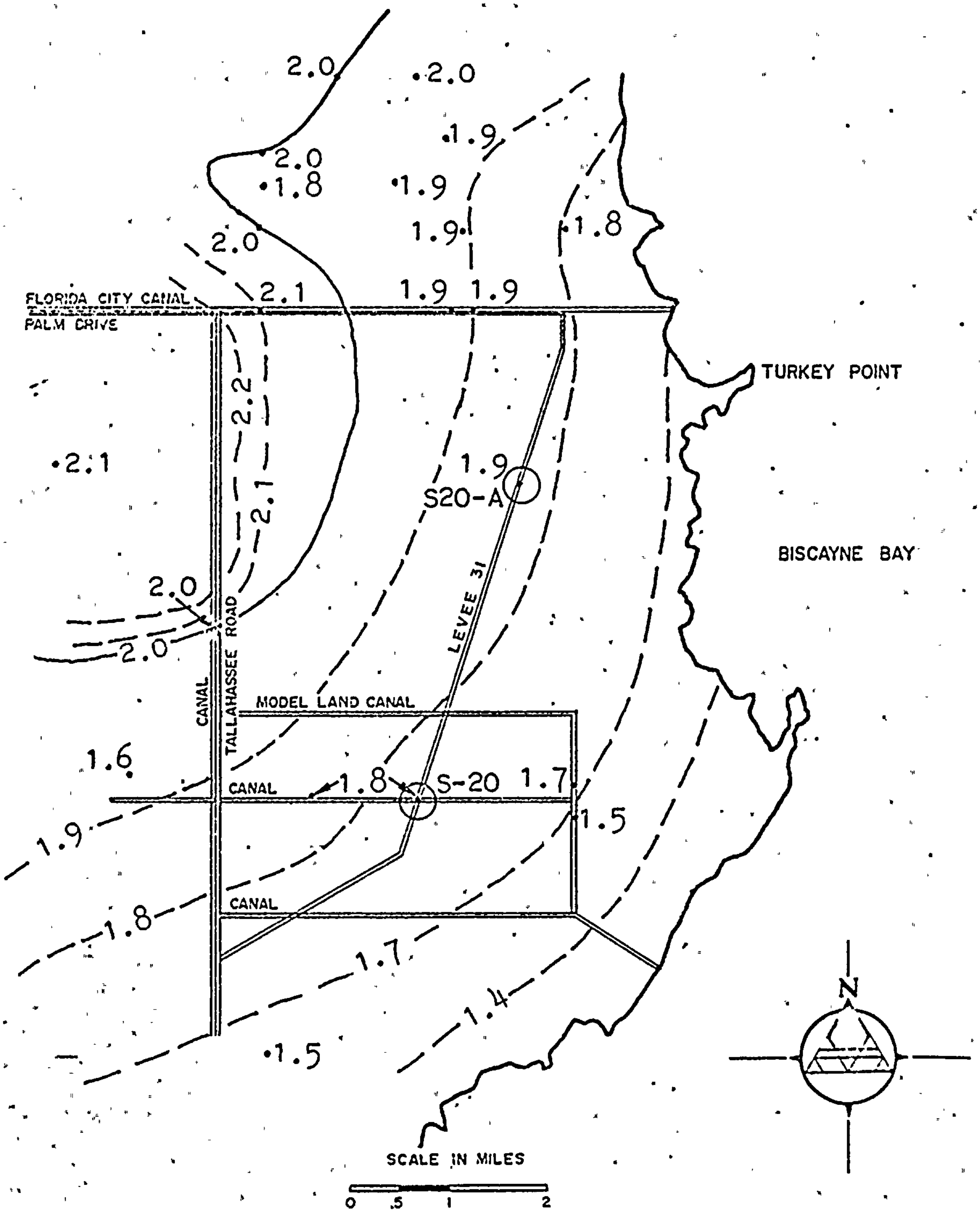
REGIONAL GROUNDWATER COMPUTER MODEL
LAYOUT OF NODES TURKEY POINT, FLA.



DAMES & MOORE

PLATE 5

WATER LEVEL CONTOURS
OCTOBER 1970
DATUM = MEAN SEA LEVEL



ref.: Dade County Water Control Board

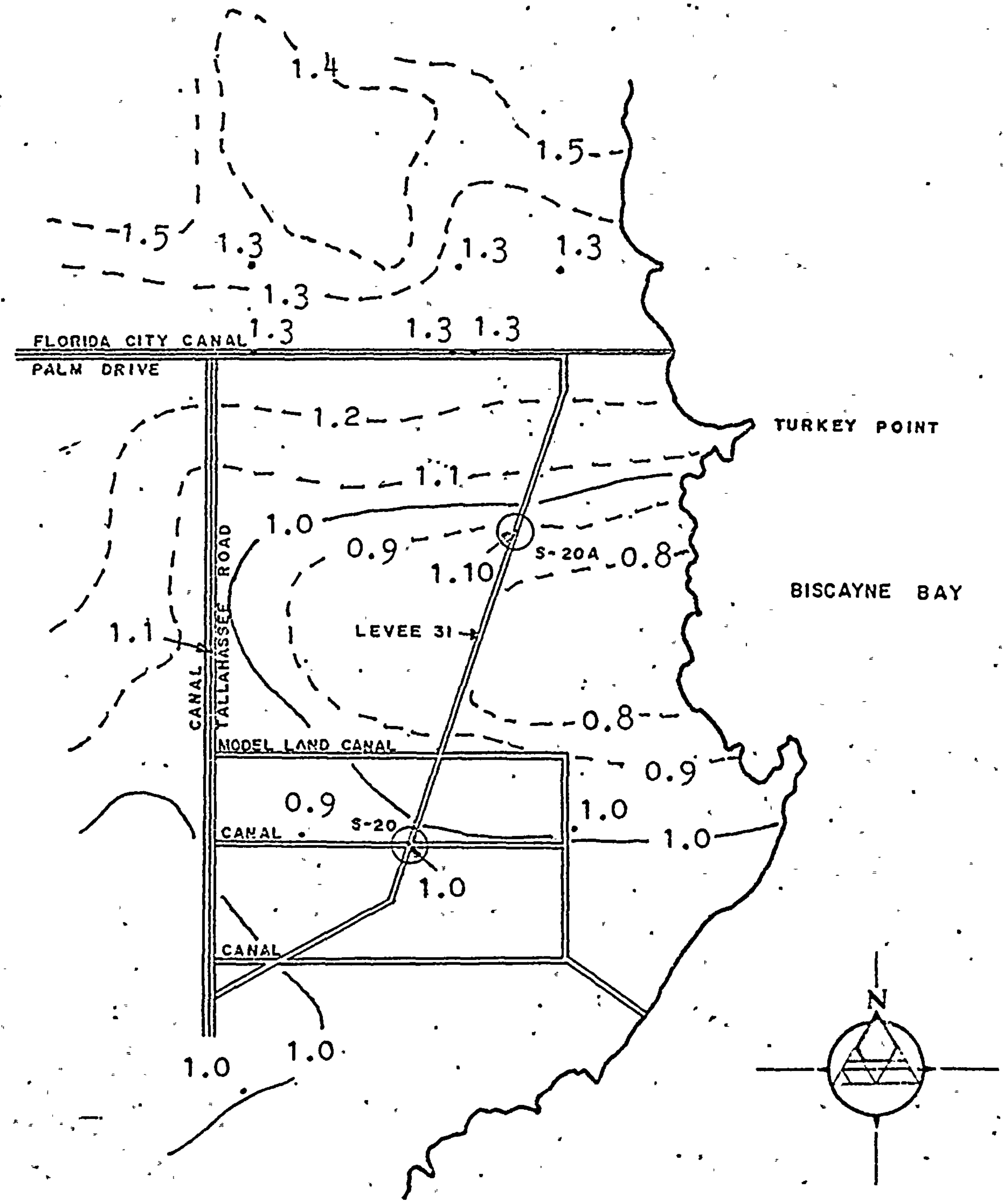
DAMES & MOORE

PLATE 6

WATER LEVEL CONTOURS

JANUARY 1971

DATUM = MEAN SEA LEVEL



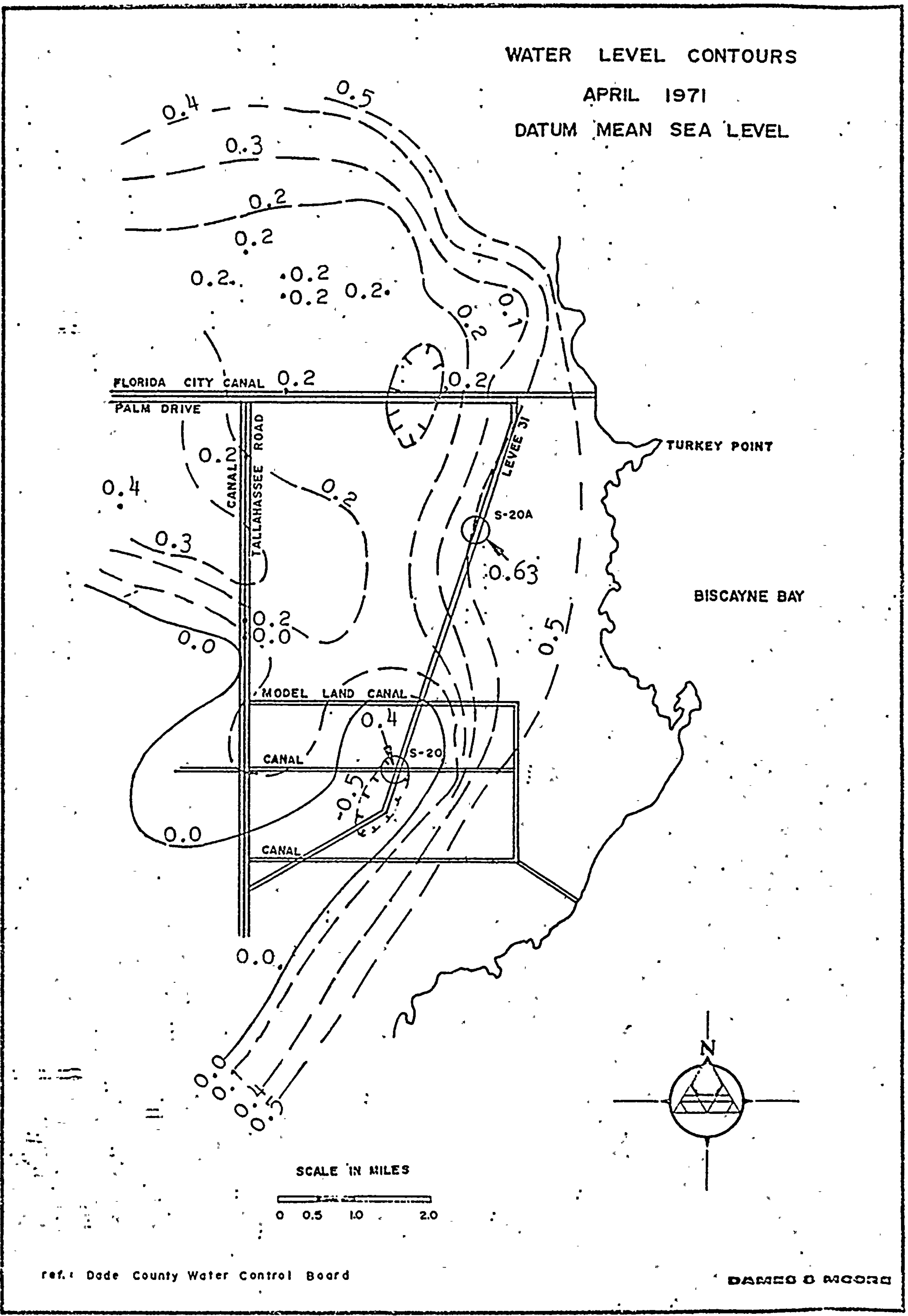
SCALE IN MILES

0.5 1.0 2.0

ref.: Dade County Water Control Board

DAMES & MOORE

PLATE 7

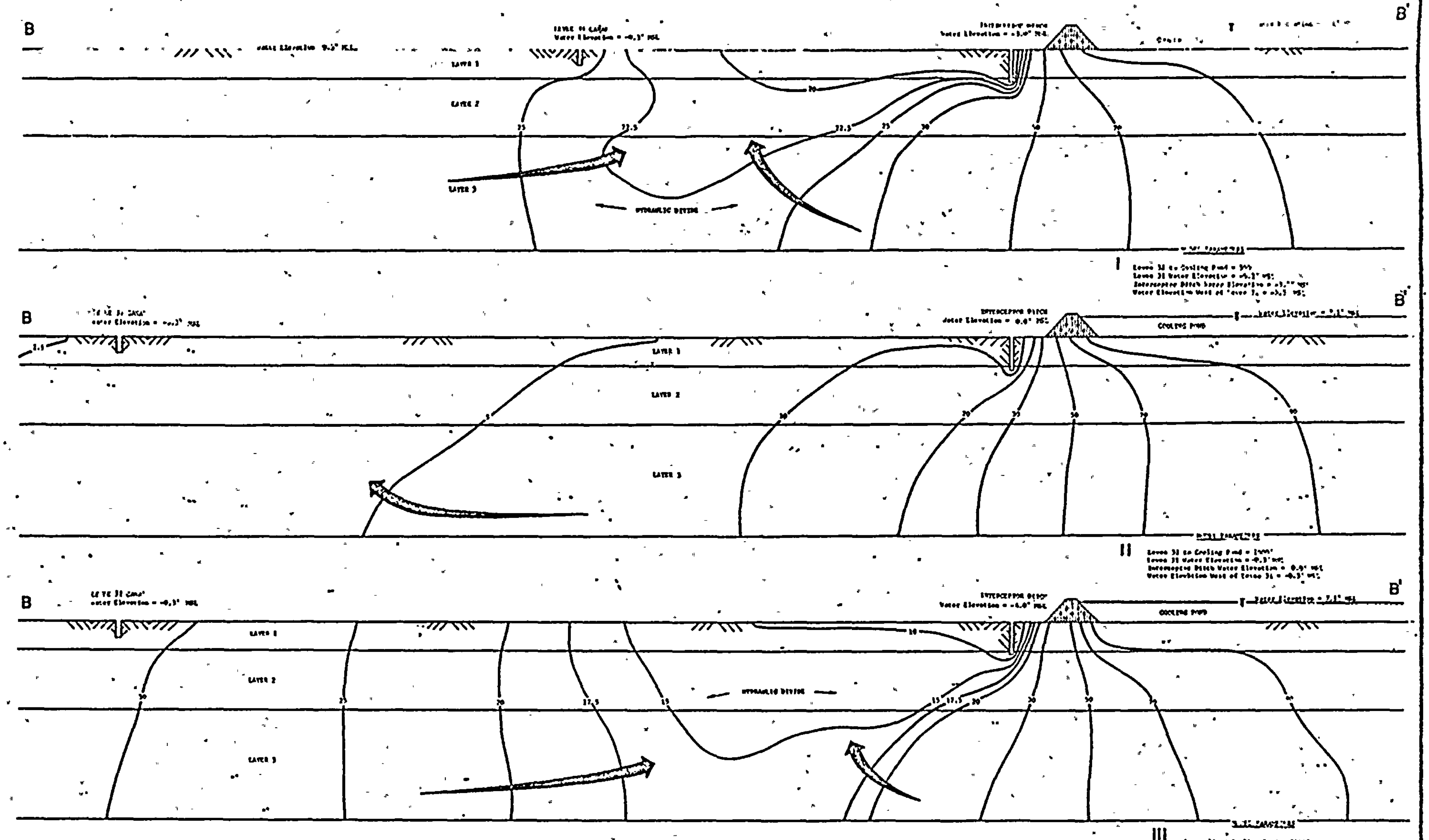


WATER LEVEL CONTOURS
APRIL 1971
DATUM MEAN SEA LEVEL

ref.: Dade County Water Control Board

DAMES & MOORE

PLATE 8



LEGEND

- Equipotential lines indicating the % of total water head.
- Flow direction which is perpendicular to the equipotential lines of the model.

HYDRAULIC DIVIDE - Area where converging flow creates a barrier to horizontal movement of waters.

Cooling Pond Water Elevation = +7.1'

Interceptor Ditch Depth = 15'

GEOHYDROLOGIC DATA

	[illegible]	TRANSMISSIVITY [illegible]
LAYER 1	[illegible]	[illegible]
LAYER 2	[illegible]	[illegible]
LAYER 3	[illegible]	[illegible]

SCALE IN FEET

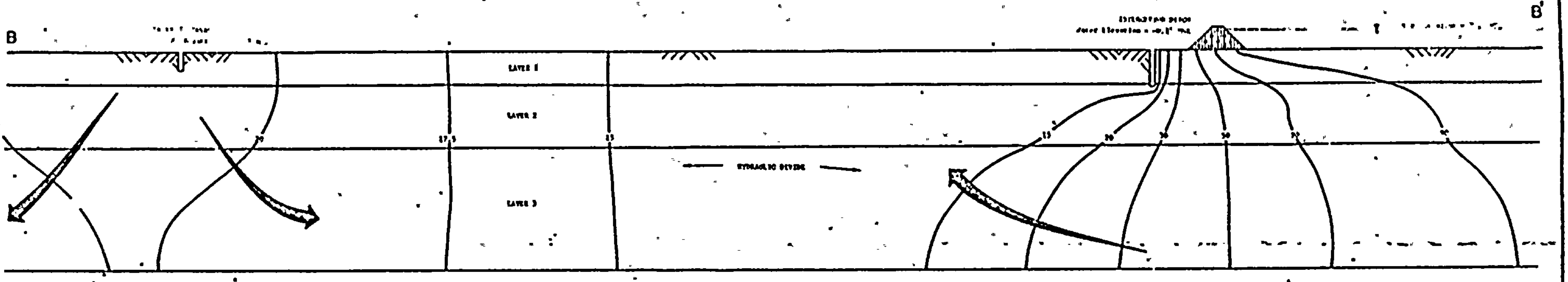
HORIZONTAL

VERTICAL

ELECTRIC ANALOG MODELS

DAMES & MOORE

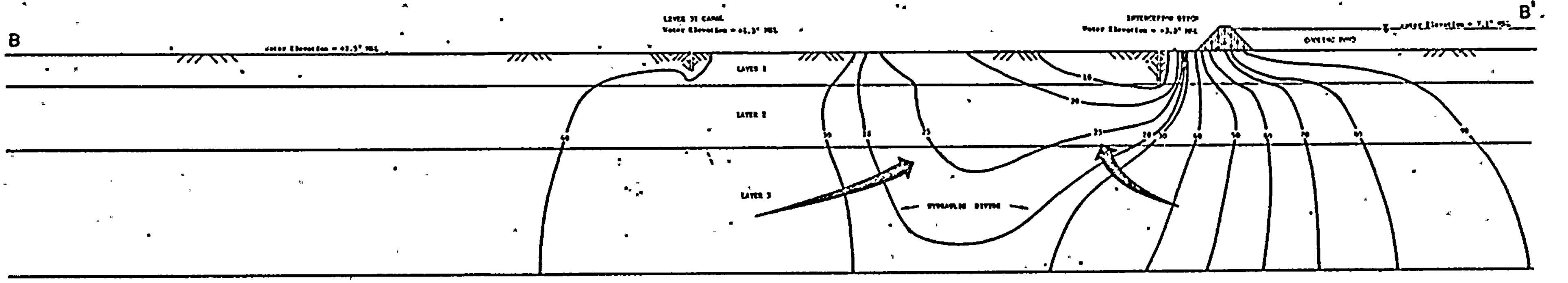
PLATE 9



I

MODEL PARAMETERS

Levee 31 to Cooling Pond = [illegible]'
Levee 31 Water Elevation = +[illegible]' MSL
Interceptor Ditch Water Elevation = +[illegible]' MSL
Water Elevation West of Levee 31 = +[illegible]' MSL



II

MODEL PARAMETERS

Levee 31 to Cooling Pond = [illegible]'
Levee 31 Water Elevation = +1.5' MSL
Interceptor Ditch Water Elevation = +[illegible]' MSL
Water Elevation West of Levee 31 = +1.5' MSL

GEOHYDROLOGIC DATA

	FORMATION	TRANSMISSIVITY (gpd/ft.)
LAYER 1	Muck + Miami Oolite	[illegible]
LAYER 2	Fort Thompson Limestone	[illegible]
LAYER 3	Fort Thompson Limestone	[illegible]

LEGEND

— 50 — = Equipotential lines indicating the % of total water head

➔ = Flow direction which is perpendicular to the equipotential lines of the model.

HYDRAULIC DIVIDE = Area where converging flow created a barrier to horizontal movement of waters

Cooling Pond Water Elevation = + 7.1'
Interceptor Ditch Depth = 19'

SCALE IN FEET

HORIZONTAL: 0 50 100 150

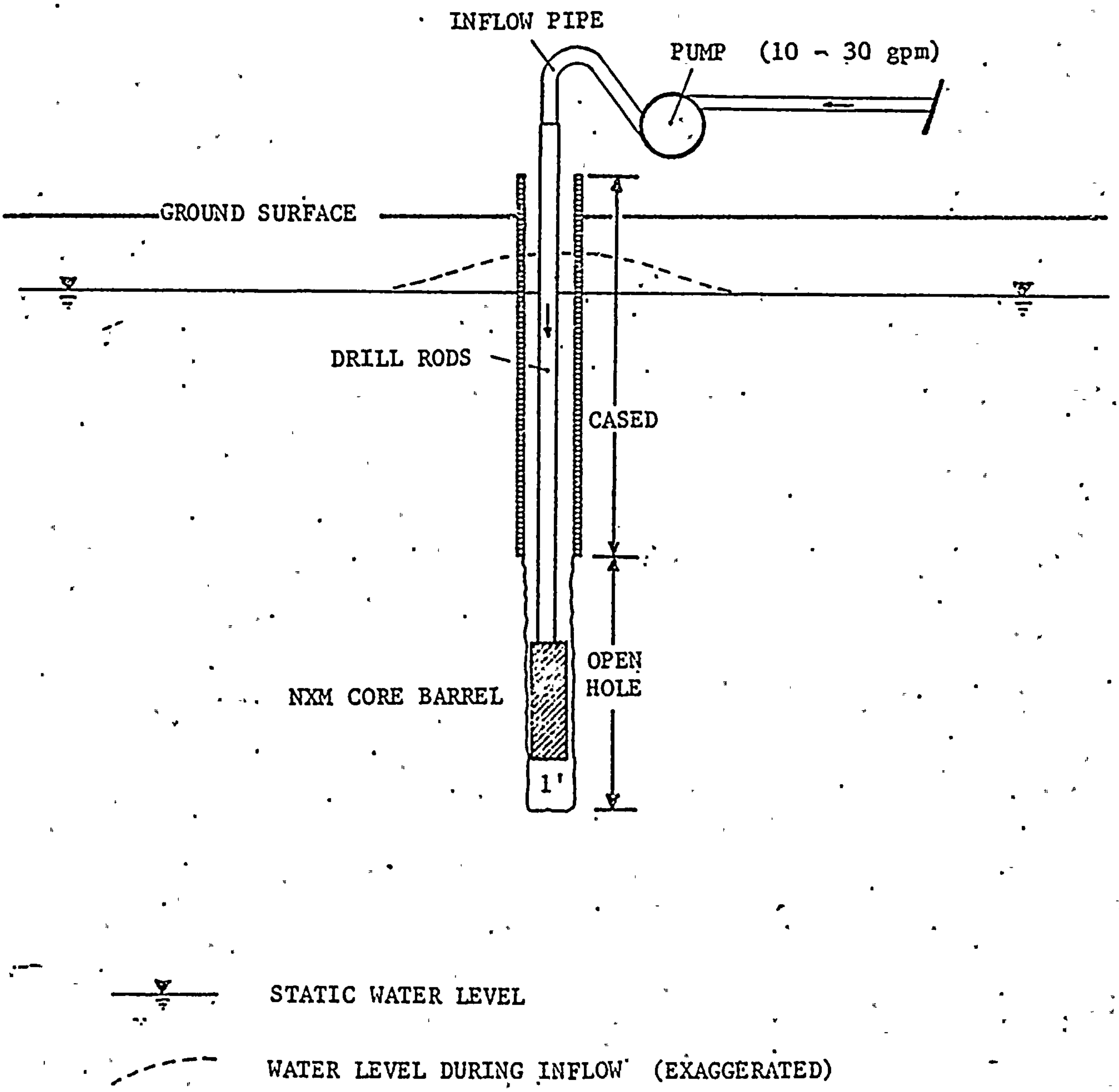
VERTICAL: 0 25 50

ELECTRIC ANALOG MODELS

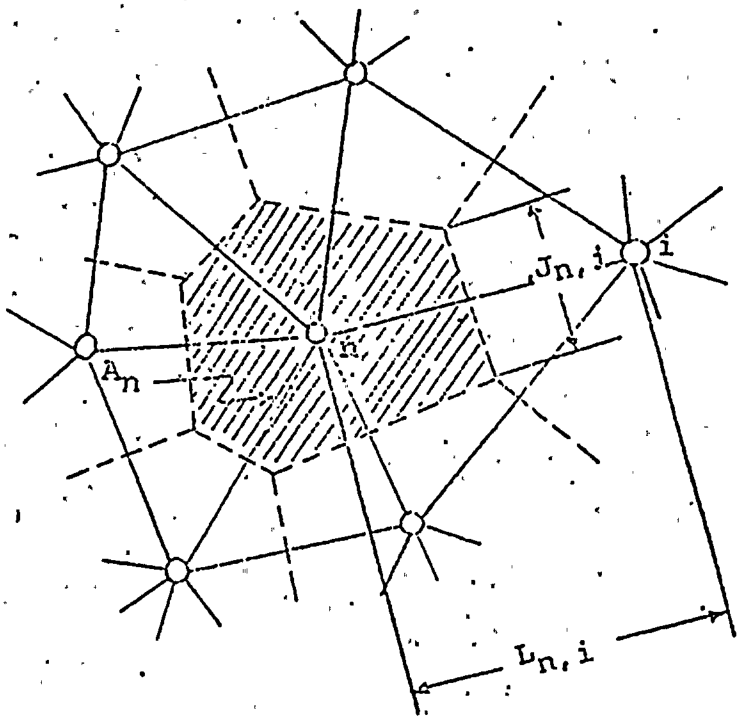
DAMES & MOORE

PLATE 10

CROSS SECTION - TYPICAL INFLOW TEST



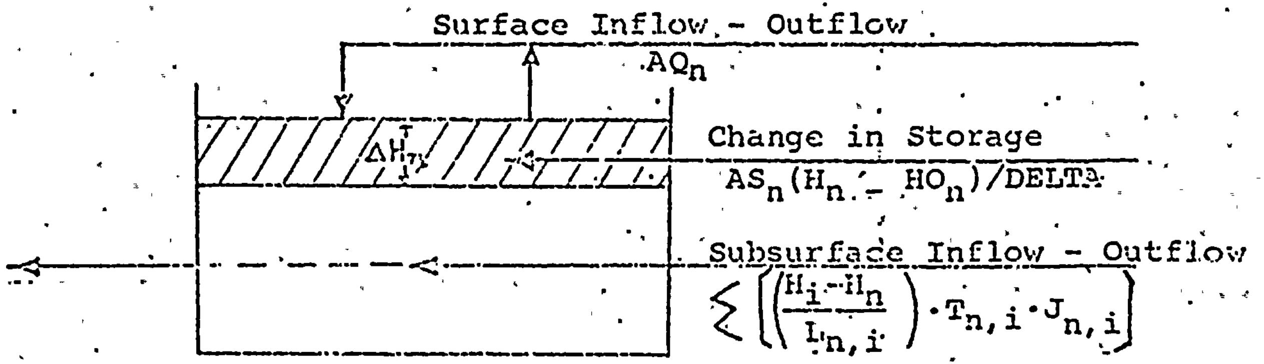
SCHEMATIC DRAWINGS OF MATHEMATICAL RELATIONSHIP



I POLYGON GEOMETRY

Equations: Net Subsurface flows + Net Surface flows = change in storage

$$\sum \left[\left(\frac{H_i - H_n}{L_{n,i}}\right) \cdot T_{n,i} \cdot J_{n,i} \right] + AQ_n = AS_n \frac{(H_n - HO_n)}{DELTA}$$



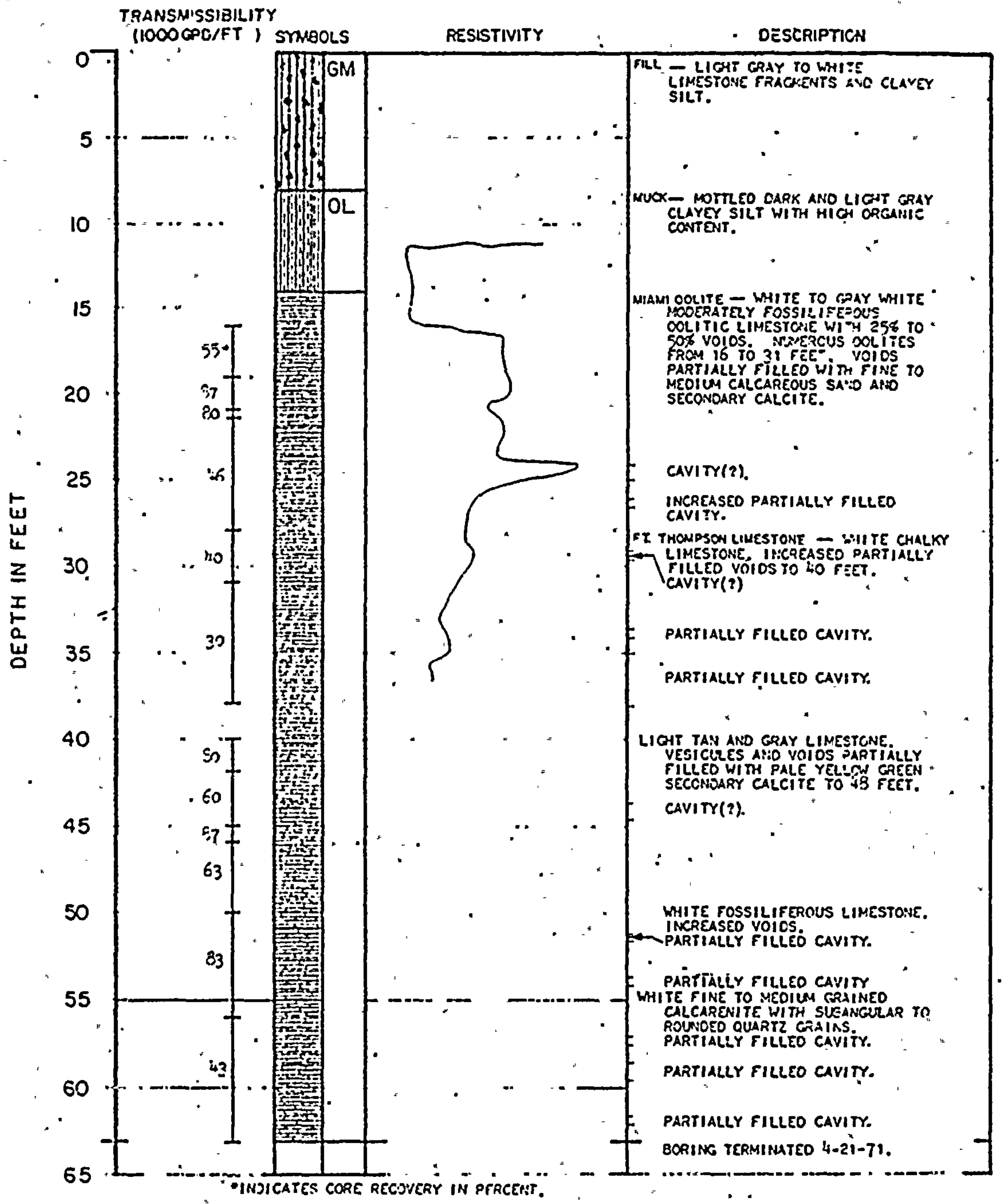
II SCHEMATIC SKETCH OF GENERALIZED GROUND WATER FLOW EQUATION

DAMES & MOORE

PLATE 12

BORING L-1

SURFACE ELEVATION: +7.7' MSL



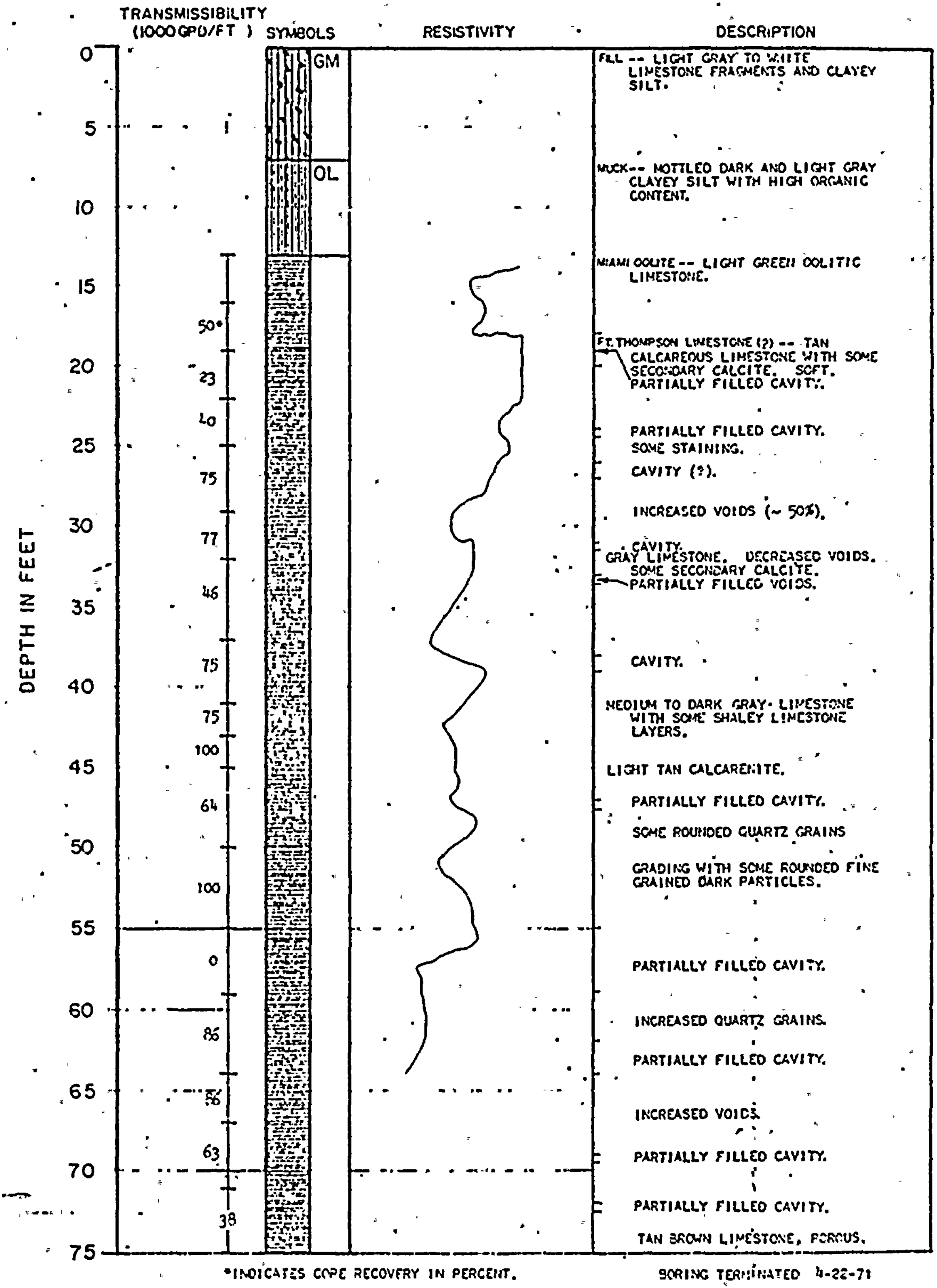
*INDICATES CORE RECOVERY IN PERCENT.

LOG OF BORINGS

DAMES & MOORE

BORING L-2

SURFACE ELEVATION: +7.7' MSL



*INDICATES CORE RECOVERY IN PERCENT.

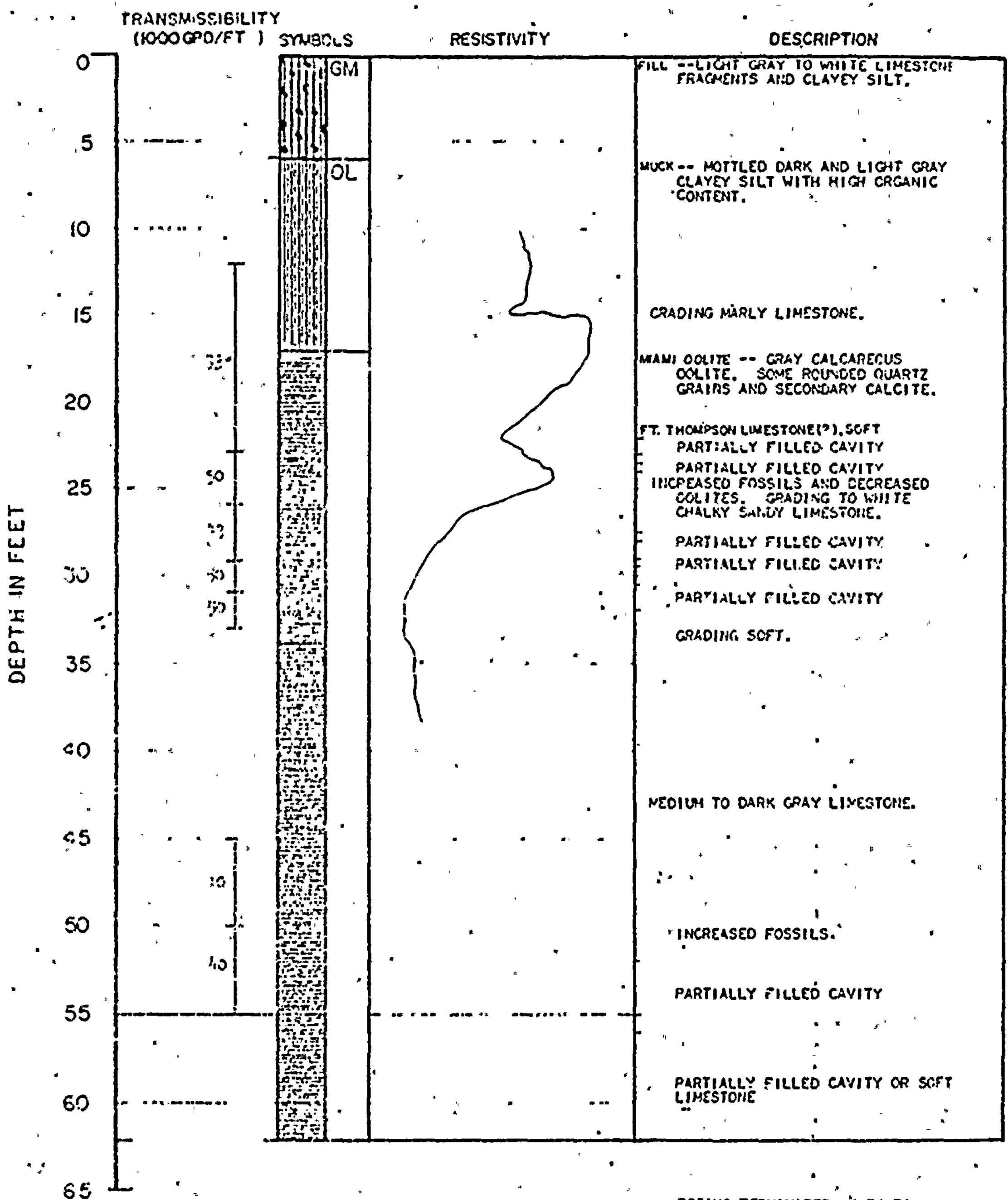
BORING TERMINATED 4-22-71

LOG OF BORINGS

DAMES & MOORE

BORING L-3

SURFACE ELEVATION: +6.3' MSL



FILL --LIGHT GRAY TO WHITE LIMESTONE FRAGMENTS AND CLAYEY SILT.

MUCK -- MOTTLED DARK AND LIGHT GRAY CLAYEY SILT WITH HIGH ORGANIC CONTENT.

GRADING MARLY LIMESTONE.

MIAMI OOLITE -- GRAY CALCAREOUS OOLITE. SOME ROUNDED QUARTZ GRAINS AND SECONDARY CALCITE.

FT. THOMPSON LIMESTONE(?), SOFT

PARTIALLY FILLED CAVITY

PARTIALLY FILLED CAVITY

INCREASED FOSSILS AND DECREASED OOLITES. GRADING TO WHITE CHALKY SANDY LIMESTONE.

PARTIALLY FILLED CAVITY

PARTIALLY FILLED CAVITY

PARTIALLY FILLED CAVITY

GRADING SOFT.

MEDIUM TO DARK GRAY LIMESTONE.

INCREASED FOSSILS.

PARTIALLY FILLED CAVITY

PARTIALLY FILLED CAVITY OR SOFT LIMESTONE

*INDICATES CORE RECOVERY IN PERCENT.

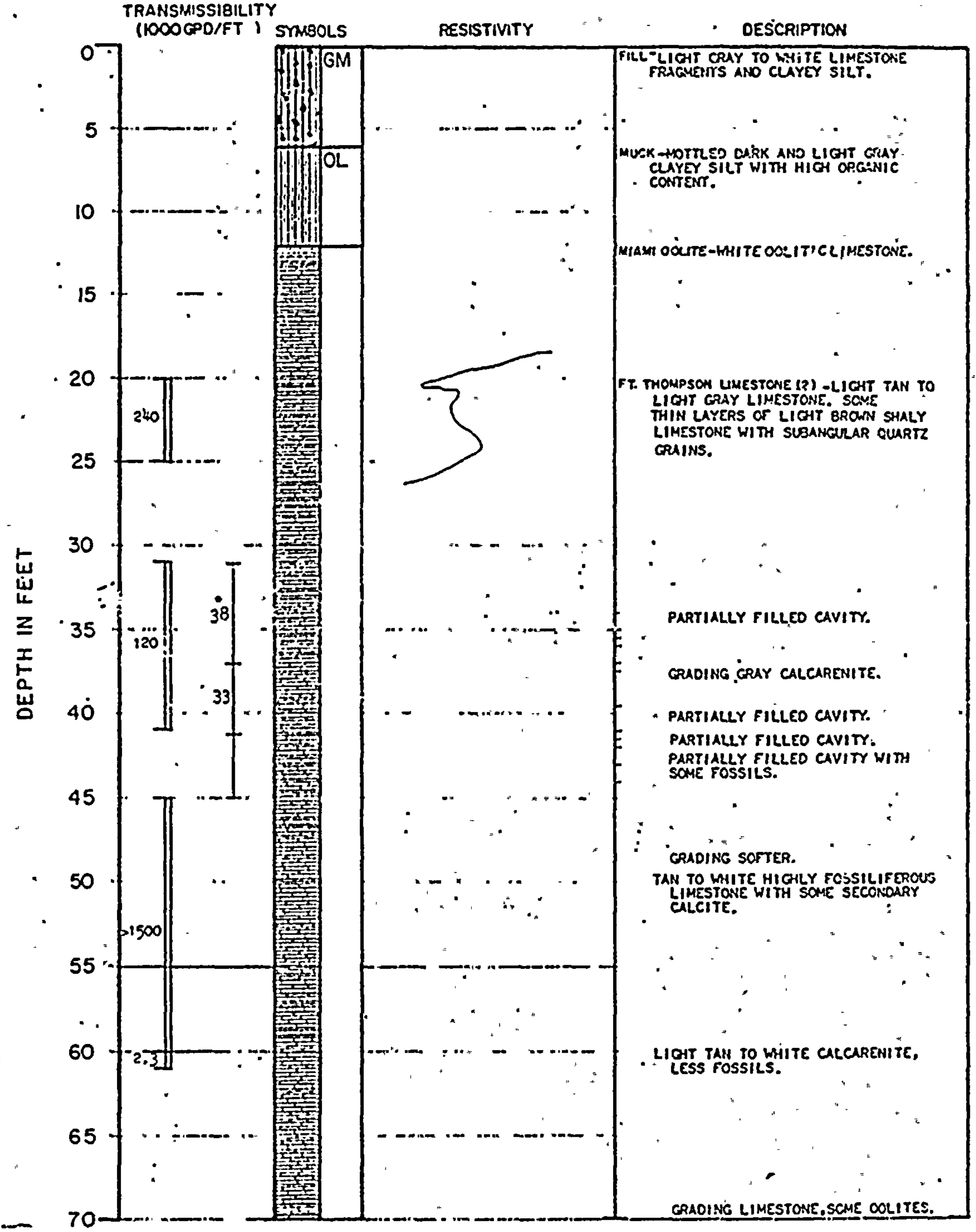
BORING TERMINATED 9-24-71

LOG OF BORINGS

DAMES & MOORE

BORING L-4

SURFACE ELEVATION: +7.0' MSL



FILL-LIGHT GRAY TO WHITE LIMESTONE FRAGMENTS AND CLAYEY SILT.

MUCK-MOTTLED DARK AND LIGHT GRAY CLAYEY SILT WITH HIGH ORGANIC CONTENT.

MIAMI OOLITE-WHITE OOLITIC LIMESTONE.

FT. THOMPSON LIMESTONE (?) -LIGHT TAN TO LIGHT GRAY LIMESTONE. SOME THIN LAYERS OF LIGHT BROWN SHALY LIMESTONE WITH SUBANGULAR QUARTZ GRAINS.

PARTIALLY FILLED CAVITY.

GRADING GRAY CALCARENITE.

PARTIALLY FILLED CAVITY.

PARTIALLY FILLED CAVITY.

PARTIALLY FILLED CAVITY WITH SOME FOSSILS.

GRADING SOFTER.

TAN TO WHITE HIGHLY FOSSILIFEROUS LIMESTONE WITH SOME SECONDARY CALCITE.

LIGHT TAN TO WHITE CALCARENITE, LESS FOSSILS.

GRADING LIMESTONE, SOME OOLITES.

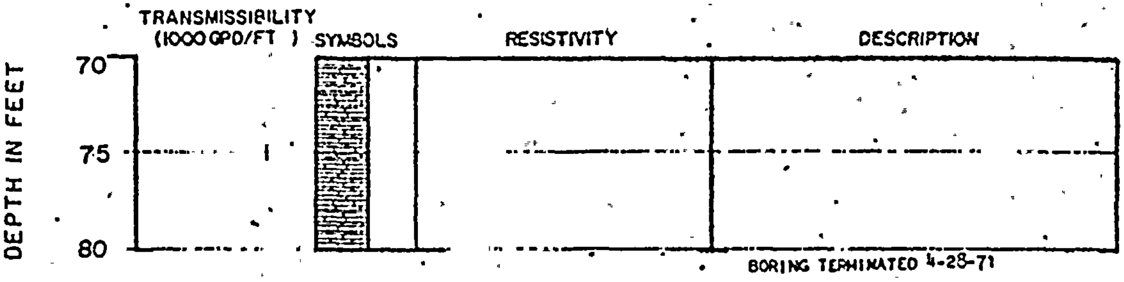
*INDICATES CORE RECOVERY IN PERCENT.

BORING CONTINUED

LOG OF BORINGS

DAMES & MOORE

BORING L-4 CONT'D



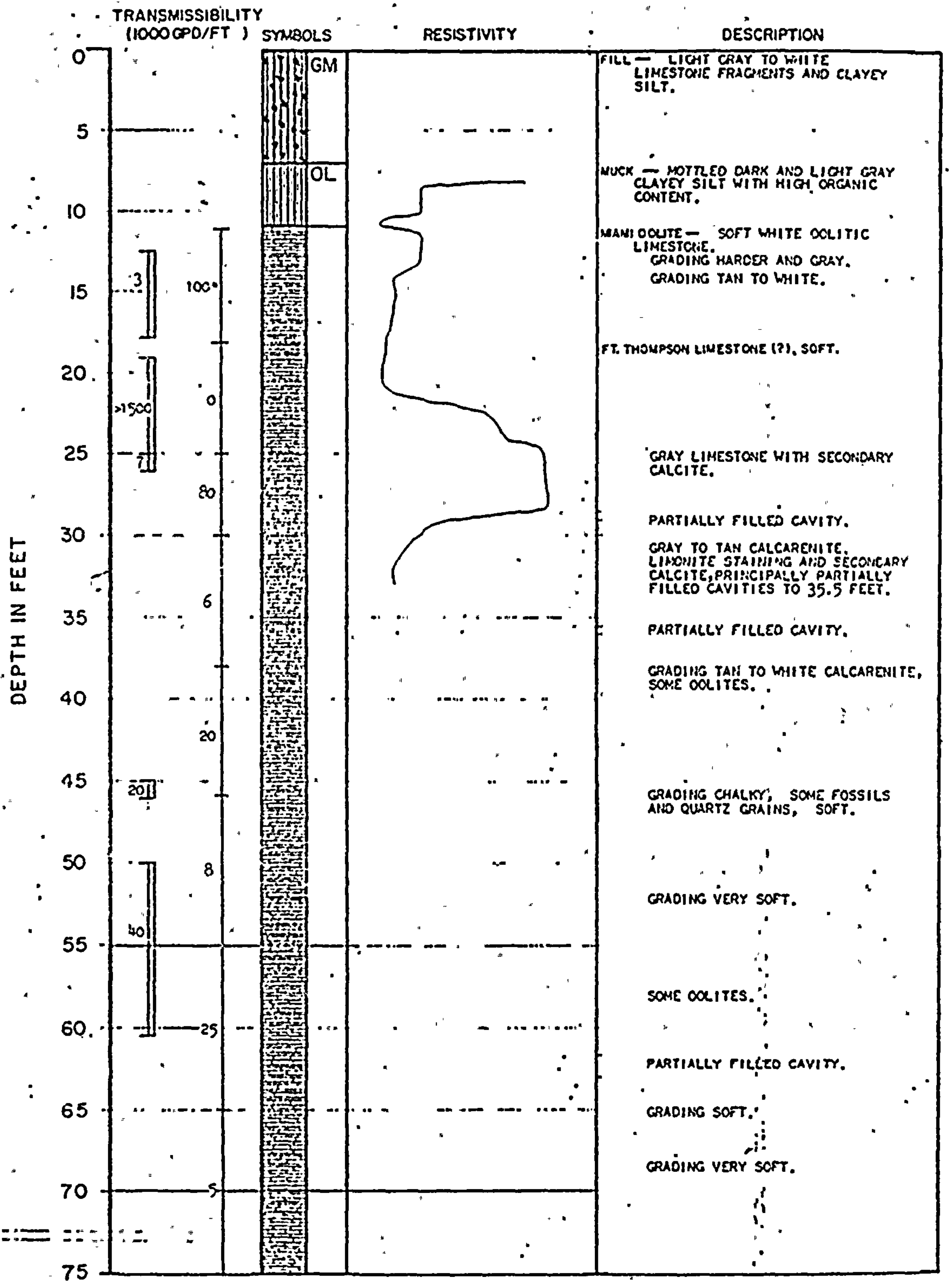
LOG OF BORINGS

DAMES & MOORE

PLATE 16A

BORING L-5

SURFACE ELEVATION: +8.3' MSL



*INDICATES CORE RECOVERY IN PERCENT.

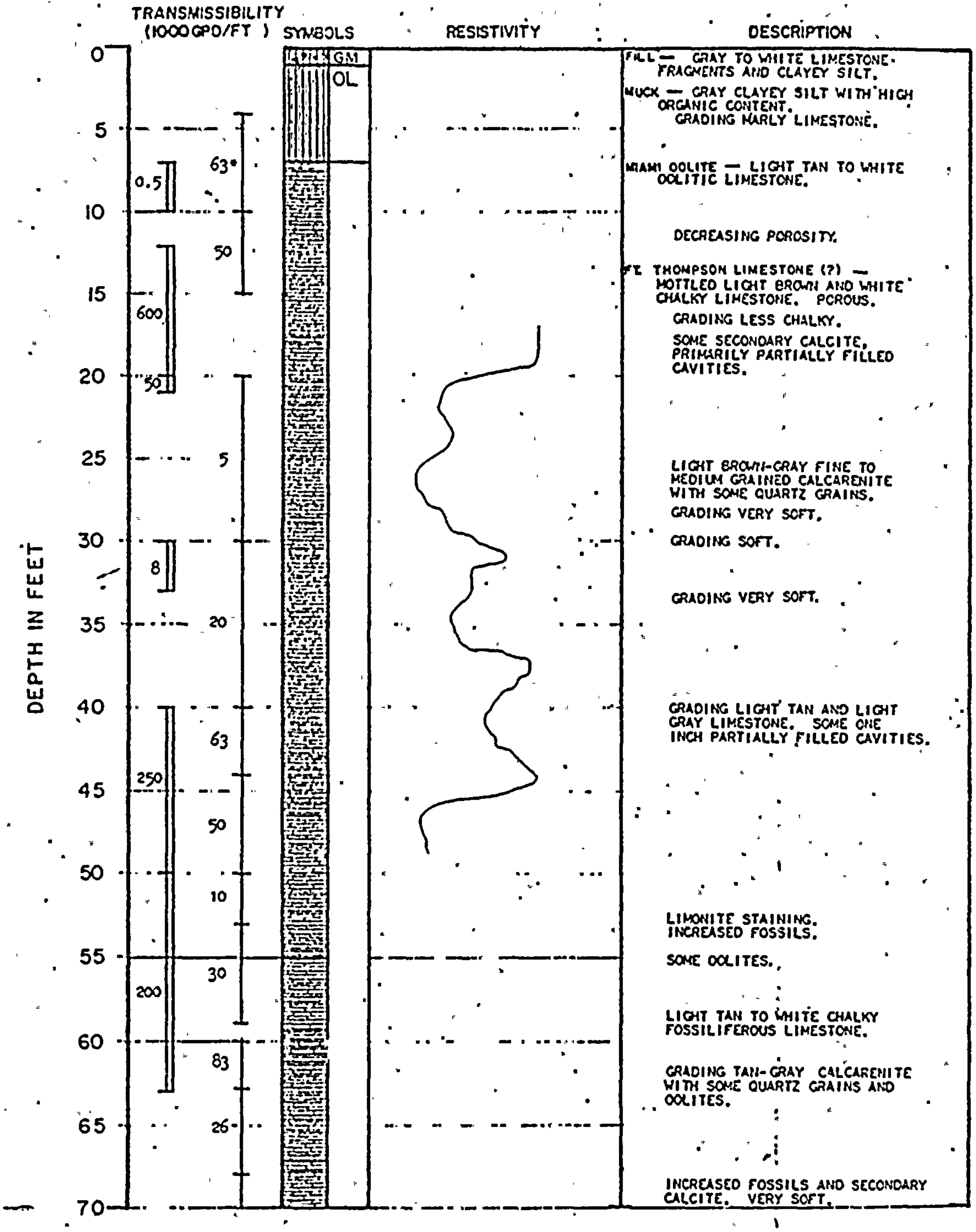
BORING TERMINATED 4-30-71.

LOG OF BORINGS

DAMES & MOORE

BORING L-6

SURFACE ELEVATION: +3.0' MSL



FILL — GRAY TO WHITE LIMESTONE FRAGMENTS AND CLAYEY SILT.

MUCK — GRAY CLAYEY SILT WITH HIGH ORGANIC CONTENT.
GRADING MARLY LIMESTONE.

MIAMI OOLITE — LIGHT TAN TO WHITE OOLITIC LIMESTONE.

DECREASING POROSITY.

FT. THOMPSON LIMESTONE (?) — MOTTLED LIGHT BROWN AND WHITE CHALKY LIMESTONE. POROUS.

GRADING LESS CHALKY.

SOME SECONDARY CALCITE, PRIMARILY PARTIALLY FILLED CAVITIES.

LIGHT BROWN-GRAY FINE TO MEDIUM GRAINED CALCARENITE WITH SOME QUARTZ GRAINS.

GRADING VERY SOFT.

GRADING SOFT.

GRADING VERY SOFT.

GRADING LIGHT TAN AND LIGHT GRAY LIMESTONE. SOME ONE INCH PARTIALLY FILLED CAVITIES.

LIMONITE STAINING.
INCREASED FOSSILS.

SOME OOLITES.

LIGHT TAN TO WHITE CHALKY FOSSILIFEROUS LIMESTONE.

GRADING TAN-GRAY CALCARENITE WITH SOME QUARTZ GRAINS AND OOLITES.

INCREASED FOSSILS AND SECONDARY CALCITE. VERY SOFT.

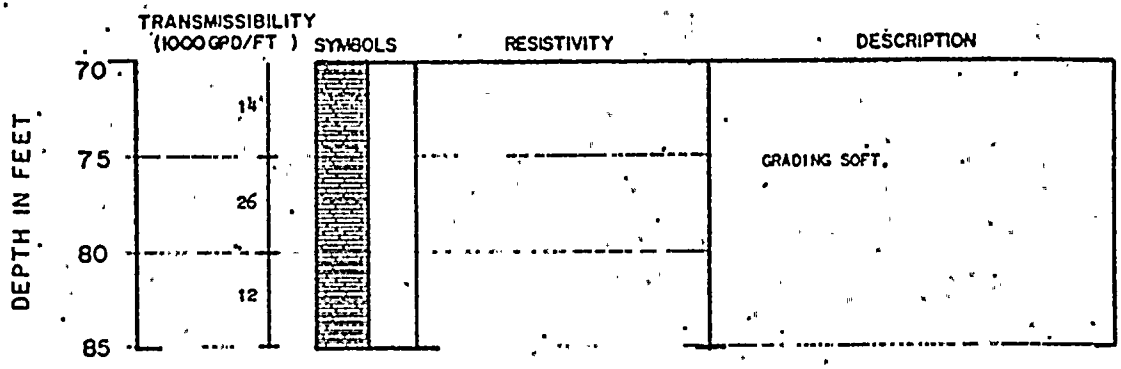
*INDICATES CORE RECOVERY IN PERCENT.

BORING CONTINUED

LOG OF BORINGS

DAMES & MOORE

BORING L-6 CONT'D

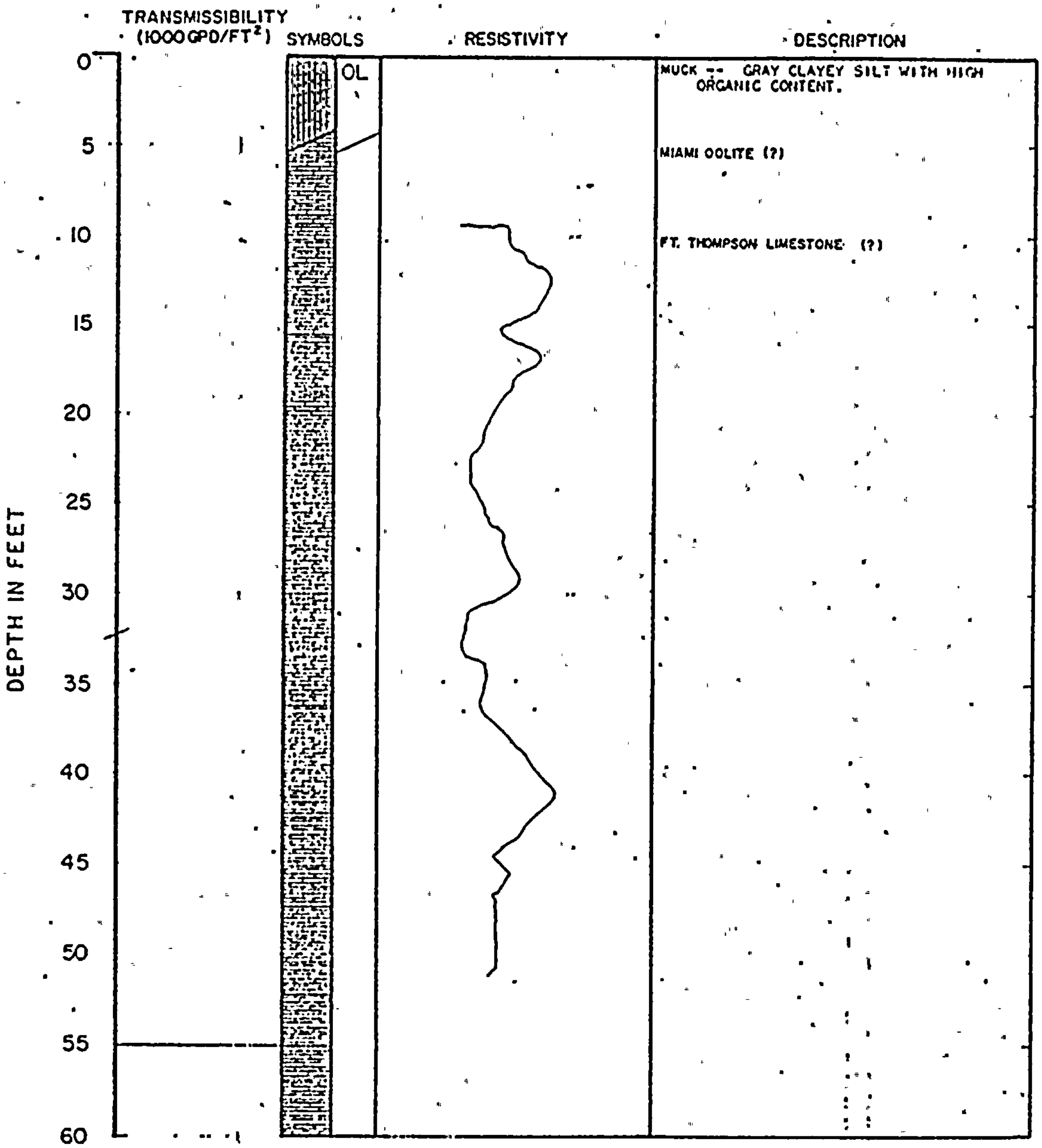


BORING TERMINATED 5-5-71.

LOG OF BORINGS

BORING GH-1

SURFACE ELEVATION: 1.1' MSL



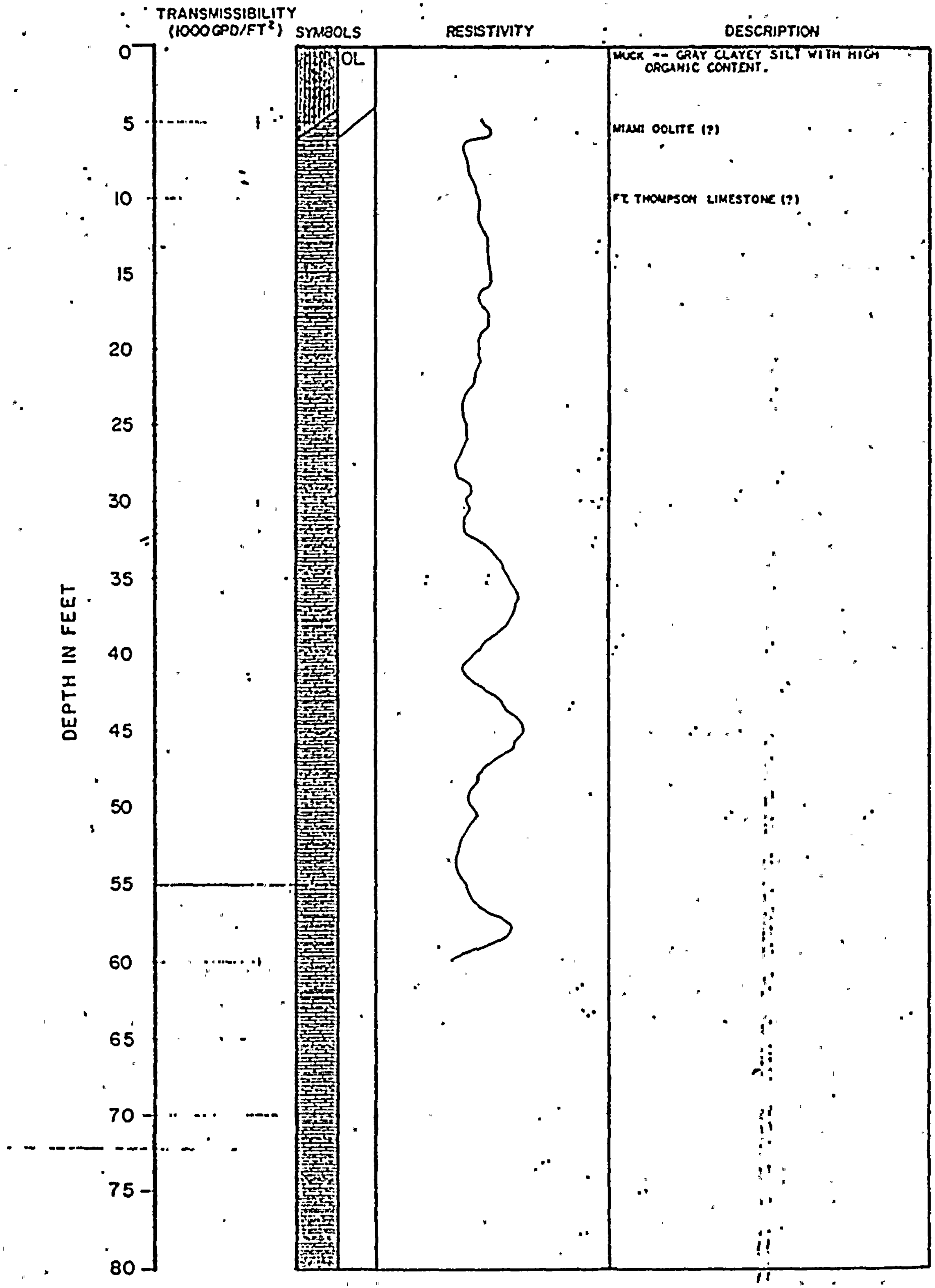
BORING TERMINATED: 5-17-71.

LOG OF BORINGS

DAMES & MOORE

BORING GH-2

SURFACE ELEVATION: 1.9' MSL



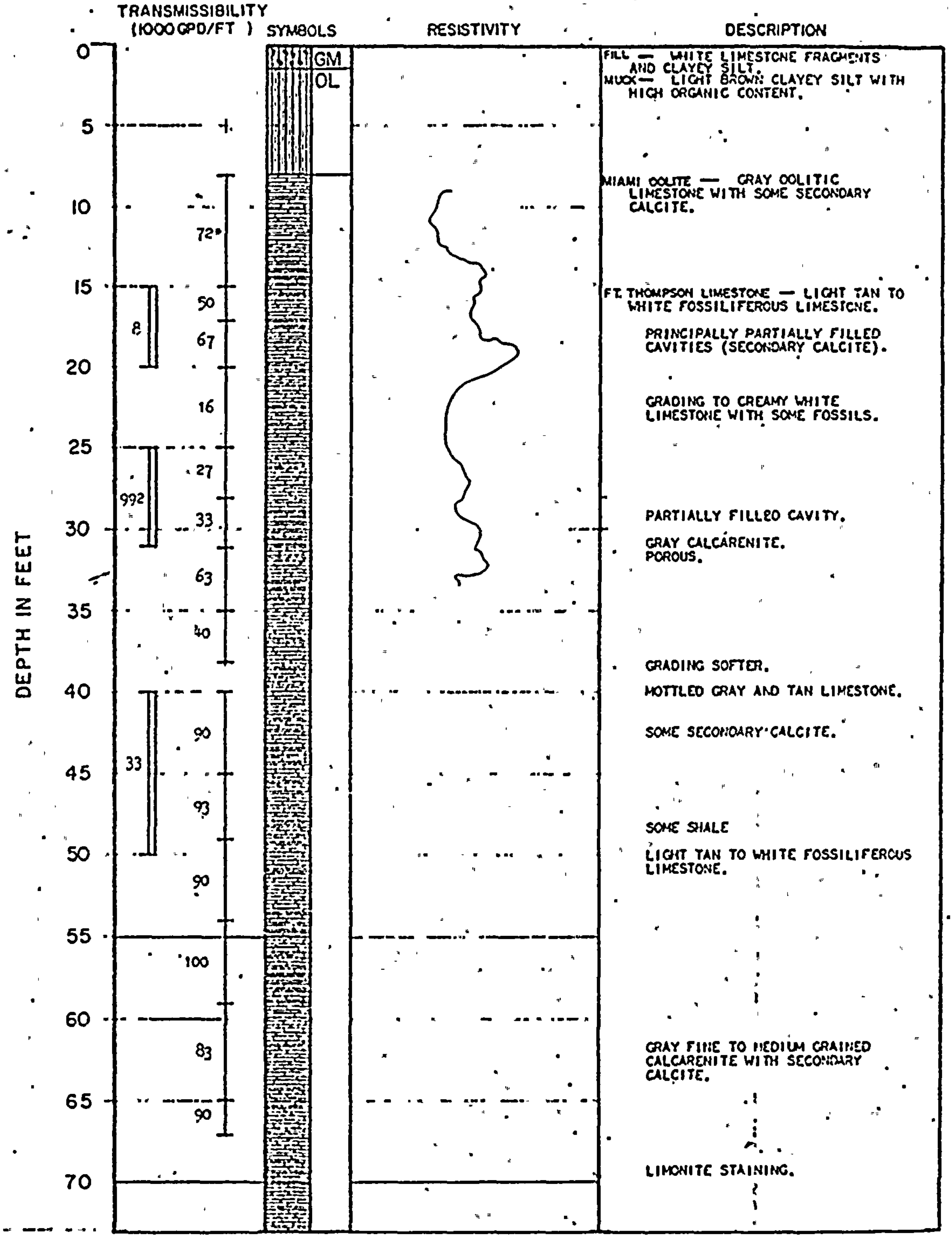
BORING TERMINATED 5-20-71.

LOG OF BORINGS

PLATE 20

BORING GH-3

SURFACE ELEVATION: +2.8' MSL



FILL — WHITE LIMESTONE FRAGMENTS AND CLAYEY SILT.

MUCK — LIGHT BROWN CLAYEY SILT WITH HIGH ORGANIC CONTENT.

MIAMI OOLITE — GRAY OOLITIC LIMESTONE WITH SOME SECONDARY CALCITE.

FT. THOMPSON LIMESTONE — LIGHT TAN TO WHITE FOSSILIFEROUS LIMESTONE.

PRINCIPALLY PARTIALLY FILLED CAVITIES (SECONDARY CALCITE).

GRADING TO CREAMY WHITE LIMESTONE WITH SOME FOSSILS.

PARTIALLY FILLED CAVITY.

GRAY CALCARENITE. POROUS.

GRADING SOFTER.

MOTTLED GRAY AND TAN LIMESTONE.

SOME SECONDARY CALCITE.

SOME SHALE

LIGHT TAN TO WHITE FOSSILIFEROUS LIMESTONE.

GRAY FINE TO MEDIUM GRAINED CALCARENITE WITH SECONDARY CALCITE.

LIMONITE STAINING.

*INDICATES CORE RECOVERY IN PERCENT.

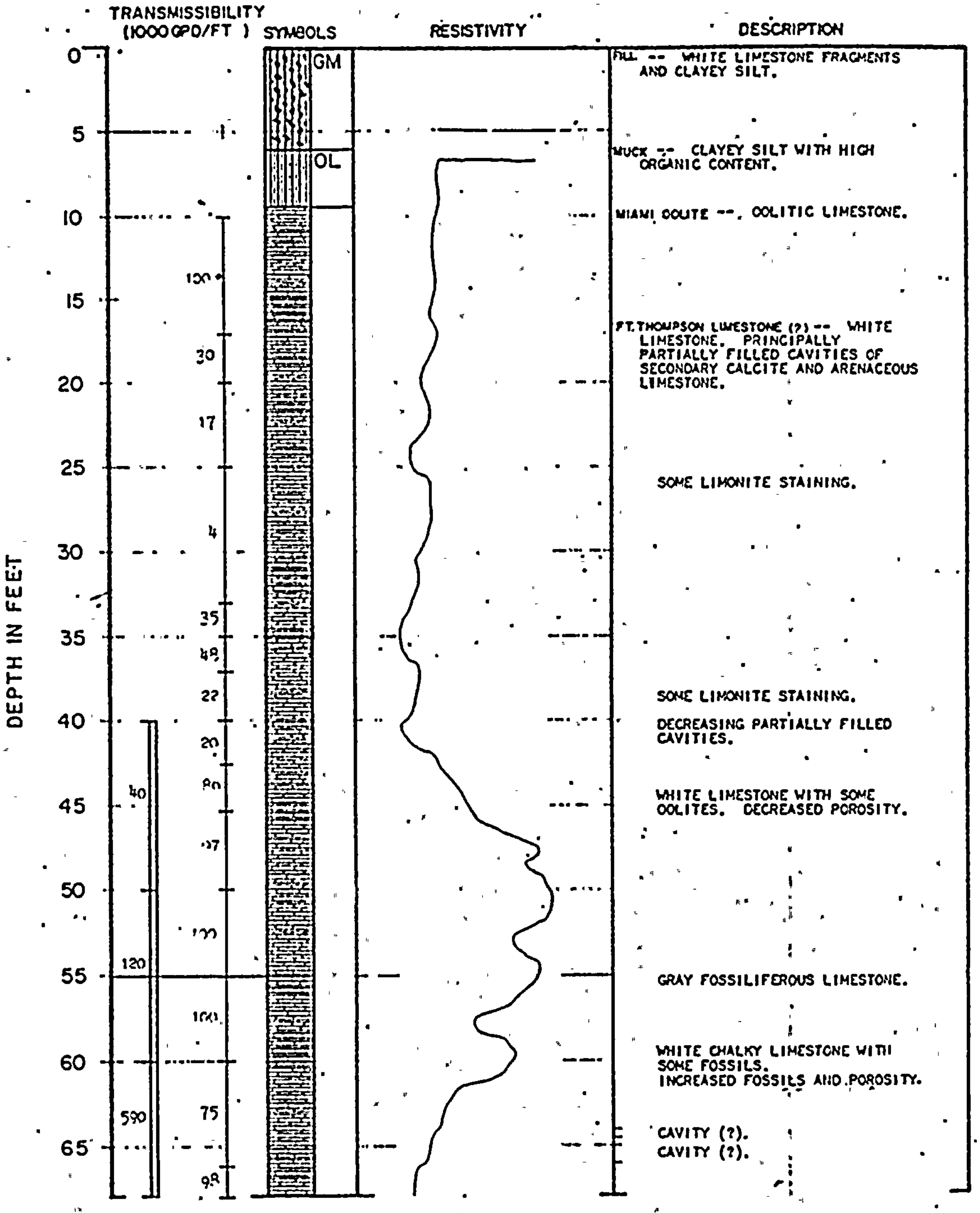
BORING TERMINATED 5-14-71.

LOG OF BORINGS

DAMES & MOORE

BORING GH-4

SURFACE ELEVATION: +5.5' MSL



FILL -- WHITE LIMESTONE FRAGMENTS AND CLAYEY SILT.

MUCK -- CLAYEY SILT WITH HIGH ORGANIC CONTENT.

MIAMI OOLITE --. OOLITIC LIMESTONE.

FT. THOMPSON LIMESTONE (?) -- WHITE LIMESTONE. PRINCIPALLY PARTIALLY FILLED CAVITIES OF SECONDARY CALCITE AND ARENACEOUS LIMESTONE.

SOME LIMONITE STAINING.

SOME LIMONITE STAINING.

DECREASING PARTIALLY FILLED CAVITIES.

WHITE LIMESTONE WITH SOME OOLITES. DECREASED POROSITY.

GRAY FOSSILIFEROUS LIMESTONE.

WHITE CHALKY LIMESTONE WITH SOME FOSSILS.
INCREASED FOSSILS AND POROSITY.

CAVITY (?).
CAVITY (?).

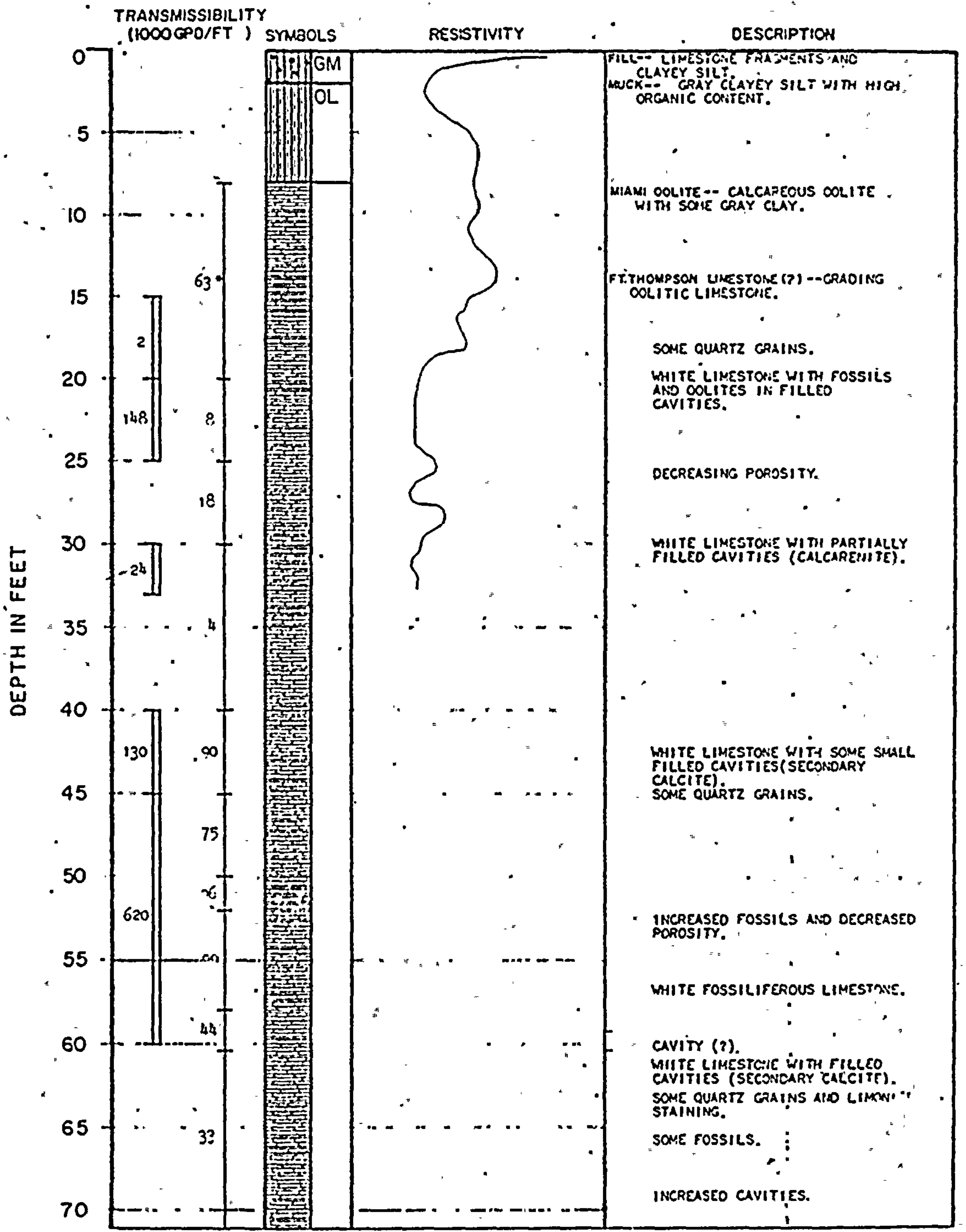
*INDICATES CORE RECOVERY IN PERCENT.

BORING TERMINATED 5-22-71.

LOG OF BORINGS

BORING GH-5

SURFACE ELEVATION: +3.0' MSL



BORING TERMINATED 5-18-71.

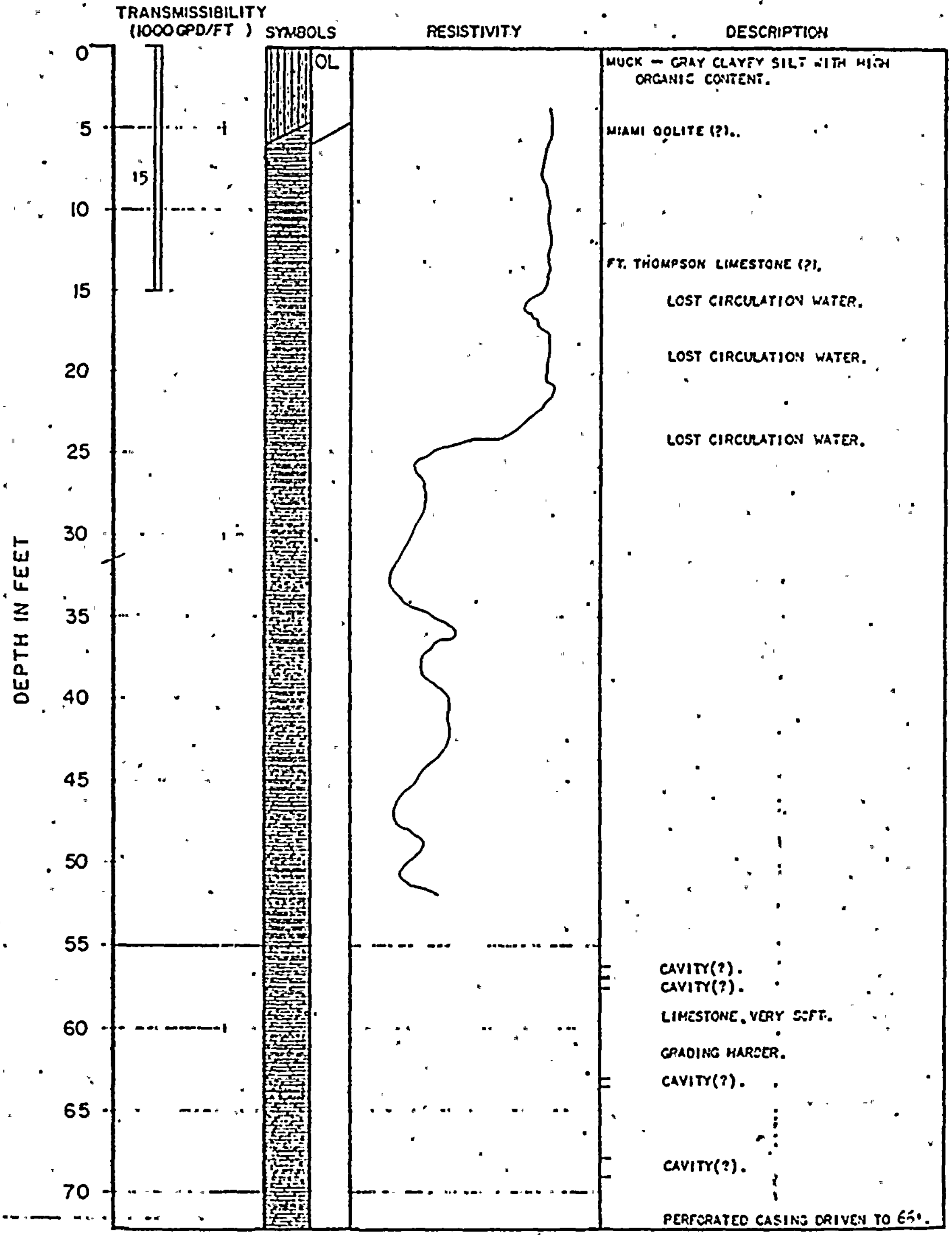
*INDICATES CORE RECOVERY IN PERCENT.

LOG OF BORINGS

DAMES & MOORE

BORING GH-6A

SURFACE ELEVATION: +1.1' MSL



BORING TERMINATED 6-3-71.

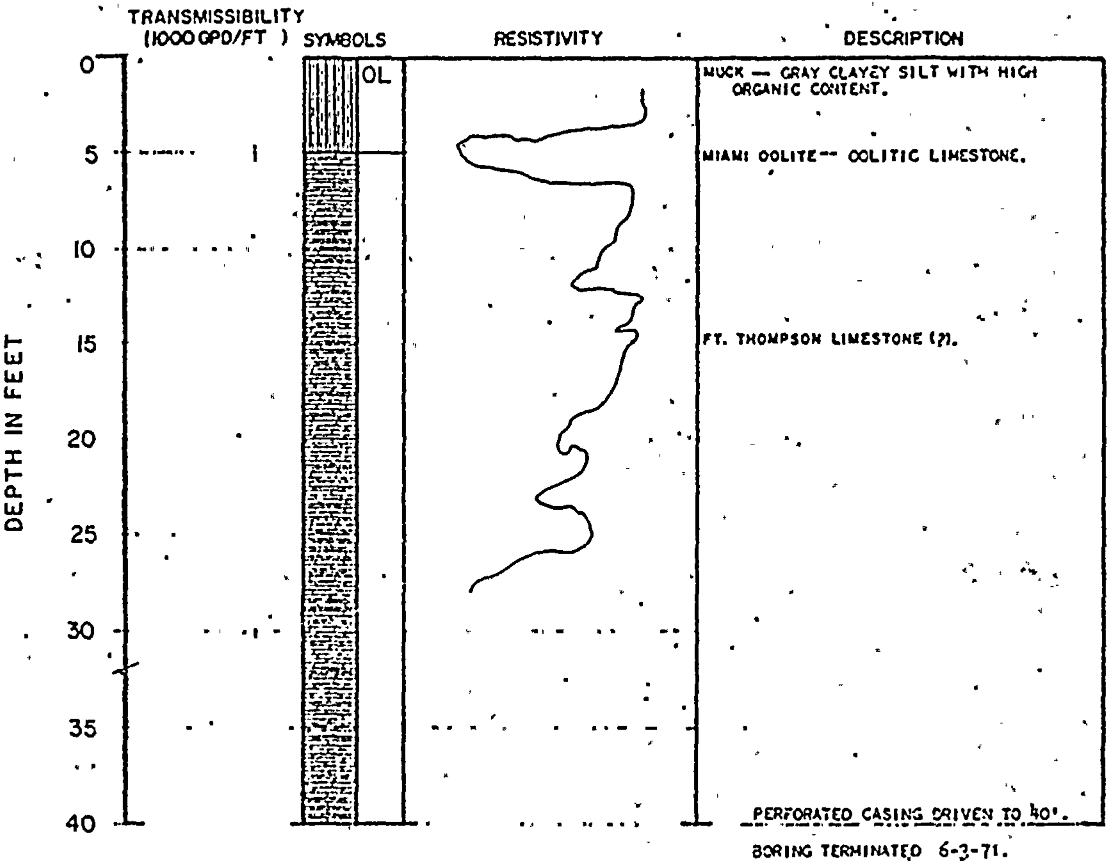
LOG OF BORINGS

DAMES & MOORE

PLATE 24

BORING GH-6B

SURFACE ELEVATION: +1.9' MSL



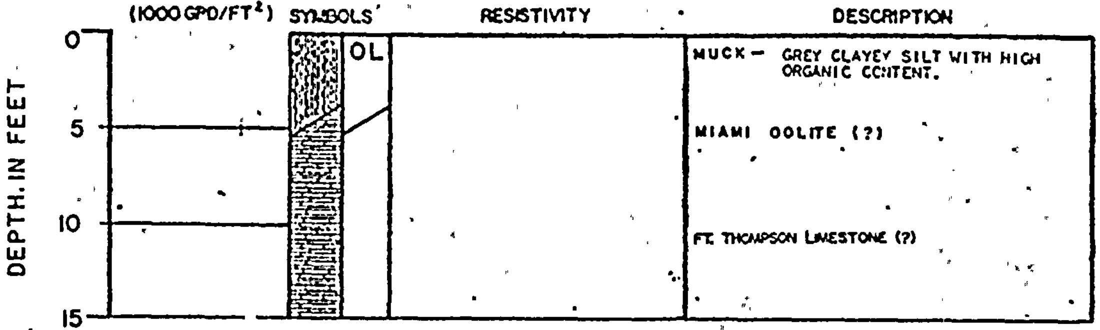
LOG OF BORINGS

DAMES & MOORE

PLATE 25

BORING GH-6C

SURFACE ELEVATION: 1.6' MSL



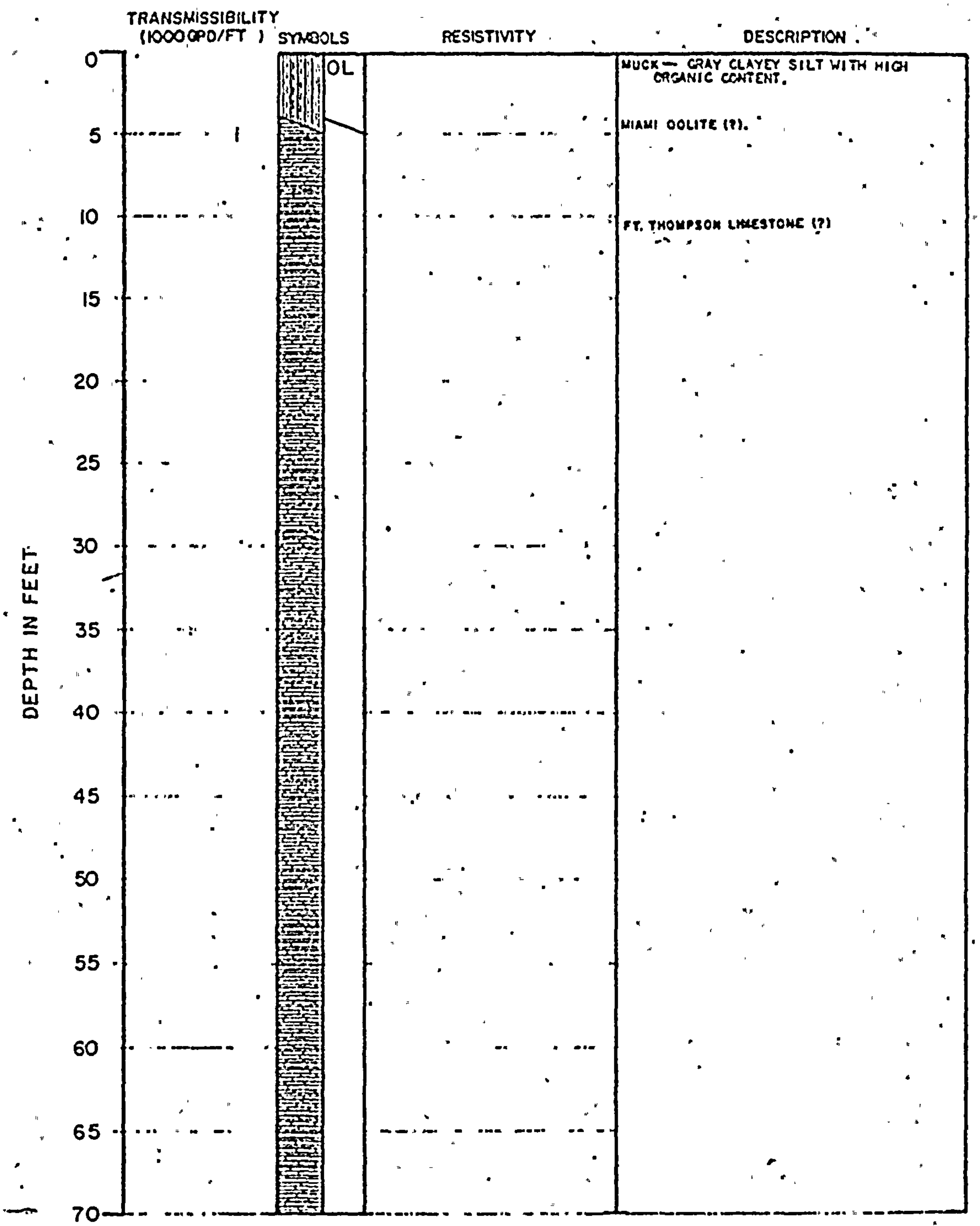
BORING TERMINATED 6-2-71.

LOG OF BORINGS

DAMES & MOORE

BORING GH-7

SURFACE ELEVATION: +1.1' MSL

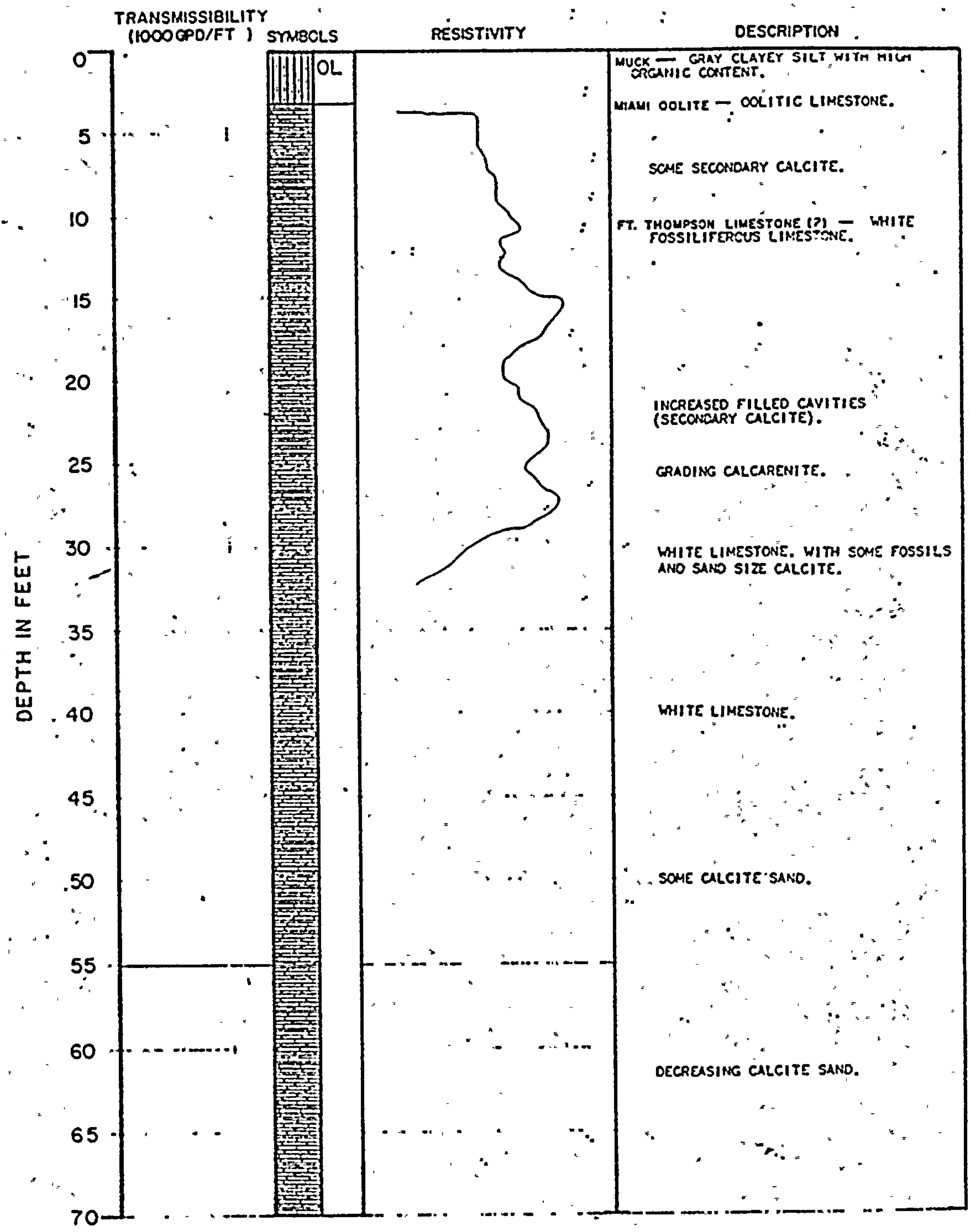


BORING TERMINATED 6-1-71.

LOG OF BORINGS

BORING GH-8

SURFACE ELEVATION: +1.0' MSL



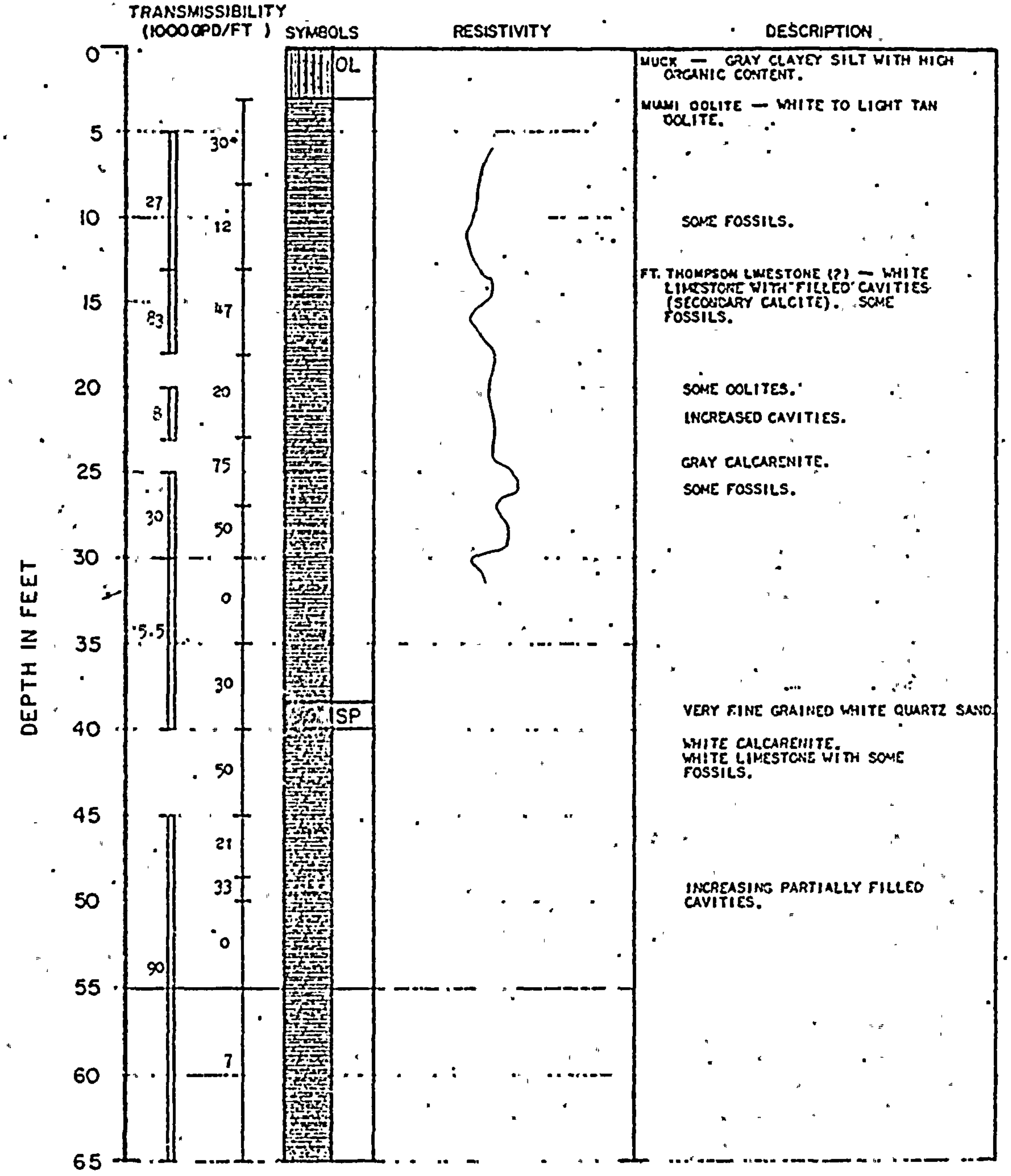
BORING TERMINATED 5-22-71.

LOG OF BORINGS

DAMES & MOORE

BORING GH-9

SURFACE ELEVATION: +1.1' MSL



*INDICATES CORE RECOVERY IN PERCENT.

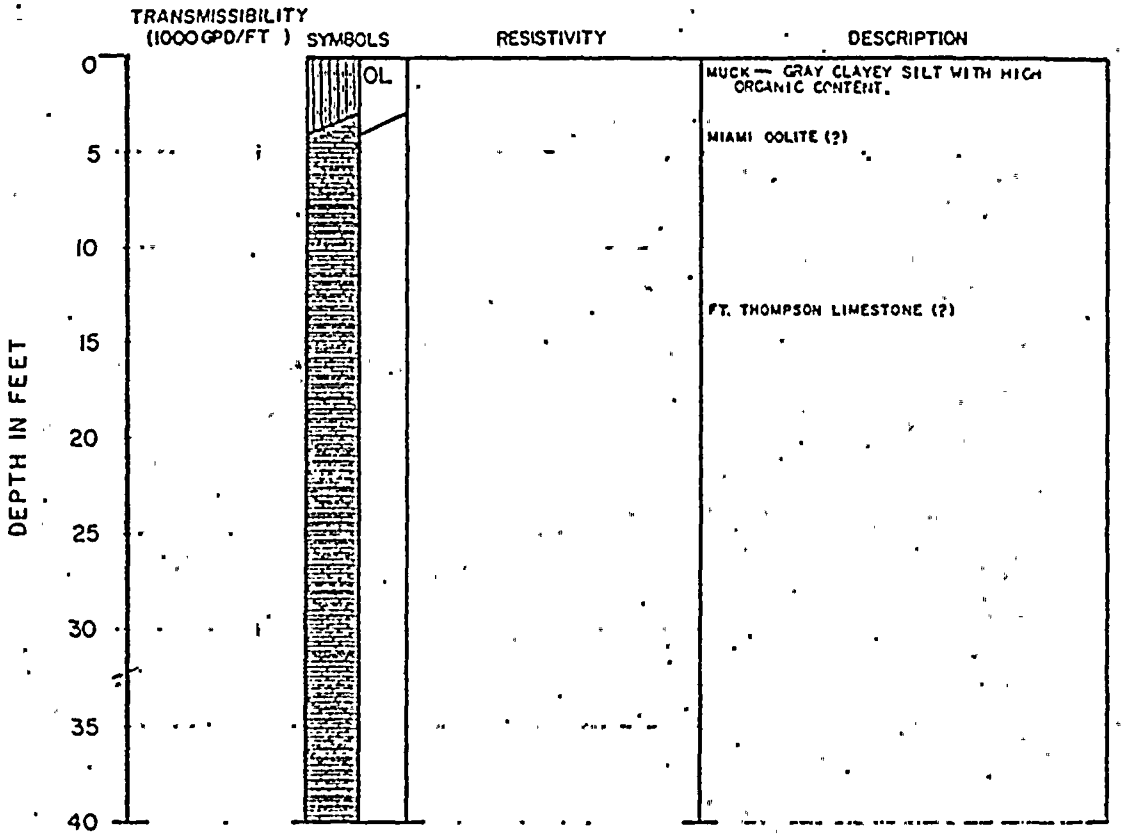
BORING TERMINATED 6-4-71.

LOG OF BORINGS

DAMES & MOORE

BORING GH-10A

SURFACE ELEVATION: +1.2' MSL



MUCK — GRAY CLAYEY SILT WITH HIGH ORGANIC CONTENT.

MIAMI OOLITE (?)

FT. THOMPSON LIMESTONE (?)

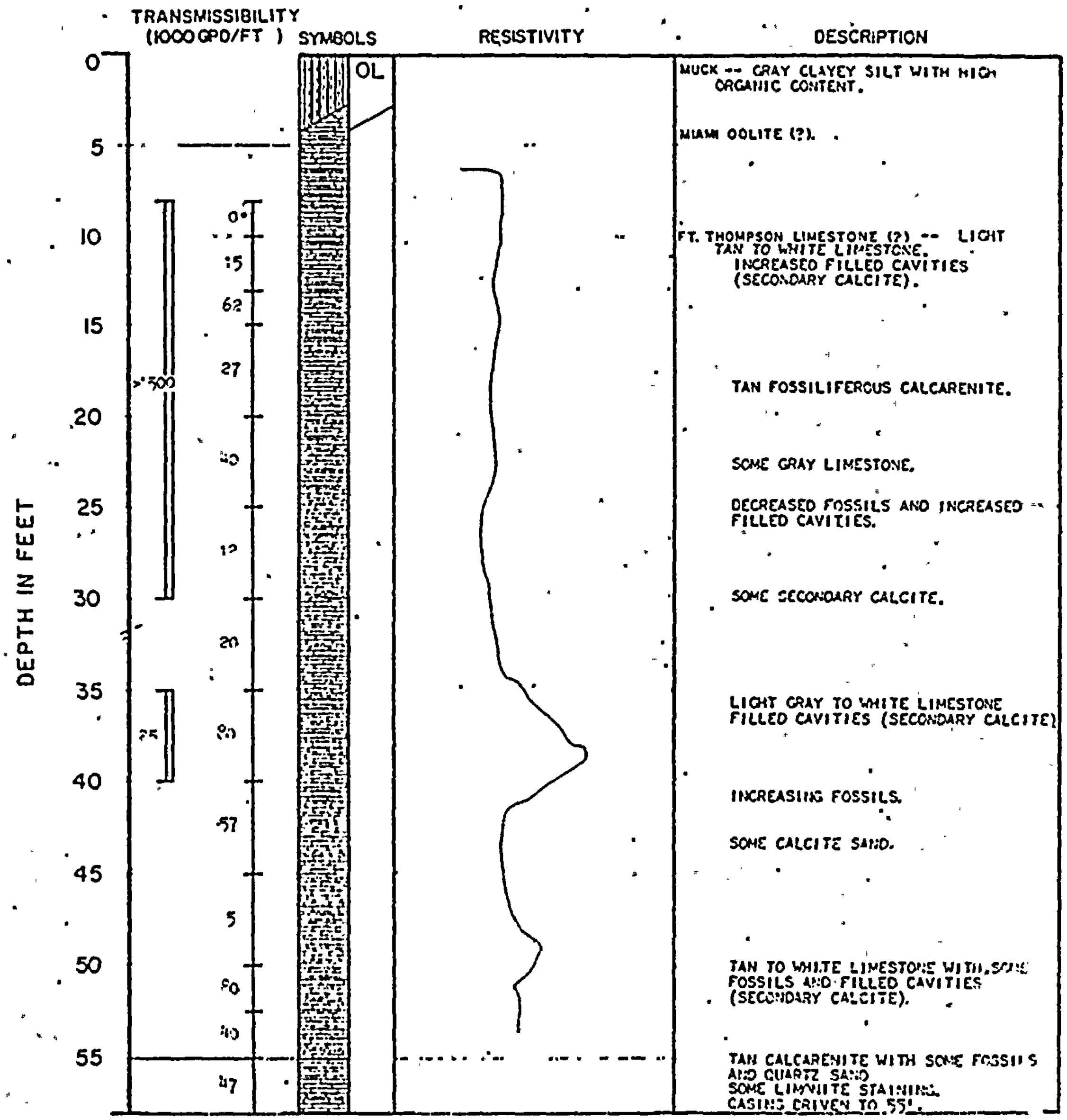
BORING TERMINATED 6-7-71.

LOG OF BORINGS

DAMES & MOORE

BORING GH-10B

SURFACE ELEVATION: +1.3' MSL



MUCK -- GRAY CLAYEY SILT WITH HIGH ORGANIC CONTENT.

MIAMI OOLITE (?).

FT. THOMPSON LIMESTONE (?) -- LIGHT TAN TO WHITE LIMESTONE.
INCREASED FILLED CAVITIES (SECONDARY CALCITE).

TAN FOSSILIFEROUS CALCARENITE.

SOME GRAY LIMESTONE.

DECREASED FOSSILS AND INCREASED FILLED CAVITIES.

SOME SECONDARY CALCITE.

LIGHT GRAY TO WHITE LIMESTONE FILLED CAVITIES (SECONDARY CALCITE)

INCREASING FOSSILS.

SOME CALCITE SAND.

TAN TO WHITE LIMESTONE WITH SOME FOSSILS AND FILLED CAVITIES (SECONDARY CALCITE).

TAN CALCARENITE WITH SOME FOSSILS AND QUARTZ SAND
SOME LIMONITE STAINING.
CASING DRIVEN TO 55'.

*INDICATES CORE RECOVERY IN PERCENT.

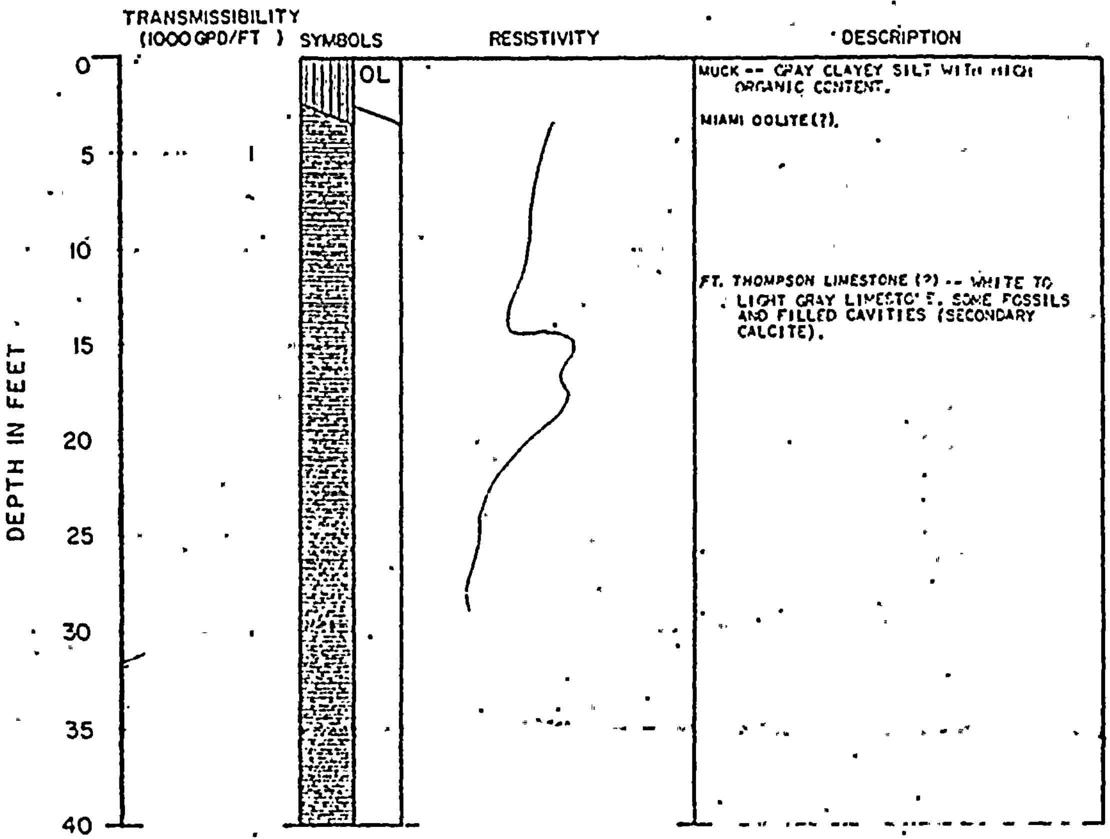
BORING TERMINATED 6-17-71.

LOG OF BORINGS

DAMES & MOORE

BORING GH-11A

SURFACE ELEVATION: +1.5' MSL



MUCK -- GRAY CLAYEY SILT WITH HIGH ORGANIC CONTENT.

MIAMI OOLITE (?).

FT. THOMPSON LIMESTONE (?) -- WHITE TO LIGHT GRAY LIMESTONE. SOME FOSSILS AND FILLED CAVITIES (SECONDARY CALCITE).

BORING TERMINATED 6-7-71.

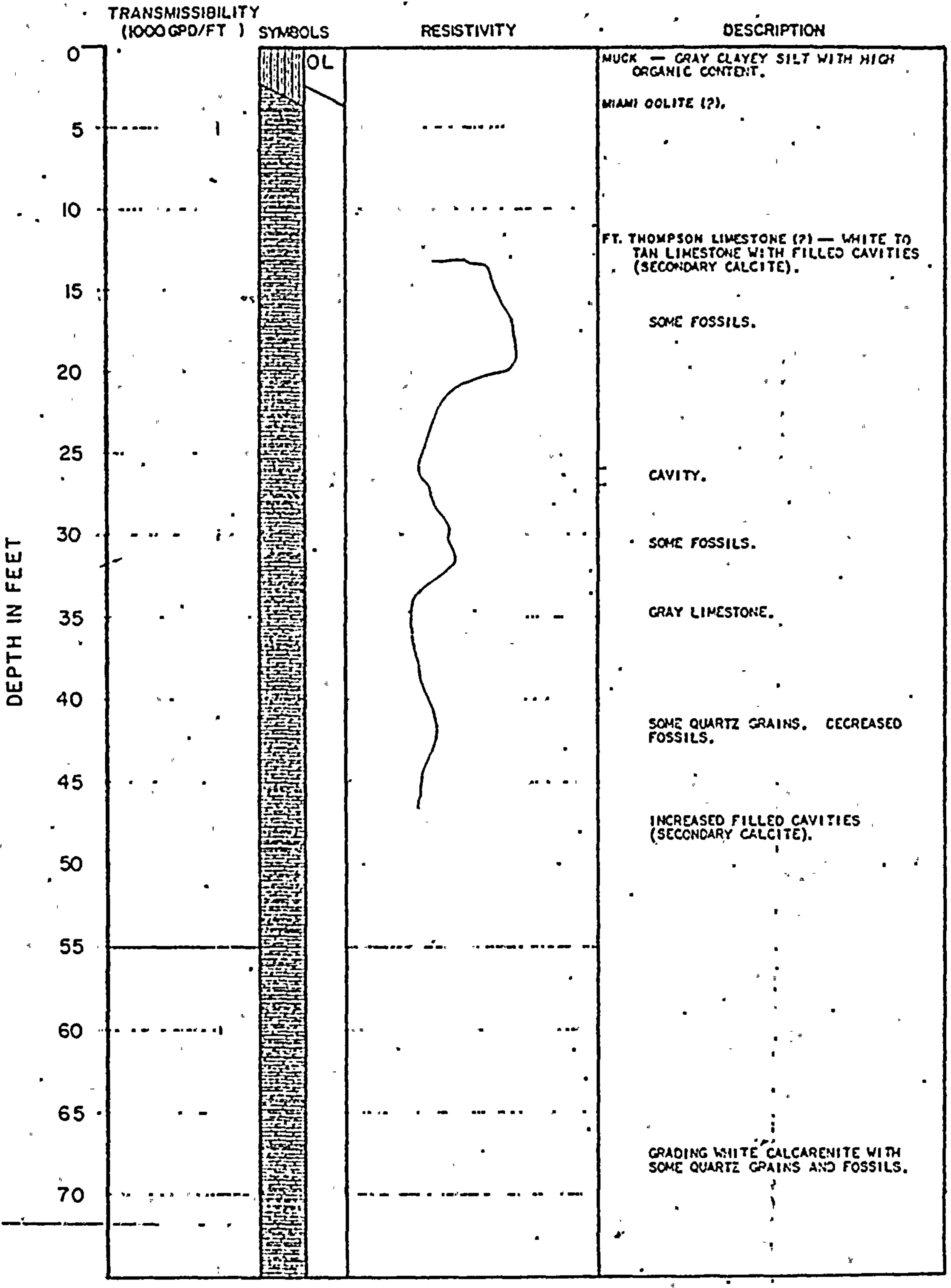
LOG OF BORINGS

DAMES & MOORE

PLATE 32

BORING GH-11B

SURFACE ELEVATION: -1.7' MSL

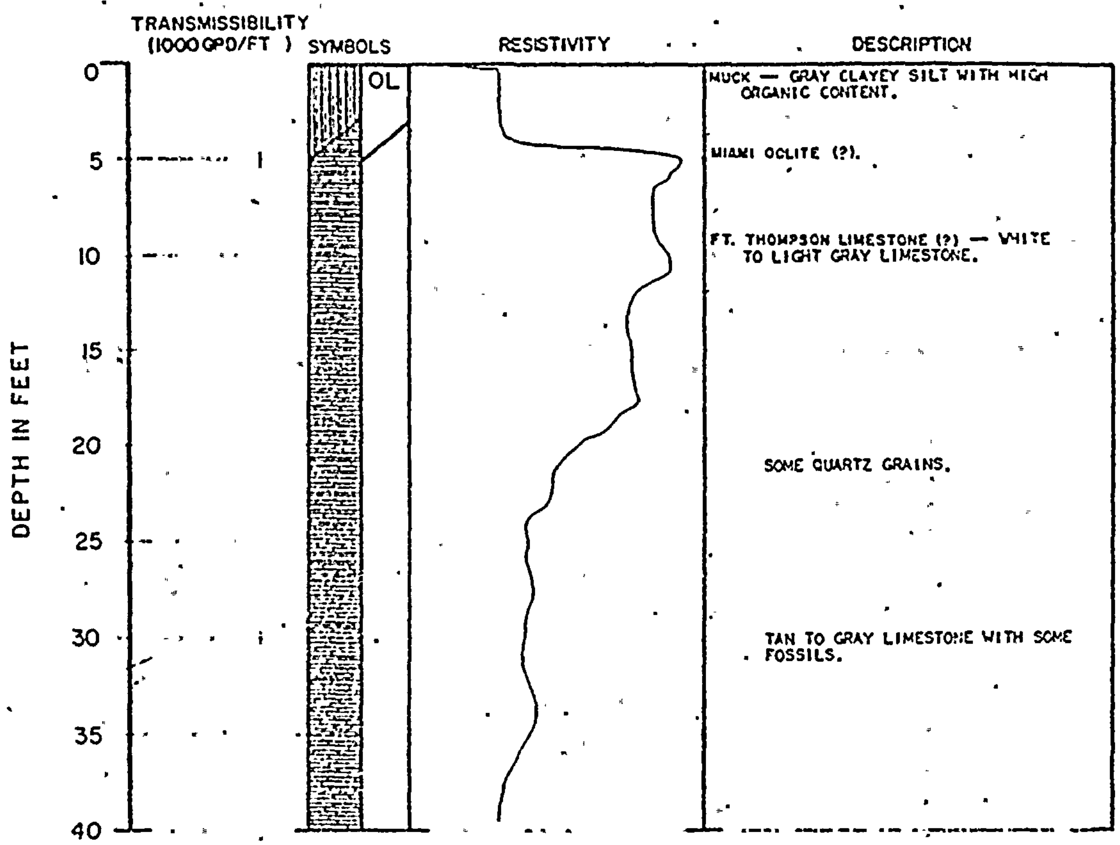


BORING TERMINATED 6-9-71.

LOG OF BORINGS

BORING GH-11C.

SURFACE ELEVATION: +1.7' MSL



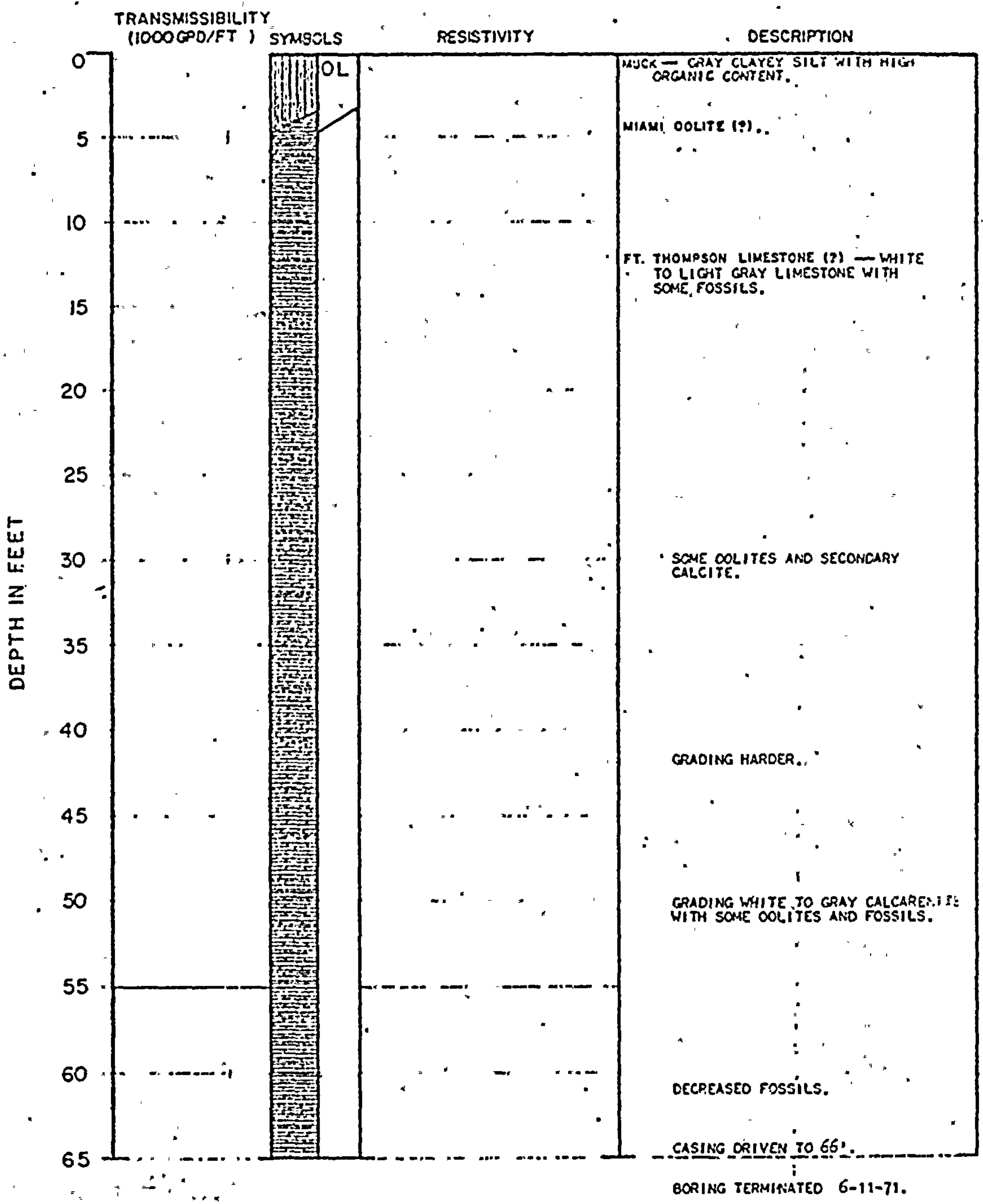
BORING TERMINATED 5-10-71.

LOG OF BORINGS

DAMES & MOORE

BORING GH-11D

SURFACE ELEVATION: +1.2' MSL

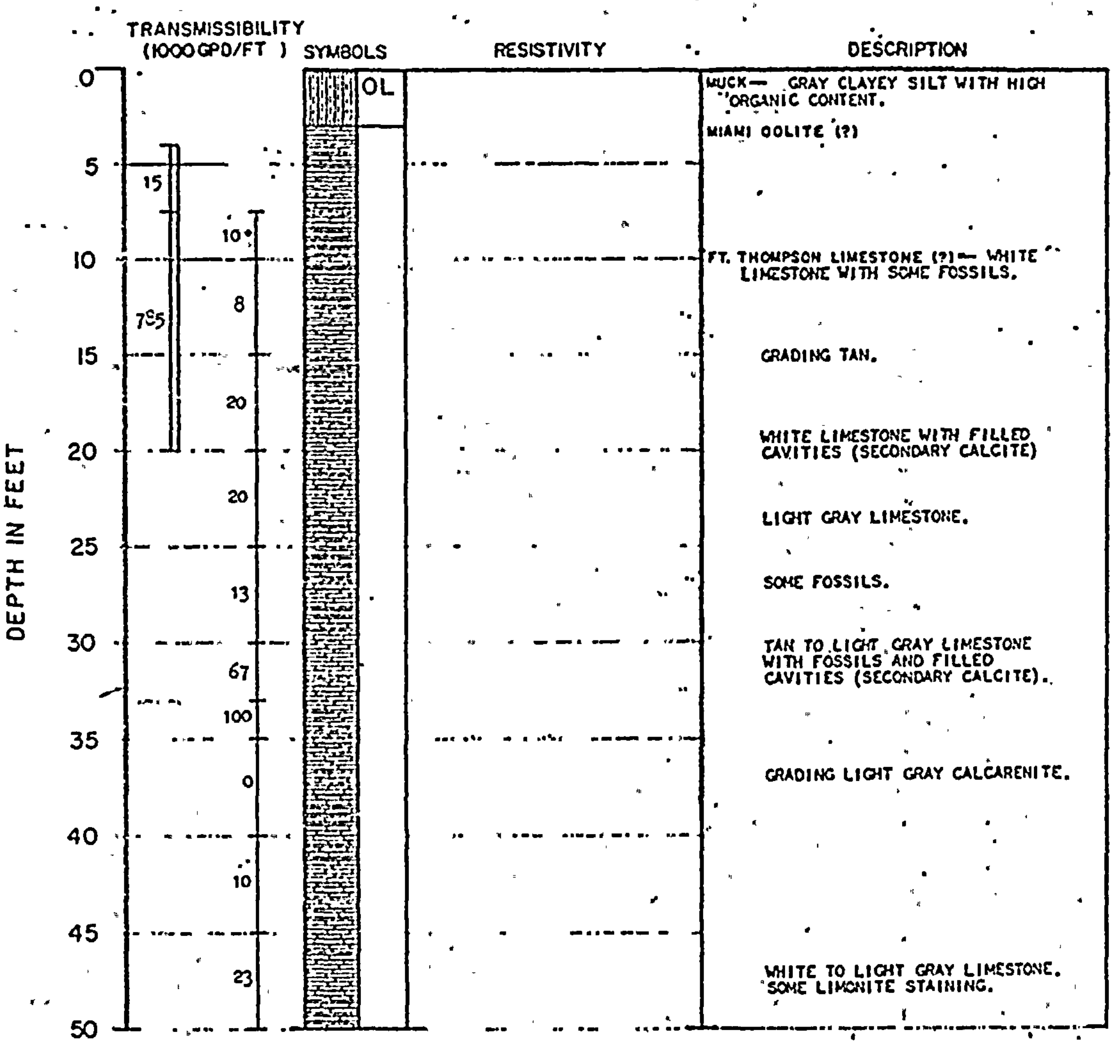


LOG OF BORINGS

DAMES & MOORE

BORING GH-11E

SURFACE ELEVATION: +1.7' MSL



*INDICATES CORE RECOVERY IN PERCENT.

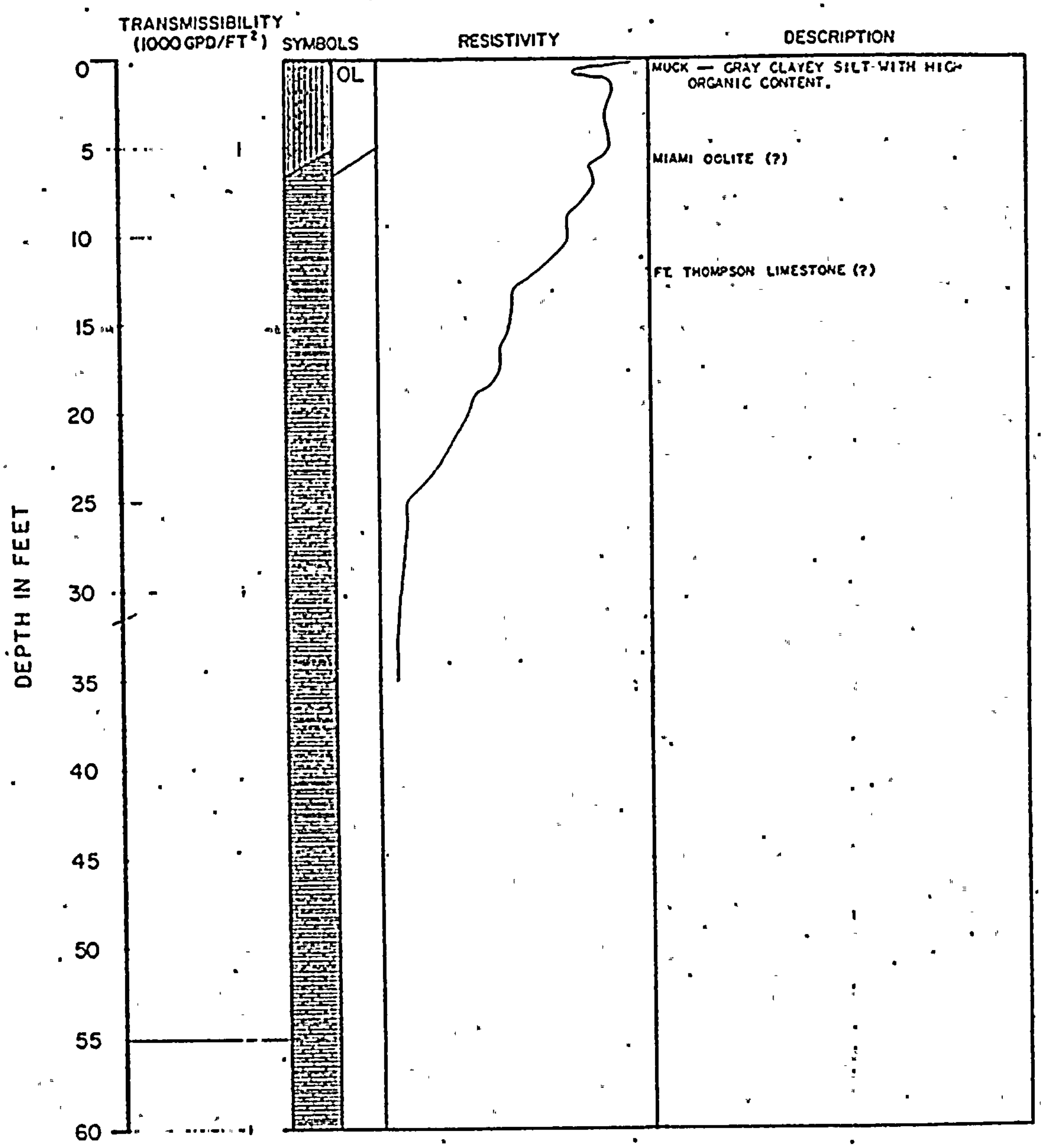
BORING TERMINATED 6-12-71.

LOG OF BORINGS

DAMES & MOORE

BORING GH-12A

SURFACE ELEVATION: 1.5' MSL



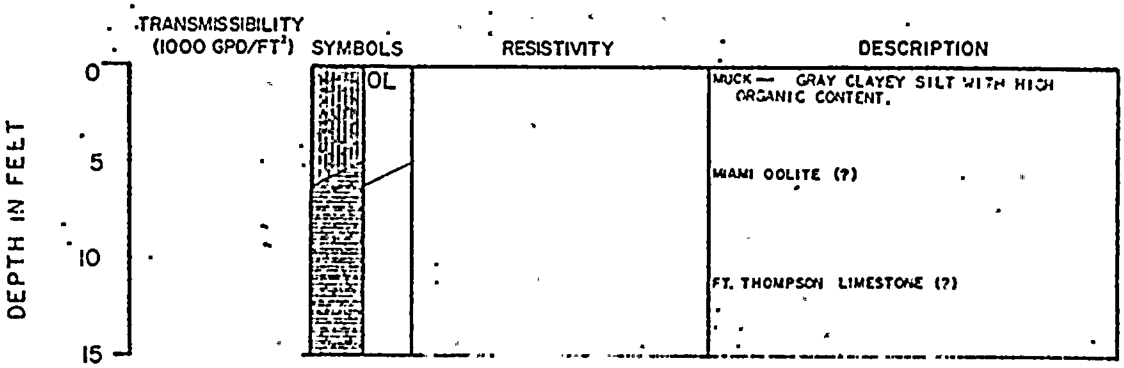
BORING TERMINATED 6-8-71.

LOG OF BORINGS

DAMES & MOORE

BORING GH-12B

SURFACE ELEVATION: 1.7' MSL



MUCK — GRAY CLAYEY SILT WITH HIGH ORGANIC CONTENT.

MIAMI OOLITE (?)

FT. THOMPSON LIMESTONE (?)

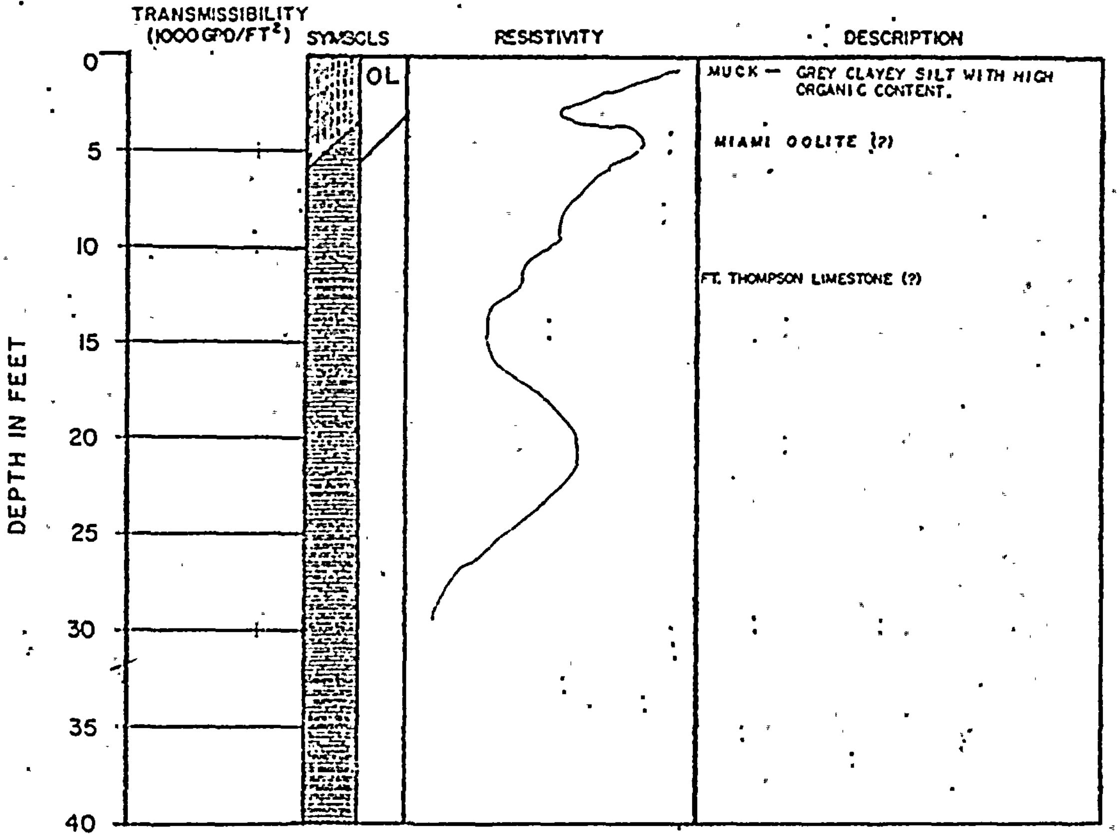
BORING TERMINATED 6-5-71.

LOG OF BORINGS

DAMES & MOORE

BORING GH-12C

SURFACE ELEVATION: 2.0' MSL



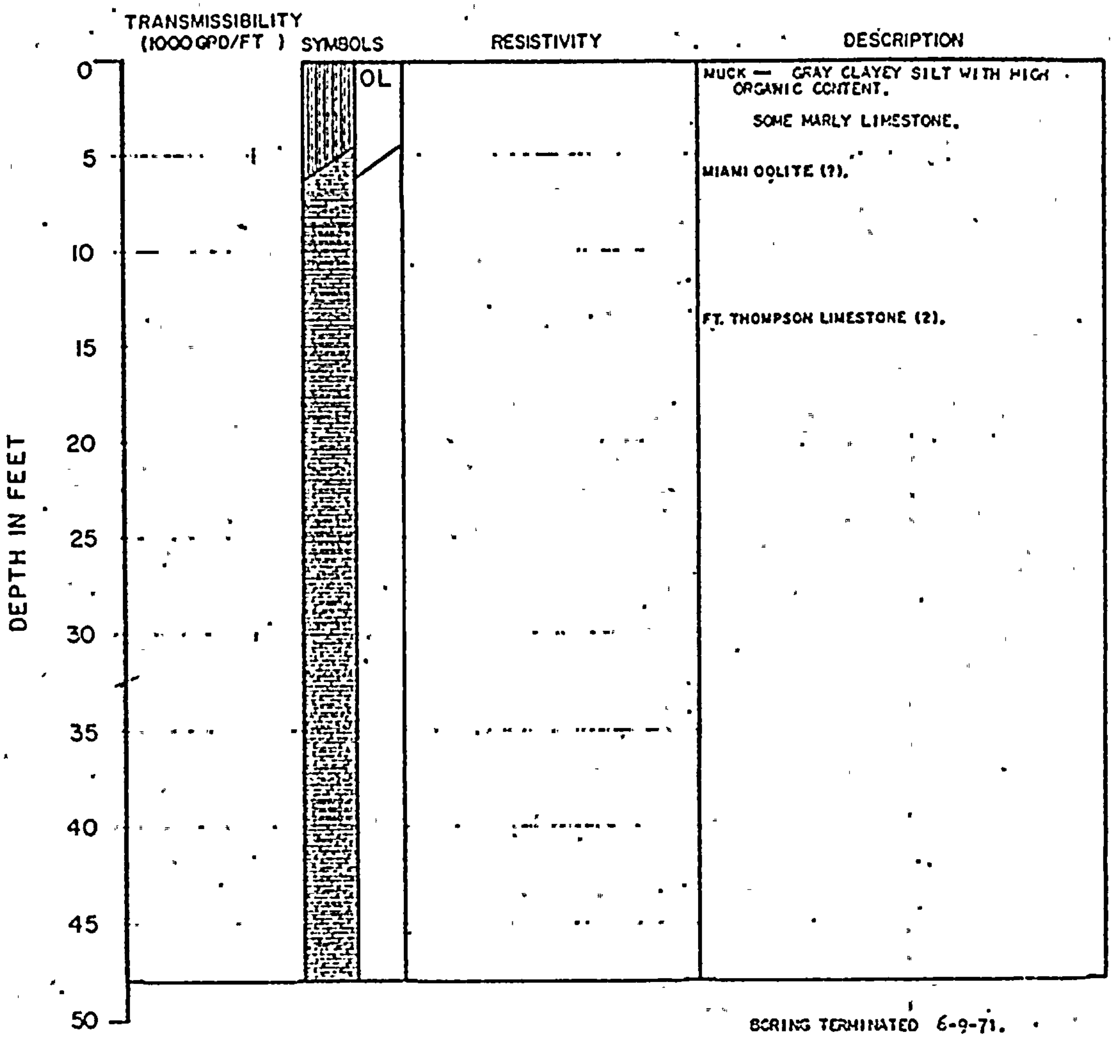
BORING TERMINATED 6-7-71.

LOG OF BORINGS

DAMES & MOORE

BORING GH-13A

SURFACE ELEVATION: +1.7' MSL



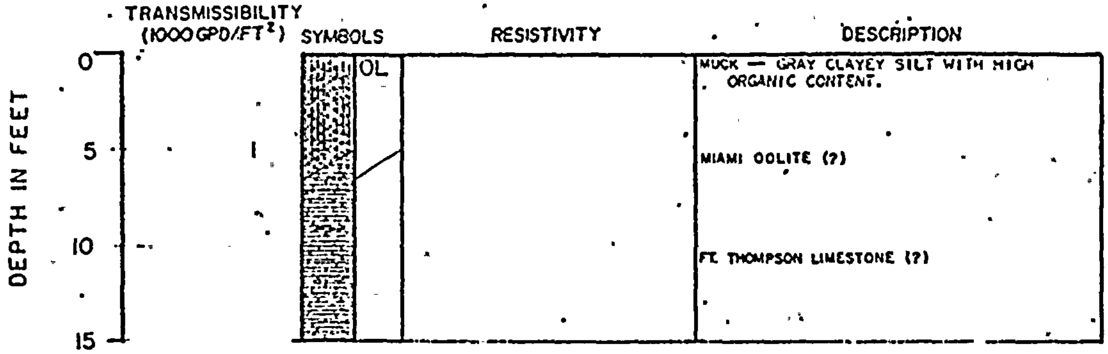
BORING TERMINATED 6-9-71.

LOG OF BORINGS

DAMES & MOORE

BORING GH-13B

SURFACE ELEVATION: [illegible] MSL



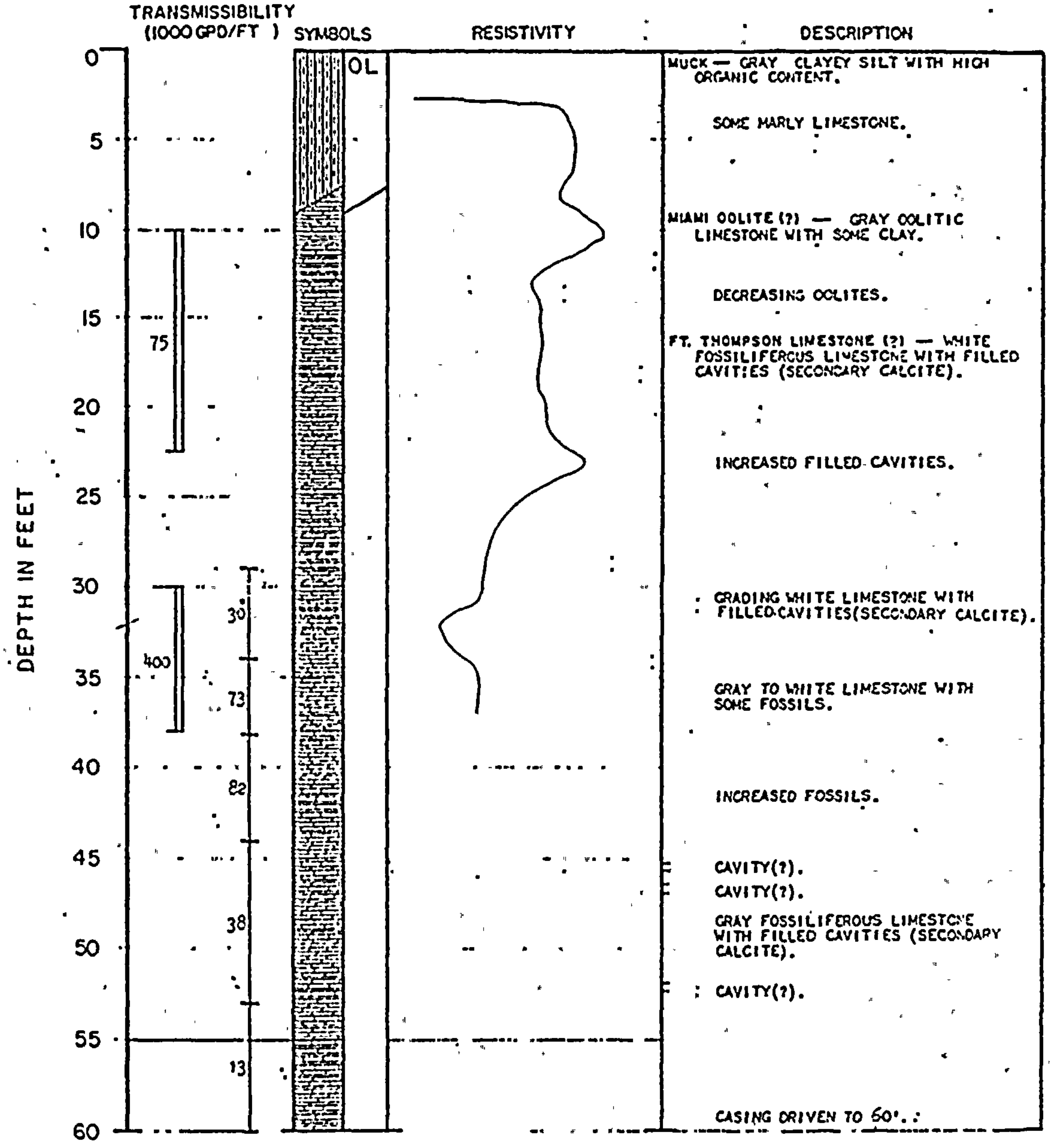
BORING TERMINATED 6-7-71.

LOG OF BORINGS

DAMES & MOORE

BORING GH-13C

SURFACE ELEVATION: +1.8' MSL



*INDICATES CORE RECOVERY IN PERCENT.

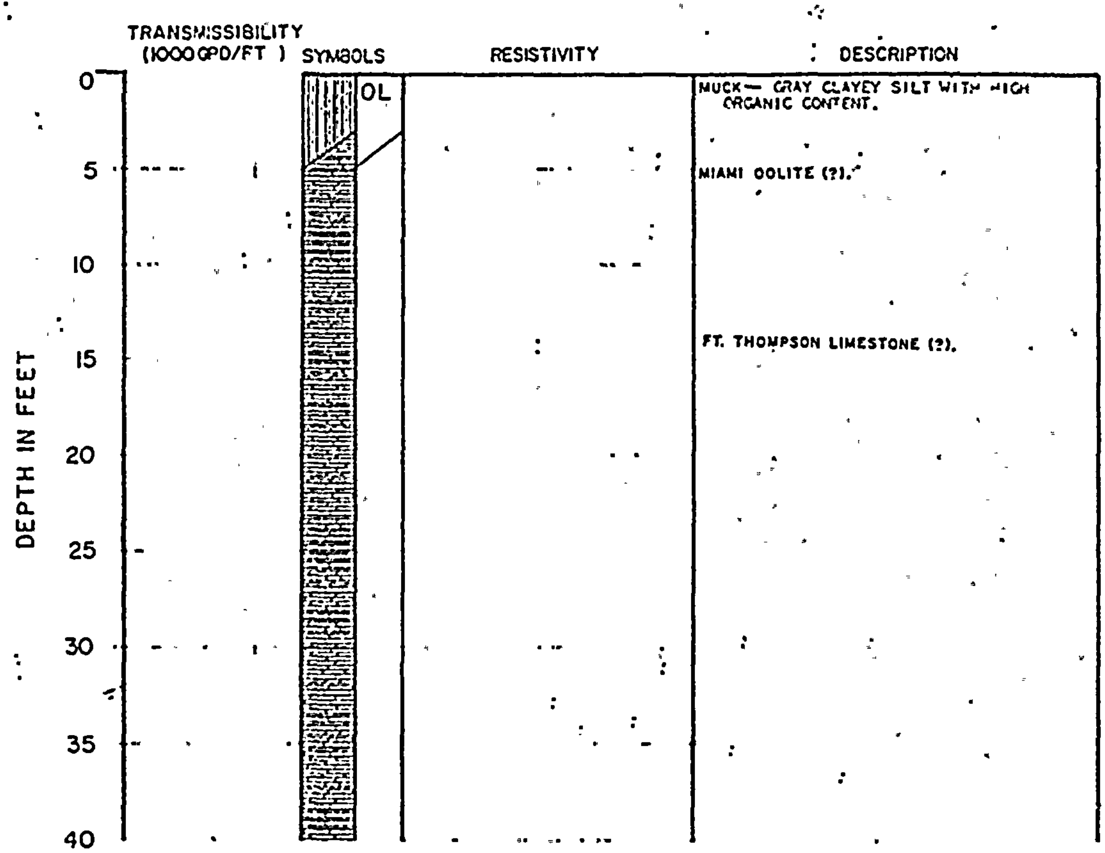
BORING TERMINATED 6-11-71.

LOG OF BORINGS

DAMES & MOORE

BORING GH-14A

SURFACE ELEVATION: +7.1' MSL



MUCK— GRAY CLAYEY SILT WITH HIGH ORGANIC CONTENT.

MIAMI OOLITE (?).

FT. THOMPSON LIMESTONE (?).

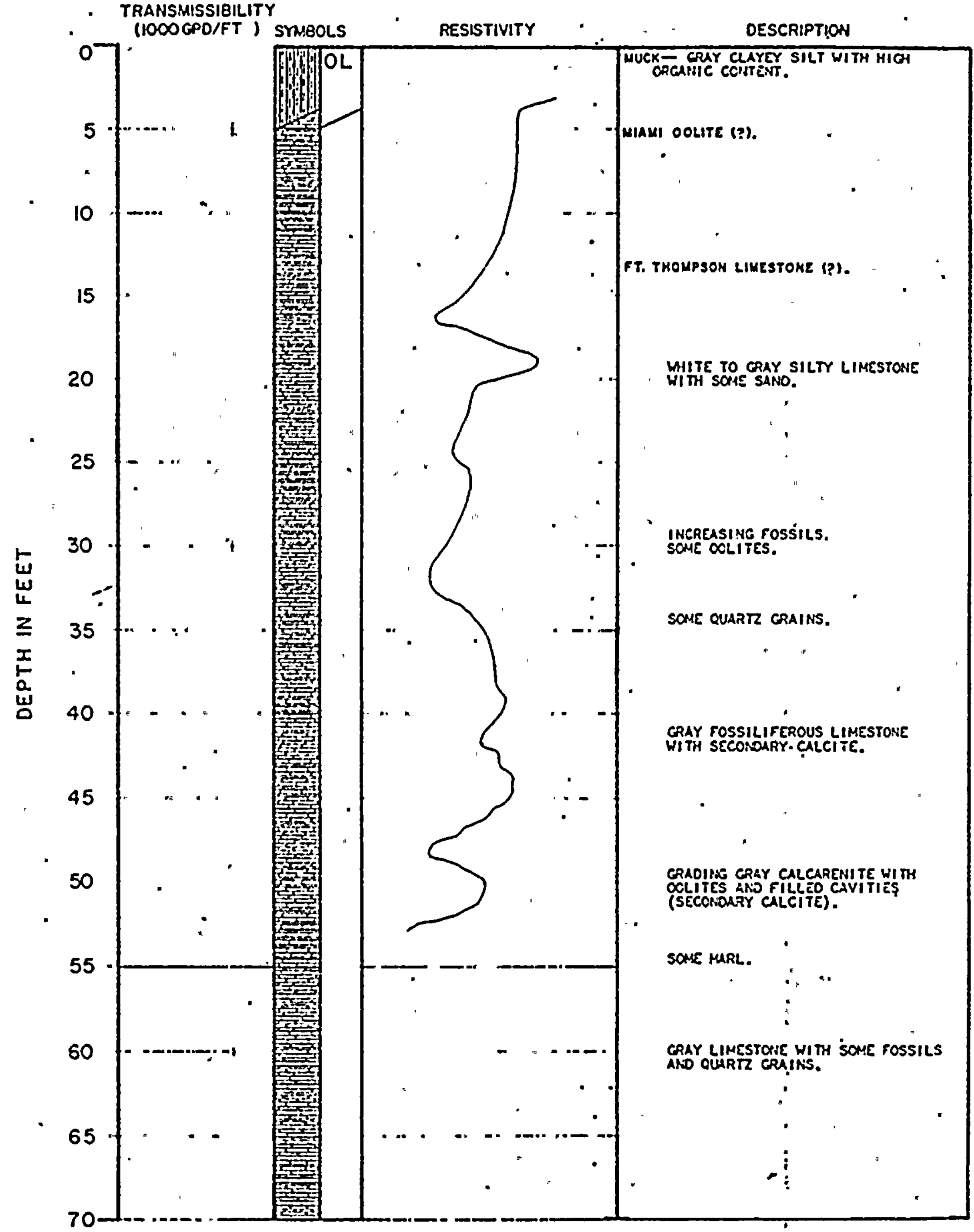
BORING TERMINATED 5-29-71

LOG OF BORINGS

DAMES & MOORE

BORING GH-14B

SURFACE ELEVATION: +1.2' MSL



BORING TERMINATED 6-1-71.

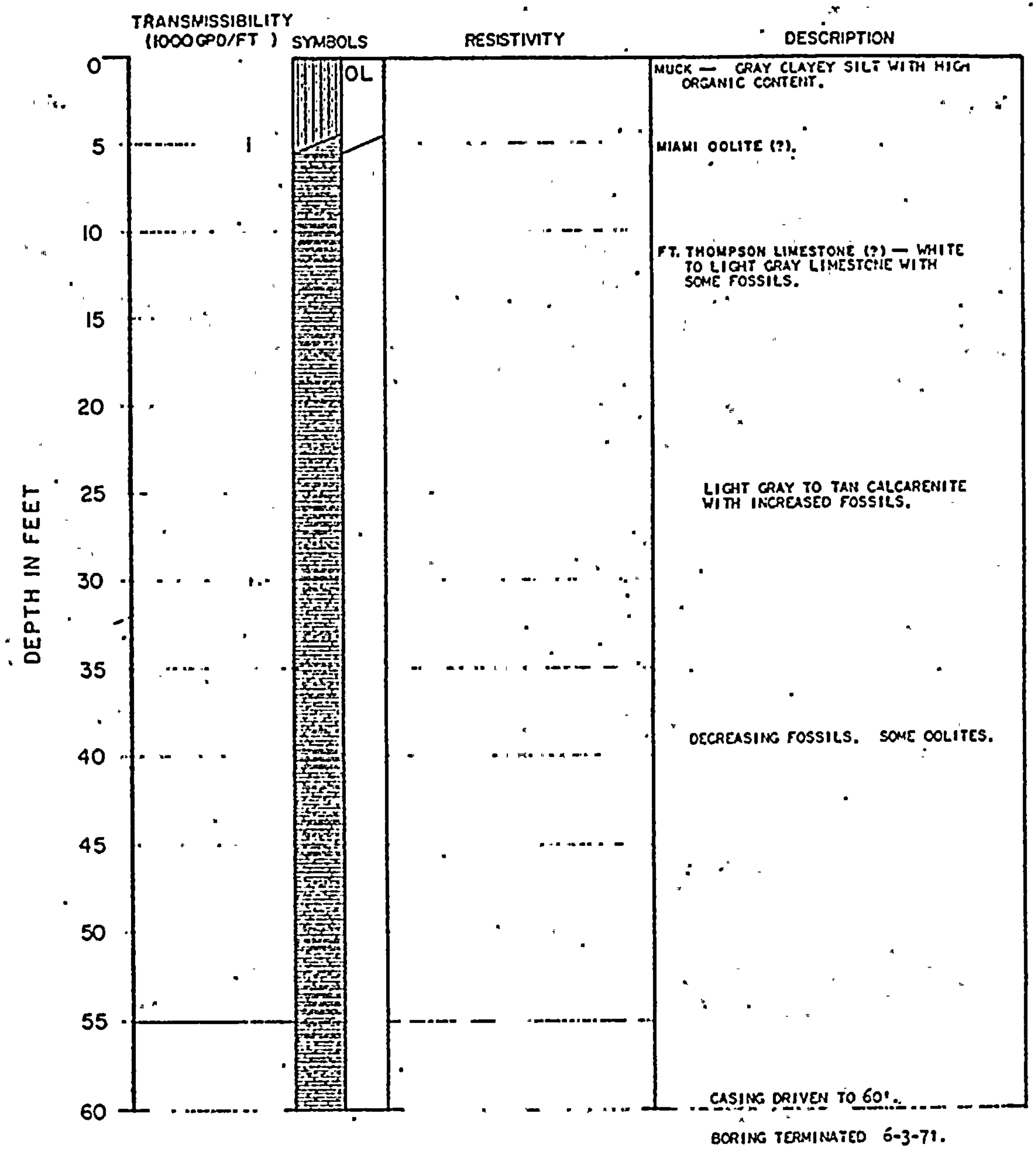
LOG OF BORINGS

DAMES & MOORE

PLATE 44

BORING GH-14C

SURFACE ELEVATION: +1.0' MSL



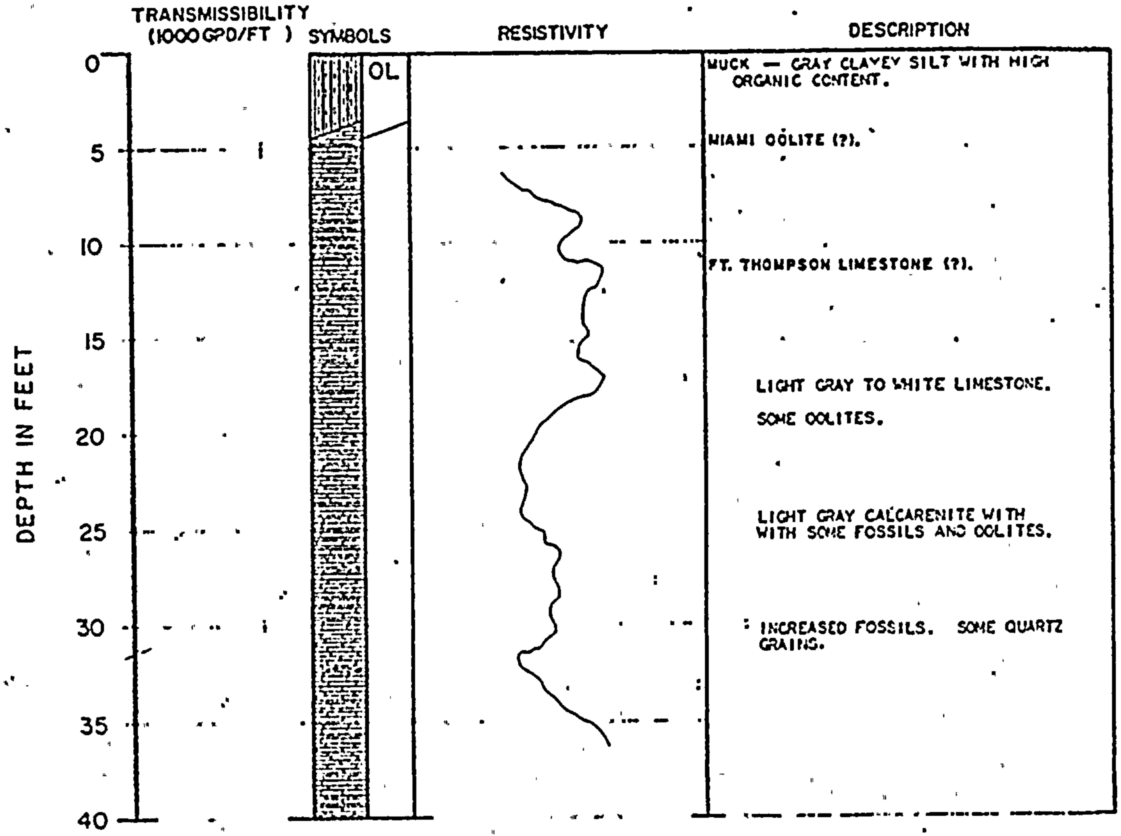
LOG OF BORINGS

DAMES & MOORE

PLATE 45

BORING GH-14D

SURFACE ELEVATION: -[illegible].2' MSL



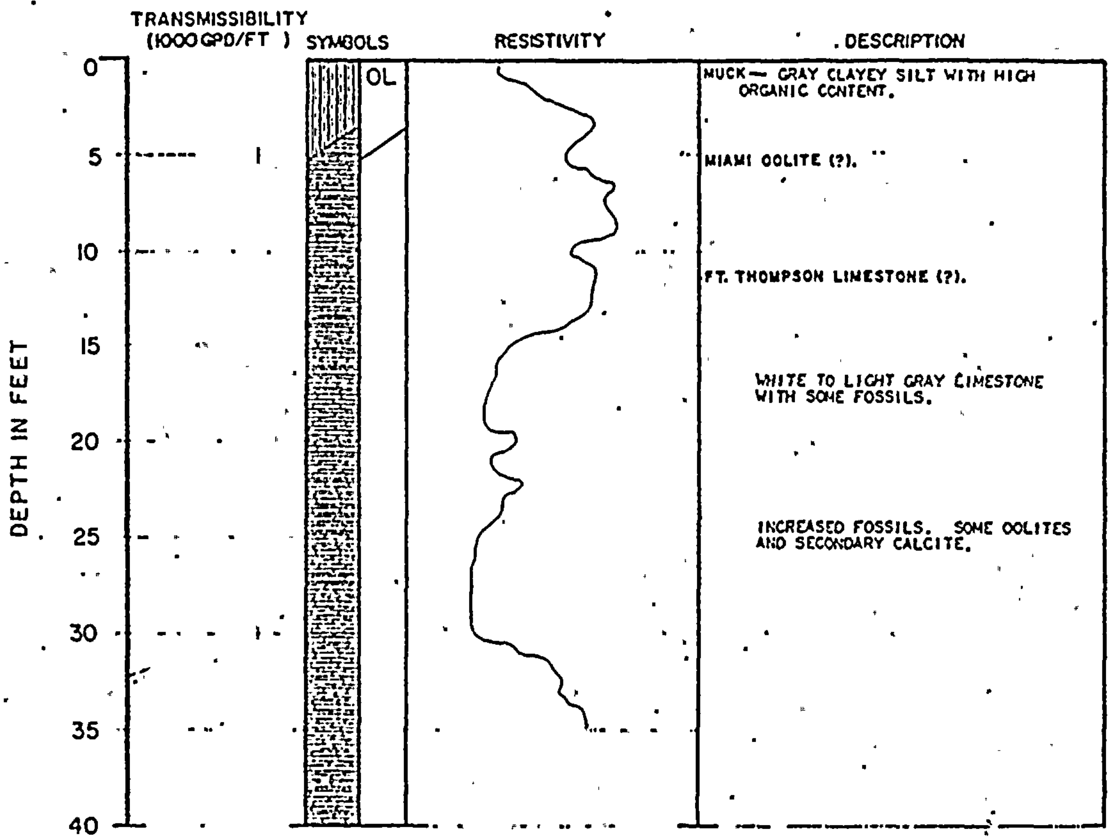
BORING TERMINATED 6-2-71.

LOG OF BORINGS

DAMES & MOORE

BORING GH-14E

SURFACE ELEVATION: +0.5' MSL

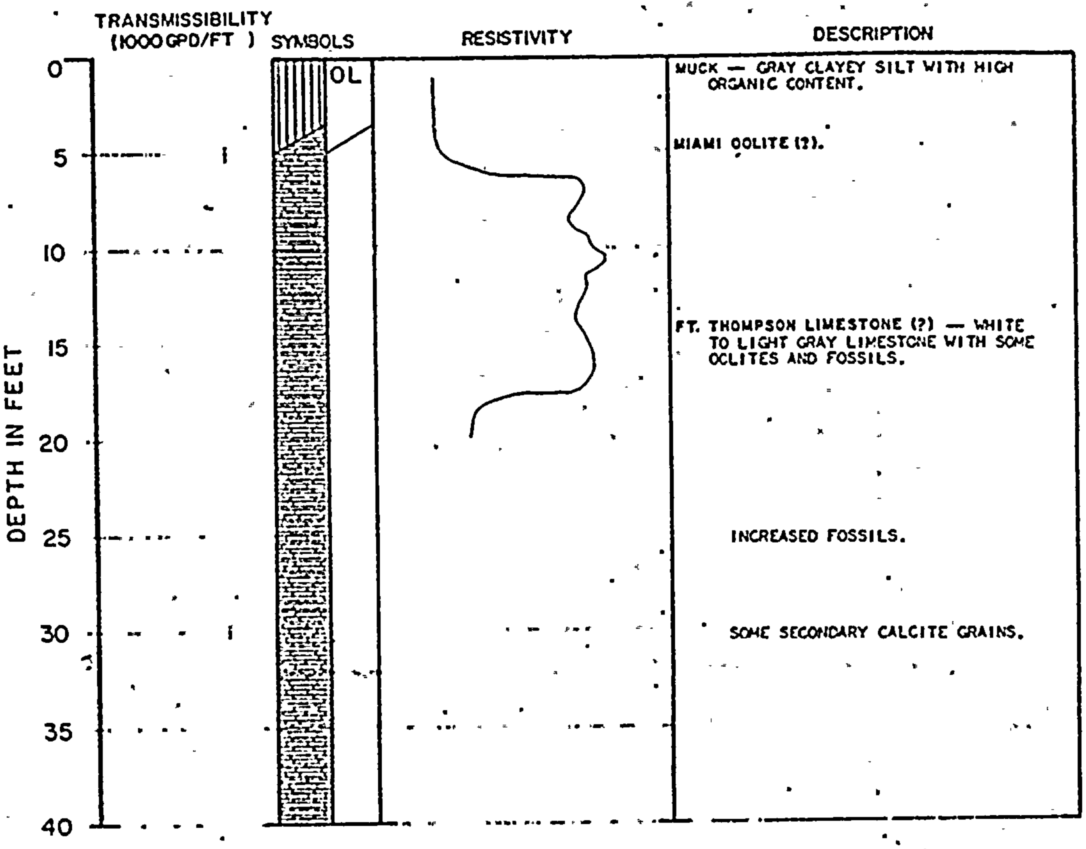


BORING TERMINATED 6-3-71.

LOG OF BORINGS

BORING GH-14F

SURFACE ELEVATION: -1.0' MSL



MUCK — GRAY CLAYEY SILT WITH HIGH ORGANIC CONTENT.

MIAMI OOLITE (?).

FT. THOMPSON LIMESTONE (?) — WHITE TO LIGHT GRAY LIMESTONE WITH SOME OOLITES AND FOSSILS.

INCREASED FOSSILS.

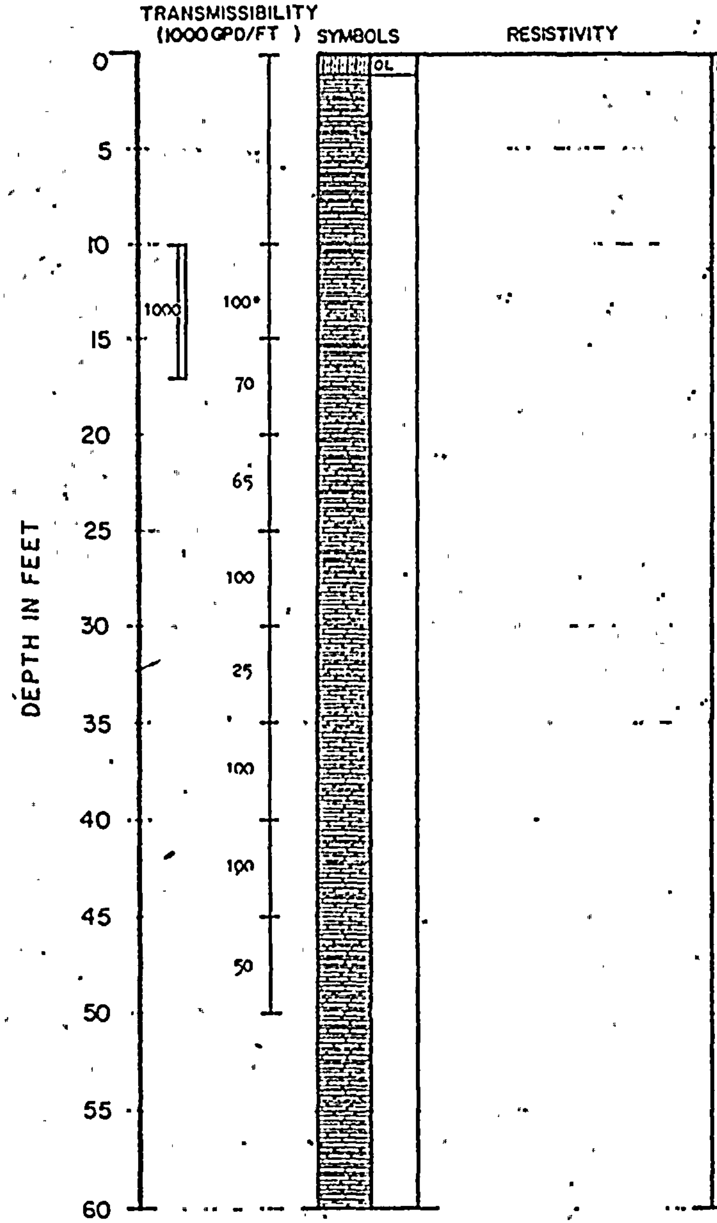
SOME SECONDARY CALCITE GRAINS.

BORING TERMINATED 6-4-71.

LOG OF BORINGS

BORING GH-15A

SURFACE ELEVATION: +1.5'±MSL



DESCRIPTION

MUCK — GRAY CLAYEY SILT WITH HIGH ORGANIC CONTENT.

MIAMI OOLITE (?) — WHITE OOLITIC LIMESTONE.

FT. THOMPSON LIMESTONE (?) — LIGHT GRAY TO TAN LIMESTONE WITH FILLED CAVITIES (SECONDARY CALCITE). SOME FOSSILS.

INCREASED FOSSILS.

DECREASED FOSSILS.

DECREASED SECONDARY CALCITE.

SOME FOSSILS. INCREASED SECONDARY CALCITE.

DECREASED FILLED CAVITIES.

GRADING INCREASED FILLED CAVITIES. (SECONDARY CALCITE).

GRADING TAN CALCARENITE.

GRAY FOSSILIFEROUS LIMESTONE.

TAN FOSSILIFEROUS CALCARENITE.

INCREASED FOSSILS.

TAN CALCARENITE.

INCREASED FOSSILS. SOME OOLITES.

CASING DRIVEN TO 60'.

*INDICATES CORE RECOVERY IN PERCENT.

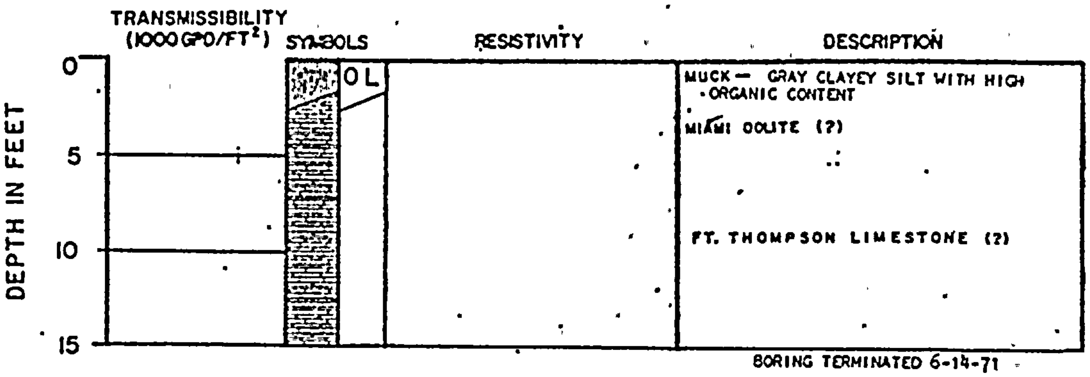
BORING TERMINATED 6-17-71.

LOG OF BORINGS

DAMES & MOORE

BORING GH-15B

SURFACE ELEVATION: +1.5'±MSL

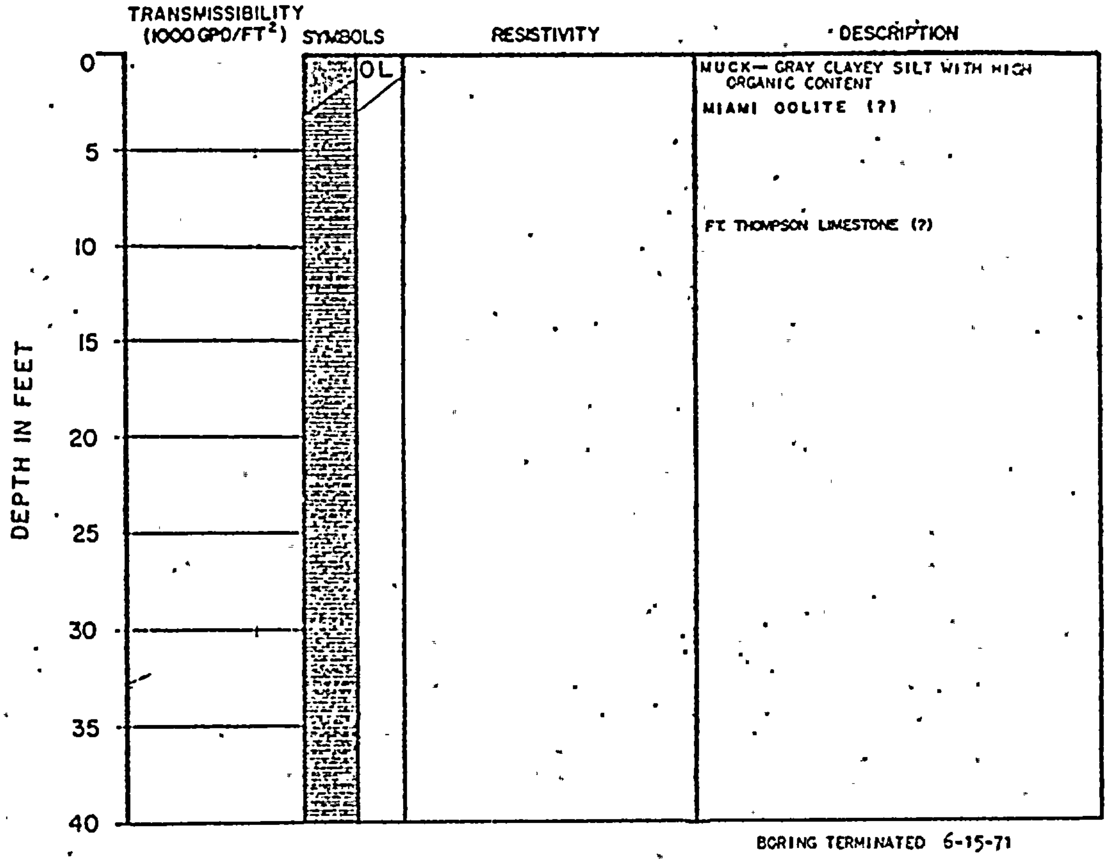


BORING TERMINATED 6-14-71

LOG OF BORINGS

BORING GH-15C

SURFACE ELEVATION: +1.5'±MSL



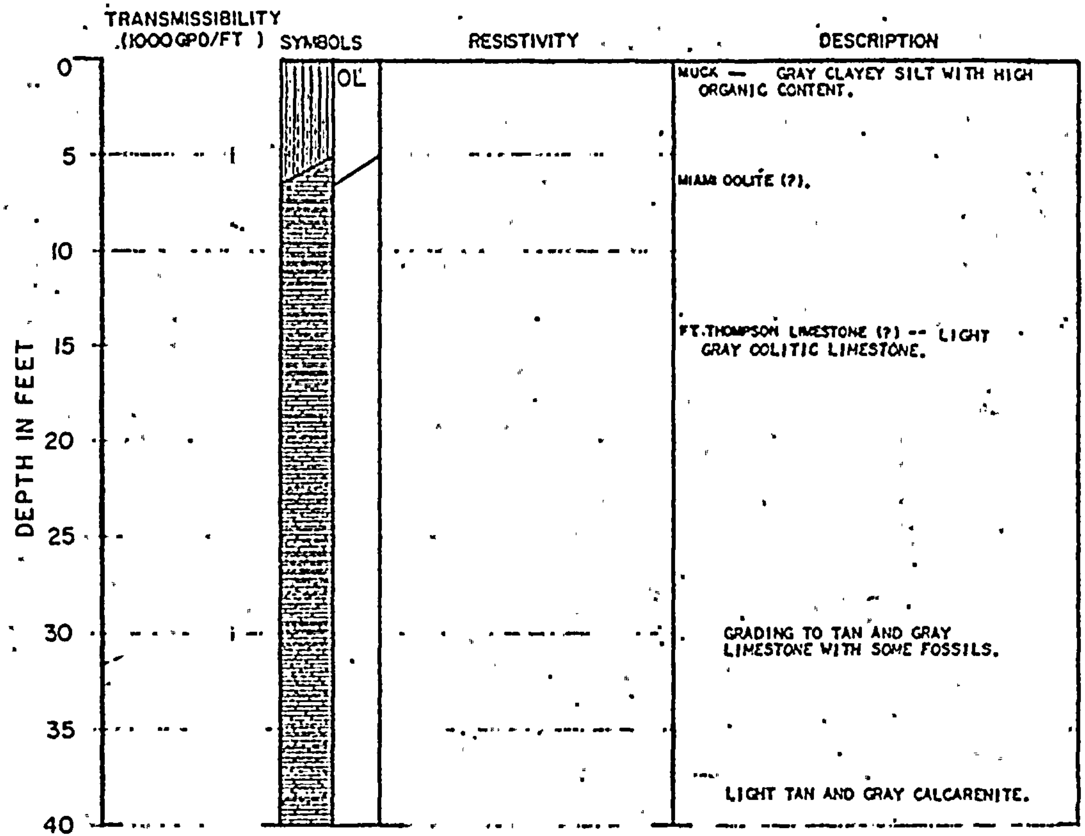
BORING TERMINATED 6-15-71

LOG OF BORINGS

DAMES & MOORE

BORING GH-16A

SURFACE ELEVATION: +1.4' MSL



MUCK — GRAY CLAYEY SILT WITH HIGH ORGANIC CONTENT.

MIAMI OOLITE (?).

FT. THOMPSON LIMESTONE (?) -- LIGHT GRAY OOLITIC LIMESTONE.

GRADING TO TAN AND GRAY LIMESTONE WITH SOME FOSSILS.

LIGHT TAN AND GRAY CALCARENITE.

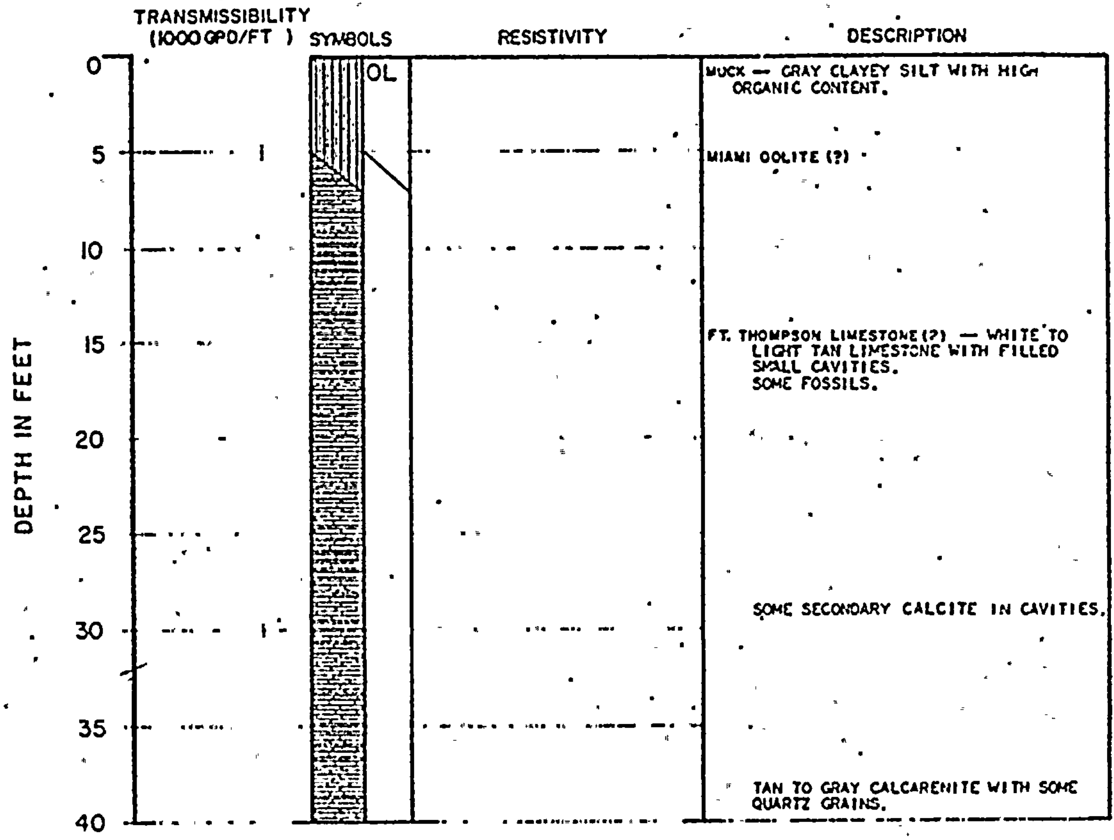
BORING TERMINATED 6-12-71.

LOG OF BORINGS

DAMES & MOORE

BORING GH-16B

SURFACE ELEVATION: +1.2' MSL



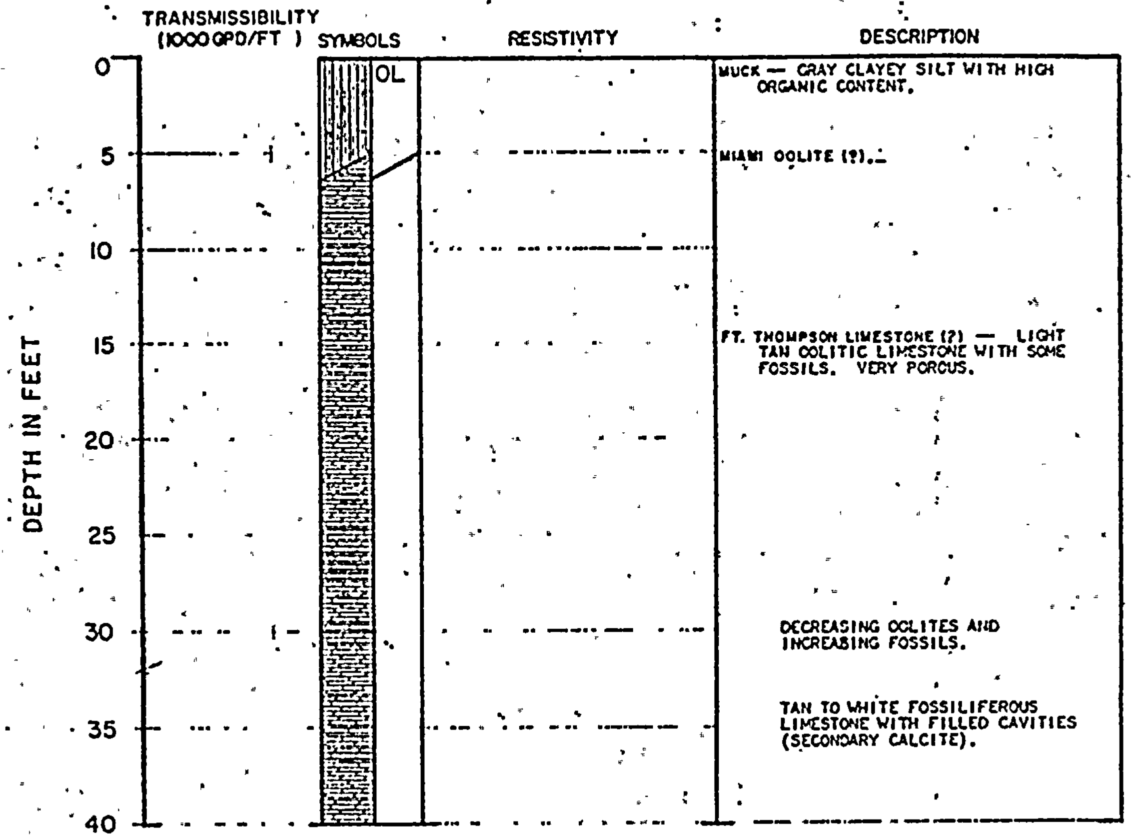
BORING TERMINATED 6-15-71.

LOG OF BORINGS

DAMES & MOORE

BORING GH-16C

SURFACE ELEVATION: +1.2' MSL



MUCK — GRAY CLAYEY SILT WITH HIGH ORGANIC CONTENT.

MIAMI OOLITE (?).

FT. THOMPSON LIMESTONE (?) — LIGHT TAN OOLITIC LIMESTONE WITH SOME FOSSILS. VERY POROUS.

DECREASING OOLITES AND INCREASING FOSSILS.

TAN TO WHITE FOSSILIFEROUS LIMESTONE WITH FILLED CAVITIES (SECONDARY CALCITE).

BORING TERMINATED 6-15-71.

LOG OF BORINGS

DAMES & MOORE

ADDENDUM REPORT
GEOHYDROLOGIC CONDITIONS
RELATED TO THE CONSTRUCTION OF COOLING PONDS
FLORIDA POWER & LIGHT COMPANY
STEAM GENERATING STATION
TURKEY POINT, FLORIDA
FOR BROWN & ROOT, INC.

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TELEX: 5-42611

August 31, 1971

Brown & Root
Post Office Box 3
Houston, Texas 77001

Attention: Mr. Carl L. Fick

Gentlemen:

We are pleased to submit herewith the requested Addendum to our report "Geohydrologic Conditions Related to the Construction of Cooling Ponds, Florida Power & Light Company Steam Generating Station, Turkey Point, Florida, for Brown & Root, Inc." dated July 23, 1971.

Our scope of work was outlined in a letter from Mr. William V. Storch of the Central and Southern Florida Flood Control District dated July 19, 1971. Additional quantitative analyses have been made as requested.

It has been a pleasure preparing this Addendum for you. Should you have any further questions concerning the Addendum or original report, please feel free to contact us.

Yours very truly,

DAMES & MOORE

Benjamin S. Persons

Leo M. Page
Leo M. Page

Porter P. Knowles
Porter-C. Knowles

BSP/LMP/PCK/ko

BENJAMIN S. PERSONS
No. 5754

ADDENDUM REPORT
GEOHYDROLOGIC CONDITIONS
RELATED TO THE CONSTRUCTION OF COOLING PONDS
FLORIDA POWER & LIGHT COMPANY
STEAM GENERATING STATION
TURKEY POINT, FLORIDA

FOR

BROWN & ROOT, INC.

INTRODUCTION

SCOPE

This addendum was prepared in response to a request from Mr. William V. Storch of the Central and Southern Flood Control District in his letter of July 19, 1971 for additional analyses to be made using the available geohydrologic data. The objectives of this addendum report were discussed further by Mr. Leo Page of Dames & Moore, and Mr. Storch.

The additional analyses consisted of:

1. Evaluation of the quantities of pumpage that would be required from the interceptor ditch to maintain specific water levels for various conditions of the ground water - surface water regime.
2. Evaluation of the flow patterns and the quantities of subsurface flow that would occur in an easterly direction from the L-31 Borrow Canal under natural conditions and with conditions subject to interceptor ditch control.
3. Evaluation of Muck-Miami Oolite sensitivity in the electric analog model and analog construction techniques.

FINDINGS AND CONCLUSIONS

On Table I is shown a summary of the pertinent data and the estimates of pumpage and/or seepage for the various conditions studied in detail. The artificial conditions with interceptor ditch control as shown on the attached Plates 1-4, are listed as A, B, B_1, B_2, C, D and E. Condition F represents a flow net of the natural condition of the ground water regime similar to that shown on Plate 4 of Dames & Moore report of July 23, 1971. From the requested electric analog conditions, detailed flow net evaluations were made on four of the analog models and are presented on Plates 5 & 6.

The maximum estimated rates of pumpage (30 gpm/lineal foot of ditch) shown on Table I for conditions B_2-1 and D-1 were based on analyses of conditions for the southerly portion of the proposed cooling pond where transmissibility values are highest. Using 30 gpm/lineal foot of ditch, the total pumpage for the 28,000 lineal feet of ditch adjacent to the L-31 Borrow Canal would be about 1800 cubic feet per second. Considering the effects of lower transmissibility, and the configuration of the proposed pond in the northerly portion of the area, it is probable that the total required pumpage would be less than this by several hundred cubic feet per second.

The estimated rates of instantaneous seepage from the L-31 Borrow Canal in an easterly direction range from about 1.5 to 5.4 gallons per minute per lineal foot of canal, affecting the phreatic surface between the Canal and Ditch. Under present conditions without a ditch, seepage of about 2.7 gpm/lineal foot of canal is estimated toward the salt water wedge. These estimates are based on the assumption that the bottom of the Borrow Canal is excavated some distance into the void zone. From the information available

on canal depth and elevation of the top of the void zone it appears that the Borrow Canal does not penetrate the void zone throughout the length of the Canal. Therefore, the estimated rates of seepage to the east are considered to be on the high side. However, under Ditch control, Levee 31 waters will not cross the hydraulic divide and flow into the interceptor ditch.

The limit of error of the quantitative calculations of pumpage from the interceptor ditch to maintain specific water levels for the various conditions is considered to be within 50 percent. If more accurate information is required it would be advisable to perform field tests on a portion of the L-31 Borrow Canal or on the existing interceptor ditch at the pilot pond.

ELECTRIC ANALOG CONSTRUCTION

Analyses of flow conditions near Levee 31 were made by utilizing electric analog techniques. The following construction evaluation is in response to specific technical questions that have been made.

Different graphite conduction paper physically representing layers of different permeabilities were connected with conductive silver paint. The painted connections between layers were generally at a spacing of 1/2 inch along layer boundaries. The success of this method of connection was concluded from a small test model after utilizing experimental connection distances under control conditions prior to construction of the full scale electric analog aquifer model. Conductivity of different papers were determined empirically.

The horizontal permeability of all three aquifer layers was constructed at nine times the vertical permeability. For construction of the analog model under this condition, it is only necessary to shrink the dimensions of a cross-section in the direction of greater permeability. If the average vertical permeability is expressed as k_v and the horizontal as k_h, the natural horizontal distances are multiplied by the square root

of k_v over k_h. The horizontal scale at one inch equal to fifty feet in the electric analog model, therefore, is one-third of the vertical scale of the model at one inch equal to sixteen and two-thirds feet.

In dealing with aquifer salinity and temperature gradients on the electric analog, it may be possible to model these parameters by treating the parameters in terms of equivalent fresh water head. This theoretical treatment, however, was not applied to the presented analog models in the report of 7/23/71 or this addendum. In view of the magnitude of operating head conditions, it is our opinion that this mathematical technique, imposed upon an already complex aquifer system, will have no significant change on the developed data, and could possibly imply a degree of accuracy inconsistent with the final quantitative values.

MUCK-MIAMI OOLITE LAYER SENSITIVITY

The muck layer overlying the site, averaging 3 feet in thickness, could possibly vary in the cooling pond area and influence predicted ground water flows. To test this possibility, the Muck-Miami Oolite layer was varied in the electric analog model by doubling the permeability and would effectively represent a 50% decrease in layer thickness.

Condition E on Plate 4 was performed with the Muck-Oolite layer permeability twice that of the layer analyzed for Condition A with Plate 1. Minor changes in equipotential lines can be seen. The hydraulic divide, nevertheless, has remained in the same relative position between L-31 and the ditch.

FRESH WATER DISCHARGE FROM LEVEE 31

A comparison has been requested between the average fresh water discharge east of Levee 31 under present conditions versus those of fresh water discharge occurring with the interceptor ditch and cooling pond in operation. Referring to Plate 1, Condition A and Plate 4, Condition F, it can be seen that fresh water would be discharging to the west and east of Levee 31. At present, fresher waters pressing eastward would meet the salt water wedge interface and build up head till eastern movement of the wedge occurred. As shown on Condition F, Plate 4, approximately 2.7 gpm per lineal foot of Levee 31 would build up against the salt water wedge as defined on Page 4 of the original report. Gradients and flows would vary under changing dynamic conditions of the wedge.

After installation of the proposed cooling pond and interceptor ditch, there will also be eastern and western movement of water from Levee 31. Levee 31 waters would build up behind the dynamic hydraulic divide, created from interceptor ditch pumping, similar to waters flowing to the west under present conditions. This rate of flow, however, would persist till equilibrium with the phreatic surface occurred, at which point, rates would drop to those required to replace evapotranspiration losses in the area. Flows from Levee 31 would not pass through the hydraulic divide to the interceptor ditch. In other words, the operation of the proposed cooling pond would result in similar effective utilization of proposed fresher ground waters from Levee 31.

It has been concluded that in the critical area between Levee 31 Borrow Canal and the interceptor ditch, some standing water might occur under anomalous surface conditions. Theoretically, however, no surface flow will occur between the Borrow Canal and the interceptor ditch due to the amount of head required to force ground water up through the muck layer above the phreatic surface.

CONDITION ANALYSIS

A summary table, Table I,of all the detailed conditions quantitatively analyzed is presented on the following page with the calculated net quantity of flow per foot of interceptor ditch.

It can be seen on Plate 1, that a hydraulic divide was not created for requested Condition B with water level in the interceptor ditch at -1.5 feet mean sea level. An attempt was made to create the divide utilizing -2.0 feet and -3.0 feet on Plate 2. A hydraulic divide was developed for the latter condition and it was this condition that has been utilized in quantitative analysis on Plate 5.

Plates 1 through 4 are the electric analog models showing equipotential lines for the requested condition. Flow lines have also been developed for your use in calculating velocities and discharges at applicable strategic points in Plates 5 & 6. The expanded scales on these plates were developed for permeability ratios of 1:20:1000:300 for the respective layers to aid in quantitative evaluations.

Although conditions occurring during the 1971 record drought have been considered, and from this standpoint the analyses can be considered to be conservative, values of permeability could have large variations between maximum and average values in the Biscayne aquifer formation. It should be clearly emphasized that, although the estimated pumping values should be used conservatively, final operating control of the proposed interceptor ditch will lie in an effective monitoring system of the area between Levee 31 Borrow Canal and the interceptor ditch. Effective use of this control system should prevent sea water intrusion to the west of Levee 31 by providing the location and movement of the hydraulic divide which, in turn, may require the adjustment of interceptor ditch pumping.

TABLE I

COOLING POND OPERATIONAL ESTIMATES

Condition	Elev. L31 Borrow Canal (ft.msl)	Elev. Interceptor Ditch (ft.msl)	Elev. Cooling Pond (ft.msl)	Dist. Between L-31 & Int. Ditch (ft.)	Flow Quantities Pumped from Ditch (gpm/lineal ft. of ditch)	Instantaneous Seepage from L-31 to East (gpm/lineal ft. of Levee 31)
A-1 (Plate 5)	+1.3	0.0	7.1	500	21	2.7
B_2-1 (Plate 5)	-0.5	-3.0	7.1	500	30	5.4
C-1 (Plate 6)	+1.3	0.0	7.1	1000	21	1.5
D_1-1* (Plate 6)	-0.5	-3.0	7.1	1000	30	3.0
F (Plate 4)	+1.3	+1.2	-	500	-	2.7

*. Modified Condition - Interceptor Ditch Elevation -3.0 feet.

ERRATA

Corrections of the July 23, 1971 report that should be brought to your attention are: a typing duplication of the top three lines on Page 9, and Boring GH-2 transmissibility of Plate 4 between 20 and 30 feet should read 600,000 rather than 6 million. Transmissibility data was omitted from Log of Borings, GH-2, Plate 20 and should be as shown on Plate 4.

The following plates are attached and complete this addendum:

Plate 1 - Electric Analog Model, Condition A & B
Plate 2 - Electric Analog Model, Condition B_1 & B_2
Plate 3 - Electric Analog Model, Condition C & D
Plate 4 - Electric Analog Model, Condition E
Equipotential & Flow Lines Condition F
Plate 5 - Equipotential & Flow Lines - A-1 & B_2-1
Plate 6 - Equipotential & Flow Lines - C-1 & D_1-1

Respectfully submitted,

DAMES & MOORE

Benjamin S. Persons

Leo M. Page

Leo M. Page

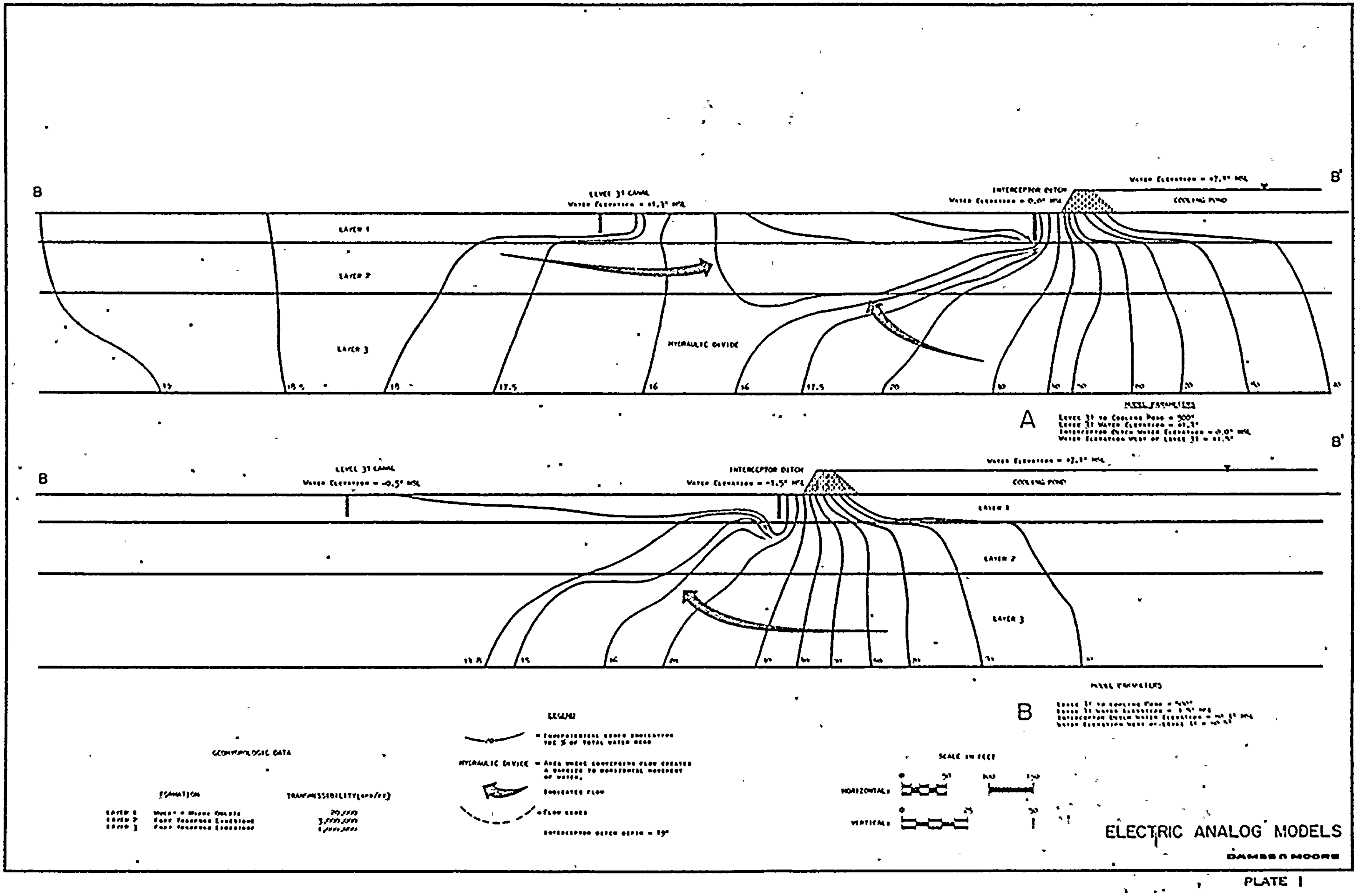
Porter C. Knowles

Porter-C. Knowles

BENJAMIN S. PERSONS
CERTIFICATE
No. 5754
STATE OF
FLORIDA
REGISTERED ENGINEER

BSP/LMP/PCK/mw.

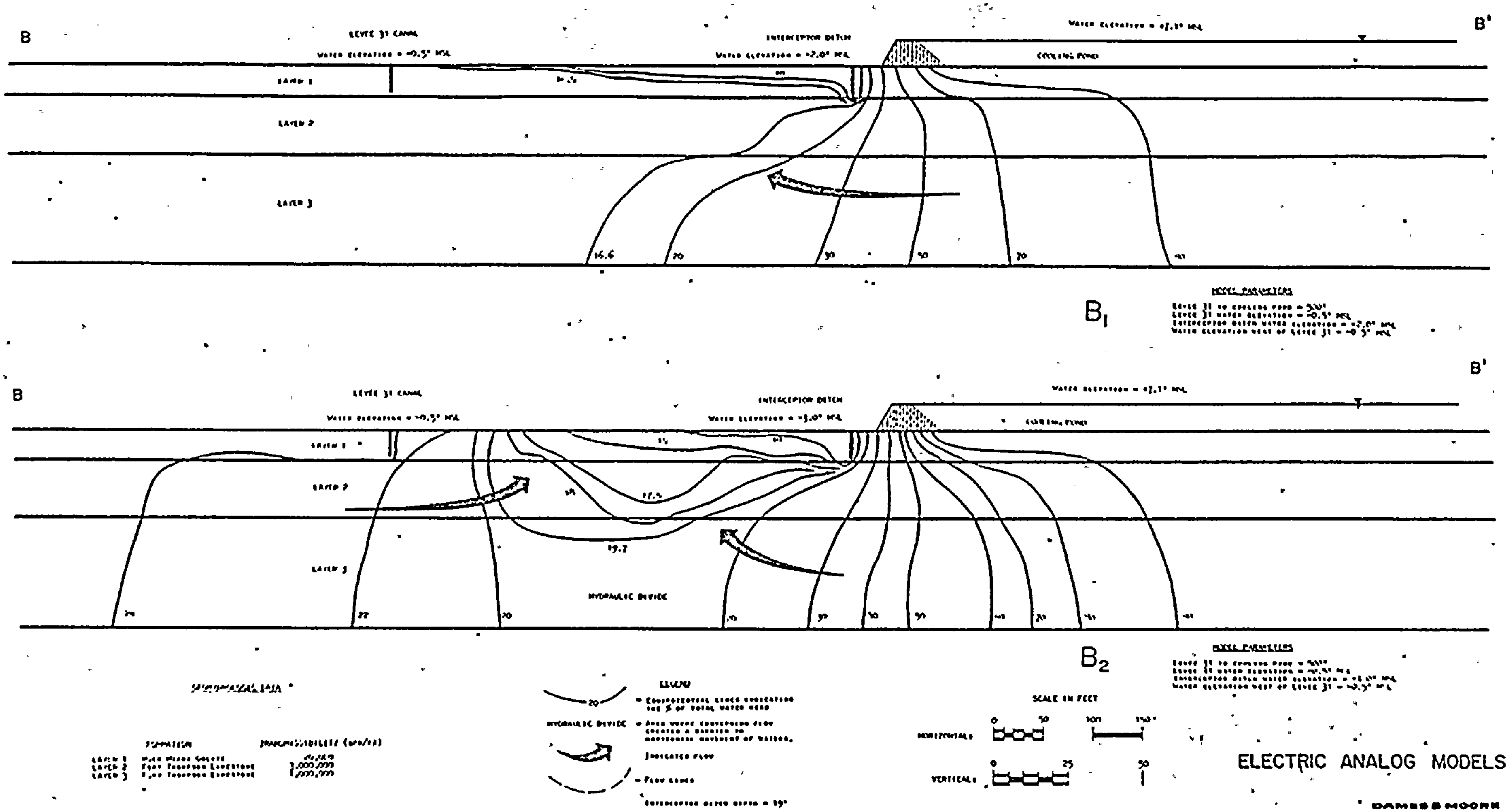
Attachments



ELECTRIC ANALOG MODELS

DAMES & MOORE

PLATE I



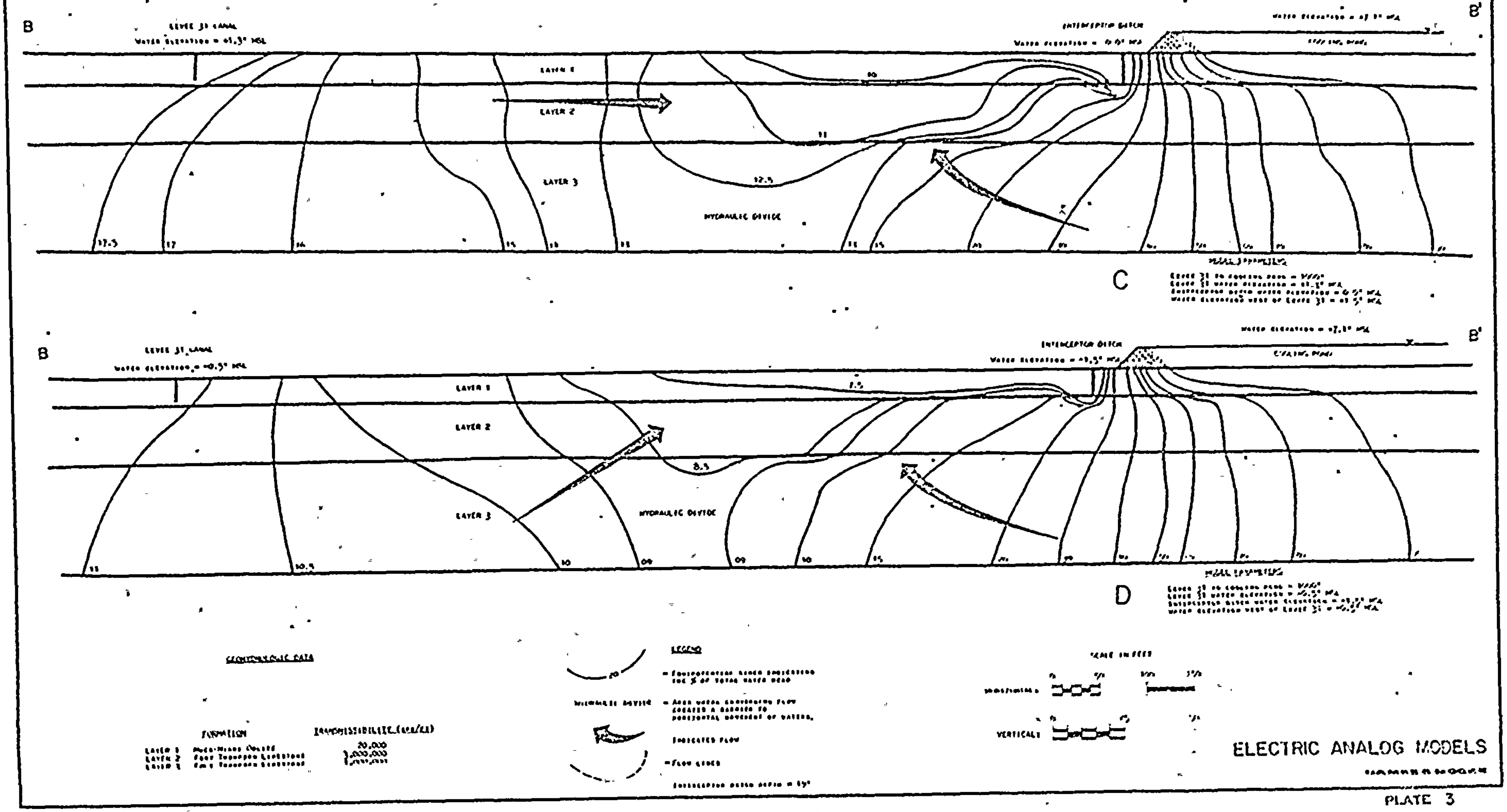
HYDROGEOLOGIC DATA

FORMATION		TRANSMISSIBILITY (GPD/FT)
LAYER 1	MIAMI OOLITE	40,000
LAYER 2	FORT THOMPSON LIMESTONE	3,000,000
LAYER 3	FORT THOMPSON LIMESTONE	1,000,000

ELECTRIC ANALOG MODELS

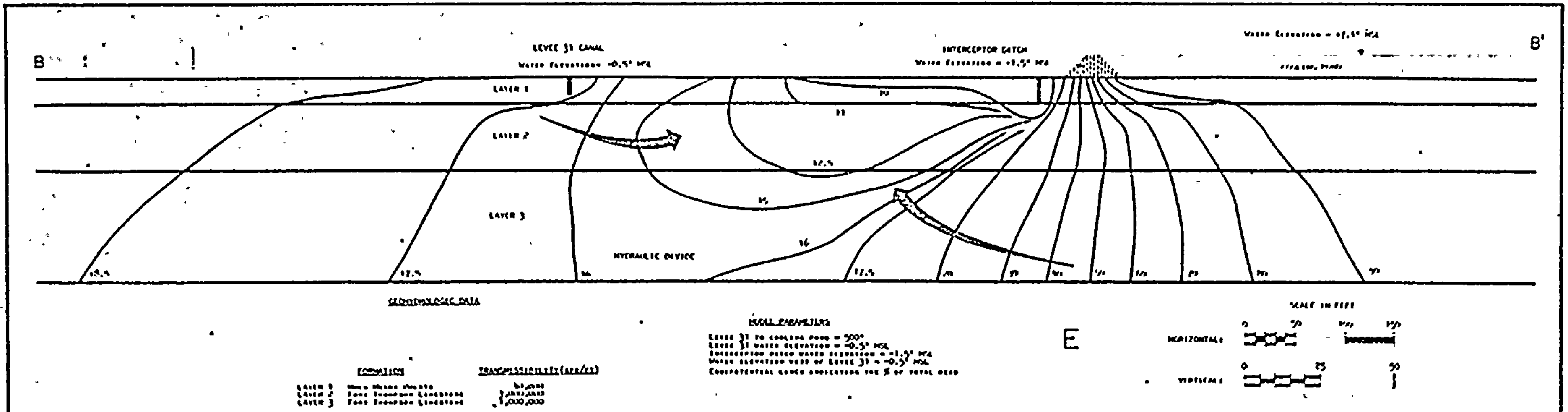
DAMES & MOORE

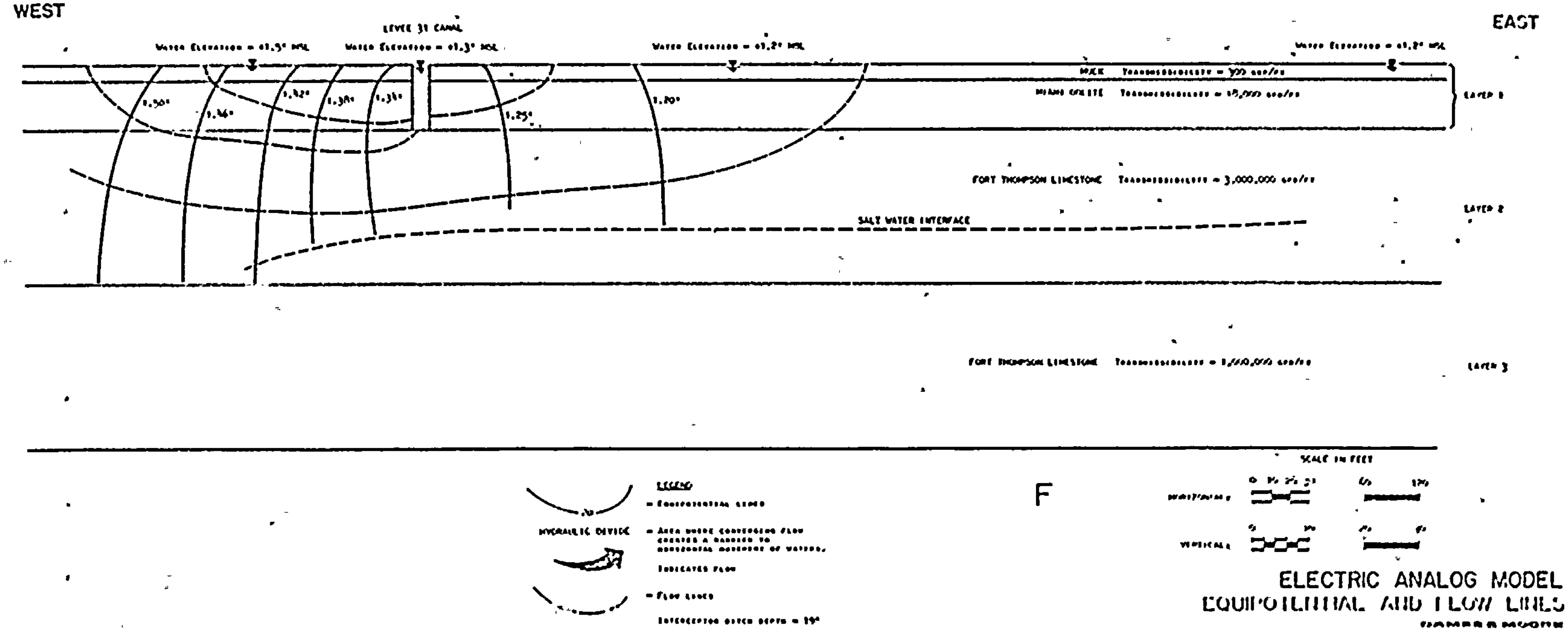
PLATE 2



ELECTRIC ANALOG MODELS

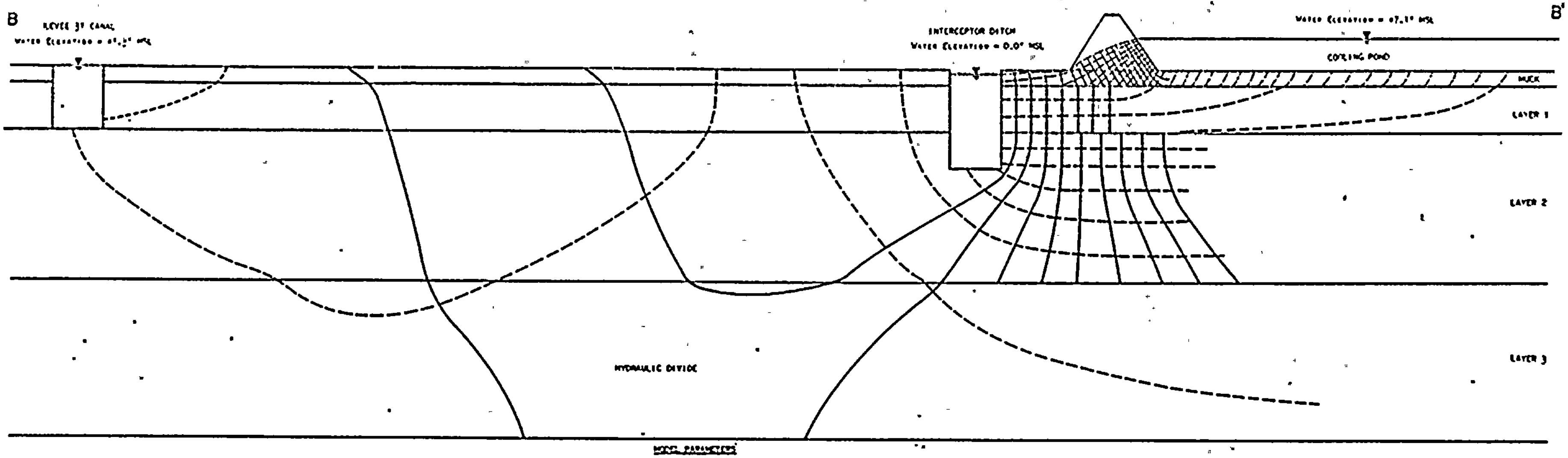
PLATE 3





ELECTRIC ANALOG MODEL EQUIPOTENTIAL AND FLOW LINES

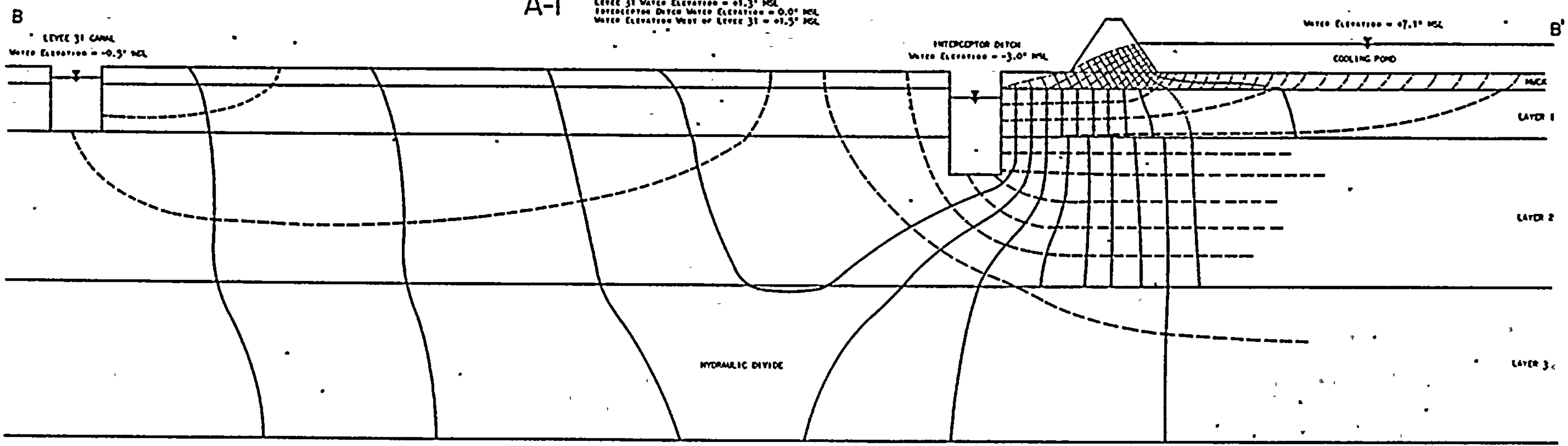
PLATE 4



A-1

MODEL PARAMETERS

Levee 31 to Cooling Pond = 500'
Levee 31 Water Elevation = +1.3' MSL
Interceptor Ditch Water Elevation = 0.0' MSL
Water Elevation West of Levee 31 = +1.5' MSL



GEOHYDROLOGIC DATA

FORMATION	TRANSMISSIBILITY (gpd/ft)
MUCK	300
LAYER 1 Miami Oolite	18,000
LAYER 2 Fort Thompson Limestone	3,000,000
LAYER 3 Fort Thompson Limestone	1,000,000

LEGEND

20 = Equipotential lines indicating the % of total water head

HYDRAULIC DIVIDE = Area where converging flow creates a barrier to horizontal movement of waters.

= Flow lines

Interceptor ditch depth = 19'

B₂-I

MODEL PARAMETERS

Levee 31 to Cooling Pond = 500'
Levee 31 Water Elevation = -0.5' MSL
Interceptor Ditch Water Elevation = -3.0' MSL
Water Elevation West of Levee 31 = -0.5' MSL

SCALE IN FEET

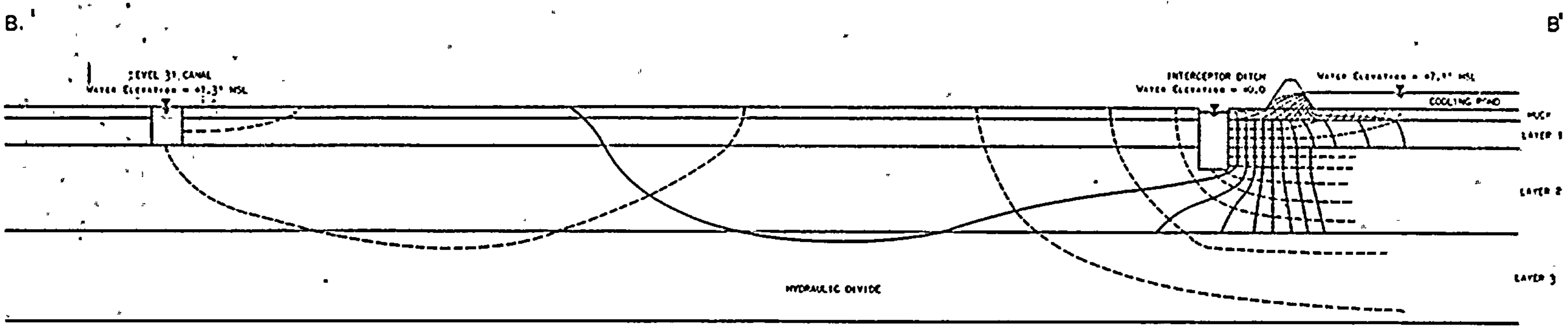
HORIZONTAL: 0 10 20 30 60 90

VERTICAL: 10 20 30

EQUIPOTENTIAL AND FLOW LINES

DAMES & MOORE

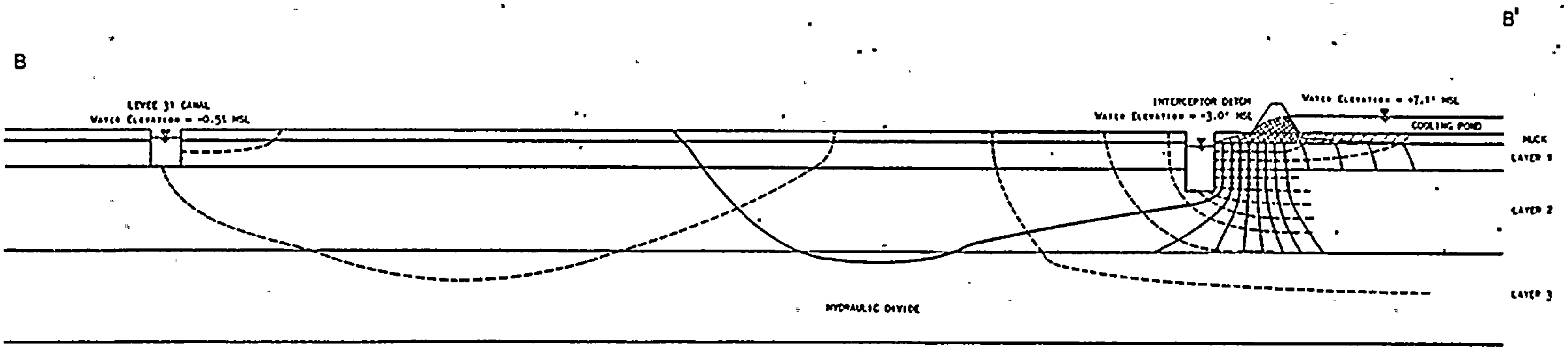
PLATE 5



C-1

MODEL PARAMETERS

Levee 31 to Cooling Pond = 1000'
Levee 31 Water Elevation = +1.5' MSL
Interceptor Ditch Water Elevation = 0.0' MSL
Water Elevation West of Levee 31 = +1.5' MSL



D_1-1

MODEL PARAMETERS

Levee 31 to Cooling Pond = 1000'
Levee 31 Water Elevation = -0.5' MSL
Interceptor Ditch Water Elevation = -3.0' MSL
Water Elevation West of Levee 31 = -0.5' MSL

LEGEND

20 = Equipotential lines indicating the % of total water head

HYDRAULIC DIVIDE = Area where converging flow created a barrier to horizontal movement of water.

= Flow lines

Interceptor ditch depth = 19'

SCALE IN FEET

HORIZONTAL 0 20 40 60 120 150

VERTICAL 0 10 20 40 60

GEOHYDROLOGIC DATA

FORMATION	TRANSMISSIBILITY (gpd/ft)
MUCK	300
LAYER 1 Miami Oolite	18,000
LAYER 2 Fort Thompson Limestone	3,000,000
LAYER 3 Fort Thompson Limestone	3,000,000

EQUIPOTENTIAL AND FLOW LINES

DAMES & MOORE

PLATE 6

AFFIDAVIT

STATE OF FLORIDA

COUNTY OF DADE

Personally appeared before me the undersigned authority, James B. Lackey, who being by me first duly cautioned and sworn, deposes and says:

My name is James B. Lackey. I live at Melrose, Florida. I have a PhD from Columbia University in Protozoology, with graduate work also in Algology. I have spent some 12 summers at Woods Hole, Massachusetts, at the two oceanographic institutions there, one at the marine laboratory of the University of Rhode Island, and two at Scripps Institution of Oceanography at LaJolla, California. Other marine research has been on Guanabara Bay, Rio de Janeiro (for the State of Guanabara), San Francisco Bay for the University of California, Logy Bay for the Memorial University of Newfoundland, and a summer at Plymouth, England, at the marine laboratory there.

I was the first aquatic biologist the TVA ever had, have taught in colleges, and was for about ten years Senior Biologist, U.S.P.H.S. at the Stream Pollution

Investigations Station, Cincinnati, Ohio. Now I am retired with emeritus status from the University of Florida, and am a consultant for various industries, cities and states. I am a partner in Water and Air Research, Inc. of Gainesville, Florida.

I have published more than 125 papers and chapters in several books. I belong to several societies including Sigma Xi, and am a member of the Aquatic Life Advisory Committee for the Ohio River Valley Water Sanitary Commission, and have been on the Office of Economic Corporation Development delegation from the United States.

PROPOSED TURKEY POINT POWER PLANT COOLING WATER SYSTEM

Based on my long study at the Turkey Point Power Plant, I do not consider that any significant damage has occurred at up to 95°F, or that any significant damage will occur at 95°F which is the maximum temperature at which the interim system proposed will discharge water into Biscayne Bay and Card Sound.

I consider that this temperature will cause an absolute minimum, if any, damage, and under no circumstances will it be irreparable.

As to the subject of entrainment of microorganisms in the plant system, my studies at Turkey Point have produced no evidence that the effects of the plant are detectable on

the phytoplankton and zooplankton of the Bay. Neither standing crop nor species list are affected.

These studies show no effect of entrainment other than a slight reduction at times of the microscopic algae and protozoa going through the plant. Numbers entering the plant are generally small and sometimes more living ones on the effluent side than on the influent side.

Even if these studies have shown some death rate on zooplankton because of entrainment, the simple fact remains that the net effect on the Bay is undetectable, principally because in my judgment the replacement potential of these waters is so great as to provide quick repopulation.

I can, therefore, easily forecast that the cooling water system plan for this plant in this decree will produce no net effect on the microorganism population of waters involved.

These are forecasts after careful examination of the interim and ultimate cooling water systems, contained in the proposed Turkey Point Power Plant consent decree before this court.

James B. Lackey
James B. Lackey

Subscribed and sworn to
before me this 2nd day
of September 1971.

Notary Public, State of Florida at Large
My Commission Expires July 13, 1973
Bonded by American Fire & Casualty Co.

AFFIDAVIT

Drs. Bader, Roessler, Voss and de Sylva came before me on this 8th day of September, 1971 and affirmed the following:

This statement prepared by Drs. R. G. Bader and M. A. Roessler, G. L. Voss and D. P. de Sylva of the Rosenstiel School of Marine and Atmospheric Sciences has been read and agreed to by the Principal Investigators of the thermal addition studies, Drs. T. Lee, M. Reeve, D. Segar, D. Tabb and A. Thorhaug.

I, Richard G. Bader am a Professor and the Associate Dean of the Rosenstiel School of Marine and Atmospheric Sciences. I received my B. S. Degree from the University of Maine and S.B., M.S. and Ph.D. Degrees from the University of Chicago. I have been an active scientist in the field of marine geochemistry since 1950 and have worked in the Miami area since 1967. I have been the principal investigator and coordinator of the programs of the Rosenstiel School of Marine and Atmospheric Sciences concerning the effects of thermal additions on the ecology of Southern Biscayne Bay and Card Sound since July, 1968.

I, Martin Roessler, am an Assistant Professor at the Rosenstiel School of Marine and Atmospheric Sciences of the University of Miami. I am employed in the division of Fisheries and Applied Estuarine Ecology. I received my education at the University of Miami and received the degree of Doctor of Philosophy in Marine Sciences in 1967. I have been actively engaged in research on the ecology of the Everglades Estuary and/or Biscayne Bay since 1960. Since June 1968, my research has been aimed at the study of the effects of thermal additions on the fishes and benthic invertebrates of the Turkey Point and I have acted as coordinator with Dr. R. G. Bader on the School's program sponsored by the United States Atomic Energy Commission, Environmental Protection Agency, National Science Foundation,

National Oceanic and Atmospheric Agency (Sea Grant) and Florida Power and Light Company on the ecology of Southern Biscayne Bay and Card Sound.

I, Gilbert L. Voss am a Professor and Chairman of the Division of Marine Biology at the Rosenstiel School of Marine and Atmospheric Sciences. I received my B. S. and M. S. Degrees from the University of Miami and my Ph.D. Degree from George Washington University. I have been active in research on the ecology of the South Florida area for 15 years. I have conducted studies in Biscayne Bay with regard to the Biscayne National Monument and ecological surveys of the upper Keys region.

I, Donald P. de Sylva am an Associate Professor of Marine Biology at the Rosenstiel School of Marine and Atmospheric Sciences. I received my B. S. Degree from Cornell University, my M. S. Degree from the University of Miami and my Ph.D. Degree from Cornell University. I have been actively engaged in the study of sports fisheries and fish larvae in Biscayne Bay for the past 10 years.

After briefly examining an abbreviated copy of the Turkey Point Cooling Water Plan, we have concluded that the plan represents a workable compromise to the problem of environmental protection and the need for power.

As stated above, Drs. Bader and Roessler have coordinated and participated in an extensive (3-1/2 years) program which has studied the ecology of South Biscayne Bay and Card Sound, Florida and Drs. Voss and de Sylva have been active in research in the area for more than 10 years. The results of this program, sponsored by the United States Atomic Energy Commission, Environmental Protection Agency, National Science Foundation, National Oceanic and Atmospheric Agency (Sea Grant) and Florida Power and Light Company have recently been summarized in a report to the United States Atomic Energy Commission (AT[40-1]-3801-3). The work has considered circulations studies, chemistry studies and biological studies.

The existing power plant has caused changes in the circulation pattern, in the chemistry of the bay water and in the distribution of plants and animals in an area of about 300 acres. Many of these changes have been detrimental to the quality of the environment.

The thermal plume into Card Sound proposed by Florida Power and Light Company should resemble the plume now being discharged into South Biscayne Bay at a rate of 2800 ft.^{3}/sec. This estimated Card Sound plume is shown in the attached Figure A.

From the biologists estimates the 3°C (5.4°F) thermal anomaly should not cause lasting death of plant communities. However, the effect of a 2750 ft.^{3}/sec. discharge may reduce the direct oceanic input into Card Sound, thereby, isolating Little Card Sound and Barnes Sound from exchange with the ocean. If the engineering is feasible, it may be better from a water exchange viewpoint to discharge 2750 ft.^{3}/sec. into South Biscayne Bay and 1500 ft.^{3}/sec. into Card Sound.

Our biological field observations which consist of diving and counting algae and sea grasses in permanently marked squares at selected stations and trawling at 20 to 40 stations with a ten foot otter trawl lined with fine mesh (1/4" bar) have been conducted since July, 1968, and are continuing. Stations have been concentrated around the present discharge site near Turkey Point and at the planned discharge site in Card Sound, although control stations have also been maintained elsewhere in the region.

Our observations indicated that areas which average 4.5°F above the ambient bay temperature (as measured on Pelican Bank) have reduced standing stock of benthic plants and animals during the summer months in an area of about 200 acres; however, in other seasons the production of the normal biota is enhanced by the higher winter temperature and the result is that on an annual basis no decrease in production occurred. At stations which averaged 6.3°F above the ambient temperature the plants and animals were severely depleted during the summer months

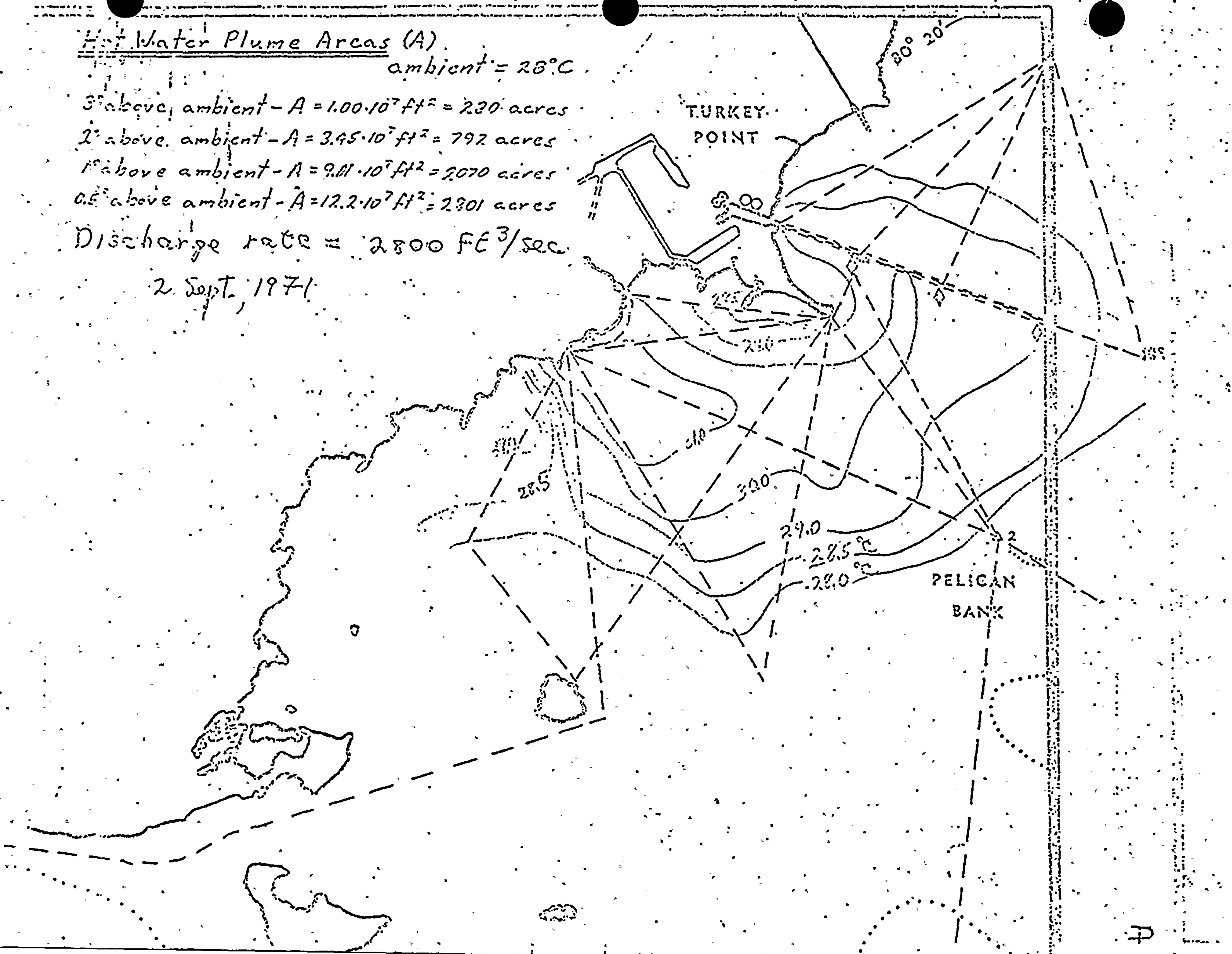
in an area of about 75 acres. Some recovery is noted in winter and early spring but the net effect is lowered annual production.. The recovery in winter does; however, indicate that if the discharge were terminated this 75 acre area would recover.

For example with an average ambient bay temperature in summer of about 89 to 90°F the addition of the temperature anomaly would develop temperatures of 95 to 96°F. Although 95°F is biologically detrimental, it appears that if the macrobenthic flora and fauna in Card Sound which is similar to that in Biscayne Bay is exposed to no more than 95°C it will recover after the discharge is curtailed.

We have observed that in an area of about 30 acres elevated 8.1°F or to an average summer temperature of 98°F, there is virtually no recovery in winter. The high temperature effects added to the increased current velocity at the outfall has caused a barren area and this area will probably only recover slowly if it recovers at all.

The proposed values of temperature and flow rate for the interim period are very close to those which appear as critical for permanent damage and every precaution should be taken to insure that a temperature of 95°F and a discharge of 2750 cfs in Card Sound and 1500 cfs in Biscayne Bay are not exceeded.

The discharge temperature of 90°F and flow of 1200 cfs recommended after construction of the cooling system will still produce some change in the Card Sound Environment but the impact of these changes on the use of the Sound by sport and commercial fishermen as well as recreational users should be minimal.



Hot Water Plume Areas (A)

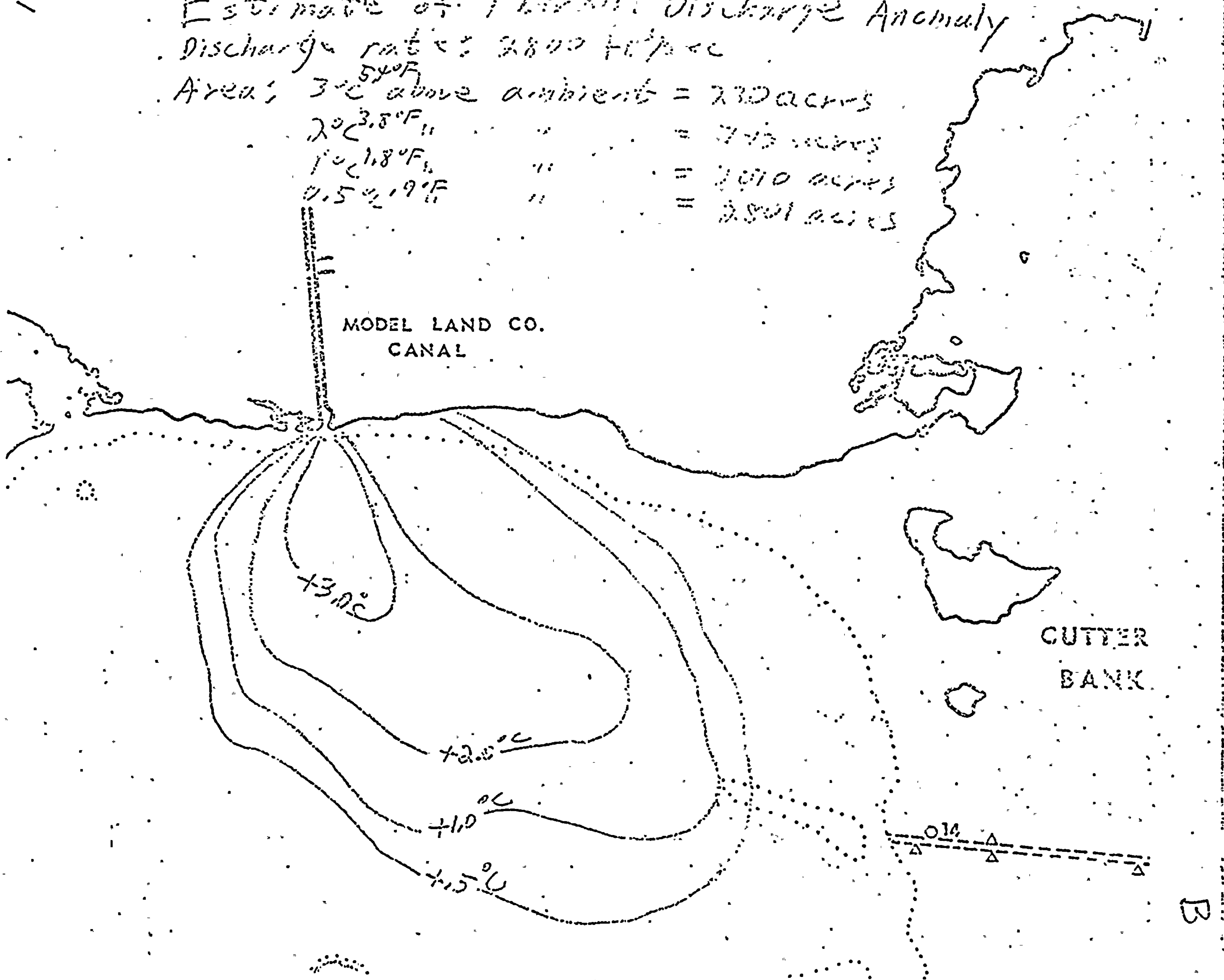
ambient = 28°C

3° above ambient - A = 1.00·10^7 ft^2 = 230 acres
2° above ambient - A = 3.45·10^7 ft^2 = 792 acres
1° above ambient - A = 9.01·10^7 ft^2 = 2070 acres
0.5° above ambient - A = 12.2·10^7 ft^2 = 2801 acres

Discharge rate = 2800 Ft^3/sec

2 Sept, 1971

Estimate of Thermal Discharge Anomaly
Discharge rate: 2800 ft³/sec
Area; 3°C 5.4°F above ambient = 230 acres
2°C 3.8°F " " = 775 acres
1°C 1.8°F " " = 1010 acres
0.5°C .9°F " " = 2501 acres



B

Richard G. Bader

Richard G. Bader

Martin Roessler

Martin Roessler

Donald P. de Sylva

Donald P. de Sylva

Gilbert L. Voss

Gilbert L. Voss

Sworn to and subscribed before me this 8th day of September

A.D. 1971.

Dorothy Blum

Notary Public

My Commission expires

NOTARY PUBLIC, STATE OF FLORIDA AT LARGE
MY COMMISSION EXPIRES FEB 22, 1974
BONDED THRU FRED W. DIESTELHORST

ROSENSTIEL SCHOOL OF MARINE AND ATMOSPHERIC SCIENCE

UNIVERSITY OF MIAMI

Rickenbacker Causeway

Miami, Florida 33149

Title:

AN ECOLOGICAL STUDY OF SOUTH BISCAYNE BAY AND CARD SOUND

Principal Investigators

R. G. Bader and M. A. Roessler

Progress Report to U.S. Atomic Energy Commission (AT (40-1) - 3801 - 3)
and Florida Power & Light Company

ML 71066 July, 1971

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I. INTRODUCTION

This report concerns a quantitative study of the ecology of South Biscayne Bay and Card Sound, Florida, with particular attention to the areas adjacent to Turkey Point and the mouth of the Model Land Company Canal. The Turkey Point program, begun in 1968, has continued and a study of the existing and relatively unspoiled biological situation of Card Sound has been conducted over the past year. This included an investigation on hydrography, chemistry, vegetation, planktonic and benthic organisms. The biology of the organisms has been considered in relation to temperature, radioactivity, salinity ranges and selected chemical characteristics. The effect of higher temperatures on the dominant and sub-dominant species has also been studied both in the laboratory and in the field.

Additional studies sponsored in part by the Environmental Protection Agency, National Science Foundation, National Oceanic and Atmospheric Administration (Sea Grant), and National Institute of Health have provided data supplementary to that obtained in the Atomic Energy Commission and Florida Power and Light Company study.

Biscayne Bay is apporximately 35 miles long and its maximum width is 8 miles (see Figure I-1). The bay is "A"-shaped, enclosed to the east by a series of barrier islands which extend north and south, leaving a shoal area (known as the "Safety Valve") open in the center. The greatest depths of 12 ft. occur in the south central area, shoaling toward the mainland and the barrier islands. The mainland side of the south bay is fringed by mangrove swamps and soft organic sediments. The southern boundary of the northern portion of the bay may be defined as Rickenbacker Causeway, which runs eastward across Virginia Key (location of the School of Marine and Atmospheric Sciences of the University of Miami) to Key Biscayne. The central portion of the bay is separated from the south by Featherbed Bank. Turkey Point is a narrow spit of land projecting from the mainland into the bay about halfway between Featherbed Bank and the south end of the bay, which is separated from Card Sound by a shallow bank (Cutter Spoil Bank) and the Arsenicker Keys. Figure I-2 shows the sampling stations in the vicinity of Turkey Point.

Card Sound is a small bay approximately five miles long and three miles wide. It is bordered on the north by shallow grass flats extending from Mangrove Point on the west to Long Arsenicker Key and between East Arsenicker Key and the Florida Keys. Figure I-3 shows the sampling stations in Card Sound.

National attention has been brought to bear on this site by the 1970 Federal hearings and injection procedures on thermal effects of Florida Power and Light Company's Turkey Point power plant. The Florida Power and Light Company announced, on June 1969, that it was seeking the permits and access necessary to alter the site of their cooling water discharge from its present

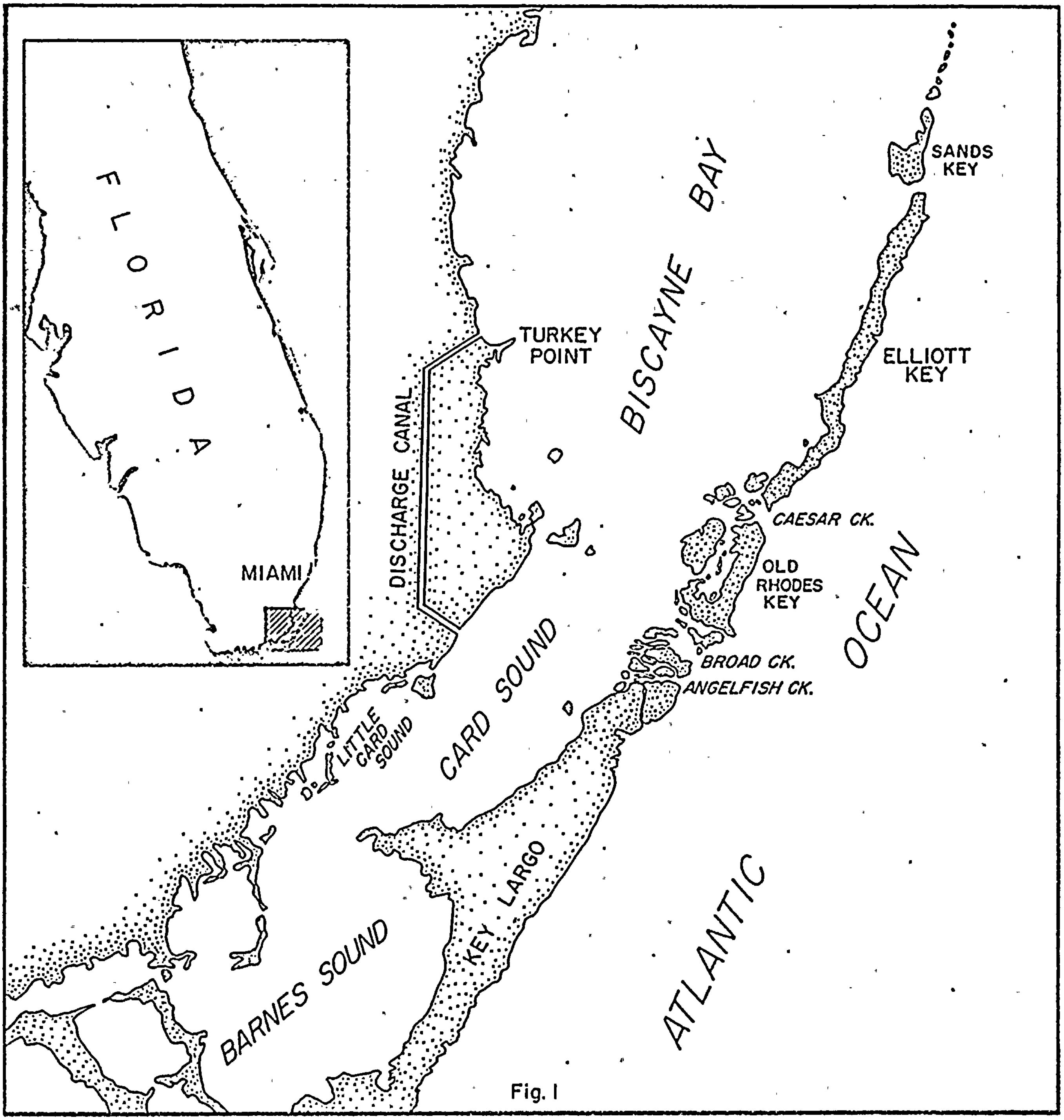

FIGURE I-1 Map of Florida showing location of study area.

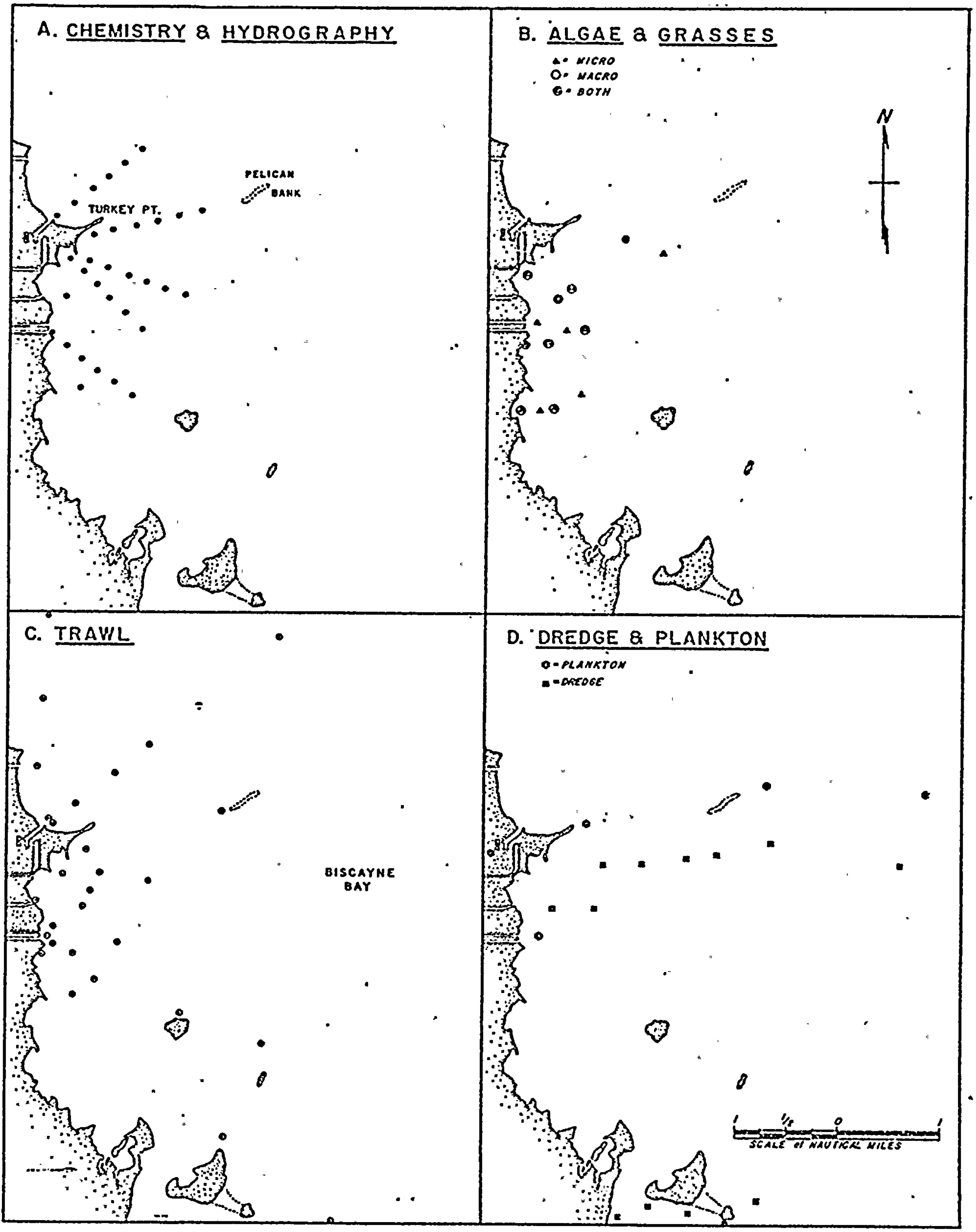

FIGURE I-2 Map of Biscayne Bay with a) chemistry stations, b) algae stations, c) trawl stations and d) plankton and dredge stations.

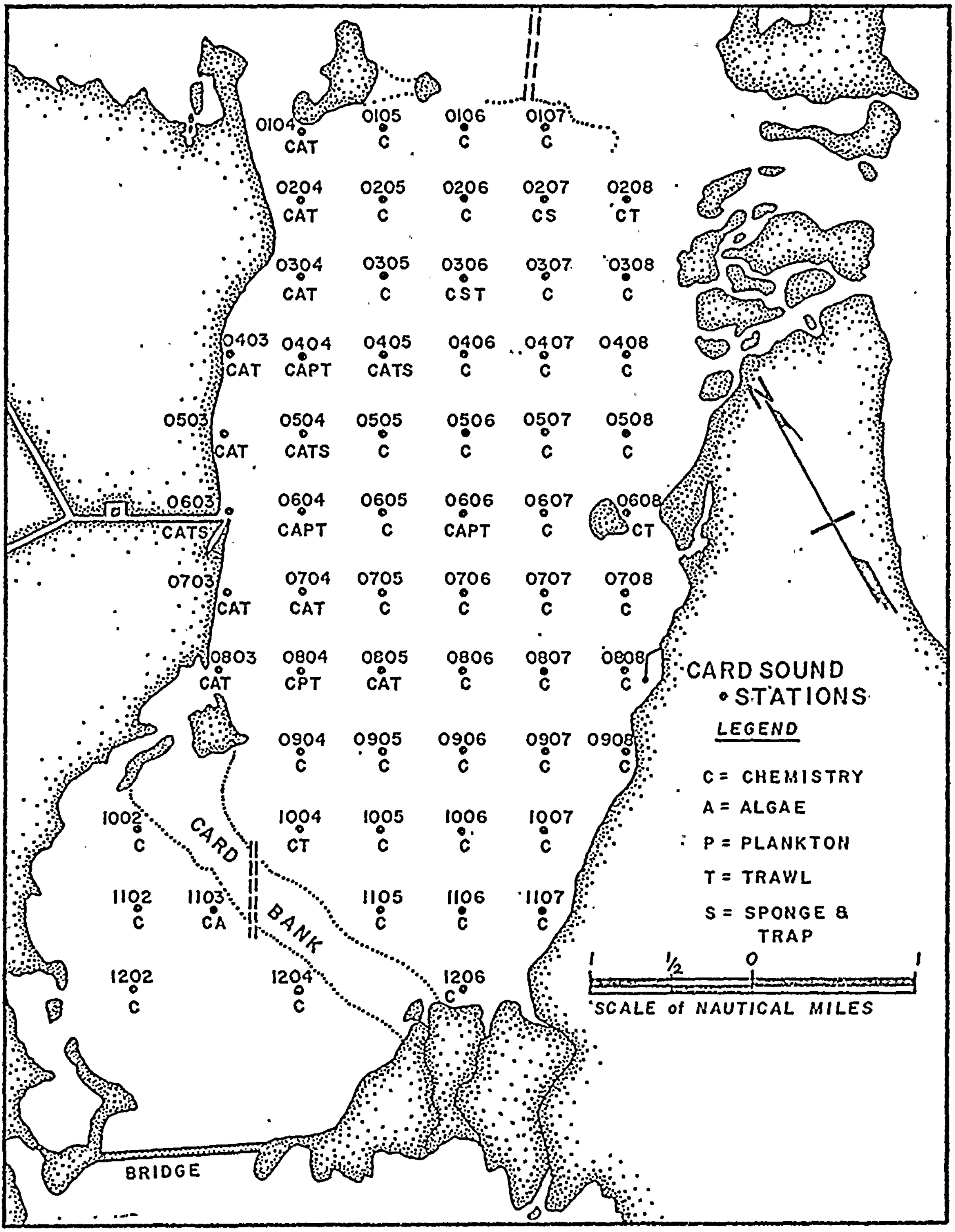

FIGURE I-3 Maps of Card Sound showing locations of sampling stations.

location, one mile south of the Turkey Point power generating plant. They proposed a canal from the existing Grand Canal six miles southward, and to discharge through the Model Land Company Canal into Card Sound. When complete, the proposed system would divert about 4,250 cu. ft. per second from the present Barge Canal. This water would pass through the plant, and the effluent temperature would be approximately 15°F above the intake temperature.

Dilution rates between 100 and 200 percent have been proposed to cool the effluent. The 100% dilution will reduce Δt temperatures by one half and the 200% dilution will reduce this by one third. An additional 1°F cooling will occur along the discharge canal and will insure that outfall temperatures entering Card Sound will not exceed 95°F. Other methods, such as cooling ponds and a canal pond system, have also been considered. The large volumes of water being used in cooling and dilution may present serious problems to the phytoplankton and zooplankton as well as to the fishes and invertebrates which may be subjected to mechanical and thermal damage in the plant or in the cooling canal.

This progress report is divided into 13 chapters which has permitted detailed discussions by individual investigators. This method may seem to produce an artificial separation of the ecosystem, however, this first step is our essential part in developing a model of South Biscayne Bay and Card Sound. In order to more effectively evaluate the existing model, more information is needed, for example, on the effects of meterological phenomena on flushing, the possibility of excessive chemical residence times and the trophodynamics of the entire ecosystem. Once this is accomplished, hopefully, the model will be applicable throughout the tropical areas of the world.

II. CIRCULATION*

GENERAL STATEMENT

The objectives of this study, as stated in the proposal, are to determine: (1) existing circulation patterns in Card Sound as a function of tide and wind forces; (2) exchange characteristics of Card Sound with surrounding water; (3) resident time and flushing rate; (4) spatial and temporal patterns of water mass properties; (5) future alterations of flow patterns and water level with the planned discharge of thermal effluent into Card Sound.

A review of the available literature shows that very little information is available as to the circulation of Card Sound Basin; however, a first look at the basin suggests that the circulation is driven by tidal forces. An Atomic Energy Commission safety analysis report (1966) made for Florida Power and Light Corporation concluded that currents in the Biscayne Bay, Card Sound System, are completely tidally driven. Using a mean tidal range of 2.6 ft., the tidal prism for Card Sound was calculated to be 2.02×10^9 ft^3 and a ratio for the mean low water volume to the tidal prism volume of 2.6/1. Thus, the basin was considered to be well flushed in 32 tidal cycles or 16 days. Schneider (1969) evaluated a year of data from 10 tide gauges positioned in the Atlantic Ocean, Biscayne Bay, Card Sound, and Barnes Sound. He found that the predominate semidiurnal lunar tide progressed south through Biscayne Bay, Card Sound and into Barnes Sound with a decreasing amplitude and increasing lag due to frictional dampening by the various shoals. He calculated a mean tidal range for Card Sound of 0.74 ft. Using the values for area and mean depth from Dean (1969) of 0.62×10^9 ft^2 and 10 ft., respectively, the volume of mean low water becomes 5.95×10^9 ft^3 and the tidal prism is 4.59×10^8 ft^3. This gives a ratio of mean low water volume to the tidal prism volume of 13/1. However, if one considers that the tidal prism of Barnes Sound must pass through Card Sound, then this ratio is roughly cut in half. If the observed currents in Card Sound are mainly produced by tidal forces, then the basin water will undergo longitudinal oscillations over the tidal excursion with small net motion in or out of the basin. The wind-driven circulation will be superimposed upon the tidal motion and help to increase the flushing rate.

METHODS

The observational program consisted of intensive investigations on a seasonal time scale coupled with semimonthly synoptic surveys of temperature and salinity. The seasonal program consisted of deploying instrumented towers for one month periods in the interior of Card Sound and in the major exchange regions connecting Card Sound with the surrounding waters. The attached instruments (Aanderaa current meters) record in situ on magnetic tape current speed, direction, temperature, salinity, and pressure. These efforts were closely coordinated with the observational programs of the U. S. Park Service and the U. S. Geological Survey. Synoptic surveying was performed with a moving boat using a Bissett-Berman, continuously recording, thermosalinograph. Meteorological information was obtained from Florida Power and Light Corporation and tidal data from the U. S. Geological Survey.

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* Thomas N. Lee and Claes Rooth

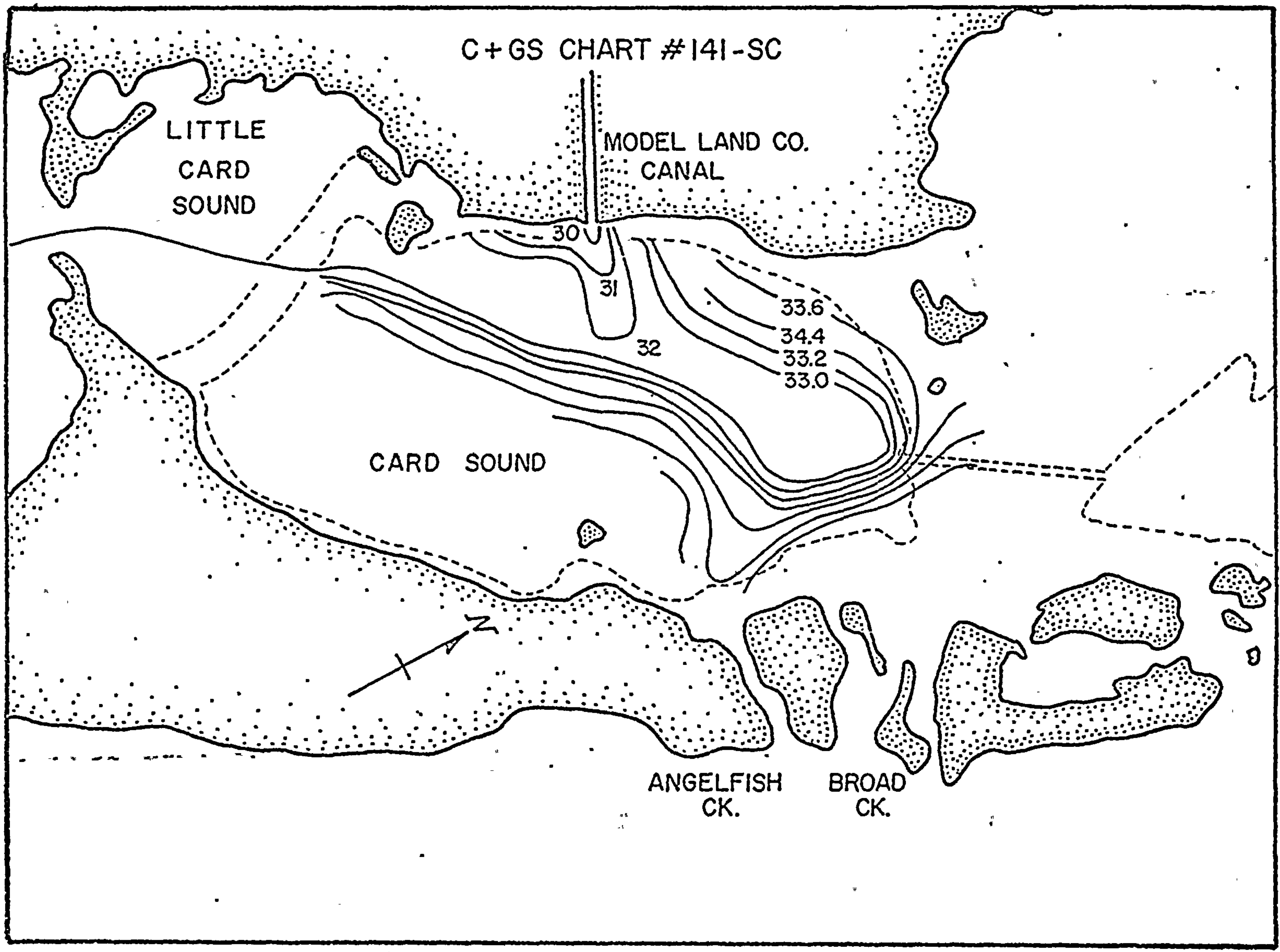

FIGURE II-1 Isohalines in Card Sound on 25 June 1970.

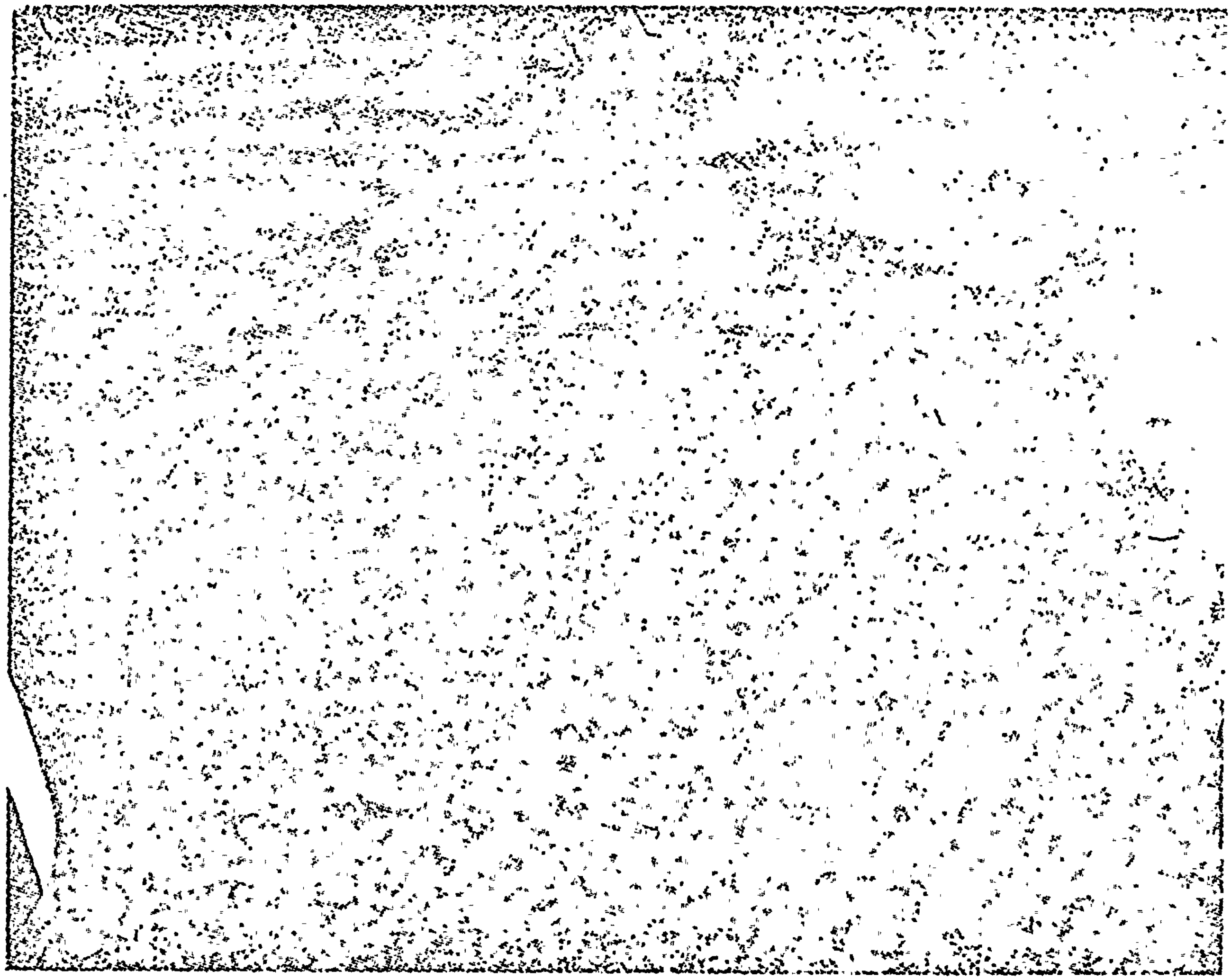

FIGURE II-2 Parallel rows of Laurencia poitei in Card Sound indicating long-shore current patterns.

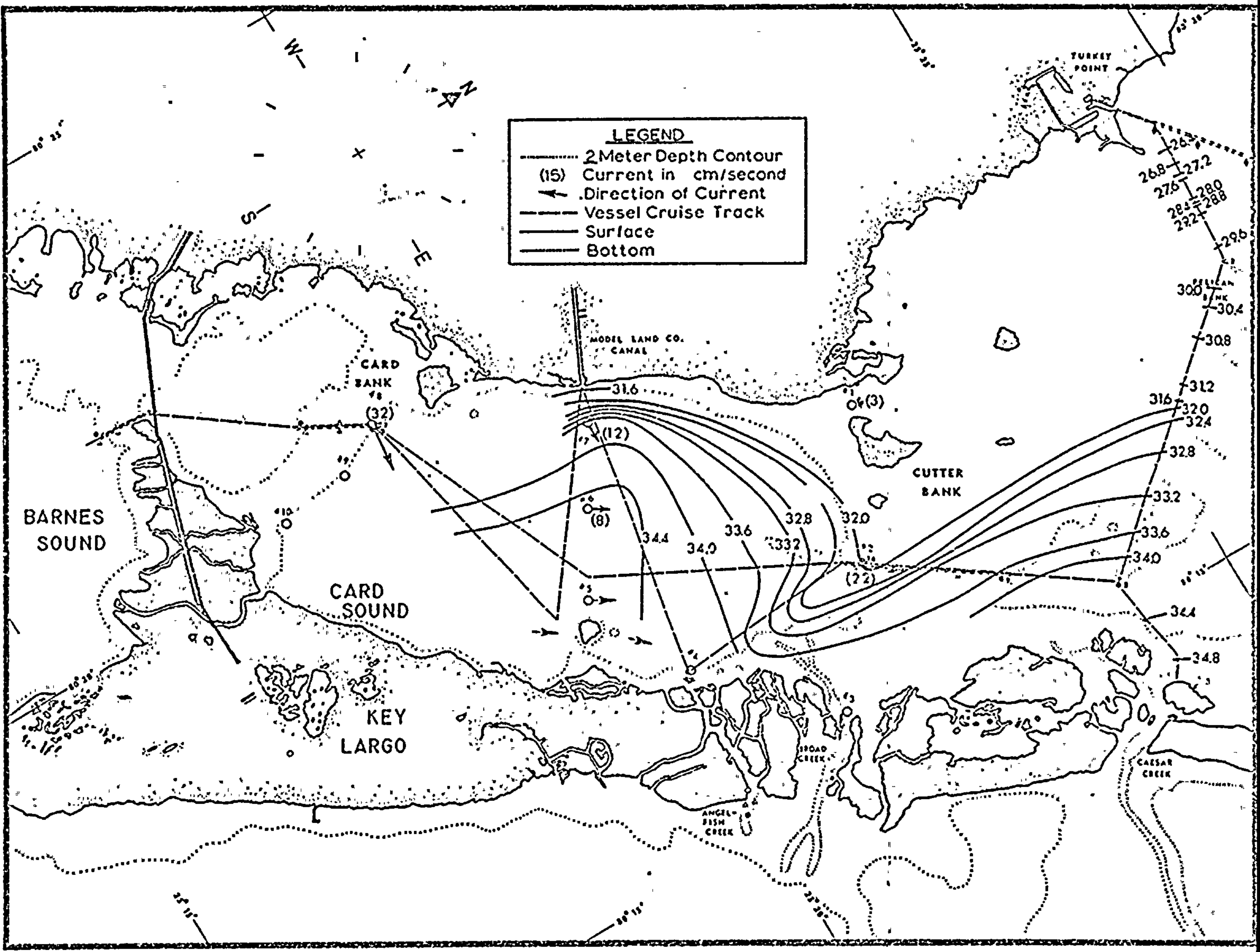

FIGURE II-3 Isohalines (ppt) in Card Sound for 0900-1230 hrs. 5 November, 1970. Wind 350°T at 10 m/sec. Ebb Tide.

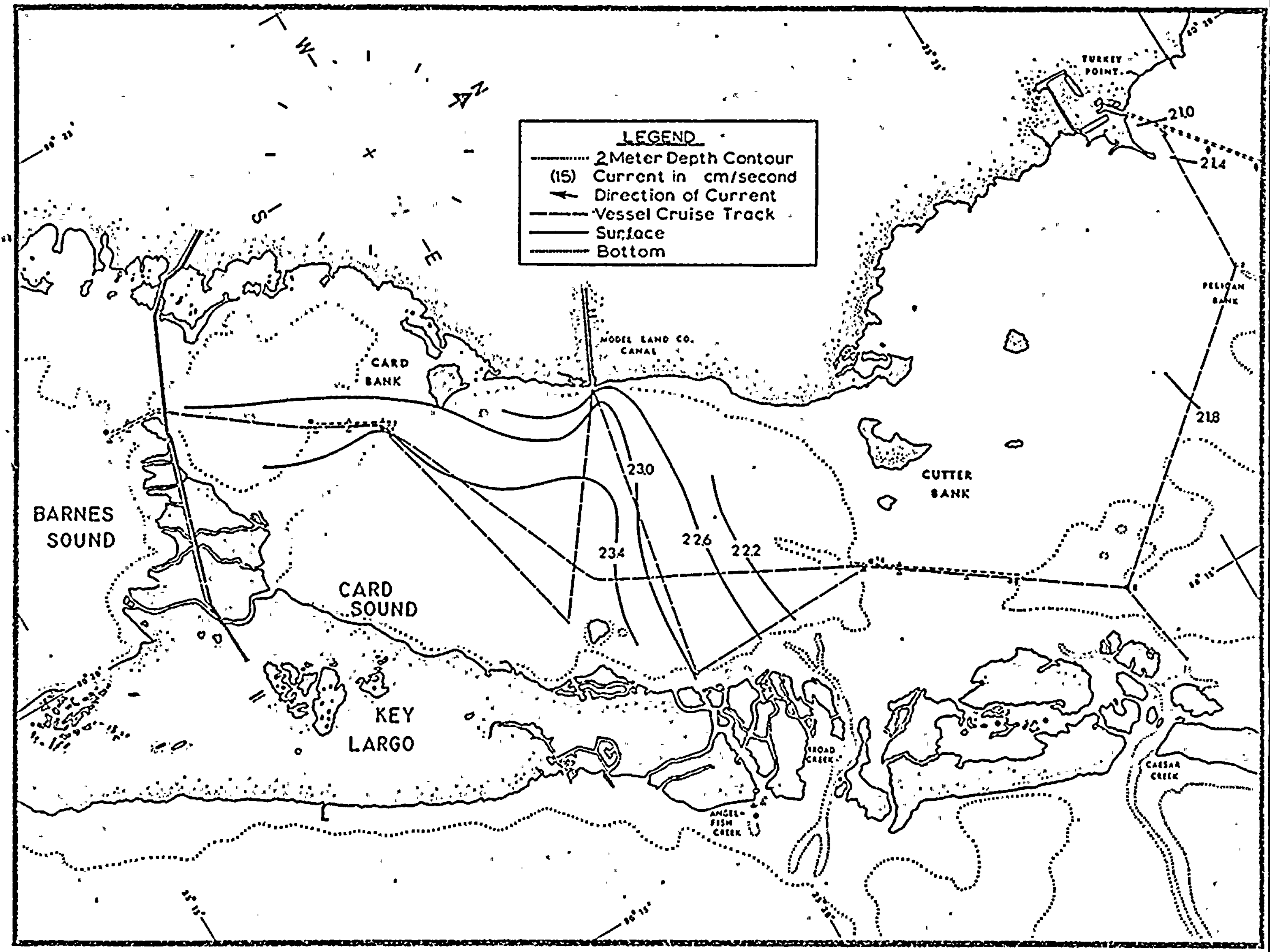

FIGURE II-4 Isotherms (^{o}C) in Card Sound for 0900-1230 hrs. 5 November, 1970. Wind 350^{o}T at 10 m/sec. Ebb Tide..

RESULTS AND DISCUSSION

Observations

On June 25, 1970, a spatial survey of temperature and salinity was conducted by making rapid traverses with a thermosalinograph (Figure II-1). The survey took place on an ebbing tide during a period of heavy rains. The low salinity runoff from Model Land Company Canal formed a mixing-dispersion plume toward the dredged navigation channel across Cutter Bank. The shape and orientation of this plume is believed to be the result of several days of mixing the mean runoff with the semidiurnal, longitudinally asymmetric tidal currents of Card Sound, during quiesence wind conditions. The planned discharge of thermal effluent, via Model Land Company Canal, should also form a mixing-dispersion plume with a similar orientation. A well-defined frontal zone was apparent along the axis of the sound indicating much greater mixing in the longitudinal direction than in the lateral.

An initial current survey was conducted on August 13 and 19 with the assistance of the U. S. Coast Guard, Seventh District. A Coast Guard helicopter was used as a platform to obtain synoptic photographs of surface dye releases. Light winds prevailed during the experiment. Aerial photographs revealed that observed tidal currents were spatially coherent in the interior and aligned with the major axis of the sound. The photographs also revealed parellel rows of free drifting <u>Laurencia poitea</u> aligned in the direction of flow (Figure II-2) and strong gradients in water clarity, changing from clear to turbid in an easterly direction. These early experiments gave rise to a theoretical formulation of asymmetric, tidally induced mixing processes in Card Sound and the surrounding embayments, which has prevailed throughout our work and is included in the modeling section of this report.

The first seasonal intensive field investigation was conducted during November 1970. It consisted of surveys of temperature and salinity in conjunction with aerial photography of dye releases using the chartered services of Sea Flight Corporation. Borrowed current meters were installed with negative results due to equipment failure. The results of this experiment are graphically shown in Figures II-3 through II-6. The observations of November 5 were conducted during the passage of a cold front with accompanying winds out of the north-northwest at 10 m/sec. The low salinities in the western region of South Biscayne Bay are believed to be the result of wind transport from the north during the cold front passage. Continuity would then suggest that a mean flow out of the bay is formed with strong northerly winds. The light wind conditions of November 11 and 13 show an essentially linear water mass displacement associated with the semidiurnal tides. Based on the observed peak tidal currents of approximately 20 cm/sec., the tidal excursion length for the interior is ± 1.5 km. These displacements occur essentially in parallel with the main Card Sound Basin.

The exchange processes of Card Sound begin to be understood from the temperature and salinity patterns of Figures II-1 through II-7. It appears that wind forcing is the most important factor controlling the mixing processes. One can sepearate the wind influence into two periods: (1) quiescent period, where tidal mixing predominates, and, (2) agitation periods, where wind stirring masks tidal effects.

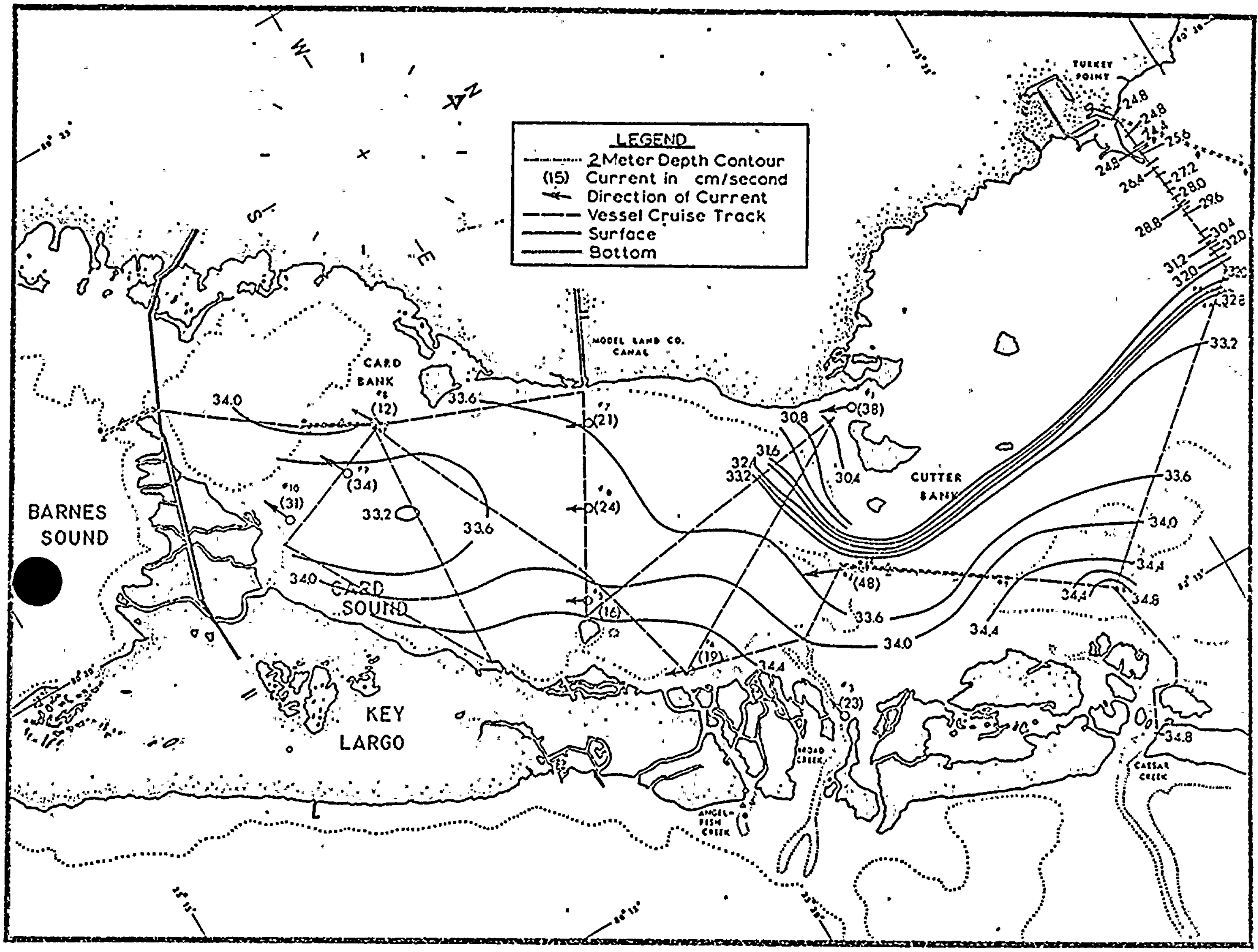

FIGURE II-5 Isohalines (ppt) in Card Sound for 0900-1250 hrs. on 11 November, 1970. Wind 270°T at 3 m/sec. Flood Tide.

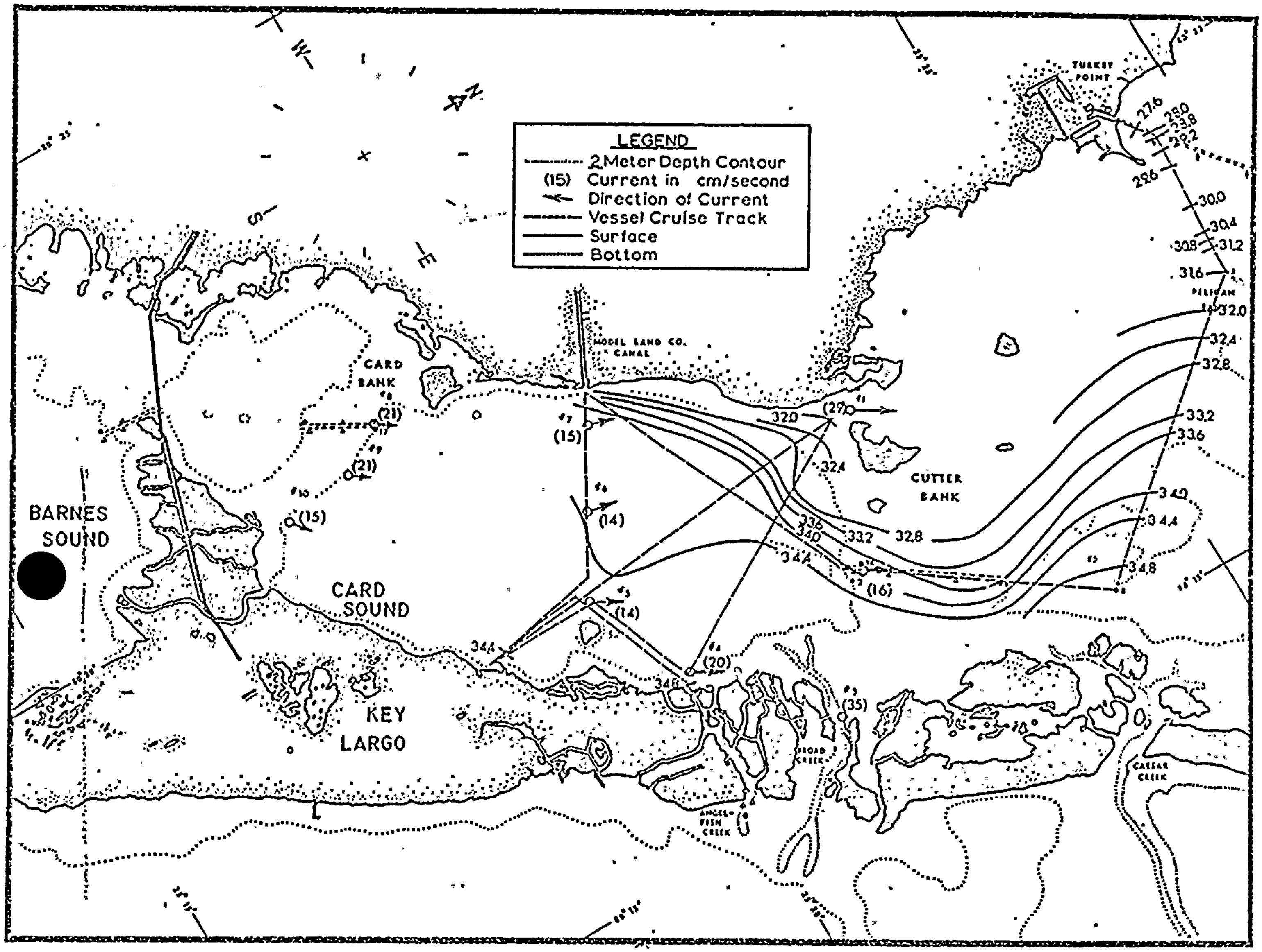

FIGURE II-6 Isohalines (ppt) in Card Sound for 1250-1620 hrs. on 13 November, 1970. Wind calm. Ebb Tide.

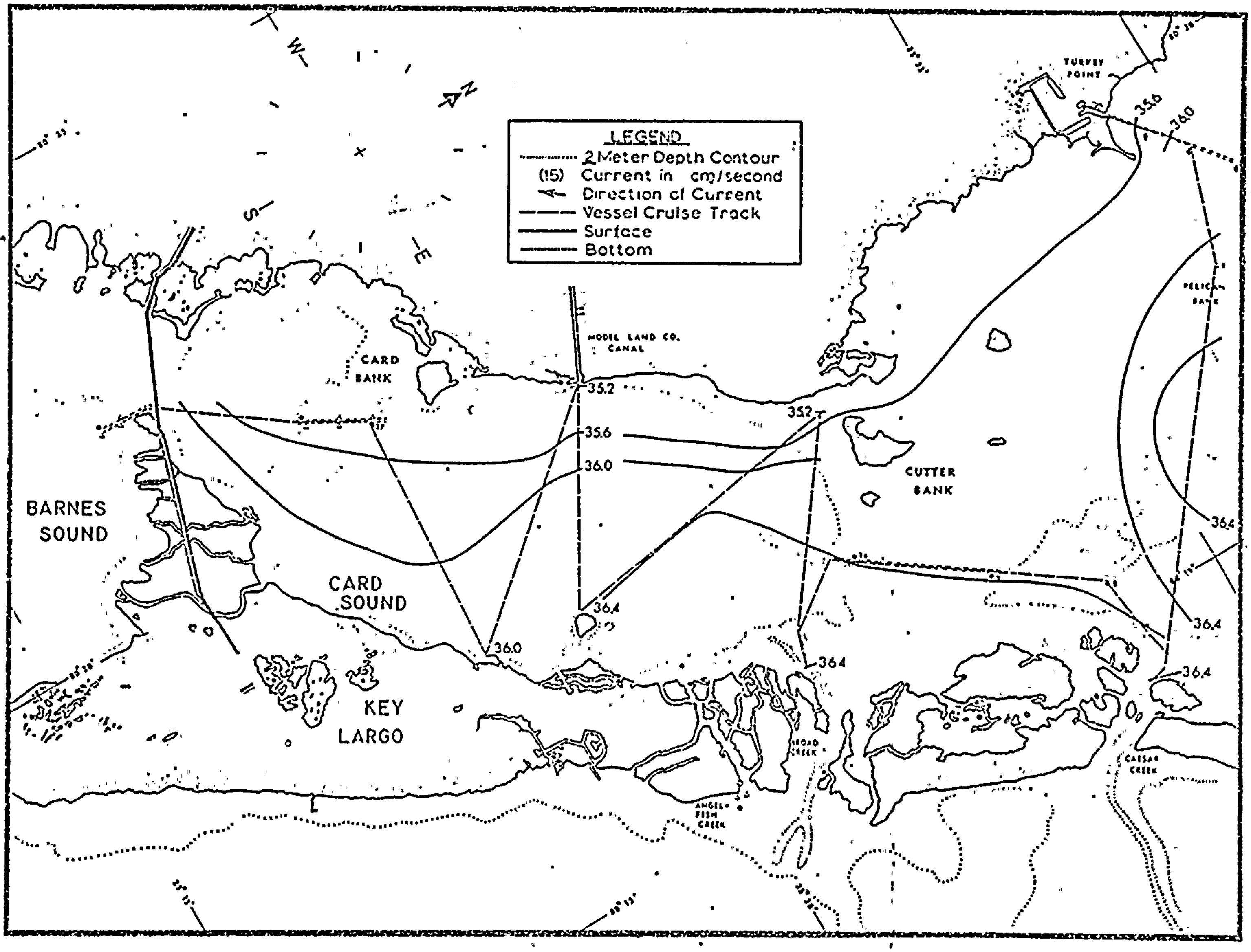

FIGURE II-7 Isohalines (ppt) in Card Sound for 0900-1245 hrs. on 8 January, 1971. Wind 5 m/sec. Ebb Tide.

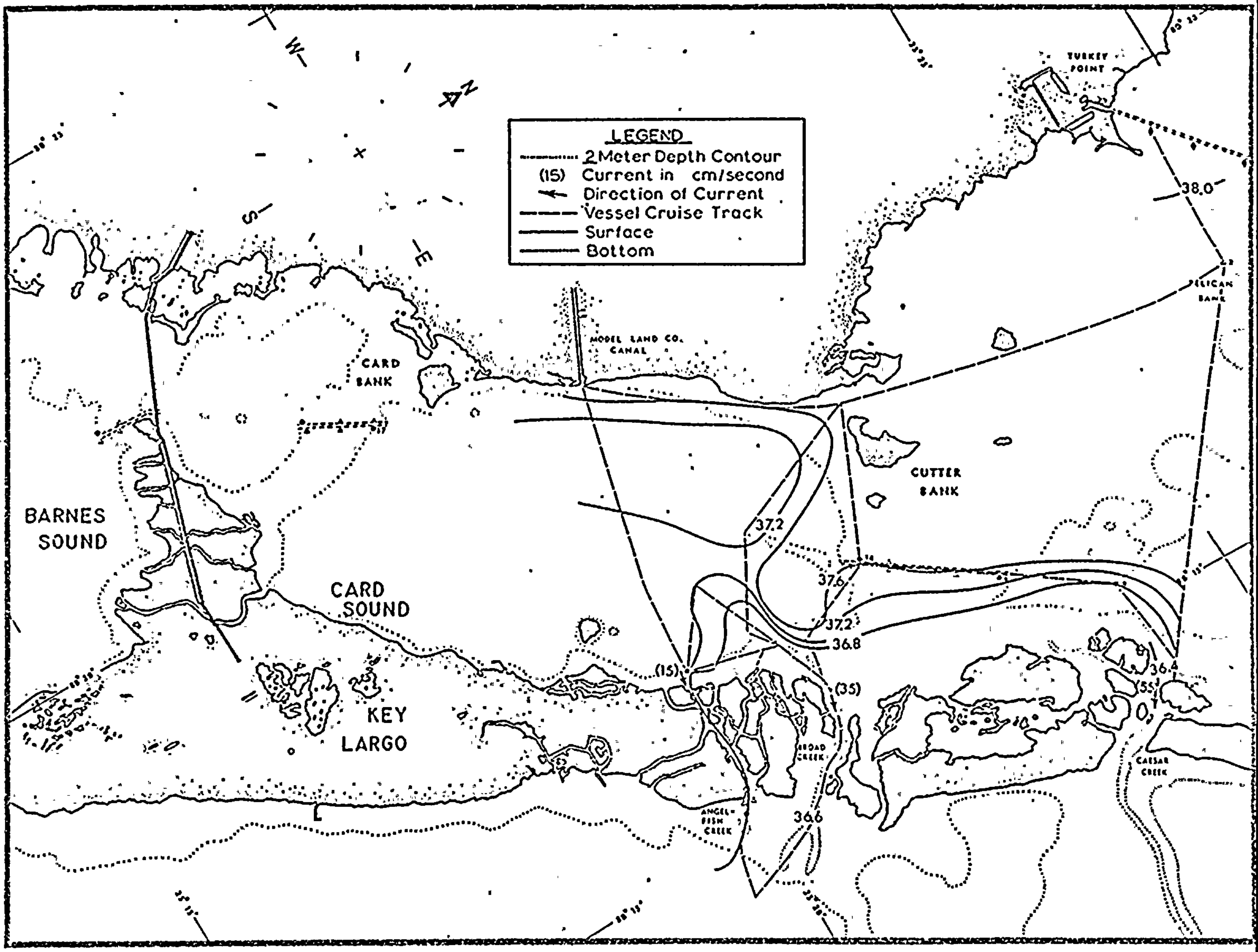

FIGURE II-8 Isohalines (ppt) in Card Sound for 0726-1115 hrs. on 5 February, 1971. Wind 140°T at 5 m/sec. Ebb Tide.

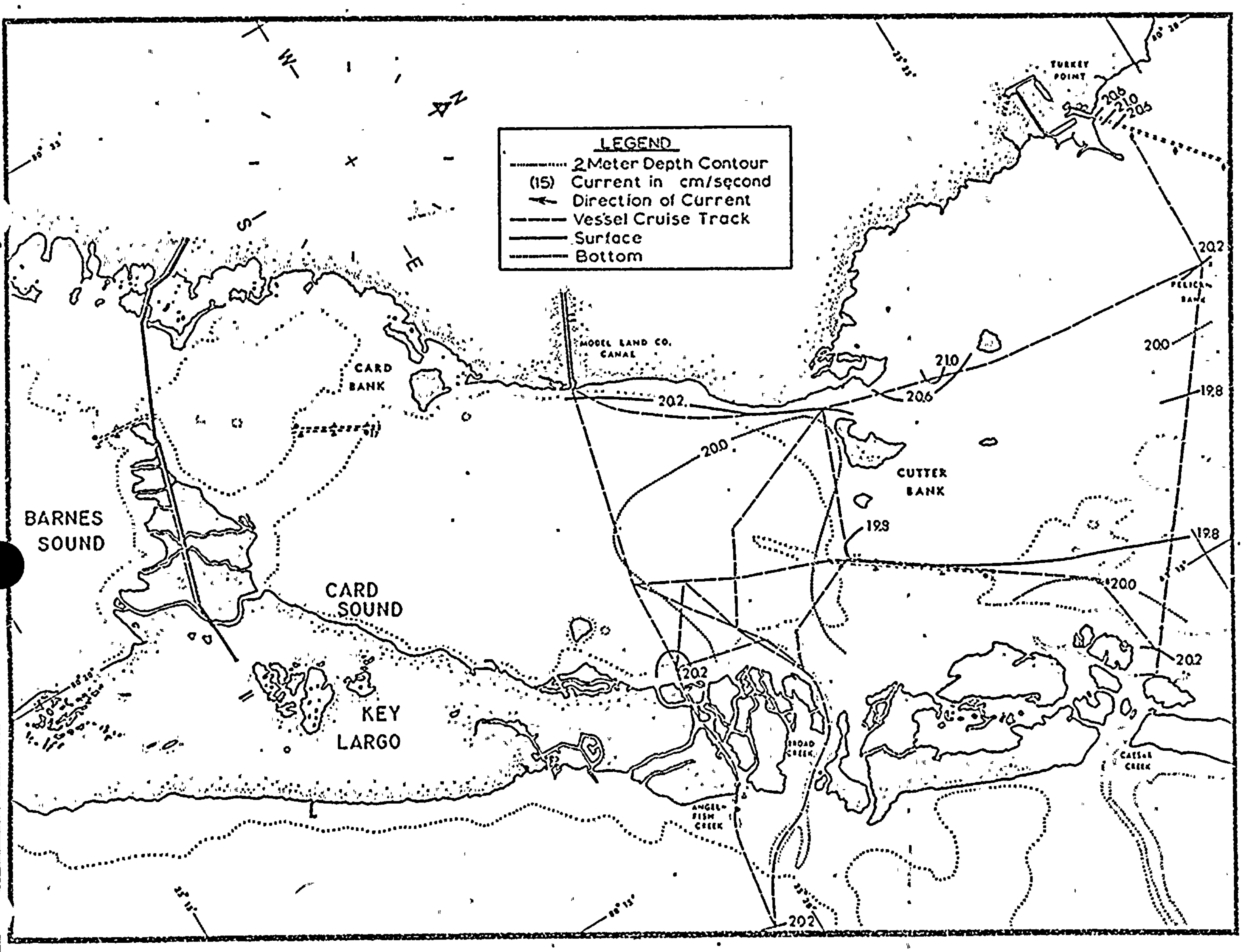

FIGURE II-9 Isotherms (^{o}C) in Card Sound for 0726-1115 hrs. on 5 February, 1971. Wind 140°T at 5 m/sec. Ebb Tide.

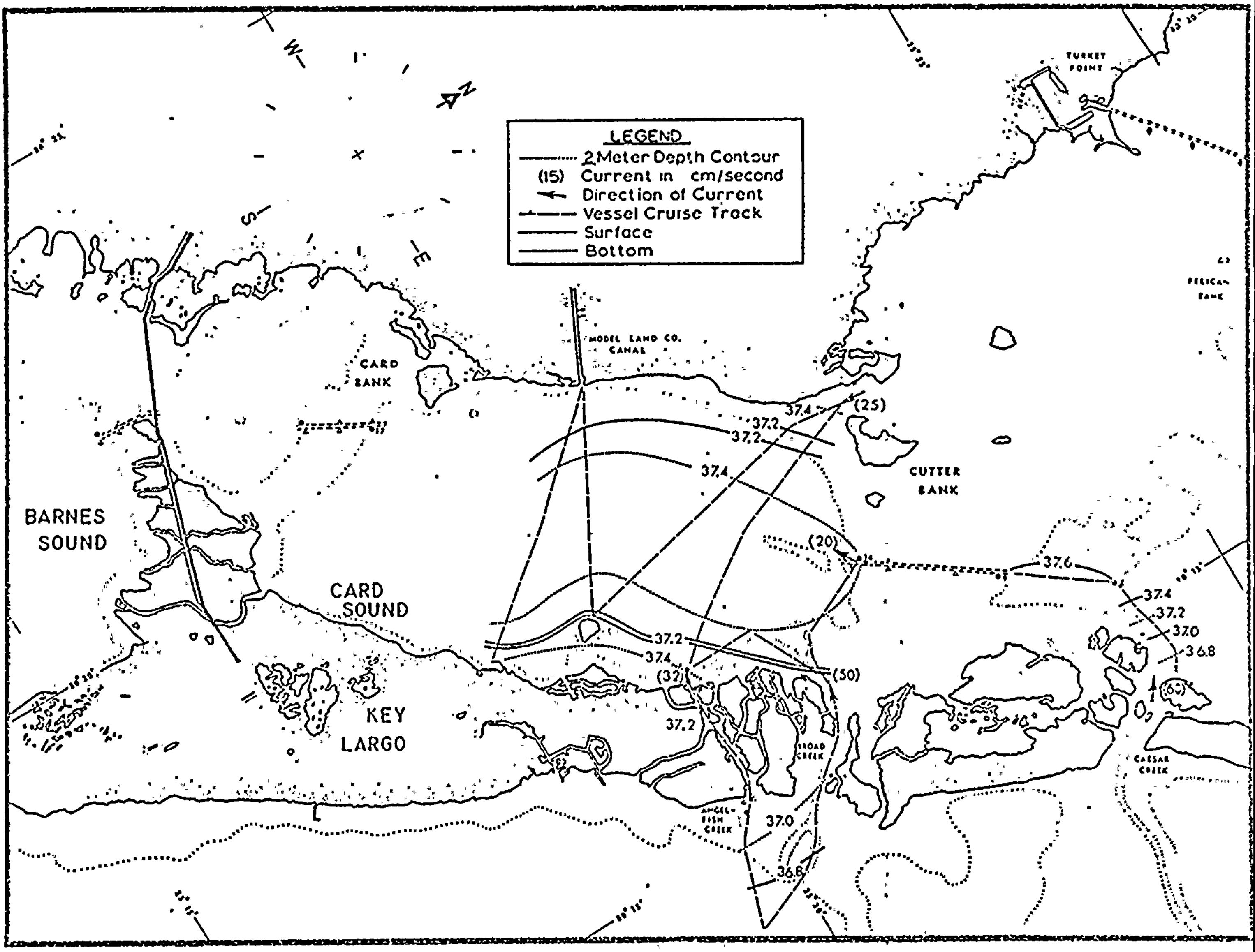

FIGURE II-10 Isohalines (ppt) in Card Sound for 1057-1427 hrs. on 15 February, 1971. Wind 090° T at 1.5 m/sec. Flood Tide.

During quiescent periods, the preferred longitudinal tidal mixing in the interior tends to produce isohalines alinged with the major axis of the sound. This asymmetric mixing will tend to develop a front along the center line of Card Sound, which inhibits exchange of interior water with the ocean. Thus, the exchange pattern is seen as communication between the inshore region of Card Sound with Biscayne Bay and Barnes Sound and the eastern section with the coastal waters through Broad and Angelfish Creeks. This mixing pattern is substantiated by the east-west gradients of sediment found by Earley and Goodell (1968), by a similar gradient in water clarity, and by the development of north-south parallel rows of Laurencia poitea. The exchange patterns of Card Sound are representative of the general coastal-estuarine exchange of the Biscayne Bay system as shown by the similarity of isohaline patterns in upper Biscayne found by DeSylva (1970).

At present, the observations of the vertical structure in Card Sound are too scattered to draw firm conclusions. The data now available show that normally the interior can be considered vertically homogeneous with differences between surface and bottom temperature and salinities of approximately 0.2°C and 0.1°/oo, respectively. However, during periods of strong atmospheric heating and low wind velocities, temperature and salinity stratification as great as 1.0°C and 1.0°/oo may develop. In the mouth of Model Land Co. Canal, low surface salinity runoff and turbid water produces intense stratification. Salinity differences from surface to bottom 12.6°/oo and temperature differences of 2.0°C have been measured. The major exchange passes through which Card Sound communicates with the surrounding water bodies have consistently been found to be vertically homogeneous due to intense turbulent mixing generated by the strong currents.

Tidal induced exchange between Card Sound and the ocean is further reduced due to the phase lag between the tide traveling south through Biscayne Bay and the ocean tide at the inlets. Michel (1970) reporting on the work of Dean (1970); showed that the tide at Cutter Bank lags the ocean tide in Broad and Angelfish Creeks by approximately three hours (90°). This means that a large portion of the tidal inflow through the inlets is caught up in the ebb across Cutter Bank reducing the oceanic input to Card Sound.

The poor flushing of the interiors of Card Sound and South Biscayne Bay is also indicated by the large salinity differences which develop between the embayments and coastal waters during dry periods (February through May). This salinity contrast clearly shows the region of coastal-estuarine interaction as a jet of low salinity water from the tidal inlets, extending approximately one nautical mile into the sound on flood tide (Figures II-8, II-1[illegible], and II-[illegible].

The effect of wind forcing on exchange processes can be seen in Figures II-8 through II-13. A cold front passed through the area on February 13 and 14 with wind speeds of 10m/sec. out of the north-northwest. The observations were all made near the end of the flood tide. The effects of the frontal passage decreased bay temperatures approximately 3°C, mixed the interior waters and created a mean circulation, which transported bay water through the inlets and retarded jetting of coastal water into the sound on flood tide. Thus, wind stirring and the production of a mean circulation, even though it may be weak in magnitude compared to tidal motion, can greatly increase the flushing rate of the inshore bay waters. This also implies that a mean flow on the order of

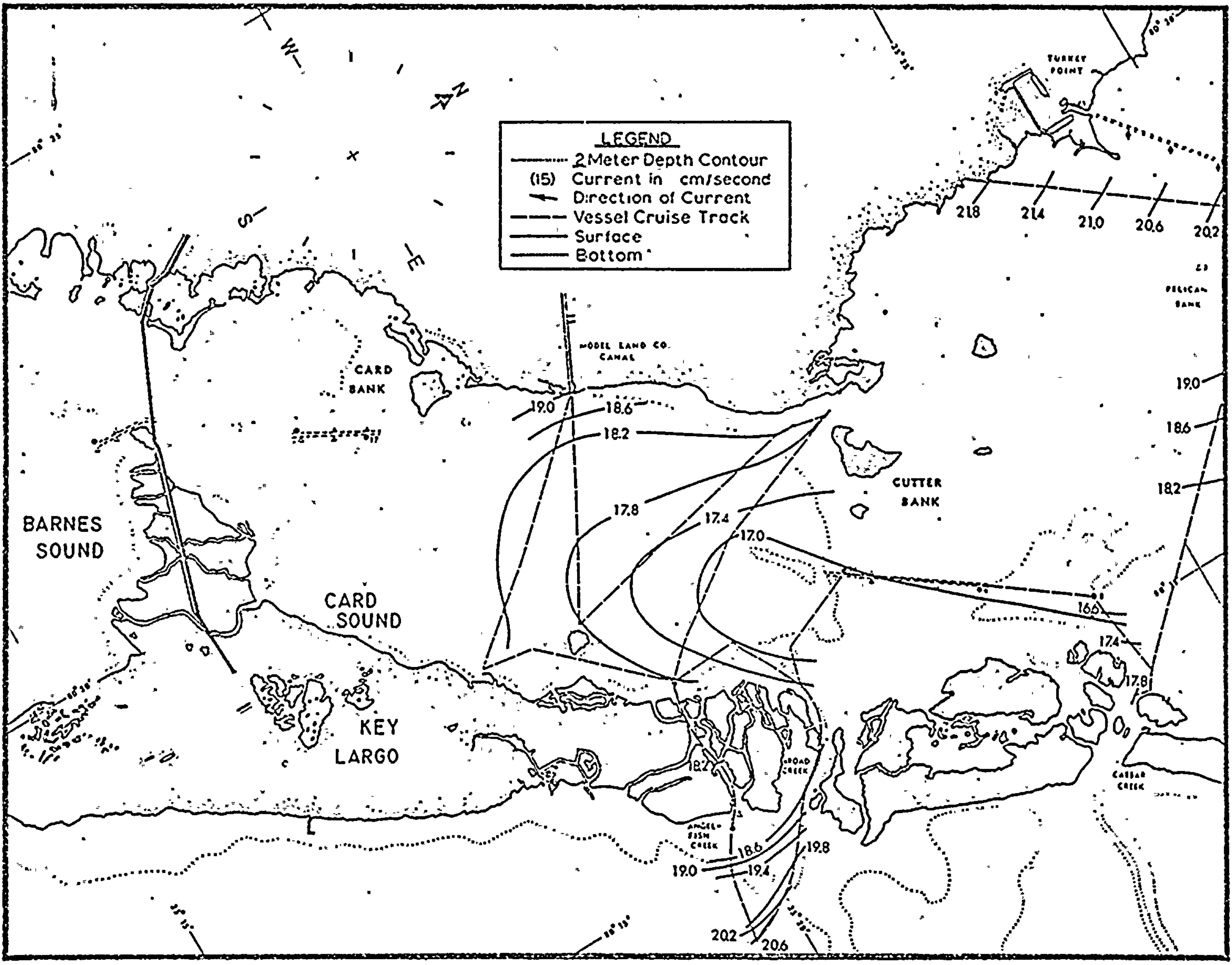

FIGURE II-11 Isotherms (°C) in Card Sound for 1057-1427 hrs. on 15 February, 1971. Wind 090°T at 1.5 m/sec. Flood Tide.

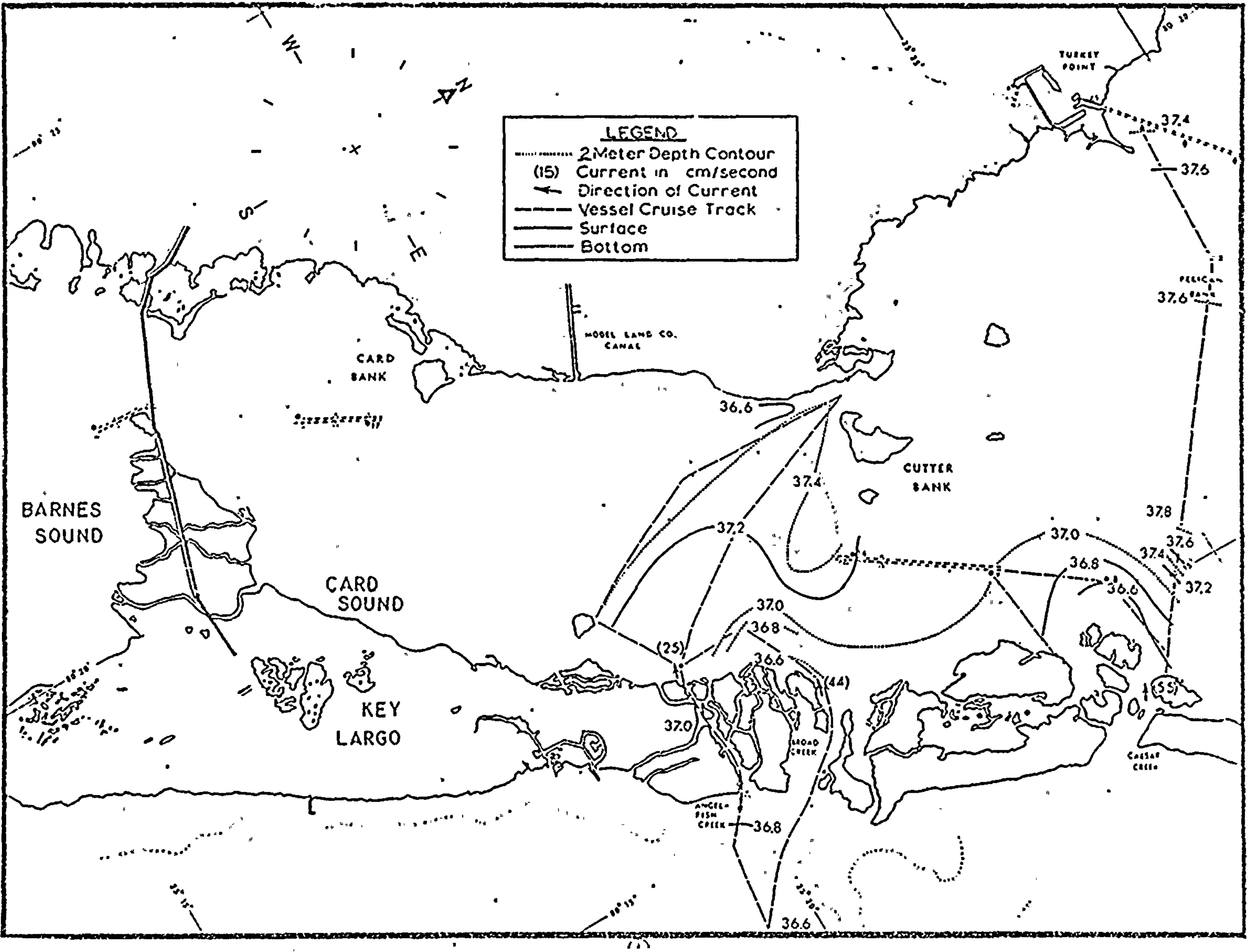

FIGURE II-12 Isohalines (ppt) in Card Sound for 1359-1651 hrs. on 19 February, 1971. Wind 100°T at 4 m/sec. Flood Tide.

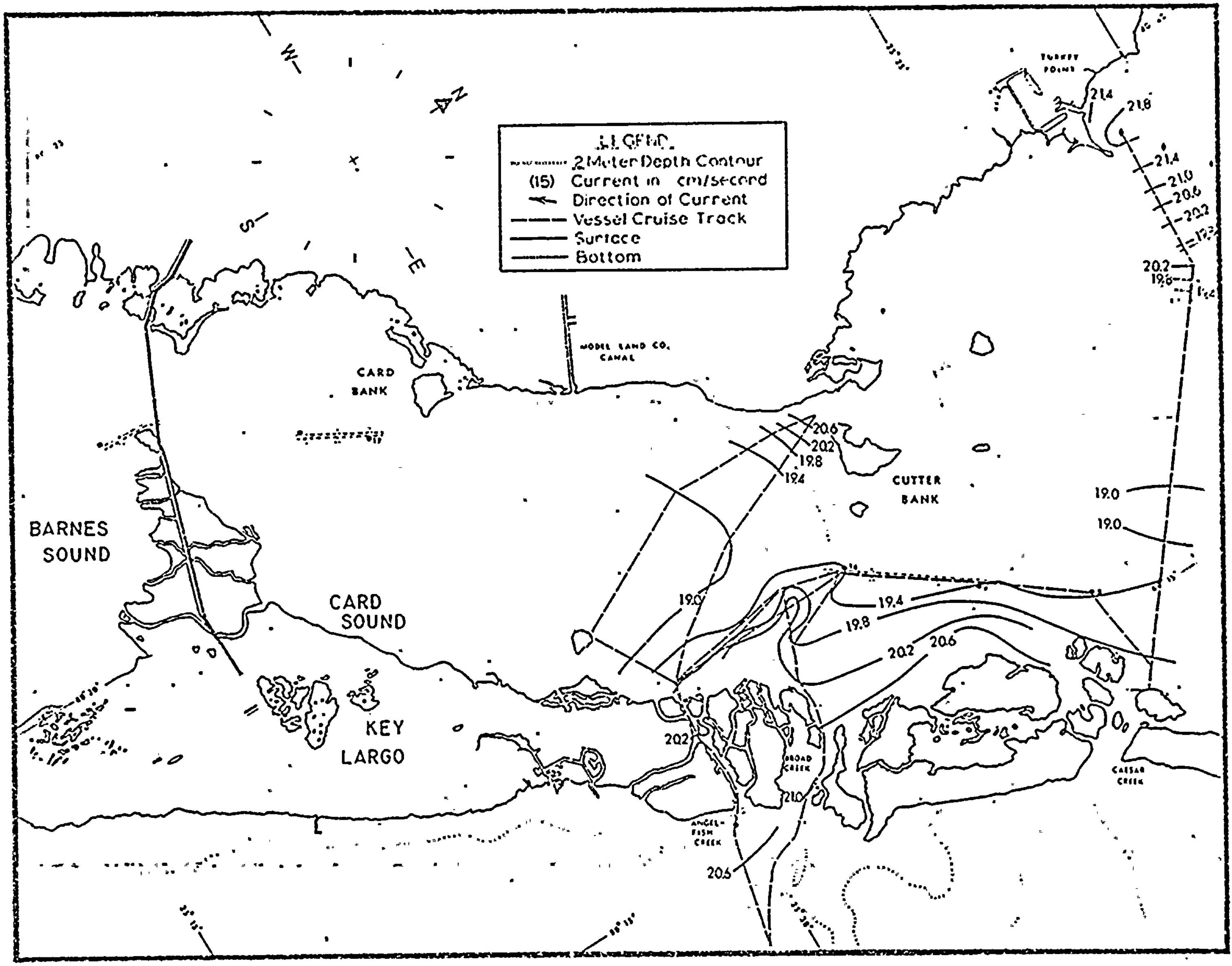

FIGURE II-13 Isotherms (°C) in Card Sound for 1359-1753 hrs. on 19 February, 1971. Wind 100°T at 4 m/sec. Flood Tide.

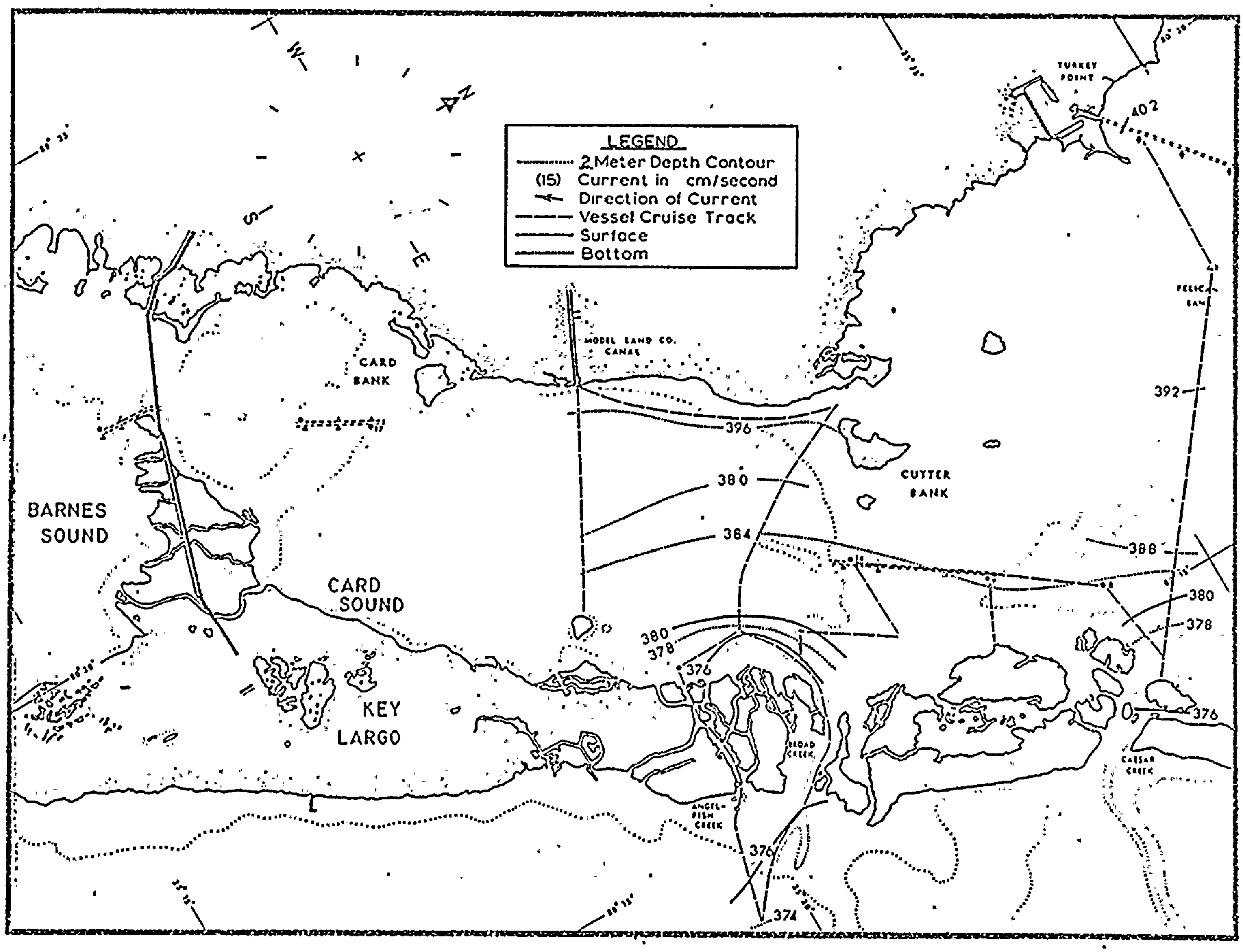

FIGURE II-14 Isohalines (ppt) in Card Sound for 0917-1308 hrs. on 25 March, 1971 Wind 155°T at 4 m/sec. Ebb Tide.

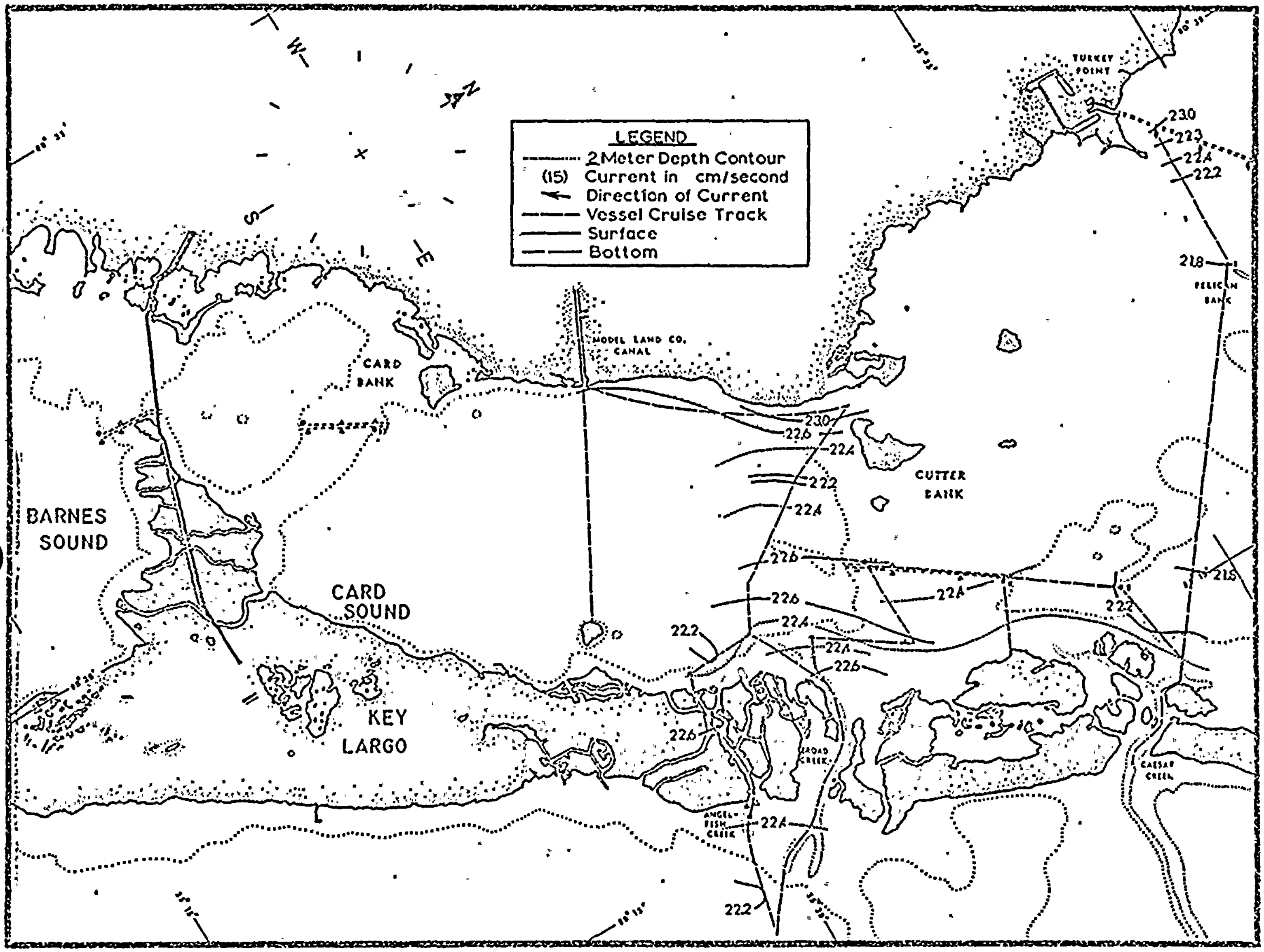

FIGURE II-15 Isotherms (°C) in Card Sound for 0917-1308 hrs. on 25 March, 1971. Wind 155°T at 4 m/sec. Ebb Tide.

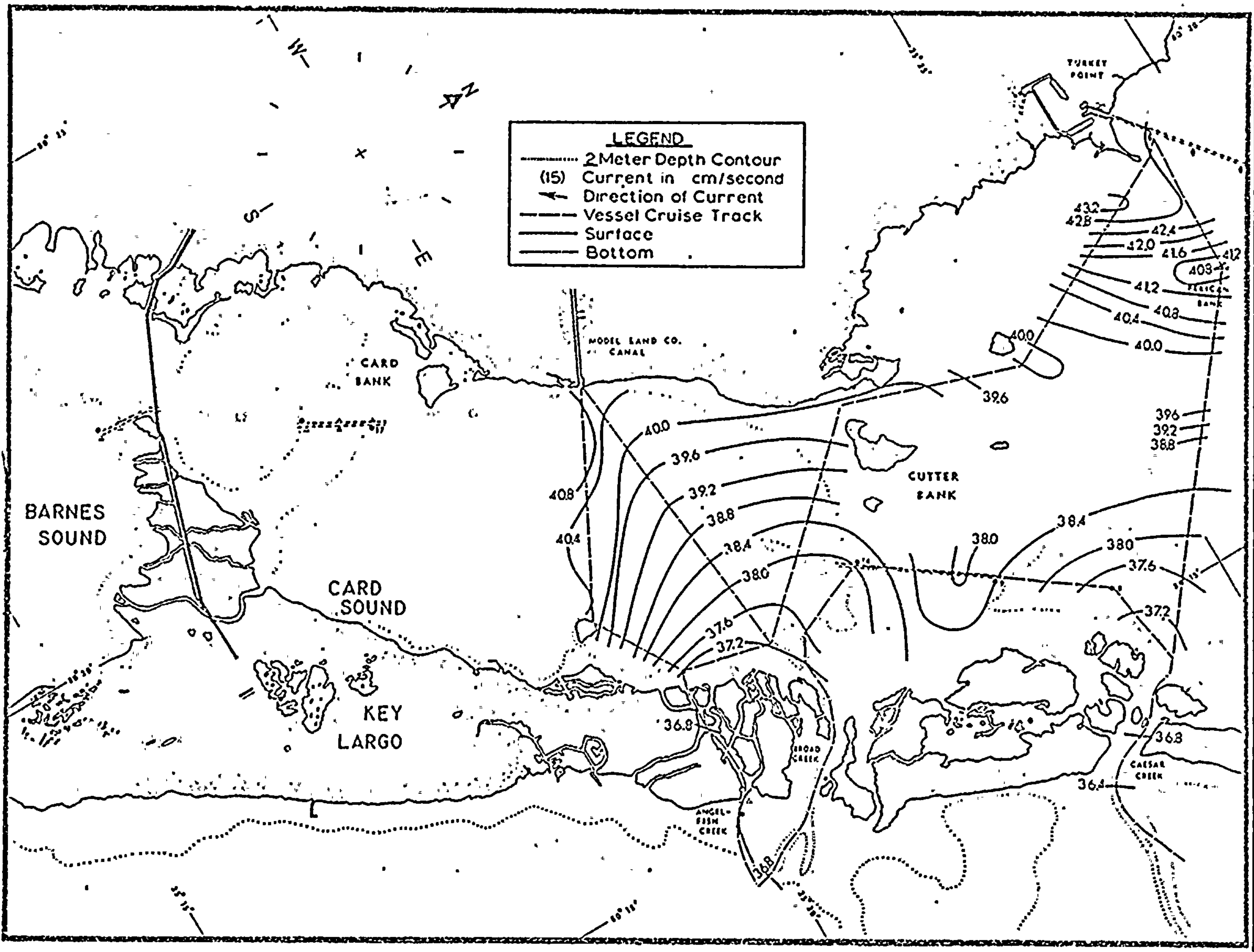

FIGURE II-16 Isohalines (ppt) in Card Sound for 1609-1944 hrs. on 20 May, 1971. Wind 090°T at 3 m/sec. Flood Tide.

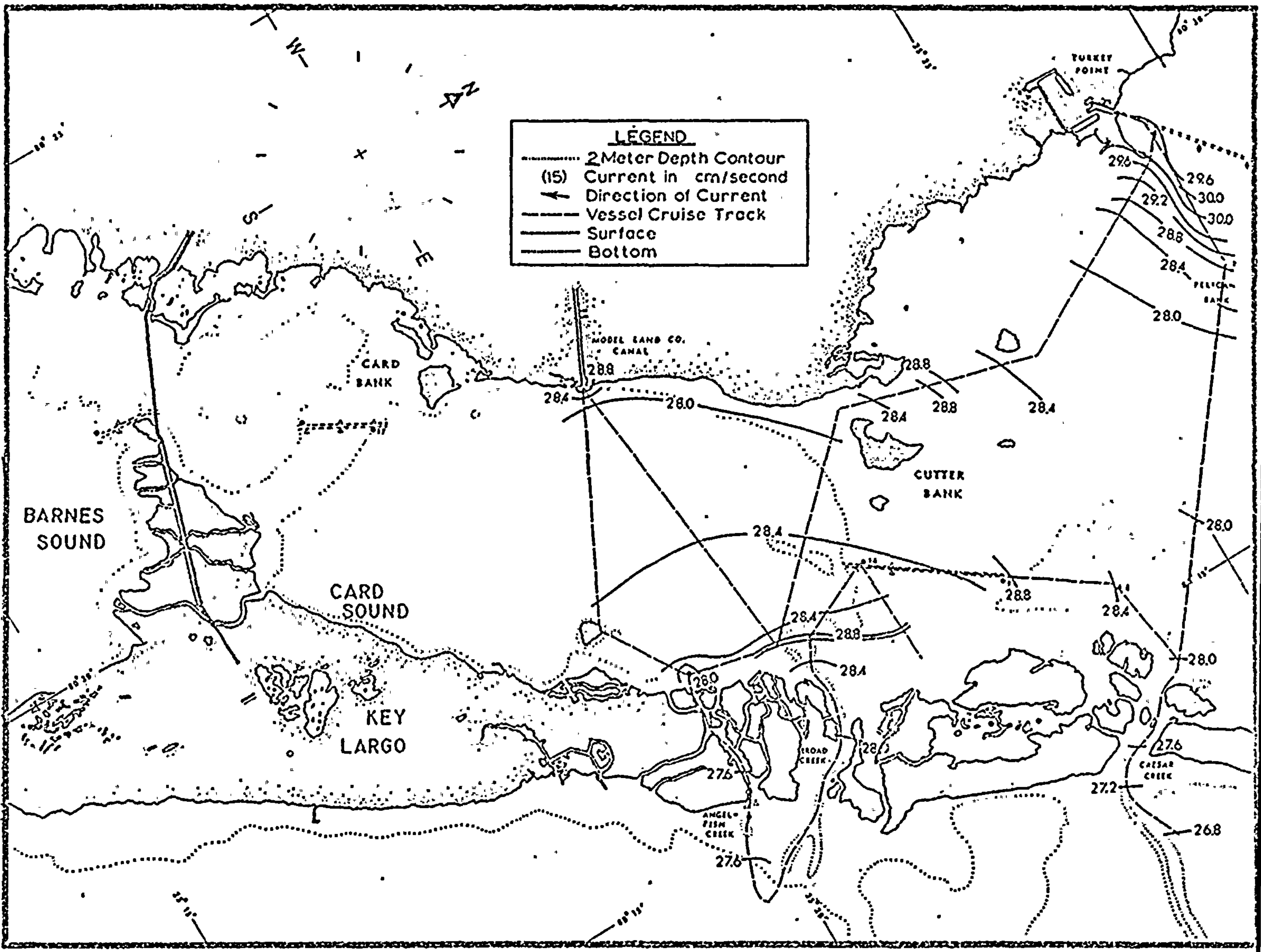

FIGURE II-17 Isotherms (°C) in Card Sound for 1609-1944 hrs. on 20 May, 1971. Wind 090°T at 3 m/sec. Flood Tide.

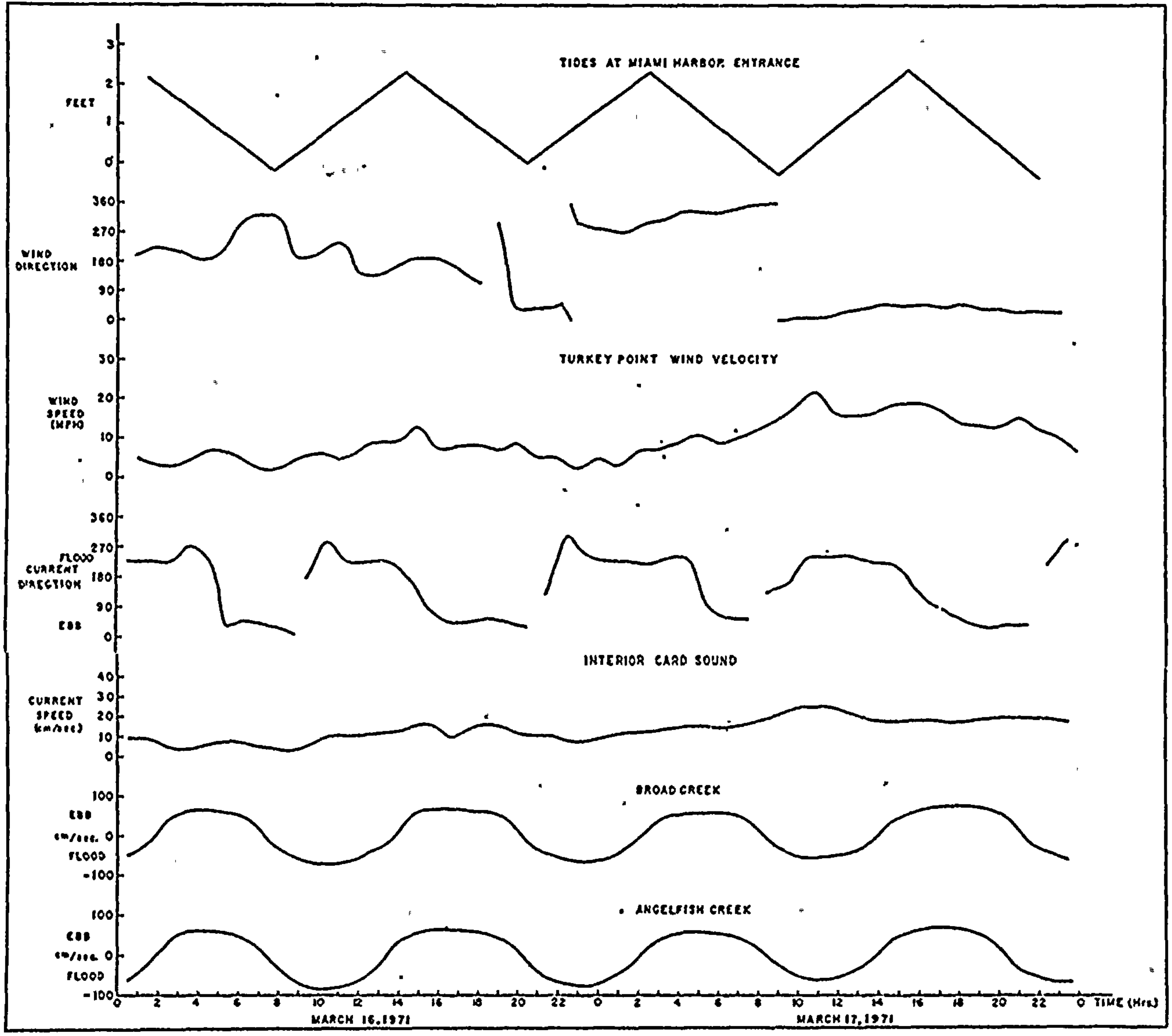

FIGURE II-18 Wind and current data for tidal passes and Card Sound, 16-17 March, 1971.

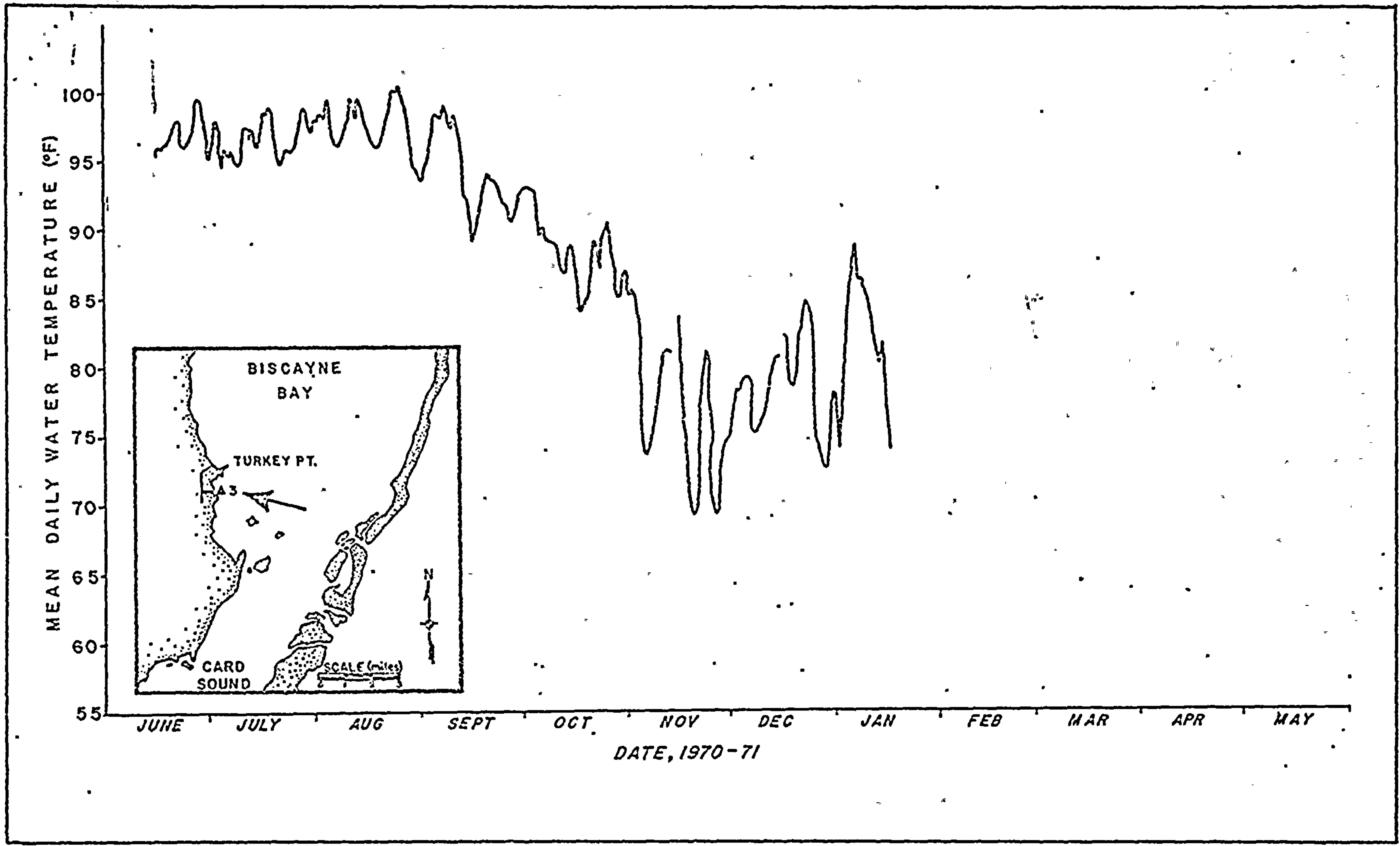

FIGURE II-19 Mean daily temperature at station 3 at the mouth of Grand Canal, Biscayne Bay.

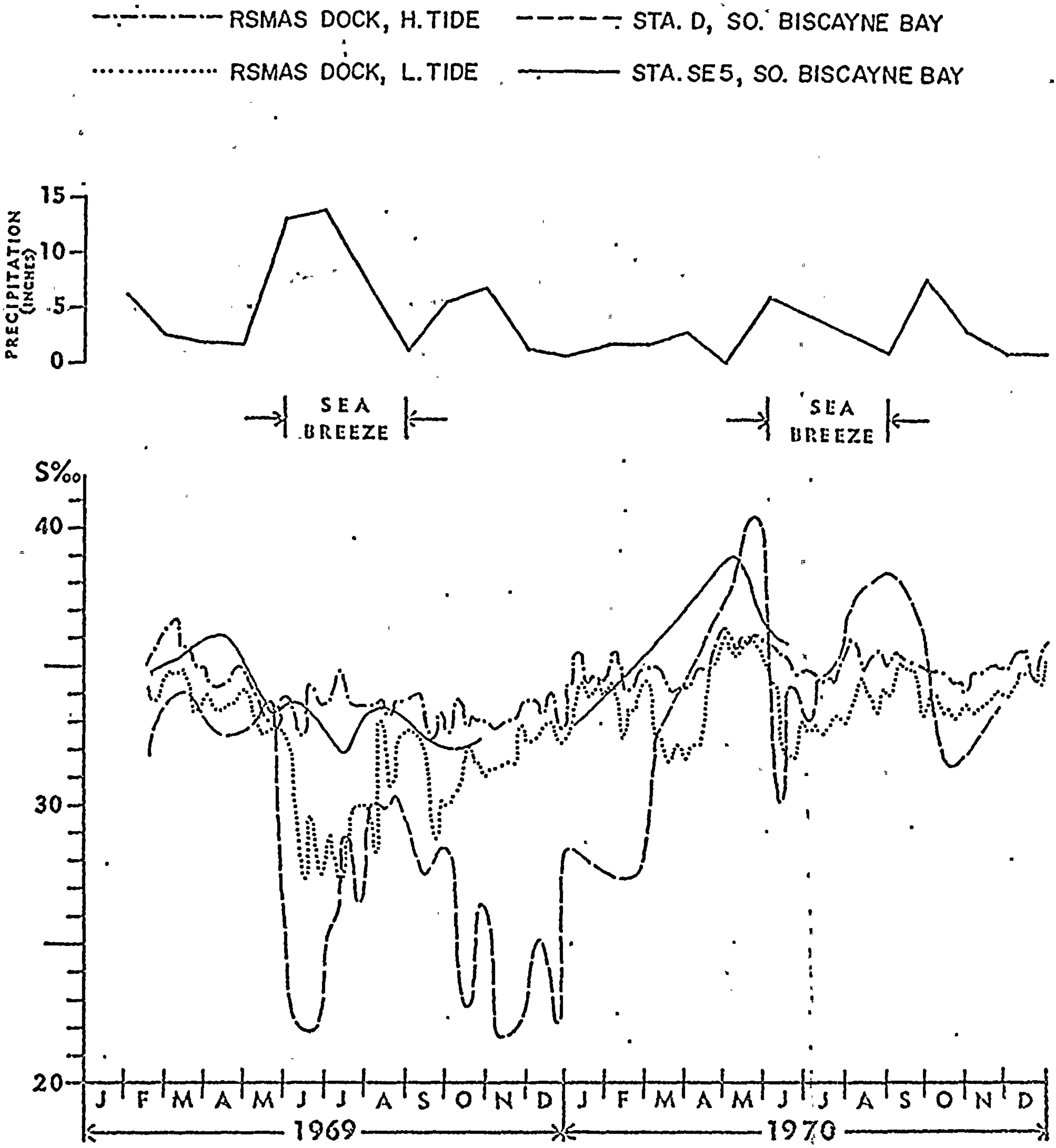

FIGURE II-20 Precipitation and salinity relation in Biscayne Bay for 1969-1970.

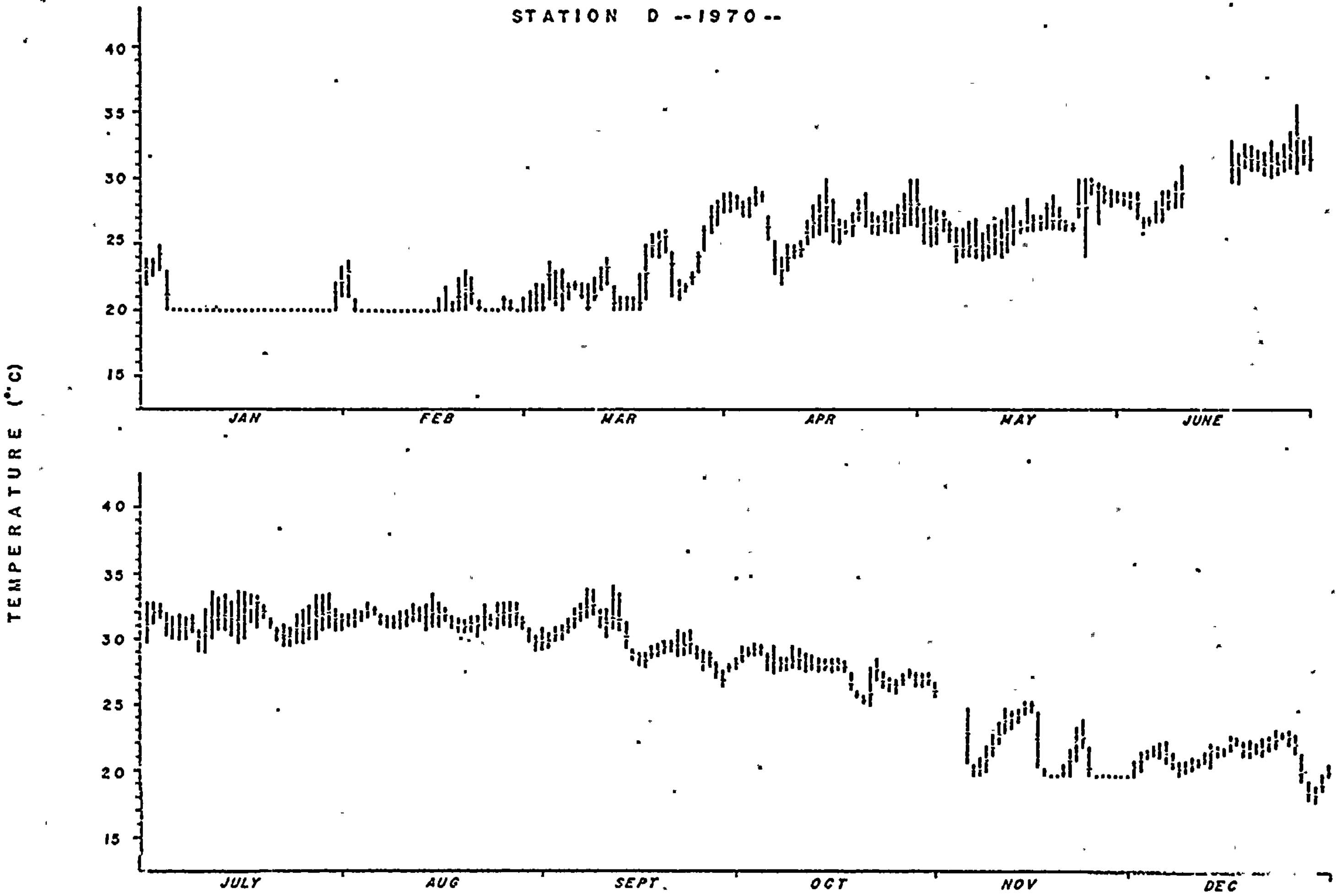

FIGURE II-21 Daily maximum, minimum and average temperature at station D. January - December, 1970.

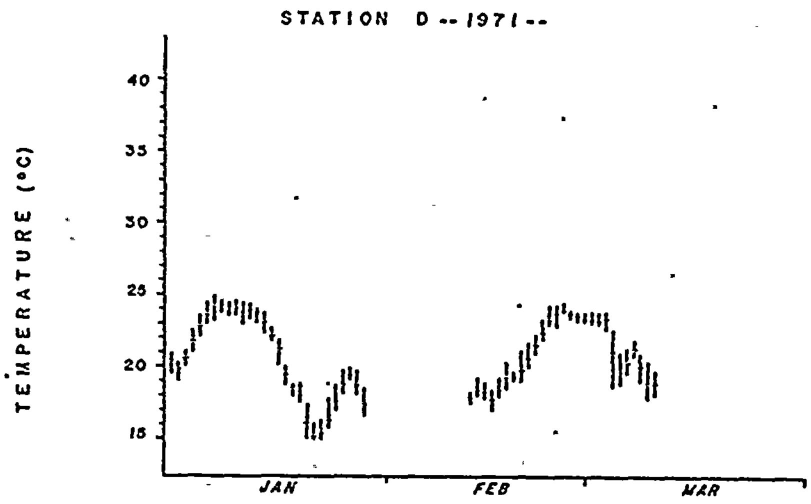

FIGURE II-22 Daily maximum, minimum and average temperature at station D. January - March 1971.

4,000 ft^3/sec. or greater as originally planned by Florida Power and Light may greatly inhibit the inflow of coastal water into Card Sound.

A second seasonal intensive measurement program was conducted during March, 1971. Aanderaa current meters were installed in Broad Creek, Angelfish Creek and in the interior of Card Sound on a line between Pumpkin Key and Model Land Co. Canal. The meters recorded over the interval from March 4th to April 21th. An intensive field program by the U. S. Geological Survey and National Park Service was also conducted during this time. Due to the fact that at the time our tape conversion unit was not completed, the tapes were sent back to the manufacturer for conversion onto an I.B.M. capatible tape. The current meter data has just been returned, thus, there has not been time for a detailed time series analysis. Figure II-18 shows two days of the current meter data along with wind data obtained at Turkey Point by Florida Power and Light and tide elevations at the Miami Harbor entrance. These two days were chosen to show the light wind condition of March 16th and the strong wind condition of March 17th during the passage of a cold front. The currents in Broad and Angelfish Creeks were in phase, responding to the semidiurnal ocean tidal forcing. The interior observations showed the longitudinal, asymmetric nature of the tidal currents with the direction of flow ranging between 230° to 240° on the flood and 30° to 50° during ebb. Tidal currents in the interior tend to lag the inlet currents by approximately one hour. On March 17th, the cold front winds attained a velosity of 22 mph from the north, parallel with the major axis of the sound. It appears that these winds have a large effect on the interior currents, increasing the magnitude and duration of flood currents, and decreasing the duration of the ebb. Also the magnitude of ebb currents in the inlets appears to be slightly greater than normal, suggesting a mean wind induced circulation out of the sound. Inspection of Turkey Point wind data revealed the presence of three cold fronts in November, one in December, four in January, two in February, seven in March and one in April. The results discussed above, based on Figure II-18, are only tentative since they are based on visual inspection. In order to obtain valid conclusions, time series analysis must be conducted with the data to determine the tidal harmonics and the wind induced flow.

Seasonal salinity patterns of South Biscayne Bay and Card Sound appear to be dominated by wind-induced circulations and the wet-dry seasons of southeast Florida. Figure II-19 is included to show a comparison between a long time series of salinity data taken at Bear Cut (next to the dock of the School of Marine and Atmospheric Science), with the accumulation of data collected during the biological studies at Turkey Point over the past year. The comparison of these seasonal salinity data for the North and South Biscayne Bay basins, suggests a profound influence by sea breeze in the mixing of this estuary system. Of the two annual salinity minima which occurred with the rainfall maxima in spring and in late summer, the latter showed large salinity differences between the basins in contrast to the spring case where the bay seems quite well mixed. This phenomenon correlates with the essential absence of sea breezes in late summer due to minimal land-sea temperature contrasts at the time of maximum water temperatures. This finding suggest maximum pollution sensitivity of South Bay in late summer, a time when the thermal stress is also at its greatest on the local biological systems.

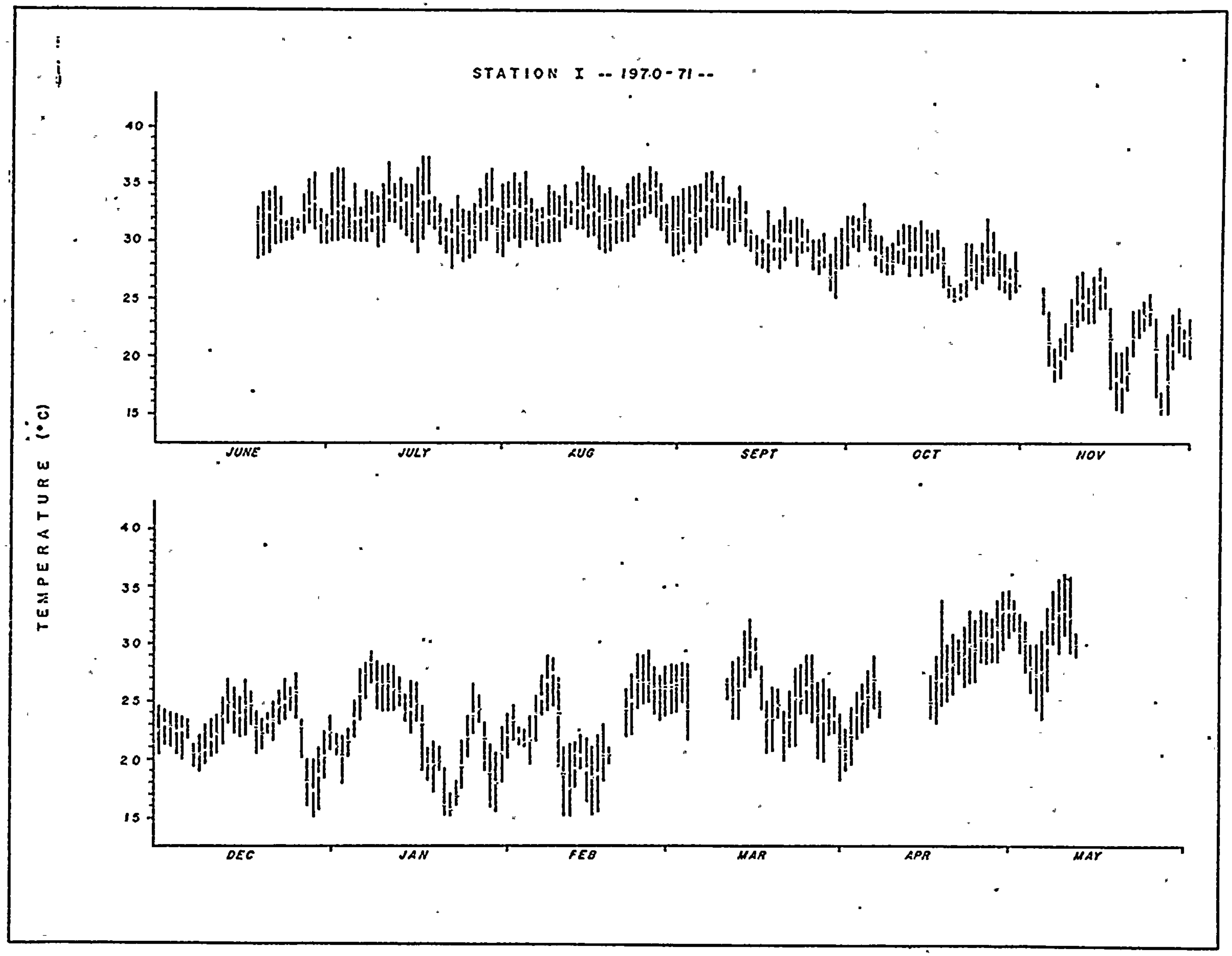

FIGURE II- 23 Daily maximum, minimum and average temperature at station I. June 1970 - May 1971.

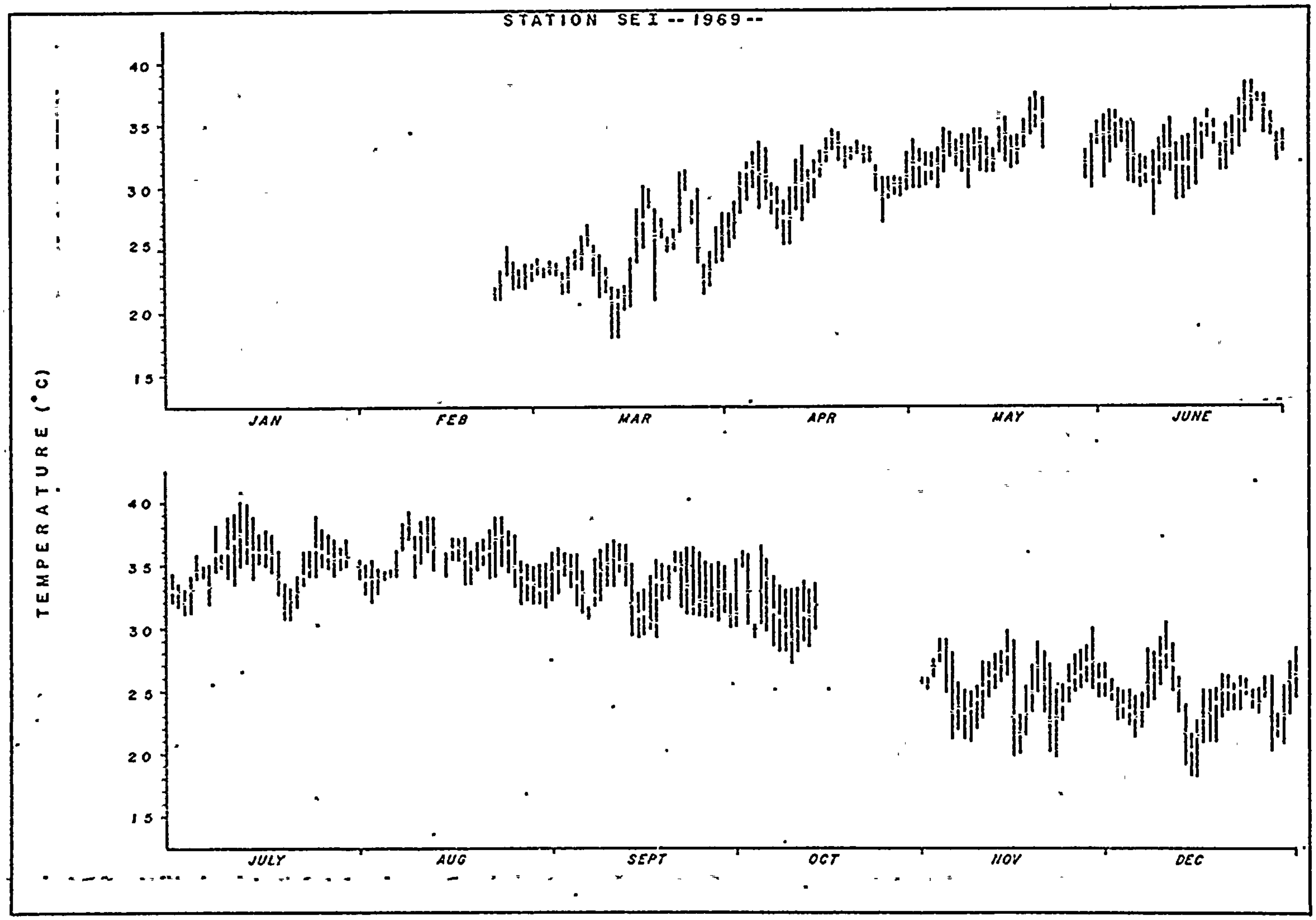

FIGURE II-24 Daily maximum, minimum and average temperature at station SEI. January - December 1969.

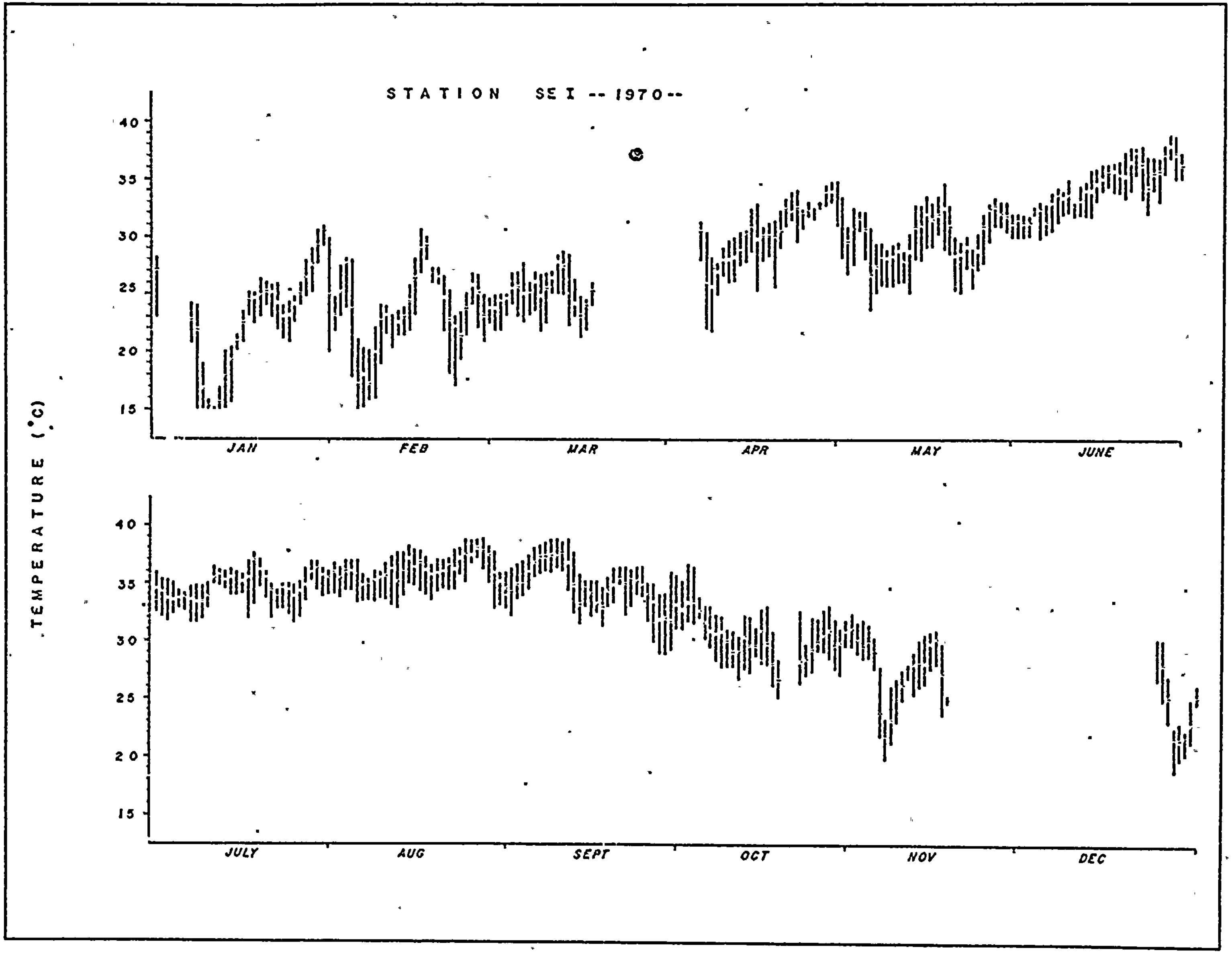

FIGURE II-25 Daily maximum, minimum and average temperature at station SEI. January - December 1970.

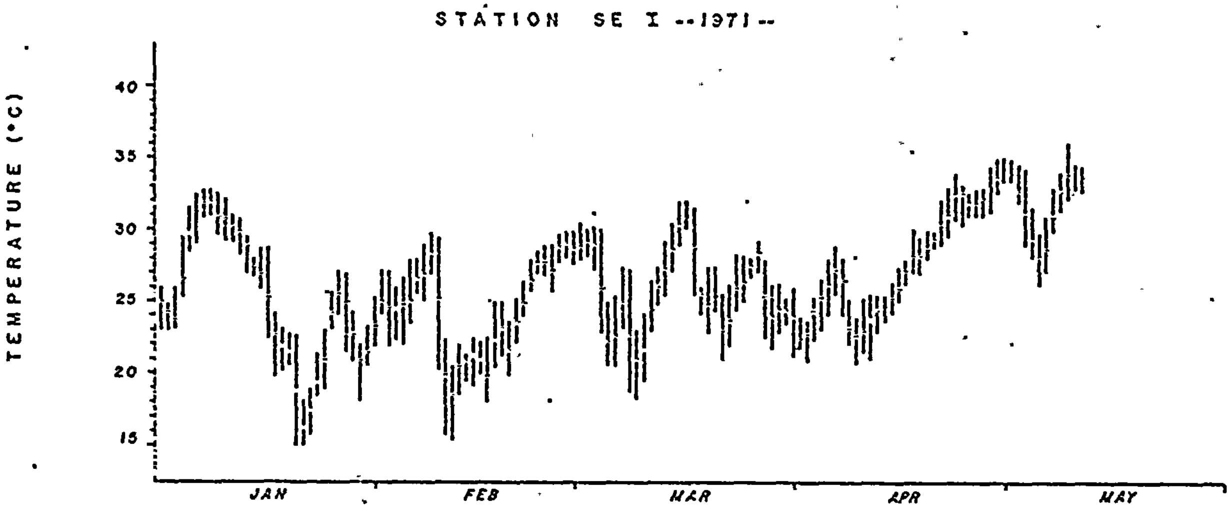

FIGURE II-26 Daily maximum, minimum and average temperature at station SEI. January - May 1971.

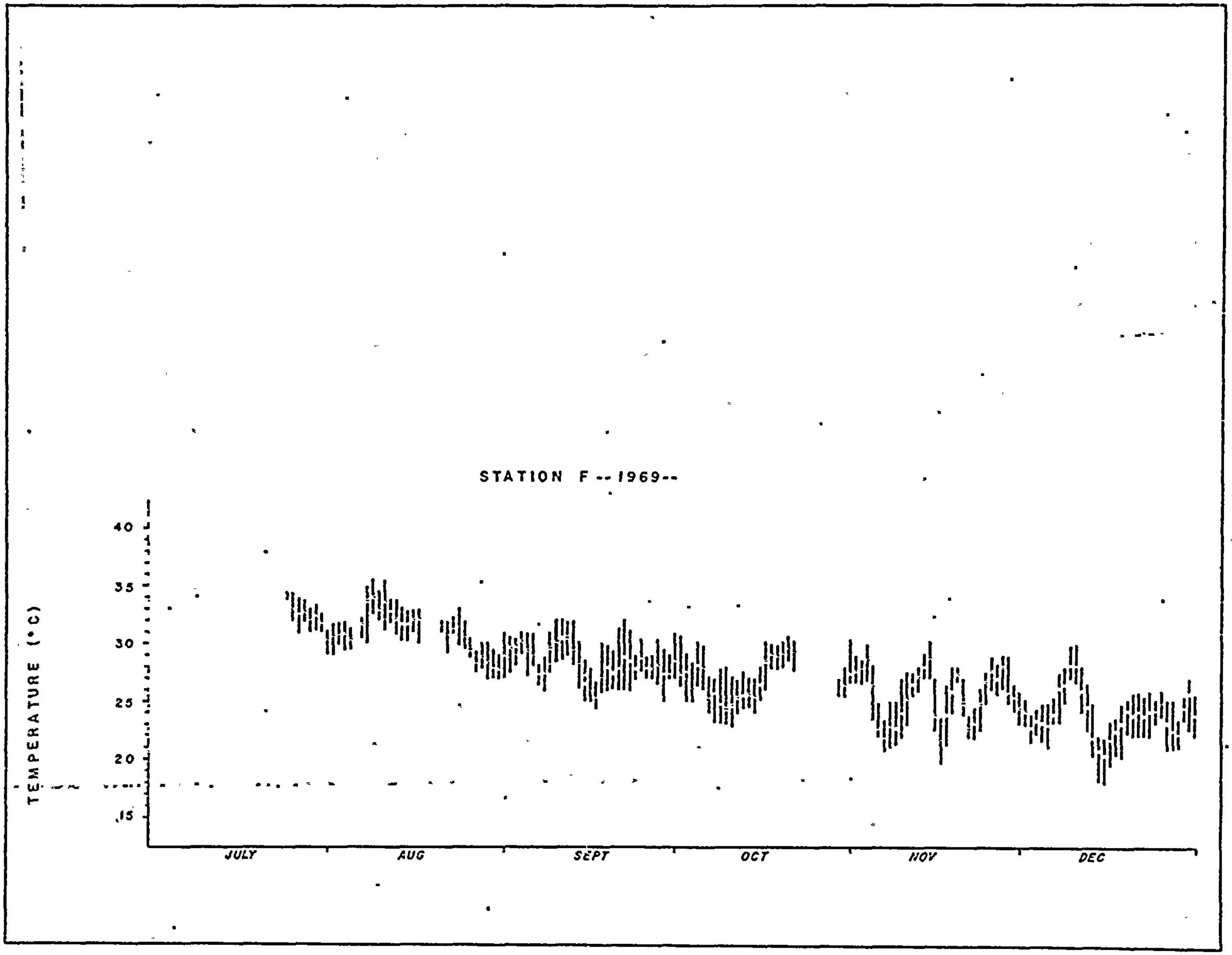

FIGURE II-27 Daily maximum, minimum and average temperature at station F. July - December 1969.

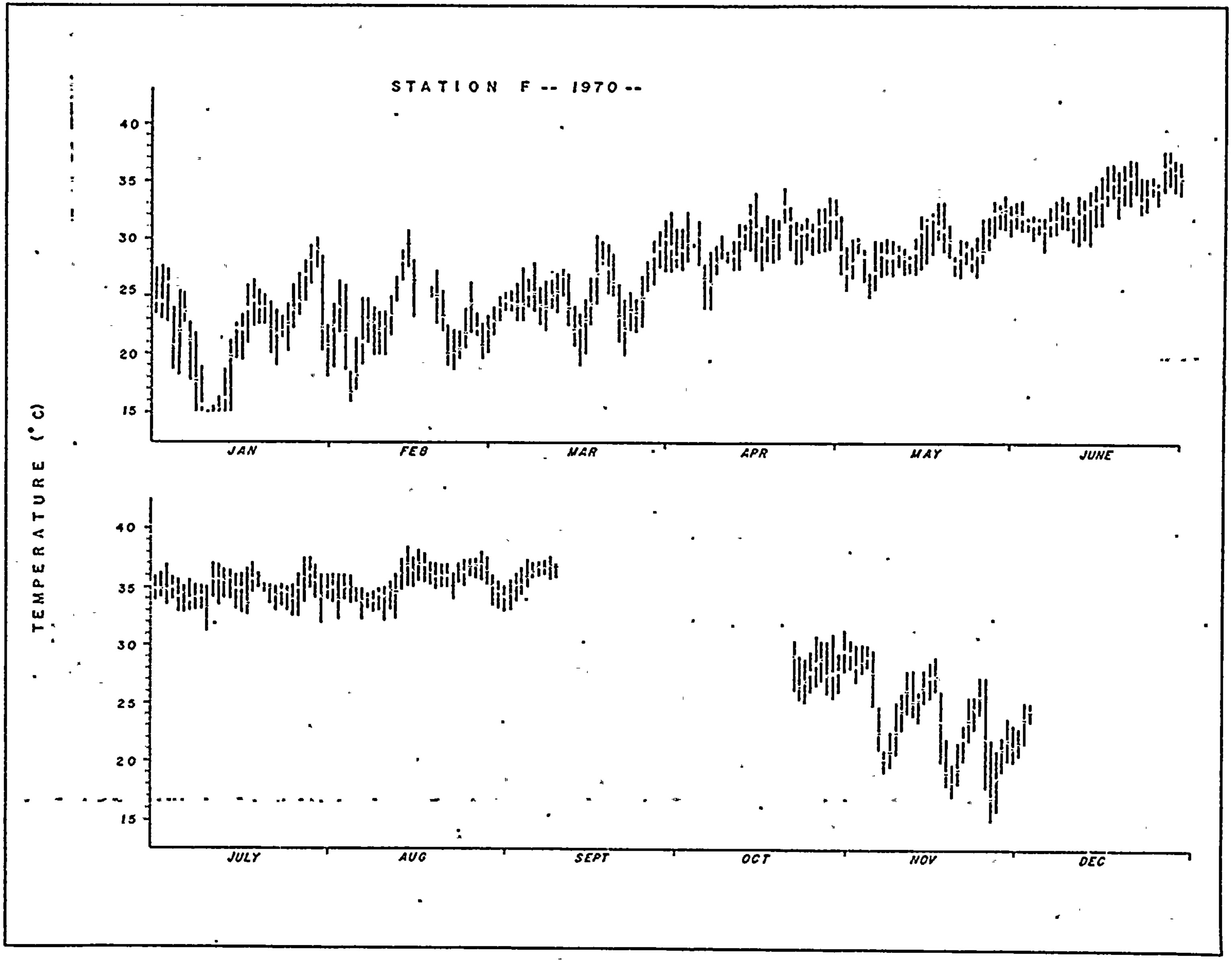

FIGURE II-28 Daily maximum, minimum and average temperature at station F. January - December 1970.

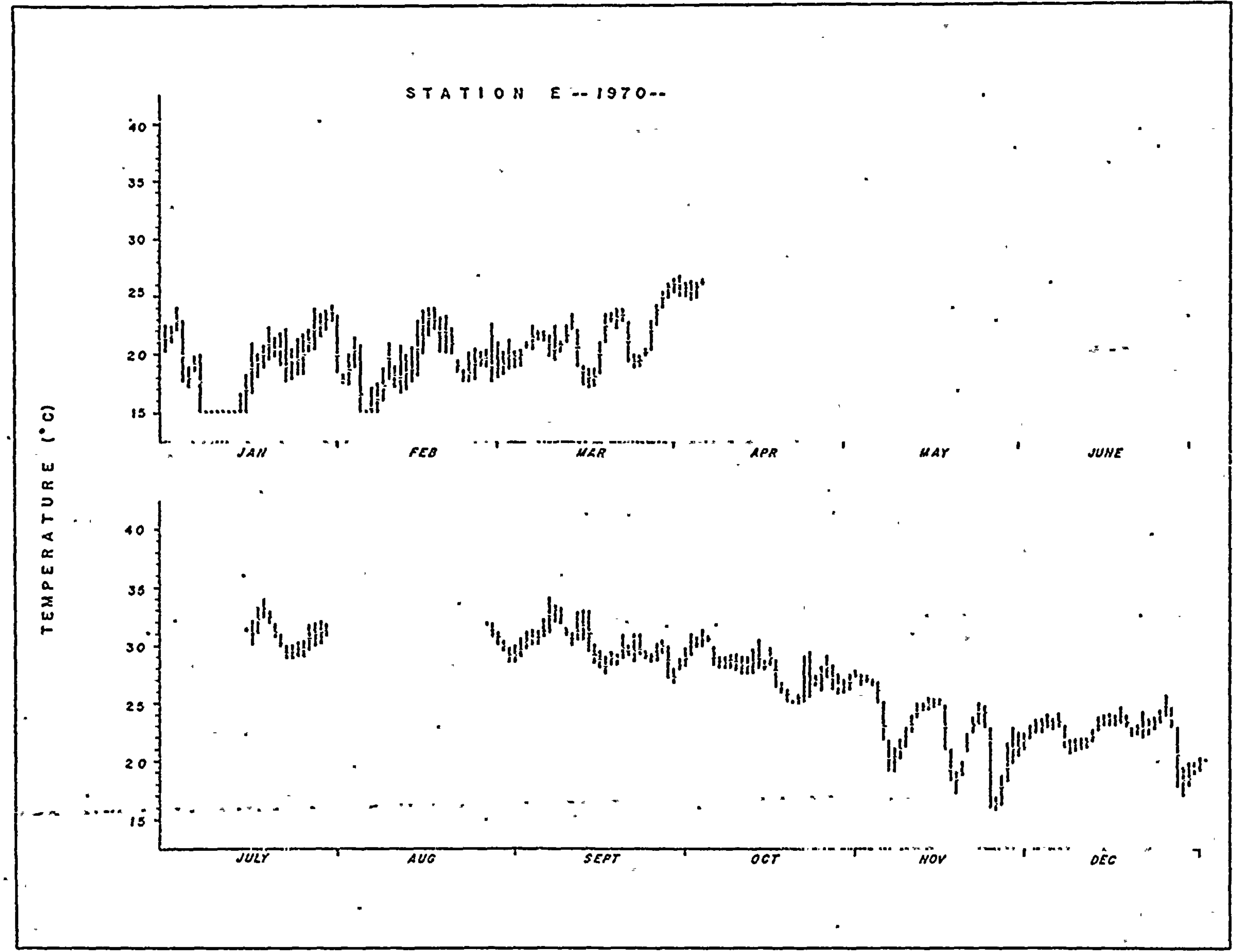

FIGURE II-29 Daily maximum, minimum and average temperature at station E. January - December 1970.

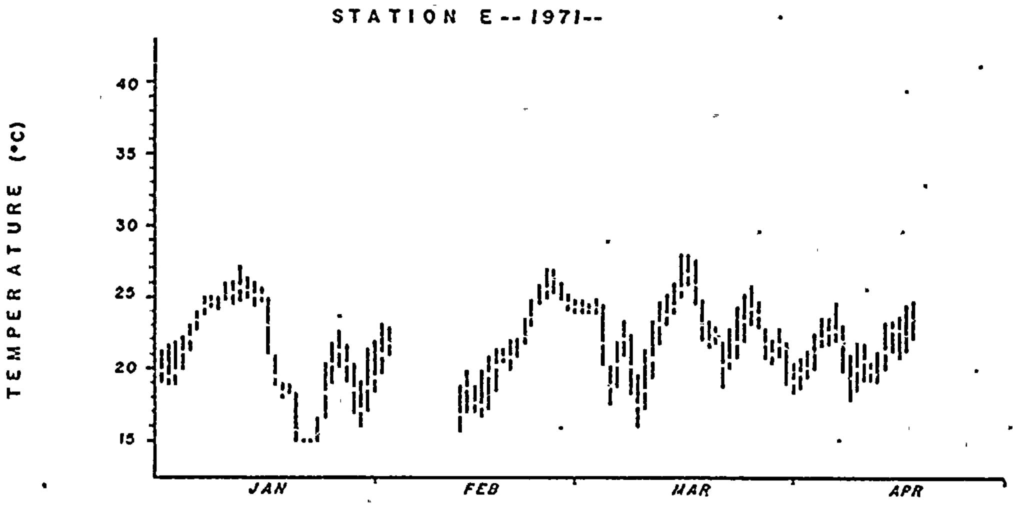

FIGURE II-30 Daily maximum, minimum and average temperature at station E. January - April 1971.

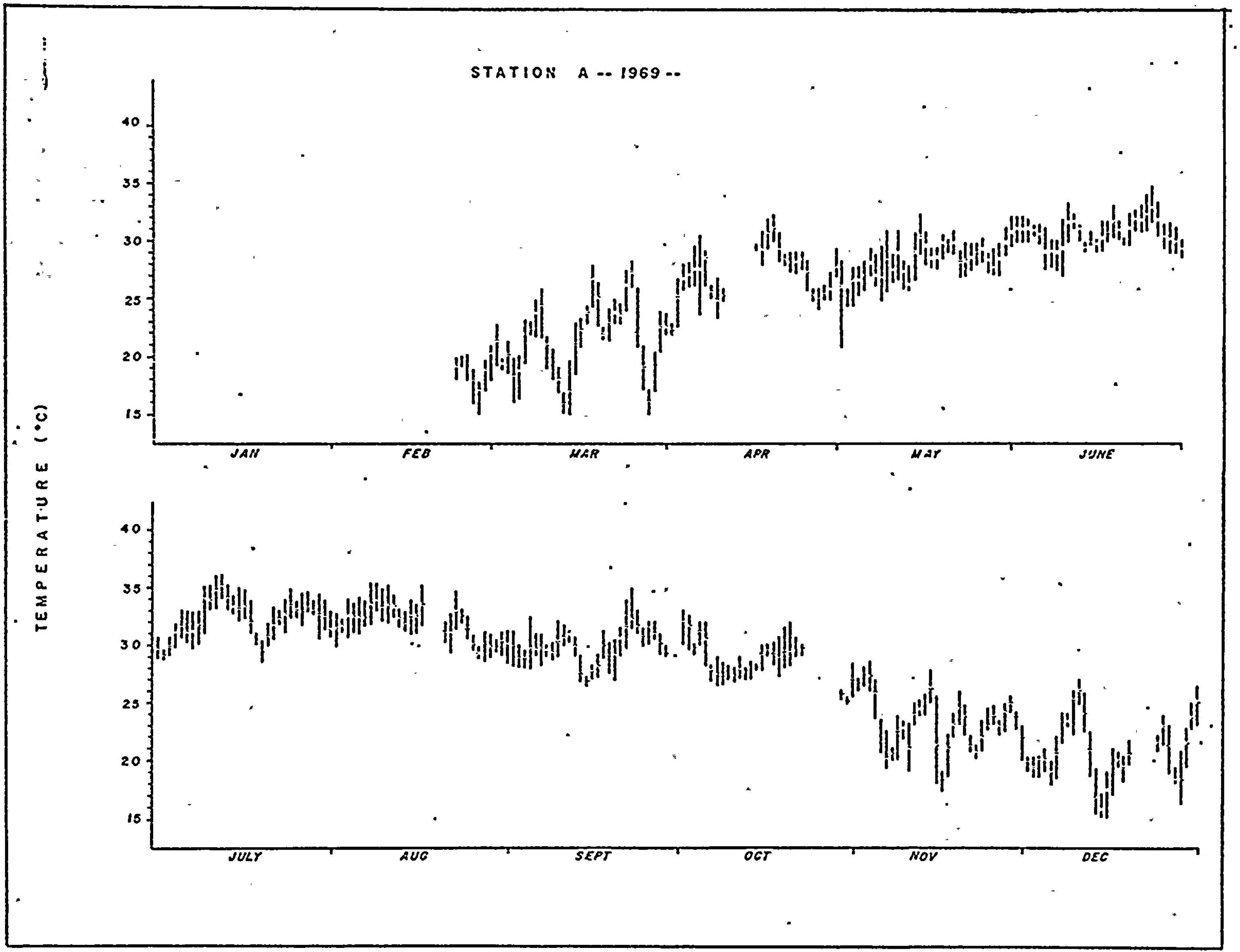

FIGURE II-31 Daily maximum, minimum and average temperature at station A. January - December 1969.

Temperature data for a control station (D) and several stations elevated above ambient are shown in Figures II-21 - II-32. The graphs show daily maxima, minima and mean based on 8 (3 hour interval) observations from Ryan continuous recording thermographs.

Thus, there is an apparent dilemma, for when bay temperatures increase greater dilution of the thermal effluent is needed which in turn reduces exchange with the ocean. The answer may be the recycling cooling pond, recently proposed by Florida Power and Light.

Modeling

Tidal Induced Mixing in Semi-enclosed Coastal Estuaries: A detailed understanding of estuarine mixing processes is becoming ever more important, as we begin to face the questions of management and protection of the coastal environment. The evidence gained from observing at close hand some of the complexities in Card Sound suggests a substantial anisotrophy in the mixing conditions, with mixing being enhanced in the direction parallel to the longer sides of the nearly rectangular basin. This direction coincides with the major flow of the tides.

It is well known from studies of exchange in the atmospheric boundary layer, as well as in shallow estuaries, that the combination of vertical shear in the mean velocity field, and vertical turbulent diffusion, leads to a horizontal dispersion effect, which can be described as an anisotropic diffusion process. As shown in a detailed treatise by Bowden (1965), this induced diffusivity is dependent on the velocity shear and on the vertical diffusion time scale in such a way that a stable stratification enhances the effect. This concept is obviously of profound significance for the analysis of pollution problems and for ecological applications in shallow tidal estuaries. Since it seemed to provide a qualitative rationalization for the observations, it was decided to undertake an attempt to extend the approach presented by Bowden (loc. cit.), together with simiiar considerations of the mixing effects due to frictional and inertial distortions of the tidal flow patterns, into a rational framework for the analysis of tidal mixing.

The fresh water tongue emanating from the Model Land Co. Canal (shown in Figure II-1) is maintained by drainage from an ill defined area of coastal low lands during the period of strong summer rains. Flow volume measurements for this period are not available but the fairly high salinity of the canal water (30°/oo) indicates a weak fresh water outflow. The shape of this tongue suggests a simple outflow pattern, however, from our analysis it appears that the dominant mechanism shaping the salinity distribution is the anisotropic diffusion effect induced by vertical shear of the tidal mixing.

For a detailed account of the problem of effective horizontal exchange in a shallow shear flow, the reader is referred to Bowden's (loc. cit.) treatise; here only the essential argument involved will be described. Consider a fluid layer of depth H, within which a turbulent shear flow of characteristic velocity U maintains a mixing process, defined by a vertical mixing time scale t_v. Let the distribution of a conservative property be defined by a scalar measure of concentration S. Suppose the vertically averaged concentration (sub-script S_o) is a linear function, $S_o = sx$. Now, the advection of the property is given by:

$$\int_o^H USdz = H\ [U_oS_o + \text{cov}(U,S)] \qquad (1)$$

U_o is the vertically averaged horizontal mean velocity. The covariance of U and S depends on the profile shapes, but the way the problem variables enter can be deduced by elementary considerations. Firstly, the characteristic fluctuations in S must clearly be of order SU_ot_v. If furthermore, the vertical exchange time scale to be determined is taken as the depth divided by the friction velocity, the following estimate is obtained:

$$\text{cov}(U,S) = -\ \mu C_D^{-\frac{1}{2}}\ |U_o|HS \qquad (2)$$

Here C_D is a coefficient dependent on such aspects of the physical situation as bottom roughness, Richardson number, etc. The covariance term (1) is thus seen to have the form of a diffusive flux, driven by the gradient.S, with a diffusion coefficient:

$$K_x = \mu C_D^{-\frac{1}{2}}|U_o|H = C|U_o|H \qquad (3)$$

In Bowden's (loc. cit.) study the combined coefficient C in the above expression, was found to range between 0.26 and 1.11, dependent on the assumptions made about the profiles, implying values of μ between 0.01 and 0.04.

If in equation (1) U_o is purely an oscillatory function of time, with zero mean value, only the diffusion term remains. Provided the diffusing property has only small effects on the density, asymmetric diffusion effect will ensue. From the form of the expression (2) it can be seen that the maximum displacement, an easily observed quantity, may be used to provide a first estimate of the mean diffusion coefficient. Denoting the displacement by L and tidal period by T gives:

$$T^{-1}\int_o^T |U_o|dt = 2LT^{-1} \qquad (4)$$

This estimate will not be degraded significantly by the fact that the assumption of profile similarity is likely to break down for low values of the velocity. Using C = 0.6 as a reasonable value based on Bowden's results, the following expression for the apparent time averaged diffusion coefficient follows:

$$K_{av} = 1.2LHT^{-1} \qquad (5)$$

Now LH is the water volume displaced between ebb and flood, or tidal prism per unit coast line length. Thus, the simple rule of thumb for tidally induced mixing results: The equivalent diffusivity is approximately one tidal prism per tidal cycle.

If the variations in Richardson number are not negligible, an asymmetry ensues, with enhanced horizontal mixing effexts during the stably stratified phase. If one is concerned with the diffusion of the density determining property, the most important aspect of this is the possibility of a breakdown of the uniform turbulent regime. Since the vertical mixing time t_v, must be much shorter than the tidal period for these arguments to apply, one must exercise some care in the extension of the simple mixing theory to cases involving substantial density fluxes.

The diffusion in the cross current direction is given solely by the turbulence in the stream. In the neutral case, symmetry between vertical and cross stream mixing is to be expected, but stable stratification will lead to enhancement of the lateral mixing due to the horizontal spreading of decaying eddies. Bowden estimates the cross stream diffusivity at most a few percent of the streamwise diffusivity as long as the stratification is sub-critical.

Another type of induced mixing due to inertial effects on the flow will arise in the vicinity of inlets. The incoming tide may give rise to a jet-like motion, while on the falling tide the flow towards the inlet is likely to be similar to an ideal potential flow towards a sink. The net results, when averaged over a complete tidal cycle, is a mean circulation corresponding to a double vortex sheet along the edges of the widening jet. A first order estimate of the penetration distance of such a jet can be made in the following manner.

Let M_O be the momentum flux through the mouth of the inlet. Let further the width of the jet be L, its characteristic velocity U, and the bottom friction $C_d U^2$. Using further the standard type of linear entrainment law, which has been found experimentally to work in most cases of turbulent jets, gives the following equations governing mass and momentum flux in the jet:

$$\frac{\partial}{\partial X} LU = \varepsilon U \tag{6}$$

$$\frac{\partial}{\partial X} LU^2 = - C_D H^{-1} LU^2 \tag{7}$$

H is again the depth of the fluid, X is a horizontal coordinate in the shear direction and ε is the entrainment constant. These equations can be immediately integrated, to give:

$$L = (L_o t \frac{\varepsilon H}{C_D}) \exp(C_D X H^{-1}) - \varepsilon H C_D^{-1} \tag{8}$$

where L_o is the initial width of the current. Note that the result is independent of the momentum flux. It is, however, naturally dependent on the momentum flux exceeding some critical value required to provide a significant inertial effect. It is concluded that significant inertial effects will be limited to a region of approximate radius of about 500 H inward from an inlet. The strenth of the induced circulation is defined by the asymptotic transport rate estimate:

$$LU \rightarrow L_o U_o (1 + \varepsilon H C_D^{-1} L_o^{-1})^{1/2} \qquad (9)$$

By setting C_D^{-1} at about 100, and the inlet width L_o at about 20 H, the asymptotic transport will be nearly two and a half times the discharge. This appears approximately as a doublet field with a source sink separation of the same order as the penetration distance of the jet. Its effects will be limited to a region of the similar linear dimensions. Thus, a semicircle is roughly defined with a radius of 500 H as the region of inertial mixing at each inlet narrow enough to produce noticeable jet effects.

A simple laboratory system for demonstration of this type of inertially induced circulation was developed by a high school student, Mr. Fellman, under a cooperative laboratory study program with Dade County Public School System.

A Method for Estimating Thermal Anomaly Areas: The accurate prediction of water temperatures in estuaries under different thermal loading conditions is hampered by several fundamental difficulties; first, basic knowledge of the heat transfer processes is only qualitatively satisfactory. But even with a perfect quantitative theory, the number of parameters influencing the problem, and which have to be observed or themselves predicted, precludes precise analysis without a substantial data gathering effort. It is frequently of interest to consider not the actual temperature, but its deviation from what it might have been without the thermal discharge under consideration. A perturbation analysis is now being undertaken. This is a task which can be carried through in general with a much greater degree of precision than the determination or prediction of absolute temperatures. If, as is frequently the case, one is primarily concerned with the problem under conditions where the environmental mean temperature is already quite high, the tasks is further simplified due to the increasing predominance of evaporation as the main cooling process.

The graphical approach to the determination of heated areas which is presented herem is intended to provide a first quick look guidance in design considerations. Because it deals only with the prediction of surface area associated with certain thermal anomaly levels, it cannot be used alone for the consideration of problems where, for example, ecological impact on bottom dwelling, benthic communities is involved. The basic physical concept underlying the approach is that since the cooling is a surface process, the rate of heat loss, which has to balance the excell thermal loading, depends only on the surface area distribution of thermal anomaly, and not at all on the thickness of the warm layer. The latter only adds thermal inertia to the system, I.E. determines rate of reaction to changes in loading, or ambient conditions.

The prediction of water temperature is based on the principle of thermal energy conservation, expressed as a balanced heat budget, where various physical processes acting on the system are identified by corresponding items in the balance sheet. By considering a shallow layer of water, perhaps of variable depth, flowing out from a source at a discharge rate q (volume/unit time), and with some initial temperature T_σ, the problem of combining the ensuing variable velocity distribution with temperature change predictions into a theory for the distribution of temperature anomalies seems a formidable task at first sight. But some simple physical considerations suggest that one part at least of the problem may be simpler than expected. Consider what happens to the temperature of flowing water, if a constant rate of heat transfer occurs at the top surface.

The heat capacity of the column is proportional to the depth. The rate of cooling of the water, like the flow velocity at fixed discharge rate, is thus inversely proportional to the depth. It follows that the downstream temperature gradient is uniform, and independent of the local depth, and flow velocity. Now a general formulation extending this argument to arbitrary flow geometries is presented.

A steady state flow pattern, where an initial temperature anomaly decreases gradually away from the source is first assumed with the steady temperature field described by a set of isothermal curves. If the vertically averaged vector velocity is V, and the component perpendicular to the local isotherm is V_n, then the total volume flow across the isotherm is:

$$q = \int_{T = \text{const}} hV_n ds \tag{1}$$

where h is the local depth, q the prescribed discharge rate and T is constant. The heat advection rate Q_a across the same isotherm is:

$$Q_a(T) = \int_T c\rho ThV_n ds = c\rho Tq \tag{2}$$

Now, the divergence of the advection of heat must balance the surface exchange rate:

$$\frac{dQ_a}{dT} + \frac{dQ_s}{dA} \frac{dA}{dT} = 0 \tag{3}$$

Here A(T) is the surface area enclosed by the corresponding isotherm, and Q_s is the total heat loss rate over the same area. Elimination of the heat advection term between the last two equations finally gives a differential equation for A(T):

$$\frac{dQ_s}{dA} \frac{dA}{dT} + c\rho q = 0 \tag{4}$$

An approach to the determination of Q_s must now be found. As indicated above, this is in general a task which can be carried out only subject to severe approximations. But if it is postulated that the ambient environmental conditions are only slowly varying, then it may be assumed that the environmental exchange would balance out at any one point, if the temperature were equal to the ambient temperature, and if the heat advection effects were neglected. Consequently, it is concluded that in the complete heat budget, the latter must be balanced by the perturbation in surface heat exchange, due to the surface temperature anomaly relative to the ambient conditions. It is, thus, formally expected to be able to find a law governing Q_s of the form:

$$\frac{dQ_s}{dA} = F\,(T-T_a, X_i) \tag{5}$$

where X_i denotes a set of parameters defining the ambient exchange conditions, and T_a the ambient equilibrium temperature. The wind speed U, defined at a suitable reference level, and T_a, are the main parameters to consider.

An important assumption underlying our arguments is of course that it is meaningful to define an unpertubed ambient condition, as a reference state. It is implied, that the thermal perturbation studied is small enough in its intensity and geographic extent not to influence appreciably the meteorological processes outside a thin boundary layer along the surface. Incoming radiation fluxes and the ambient wind conditions may then be taken as being controlled by other processes and independent of the thermal perturbation field. There remain, in the heat budget balance sheet three items sensitive to the actual surface temperature, namely the latent heat used in evaporation of water, the sensible heat transfer by convection and the outgoing infra-red radiation. Since the first two processes both depend on turbulent transfer, they are treated together. In full appreciation of its limitations, c.f. e.g. Kraus (1969), the bulk transfer coefficient method of estimating the fluxes is used. The evaporation ξ, and the sensible heat flux S, are given by:

$$\xi = C_D U \rho_a \frac{\partial x_s}{\partial T} (T-T_a)$$

$$S = C_D U \rho C_p \quad (T-T_a) \qquad (6)$$

with C_D = drag coefficient (1.4×10^{-3}), U = wind speed at reference level, ρ_a = density of air at ambient temperature and pressure, X_s = saturation mixing ratio for water at T_a, and C_p = specific heat of air at constant pressure.

The heat loss associated with the evaporation is found by multiplying the evaporation rate by the latent heat of evaporation L, thus allowing us to write the sum of sensible plus latent heat fluxes H, as:

$$\begin{aligned} H &= S + LE \\ &= U C_D \rho_a [C_p (T-T_a)_o + LX_s(T) - LX_s(T_a)] \\ &\approx UC_D \rho_a [C_p + 0.06LX_s] \quad (T-T_a) \qquad (7) \end{aligned}$$

The sensible heat flux, represented by the first term C_p, in the square brackets contributes only about 20% in the range of temperatures considered here. This is barely significant, considering the uncertainties involved in the application of the bulk aerodynamic flux method. Since the effect is systematic, it should be included in computations. However, for the purpose of analytical calculations, the temperature dependence of H will be represented by a simple exponential expression. This corresponds to the use of an "equivalent evaporation potential", based on an adjusted saturation mixing ratio x'_s, and a weaker temperature dependence of ca 5% per C, as compared to ca 6% per C for the water saturation curve. Our simplified expression for H is then:

$$H = UC_D \rho_a L x'_s \; [\exp 0.05 \; (T-T_a) - 1] \qquad (8)$$

The allowance for radiation effects can be developed along the same lines. A nomogram approach is being developed including all of these effects in a heated area estimates at constant wind speed of 10 knots, or ca 5 m/sec has been derived and compared with data from Turkey Point. Figure II-33a gives a set of curves for various discharge rates, evaluated for evaporation alone. Temperature scale can be read in any units, since the decay is exponential. The dashed lines represent the effect of dilution of initial water flow (in parenthesis) to twice the original volume, thus, halving the temperature anomaly. It should be noted that the anomaly areas are identical by the time the temperature excess is down to of the outfall temperature anomaly. Beyond that point, increased flow rate makes the heated area larger for the diluted flow situation than without dilution. For an initial flow of 600 ft^3/sec, Figure II-33a gives the following:

	Discharge	Initial Temp. Excess	Transition Temp.	Transition Area
Undiluted	600	6°		
2x dilution	1200	3°	1.5°	580 acres
4x dilution	2400	1.5°	0.94°	770 acres

The transition point is the point at which the dilution causes an increase rather than a decrease in heated area. For comparison, Figure II-33b presents data on plume areas from IR surveys made on August 5, 1968 at Turkey Point. The discharge rate typical at this time was ca 1230 ft^3/sec. This line is similar to the 1000 ft^3/sec line on Figure II-33a, although agreement appears satisfactory, further information is necessary to establish its prevailing nature. It should also be kept in mind, that excessive initial dilution may lead to enhanced circulation perturbations. A balancing of the different factors is therefore essential in design considerations for cooling water circulation.

SUMMARY

This year a systematic data collection program was initiated, it consisted of intensive seasonal measurements with instrumented towers and synoptic surveying of temperature and s[illegible]. These activities were closely coordinated with the data collection programs of the U. S. Geological Survey and U. S. National Park Service.

Initial results show that Card Sound and South Biscayne Bay are poorly mixed by tidal action alone. Tidal exchange between these embayments and the ocean is restricted to a small area on the eastern side near Caesar, Broad and Anglefish Creeks and has a time scale on the order of a few days. The central and western sections of Card Sound exchange with South Biscayne Bay and Barnes Sound due to longitudinal reversing tidal currents with maximum speeds of about 20 cm/sec. Exchange between the interior and the ocean is believed to be enhanced by wind stirring. Passage of cold fronts with winds greater than 6 m/sec, with a duration of at least one tidal period are believed to mix the interior and set up a mean circulation that transports interior water in a southerly direction and out the inlets, thus, increasing the flushing rate.

These initial investigations suggest that a mean flow of the magnitude

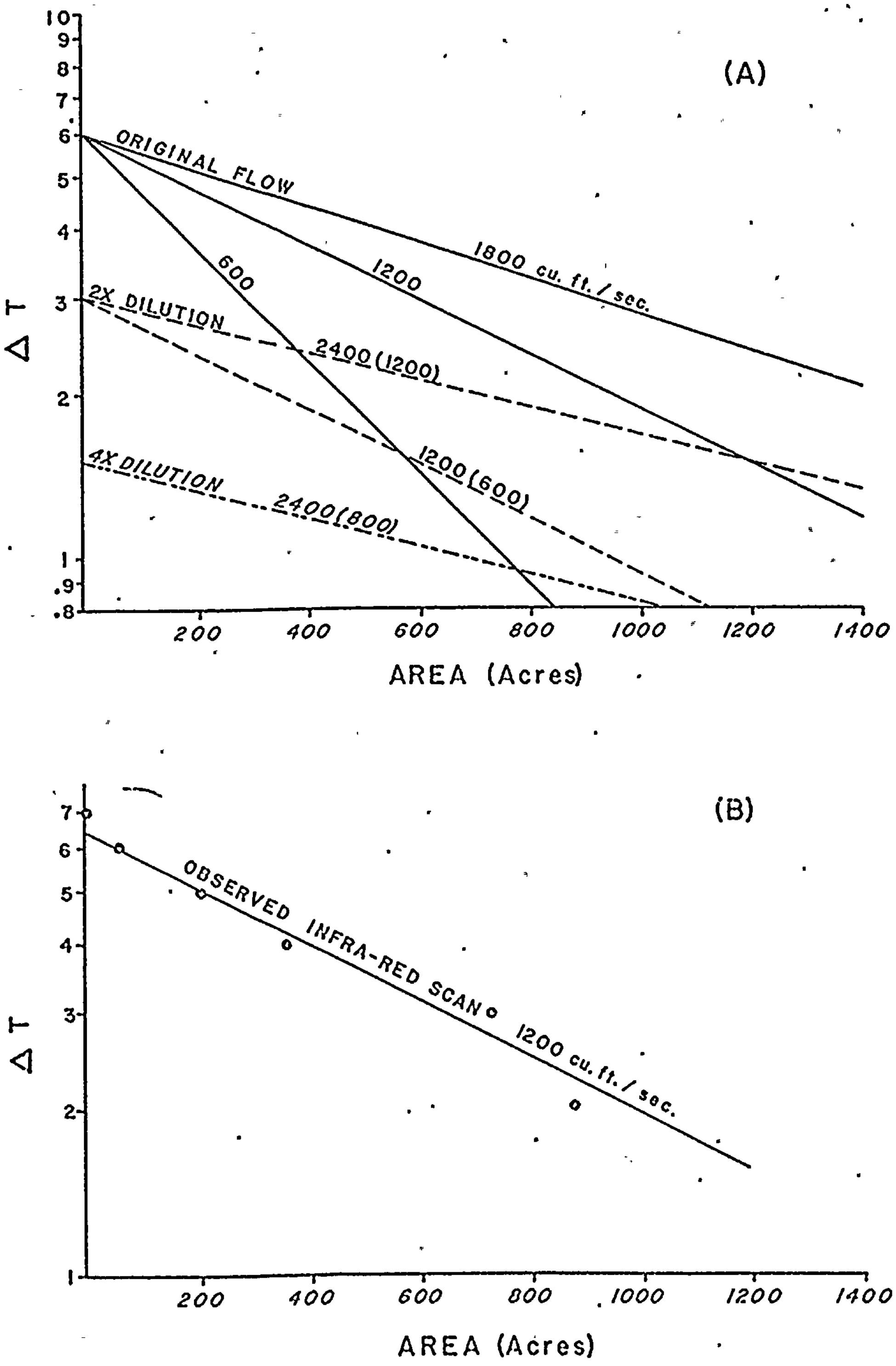

FIGURE II-33 Temperature - area observations and predictions with various dillution schedules for the Turkey Point effluent.

III. BOUNDARY CONDITIONS *

GENERAL STATEMENT

This phase of the work is based on the premise that circulation in an area such as that affected by the Turkey Point Plant can be directly correlated to water surface elevations, surface stresses and bottom stresses.

Water surface elevations result from the astronomical tide coupled with the effects of wind and the geometry of the system. Differences in these elevations, along with surface stresses caused by wind, drive the circulation which is impeded by bottom friction.

Therefore, if these effects are correlated for a variety of conditions, a simple model of the system utilizing only variables that are easy to measure can be developed. These are: a) water surface elevations, b) astronomical tide, and c) wind velocity and direction.

To orient the investigative efforts along the most productive lines possible, two distinct but related areas of study have been selected: the shoals and inlets, and the relatively deep, large basin areas. Over the shoals and in the inlets, velocities are generally high and bottom stresses are significant in the fluvial relationships. On the other hand, as these areas are relatively small, surface stresses are much less important. The basins having much larger areas and volumes are significantly affected by the wind and tide and much less by bottom stresses except as they contribute to wind set-up. Differences in the water surface elevations between basins provide the driving force for the circulation in the inlets or shoals connecting them. Figure III-1 shows the divisions between the basin and shoal-inlet areas.

METHODS

Inlet Studies

For the study of shoals and inlets, the Broad Creek, Angelfish Creek and Old Rhodes Channel complex connecting the Atlantic Ocean to Card Sound was selected as the first to investigate. As this is by far the most complicated area, methods developed for modeling it would be likely to apply elsewhere.

Taylor (1971) applied a system based on Manning's formula to this inlet. This system originally utilized by Michel (1968) for studies of Bear Cut divides an inlet into a series of areas on a grid system. The size of the areas depends upon the geometry of the inlet or channel. The resistance of the areas to flow is calculated by means of Manning's formula and integrated over the width and length of the channel to determine a coefficient of resistance "k" so that

$$\Delta n = kQ^2$$

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* J. F. Michel

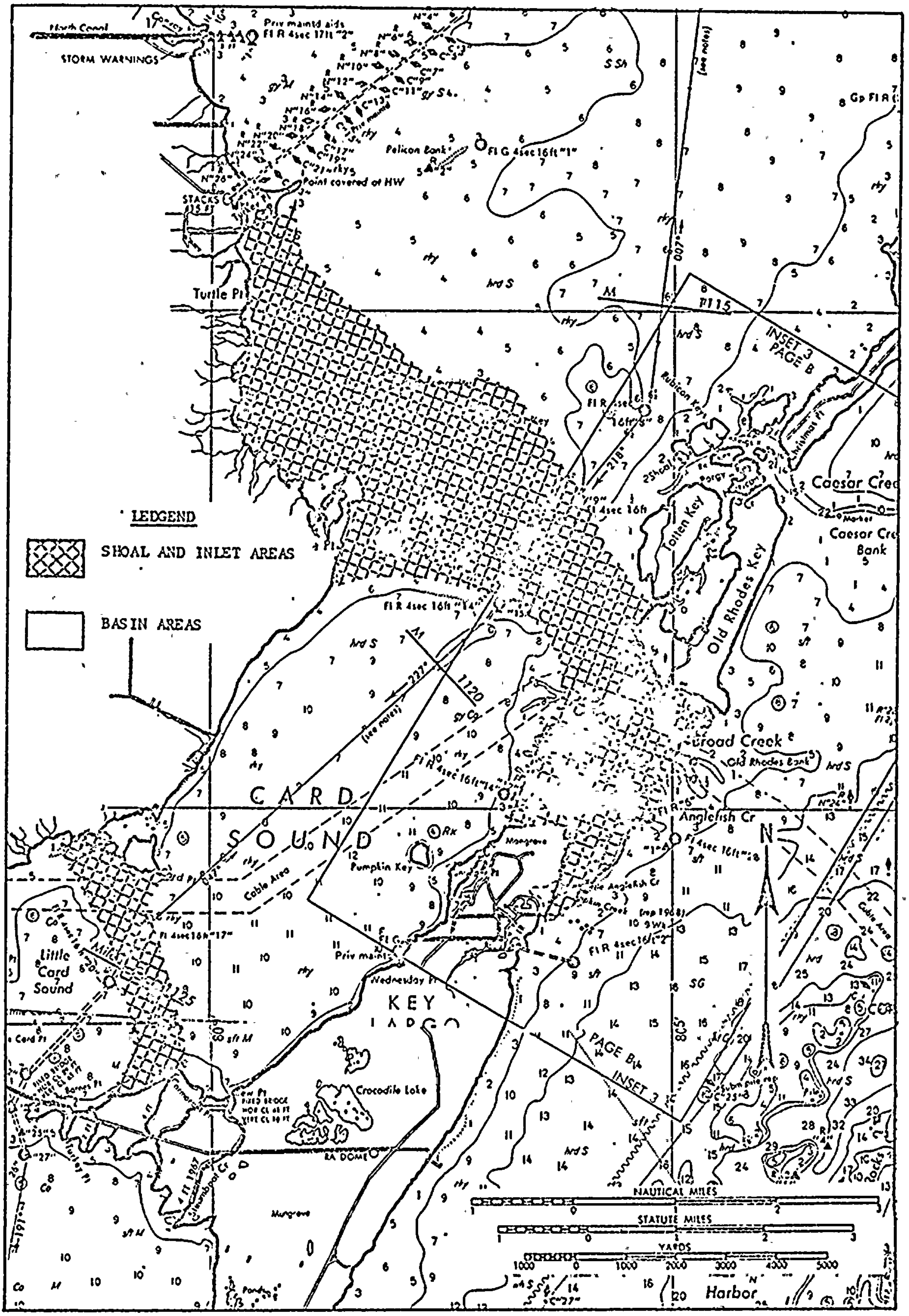

FIGURE III-1 Area map showing inlets and basins

where: Δn = difference in head between ends of the channel in ft. and Q = total flow through the channel in ft^3/s.

The inlet studied consisted of a group of 46 separate interconnected channels having resistance coefficients varying from $.25 \times 10^{-9}$ to 13.798×10^{-9} s^2/ft^5 (see Figure III-2). A standard computer program utilized for flow in pipes was modified to analyze this network at varying stages of the tide in the ocean and in Card Sound.

A limited amount of field work was done to check the calibration of the model by the occupation of selected stations. At these stations, current velocity and direction were measured. Data on water surface elevation was obtained from the Coastal and Oceanographic Engineering Department of the University of Florida which had tide gauges in operation at the time.

Basin and Wind Stress Studies

In studying the basin areas, it was decided to concentrate efforts on the water surface elevations with special emphasis on their relationship to the speed and direction of the wind. If the water surface elevation at both ends of an inlet can be determined accurately for a variety of conditions, flow through the inlet can be predicted.

The effect of wind can best be related to water surface elevation by utilizing a wind stress parameter which is commonly used in studies of wind set-up. This parameter, the product of the wind speed and its component in a selected base direction, is commonly used in studies of wind set-up. On enclosed bays and lakes the base direction giving the best correlation with set-up is toward shore. On the shore of the open ocean, the component parellel to the shore must also be considered due to the Coriolis effect of the along-shore current. A study of this relation for the Miami Beach Tide Station was made by Fisher (1968) of conditions prior to and during Hurricane Betsy as a thesis project under the direction of this investigator.

Prior to the commencement of this project the investigator with the help of funding under the Sea Grant Program had managed to assemble considerable data already available for the area. These data consisted of wind speed and direction as recorded by the Weather Bureau at Miami International Airport and by the Florida Power and Light Company at Turkey Point as well as copies of actual charts for nine tide gauges utilized by Schneider (1969) of the U. S. Geological Survey in his excellent study of tidal relations in the area. Hourly gauge heights for the National Ocean Survey master tide gauge at Miami Beach were also available (see Table III-1).

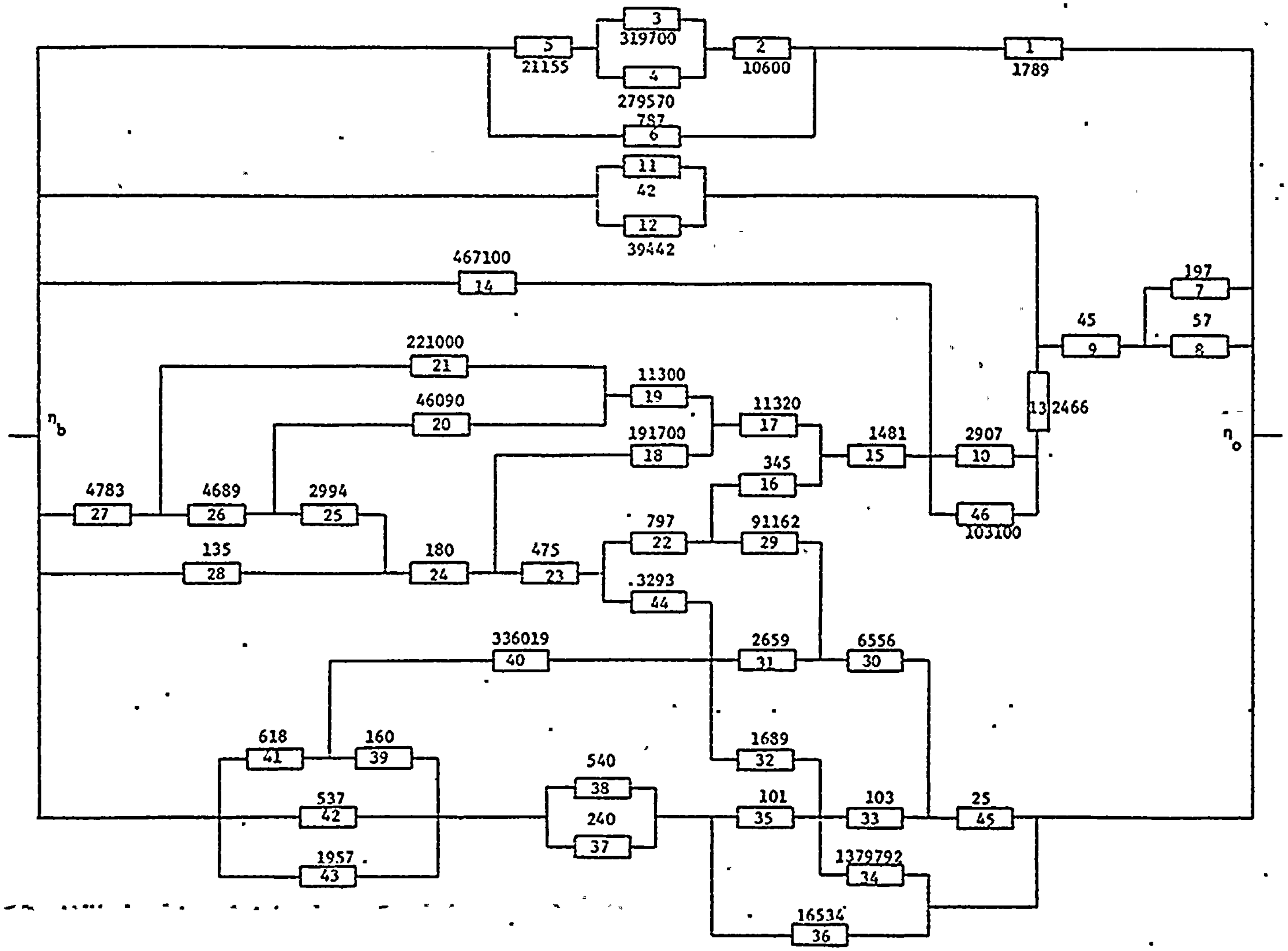

FIGURE III-2 Flow resistance network model for the Broad Creek, Angelfish Creek, and Old Rhodes Channel complex

TABLE III-1

TIDE GAUGE STATIONS

1. Miami Beach Primary Tide Station (U. S. Coast & Geodetic Survey)*
2. Biscayne Bay at Coconut Grove
3. Biscayne Bay at Key Biscayne
4. Cutler Drain at Structure 123 (Central and Southern Florida Flood Control District)
5. Biscayne Bay near Homestead
6. Biscayne Bay at Elliot Key
7. Card Sound at Model Land Canal
8. Barnes Sound at Card Sound Road
9. Manatee Bay at Canal 111
10. Garden Cove on Key Largo (ocean)

Originally it was intended to deduce the components of the astronomical tide by analyzing records of water surface elevations during periods of low wind stress. From these the astronomical tide during periods of high wind stress could be separated from the actual water surface elevation to give the wind set-up for correlation with the wind stress. In February 1971 it became evident that this program was too ambitious for the limited funds available. Therefore, a more direct, if less thorough, approach was sought.

Screening of the tide charts showed that during the period 1-7 June 1968, extremely high and extremely low tides occurred at all stations. The wind records for the same period showed a slow but steady increase in velocity to 30 miles per hour from a generally easterly direction, a shift during a 24-hour period to the southwest and then a steady decline in velocity. This wind pattern was caused by the passage, at a considerable distance to the west, of tropical Hurricane Abby which had a typical cyclonic wind circulation. Rough plots and curve fittings by visual means confirmed that the variations in the mean tide level were closely in phase with the wind stress. It was therefore decided to concentrate effort on the period 1-7 June 1968 to relate water surface elevations to wind stress.

About this time an APL terminal connected to the University Computer Center became available; this system allows the storage and processing of data from a typewriter terminal. The language is extremely simple and powerful

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* Unless otherwise noted, all gauges were operated by the U. S. Geological Survey.

and a good selection of programs for statistical analysis and plotting is available.

To develop and test the plan for processing the data, a library was loaded with hourly values for wind speed and direction at Turkey Point and hourly tide gauge readings for Miami Beach, Elliott Key, Homestead, Card Sound and Barnes Sound. Tri-hourly wind readings for Miami International Airport were also entered. Programs were developed to select data for any period of time and to convert wind speed and direction into a wind speed parameter related to any selected direction.

Initially one data point was selected for each six hours of record and the wind stress from 90° (East) was computed. In order to filter short term fluctuations a least squares fit to a fifth degree polynomial was made. A curve of actual values and the fitted data is shown on Figure III-3.* The astronomical tide was filtered by the same method from readings of the Card Sound Tide Gauge giving Figure III-4.

It was immediately seen that the filtered values of wind stress and water level were closely related in phase and that the maximum variation occurred during the second 48 hours of record (0100 3 June to 2400 4 June). Hourly data during this period were analyzed in the same manner to give the curves shown on Figure III-5 and 6. In addition, the net average hourly flow into Card Sound and differences in elevations between the Ocean and Card Sound are shown on Figure III-7.

At this point it should be stressed that the tidal data had not all been correlated to the same datum, nor was it related to mean half tide as determined by Schneider (1969). Therefore, trends are shown accurately but absolute values are not.

RESULTS AND DISCUSSION

Inlet Analysis

So far, only the inlets between the ocean and Card Sound have been studied. Values obtained for the tidal exchange through these inlets are in accord with those obtained by the Department of Coastal and Oceanographic Engineering of the University of Florida in a separate study as shown by Dean (1970) and presented in Table III-2.

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*On Figures III-3 through 7 the circles represent actual data points. The line of asterisks shows a least squares fit to the data.

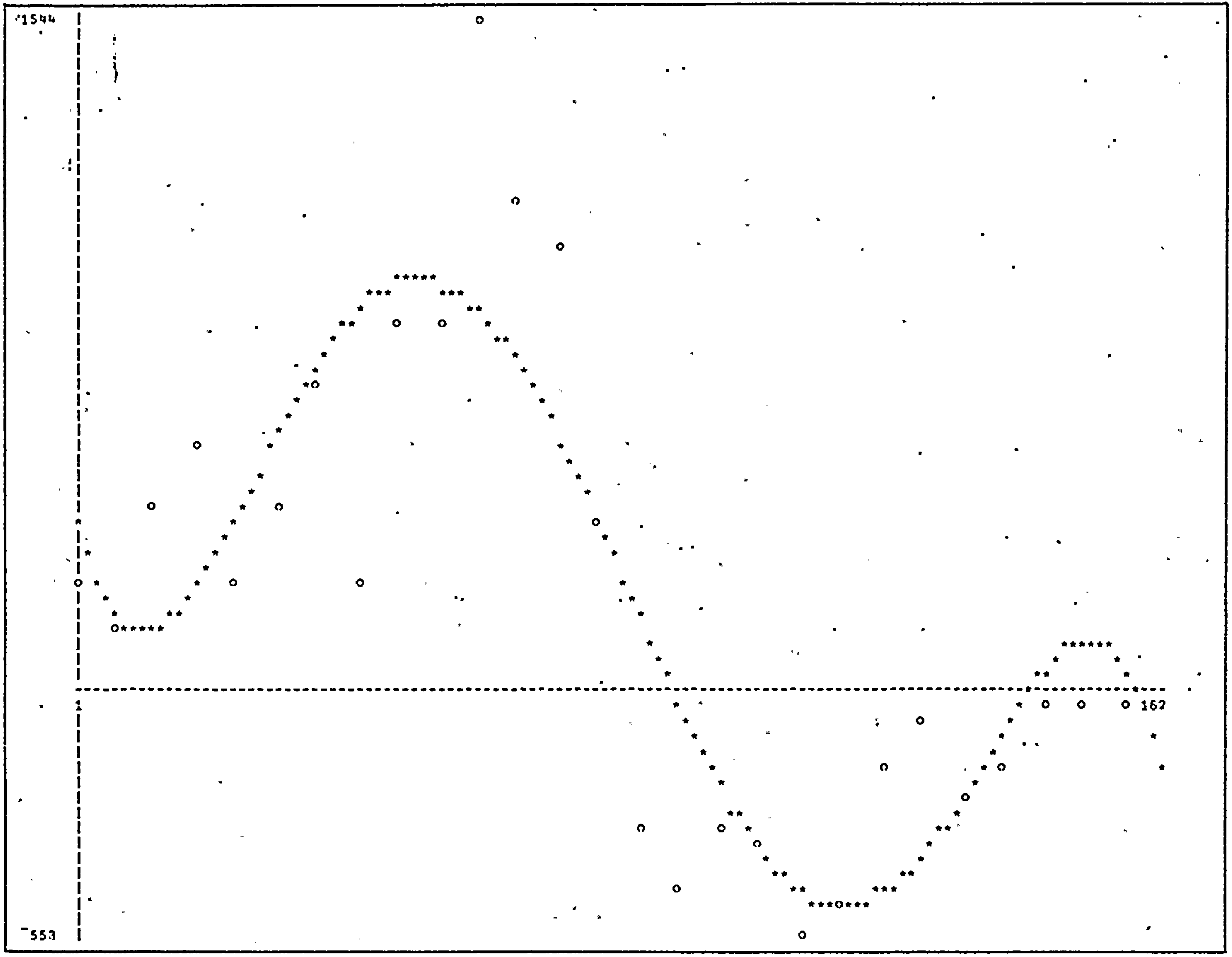

FIGURE III-3 Wind stress parameter at Turkey Point from 0100 1 June to 1800 7 June 1968

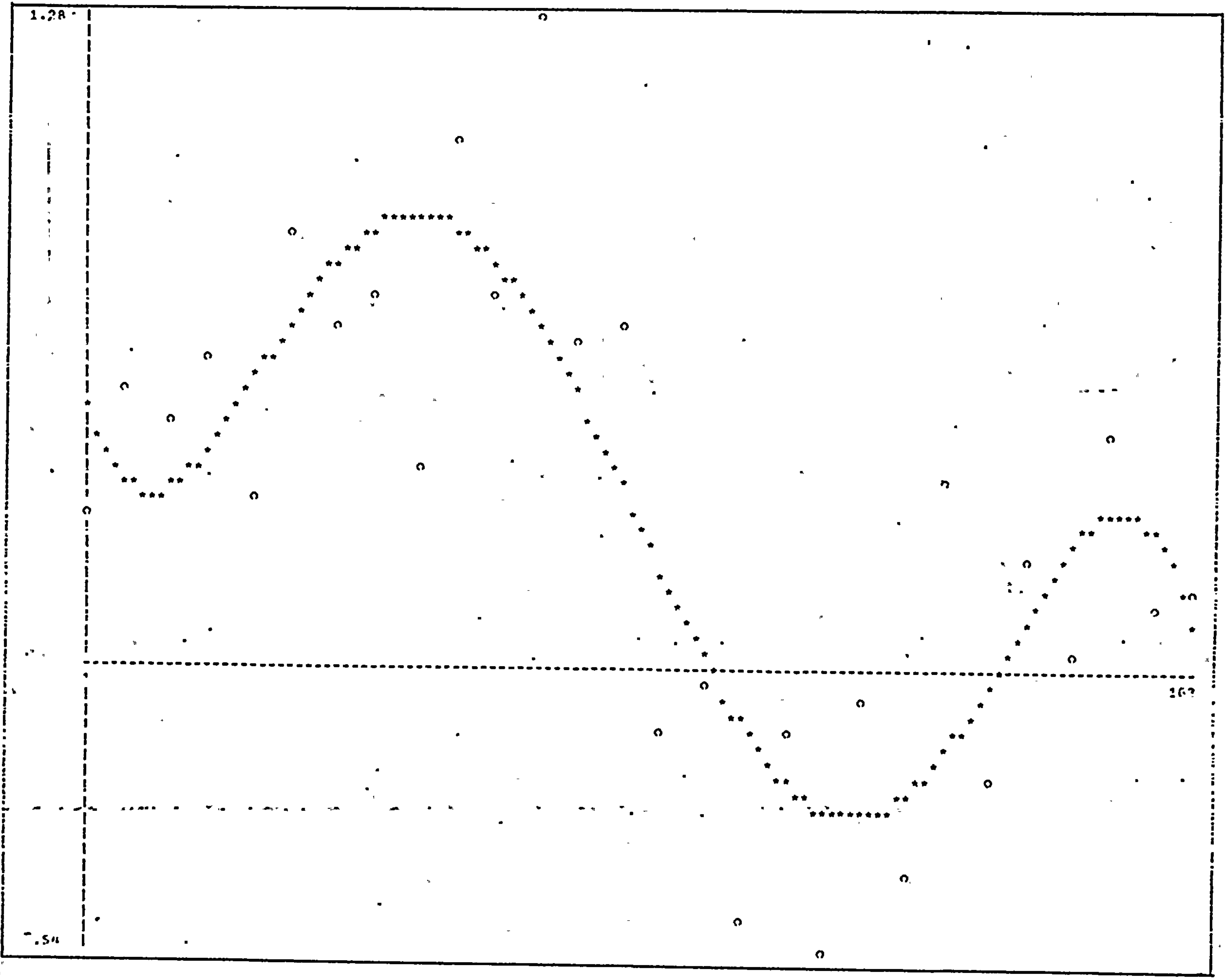

FIGURE III-4 Water surface elevation at Model Land Company Canal, Card Sound from 0100 1 June to 1800 7 June 1968

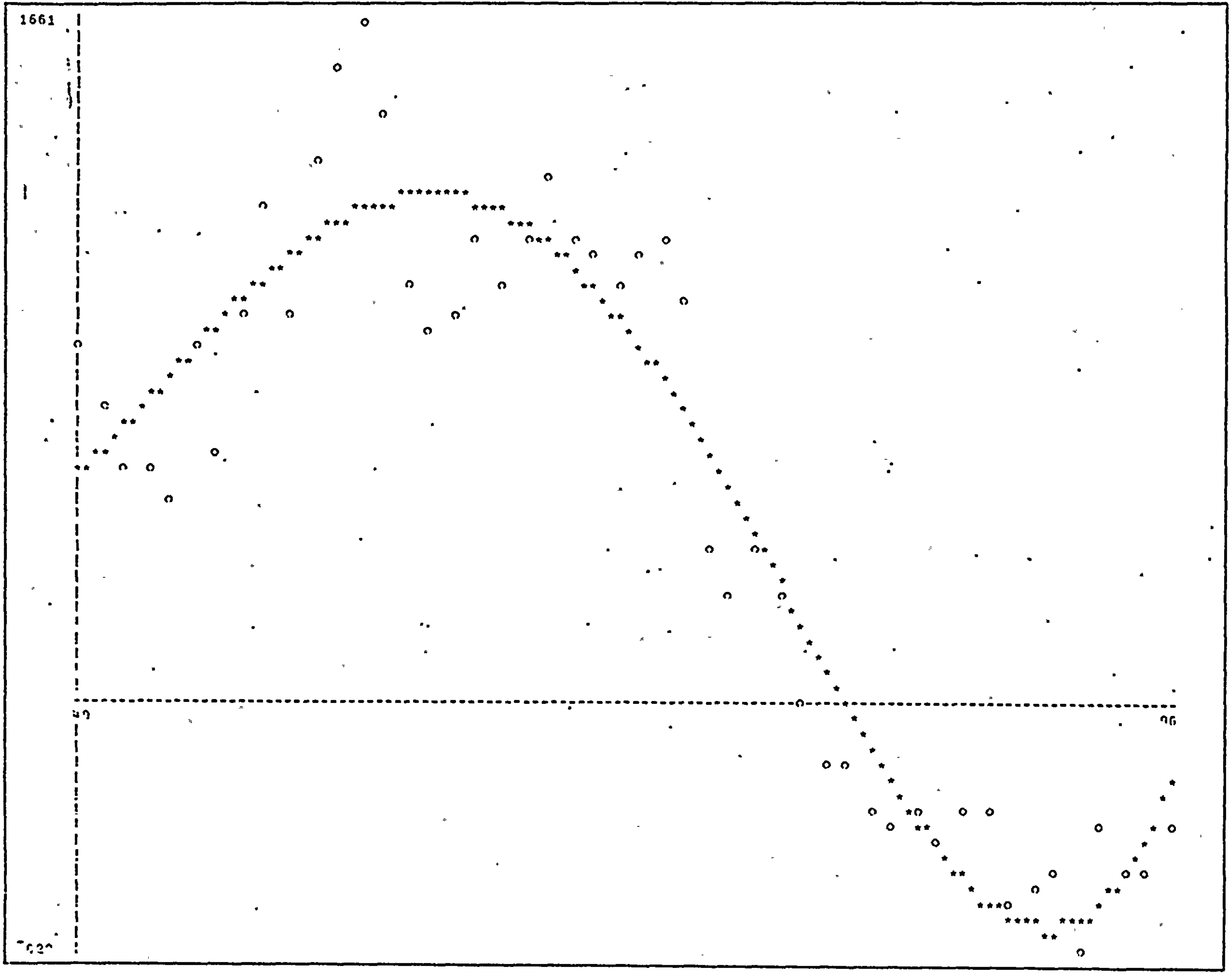

FIGURE III-5 Wind stress parameter at Turkey Point from 0100 3 June to 2400 4 June 1968

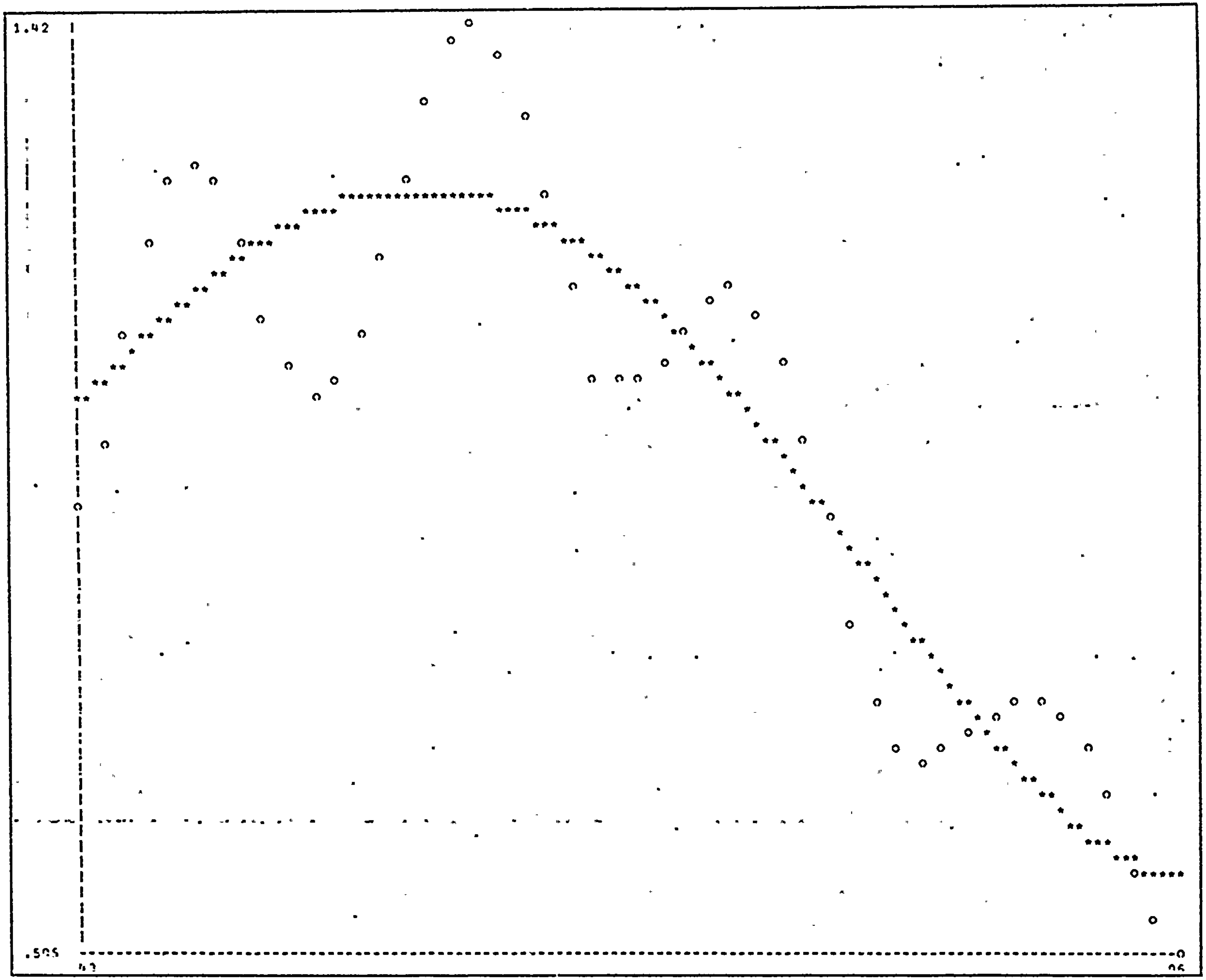

FIGURE III-6 Water surface elevation at Model Land Company Canal, Card Sound from 0100 3 June to 2400 4 June 1968

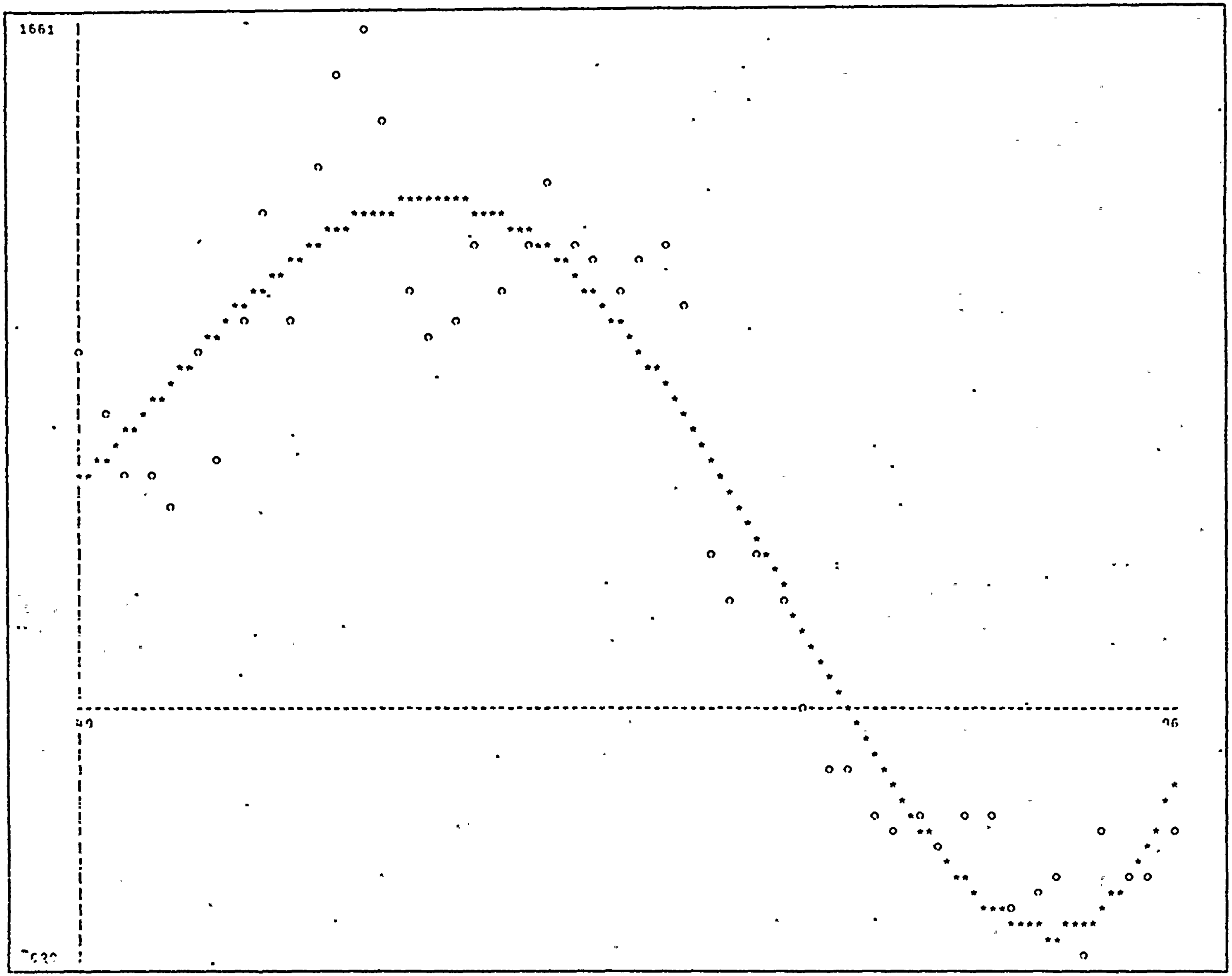

FIGURE III-5 Wind stress parameter at Turkey Point from 0100 3 June to 2400 4 June 1968

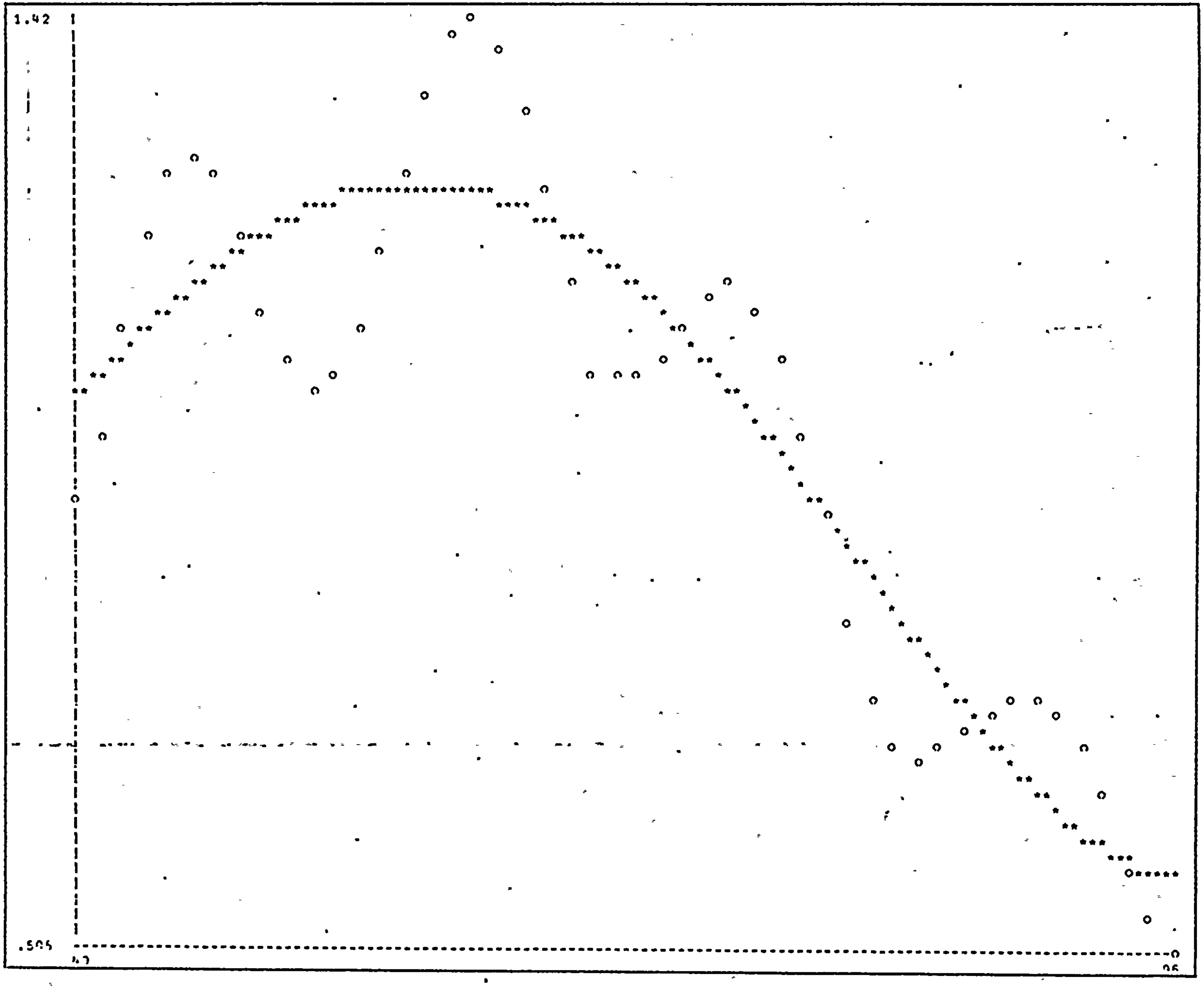

FIGURE III-6 Water surface elevation at Model Land Company Canal, Card Sound from 0100 3 June to 2400 4 June 1968

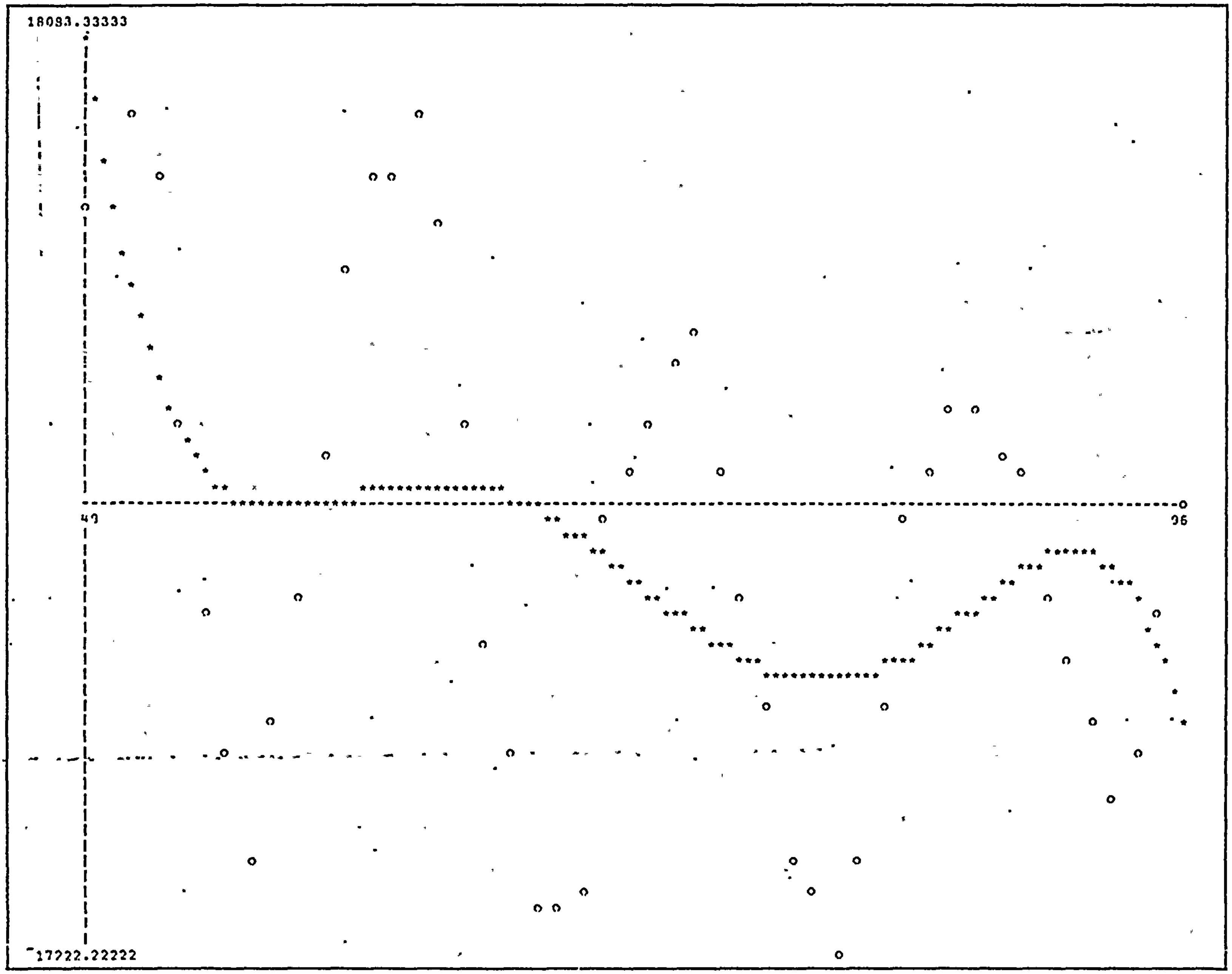

FIGURE III-7 Net hourly average flow into Card Sound from 0100 3 June to 2400 4 June 1968

TABLE III-2

COMPARISON OF TIDAL EXCHANGE AND FLOW RATE RESULTS WITH DEPARTMENT OF COASTAL AND OCEANOGRAPHIC ENGINEERING DATA

Item	Department of Coastal and Oceanogtaphic Engineering (Dean 1970)	This Study
Peak Q_{tot} (flood)	68059 ft^3/sec	57094 ft^3/sec
Peak Q_{tot} (ebb)	52325 ft^3/sec	59534 ft^3/sec
Tidal Exchange (flood)	0.913×10^9 ft^3	0.97254×10^9 ft^3
Tidal Exchange (ebb)	1.002×10^9 ft^3	1.01754×10^9 ft^3
Net Transport (to sea)	89×10^6 ft^3	45×10^6 ft^3

Volume of 0.97254×10^9 cubic feet (flood) and 1.01754×10^9 cubic feet (ebb) indicate a net transport of 45 million cubic feet of water from Card Sound to sea per tidal cycle. This value is approximately one-half of the net transport to sea as determined by Dean (1970). The mean value of the tidal exchange represents approximately 16 percent of the total volume of water in the Card Sound basin and 46 percent of the total amount of water exchange in Card Sound per tidal cycle. In comparison, the volume of heated effluent to be discharged into Card Sound from the Turkey Point facility, during one tidal cycle, assuming maximum flow conditions of 10,625 ft^3/sec, is 4.473×10^8 cubic feet or 7.2 percent of the total basin volume.

Flow rates as calculated from the inlet model are distributed as follows:

Ocean side

Broad Creek	54.1%
Angelfish Creek	31.5%
Old Rhodes Channel	11.2%
Pumpkin Creek	2.9%
Little Angelfish Creek	0.3%

Bay side

Broad Creek	49.7%
Angelfish Creek	12.0%
Old Rhodes Channel	10.3%
Middle Creek	10.1%
Linderman Creek	7.7%
Little Pumpkin Creek	5.8%
Others	4.4%

Field work to establish accurate bathymetry and current profiles for the shoals of the Cutter Bank-Arsenicker platform and Card Bank has not yet been completed. Although the system we have developed appears to be the best available method for representing these conditions, additional work must be done. Since the resistance coefficient is dependent on the depth, it will vary with the tidal level. This variation is more important in shallow areas than deep ones. A correction for this effect can be introduced by computing the coefficient for several stages of the tide and using it as a variable when indicated. When these are established, these areas can be incorporated into a useful model by utilizing the same technique as for the inlets already studied.

Basin and Wind Stress Analysis

At this time no quantitative results can be reported for this phase of the work. However, a good model to analyze the effect of wind on water surface elevation is available.

It is interesting to note from Figure III-7 that during a part of the period, discharges from Card Sound were considerably higher than those caused by the astronomical tide. A detailed study will probably show that conditions during this time approximate the effects of the proposed discharge from the power plant.

More work is necessary to standardize the data for the 1-7 June period, but this will be minor. Once this is done, the following data can be accurately hindcast for that period: a) water surface elevations on both sides of each of the inlets, b) net hourly flows into and out of South Biscayne Bay, Card Sound and Little Card Sound.

By combining these data with the inlet models, a composite circulation model of the entire system can be made. Data from later periods of observations including fresh water runoff, temperature and salinity can be incorporated into the model with very little difficulty.

So far the results of the study corroborate the original premise that the circulation of an area such as this can be monitored on a long term basis by means of recording tide gauges and a wind station. Data from thermographs and salinographs can be included where necessary.

SUMMARY

Notwithstanding a severe curtailment of the anticipated funds, work has progressed to a point where additional effort will really pay off in establishing base line data and in providing a system to monitor future conditions.

The system developed for describing inlets and shoal areas in accordance with Manning's formula shows a good correlation with measurements in the field. It is simple to use and it can be developed into a highly accurate technique.

The computer routines developed to analyze the relation between wind and water surface elevations and circulation is accurate and extremely efficient. It will be extremely useful in processing data gathered during this study and it can be readily adapted to include other parameters such as fresh water runoff, temperature and salinity.

IV. CHEMISTRY*

GENERAL STATEMENT

The chemistry of semi-enclosed ecosystems such as Biscayne Bay and Card Sound is synergistically related to the physical and the biological properties of the ecosystem. Thus, for example, the chemistry of the water, sediments, and biota is controlled by, and in turn controls the quantity and quality of the living organisms, while the physical dynamics of the system primarily control the distribution of the chemical constituents of the water and sediments.

This report concerns a study of the ecological effects of a power plant utilizing natural estuarine waters for cooling purposes. It is instructive to review briefly the various ways in which such a utilization of natural waters can alter the chemistry of the ecosystem. Two distinct types of effects can be envisaged, direct effects of added pollutants or altered chemical equilibria in the discharge water, and the indirect effects brought about by changes in the physical parameters acting directly upon the biota within the ecosystem to produce consequential chemical changes.

Among the direct effects are the addition of pollutants to the cooling water during its passage through the plant and canal system (e.g., trace metals, radionuclides, and particles producing increased turbidity), and altered solubilities or speciation equilibria (e.g., dissolution or precipitation of $CaCo_3$, exchange of gases, alteration in stabilities of organic-inorganic complexes).

Indirect effects due to changes in the biota induced by increased temperature, turbidity or turbulence will be manifested in a number of ways. The concentration of certain chemical species such as the dissolved inorganic micronutrients and dissolved organic carbon will be altered if organisms are being killed or thermally stressed so that they cannot maintain the normal concentration gradients of chemical species across their cell membranes. The distribution and the chemical nature of sediments may be altered if the contributing plant and animal life is killed or substantially modified in its distribution. The trace element regulation of organisms themselves may be altered so that they accumulate higher or lower than normal concentrations of these elements (e.g., Roosenberg, 1969).

The chemical changes taking place due to a power plant effluent may be relatively small, nevertheless, it must be recognized that they can be of profound importance in regulating the ecology. Thus, because of the diverse nature of possible effects and their expected magnitude, sophisticated and extensive studies are necessary to determine the effects of thermal pollution.

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A limited chemical investigation of the area currently receiving thermal discharge from Turkey Point Power Plant has been carried out starting in early 1969. The results of this study up to Dec. 1970 are presented in Chemistry Appendix II of this report. This investigation indicated that many chemical properties are indeed altered by the operation of a cooling system using natural bay water. However, a considerable problem has arisen in interpreting the data obtained because of the total lack of baseline information relating to the chemistry of the ecosystem of which the thermal discharge area is a part. The Florida Power and Light Company's plan to alter its discharge point to the center of Card Sound represented an opportunity to obtain baseline data for a discharge area before the inception of the discharge. In addition, the Card Sound basin represents a similar but not identical ecosystem to that found at Turkey Point so that data obtained in Card Sound may be cautiously used as comparative information relative to that obtained at Turkey Point.

The primary objectives of this program during the past twelve months have, therefore, been twofold. To upgrade the instrumental and technical capabilities of the chemistry group working on this project so that more extensive and more specific studies can be made and to obtain baseline information for the chemistry of the water, sediments, and when possible, the biota within Card Sound, so that any changes due to the projected discharge can be more clearly identified. In addition to these primary objectives, research has continued in the area of the present discharge with emphasis being placed upon the study of specific problems indicated by the earlier work.

METHODS

A number of necessary instrumental analysis systems have been acquired under the aegis of this program and elsewhere during the past twelve months. A proportion of the effort has been devoted to the setting up and calibration of these instruments and the training of the necessary personnel in their use. The following instruments are now in regular use for the Turkey Point-Card Sound studies.

A Technicon CSM6 six channel AutoAnalyzer is in routine use for nutrient analysis. At present, only four channels, those for the determination of nitrate, nitrite, silicate and phosphate (Grasshoff, 1970) are in satisfactory operation. It is hoped that a fifth channel will be operational soon for ammonium ion determinations and that the sixth channel can be used eventually for either organic phosphorous or, preferably, organic nitrogen. Prior to January, 1971, nutrient analysis were carried out by the manual methods of Strickland and Parsons (1968). AutoAnalysis methods now enable the completion of sample analysis within 24 hours after the return of samples to the laboratory. As many as 250 samples can be easily handled during a normal working day.

A Beckman 915 Total Organic Carbon Analyzer is in use for the determination of dissolved organic and inorganic carbon (Van Hall and Stenger, 1967).

Samples are fixed with mercuric chloride in amber glass bottles and analyzed within 48 hours from collection.

A Perkin Elmer 403 atomic absorption spectrophotometer equipped with an HGA-70 graphite tube furnace is in use for the determination of trace metals in water samples and will be utilized in the analysis of biological samples and sediments which are at present stored (see below). Some modifications of the tube furnace were required (see Chemistry Appendix III), and two successive trained technicians have left for other employment so that this instrument is as yet not being operated routinely to capacity.

Water samples are analyzed for trace metals by a modification of the method of Brewer, et al. (1969). Prior to January 1971, Cu and Fe were determined by methods of Alexander and Corcoran (1967) and Corcoran and Alexander (1967), respectively. It should be noted that the methods used prior to January 1971, determine total dissolved metal concentrations, that is all forms of the metal that pass a 0.45µ filter, whereas the currently employed method will determine only the fraction capable of complexing with pyrrolidine dithiocarbamate in the acidified water samples. This differential is discussed below.

A Perkin Elmer 240 CHN analyzer is being used for carbon, hydrogen and nitrogen elemental analysis of biological samples, sediments and suspended particulate matter. Due to the long delivery time and set-up procedures, this instrument became fully operational only in April, 1971. An R-F low temperature asher is being used for the oxidation of organic carbon in biological materials and sediments.

There are two other essential instruments used in this study. A Perkin Elmer 180 infra red spectrophotometer is being used for partial characterization of organic matter and minerals in particulate matter and sediments. The Perkin Elmer 356 dual beam double wavelength spectrophotomer is not yet totally operable due to faults in manufacture. Alternative instruments have been available elsewhere for the work requiring this type of analysis.

The radioactivity study of the Card Sound program utilizes alpha, beta and gamma counting systems and has been set-up according to the guidelines of the Atomic Energy Commission and the Bureau of Radiological Health. These agencies have provided a technical basis for criteria in establishing environmental radioactivity surveillance programs (Harley, 1967; ITAC., 1965)

The overall surveillance program is outlined in Table IV-1. The water samples for gross alpha and beta counting are prepared using procedures similar to the State of Florida, Radiological Laboratory at Orlando (Johnson W. Personal Communication) and counted on a nuclear Chicago Model 1152, low background, gas proportional counter, calibrated with Plutonium-239 and Strontium-90/Yttrium-90 standards for alpha and beta activities respectively. Calibrated alpha, beta and gamma standards were obtained from the Analytical Quality Control Service, National Center for Radiological Health, Winchester, Massachusetts. These same standards were used to determine counting efficiencies, self-absorption coefficients and backscatter factors.

TABLE IV-1

CARD SOUND ENVIRONMENTAL RADIOACTIVITY SURVIELLANCE PROGRAM

SAMPLES	SAMPLING FREQUENCY 1970-71	1971-72	ANALYSIS 1970-71	1971-72	SAMPLING LOCATIONS
Water	Quarterly	Bi-Monthly	Gross Beta (GPC) Gross Alpha (GPC)	Gross Beta ^{40}K (GPC) Gross Alpha (GPC) & selected Alpha Spect.	Intake & Discharge Canal & Card Sound
			Diff. Gamma- (Gamma Spec. Analysis for Selected Radionuclides)	Diff. Gamma	
Water - ^{3}H	Few Background samples	Monthly		Tritium (LSC), with some Electrolysis enrichment	Intake Canal Discharge Canal, Card Sound, South Biscayne Bay, Open Ocean
Bottom Sediments	Semi-annually	Semi-annually	Gross Beta (GPC) Gross Alpha (GPCP Diff. Gamma (GSS)	Gross Beta-^{40}K Gross Alpha Diff. Gamma	Card Sound
Aquatic Biota	Variable	Variable	Gross Beta Diff. Gamma	Gross Beta-^{40}K Diff. Gamma	Card Sound & South Biscayne Bay

Each planchet is counted for 40 minutes at the beta plateau and 40 minutes at the alpha plateau. The raw data is computed manually for determination of the activity in terms of pCi/unit weight and pCi/unit volume of sample, and then analyzed by computer for statistical variation and statistical (0.05 level) significance.

Gross alpha and gross beta activities in fractionated sediment samples are currently being measured, using the mechanical sieving technique described by Johnson and Abrahams (1966) to enhance the detection efficiency for low level environmental radioactivity. Sediment particle size ranges being studied are; coarse (>177μ), fine (61-177μ), and silt (<61μ).

Gross beta activity measurements of selected samples of biota are to be carried out as soon as the samples can be collected.

Gamma spectrum analysis is being carried out to determine the preoperational background levels of selected natural and artificial gamma emitters in water, sediment and selected biota samples as outlined in Table IV-1. One liter water samples are counted for gamma activity for 40 minutes in cylindrical (7 x 14.5 cm) plastic containers lined with plastic bags as illustrated in Figure IV-1, while sediment and biota samples are counted in small plastic disposable beakers. The gamma counting system (Figure IV-1) consists of a heavily shielded counting chamber (6" steel walls with 1/8" lead and several layers of 1/8" tin) housing two matched 4 x 8" Harshaw NaI(Tl) crystals, each with three photomultiplier tubes and a mixer. The signals from the mixers go to an anti-coincidence unit, then to the pre-amplifier and are then analyzed using a Nuclear Data 512, No. 180 FMIZ Analyzer. Data from the analyzer can be printed out on an IBM typewriter, plotted by an X, Y plotter or fed into the interface system for storage on high speed magnetic tape. The Nuclear Data 512 unit will be replaced shortly by a Nuclear Data 1024 unit with an on line 8D computer.

Data acquisition and storage for the gamma samples has been achieved by use of a Cypher model 7H magnietic tape unit, which require 3 seconds for complete transfer of 512 channels of data from the Nuclear Data 512 analyzer to the tape. All electronic equipment order or fabricated for this system in the fall of 1970, e.g. interphase system, gamma-gamma-coincidence amplifier, sample changer, nin-bin and power supply, magnetic tape recorder and mixer preamplifier were installed and operating by March, 1971. The system in routinely operated at 3.9 KeV. per channel, has good linearity over the energy range used (0.1 to 1.95 MeV), has less than a 1 channel drift and has a background spectrum comparable to those routinely obtained by other laboratories with low backgound, NaI-Nuclear Data Systems. Table IV-2 lists the eleven gamma emitters being studied in this program and the corresponding photopeak efficiency and minimal detectable activities for this system. The photopeak efficiencies and minimal detectable activities values for this system will be improved significantly upon installation of the new ND-1024 analyzer.

The gamma spectrum data stored on magnetic tape is analyzed for the gamma-ray energies and intensities of the eleven selected gamma emitters using a modified Fortran IV, Sisyphus-II, program described by Helmer et al. (1967). In order to

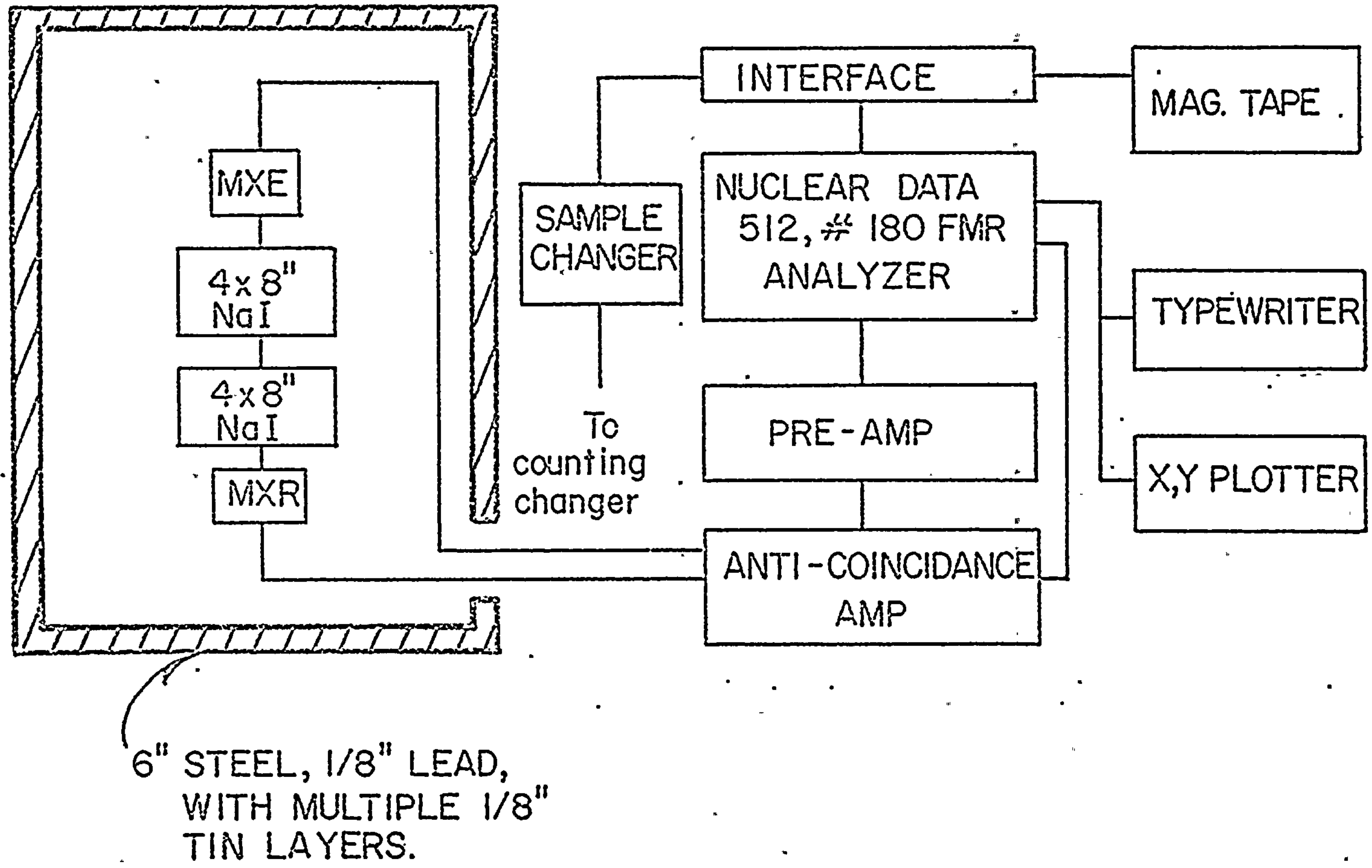

FIGURE IV-1 Gamma Counting System

TABLE IV-2

GAMMA EMITTING RADIONUCLIDES ANALYZED IN CARD SOUND SAMPLES

RADIONUCLIDE	TOTAL PHOTOPEAK EFFICIENCY	MINIMAL DETECTABLE ACTIVITY * (pCi/liter)
$^{144}Ce^{144}Pr$	8.0	17.0
^{131}I	18.3	15.0
$^{106}Ru^{106}Rh$	2.2	13.6
^{137}Cs	14.6	13.0
$^{95}Zr^{95}Nb$	@11.1	10.2
^{54}Mn	12.4	11.1
^{65}Zn	5.0	9.3
^{22}Na	4.8	7.9
$^{60}Co(1.33)$	7.5	8.5
^{40}K	@1.0	@20
^{140}Ba	@13.2	9.2

*Minimal Detectable Activity = 3 $\sqrt{\text{Background}}$

(Counting time - 40 minutes)

utilize this sophisticated program for gamma analysis with our system, considerable effort was required for: (1) modification of data collection equipment and verification of data input to the magnetic tape; (2) the writing of a new program for interfacing data collection and data print out; (3) a second new program to allow data from the magnetic tape as input into the Sisyphus-II program and; (4) technical modification in the program to allow more efficient machine utilization and permit the use of the IBM 370 Model 155 computer system located at the University of Miami.

RESULTS AND DISCUSSION

Turkey Point

Investigations carried out during the past year in the immediate Turkey Point area (Figure IV-2) have been limited because of the necessity of of installing and calibrating new instrument systems and the priority placed on obtaining sufficient baseline data for Card Sound. Nevertheless, a certain amount of work has been carried out for nutrient species to provide correlatable data for continuing biological investigations. A study of the Eh, pH, dissolved organic carbon, iron, and copper has been conducted. Sediment samples from each station have been collected and partially analyzed, and the suspended particulate load in the effluent canal has been investigated. All of the data obtained during the period September 1970 - May 1971 is reproduced in Chemistry Appendix I.

The chemical and associated hydrographic data obtained at Turkey Point during the period January 1969 to December 1970 has been collated and interpreted. The results of this assessment were presented at the Third National Symposium on Radioecology at Oak Ridge, Chemistry Appendix II. The findings can be briefly summarized as follows:

(1) Measurements of sediment temperatures have revealed that benthic infaunal, bacterial and fungal populations may not be subjected to as wide a range of temperature fluctuations as organisms living in contact with the water column itself. This phenomenon and its possible importance has been further discussed in a paper submitted for publication Chemistry Appendix IV.

(2) Some evaporation due to the heating effects of the power plant was detectable from the salinity measurements. The extent of this evaporation was small enough as to alter the salinity by less than 1 ppt., a very small change when compared to the natural seasonal variations.

(3) Oxygen concentrations were never below levels required for respiration and normally indicated supersaturation. The frequency of occurrence and extent of supersaturation at stations very close to the effluent canal mouth was reduced with time. This was presumably related to the death of algae and sea grasses in these areas.

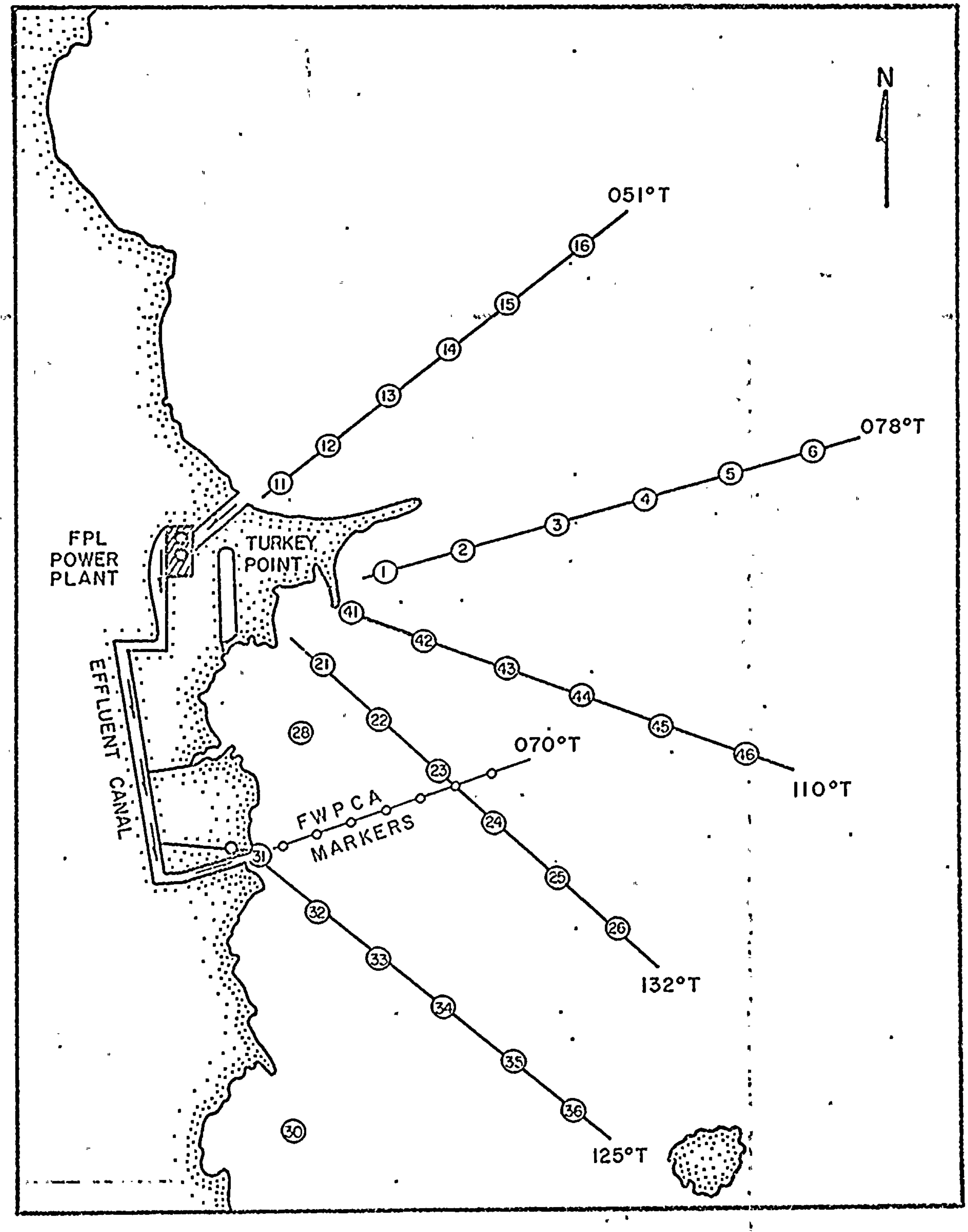

FIGURE IV-2 Chemistry Stations at Turkey Point

(4) Nutrient concentrations were with a very few exceptions enriched in the discharge as compared to the intake water. This may be related to the death or thermal stress of entrained planktonic organisms or it may be derived from leaching of the canal walls and the limited biota within the canal.

(5) The specific alkalinity was unusually high within the area of the plume. The total inorganic carbon was also higher in the plume than elsewhere. This would indicate that active carbonate dissolution is taking place within the canal and plume, particularly as the pH within the area was almost constant. This conclusion is somewhat tentative and should be further investigated. Dissolution of carbonates may be aided by complexation of calcium with dissolved organic matter which was observed to be higher within the area of the plume.

(6) The dissolved organic carbon content of the water close to the mangrove fringe and particularly in the effluent water from the power plant was high. Some of the excess dissolved organic carbon within the effluent plume may be derived from mangrove runoff; however, it is believed that some of the excess is derived from lysis of entrained organisms or released to the water by the organisms when subjected to thermal stress.

(7) No discernable pattern was observed in the distribution of total dissolved copper in the Turkey Point area.

(8) High concentrations of total dissolved (0.45μ filterable) iron were observed within the plume. Concentrations remained high during periods of drought. Thus, it is unlikely that the iron is derived exclusively from land runoff addition. The excess iron may represent corrosion products from the power plant, leaching of iron from the canal system walls and bottom or leaching from the few plants within the canal system. Measurements of pH did not reveal any significant acidification due to the power plant that would lead to solubilization of iron. Measurements of Eh have so far not been reliable due to instrumental difficulties. However, as the water is always near or above saturation with respect to oxygen, it would seem unlikely that its Eh would be so low as to reduce ferric to ferrous iron. Solubilization of the iron may be aided by complexation with dissolved organic matter which was found in high concentrations within the plume. No time series study of the discharge of iron from the effluent canal has been made. However, the data available so far would seem to indicate that the discharge is probably of somewhat sporadic nature.

Subsequent to this analysis of the results obtained at Turkey Point further information has been obtained with respect to several of the conclusions above.

Salinity: During the drought period experienced in South Florida from June 1970 through May 1971, salinity values in the Turkey Point vicinity have been consistently higher than those observed at corresponding times in previous years. The highest salinity observed during this period was 44.4 ppt. at a station close to the mangrove fringe but not within the main body of the thermal plume

(Chemistry Appendix I, Tables 3 and 4).

Nutrients: Data obtained in Card Sound can be used tentatively as a baseline comparison with the data obtained at Turkey Point. No significant difference appear to exist between the concentration levels of nutrients (NO_3, NO_2, PO_4, SiO_4) at Turkey Point (Chemistry Appendix I, Tables 7 - 15) and with Card Sound (Chemistry Appendix I, Tables 34 - 42). However, nutrient concentrations almost always appeared slightly higher in the area of the discharge than in the area of the intake canal despite the lack of fresh water runoff and the very low fresh water table caused by the twelve-month drought. This differential became less clear in the latter stages of the drought as the nutrient levels became consistently low throughout the area, approaching the detection limits of the analytical system employed. Values obtained in March 1971 were within the following ranges: silicate, 0.2 to 1.1µg.at. SiO_4.Si/1 (5.6 to 311µg. SiO_4.Si/1); nitrate, 0.09 to 0.11µg.at. NO_2.N/1 (1.3 to 1.5µg. NO_2.N/1); nitrite, 0.01 to 0.10µg.at. NO_3.N/1 (0.14 to 1.4µg. NO_3.N/1); and reactive phosphate, 0.05 to 0.25µg.at. PO_4P/1 (1.6 to 7.7µg. PO_4.p/1). Only phosphate concentrations were within the range observed during 1969 and 1970 (see Chemistry Appendix II) and it is possible that the phosphate concentrations may be overestimated due to the interference of arsenate in the determination methods. Arsenic compounds are used extensively in Florida agriculture and thus may be present in solution at significant concentrations. A limited number of arsenate analyses are planned for the near future to resolve this possible error.

Nutrient data obtained from Turkey Point indicate that although ecological damage has taken place in the area of the mouth of the discharge canal, no major destructive alteration has occurred to the overall ecosystem of South Biscayne Bay. As discussed earlier, some evidence is apparent to suggest that entrainment of planktonic organisms may lead to increases in the nutirent and dissolved organic carbon concentrations in the discharge water as compared to the intake water, the increase being probably derived either from lysis of the organisms or stress induced excretion. This problem will shortly be more closely studied by means of integrated biological, biochemical and chemical studies within the canal system itself.

Carbonate equilibrium: Total inorganic carbon values obtained at Turkey Point (Chemistry Appendix I, Tables 16 and 17) are high compared to most ocean and estuarine waters. Preliminary indications that carbonate dissolution might be occuring within the effluent canal have not been confirmed by the later analyses. Total inorganic carbon values in the region close to the outfall are often lower than those close to the intake. This may be due to partial loss of carbon dioxide in the entrainment process and it is not possible to predict from the data obtained what effect this will have upon the carbonate balance. In addition, the values of dissolved inorganic carbon concentration observed at Turkey Point are within the same range as observed in Card Sound. High dissolved inorganic carbon concentrations appear to be naturally occurring in Biscayne Bay and sufficient information is not presently available to determine the effect of the power plant operation upon the carbonate equilibrium in the entrained water. Simultaneous measurements of alkalinity, total carbon dioxide and pH within the intake and outfall canals would be required to study this effect.

Dissolved Organic Carbon: Total dissolved organic carbon (TOC) concentrations in the area of the effluent discharge are consistently higher than those observed close to the intake canal (Chemistry Appendix I, Tables 18 and 19). Concentrations are sometimes high at stations removed from the canal system but close to the mangroves and also in the Card Sound basin (up to 24.4 ppm). Nevertheless, the highest TOC concentrations at Turkey Point are always associated with the effluent plume. It is considered likely that some of this dissolved organic carbon is derived from lysis or excretion of stressed organisms during entrainment. TOC concentrations have become somewhat lower during the progress of the drought reflecting the probable origin of a fraction of the dissolved compounds from mangrove detritus during periods of normal runoff. However, insufficient data is available to delineate a seasonal variation in the TOC or the seasonal effect, if any, upon the differential of TOC between the intake and outfall. Thus, the need is indicated for time studies for dissolved organic carbon within the canal system itself.

Trace Metals: The distribution of trace metals in the Turkey Point area has also received study. Prior to January 1971, total dissolved iron and copper concentrations were determined by the methods of Corcoran and Alexander (1964) and zinc concentrations have been determined by a modification of the method of Brewer et al. (1969). An important differential exists between the currently used and previous methods. The trace metals present in the "dissolved" state in sea water may be present in one or more of a number of different forms. For example, Cooper (1948) has suggested four different types of dissolved iron: ionic iron, inorganically complexed iron (e.g., ferrifluoride), crystalloid or dispersed colloidal organic complexes, and colloidal inorganic compounds. All other transition metals may also exist in one or all of these forms as well as in truly dissolved organic complexes. The methods of Corcoran and Alexander (1967) determine the total dissolved metal and do not differentiate between the various forms listed above. The method of Brewer et al. (1969) determines only that fraction of the metal which is brought into the ionic dissolved form upon acidification and subsequently complexed with pyrrolidine dithiocarbamate (the "ionic" fraction). Thus, metals locked up in colloidal organic molecules, very strong organic complexes and some colloidal inorganic compounds (e.g., ferric phosphates) will not be determined. For the purposes of study of power plant effluents, the "ionic" fraction is the most important fraction of the dissolved metal because metals and radionuclides added as pollutants by the plant operation would be expected to be in this or in particulate form. However, differential studies are also indicated to delineate the speciation of dissolved metals in the area of thermal discharge.

The high total iron concentrations of the water in the Turkey Point area were also found in Card Sound so that addition from the power plant cannot account for the major fraction of the total iron concentrations in the Turkey Point area. Most of the total iron was probably colloidal inorganic, or colloidal organic derived from mangrove detritus. Values obtained for "ionic" iron both at Turkey Point (Chemistry Appendix I, Tables 20 and 21) and in Card Sound represented about 10-30% of the total dissolved iron although this conclusion is somewhat

tentative as both techniques of analysis have as yet not been employed for the same samples. Highest values of "ionic" iron observed at Turkey Point did not exceed those observed in Card Sound but the values observed at Turkey Point within the area of the plume were somewhat higher than the average values in Card Sound. As was true in the case of the total iron concentrations, "ionic" iron concentrations tend to be highest in the mouth of the outfall canal and to fall with distance from the axis of the plume and the canal mouth. Only one set of "ionic" iron analyses for the Turkey Point area are available at the moment, and more analyses are required before the areal distribution can be fully delineated with respect to the thermal plume.

"Ionic" copper concentrations found both in the Turkey Point area and in Card Sound represent about 10% of the total copper concentrations previously determined. The single set of analyses of ionic copper at Turkey Point (Chemistry Appendix I, Tables 22 and 23) indicates a possible tendancy for increased values to be found within the thermal plume area. Such a tendancy was not found for total copper concentrations but, with the limited available data, it is impossible to say at present that "ionic" copper is being introduced by the power plant operation and other forms of copper are not. Further data should become available within a few months.

"Ionic" zinc concentrations have also been determined in the Turkey Point area (Chemistry Appendix I, Table 24). In the single set of analyses so far, the range was from 0.32 to 3.51μg/Kg with the highest values being obtained within the mouth of the outfall canal and close to the shore within the plume. The thermal plume was deflected towards the southeast during this sampling period with strong winds blowing so that correlation of "ionic" zinc with the plume was not well defined. However, from the results obtained, it would appear likely that the concentration of "ionic" zinc in the outfall water is increased by the power plant operation.

The graphite tube furnace atomic absorption technique has been utilized to analyze a few selected samples for Co, Ni, Cd and Pb concentrations after extraction by the method of Brewer et al. (1969). Very few such analyses have so far been carried out and the results fall close to the detection limits with the sample volumes taken and the extraction system utilized. Thus, no conclusions can be drawn, at present, from the results. The levels of samples showing values of up to 1μg/Kg, Cd almost all below 0.1μg/Kg, Co below 0.1μg/Kg, and Ni less than 2μg/Kg.

Trace metal data so far obtained indicate that there may be a significant increase in the concentrations of at least the "ionic" fraction of several transition elements in the cooling waters during passage through the power plant and canal system. This may indicate either the introduction of "ionic" metals by the power plant or the altering of the speciation of dissolved metals in the entrained water, or both. Further studies are planned to include analysis of the intake and outfall waters for trace metals in "ionic" form, those brought into

solution by UV oxidation (Armstrong et al. 1966), those that are associated with organic matter, and total dissolved trace metals determined after stong acid digestion (Alexander and Corcoran, 1967; Corcoran and Alexander, 1964). A study will be made of the distribution in these dissolved fractions of radionuclides derived from the power plant after the nuclear generators are activated. This is an important consideration as the different forms of trace elements in solution have different uptake and accumulation patterns in the biota (Bowen, 1966).

Particulate Matter: Visual observations in the area of the discharge canal have revealed the presence of appreciable quantitites of flocculent particulate matter in the discharge water, which apparently settles out and forms a layer on the surfaces of grass and algae. This layer may inhibit the photosynthesis of the plants and, thus, it is important to study its nature. A preliminary investigation has been carried out of the nature of the particulate suspended matter collected in the mouth of the discharge canal. It is intended to follow this up with comparative analyses of the particulate load within the intake and discharge systems and of the material covering the algae.

About 20 l. of water from about 10 ft. depth within the discharge canal were filtered with a peristaltic pump through a 0.45μ membrane filter using positive pressure. Visual and microscopic examination of the filter did not reveal the presence of flocculent material. Flocculent material may have been broken up during passage through the peristaltic pump, but visual examination of the water before filtration indicated that the flocculent material previously observed was probably either not present or present at much lower concentrations than expected. This may be attributable to the lack of fresh water runoff as sampling was carried out during a period of severe drought. Nevertheless, considerable quantities of particulate matter were collected by the filter and this material was subjected to microscopic and partial chemical analysis.

Under the microscope, the bulk of the particulates appeared to be a mixture of amorphous and crystalline white particles. Also present were three other types of particles; small black or dark coloured particles of uncertain character and irregular shape; particles of irregular shape but exhibiting an apparently metallic shean under certain light conditions; a few green regularly shaped particles which appeared to be intact chlorophyll containing plant cells of undetermined taxonomy.

The freeze dried particulate matter was subjected to limited chemical analysis. Total carbon, hydrogen and nitrogen content were 10.11%, 0.32%, 0.86% respectively with an ash content of 30.9% after ignition at 1000°C in an oxygen atmosphere. Differential carbon determination after the method of Konrad et al. (1970) showed that the particulate material contained 2.77% of organic carbon and thus, by difference, the inorganic carbon cntent was 7.34%. Assuming that all of the inorganic carbon was present as calcium carbonate, the particulate matter contained a maximum of 61.2% calcium carbonate. The infrared absorption spectrum of a KBr pellet containing 2.1%w/w of the particulate matter was determined. Absorption bands for calcite and aragonite were identified.

Although rigorous band assignment was not attempted, bands in the stretching region of aliphatic carbon/hydrogen bonds were observed. These were: 2960 and 2873 cm^{-1} (asymmetrical and symmetrical stretching respectively for CH_3) and, 2925 and 2855 cm^{-1} (asymmetrical and symmetrical stretching respectively for CH_2). The bands near 2890 cm^{-1} and in the region of 3000 to 3100 cm^{-1} corresponding to CH, and aromatic carbon hydrogen stretching frequencies respectively were absent.

Sediments: Sediment samples were collected from each of the chemistry stations at Turkey Point (Figure IV-2). Samples were collected with a hand corer. Immediately the samples were brought on board the boat, the Eh and pH were determined by inserting electrodes into the sediment.

Sediments were classified by visual examination into the three somewhat arbitrary classifications of sand, mud and peat and combinations thereof (Chemistry Appendix I, Table 27). Sandy sediments contained predominantly large mineral particles with no fibrous organic material, mud consisted of fine silt size particles, and peat comprised primarily fibrous low density material. The distribution of the various types of sediments is shown in Figure IV-3. The boundaries drawn between the different types are not clearly defined and serve only to show the general trend in the nature of the sediments.

The Eh of sediments appears to be a useful parameter in describing the degree of stagnation of their pore waters although no quantitative significance can be drawn from it (Whitfield, 1969). The pH of sediments can also be of significance in describing the nature of a sedimentary environment (ZoBell, 1946) but does not appear to be helpful in the present study. The range of values of the pH's observed for these sediments was relatively small (6.5 to 7.4) compared to the range observed in other studies (6.4 to 9.5, ZoBell, 1946), and also in comparison to the errors inherent in measuring pH's in sediments particularly under the nonideal conditions on a small boat, or after a time lapse if the samples are returned to the laboratory.

The Eh of a sediment is determined primarily by two factors; the quantity of organic material undergoing bacterial decomposition within the sediment and the degree of stagnation of the pore water of the sediment. Thus, the distribution of sediment Eh at Turkey Point (Figure IV-4) can be discussed with reference to the nature of the sediments (Figure IV-3) and the known circulation patterns of the bay water in the area. Ideally, the organic carbon content of the sediments should also be considered but these analyses are not yet completed for the Turkey Point area.

The Eh of sandy sediments at Turkey Point should be positive or at most near zero as the organic carbon content of such sediments is usually low and the large grain size allows relatively free percolation of pore waters out of the sediment and oxygenated overlying water into it. This is true in almost all instances of samples taken at Turkey Point. The only exceptions were at stations 02 and 34. The sediment from station 02 comprises relatively fine grain sand but the sediment from station 34 appeared to be anomolous. Peat type sediments should also have

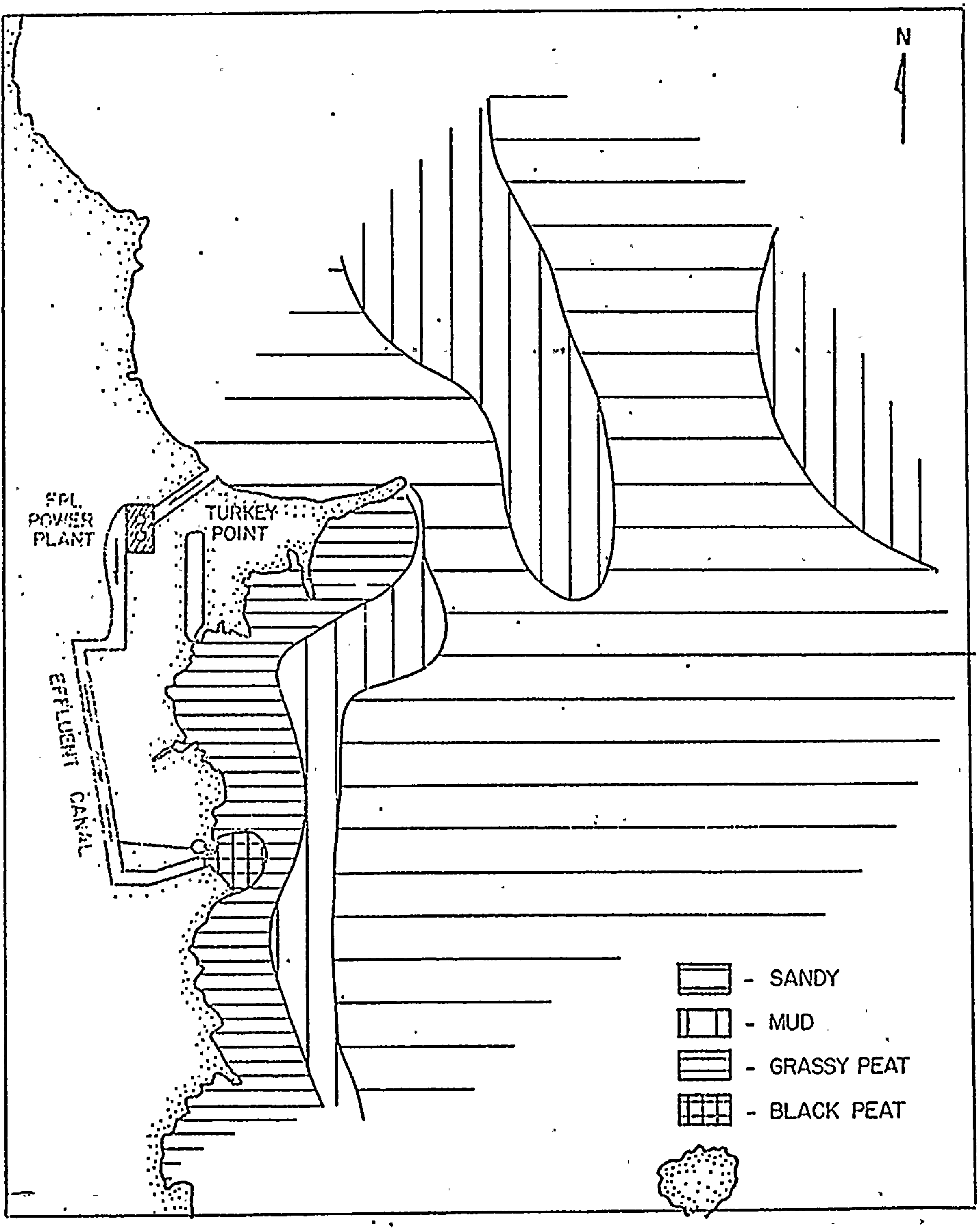

FIGURE IV-3 Sediment Type Distribution - Turkey Point

Although rigorous band assignment was not attempted, bands in the stretching region of aliphatic carbon/hydrogen bonds were observed. These were: 2960 and 2873 cm^{-1} (asymmetrical and symmetrical stretching respectively for CH_3) and, 2925 and 2855 cm^{-1} (asymmetrical and symmetrical stretching respectively for CH_2). The bands near 2890 cm^{-1} and in the region of 3000 to 3100 cm^{-1} corresponding to CH, and aromatic carbon hydrogen stretching frequencies respectively were absent.

Sediments: Sediment samples were collected from each of the chemistry stations at Turkey Point (Figure IV-2). Samples were collected with a hand corer. Immediately the samples were brought on board the boat, the Eh and pH were determined by inserting electrodes into the sediment.

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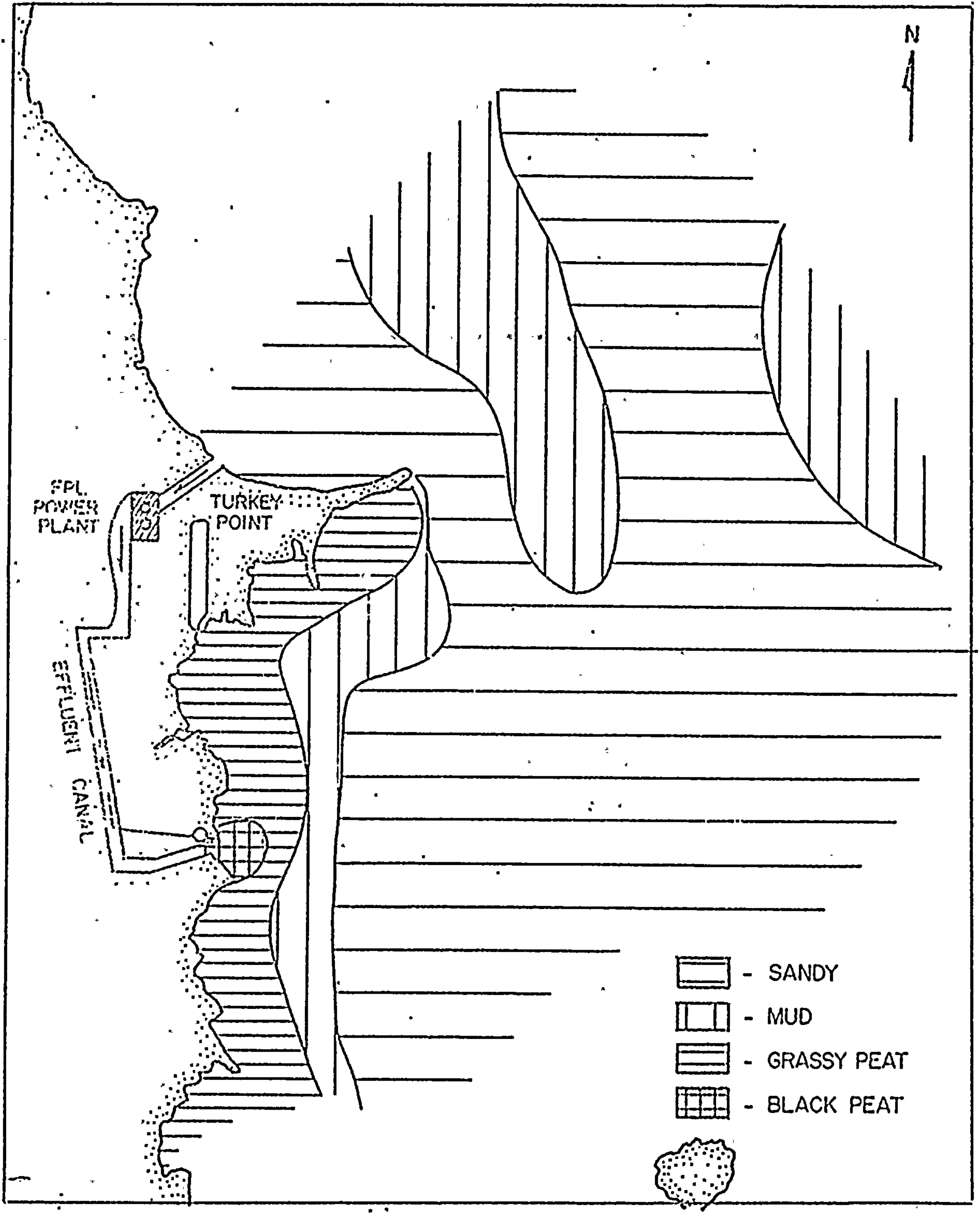

FIGURE IV-3 Sediment Type Distribution - Turkey Point

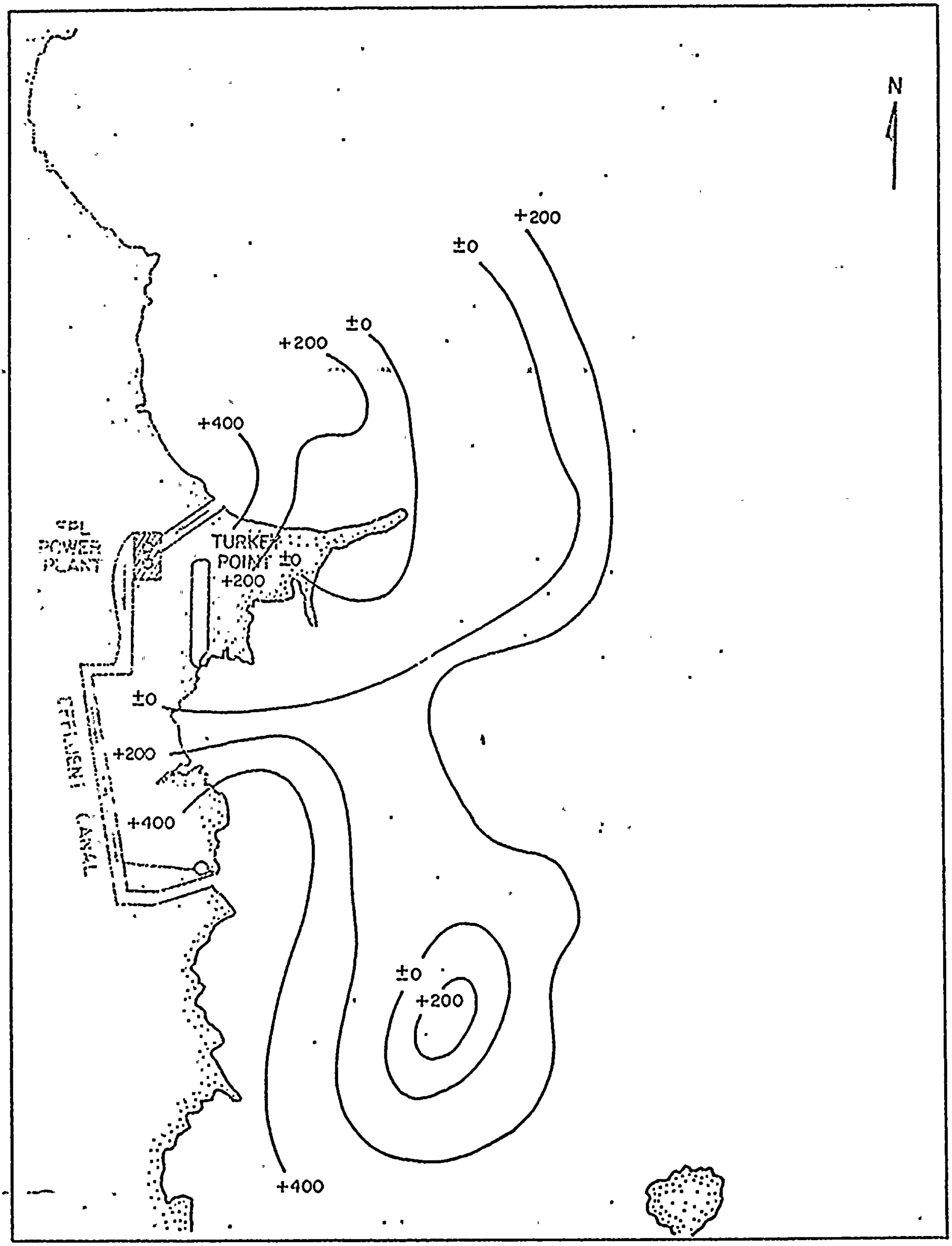

FIGURE IV-4 Sediment Eh - Turkey Point

positive Eh's as percolation is facilitated by the open fibrous nature of the surface layers of these sediments. Thus, even if considerable oxidation of the organic matter in this type of sediment does occur, unless the sediment is compacted, the oxygen is not exhausted in the pore waters and Eh's remain positive. Each of the stations described as peat at Turkey Point did indeed follow this rule except for Station 41, a sediment containing a proportion of fine silt and located in an area of low overlying water velocities. Mud samples should show negative Eh's as the grain size of the sediments inhibits percolation. This should be true except in those areas where rapid bottom currents increase percolation and reworking of the sediments. Thus, of all the stations labelled as mud type, only the sample from Station 32 exhibited a positive Eh. This station is close to the canal outfall, an area with relatively high velocity currents in the overlying water.

The study of sediment Eh values is of particular interest because of the recent suggestion that decaying organic material and a reducing potential within the sediments may be vital to the reproduction of Thalassia testudinum (Tabb, personal communication). Further studies are planned particularly in the area of Station 32. Samples will be collected both within patches of Thalassia testudinum and from adjacent areas where the plant is not found.

The sediment samples obtained at Turkey Point are being analyzed for organic carbon and inorganic carbon and, when time permits, will be analyzed for various major and trace elements. Of particular interest is the composition of sediments close to the outfall canal which are presumably partially or wholly derived from the particulate material brought into the bay by the cooling water canal.

Card Sound

Sixty-two stations have been established within Card Sound (Figure IV-5) on a half mile grid pattern. This array of stations covering the entire Sound and also part of Little Card Sound permits the study of the large scale exchange processes of chemical species within the Sound and the use of Little Card Sound as a comparative baseline. The primary objective has been to obtain sufficient baseline data of the chemical ecology of Card Sound in order that any significant changes occurring after the planned introduction of cooling water from the nuclear reactors at Turkey Point, may be detected. Chemical constituents of the bay water sediment and biota that are being measured include micronutrients, inorganic and organic carbon, trace metals and radionuclides. Sediments are collected every six months, biota on an irregular schedule and water samples once a month. Water samples are routinely collected from the stations occupied by other investigators in the biological phases of this investigation (see Sections V and X). This data not only provides the necessary chemical baseline but also will act as directly applicable data for the study of chemical mediation of the distribution of the various marine organisms under study. In addition to the sampling carried out at the limited number of biological stations, sampling has been extended to cover all of the 62 stations marked on three occasions. Subsurface and nearbottom samples are normally obtained from all stations except those with depths less than 2-3 ft. This ha

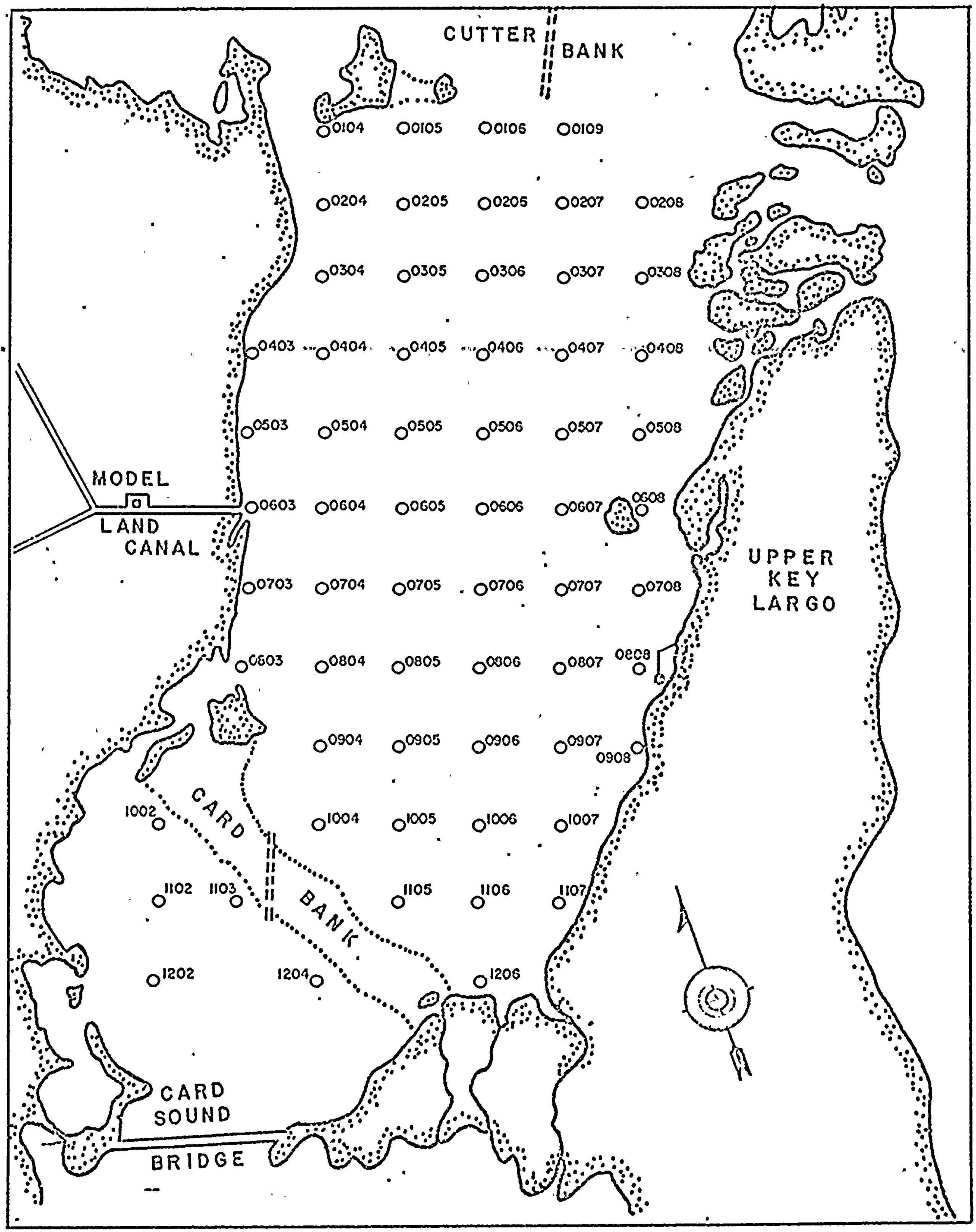

FIGURE IV-5 Chemistry Stations - Card Sound

provided a good overall synoptic view of the circulation and distribution of chemical species and the suspended particulate matter as discussed below. Unfortunately, baseline data is only available for one particular set of climatological conditions; winter and spring periods during the passage of successive cold fronts and severe drought conditions. The drought in South Florida has produced twelve successive months of below average rainfall (June 1970 through May 1971) and, during the period of study of Card Sound reported here (September 1970 - May 1971) rainfall runoff has been exceptionally small and the water table unusually low. The water table level is important in Card Sound because of the reported existence of several fresh water springs particularly along the western shore.[7]

It is hoped that if the summer rainfall during June, July and August reaches normal levels, baseline information with regard to the distribution and circulation of chemical species in a high runoff period will be obtained. In any event, baseline information for extended calm summer weather and thus poor mixing should be obtained.

Complete analysis of all the data obtained in Card Sound has not yet been carried out. The results to date are discussed in terms of the ranges and distributions of the different parameters and then aspects of the data are discussed in terms of the overall dynamics of the Sound and the possible distribution of any pollutants introduced by the power plant effluent into the Sound.

Salinity, temperature, dissolved oxygen: Salinity distributions in Card Sound are more fully discussed in the circulation studies section of this report (section II). However, salinities are routinely measured on all chemistry sampling stations to provide details of the status of the bay-water/ocean-water mixing system at the time of sampling. The results are tabulated in Chemistry Appendix I, Tables 30 and 31.

Salinities ranged from 30.0 to 42.1 ppt. Much lower salinities are expected when rainfall returns to normal. Salinity distributions for three dates are shown in Figures IV-12, IV-19 and IV-27. These figures will be discussed below.

Water temperatures were uniform in the Sound during the entire period of study to date (Chemistry Appendix I, Tables 28 and 29). The range of temperatures observed was usually only 2 or 3°C and no geographical pattern was observed. Somewhat higher temperatures were observed in the shallow parts of the bay than in the deeper central section.

The entire body of water within the Sound appears to be well oxygenated (Chemistry Appendix I, Tables 32 and 33). Values observed have been close to saturation in all cases.

No significant vertical stratification in salinity, temperature, oxygen or any chemical constituent measured has been observed. No rainfall runoff has been present at the times of sampling and wind mixing has been appreciable during

the entire period of study. However, stratification may be observed in the future particularly during the summer with high rainfall, surface solar heating and generally light southeasterly winds. The introduction of the heated effluent from the Turkey Point nuclear reactors may under some conditions enhance such stratification and during periods of prolonged calm weather, it is conceivable that an essentially stagnant bottom water layer may be formed within Card Sound. Biological activity on the bay bottom is sufficiently intense that chemical changes may occur in any such occluded layer. Of particular interest might be the oxygen/carbon dioxide equilibrium as the effluent from the power plant could be turbid as at Turkey Point. This may inhibit photosynthesis particularly if a strong pycnocline is formed that will decrease the sedimentation rate. Studies of possible stratification will continue in conjunction with the physical oceanographers. This may permit predictions to be made as to the possibility of formation, and the effects of, stratification due to thermal discharge into Card Sound under varying climatological and hydrological conditions.

<u>Nitrate, Nitrite, Phosphate, Silicate</u>: Concentrations of the micronutrients observed in Card Sound are tabulated in Chemistry Appendix I, Tables 34 - 42. Nitrite has been within the range 0.01 - 0.20μg. at. NO_2.N/1 (0.14 - 2.8μg NO_2.N/1), nitrate within the range 0.01 - 1.7μg.at. NO_3. N/1 (0.14 - 23.8μg. NO_3.N/1) with a small number of exceptions discussed below, inorganic phosphate within the range 0.05 - 3.1μg.at. PO_4.P/1 (1.55 - 96.1μg.PO_4.P/1), total dissolved phosphate 0.19 - 1.1μg.at. P/1 (determinations only carried out on one date), and silicate from below detectable levels to 7.0μg.at. SiO_4.Si/1 (19.6μg. SiO_4.Si/1).

These concentrations fall within the levels found during the previous two years of studies at Turkey Point except for the lowest values, which were observed during May 1971. During May, the concentrations of silicate and nitrite were exceptionally low whilst the concentrations of nitrite and phosphate approached the lowest levels previously determined at Turkey Point. These low levels are almost certainly related to the lack of runoff addition of nutrients to the bay because of the drought, and the spring increase in biological productivity. In normal weather conditions, considerable runoff occurs during May and, thus, nutrient levels observed in previous years have not reached exceptionally low levels. Thus, it appears that the South Biscayne Bay Card Sound area may receive its nutrients during the calm summer months from runoff addition, and during the winter months by regeneration and stirring of the bottom deposits and input of ocean water aided by wind induced mixing. Closely spaced nutrient data is not available for any station in the area to adequately test this hypothesis.

During the sampling on February 17, 1971, three surface samples from adjacent stations showed anamolously high nitrate concentrations (Chemistry Appendix I, Table 36) while the corresponding bottom samples showed no similar enrichment (Chemistry Appendix I, Table 37). No explanation can be forwarded for these results. It seems unlikely that they are due to contamination as surface and bottom samples are drawn and analyzed in alternate sequence.

Dissolved inorganic carbon: The total dissolved inorganic carbon concentrations observed in Card Sound range from 16.8 - 35.3 mg C/1 with most samples falling within the range 17 - 25 mg C/1 (Chemistry Appendix I, Tables 43 and 44). During relatively calm periods, the lowest values are generally found in the northeast corner of the bay where tidal exchange with the ocean occurs (Figure IV-6). The theoretically expected values for sea water over the temperature and salinity range observed for Card Sound, with a pH range of 7.8 to 8.4 would be about 20 to 25 mg C/1.

Dissolved organic carbon: Total dissolved organic carbon concentrations varied over a wide range of 0.3 to 40.3 mg C/1 (Chemistry Appendix I, Tables 45 and 46). The distribution of organic carbon within the Sound appears to be complex (Figure IV-7). Results so far indicate that highest concentrations are usually observed along the western shore of the Sound and lowest concentrations are often observed in the water exchanged tidally with the ocean and in the center of the Sound in calm periods.

Limited spectral and chromatographic investigation of the nature of the dissolved and colloidal organic compounds have been carried out. This study is important because of the detrital nature of the food chain in South Biscayne Bay, and because of the large fraction of organically bound trace metals.

Alkalinity: The specific alkalinities observed in the Sound (Chemistry Appendix I, Table 53) varied between 0.126 and 0.184. Lowest values were observed in the northwest of the Sound where mixing with ocean water takes place. The highest values were observed at stations close to the mangrove fringe along the western shore of the Sound. The high specific alkalinities combined with high total dissolved inorganic carbon concentrations indicate the possibility of carbonate dissolution.

Trace metals: Iron, copper and zinc have been determined in Card Sound water samples and some preliminary analysis have been made for Pb, Co, Ni and Cd. Total dissolved iron was present in concentrations of 16-127μg/Kg, while "ionic" iron was present in concentrations between 1.0 and 55μg/Kg, (Chemistry Appendix I, Tables 47 and 48) with a few higher values observed particularly in bottom water samples during periods of strong wind induced mixing (up to 490μg/Kg). Total dissolved copper was found in concentrations of 5 - 25μg/Kg, while "ionic" copper was in the range 0.15 - 4μg/Kg (Chemistry Appendix I, Tables 49 and 50). The difference between the total dissolved trace metal determinations and the "ionic" dissolved trace metal determinations has been discussed above. "Ionic" zinc ranged in concentration from below the minimal detectable level (approx. 0.01μg/Kg) to 31.5μg/Kg (Chemistry Appendix I, Tables 51 and 52). Distributions of these trace metals particularly iron and zinc appear to be closely related to the major circulation pattern within the Sound and are discussed further below. Generally, however, the highest values of trace metal content are observed in bottom water samples in shallow areas and along the fringes of the Sound.

Trace metal concentrations appear to be extremely patchy in many parts of the Sound. The patchiness appears to be genuine as revealed by a set of analyses where one station was resampled after an adjacent station had been run.

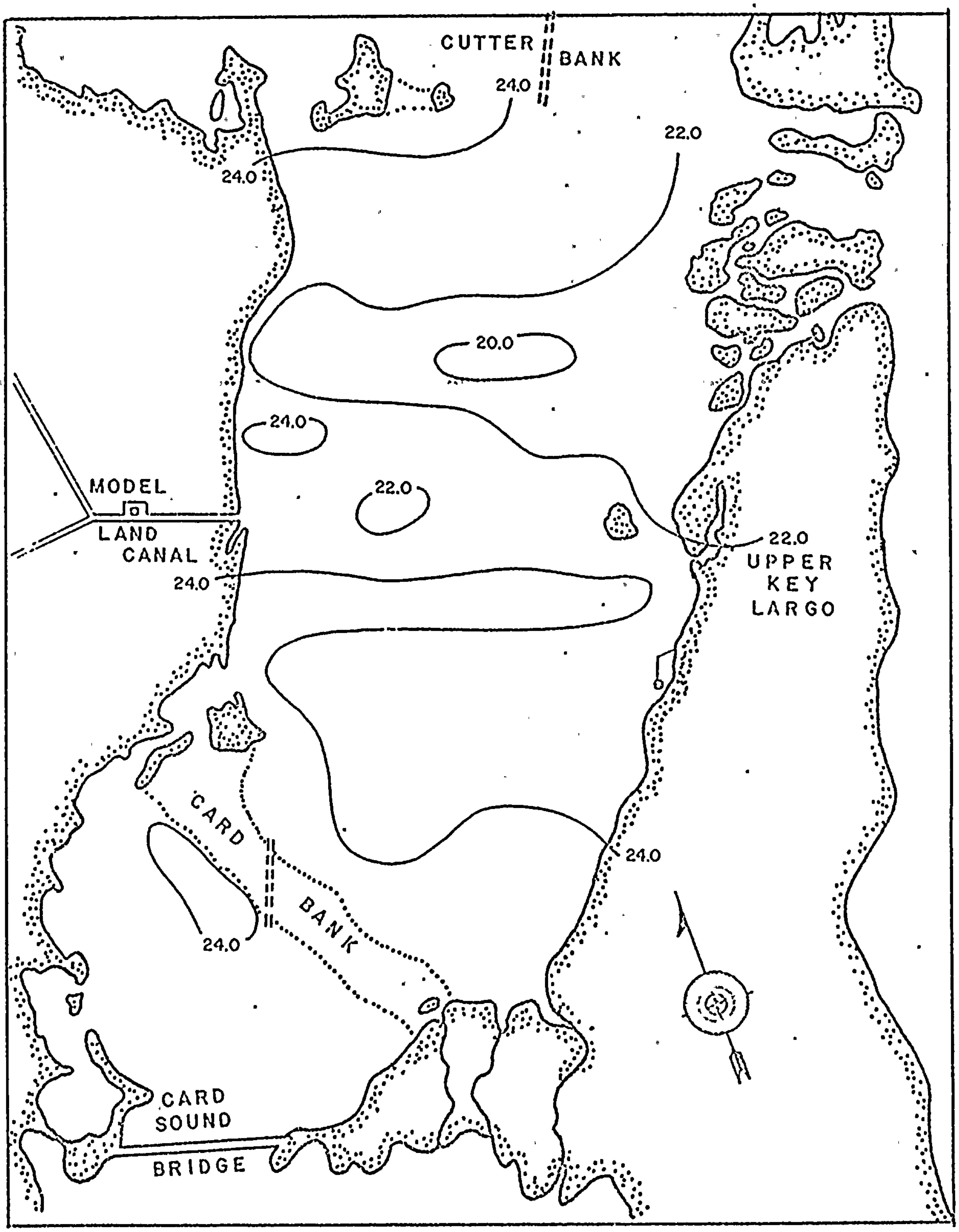

FIGURE IV-6 Surface Total Dissolved Inorganic Carbon (mgC/ℓ) Card Sound 17th Mar. 1971

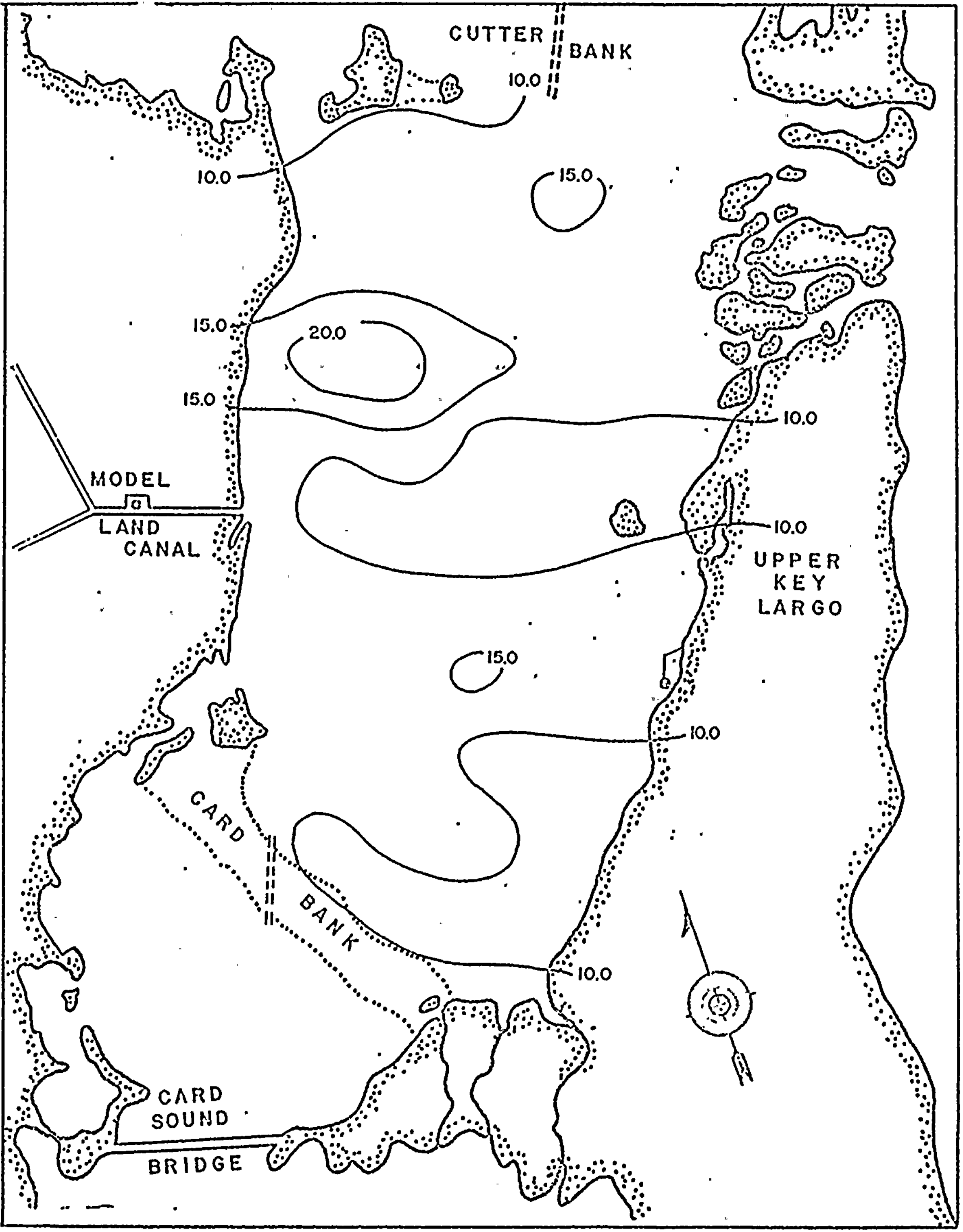

FIGURE IV-7 Surface Total Dissolved Organic Carbon (mgC/ℓ)
Card Sound 17th Mar. 1971

Thus, stations were sampled in the following order: 1105, 1206, 1106, 1107, 1106 again, 1007, 1006 and 1005. Surface and bottom samples were taken at each station. The results obtained for Cu, Zn and Fe are shown in Figure IV-8. A very large scatter of results can be observed within this mile square area but the resampling at station 1106 shows a trace element distribution very similar to the earlier sampling. However, all of the results except for the surface copper determination show values clearly tending towards those observed considerably earlier (29 minutes) at station 1105. Thus, it can be seen that either the water from station 1105 has moved towards station 1106 or the boat was positioned on the east side of the 1105 marker buoy the first time and the west side subsequently. More significantly, this provides direct evidence that the patchy distribution of trace elements with concentrations grading over on order of magnitude within half a mile is a genuine feature and is not related to sampling or analysis errors.

A limited number of samples have been monitored for "ionic" Pb, Cd, Co and Ni concentrations using the graphite tube furnace atomic absorption technique. "Ionic" Co and Ni concentrations were all either very close to or below the limits of detection of the present analytical method i.e., Co 0.1µg/Kg, and Ni 2µg/Kg. These detection limits will be improved by an order of magnitude in future. "Ionic" Cd and Pb concentrations also fell normally below the currently utilized detection limits i.e., Cd 0.1µg/Kg/ and Pb 0.3µg/Kg. However, several samples had concentrations of between 0.8 and 1.0µg/Kg/ of Pb and of up to 0.5µg/Kg of Cd. Most of these samples came from the stations in the northwest corner of Card Sound (0304, 0305, 0404, 0405) but insufficient numbers of samples have so far been analyzed to attempt to delineate distribution patterns within the Sound.

A small ultra violet oxidation unit is currently under construction and future trace element analyses in Card Sound will be extended to include the "ionic" fraction of the metal, the organically bound metal released by UV oxidation and the total dissolved metal determined after strong acid digestion.

Sediments: Sediments samples have been collected from each of the 62 marked stations in Card Sound (Figure IV-5). Some stations have been sampled in duplicate. The Eh and pH of the sediment samples were determined immediately after collection and the organic carbon content of samples from most stations have been determined. These results together with a visual description of the nature of the sediments are given in Chemistry Appendix I, Table 54. The pH's measured were within a narrow range (7.01 - 7.75) and the values for duplicate samples differ appreciably. Thus, pH does not seem to be a reliable parameter for the description of sediment variations within the Sound. The values for EH (Figure IV-9) and organic carbon content (Figure IV-10) show significant geographical variations.

The sediments of the Sound can be visually separated into five zones although the boundaries of these zones are by no means clear (Figure IV-11). The distribution of organic carbon content and Eh's agree well with this delineation.

Along the northern shallow flats from the western shoreline, south of the Arsenicker Keys and down the eastern shoreline to below Broad Creek and Angelfish

Sta. 1005

	Surface	Bottom
Fe	9.3	11.3
Cu	0.97	0.76
Zn	0.79	1.64

Sta. 1006

	Surface	Bottom
Fe	7.8	9.1
Cu	0.59	0.92
Zn	0.04	1.77

Sta. 1007

	Surface	Bottom
Fe	10.0	7.3
Cu	0.95	0.87
Zn	--	6.49

Sta. 1105

	Surface	Bottom
Fe	55.0	314.
Cu	0.94	0.91
Zn	6.75	12.4

Sta. 1106

1st Sample

	Surface	Bottom
Fe	10.5	11.0
Cu	0.60	0.70
Zn	BDL	1.35

2nd Sample

	Surface	Bottom
Fe	17.2	16.1
Cu	1.30	0.90
Zn	5.11	2.50

Sta. 1107

	Surface	Bottom
Fe	6.9	8.3
Cu	0.69	0.87
Zn	0.15	28.2

Sta. 1206

	Surface	Bottom
Fe	15.5	18.4
Cu	0.45	0.78
Zn	BDL	0.26

FIGURE IV-8 Indication of patchy distribution of trace metals

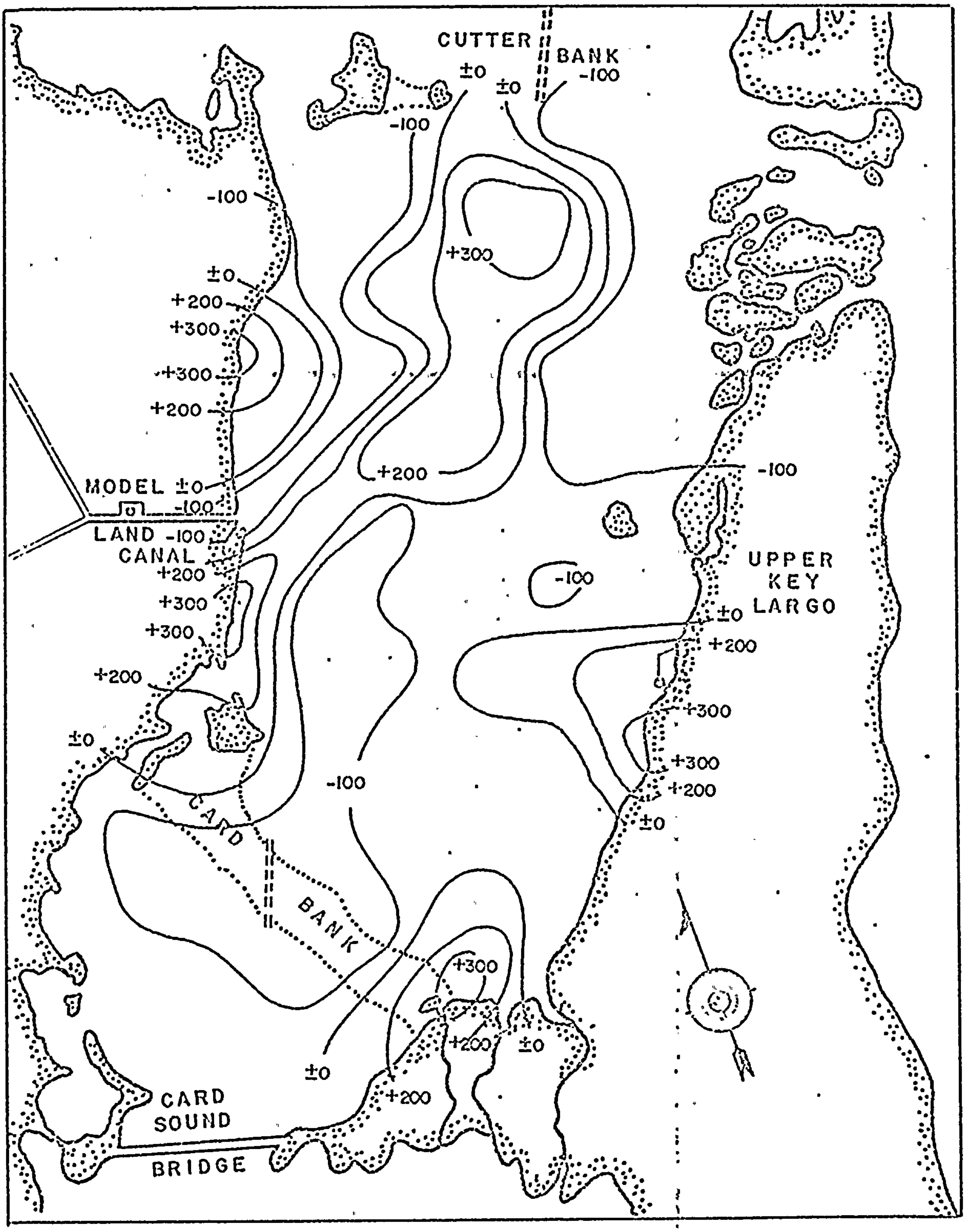

FIGURE IV-9 Sediment Eh - Card Sound

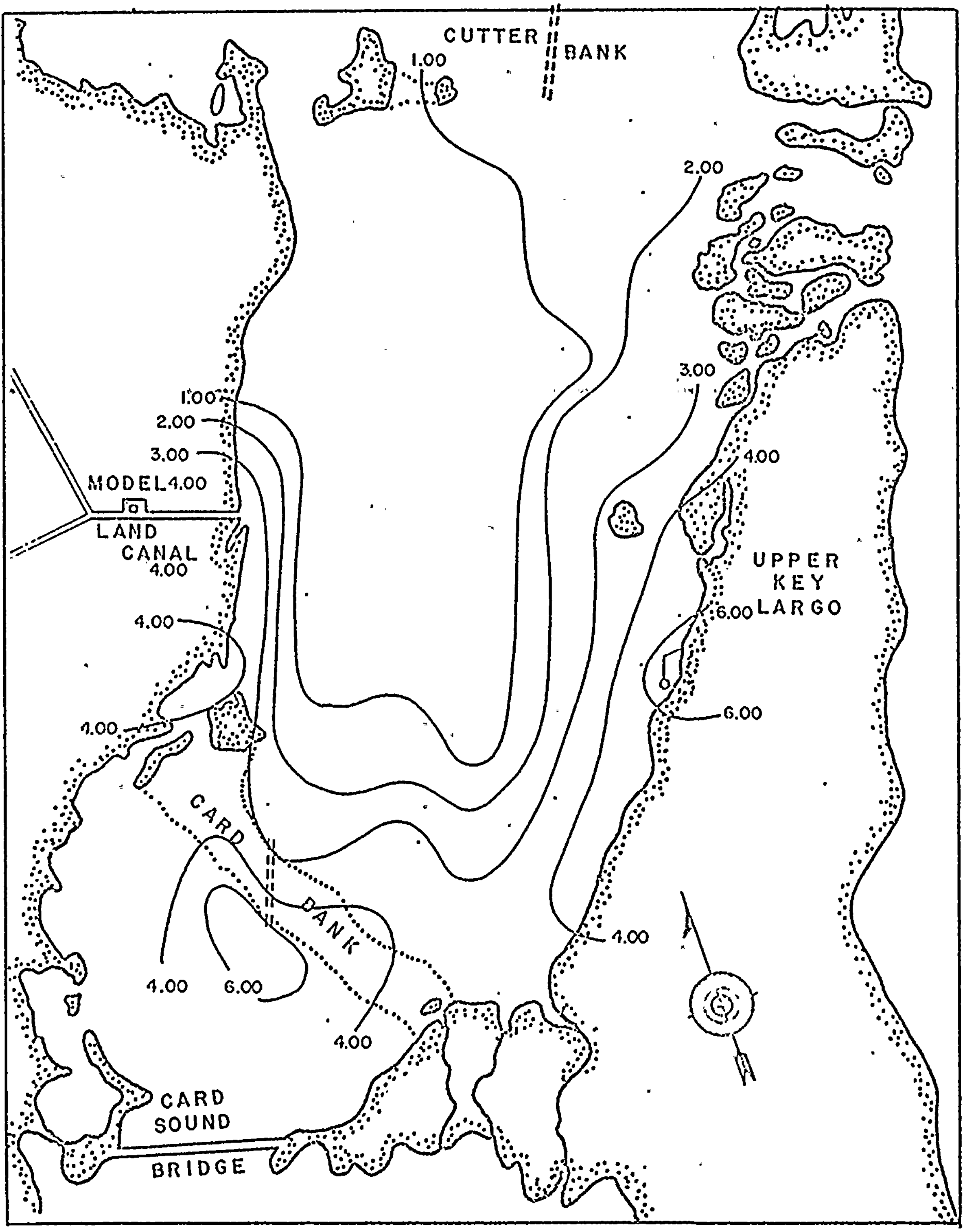

FIGURE IV-10 Sediment Organic Carbon Content (%) Card Sound

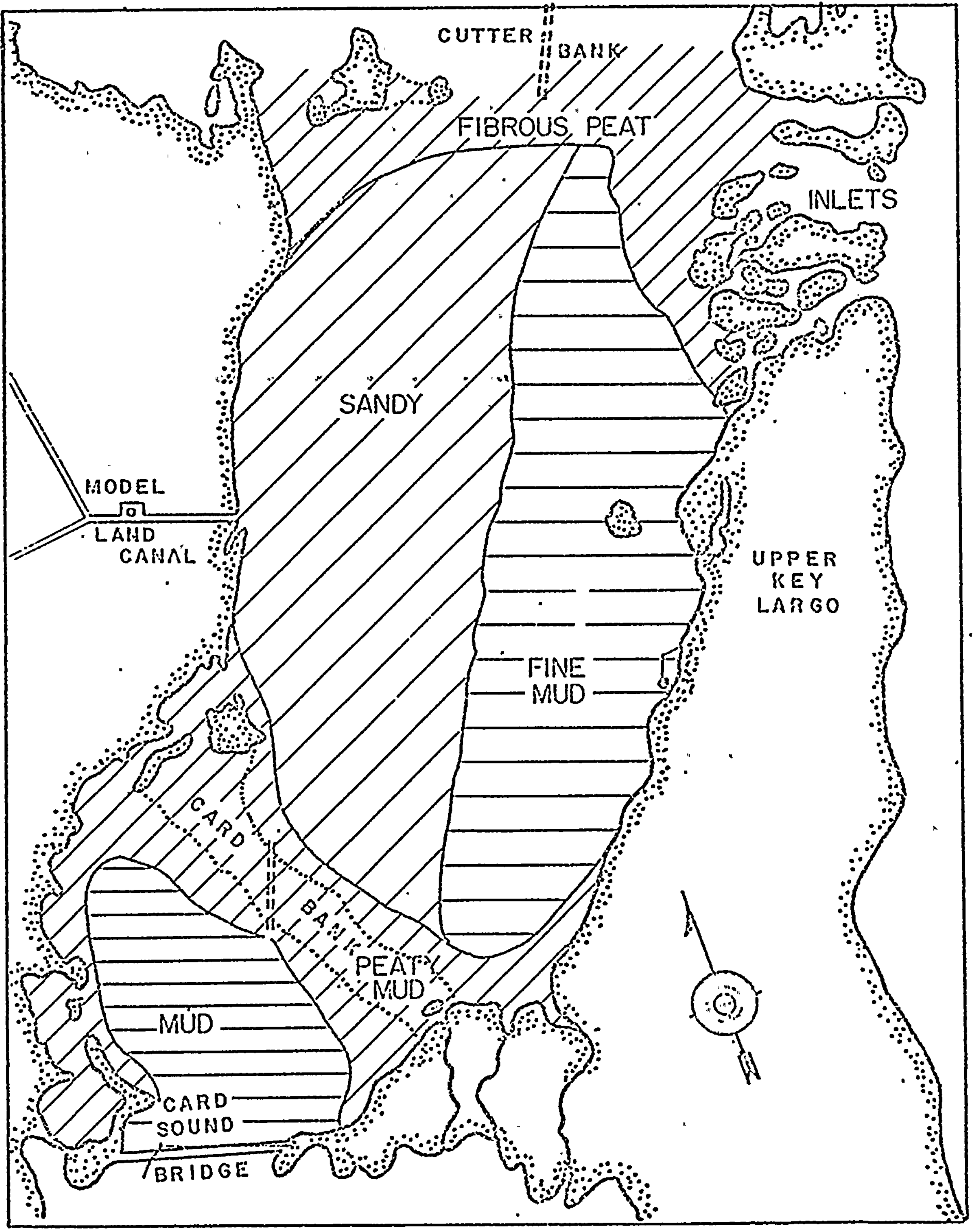

FIGURE IV-11 Sediment Type Distribution - Card Sound

Creek, the sediments are of a fibrous peaty nature. Organic carbon contents are of intermediate values within the Sound and the Eh's are variable but mainly negative. The very high grass and algae productivity in these regions (see section X) produces considerable amounts of detrital organic matter which decomposes rapidly. Thus, although water movement is rapid at some of these stations and the sediments are relatively fibrous and open to percolation of oxygenated overlying waters, the decomposition of the abundant organic matter is probably responsible for maintaining negative Eh's within the sediments.

The sediments within the western half of the deeper part of the Sound consist primarily of coarse grained sand with some peaty organic matter at stations close to the shoreline. Organic carbon contents are relatively low except at the shoreline stations and the Eh values are variable. Positive Eh's were observed along the shoreline except in the immediate vicinity of the mouth of the Model Land Canal, where sediments of high organic content are found. Negative Eh's were observed in the deeper parts of the Sound despite the low organic carbon content and may be indicative of slow movement of the overlying oxygenated water, and of low rates of percolation.

Within the eastern half of the Sound the sediments are fine mud with much higher organic carbon contents than those on the western side. Eh values are negative with the exception of samples from two distinct areas. In the extreme southeast corner of the Sound and, in an area running out into the bay from the Key Largo Ocean Reef development. The positive values in the southeast corner are difficult to explain but may be caused by frequent reworking of the sediments by wave action during the passage of cold fronts (see below). The positive values offshore from the Ocean Reef development are interesting in that they might be caused by the deposition of a layer of sediment derived from suspended material released during development of the yacht basin. The high organic carbon content of the sediment sample from immediately adjacent to the yacht basin could possibly be due to deposition of particulates from sewage effluents. This area deserves further study as the effect of particulate material introduced during the development of the Bay front may be analogous to the effects that will be produced by the opening of the Card Sound canal.

The shallow area of Card Bank consists of a predominantly fine grained peaty mud with high organic carbon content and expected negative Eh values. This area seems to act as a collecting agent for the fine grained sedimentary material within the Sound. Sediment depths on the Bank and within Little Card Sound often exceed six feet while depths within the deeper part of Card Sound average only a few inches. The few stations sampled in Little Card Sound all have fine mud sediments with high organic carbon contents and low or negative Eh's.

The results of the sediment analyses so far obtained agree with, and complement, the findings of Earley and Goodell (1968). The grain size distribution found by Earley and Goodell (1968) and the distribution observed in the present study is discussed below when sediment transport mechanisms are considered.

Chemical analyses for trace and major elements and mineralogy of the sediments already collected are planned. Further sediment samples will be obtained at about six monthly intervals. The stations close to the mouth of the proposed canal will be more intensively sampled immediately after the canal is opened.

Trace metal analyses of the sediments are of considerable importance. The major portion of many radionuclides introduced into the aquatic environment by power plant operations or other means, are strongly sorbed by clay mineral particles and, thus, are removed from solution and rendered unavailable for uptake by most marine organisms. Earley and Goodell (1968) have reported the absence of any clay minerals within Card Sound. They report that the sedimentary minerals are predominantly calcite, aragonite and quartz. None of these minerals have strong sorbtive properties similar to those of the clay minerals and, thus, it is likely that trace metals introduced to the Sound in solution will either remain in solution, be sorbed to precipitating humic material, or be taken up by organisms. The death of the organisms will transport the trace metals to the sediments but it is necessary to determine whether or not the metals are recycled back into solution during decay process of the organisms and humic material in the sediments.

Radioactivity: The mean gross alpha and gross beta activities determined in Card Sound water samples are shown in Table IV-3. Alpha activities for individual samples are listed in Chemistry Appendix I, Tables 55 to 58, and beta activities are listed in Chemistry Appendix I, Tables 59 to 62. Both alpha and beta activities were determined in the particulate matter and in solution in samples of both surface and bottom water. Activity levels per litre were consistently lower in the particulate matter than in the dissolved salts.

Analyses of alpha and beta data did not show any statistically significant differences in variance or between the means of surface and bottom water samples, or of samples from different stations. Thus, gross alpha and beta activities in Card Sound water appear to be uniformly distributed in the entire body of water sampled. In addition, no statistically significant differences were found between activity levels in water samples obtained in January, February or March 1971. Apparently background activities of alpha and beta radiation are invariable in Card Sound and sufficient data has now been collected to clearly establish these background levels prior to the operation of the nuclear reactors of Turkey Point.

Gross alpha and beta activities in the dissolved solids of water samples from Card Sound are higher than values reported for Gulf of Mexico seawater (Flora and Wukasch, 1965; Stewart and Wukasch, 1966). However, the difference can be accounted for by the inclusion of potassium-40 in activities measured in the Card Sound samples. Water samples from Homestead Bayfront Park (about 5 miles north of Turkey Point) and Turkey Point were assayed (May 1966 - August 1969) by the State of Florida, Dept. of Health and Rehabilitative Services for alpha and beta activities by analytical and counting techniques similar to those employed in this study. These samples were found to have gross alpha and beta activities in the dissolved solids of 7 to 15 pCi/l and 40 to 380 pCi/l respectively. These values agree well with those currently determined in Card Sound.

TABLE IV-3

MEAN GROSS ALPHA AND BETA RADIOACTIVITY IN CARD SOUND WATER SAMPLES

DATE	NUMBER OF SAMPLES	pCi/gm ASH IN PARTICULATES	pCi/L IN PARTICULATES	pCi/gm RES IN SALTS	pCi/L IN WATER	pCi/gm ASH IN PARTICULATES	pCi/L IN PARTICULATES	pCi/gm RES IN SALTS	pCi/L IN WATER
GROSS ALPHA									
11-13-17	38	5±7	<3	<3	13±29	5±7	<3	<3	32±41
2-17-71	71	<3	<3	<3	46±41	<3	<3	<3	30±36
3-24-71 *	70	4±5	<3	<3	24±22	4±4	4±6	<3	35±31
GROSS BETA									
1-13-71	38	49±70	<6	7±3	251±107	46±60	<7	7±2	266±92
2-17-71	41	15±16	<6	7±2	259±71	23±19	<7	7±2	236±70
3-24-71 *	70	23±19	<6	9±3	265±88	35±26	<7	10±6	252±83

* Data Incomplete

Most of the water samples monitored for alpha and beta activity have been subjected to gamma sprectral analysis. No significant gamma-ray peaks other than potassium - 40 (approx. 300 pCi/l) were detectable using manual calculation procedures. In order to facilitate more precise analysis for the low level gamma emitters, a computer spectrum analysis program (SISYPHUS-II) has been obtained and modified for use on the University of Miami IBM-370 computer. This program achieves background subtraction, spectrum fit of selected gamma emitters using a direct search method for producing a converging set of iterations, and corrections for gain shift encountered during spectrum accumulation. The program is not yet in fully acceptable operation, but the gamma spectrum data for a large number of water samples is stored on magnetic tape and will be analyzed using the program when it can be perfected.

Manual analysis of the spectra obtained from Card Sound water samples are in good agreement with those obtained by the State of Florida, Dept. of Health and Rehabilitative Services for water samples from Homestead Bayfront Park, and Turkey Point.

Gamma spectral analysis of sediment samples from Card Sound have not yet been completed. However, State of Florida, Dept. of Health and Rehabilitative Services samples from Biscayne Bay showed detectable activities of cerium-144; ruthenium-106, caesium-137, zirconium-95, manganese-54, iodine-131 and potassium-40. Analysis of the sediments from Card Sound will be compared with the results obtained for these samples.

General Discussion: When considering the effects of a thermal discharge from a power plant, not only the distribution and effects of the excess heat but also the fate of specific pollutants such as radionuclides in the effluent must be elucidated.

The chemistry data when considered synoptically with the results of circulation studies in Card Sound allows us to establish a tentative qualitative model for the distribution of any pollutants which may be introduced into the Sound from a point source such as the Model Land canal or the projected Florida Power and Light canal.

The data for this model is drawn mainly from the chemistry observations made at all 62 stations marked in Card Sound on only three occasions: January 13th, February 17th and March 17th, 1971. Data obtained during chemistry sampling on a more limited sampling grid is not extensive enough to be useful in studying the large scale circulation processes.

Cold fronts are considerable factors in determining Card Sound circulation patterns as they provide strong northerly winds aligned with the major axis of the Sound. Fortuitously, cold fronts passed through the Card Sound area on the sampling date in March (17th) and two to four days before the sampling date in February (13th to 15th). A weak front passed through the area three to four days before the sampling in January (9th - 10th). The distribution of various parameters in the Sound for each sampling date is discussed below to illustrate the basis for the model of circulation and pollutant distribution discussed subsequently.

(1) The surface salinities on January 13th, 1971 are shown in Figure IV-12. Calm weather prevailed during the period before this set of observations with a weak cold front (maximum winds 13 m.p.h.) having passed through the area on the 9th and 10th of the month. The salinity patterns indicated that an ill defined salinity front separated the northeast quarter from the main body of the Sound. Mixing with ocean water was taking place due to tidal flushing within this NE quarter while the rest of the bay remained partially cut off from exchange with the ocean. Distributions in the surface water of nitrite (Figure IV-13), nitrate (Figure IV-14), inorganic phosphate (Figure IV-15), dissolved "ionic" iron (Figure IV-16), dissolved "ionic" copper (Figure IV-17) and dissolved "ionic" zinc (Figure IV-18) are shown. Examination of these distribution patterns shows much more clearly the extent of isolation from exchange with the ocean of all except the northeast quarter of the Sound. Thus, nitrite, nitrate and "ionic" zinc were all present in lower concentrations in the northeast quarter of the Sound and presumably were also lower in the ocean water than in the rest of the Sound. "Ionic" iron was present in variable amounts within the Sound and had a somewhat patchy distribution as discussed above, but the more uniform values in the northeast quarter of the Sound clearly shows the enhanced mixing in this area. "Ionic" copper and inorganic phosphate concentrations do not follow the pattern established by the other parameters as concentrations in the ocean water mixing into the northeast quarter appear to be similar to those present in the rest of the sound.

An important feature of the distributions of all the chemical constituents discussed is the higher concentrations usually observed in Little Card Sound, over Card Bank and in the southeast corner of the Sound. Higher concentrations of some constituents were also observed at points along the western shoreline and along the eastern shoreline close to the Ocean Reef development.

(2) The surface salinities observed on March 17th, 1971 are shown in Figure IV-19. A strong cold front passed through the Card Sound area during the morning of March 17th after a period of about 10 days of calmer weather. Winds up to 22 m.p.h. were observed (Turkey Point weather data). Strong winds from the NNE to NE were blowing from 0800 hrs EDT until about 1300 hrs EDT when the wind began to moderate and veer towards the south. Sampling of all of the 62 stations within the Sound was completed during the period 1000 hrs to 1400 hrs EDT. The salinity distribution indicates that a body of water from the northeast corner of the Sound having a salinity close to that of ocean water was being transported southwards and towards the west by the action of the wind. Water of slightly higher salinity was entering the northeast corner presumably from South Biscayne Bay. Distributions of nitrite (Figure IV-20), nitrate (Figure IV-21), inorganic phosphate (Figure IV-22), silicate (Figure IV-23) "ionic" iron (Figure IV-24), "ionic" copper (Figure IV-25) and "ionic zinc (Figure IV-26) are shown. Nitrite, nitrate, silicate and "ionic" iron were distributed in a pattern which correlated well with the salinity distribution. Lower concentrations of each of these parameters were predominant in the center of the eastern section of the Sound in the water mass presumed to be derived from the northeast quarter of the Sound. "Ionic" copper and inorganic phosphate concentrations were relatively uniform within the Sound while the "ionic"

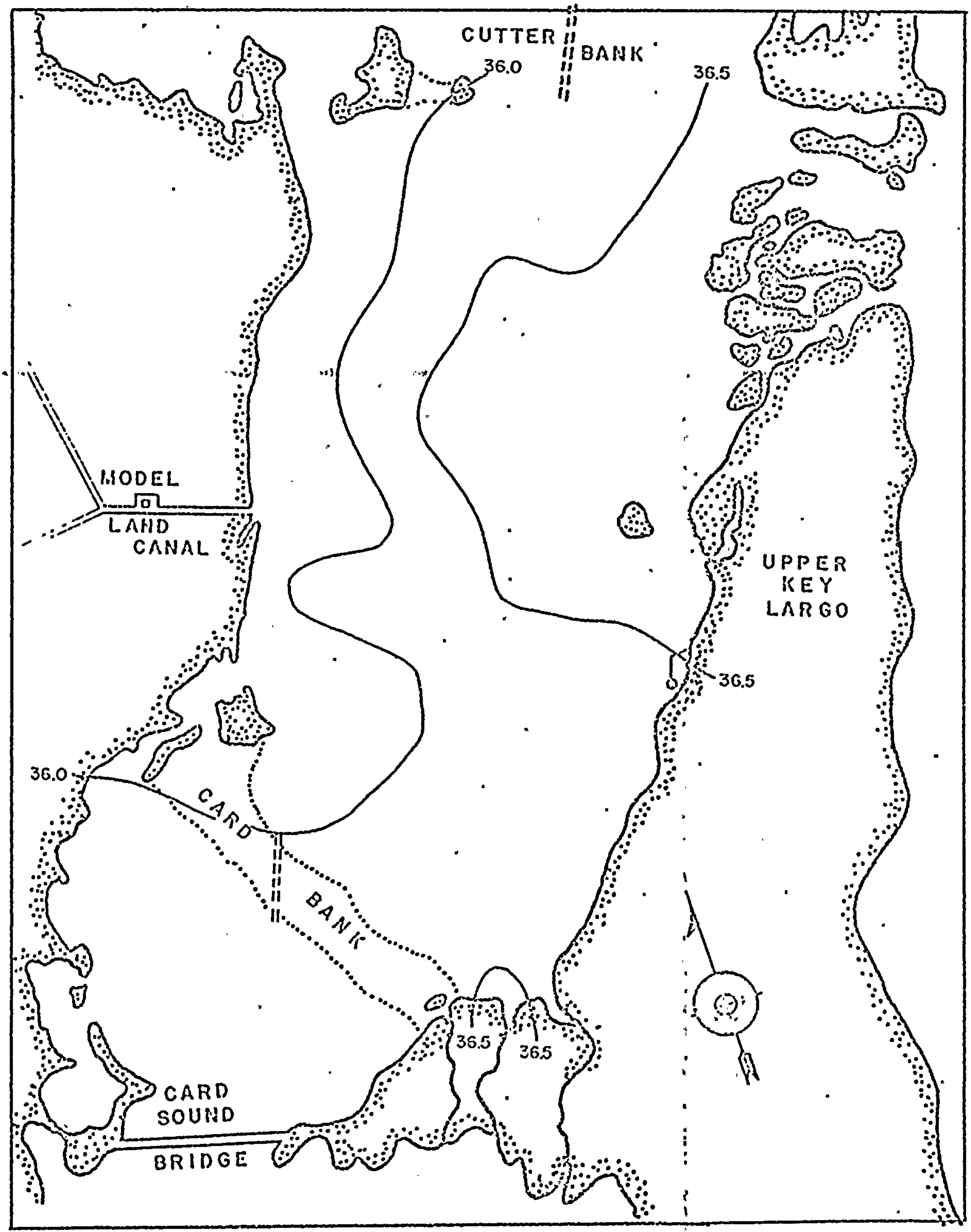

FIGURE IV-12 Surface Salinities ($^{\circ}$/oo) - Card Sound 13th Jan, 1971

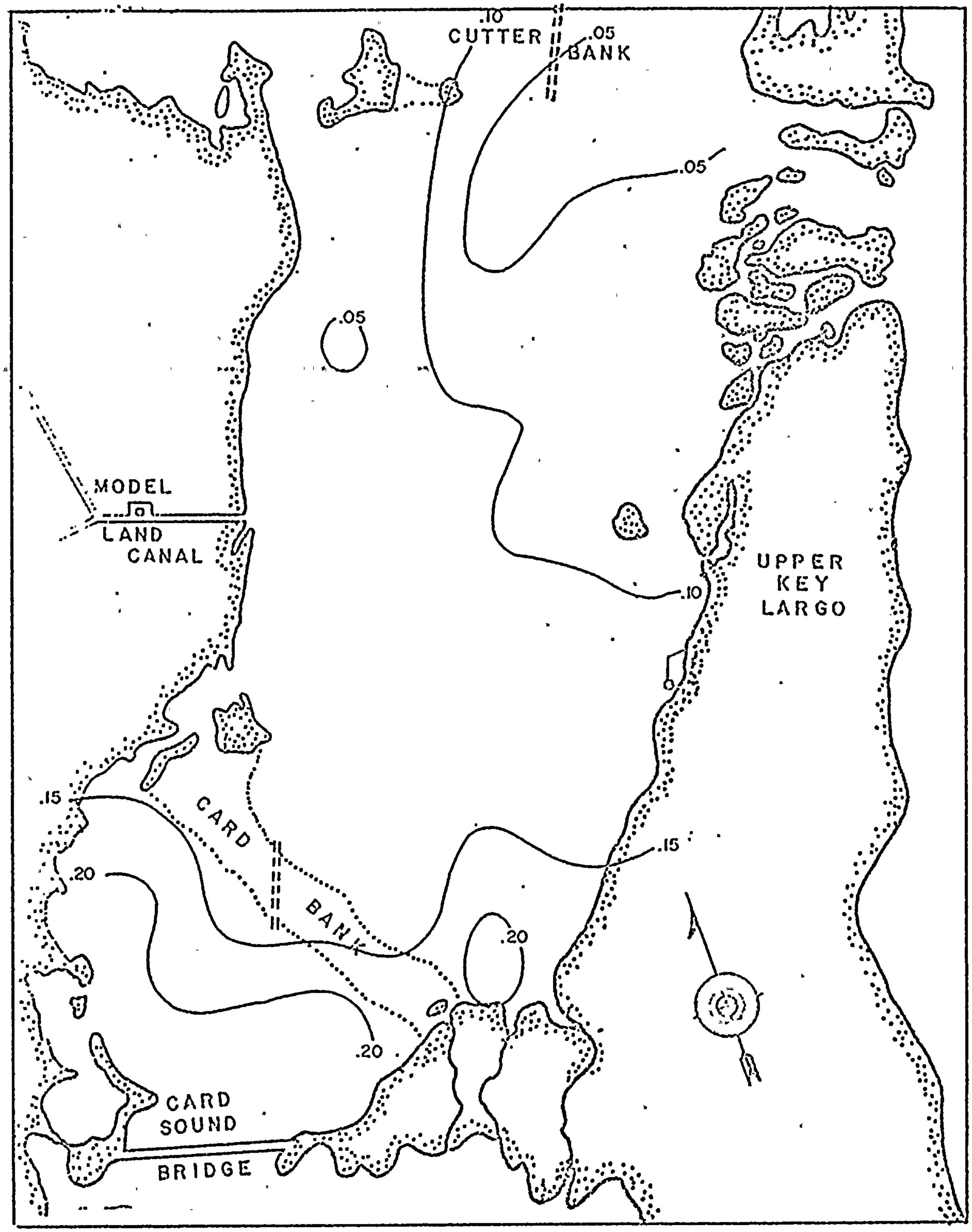

FIGURE IV-13 Surface Nitrite (µg. at. $NO_2 \cdot N/\ell$) - Card Sound 13th Jan. 1971

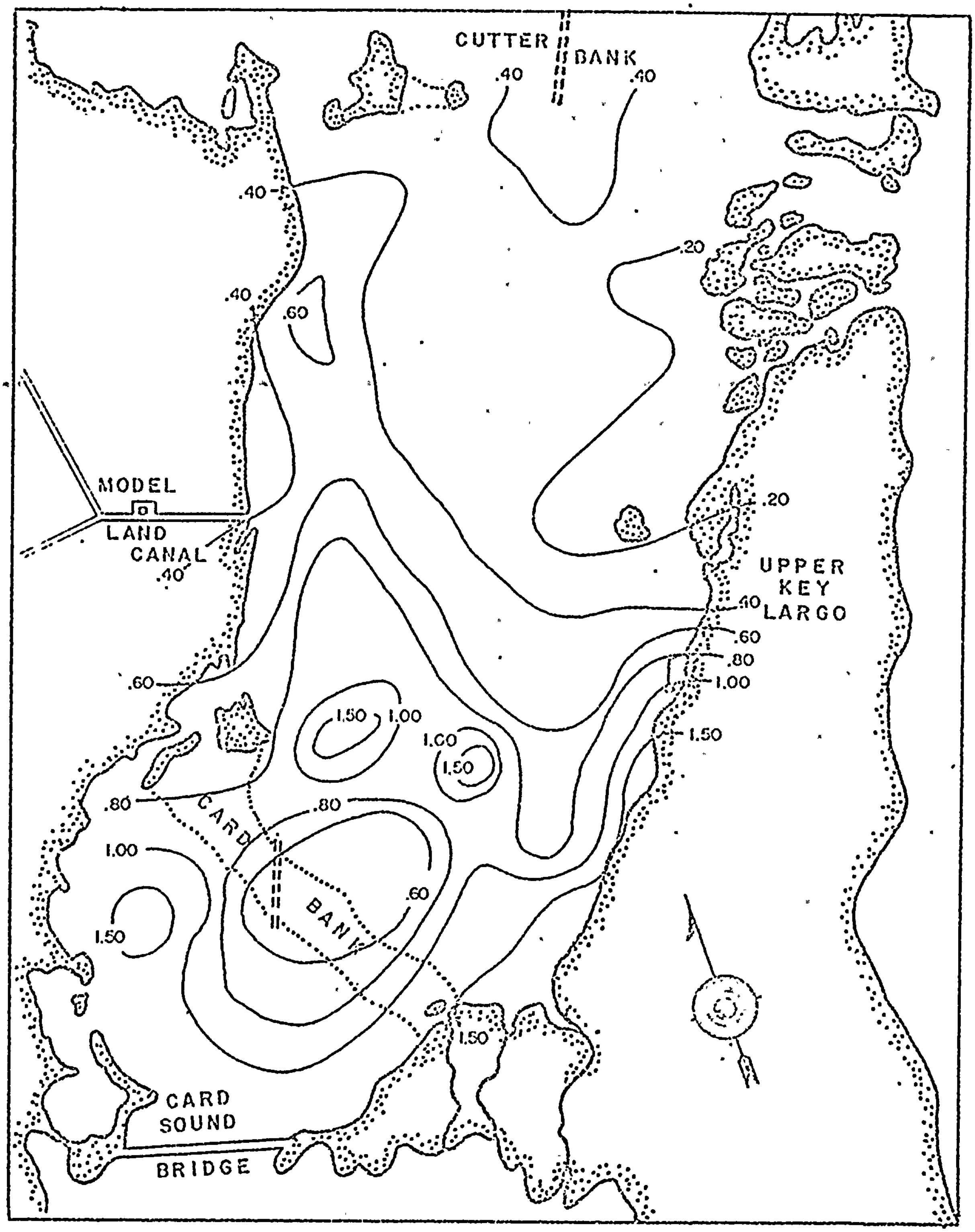

FIGURE IV-14 Surface Nitrate (µg. at. $NO_3 \cdot N/\ell$) - Card Sound 13th Jan. 1971.

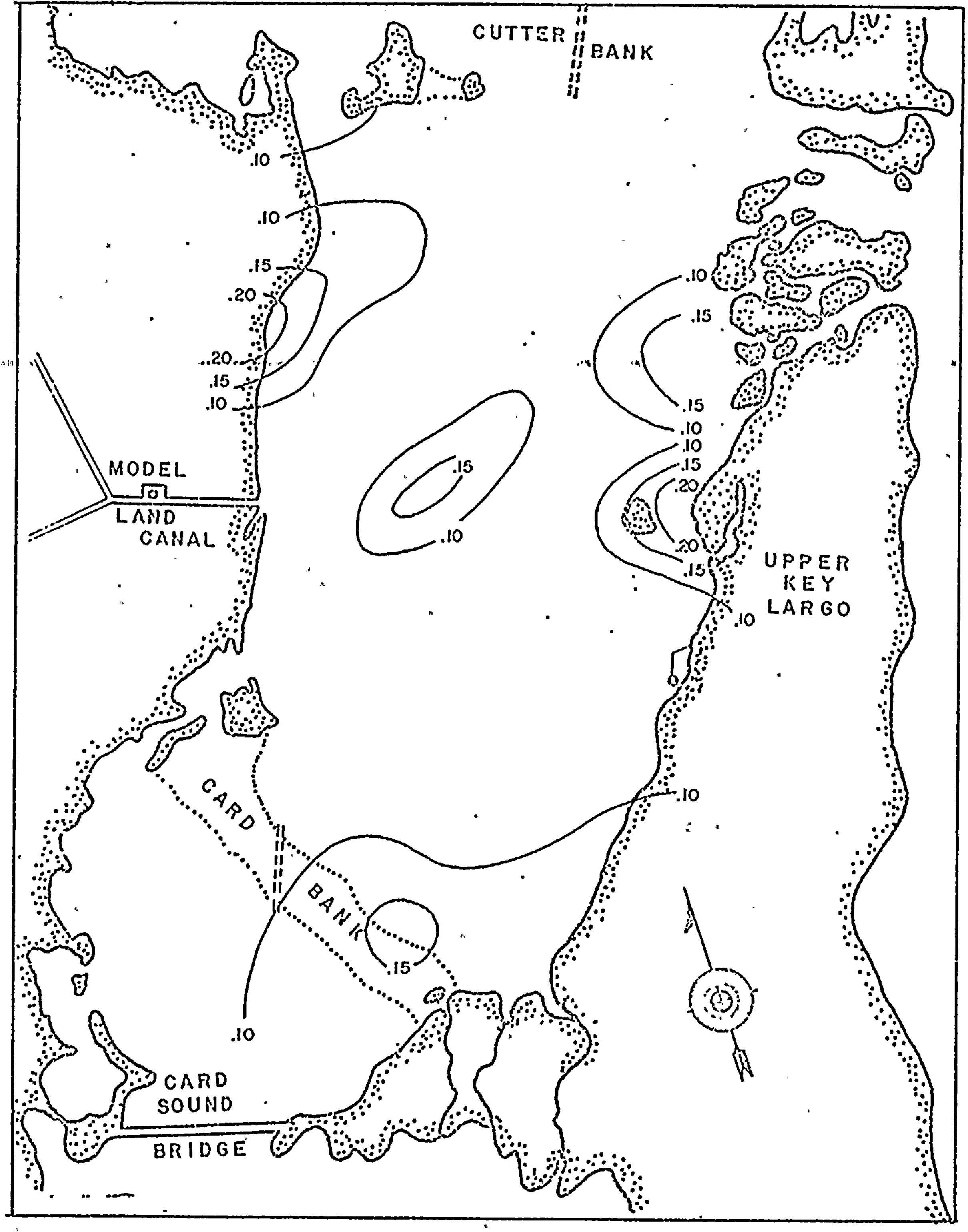

FIGURE IV-15 Surface Inorganic Phosphate (μg. at. PO_4.P/ℓ). Card Sound 13th Jan. 1971

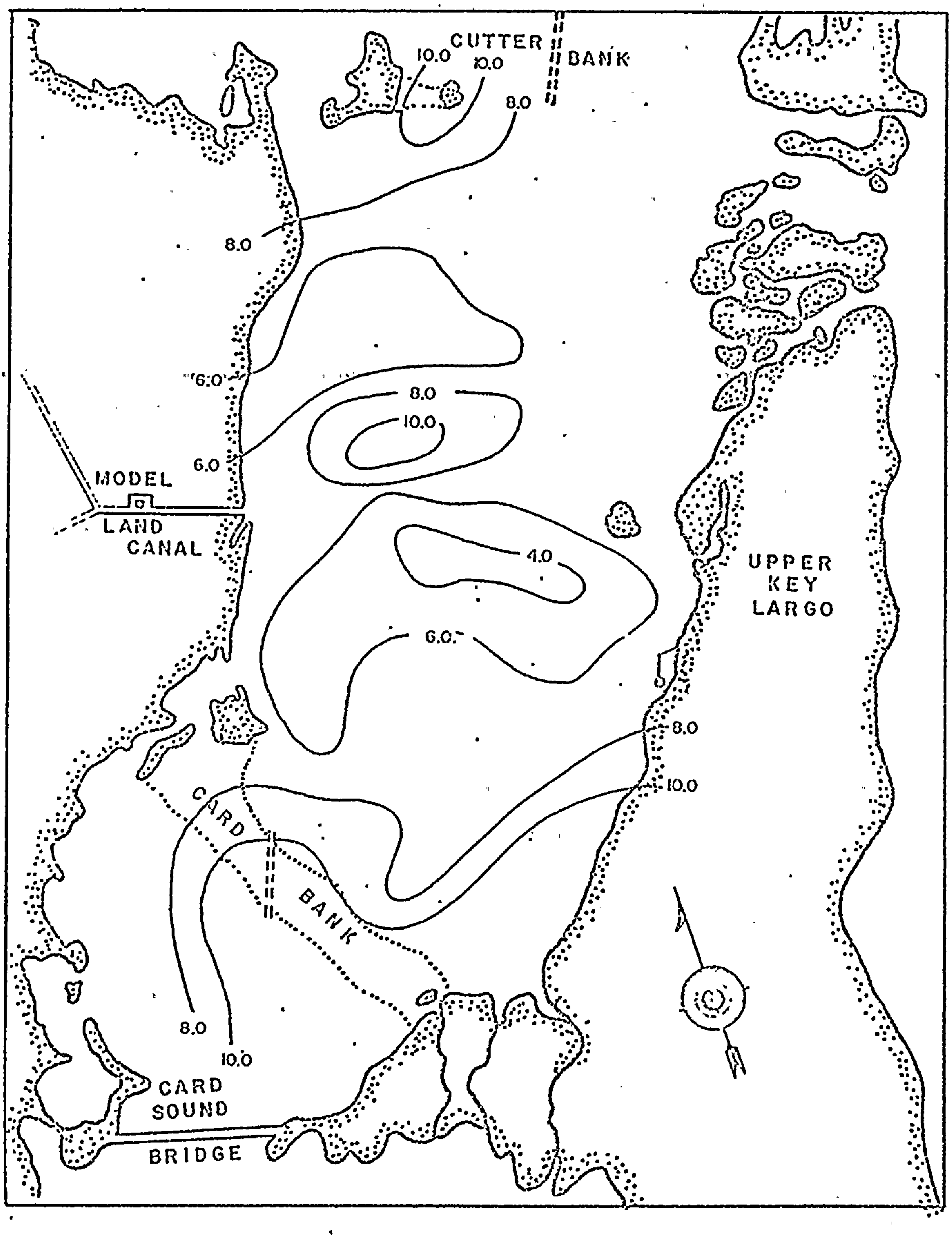

FIGURE IV-16 Surface "Ionic" Iron (μg/Kg) Card Sound 13th Jan. 1971

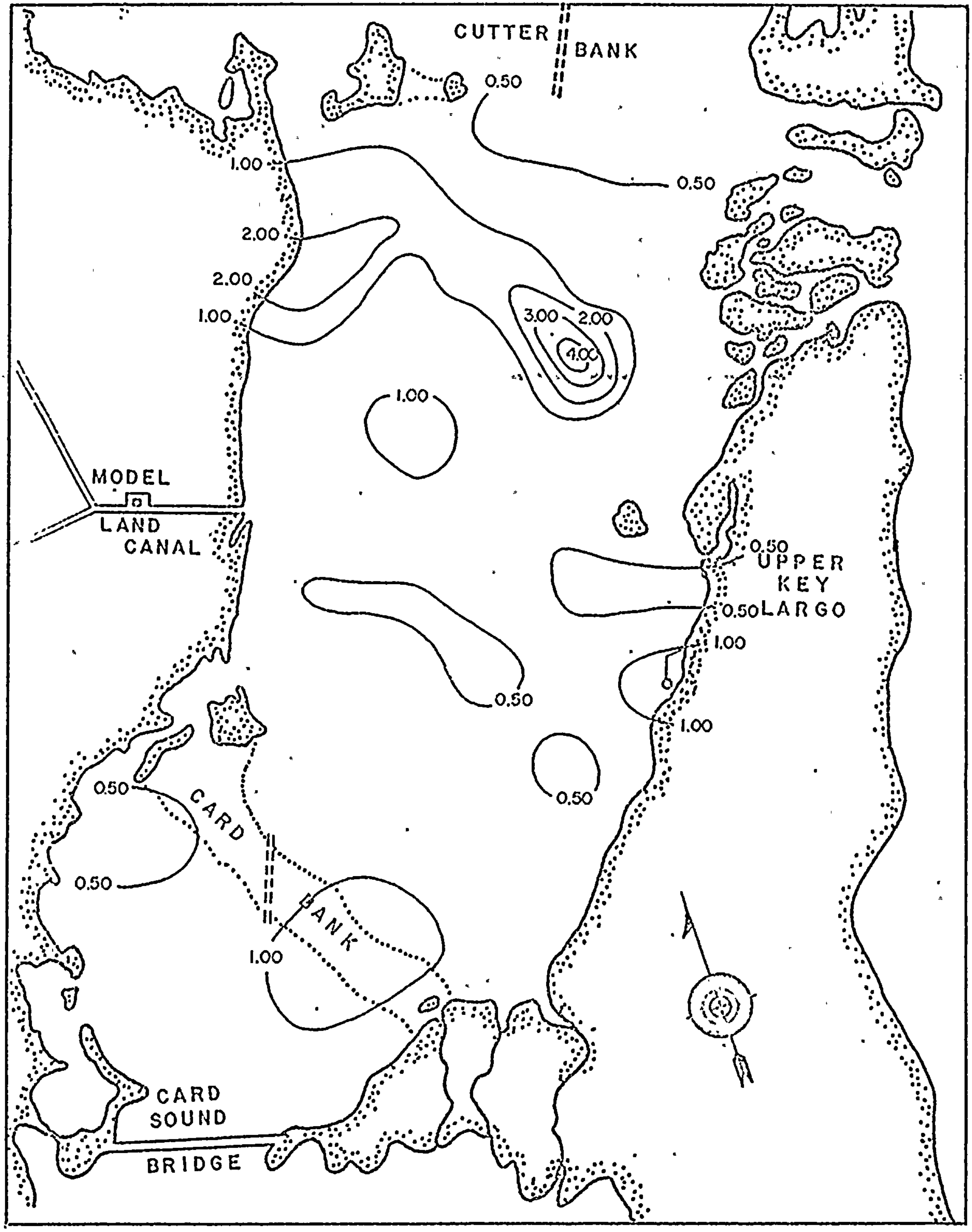

FIGURE IV-17 Surface "Ionic" Copper (μg/Kg) Card Sound
13th Jan. 1971

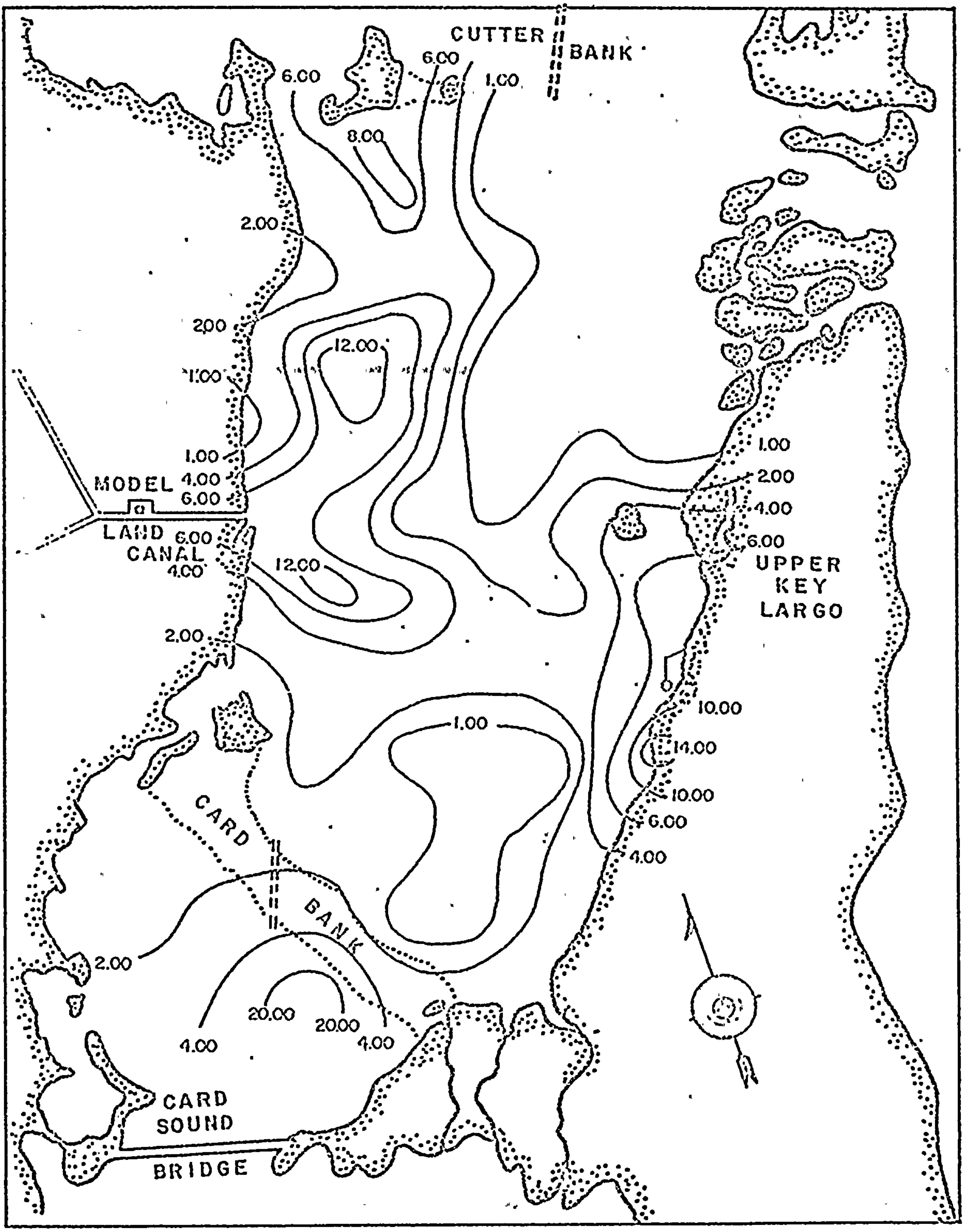

FIGURE IV-18 Surface "Ionic" Zinc (ug/Kg) Card Sound 13th Jan. 1971

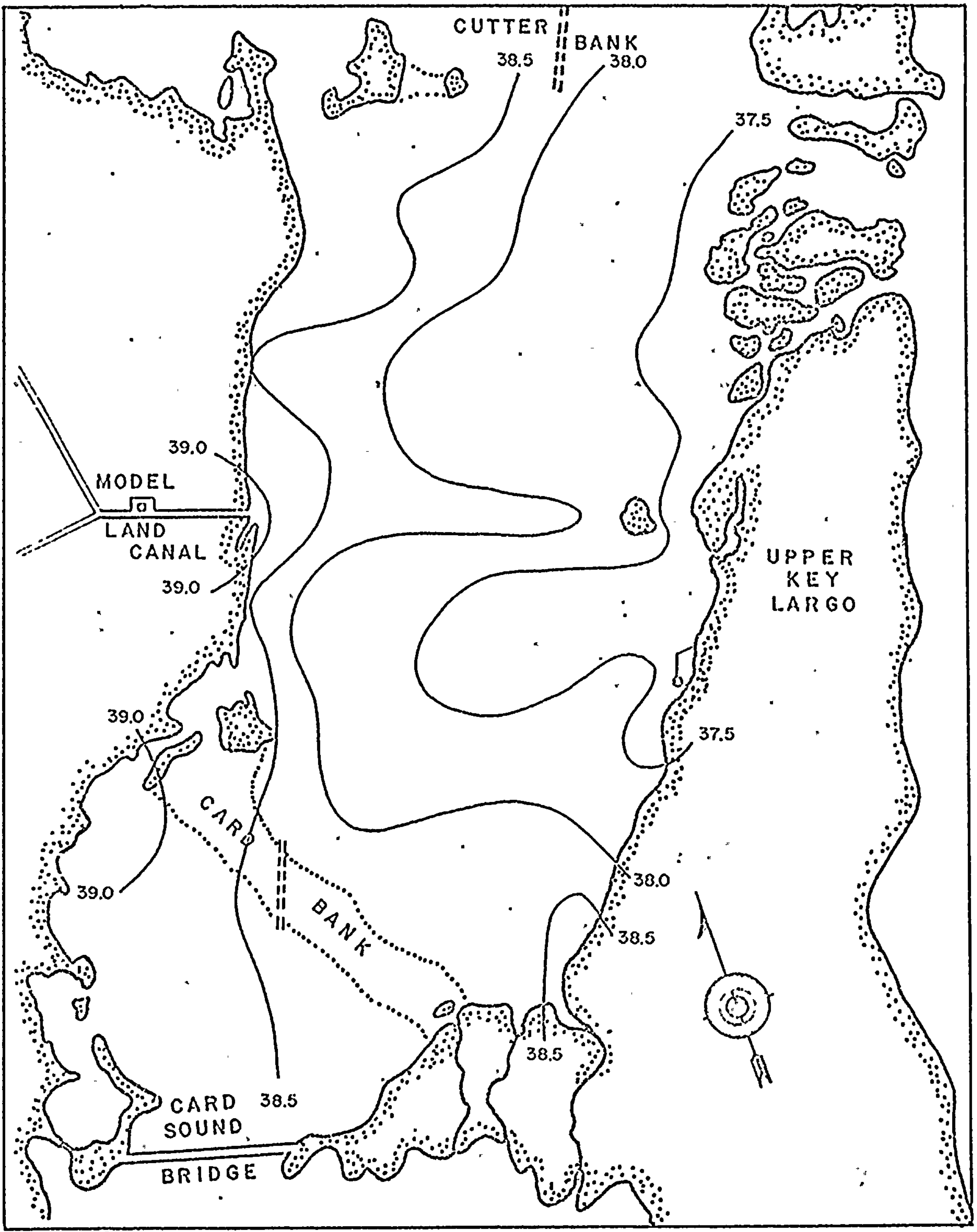

FIGURE IV-19 Surface Salinities (°/oo) - Card Sound 17th Mar. 1971

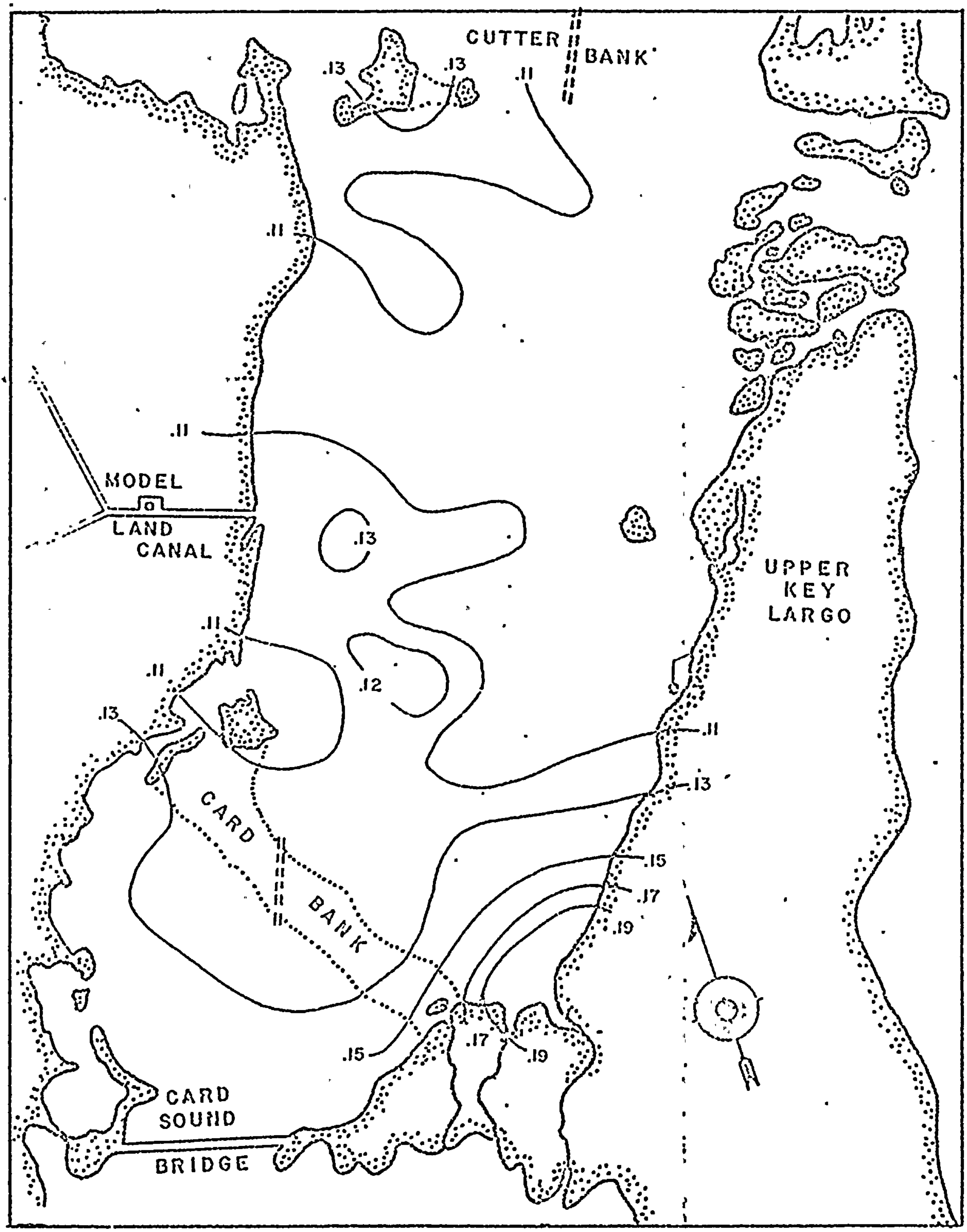

FIGURE IV-20 Surface Nitrite (µg. at. NO_2.N/l) Card Sound 17th Mar. 1971

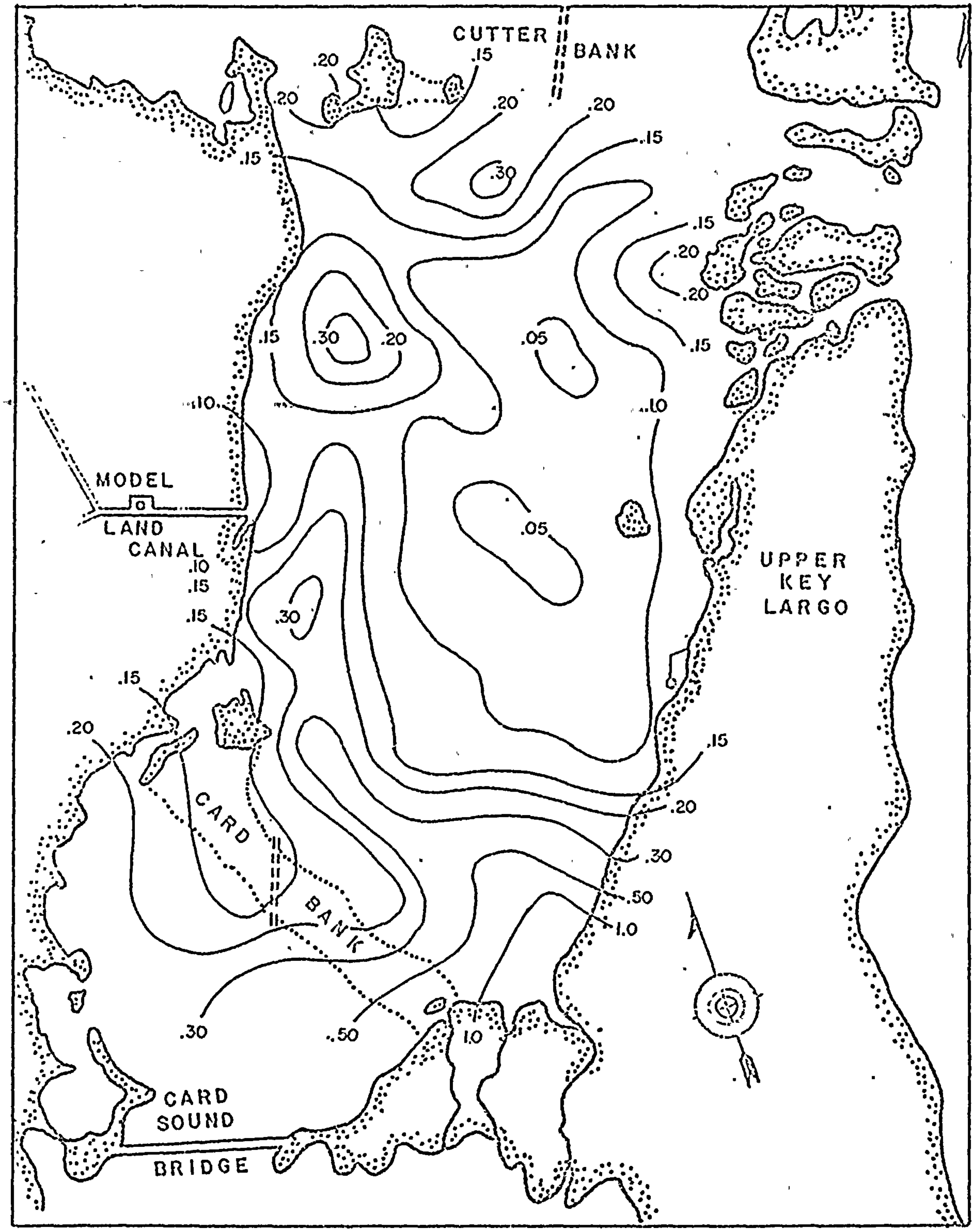

FIGURE IV-21 Surface Nitrate (µg. at. NO_3.N/ℓ) Card Sound 17th Mar. 1971

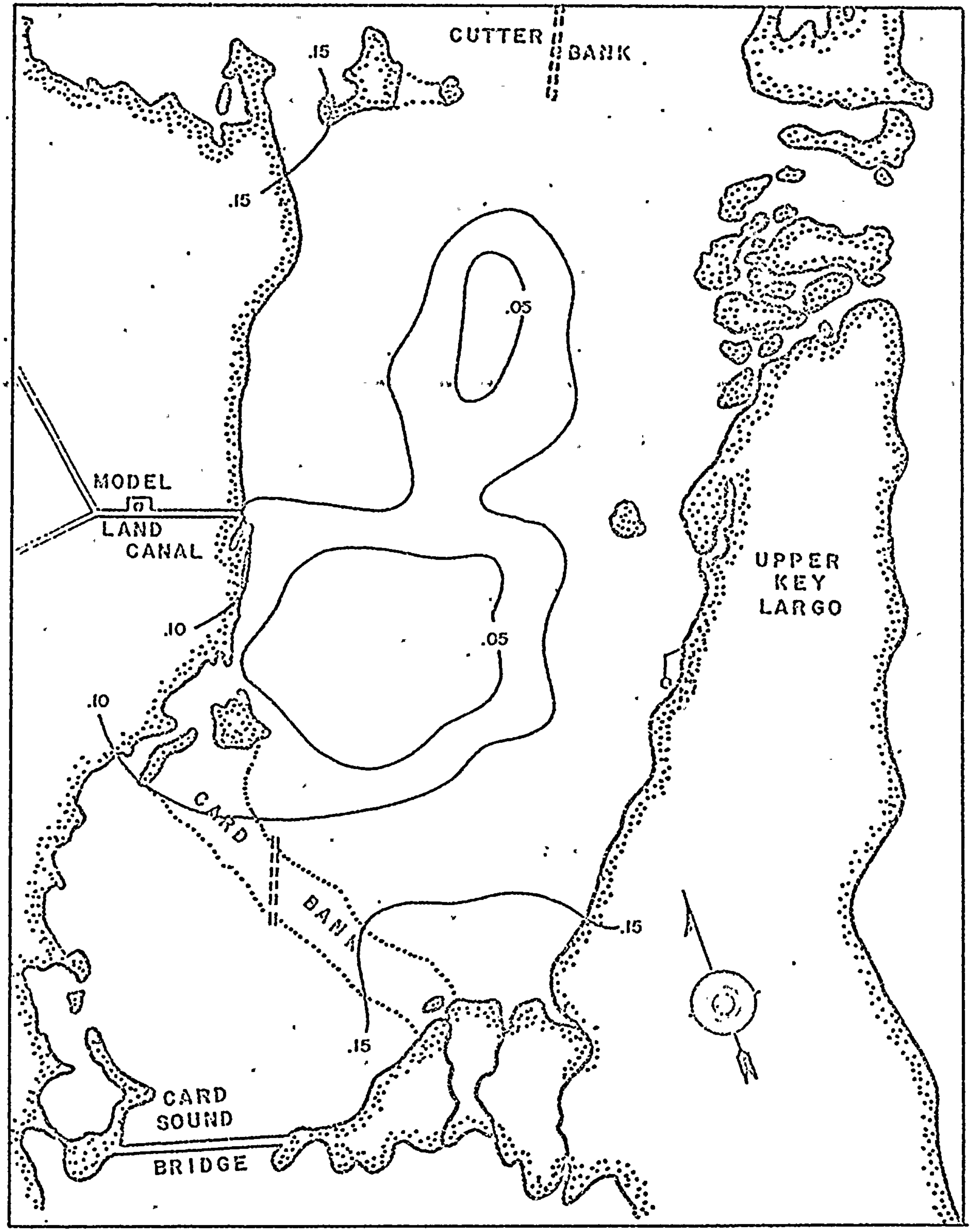

FIGURE IV-22 Surface Inorganic Phosphate (µg. at. PO_4.P/ℓ) Card Sound 17th Mar. 1971

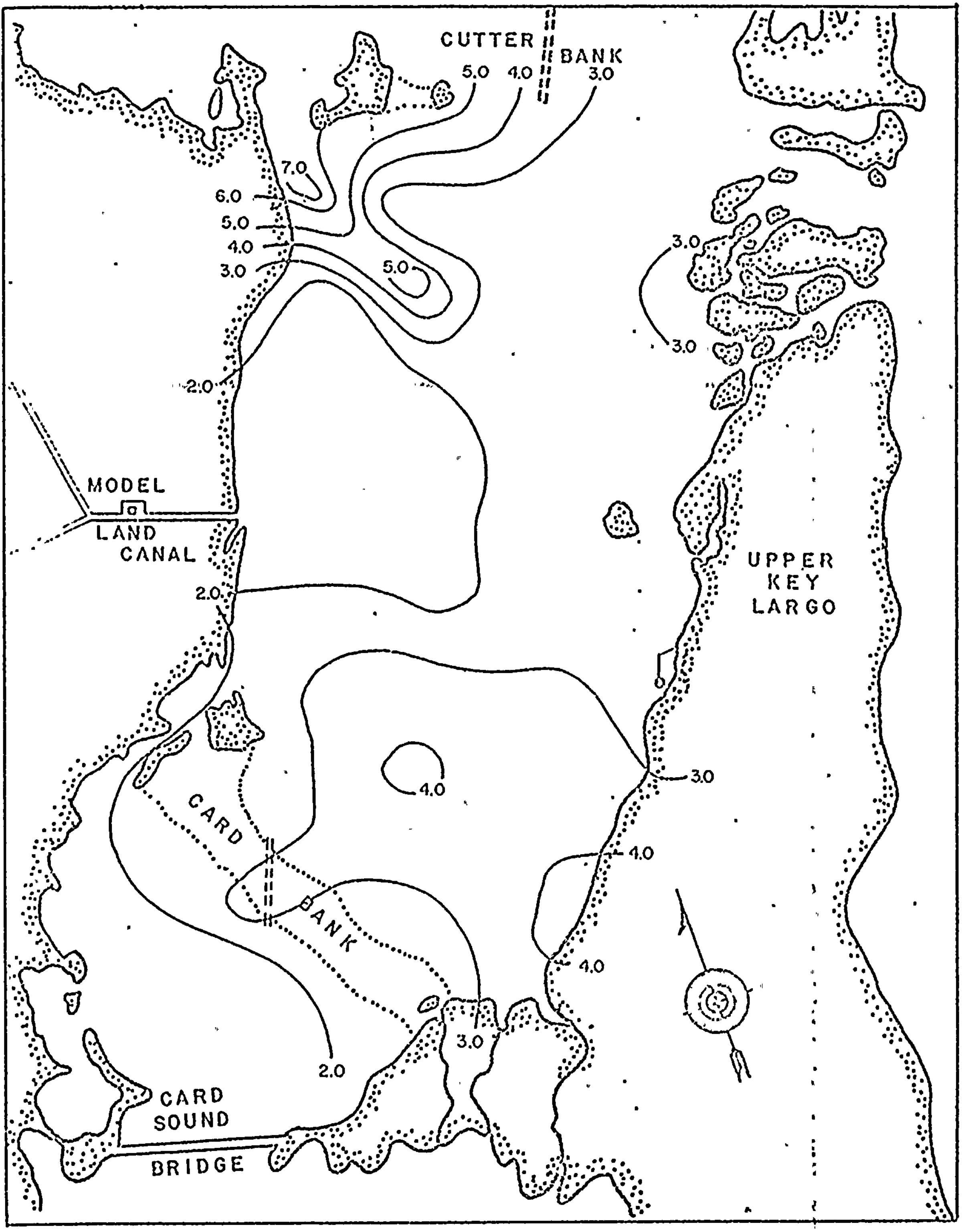

FIGURE IV-23 Surface Reactive Silicate (μg. at. $SiO_4.Si/\ell$)
Card Sound 17th Mar. 1971

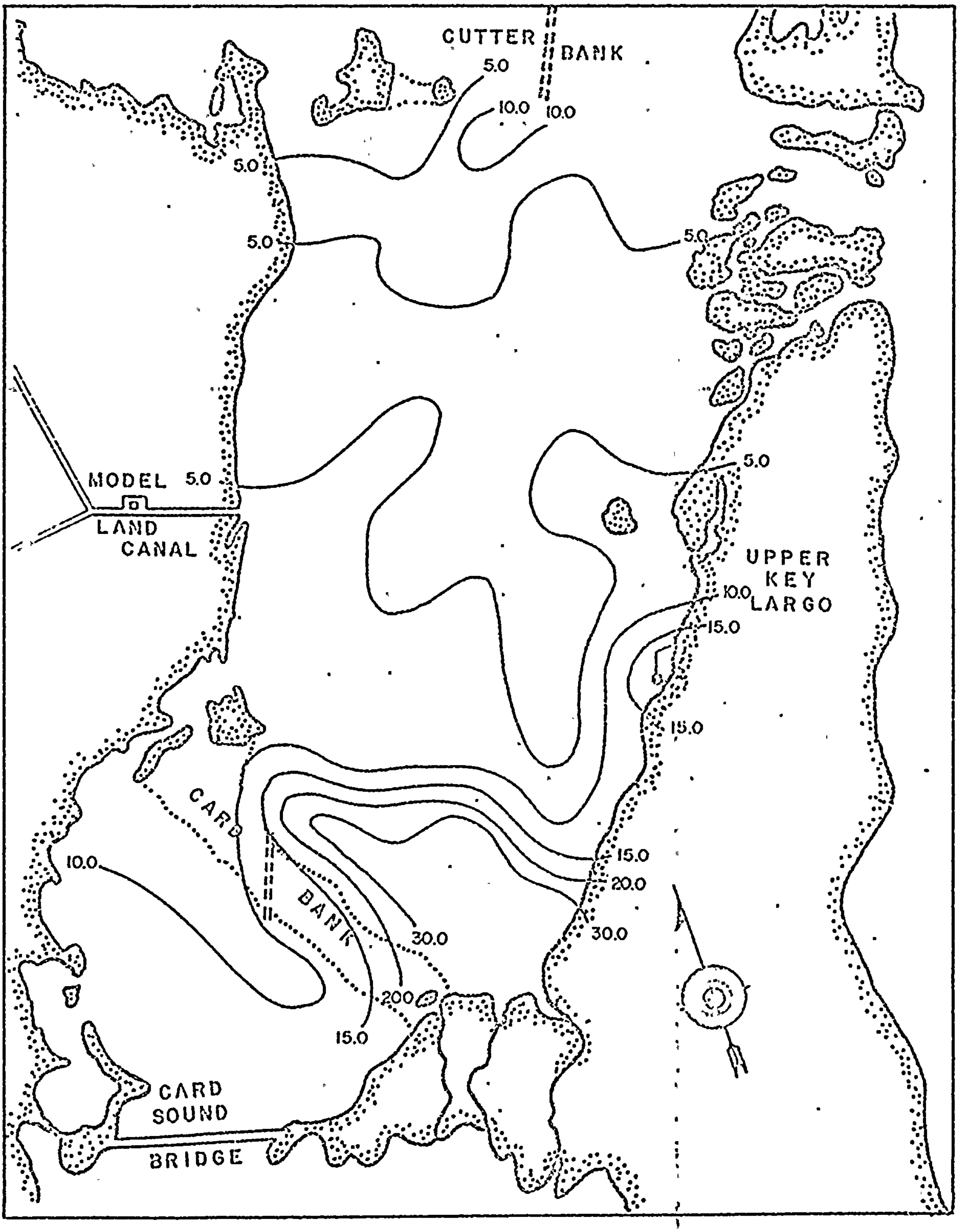

FIGURE IV-24 Surface "Ionic" Iron (μg/Kg) Card Sound
17th Mar. 1971

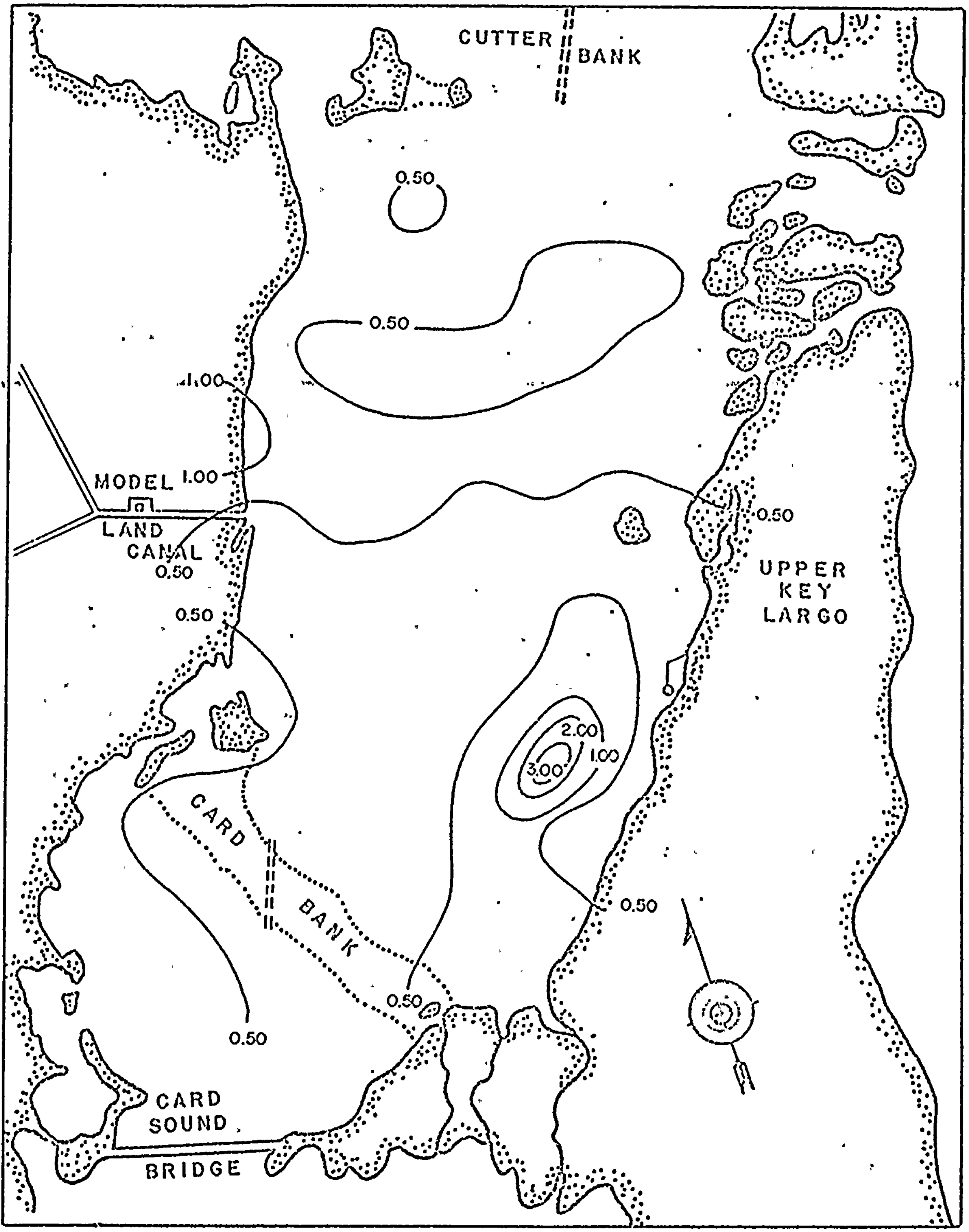

FIGURE IV-25 Surface "Ionic" Copper (μg/Kg) Card Sound
17th Mar. 1971

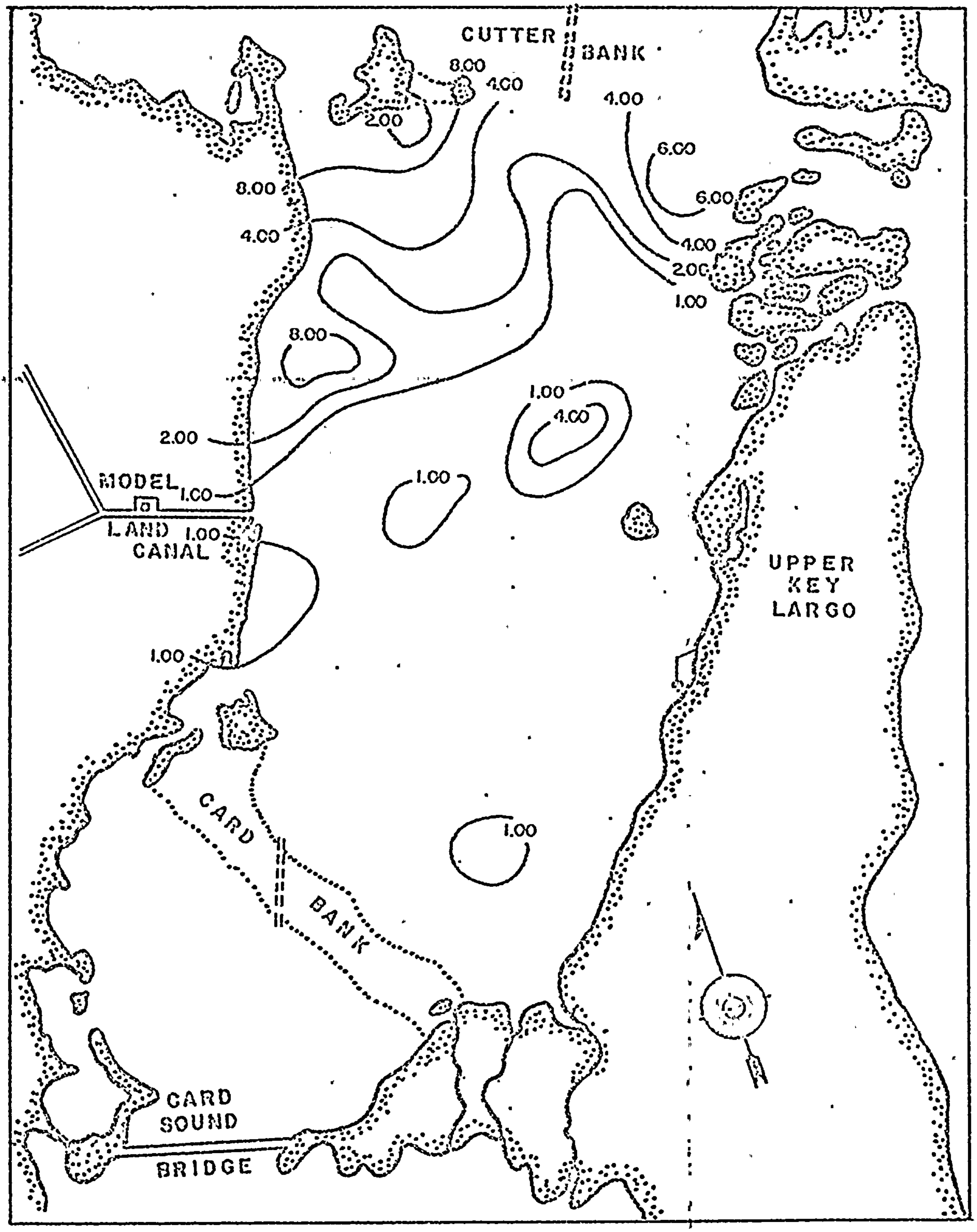

FIGURE IV-26 Surface "Ionic" Zinc (µg/Kg) Card Sound 17 Mar. 1971 zinc distribution was consistent with the salinity pattern except that the former appears to have been in low concentration in the entire southern section of the Sound.

Higher concentrations of different constituents were not found over Card Bank as they had been in January although some higher concentrations were found in Little Card Sound. The water from Card Bank may thus have been transported southeastward into Little Card and Barnes Sounds and the water mass sampled over Card Bank at the time of these observations may have been derived from the central part of Card Sound.

Higher concentrations of all dissolved constituents investigated were present in the extreme southeast corner of the Sound and it would appear that the water in this area might not be readily flushed out by the action of cold fronts.

Higher concentrations of some constituents particularly silicate and "ionic" zinc were observed in the northwest corner of the Sound. This might indicate the forcing of water from the shallow flats in South Biscayne Bay southwards over the Arsenicker platform.

Visual observations during the passage of the cold front through Card Sound are of interest. During the period of maximum wind, approximately three foot waves were observed building up along the length of the Sound. The waves were breaking on Card Bank, particularly in the southeast corner of the Sound while Little Card Sound remained relatively calm with wave heights of about 6 inches. The turbidity of the water particularly in the western half of the Sound was markedly increased as the wave heights built up.

Information gathered by current meters during March correlated well with the chemical observations discussed above. These current meter observations are summarized in the circulation studies report (section II).

(3) The surface salinity distribution observed on February 17th, 1961 is shown in Figure IV-27. A strong cold front with maximum winds of 20 m.p.h. passed through Card Sound during the 13th, 14th and 15th of February. This was preceded by another series of fronts on the 8th, 9th, 10th and 11th. Thus, for eight days preceding the series of measurements, winds had been predominantly from the north and northeast. The salinity within the Sound was extremely uniform reflecting the almost complete flushing of the Sound during the preceding days. Observations of this flushing during February 13th and 14th are discussed in the section of this report dealing with circulation (Section II).

The nitrite (Figure IV-28), nitrate (Figure IV-29), inorganic phosphate (Figure IV-30), "ionic" iron (Figure IV-31), "ionic" copper (Figure IV-32), and "ionic" zinc (Figure IV-33) distributions observed on February 17th are shown. The distribution of these chemical constituents tended to confirm the completely flushed state of the Sound indicated by the salinity distribution. No distinct distribution pattern could be seen such as was observed in the January and March investigations. Variations in each of the chemical parameters measured

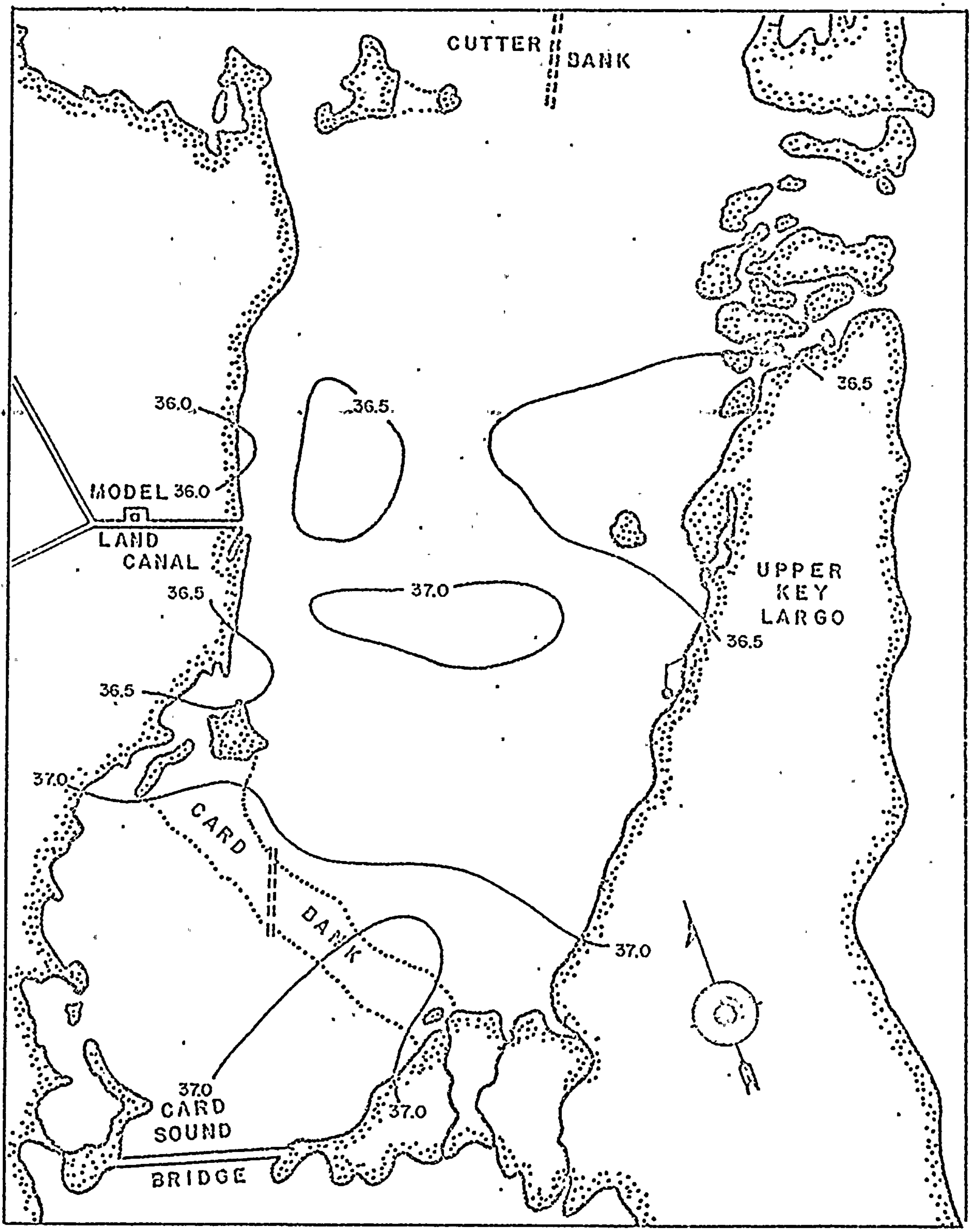

FIGURE IV-27 Surface Salinities (^{o}/oo) Card Sound 13th Feb. 1971

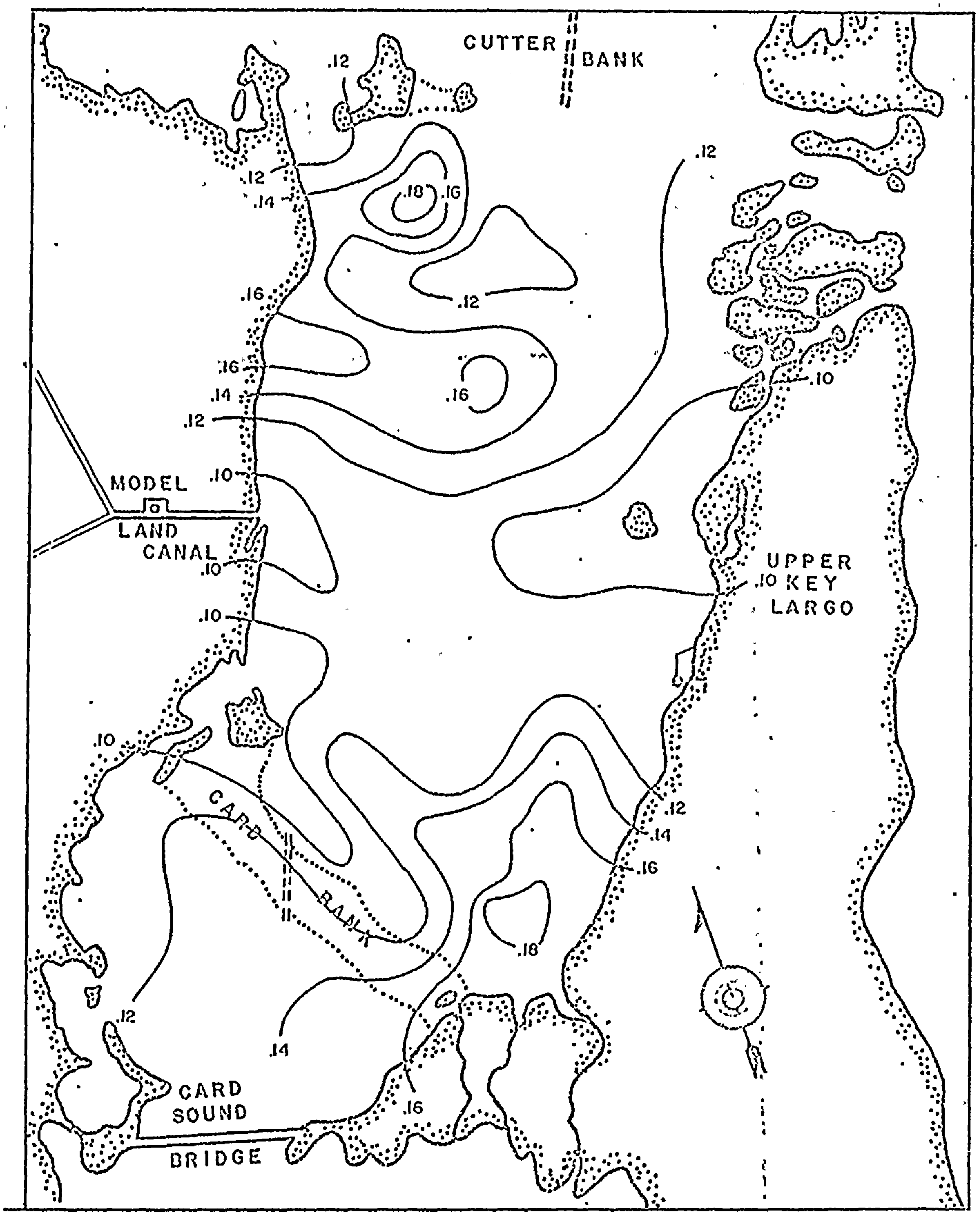

FIGURE IV-28 Surface Nitrite (µg. at. NO_2.N/ℓ) Card Sound 13th Feb. 1971

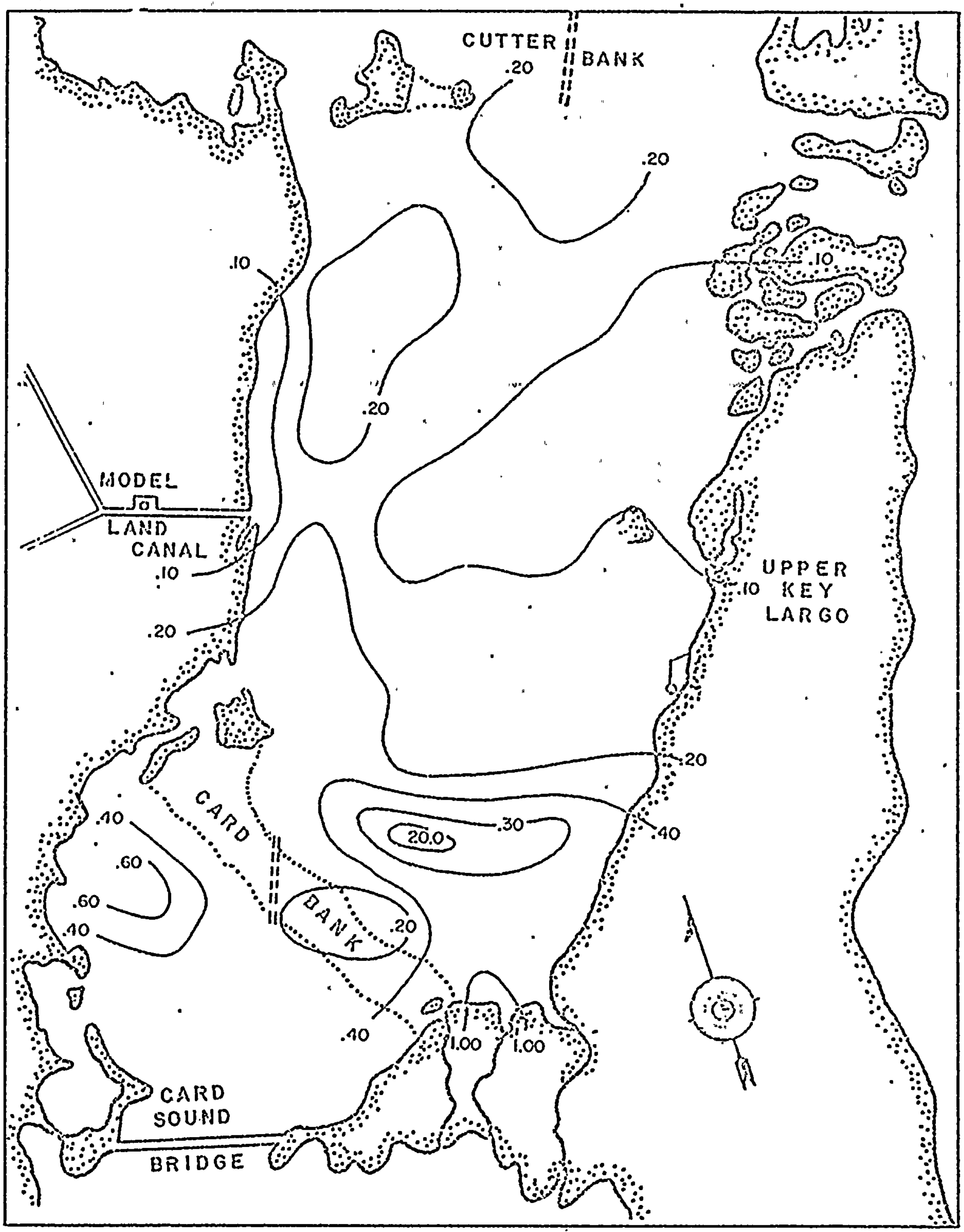

FIGURE IV-29 Surface Nitrate (µg. at. NO_3.N/ℓ) Card Sound 13th Feb. 1971.

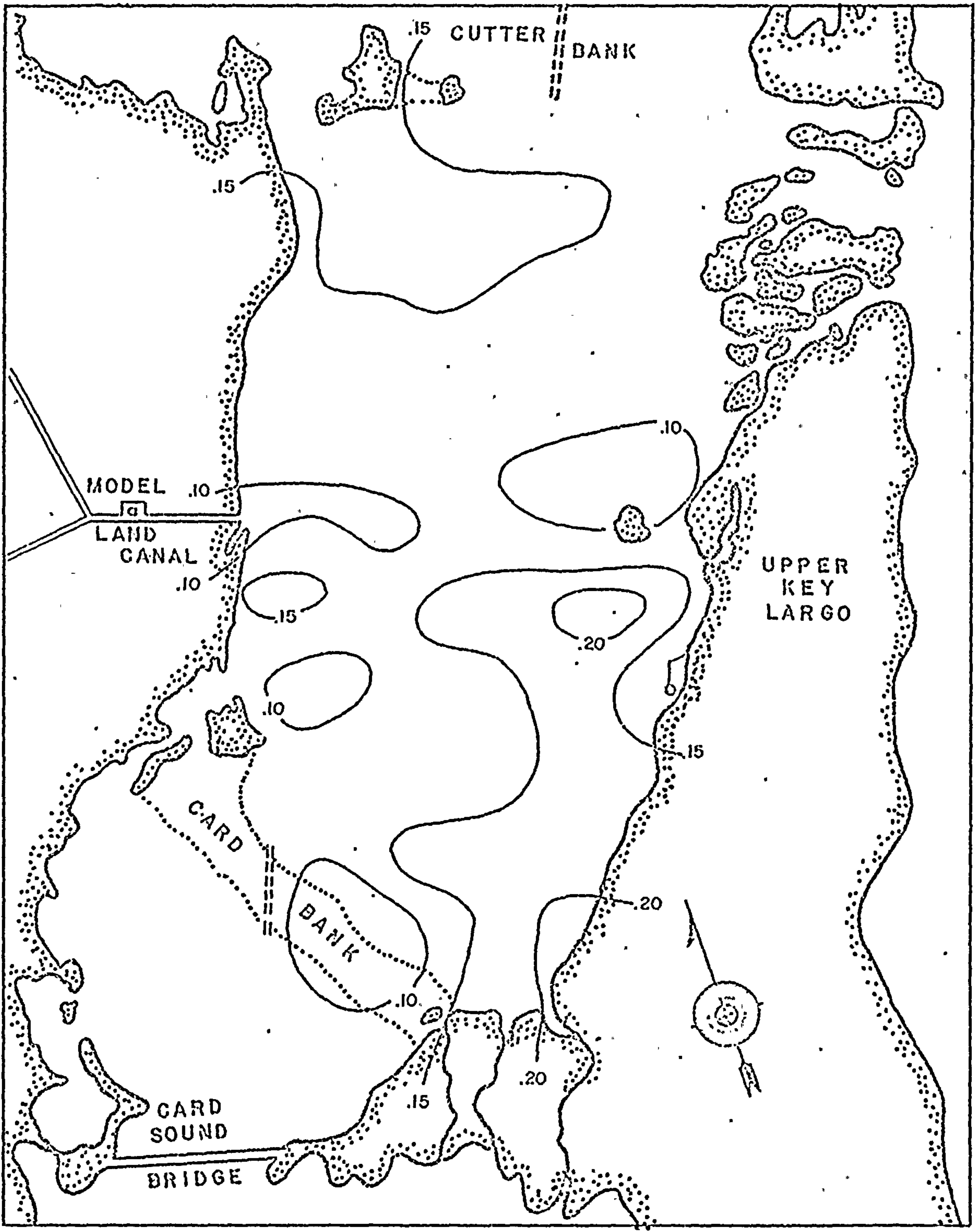

FIGURE IV-30 Surface Phosphate (µg. at. PO_4.P/ℓ) Card Sound 13th Feb. 1971

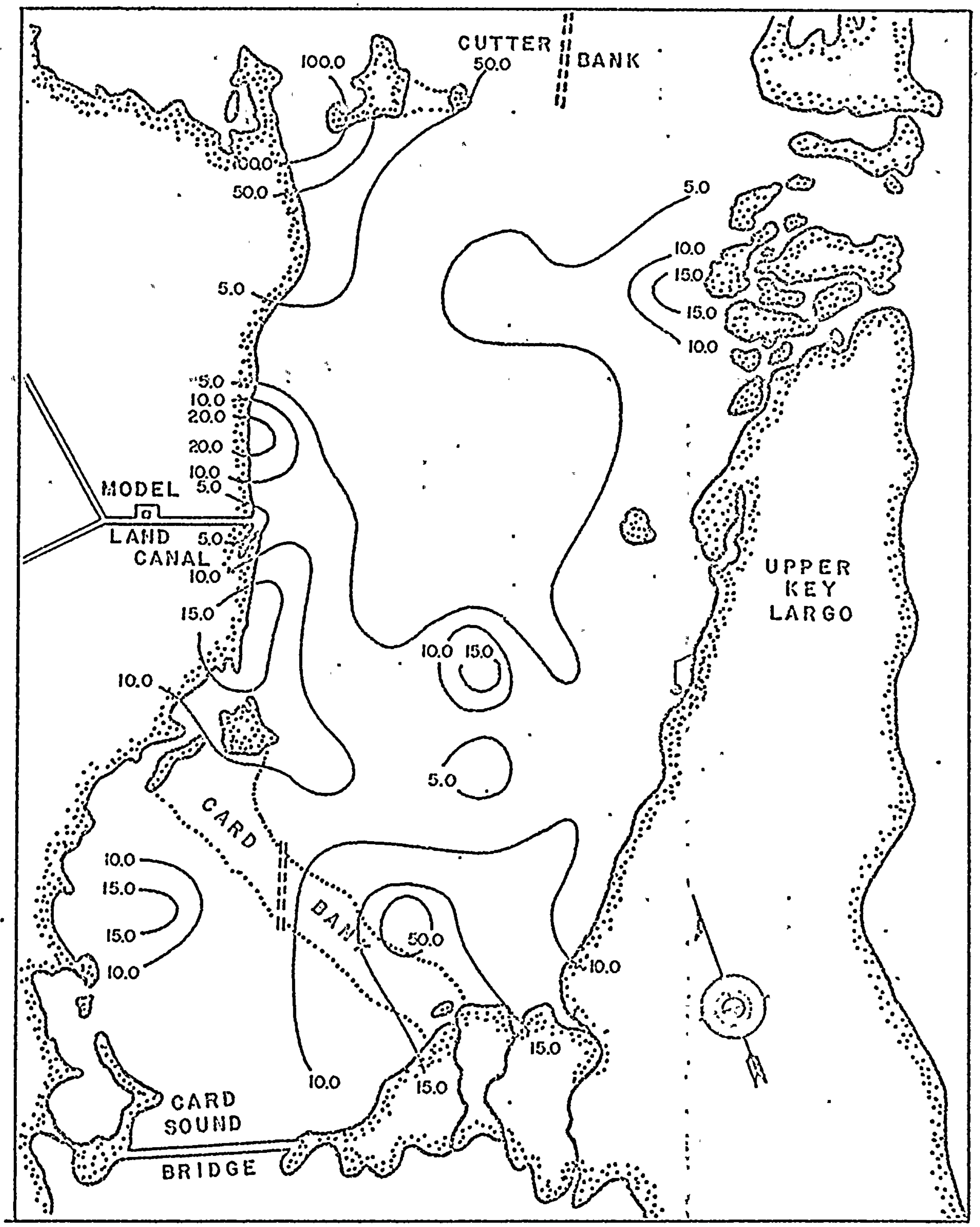

FIGURE IV-31 Surface "Ionic" Iron (μg/Kg) Card Sound
13th Feb. 1971

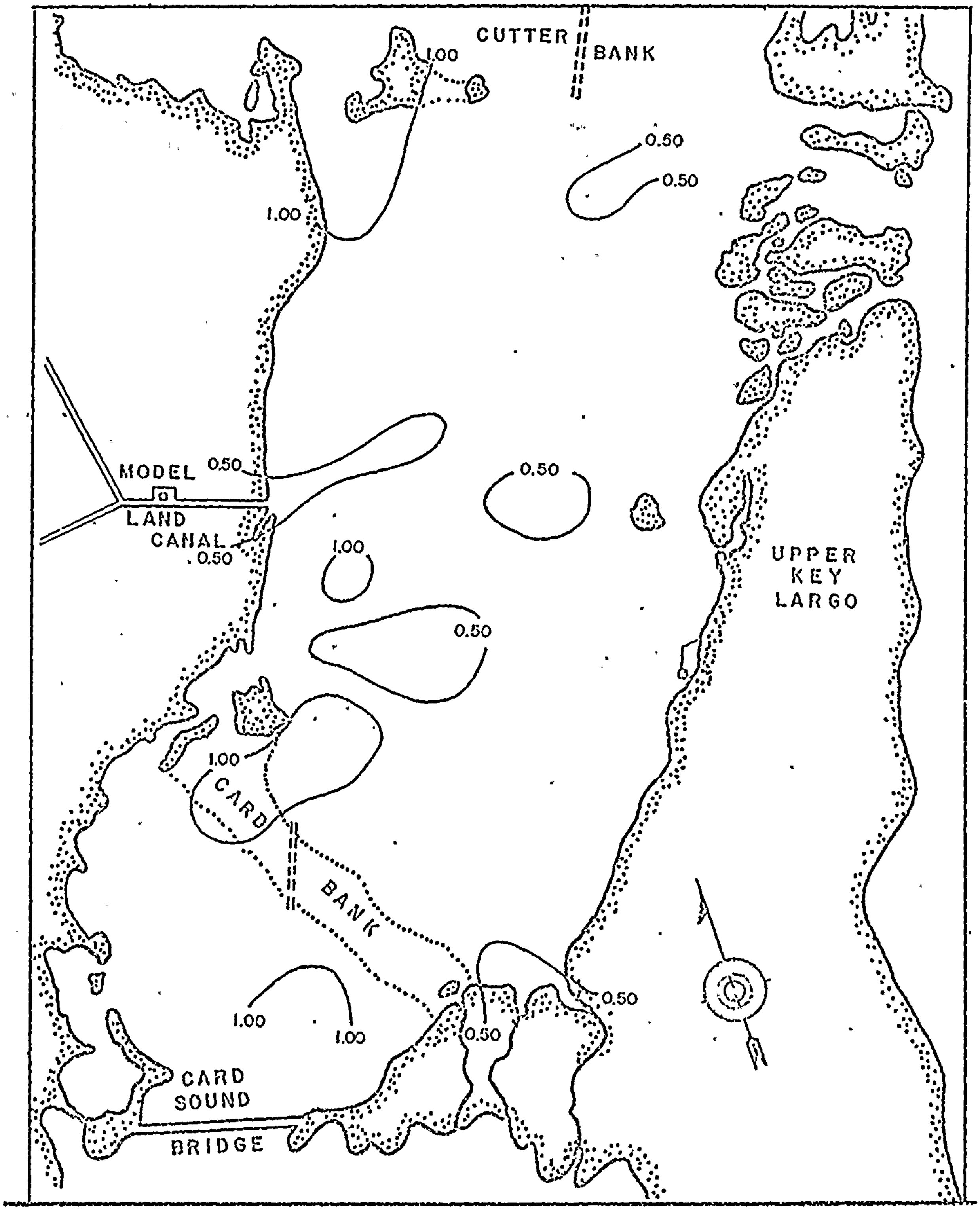

FIGURE IV-32 Surface "Ionic" Copper (µg/Kg) Card Sound 13th Feb. 1971

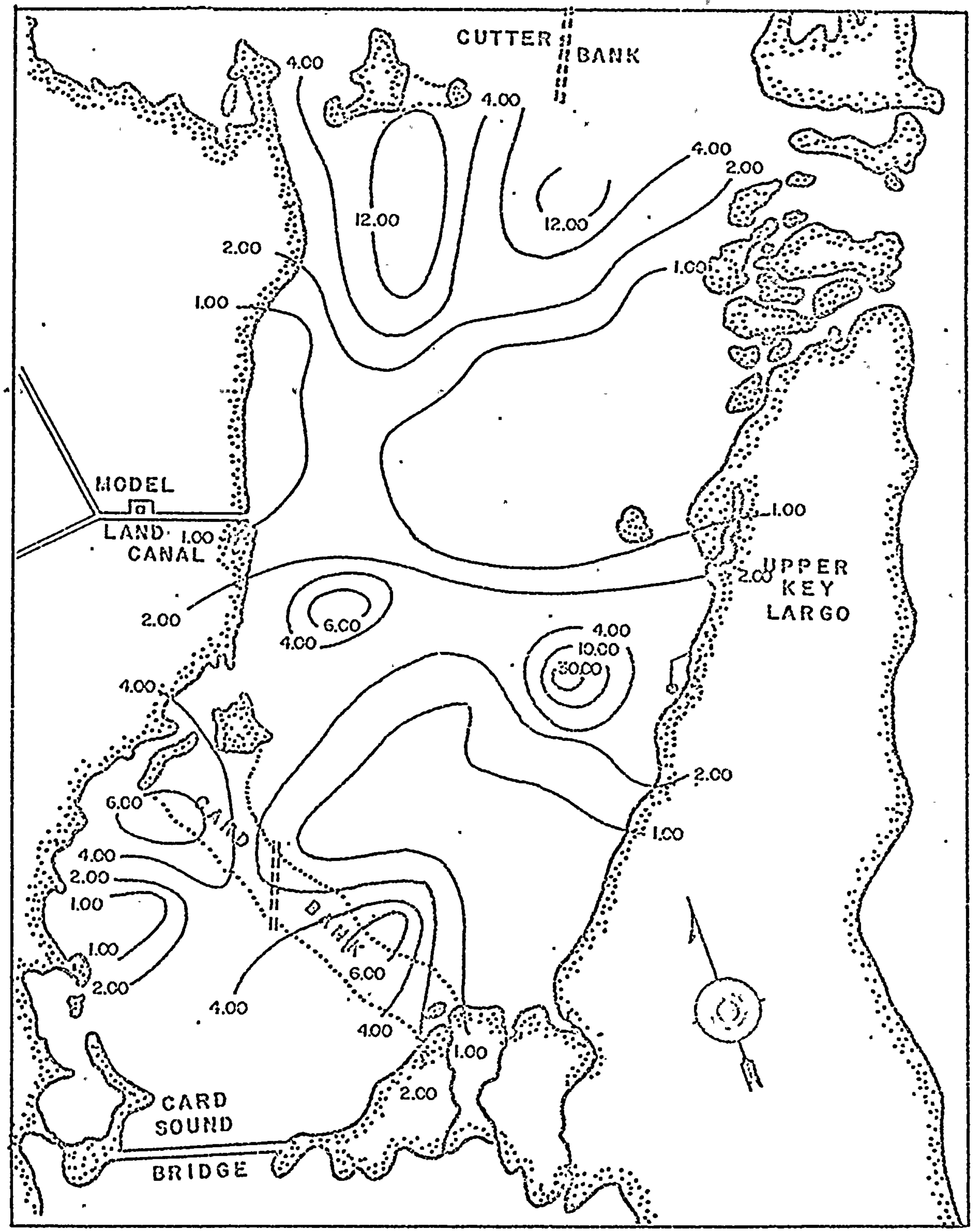

FIGURE IV-33 Surface "Ionic" Zinc (μg/Kg) Card Sound 13th Feb. 1971

were observed within the Sound. However, the only distinct area was in the southeast corner which was high in nitrite, nitrate, phosphate and "ionic" iron, and low in "ionic" zinc. In addition, higher values of all trace metals and of nitrate were observed over Card Bank. This might represent decomposition products of newly deposited organic detritus on the Bank and/or interactions of the water with suspended fine particulate material thrown up from the bottom by wave action.

The distribution of "ionic" zinc was interesting as values throughout the Sound were higher than had been seen in the ocean water mixing zone in January and March. This might indicate that the water flushing the Sound during the passage of cold fronts was derived mainly from South Biscayne Bay and not from the ocean. This conclusion is in agreement with the findings discussed under the circulation studies program (Section II). Unfortunately, no direct measurement of the "ionic" zinc concentration in the ocean water or inlets was made at the time of sampling so that this conclusion is somewhat tentative. A sampling station in Angelfish Creek and one just offshore in the ocean will be added to the station grid in any future synoptic surveys.

The results of the circulation studies (section II) and the chemistry studies in Card Sound as described above, can be interpreted with respect to the probable fate of pollutants such as radionuclides added to Card Sound from a point source canal on the western shore near the center of the Sound. Pollutants may be added either in the dissolved state or as particulate matter and will have many different possible pathways in the environment according to their reactions with the hydrosphere, biosphere and sediments. Nevertheless, some generalized prediction can be made with respect to the initial dispersion patterns of pollutants in Card Sound.

During periods of calm weather when wind induced transport is negligible, the northeast quarter of the Sound will be well mixed with tidal flushing while the rest of the Sound will mix to some extent with South Biscayne Bay and Little Card Sound. Dynamical models predict that even the mixing in the northeast quarter of the Sound will be restricted to a much smaller area by the volume of water introduced by the projected discharge from the Turkey Point nuclear power plants. Water introduced into the Sound from these reactors will mix north and south with the tidal flow. Diffusive mixing will transport fractions of dissolved pollutants into South Biscayne Bay over the Arsenicker ridge and to the South, over Card Bank, into Little Card Sound, and into the South East corner of Card Sound. A small fraction will be transported out into the ocean across the salinity front when it is present. Unless the pollutants are removed from solution, the extent of their dispersion will be over a greater area than that subjected to increased temperatures. To the north mixing will disperse the pollutants into South Biscayne Bay over a wide area as South Biscayne Bay is somewhat better flushed than Card Sound. To the south, however, the area of dispersion is severely limited as Little Card Sound is very poorly flushed. Thus, pollutants would tend to accumulate in the south end of Card Sound and in Little Card Sound until their concentrations will reach a steady state equal in magnitude to those at the outfall. If processes such as biological

uptake and removal into the sediments take place then an accumulation of pollutants will occur in Little Card Sound and on Card Bank. Periodic flushing by the action of cold front induced winds will only minimize this accumulation during the winter period.

During periods of calm weather, suspended particulates introduced into the Sound by the power plant effluent will settle out in the deeper parts of the Sound as the velocity of the effluent water drops during its initial dispersion at the outfall. Existing sediment distributions (Earley and Goodell, 1966 and this report) indicate that the fine fraction of this particulate material will not remain in the original site of deposition in the center of the Sound. Fine sediments are being introduced from the runoff on the western coastline of the Sound and probably have been so introduced for a considerable length of time. However, sediments in the deep basin of Card Sound are very shallow in depth and consist predominantly of coarse grained particles. Sediment transport takes place during periods of high winds when fine particles are resuspended in the water column. High winds which produce significant wave action are primarily produced by occasional hurricanes and by the frequent passage of cold fronts during the winter. Not considering hurricanes, the major wind induced waves are produced by the northeast winds associated with cold fronts. The wave action will resuspend fine particulate material at the same time that the water mass within the Sound is being transported southward to Card Bank. The wave breaking action of Card Bank and the calm waters in Little Card Sound will allow the transported particulates to be redeposited leading to their accumulation in this area.

Many radionuclides are known to be associated with particulate material in discharges from power plants. The situation may be somewhat different in Card Sound due to the absence of clay minerals (see above). Nevertheless, removal of radionuclides to the sediments will take place in the absence of clay minerals by mechanisms such as biological uptake, precipitation due to solubility equilibria, and scavenging by humic material. Thus, if any radionuclides are added to the water they may be expected to accumulate in the sediments of Card Bank, Little Card Sound and just north of Card Bank in the southeast corner of Card Sound.

Although winter cold front induced flushing of the Sound will tend to remove accumulations of dissolved substances, it may also tend to concentrate particulate pollutants in one area and therefore affect the living organisms in this area, particularly the filter feeding animals.

Considering this model of particulate transport in Card Sound, it would appear to be more acceptable to complete the Card Sound Canal and introduce the first flow of cooling water into Card Sound in the early part of the winter than at any other time of the year. A considerable quantity of particulate material will undoubtedly be introduced into the Sound at this time despite any precautions taken to minimize it. Thus, it would be better to allow this to happen during the period when the fine material would be transported to a deposition site already consisting of fine grained material. In this way, the risk of smothering plant and animal life in the central part of the Sound would be minimized. Organisms within the depositional sites already having fine grained sediments should be less affected by the rapid deposition of a layer or material

SUMMARY

The chemical ecology of any estuary is complex. The study of a tropical marine estuary is particularly difficult because of the sparsity of knowledge of tropical oceanography and tropical marine biology. Thus, the present study must include not only investigations aimed directly at the delineation of the ecological effects of the Turkey Point power plant, but also more general studies to improve our understanding of the natural processes fundamental to the maintenance of the natural ecological balance within the estuary.

Accordingly, the results of this study are many and varied, and provide only an outline for the understanding of the chemistry of the South Biscayne Bay and Card Sound ecosystem. In addition, the specific study of the possible effects of the power plant operation has indicated a number of changes in the chemistry of the Bay water which can be tentatively ascribed to its use for cooling by the power plant.

The results of the Turkey Point study to date can be briefly summarized as follows:

1) The temperature fluctuations within the bottom sediments underlying the thermal plume are of smaller magnitude than those in the overlying water. Thus, organisms living within the sediments will experience a different temperature stress pattern to that experienced by those living free within the water. This may either aid the survival or hasten the death of such organisms.

2) The increase in temperature of the discharge water from the power plant aids evaporation and increases salinities in the Bay, but only by a small fraction of the natural range.

3) Passage of cooling water through the power plant allows the water to degass or dissolve atmospheric oxygen to bring the concentration closer to the saturated value. The temperature and salinity of the water determine saturation value and thus oxygen concentrations in the heated discharge water are normally lower than in the intake water. The lowest oxygen concentrations in the discharge water are observed at the highest temperatures and salinities.

4) Inorganic micronutrient concentrations (NO_3, NO_2, SiO_4, and PO_4) and total dissolved organic carbon are usually slightly enriched in the water discharged into the Bay compared to the intake water. This increase could be related to the death or extreme stress of entrained organisms. Further study particularly within the intake and discharge canal systems is essential to investigate this possibility.

5) Some evidence has been obtained which suggests that the dissolved carbon dioxide/carbonate system in the entrained water is altered by the power plant. This system appears to be naturally variable within the Bay.

Thus, further research within the canal system would be required to investigate the possible effects of the power plant.

6) The trace transition elements iron, copper and zinc are enriched in the area of circulation of heated water within the Bay. The "ionic" fraction of these elements appears to be particularly enriched in this area and in the outfall canal. A more intensive study of the speciation of trace metals within the canal system is planned. The possible addition to the discharge water of other metals such as Pb, Co, Ni, Cd and Mn will also be investigated.

7) Preliminary analyses of sediments collected within the area of the discharge plume have been carried out. Further analyses particularly for trace metals are planned in order to determine the effects of the particulate material introduced to the bay from the discharge canal and the ultimate fate of any polluting metals.

8) Preliminary chemical analyses of the particulate load in the discharge water from the Power Plant indicate that this material probably consists of calcite and aragonite crystals with some organic carbon containing particles and perhaps other material. Further analyses of this material are planned. The results of such analyses will be compared with the sedimentary analyses carried out on samples from the area close to the discharge canal mouth.

The results of the Card Sound investigation can be summarized as follows:

1) Baseline data of the chemical ecology of Card Sound has been obtained for winter and spring climatological conditions under the influence of severe drought. The effects of changes in these conditions will be studied during the coming summer and fall. Parameters that have been determined in Card Sound water are nitrite, nitrate, inorganic phosphate, silicate, total dissolved phosphorus, temperature, salinity, oxygen, alkalinity, total inorganic carbon, total organic carbon, total dissolved iron, total dissolved copper and "ionic" dissolved iron, copper, zinc, lead, cadmium, nickel and cobalt.

2) Sediment samples from Card Sound have been collected and partially analysed. Further analyses will be carried out on these samples and compared with analyses of samples obtained subsequent to the introduction of heated effluent into Card Sound.

3) Water and sediment samples have been monitored for the background levels of alpha and beta activity and for gamma emitting radionuclides. This data is not yet complete but sufficient samples have been obtained to clearly establish the baseline activity levels in the water and sediments. Biological organisms are to be collected and monitored for background levels of activity.

Synoptic chemical studies completed within Card Sound considerably complement physical observations of circulation patterns and permit the

following initial predictions of the distribution of pollutants introduced by the projected effluent canal:

1) Dissolved pollutants will be mixed northwards into South Biscayne Bay and southwards over Card Bank into Little Card Sound. Flushing of Little Card Sound and the water in the southeast corner of Card Sound is very limited except under the action of cold front induced southward water transport. Thus, these areas represent probable accumulation sites of dissolved pollutants particularly those that will be slowly removed from solution by biological uptake or sedimentation processes.

2) Suspended particulate material introduced to the Sound from the projected canal will settle out on the bottom of the deeper central part of the Sound during periods of calm weather. During the passage of cold fronts, the fine fraction of this material will be resuspended and transported to Card Bank and Little Card Sound where it will be redeposited. Thus, Card Bank and Little Card Sound will be the primary accumulation sites of pollutants such as some radionuclides which are associated with particulate material.

3) As the frequency of cold fronts is greater in the winter and spring, it would be favorable to open the effluent canal into Card Sound and to begin pumping water during the early part of the winter season. This would minimize the build up in the center of Card Sound of a layer formed from the considerable quantities of particulate material that will be introduced at that time. Thus, the chances of "smothering" organisms in this area would be minimized and the particulate material would be spread over Little Card Sound and Card Bank which already consist of very fine grained sediments.

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V. BENTHIC ANIMALS AND FISHES*

GENERAL STATEMENT

The overall objective of the benthic animal and fishes study is to quantitatively determine the kinds and numbers of animals present in South Biscayne Bay and Card Sound and to relate changes in abundance to changes in other variables in the environment.

In order to accomplish this objective, seven replicate trawl samples were taken at each of 10 stations in Card Sound on a monthly schedule. In addition 20 stations in South Biscayne Bay and 10 additional ones in Card Sound were sampled under an Environmental Protection Agency supported study. The net, a 10 foot otter trawl, lined with 1/4" bar mesh was selected because it was successfully used in upper Biscayne Bay by Roessler (1965) and Tabb (personal communication) in Everglades National Park. Statistical analysis by Roessler and by Tabb indicated the need for seven replicates at each station to detect 50% change in population with 95% confidence. The gear was successful in catching fishes and larger invertebrates in the previous studies and is believed to be an adequate sampling gear in Card Sound. Low catches of fishes in the Turkey Point area and Card Sound have been substantiated by diving in the area of fishing; few fishes were seen.

Certain animals are not adequately represented by trawl samples. These include cryptic fishes and invertebrates, benthic infauna, sponges, corals and alcyonarians. Also selected species of pelecypods which were too numberous and difficult to count because of spat settlement and attachment on the red algae _Laurencia_ and _Digenia_ are not properly represented. Separate studies to cover these groups are in progress or preparation. Also detailed biological studies have been conducted by Dr. H. B. Moore, on selected species and fouling organisms. Dr. Moore has previously reported on dredging and grab sampling in the Turkey Point area (Bader, 1969; Bader and Tabb, 1970). Mr. Hatfield plans to extend this work into Card Sound. Mr. J. Gilio has completed a six month survey on _Brachiodontes exustus_ (mussels) in Card Sound. Mr. R. Smith is studying the growth of commercial sponges and conducting a quantitative survey of the other sponges in Card Sound by visually counting them on a quadrant basis. Mr. R. Hixon has constructed traps and artificial habitats to investigate the cryptic fish and invertebrate populations and these traps are to be placed in the Sound in June. Mr. Perkerson of Environmental Protection Agency is working on the coral and alcyonarious of the sound and his associates are also working with artificial habitats.

The data collected in Card Sound thus far serve as a baseline to interpret anticipated changes due to the planned discharge from Florida Power & Light Company's fossil and nuclear power generators. Relations between the fauna and physical, chemical, and floral variables are being examined and hopefully these analysis will be able to allow the separation of these variables from the effects of temperature.

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METHODS

Trawling was conducted by making a two minute two with a ten foot mouth opening otter trawl lined with 1/4" bar mesh. Seven replicale samples were made at each station once a month. Samples were placed in wash tubs and rough sorted aboard the vessel. The algae was weighed to the nearest 1/2 lb. and discarded. The animals were preserved in 10% formalin and later sorted to species, identified and counted. Sponge studies involved transplants and counts in situ. Trap experiments are just getting underway. Autecology methods are considered in the results and discussion section.

RESULTS AND DISCUSSION

Trawling Survey

Six hundred thirty trawl samples have been collected at the ten stations in Card Sound. Data on temperature, salinity and oxygen have been recorded at each station - each month during the trawling operations. Since March additional data on nutrient chemicals have also been obtained. The animals have been identified, counted and the data for the first 4 months have been transfered to hollarith cards for later analysis. An additional 840 samples have been taken in Card Sound at 10 additional stations under Environmental Protection Agency support. A one year baseline study in Card Sound will be completed as of July 1971 and data on the numbers caught is shown in Table V-1.

In addition 1680 samples were taken in Biscayne Bay during the past year with the support of Environmental Protection Agency bringing the total since July 1968 to about 4900. Data on catches are presented in Table V-2. A direct comparison of Biscayne Bay and Card Sound is difficult because the time period, effort and number of stations are unequal. However, during the month of October 1970, twenty stations in each area were visited and a rough comparison can be made. Figure V-1 indicates that Card Sound is more productive than Biscayne Bay. However, if one divides the catches of animals by the amount of vegetation (mostly Laurencia) the numbers of animals per pound of weed is similar (Figure V-2). Exceptions are mollusks, porifera and echinoderms which are more abundant in Card Sound. This pattern of greater abundance in Card Sound was true throughout the fall and winter but we are currently obtaining lower catches in Card Sound and considerable seasonal variation may be present. This drop in spring catches could explain the low catches reported by Iversen and Roessler (1969) and emphaiszes the need for data on a monthly basis for at least one year before predictions are made on the suitability for power plant sites. Another possibility is that during the spring of 1971 salinities in excess of 43 ppt

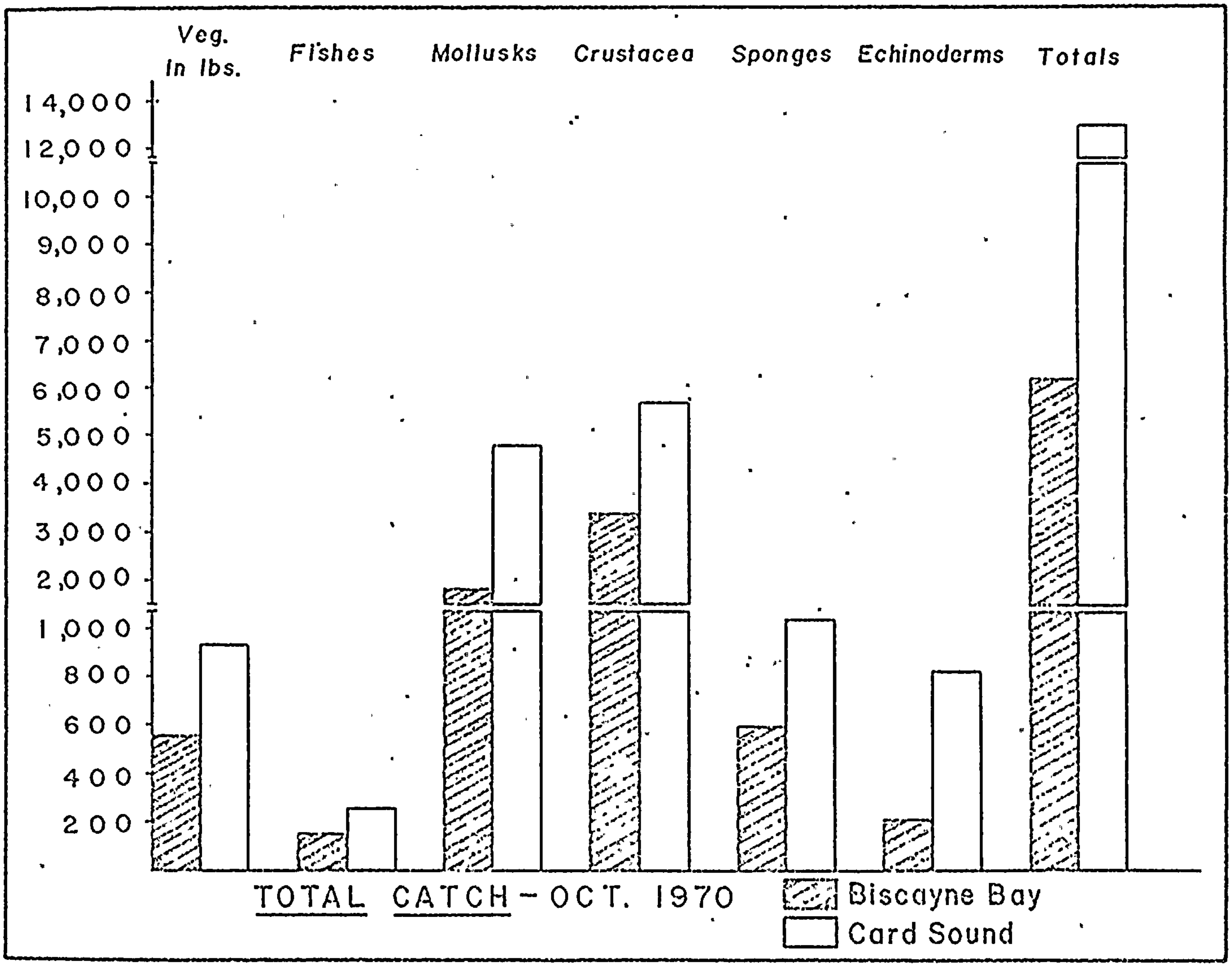

FIGURE V-1 Comparison of catches of animals between Card Sound and Biscayne Bay.

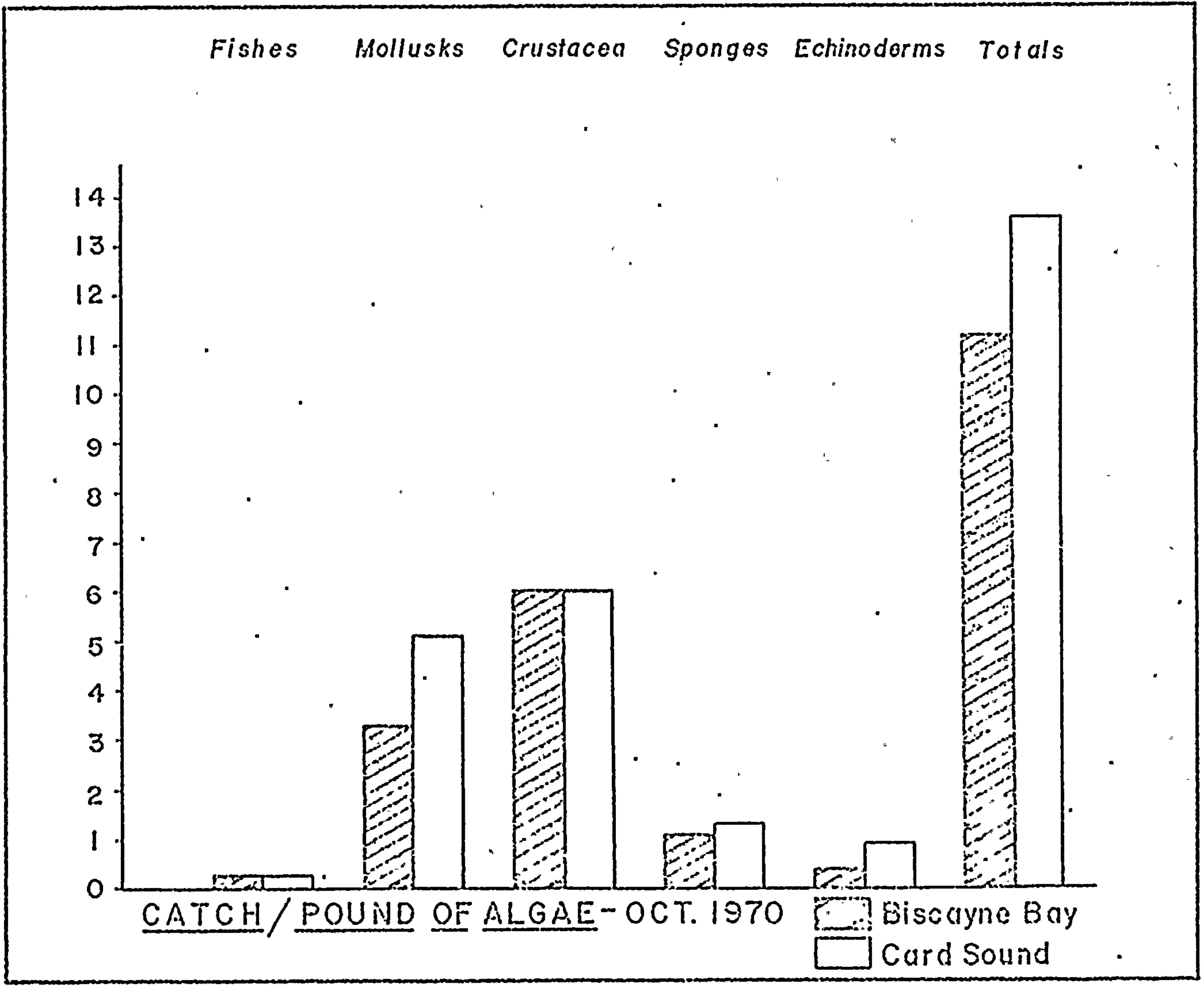

FIGURE V-2 Comparison of the catch per pound of vegetation between Card Sound and Biscayne Ba have been observed and these hypersaline conditions may be adversely effecting the algae and animals.

Card Sound has produced 24 species of animals not collected in Biscayne Bay. These are organisms such as brittle stars, mollusks and crustaceans which are associated with the sponge community, and are found only in the eastern portion of Biscayne Bay but occur close to the mainland shore in Card Sound. The differences in distribution of sponges in the two areas probably reflects circulation patterns and salinity gradients. At least one economically important species Panulirus argus is known to utilize sponges for shelter in their juvenile stages (Khandker, 1964).

Biscayne Bay has produced 153 species not found in Card Sound. These are generally mainland shelf forms or very uncommon organisms. Because of the much greater effort expended in Biscayne Bay - 5,000 tows compared to 1,500 in Card Sound, this is not unexpected as the probability of capturing rare animals increasesas the amount of sampling increases. An unusual species of nudibranch described by Marcus and Marcus (1967) from two specimens taken near Rickenbacker Causeway and known only from Biscayne Bay is relatively common in Card Sound. A small Rissoid gastropod, apparently an undescribed species of the genus Barleeia, occurs on the Cutter Bank - Arsenicker Key shallows. The role of these organisms is not known but it is not unexpected to find new species in this unique area which has been partially protected by the establishment of Biscayne National Monument:

Analysis of data collected under the support of Environmental Protection Agency in South Biscayne Bay in the vicinity of the present discharge of Turtle Point has revealed that temperatures elevated 3-4° C or higher produce low catches of animals. Temperatures elevated 2-3° C produce low catches in summer when temperatures exceed 33° C but recover in winter and the annual production is equal to or higher than in control areas. Figure V-3 shows data for one species of caridean shrimp Thor floridanus from a control area station SE III, station F elevated by 1.6° C and station SE I elevated by 3.5° C. The precipitous drop at 33° C is shown by several other species but many more are found at station F raised 2-3° C but are virtually absent at hotter stations. This could be directly caused by temperature or may be the result of temperature killing the algae which are necessary to the animals as food or shelter (see Zieman, 1970 and section X of this report). Data for 15 species is presented in Table V-3. Multivariate analysis using weed weight, temperature and salinity are being run presently to attempt to separate the effects of these three variables.

For the data collected from July 1968 - June 1970 the catch per tow of each species was tabulated at 1° C intervals. The range of temperature was from 14° C to 39° C. A total of 354 species were collected. The maximum temperature, minimum temperature and temperature where the highest catch per tow was recorded for each species. Frequency distributions were constructed and the cummulative percent of the number of species was plotted against temperature. A curve was mathematically

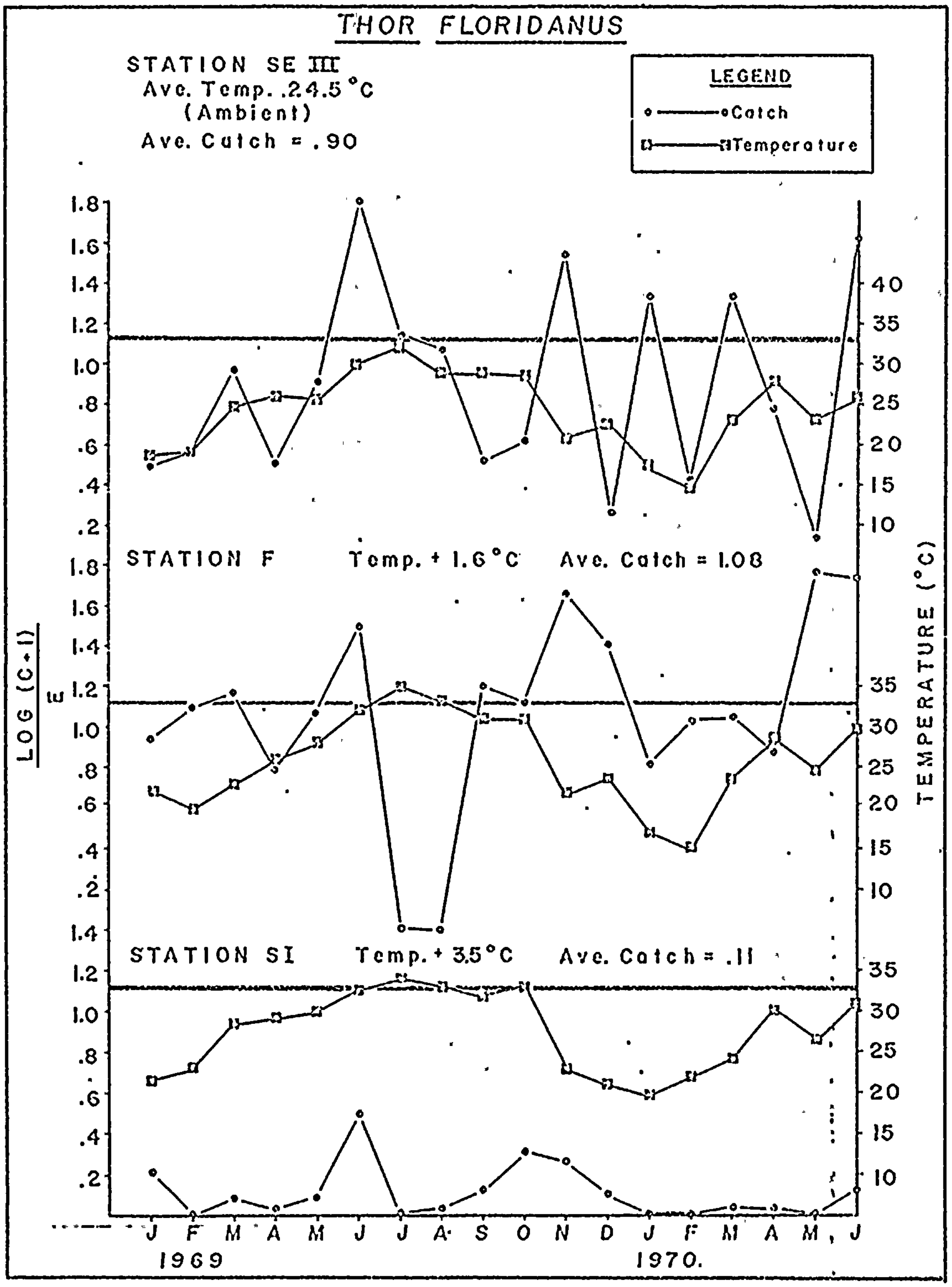

FIGURE V-3 Comparison of index of abundance of Thor floridanus and temperature at three stations in Biscayne Bay.

plotted through the data points by the use of a probit transformation and least square regression of temperature versus the probit of the cumulative probability. This produces three curves: (1) Upper exclusion temperature curve (2) Lower exclusion temperature curve, and (3) Maximum catch per tow curve. The upper exclusion temperature curve indicates the percent of the species excluded at or below any temperature. The lower exclusion temperature curve indicates the percent of species excluded at or above any given temperature. The intersection of these two curves indicates the optimal temperature where the greatest diversity of species will occur. The maximum catch per tow curve indicates the percent of species which are above or below their optimal temperature (indicated by highest catches). The temperature corresponding to intersection of this line with the 50% line is the optimal temperature or the median where exactly half the species were caught in greatest numbers. Above or below this temperature less than 50% of the species have the highest catches, therefore this temperature should represent the optimum temperature with maximum numbers of individuals.

Figure V-4 shows a graph of the above data. Six points of interest are signified by the graph. Number 1 represents the temperature (14.3° C) where 75% of the species are excluded by cold. Number 2 represents the temperature (19.1° C) where 50% of the species are excluded by cold. Number 3 is the optimal temperature for numbers of individuals (25.7° C) where 50% of the species have their highest catches. Number 4 is the optimal temperature for diversity (26.3° C) where the greatest number of species occurred. Number 5 is the temperature (33.4° C) where 50% of the species were excluded by heat. Number 6 is the temperature (38.7° C) where 75% of the species were excluded by heat.

It is interesting to note that the 50% exclusion temperatures are close to the normal bay temperature ranges and that the two estimates of an optimal temperature, for numbers of individuals and for diversity, vary by less than 1° C.

Data for each major taxa (Fish, Mollusks, Crustacea, Porifera, Coelenterates, and Echinoderms) will be presented in the final report of Environmental Protection Agency.

The mathematically fitted line deviates from the observed points at the high end of the upper exclusion temperature curve of all species combined because the number of species excluded between 30 and 34° C is greater than would be predicted with the normal distribution. Direct linear interpolation of the temperature would produce a 50% upper exclusion temperature of 32° C and a 75% upper exclusion temperature of 37° C.

Sponge Studies

The key grass sponge Spongia gramminea, which is commercially harvested in south Biscayne Bay and Card Sound has been selected for extensive study. In April, 1971 sponge transplants were set out at five stations in Card Sound. These

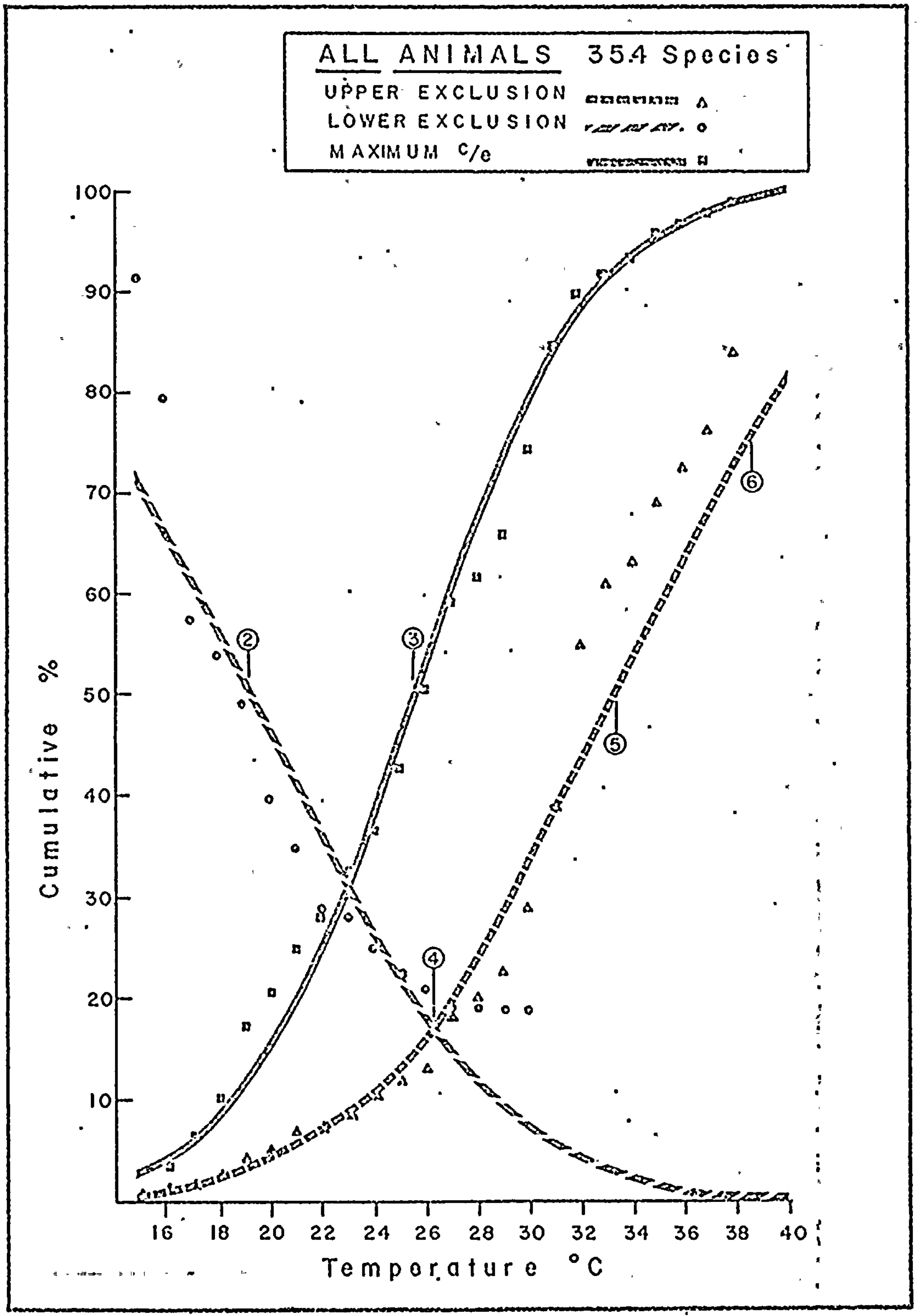

FIGURE V-4 Optimum and exclusion temperatures of animals collected in Biscayne Bay, July 1968 - June 1970.

stations are 0603, 0504, 0405, 0306, and 0207 (See Figure I-3). This forms a diagonal line from the mouth of the projected effluent canal to Broad Creek. Studies have not been undertaken in South Biscayne Bay as this sponge is located east of Arsenicker Keys which is outside the influence of effluent.

Subsequent examination in May indicated that the transplants have survived and all had grown slightly except those at the inshore station 0603.

In addition a one hundred meter by 2 meter transect at each station was permanently established. All sponges in the transect are being identified and counted. These counts will form base line data to measure potential changes when the effluent enters Card Sound.

Artificial Habitat - Trap Studies

Five fish traps have been built and placed in Card Sound; studies of this nature have not been conducted for the Turkey Point area. The traps are 1 meter cubes and are filled with an artificial weed like substance (3M Company extruded vinyl No. 200 conservation net). The traps are expected to attract fishes such as mangrove snapper (Lutjanus, grisieus) and grunts (Haemulon spp) which are not adequately sampled by the trawl gear because of their ability to avoid the net and because of their preference for obstructions, such as rock, roots and other snags. The artificial habitat should also attract invertebrates including important forms such as Panulirus argus the spiny lobster (Ingle & Witham, 1969). In addition to the larger forms, the fouling organisms are sampled by removing the panels and collecting the animals from the panels. These specimens will be identified, sorted and counted in the laboratory. The seasonal succession of settlement can be determined and later compared between heated and unheated areas.

Autecology

For a number of years studies have been based on the premise that it is necessary to understand the animal under "normal" conditions before the effect of pollution can be assessed. With support from the Department of Health, Education and Welfare and later from the Environmental Protection Agency, studies have been conducted in the upper part of Biscayne Bay. Data on about 15 invertebrate species are now available. It must be remembered that there are about ten times as many species in such a tropical habitat as there are in comparable temperate habitats and there are fewer dominant species so correspondingly more studies are needed here. Studies conducted in this laboratory cover abundance, growth rate, spawn production and productivity of selected invertebrates. The latter is important since one of the most vital aspects of pollution is what is will do to the productivity of the area. In general, the annual somatic and gonad production of these invertebrates amount to one to three times the standing crop. Relationships of productivity and survival to temperature and salinity have also been studied.

Because the work supported by AEC and that supported by EPA interlocks so closely and so profitably, some of the work cannot properly be attributed solely to either agency. The first step in the study of the Turkey Point and Card Sound areas, was a survey of the species present and their relative abundance. The results of this survey have already been documented in previous Annual Reports. The next step was to select species with good background information which occur in areas of normal conditions. A study of these should allow the mapping of their "well being" in different parts of the bay and relate this to environmental conditions. Data from the laboratory experimental studies (Section X[illegible], also fit into this study.

The first animals to be studied were barnacles; data has been collected in the upper bay for 28 years. Such studies, and those of Smith, Williams and Davis (1950) and of McNulty (1970), have indicated that both rate of settlement and rate of growth of *Balanus amphitrite*, *B. eburneus* and *B. improvisus* will be favoured by sewage pollution and increased temperature. Slate test panels were exposed in the Turkey Point area, and are currently exposed in Card Sound. As predicted, settlement and growth have been considerably less than in the more polluted waters of the upper bay. Both settlement and growth were high in the warmed waters of the discharge canal (Nugent, 1970). Settlement was very low away from the discharge water.

Stations D & E at Turkey Point, both outside the temperature plume, showed little barnacle settlement. Station D produced no barnacles, station E produced 2 specimens in June 1970. Station F elevated about 2° C produced 26 barnacles in June 1970 and 104 barnacles in January 1971. Station SEI elevated about 4° C produced 5 barnacles in June and 213 in January. The Card Sound panels were not set out early enough to obtain larval settlement from the summer spawning season of 1970. The low settlement rate observed so far is perhaps associated with the normal low temperatures of winter, heavier settlement may occur this summer.

Along with the barnacle studies in the upper bay data on water temperature was obtained. Figure V-5 shows the deviations of the annual mean temperature in the upper bay since 1943. For the last ten years there has been a steady drop of about 3° C. If this is part of a long term cycle, it may be assumed that the temperature will rise again. Since relatively small temperature changes due to thermal addition may be ecologically important, a temperature regulation on degrees above ambient must take into account the possibility of having the ambient temperature at least 3° C higher than the present annual temperature.

In setting such regulations there is another aspect to be considered. In temperate waters growth rate increases with increasing temperature throughout the normal range of the locality (Moore, in press). In tropical waters, on the other hand (Fig. V-6), many species grow in the winter, and become relatively dormant in summer. The seriousness of raising winter temperatures as well as summer ones must be considered.

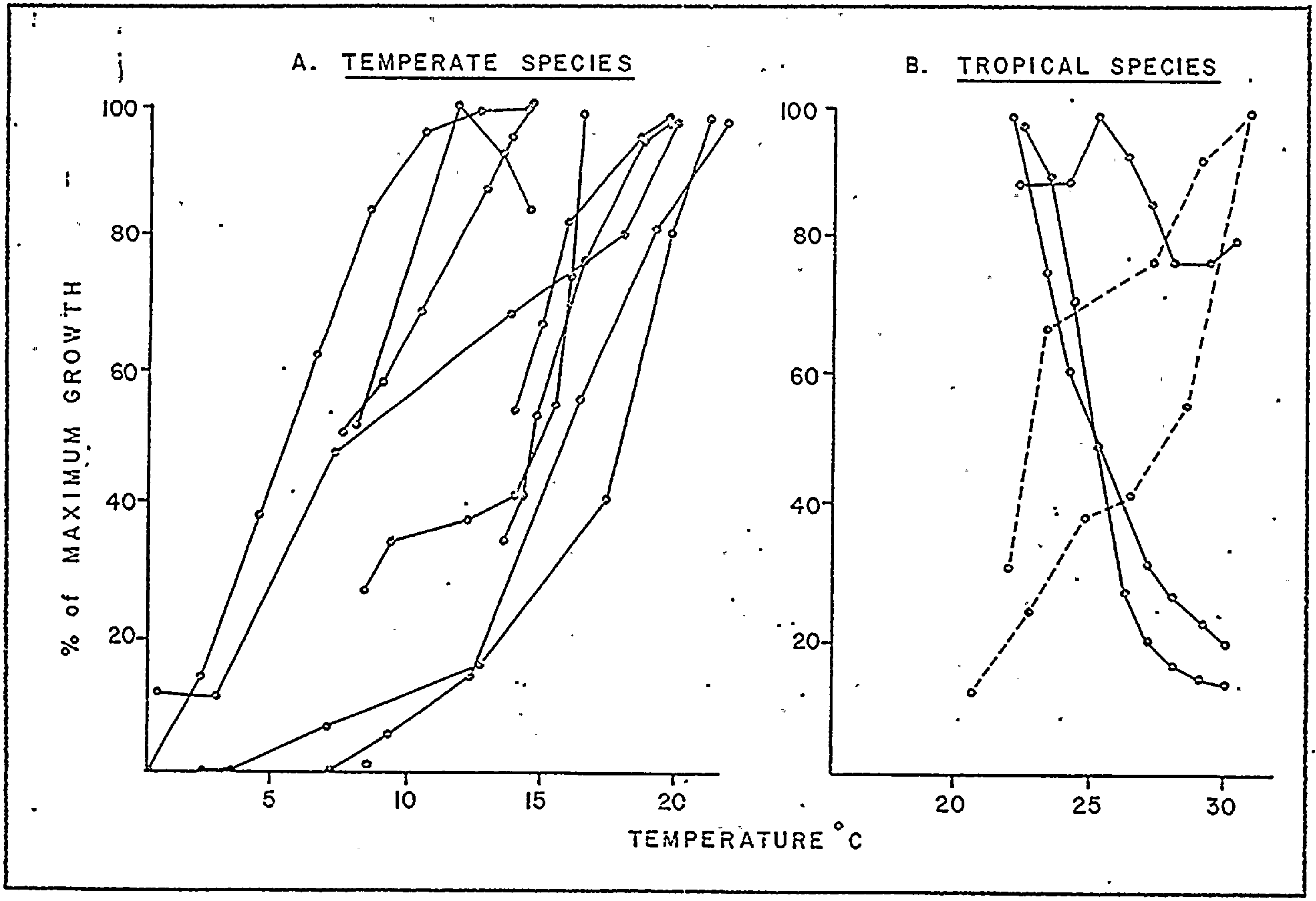

FIGURE V-6 Comparison of growth rate patterns, expressed as per cent of the maximum size in relation to temperature between temperate and tropical species.

The urchin *Lytechinus variegatus* is a winter-growing species. This urchin plays an important role in the Bay since it is one of the few species which directly eats the sea grass *Thalassia*. The cages used for field growth study of *Lytechinus* were periodically moved and a substantial decrease in the amount of *Thalassia* was noted in the areas of the urchin cages. Other species either graze on epiphytes on the *Thalassia* or eat the fragmented detritis of the original plant. Although preyed on by few other animals, *Lytechinus* produces a large amount of eggs and sperm which are available to the many filter feeders of the bay. Ten years of observations on the gonads of this species have been analysed and correlations exist on the urchin's gonad size, spawning date and pattern of spawning with temperature and rainfall. On the basis of these the 1971 spawning has been predicted with errors of only twelve days in date and ten percent in gonad size. (Fig. V-7).

Routine studies of the upper Bay populations of *Lytechinus* as a control will continue as well as the established control of a similar population on East Arsenicker Key. Gonad size of populations in different parts of Card Sound are now being used as an index of their well-being. Preliminary observations have proved very promising, though, and a marked difference in gonad index has been found in different parts of the sound. The index at Station SV was 0.15; at Station 0205, 0.61; at Station 0211, 0.26; and at Station 1102, 0.39. The results of studies on the effects of temperature and salinity on this species will be described in Section XI.

In order to measure growth rates of *Lytechinus* they have been kept in wire mesh pens at several locations. The pens have not been set for long and there has been some loss by interference, thus, little data is now available. A method described in Jensen (1969) of interpreting annual growth rings in the plates of the test of *Lytechinus* will be tested. This method was successfully used on a temperate urchin *Echinus* (Moore, 1935). If the method proves effective, it should be possible to determine age and growth rates in different parts of Card Sound and relate these to the local conditions.

Another animal which has been investigated for a number of years is the bivalve *Chione cancellata* (Moore and Lopez, 1969). The gonad size of this pelecypod is determined by seasonal changes in tissue weight. Studies on this species in the upper bay as a control population are continuing. The species is common also in Card Sound. *Chione* plays an important role in the productivity of the bay, a tentative estimate of its annual production in the area from Rickenbacker Causeway down to the Arsenicker Keys was eighty metric tons dry tissue weight, of which about half is in the form of spawn.

Studies of another imporatnt species *Brachidontes* have been commenced. This small mussel which may occur in dense sheets on hard surfaces was also found attached to the sea grass *Thalassia* and red algae *Laurencia* and *Digenia*. It may prove to be one of the most abundant invertebrates by weight in Card Sound. There are at least two species of *Brachidontes* present, *B. exustus* and *B. dominguensis*, and in addition, a brackish water species *Mytilopsis leucophaeatus*. The yearly

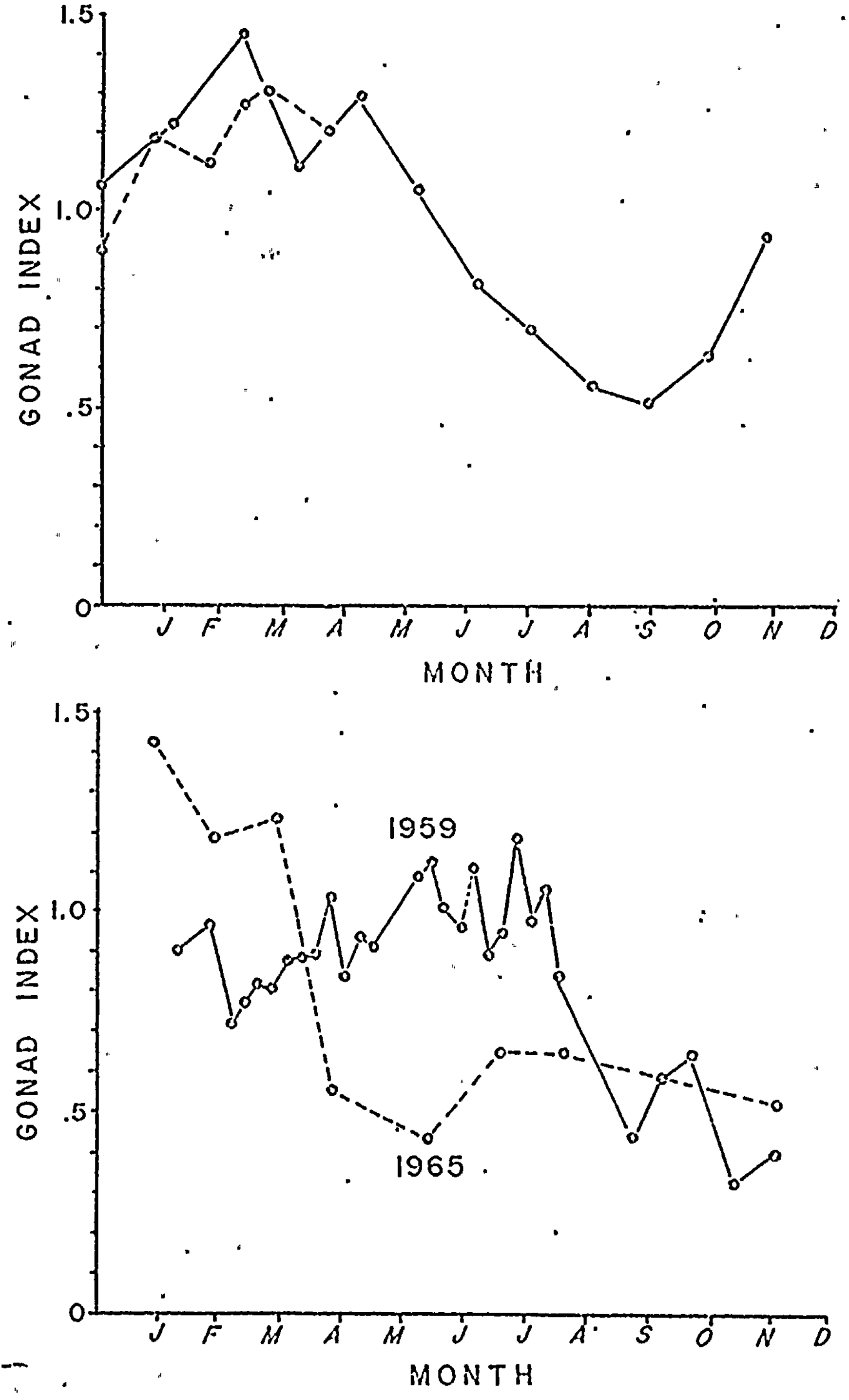

FIGURE V-7 Prediction of the seasonal pattern of spawning for Lytechinus for 1971. Upper graphs - the predicted values (whole line) and those so far observed (broken line). Lower graphs - the extremes of spawning patterns observed between 1959 and 1965.

growth rate was estimated to be 6-7 mm. This organism apparently lives for three years or more, as the largest individual observed was 18.7 mm in length. Slightly over 12 months were needed for this organism to reach sexual maturity. The rate of growth is higher in the fall than in winter. The slow growth apparently coincided with gonad development.

Another abundant species under investigation is the gastropod Anachis avara. There are doubts about its taxonomy, but it should be distinguishable from Anachis translirata and other columbellids also present in the area. A. avara is found in large numbers on Thalassia flats in southeastern Florida. From observations to date, it breeds continuously from late winter through the middle of the summer. Its small size, up to approximately 13 mm., makes Anachis available to predaceous crabs which can easily cut through its shell. Continuing studies of this organism and other abundant micromollusks should add an important aspect to the consideration of productivity and food chains in the Card Sound area. Investigations on the pen shell Atrina rigida one of the intertidal Thalassia flat inhabitants, has just begun. One month's growth of this bivalve held at constant temperatures in laboratory aquaria shows growth at 27° C to be appreciably higher than at 23° C and several times that at 31° C and 35° C.

CONCLUSIONS

Exclusion temperatures have been calculated which indicate the optimum bay temperature is near 26-27° C. The 50% upper exclusion temperature is at 32-33° C. The 50% lower exclusion temperature is at 19° C.

A strong relation between types and numbers of animals and the presence of sea grasses and algae particularly the red alga Laurencia has been observed. As discussed in the section "Grasses and Algae" the heated effluent adversely effects the algae. Thus the exclusion of animals may be directly related to temperature or may be a consequence of heat damaging the algae and thus removing shelter or a food source for the animals. Laboratory studies have shown animals are killed at temperatures considerably higher than the exclusion temperature calculated from field data. However, animals very likely move from an area before death occurs. Research on the diet of the invertebrates living in the sea grass and algae might indicate if the algae is used as food or as shelter or both. A qualitative food web study is needed to plan more extensive energy flow systems ecology which will permit evaluation of the effects of stresses on the productivity of the system and may answer the question of how to channel the exsisting productivity into a more useful end.

Dynamics studies are already in progress on some species such as the urchin Lytechinus variegatus, the clam Chione cancellata and the mussel Brachidontes exustus. Productivity figures for these species are being compared between control areas and heated areas.

The 50% exclusion temperature data together with analysis of seasonal abundance of species such as Thor floridanus indicate that maximum summer temperatures in excess

of 33° C caused damage to the fauna. Temperature elevations of 2-3° C above ambient appeared to cause damage during the hottest months of summer but increased numbers of animals are present in the winter. Thus the standing crop viewed on an annual basis is average or above average in this zone. Temperature elevations of 3-4° C cause decreases in the animal populations which are not reversible in the winter and hence the standing crop on an annual basis is low.

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TABLE V-1

SPECIES, NUMBER OF INDIVIDUALS AND CATCH PER UNIT OF EFFORT IN TRAWL SAMPLES AT CARD SOUND SEPTEMBER 1970 - FEBRUARY 1971

	Stations									
Fish Species	0104	0208	0405	0503	0504	0603	0604	0608	0703	1004
Ginglymostoma cirratum										
Raja texana										
Urolophus jamaicensis							1	2		
Rhinobatos lentiginosus										
Narcine brasiliensis										
Anchoa mitchilli										
Synodus foetens		2	1							
Gymnothorax nigromarginatus										
Lucania parva	3									1
Corythoichthys albirostris										
Hippocampus erectus		1	1		1			3		
Hippocampus zosterae					2		1	4	3	4
Micrognathus crinigerus	4		6	44	23	11	31		8	20
Syngnathus floridae										
Syngnathus louisianae										
Syngnathus scovelli										
Mycteroperca microlepis										
Lutjanus analis										
Lutjanus apodus										
Lutjanus griseus								1		
Lutjanus jocu										
Lutjanus synagris										
Astrapogon alutus										
Astrapogon stellatus										
Eucinostomus argenteus		3					1	3		1
Eucinostomus gula								16		
Haemulon aurolineatum								2		2
Haemulon carbonarium										
Haemulon parrai										
Haemulon plumieri								3		
Haemulon sciurus						1				
Haemulon sp. (juv.)										
Bairdiella chrysura										
Calamus calamus						1				
Lagodon rhomboides		1	1	1			1	12		3
Nicholsina usta			2		1			1		
Scarus coeruleus										
Sparisoma rubripinne										
Garmannia macrodon		2	1	2			5	5		5
Lophogobius cyprinoides										
Gobiosoma robustum	6			9	3	1		1		4
Unidentified goby										
Scorpaena brasiliensis		2		1				2	1	
Scorpaena grandicornis		1							1	

TABLE V-1 (CONTINUED)

	Stations									
Fish Species	0104	0208	0405	0503	0504	0603	0604	0608	0703	1004
Prionotus scitulus										
Opisthognathus maxillosus										
Dactyloscopus tridigitatus										
Callionymus pauciradiatus										
Paraclinus fasciatus			1	2	3		2			3
Paraclinus marmoratus				1						
Chasmodes saburrae										
Ogilbia cayorum										
Sphyraena barracuda								1		
Bothus ocellatus		1								
Citharichthys macrops										
Citharichthys spilopterus		1								
Paralichthys albigutta		2				4		4		1
Achirus lineatus		1						2		2
Trinectes inscriptus										
Symphurus plagiusa										
Alutera schoepfi		1				1		1	2	
Monacanthus ciliatus		10					1	5		
Monacanthus hispidus		4	1				2	10	3	2
Acanthostracion quadricornis	1	14	13	6	11	3	8	53	19	22
Lactophrys trigonus		1								
Lactophrys triqueter						1				
Sphaeroides nephelus		2				1	1	1		1
Sphaeroides spengleri		1				2		2	1	
Sphaeroides testudineus										
Chilomycterus schoepfi	6	4	4	2	3	6	3	7	3	9
Opsanus beta	3	3	16	22	11	1	26	6		10
Syacium papillosum										
Corythoichthys brachycephalus			1							
Diplectrum formosum		1			1			1		
Astropogon puncticulatus								2		
Haemulon album								1		
Orthopristis chrysopterus	1							1		
Hemipteronotus novacula							1			
Gobiesox strumosus			1							
Balistes capriscus									1	
Porichthys porosissimus								1		
No. of species	7	21	13	10	10	12	14	29	10	16
Total animals	24	58	49	90	59	33	84	153	42	90
Catch/tow	0.57	1.38	1.17	2.14	1.40	0.78	2.00	3.64	1.00	2.14

TABLE V-1 (CONTINUED)

	Stations									
Mollusc Species	0104	0208	0405	0503	0504	0603	0604	0608	0703	1004
Acmaea sp.	2	1	112	6	6	4	15	14		4
Acteon punctostriatus							2			
Aequipecten gibbus nucleus		2								
Aequipecten irradians	1	1	1	1	1		2	1		4
Amygdalum papyria										
Anachis obesa										
Anachis pulchella	27	1		5						
Anachis translirata	2	1	13	12	15	7	23		1	28
Anomalocardia cuneimeris										
Anomia simplex			2	1	1	2		7	1	9
Arca imbricata										
Arca sp.										
Arca zebra		1	2							
Arcopsis adamsi		2	2	7	2	1	2			
Arene tricarinata										
Astraea americana	2		6	3	5	1	4		1	
Astraea caelata										
Astraea phoebia			4	1	1		3			
Bailya intricata				1						
Balcis intermedia	2			112	3	6	10		3	
Barbatia cancellaria				5						
Batillaria minima										
Bittium varium										
Brachidontes exustus										
Bulla umbilicata	24			49	24	1	34	1	16	
Busycon spiratum									5	
Anadara notabilis										
Cardiidae										
Calliostoma adelae										
Cardita floridana	19									
Cerithidea scalariformis										
Cerithiopsis latum										
Cerithiopsis emersoni				17	2					2
Cerithium algicola				5	1	13	12		1	1
Cerithium eberneum	15		17	11	5	24	5		32	45
Cerithium literatum										
Cerithium muscarum	12				10	6	1	1	6	
Cerithium variable										
Cerodrillia thea										
Chione cancellata				1						
Codakia orbicularis										
Columbella mercatoria										
Columbella spp. (juv.)	8		43	9	7	6	9		5	9
Columbella rusticoides	13		26	27	22	22	30		24	41
Congeria leucophaeta										
Conus jaspideus	5			2	2		4			
Crassispira fuscescens										

TABLE V-1 (CONTINUED)

Mollusc Species	Stations 0104	0208	0405	0503	0504	0603	0604	0608	0703	1004
Crassispira leucocyma	13		6	19	4	3	2		1	2
Crassispira nigrescens										
Crassispira ostrearum	3			5	1		3			1
Crassostrea virginica										
Crepidula aculeata			1	1	1			2	2	
Crepidula glauca										
Crepidula fornicata	3	1	1		1		1			1
Crepidula plana	3									
Cyclostremiscus beauii										
Cylichna krebsi										
Dentalium texasianum										
Diodora cayenensis			16	10	29	12	18	5	6	14
Diodora dysoni										
Diodora listeri										
Epitonium echinaticostum				10	1		3			
Epitonium foliaceicostum										
Epitonium rupicolum										
Eupleura sulcidentata										
Fasciolaridae										
Fasciolaria hunteria										3
Fasciolaria tulipa					1		1			1
Gibberulina ovuliformis					1					
Haminoea elegans										
Hyalina avenacea	3			29	4	9	10		6	3
Hyalina tenuilabra	1									
Hyalina torticula	1		10	55	16	8	31		1	26
Laevicardium laevigatum										
Laevicardium mortoni				3				1		1
Lima pellucida	1		22	48	57	19	104	3	12	14
Litiopa melanostoma										
Lobiger souverbii						1				
Lucapina sowerbii										
Macoma sp.										
Mactridae										
Mangelia plicosa										
Marginella aureocincta			1	33	28	9	23		3	46
Marginella eburneola										
Mitra gemmata	17	1	10	552	139	11	338		6	20
Mitra hanleyi			2	5	2					1
Mitrella lunata			1			1				1
Mitrella sp.										
Modulus modulus	17	4	9	6	16	22	13		8	35
Murex cellulosus	1					4				
Murex florifer	1									
Nassarius albus	4		1	3		4	19			1
Nassarius vibex					2					
Natica sp.										

TABLE V-1 (CONTINUED)

Mollusc Species	Stations									
	0104	0208	0405	0503	0504	0603	0604	0608	0703	1004
Neritina virginea										
Nitidella sp.										
Nitidella ocellata										
Octopus joubini			1							
Odostomia canaliculata							1			
Odostomia niveus				2						
Odostomia laevigata			1							
Parviturboides interruptus				14						
Persicula catenata	1									
Persicula lavalleeana			2	17	1	4	3		2	51
Pteria longisquamosa	2	1	24	21	54	12	38	8	1	18
Prunum apicinum	3				1	10			2	23
Pseudochama radians										
Pseudoneptunea multangulus	1		1	2	4	2	1	2		5
Pteria colymbus										1
Pyramidella candida										
Pyramidella sp.										
Retusa bullata										
Rissoina browniana										
Rissoina cancellata	1			1	2		4	1		
Rissoina chesneli										
Seila adamsi				2						
Tagelus plebeius										
Tegula fasciata	10					1				
Teinostoma sp.										
Teinostoma cryptospira										
Tellina martinicensis										
Tellina meria					1					
Tellina texana										
Trachycardium egmontianum							2			
Tricolia affinis	241	1	46	3422	99	216	178		122	233
Tricolia bella			1							
Tricolia tessellata						4				
Triphora nigrocincta			3	4	1	2	2			
Trivia quadripunctata										
Turbonilla sp.							1			
Turbo castaneus	65			2						1
Turridae				1			2			
Turridae stellatopoma stellata				4			2			
Vermicularia spirata	15	25	120	96	268	28	135	13	31	85
Volsella americanus			48	4	34	5	10	3	3	15
Mitra floridana	1		1	6	1	1				
Nudibranchs			9	8	14	4	10	10	2	5
Chitons	20	4	26	26	27	17	22	6	25	58
Americardia media			6		1		4	1		1
Alabina cerithioides										
Atys caribaea				1			1			
Cerithiopsis greeni			18	30	5		4		2	7
Crepidula maculosa	2	1			1		1	2		1
Felimare bayeri							1			
Lyropecten antillarum			5		1		4			2

TABLE V-1 (CONTINUED)

	Stations									
Mollusc Species	0104	0208	0405	0503	0504	0603	0604	0608	0703	1004
Musculus lateralis							1			
Oxynoe antillarum					7			1		1
Stigmaulax sulcata					1					
No. of species	38	15	39	52	51	37	50	20	29	42
Total animals	562	47	620	4717	933	502	1149	89	330	821
Catch/tow	13.38	1.12	14.76	112.31	22.21	11.95	27.36	2.12	7.86	19.55

TABLE V-1 (CONTINUED)

	Stations									
Crustacean Species	0104	0208	0405	0503	0504	0603	0604	0608	0703	1004
Alpheus armillatus										
Alpheus formosus										
Alpheus heterochaelis						5				
Alpheus normanni	1	4	2	3	9	1	21			20
Callinectes dani										
Callinectes ornatus		4				7		3	2	4
Callinectes sapidus						7		1		
Callinectes similis										
Callinectes spp (juv.)	1					5	1			
Epialtus dilatatus			10	23	11	2	15		2	23
Eucratopsis airssimanus										
Eurypanopeus depressus										
Eurypanopeus dissimilis										
Hippolysmata wurdemanni										
Hippolyte pleuracantha.	4		2	6	6	4	1	1	1	13
Latreutes fucorum										
Leander tenuicornis			1	5	1	14		1	1	
Libinia dubia		1		1		1			1	1
Macrocoeloma camptocerum		1	2					3		10
Macrocoeloma trispinosum			1	3	2				2	11
Menippe mercenaria	1		3					5	2	1
Microphyrys bicornutus	1	1								
Mithrix pleuracanthus		2	1							
Neopanope texana										
Neopanope packardii	6	1	21	89	13	56	28	5	37	222
Paguristes tortugae	16		4	144	21	31	73		4	34
Pagurus bonairensis	85	1	9	187	7	154	7	3	80	163
Palaemonetes intermedius										
Panopeus herbstii										
Panopeus occidentalis		1				1		1		
Panulirus argus	1		6		7	1	2	9		3
Pelia mutica			1		3		1	1	1	4
Penaeus aztecus										
Penaeus brasiliensis										
Penaeus duorarum		6		1	1	2		7		4
Penaeus spp. (juv.)		1				9	1			2
Periclimenaeus wilsoni										
Periclimenes americanus		11	3	5	4	7	3	4	1	11
Periclimenes longicaudatus										2
Periclimenes sp.										
Pilumnus dasypodus										
Pilumnus holoserecus										
Pilumnus lacteus										
Pilumnus marshii										
Pilumnus pannosus			1					2	1	
Pitho anisodon		3	1	2		2				3

TABLE V-1 (CONTINUED)

	Stations									
Crustacean Species	0104	0208	0405	0503	0504	0603	0604	0608	0703	1004
Portunus depressifrons		5				1		1		1
Portunus gibbessi		1								
Portunus sebae								1		
Portunus spinimanus			2			2			1	
Portunus sp.			1							
Processa bermudensis										
Synalpheus minus	2			1			6			
Thor floridana	685	23	909	2504	1361	457	1558	95	136	942
Tozeuma carolinense										
Uca minax										
Balanus sp.										
Balanus improvisus										
Balanus eberneus										
Balanus titanabulum										
Pycnogonid				3	1	1	3		1	1
No. of species	11	16	19	15	14	22	14	17	16	21
No. of animals	803	66	980	2977	1447	770	1720	143	273	1475
Catch/tow	19.12	1.57	23.33	70.88	34.45	18.33	40.95	3.40	6.50	35.12

TABLE V-1 (CONTINUED)

Porifera species	Stations 0104	0208	0405	0503	0504	0603	0604	0608	0703	1004
Spongia barbara				2	1		1			1
Spongia cheiris										
Spongia graminea	1	1	7	12	17		14	6	7	4
Hippiospongia lachne										
Ircinia fasciculata	7	13	37	20	27		30	18	15	32
Ircinia campana		1	4	1						3
Ircinia strobilina		2	3		2	1	1	4	1	
Verongia sp.			10	1	3		3	1	1	
Dysidea etheria	5	13	3	4	7		8	7	6	2
Haliclona molitba	5		9	6	8		12	1		
Haliclona viridis	8	14	3	5	14		8	7	4	
Neopetrosia longleyi	1	6	2	4	3		7	3	4	
Sphecciospongia vesparia		1	6		7		5	7	1	1
Tethya diploderma	1	3	6	90	15	2	8		5	4
Geodia gibberosa	8	22	4	6	12		10	6	6	1
Cinachyra cavernosa							5		2	
Chondrilla nucula	33	5	288	221	177	10	116	21	39	178
Brown bay sponge	9	3		4		1	2		3	
Unidentified sponges	1	1	13	5	8		3	8		1
Clione sp.								3		
Tedania ignis	1	1	20	5	15		6	29	2	9
Scypha sp.		3	3	6	8	1			1	2
Aaptose aaptose	1	1			3				1	
No. of species	13	16	16	16	17	5	17	14	16	12
No. of animals	81	90	418	392	327	15	239	121	98	238
Catch/tow	1.93	2.14	9.95	9.33	7.78	0.36	5.69	2.88	2.33	5.66

TABLE V-1 (CONTINUED)

	Stations									
Miscellaneous groups	0104	0208	0405	0503	0504	0603	0604	0608	0703	1004
Manicina areolata										
Porites porites		10	1	2	4	2			3	
Siderastrea siderea				2			1		1	
Solenastrea hyades				1						
Millepora				1	2		3			
Jellyfish			1		1					
Sea anemones			6	2	4		6		1	1
Eunicea asperula					2					
Pterogorgia anceps					2		2			1
Pseudopterogorgia acerosa					3			4		
Unidentified gorgonids			1							
Muricea elongata							1			
Hydroids										
Bryozoans			16			2	2	3		
Tunicates			2	1	4		1	1		
No. of groups	0	1	6	6	8	2	7	3	3	2
Total animals	0	10	27	9	22	4	16	8	5	2
Catch/tow	0	0.24	0.64	0.21	0.52	0.10	0.38	0.19	0.12	0.05

TABLE V-1 (CONTINUED)

Echinoderm species	Stations 0104	0208	0405	0503	0504	0603	0604	0608	0703	1004
Diadema antillarum										
Lytechinus variegatus		45	3	8	1	7	2	3	3	20
Luidia alternata										
Echinaster sentus	3									6
Amphiura stimpsoni								3		
Ophiophragmus sp.										
Amphipholis squamata			4		5					
Amphipholis pachybactera								1		
Ophiostigma isacanthum	2		1	28	44	7	68	1	13	
Amphiodia pulchella			2			1	2		1	
Ophiactis savignyi	13	7	66	117	155	34	125	6	72	24
Ophiothrix orstedii	1	3	5	2	5		6	4	2	6
Ophionereis squamulosa										
Ophiopsila riisei	2		41	72	223	7	137	11	13	5
Ophioderma brevispinum	3		2	12	20	2	23	3	2	
Holothuria floridana	2	2		5		13			6	1
Cucumariidae						1				
Leptosynapta parvipatina	36	2	37	144	84	15	73	1	75	1
Chiridota rotifera								4	1	1
No. of species	8	5	9	8	8	9	8	10	10	8
Total animals	62	59	161	388	537	87	436	37	188	64
Catch/tow	1.48	1.40	3.83	9.24	12.79	2.07	10.38	0.88	4.48	1.52

<u>Grand Totals</u> of species and numbers of individuals and catch per unit of effort by station of trawl samples in Card Sound September 1970 - February 1971.

No. of species	77	74	102	107	108	87	110	93	84	101
No. of animals	1532	330	2255	8573	3325	1411	3644	551	936	2690
Catch/tow	36.48	7.86	53.69	204.12	79.17	33.59	86.76	13.12	22.28	64.05

TABLE V-2

SPECIES, NUMBER OF INDIVIDUALS AND CATCH PER UNIT EFFORT IN TRAWL SAMPLES AT TURKEY POINT - JULY 1968 - JUNE 1970

FISH

	NI	NII	NIII	NIV	NV	NEI	NEII	NEIII	NEIV	NEV	SEI	SEII	SEIII	SEIV	SEV	SI	SII	SIII	SIV	SV	A	B	C	D	E	F	G	H
Ginglymostoma cirratum										3																		
Raja texana										1																		
Narcine brasiliensis													1															
Rhinobatos lentiginosus										1																		
Urolophus jamaicensis								3		3					2					4								
Harengula pensacolae								1																				
Anchoa mitchilli				1			1																					
Synodus foetens	2	2								1				1		1				2					1			
Gymnothorax nigromarginatus												1																
Lucania parva	177	610	359	17	152	139	73	14			14	2	14			2	9	4		1	66	49		1	1	1		18
Corythoichthys albirostris		4												1		1							1					1
Hippocampus erectus			1	1		4	1	1		2	1	4	3	2	2		2	2	2	4			2		5	1		2
H. zosterae	4	6	7	7		20	16	11	4	4	9	7	10	11	5	11	23	20	7	2	6	6	8	2	15	6		6
Micrognathus crinigerus	37	4	49	53	3	68	143	168	27	4	2	147	138	16	2	3	64	57	8	2	7	8	92	22	28	9	1	34
Syngnathus floridae	1	1	2		1					1		1	2	2					1 1	1		1	1	2	1			
S. pelagicus																1												
S. louisianae																2									1			
S. scovelli		1			9	2					1			1		1		1	1						1			
Mycteroperca microlepis	1										1										1							
Lutjanus analis											2	1									1							1
L. apodus																1												
L. griseus	1	3	2		1	1		1			4	1	4	1		1			1		6	5			1	2		1
L. jocu																											1	
L. synagris															3													
Astrapogon alutus																									1			
A. stellatus																			1									
Eucinostomus argenteus		4	3	1	1	1		1		1	36	3	3	7	5	28	2	4	11	1	7	2	3	6	6		17	1
E. gula		2	6	3	2	4	2	1		1	14		1	5	1	3	1	5			6		1	4	3		2	
Haemulon aurolineatum													1															
H. carbonarium		1				1																						
H. parrai								1			2												1	3				
H. plumieri																								3	1			
H. sciurus			1			1		4	1							2								3		1		1

TABLE V-2 CONTINUED

	NI	NII	NIII	NIV	NV	NEI	NEII	NEIII	NEIV	NEV	SEI	SEII	SEIII	SEIV	SEV	SI	SII	SIII	SIV	SV	A	B	C	D	E	F	G	H
H. species																								1				
Orthopristis chrysopterus												1													2			
Bairdiella chrysura											1										1	1		1				
Cynoscion nebulosus																1												
Archosargus rhomboidalis			1				2																					1
Calamus calamus				1																								
Lagodon rhomboides	7	26	10	4	17	3	5	7			45	4	9	1		27	4	4	11		13	11	3	15	10	1	4	
Nicholsina usta												1	1	1		2			1	1	1			1				
Scarus coeruleus							1									1			1	1				1				
Sparisoma rubripinne		1																		1	1							
[illegible] macrodon							1													10		1						
Lophogobius cyprinoides			1																									
Gobiosoma robustum	16	51	186	55	889	46	68	42	3		12	25	29	1		4	83	9	2		29	16	4	2	1	128	2	80
Goby A			1																									
Scorpaena brasiliensis								1	2						2		1	1				1				1		
S. grandicornis							1																		1			
Prionotus scitulus															1								1					
P. tribulus																	1											
Opisthognathus maxillosus																		1										
Callionymus pauciradiatus	1												1			1		2										
Paraclinus fasciatus	2		7	2	1		8	6	1			3	7		2		1	1	2	2	2		5			1		2
P. marmoratus			3				1	8	2			2	2	3									1	1	2			
Stathmonotus hemphilli													1															
Chasmodes saburrae	7	1	3	3	13	1	3				2						2				1			1		3		
Ogilbia cayorum								1									1	1										1
Sphyraena barracuda			1														1		1									
Bothus ocellatus													1		6					2			1					
Citharichthys macrops															1													
Paralichthys albigutta			1						1		1	1	2	3		2	3		1	1			2					
Syacium papillosum															1		6											
Achirus lineatus	1		1								1	3				2												

TABLE V-2 CONTINUED

	NI	NII	NIII	NIV	NV	NEI	NEII	NEIII	NEIV	NEV	SEI	SEII	SEIII	SEIV	SEV	SI	SII	SIII	SIV	SV	A	B	C	D	E	F	G	H
Trinectes inscriptus															1													
Symphurus plagiusa																		1										
Alutera schoepfi									1				1		1								1					
Monacanthus ciliatus									1	1				2	40			1		1							1	
M. hispidus				1	1				1	2		1	1	1	16				1	6				1	1			
Acanthostracion quadricornis	2	1	1	9		2	8	14	20	14		11	8	6	39	1	4	9	3	37		2	29	4	14			1
Lactophrys trigonus							1	1	1		3		1	3	2				1				2	1				
L. triqueter											1			4	2				1				1	5	2			
Sphaeroides nephelus					1		2		1			1				2	2	3					1			1		
S. spengleri		2		1	1	1				1		3		2	2	1		1	1	1			1					
S. sp.																				1								
S. testudineus		7				3	2				1					11	2	1					1					1
Chilomycterus schoepfi	1	1	1	13	1	4	3	10	3			15	1	3	3	2	4	12	2	5	3	4	7	16	25	2		
Opsanus beta	16	37	121	42	239	39	40	77	3	6	8	12	83	5	1	6	49	18	7	2	24	9	32	13	26	152		16
SPECIES	16	21	22	17	17	18	21	21	16	17	21	23	26	23	23	28	21	22	21	22	16	14	23	23	24	15	8	16
Total Catch	276	766	767	214	1333	340	382	368	72	47	161	250	326	82	140	121	265	158	66	88	174	116	200	109	150	310	29	168
Catch/Effort	1.62	4.51	4.51	3.57	22.22	2.00	2.25	2.17	1.20	0.78	0.94	1.47	1.92	1.37	2.33	0.71	1.56	0.93	1.10	1.47	1.12	0.92	1.59	0.87	1.19	2.46	0.23	1.33

TABLE V-2 CONTINUED

MOLLUSKS

	NI	NII	NIII	NIV	NV	NEI	NEII	NEIII	NEIV	NEV	SEI	SEII	SEIII	SEIV	SEV	SI	SII	SIII	SIV	SV	A	B	C	D	E	F	G	H
Acmaea sp.																					1							
Acteon punctostriatus	3								1									1								1		
Aequipecten gibbus nucleus	1	1							1	1				3	18				1									
A. irradians	25	2	219	318	4	34	49	55	4			175	179	82	17		14	80	119	4	6	24	10	25	43	42		5
Amygdalum papyria	2	13	66	5	3678		1				2	2				4	7	1				1				1		2
Anachis avara																							3					
A. obesa								3																				
A. pulchella				2		1	1	36	18	1	1	17	45	3		1		42	9	4	1	1	49	18	97	1		5
A. translirata			1					77	4	9		12	16					3					13	6	15			
Anadara notabilis								1																				
Anomalocardia cuneimeris	1	2	1		120											2									1			
Anomia simplex										1					1				1							1		
Arca imbricata																				1								
Arca sp.					1																							
A. zebra														1				1		1								
Arcopsis adamsi		15	32	14	1			11			5	26	3			1	32	28	8	2	3		1		22	20		
Arene tricarinata							1					1	17					2	6		2			6	10			
Astrea americana									1				3	1	2		1		1	6				3				
A. caelata																	1											
A. phoebia													2	4					1									
Bailya intricata								1								1	1	1							1	2		1
Balcis intermedia			4	1	1		2	56	13			8	16	23			2	9	1				21	4	23			1
Barbatia cancellaria									1	1									1	7					1			
Barleeia sp.			3	1				3	1		1	4	7	3	2		4	4	1		1		1	2	9			1
Batillaria minima		2						5			11	1	1			4	41	2								2	18	1
Bittium varium	Not counted - very abundant in algae stations																											
Brachidontes exustus	Not counted - very abundant on *Laurencia* and *Digenia*																											
Bulla umbilicata	285	748	709	342	39	2089	713	80	4	7	104	215	129	3		53	692	147	7		1430	98	17	5	56	1030	3	689
Bursatella leachi plei					2																							
Busycon spiratum										1																		
Cantharus cinctus																				1								
Cardiidae														1														
Calliostoma adelae										1														1				
Cardita floridana				1				3				14	331				5	13	11	1				4				1
Cerithidea scariformis											1						2	1								1		4

TABLE V-2 CONTINUED

	NI	NII	NIII	NIV	NV	NEI	NEII	NEIII	NEIV	NEV	SEI	SEII	SEIII	SEIV	SEV	SI	SII	SIII	SIV	SV	A	B	C	D	E	F	G	H
Cerithiopsis latum								3				7	3				1	8					1		6	2		1
C. emersoni			2		1		19	7			3	1	1	7			4	15					3		6	2		
C. algicola				8			2	16	5			54	2				71	14					24	1	28	10		2
Cerithium eburneum	18	77	107	9	3	2	16	142	6		466	353	63	13	1	4	2272	153	8		76	6	39		56	230		95
Cerithium sp.																					1							
C. literatum			1								4														1			
C. muscarum	623	2160	4695	410	153	379	615	142	11	6	1939	319	352	54	2	250	2327	132	31	3	891	106	11	39	26	5035	5	1834
C. variable	6	49	22	11	12	3	7	7			10	11	1	5		7	41	19		1	6	1	3	4	5	71		10
Cerodrillia thea													1					1					2		1			
Chama macrophylla																				1								
Chione cancellata	7	6	106	36	37	11	44	16		1		41	3		11	2	30	15	8	1	3	2	2		7	18		10
Codakia orbicularis			1		1			1								1	2		1	2						1		
Columbella mercatoria				3				5	15	2		14	52	16			1	7	1				2	4	2			1
C. spp. (juv)			4	57	2	3	23	530	49	2	6	639	143	38	1	2	214	390	4	2	8	10	130	87	183	1		5
C. rusticoides	1		4	104		1	20	360	15	1		463	183	4			55	166	11		7	15	45	39	52	3		3
Congeria leucophaeta	1	1	2	5	1193												1											
Conus jaspideus			1									2					1						2					
Crassispira/fuscescens								1		1			16										1		1			
C. leucocyma				4		1	1	20	1			14	11	3			3	14					23	6	11	2		5
C. nigrescens								1					1															
C. ostrearum													4				1											
Crassostrea virginica	5		19	5	1470	8		1			4			1		2											4	
Crepidula aculeata							3		1		1		1						1	2					1			
C. glauca		16	14	22	8	5	2		1	5	3	1	11	1	6	2	11	5	12	2	38					2		3
C. fornicata	15	186	1	17		25	28				8	2	30	3	1	2	26	7	6	1	144	17		1		22	1	45
C. plana																				1								
Cylichna krebsi													1															
Dentalium texasianum						1			1																			
Diodora cayenensis	3	12	47	69	1	12	34	73	13	2	1	63	13	4			33	48	43	12	7	5	5		49	51		21
D. dysoni												2																
D. listeri							1	1	2				1					1		1								
Epitonium echinaticostum	1		1	6		14	7	6				6	3					3					5	4	3	1		
E. foliaceicostum								1																	2			
E. rupicolum	1			3		5	4									1	3											

TABLE V-2 CONTINUED

	NI	NII	NIII	NIV	NV	NEI	NEII	NEIII	NEIV	NEV	SEI	SEII	SEIII	SEIV	SEV	SI	SII	SIII	SIV	SV	A	B	C	D	E	F	G	H
Eupleura sulcidentata												1				1		1										10
Fasciolaridae				1	1		1					22					2			2			1		5			
Fasciolaria hunteria				2			3	7			2	4	6				9	1			4	2				6		4
F. tulipa				2			1	8	1				8				3	2			4		4	1	2	2		1
Gibberulina ovuliformis			1	1				1			1		2				5	1			7	1		1		1		10
Haminoea elegans	12	252	284	51	22	33	34	4	4		31	12	4			9	97	5			20	2		2	1	318		26
Hyalina avenacea			1	9		9	5	36				31	22	5			3	13	2		3		35	2	11			
H. tenuilabra									1			2	1	3				1							1			
Hydrobiidae	13	2	7	2	1823		1		3		233		1			5	1	2	1					4				3
Laevicardium laevigatum								1							5	1	1					1				2		
L. mortoni		1	12	10	5	1	3	10	2	1	1	7	2			4	21	6	2				1	2	3	1		1
Lima pellucida	1	10	66	24	1	3	28	274	14	16	12	415	58	5	1	6	79	190	9	41	3	4	51	29	175	129		14
Lobiger souverbii								16																2				
Lucapina sowerbii									1				2	1														
Littorina nebulosa							1		3					4														
Macoma sp.				2															1									
Mactridae												1																1
Mangelia plicosa	7		37	17	14	2	10	3	1		8	12	1	1		3	27	11			1	3	1		4	54		4
Mangelia trilineata																			1									
Marginella aureocincta	3	3	19	86		96	106	26	2			24	12				1	48		1	25	8	15	2	18	1		39
Marginella eburneola				6	1	5	2	93			1	112	47				11	39	1		1	2			13	2		20
Mitra floridana	7		19			17	4	6			4	4					6	4							4	7		7
Mitra gemmata			5	3		1	1	40	21	1	2	53	198	189		1	6	54	1			1	100	102	81	3		3
Mitra hanleyi								3										3					2	1	2			1
Mitrella lunata	823	1100	8830	944	18,071	2022	1854	365	4	3	1465	114	49	7		377	3873	152	3		787	543	28	19	16	3551	13	2133
Mitrella sp.						1							1					1										
Modulus modulus	934	1778	304	654	3	865	538	237	19	3	21	326	234	37	2	22	1351	100	48	6	1033	318	101	13	64	1430		374
Murex cellulosus								6				6	1															
Murex florifer				1								2	1										1					
Musculus lateralis																				1								
Nassarius albus		1										1											1		3			
Nassarius vibex	19	15	34	9	53	11	15	20			19	19	2			15	64	9			3	1	11		8	72		19
Natica sp.																							1					
Neritina virginea	5	68	8		69						5					2												
Niticella sp.													4															1
N. ocellata	1						1	9	10			6	334	32		2	1	67	6	2			132	9	99			2
Rissoina chesneli	270	332	9988	3677	78	1016	724	211	6	1	206	1825	65	14	3	73	2734	403	6	2	291	208	21	15	118	4479	3	1961

TABLE V-2 CONTINUED

	NI	NII	NIII	NIV	NV	NEI	NEII	NEIII	NEIV	NEV	SEI	SEII	SEIII	SEIV	SEV	SI	SII	SIII	SIV	SV	A	B	C	D	E	F	G	H
Cetorus loubini																			1	2								
Odostomia canaliculata							1	1				1																
O. niveus	1							3				6						7					1		7			
O. laevigata			3	1	1	1		1	8			9	1				2	2						1	1			
Olivella mutica					4			1					2				1		2	1			3					3
Oxynoe antillarum																												
Parviturboides interuptus									1							1												
Persicula catenata													2															
P. lavalleeana	2		7	8		3	5	24	1	1	1	30	50	2		2	5	9	2		2	1	1	4	2	3		21
Prunum apicinum	186	1071	1325	63	21	198	176	120			65	124	161	1		4	207	28			159	87	11		4	431		264
Pseudochama radians									1																			
Pseudoneptunea multangulus				10				28	1		1	17	27	1				15		1	1	1	21	9	16	1		
Pteria colymbus									1														1		1			
P. longisquamosa	14	5	19	13	2	7	22	20	7	3		33	27	4			16	10	1	4	6	1	8	5	21	10		
Pyramidella candida							1																			1		
Pyramidella sp.					1																		2					
Retusa bullata	12	4	17	3	8	13	3				7	1				31	4	4			1			1	2	3		5
Rissoina cancellata			272	1		1	1	19			2	57	4			1	5	57				2	4	3	39	6		
Seila adamsi	2			1			17	12				15	1			1	7	5			4		3					10
Stellatoma stellata	1		23	59	1	1	8	15	1			1	1				2	6			2	1	3			3		45
Tagelus plebius					7																							
Tegula fasciata		3	1				71	77	21			29	55	2	1			5	1			1	40	74	76	3		
Teinostoma sp.			2		3	1	4					1		1										2				
T. cryptospira		2	8		6	1	4					4		2			20	8						1		4		3
Tellina martinicensis									2	1		2								1								
Tellina meria																	1											
T. texana			1		8																							
Thais haemastoma floridana								1																				
Trachycardium egmontianum										1																		
Tricolia affinis	169	6	27	9	6	81	254	2303.	147	56	9	252	1616	315	6	5	152	400	17	6	237	96	449	1518	431	237	3	108
T. bella																				2			2					
T. tessellata								6	1			1	1	7				1			4		1	3	2	1		1
Triphora nigrocincta	6	8	169	46	1	29	88	52	1		31	24	3	3			66	42			63	22	7	3	20	564	3	498
Trivia quadripunctata														1					2									
Turbonilla sp.	1	2	11		1	6	1	4			2		2				4		3				25	1	9	9		1
Turbo castaneus	28	2	4		1	28	33	17			1	40	1048	22	4	2	3	18	3	1	2	2	1	596	24	3		1

TABLE V-2 CONTINUED

	NI	NII	NIII	NIV	NV	NEI	NEII	NEIII	NEIV	NEV	SEI	SEII	SEIII	SEIV	SEV	SI	SII	SIII	SIV	SV	A	B	C	D	E	F	G	H
Turridae	1				1	1	1		1			2						2										
Vermicularia spirata	5	5	21	144		5	33	653	70	17	3	1636	121	25	7	13	1496	920	195	15	8	59	355	44	647	290		51
Volsella americanus			3	8			6	11	2	1		18			3		6	7		8		1	6	2	8			
Nudibranchs	61	94	107	90	1	186	472	174	8	5	10	108	37	9		8	143	104	5	22	76	33	33	17	79	98		79
Felimare bayeri										1																		
Chitons	1	3	4	11		8	10	12			5	12	33	3	2	1	9	22	3		38	118	14	38	91	7		132
SPECIES /	45	38	60	53	48	48	61	72	56	32	44	74	75	51	22	41	74	74	47	39	41	39	63	54	67	59	9	60
Total Catch	3583	8057	27741	7421	26941	7246	6136	6593	535	153	4714	7889	5892	969	97	929	16848	4117	609	174	5409	1805	1909	2785	2826	18283	53	8601
Catch/Effort	21.1	47.4	163.2	123.7	449.0	42.6	36.1	38.8	8.9	2.6	27.7	46.4	34.7	16.2	1.6	5.5	99.1	24.2	10.2	2.9	34.7	14.3	15.2	22.2	22.4	145.1	0.4	68.3

TABLE V-2 CONTINUED

CRUSTACEA

	NI	NII	NIII	NIV	NV	NEI	NEII	NEIII	NEIV	NEV	SEI	SEII	SEIII	SEIV	SEV	SI	SII	SIII	SIV	SV	A	B	C	D	E	F	G	H
Alpheus armillatus															1				1									
A. formosus									1			1			1			2										
A. heterochaelis		3	44	15	101	1	2				5		7			6	23	1							2	34		7
A. normanni			2	20		1	2	3		1		9	6			1	22		1	3			8		3	22		1
Balanus improvisus							1				1																	
B. eburneus								1											1	1							8	1
B. tintinnabulum					3																							
B. venustus niveus			1																									
B. amphitrite								1															1					
Callinectes ornatus	38	31	6	2	27	33	23	29	3	2	39	11	18		4	131	28	20	11		3		18			27	40	22
C. sapidus	9	19	5		2	4	7				41	3				30	6	2			4	1				5	12	3
C. similis					2			1			2		1			6	2						1			1	14	
C. spp. (juv.)	9	2	5		8	24	22	6			35	4	6			61	11	1					4	2		13	11	22
Epialtus dilatatus			1	5		1	7	25	11	2		26	18	3			3	5	3	1			15					
Eucratopsis crassimanus											1																	
Eurypanopeus depressus					27																					2	2	
E. dissimilis																											1	
Hippolysmata wurdemanni				1						2								1					1					
Hippolyte pleuracantha	1010	837	1145	225	859	1366	1271	267	9	2	57	162	126	2		12	190	198	8	1	416	205	95	72	84	377		460
Latreutes fucorum			1								1		1		1						2							
Leander tenuicornis	8	2	4	5		7	5	5		1	1	1	3				1											
Libinia dubia	9	4	15	6	3	14	11	11			12	6	6			2	9	6	1		4	2	14		5	12	4	2
Macrocoeloma camptocerum				1				3	1		1	1	6	2									1					
M. trispinosum								2		3		1		1					3	3								
Menippe mercenaria	2	1	1	7	1	4	4	2	1			1	7		1				1	1						2		2
Microphrys bicornutus			1										1							1	1				1			
Mithrax pleuracanthus													4		2				2									
Neopanope texana	3		8	2	44	13	5	4				3	7	2		1	5	2				1		1		1		
N. packardii	218	39	357	401	1236	401	445	642	66	30	125	289	461	23	3	71	321	73	19	2	30	27	130	35	23	374	3	75
N. sp.	4																											
Paguristes tortugae	11	12	1	8			2	106	102	16		97	81	11	1		12	53	2		1		182	13	60	15		
Pagurus bonairensis	4417	1352	7817	4588	2221	5978	7041	5401	261	23	1093	4187	2861	73	8	495	6951	2245	54	12	1461	1282	1062	230	940	8993	78	3470
Palaemon floridanus						1																						
Palaemonetes intermedius	2	122	8	4	310								7			2										1		1
Panopeus herbstii							1														2					1		
P. occidentalis	2	2	23	2	10	31	15	15			2	3	8		4	1	29	5	2				3	5	2	36		16

TABLE V-2 CONTINUED

	NI	NII	NIII	NIV	NV	NEI	NEII	NEIII	NEIV	NEV	SEI	SEII	SEIII	SEIV	SEV	SI	SII	SIII	SIV	SV	A	B	C	D	E	F	G	H
Panulirus argus							1	3	1	14		3		8	1		1		15	16			5	13	3			1
Pelia mutica								2	2	2									1	2		1	3					
Penaeus aztecus			2										1		1			1	1				1					
P. brasiliensis					1		1															1					1	
P. duorarum	1	19	9	2	4	4	2	4	1		44	4	1		1	85	6	5	7	1	5	14	7	2	4	6	6	10
P. spp. (juv.)	9	37	21	6	35	22	5	8	2	2	95	8	11	3	2	204	14	27	9		3	2	2		3	8	32	24
Periclimenaeus wilsoni									1																			
Periclimenes americanus	5	11	8	10		2	6	79	23	34	3	36	282	3	2	3	6	16	6	8	5	2	58	93	10	20		3
P. longicaudatus					3			1	1	2	1		1	2										1	1	1		
Pilumnus dasypodus																				2								
P. holoserecus																			1	1								
P. lacteus																		1										
P. marshii																				1								
P. pannosus																			1	4								
Pitho anisodon	9		1	6		6	8	11	1	1		3	27	3			4	1		1	2	1	4		1	2		
Podochela riisei			1																									
Portunus depressifrons									1			1	2		2			1					6	1				
P. gibbesi															1													
P. spinimanus								1		1					2													
Processa sp.					1																							
P. bermudensis		3											1															
Rhithropanopeus harrisii					3																							
Synalpheus sp.															1				1	1								
S. minus								1	4	2			10		1				2	7			1					
S. townsendi																				1								
Thor floridana	786	123	1141	752	7	1253	2871	4317	274	147	97	4525	4980	250	15	44	2856	3337	159	26	583	265	1725	769	1781	3811	1	1427
Tozeuma carolinense	2	3	4		1		1	2	1	1	1				1	9	2			1	5	1		2	2	2		1
Uca minax																											1	
Pycnogonid		1						2			1	2	1		1	1	1	2		1			1	1	1	4		
Pagurapseudes sp.	5	2	6	1		26	9	48	9		2	228	43	14			5	138			30		16	8	209	1		3
SPECIES	21	21	28	22	22	21	27	32	22	20	22	27	29	14	23	19	24	24	26	23	16	14	26	16	19	26	17	20
Total Catch	6559	2625	10638	6072	4906	9192	11769	11003	777	287	1709	9616	8986	398	57	1165	10508	6143	313	98	2556	1805	3364	1248	3135	13771	214	5541
Catch/Effort	38.6	15.4	62.6	101.2	81.8	54.1	69.2	64.7	13.0	4.8	10.1	56.6	52.9	6.6	1.0	6.9	61.8	36.1	5.2	1.6	16.4	14.3	26.7	9.9	24.8	109.3	1.7	44.0

TABLE V-2 CONTINUED

PORIFERA

	NI	NII	NIII	NIV	NV	NEI	NEII	NEIII	NEIV	NEV	SEI	SEII	SEIII	SEIV	SEV	SI	SII	SIII	SIV	SV	A	B	C	D	E	F	G	H
Spongia barbara															1				1	2								
Spongia cheiris												1	4															
Spongia graminea				1			1	2	6	3		1	22	3				1	12	14			8	5	1			1
Hippiospongia lachne																			1					2				
Ircinia fasciculata						2		6	29	10		9	48	13	10		1	2	99	53			22	19	9			
I. campana								2	7	7			2	7	1				7	8			2	4				
I. strobilina									1										1	1								
Verongia sp.																			1	22					1			
Dysidea etheria								6	5	1			6	1					4	9			2	2	5			
Haliclona molitba								5	4	10		4		3	2				24	16		1	3	1	1			
H. viridis									7	1		3	11	7	1			1	104	39			7					1
Neopetrosia longleyi								2	2				1	1	5				4	21			4		2			
Spheciospongia vesparia								2	6			1	8	2				1	8	3			6	1	1			
Tethya diploderma		1	2					1				1	1	1			1	3	2					88		8		
Geodia gibberosa								1	7	1		2	9	8	1				103	41			5		1			
Cinachyra cavernosa														1						4								
Chondrilla nucula	6	2	19	2	1	9	28	56	1	2	22	174	178	1	2	7	51	79	23	9	220	14	21	1822	12	919		6
Brown bay sponge	214	6	14	63		134	125	14	3	1		52	8	3			12	42	3	2	24	5	15	1	15	4		95
Tedania ignis								5	8	2		4	3	5					1	21			6	4	13			
Unidentified sponges	13	2	3	48		39	65	7	32	13		4	6	1	3		3	5	11	8			4		1	1		76
Scypha sp.	17		79	2		10	11	5					2					1		1	10	8		4	5	4	1	1
Aaptose aaptose								1						1														
SPECIES	4	4	5	5	1	5	5	15	14	11	1	12	15	16	9	1	5	9	18	18	3	4	13	12	13	5	1	6
Total Catch	250	11	117	116	1	194	230	115	118	51	22	256	309	58	26	7	68	135	409	274	254	28	105	1953	67	936	1	180
Catch/Effort	1.47	.07	.69	1.93	.02	1.14	1.35	.68	1.97	.85	.129	1.51	1.82	.97	.43	.04	.40	.79	6.82	4.57	1.63	.22	.82	15.25	.52	7.31	.01	1.41

TABLE V-2 CONTINUED

COELENTERATES

	NI	NII	NIII	NIV	NV	NEI	NEII	NEIII	NEIV	NEV	SEI	SEII	SEIII	SEIV	SEV	SI	SII	SIII	SIV	SV	A	B	C	D	E	F	G	H
Manicina areolata															2													
Porites porites								1	3	8				7	26				1	22								
Siderastrea siderea				1			1	3				1						1		1				1		2		
Solenastrea hyades				1				1	1										1				1					
Millepora sp.									1	4				1	2					13		1		1				
Jellyfish	2	6				1	2	1			1	1	1		2					1			5	1	1	1		7
Sea anemones	18		3	2	1	1	2	10		1		14	4		1	1		2	1				10	21	9	1		1
Condylactis sp.									2																			
Eunicea asperula									1	1										11								
Pterogorgia anceps									12					1						16				2				
Pseudopterogorgia acerosa									4					2						28								
Unidentified gorgonids										1				3						4				24				
Hydroids									1																			
SPECIES	2	1	1	3	1	2	3	5	8	5	1	3	2	5	5	1	0	2	2	9	0	1	3	6	2	3	0	2
Total Catch	20	6	3	4	1	2	5	16	25	15	1	16	5	14	33	1	0	3	2	97	0	1	16	28	10	4	0	8
Catch/Effort	.12	.04	.02	.07	.02	.01	.03	.09	.42	.25	.01	.09	.03	.23	.55	.01	.00	.02	.03	1.62	.00	.01	.13	.22	.08	.03	.00	.06

ECHINODERMS

	NI	NII	NIII	NIV	NV	NEI	NEII	NEIII	NEIV	NEV	SEI	SEII	SEIII	SEIV	SEV	SI	SII	SIII	SIV	SV	A	B	C	D	E	F	G	H
Diadema antillarum													1											1				
Lytechinus variegatus									6	36			2	3	425			1	187	56			1	2				
Luidia alternata									1	1															1			
Echinaster sentus			5	151			7	316	8	1		106	95	4	1		4	61	1	2			117	22	68			122
Amphiura stimpsoni														1														
Ophiophragmus filograneus																1												
Ophiophragmus sp.																3	1	1							2			
Amphipholis squamata								2	2					2											2			

TABLE V-2 CONTINUED

	NI	NII	NIII	NIV	NV	NEI	NEII	NEIII	NEIV	NEV	SEI	SEII	SEIII	SEIV	SEV	SI	SII	SIII	SIV	SV	A	B	C	D	E	F	G	H
Amphipholis pachybactera				1													1			1					1			
Ophiostigma isacanthum								4	14	1		7	4				3	4	11	12			8	1	9			
Amphiodia pulchella								1				3	1				2	2		1								
Amphioplus thrombodes				1		1																						
Ophiactis savignyi				146		1	1	29	36	15	3	204	62	6	2		6	216	34	113	1	1	33	8	140	1		4
Ophiothrix orstedii								89	73	11		10	57	7					61	68	1	-	114	9	2			
Ophionereis squamulosa									7					3						2								
Ophiopsila riisei							1	16	47	16		6	7	6				1	104	67		1	45		104			
Ophioderma brevispinum				2				18	4			24	4	5				8	1	6			83	6	45	1		
Holothuria floridana									30	1			13	2	2				11	6			1	9				
H. floridana X *mexicana*																			1									
Cucumariidae			1																									
Leptosynapta parvipatina		1	4	144		65	130	270	146	25		803	405	56	2	2	274	736	28	14	4	13	322	54	348	2		15
Chiridota rotifera																				1			1	1	3			
SPECIES	0	1	3	6	0	3	4	9	12	9	1	8	11	11	5	3	7	9	10	13	3	4	10	10	12	3	0	3
Total Catch	0	1	10	445	0	67	139	745	374	107	3	1163	651	95	432	6	291	1030	439	349	6	18	725	113	725	4	0	141
Catch/Effort	.00	.01	.06	7.42	.00	.39	.82	4.38	6.23	1.78	.02	6.84	3.83	1.58	7.20	.04	1.71	6.06	2.58	2.05	.04	.14	5.75	.90	5.75	.03	.00	1.12

MISCELLANEOUS

	NI	NII	NIII	NIV	NV	NEI	NEII	NEIII	NEIV	NEV	SEI	SEII	SEIII	SEIV	SEV	SI	SII	SII	SIV	SV	A	B	C	D	E	F	G	H
Flat worms		4	29	3		9	6	16	4			13	5			1	9	4		1	6		9	6	3	13		2
Bryozoans									1															3				
Tunicates	9	1	4				8	1	1			8	1				69				1	2	1	5	1	4		
SPECIES	1	2	2	1	0	1	2	2	3	0	0	2	2	0	0	1	2	1	0	1	2	1	2	3	2	2	0	1
Total Catch	9	5	33	3	0	9	14	17	7	0	0	21	6	0	0	1	78	4	0	1	7	2	10	14	4	17	0	2
Catch/Effort	.05	.03	.19	.05	.00	.05	.08	.10	.08	.00	.00	.12	.04	.00	.00	.01	.46	.24	.00	.02	.04	.01	.08	.08	.03	.13	.00	.01

TABLE V-3

CATCH (LOG CATCH + 1) OF *AMYGDALUM PAPYRIA* BY MONTH AND STATION. EACH VALUE IS THE SUM OF ANIMALS TAKEN IN 7 TOWS.

	STATION																				
	NI	NII	NIII	NIV	NV	NEI	NEII	NEIII	NEIV	NEV	SEI	SEII	SEIII	SEIV	SEV	SI	SII	SIII	SIV	SV	TOTAL
1968																					
July			0.30	0.90	16.25												0.48				17.93
Aug.					9.09												0.30				9.39
Sept.	0.60				5.88																6.48
Oct.			0.30		5.51											0.30					6.11
Nov.		0.60			2.10		0.30				0.60										3.60
Dec.		0.60			4.37							0.30				0.30		0.30			5.87
Total	0.60	1.20	0.60	0.90	43.20	0.00	0.30	0.00	0.00	0.00	0.60	0.30	0.00	0.00	0.00	0.60	0.78	0.30	0.00	0.00	49.38

	NI	NII	NIII	NEI	NEII	NEIII	SEI	SEII	SEIII	SI	SII	SIII	A	B	C	D	E	F	G	H	TOTAL
1969																					
Jan.			1.56					0.30													1.86
Feb.		0.30	3.62							0.48	0.90			0.30				0.30		0.60	6.50
March		1.68	3.68																		5.36
April			1.98																		1.98
May			0.30																		0.30
June																					
July																					
Aug.																					
Sept.																					
Oct.																					
Nov.																					
Dec.																					
Jan.'70																					
Feb.																					
March																					
April																					
May																					
June																					
Total	0.90	2.28	10.84	0.00	0.00	0.00	0.00	0.30	0.00	0.48	0.90	0.00	0.00	0.30	0.00	0.00	0.00	0.30	0.00	0.60	16.00

TABLE V-3 CONTINUED

										STATION										
	NI	NII	NIII	NIV	NV	NEI	NEII	NEIII	NEIV	NEV	SEI	SEII	SEIII	SEIV	SEV	SI	SII	SIII	SIV	SV	TOTAL
1968																					
July	0.30	5.67	3.13	1.86	3.18	1.56		1.18		0.30			0.30				3.85		0.30		21.63
Aug.		0.30	2.11	4.29	0.90	3.64	3.84	1.94	0.30			1.30	1.78	0.30			5.36	0.30			26.36
Sept.	2.30	1.86	0.60	0.90	0.30	4.24	1.56			0.60		1.08	1.26	0.30		3.11	1.80	1.92	0.60		22.43
Oct.	0.30	2.32	1.38	1.73		0.30	3.25	0.30				5.94	1.08			0.70	1.91		0.30		19.51
Nov.		1.38	0.60	2.16			0.30		0.30		0.30		0.95				3.28	0.78	0.60		10.65
Dec.				0.30					0.30	0.60		2.67	1.60				2.70	0.30			8.47
Total	2.90	11.53	7.82	11.24	4.38	9.74	8.95	3.42	0.90	1.50	0.30	10.99	6.97	0.60	0.00	3.81	18.90	3.30	1.80	0.00	109.05

	NI	NII	NIII	NEI	NEII	NEIII	SEI	SEII	SEIII	SI	SII	SIII	A	B	C	D	E	F	G	H	TOTAL
1969																					
Jan.		0.78	0.60				0.70	2.41	1.90	0.48	5.51	0.30		0.30			0.30	3.27		2.85	19.40
Feb.				0.30			0.30	1.08	1.86	1.08	4.14	1.38						4.76		2.03	16.93
March		0.90	0.60	0.30	1.38		0.48	2.46			6.22	3.28			0.60		0.48	7.95		1.56	26.21
April	3.03	0.90		8.25	3.04	0.90	2.28	0.30	1.08	0.90	2.61		1.98	0.78			0.95	5.19		8.58	40.77
May	3.38	5.22	0.60	8.71	3.73	1.38	1.64		1.48		0.30	0.90	2.26	3.45				4.02		5.52	42.59
June	1.08	6.07	2.76	6.18	1.98		5.27	0.30	1.20	1.51	1.78	0.60	7.46	3.29	0.30	0.78	1.68	4.83	0.90	5.64	53.61
July	4.03	11.80	1.08	13.59	8.11	0.90	3.59	2.65	0.95	0.78	3.11		14.41	0.90			0.30	8.18		2.46	76.84
Aug.	6.22	1.08	1.81	10.19	7.88	2.95	0.48		0.70		3.05	0.60	3.23	0.60	0.30		1.48	10.93		0.60	52.10
Sept.	6.40	0.78	9.05	8.41	4.33	1.56	1.56	1.78				1.78	1.38	1.38	0.60		1.08	5.51		2.51	48.11
Oct.	4.32	7.54	6.46	9.51	3.51	0.30	0.48	1.90	0.60		0.60	1.30	1.20				0.60	2.16		7.40	47.88
Nov.	2.28		5.24	4.63	0.30	1.38	0.30	2.89			3.20	4.11					0.30	3.75		2.56	30.94
Dec.	2.32	1.20	5.43	0.90	2.65	2.03		1.20			0.60						0.78	2.03		1.08	20.22
Jan.'70	1.08		6.45	0.60	0.60		0.60	0.78		0.30	4.56	3.66	0.60				0.30	5.06		2.26	26.85
Feb.	0.60	1.60	4.26	0.78	3.95			1.00			6.65	0.30	0.90	1.81				0.30		6.81	28.96
March	1.26		4.20	2.55	1.68		0.30	0.90		0.60	7.37	1.60	5.35	0.30	0.30			1.85		3.33	31.59
April	0.90	1.26	2.58	2.33	0.90			1.20			3.77	1.08	1.60	2.86	0.30			3.00		3.38	25.16
May	0.30	1.38	2.88	10.12	5.26	0.30		0.48	1.98		5.65	0.30	1.90	1.81	0.30			6.82		1.56	41.04
June	0.78			2.38	4.89	1.26		1.98	5.07		2.51	3.48	0.30	0.48	1.56		2.66	0.60		3.16	31.11
Total	37.98	40.51	54.00	89.73	54.19	12.96	17.98	23.31	16.82	5.65	61.63	24.67	42.57	17.96	4.26	0.78	10.91	80.21	0.90	63.29	660.31

TABLE V-3 CONTINUED

										STATION											
	NI	NII	NIII	NEI	NEII	NEIII	SEI	SEII	SEIII	SI	SII	SIII	A	B	C	D	E	F	G	H	TOTAL
1969																					
July		3.02				0.60		4.12			8.98			0.78				1.43		0.95	19.88
Aug.				0.06		0.95		1.38			14.65	1.38									18.96
Sept.	0.48		3.47		0.48	0.30		3.36		1.08	5.70	0.30	3.45	0.30			0.48	4.91			24.31
Oct.	2.23	5.80	0.78			1.08	12.16	1.08			3.38							3.88		1.48	31.87
Nov.					0.30			1.68	0.90		6.66	0.60						2.73		3.24	16.11
Dec.						6.14		1.18			1.88				0.30		0.60			1.90	12.00
1970																					
Jan.								2.10	1.00		10.15	3.53					0.30	1.30		0.90	19.28
Feb.			0.30			1.98		2.56			8.10						0.48			2.74	16.16
March								2.46	1.51		11.08	1.75						0.85		1.08	18.73
April	0.30				0.60			1.30			7.89	1.38			0.30			0.30		1.18	13.25
May					0.30						5.07				2.18		0.48			0.30	8.33
June					1.08	2.03		3.92	2.05		3.72	3.49			2.73		2.60			0.30	21.92
Total	3.01	8.82	4.55	0.60	2.76	13.08	12.16	25.14	5.46	1.08	87.26	12.43	3.45	1.08	5.51	0.00	4.94	15.40	0.00	14.07	220.80

TABLE V-3 CONTINUED

										STATION											
	NI	NII	NIII	NIV	NV	NEI	NEII	NEIII	NEIV	NEV	SEI	SEII	SEIII	SEIV	SEV	SI	SII	SIII	SIV	SV	TOTAL
1968																					
July	0.60	1.08			4.48	1.48	1.38	5.30			0.95	1.00	3.75				4.85	2.16			27.03
Aug.	3.26	2.08	2.87	0.90	3.36	5.08	1.20	2.05	0.60		1.38	5.07	2.98	1.08			6.17	1.68	1.08		40.84
Sept.	3.20	1.86	2.03	1.08	2.80	3.68	2.41	0.90			3.91	0.48	0.90	2.00	0.30	0.30	4.94	0.60	2.46		33.85
Oct.	0.48	2.51	3.76	0.48	1.20	0.30	1.68		0.60	0.30	1.08	4.03	1.45	0.30		0.90	3.11	0.30	0.30		22.78
Nov.	0.90	1.30	2.35	4.27	0.30	0.30	1.26		0.30	0.70	1.68	0.78	2.08	0.78			5.32	0.78	0.60		23.70
Dec.		0.48	1.26	1.95	0.30		0.60					4.52	3.07	0.78		0.48	4.71	1.51	2.08	0.30	22.04
Total	8.44	9.31	12.27	8.68	12.44	10.84	8.53	8.25	1.50	1.00	9.00	15.88	14.23	4.94	0.30	1.68	29.10	7.03	6.52	0.30	170.24

	NI	NII	NIII	NEI	NEII	NEIII	SEI	SEII	SEIII	SI	SII	SIII	A	B	C	D	E	F	G	H	TOTAL
1969																					
Jan.	1.68	8.07	2.56		1.08	0.60	1.62	4.88	5.23		7.38	2.48	1.30	2.64		0.78		6.86	0.30	9.28	56.74
Feb.	7.27	1.73	5.52	1.08	0.30	2.64	0.48	5.61	5.36	2.98	6.95	2.16	0.78	3.23	0.30	2.97	0.78	4.70		8.62	63.46
March	2.08	5.09	4.10	1.08	2.89	1.08	0.90	2.58	3.49		2.98	5.09	1.92				0.48	6.48		8.67	48.91
April	4.80	1.58	4.63	5.47	5.98		0.30	0.60	2.98				4.24	2.73			0.48	1.51		9.00	44.30
May	4.77	8.16	6.55	4.68	4.58	0.60	5.68	0.48	1.81	0.95	0.30	0.30	5.16	0.90	0.60			4.02		7.22	56.76
June	8.95	9.79	10.89	5.98	2.76		10.05	0.90	1.26	2.81	2.81	1.20	9.97	2.33	0.30	1.08	0.70	4.79	0.60	8.70	85.87
July	4.36	12.81	9.69	3.10	2.42	1.56	11.58	0.60	2.26	5.88	6.06	1.81	8.98	1.78	0.30		0.70	12.00		0.48	86.37
Aug.	8.10	7.78	12.78	1.98	3.49	3.13	4.36	0.90	0.70	1.38	12.77	0.78	5.64	1.51		0.30	1.08	17.27		3.16	87.11
Sept.	3.81	3.05	12.34	2.28	4.77	2.08	13.42	2.83	0.78	1.00	6.54	1.38	4.70	0.30	1.08	0.30	0.30	12.64		3.65	77.25
Oct.	0.78	2.38	8.79	1.08	1.68		5.81	2.64	0.60		12.67	0.30	3.32	1.08		0.30	0.60	7.60	0.30	4.89	54.82
Nov.	2.38		7.41	1.26	0.90	1.95	7.55		2.33	2.45	7.98	0.78						10.80		7.66	53.45
Dec.	2.35	3.13	8.96	3.11	2.68	0.30	3.30	0.60	0.30		1.60		0.30					9.21		2.56	38.40
1970																					
Jan	0.30	6.36	12.12	1.81	1.48		7.01	0.30	0.60	0.48	12.56	0.78	5.09					12.32		6.27	67.48
Feb.	2.16	3.36	10.93	2.28	4.61		1.08		0.30		9.92		0.78	0.48				7.84		9.28	53.02
March	0.90	12.38	12.21	4.02	6.95		3.96		0.60	0.60	8.94		6.97	0.95				7.71		7.51	73.70
April	4.33	9.77	10.02	2.23	5.56		0.48		0.60	0.30	4.74	0.30	1.98	1.68			0.48	3.32		8.28	54.07
May	3.96	6.92	12.47	2.58	4.76		0.30	1.08	1.86	0.78	4.08		1.38					6.17		1.86	48.20
June					2.82		1.65	1.08	2.58		5.16	1.38	1.51		0.30			6.50		5.91	28.89
Total	62.98	102.36	151.97	44.02	59.71	13.94	79.53	25.08	33.64	19.61	113.44	18.74	64.02	19.61	2.88	5.73	5.60	141.74	1.20	113.00	1078.80

TABLE V-3 CONTINUED

										STATION											
	NI	NII	NIII	NIV	NV	NEI	NEII	NEIII	NEIV	NEV	SEI	SEII	SEIII	SEIV	SEV	SI	SII	SIII	SIV	SV	TOTAL
1968																					
July		0.30	0.60	0.30	3.16	1.08	0.30					0.90	0.60				1.20	0.30			8.74
Aug.	3.96	4.74	0.48	1.98	0.60	3.45	0.30	0.70					0.30				0.30	0.30			17.11
Sept.	1.30	0.30	0.60	2.58	2.64	1.68										0.60					9.70
Oct.	0.48			0.30	2.38	2.46	2.16				0.48					2.38			0.30		10.94
Nov.	0.60	1.38	0.30	0.30							3.43					0.30	0.78	0.30			7.39
Dec.	1.81	0.90	2.16	1.40	4.54	2.16	2.99	1.20	0.30		1.81			0.30		1.51	0.30				21.38
Total	8.15	7.62	4.14	6.86	13.32	10.83	5.75	1.90	0.30	0.00	5.72	0.90	0.90	0.30	0.00	4.79	2.58	0.90	0.30	0.00	75.26

	NI	NII	NIII	NEI	NEII	NEIII	SEI	SEII	SEIII	SI	SII	SIII	A	B	C	D	E	F	G	H	TOTAL
1969																					
Jan.	6.65	9.00	6.58	2.43	8.62	2.53	1.38	1.48		3.51	3.05		2.88	7.23		0.30		8.80	0.78	4.20	69.42
Feb.	7.40	1.68	12.06	3.54	4.70	2.41	0.48	0.30		6.91	3.33	2.05	1.48	9.64	1.08	0.30		8.31		5.99	71.66
March	2.33	7.28	13.40	2.94	5.35	0.60	2.96	1.86		1.85	4.70	1.51	2.43	1.56			0.30	10.59		4.48	64.14
April	3.64	3.53	16.08	9.44	4.80	0.30	3.89	0.30	0.60	2.69	2.03	1.15	5.30	3.00			0.48	7.16		8.69	73.08
May	4.03	4.92	12.30	8.38	5.97	0.30	5.73		0.60		2.98		4.57	2.56		2.16		7.56	1.68	6.50	70.24
June	6.96	2.53	13.91	1.81	4.38		2.49	0.30	2.53	1.86	3.10	0.30	7.68	7.03	0.30	0.30	0.30	8.13		5.24	69.15
July	4.52	6.49	12.93	8.04	2.76		0.48		0.30	0.30		0.30	10.04	4.20		0.30		5.79			56.45
Aug.	5.68	2.45	1.98	3.25	0.90		0.30		0.30		1.38		2.68	1.81				5.04		0.30	26.07
Sept.	2.56		12.42	5.70	4.02		1.26	2.86					3.55	1.68	0.30		0.30	0.30		1.30	36.25
Oct.	1.56	3.36	8.16	4.52	3.69		1.56			0.30	1.51		2.08					1.68		1.97	30.39
Nov.	0.30	0.90	8.85	1.08			3.66			1.08	1.68							2.05		2.98	22.58
Dec.	1.98	3.36	7.68	0.90	3.71	6.64	11.00	1.68	0.60	0.30			0.30			0.30	1.60	7.25		2.28	53.96
1970																					
Jan.	4.09	5.33	12.19	2.92	6.65		12.17	1.08	2.08	2.28	12.30	4.37	2.66	0.60			0.30	11.55		3.68	84.25
Feb.	6.78	3.48	10.88	10.16	8.68	6.46	2.65	3.06	0.90		10.49	2.08	2.94	2.05	1.08	0.78		9.88		13.40	95.75
March	6.71	10.15	12.80	11.94	6.38	2.40	10.88	1.20	0.48	5.94	15.53	5.82	7.52	3.96				11.20		9.53	122.44
April	5.52	4.77	10.03	10.69	9.32	3.58	0.30	1.32	0.90	4.58	12.97	1.86	2.46	2.13	1.90			6.26		9.16	87.85
May	3.40	3.66	10.17	9.73	10.28	4.26	6.79	1.60	0.48	0.70	10.89	0.90	1.48	1.70	0.30		0.60	13.20		3.58	83.72
June	3.91			5.85	6.85	4.29	2.79	2.96	0.90		12.80	1.98	1.26	1.08	0.90			9.42	0.78	11.58	67.35
Total	78.02	72.89	182.42	103.32	97.06	33.77	70.77	20.00	10.67	32.30	102.82	22.62	61.31	50.23	5.86	4.44	3.88	134.17	3.24	94.86	1184.65

TABLE V-3 CONTINUED

										STATION											
	NI	NII	NIII	NIV	NV	NEI	NEII	NEIII	NEIV	NEV	SEI	SEII	SEIII	SEIV	SEV	SI	SII	SIII	SIV	SV	TOTAL
1968																					
July	2.30	0.90	0.90	1.86	0.30	1.38	0.30	1.08			0.30		3.64				2.90	0.30	0.30		16.46
Aug.	4.31	0.30	3.03	5.10		2.28	1.56	1.00	0.30		0.30	1.60	4.24	1.08	0.30	0.48	4.30	0.30	1.08	0.30	31.86
Sept.	2.81	0.78	2.95	4.78		3.83	1.73	0.60		0.60	0.78	0.30	1.51	1.48		0.90	1.78	0.60	1.86		27.29
Oct.	0.60	2.05	2.28	5.98		0.90	2.16		0.78			2.28	1.30			1.26	1.81				21.40
Nov.	0.30	0.60	0.30	5.78		0.30	0.78	2.26				1.48	0.48						1.26		13.54
Dec.	0.30			2.76	0.30	0.90	0.90	0.30			0.30	2.26	2.62	0.78			1.73	0.60	0.60	0.30	
Total	10.62	4.63	9.46	26.26	0.60	9.59	7.43	2.98	1.08	0.60	1.68	6.44	15.57	3.34	0.30	2.64	14.00	2.28	5.10	0.60	125.20

	NI	NII	NIII	NEI	NEII	NEIII	SEI	SEII	SEIII	SI	SII	SIII	A	B	C	D	E	F	G	H	TOTAL
1969																					
Jan.		1.38	0.78		0.48	1.26	0.78	2.62	2.70		5.62		3.54	4.79			0.30	2.88		1.56	28.69
Feb.			1.26	0.60	0.60	0.95		1.51	2.10	0.48	4.12	0.90		4.31		1.08	0.78	3.08		0.90	22.67
March	0.78		0.70	1.98	3.60	0.60	0.30	4.79	1.48		6.70	2.18	0.30			0.60	0.90	3.16		1.56	29.63
April	0.60	1.08		3.51	4.36	1.38		1.08	1.30		3.59	0.60	1.78	2.48	0.30	0.48	1.08	3.18		1.51	28.31
May	2.03	2.81	0.60	4.77	4.21	0.30		0.60	1.68	0.60	3.36	1.38	3.71	1.86	0.90		0.60	5.01		0.95	35.37
June	6.08	7.04	0.60	6.16	1.26	0.30	1.48	2.11	2.08	0.30	6.08	3.62	8.14	3.64	3.32		2.26	7.03		3.04	64.54
July	7.61	12.29	0.90	2.61	4.46	1.51		3.33	1.56	1.08	11.10	1.68	7.78	2.26	3.54		1.86	12.50		2.28	78.35
Aug.	9.11	8.78	0.60	2.48	3.54	4.72	0.30	3.58	3.88		9.95	0.60	7.76	1.68	2.69	0.90	2.08	11.46		0.30	74.41
Sept.	7.53	7.45	3.36	3.73	5.10	3.37		4.87	0.78		2.73	0.30	9.50	3.16	0.78		1.08	6.25		1.68	63.21
Oct.	4.56	12.80	1.68	6.95	3.33	1.00		3.71	0.60		7.37		2.64	1.56	0.30	0.30	0.30	3.84		3.03	53.97
Nov.	4.06	0.78	2.08	6.17	0.60	1.92	0.30	0.60	3.58		4.41	0.90	0.60	5.19			0.60	7.07		6.31	45.17
Dec.	7.68	4.25	2.28	5.98	3.16	4.01		1.86	0.48				0.60	1.68		0.30	0.78	3.83		1.98	38.87
1970																					
Jan.	3.68	8.05	3.33	5.13	4.35	0.30		2.94			5.54	1.20	3.74	2.70				4.00		3.24	48.20
Feb.	5.97	1.56	2.98	6.54	6.38	0.48		2.64	0.30		2.16		4.03	4.66				3.86		7.83	49.39
March	5.33	8.57	3.84	8.38	5.10			2.11	0.60	0.30	3.51	0.78	6.55	6.12				4.52		5.15	60.86
April	6.07	5.08	5.23	9.26	5.96	0.70		2.19	0.85		0.90	1.18	0.48	1.08	0.30			2.65		3.10	45.03
May	6.28	8.57	8.12	5.53	5.00	1.26		1.68	0.30		3.16		3.13	2.46	0.30			7.18		1.08	54.05
June	0.60			1.86	2.33	5.01	0.48	4.13	3.40		3.49	2.86	1.08	0.90	1.73		2.16	5.29		4.02	39.34
Total	77.97	90.49	38.34	82.82	63.82	29.43	3.64	46.35	27.67	2.76	83.79	18.18	65.36	50.53	14.16	3.66	14.78	96.79	0.00	49.52	860.06

TABLE V-3 CONTINUED

	STATION																				
	NI	NII	NIII	NIV	NV	NEI	NEII	NEIII	NEIV	NEV	SEI	SEII	SEIII	SEIV	SEV	SI	SII	SIII	SIV	SV	TOTAL
1968																					
July	0.60	0.30			1.60	0.60		0.60				0.60	6.86				1.68				12.84
Aug.	2.32	2.73	1.95	0.78	1.56	1.38	0.60	0.70					3.70				2.56				18.28
Sept.	2.60	0.78	0.60	0.60	0.60	0.30	1.08					0.48					1.08	0.30			8.42
Oct.		0.78	0.30	0.30								0.30	0.60			0.30	0.90				3.48
Nov.		0.60		0.90							0.60		1.00				0.78				3.88
Dec.		1.20	0.30									3.00	0.78				0.30	0.30			5.88
Total	5.52	6.39	3.15	2.58	3.76	2.28	1.68	1.30	0.00	0.00	0.60	4.38	12.94	0.00	0.00	0.30	7.30	0.60	0.00	0.00	52.78

	NI	NII	NIII	NEI	NEII	NEIII	SEI	SEII	SEIII	SI	SII	SIII	A	B	C	D	E	F	G	H	
1969																					
Jan.	1.75	7.83			0.48		0.60	2.05	2.08		1.20		0.78	2.64				4.93		3.23	27.57
Feb.	2.51	0.60	0.60	0.30	0.30			1.26	1.86		1.00		0.30	3.91				3.14		5.46	21.24
March	0.78	4.07		0.48				4.66	0.30		1.20	0.60	0.30	0.30				4.03		4.63	21.35
April	0.30	0.60	1.38	3.34	1.84	0.60	0.60	1.00	0.48		1.30	0.48	2.64	3.80				0.78		4.19	23.33
May	0.30	7.28	2.38	0.78	0.60	0.60	1.60		0.30		0.30		1.92	0.90	0.48			0.30		2.28	20.02
June	1.38	7.95	8,87	0.78		0.30	4.05	0.60	0.30	0.48	1.38	1.08	3.03	0.78	0.30			3.30		2.60	37.18
July	2.58	10.69	4.65	0.90	1.86	1.68	0.60	1.30		0.30	4.23	0.60	4.75	1.20	0.30		0.30	6.28		0.30	42.52
Aug.	4.21	3.96	7.86	1.56	0.60	2.64		2.46			1.38	0.90	1.08		1.26		0.30	3.50		0.30	32.01
Sept.	3.86	0.48	8.15	1.95	1.92	0.70	0.48	0.60			0.30		0.30					1.26		0.30	20.30
Oct.	0.78	6.08	2.65	2.38	0.30	0.30		3.06					1.08					1.46		1.68	19.74
Nov.			3.79	2.03		0.78		0.30			1.73	1.08						6.17		1.91	17.79
Dec.	1.08	1.56	2.94	2.64	2.15	3.78	0.30	0.30			0.90							3.84		1.56	21.05
1970																					
Jan.	0.78	4.35	7.97	0.60	1.08		1.86	0.30			3.16	0.30	2.08					5.88		1.75	30.11
Feb.	0.90	2.56	7.39	1.38	4.02	0.85		1.51					0.60					1.38		3.41	24.00
March	2.28	9.34	9.53	4.31	2.83		0.60	2.55	0.30				4.91	1.78				2.76		2.33	43.52
April	3.62	5.41	8.06	3.76	3.30	0.30	0.30		0.30		1.51		0.90	0.30	0.30			1.48		3.18	32.72
May	2.35	3.61	8.30	2.28	1.08	0.30		0.30	0.48		1.00		0.48	0.30				4.68			25.16
June				0.60	2.25	2.02	0.60	0.78	1.32		1.68	0.90	0.60	0.30	0.30		0.48	0.85		1.56	14.24
Total	29.46	76.37	84.52	30.07	24.61	14.85	11.59	15.91	7.42	0.78	29.39	6.24	25.75	16.21	2.94	0.00	1.08	55.99	0.00	40.67	473.85

TABLE V-3 CONTINUED

	NI	NII	NIII	NIV	NV	NEI	NEII	NEIII	NEIV	NEV	SEI	SEII	SEIII	SEIV	SEV	SI	SII	SIII	SIV	SV	TOTAL
1968																					
July												0.30	12.11				0.30				12.71
Aug.	0.30				0.30		0.30		1.90					0.30				0.90		0.30	4.30
Sept.	0.78	0.30				0.30	2.68	6.45		0.70		1.08	0.90	1.15				0.30	0.60		15.24
Oct.					0.78			1.48	1.38	0.30		2.08	0.30			0.78			0.60		7.70
Nov.		0.30						0.30	1.38		0.78	0.60	1.60	3.57				0.60			9.13
Dec.									0.90			1.68	0.78	1.30	0.90				0.48	0.60	6.64
Total	1.08	0.60	0.00	0.00	1.08	0.30	2.98	8.23	5.56	1.00	0.78	5.74	15.69	6.32	0.90	0.78	0.30	1.80	1.68	0.90	55.72

	NI	NII	NIII	NEI	NEII	NEIII	SEI	SEII	SEIII	SI	SII	SIII	A	B	C	D	E	F	G	H	TOTAL
1969																					
Jan.								1.86			0.90	6.45				3.33	1.86	0.70			15.10
Feb.				0.30	0.30	1.68		2.08	7.57		1.48	0.30		0.48	0.78	1.08	2.16	5.07		0.90	24.18
March	0.30		0.30		1.18	1.90		4.60	1.58		0.60	3.10		0.30	0.48	0.78	0.30	5.57			20.99
April	1.08	0.30		2.08	4.46	4.15		3.28	6.21	0.30	2.17	2.98	1.48	0.90		0.30		4.53		0.78	35.00
May	3.29	0.30	1.00	2.57	4.41	3.89	1.38	2.08	4.00		0.60	4.46	3.03	1.78	2.58		0.90	3.75	0.30	3.78	44.05
June	7.47		2.26		4.60	2.89	0.30	0.90	7.12	0.30	3.26	3.05	8.57	5.08	1.38		1.45	4.43		2.79	55.85
July	1.92			0.90	1.08			0.60	1.98			2.03	0.60		0.60		0.90			1.20	11.81
Aug.	0.60							0.48	0.30			0.30		0.78	5.68	0.30	1.98				10.42
Sept.	3.17	0.30	0.78	2.32	2.46	0.30			0.30			0:78		0.60	2.16	0.30	1.68	1.38	0.60	0.30	17.43
Oct.	1.68			3.98	5.32	5.49		0.78	0.30			0.70			1.00	3.06	3.13	0.30			25.74
Nov.					0.30			3.11	5.82		0.48	7.46		0 60	0.48	6.72	4.10				29.07
Dec.					3.94	12.97		2.90				2.31	0.78	1.34	5.18	4.64	7.85				41.90
Jan. '70					0.60			0.48	4.44			1.18				5.60	2.00				14.30
Feb.					0.78	8.15		1.30	0.70				0.30		2.03	7.95		0.30			21.51
March					0.60	0.70		0.30			0.90	1.68		0.30	1.20	6.89	3.33				15.90
April						0.78					0.30	0.60			1.18	3.78					7.24
May	0.30	0.30	0.60	0.48	1.68	1.86					1.08		0.30		0.60		0.48	0.60			8.28
June	0.30				0.90	3.66		0.30			1.20	1.95			5.38	1.45	1.20	0.60		0.78	17.72
Total	20.11	1.20	4.94	12.63	32.61	50.28	1.68	24.04	46.77	0.60	12.07	32.88	15.06	12.76	30.71	46.17	33.32	27.23	0.90	10.53	416.49

TABLE V-3 CONTINUED

										STATION											
	NI	NII	NIII	NIV	NV	NEI	NEII	NEIII	NEIV	NEV	SEI	SEII	SEIII	SEIV	SEV	SI	SII	SIII	SIV	SV	TOTAL
1968																					
July	0.30	0.30		2.51			0.30	1.20	2.53	1.26	0.30	2.92	3.23			0.30	6.46	3.10	4.26	0.30	29.27
Aug.			0.30	1.26			0.30	1.56	2.80			7.24	1.85	0.90		0.60	5.66	1.38	3.11	0.30	27.26
Sept.				2.86			1.98	1.90	1.30	0.78		4.80					4.64	1.20	1.95		21.41
Oct.	0.30	0.48		1.00					1.00			5.46			0.30		3.71	2.89	1.98		17.12
Nov.							0.30		0.30	0.48		0.30	0.78	1.08		0.30	4.84	1.68	4.53	0.30	14.89
Dec.								0.30	2.16		0.60	8.29	2.76	0.30	1.00	1.08	6.50	3.28	5.87	1.48	33.62
Total	0.60	0.78	0.30	7.68	0.00	0.00	2.88	4.96	10.09	2.52	0.90	29.01	8.62	2.28	1.30	2.28	31.81	13.53	21.70	2.38	143.57

	NI	NII	NIII	NEI	NEII	NEIII	SEI	SEII	SEIII	SI	SII	SIII	A	B	C	D	E	F	G	H	TOTAL
1969																					
Jan.						4.74		5.92	2.53	0.30	9.75	4.58		2.53	0.30		4.53	5.00		1.51	41.69
Feb.			0.30			2.98		7.51	2.05	0.60	3.69	4.93		3.58	1.86	3.36	6.38	2.28		0.48	40.00
March					0.30	3.16		9.02	1.86		8.12	9.89		0.90	2.08	1.08	5.36	2.56		0.78	24.23
April			0.30	0.30		2.56		3.46	1.38	0.30	3.32	4.08		0.30	0.70	0.48	2.26	3.64		1.85	24.93
May			0.60		0.30	2.16		3.34	0.78		1.65	3.46		0.90		0.30	0.90	3.03		0.30	17.72
June	0.30	0.48	1.20			0.90		2.28	0.48		6.68	6.15	0.30	1.08	3.53	0.60	6.45	4.37		1.92	36.72
July			0.78		1.08	4.26		7.98	0.30	0.30	8.31	4.64	0.30	0.90	3.79		3.22	7.07		2.11	45.04
Aug.			0.60			4.59		7.60			6.54	4.47		1.20	6.10	0.70	2.75	1.08			35.63
Sept.			0.70		0.90	3.24		6.50			1.20	2.56		0.60	1.56	0.48	2.57	1.08			21.39
Oct.					0.60	2.03		5.74	0.90		1.98	0.95			0.60		0.60	0.60			14.00
Nov.	0.30			0.30		1.90		3.98	0.60		3.71	6.55			0.78		0.78	0.78		0.30	19.98
Dec.	0.30		0.30	0.30	0.30	9.00		4.88				1.64			1.18	0.30	3.80			0.30	22.30
1970																					
Jan.				0.60	0.30	0.90		3.38	1.75		1.60	6.50	0.30		0.48	0.30	2.53				18.64
Feb.					0.30	5.99		4.42	0.78		0.30	1.98	0.30		0.90		0.30				15.27
March						1.08		3.41	1.86		0.60	5.86			0.30	0.30				0.60	14.01
April			0.30		0.48	0.48		1.38			0.30	2.11			4.00		1.68			0.30	11.03
May						0.30		0.90				0.30			2.78		2.33				6.61
June						3.80		1.92	0.30		0.30	1.60			2.08		3.36				13.36
Total	0.90	0.48	5.08	1.50	4.56	54.07	0.00	83.62	15.57	1.50	58.05	72.25	1.20	11.99	33.02	7.90	49.80	31.49	0.00	10.45	443.43

TABLE V-3 CONTINUED

										STATION										
	NI	NII	NIII	NIV	NV	NEI	NEII	NEIII	NEIV	NEV	SEI	SEII	SEIII	SEIV	SEV	SI	SII	SIII	SIV	SV	TOTAL
1968																					
July	1.38			0.78		3.00	0.30					0.30	0.30								6.06
Aug.	4.75	2.33	1.08			4.54	1.68	1.08				0.60	0.78								16.84
Sept.	4.26	7.42	1.30	0.78	0.48	2.11	0.30									0.30			0.30		17.25
Oct.				1.26		1.26	2.08		0.30			0.60	0.60				0.48				6.58
Nov.	3.41	0.60	0.78	1.38	0.90	2.33	3.30				0.30		0.30								13.30
Dec.	1.34	2.08	4.23	1.20	5.56	0.60	4.01	2.08	0.78		0.30	2.20	2.56	0.30		0.30	0.30			0.30	28.14
Total	15.14	12.43	7.39	5.40	6.94	13.84	11.67	3.16	1.08	0.00	0.60	3.70	4.54	0.30	0.00	0.60	0.78	0.00	0.30	0.30	88.17

	NI	NII	NIII	NEI	NEII	NEIII	SEI	SEII	SEIII	SI	SII	SIII	A	B	C	D	E	F	G	H	
1969																					
Jan.	5.59	8.44	2.43	0.60	3.81	5.53	1.00	2.76	4.24	0.30	0.60	1.00	0.48	4.95		1.38		2.82		4.19	50.12
Feb.	3.16	1.98	4.72	2.16	1.26	0.78	2.08	1.08	1.38	0.30	1.20	0.30	0.60	4.81	0.30	0.90		3.85		3.76	34.62
March	3.67	5.51	3.26	1.60	3.24	0.78	0.30	3.19	1.68	0.48	1.56	1.20		0.30				3.94		5.08	35.79
April	4.18	1.38	6.34	3.20	1.56	0.30	0.60	0.30	0.48				1.20	2.53		0.60	0.30	0.30		1.90	25.17
May	1.86	3.84	5.53	2.58	1.56	0.30		0.30	0.30		0.30	1.68	3.84	1.81		0.30		0.60		2.40	27.20
June	6.45	5.72	8.25	5.24	5.25	2.89	1.38	0.30	2.16		1.18	1.51	4.80	3.19	1.38	0.30	1.70	2.60		5.35	59.65
July	6.93	0.90	7.91	4.74	4.44	0.30		0.78	0.30				4.07	1.30	0.30						31.97
Aug.	7.01	1.30	7.02	2.92	5.48	0.90		0.30			0.60	0.60		0.60							26.73
Sept.	6.39	5.70	5.21	8.67	1.60	0.30			0.30		1.00	0.30	0.30	0.90						3.32	33.99
Oct.	1.38	0.48	5.94	7.93	8.64	0.60					0.95	0.30		0.30				0.90		1.86	29.28
Nov.	1.78		3.00	7.22	0.90	1.78	0.90		2.11		0.48	2.05		0.30		0.60	0.30	4.21		4.26	29.89
Dec.	7.22	2.43	3.71	6.31	4.39	4.83	0.78	1.98			1.08	1.08		0.60	2.28	1.00	0.78	3.48		0.30	42.25
1970																					
Jan.	3.13	5.45	7.26	6.26	4.32		1.98	1.81	0.78	0.30	7.72	5.33	5.29	0.30	1.08	1.65	1.56	7.18		3.15	64.55
Feb.	7.20	4.73	9.18	8.62	8.65	3.02	0.30	1.45			3.70	1.56	1.68	1.38	2.35	2.40	0.78	6.43		5.63	69.06
March	5.89	9.50	8.45	11.27	7.10	1.08		0.60	0.30	0.60	2.76	5.64	10.48	5.24	1.56	1.81	0.30	4.41		5.30	82.29
April	7.64	5.02	4.85	6.99	8.16	1.30	1.20	1.95		0.78	1.20	2.46	1.26	3.38	1.53	1.60	0.90	1.51		3.61	55.34
May	6.06	5.17	6.38	6.07	8.62	4.40	0.30	1.08	0.30		0.90	0.30	0.90	0.95	2.78		0.78	3.55		1.38	49.92
June	1.92			4.02	8.24	4.98	0.30	4.56	2.28		1.20	4.40	0.90	0.30	3.64		6.21	1.38		7.25	51.58
Total	87.46	61.85	99.93	92.94	94.29	35.37	11.42	22.44	16.61	2.76	26.43	29.71	35.80	33.14	17.20	12.54	13.61	47.16	0.00	58.74	799.40

TABLE V-3 CONTINUED

										STATION											
	NI	NII	NIII	NIV	NV	NEI	NEII	NEIII	NEIV	NEV	SEI	SEII	SEIII	SEIV	SEV	SI	SII	SIII	SIV	SV	TOTAL
1968																					
July	2.64		1.08	3.41	11.50	3.64	3.46	3.97		0.30		1.26	6.52		0.48	0.70	3.04	0.30	0.30		42.60
Aug.	6.66	0.30	4.22	4.59	10.07	6.95	4.62	4.43	3.06		1.18	2.86	3.75	0.60		0.30	2.90	1.38	0.60		58.47
Sept.	4.72	0.95	1.26	3.46	8.82	4.83	2.13	6.79	0.30	0.60	1.56	1.81	0.48	0.78		0.90	1.38	0.90			41.67
Oct.	0.78		6.35	6.07	7.29	2.30	5.19	1.20	2.52	0.78	1.38	3.55	2.11			4.11	2.99		0.90		47.52
Nov.	2.33		2.00	8.07	7.66	2.16	7.78	0.30	1.78		4.78		2.42	0.30		0.60	3.36	1.20	0.60		45.34
Dec.	1.43	0.60	4.02	5.37	7.62	0.90	4.91	1.78	0.60	0.30	1.08	6.09	4.57	2.10	0.30	2.58	2.51	0.90	1.20		48.68
Total	18.56	1.85	18.93	30.97	52.96	20.78	28.09	18.47	8.26	1.98	9.98	15.57	19.85	3.78	0.78	9.19	16.18	4.68	3.60	0.00	284.46

	NI	NII	NIII	NEI	NEII	NEIII	SEI	SEII	SEIII	SI	SII	SIII	A	B	C	D	E	F	G	H	
1969																					
Jan.	3.58	1.56	4.05	1.51	3.61	5.87	3.10	5.16	5.26	0.30	2.68	1.20	0.30	1.56	0.48	0.60		3.67		2.38	46.87
Feb.	1.08	0.30	4.49	3.11	2.38	4.29	1.20	2.58	6.02	2.08	2.35	0.30	0.48	1.65	1.78	0.78	0.30	1.30		2.21	38.68
March	0.95		3.11	0.60	2.16	2.64	0.78	5.61	5.49	1.18	2.11	0.78		0.60	0.30	0.30	0.60	3.55		1.86	32.62
April	0.90		4.14	4.02	3.72	3.33	0.78	1.30	3.66	0.90	0.30	0.60	0.30		0.60	0.30	0.30	3.48		1.08	29.71
May		0.30	4.21	1.30	1.98	2.75	1.20	0.48	0.60		0.78		0.78	0.90	2.05			2.33		0.60	20.26
June	0.30	0.90	3.08	1.08	0.30	1.56	1.92	0.90	1.68		1.38	1.20	1.60	0.30	0.90	0.30		2.00		1.56	20.96
July	1.73	0.90	1.48	1.68	1.56	2.28		0.48	1.38	0.30	3.17	0.60	0.60	0.78	1.26			4.00		0.30	22.50
Aug.	0.30	0.48	1.86	0.30	1.38	3.08		0.78	0.30		4.24	0.60			1.56	0.70		3.10		0.30	18.98
Sept.	0.60		1.26	1.56	2.40	1.80	0.60	0.78	0.30		3.03			0.60	1.38			3.58		0.30	18.19
Oct.			0.60	0.78	1.20	2.15	0.90	1.08			3.22	0.48			0.30	0.48		3.24		0.30	14.73
Nov.			1.51	0.30		0.90	1.26	1.08	1.38		2.68	0.48						3.33		0.78	13.70
Dec:	0.30		0.30	0.78	0.30	4.36		1.08							1.30	0.90	0.30	3.11		0.90	13.63
1970																					
Jan.		0.30	1.20	0.30	0.30		0.30	1.08	0.30		4.14	1.86	0.30		0.30	0.60	0.60	5.46		0.78	17.82
Feb.			1.81	2.38	1.08	3.96		2.33	0.48		2.69				1.08	0.30		3.11		0.30	19.52
March	1.18	2.46	2.70	5.98	1.68	0.30		2.51	1.86		4.43	2.89	1.98		1.78	1.78	0.30	4.94		1.00	37.77
April	0.30	0.30	1.30	2.95	1.51	0.48	0.60	0.90			1.60	1.08	0.60	0.30	2.50	0.30	0.90	4.36	0.30	1.15	21.43
May	0.30	0.60	1.98	1.98	2.86	0.60		0.30		0.30	2.51		0.30		2.05			5.46		0.30	19.54
June	0.48			0.78	1.56	3.27		1.00	1.00		1.38	0.90			2.32	0.90	2.46	2.56	0.48	2.03	21.12
Total	12.00	8.10	39.08	31.39	29.98	43.62	12.64	29.43	29.71	5.06	42.69	12.97	7.24	6.69	21.94	8.24	5.76	62.58	0.78	18.13	428.03

TABLE V-3 CONTINUED

	STATION																				TOTAL
	NI	NII	NIII	NIV	NV	NEI	NEII	NEIII	NEIV	NEV	SEI	SEII	SEIII	SEIV	SEV	SI	SII	SIII	SIV	SV	
1968																					
July	10.07	1.78	6.87	7.58		8.56	4.93	6.81	1.08		0.60	5.90	9.39		0.85	0.78	8.29	7.17	0.30		80.96
Aug.	11.42	7.76	8.22	9.63	1.78	10.64	7.41	9.35	5.13		0.30	10.12	6.91	1.00			10.11	10.11	1.68		111.57
Sept.	12.36	4.41	5.97	7.44	6.08	11.06	7.13	7.30	0.30	1.34	2.38	6.98	1.26	2.43		1.68	5.74	3.73	0.60		88.19
Oct.	4.35	1.68	10.53	11.16	1.60	6.62	10.54	3.35	4.16		1.68	7.59	3.40			1.56	8.22	4.35	0.30		81.09
Nov.	8.40	0.30	7.08	12.80		5.22	12.28	0.30	4.13	0.30	6.08	1.00	6.57	2.68		0.90	9.04	2.71	0.60		80.39
Dec.	2.71	1.51	5.86	6.77	4.07	2.33	5.98	3.46	2.89		2.94	9.77	8.70	2.49	0.30	3.81	6.72	4.02	1.08	0.90	76.31
Total	49.31	17.44	44.53	55.38	13.53	44.43	48.27	30.57	17.69	1.64	13.98	41.36	36.23	8.60	1.15	8.73	48.12	32.09	4.56	0.90	518.51

	NI	NII	NIII	NEI	NEII	NEIII	SEI	SEII	SEIII	SI	SII	SIII	A	B	C	D	E	F	G	H	
1969																					
Jan.	8.28	8.07	7.11	4.38	8.86	10.63	9.27	8.65	11.68	2.94	10.32	3.91	2.38	7.38	0.60	4.04	2.21	11.47	1.08	7.08	130.34
Feb.	8.45	3.35	10.54	7.50	8.85	7.69	3.80	8.51	8.66	8.92	9.22	4.81	1.15	10.03	2.96	3.76	3.15	10.57	0.30	10.39	132.61
March	7.32	7.25	9.05	4.97	9.03	9.64	7.58	12.60	7.46	6.67	9.70	6.64	1.62	2.60	3.06	3.46	3.83	11.79	1.56	7.07	132.90
April	8.29	1.73	9.79	9.15	10.46	11.32	7.73	7.55	8.35	3.08	4.68	3.29	5.21	8.72	1.00	0.60	6.46	8.60	1.38	6.65	124.04
May	8.96	7.57	9.75	9.67	11.62	9.34	9.42	6.61	4.21	2.08	5.05	6.98	6.40	8.85	6.53	0.60	4.06	8.99	3.97	6.48	137.14
June	13.39	9.78	11.31	12.27	11.74	8.83	5.75	8.91	9.47	2.88	6.20	9.29	10.48	9.46	6.59	1.45	6.67	7.99	1.20	7.59	161.25
July	10.01	7.69	10.64	9.81	11.25	9.66		10.52	6.42		11.38	6.75	11.95	8.29	5.33	0.30	3.11	13.79		6.59	143.49
Aug.	12.18	4.81	13.18	6.55	11.30	11.74		8.57	3.86		10.92	7.00	6.11	5.72	3.74	1.08	2.80	11.82		7.67	129.03
Sept.	10.36	1.38	13.12	8.31	10.17	9.29	0.90	8.42	2.02		5.47	4.69	4.50	3.78	4.69	0.30	2.83	11.76		4.55	106.54
Oct.	5.21	3.91	11.37	7.61	5.87	5.55		6.53	0.30	0.30	10.12	1.98	1.73	2.00	0.30	1.68	1.48	9.06		3.18	78.18
Nov.	3.33		8.17	8.56	2.98	5.84	0.70	1.08	3.13	3.45	9.27	5.16	0.30	1.68		1.75	1.08	11.42	2.33	6.42	76.65
Dec.	7.72	2.46	10.21	9.36	6.88	9.71	2.83	5.26	0.90	1.65	5.72	1.81	1.08	0.60	1.98	0.90	2.94	11.23		4.42	87.66
1970																					
Jan.	6.05	6.68	12.60	7.42	6.39		3.99	3.36	5.50	6.67	15.83	8.81	4.26	0.70		1.95	1.38	16.30		5.74	113.63
Feb.	9.48	5.17	13.18	12.11	12.08	8.79	0.78	6.05	2.19		14.33	5.17	4.95	4.92	6.08	3.20	1.08	13.61		13.98	137.15
March	8.35	7.50	13.90	13.54	12.60	2.03	3.94	8.23	7.98	5.02	14.65	10.73	10.32	4.89	1.30	4.30	1.92	11.81	1.08	12.87	156.96
April	10.17	4.91	10.47	14.43	12.39	7.84	5.59	6.45	4.09	2.60	10.25	5.82	3.29	4.84	6.39	2.83	4.34	13.23	0.30	11.43	141.66
May	8.84	12.92	20.94	11.60	12.44	9.52	0.95	4.79	5.44		10.77	2.16	4.63	2.76	6.86	0.30	1.38	13.52		6.11	135.93
June	5.64			10.12	11.71	13.03	2.18	12.77	11.44		8.72	12.12	3.14	1.86	9.66	1.45	12.57	10.81	0.90	13.15	141.27
Total	152.03	95.18	195.33	167.36	176.62	150.45	65.41	134.86	103.10	46.26	172.60	107.12	83.50	89.08	67.07	33.95	63.29	207.77	14.10	141.37	2266.45

TABLE V-3 CONTINUED

	STATION																				
	NI	NII	NIII	NIV	NV	NEI	NEII	NEIII	NEIV	NEV	SEI	SEII	SEIII	SEIV	SEV	SI	SII	SIII	SIV	SV	TOTAL
1968																					
July	5.54	0.30	5.51	7.03	0.30	6.23	6.18	7.89	0.78		0.78	5.70	13.97	0.78	0.78	0.30	7.23	6.66	0.78	0.60	77.34
Aug.	10.66	0.30	6.04	5.61	0.90	9.48	7.58	7.80	3.28	0.78	0.78	7.43	10.49	3.67	0.90	1.38	6.47	4.49	2.70	1.20	91.94
Sept.	9.64	7.10	4.40	3.69		10.76	5.23	7.10	0.60	2.35	1.38	8.39	3.47	6.82	0.30	3.00	2.87	5.82	3.73	0.30	86.95
Oct.	0.30			3.11			4.08	2.86	4.03	0.30	0.30	8.22	6.40			0.30	4.95	5.06	3.58		43.49
Nov.			0.30	2.76			9.36	0.30	1.98	0.95	2.65	0.85	8.48	3.41			3.92	2.64	1.98	0.48	40.06
Dec.				2.76	0.30		2.15	1.88	1.51	0.30		10.99	7.12	2.68	1.00	0.60	1.08	1.08	2.16	1.68	37.29
Total	26.14	7.70	16.25	24.96	1.50	26.47	34.58	27.83	12.18	4.68	5.89	41.58	49.93	17.36	2.98	5.58	26.52	25.75	14.93	4.26	377.07

	NI	NII	NIII	NEI	NEII	NEIII	SEI	SEII	SEIII	SI	SII	SIII	A	B	C	D	E	F	G	H	
1969																					
Jan.	0.30		0.60	0.30	4.07	8.34	1.52	9.28	12.02		4.75	3.65	1.08	4.65	0.30	3.18	2.00	6.59		1.86	64.49
Feb.		0.30	2.11		1.56	5.84		7.07	8.34	0.30	4.38	4.23	0.95	4.45	1.30	3.58	3.06	7.71		1.98	57.16
March			1.08		1.95	1.56	0.60	11.65	8.24	0.30	4.43	6.92			0.30	0.90	1.81	8.16		0.60	48.50
April			1.08	0.30	3.56	5.04	0.30	3.13	6.98	1.38	1.78	3.60		1.85		1.04	0.90	5.49		0.30	36.73
May	0.30		0.60	1.26	3.20	4.77	0.60	3.64	2.53	0.90	4.52	6.41	1.20	1.60	4.94	0.30	0.48	7.46		2.64	47.35
June	3.11	0.60	6.02	2.68	7.38	5.46	3.51	8.35	11.74	0.90	9.22	12.86	9.12	5.60	7.77	2.46	7.41	10.48		8.37	123.04
July	2.48	0.30	4.04	2.33	10.92	11.49		13.06	6.14	0.30		8.03	7.84	3.53	6.64	0.30	5.70	0.90		4.49	88.49
Aug.	1.56		7.62	0.60	10.79	13.03	0.30	8.98	0.30		5.57	7.66	5.29	3.37	6.96	0.30	3.99			3.05	79.37
Sept.	2.56		7.47	4.62	10.37	10.10	0.90	7.95			4.08	3.77	3.11	2.16	5.31	1.32	4.13	8.38			76.23
Oct.	2.83	2.28	7.41	8.20	11.26	5.43	2.21	6.43	1.00	0.30	9.71	4.43	2.68	0.90	2.46	3.73	3.64	7.83		4.17	86.90
Nov.	1.78		2.63	6.35	1.51	5.85	1.86	4.49	10.48		9.40	10.89		0.30	0.48	3.00	2.33	11.64		11.54	84.53
Dec.	4.37	0.48	3.78	5.27	5.96	12.72	0.78	5.45	1.08		3.03	1.95	0.90	1.00	4.68	4.68	4.71	9.77		3.03	73.64
1970																					
Jan.	0.30		4.08	2.26	2.26	0.60		4.20	3.95	0.30	12.29	9.40	3.82		2.35	3.35	3.11	12.81		2.49	67.57
Feb.	1.51		3.00	4.10	6.51	5.74		4.24	0.90		7.58	2.64		1.20	4.19	3.18	0.30	7.22		7.60	59.91
March		0.30	5.22	5.43	9.37	0.60		4.15	2.56		10.08	9.47	7.01	2.62	2.36	4.67	1.56	7.34		6.59	79.33
April	2.11		1.68	3.36	7.00	1.51	0.30	3.59	0.60		5.46	5.45		0.60	6.01	1.68	1.08	6.03		5.39	51.85
May	3.24	0.30	12.50	6.36	5.35	1.56		3.47	1.38		7.41	0.90	1.60	0.90	5.07		3.92	12.42		3.28	69.66
June	3.62			6.15	9.68	10.71	0.90	12.45	7.58	11.00	11.78	11.41	3.81	1.56	9.34	1.49	14.38	12.17	0.30	12.20	129.53
Total	30.07	4.56	70.92	59.57	112.70	110.35	13.78	121.58	85.82	4.68	115.47	113.67	48.41	36.29	70.46	39.16	64.51	142.40	0.30	79.58	1324.28

TABLE V-3 CONTINUED

	STATION																				
	NI	NII	NIII	NIV	NV	NEI	NEII	NEIII	NEIV	NEV	SEI	SEII	SEIII	SEIV	SEV	SI	SII	SIII	SIV	SV	TOTAL
1968																					
July					0.30		0.48	1.26					0.70		0.60	0.90					4.24
Aug.				0.30			1.08	0.30				0.30	2.47				0.90				5.35
Sept.						0.60	0.90	0.48			0.60		0.90						0.30		3.78
Oct.							1.18					0.90	0.78					0.30		0.60	3.76
Nov.							1.26				0.78		0.90	0.30			0.60			0.30	4.14
Dec.													0.78				0.60	0.30	0.48	0.48	2.64
Total	0.00	0.00	0.00	0.30	0.30	0.60	4.90	2.04	0.00	0.00	1.38	1.20	6.53	0.30	0.60	0.90	2.10	0.60	0.78	1.38	23.91

	NI	NII	NIII	NEI	NEII	NEIII	SEI	SEII	SEIII	SI	SII	SIII	A	B	C	D	E	F	G	H	
1969																					
Jan.						0.30	0.90	3.43	4.71		0.70	1.20	1.60	0.70	0.30	10.83	0.30	4.93			29.90
Feb.								1.81	0.78		1.48		2.28	0.30	1.00	8.85		5.78			22.28
March						0.48	0.78	2.16			1.08	1.78	2.80		0.30	9.35		6.25			24.98
April			1.08		0.70	0.30	0.90	1.20	2.30			1.95	1.81	0.30		2.51		2.64			15.69
May								0.78	2.08		0.30	0.60			0.30	3.98		1.88		0.90	10.82
June							0.30		0.95		0.30	0.48	0.60	0.48		6.41	0.30	3.98			13.80
July								1.68	0.48			0.70	0.78	0.48	0.48	3.15	0.30	2.90			10.95
Aug.				0.30		1.08			3.38		0.30	0.30	0.30			8.73		3.83			18.22
Sept.		0.30	0.95	1.08				3.11	0.48			0.78		0.48		8.10		3.53			18.81
Oct.		0.30			0.30	0.30		1.38	1.68		1.08		1.38			11.88	0.90	2.98			22.18
Nov.						0.48		1.92	1.75		1.20	1.85				8.62		7.37		0.48	23.67
Dec.					0.30	2.16		2.41	0.60				0.90		1.60	6.98		4.23			19.18
1970																					
Jan.						1.00		2.05			0.30	0.85	0.48			4.93	0.60	5.98			16.19
Feb.					0.30	0.60		1.68	0.78							5.02	0.30	2.89			11.57
March				0.30	0.30	0.85		0,78	1.38		1.56	1.45	3.98	0.60		3.94		4.38			19.52
April						0.60		0.48	0.30		0.48	0.78				2.20		2.79			7.63
May			1.30										4.00			0.60	0.30	5.79			11.99
June	1.38					1.30		3.08			1.08	0.60				4.44		4.96		0.30	17.14
Total	1.38	0.60	3.33	1.68	1.90	9.45	2.88	27.95	20.87	0.00	9.86	14.10	20.91	3.34	3.98	110.52	3.00	77.09	0.00	1.68	314.52

TABLE V-3 CONTINUED

	STATION																				
	NI	NII	NIII	NIV	NV	NEI	NEII	NEIII	NEIV	NEV	SEI	SEII	SEIII	SEIV	SEV	SI	SII	SIII	SIV	SV	TOTAL
1968																					
July				4.59				1.51				1.98	2.08	0.60			2.46	2.84	0.48	0.48	17.02
Aug.			0.30	5.89			0.48	1.78				5.75	1.45	0.90			4.98	2.48		0.78	24.79
Sept.			0.60	6.35		5.33	8.68	1.68	1.00	1.98		8.22	3.61	2.23		0.30	8.69	3.83		0.60	53.10
Oct.								0.48				4.76	2.55					1.98			9.77
Nov.							0.30	2.00	3.79	0.30		0.30	0.78	2.33	0.48			5.05	0.30	0.60	16.23
Dec.									3.16	0.30		8.09	2.78	0.78		0.30		5.47	0.90	0.60	22.38
Total	0.00	0.00	0.90	16.83	0.00	5.33	9.46	7.45	7.95	2.58	0.00	29.10	13.25	6.84	0.48	0.60	16.13	21.65	1.68	3.06	143.29

	NI	NII	NIII	NEI	NEII	NEIII	SEI	SEII	SEIII	SI	SII	SIII	A	B	C	D	E	F	G	H	
1969																					
Jan.						1.38		5.97	6.29		0.78	5.11			0.78	0.60	2.28			0.60	23.79
Feb.						0.60		3.78	3.46		0.60	4.19			1.20	2.35	4.36				20.54
March								3.24	1.98		3.80	6.67		0.78	2.08	0.90	6.76	0.30			26.51
April						0.30		2.35	3.36		1.08	1.51		0.30	0.30	0.60	1.86				11.66
May								2.64	3.36		1.08	0.85			5.36		0.60			0.48	14.37
June								1.38	2.25		0.90	1.81			3.23		1.86				11.43
July								0.78	0.90			0.60			1.20					0.30	3.78
Aug.						2.08						0.90				0.30	1.98				5.26
Sept.						0.90		2.20	0.78						1.08		2.12				7.08
Oct.		0.30				6.11						1.56			2.90	0.90	3.18	0.30			15.25
Nov.								7.05	8.52					1.86	0.30		3.32				21.05
Dec.						6.37		5.99	0.95			5.30			3.95	0.30	4.86			2.38	30.10
1970																					
Jan.			0.30			2.81		5.74	3.21			7.30			3.44	0.60	2.96				26.36
Feb.						3.54		5.94	5.48			4.32			6.48	1.68	1.38				28.82
March.						0.30		3.75	3.88			6.41			1.51	1.00	0.70				17.55
April						0.78		2.43	0.60		1.08	0.90			2.08	0.78					8.65
May											0.78				2.81		3.94				7.53
June						0.90		1.20	2.20			0.30			5.43	0.78					10.81
Total	0.00	0.30	0.30	0.00	0.00	26.07	0.00	54.44	38.70	0.00	10.10	56.25	0.00	2.94	44.13	10.79	42.16	0.60	0.00	3.76	290.54

Catch is higher than average

Catch is lower than average

VI ZOOPLANKTON *

GENERAL STATEMENT

The major thrust of this study has been to acquire detailed information on the species composition and biomass of zooplankton seasonally in South Biscayne Bay and subsequently in Card Sound, since there are no quantitative data extant for either of these localities. In the first case, some degree of thermal addition had already begun, and more was expected; in the second case, thermal addition appeared imminent but had yet to occur. There was a need to obtain a good estimate of the existing zooplankton community structure prior to the addition of thermal effluent. Additionally, some attention was paid to the possibilities of assessing the effects of the Power Plant over short periods using these environmentally collected, preserved samples. A secondary area of study involved an evaluation of the problems concerned with determining effects of entrainment through the Power Plant on particular organisms.

The research goals have changed during the course of the program because of modifications in plans for discharging the heated water, because less profitable avenues are dropped and more profitable ones developed, and because some projected operations proved to be logistically impractical. In order to preserve a sense of continuity, therefore, the "Results and Discussion" section is presented chronologically, to better relate the various phases of the study and demonstrate the direction in which future work might be planned.

METHODS

South Biscayne Bay

Seasonal Survey of Zooplankton: Five surface stations (Figure I-2) were sampled approximately twice each month from November, 1968, to November, 1969. Station 1 was near the head of the outflow canal, just downstream from the outfall of the plant itself. Since passage of water through the plant requires only a few minutes, station 1 received water which was recently removed from the sea adjacent to the intake canal. Station 2 was in the bay, 200 yards east of the opening of the outflow canal. Station 3 was immediately offshore from the Point. These three stations are collectively referred to as the "inshore" stations.

Station 4 was located on the eastern side of the buoy at the eastern end of Pelican Shoal, about 1 1/2 miles east of Turkey Point with a water depth of 6 feet. Station 5 was three miles east of Turkey Point at the Intracoastal Waterway in 8 feet of water. These two stations are together referred to as the "midbay" stations.

Plankton samples were collected using two nets. The first was a macroplankton net of mesh-opening size of 300 μ and mouth diameter of 1/2m (20 inches), and the second was a microplankton net of mesh-opening size of 35 μ and mouth diameter of 30 cm (12 inches). A small flowmeter was suspended in the mouth of each net. Samples were preserved in 5% buffered formalin. Temperature, salinity, and dissolved oxygen concentration were also measured at each station.

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* M. Reeve and E. Cosper

Summer Plankton Synoptic Distribution: On June 16, 1970, a sequential series of samples were taken over 2.5 hours using two boats which covered 42 stations beginning north of Turkey Point near the intake canal and ending south of the Point in the vicinity of the mouth of the cooling canal. The siting of stations was governed by the locations of existing buoys, which precluded any regular grid pattern. For speed, samples (comprised of single tows using a 1/2 meter 64μ-mesh net) were dry weighed. On this occasion very small amounts of detritus were present, and any samples estimated visually to contain more than 10% detritus were not weighed. The dry weights (in mg/m^3) derived, therefore, refer substantially to living zooplankton.

Summer Plankton Sequential Distribution: Plankton samples were collected approximately every two weeks from June to October, 1970, north of Turkey Point immediately outside the intake canal and south of the Point just offshore of the mouth of the outflow canal in the thermal plume. At each station 4 tows were usually made using both 64 and 200μ-mesh 1/2-meter nets.

Entrainment Studies

Acartia tonsa in the Laboratory: Plankton were collected with the aid of a 300μ-mesh net from the Rosenstiel School of Marine and Atmospheric Sciences dock between March, 1970, and January, 1971. Approximately 100 copepods were transferred by pipette into each of several glass tubes which were 30 cm long and contained 250 ml of 1.2μ-filtered seawater at ambient temperature. Apart from the ambient controls, 2 tubes were placed in each of several water baths at temperatures between 32 and 37°C (±0.05) for periods up to 6 hours, after which time they were returned to an ambient water bath. The following morning animals in each tube were recovered by filtering through gauze and rinsing into a tray, where total numbers and numbers dead were counted with the aid of a microscope.

Incubation Experiments: One minute shore tows were made within 15 minutes of each other at the Turkey Point power plant intake and outfall using a 200 and 64μmesh net. The samples were gently transferred into plastic insulated 3-gal. containers filled with water from the same location. Since there were no facilities for dealing with these samples at Turkey Point they were returned to the laboratories at the School of Marine and Atmospheric Science some 35 miles away. Three hours from the time the outfall samples were collected they were allowed to cool down to the temperature of the intake samples, and all the samples were transferred to 4-liter separatory funnels. Any material which settled to the bottom was drawn off. This contained detritus, dead animals and a few live animals which were replaced. The rest was preserved. After 24 hours the process was repeated and the remaining live animals were also collected and preserved.

Card Sound

Seasonal Survey of Zooplankton: The sampling program was started in November, 1970, and consists of occupying four stations every 2 weeks. Past experience indicated that several tows on each of fewer stations would reduce variability due to errors of random sampling and micro-patchiness. Three sequential quantitative samples were, therefore, taken by each method described below on each of four stations. These were at stations 0404, 0604, 0804 and 0606. From the station located off the mouth of the canal, the other three radiated one mile along the shoreline northerly and southerly and across the Sound.

Two 1/2 m mouth diameter nets are used having 200 and 64μ mesh openings. The 200μ mesh has been adopted as the dividing line between "macro and micro" plankton. This is also practical in that the 200μ mesh retains quantitatively the adults of the major copepod species (except Oithona). The 64μ mesh clogs less readily than 35μ nets used previously and so provides more reliable flow meter readings. For the smallest micro-zooplankton, whole water samples (24 liters) were sieved through 20μ cloth. Between these three meshes, it is assumed that all stages of all organisms are quantitatively recovered. This supposition was checked by using both larger and smaller meshed nets from time to time. Aliquots of the net samples were immediately frozen over dry ice for subsequent dry weight, carbon, and nitrogen analysis, and the rest preserved in formalin. Samples for pigment analysis were also taken. All 64μ samples were passed through a 200μ net in the laboratory to remove macroplankton.

Synoptic Survey: On January 6, 35 stations were sampled in Card Sound by making a single tow on each with a 64μ net. The standard 1/2-mile grid system of buoys were used starting at the northeast and working down to the southwest end of Card Sound.

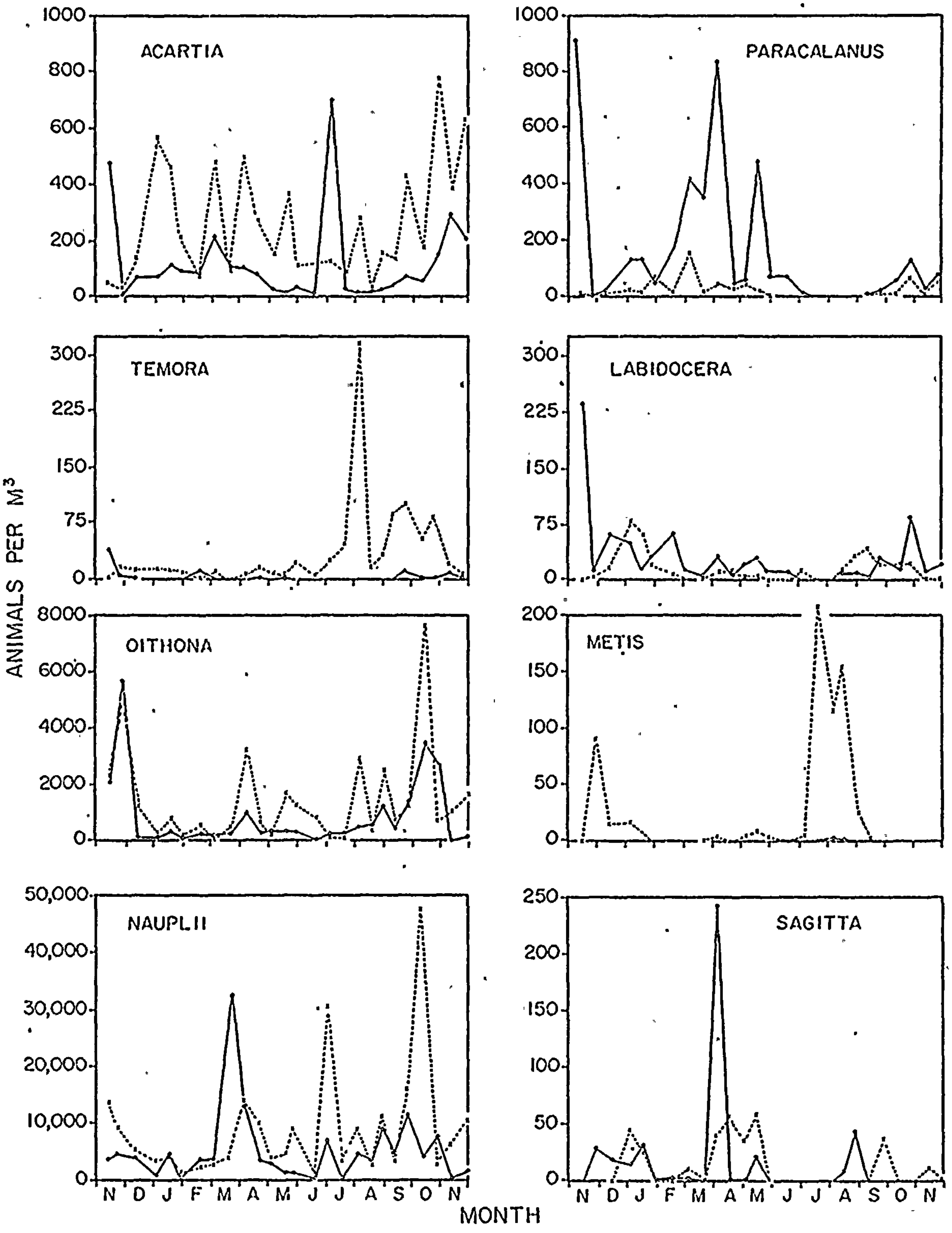
Vertical Survey: In order to sample at a point below the surface, a net was modified by attaching a thin cane pole across the mouth ring to project about 8 ft. in one direction. In the water the buoyancy of the pole caused it to project vertically upwards from the net when the latter was weighted. By marking clearly one-foot intervals along the pole, the towing speed could be adjusted so that the net fished at a specified depth, which was chosen to be five ft. Over most of the tow, this was maintained to within ±1 ft.

RESULTS AND DISCUSSION

South Biscayne Bay

Seasonal Survey of Zooplankton: Preliminary results of one year of zooplankton sampling around Turkey Point were included in their raw form in the previous annual report. The data were subsequently worked up in detail and presented in a paper (Reeve, 1970).

In summary, the seasonal variation in zooplankton from five stations in South Biscayne Bay (Figure I-2) were analyzed and the data condensed into two groups, inshore and midbay. The inshore stations (1, 2, and 3) were characterized by generally lower and more variable salinity and higher temperature compared to the midbay (4 and 5). Two nets were used with mesh sizes of 35 and 300μ to cover as wide a range of organisms as possible. The quantitatively important copepods were confined to six genera, which were dominated by a single species. These were Acartia tonsa, Paracalanus parvus, Temora turbinata, Labidocera scotti, Oithona nana and Metis jousseaumei. The seasonal fluctuations in number are given for each (Figure VI-1) which could be related to temperature and salinity. Paracalanus and Labidocera, for instance, disappeared during the height of the summer. Since numbers provide a poor basis for comparison of variously-sized species, dry-weight estimates were obtained which emphasized that the numerically dominant but diminutive Oithona had a biomass in the same order of magnitude as the numerically unimportant but many times larger Labidocera (Figure VI-2 and VI-3). The inshore



GURE VI-1 Seasonal variation of holoplankton in numbers per m^3 inshore (crosses and broken lines) and in midbay (circles and unbroken lines), in South Biscayne Bay, 1968-69

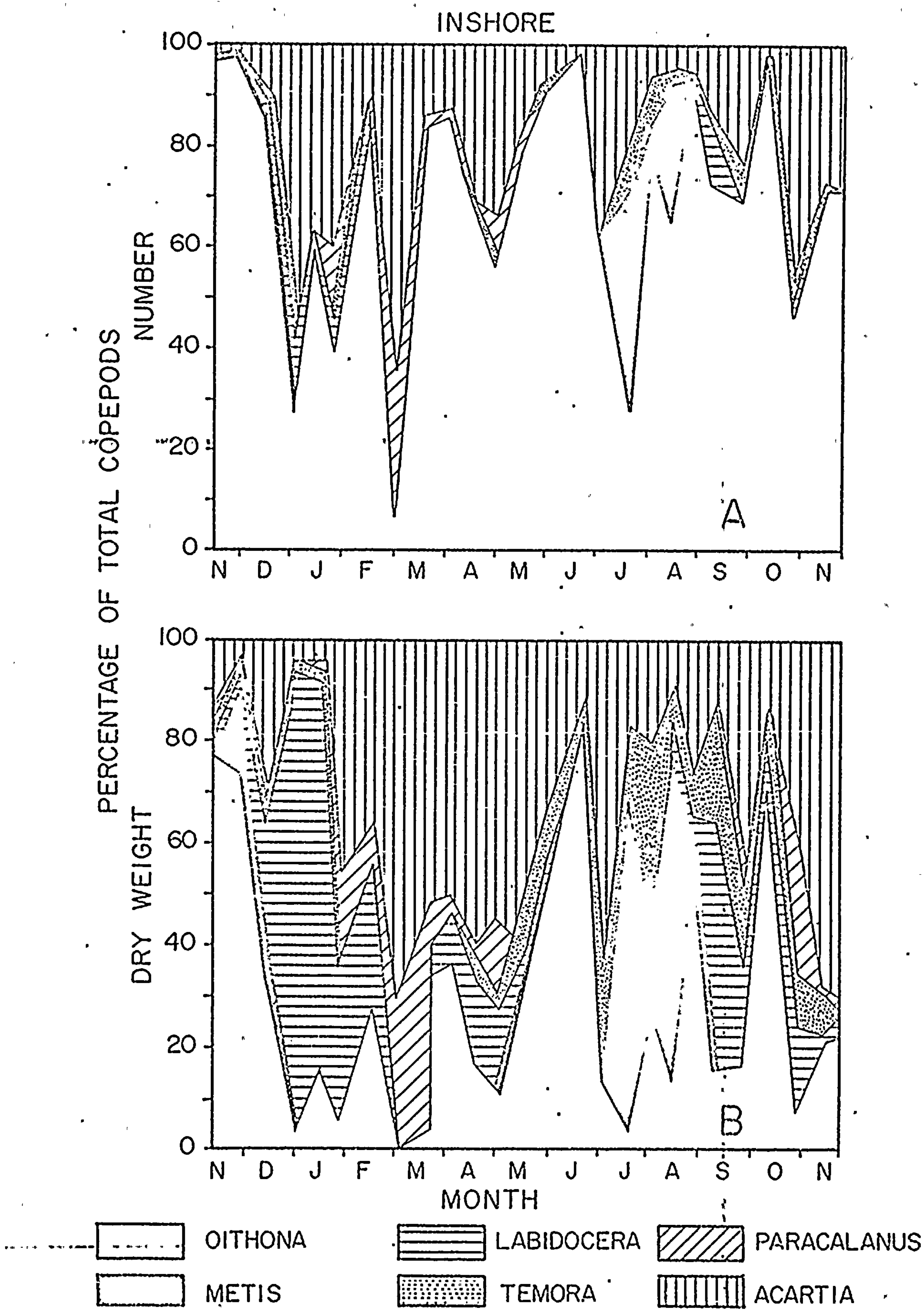


FIGURE VI-2 A, Percentages of numbers; and B, percentages of dry weight contributed to the total by the constituent species of copepods inshore in South Biscayne Bay, 1968-69

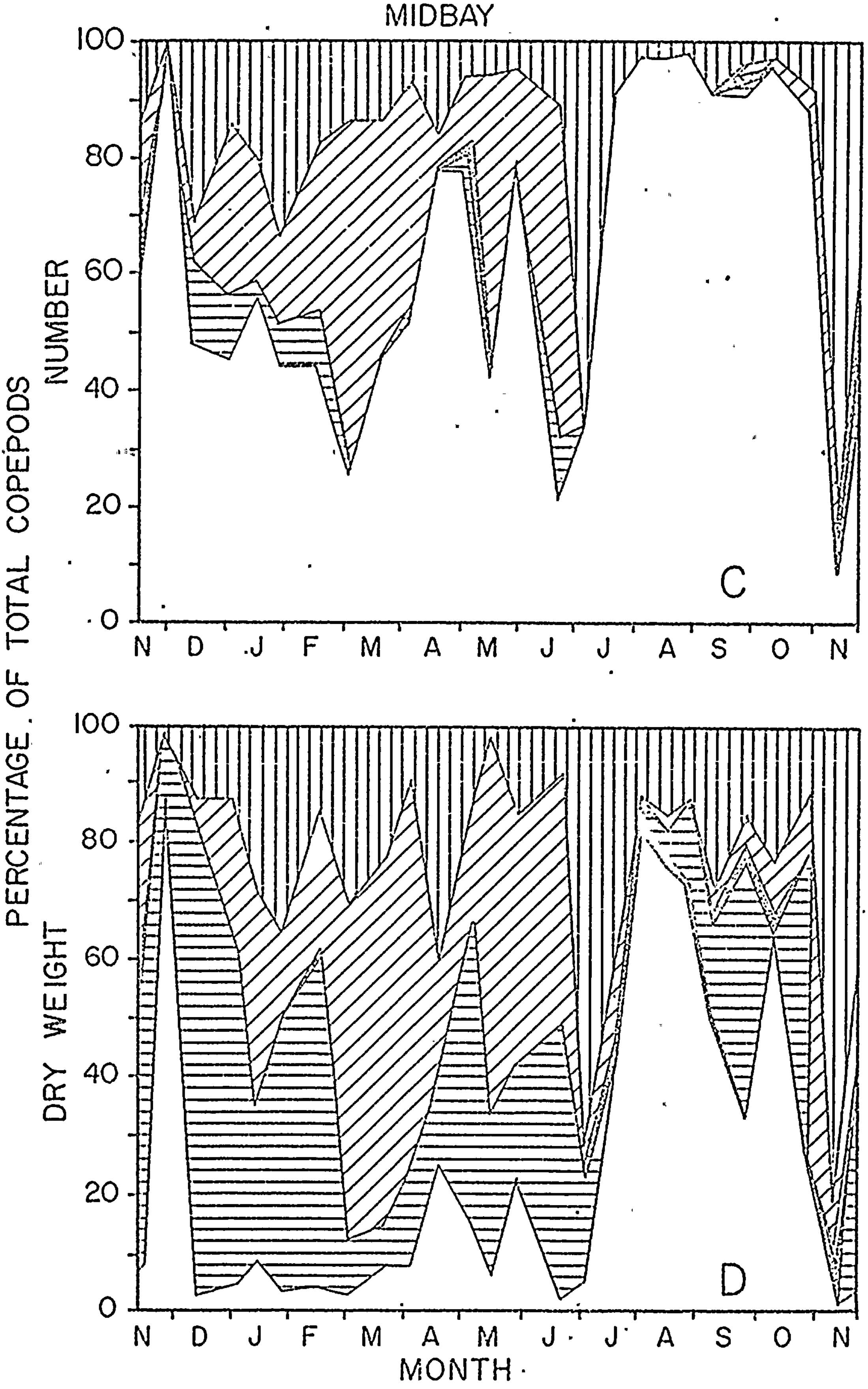


FIGURE VI-3 A, Percentages of numbers; and B, percentages of dry weight contributed to the total by the constituent species of copepods in midbay (For key, see Fig. 2) in South Biscayne Bay, 1968-69

population of copepods was dominated largely by Acartia and Oithona with a substantial contribution by Labidocera in the winter. Small amounts of Metis and Temora, mostly confined to the summer and inshore, alleviated a summer low in copepod biomass which was much more marked in midbay where Paracalanus and Labidocera dominated.

The suggestion of summer minimum, and a major autumnal burst in biomass of copepods at both locations (Figure VI-4) agreed with phenomena reported by previous workers, and reinforced several years of personal observations in this region.

Both the mean naupliar count and copepod dry weights were similar over the year inshore and in the midbay. The major meroplanktonic components (Figure VI-5) were decapod larvae, molluscan veliger larvae, and the larvae of polychaetous annelids. All were more abundant inshore, partly due to the concentrating effect of the shallower water column. The decapod larvae, especially, were very reduced in number during the summer.

This study provided useful information on the distribution of zooplankton in South Biscayne Bay. It indicated that biological fluctuations could be rapid and extreme and that gross physical characteristics of the environment varied widely.

In an attempt to use this survey to distinguish any Power Plant effects, the average number of organisms at the outfall (station 1) was compared with those at the end of the canal (station 2) over 16 summer (1969) sample dates (Table VI-1). It was assumed that some of the organisms damaged by passage through the Plant would die en route down the outflow canal and sink out of the range of the surface nets at the end of the canal. In some cases, (copepod nauplii, Metis, Oithona, gastropod and polychaete larvae) there was some evidence of reduced numbers at station 2, in some cases there was no clear trend, and the decapods showed the reverse pattern. Presumably, the decapods have been added from the mangroves fringing the canal, but this could also have happened in any of the other groups, which could lead to underestimations of any effects in terms of thermal kills.

The results are also inconclusive because nothing is known of the prior physiological condition of subsequently preserved animals at station 2, some of which might have subsequently died. For a detailed account of this study, the reader is referred to Reeve (1970).

The inherent natural variability of physical parameters, the patchiness of plankton, the poor reliability of single samples as a measure of true population levels, year-to-year variation and rapid life cycles of tropical environments all minimize the likelihood of detecting any effects of disturbances such as that produced by artificially heated water by analysis of preserved environmental samples. This tentative conclusion based on the limited sampling program above was examined more closely during the following summer (1970) when any effects might be expected to be at their most extreme.

TABLE VI-1

DIFFERENCES BETWEEN NUMBERS AVERAGED OVER THE SUMMER FOR SPECIFIED ORGANISMS AT THE OUTFALL (STATION 1) AND IN THE BAY AT THE CANAL'S EXIT (STATION 2)

	OUTFALL (No/m^3)	BAY (No/m^3)	NUMBERS IN BAY AS A PERCENTAGE OF OUTFALL
Acartia	219	215	98
Temora	46	46	100
Metis	67	33	49
Oithona	2470	1198	44
Nauplii	20,400	7670	38
Sagitta	8	7	88
Decapod crab larvae	8	68	850
Shrimp larvae	11	20	182
Gastropod veligers	5570	3520	63
Bivalve veligers	4170	4470	107
Polychaete larvae	490	330	68

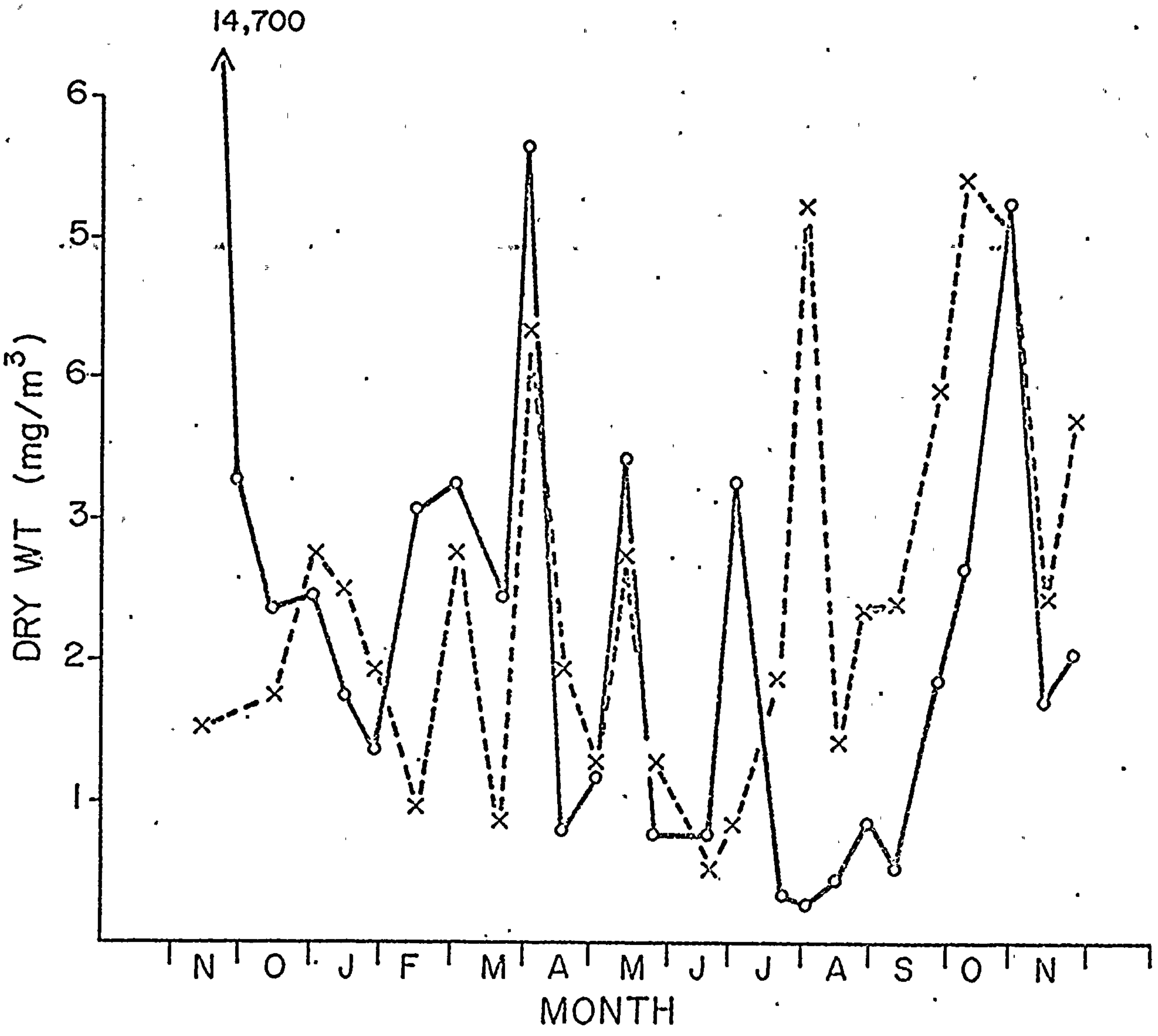


FIGURE VI-4 Seasonal variation in total dry weight of adult copepods inshore (crosses and broken lines) and midbay in South Biscayne Bay, 1968-69

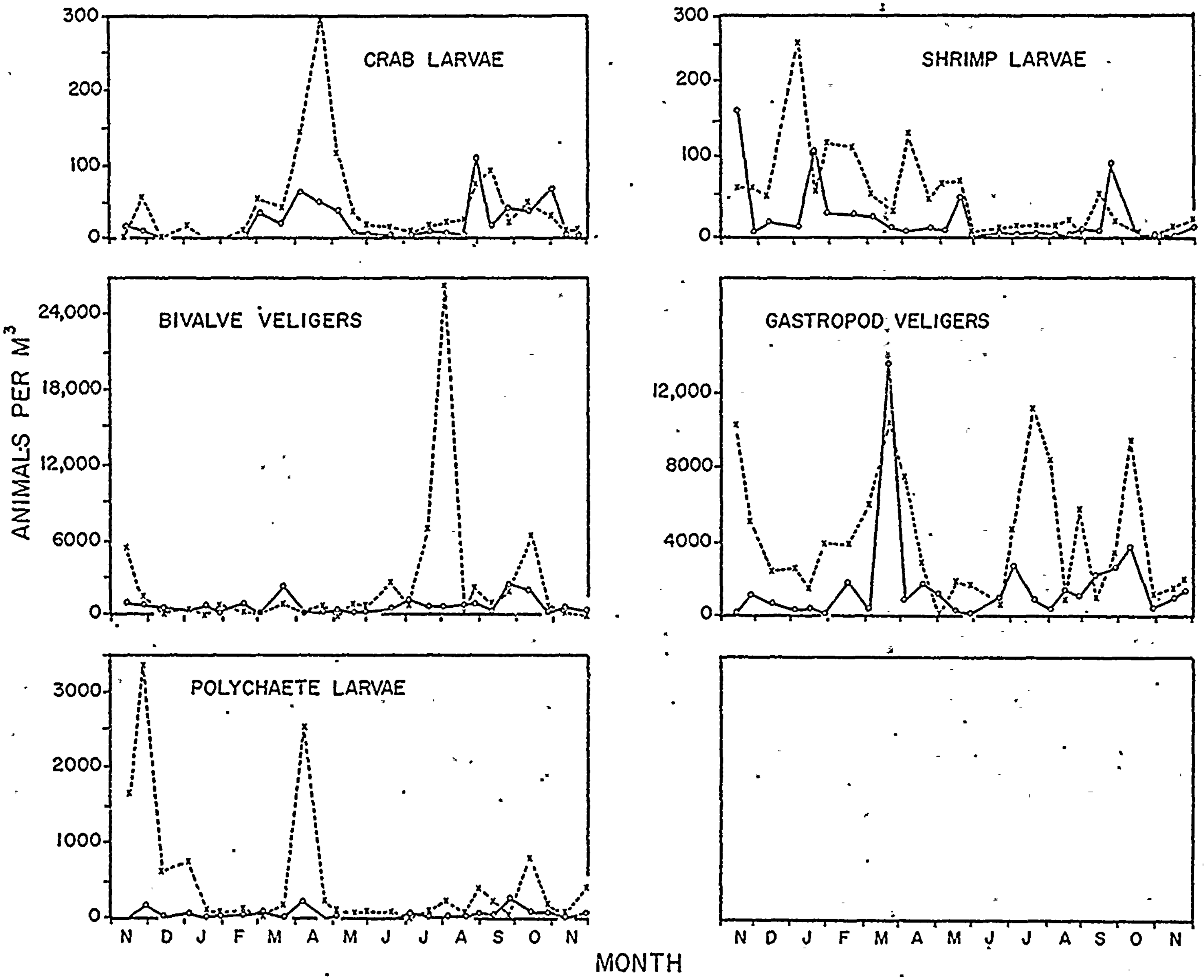


FIGURE VI-5 Seasonal variation of meroplankton inshore (crosses with broken lines) and midbay in South Biscayne Bay, 1968-69

Synoptic Distribution: The dry weight of particulate material at each station is indicated in Figure VI-6 except when the detrital content was estimated to exceed 10%. Contours have also been drawn on the basis of biomass ranges namely less than 10, 10 to 20, 20 to 50 mg/m^3. These indicate that the distribution was not random on this occasion in the area but subject to considerable patchiness. Nearly half of the total stations lie in the intermediate 20 to 50 mg range, and are both north and south of Turkey Point. A denser patch occurs in the immediate vicinity of the intake canal, while south of the Point biomass density diminishes progressively towards the shore. As determined by simultaneous temperature measurements, (and elsewhere in this report) the thermal plume followed a course the northern boundary of which approximates the 20 mg contour, i.e., the low density regions were outside the plume and at temperatures similar to those north of the Point. The plankton densities in the plume were lower than those in the immediate vicinity of the intake, but this appears to be a patch of very limited size and not characteristic of the area in general. There is evidence (based on the study where sampling was limited to two sites in order to reduce the volume of material to be analyzed but replicated over the summer) that the rich patch was fortuitous.

Summer Plankton Sequential Distribution: The total number of zooplankton in each net is shown in Figure VI-7. Where three or more replicate samples were taken, confidence intervals were established for their averaged values by first transforming the data to logarithms on the basis of which 95% confidence intervals were calculated, this was done for 11 of the 16 pairs. In none of these cases were the means found to be significantly different. In four of the other five pairs, it is obvious that their closeness is such that the same conclusion would apply. On the basis of this series, then, there were no discernable effects attributable to Power Plant operation. The results, however, are of considerable further interest in this connection from two points of view.

First, the smoothness of the curves which extend over four months is remarkable when compared with the erratic frequent peaks of the seasonal study above. This is, no doubt, partly due to the fact that multiple samples on one station tended to reduce variability due to random sampling and patchiness of the order of the length of the tow track. It might also suggest that the normal seasonal pattern of rapid fluctuation resulting from the interplay of a variety of variable parameters (food, salinity, temperature, etc.) is being overshadowed by a single dominating effect over the summer. The obvious correlating factor would be sustained temperatures above 30°C. If this single dominating factor is accepted, the second point becomes very significant. This is the shape of the curves indicating low plankton numbers sustained beyond two-week intervals and as low or lower than any other low points throughout the year. This sustained summer minimum may be compared with the seasonal survey extending over the previous summer as reflected in total copepod dry weight (Figure VI-4) where in the midbay a summer minimum covered five sampling dates between July and September. An inshore summer minimum was in evidence also but was broken by one sample in August caused by a burst of cyclopoids and harpacticoids. For further details see Reeve (1970) in which it was noted that a low point in zooplankton numbers was also seen by Smith et al (1950), Woodmansee (1958) and Reeve (1964) in other parts of the Bay. Further comparison is possible for the following months with data for Card Sound (Figure VI-12) which will be discussed below.

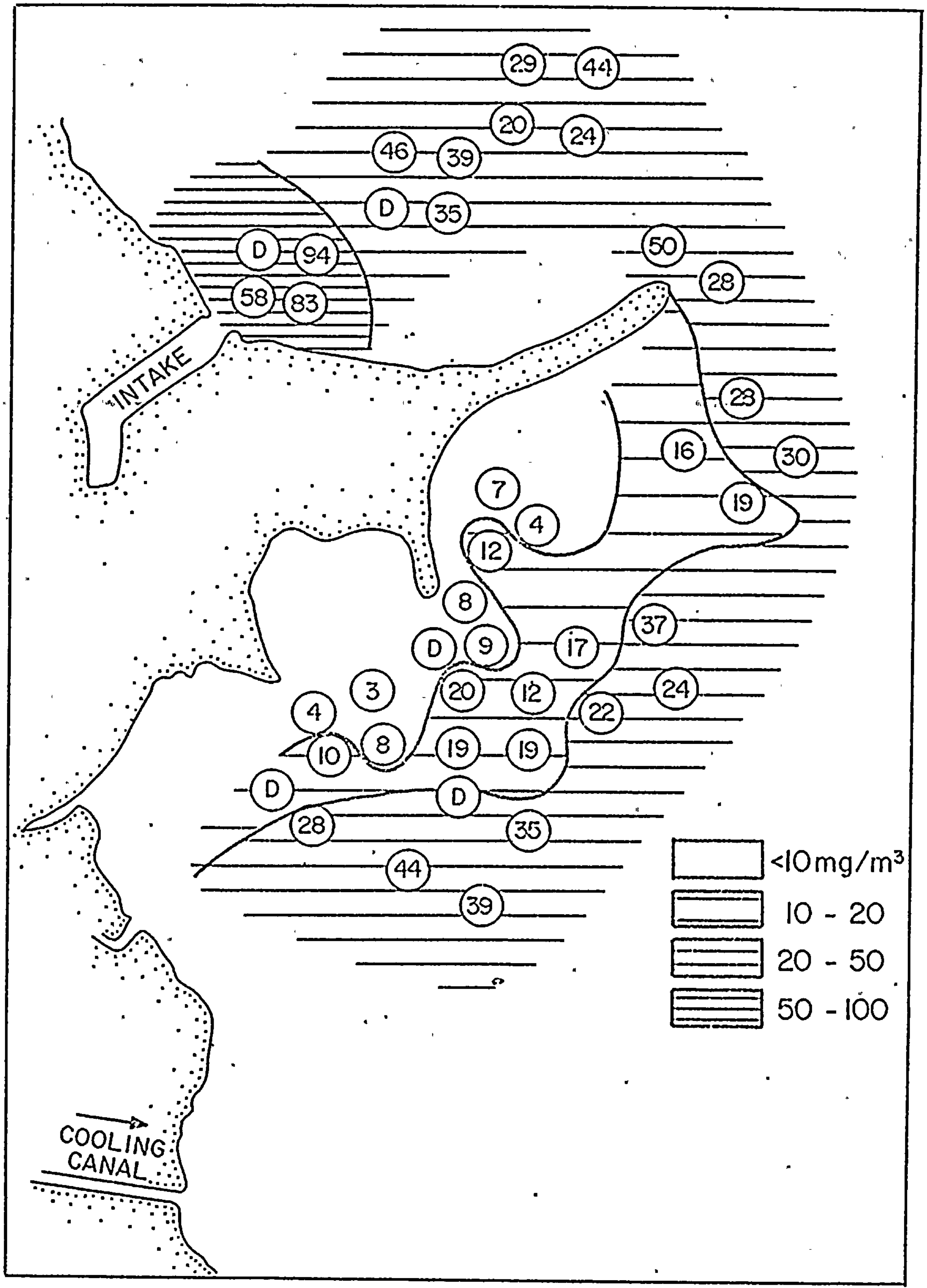


FIGURE VI-6 Particulate dry weight at stations in the vicinity of Turkey Point using a 64μ net. "D" indicates presence of over 10% detritus

The earlier conclusion that environmental sampling to detect current Power Plant effects does not work appears to hold, especially in the summer. Natural environmental changes, themselves possibly temperature effects, extend over at least one order of magnitude and apply throughout the region tending to swamp any effects of lesser magnitude over a very localized area. This situation is probably no different throughout the rest of the year when fluctuations, though less extreme, are more frequent because natural low-level stability gives way to rapid fluctuation (e.g. Figure VI-12). This approach would have possibilities only if there was greater long-term stability and/or a larger heat input. These will be discussed in connection with Card Sound below.

Entrainment Studies

Concurrently with the work described above, limited preliminary attempts were made during 1970 to obtain more direct assessments of the effects of temperature on zooplankton. The best documented study was that described in a paper presented to the FAO Technical Conference on Marine Pollution in Rome (Reeve and Cosper, 1970).

Acartia tonsa in the Laboratory: A. tonsa was chosen as the test organism because it shared with Oithona dominance of the copepods around Turkey Point (Figure VI-8) and being much larger than the latter was easier to work with. As a species ubiquitous along the coast of the entire eastern seaboard (and elsewhere) physiological responses of this southern population may be compared to those at other latitudes.

The experimental series continuing over one year was designed to assay the acute effects of elevated temperatures in a regime similar to that imposed by the Power Plant.

The dates of the experiments and ambient water temperatures are recorded in Figure VI-8, A.-, which graphs the results of each experiment in terms of percentage survival (taking control survival as 100%) at each temperature for periods up to six hours. Experiment A took place at the end of the winter when ambient temperatures had been below 21°C for several months. Shock temperatures above 32°C produced over 50% mortality within three hours. By April 6, the bay water had warmed rapdily and the population appeared to have acclimated, yielding higher experimental survival rates than before. The bay water stabilized in this temperature range for over two months, during which period further acclimation occurred, except at 37°C. By the middle of July, when summer temperatures had been reached, acclimation had proceeded to the point where no more than 25% mortality occurred over six hours at 36°C. There was, however, still no acclimation at 37°C. This temperature, therefore, appears to be beyond the limit of tolerance of Acartia tonsa over three hours whatever the season. At the beginning of October, there had been little change in either ambient temperature or acclimation ability. Rapid environmental cooling reduced the ambient temperature to 22°C by December resulting in the previous winter acclimation pattern. By late January, only a slight further reduction of acclimation was detectable.

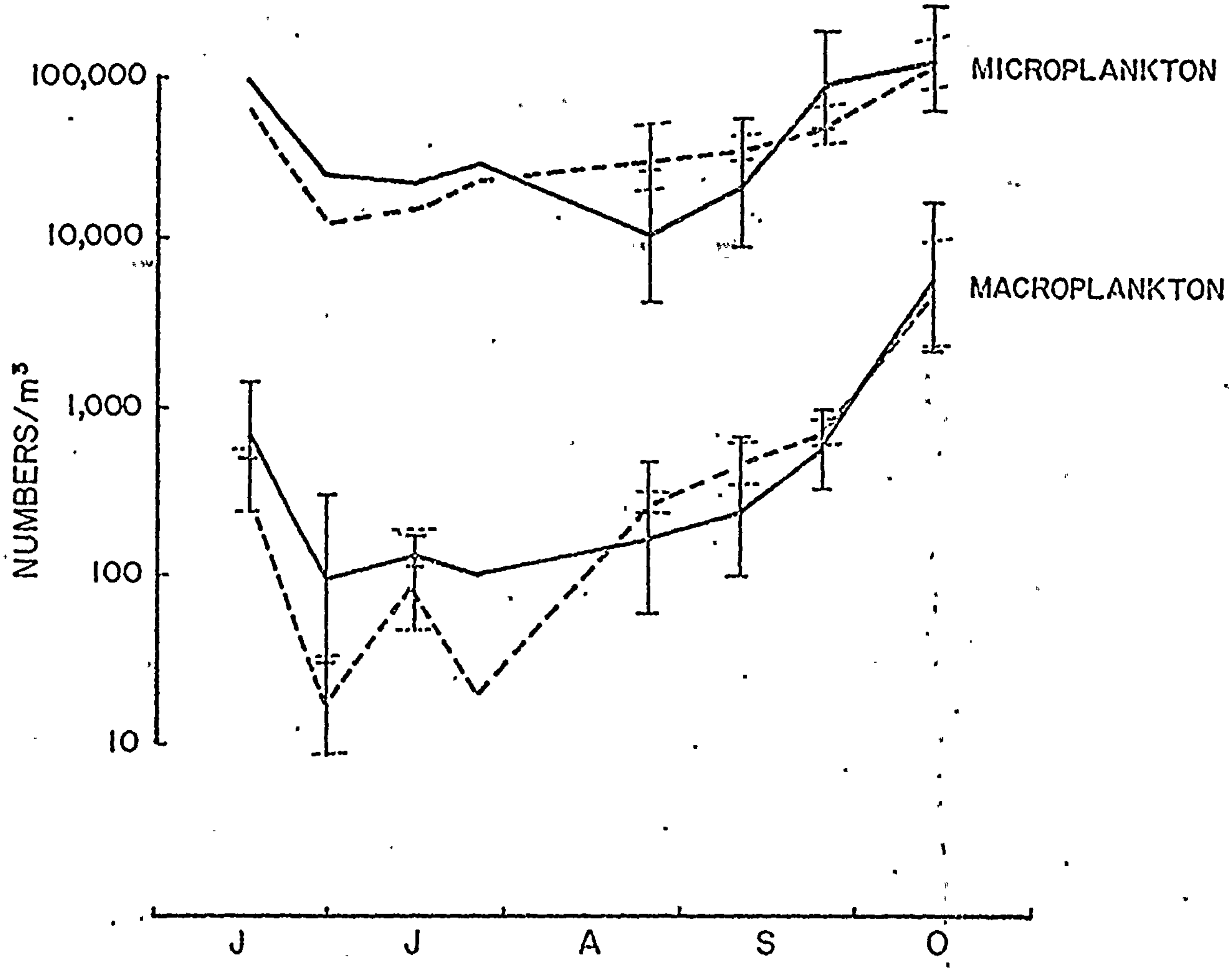


FIGURE VI-7 Numbers of macro and microplankton north (continuous line) and south (dashed line) of Turkey Point over the summer, 1970. Vertical bars indicate 95% confidence intervals of mean

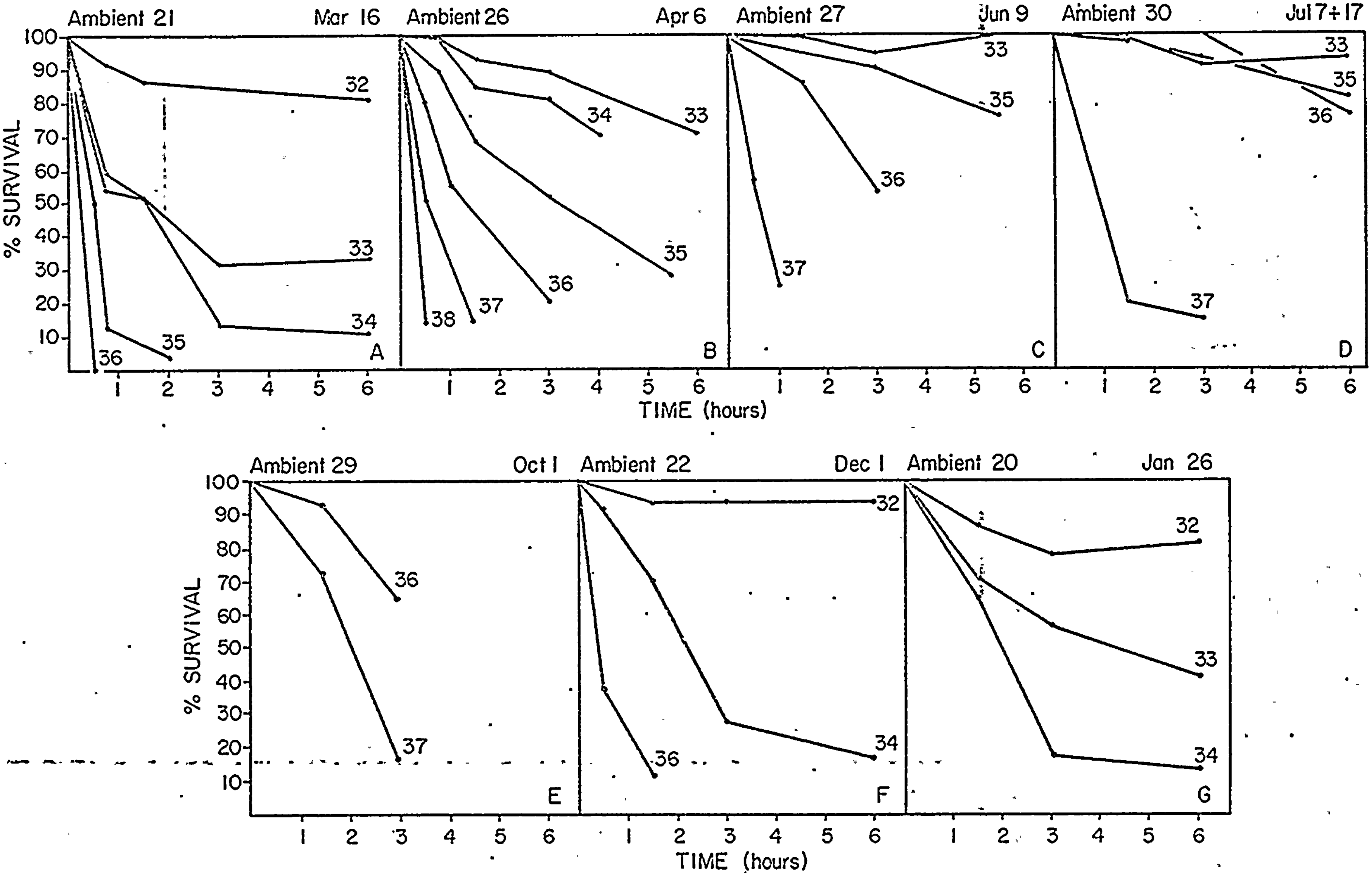


FIGURE VI-8 The percentage survival of populations of *Acartia tonsa* held at elevated temperatures for up to 6 hours

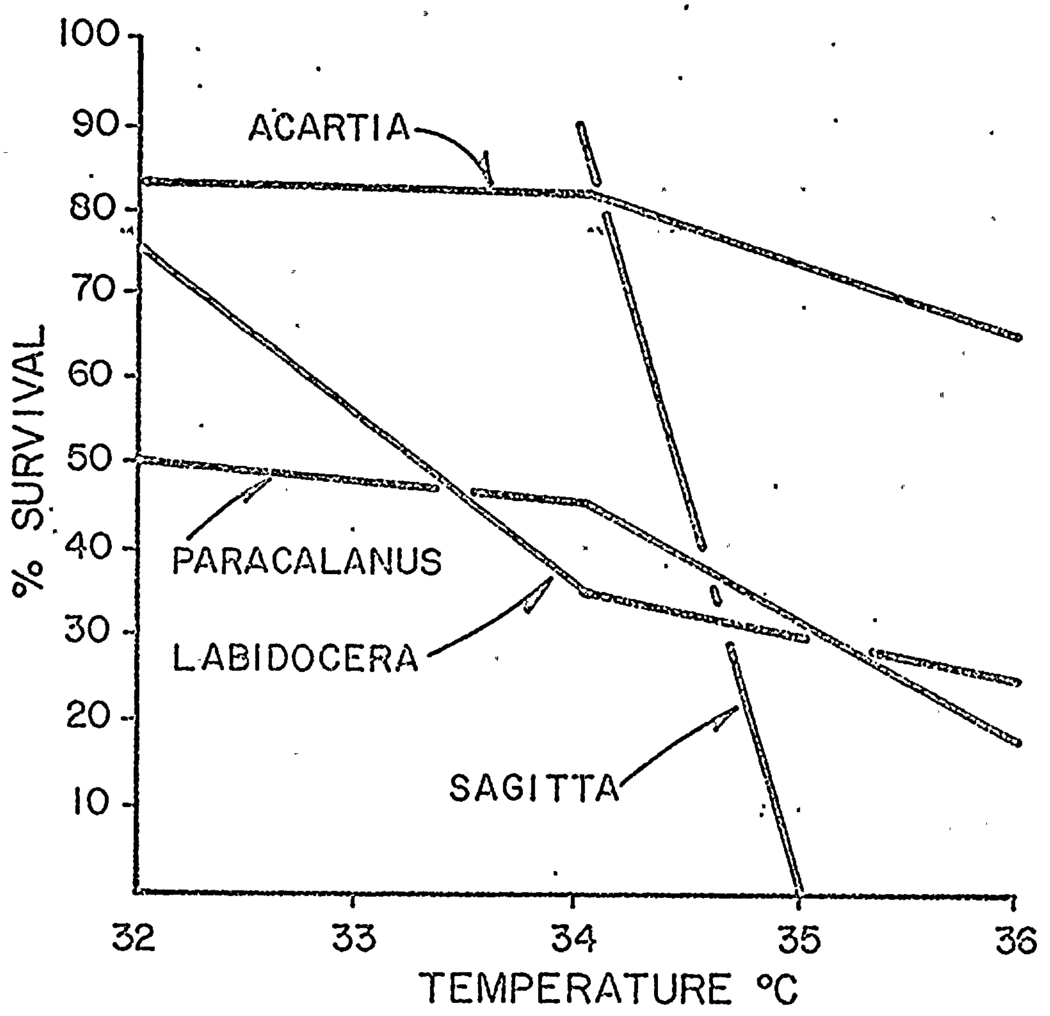
The paper discussed the applicability of the experimental regime to the actual conditions of the Power Plant, as well as problems of control mortality, criteria of death and the possibility that the derived mortality rates for any temperature were conservative. Under conditions of temperature stress, other stress factors not considered here might assume importance such as mechanical effects of entrainment, and low salinity which tends to occur during the summer. More important than this, perhaps, in underestimating the adverse effects of any specific temperature, is the acute death criterion. Some portion of the population might suffer death beyond the period designated, and it is almost inevitable that a specific thermal shock would produce a train of lesser effects in those which did not suffer rapid death.

During the early summer of 1970 a few tests were also run on other species. No attempt was made to continue these systematically throughout the year. This preliminary data is interesting in that it suggests that within the range of tested temperatures, although some degree of mortality occurs in each species, the form of response is variable, and that within this group at least, Acartia tonsa has a higher than average thermal tolerance. The lesser tolerance of the other two copepods (Paracalanus and Labidocera) and Sagitta correlate very well with the fact that they are totally absent from samples over varying periods during the summer (Figure VI-9).

Of interest also is the temperature range over which death occurs. In the case of Sagitta the temperature spread between 100% and zero survival is much narrower. This may be nothing more than an effect of dying rate rather than lower population variability. A dying chaetognath appears to lose control over its internal hydrostatic balance within seconds becoming opaque and shrivelled even before it has sunk to the bottom of the container. There are no intermediate stages which would require an interval of 24 hours to detect such as seen in Acartia tonsa.

Tests performed on groups likely to contain several species, such as "nauplii" and "decapod" larvae, produce more erratic results depending, one assumes, on the exact species composition at the time of the test.

Incubation Experiments: The above experiments were laboratory exercises. A more satisfactory experiment, in theory, would utilize the Power Plant itself by attempting to directly assess mortalities of organisms which had actually passed through it. Such a procedure, in practice, poses many problems. Ideally, organisms would be withdrawn from the intake canal and the end of the cooling canal, and the relative proportion of live and dead determined. However during passage down the cooling canal, some organisms may be added from the mangroves which had not passed through the Plant, and any dead might have sunk down out of the range of the collecting nets. To avoid these possibilities, plankton may be collected immediately following passage through the Plant at the head of the cooling canal. Since they would then avoid passage down the canal during which they would be exposed to several hours of continued elevated temperatures, they must be maintained in some kind of incubation experiment designed to simulate that condition.



URE VI-9 The percentage survival of four zooplankton species at specified temperatures above ambient (26°C) for three hours

The maintenance of marine zooplankton is not a routine laboratory procedure. There are very few organisms that have been successfully kept over a period of days and even fewer which have been maintained in a breeding culture. The act of catching itself introduces a serious possibility for damage. The attempted maintenance of a mixed sample in which there may be active carnivores also obviously introduces a second problem. The most difficult problem, and the one which probably accounts for most of the mortality seen in (control) samples which have not passed through the Plant is that of "water quality".

Experience makes it clear that in experimental procedures involving biological systems at ambient temperatures in the upper twenties and above, situations are highly sensitive to even the slightest modification, including removal and isolation from the original system. A better understanding of the factors working to stabilize the natural system may be the most important requirement in laboratory studies of tropical environments. These problems are evident in two experiments performed towards the end of the summer, 1970, when temperatures at the outfall were 36.8 and 34.5°C respectively.

The data from these two incubation experiments appear in Tables VI-1 and VI-2. On the first date, the intake (control) mortality was very high after 24 hours (38 and 77% for the macro and microplankton, respectively), which would obviously cast doubt on the experiment as a whole. On the assumption that overcrowding might have contributed to this, the samples of the second date were set up at a much lower density. In this case, control mortalities were reduced to 20 and 18%. Although some entrainment mortality was evident in the macroplankton, this did not manifest itself in the microplankton. Since control mortalities are still substantial compared with any effect in the entrained plankton, the only certain conclusion can be that more study is required to refine such incubation-type tests to the point where control mortalities are reduced below 10% over 24 hours, and then to extend the capability over longer periods (i.e. 48 or 96 hours). Only in this way would relatively small effects in the range of 10 to 30% be adequately demonstrable.

Other possibilities for direct examination of entrainment effects were considered. One of these was in the use of dyes which could be applied to a sample in the hope of differentiating living and dead organisms. After subsequent preservation of the whole sample, it might then be left for later examination whenever convenient. Methylene blue stains dead organisms, but living animals convert it to a colorless form. Experience showed that dying animals were less efficient at this; and so, grades of staining resulted which had to be arbitrarily divided into the two categories. Neutral red, on the other hand, stained only the living animals and resulted in less intermediates. It was also found to resist fading over several weeks after animals were preserved in formalin. Of course, application of dyes to samples withdrawn from the outfall or end of the canal suffered all the objections detailed above. The only real advantage in the use of dyes would be in the incubation studies if it was not convenient to analyze the ratio of living and dead directly immediately following the incubation period.

An alternative to laboratory incubation would be the confinement of a sample caught at the outfall in a floating container which was allowed to drift down the cooling canal. The advantage of this would be in reproducing exactly the time/temperature regime of the outflow canal. Capture and small container problems

TABLE -2

TURKEY POINT INCUBATION EXPERIMENT
SEPTEMBER 22, 1970

	Intake	Outfall
Temp.	30°C	36.8°
Salinity	38.4°/oo	37.1°/oo

	COPEPODS			LARVAL TYPES				
200uNet	Calanoid	Harpacticoid	Cyclopoid	Veliger	Decapod	Larvacea	Polychaete	Chaetognatha
Intake								
% Total Catch	18	4	1	75	0.5	0.5	0.3	0.7
% Dead								
3 hours	36	33	78	5	31	100	0	28
24 hours	60	60	84	30	31	100	41	32
Outfall								
% Total Catch	26	3	2	67	1	0.1	0.1	0.6
% Dead								
3 hours	50	50	96	12	63	100	0	89
24 hours	74	71	97	47	85	100	20	97

GRAND TOTAL % DEAD AT 24 HOURS: Intake 38
Outfall 57

TABLE VI-2 CONT.

TURKEY POINT INCUBATION EXPERIMENT
SEPTEMBER 22, 1970

64μNet	Nauplii	Copepodites	Cyclopoids	LARVAE Veliger	 Polychaete
Intake % Total Catch	8	2	5	81	2
% Dead 3 hours	82	22	3	53	21
24 hours	87	47	14	80	52
Outfall % Total Catch	9	2	4	84	2
% Dead 3 hours	88	53	78	69	70
24 hours	95	73	83	94	86

GRAND TOTAL % DEAD AT 24 HOURS: Intake 77
Outfall 93

would still exist, organisms would still have to be held at ambient temperature for some hours after passage down the canal, and the time involved in monitoring their passage would have to be taken into account.

Card Sound

In October 1970, when all the above-described studies had been performed, it appeared that a new outfall canal might terminate in Card Sound. Since there were no detected zooplankton changes in the Turkey Point region, studies were discontinued and started in Card Sound where the main aim has been to accumulate good environmental zooplankton data.

Since this study is only six months old in terms of data collection, it must be appreciated that much of the data has yet to be worked up. The results that are presented below, therefore, provide an indication of the scope of the study rather than any final, or even provisional, analysis of it.

Seasonal Survey of Zooplankton: Three levels of progressively detailed analysis of these samples might be undertaken. The most detailed, size/frequency distributions for each species, is out of the question because of the time involved and the taxonomic problems associated with most larvae. A few of the more significant contributors to the total biomass will hopefully be treated in this manner. A start is being made by measuring the size/frequency distribution of *Sagitta hispida* because the information can be combined with accumulating data on its growth rate and fecundity from laboratory studies to estimate its production in Card Sound. At an intermediate level of analysis, selected groups and species which constitute the bulk of the biomass in each sample are being counted. These categories are largely those used in the South Biscayne Bay studies cited earlier. The average counts for these are graphed (Figures VI-10 and VI-11) for the six months from November, 1970, to April, 1971, inclusive. Since a year of data has not yet been collected, and no statistical analyses have yet been made, it is premature to go into any extensive discussion at this stage. Suffice it to say that the plankton composition in Card Sound, with *Paracalanus parvus* dominating the larger copepods, and substantial numbers of *Labidocera* and the chaetognath *Sagitta hispida* more closely resembles the midbay rather than Turkey Point South Biscayne Bay fauna. This could be predicted simply on the basis of the high salinities and low temperatures.

On a gross level, estimates of total biomass are being sought. The great problem here, which has traditionally plagued planktonologists, is an easy rapid method of distinguishing detritus from zooplankton. Visual examination and counting achieves this, but totalized counts provide only a relative comparison and depend on a constant counts/biomass ratio. The consistency of this ratio may be a reasonable assumption, especially if, as in Figure VI-12, two size fractions are recognized and are mutually exclusive. With enough measurements, an average counts/biomass ratio could be derived to convert the data into dry weight values as was attempted for copepods in Figure VI-4. Figure VI-12 does at least demonstrate that, as noted for South Biscayne Bay, seasonal fluctuations can be large and rapid, but compared to summer events (for Turkey Point) are usually neither so long-sustained or of as great magnitude.

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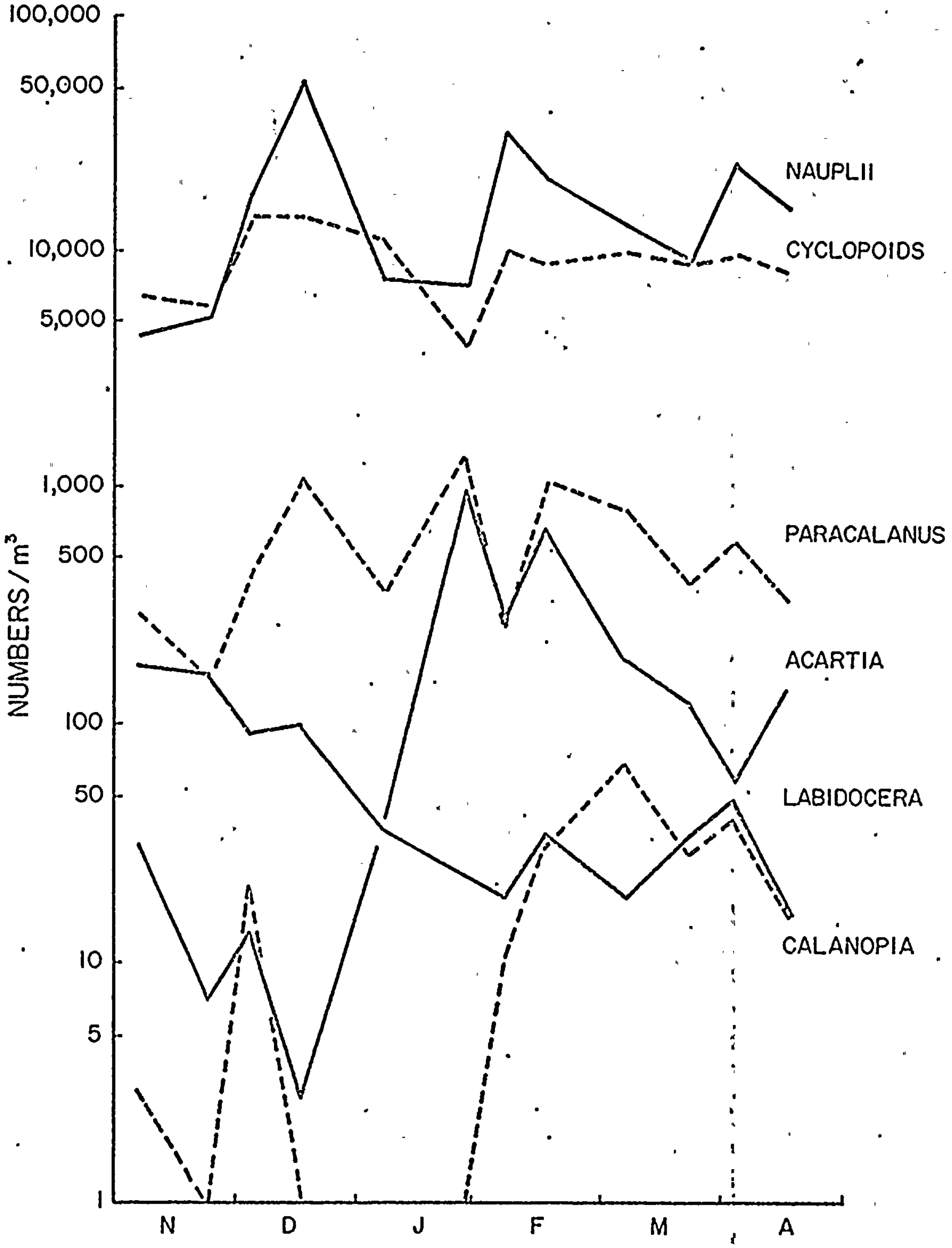

FIGURE VI-10 Seasonal variation of specified zooplankton organisms averaged for Card Sound stations

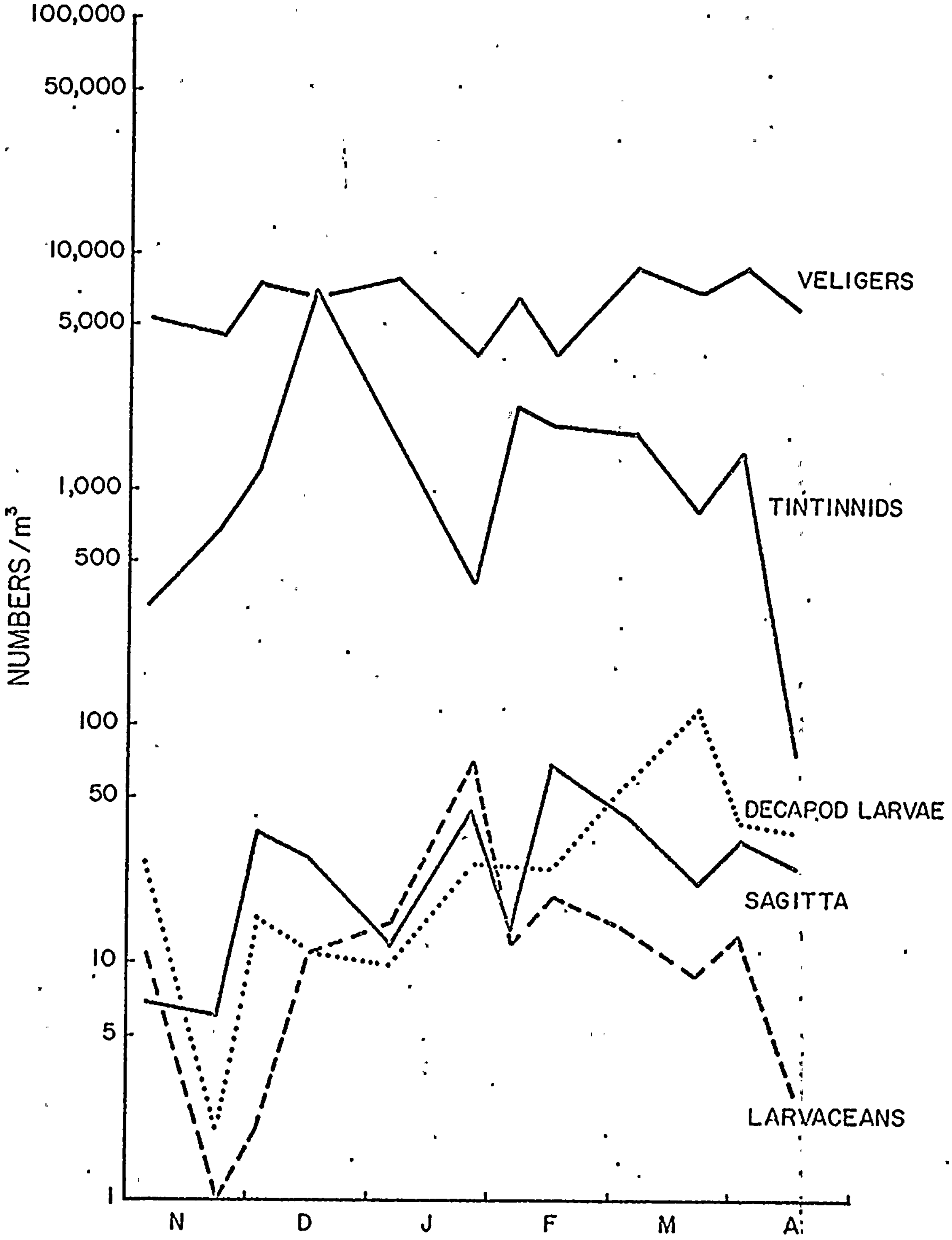

FIGURE VI-11 Seasonal variation of specified zooplankton organisms averaged for Card Sound stations

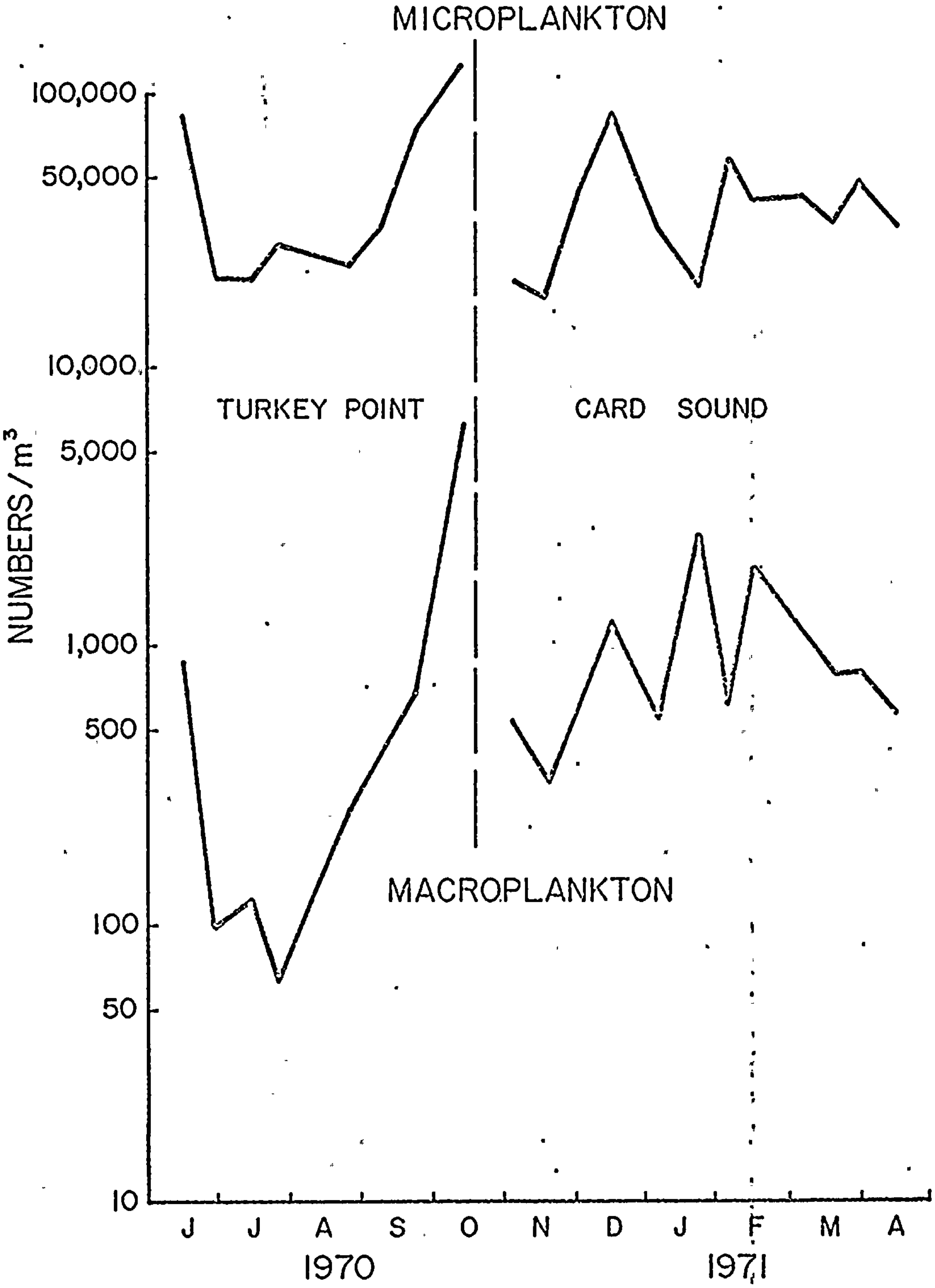

FIGURE VI-12 - Seasonal variation of total micro and macrozooplankton between June, 1970, and May, 1971, using data from Turkey Point and Card Sound.

TABLE VI-3

TURKEY POINT INCUBATION EXPERIMENT
OCTOBER 6, 1970

	Intake	Outfall
Temp.	27.8°C	34.5°C
Salinity	25 °/oo	25 °/oo

	COPEPODS			LARVAL TYPES					
200μNet	Calanoid	Harpacticoid	Cyclopoid	Veliger	Decapod	Larvacea	Polychaete	Chaetognatha
Intake								
% Total Catch	48	0.5	20	14	0.4	0.3	16	0.9
% Dead								
3 hours	7	65	5	25	50	100	21	21
24 hours	11	65	12	48	50	100	27	21
Outfall								
% Total Catch	51	2	23	20	0.3	0.09	2	0.7
% Dead								
3 hours	14	88	15	19	0	0	4	0
24 hours	25	96	32	76	0	100	26	13

GRAND TOTAL % DEAD AT 24 HOURS:

Intake	20
Outfall	36

Rapid gross biomass estimates can be made using the frozen samples. Aliquots immediately deepfrozen at Card Sound are kept in this condition until required for analysis. On being defrosted, duplicate sub-samples of approximately 5 to 10 mg will be passed through a 25 mm glass-fiber filter on which the particulate matter is retained, this is rinsed with a solution of ammonium formate to remove the seawater. The filter and contents are then dried at 60°C and reweighed. The dried samples must be restored deepfrozen until they can be analyzed for organic carbon, nitrogen and hydrogen.

The above analyses concern total particulates which contain a variable amount of non-animal material. This non-animal fraction is largely organic detritus, and in the finer net can also consist of phytoplankton (in bloom conditions) and fine sediment (in rough weather). A method has been worked out to estimate what fraction of the total particulates is zooplankton. This is based on an examination of a cleared millipore filter onto which a preserved aliquot from the same sample has been collected. Adapted from microstereology techniques, a Weibel graticule is employed on which is inscribed a series of fixed points. By determining the nature of the particulate material under each of these points, a figure for the relative area of animal material as a function of that covered by the total particulate material in the field can be obtained. This fraction can then be applied to the values determined for dry weight, etc., to obtain a corrected dry weight of animal material. There are several assumptions inherent in the technique which are being checked. Even if the method attains a minimal accuracy, it provides valuable information which cannot be gathered any other way short of actual separation by micromanipulative procedures; impossible on a large scale.

An indication of the extent of data routinely being obtained for any sample date by all these methods, see Table VI-4 for January 23, 1971. The available information is not exhaustive since the samples have not been examined with regard to detailed size/frequency analysis within individual species or groups.

Synoptic Survey: As before, the survey was not truly synoptic, it took nearly three hours to collect all the samples during which time water movements were taking place. The samples were processed by passing each through a 200μ net in the laboratory in order to separate the macro and microplankton. Total counts were obtained for each fraction and appear as the bottom distributions in Figure VI-13. Distributions for three copepods, a chaetognath, tunicates and decapod larvae also appear. The distributions are based on logarithmic frequency intervals corresponding to those of the previous survey around Turkey Point (Figure VI-6). For total microplankton the numbers must be multiplied by 10^2. The pattern for microplankton was not unlike that obtained on some occasions for dissolved nutrients (see Section IV). The two patches higher than average were near the western shore and the shallow banks at either end of the Sound. The stations with lower density occurred in the creeks connecting with the ocean where water may have been of mixed inshore and offshore origin. The pattern was not seen as clearly for total microplankton; here, where concentration was 2 orders of-magnitude lower, the patches were strongly influenced by individual species. This can be seen clearly for the eastern highest density patches which

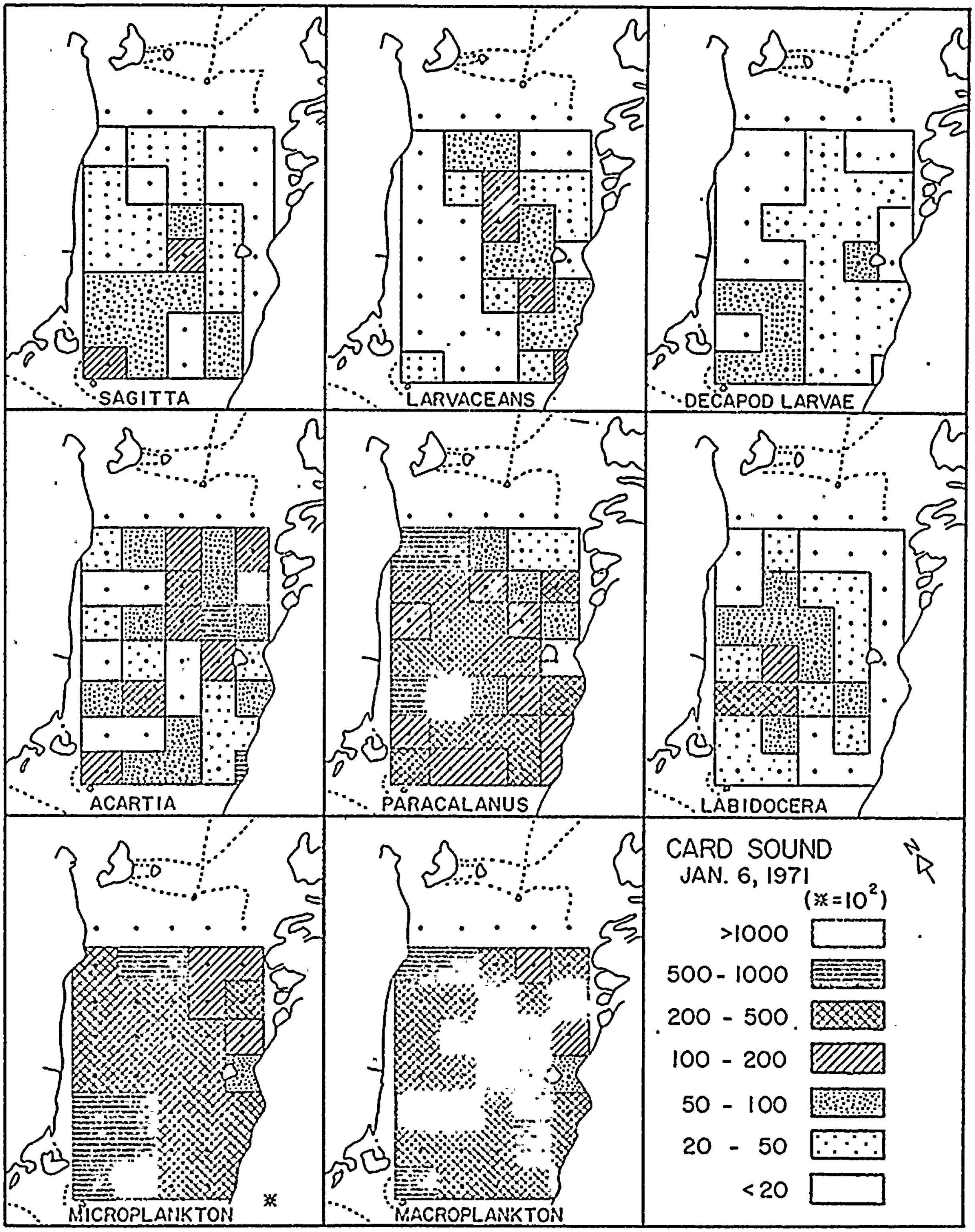

FIGURE VI-13 Density of total micro and macroplankton (lower row) and specified components at 35 stations over Card Sound, January 6, 1971. Densities for total microplankton to be multiplied by 10^2.

TABLE VI-4

STANDARD ANALYSIS FOR A SINGLE SAMPLING DATE IN CARD SOUND

STATIONS:		0404	0604	0804	0606	MEAN
Chl a mg/m^3		0.298	0.267	0.396	0.261	0.305
Plankton No. $\#/m^3$						
200µNet						
A. tonsa		657	464	537	2,282	985
P. parvus		2,011	1,116	1,163	1,125	1,354
Labidocera		13	20	16	45	24
S. hispida		33	45	29	72	45
Tunicates		204	32	16	28	70
Decapodlarvae		20	43	12	28	26
Total		2,972	1,736	1,780	3,585	2,518
64µNet						
Nauplii		2,234	5,409	11,666	9,646	7,238
Copepodites		5,508	5,819	3,333	3,804	4,616
Cyclopoids		3,813	5,245	3,888	2,785	3,932
Veligers		3,158	6,311	4,444	1,155	3,767
Tintinnids		77	328	972	272	412
Total		14,791	23,114	24,305	17,663	19,968
20µNet						
Nauplii		16,800	26,407	30,492	17,220	22,729
Copepodites		2,310	8,330	2,911	840	3,597
Cyclopoids		4,200	12,229	2,911	2,940	5,570
Veligers		9,765	12,937	1,802	2,940	6,861
Tintinnids		7,980	4,076	11,365	8,610	8,007
Total		41,160	63,978	49,480	32,550	46,790
Dry Weight	200µ	3.58	3.81	5.37	5.55	4.58
mg/m^3	64µ	4.51	7.51	6.93	4.65	5.90
%	200µ	7	7	5	6	6
Detritus	64µ	5	17	18	7	12
%	200µ	5	12	7	2	6.5
Ash	64µ	3	3	26	0	8
%	200µ	7.90	9.16	6.39	9.38	8.20
N	64µ	7.94	5.47	5.52	9.66	7.15
%	200µ	51.15	52.25	39.64	52.31	48.83
C	64µ	52.54	36.76	39.72	43.64	43.16
%	200µ	6.89	6.97	5.28	7.62	6.69
H	64µ	7.46	4.59	4.65	5.73	5.60

were largely Acartia while the patch off the Model Land Canal was composed mainly of Paracalanus and Labidocera. Sagitta hispida was localized in the southwestern part of the Sound while tunicates were aligned north to south down the length of it. The decapods, probably composed of a large variety of species, were somewhat more uniformly distributed. This type of survey if taken together with chemical and hydrographical studies, could provide much better data for correlation with localized effects such as thermal addition at one point in time.

Vertical Survey: Figure VI-14 shows the results of a series of tows made between noon and 2000 hours on one station at the surface and at five feet depth in terms of total micro and macroplankton. Clear indications of diurnal migration of plankton are seen. A second attempt to quantify this phenomenon was made recently using a 50 gal/min. submersible pump and hose system, which permitted a very accurate depth determination. A similar series of samples were made utilizing three depths (near bottom, mid-depth and surface); these have not yet been analyzed. Similar experiments will continue to be performed in order to obtain a factor which may be applied to daytime surface samples thus giving average water column counts. They will also be used to investigate the role of the hyperplankton in mediating sediment/water column interchanges.

SUMMARY

A seasonal survey of zooplankton in South Biscayne Bay showed there were differences in community structure between inshore waters adjacent to Turkey Point and the midbay but the total quantities (as indicated by adult copepod dry weight or naupliar count) were similar. Despite extreme and rapid fluctuation, a major pattern of a summer minimum and autumn bloom were suggested. No effects could be correlated with certainty to power plant activity.

By sampling an extensive grid pattern around Turkey Point, patches of varying density could be identified but this operation could not be repeated for logistic reasons. A more limited survey sampling intensively at two stations over the summer confirmed the summer paucity followed by an autumn burst of plankton, as well as the inability to identify thermal effects upon plankton over the period through examination of preserved environmental samples. It is believed that temperatures over 30°C in the summer in Biscayne Bay may be the single most important dominating effect depressing plankton biomass which would tend to swamp effects of lesser magnitude over any very localized area.

Laboratory tests for acute thermal shock effects on the copepod Acartia tonsa were conducted over one year and demonstrated its changing tolerance with season, although it had an upper absolute temperature limit of 37°C; some other species had lower tolerances. The problems of assessing direct effects due to entrainment were discussed together with two preliminary experiments involving incubation of entrained organisms.

The current seasonal survey of Card Sound plankton was outlined to demonstrate the relatively more detailed approach resulting from experience gained in the previous studies. Methods to obtain total biomass estimates and distinguish non-zooplankton particulate material were outlined as well as those designed to estimate vertical distribution of organisms.

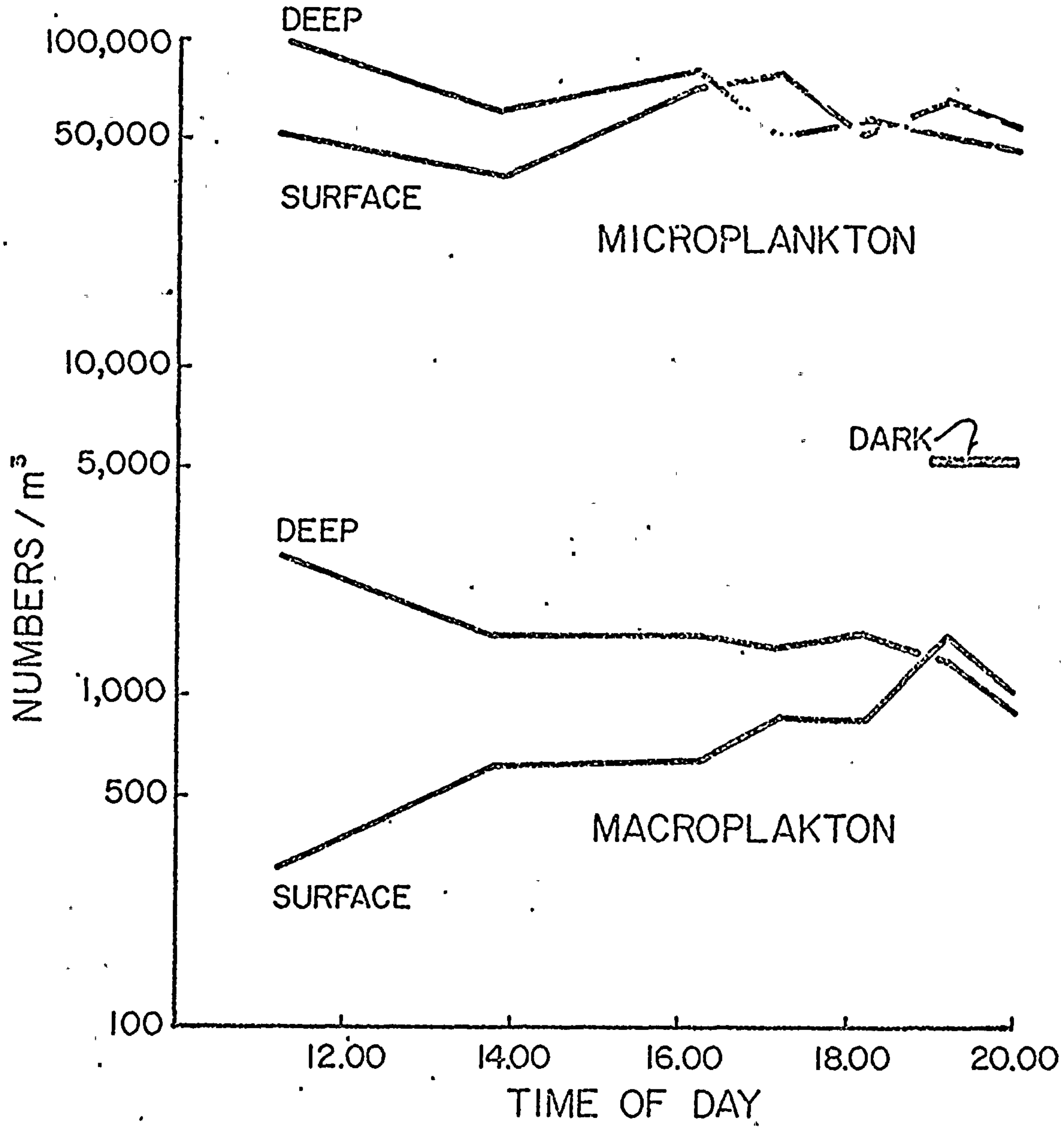

FIGURE VI-14 Distribution of total micro and macroplankton at stations at the surface and a depth of 5 ft. over an eight hour period up to 20.00 (one hour after darkness).

These studies suggest that future work should be conducted along the following lines. After a year of twice-monthly samples in Card Sound, sampling should be concentrated into synoptic surveys conducted at the same time as water chemistry measurements every two months over the entire Sound. Wide-area synoptic surveys can probably yield more information concerning small-scale influences than limited time-series samples. Zooplankton entrainment studies should concentrate on improving control survival by better experimental techniques so that entrainment mortalities in excess of 10% of control animals could be reliably measured. Longer term, sublethal effects on entrained plankton should be studied especially in the areas of fecundity and growth rate, since these may be more important than initial death rates. Greater attention should be focussed on the effects of the Power Plant prior to and following the summer when plankton biomass may be over an order of magnitude greater and summer ambient temperatures little reduced. A 10% kill-off at the initiation of the autumn bloom could potentially lead to much greater biomass losses than 90% kill-off at the height of the summer. A third line of inquiry which may have great significance in the ecology of Card Sound is the interrelationship between the sediment and plankton food chains and the role of detrital degradation.

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VII DIATOMS*

GENERAL STATEMENT

The principle purpose of this work was to determine if a diatom population can be used as an indicator of thermal stress conditions. The investigation provides a comprehensive description of the epiphytic diatom population in the Turkey Point area and attempts to relate chemical and physical data with changes in this population. The major difficulty has been the dearth of knowledge relating marine diatoms to the environment. Since this study began in September 1969 a major effort has been made to overcome this handicap. The first six months were spent establishing methods, determining significant sampling intervals and seeking a suitable substrate for diatom attachment.

Most of the data were obtained between March 1970 and April 1971. However, the basic species distribution began in September 1969. Station locations are shown in Figure VII-1. Most of these are the same stations used by Zieman (1970) in studying the effects of thermal stress on sea-grasses and macroalgae. Station SE-I, not used by Zieman, has a Ryan constant-reading thermograph installed. The temperature data were obtained during physical and chemical measurements discussed in sections II and IV, and averaged for the time period of the sampling interval.

Estimates of chlorophyll-a content of the diatoms is also being made with the hopes that they will result in a measure of the potential photosynthetic capacity. Although the chlorophyll content will vary with species, age, size and various physiological conditions such information should provide a more reliable measure of relative productivity than cell counts. Chlorophyll content and cell count data may not correlate but if the composition of the diatom population is taken into account, the source of most discrepencies should be revealed. This has been demonstrated by Graham (1943) who showed that in a well mixed sample the chlorophyll content will correspond with the cell count.

METHODS

Field Collection

Two glass slides are placed at each station held approximately 14" above the sediment in a plexiglas stalk (Figure VII-2). The diatoms are allowed to accumulate on the glass slides for approximately one month in the autumn, winter and spring and for two week intervals during the summer. The plexiglas stalk has proved to be sea worthy and inexpensive. A beneficial modification, would be to reduce the overhang on the edges which cause a small strip on both sides of the slide to have atypical diatom distribution. At the time of collection the back of the slides are carefully wiped clean and only those diatoms on the front of the slide were identified

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* J. Sprogis

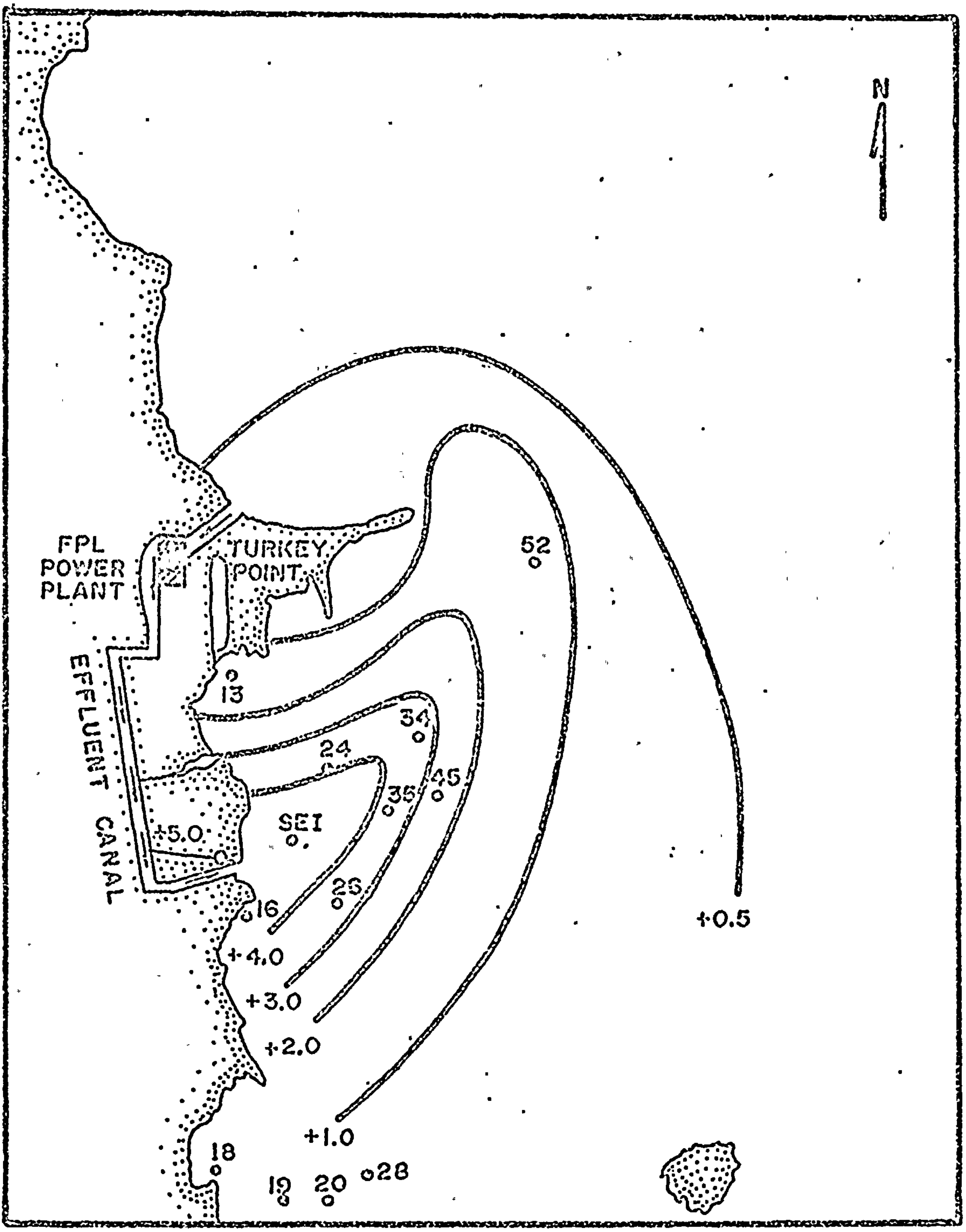


FIGURE VII-1   Diatom Stations at Turkey Point

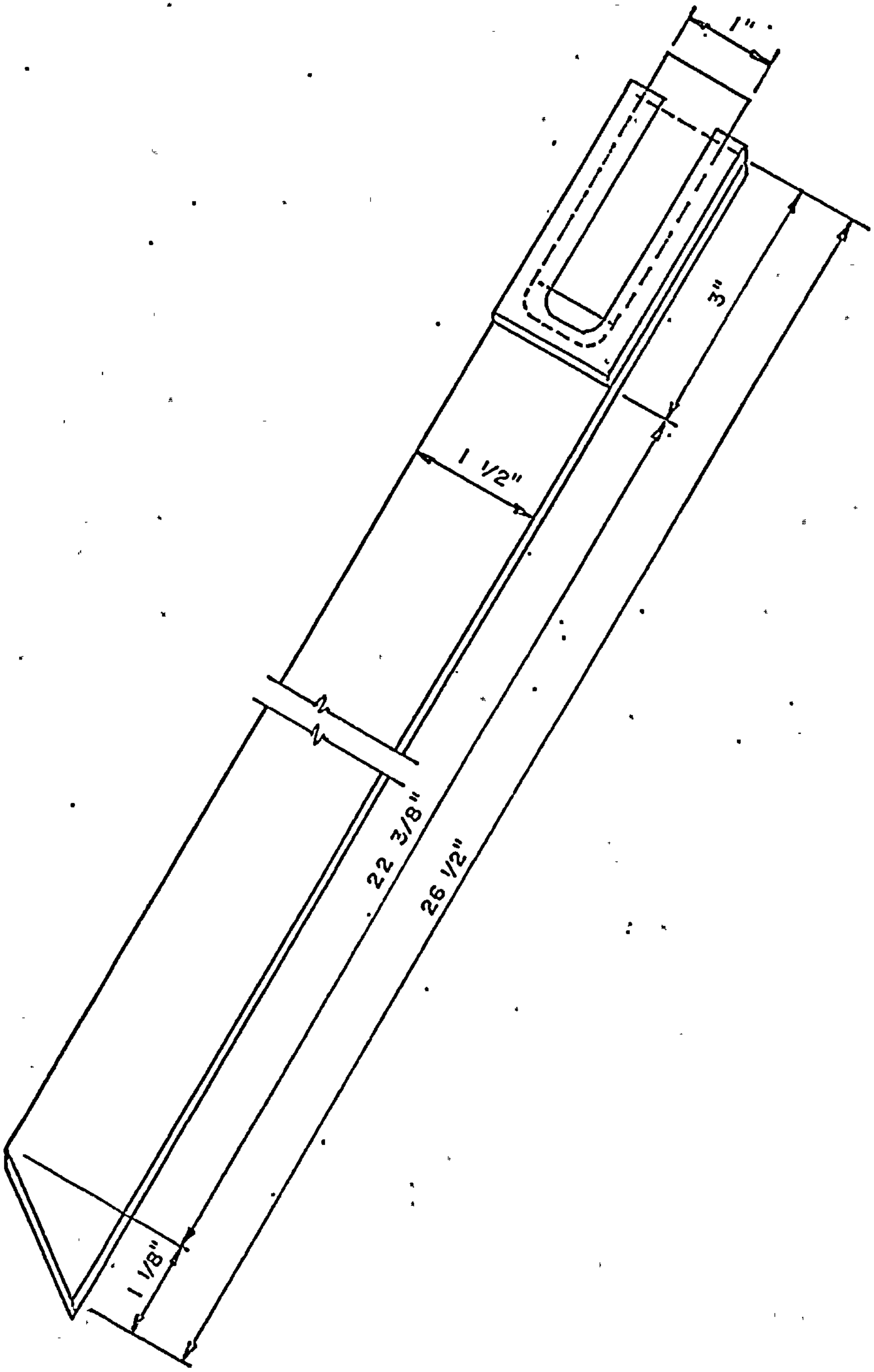


FIGURE VII-2 Plexiglass Stalk

and analyzed. The slides were kept in sea water and in the dark while being returned to the laboratory.

Chlorophyll-a Analysis

To preserve the pigment structure the samples were freeze dried (Corcoran, personal communication). This occurred during the night following the collection. When dried each slide was placed in 35 ml of 90°/₀₀ acetone for 18 hours. Optical density readings for the extract were made on a Beakman DU-2 spectrophotometer at wave lengths of 700, 665, 645, and 630mμ wave lengths. The chlorophyll calculations were made based on the equation of Richards and Thompson (1952) with the modification made by Strickland and Parsons (1970) for turbidity correction when using a 10-cm light path. The calculation for Chlorophyll-a is as follows: subtract the 700mμ value from each of the values at 665, 645, and 630 mμ and employ the equation: Ch (chlorophyll-a) = $15.6\ E_{665} - 2.0\ E_{645} - 0.8\ E_{630}$. Multiply this value now by a constant (3.5) to express the chlorophyll-a m μg/slide..

The DK-2 Beckman Ratio Recording Spectrophotometer has been used to verify the DU-2 values. The correlations were excellent. The DK-2 showed no skewing in the peaks which is evidence that the extraction methods are satisfactory.

Visual Examination

The slides were made ready for visual examination, identification and cell counts by bathing them in concentrated HCl for approximately 1/2 hour, followed by a thorough rinsing in distilled water, and air drying. A cover slip was mounted using Permount mounting preparation. This bathing process dissolved the calcareous and organic matter, leaving clean diatom frustules (Wood, personal communication).

The slides from the Thalassia blades were made by scraping the diatoms from the blades with a razor. This conglomerate of epiphytic material was boiled in a solution of concentrated hydrochloric acid and sodium nitrite for five minutes. The diatoms were then centrifuged and washed three times; permanent slides were made using Permount mounting preparation. These collections were compared with those that accumulated on the glass slides.

A Reichert Zetopan phase contrast microscope was used to make a detailed examination of the slides to determine: 1) all species, 2) dominant species, 3) species associations, 4) general mode of accumulation, i.e., patchiness, even spacing, touching, and layering, and 5) cell counts. A significant portion of this detailed examination has yet to be completed.

RESULTS AND DISCUSSION

Table VII-1 is a list of all species of diatoms collected at the Turkey Point area from September 1969 to April 1970 as identified by Professor Ferguson Wood. The majority of these are epiphytes but a few sediment samples are included.

TABLE VII-1

LIST OF DIATOM SPECIES

Achnanthes brevipes
A. curvirostrum
A. delicatula
A. longipes

Amphiprora alata
A. gigantea

Amphora acuta
A. acutiuscula
A. angusta
A. bigibba
A. bigibbosa
A. binodis
A. capensis
A. coffeaeformis
A. costata
A. dubia
A. egregia
A. gigantea
A. granulata
A. hyalina
A. laevis
A. laevissima
A. lanceolata
A. meandrina
A. mexicana
A. obtusa
A. ostrearia
A. porcellus
A. proteus
A. robusta
A. terroris
A. turgida
A. ventricosa

Auricula marginata

Bacillaria paxillifer

Biddulphia pulchella

Caloneis brasiliensis
C. formosa
C. liber
C. powelli

Campylodiscus biangulatus
C. crebrecostatus

Campylostylus striatus

Chaetocerus cinctus

Climacosphenia moniligera

Cocconeis disculoides
C. disculus
C. placentula
C. pseudomarginata
C. scutellum

Cyclotella comta
C. meneghiniana
C. striata
C. stolorum

Cymatosira belgica
C. lorenziana

Cymbella cistula

Diploneis beyrichiana
D. bombus v. bombiformis
D. campylodiscus
D. chersonensis
D. crabro
D. eudoxia
D. eugenia
D. fusca
D. giebelli
D. mediterranea
D. notabilis
D. ovalis
D. pseudobombiformis
D. smithii
D. suborbicularis

Fragillaria constricta
F. pinnata

Frustulia saxonica v. rhomboides

Grammatophora marina
G. oceanica
G. serpentina

Gyrosigma balticum

Licmophora abbreviata
L. curvata
L. ehrenbergii
L. flabellata
L. grandis
L. remulus

Mastogloia achnanthoides
M. acutiuscula
M. affinis
M. affirmata
M. angulata
M. angusta
M. apiculata
M. asperula
M. asperuloides
M. bahamensis
M. baldjikiana
M. barbadensis
M. beyrechiana
M. binotata
M. braunii
M. cocconeiformis
M. concinna
M. cribrosa
M. crucicula
M. decipiens
M. densistriata
M. elegans
M. entoleia
M. erythraea
M. euxina
M. fallax
M. fimbriata
M. foliolum
M. frickei
M. gibbosa
M. gilberti
M. gracilis
M. graciloides
M. granulata
M. grunowi
M. horvanthiana
M. inaequales
M. jelineck
M. labuensis
M. laminaris
M. lanceolata
M. lata
M. latercostata
M. latercia
M. lineata
M. manifera
M. ovalis
M. ovata
M. ovulum
M. ovum paschale
M. parva
M. peragalli
M. pisciculus
M. pulchella
M. pumila
M. punctifera
M. pusilla
M. quinquecostata
M. regula
M. robusta
M. rostellata
M. schmidti
M. smithii
M. splendida
M. splendidula
M. subaffirmata
M. submarginata
M. tenera
M. undulata
M. varians

Navicula acus
N. capensis
N. clematis
N. cuspidata
N. directa
N. elegans
N. forcipata
N. granulata
N. hennedyi v. manca
N. lacustris

N. longa
N. maculata
N. marina
N. peregrina
N. rhombicula
N. subcarnata
N. subtilissima cleve
N. supralitoralis
N. viridula
N. yarrensis
N. zosteretti

Neidium affine
N. iridis

Nitzschia sp.
N. acicularis
N. apiculata
N. closterium
N. circumsuta
N. gracilis
N. grandis
N. granulata
N. hungarica
N. kittli
N. linearis
N. longissima
N. lorenziana
N. martiana
N. mediterranea
N. navicularis
N. palea
N. panduriformis
N. plana
N. pseudolinearis
N. punctata
N. seriata
N. sigma
N. sigma v. maxima
N. sigmatella
N. sigmoidea
N. socialis
N. tryblionella
N. vermicularis
N. vitrea

Peridinium sp.

Pleurosigma sp.
P. affine
P. angulatum
P. compactum
P. decorum
P. formosum
P. gyrosymadecora
P. hippocampus
P. longum
P. naviculaceum
P. spencerii
P. strigosum

Pseudonitzschia sicula

Rhabdonema adriaticum

Rhopalodia gibba
R. gibberula
R. musculus

Stenopterobia intermedia

Striatella interrupta
S. unipunctata

Surirella fastuosa
S. gemma

Synedra acus
S. baccillaris
S. crystallina
S. frauenfeldii
S. fulgens
S. gailloni
S. hennedyana
S. splendida
S. ulna
S. undulata

Trachyneis aspera

Tropidoneis sp.
T. lepidoptera
T. sinata

Figure VII-3 is a bar graph of the total number of these species found at each station during the period. The data indicates a distinct decrease in diversity at those stations strongly influenced by the effluent outflow. Further specific identifications have not been carried out by the present investigator due to lack of time. The average temperature for each sampling interval is recorded in Table VII-2.

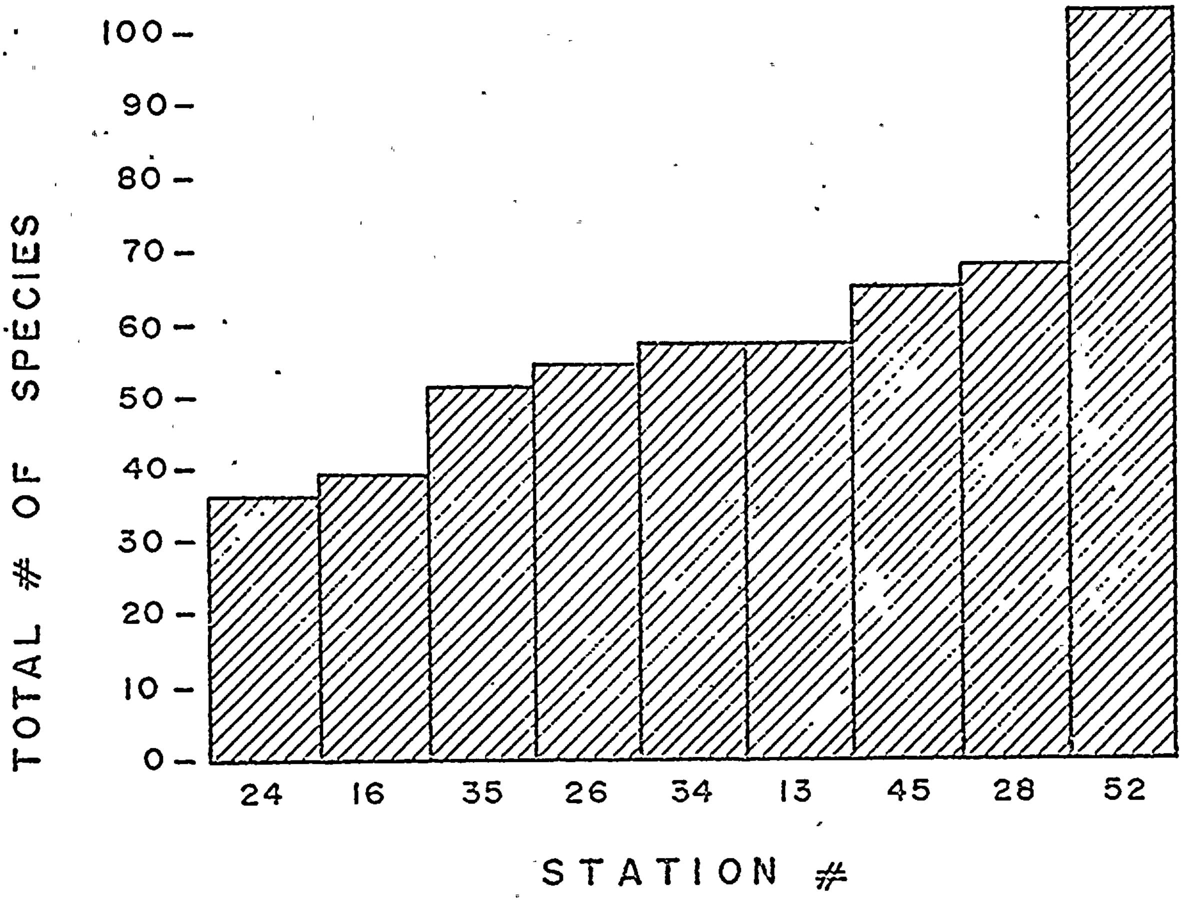
Table VII-3 shows the species and temperature distribution of the dominant epiphytic diatoms at the Turkey Point area; the two major dominant species were Cocconeis placentula and Frustulia saxonica v. rhomboides. Periodically, the genera Mastogloia and Synedra appeared as the dominant species. In most instances, the mixture of species within the genus Mastogloia was so diverse that the specific names have not been given. The most abundant species within the genus was Mastogloia punctifera. The species of Synedra have not yet been identified but the data suggests two distinct species with different temperature optimums. One of these is directly associated with Frustulia. Temperature relations and seasonal appearance indicate the dominance of mixed Mastogloia as a transitional condition, although the genus Mastogloia was found diving all seasons except at the peaks of the Cocconeis and Frustulia growth.

The optimum growth period for Cocconeis was within the cooler temperature range of 25 to 27° C with a second peak between 30 to 33° C (Figure VII-4). This second growth peak was found during the fall transition period. Cocconeis never was the dominant species at the two stations (52 and 28), farthest away from the effluent and least effected by it. Cocconeis occasionally dominated at both high and low temperatures at Station 45, farther offshore than Station 28 and equally as deep as Station 52. This suggests that something in the plume area is necessary for its dominance or that something offshore is inhibiting it; neither possibility is directly related to temperature.

At all stations during some interval throughout the year Frustulia was found to be dominant. Even though it is eurythermic, it has its prime dominance in late spring, lasting through the summer at a temperature range of 31 to 36° C.

During the spring (23 to 29° C) and fall (28 to 30° C) there was a tendency for Cocconeis and Frustulia to appear as co-dominants. Also there is a suggestion that cooler stations approach transitional stages before the warmer stations, thus though cyclic patterns may be similar, there is a lag or gain in phase at some stations in fall and spring respectively, at the effluent effected stations.

Table VII-4 shows the average daily chlorophyll concentrations at each station per sampling interval. The equation Ca (chlorophyll-a) = $15.6\ E_{665} - 2.0\ E_{645} - 0.8\ E_{630}$ was used to derive these values. Richards and Thompson (1952) used a version of this equation on pigments that were extracted in 1 litre of 90% acetone and measured in a 1-cm spectrophotometer cell and thus their chlorophyll-a units were in mg Chl.a/L. In this investigation the pigments are extracted in 35 ml of 90% acetone and measured in a 10-cm cell, therefore, the values given in Table VII-4 may be converted into units of µg chlorophyll-a per 1" x 3" slide by multiplying by 3.5.



STATIONS 18 & SEI OMITTED DUE TO LACK OF DATA

FIGURE VII-3 Bargraph of Species Diversity (Sept. 1969-April 1970)

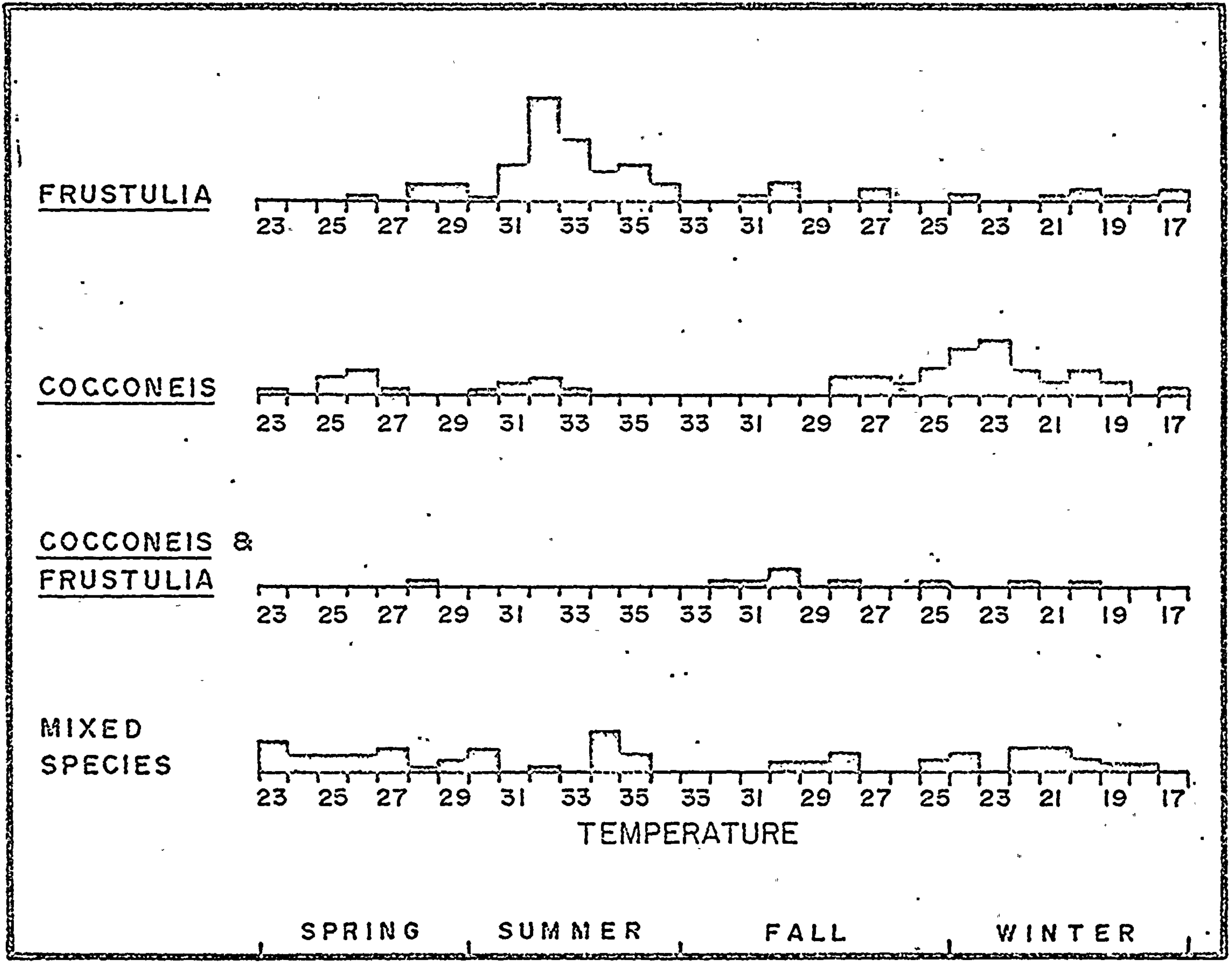


FIGURE VII-4 Histogram of Species Related to Temperature (Sept. 1969-April 1970)

TABLE VII-2

AVERAGE TEMPERATURES AT ALL STATIONS PER SAMPLING INTERVAL

MARCH 1970 - APRIL 1971

SAMPLING INTERVAL	SEI	24	35	16	34	26	45	13	52	18	28	TOTAL AVG. TEMP. WITH SEI	TOTAL AVG. TEMP. W/O SEI
1970													
3/23 - 4/22	29.2	28.4	28.4	28.1	27.5	27.3	26.2	25.9	25.7	25.2	25.1	27.0	26.8
4/22 - 6/2	30.7	29.9	29.9	29.6	29.0	28.8	27.7	27.4	27.2	26.7	26.6	28.5	28.3
6/2 - 6 18	33.2	32.4	32.4	32.1	31.5	31.3	30.2	29.9	29.7	29.2	29.1	31.1	30.8
6/18 - 7/21	35.1	34.3	34.3	34.0	33.4	33.2	32.1	31.8	31.6	31.1	31.0	33.0	32.7
7/21 - 8/4	35.0	34.2	34.2	33.9	33.3	33.1	32.0	31.7	31.5	31.0	30.9	32.8	32.6
8/4 - 8/17	35.8	35.0	35.0	34.7	34.1	33.9	32.8	32.5	32.3	31.8	31.7	33.6	33.4
8/17 - 9/3	36.2	35.4	35.4	35.1	34.5	34.3	33.2	32.9	32.7	32.2	32.1	34.0	33.8
9/3 - 9/25	35.5	34.7	34.7	34.4	33.8	33.6	32.5	32.2	32.0	31.5	31.4	33.3	33.1
9/25 - 10/21	31.0	30.2	30.2	29.9	29.3	29.1	28.0	27.7	27.5	27.0	26.9	28.8	28.6
10/21 - 11/18	28.2	27.4	27.4	27.1	26.5	26.3	25.2	24.9	24.7	24.2	24.1	26.0	25.8
11/18 - 12/16	20.9	20.1	20.1	19.8	19.2	19.0	17.9	17.6	17.4	16.9	16.8	18.7	18.5
1971													
12/16 - 1/23	25.5	24.7	24.7	24.4	23.8	23.6	22.5	22.2	22.0	21.5	21.4	23.3	23.1
1/23 - 2/24	23.3	22.5	22.5	22.2	21.6	21.4	20.3	20.0	19.8	19.3	19.2	21.1	20.9
2/24 - 3/29	26.2	25.4	25.4	25.1	24.5	24.3	23.2	22.9	22.7	22.2	22.1	24.0	23.8
3/29 - 4/30	27.2	26.4	26.4	26.1	25.5	25.3	24.2	23.9	23.7	23.2	23.1	25.0	24.8

TABLE VII-3

SPECIES AND TEMPERATURE DISTRIBUTION AT ALL STATIONS

SEPTEMBER 1969 - APRIL 1971

STATION: DEPTH:	SEI (1.5m)	24 (1.3m)	35 (1.8m)	16 (1.0m)	34 (1.8m)	26 (1.6m)	45 (2.0m)	13 (1.0m)	52 (2.0m)	18 (1.0m)	28 (1.5m)
1969											
9/3 - 10/1	33.0	C 32.2	F-C 32.2	F 31.9	C 31.3	C 31.1	C 30.0	C-F 29.7	F-mS 29.5	F 29.0	mS-F 28.9
10/1 - 10/15	31.4	30.6	F-C 30.6	F 30.3	F 29.7	29.5	C 28.4	28.1	mS 27.9	27.4	27.3
10/15 - 11/13	25.4	C 24.6	C 24.6	C 24.3	F 23.7	C 23.5	C 22.4	C-F 22.1	mS 21.9	21.4	mM 21.3
11/13 - 12/31	24.6	C 23.8	C-mS 23.8	C 23.5	C 22.9	C 22.7	mS-C 21.6	C 21.3	mM-mS 21.1	20.6	F-mM 20.5
1970											
12/31 - 3/23	23.7	C 22.9	C 22.9	C 22.6	C 22.0	C 21.8	F 20.7	C 20.4	F 20.2	19.7	F-mS 19.6
3/23 - 4/22	29.2	F 28.4	F 28.4	C-F 28.1	F 27.5	mM-F 27.3	m 26.2	C 25.9	F 25.7	25.2	m 25.1
4/22 - 6/2	30.7	mM 29.9	mM 29.9	mM 29.6	mM-F 29.0	mM-F 28.8	mM 27.7	m 27.4	mM 27.2	26.7	mM 26.6
6/2 - 6/18	33.2	F 32.4	F 32.4	F 32.1	F 31.5	F 31.3	mM 30.2	F 29.9	F 29.7	F 29.2	F 29.1
6/18 - 7/21	35.1	F 34.3	F 34.3	m 34.0	F 33.4	F 33.2	F 32.1	C 31.8	F 31.6	F 31.1	F 31.0
7/21 - 8/4	F 35.0	mS 34.2	F 34.2	F-mS 33.9	F 33.3	F 33.1	F 32.0	F 31.7	F 31.5	F 31.0	F 30.9
8/4 - 8/17	F 35.8	F 35.0	F 35.0	F 34.7	F 34.1	mS 33.9	F 32.8	F 32.5	m 32.3	F 31.8	F 31.7

TABLE VII - 3 CONT.

SPECIES AND TEMPERATURE DISTRIBUTION AT ALL STATIONS

STATION: DEPTH:	SEI (1.5m)	24 (1.3m)	35 (1.8m)	16 (1.0m)	34 (1.8m)	26 (1.6m)	45 (2.0m)	13 (1.0m)	52 (2.0m)	18 (1.0m)	28 (1.5m)
8/17 - 9/3	F 36.2	mS 35.4	F 35.4	F 35.1	mS 34.5	mS 34.3	F 33.2	C 32.9	F 32.7	F 32.2	F 32.1
9/3 - 9/25	F 35.5	mS 34.7	F 34.7	F 34.4	mS 33.8	mS 33.6	F 32.5	C 32.2	F 32.0	F 31.5	F 31.4
9/25 - 10/21	F 31.0	C-F 30.2	C-mM 30.2	C-F 29.9	F 29.3	C-mM 29.1	m 28.0	C 27.7	mS 27.5	C 27.0	F 26.9
10/21 - 11/18	C 28.2	F-C 27.4	C 27.4	C 27.1	F 26.5	C 26.3	m 25.2	C-F 24.9	mS-F 24.7	C 24.2	F-mS 24.1
11/18 - 12/16	C 20.9	C 20.1	F-C 20.1	F 19.8	F 19.2	C 19.0	m 17.9	F 17.6	F 17.4	C 16.9	F 16.8
1971 12/16 - 1/23	C 25.5	C 24.7	C 24.7	C 24.4	C 23.8	mS-mM 23.6	C 22.5	C 22.2	mS-m 22.0	C 21.5	mS 21.4
1/28 - 2/24	C 23.3	C 22.5	C 22.5	C-mS 22.2	21.6	21.4	C 20.3	C 20.0	mS 19.8	C 19.3	mS 19.2
2/24 - 3/29	C 26.2	C 25.4	C 25.4	m 25.1	C 24.5	24.3	m 23.2	C 22.9	m 22.7	22.2	m 22.1
3/29 - 4/30	C 27.2	C 26.4	mM-mS 26.4	m 26.1	C 25.5	m 25.3	m 24.2	m 23.9	mM 23.7	m 23.2	m 23.1

C	-	*Cocconeis placentula*
F	-	*Frustulia saxonica* v. *rhomboides*
m	-	mixed dominents
mM	-	mixed species of *Mastogloia* - mostly *Mastogloia punctifera*
mS	-	mixed species of *Synedra*

TABLE VII - 4

AVERAGE DAILY CHLOROPHYLL a CONCENTRATIONS (*) PER SAMPLING INTERVAL

MARCH 1970 - APRIL 1971

SAMPLING INTERVAL	NO. OF DAYS	SEI	24	35	16	34	26	45	13	52	18	28	TOTAL AVG. WITH SEI	TOTAL AVG. WITHOUT SEI
1970														
3/23-4/22	30		.026	.036	.054	.030	.052	.059	.024	.019		.064		.040
4/22-6/2	41		.040	.078	.056	.047	.064	.036	.024	.044	.024	.044		.046
6/2-6/18	16		.113	.135	.188	.100	.181	.129		.087	.068	.071		.119
6/18-7/21	33		.023	.049	.035	.100	.080	.058	.014	.034	.030	.051		.031
7/21-8/4	14	.184	.024	.039	.080	.031	.064	.027	.013	.023	.049	.045	.053	.040
8/4-8/17	14	.076	.022	.060	.057	.041	.153	.062	.019	.021	.039	.045	.054	.052
8/17-9/3	17	.118	.108	.112	.193	.088	.124	.047	.014	.028	.039	.065	.085	.082
9/3-9/25	22	.195	.059	.085	.103	.101	.216	.031	.014	.026	.028	.048	.082	.071
9/25-10/21	26	.043	.030	.032	.048	.055	.027	.046	.045	.031	.052	.059	.043	.043
10/21-11/18	28	.060	.043	.039	.026	.043	.042	.068	.017	.040	.026	.082	.044	.043
11/18-12/16	28	.216	.033	.024	.043	.036	.027	.030	.020	.013	.014	.031	.044	.027
1971														
12/16-1/23	38	.066	.016	.032	.032	.023	.053	.020	.017	.014	.015	.032	.029	.025
1/23-2/24	32	.072	.021	.046	.028	.026		.017	.020	.008		.027	.029	.024
2/24-3/29	34	.065	.044	.015	.024	.022		.024	.015	.015	.015	.018	.026	.021
3/29-4/30	33	.040	.044	.045		.024	.051	.037	.023	.025	.015	.027	.033	.032

* To obtain μg chlorophyll a/1"x3" slide, these values are multiplied by 3.5.

This unit of measure is designated throughout this report by the label, chlorophyll-a concentration (*).

Figure VII-5 shows temperature plotted against chlorophyll-a concentration, can be throughout the entire year the chlorophyll-a values were generally higher at those stations within the effluent plume (Stations SE-I, 24, 35, 16, 34, 26). During the winter when the temperature was 17 to 25° C Cocconeis was the dominant species at these stations and the corresponding chlorophyll-a values are relatively low. The transitional stations 45 and 13, show either Cocconeis, Frustulia, or mixed Synedra as dominant (except Station 13, which was generally anomalous) during the winter intervals.

During the spring and fall when the temperature ranged from 25 to 31° C there was an increase in chlorophyll-a content at all stations (there is no data for the spring of 1970). At Stations 28, 13, 52, and 18, away from the plume, the spring and/or fall chlorophyll-a averages were the highest values for the year.

The highest chlorophyll-a values occurred during the summer (31 to 36° C) at the stations within the effluent plume (Sta. SE-I, 24, 35, 16, 34, 26) and these values correspond with dominance of Frustulia and mixed species of Synedra. At each one of these stations the values fluctuated between the highest for the year, to those typical of the spring and fall concentrations. At Station 24 and 16, the chlorophyll concentrations dropped to extremely low values. These extreme fluctuations may indicate that the organisms are thriving at a temperature so close to their critical level, that any change of another parameter could drastically alter productivity.

During the summer months the stations with little or no influence from the effluent, (Stations 52, 28, 18, 13) were also dominated by Frustulia (except for Station 13 which has both Cocconeis and Frustulia showing as dominant), but the chlorophyll values were not high. At Station 52, 28, and 18, they were similar to the spring and fall concentrations and at Station 13 they were lower than the winter concentrations. Further analysis of this data is being conducted.

Figure VII-6 shows average daily temperature, chlorophyll-a, and diatom weight values for the entire Turkey Point area at each sampling interval. There is an apparent correlation between chlorophyll-a concentration and weight, but the ratio of diatoms to the total accumulated weight has not been calculated. Analysis of individual stations, such as SE-I shown in Figure VII-7, may supply some answers concerning the relationship of the diatoms to the accumulation of other periphyton. For example, an extremely high chlorophyll concentration and a corresponding low weight value occurred during the interval ending December 16, 1970, at a time where the species population of the slide was 99% Cocconeis. The oval Frustules of the Cocconeis on the slide were touching one another at all points possible but there was no overlapping or second layer formed. The corresponding low weight may indicate that with a high number of this particular type of diatom cell covering the entire surface of the slide, there was little surface room available for attachment of other organisms, thus the weight may be attributed mainly to diatoms, and its low value to the lack of attachment of other periphyton (Table VII-5).

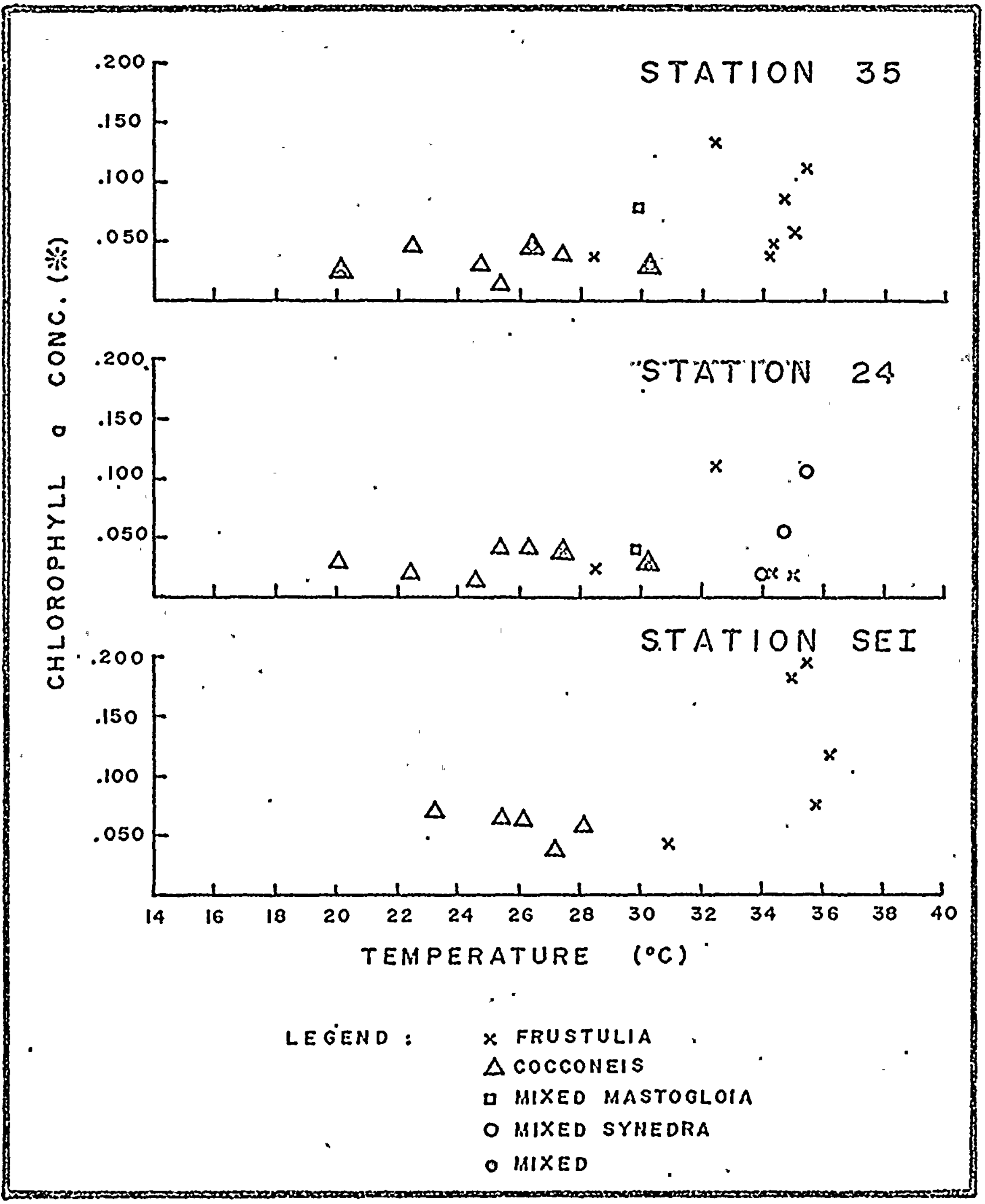


FIGURE VII-5 Scattergrams of Temperature (°C) vs. Chlorophyll a concentration (* See Table VII-4) For All Stations (Sept. 1969-April 1970)

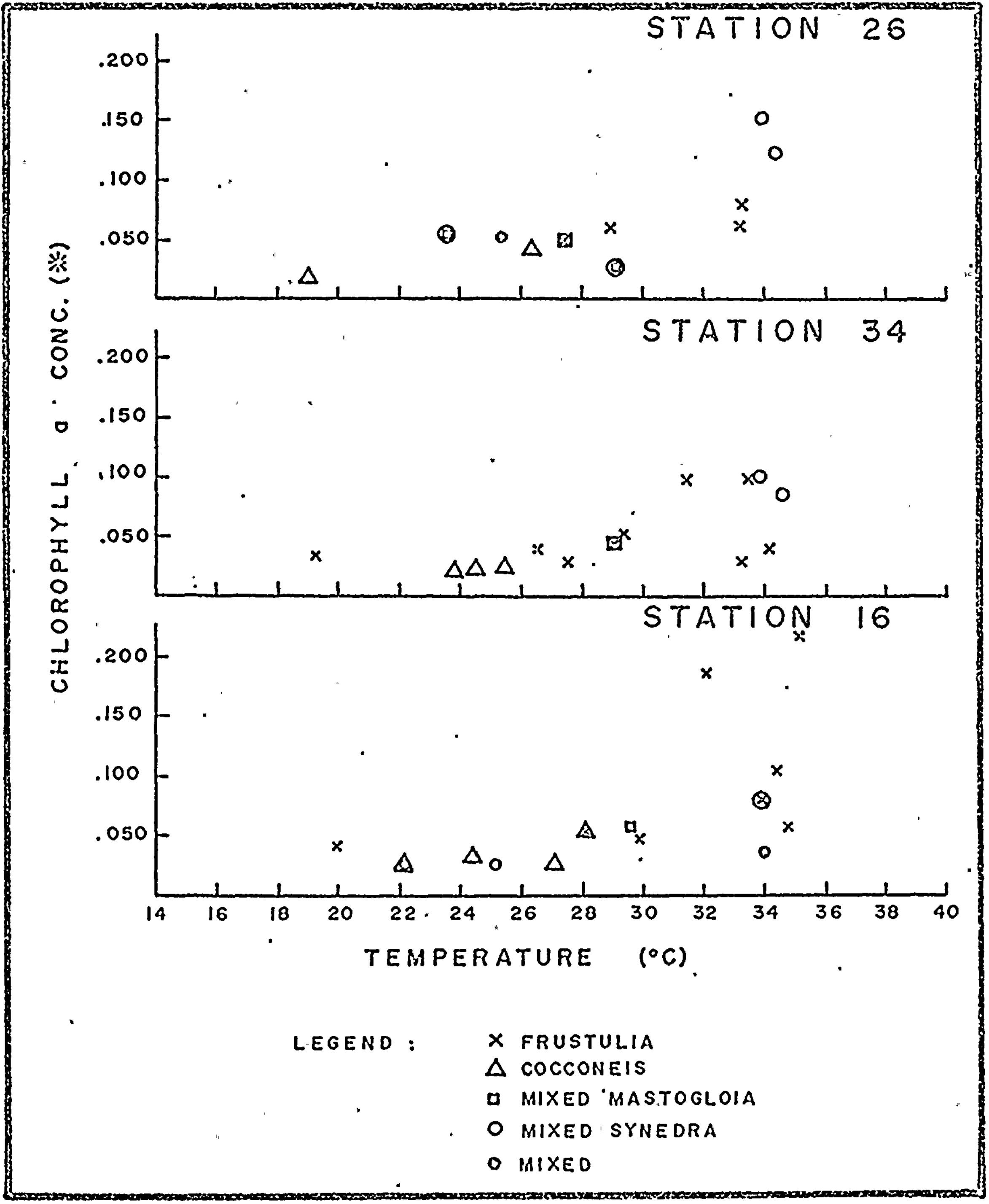


FIGURE VII-5 Continued

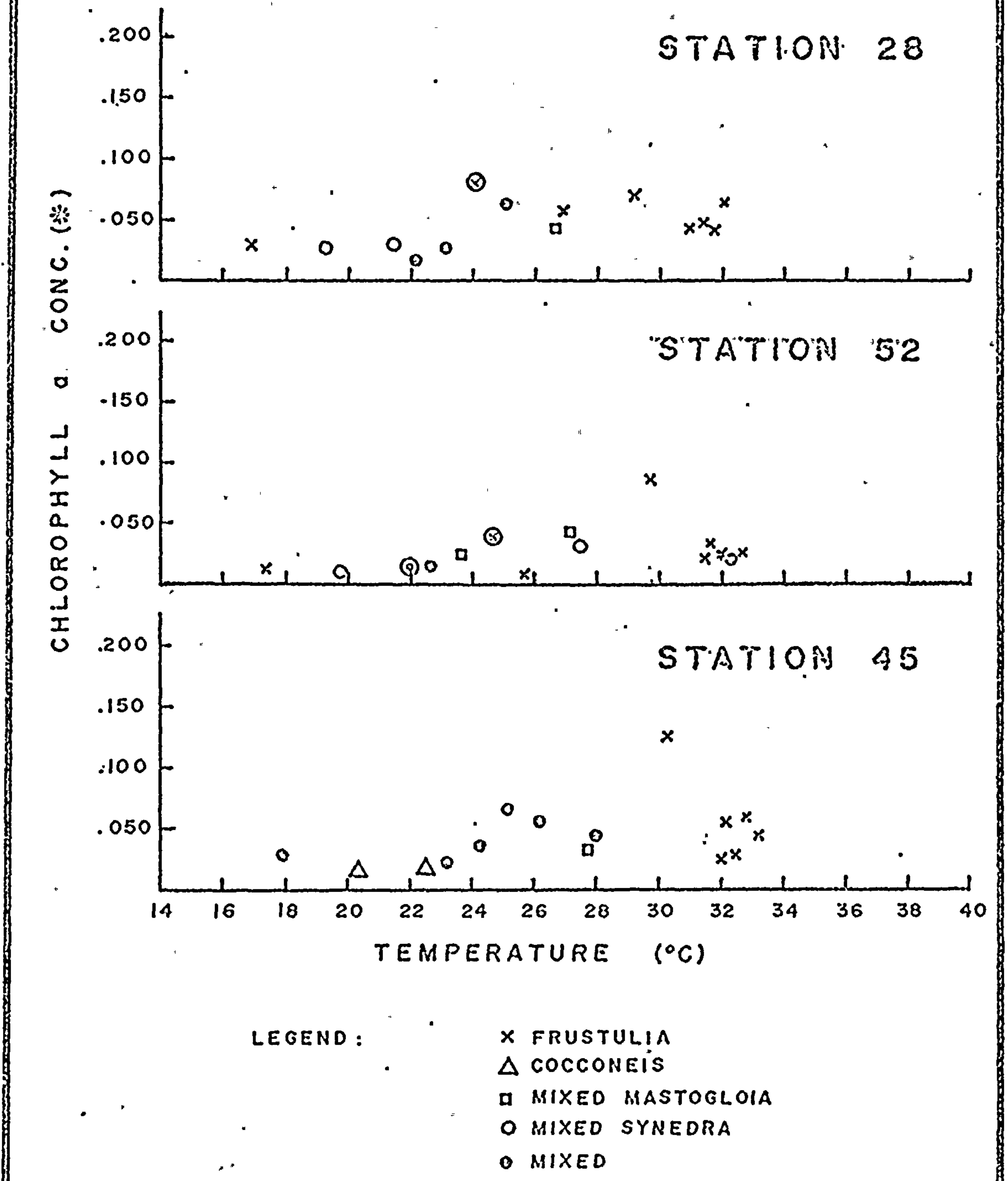


FIGURE VII-5 Continued

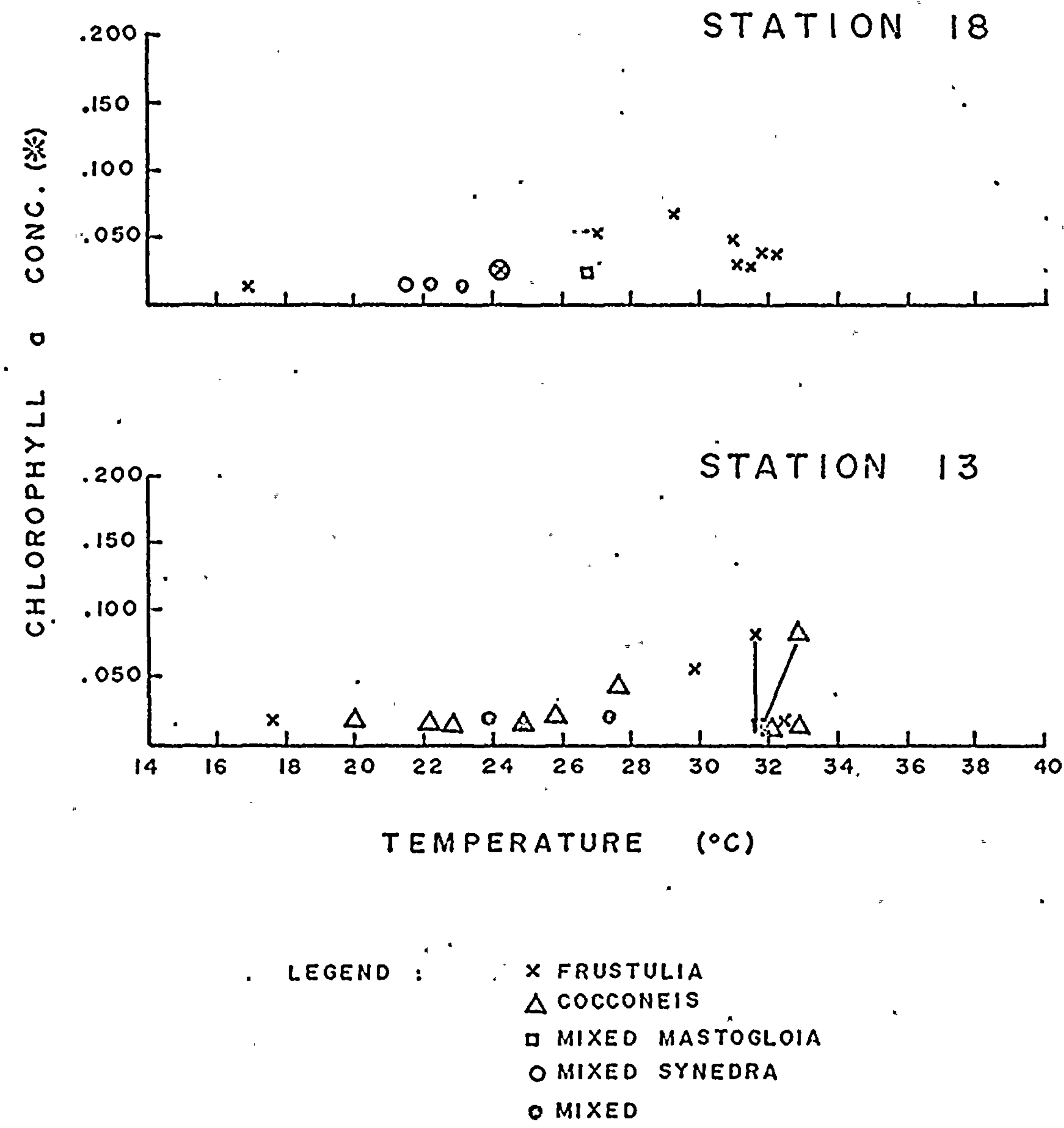


FIGURE VII-5 Continued

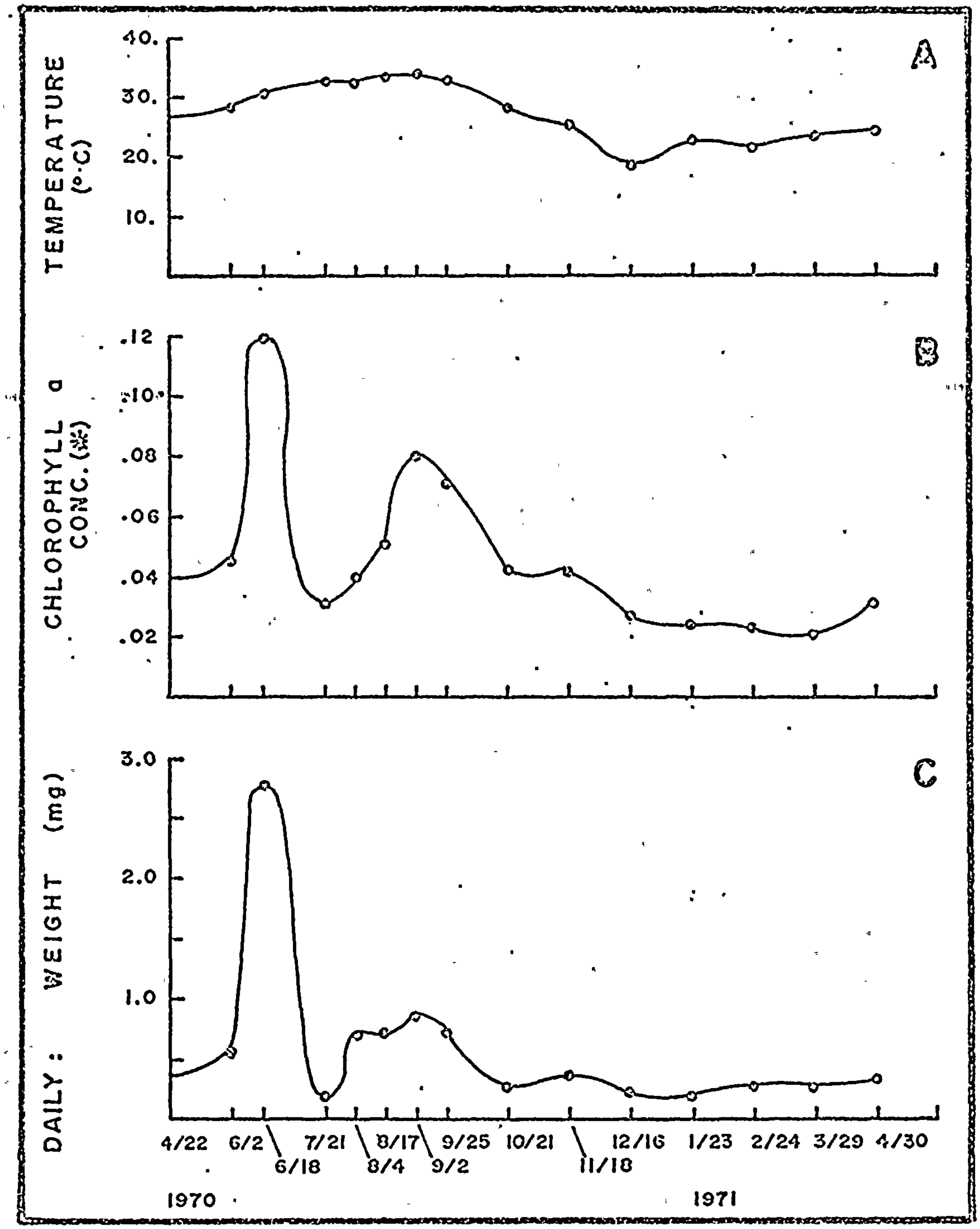


FIGURE VII-6 Total Averages of All Stations - excluding SEI Per Sampling Interval (March 1970-April 1971)
A. Temperatures (°C)
B. Daily Chlorophyll a Concentration (* See Table VII-4)
C. Daily Weights (mg)

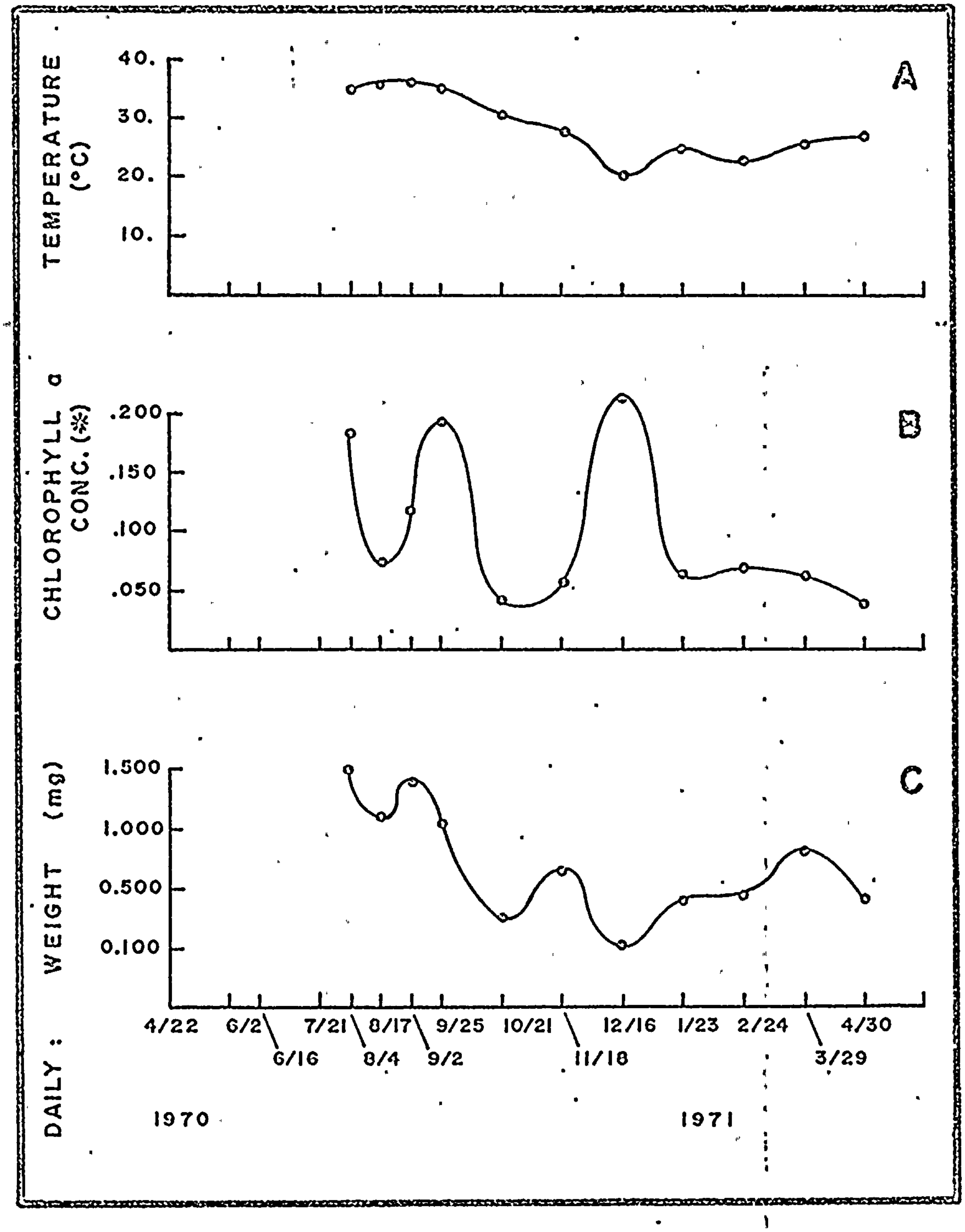


FIGURE VII-7 Total Averages For Station SEI (August 1970-April 1971):
A. Temperatures (°C)
B. Daily Chlorophyll a Concentrations (* See Table VII-4)
C. Daily Weights (mg)

TABLE VII - 5

AVERAGE WEIGHT IN MILLIGRAMS PER DAY PER SAMPLING INTERVAL

MARCH 1970 - APRIL 1971

SAMPLING INTERVAL	NO. OF DAYS	SEI	24	35	16	34	26	45	13	52	18	28	TOTAL AVG. WITH SEI	TOTAL AVG. WITHOUT SEI
1970														
3/23-4/22	30		.193	.300	.527	.537		.613	.287	.223				.383
4/22-6/2	41		.461	.763	.466	.512	.695	.446	.498	.591	.456	.756		.564
6/2-6/18	16		2.994	3.200	3.069	2.975	.825	2.987	2.906	3.076	3.006	2.900		2.794
6/18-7/21	33		.042	.152	.127	.215	.200	.382	.291	.136	.370	.109		.202
7/21-8/4	14	1.486	.600	.936	.736	.721	.936	.650	.536		.671	.671	.794	.717
8/4-8/17	14	1.129	.650	.671	.707	.786	1.150	.650	.500	.614	.614	.629	.736	.697
8/17-9/3	17	1.365	.971	1.188	1.435	.982	1.029	.682	.394	.465	.682	.918	.919	.875
9/3-9/25	22	1.059	.655	.691	.855	.895	1.491	.391		.459	.532	.623	.765	.732
9/25-10/21	26	.246	.250	.215	.262	.296	.200	.235	.312	.412	.239	.292	.269	.271
10/21-11/18	28	.671	.279	.271	.221	.346	.396	.536	.211	.350	.329	.711	.393	.365
11/18-12/16	28	.136	.171	.214	.150	.254	.236	.293	.168	.200	.104	.436	.215	.223
1971														
12/16-1/23	38	.413	.058	.261	.145	.150	.245	.168		.113	.121	.329	.216	.192
1/23-2/24	32	.463	.250	.238	.291	.356		.181	.228	.194		.466	.296	.276
2/24-3/29	34	.832	.291		.347	.168		.253	.144	.206		.303	.318	.245
3/29-4/30	33	.403	.403	.303		.203	.300	.276	.342	.224	.485	.276	.322	.312

The two high chlorophyll-a peaks shown during the summer month correspond to Frustulia dominance and the overall high values of these peaks all seem to arise from the high values of those stations with strong influence (Figure VII-5).

Table VII-6 shows the daily average chlorophyll-a concentrations, weights and temperatures of SE-I, the stations under strong effluent influence grouped and averaged together as did the stations with little or no effluent influence. These values were then used to plot the graphs in Figures VII-8 and VII-9. Once again there are two noticable summer peaks in both chlorophyll-a concentration and weight values, the heights of which may be attributed to the influence of the effluent plume.

SUMMARY

This preliminary investigation has surveyed the epiphytic diatom population at Turkey Point, defined the dominant species and their respective temperature ranges, detected seasonal cycles, and determined a distrinction in speciation and diversity of species between stations within the thermal influence and those stations out of it.

There was an overall correlation between chlorophyll-a concentration and weight values and these correspond with changes in speciation. The distinction between stations within the outside thermal influence was evidenced by all the parameters investigated; change in speciation, chlorophyll-a concentration and weight values.

The diatom Frustulia flourished in the warmest water and produced the highest average chlorophyll-a values, but individual analysis of these values at each station within the effluent shows rapid and extreme increases and decreases in chlorophyll-a concentrations within the 31 to 36°C temperature range. This suggests that during the summer months the diatoms at these stations are extremely close to their critical temperature level and that alteration of another parameter could drastically alter productivity. Detailed analysis of this will be undertaken in conjunction with the chemical data. The possible effects of short term temperature fluctuations will also be examined.

Cell counts and mode of cell attachment will be undertaken to determine if there is a significant relationship between diatom numbers and chlorophyll-a concentration. The mode of attachment of the diatoms may effect the accumulation of other periphyton and thus a ratio of specific diatoms to total weight may be established with further investigation.

The locations of the stations now being used have served adequately for a preliminary study, but the information on diatom distribution, the constancy of the thermal plume and the circulation pattern extending from the effluent canal, would suggest a more efficient and informative set of stations. One series would follow the axis of the plume and a second series of control stations would be set

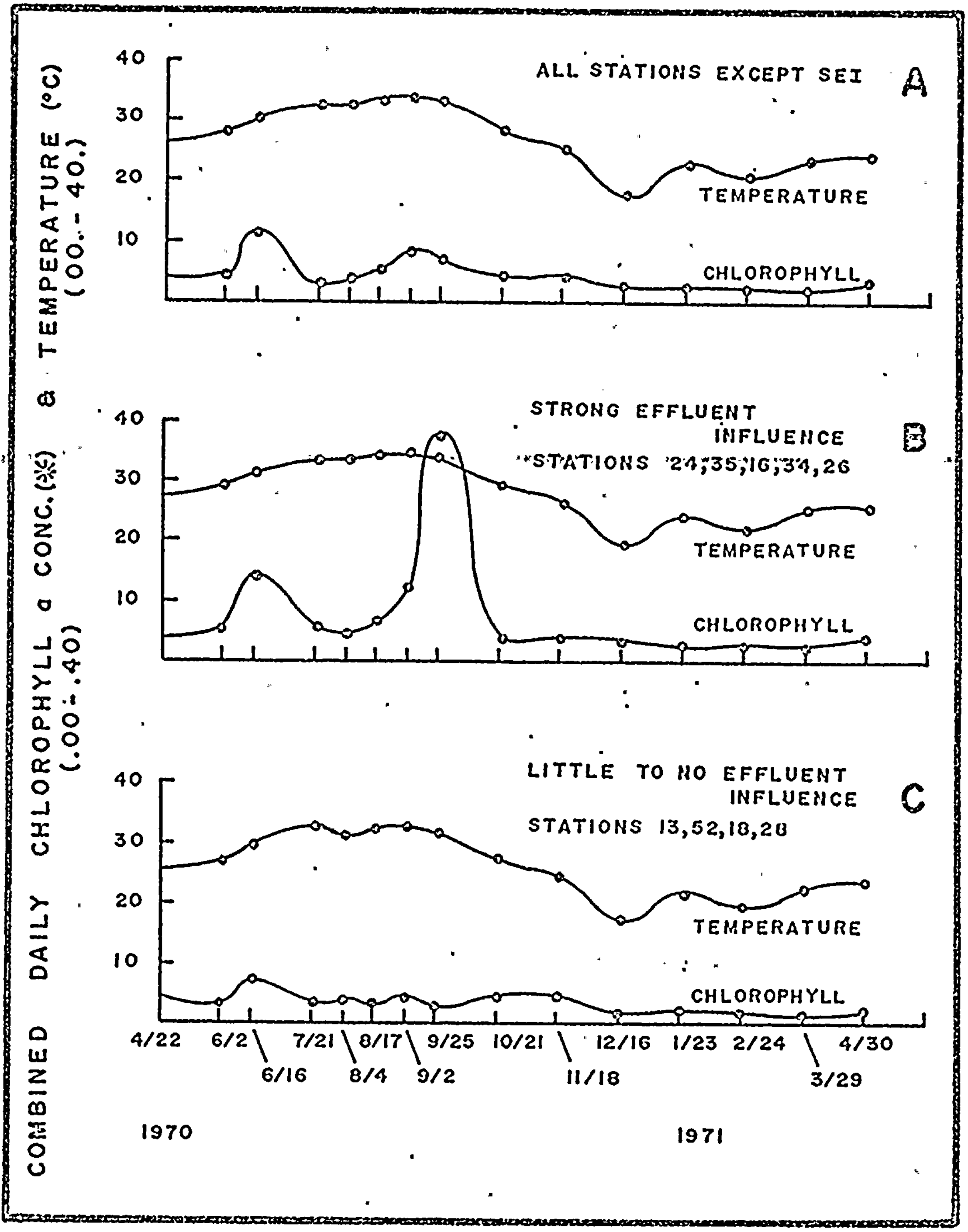


FIGURE VII-8 Total Average Temperatures (°C) and Daily Average Chlorophyll a Concentrations (* See Table VII-4) Per Sampling Interval (March 1970-April 1971)

A. All Stations - excluding SEI

B. Stations With Strong Effluent Influence (Sta. 24, 35, 16, 34, 26)

C. Stations With Little Or No Effluent Influence (Sta. 13, 52, 18, 25)

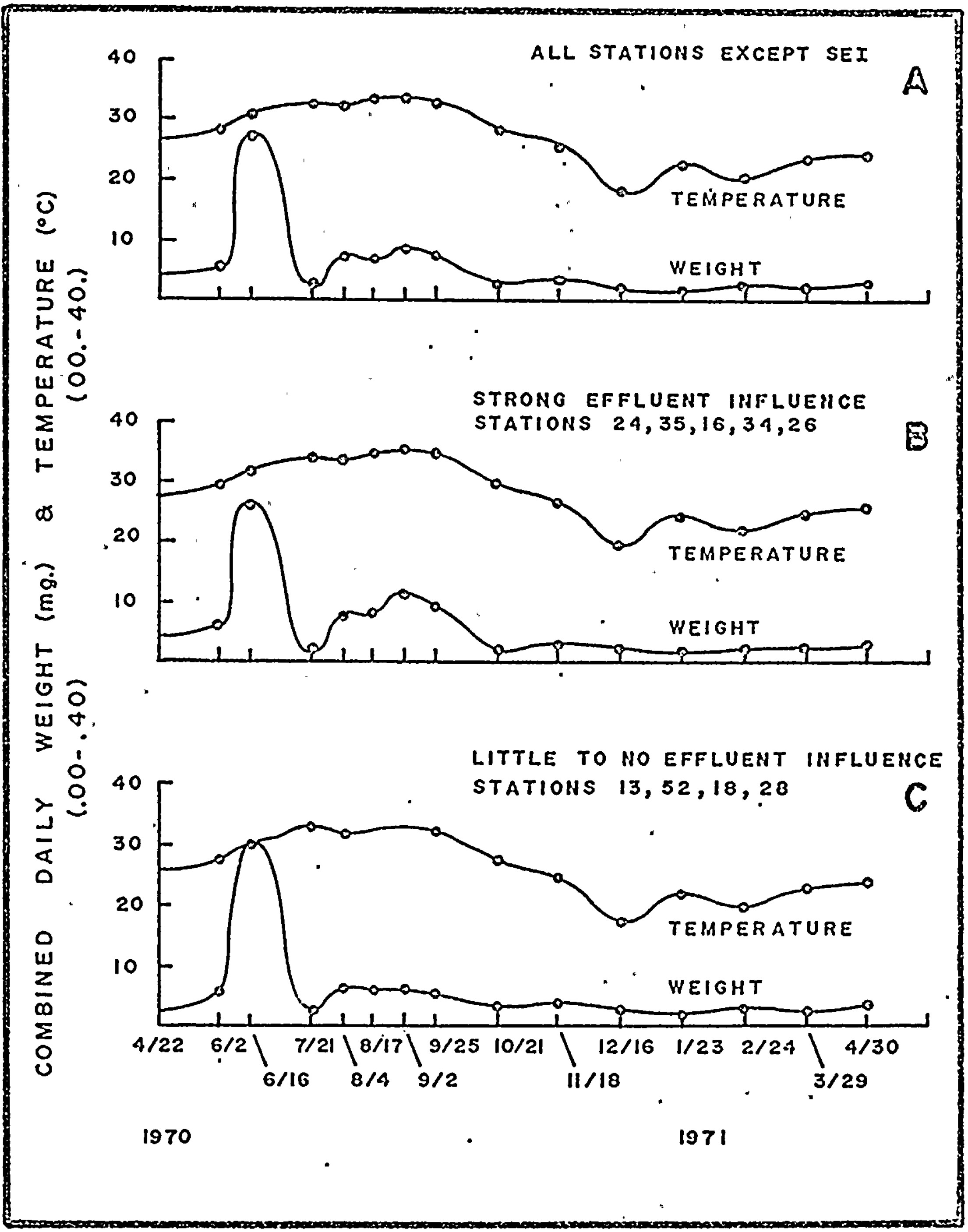


FIGURE VII-9 Total Average Temperatures and Average Daily Weights Per Sampling Interval (March 1970-April 1971):

A. All Stations - excluding SEI

B. Stations With Strong Effluent Influence (Sta. 24, 35, 16, 34, 26)

C. Stations With Little Or No Effluent Influence (Sta. 13, 52, 18, 25)

TABLE VII - 6

TOTAL AVERAGES (MARCH 1970 to APRIL 1971) OF DAILY CHLOROPHYLL a CONCENTRATIONS (*), DAILY WEIGHTS (mg) AND TEMPERATURES (°C) AVERAGED BY: A. STATIONS WITH STRONG EFFLUENT INFLUENCE (STATIONS 24, 35, 16, 34, 26), B. STATIONS WITH LITTLE OR NO EFFLUENT INFLUENCE (STATIONS 13, 52, 18, 28), AND C. STATION SEI ALONE

SAMPLING INTERVAL	CHLOROPHYLL a AVG.			WEIGHT AVG.			TEMPERATURE AVG.		
	SEI	A (24,35, 16,24, 26)	B (13,52, 18,28)	SEI	A (24,35, 16,24, 26)	B (13,52, 18,28)	SEI	A (24,35, 16,24, 26)	B (13,52, 18,28)
1970									
3/23 - 4/22		.040	.036		.389	.255		27.9	25.5
4/22 - 6/2		.057	.034		.579	.575		29.4	27.0
6/2 - 6/18		.143	.075		2.613	2.972		31.9	29.5
6/18 - 7/21		.057	.032		.147	.227		33.8	32.4
7/21 - 8/4	.184	.048	.033	1.486	.786	.626	35.0	33.7	31.3
8/4 - 8/17	.076	.067	.031	1.129	.793	.589	35.8	34.5	32.1
8/17 - 9/3	.118	.125	.037	1.365	1.121	.615	36.2	34.9	32.5
9/3 - 9/25	.195	.372	.029	1.059	.917	.538	35.5	34.2	31.8
9/25 - 10/21	.043	.038	.047	.246	.245	.314	31.0	29.7	27.3
10/21 - 11/18	.060	.039	.041	.671	.303	.400	28.2	26.9	24.5
11/18 - 12/16	.216	.033	.020	.136	.205	.227	20.9	19.6	17.2
1971									
12/16 - 1/23	.066	.029	.020	.413	.200	.188	25.5	24.2	21.8
1/23 - 2/24	.072	.030	.018	.463	.284	.296	23.3	22.0	19.6
2/24 - 3/29	.065	.026	.016	.832	.269	.218	26.2	24.9	22.5
3/29 - 4/30	.040	.041	.023	.403	.302	.332	27.2	25.9	23.5

*See TABLE VII-4

outside the plume but at similar depths. Perhaps the close inshore stations should be eliminated (except at the mouth of the canal), as they are greatly influenced by land runoff, solar radiation, and a circulation pattern significantly different from the stations off shore. This is suggested by the anomalies that appear at Stations 13 and 18. A more efficient set of locations would reduce the number of stations necessary and make it more feasible to have constant reading thermographs at each station to achieve specific temperature data. While the calculated temperature data used to date may not vary significantly from the actual temperatures, constant temperature data should be taken at each station.

The one month sampling interval seems satisfactory, as suggested by preliminary studies offshore at Key Biscayne, to show seasonal changes and differences between stations of similar and dissimilar nature, but a detailed evaluation of the rates of accumulation of diatoms at the Turkey Point area should be made. A series of slides for such an investigation has been collected, but the data has not been analyzed. It should be pointed out that a diatom population can and does change within one or two days, so other parameters must be considered as well as the number of days involved.

Comparison of the dominant species on the glass slides and the Thalassia blades has recently shown some selectivity between the two substrates. Further investigation will be made, but because of this, all consideration of data to date is based on a comparative study using glass slides, a technique employed by Patrick, Hohn and Wallace (1954).

There may be more definitive methods of chlorophyll-a or pigment analysis than the procedure employed, but the strong correlation of chlorophyll-a data with speciation, seasonal changes and weight data support its adequacy for a base line study. Other techniques are being researched as to feasibility in terms of time, expense and application to this situation. Further consideration of these techniques is eminent for some measure of primary productivity essential (see Section IX).

The overall results to date are that basic seasonal patterns and relationships between stations have been established which may be used as the foundation for more detailed analysis, and significant problems for future investigations have been indicated.

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VIII MICROBIOLOGY*

GENERAL STATEMENT

Experience over the last few months has lead to the conclusion that the microbial component of the Card Sound system is likely of major importance in the production and turnover of organic materials. Certainly, we are convinced that the system cannot be described or understood without good information on microbial activities.

Good information in this are can be obtained only if support is available for the development of reliable techniques. A recent meeting convened by the Scientific Council on Oceanographic Research, at which Dr. Bunt was an invited consultant, made this fact especially apparent. Given suitable techniques, the distance of Card Sound and its biological variability are such that adequate personnel and field laboratory support is crucial to make programs of this description minimally effective.

METHODS

Station Keeping

The success of programs which call for the assessment of microbial standing stocks and activities is critically dependent upon facilities for rapid processing of samples and experimental materials. Card Sound is sufficiently distant from laboratories at the School of Marine and Atmospheric Science that a small research vessel is as essential as the most remote oceanic investigation. Faced with inflexible experimental needs and the logistic problems of providing an assortment of working equipment in the field, early efforts with small boats were frustrating and abortive. Measurements of carbon fixation and other processes in situ were not feasible and time inadequate for sample treatment following a day of collecting.

Ultimately, a minimal program was initiated as an extension of studies being conducted with National Science Foundation support using R/V CALANUS for 24 hour periods roughly at monthly intervals as permitted by existing ship scheduling. Under these conditions, it is possible to occupy three stations on each visit to the Sound. Station positions are shown in Figure I-3. All samples are collected using SCUBA with assistance, where necessary, from the ship's winch equipment. Routinely, water samples are taken in Niskin samplers held horizontally and manually tripped immediately below the surface, immediately above the bottom and at middle depth. Sediment samples are collected in plastic cores in triplicate at each station to a depth of 5 cm. After pouring away the supernatant, the sediments from each station are bulked together and mixed in sterile plastic bags.

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* Dr. J. Bunt

Standing Stocks

Photosynthetic Pigments: The final method of analysis was essentially that described by Strickland and Parsons (1965) although our spectrophotometer cannot accommodate a 10 cm cuvette. This fact creates difficulty in filtering sufficient water for extraction. In the past, this has limited the number of water samples that could be handled because the rate of filtering through standard 0.45μ Millipore filters is too slow. Currently we are using slightly coarser teflon-coated glass fiber filters and these are giving promising results, making it possible to treat surface, midwater and bottom water samples at each station. Even with 10 cm cuvettes it is likely that it would be necessary to filter inconvenient volumes of water for this analysis.

For the determination of pigments in sediment materials, samples of known volume are placed in 90% acetone for extraction immediately after collection and stored below freezing and in darkness pending return to the laboratory. There, a final extraction is made by repeated acetone washing and centrifugation. Parallel sediment samples are used for determination of wet and oven-dry weight. In reduction of data, no allowance is made for the existence of breakdown products of chlorophyll and other pigments. Expression of results in terms of chlorophyll a, etc., are, therefore, assumptions.

Particulate Carbon: The analysis for particulate carbon follows the method described by Parsons and Strickland (1965). Water samples are filtered directly through glass fiber filters. Sediment samples are taken from dilution series prepared for microbial viable counts and other purposes.

Plate Counts for Heterotrophic Microorganisms: This procedure has been adopted routinely to provide supplemental information to index the microbial populations. It suffers from all the shortcomings of such techniques but, in accumulation, is expected to provide data of comparative value.

Samples of water are taken with hand-held sterile syringes, measured aliquots of which are filtered through sterile assemblies supporting 0.45μ Millipore filters. The filters are transferred aseptically to the surface of a seawater nutrient agar based on a medium devised elsewhere for soil microbial populations. This medium, the composition of which appears below, has been found to give markedly higher colony counts than several other media tested. Dilution series are prepared from sediment samples and aliquots filtered from selected dilutions.

CULTURE MEDIUM FOR HETEROTROPHS

K_2HPO_4	2 mg
KNO_3	20 mg
Asparagine	0.5 g
Mannitol	1.0 g
Agar	15.0 g
Seawater	1 liter

Only one filter each was plated from the surface, mid and bottom water as well as sediment at each station; replication was not possible. Plates so prepared are incubated at 30°C and counted after 2-3 days and again after 14 days.

Metabolic Activities

Carbon Fixation By Photosynthesis: Photosynthetic activity is measured in situ using standard procedures essentially the same as described by Strickland and Parsons (1965). For logistic reasons, incubations of all water and sediment samples are made at Station 1. One light and one dark bottle are filled with water taken at the surface, mid-depth and bottom at each station. An additional light and dark bottle receive 1 ml each of a selected sediment dilution and are filled with filtered water. Each bottle is then injected with 10μCi NaH^{14}CO$_3$ and the bottles suspended on moored lines away from the influence of the ship's hull. Incubation is allowed to continue for four hours from 1000-1400 hours, after which the contents of the bottles are filtered through 0.45μ Millipore filters and dried for transport back to the laboratory. The filters are not fumed with HCl but are washed with a small volume of "cold", filtered estuarine water.

The filters are counted for 10 minutes in a low background, high efficiency end window gas flow counting system using precounted planchettes.

Some exploratory measurements have been made also of carbon-14 uptake by selected macroalgae using liquid scintillation techniques for counting. A number of technical problems have had to be solved in the course of this work; hopefully the procedures will be improved.

At the present time the technique being used involves exposure of small pieces of algal thallus to NaH^{14}CO$_3$ in unenriched filtered estuarine water either on deck or in situ. After various incubation times, both light and dark, samples of thalli are removed from the flasks, washed rapidly and then stored in plastic vials in the freezer. After return to the laboratory, the thallus samples are dried to constant weight, powdered, and the activity of small aliquots determined by liquid scintillation. Samples also are counted from the fluid in which the algae were suspended.

Respiratory Activity: This aspect of the work has raised a number of technical difficulties. Early attempts to measure the oxygen consumption of all planktonic materials larger than 0.45μ proved impractical because we lacked the personnel and the facilities to filter sufficiently large water samples to satisfy even the highly sensitive oxygen electrode assembly being used. The same electrode was chemically poisoned when exposed to the highly anaerobic sediments of the Sound.

Some effort was made to use Warburg techniques although it is doubtful what meaning should be attached to results based on materials which normally are oxygen starved and not engaged in aerobic processes except, perhaps, at

the immediate surface. In any case, routine use of manometry could not be contemplated because the production of unidentified gases sometimes obscured any oxygen consumption that may have been taking place.

Currently, degradative metabolic activity including detection of methane production with gas chromatography are being explored. It is important that a solution be found to this difficulty so that some indication be available of microbially induced organic overturn.

Nitrogen Fixation: Under anaerobic conditions, or in situations supporting heterocystous blue-green algae, it would be expected that biological nitrogen fixation might contribute significantly to estuarine fertility. To explore this possibility, a technique modified by Bunt, et al. (1970) for underwater use and depending on acetylene reduction to reflect the existence of nitrogen fixation has been applied. Until recently, incubation of sediment samples has been for 2-3 hours. This incubation was too short, however, good positive data now has been obtained by extending incubations to 24 hours or even longer.

RESULTS AND DISCUSSION

Photosynthetic Pigments

Levels of chlorophyll a found in the sediments are listed in Table VIII-1 and levels in the overlying water in Table VIII-2. Concentrations of chlorophyll a in the water have been remarkably low up to the present but relatively uniform between stations and with depth. In contrast, concentrations of the pigment in the sediments have been high and widely variable. Accordingly, it is our intention to take a larger number of cores on subsequent samplings and to make extractions of each core individually.

If all the chlorophyll a determined came from viable algal cells and if one assumes a reasonable ratio of 50 for cell carbon: chlorophyll a, one would reach the conclusion that phytoplankton standing stocks have been no greater than 13.5 mg carbon/m^3 while the benthic microalgal populations have been in the range of at least 50 mg carbon/m^2 up to as high as 630 mg carbon/m^2. It will be necessary to establish what proportion of the recorded pigment came from living cells.

Particulate Organic Carbon

The few data for this parameter are given in Tables VIII-3 and VIII-4. Levels in the water may be considered in comparison with common open ocean values around 250 mg carbon/m^3. The bulk of the standing stocks of carbon in the water presumably are non-algal and are believed to be detrital. It is this material that makes Millipore filtration so slow.

Only a very small part of the organic carbon in the sediments can be associated with living microalgae and it is safe to assume that the bulk is detrital.

TABLE VIII-1

CONCENTRATIONS OF CHLOROPHYLL a IN THE SEDIMENTS AT THREE STATIONS IN CARD SOUND ($\mu g/g$ DRY WEIGHT SEDIMENT)

	STATION		
	1	2	3
November, 1970	1.75	1.88	1.78
February, 1971	3.50	2.78	10.80
March, 1971	5.88	8.00	12.60
May, 1971	1.58	0.99	2.05

TABLE VIII-2

CONCENTRATIONS OF CHLOROPHYLL a IN WATER SAMPLES AT THREE STATIONS IN CARD SOUND (mg/m^3)

	STATION		
	1	2	3
December, 1970			
Surface Water	----	----	0.27
Bottom Water	----	----	0.25
March, 1971			
Midwater	<0.25	<0.25	0.32
May, 1971			
Surface Water	0.21	0.23	0.09
Midwater	0.17	0.25	0.21
Bottom Water	<0.17	<0.17	<0.17

TABLE VIII-3

STANDING STOCKS OF ORGANIC CARBON IN THE SEDIMENTS AT THREE STATIONS (mg/g DRY WEIGHT)

	STATION 1	2	3
March, 1971	2.6	3.5	11.1
May, 1971	22.0	5.0	17.1

TABLE VIII-4

STANDING STOCKS OF PARTICULATE ORGANIC CARBON IN THE WATER AT THREE STATIONS (mg/m^3)

Midwater	STATION 1	2	3
March, 1971	85	890	189
May, 1971	300	392	431

TABLE VIII-5

PLATE COUNTS OF MICROORGANISMS (MAINLY BACTERIA) IN SEDIMENTS AT THREE STATIONS (MILLIONS/g.d.w.)

	STATION 1	2	3
December, 1970	2.15	2.90	3.35
February, 1971	8.10	0.80	2.33
March, 1971	Method Failure		0.41
May, 1971	0.75	0.22	1.73

On the basis of present analyses, the mean organic carbon content is 460 g carbon/m^2 in the surface 5 cm but can range as high as 1245 g carbon/m^2 as in the samples from Station 1 in May.

We consider it important to take more extensive sediment samples to better characterize the distribution of detrital organic materials.

Plate Counts of Heterotrophic Microorganisms

With the medium in use, only bacteria have been recovered up to the present time. Viable counts in the water, as shown in Table VIII-6 are remarkably low but relatively uniform in terms of density.

Much higher numbers have been recovered from the sediments (Table VIII-5). Considering the strongly anaerobic nature of the sediments, these counts probably represent only a small proportion of the total population. Assuming an average cell size of 2 x 1μ, a cell moisture content of 50% and that 50% of the cell organic matter is carbon, it may be calculated that, in May, the populations recorded would have amounted to 17, 6 and 16 mg carbon/m^2 in the surface 5 cm at Stations 1, 2 and 3 respectively. With total particulate carbon levels of 1245, 360 and 410 g/m^2 in the top 5 cm at the same stations at this time, the bacterial populations recovered represent respectively 0.0013, 0,0016 and 0.0039% of the detrital carbon. The total population could represent at least 0.01% of the organic reserve, not including fungi, protozoa, etc.

Were the microbial populations to replace themselves every two hours, on the average, then complete turnover of the organic reserve would require something like three years. Although this is a purely speculative argument, it will be one useful point of reference in attempting to establish whether or not the Card Sound estuary is changing in character with time.

According to Heald (personal communication), mangroves in South Florida produce around 1-2 g carbon/m^2/day. If this material alone were to reach Card Sound at these levels/unit area, it is likely that total decomposition could be accomplished by the indigenous microflora. It is hoped that additional data and a refinement of techniques will improve the reliability of this type of budget keeping.

Carbon Fixation by Photosynthesis

Data for this work is listed in Tables VIII-7 and VIII-8. A considerable increase in activity was found to occur between March and May both in the sediments and the water column. Further, the levels of photosynthetic carbon fixation were much higher in the sediments than in the water column. Note that in March highest rates of carbon fixation were recorded in midwater. In May, however, highest rates were found close to the bottom.

TABLE VIII-6

PLATE COUNTS OF MICROORGANISMS (MAINLY BACTERIA) IN WATER AT THREE STATIONS (COLONIES/ml)

	STATION 1	 2	 3
February, 1971			
Surface Water	95	45	17
Midwater	74	38	38
Bottom Water	39	38	36
March, 1971			
Surface Water	--	--	25
Midwater	--	--	40
Bottom Water	--	--	91
May, 1971			
Surface Water	25	23	24
Midwater	27	19	31
Bottom Water	27	32	8

TABLE VIII-7

RATES OF PHOTOSYNTHETIC CARBON FIXATION IN SEDIMENT ALIQUOTS AT THREE STATIONS (mg C/m^2/hr)*

	STATION 1	 2	 3
March, 1971	30.8	65.9	68.5
May, 1971	106.4	190.0	237.0

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*Assumes all photosynthetic cells are at surface of sediment. Data based on sampling surface 5 cm.

TABLE VIII-8

RATES OF PHOTOSYNTHETIC CARBON FIXATION INTO CELL MATERIAL AT THREE STATIONS (mg C/m^3/hr)

	STATION					
	1	Mean	2	Mean	3	Mean
February, 1971						
Surface Water	----		----		1.50	
Midwater	0.91		----		----	
Bottom Water	----		----		----	
March, 1971						
Surface Water	1.15		0.73		0.73	
Midwater	1.69		1.60		2.44	
Bottom Water	1.74	1.53	0.91	1.08	1.66	1.61
May, 1971						
Surface Water	2.65		3.25		2.64	
Midwater	2.60		3.69		3.86	
Bottom Water	3.07	2.77	4.62	3.85	4.24	3.58

It is especially interesting that the mean rate of fixation/m^2/day (based on the hourly rate x 10) of 1.8 g carbon is at least equivalent to the rates of mangrove leaf and twig production close to 1.2 g carbon/m^2/day reported by Heald (personal communication). These data place microalgal photosynthetic processes in the sediments equal to other major productive components of this ecosystem.

A number of measurements of carbon fixation by several species of macroalgae have been obtained; all indicate extremely low levels of activity. Until the reliability of these data are checked more fully, this information will not be presented. The problem, if there is one, may be associated with seasonal growth and we require time to explore this possibility.

Nitrogen Fixation And General Metabolic Activity

Initial results suggested that nitrogen fixation was not occurring in Card Sound. Now, however, on the basis of much longer incubations, there is clear evidence for this type of activity. The quantitative basis, to date, is not particularly good so the data is not tabulated here. However, recent trials demonstrate that this activity and, at the same time, methane production can be measured at least as well as other processes. Early difficulties appear to have been associated with failure to maintain anaerobic conditions completely. The nitrogen fixation indicated by these studies is likely the activity of a mixed microflora rather than any particular species. Blue-green algae certainly do not appear to be important in this respect, at least to the present.

In future studies, reliable information should be obtained on oxygen consumption at the sediment surface, methane production below the surface, and nitrogen fixation. The capacity to measure these activities should place us in a strong position to evaluate the microbial component of the system in acceptable and useful quantitative terms.

SUMMARY

A program has been initiated to measure standing stocks of photosynthetic pigments, particulate carbon and microbial populations in the water and sediments at three stations in Card Sound. In addition, measurements are made of carbon fixation into cell material in the phytoplankton and benthic microflora as well as rates of sediment respiration, nitrogen fixation and methane production.

Data to the present indicate that microbial processes in the sediments must play a crucial role in the function of the Card Sound ecosystem.

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IX FUNGI*

GENERAL STATEMENT

A major source of organic material in Biscayne Bay is contributed by the mangrove system. In a study of the mangrove forests in Everglades National Park, Heald (1969) and Odum (1970) determined that over 80% of the organic debris produced by mangrove trees is through the leaves and that the annual contribution of debris to the estuarine ecosystem, through leaf fall, exceeds 3 tons (dry wt.) per acre. These authors reported that the fallen leaves are converted by microbial activity to detrital particles which support large populations of detrital consumers such as amphipods, nematodes, polychaetes, small crabs, shrimps and fishes. In turn, these detrital consumers are a primary source of food for game and commercial fishes such as tarpon, snook, grey snapper, sheepshead and spotted seatrout.

Because of the importance of this food chain to the estuary, it is necessary to ascertain the sequence of events in the degradation of the mangrove (Rhizophora mangle) leaves and the subsequent consumption of detritus by marine invertebrates. It should be possible through culturing and rearing studies to reproduce the system under laboratory conditions and study the effects of alterations of environmental conditions.

Fungi and nematodes, functioning independently and in association, are two of the important links in this food chain. It is the current assumption that fungi play a major role in the conversion of mangrove leaf carbohydrates to microbial protein which in turn is consumed by small invertebrates, such as nematodes that inhabit the decaying leaves. The heavy fungal infestation of the leaf is evident upon sectioning and microscopic examination of the leaf. In a study of elm leaves (Ulmus americana) Kaushik and Hynes (1968) observed an increase in protein during the degradation of the leaves in fresh water streams and attributed this increase to the associated fungi and not to the bacteria. It is quite feasible that a substantial basis for productivity in Biscayne Bay is dependent on the production of fungal protein as a food source for the detrital consumers.

A critical problem is the potential alteration of the composition of fungal communities, and their functions, within the ecosystem with consistently higher than normal temperatures. Such alterations in environmental conditions may cause an imbalance in stable fungal-plant or animal relationships. For example, the wasting disease of eel grass was caused by an infection of Labyrinthula (Johnson and Sparrow, 1961) effected by changes in salinity and possibly temperature. The addition of various other industrial and domestic materials to the Bay, such as sewage, insecticides, fuel oils, etc. could similarly affect fungal relationships in the mangrove detrital system and as a result the entire food chain. The

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*J. Fell, I. M. Master, R. Cefalu, S. Newell. Principle source of funding NIH Grant 5R01 FD 00031.

program that we have developed is designed to: (1) determine, on a seasonal basis, the fungi associated with the degradation process of the mangrove (Rhizophora mangle) leaves; (2) examine the protein production and ascertain which specific fungi are instrumental in the conversion process; (3) develop laboratory techniques for pure or mixed culture production of this protein in order to examine environmental effects on the degradation process and (4) through rearing studies to examine the subsequent effects on the feeding and life cycle responses of selected invertebrates.

Another source of organic material from the mangroves is made available through the degradation of the mangrove seedlings. These seedlings range in length from 15 to 29 cms. with an average dry weight of 10 gms. According to Davis (1940) each tree produces an average of 300 seedlings/year. The amount of organic material contributed by the mangrove seedlings has not been determined precisely, but it is estimated to be nearly equal to that contributed by the leaves. A program has been developed, as a doctoral dissertation by Mr. Steven Y. Newell, to ascertain the importance of this material to the ecosystem and to examine the sequence of events in the breakdown process.

In addition, because nematodes are one of the principal consumers of organic materials, we have undertaken an analysis of the nematode community structure in Card Sound and at Turkey Point in order to evaluate effects of alterations in environmental conditions. Nematodes are an excellent choice of biological organisms with which to work due to their small size and to the great numbers of individuals usually encountered from relatively small amounts of substratum, i.e. up to more than 500 specimens in 10 cc of surface bottom sediment. Marine nematodes have the further advantage that active migration is curtailed by the lack of pelagic life stages, along with morphological adaptations insuring against accidental removal from their habitats, i.e. the use of caudal adhesive organs and the habit of larger species of twisting around particles of substratum when disturbed. It would seem that only catastrophic movement of bottom sediments would be sufficient to seriously confuse the population structure at relatively stable localities. Even those areas continuously exposed to surf action are known to have nematode populations adapted to such extreme rigors.

METHODS

Mangrove Leaf Degradation Studies

Three collection areas have been selected for study: the mangrove swamp at Turkey Point, which is adjacent to the power plant and subjected to thermal effluents; Mangrove Point, which is approximately 3 1/2 miles south of Turkey Point and free from any power plant influences; an offshore station in Card Sound. This offshore station was included because of the large number of mangrove leaves that are swept into the bay where they are degraded. At the inshore collection areas, several station sites have been selected to reflect differences in temperature, salinity and tide.

The sequences of fungal infestation and protein formation were obtained by the following methods: dead yellow leaves were picked from the trees and placed in mesh bags with pore sizes of 2.5 mm sq (50 leaves/bag); these bags were tied at ground level below the low tide line. Samples were taken at 1-2 week intervals for a total of 3 months. Fungi were sampled by modifications of standard culture techniques and protein levels in the leaves by the Price (1965) modification of the Lowry *et al.* (1965) method. Relative amounts of carbon and nitrogen were determined with a Perkin-Elmer CHN analyzer.

In vitro degradation studies utilize naturally infested leaves, however, once the principle protein producing fungi are determined, pure culture studies will be undertaken. Emphasis will be placed on determining levels of proteins that are formed, under natural and abnormal environmental conditions, and the feeding and life cycle responses of various invertebrates, such as nematodes and harpacticoid copepods, to these alterations. In addition to temperature and salinity effects, various effluents such as fuel oils and pesticides will be considered.

Methods of studying degradation processes in mangrove seedlings are similar to the plan outlined for the leaves.

Nematode Community Analysis

The species and their abundance in several different habitats are now being determined; this should give basic diversity indices. Subsequently, a model of the community structure along predetermined trophic levels will be developed and statistically evaluated. Eventually, additional widely separated habitats will be compared, not necessarily on the basis of the same species being present, but on a comparison of energy conversion. The information from the various areas should result in a direct comparison of productivity and the effects of alterations in environmental conditions such as additions of pollutants.

Samples were collected on a quarterly basis in October, January, April and July in order to ascertain seasonal variations in populations that may reflect normal changes in temperature and salinity. Four stations were sampled in Card Sound and three at Turkey Point (see Fig. IX-1 and Table IX-1). At each station 8 sediment samples were collected with a corer made from a 30 cc plastic syringe. Each sample was taken to a sediment depth of 2.6 cm. and had a volume of 10 cc. The sediment samples were frozen and stored until processing. Water temperatures and salinities were recorded at each station.

Nematodes were extracted from the sediment in two steps. First, the thawed sediment was processed through the separator (see extraction procedure in progress report) where 90% of the animals were concentrated along with small particles of organic detritus. The coarse, heavy fraction was discarded. The nematode-detritus mixture was then fixed by adding an equal volume of 10% seawater-formalin. After at least 24 hrs. the nematodes were hand picked from the detritus using a dissecting microscope and a fine needle, and put into 10% glycerine in methanol for clearing. This solution was placed in a 55° C oven for 20 min. to evaporate the methanol. The nematodes prepared in this manner can be stored indefinitely in a desiccator.

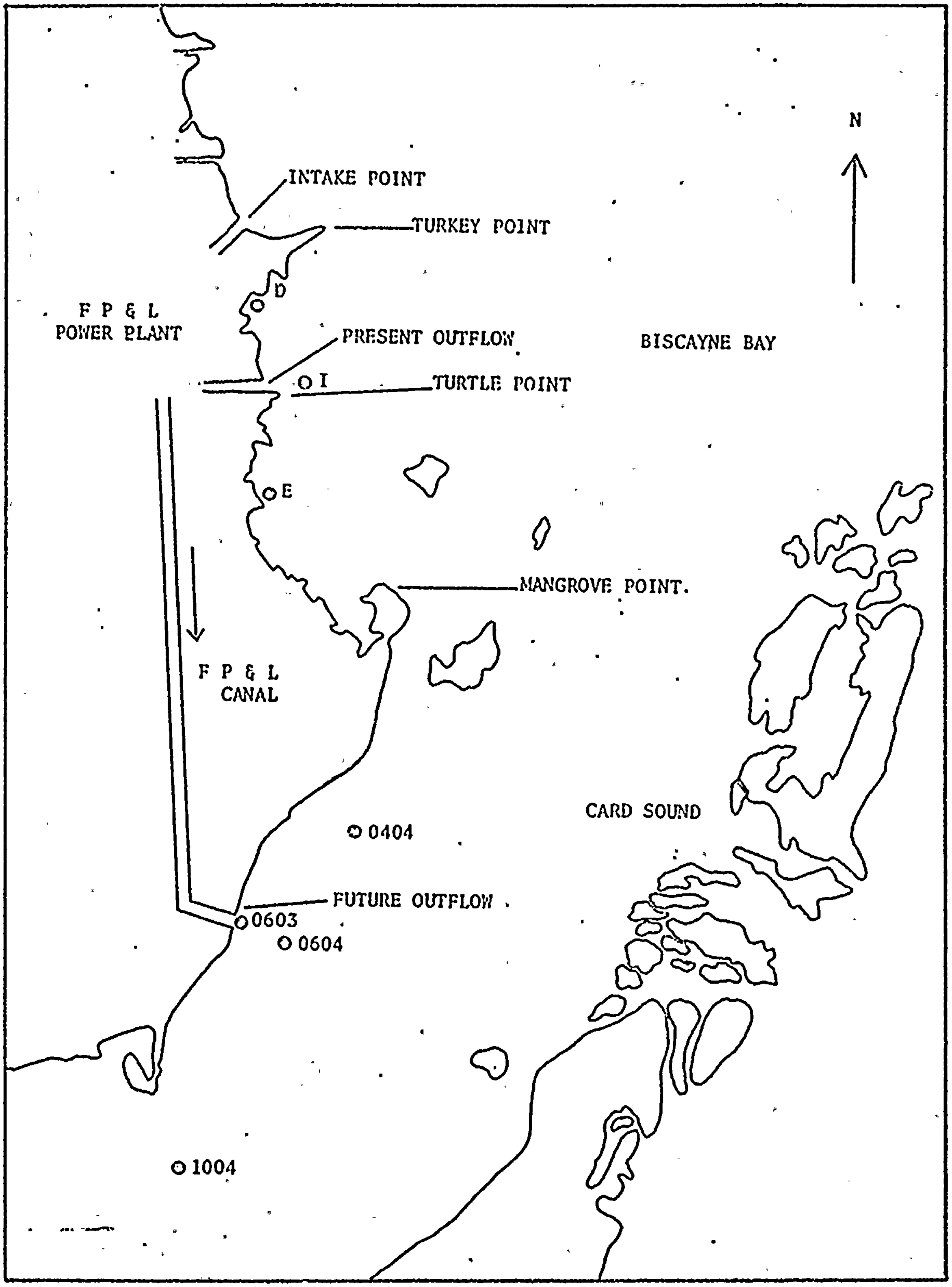

FIGURE IX-1 Nematode Collecting Stations

TABLE IX-1

DESCRIPTIONS OF NEMATODE SAMPLING STATIONS

Station	Location	Description of Sediment	Water Depth
0603	At mouth of present canal	Soft sand/peat	8 ft. depth
0604	1/2 mile east of 0603	Very coarse sand	8 ft. depth
0404	1 mile north-east of 0604	Similar to 0604	10 ft. depth
1004	2 miles south-west of 0604	Very soft silt/clay	8 ft. depth
Turkey Point I	Mouth of hot water outflow	Shallow sediment	4 ft. depth
Turkey Point D	1 mile north-west of I, within hot water effluent	Very dense grass	3 ft. depth
Turkey Point E	1 mile south-west of I, not affected by effluent	Very dense grass	3 ft. depth

Identifications were made by examination of the nematodes under a compound microscope. Easily recognized species were recorded, but unusual or unknown specimens were prepared in permanent mounts and kept in a special collection for reference or further identification. The majority of the taxonomically difficult specimens were shipped to B. E. Hopper (Research Scientist, Nematology Section, Entomology Research Institute, Canada Dept. of Agriculture, Ottawa, Canada and Adjunct Professor, RSMAS) for identification.

The current sampling schedule will be continued until the results of at least three years activities have been accumulated. Such an extended period is necessary to avoid errors which may accompany results gathered from a single seasons investigation. Sampling for three full years at the Card Sound sites, for example, will yield a total of 12 sampling periods, 48 sampling sites, 384 individual samples and a conservative estimate of some 40,000 nematode specimens distributed in over 100 species. This sampling program should be sufficient to detect seasonality within and between populations.

Data has been and will continue to be recorded in such a manner as to detect aberrations in the sex ratios of the various species. It is possible that physical events may be expressed not only in the ultimate population size of any particular species, but also in the distribution of the sexual forms of that species. Marine nematodes exist essentially as dioecious species, there being very few hermaphroditic and parthenogenetic forms. There is some evidence that more than one mode of reproduction may be operative in some species, i.e. of the genus *Viscosia*. Hopper and Meyers (1966) found that populations of *V. macramphida* (Chitwood, 1951) existing in degrading cellulosic water filters, maintained themselves under laboratory conditions without the males customarily encountered in their more normal sandy, oceanic habitats. Similarly, *Spilophorella paradoxa* (de Man, 1888) appears to exist in two reproductive forms, a dioecious population consisting of normal sized males and females, and a second form composed of enlarged individuals having the appearance and function of females. It is probable that these have a polyploidal chromosome number (unreported observations).

RESULTS AND DISCUSSION

Mangrove Detrital System

Fungi associated with leaf degradation: The fungi isolated from the leaves are still in the process of being identified, in most cases the identification has been limited to the genus. Species identifications were not usually attempted due to the considerable time required and the difficulties in fungal taxonomy. However, later in this study specific identifications will be made of those organisms found to be important in the food chain. To date, 56 different genera have been identified (Table IX-2) which probably comprise more than 90 different species.

Although many of the genera listed were only encountered infrequently, certain genera were prevalent and a sequence of infestation was apparent. The fresh growing leaves were often parasitized by *Pestalotia*, *Colletotrichum*, *Phyllosticta* and three unidentified ascomycetes. Several saprophytes also inhabited living leaves:

TABLE IX-2

PRELIMINARY LIST OF FUNGI ISOLATED FROM MANGROVE LEAVES

- Deuteromycetes
  - Order Melanconiales
    - Genera *Pestalotia*
      - *Colletotrichum*
  - Order Moniliales
    - Genera *Gonytrichum*
      - *Helminthosporium*
      - *Cladosporium*
      - *Cephalosporium*
      - *Fusarium*
      - *Verticillium*
      - *Cylindrocephalum*
      - *Aspergillus*
      - *Penicillium*
      - *Arthrobotrys*
      - *Gliocladium*
      - *Trichoderma*
      - *Stachybotrys*
      - *Botryosporium*
      - *Dendryphiella*
      - *Gloeosporium*
      - *Trichocladium*
      - *Geotrichum*
      - *Monocillium*
      - *Curvularia*
      - *Alternaria*
      - *Nigrospora*
      - *Paecilomyces*
      - *Cylindrocladium*
      - *Sporotrichum*
      - *Zygosporium*
      - *Cirrenalia*
      - *Isaria*
      - *Scolecobasidium*
      - *Cercospora*
      - *Beltrania*
      - *Epicoccum*
      - *Monilia*
      - *Dictyosporium*
      - *Pithomyces*
      - *Virgaria*
      - *Aureobasidium*
      - *Myrothecium*
      - *Stemphylium*
      - *Varicosporina*
      - *Cholobotryum*
      - *Idriella*
  - Order Sphaeropsidales
    - Genera *Phoma*
      - *Phomopsis*
      - *Phyllosticta*

- Ascomycetes
  - Order Chaetomiales
    - Genus *Chaetomium*
  - Order Sphaeriales
    - Genus *Lulworthia*

- Phycomycetes
  - Order Saprolegniales
    - Genera *Schizochytrium*
      - *Thraustochytrium*
  - Order Mucorales
    - Genus *Mucor*
  - Order Peronosporales
    - Genus *Phytophthora*
  - Order Chytridiales
    - Genus *Rhizophydium*

- Myxomycetes
  - Order Labyrinthulales
    - Genus *Labyrinthula*

- Actinomycetales
  - Genus *Streptomyces*

Nigrospora, *Zygosporium*, *Alternaria*, *Phoma*, *Cephalosporium*, *Fusarium*, *Verticillium*, *Cylindrocephalum*, *Curvularia*, *Dendryphiella* and *Cladosporium*. Activities of the parasites probably diminish with the initiation of decay as their occurrence was less frequent with progression of decay.

In the early stages of decay, after 1-3 weeks of submergence in the water, two phycomycetes, *Phytophthora* and *Rhizophydium* were extremely abundant, particularly in the spring and early summer. They were rarely encountered after three weeks of decay or at other times of the year. Certain genera, particularly *Cephalosporium*, *Fusarium* and *Verticillium*, were found throughout the decay process. In later stages of decay, generally after three weeks, the cellulolytic fungi were prevalent, *Lulworthia*, *Cirrenalia*, *Dictyosporium* and *Zalerion*.

Most species are ubiquitous in the study area, although there are some species that appeared to have geographic and tide limitations. However, at present the data is insufficient to rule out sampling error.

It is not possible at this time to ascertain which fungi are instrumental in the decay process and it is probable that some genera, such as *Aspergillus*, *Penicillium* and *Trichoderma*, are transients. Evidence for this is that they were removed by surface sterilization of the leaf.

Fungi associated with mangrove seedlings: Mr. Newell has finished 6 months of his doctoral research and has made the following preliminary observations. The normal seedlings which were placed in the water had not undergone any externally noticable decay, although there were a considerable number of fungal genera associated with the epidermal and cortex layers. It is normal for a large percentage of the seedlings to be injured by insects, etc., while they are on the tree; also they are partially eaten on the ground by land crabs, hermit crabs, rabbits, etc. Therefore, the seedlings enter the estuarine system in an injured state where they decay at varied rates. The decay of artificially injured seedlings was studied and it was found that the fungi invade primarily those tissues exterior to the vascular tissue, i.e. the cortex, epidermis and phelloderm. It is suggested that the role of fungi in the degradation of the seedlings is to breakdown the epidermal and cortex layers, hence the seedlings physical defenses, and allow a heavy colonization of the interior by bacteria, protoza, and nematodes. Presumably they obtain their nourishment from the large amounts of starch in this interior region.

Protein levels associated with leaf degradation: Portions of the leaves that were incubated in the field and sampled for fungi were dried, ground and sampled for protein and total nitrogen. This study has not been completed and these results must be considered as preliminary observations.

In general, it was found that there was an increase in protein after 7 to 14 days of incubation that may continue for 2 months. This increase varied considerably, but on the average doubled the protein content; starting at about 2% protein/leaf dry wt. with an increase to 4% and an extreme high of 8%. It must be emphasized that the increases observed were variable and not consistent

as the protein levels may continue to increase, level off, or decrease. Nitrogen values, as determined with the CHN analyzer, indicated similar, though erratic increases; beginning at about 0.4% N/dry wt. with increases to about 0.9 to 1.0% after 6 weeks.

There are difficulties in this type of sampling, particularly where the data is used in interpreting the reasons for the protein increase. Microorganisms, particularly fungi, are not the only organisms inhabiting the leaves. As previously discussed, the leaves were heavily infested with a variety of invertebrates; the hypothesis that the protein originates largely from the utilization of leaf carbohydrates (plus inorganic nitrogen from sea water) requires considerable scrutiny. It is felt that the best approach will be through controlled degradation studies in the laboratory. The first attempts have shown promise of success; using naturally infected leaves, it appears that the same degradation process that occurs in the field can be duplicated in the laboratory. This includes the growth of the various invertebrates as well as the microbes. In experiments now underway, the population components of the system are being examined individually in pure culture to determine specific contributions to the protein formation process.

Environmental effects on the degradation process: Experimentation to date has been limited to temperature effects on available laboratory systems. The first set of experiments compared the isolation of fungi from leaves incubated at the routine isolation temperature of 25°C and at 37°C which is the summer high in the Turkey Point mangroves. While a wide variety of fungi were isolated at lower temperatures, no fungi were observed to be growing on any of the leaves at 37°C. This study was followed by an examination of 53 isolates representing more than 25 different genera of fungi. These fungi had been isolated from mangrove leaves and seedlings and were grown on corn meal agar at 24, 31 and 37°C. All isolates grew at 24 and 31°C, but only 10 grew at 37°C and 18 isolates were killed at 37°C. It would be possible to postulate a significant effect on the food chain by this temperature increase, but considerable additional experimentation will be required before any conclusions can be developed.

Culturing of associated nematodes: Although a fairly new innovation in marine nematology, culturing has been proved to be feasible by several researchers (Dougherty, 1960; Lee, 1970; Nicholas, 1959; Tietjen, 1970). Our interest in nematode culturing is to determine the role of these organisms in the detrital food chain and to examine the effects of alterations in environmental conditions.

A monhysterid nematode, tentatively identified as *Diplolaimelloides delyi* (Andrassy, 1958; Timm, 1966), has been found to be abundant within decaying mangrove leaves and seedlings. This animal is considered an omnivorous microbial feeder that appears to consume bacteria and fungi. It has, during these studies, been observed inserting its head into phycomycete sporangia apparently consuming the cytoplasmic contents.

Culturing techniques have been successful; the animals can be raised on artificial media, using bacteria as the principal food source. A wide variety

of media has been employed with varying degrees of success; however, optimal growth and reproduction occur with corn meal agar. All stages of the life cycle of the nematode can be observed and, through subculturing, they have been maintained for a period of 5 months with an average life cycle of 6 days.

Studies on the ability of this animal to utilize various food sources, particularly a variety of fungal species, are underway. There are some preliminary indications, that with alterations in food source, significant changes in the life cycle occur. As soon as it is possible to produce artificially decaying leaves, the responses of the nematode populations in that system will be examined.

Nematode Community Analysis

Extraction procedures: Because of the need for accurate quantitative data, considerable experimentation was devoted to obtaining a technique for extraction of nematodes from the sediment samples. For various reasons the reported methods such as decanting and sieving, the Baerman funnel, flotation and centrifugal flotation techniques were found unsuitable for this work. In contrast, extraction by elutriation gave significantly higher yields. Because of the rather elaborate equipment used in previously reported elutriation techniques, an inexpensive, easily constructed apparatus, for simultaneously processing all 8 samples from a collection site, was developed. Separation was effected in a glass tube, by an upward current of sea water passing through the sediment sample so that the nematodes and particles of low specific gravity (organic matter, plant detritus, silt clay) were carried over, while the heavier materials (sand, shell fragments and other large particles) remained. The overflow was collected in a sieve with 42μ diameter openings. The sea water was recirculated through the system by a positive pressure pump. The material collected on the sieve was preserved and the nematodes were later picked by hand for the final separation. The extraction yield was 90% or better; the loss was 1% from that which remains with the heavy fraction, 1-6% that passes through the sieves, and 3% that is lost in handling, picking and counting.

Effects of thermal effluents on benthic populations: Currently a baseline of community structures under existing environmental conditions is being established; this will permit the interpretation of any alterations that accompany any changes in water temperatures at Turkey Point and Card Sound.

At Turkey Point samples were taken yearly (November, 1968, 1969, 1970) and quarterly following the 1970 sample (January and April, 1971). Card Sound collections were quarterly beginning in November, 1970. These collections are in various stages of completion and the results discussed below are based on this incomplete data and can only be considered as tentative observations.

Card Sound appears to have a unique nematode fauna; the species that occur there are either rare or have never been collected from the rest of Biscayne Bay. The most prevalent families in Card Sound are Desmodoridae and Desmoscolecidae, whereas in Biscayne Bay members of the Oncholaimidae, Monhysteridae, Cyatholaimidae and Chromadoridae are frequently encountered (Hopper and Meyers, 1967; Weiser and Hopper, 1967). These preliminary results in Card Sound indicate that Station 1004

(Figure IX-1) has the most numerous nemic fauna (275 animals/sample, 80 different species); 0603 has the most diverse fauna (60/sample, 32 spp.); while Station 0404 (30/sample, 11 spp.) and 0604 (30/sample, 13 spp.) were quite similar. This similarity could be a reflection of similar environmental conditions including the types of sediments (Table IX-1). Species distributions followed a similar pattern. Although many of the same animals appeared throughout the entire area, certain species were prevalent at specific stations. The prevalent species at Station 1004 were either restricted to low numbers at the other stations or were not found. Stations 0404 and 0604 had nearly identical community structures. Station 0603, with its diverse populations, contained many of the species found at the other stations plus several that had not been previously collected. These results support unreported observations by Hopper and Meyers in Biscayne Bay, that discrete community structures were attendant within specific habitats of relative stability.

In evaluating this data, the particular concern was with the statistical accuracy resulting from the sampling procedure. As anticipated, variations were found among samples taken at a particular station. However, statistical computation showed a comparable variance among the four areas and that the improvement of these variance figures by two would require taking four times as many samples; this is not feasible under existing conditions.

The collections from Turkey Point were quantitated for 1968 and 1969 but identifications have not yet been made. As explained under Extraction Procedures, techniques used at that time were not sufficiently refined to produce data that could withstand rigorous statistical treatment. What can be reliably seen is that Turkey Point Stations I and E had larger numbers of nematodes per sample than three of the Card Sound areas, approaching the large numbers found at Station 1004. Turkey Point Station D, however, contained lower numbers of animals, more like the three Card Sound stations.

SUMMARY

The degradation of the mangrove (Rhizophora mangle) leaves, and possibly also the mangrove seedlings, contributes a significant portion of the organic material that is the basis for the estuarine food chain. Because of the rapidly changing conditions in Biscayne Bay, it is important to understand the degradation system and, through laboratory modeling, to determine the effects of differing environmental conditions on the system. Our present studies are designed to determine the specific micro-organisms that convert the mangrove carbohydrate to microbial protein during the leaf degradation process and to study the incorporation of this microbe-mangrove complex into the food chain through detrital feeders such as the nematode populations.

Currently, the individual components of the system are being examined. Fifty-six different genera of fungi have been identified from the degrading leaves and preferential seasonal and sequential infestations have been noted. Temperature studies suggest an inhibiting effect on the degradation process at high (37°C) temperatures. Studies of the seedlings are also underway. Preliminary protein and nitrogen studies have indicated significant increases during the degradation process. Laboratory controlled degradation studies have been initiated and culturing of nematodes associated with the degradation leaves has been successful.

Because of the possible importance of nematodes in the food chain as a direct link from the detritus to the estuarine fishes and invertebrates, the possible effects of thermal effluents on community structures are being examined in Turkey Point and Card Sound. Baseline studies of the community structures in both regions are in progress and will be continued through the shifts in the location of thermal discharges.

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X GRASSES AND MACROALGAE*

INTRODUCTION

The most important community in Biscayne Bay is that of the turtle grass, *Thalassia testudinum*. This community acts as a primary producer and substantial contributor to the detritus. In addition, the plants are necessary for the shelter and the substrate of the small organisms including foraminifera, polychaetes, carideans, molluscs, crabs and small fishes. Also, the extensive root system of the grass and rhizoids of the algae act as sediment accumulator and stabilizer (Hay, 1967). Some of the inorganic sediment comes directly from the tests of foraminfera and from the calcareous algae.

The grass is often thickly interspersed with macroalgae such as *Penicillus capitatus*, *Halimeda incrassata*, and *Laurencia poitei* (extremely abundant in some areas). Less frequently encountered macroalgae are *Anadyomene stellata*, *Digenia simplex*, *Rhipocephalus phoenix*, *R. oblungus*, *Udotea flabellum*, *Avranvillia levis*, *Batophora oerstedii*, *Caulerpa serpularioides*, *Dictyosphaeria cavernosa*, *Valonia macrophysa*, *Padina vickersiae*, *Acetabularia crenulata*, *Halimeda tuna*, *H. opuntia*, the grasses *Syringodium* and *Diplanthera wrightii*.

The role of the grass and algae in the conversion and storage of energy has not been studied so that at present its relative importance is not clear. However, the large standing crop in the Bay and the rapid rate of turnover would argue that a large amount of carbon is fixed, and that a large amount of energy is stored by the *Thalassia*. Although Odum (1970) argued that in some regions close to shore the primary source of the detritus is from mangrove leaves, it appears that the grass-algae community is a significant contributor both offshore and inshore.

Humm (1964) and Voss *et al* (1969) reported on the grass and algae in the Bay and Jones (1968) has summarized the literature on *Thalassia*. Although no previous work prior to the Turkey Point investigations was done on *Thalassia* temperature limits, Beibl and McRoy (1971) carried out work on heat stress on *Zostera marina*, a subtidal temperate marine grass related to *Thalassia*. They found that it could withstand temperatures only up to 30°C after 12 hours exposure. The tolerable midsummer high temperature was 27°C and the photosynthetic rate fell dramatically very near 30°C. Beibl (1962) also studied the temperature dependencies of several tropical marine species which are important in Biscayne Bay, including *Laurencia poitei* which he found could withstand temperatures up to 35°C for 12 hours. This research by Beibl and co-workers was of limited applicability because of the limited number of plants observed and the very short time period of observation. Jones (1968) noted a marked decrease in the rate of photosynthesis of *Thalassia in situ* in Biscayne Bay at 30°C to 35°C.

Zieman (1970) measured the growth rate of leaves, the number of blades, and the rate of emergence of new blades of *Thalassia* at Turkey Point. He stated that 50 to 60 acres at the mouth of the canal delivering heated effluents had been denuded of *Thalassia* between June, 1968, and September, 1969. In addition,

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* A. Thorhaug

an area of 50 to 60 acres was "virtually bare"; another 70 to 75 acres had some Thalassia populations, but the algae populations were "almost completely destroyed" An additional 160-170 acres showed some damage to the algal populations.

The investigation now underway includes a study of the effect of heated effluents at Turkey Point and the formulation of a baseline for Card Sound. When Zieman (1970) began his study at Turkey Point, the effluent was already present. In this report, data from April, 1970 to May, 1971, are presented and an attempt is made to incorporate Zieman's earlier data. The study at Card Sound will provide information on the distribution, abundance, growth, turnover rate, and seasonal variation of grass and macroalgae. In addition, it is hoped that this information will assist in evaluating the Turkey Point data. Hopefully, useful predictions of the effect of heated effluents on tropical marine grasses and algae will result.

METHODS

The effect of heated effluents on marine grasses and macroalgae is a complicated ecological and physiological problem. It is made more difficult when tropical organisms are being tested since scant information is available on the ecology of tropical estuaries. With the exception of the data presented in Section XI of this report and a very small amount of information on some of the dominant species in Southeast Florida (Biebl, 1962), no information is available about the death of these tropical marine plants. To assist in the design and interpretation of this work, a panel of distinguished investigators in marine plant ecology and temperature responses of marine plants was consulted. They include: (1) Prof. L. R. Blinks, Marine Algal physiologist and ecologist, Stanford University; (2) Prof. Harold Humm, Marine plant ecologist and systematist, University of South Florida; (3) Prof. Richard Biebl, Algal physiologist, University of Vienna, Austria; (4) Prof. Jack Dainty, Plant ecologist and biophysicist, Chairman, Dept. Botany Univ. Toronto; (5) Prof. Richard Newell, Marine ecologist and physiologist, University of London and (6) Dr. William Doyle, Marine algae ecologist, University of California at Santa Cruz.

These investigators suggested various procedures and the following methods were devised from their advice, keeping within the budget, time and personnel.

Field Procedures for Thalassia

Eight of the 15 stations of Zieman (1970) were continued in the present study. In addition to these, 16 stations were selected in Card Sound (Figure I-3) after consulting with Dr. Rooth and Mr. Lee regarding the most probable effluent path in Card Sound.

In the Turkey Point area counting was done with $1/25\text{m}^2$ aluminum (6061-T6 alloy) squares. An additional smaller square $1/100\text{m}^2$ was used to define the area in which the Thalassia blades were marked for growth and production studies.

In Card Sound a $1/25\text{m}^2$ frame was used for counting in stations where Thalassia blades were abundant ($>$1,000 blades/m^2). In areas where Thalassia was sparce ($<$1,000 blades/m^2) a square $1/4\text{m}^2$ was used. Comparative counts were made to permit statistical evaluations.

In both Turkey Point and Card Sound the field sampling procedure was: a) Grass blades were counted biweekly during the first and third weeks of each month (Zieman, 1970). During the summer of 1971, weekly counts are being made at Turkey Point to obtain better resolution of heat-induced changes in Thalassia density; b) The marking square was placed near the permanently fixed counting square and the individual blades were marked in the first week of the month with plastic-coated staples (Zieman, 1970). The staples were placed at the point where the grass blades emerged from the stipes; c) Collecting was accomplished by breaking off at the point where the blades emerged from the stipes, all of the blades within the marking square; d) Each counting square was photographed during the third week of each month. This was accomplished with an underwater camera and strobe. The same camera angle to the square was used each time so that the pictures for any one square may be superimposed and a sequence of plant succession recorded; e) Peripheral data, including information on attached animals and plants, fish, water turbidity, wind, current, etc.

Field Procedure for Algae

Of the original 15 algal stations at Turkey Point, 8 have been retained. In Card Sound, aluminum frames were placed at 16 stations in March, 1971. The sampling procedures were significantly modified from those of Zieman (1970) and consisted of: a) The algae in a one square meter area were counted biweekly (during the summer of 1971 counting is being done weekly). Each of the meter squares was subdivided into 4 equal sections with 1/8" polyethlene cord to facilitate counting. The number of each species present in each quadrant was recorded and can be used as replicate counts. The number of plants of each species which were in the reproductive phase were recorded. The number of juvenile, scenescent and dead and/or dying plants of each species was also recorded; b) Growth of algae was determined by measuring plants in one of the $1/4m^2$ quadrants on a biweekly basis. Measurements of Penicillus, Halimeda, Rhipocephalus, Udotea and Avranvilla were measured with vernier calipers according to the methods of Thorhaug (1965). A method for measuring the anastomosing red alga Laurencia and for identifying an individual plant of this "rolly moss" is being devised; c) Photographs were taken of the algal squares in a similar manner to that described for Thalassia.

Laboratory Procedure for Thalassia Growth and Weight

The blades collected in the field were measured in a manner similar to that of Zieman (1970). For each station: a) Blades were measured from the bottom of the blade to the bottom of the staple; b) Length of all blades was measured; c) Width of all blades was measured; d) The blades were divided into two groups for weighing: new blades and mature marked blades; e) Each group was washed in 5% reagent grade phosphoric acid for 1-5 minutes (until clean) while being shaken. This removed attached organisms, predominately foraminifera and micromolluscs. The blades were then washed with tap water; f) The new growth (below the staple) was divided from the rest of the blade; g) The two groups (new blades and new growth of mature blades) were ashed for 3 days at 110°C, then cooled in a desiccator and weighed in random order.

Mathematical Procedure

The abundance of grasses was reported in RESULTS as the number of blades/m^2, calculated directly from field counts. Growth was reported as cm^2/blade/day. It was calculated from marked specimens by multiplying width times length of growth since marking. The thickness was relatively constant and below our precision of measuring.) Dry weight was reported as g/m^2/day. We have selected these methods of analyzing the grasses and algae for several reasons. First, the total abundance growth and biomass reflected our visual estimations quite well. Second, with many non-biologists utilizing this data, we felt that the most direct expression would be the clearest.

Two major criticisms are involved in the use of $\overline{H}$ measurements of algal diversity previously used (Zieman, 1970). First, these tropical marine macroalgae do not follow the usual cycle or distribution patterns for which these theories were devised. Second, can heat stress and "indirect" heat death (Levitt, 1956) adequately be described by information theory?

The assumption that thermal stress can be identified and explained in the context of information theory has been made by Yockey (1958), who compares high temperature heat killing in insects to scenescence and radiation death in these species and explains all three in terms of information content of these systems. Zieman (1970) assumed that what Levitt terms "indirect" heat death (death due to temperatures close to those naturally encountered and survived), not high temperature death such as that studied by Yockey, could be described by information theory. Even without a discussion of the basic thermodynamic principles it is not clear, and has never been adequately tested, what occurs to the entropy or information content of the organism under heat stress. Thus, to make this assumption that information theory can describe indirect heat death appears premature. A straightforward description of abundance, growth rate, state of health, (a strong indicator of temperature stress) and biomass appears preferable.

The original diversity concept of Margalef (1968) was based partially on a population of planktonic organisms. The comparison with other methods of measuring diversity was developed by Saunders (1968) who studied populations of shallow tropical and deep-sea polychaetes and bivalves which were usually in excess of 200 individuals. It is stated by Saunders in his conclusions that in small-sized samples, this information function will not hold. In addition, the chief method of propagation in the algal species studied is asexual. This produces large clumps of daughter plants around a parent plant and ultimately leads to extreme patchiness. Thus, there are often a great number of individuals of one species in a particular area while a few meters away there are a great number of a second plant. This decrease in diversity is often not associated with stress as discussed by Saunders but rather by time and space domination due to asexual propagation.

We have noted from field and laboratory experience that temperature stress above the mean mid-summer high eventually weakens the green and red macroalgae. The temperature-stressed physiological condition identified by morphological changes can be measured due to the cooperative field and laboratory work and appears as a better indicator of stress than the $\overline{H}$ index.

RESULTS AND DISCUSSION

Turkey Point

The following results will include the work of the present investigators from summer 1970 to May, 1971. Where possible, the data of Zieman (1970) has been utilized to give a long-range view to interpret the events we have seen during the past year.

The principal findings of the past year for the grass and macroalgae were that: 1) In an area near the mouth of the effluent canal in which the mean temperature was elevated 5°C, blue-green algae became the dominant species and grass and macroalgae virtually disappeared. Thalassia, Penicillus, Halimeda and Laurencia virtually disappeared. A few Diplanthera plants, Acetabularia and Batophora, appeared during the winter months; 2) In an area where the mean annual temperature was +4°C above ambient, growth and abundance of Thalassia and other macroalgae were much less than at stations with lower temperature.

Station 52 (see Figure I-2) was situated well away from the shoreline and furthest from the mouth of the effluent canal. The seasonal fluctuation of mean temperature was from 16°C in December, 1970, to 32.5°C in mid-summer 1969 and 1970. Abundance of Thalassia blades and growth per blade fluctuated seasonally (Figures X-1 and X-2). In the spring of 1969 and 1970, there was an increase in number of blades as the temperature increased. When the temperature exceeded 31°C, the abundance of blades fell. In the fall, as soon as the mean daily temperature fell below 30°C, there was an increase in the number of blades (especially in the fall of 1969). However, as the temperature dropped further, the abundance fell to a low winter value, which was retained until warming in the spring. Other conditions such as shortened length of day were also minimal in winter and low temperature cannot be isolated presently as the single cause of low abundance. It was noted that the low winter level in 1969 (approximately 1,700 blades/m^2) was lower than either 1970 (approximately 2,800 blades/m^2) or 1971 (approximately 2,800 blades/m^2). The abundance in the winters of 1969 and 1970 could be interpreted as showing a dormancy period or time of no appreciable changes in growth at temperatures below about 22°C.

Biomass (measured as g/m^2/day) increased in the spring of 1970 from the low December values. There was a drop in July followed by an increase in August. Finally a drop occurred in December and a minimum was reached in April (Table X-1). The increase in biomass was much stronger in the fall of 1971 than the fall of 1970.

The algae at Station 52 were mainly Penicillus capitatus, Halimeda incrassata, Acetabularia crenulata, Laurencia and Valonia. Anadymone was common in spring and summer. Digenia simplex was found in July and December, 1970. Rhipocephalus and Batophora were occasionally present. Although incomplete information is available from the summer of 1969, the general pattern (Table X-2) appeared to be that H. incrassata was abundant in spring and summer and less abundant in winter. In December, 1970, there was an increase in Halimeda, but it was not as strong as that seen at Station 35. There is not a large population of Halimeda at present, nor

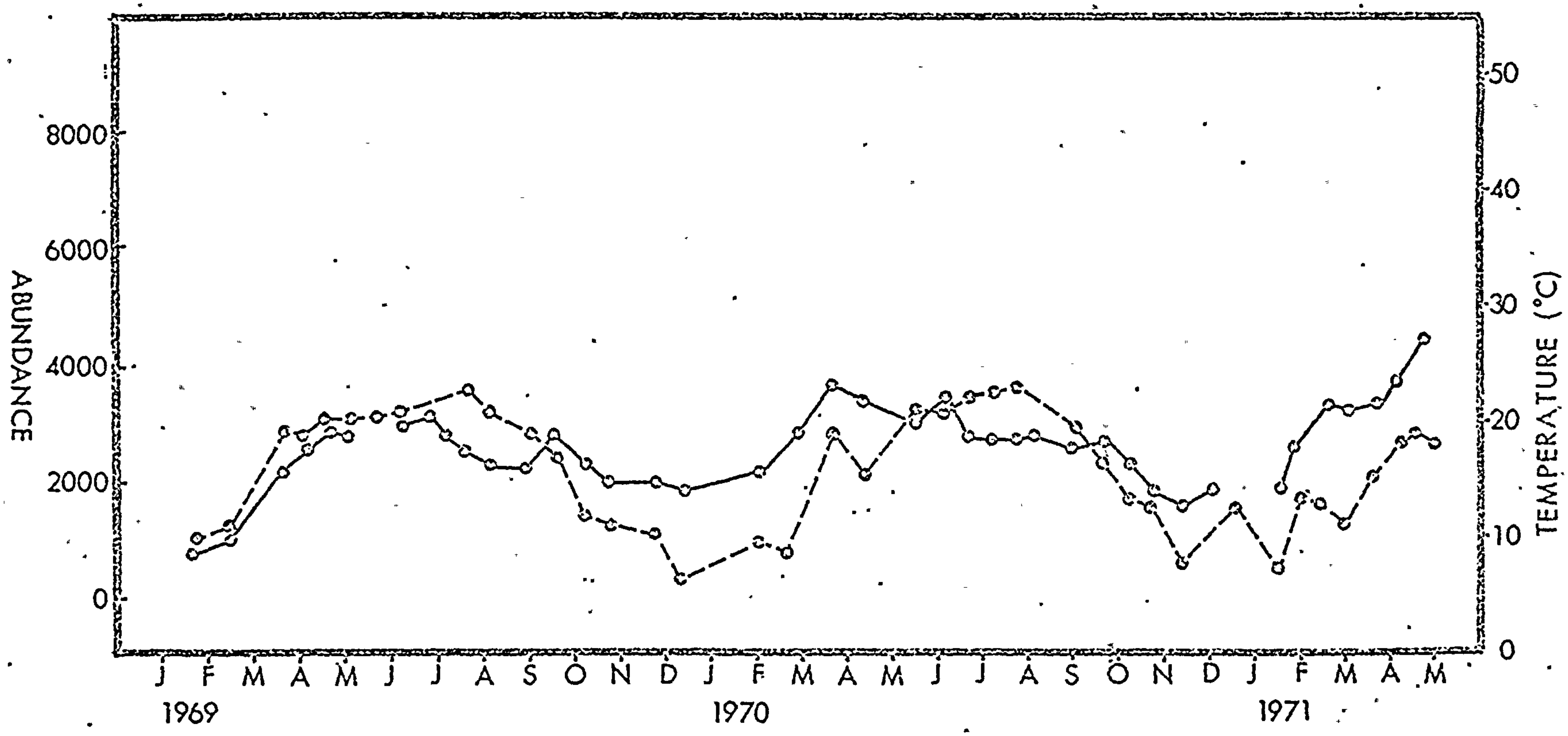

FIGURE X-1 Turkey Point, Biscayne Bay, Florida, Station 52, Mean Temperature (dotted line) and Thalassia abundance (solid line) per square meter

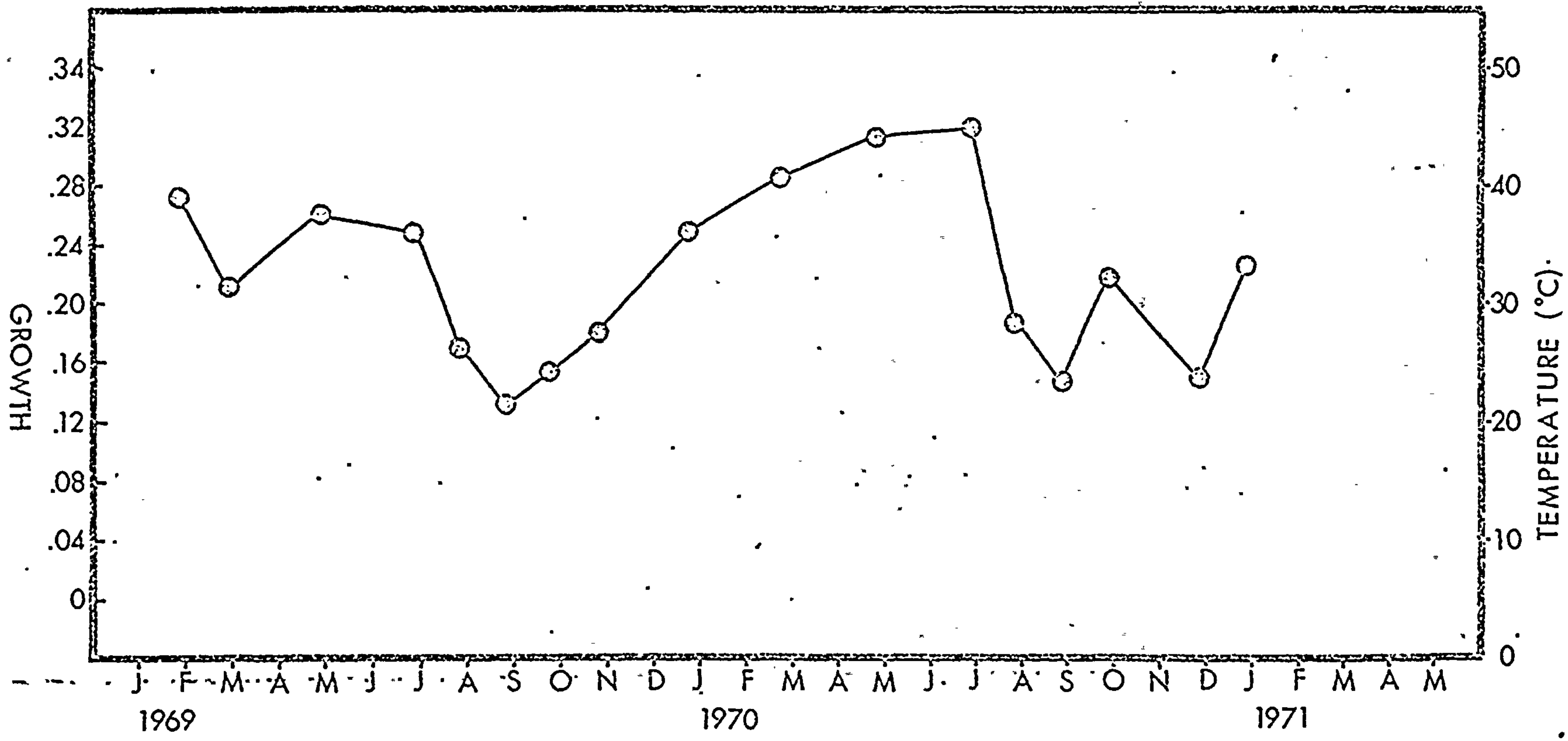

FIGURE X-2 Turkey Point, Biscayne Bay, Florida, Station 52, Mean <u>Thalassia</u> growth (cm^2) per blade per day. (Dotted line indicates unavailable data)

Table X-1, Turkey Point, Key Biscayne, Florida Stations, <u>Thalassia</u> abundance per square meter, mean grams of dry weight (biomass) of new growth per blade per days, and mean square centimeter of growth per blade per day versus monthly temperatures.

TURKEY POINT THALASSIA SUMMARY

	STATION 13				STATION 14			
DATE	T°C	ABUN.	BIOMASS	GROWTH	T°C	ABUN.	BIOMASS	GROWTH
3/7/69	21.3	2450			23.0	2525		
3/20/69	20.7	2850	-*	-	22.4	2425	-	-
4/23/69	29.1	4225			30.8	3625		
5/9/69	28.3	4650	.062	.106	30.0	3500	.093	.110
5/22/69	30.6	4925			32.3	3750		
6/4/69	30.5	4725	.036	.121	32.2	3650	.040	.113
6/25/69	30.8	4900			32.5	4275		
7/10/69	30.4	4900	.040	-	32.1	4500	.037	.128
7/22/69	30.8	4900			32.5	4550		
8/6/69	31.4	4350	.047	-	33.1	3750	.028	.077
8/19/69	32.8	4900			34.5	4000		
9/3/69	30.7	5425	.064	.149	32.4	4850	.041	.098
10/1/69	29.0	4225			30.7	5175		
10/14/69	27.7	5300	.032	.085	28.4	4925	.050	.123
11/11/69	22.0	5800			23.7	4850		
11/25/69	21.5	5025	.024	.072	23.2	4450	.045	.138
12/29/69	20.9	3525			22.6	3425		
1/13/70	16.7	3275	-	.113	18.4	2700	-	.116
3/3/70	19.9	2850			21.6	2875		
3/23/70	18.8	3700	-	.094	20.5	3600	-	.127
4/29/70	29.1	4750			30.8	4075		
5/12/70	25.4	4650	.142	.102	27.1	4425	.163	.168
6/18/70	30.9	5200			32.6	4825		
7/8/70	31.0	5625	.073	.079	32.7	4475	.103	.112
7/21/70	32.2	4800			33.9	4775		
8/5/70	32.4	4750	.196	.148	34.6	4625	.154	.124
8/20/70	32.8	4600			34.5	4875		
9/2/70	33.0	4600	.203	.110	34.7	4425	.168	.099
10/2/70	29.9	4575			31.6	4600		
10/15/70	26.7	4750	.294	.121	28.4	4850	.154	.137
11/9/70	23.6	4625			25.3	4300		
11/23/70	23.6	4775	.177	.059	22.3	4150	.259	.079
12/16/70	18.2	3525			19.9	3600		
1/4/71	20.4	3200	.167	.068	22.1	3700	.131	.074
1/19/71	23.2	-			24.9	-		
2/4/71	20.4	-	-	-	22.1	-	-	-
2/19/71	17.5	3875			19.2	3550		
3/1/71	24.0	3875			-	-		
3/19/71	23.5	4675	.031	.094	25.7	4500	.038	.123
4/6/71	21.2	4300			22.9	4775		
4/23/71	25.3	3450	.031	.071	27.0	4100	.046	.113
5/6/71	28.4	4325			30.1	5175		
5/18/71	29.8	4950	-	-	31.5	5325	-	-
6/2/71	28.1	5550			29.8	5525		

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* - indicates missing

	STATION 16				STATION 24			
DATE	T°C	ABUN.	BIOMASS	GROWTH	T°C	ABUN.	BIOMASS	GROWTH
3/7/69	23.5	2250						
3/18/69	22.9	2725	-	-	23.2	2175	-	-
4/22/69	31.3	4625			31.6	2775		
5/6/69	30.5	3825	.160	.185	30.8	3400		.193
5/21/69	32.8	3800			33.1	3625	.103	
6/3/69	32.7	5200	.073	.165	-	-		
6/25/69	33.0	4225			33.3	3150		
7/10/69	32.6	4025	.039	.119	32.9	3350	-	.179
7/22/69	33.0	3875			33.3	3300		
8/6/69	33.6	4275	.019	.060	33.9	3325	.040	.106
8/19/69	35.0	4225			35.3	2675		
9/3/69	32.9	3950	.050	.143	33.2	2950	.041	.064
10/1/69	31.2	3725			31.5	3650		
10/14/69	29.9	4175	.041	.089	30.2	4025	.022	.085
11/11/69	24.2	4100			24.5	3875		
11/25/69	23.7	3600	.053	.118	24.0	3750	.062	.039
12/29/69	23.2	2575			23.4	3425		
1/13/70	18.9	2925	-	.071	19.2	3325	.018	.047
3/3/70	22.1	3075			22.4	3350		
3/23/70	21.0	3800	-	.147	21.3	4200	-	.126
4/30/70	31.3	4450			31.6	4900		
5/12/70	27.6	4600	.168	.171	27.9	5175	.118	.124
6/18/70	33.1	4325			33.4	5950		
7/8/70	33.2	4550	.127	.116	33.5	5325	.139	.084
7/21/70	34.4	4075			34.7	4500		
8/5/70	34.6	3875	.134	.123	34.9	3975	.235	.088
8/20/70	35.0	4075			35.3	4325		
9/2/70	35.2	4025	.168	.134	35.5	3625	.149	.022
10/2/70	32.1	3375			32.4	2325		
10/15/70	28.9	3650	.243	.169	29.2	2200	.098	.074
11/9/70	25.8	3650			26.1	5125		
11/23/70	22.8	3525	.210	.059	23.1	3925	.149	.059
12/16/70	20.4	2950			20.7	4875		
1/4/71	22.6	2650	.175	.081	22.9	4300	.085	.068
1/19/71	25.4	-			25.7	-		
2/4/71	22.6	-		-	22.9	-	-	-
2/19/71	19.7	3075	-		20.0	3600	-	
3/1/71	26.2	3075			26.5	3900		
3/19/71	25.7	3200	.059	.114	26.0	4525	.037	.121
4/6/71	23.4	3400			23.7	4800		
4/23/71	27.5	3850	.070	.185	27.8	5200	.040	.104
5/6/71	30.6	3800			30.9	5475		
5/18/71	32.0	4175			32.3	5700		
6/2/71	30.3	4925			30.6	6150		-

	STATION 26				STATION 34			
DATE	T°C	ABUN.	BIOMASS	GROWTH	T°C	ABUN.	BIOMASS	GROWTH
3/7/69	22.7	2050			21.4	1250		
3/18/69	22.1	2250	-	-	22.3	1775	-	-
4/22/69	30.5	2775			30.7	2075		
5/6/69	31.7	2900	.102	.214	29.9	2550	.125	.212
5/21/69	32.0	3300			32.2	2300		
6/3/69	31.9	3225	.134	.344	32.1	3050	.058	.210
6/24/69	32.2	3100			32.4	2425		
7/8/69	31.8	2525	.032	.084	32.0	2775	.063	.171
7/23/69	32.2	2500			32.4	3250		
8/5/69	32.8	2700	.019	.048	33.0	3350	.036	.105
8/20/69	34.2	2275			34.4	3050		
9/3/69	32.1	2550	.024	.061	32.3	2900	.051	.151
10/1/69	30.4	2150			30.6	3525		
10/14/69	29.1	2325	.063	.121	29.3	3950	.046	.113
11/12/69	23.4	2000			23.6	3950		
11/25/69	22.9	1700	.033	.061	23.1	3225	.026	.056
12/30/69	22.3	1625			22.5	2400		
1/19/70	18.1	1675	-	.052	18.3	2525	-	.099
3/3/70	21.3	1550			21.5	2150		
3/23/70	20.2	-	-	-	20.4	2800	-	.090
4/30/70	30.5	1800			30.7	3475		
5/12/70	26.8	2000	.188	.153	27.0	3850	.171	.149
6/18/70	32.3	2675			32.5	3900		
7/8/70	32.4	2625	.087	.105	32.6	3750	.147	.130
7/21/70	33.6	2350			33.8	3325		
8/5/70	33.8	2150	.132	.077	34.0	3125	.234	.106
8/20/70	34.2	1900			34.4	3175		
9/2/70	34.4	2025	.171	.138	34.6	2925	.182	.111
10/2/70	31.3	2525			31.5	2950		
10/15/70	28.1	2425	.167	.122	28.3	3500	.161	.112
11/9/70	25.0	2250			25.2	3700		
11/23/70	22.0	2375	.203	.039	22.2	3425	.259	.061
12/16/70	19.6	1625			19.8	2900		
1/4/71	21.8	2000	.166	.082	22.0	2800	.179	.099
1/19/71	24.6	-			24.8	-		
2/4/71	21.8	-			22.0	-		
2/19/71	18.9	2400	-	-	19.1	2775	-	-
3/1/71	25.4	3075			25.6	3175		
3/19/71	24.9	2225	.067	.025	25.1	2900	.064	.165
4/6/71	22.6	1850			22.8	3000		
4/23/71	26.7	1625	.080	.017	26.9	2800	.056	.090
5/6/71	29.8	2075			30.0	3200		
5/18/71	31.2	2100			31.4	3225		
6/2/71	29.5	2250			29.7	3300		

	STATION 35				STATION 52			
DATE	T°C	ABUN.	BIOMASS	GROWTH	T°C	ABUN.	BIOMASS	GROWTH
2/27/69					19.6	1725		
3/20/69					20.5	1975	-	-
4/23/69					28.9	3150		
5/6/69					28.1	3500	.089	.137
5/22/69					30.4	3825		
6/5/69					30.3	3675	.088	.211
6/24/69					30.6	-		
7/8/69	32.9	2575	-	.122	30.2	3925	-	-
7/23/69	33.3	2775			30.6	4050		
8/5/69	33.9	2875	.025	.090	31.2	3650	-	.143
8/20/69	35.3	3025			32.6	3400		
9/3/69	33.2	2500	.044	.129	30.5	3125	.101	.215
10/1/69	31.5	2425			28.8	3100		
10/13/69	30.2	2625	.061	.075	27.5	3625	.087	.173
11/12/69	24.5	2450			21.8	3125		
11/26/69	24.0	2075	.031	.131	21.3	2850	.020	.041
12/30/69	23.4	2225			20.7	2875		
1/19/70	19.2	1900	-	.042	17.2	2775	-	.058
3/2/70	22.4	2100			19.7	3050		
3/23/70	21.3	2100	-	.092	18.6	3750	-	.073
4/29/70	31.6	2700			28.9	4600		
5/12/70	27.9	3050	.110	.235	25.2	4300	.255	.116
6/18/70	33.4	3175			30.7	4000		
7/8/70	33.5	3350	.074	.103	30.8	4375	.172	.182
7/21/70	34.7	3300			32.0	3650		
8/5/70	34.9	3350	.220	.128	32.2	3625	.375	.207
8/20/70	35.3	3275			32.6	3650		
9/2/70	35.5	3100	.215	.131	32.8	3700	.358	.234
10/2/70	32.4	2900			29.7	3575		
10/15/70	29.2	2525	.158	.101	26.5	3625	.317	.192
11/9/70	26.1	2775			23.4	3250		
11/23/70	23.1	2625	.189	.066	23.4	2700	.396	.111
12/16/70	20.7	2575			18.0	2575		
1/4/71	22.9	2175	.156	.082	20.2	2800	.239	.101
1/19/71	25.7	-			23.0	-		
2/4/71	22.9	-			20.2	-		
2/19/71	20.0	2525	-	-	17.3	2825	-	-
3/1/71	26.5	2500			23.8	3600		
3/19/71	26.0	2450	.045	.151	23.3	4275	.046	.151
4/6/71	23.7	2725			21.0	4175		
4/23/71	27.8	2300	.064	.166	25.1	4300	.044	.089
5/6/71	30.9	2650			28.2	4625		
5/18/71	32.3	2675			29.6	5450		
6/2/71	30.6	3300			27.9	-		

Table X-2, Abundance of the predominate species of Algae per square meter at Turkey Point, Biscayne Bay, Florida, stations from March, 1969 to May, 1971.

SUMMARY TURKEY POINT ALGAE ABUNDANCE

Date	Pen.	Hal.	Acetab.	Anad.	Digen.	Laur.	Rhipo.	Udot.	Avan.	Batoph.	Caulp.
Station 13											
3- 7-69	123	71	0							4	
4-23-69	131	84	54						1	20	
5-22-69	113	74	110						1	4	
10-14-69	440	51	3							8	
11-11-69	407	54	0							1	
12-29-69	515	24	0							15	
3- 3-70	489	24	16						1	31	
4-29-70	180	76	244			1.0%				60	
6-18-70	237	60	400							26	
7-21-70	124	56	0			6.0%				30	
8- 5-70	166	84	105			5.0%				30	
10- 2-70	55	67	10	1		7.0%		1		44	
11- 9-70	98	57	0								
12-16-70	110	31	0	1		5.0%					
2-19-71	228	61	9			16.3%				22	
3- 1-71	237	51	0			3.4%					
4- 7-71	94	54	6			2.5%					
5- 3-71	105	62	11			5.0%					

Date	Pen.	Hal.	Acetab.	Anad.	Digen.	Laur.	Rhipo.	Udot.	Avan.	Batoph.	Caulp.
Station 14											
3- 7-69	480	68	0							1	
4-23-69	67	70	9							6	
5-22-69	55	75	0								
10-14-69	34	18	4							3	
11-11-69	46	9	0								
12-29-69	35	11	0							2	
3- 3-70	138	15	0							4	
4-29-70	169	26	8							1	
6-18-70	188	12	4							11	
7-21-70	40	19	0								
8- 5-70	123	12	0								
10- 2-70	910	12	0								
11- 9-70	138	7	0								
12-16-70	88	7	0								
2-19-71	101	13	0								
3- 1-71	134	7	0								
4- 7-71	94	54	6			2.5%					
5- 3-71	105	62	11			5.0%					
Station 16											
3- 7-69	422	54	0								
4-23-69	430	58	0								
5-22-69	331	68	0								
10-14-69	0	0	0							50	
11-11-69	0	0	0			2.0%					
12-29-69	0	0	0			2.0%				1	
3- 3-70	0	0	0			5.0%					
4-29-70	3	0	1							2	
6-18-70	3	1	0								
7-21-70	7	0	0			19.0%					
8- 5-70	7	0	0			4.0%					
10- 2-70	17	0	0								
11- 9-70	47	0	0			1.0%					
12-16-70	92	0	0			1.0%					
2-19-71	123	0	0			1.5%					
3- 1-71	171	0	0			0.5%					
5- 3-71	188	0	0								

Date	Pen.	Hal.	Acetab.	Anad.	Digen.	Laur.	Rhipo.	Udot.	Avan.	Batoph.	Caulp.
Station 34											
3-20-69	85	7	3							160	
4-23-69	22	7	117	1		2.5%				285	
5-21-69	18	7	300	2						105	
10-14-69	14	0	13		5					3	
11-11-69	18	0	0		2					4	
12-30-69	24	0	2	1						7	
3-03-70	72	0	14	3		1.3%				50	
4-29-70	16	0	60	2	5					140	
6-18-70	11	12	3		4						
7-21-70	25	0	25			1.3%				21	
8- 5-70	36	0	4		5					6	
10- 2-70	42	0	0		5						
11- 9-70	12	0	0		5						
12-16-70	20	0	0		1					39	
2-19-71	39	2	0							22	
3- 1-71	59	5	0								
4- 7-71	42	7	0								
5- 3-71	51	6	0								
Station 35											
10-14-69	0	0	124		2	1.5%				7	
11-11-69	0	1	250		10	2.0%				4	
12-30-69	0	2	255		5	3.8%				36	
3- 2-70	1	8	315		2	5.3%				22	
4-29-70	0	27	400		1	5.0%				4	
6-18-60	1	0	0							1	
7-21-70	5	58	177			11.3%				50	
8- 5-70	4	90	164	1	5	7.5%				20	
10- 2-70	14	82	19		19	2.8%				29	
11- 9-70	9	98	4		10	5.5%				198	
12-16-70	27	111	18		2	3.0%					
2-19-71	49	88	39			5.0%				15	
3- 1-71	52	114	34			8.0%					
4- 7-71	51	170	131								
5- 5-71	48	199	250								

Date	Pen.	Hal.	Acetab.	Anad.	Digen.	Laur.	Rhipo.	Udot.	Avan.	Batoph.	Caulp.
Station 24											
3-20-69	502	22	83	1	10	8.0%				60	
4-23-69	242	26	415	3	20	3.0%				30	
5-28-69	212	31	500	4	30	6.0%				12	
10-14-69	0	4	24		1					2	
11-11-69	3	2	35	1	3					4	
12-30-69	3	2	36		12	1.0%				21	
3- 3-70	14	5	80		26	1.0%				13	
4-29-70	4	24	304		30	3.0%				25	
6-18-70	2	51	191		20	3.0%				12	
7-21-70	2	13	3		107						
8- 5-70	0	25	2		153	6.0%				1	
10- 2-70	0	13	0		268						
11- 9-70	0	0	33		189	1.0%					
12-16-70	0	1	32	2	182	1.0%				1	
2-19-71	0	34	0			0.5%				11	
3- 1-71	0	49	0			0.5%					
4- 7-71	0	62	0			1.0%					
5- 3-71	0	84	28								
Station 26											
3-18-69	502	22	83	1	10	7.5%				60	
4-23-69	29	24	1		5	1.3%				12	
5-21-69	437	29	1		15	2.5%				6	
10-14-69	0	0	402							2	
11-11-69	0	0	155							1	
12-30-69	0	0	9							4	
3- 3-70	0	0	132		1					3	
4-29-70	0	0	15							4	
6-18-70	24	14	187	4	6	6.25%				35	
7-21-70	1	0	5							6	
8- 5-70	0	3	97					2		105	
10- 2-70	0	1	0							3	
11- 9-70	0	3	0							2	
12-16-70	0	10	0							50	
2-19-71	0	51	0								
3- 1-71	0	66	0								
4- 7-71	0	84	0								
5- 3-71	0	12	4								

Date	Pen.	Hal.	Acetab.	Anad.	Digen.	Laur.	Rhipo.	Udot.	Avan.	Batoph.	Caulp.
Station 52											
3-20-69	6	40	12	2	20	18.8%	12	18		10	
4-23-69	3	70	108	2	55	15.0%	22	14		12	
5-22-69	9	97	136	3	0	3.8%	17	9		10	
10-15-69	9	40	13		30	4.0%	14	2		65	
11-11-69	12	23	3		35	1.8%	5	2		40	
12-30-69	7	29	1		20	7.8%	9	7		25	
3- 2-70	11	17	5	4	32	17.5%	15	4		30	
4-29-70	2	25	24	6	11	5.0%	17	5			
6-18-70	0	60	68	1	5		0			110	
7-21-70	6	53	16	3	60	36.3%	17	9		17	
8- 5-70	3	38	7	2	11	65.0%	21	17		40	
10- 2-70	6	37	0		2	70.8%	16	10		4	
11- 9-70	3	26	0		2	86.3%	1	6			
12-16-70	2	56	0		32	57.5%	2	10			
2-19-71	2	35	0		0	88.0%	2	1			
3- 1-71	8	52	1		0	80.0%	11	2		11	
4- 7-71	15	50	2		0	88.0%	5	1		25	
5- 5-71	6	62	14		0	84.0%	12	13		18	

**LEGEND:

Pen. - *Penicillus*
Hal. - *Halimeda*
Acetab. - *Acetabularia*
Anad. - *Anadyomene*
Digen. - *Digenia*
Laur. - *Laurencia*
Rhipo. - *Rhipocephalus*
Udot. - *Udotea*
Avan. - *Avanvillia*
Batoph. - *Batophora*
Caulp. - *Caulerpa*

was there when the counts were begun by Zieman in 1969. This may be explained by the covering of Laurencia which was often encountered at this station. This mat-like covering over rooted algae may cause less light penetration and therefore lowered photosynthesis and slower growth (Section XII). One of the most abundant species of plants at this station in the spring of 1971 was Valonia macrophysa. The Acetabularia population increased in the spring of 1969 and 1970, with low numbers being observed in summer and winter.

Station 13 was the station considered as a control. Sea grasses were firm and their color was good. However, a great deal of sediment had settled in this area. As in Station 52, there are large fluctuations in abundance of Thalassia (Figure X-3) and its growth (Figure X-4) between summer and winter. In the spring of 1969, 1970 and 1971, as the temperature increased, there was an increase in abundance of Thalassia (the blades approximately doubled in number - Table X-1). In the summer of 1970 when the mean temperature increased from 31 to 32°C, there was a decline in the number of blades/m^2. The blade count continued downward until the temperature dropped to 30°C in September. At this point, there was an increase until the dropping temperature in the fall months curtailed growth. In October, the abundance fell to a minimum fall value. Growth (Figure X-4) decreased both in 1969 and 1970 when the temperature reached 33°C. There was a decrease in the growth rate as the temperatures neared 31°C. This was followed by a rise in the growth rate which continued until mid-summer (late July to early August). Slowest growth rates were encountered from October to March in 1970 and 1971.

The Laurencia cover seemed to be more dense toward the middle of the Bay (Station 52) and less dense near the shore. This general pattern was modified when winds were strong enough to move the unattached Laurencia. Depressions in the bottom which are suitable for collection of Laurencia accumulated large populations at such times. When the Laurencia became less dense at Station 13 larger populations of Halimeda and especially Penicillus were found to occur in this area (Table X-2). In October, 1970, a large Penicillus population was measured. The abundance fell in March, then increased slightly until June, then fell again to a low level in the summer months. In October, when the temperature fell, the population increased. This might be explained by winter temperature conditions above normal which allowed increased growth. Studies in spring and summer from many parts of the Bay (Section XIII) showed Penicillus abundance generally increased in the summer months. Data from Card Sound showed that 9 stations had increased populations of Penicillus in summer, while 4 had decreased. Until further information is available about the patchiness and dynamics of Penicillus growth, we can only speculate that either the summer decrease was due to heat stress or it was due to random causes such as seen at stations 0805 in Card Sound. The silting may also be a factor at Station 13.

Halimeda was less abundant in the winter at Station 13 than in the summer. Halimeda observed in laboratory experiments (Section XI) appeared to have a slightly higher temperature tolerance than Penicillus. We may be seeing the effect of a slight differential between their upper temperature limits reflected in the dominance pattern at this station which is 1.5°C above the mean Bay temperature. Batophora increased in numbers from winter to spring 1970. Abundance decreased in the summer. Many of the algae found at Station 52 and in Card Sound were not found here.

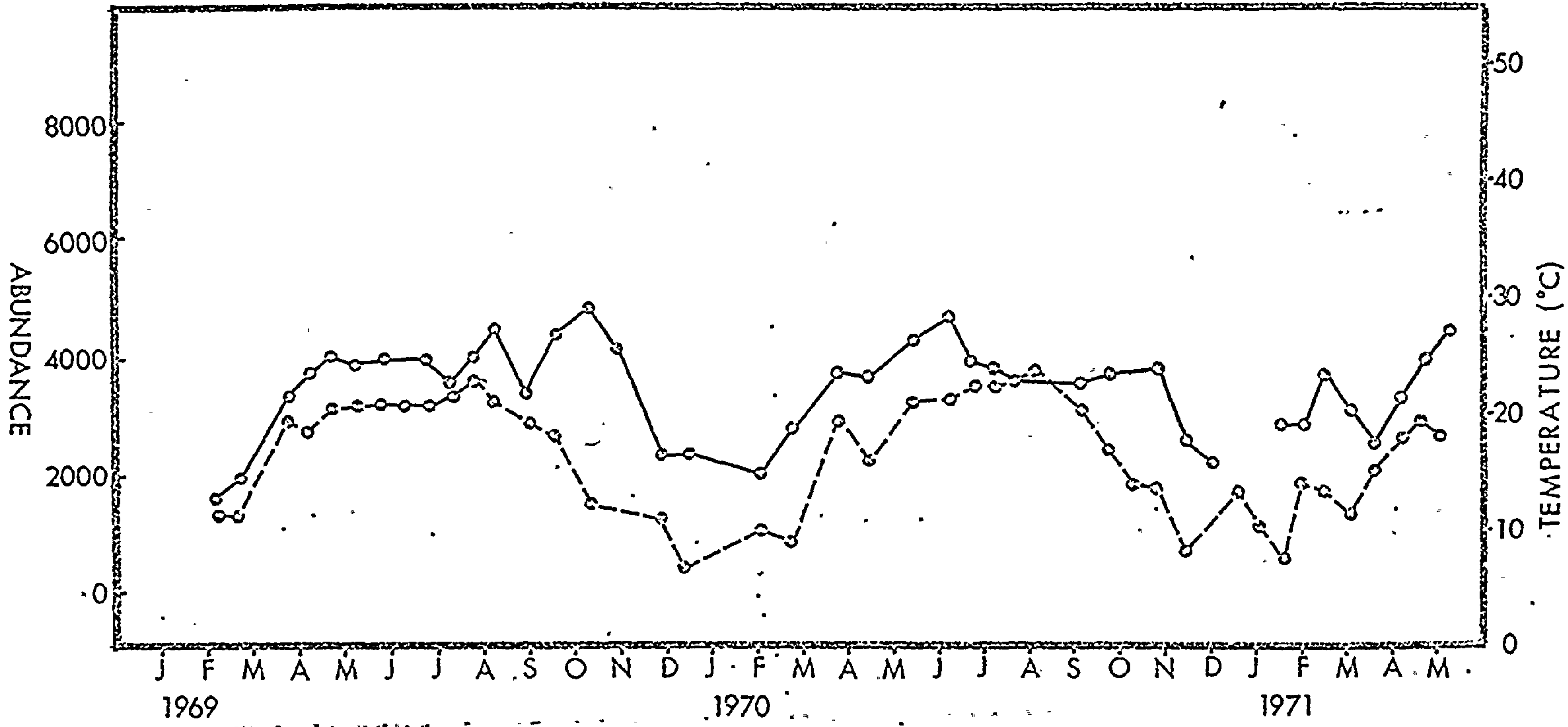

FIGURE X-3 Turkey Point, Biscayne Bay, Florida, Station 13, Mean Temperature (dotted line) and *Thalassia* abundance (solid line) per square meter

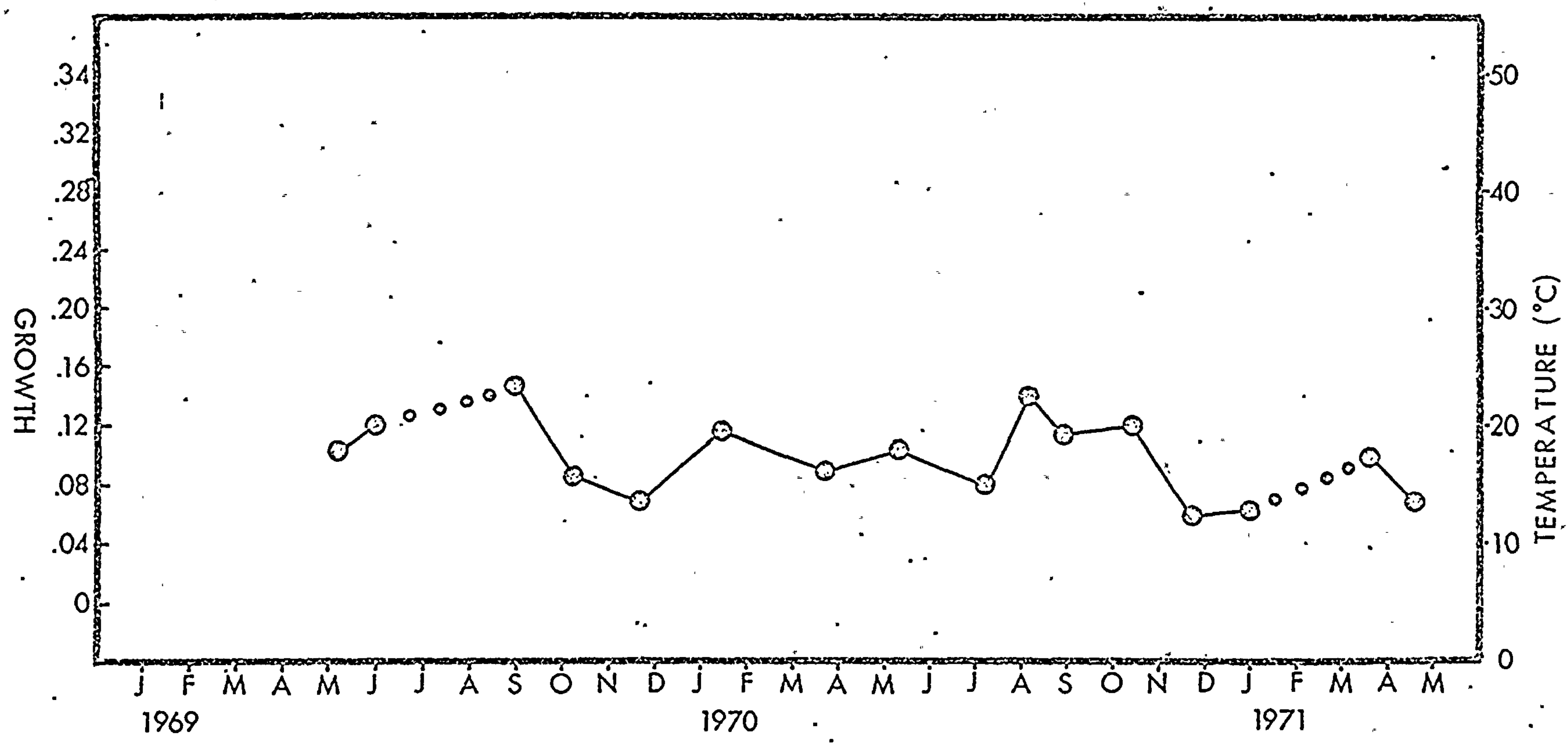

FIGURE X-4 Turkey Point, Biscayne Bay, Florida, Station 13, Mean *Thalassia* growth (cm^2) per blade per day. (Dotted line indicates unavailable data)

Station 26 was slightly offshore and to the south of the mouth of the effluent canal. It was in an area which averaged 2.9°C above ambient with some fluctuations due to tide, wind direction and other factors. The abundance of Thalassia (Figure X-5) showed less seasonal variation than at Stations 13 and 52. The abundance of Thalassia blades increased 50% from February, 1969, to February, 1971. The maximum for 1969 was 3,300 blades/m^2 in April and for 1970 only 2,700 in May. The growth rate observed in spring 1969 climbed as the temperature neared 31°C to a rate comparable to that observed at Station 13 in August. During summer months the growth rate at Station 26 fell precipitously but recovered in September when the temperature fell below 30°C (Figure X-6). This agrees with measurements of photosynthesis of Biscayne Bay Thalassia by Jones (1968) who found photosynthesis reached a peak at 30°C and then fell abruptly when temperatures rose above 30°C. This information would imply that growth, which in plants is a direct result of the rate of photosynthesis, would reach its maximum in a temperature interval around 30°C and decrease above this. The obvious problems in extrapolating from Jones' measurements are that fluctuating temperatures such as encountered at the stations under discussion were not considered and that long term measurements at 31°C and above were not considered.

We are aware that certain theoretical and methodical arguments pertain to photosynthetic and respiratory investigation conducted in situ. However, the surprising similarity between Jones' measurement and our growth results at Turkey Point reinforce our opinion that temperature is a fundamental factor in the ecology of Thalassia as well as other tropical marine estuarine organisms. Thus, despite the three different approaches (laboratory studies, in situ photosynthesis and field growth) used to examine temperature dependence and the errors inherent in each of the various methods employed, the same controlling temperature is obtained.

The Penicillus population was large in the winter of 1969, fell to low levels during summer and never recovered. The Halimeda population increased in the spring of 1969 but fell to zero during the summer. It began to recover during the spring of 1970, but fell to very low levels in June, 1970, when the temperature climbed above a mean of 32°C. In October a recolonization began, which climbed steadily until a high in May, 1971. Observations on June 3, 1971, showed that many of the plants were becoming unhealthy and the temperature was above 32°C. Laurencia was very prevalent here in June, 1970, and then disappeared. Batophora appeared to increase during the summer of 1970. Some Anadymone and Digenia appeared in June, 1970, but rapidly disappeared during the next several months.

Station 34 had an average mean temperature about +3.1°C above the Bay ambient. The station lies out from shore northeast of the mouth of the effluent canal. It differed somewhat from Station 26, also within the +3°C isotherm, because the wind and tidal conditions have less effect thereby producing a more stable temperature regime.

The abundance of Thalassia (Figure X-7) was low and similar to Station 26 with the maximum population in October, 1969, being approximately 3,900/blades/m^2 and the high for 1970 approximately 3,900/blades/m^2 in June. The seasonal variability during 1971 was lower than that seen in 1969. Like most Thalassia stations, this station experienced increased abundance in the spring of 1969. In May when the temperature rose from near 30°C to 32°C, both the growth (Figure X-8)

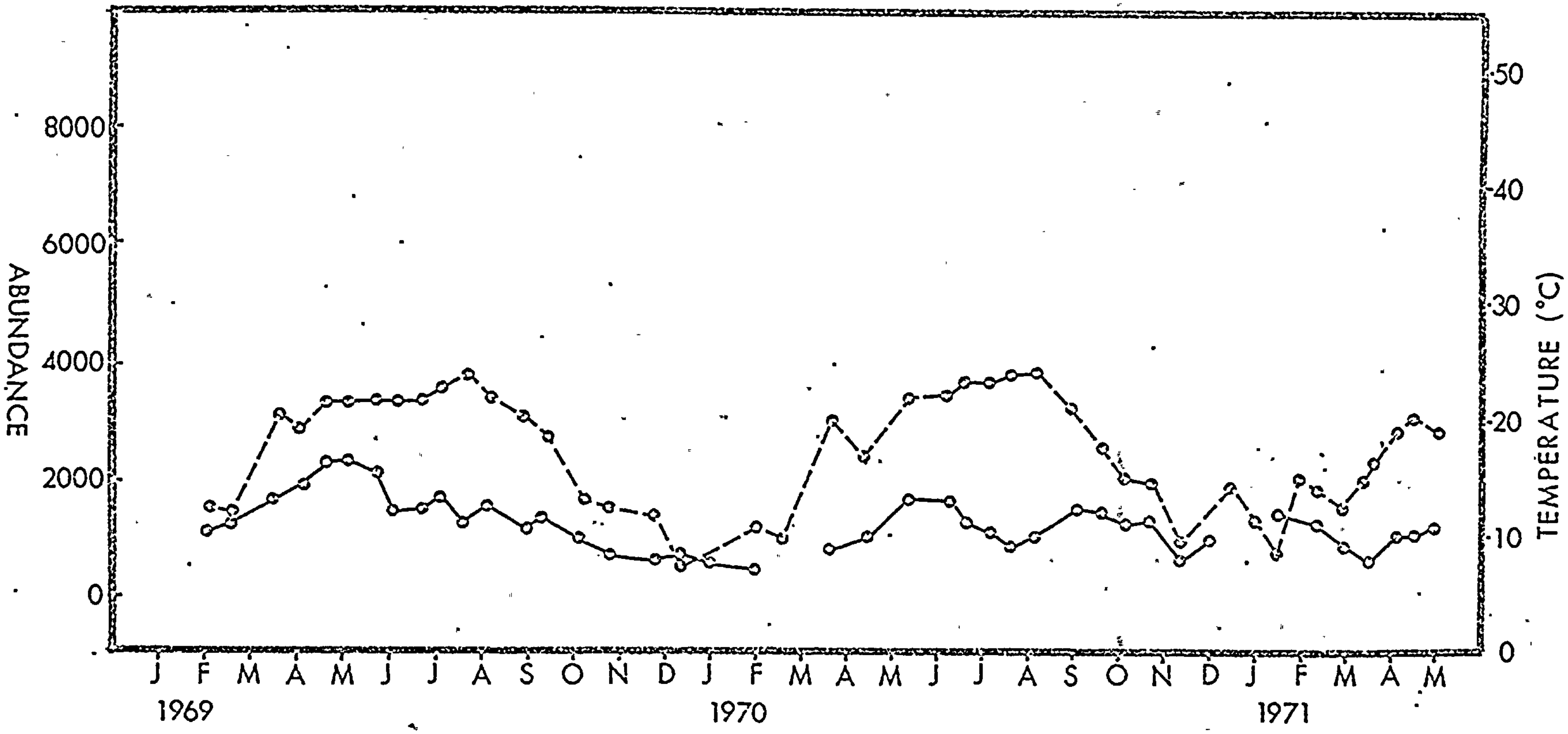

FIGURE X-5 Turkey Point, Biscayne Bay, Florida, Station 26, Mean Temperature (dotted line) and *Thalassia* abundance (solid line) per square meter

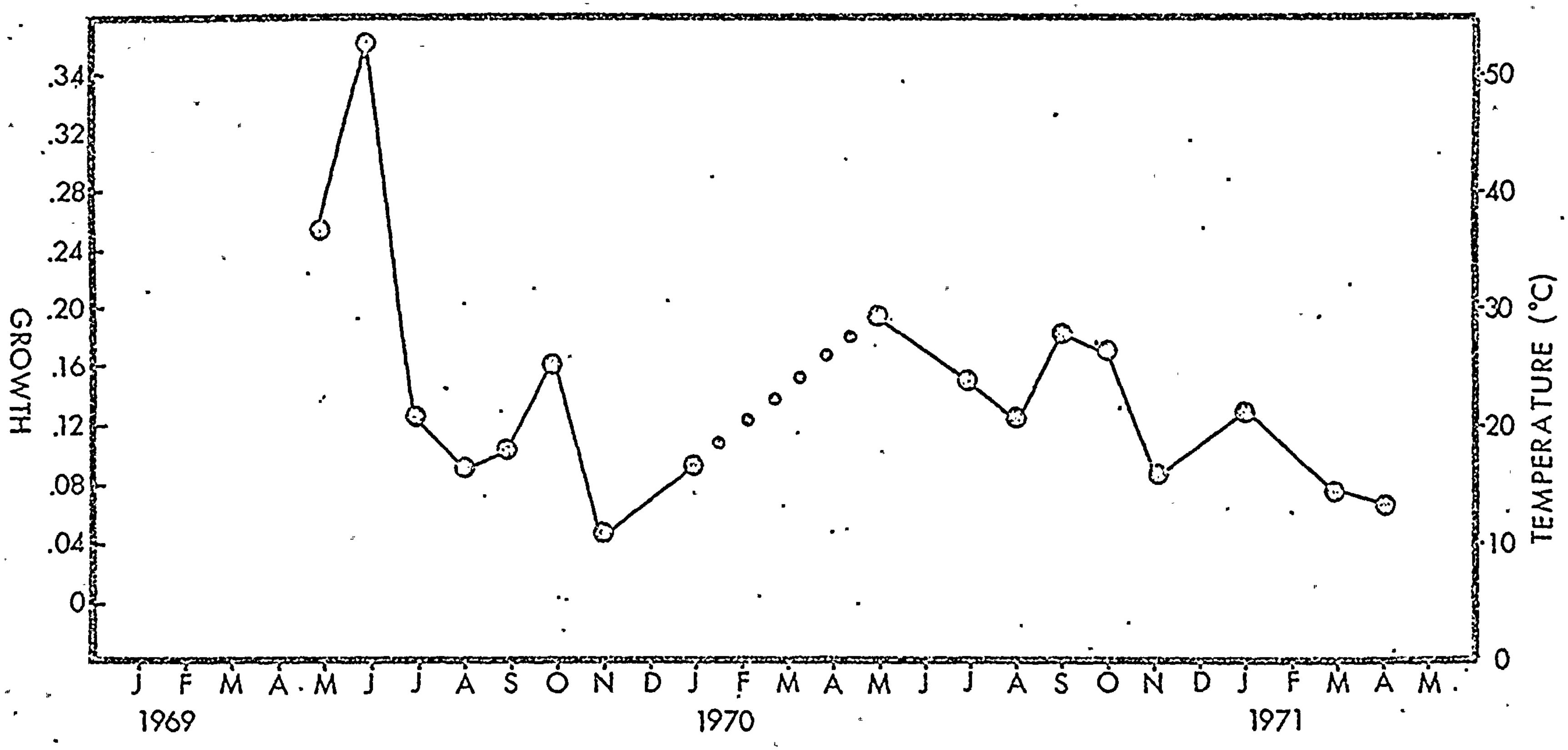

FIGURE X-6 Turkey Point, Biscayne Bay, Florida, Station 26, Mean Thalassia growth (cm^2) per blade per day. (Dotted line indicates unavailable data)

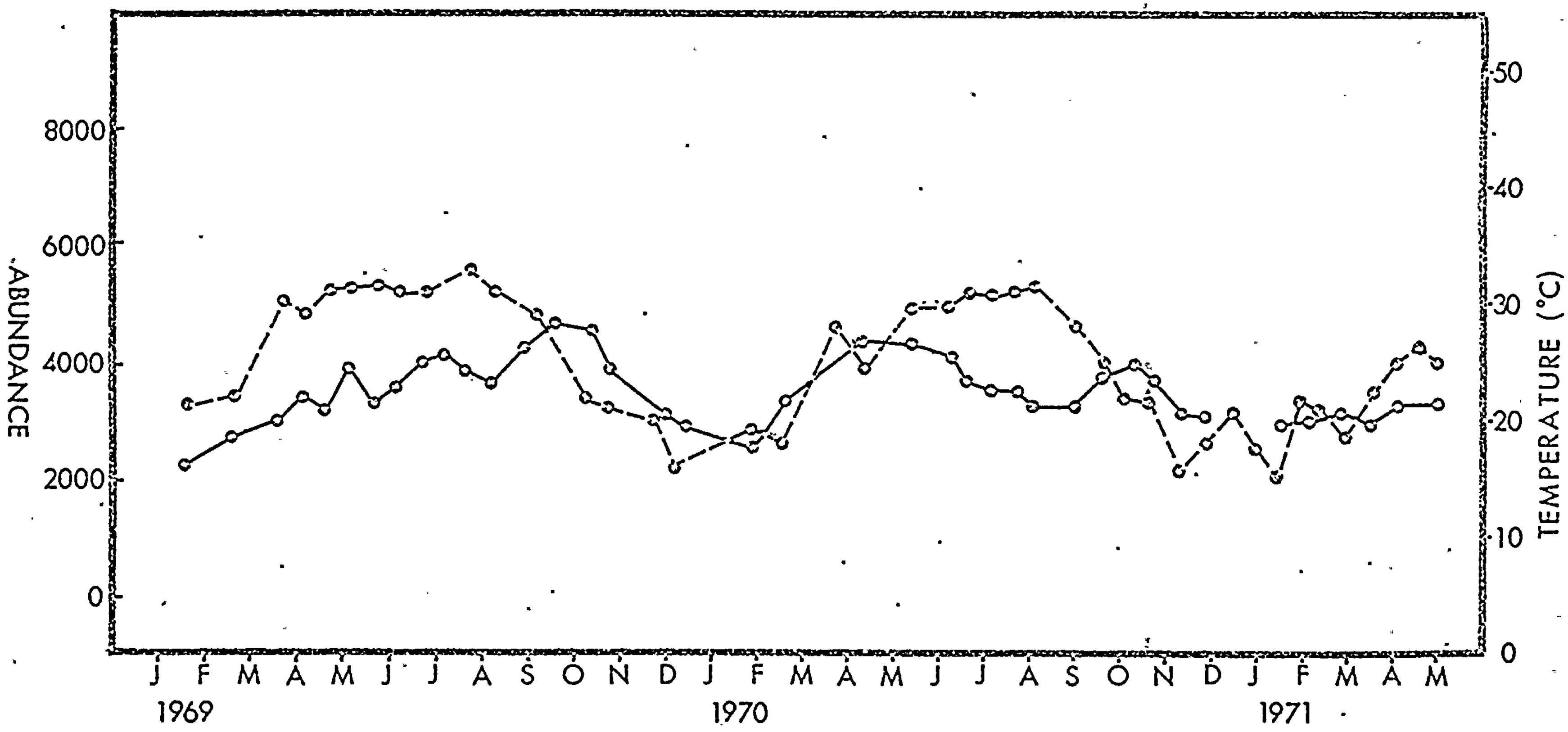

FIGURE X-7 Turkey Point, Biscayne Bay, Florida, Station 34, Mean Temperature (dotted line) and *Thalassia* abundance (solid line) per square meter

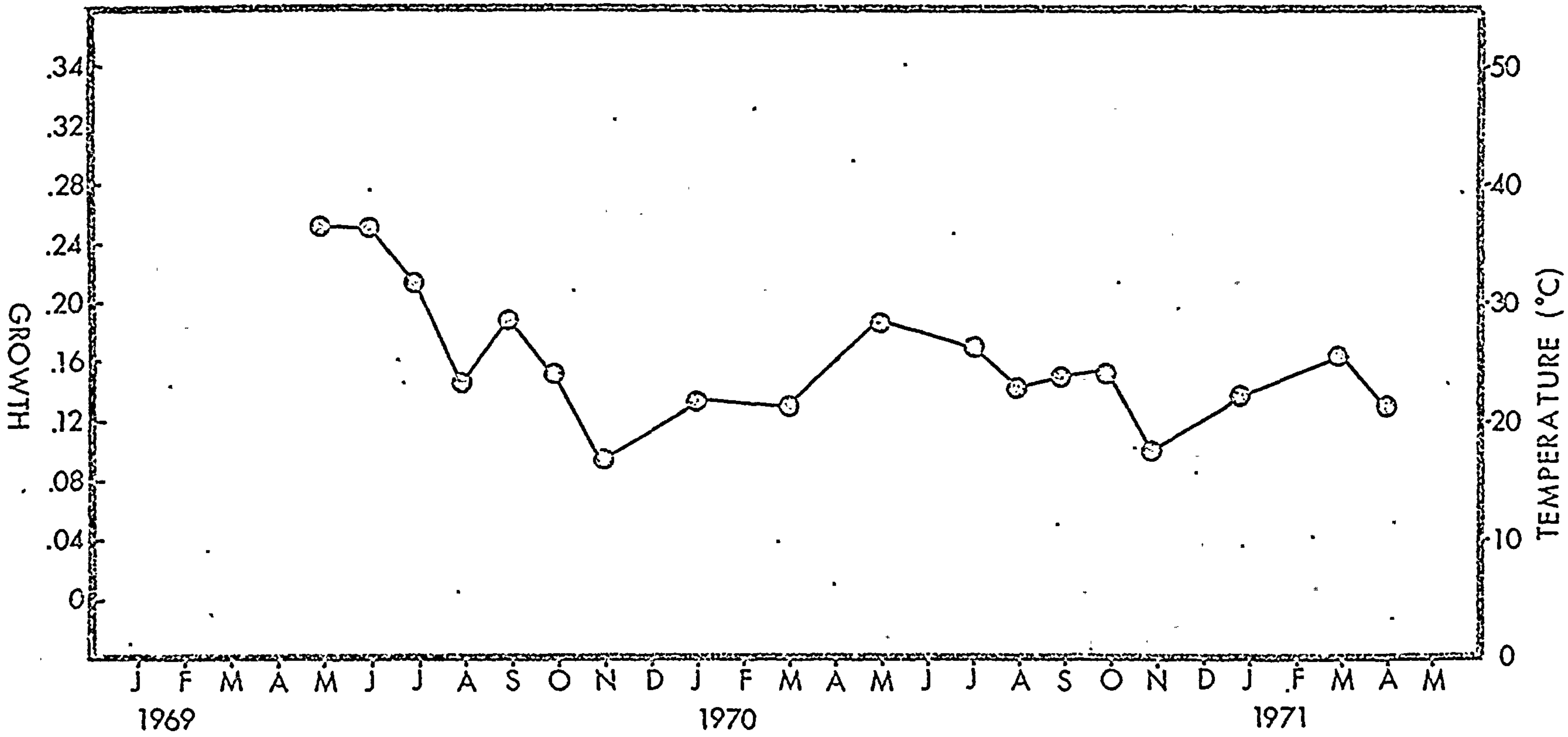

FIGURE X-8 Turkey Point, Biscayne Bay, Florida, Station 34, Mean *Thalassia* growth (cm^2) per blade per day. (Dotted line indicates unavailable data)

and biomass (Table X-3) decreased. In October when the temperature dropped below 30°C, the growth increased. In about a month the biomass reflected this increase. In May, 1970, when the temperature jumped above 32°C, the growth decreased and remained low until September when the temperature jumped above 32°C, the growth decreased and remained low until September when the temperature fell below 30°C. This slight increase in growth was reflected by increased biomass. After the fall bloom, the biomass remained low over the winter. The February, 1971, number of blades of grass was 133% higher than in February, 1961. The biomass in fall 1970 also was substantially above that observed in the fall of 1969.

This pattern of increase in number of blades of Thalassia was seen at several of the stations. There are several possible explanations, none of which can be definitely proved with the presently existing data. First, the severity of the 1968 summer heated effluents which exceeded the temperatures recorded during 1969 and 1970 may have severely damaged the population and thus the area is returning to a less severely stressed level. Second, the opening of the canal was coupled with siltation, which well may have had a detrimental effect on the grasses. This has been witnessed many times in Biscayne Bay and the Florida Keys during dredging. Eventually, the plants may return. The third possible hypothesis for the increase in blades is that since the blades do not winter over at the normal low temperatures in these areas, a higher productivity per year may be realized despite the drop in summer growth due to heat stress. The fourth possible explanation is that a rapid increase in growth may occur and then suddenly this explosive system will collapse and die.

The algae at Station 34 showed more stress than the grass. Penicillus abundance decreased in June, 1969, remained low throughout the summer and fall, but returned in the winter of 1970. There was decreased abundance in the spring of 1970 and then increased abundance until October, 1970. March, 1971, produced maximum numbers for the year. Halimeda had an increase in abundance in spring but counts in July and August were low. Laurencia was found here in the spring only in small amounts. Batophora was found in large numbers in the spring and diminished steadily until August. Few other macroalgae were seen.

Station 14 was near shore and near the mouth of a secondary thermal effluent canal. It had a mean temperature of 3.2°C above the Bay ambient but the duration of exposure to high temperatures is restricted to the period of time when effluent comes through the canal. The extent of these tidal variations was not measured. The Thalassia abundance has decreased from 1969-70 to 1970-71 (Figure X-9). However, in February, 1971, there were almost 100% more blades (4,400/m^2) than in February, 1969, (2,400/m^2). When the temperature exceeded 32°C, the abundance fell. The growth also fell abruptly in May of 1969 and 1970 (Figure X-10). There was little available data for the winter and spring of 1970, but December, 1970, figures are the highest for the entire study period.

P. capitatus was abundant in March, 1969, and fell abruptly when the temperature exceeded 30°C in April. By March, 1970, there was recolonization. In June, 1970, as the temperature jumped from 27.5 to 32°C, the population fell. Penicillus increased to more than 900 plants/m^2 in October, 1970 when the temperature fell below 30°C.

Table X-3, Frequency of *Thalassia* reproductive bodies per square meter at Card Sound and Turkey Point stations for May, 1971.

CARD SOUND AND TURKEY POINT THALASSIA

REPRODUCTIVE BODIES

DATE	STATION	ABUN.	Flowers/m^2	Buds/m^2	Fruit/m^2	Totals	AVG. RB/m^2
Card Sound 5/3/71	0104	5200	100	0	0	100	
	0204	3950	0	0	0	0	
	0304	2550	50	0	0	50	40
	0403	2250	50	0	0	50	
	0405	2225	0	0	0	0	
Turkey Point 5/6/71	13	4325	25	0	0	25	
	14	5175	0	0	0	0	
	16	3800	0	0	0	0	
	24	4725	0	0	0	0	19
	26	2075	0	0	0	0	
	34	3200	25	0	0	25	
	35	2650	75	0	0	75	
	52	4625	25	0	0	25	
Card Sound 5/17/71	0104	5875	100	75	0	175	
	0204	4675	25	0	0	25	
	0304	2900	0	25	0	25	45
	0403	2500	0	0	0	0	
	0405	0	0	0	0	0	
Turkey Point 5/18/71	13	4950	0	25	0	25	
	14	5325	0	0	0	0	
	16	4175	0	0	0	0	
	24	5700	0	25	0	25	16
	26	2100	0	0	0	0	
	34	3225	0	0	0	0	
	35	2675	0	0	0	0	
	52	5450	0	75	0	75	

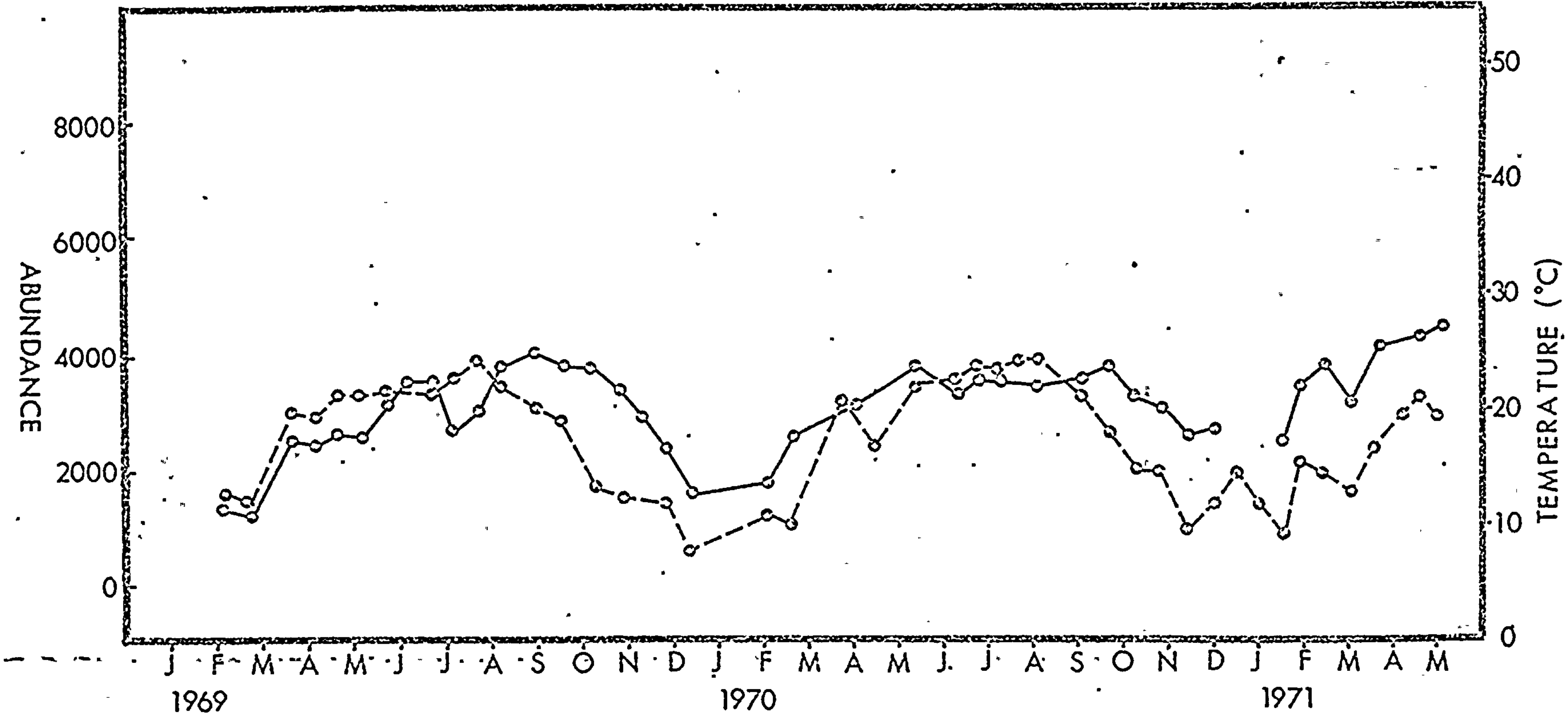

FIGURE X-9 Turkey Point, Biscayne Bay, Florida, Station 14, Mean Temperature (dotted line) and Thalassia abundance (solid line) per square meter

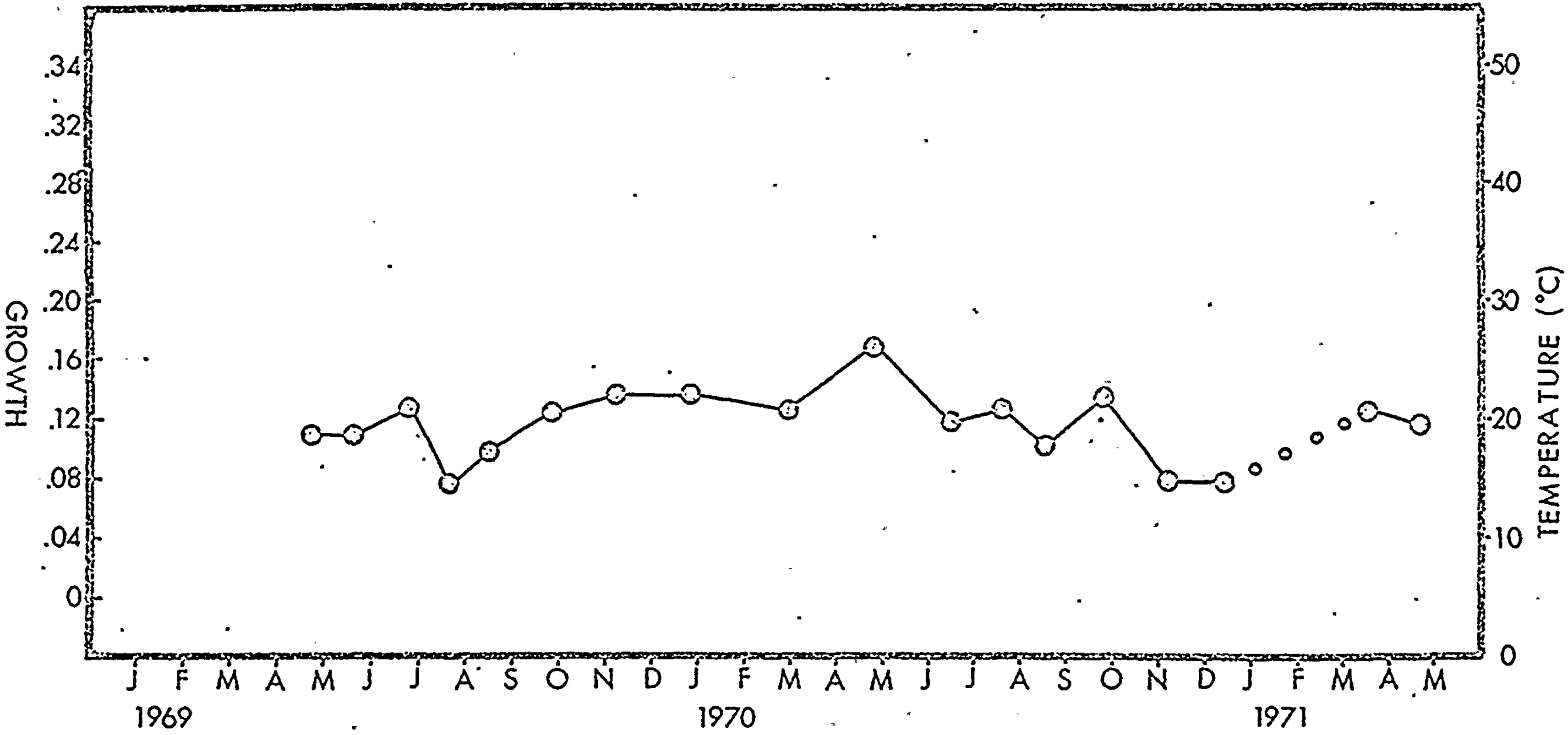

FIGURE X-10 Turkey Point, Biscayne Bay, Florida, Station 14, Mean Thalassia growth (cm^2) per blade per day. (Dotted line indicates unavailable data)

Halimeda abundance decreased in the summer of 1970 and did not recover until the spring of 1971, Acetabularia and Laurencia were scarce until the spring of 1971. Batophora had been seen on various occasions but had always been sparse.

In summary, the summer temperatures of 3°C above ambient made the Thalassia growth and abundance, as well as the macro-algal population levels, abnormal and somewhat erratic compared to other populations found at lower temperatures in Card Sound, at Turkey Point and in various other localities in Biscayne Bay.

Station 16 averaged about 3.7°C above the Bay temperature and was located near a shoreline mangrove community. It is located south of the mouth of the effluent canal. Even more than Station 26, this station had a variable temperature regime depending on the wind, tides and other hydrographic conditions. The abundance (Figure X-11) and growth (Figure X-12) of Thalassia dropped when the temperature rose above 32.5°C. From May to mid-September, the biomass and abundance of Thalassia was depressed. In mid-September, when the temperature fell below 31°C, there was some recovery. A 37% increase in abundance from February, 1969, to February, 1971, was observed at this station.

The abundance pattern of Penicillus was similar to that at the last station. The original population seen in spring of 1969 fell during summer of 1969, but recovered during the fall. Halimeda decreased in numbers in the summer of 1969 and has not recovered. The alga Batophora was occasionally observed. In July, 1970, Laurencia increased but abruptly fell never to recolonize the area. Few of the other normal forms of macroalgae were found.

Station 24 was located away from the shore and northeast of the mouth of the effluent canal. The average temperature was 4°C above ambient. When the temperature in the spring of 1969 increased from 31 to 33°C, the abundance (Figure X-13) and growth (Figure X-14) of Thalassia declined abruptly and remained low until September when the temperature fell from 31 to 30°C. In the following spring, there was an increase in biomass followed by a drop when the temperature rose from 28°C to 33°C in May. The abundance continued to drop from 6,000 blades/m^2 in May to 2,200 blades/m^2 in September. Then, when the temperature fell from 32 to 29°C, the abundance increased to 5,100 blades/m^2 within a month. The sequence in 1970 was a clear demonstration of the effect of temperature on Thalassia. At this station abundance fell sharply when temperature rose above 32 or 33°C. The abundance, however, increased from March, 1969, to March, 1971.

Penicillus counts fell drastically from near 500 plants/m^2 to near zero after the high temperatures measured in the summer of 1969. This population never returned. Halimeda abundance was low in 1969 and remained low until the winter of 1971 when the population began to increase. The increase in abundance continued until May. The observation of June 25, 1971, indicated that the growing tips of Halimeda were unusually thin and lighter green than those seen on growing tips of normal plants. Acetabularia had a spring bloom in 1970 but counts dropped in July. Batophora was occasionally present here. There was no Laurencia in the area during the study. Only macroalgae with known sexual propagation appeared in 1970 and 1971.

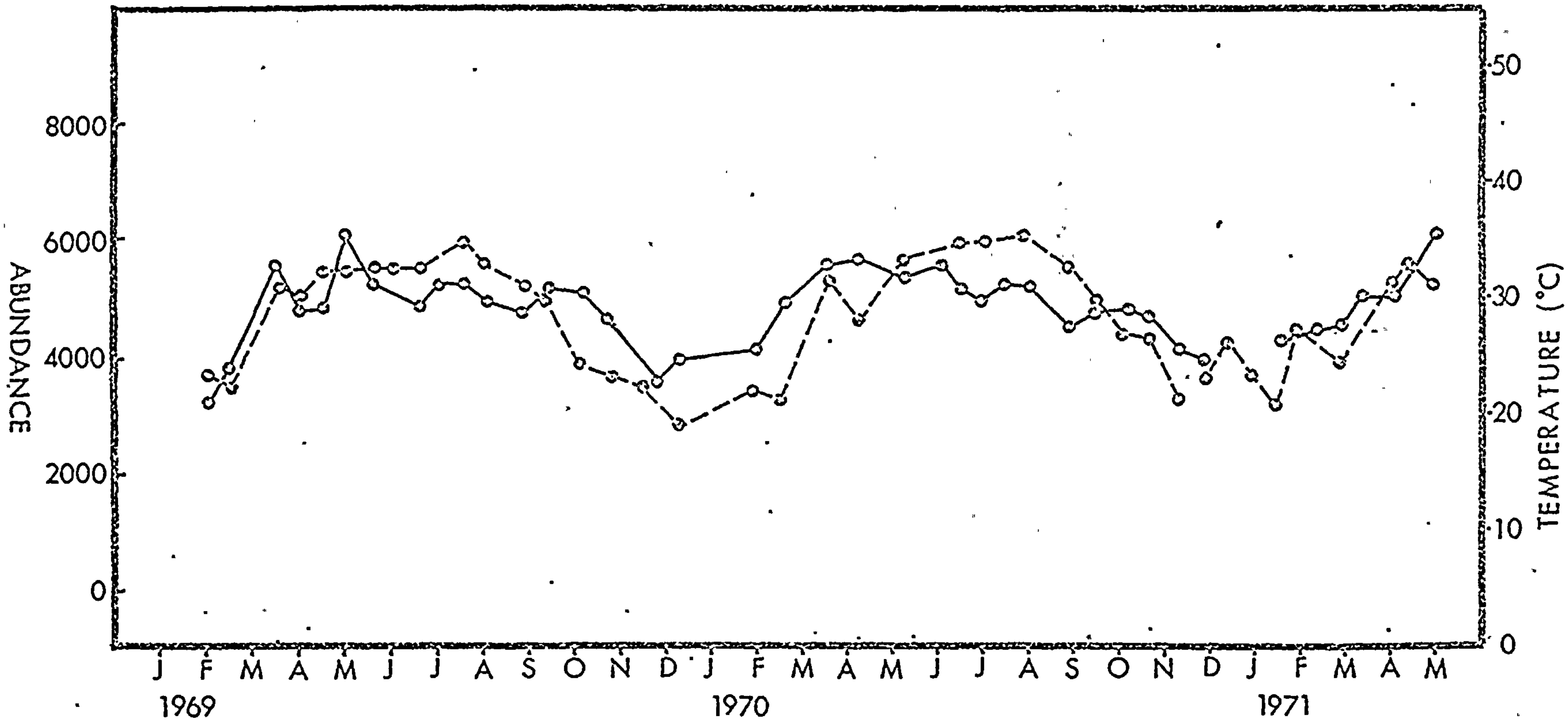

FIGURE X-11 Turkey Point, Biscayne Bay, Florida, Station 16, Mean Temperature (dotted line) and *Thalassia* abundance (solid line) per square meter

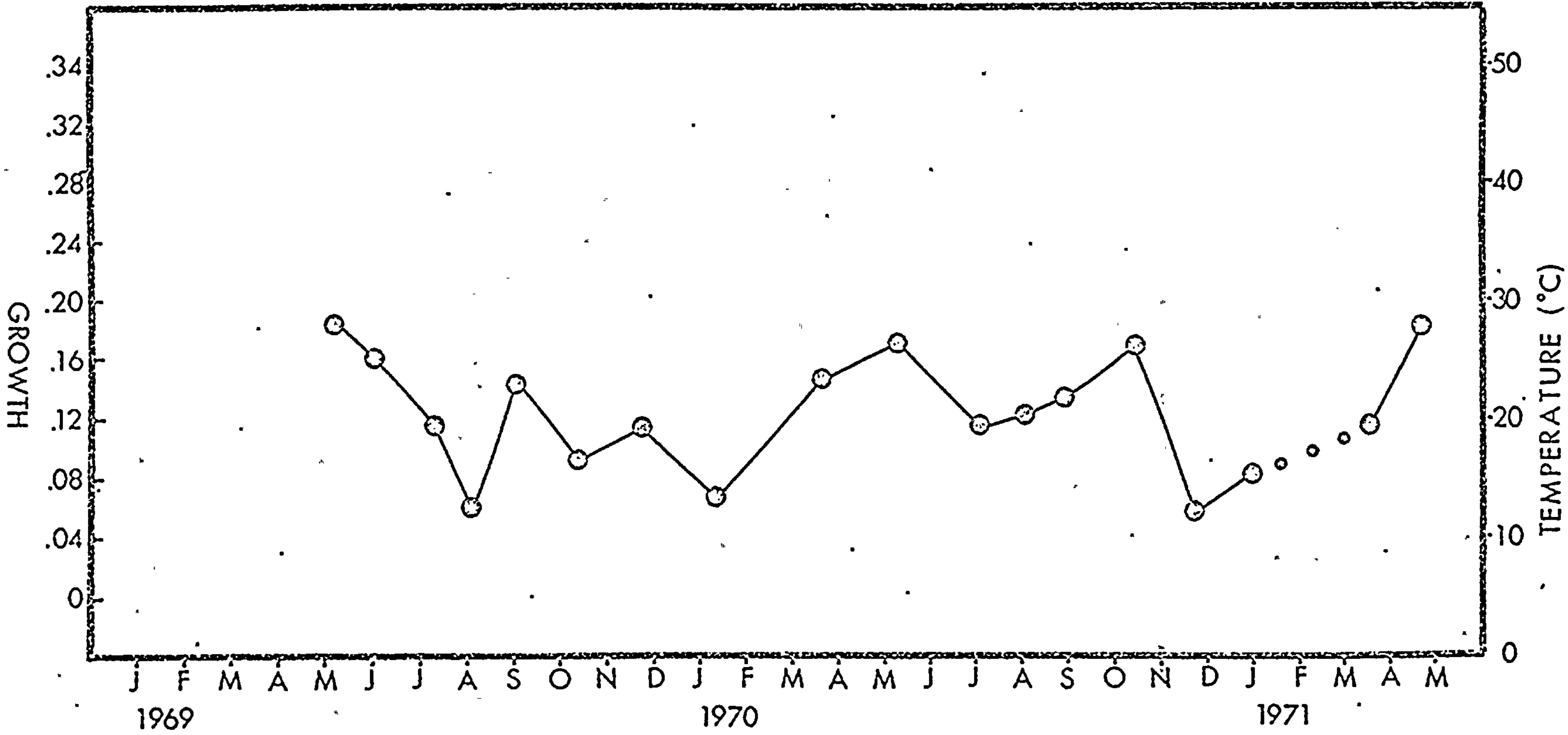

FIGURE X-12 Turkey Point, Biscayne Bay, Florida, Station 16, Mean Thalassia growth (cm^2) per blade per day. (Dotted line indicates unavailable data)

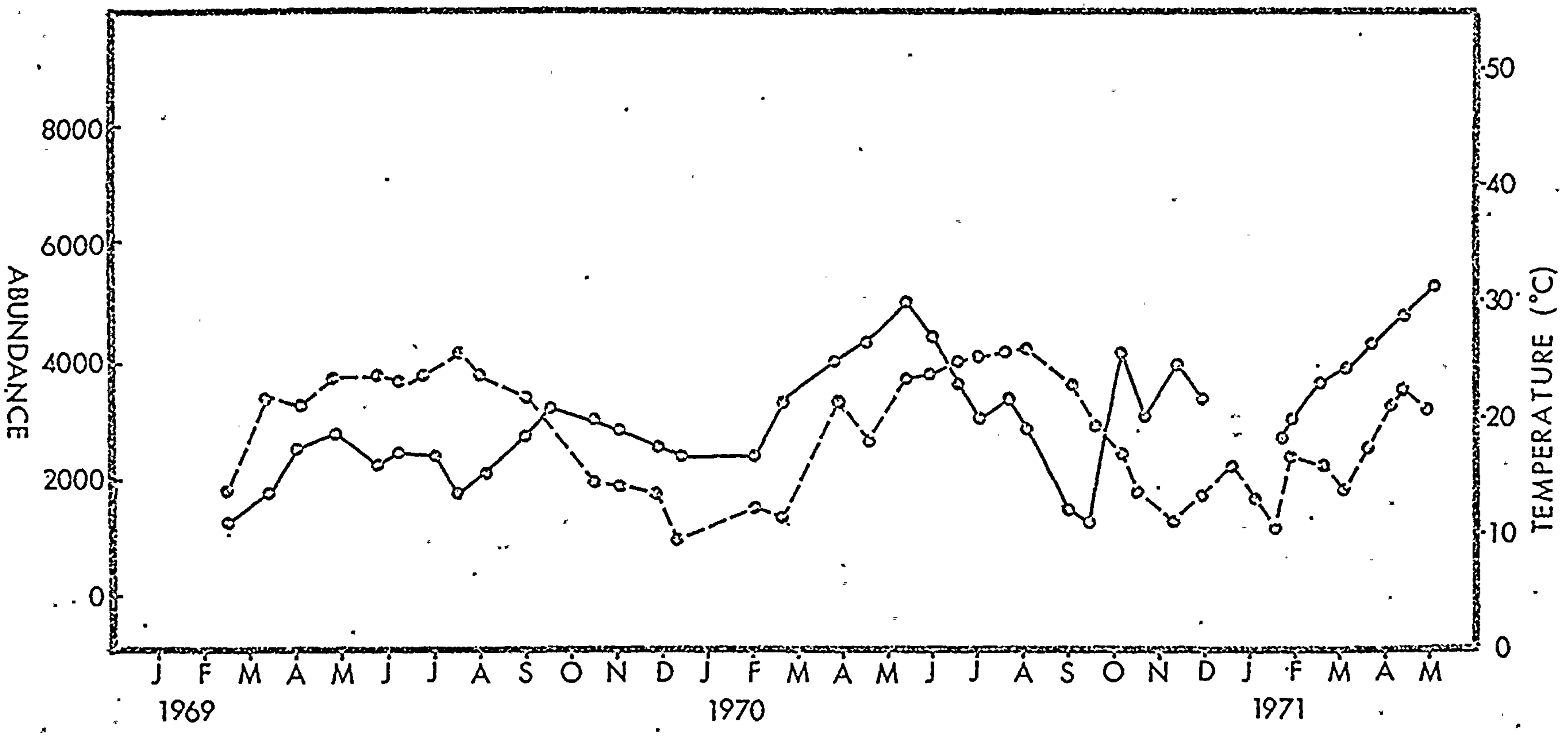

FIGURE X-13 Turkey Point, Biscayne Bay, Florida, Station 24, Mean Temperature (dotted line) and *Thalassia* abundance (solid line) per square meter

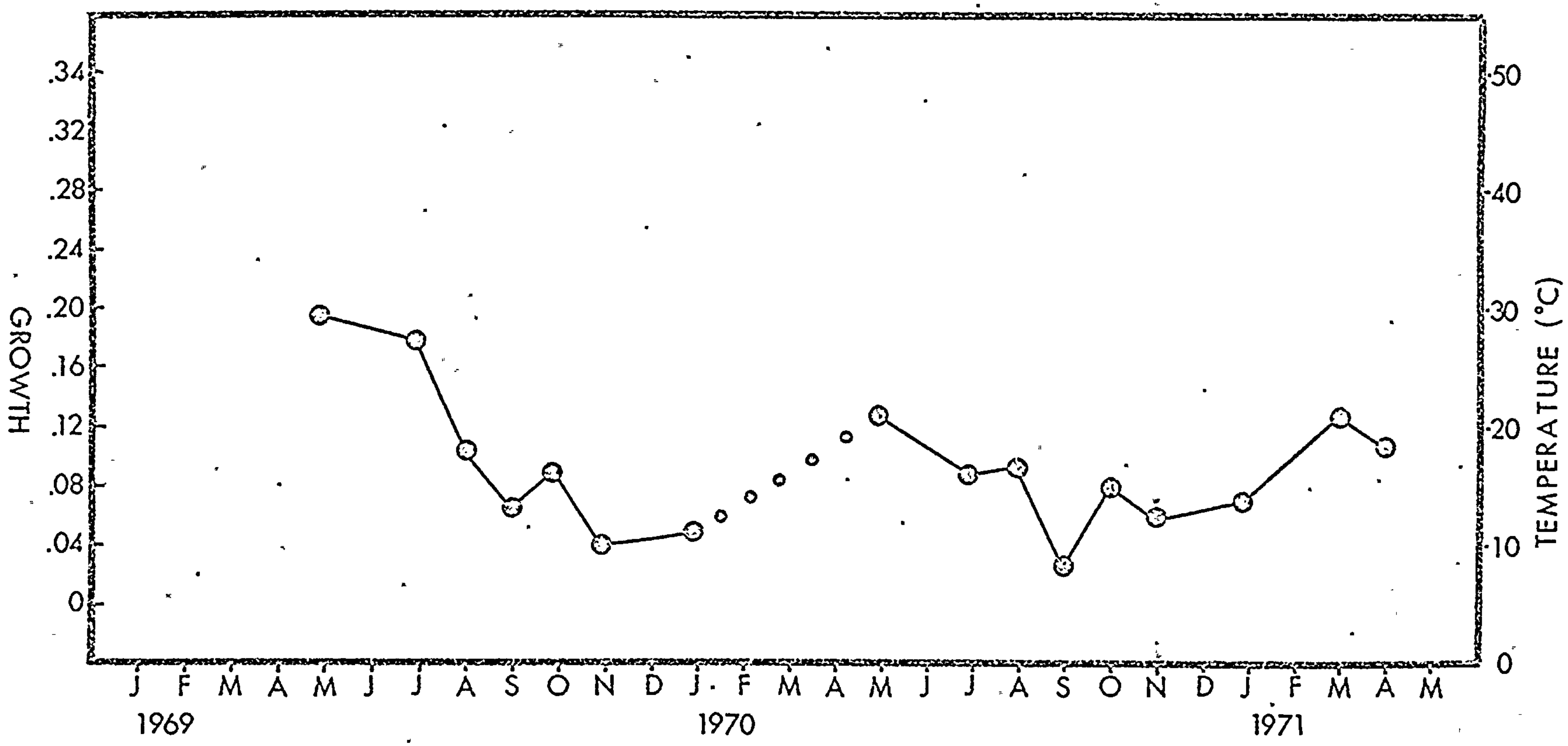

FIGURE X-14 Turkey Point, Biscayne Bay, Florida, Station 24, Mean Thalassia growth (cm^2) per blade per day. (Dotted line indicates unavailable data)

Station 35 had an average temperature of 4.0°C above the Bay ambient. There was a relatively small Thalassia population with little fluctuation between summer and winter (Figure X-15). The health of the Thalassia in summer appeared poor (flaccid leaves and drab green color). Growth appeared to fall when temperatures rose from 28 to 33°C in May (Figure X-16). The abundance remained constant during the summer. Growth and abundance appeared to increase in the following spring..

The algae population was abnormal. As at Station 24, most of those greens without known sexual stages were not present; for instance, Penicillus populations were almost non-existent except for some small recolonization during this past spring. Halimeda exhibited a low population in the spring of 1970, began to grow back in the fall and by the spring of 1971 was large. Acetabularia was abundant in April, 1970, but dropped greatly by June. In the spring of 1971 a large recolonization occurred. Laurencia was seen here in the winter and spring but declined in August. Batophora increased in the fall of 1970.

Card Sound.

To meaningfully interpret field studies, it is necessary to have a cycle of at least one year to understand seasonal fluctuations. It was hoped that the Card Sound study would provide background data on the natural conditions before thermal additions altered the ecology. However, heavy fall storms delayed palcing of stations, and therefore a full year's pre-stress measurements will not be available until this fall. Another factor, the lack of rain from July, 1970, until June, 1971, produced one of the worst droughts experienced in south Florida. This drought caused hypersaline conditions in Card Sound which may produce atypical algal communities and sea grass growth figures in the base-line.

Although much of Card Sound has shallow sediments with patchy Thalassia and macroalgae, the northwest corner of the Sound and much of the Arsenicker Key/Cutter Bank area has dense Thalassia stands. Blade counts as high as 5,500 blades/m^2 were observed in May. These figures indicate production is as high as observed in temperate marine Zostrea grass beds and comparable to pine forest communities (Odum, 1957).

The sediment fringe along the shoreline appears most productive. Patchiness is evident even in this area as can be seen by aerial photography (See Figure X-17). The dark areas correspond to thick patches of Thalassia and the light areas appear as flat coral rock substrate with sparse populations of macroalgae when surveyed underwater.

The Thalassia-sediment relation in Card Sound needs further evaluation. The Thalassia generally decrease in abundance toward the southeast corner of the Sound and in the center of the Card Sound Basin.

The total number of algae were greater in the northwest than in the southwest of the Sound although there is great patchiness seen for any one species. The area in front of and north of the model land canal (Stations 0603 and 0503) appeared to be one of the least productive of both Thalassia and macroalgae (Table X-4 and X-5). This may be due to land runoff in this area causing lowered salinities and

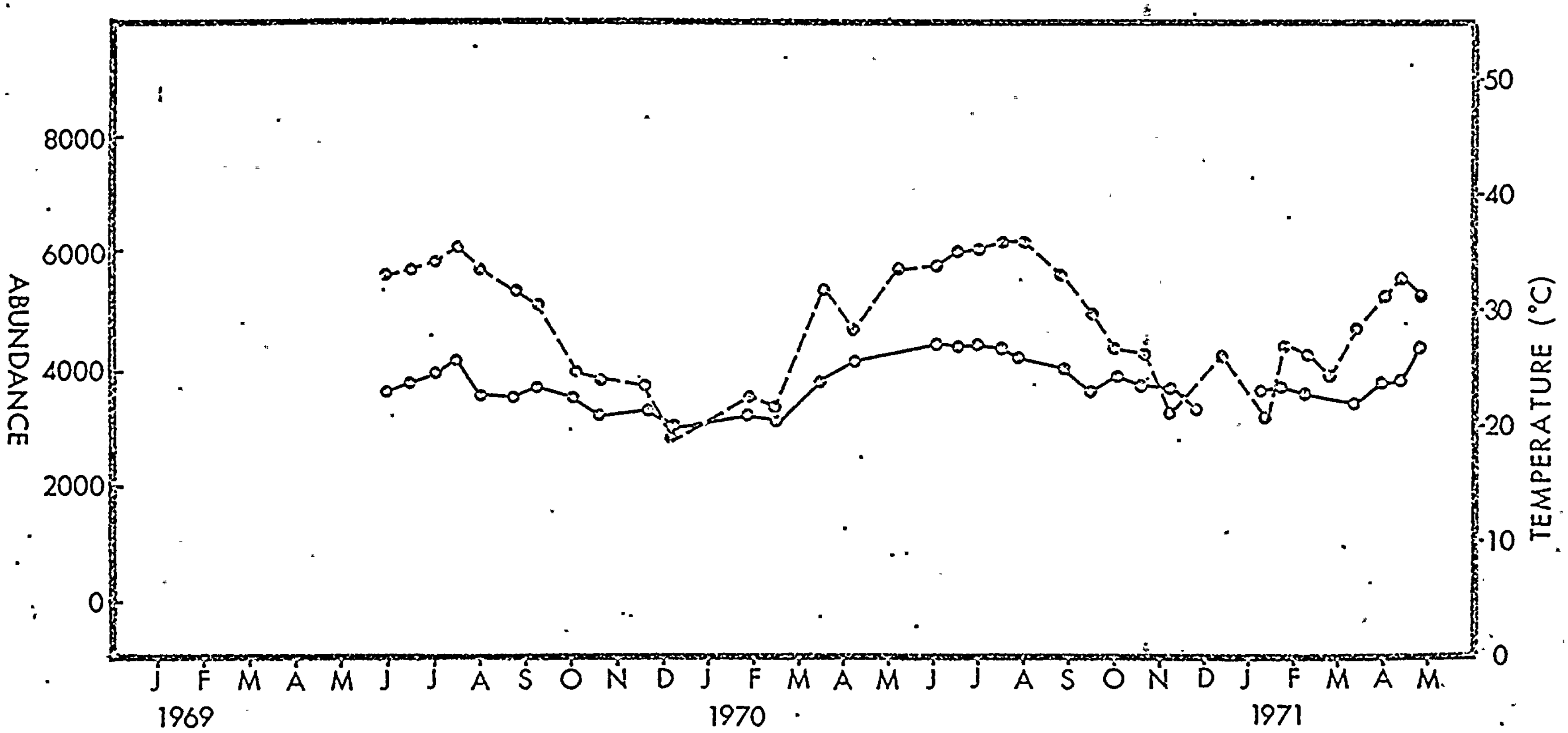

FIGURE X-15 Turkey Point, Biscayne Bay, Florida, Station 35, Mean Temperature (dotted line) and Thalassia abundance (solid line) per square meter

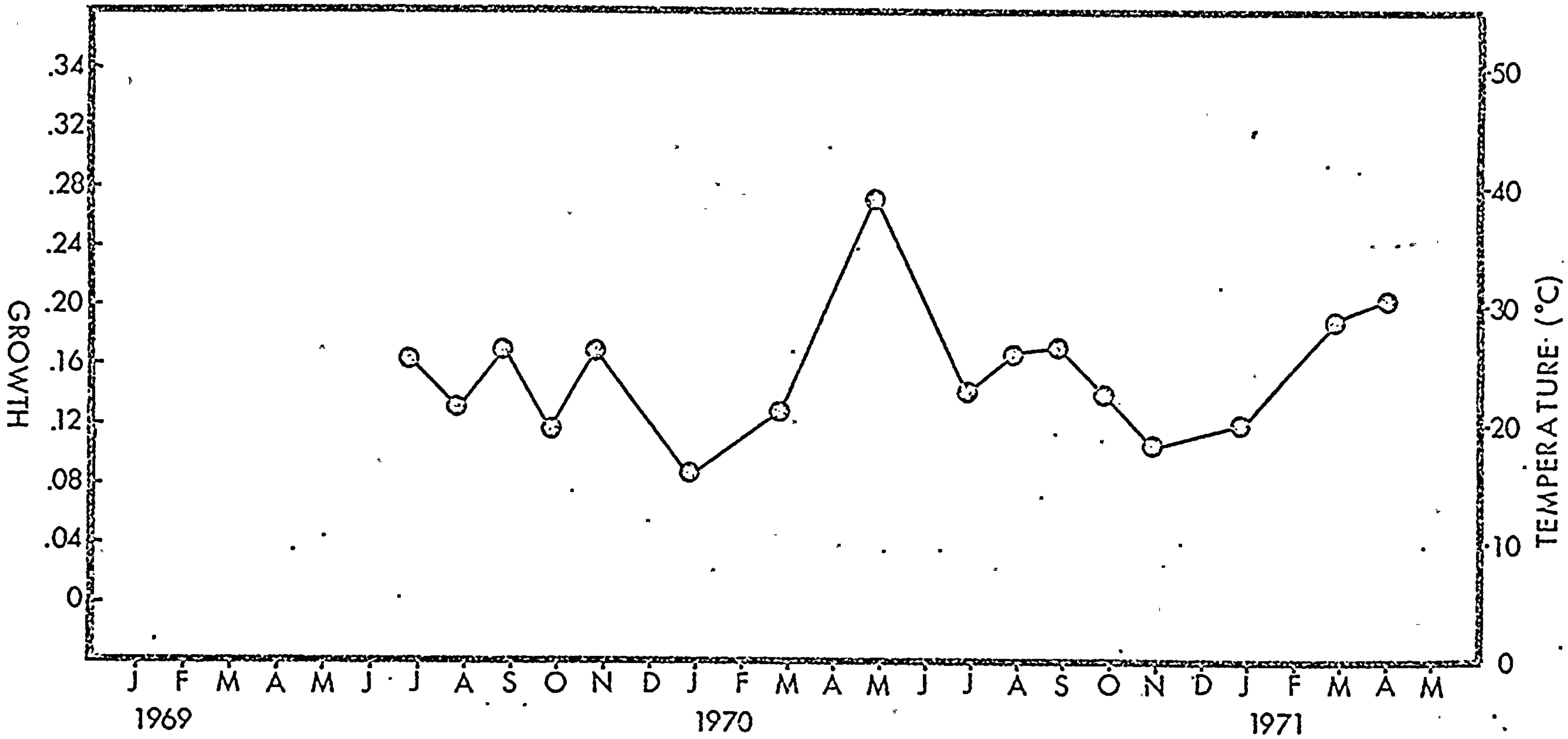

FIGURE X-16 Turkey Point, Biscayne Bay, Florida, Station 35, Mean *Thalassia* growth (cm^2) per blade per day. (Dotted line indicates unavailable data)

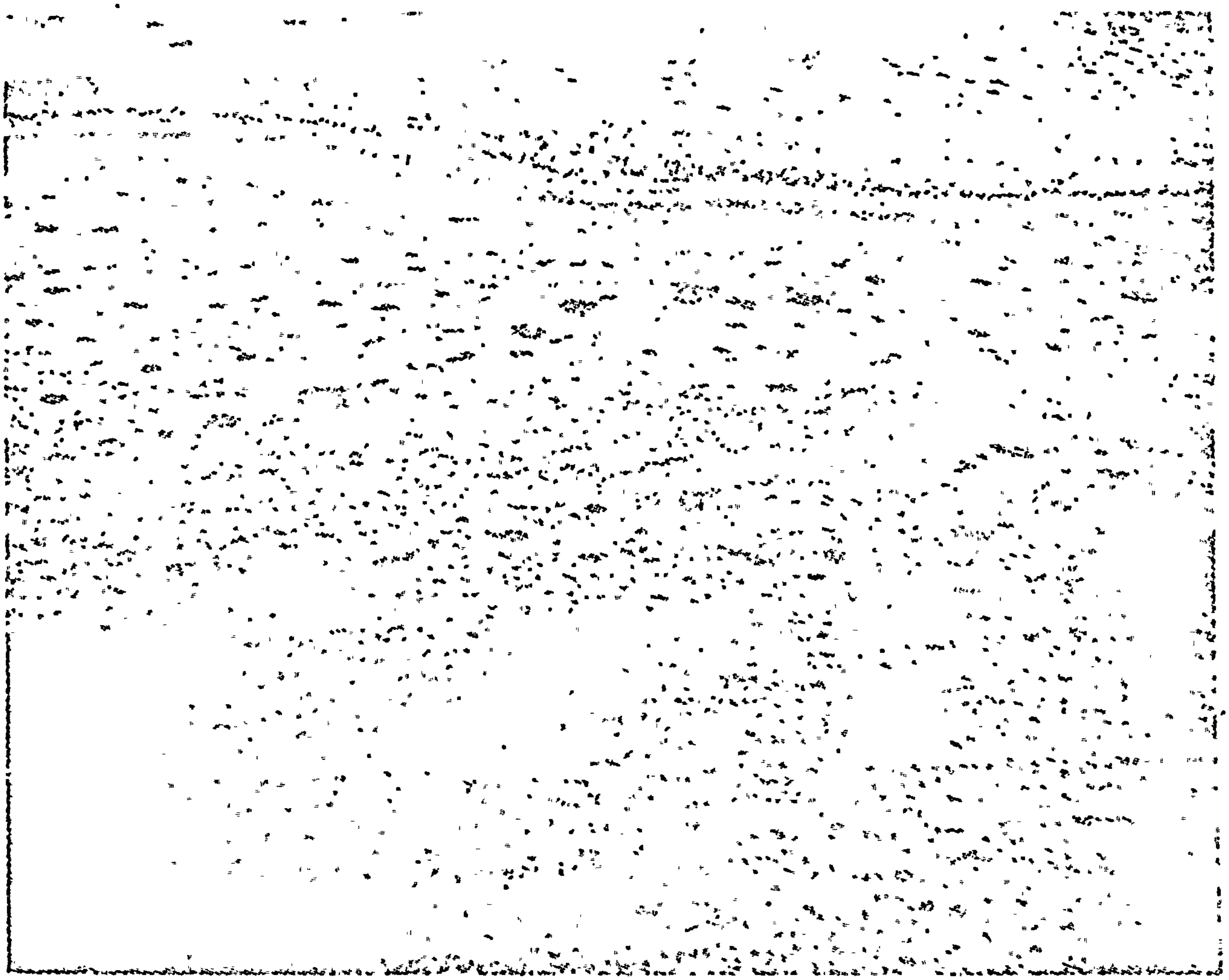

FIGURE X-17 Photograph showing patches of Thalassia and windrows of Laurencia.

Table X-4, Card Sound, Florida stations, *Thalassia* abundance per square meter, mean grams of dry weight (biomass) of new growth per blade per day; and mean square centimeter of growth per blade per day, versus monthly temperatures.

DATE & STATION	T°C	ABUN.	BIOMASS	GROWTH	T°C	ABUN.	BIOMASS	GROWTH
0403					0803			
2/2/71	16.2	1750			16.6	364		
2/21/71	20.5	Vis: "0" - rough seas			19.6	436		
3/10/71	20.9	2150	.099	.03	20.9	428	.008	.09
4/8/71	22.4	2375			22.3	464		
4/22/71	24.3	2400	.042	.06	24.8	Stn. buoy missing		
5/3/71	26.4	2250			27.7	452		
5/20/71	27.5	2500			28.9	480		
6/2/71	27.0	2775			28.8	500		
0503					1103			
2/2/71	16.5	308			16.8	1300		
2/21/71	20.8	376			18.0	0950		
3/10/71	20.8	436	.007	.08	20.5	1625	.065	.12
4/8/71	22.0	404			22.3	1700		
4/22/71	24.6	404	.008	.09	25.0	1625	.065	.12
5/3/71	26.8	472			27.6	1725		
5/20/71	27.9	464			28.8	1750		
6/2/71	27.1	524			27.9	1800		
0603					0104			
2/2/71	16.5	480			13.5	3 50		
2/21/71	20.7	512			18.7	3700		
3/10/71	20.8	546	.009	.10	20.8	3725	.042	.10
4/8/71	22.4	640			19.5	4900		
4/22/71	24.4	584	.006	.07	23.6	4450	.142	.08
5/3/71	26.5	628			27.0	5200		
5/20/71	27.7	620			28.1	5875		
6/2/71	27.6	672			29.1	5750		
0703					0204			
2/2/71	16.8	352			16.4	1900		
2/21/71	19.8	372			18.9	2650		
3/10/71	21.0	440	.006	.07	20.2	2675	.047	.08
4/8/71	22.1	580			21.8	3575		
4/22/71	25.0	520	.006	.06	23.9	3375	.044	.08
5/3/71	26.9	600			27.7	3950		
5/20/71	28.0	656			28.9	4675		
6/2/71	27.7	584			29.0	4800		

DATE & STATION	T°C	ABUN.	BIOMASS	GROWTH	T°C	ABUN.	BIOMASS	GROWTH
0304					0704			
2/2/71	16.5	2225			16.5	880		
2/21/71	18.7	2225			18.4	824		
3/10/71	20.4	2075	.027	.05	20.4	992	.006	.07
4/8/71	22.1	2400			22.0	1236		
4/22/71	25.3	2250	.018	.03	25.1	1168	.006	.07
5/3/71	28.0	2250			27.8	1412		
5/30/71	29.0	2900			28.8	1500		
6/2/71	28.6	3050			28.0	1584		
0404					0405			
2/2/71	16.6	668			16.2	860		
2/21/71	19.1	688			18.7	1475		
3/10/71	20.3	780	.007	.09	19.9	1650	.084	.16
4/8/71	22.0	944			21.8	2000		
4/22/71	26.0	924	.007	.09	23.5	1775	.031	.07
5/3/71	27.3	1008			26.7	2250		
5/20/71	28.3	1008			27.8	2250		
6/2/71	28.0	1040			27.7	2028		
0504					0805			
2/2/71	16.3	824			16.8	764		
2/21/71	19.2	1300			18.2	680		
3/10/71	20.3	948	.006	.07	20.2	892	.007	.08
4/8/71	22.0	1100			22.1	1064		
4/22/71	25.1	1164	.007	.08	23.8	1120	.009	.10
5/3/71	28.0	1192			27.0	1194		
5/20/71	29.0	1508			27.9	1268		
6/2/71	28.3	1276			27.8	1296		
0604					0606			
2/2/71	16.5	776			16.2	869		
2/21/71	19.4	1400			18.5	524		
3/10/71	20.4	896	.006	.08	20.1	880	.006	.08
4/8/71	22.0	948			22.1	1068		
4/22/71	24.0	1120	.005	.05	25.3	1072	.006	.08
5/3/71	25.8	1232			27.1	1380		
5/20/71	28.9	1336			28.1	1364		
6/2/71	28.1	1248			27.6	1340		

Table X-5, Algal abundance of predominate species per square meter in Card Sound stations, including the number of healthy, unhealthy, and juveniles for each species.

CARD SOUND ALGAE SUMMARY

Date & Station	Condition	Pen.	Hal.	Acetab.	Laur.	Rhipo.	Udt.	Bat.	No. Species
0104 2-02-71	H	11	19		.5%				5
	U	6	3	1					
	J								
	T	17	22	1	.5%				
3-10-71	H	12	20	1	.5%		4	5	7
	U	8							
	J	1	1						
	T	21	21	1	.5%		4	5	
4-07-71	H	10	20		.5%		1	30	6
	U	4					3		
	J	1							
	T	15	20		.5%		4	30	
5-04-71	H	6	20	1	90%		1	37	6
	U	6					1		
	J								
	T	12	20	1	90%		2	37	
0204 2-02-71	H	4	5					300	4
	U								
	J								
	T	4	5					300	
3-10-71	H	3	4	1	.5%		1	220	8
	U	2					2		
	J	1	1						
	T	6	5	1	.5%		3	220	
4-07-71	H	6	5		.5%			170	5
	U								
	J								
	T	6	5		.5%			170	
5-04-71	H	6	5		1%			85	5
	U	3							
	J	1	1						
	T	10	6		1%			85	

Date & Station	Condition	Pen.	Hal.	Acetab.	Laur.	Rhipo.	Udt.	Bat.	No. Species
0304									
2-02-71	H	3	13		.5%	4	3	85	6
	U	1	4			2			
	J		1			1			
	T	4	18		.5%	7	3	85	
3-10-71	H	1	14	2	1%	3	1	150	8
	U	3	3				1		
	J								
	T	4	17	2	1%	3	2	150	
4-07-71	H	1	9		.5%	3		150	8
	U	3	5	1		1	1		
	J		3						
	T	4	17	1	.5%	4	1	150	
5-04-71	H	1	8		2%	2	2	95	7
	U	2	2			2			
	J	2	1						
	T	5	11		2%	4	2	95	
0403									
2-02-71	H		2	1	6%			1600	7
	U								
	J								
	T		2	1	6%			1600	
3-10-71	H		2	1	30%	1	2	1800	9
	U						1		
	J								
	T		2	1	30%	1	3	1800	
4-07-71	H		2	1	35%	1	1	150	10
	U		1				3		
	J								
	T		3	1	35%	1	4	150	
5-04-71	H		1		9%	1		150	8
	U		1				4		
	J								
	T		2		9%	1	4	150	

Date Station	Condition	Pen.	Hal.	Acetab.	Laur.	Rhipo.	Udt.	Bat.	No. Species
0404									
2-02-71	H				2%	9	2	100	6
	U	1				5			
	J					2			
	T	1			2%	16	2	100	
3-10-71	H				2%	9	1	200	6
	U					5			
	J								
	T				2%	14	1	200	
4-07-71	H				4%	5	1	240	6
	U					8			
	J								
	T				4%	13	1	240	
5-04-71	H	1			11%	9	2	450	7
	U					4			
	J	2							
	T	3			11%	13	2	450	
0405									
2-02-71	H	3	5	105	4%	3	32	55	7
	U	4				1			
	J	3		1					
	T	10	5	106	4%	4	32	55	
3-10-71	H	1	9	100	10%	2	11	130	8
	U	6	1	30		2	8		
	J			15		1			
	T	7	10	145	10%	5	19	130	
4-07-71	H	2	11	75	25%	4	4	95	8
	U			19		3	11		
	J	1	2						
	T	3	13	94	25%	7	15	95	
5-04-71	H		16	59	36%	10	2	85	7
	U					3	4		
	J		1	10					
	T		17	69	36%	13	6	85	

Date & Station	Condition	Pen.	Hal.	Acetab.	Laur.	Rhipo.	Udt.	Bat.	No. Species
0304 2-02-71	H	3	13		.5%	4	3	85	6
	U	1	4			2			
	J		1			1			
	T	4	18		.5%	7	3	85	
3-10-71	H	1	14	2	1%	3	1	150	8
	U	3	3				1		
	J								
	T	4	17	2	1%	3	2	150	
4-07-71	H	1	9		.5%	3		150	8
	U	3	5	1		1	1		
	J		3						
	T	4	17	1	.5%	4	1	150	
5-04-71	H	1	8		2%	2	2	95	7
	U	2	2			2			
	J	2	1						
	T	5	11		2%	4	2	95	
0403 2-02-71	H		2	1	6%			1600	7
	U								
	J								
	T		2	1	6%			1600	
3-10-71	H		2	1	30%	1	2	1800	9
	U						1		
	J								
	T		2	1	30%	1	3	1800	
4-07-71	H		2	1	35%	1	1	150	10
	U		1				3		
	J								
	T		3	1	35%	1	4	150	
5-04-71	H		1		9%	1		150	8
	U		1				4		
	J								
	T		2		9%	1	4	150	

Date Station	Condition	Pen.	Hal.	Acetab.	Laur.	Rhipo.	Udt.	Bat.	No. Species
0404 2-02-71	H				2%	9	2	100	6
	U	1				5			
	J					2			
	T	1			2%	16	2	100	
3-10-71	H				2%	9	1	200	6
	U					5			
	J								
	T				2%	14	1	200	
4-07-71	H				4%	5	1	240	6
	U					8			
	J								
	T				4%	13	1	240	
5-04-71	H	1			11%	9	2	450	7
	U					4			
	J	2							
	T	3			11%	13	2	450	
0405 2-02-71	H	3	5	105	4%	3	32	55	7
	U	4				1			
	J	3		1					
	T	10	5	106	4%	4	32	55	
3-10-71	H	1	9	100	10%	2	11	130	8
	U	6	1	30		2	8		
	J			15		1			
	T	7	10	145	10%	5	19	130	
4-07-71	H	2	11	75	25%	4	4	95	8
	U			19		3	11		
	J	1	2						
	T	3	13	94	25%	7	15	95	
5-04-71	H		16	59	36%	10	2	85	7
	U					3	4		
	J		1	10					
	T		17	69	36%	13	6	85	

Date & Station	Condition	Pen.	Hal.	Acetab.	Laur.	Rhipo.	Udt.	Bat.	No. Species
0503 2-02-71	H		5	2	6%				4
	U		2	1					
	J								
	T		7	3	6%				
3-10-71	H	3	4		2%	4	1	15	7
	U		1						
	J	2	2						
	T	5	7		2%	4	1	15	
4-07-71	H	5	8		5%	3	4	5	7
	U		1			1			
	J	4							
	T	9	9		5%	4	4	5	
5-04-71	H	1	6	9	8%	1	5	40	11
	U	4	1	2			2		
	J	3	2						
	T	8	9	11	8%	1	7	40	
0504 2-02-71	H	7	14	20	.5%	2		110	6
	U	4	4	2		4			
	J	8							
	T	19	18	22	.5%	6		110	
3-10-71	H	5	17	12	1%	4	1		6
	U	5	1	3		1	1		
	J	3		1					
	T	13	18	16	1%	5	2		
4-07-71	H	7	13	2	1%	3			7
	U	7	1			1			
	J	1							
	T	15	14	2	1%	4			
5-04-71	H	10	10	13	1%	4	3	170	8
	U	5	2			1	2		
	J	2		1					
	T	17	12	14	1%	5	5	170	

Date & Station	Condition	Pen.	Hal.	Acetab.	Laur.	Rhipo.	Udt.	Bat.	No. Species
0603									
2-02-71	H		2	3	7%	2	4	17	7
	U		9	1				2	
	J		1						
	T		12	4	7%	2	4	19	
3-10-71	H		7		1%	4	13		8
	U	1	8						
	J		3						
	T	1	18		1%	4	13		
4-07-71	H	1	7		2%	7	10		8
	U		7				3		
	J		4						
	T	1	18		2%	7	13		
5-04-71	H		29	2	9%	9	13		10
	U		7	1		1	2		
	J	5	2	2					
	T	5	38	5	9%	10	15		
0604									
2-02-71	H	6	10	19	.1%	3	11	45	8
	U		2			1	4		
	J	2							
	T	8	12	19	.1%	4	15	45	
3-10-71	H	6	2	33	1%	3	7	65	8
	U	3	2	7			2		
	J			14					
	T	9	4	55	1%	3	9	65	
4-07-71	H	4	3	87	2%	2	4	240	7
	U	3	2	22			3		
	J	2							
	T	9	5	109	2%	2	7	240	
5-04-71	H	4	6	52	.5%	2	2	180	8
	U	4				1	4		
	J	5		8					
	T	13	6	60	.5%	3	6	180	

Date & Station	Condition	Pen.	Hal.	Acetab.	Laur.	Rhipo.	Udt.	Bat.	No. Species
0606									
2-02-71	H	20	17	75	2%	1	14	45	7
	U	13	4			2	2		
	J	8							
	T	41	22	75	2%	3	16	45	
3-10-71	H	15	10	75	8%	5	4	160	7
	U	15	2	12		4			
	J	2		14		3			
	T	32	12	100	8%	12	4	160	
4-07-71	H	24	9	51	4%	3	5	80	7
	U	10	1				4		
	J	6	3	10					
	T	40	13	61	4%	3	9	80	
5-04-71	H	33	18	48	3%	2	3	115	8
	U	17		2		1	2		
	J	9		5					
	T	59	18	55	3%	3	5	115	
0703									
2-02-71	H	5	9	1	7%	4	22	5	8
	U	3	3	1					
	J	1	1						
	T	9	13	2	7%	4	22	5	
3-10-71	H	3	4		3%	4			6
	U	2	6			2			
	J	2							
	T	7	10		3%	6			
4-07-71	H	1	3		2%	4	1	40	9
	U	5	6			1			
	J	7	4						
	T	13	13		2%	5	1	40	
5-04-71	H	1	9	1	5%	5	1	55	9
	U		2			1			
	J	9	1						
	T	10	12	1	5%	6	1	55	

Date & Station	Condition	Pen.	Hal.	Acetab.	Laur.	Rhipo.	Udt.	Bat.	No. Species
0704 2-02-71	H	5		75			2	220	4
	U	7							
	J	1							
	T	13		75			2	220	
3-10-71	H	8	4	60	1%		1	250	6
	U	8		10					
	J	2		30					
	T	18	4	100	1%		1	250	
4-07-71	H	8	6	64	.5%		1	340	7
	U	6	1						
	J	3		15					
	T	17	7	79	.5%		1	340	
5-04-71	H	9	9	65				155	6
	U	9	1						
	J	1		12					
	T	19	10	77				155	
0803 2-02-71	H	3	4		.1%	2	1	70	7
	U		5				1		
	J								
	T	3	9		.1%	2	2	70	
3-10-71	H	1	15	3	4%			200	8
	U	3	1	1					
	J		2						
	T	4	18	4	4%			200	
4-07-71	H	1	12	2	4%	3		250	8
	U		3			1			
	J		3						
	T	1	18	2	4%	4		250	
5-04-71	H	3	5	3	1%	6	5	450	11
	U	3		1		2	2		
	J	1	1	1					
	T	7	6	5	1%	8	7	450	

Date & Station	Condition	Pen.	Hal.	Acetab.	Laur.	Rhipo.	Udt.	Bat.	No. Species
0805 2-02-71	H	35	22					5	4
	U	35	4				1		
	J	11	2						
	T	81	28				1	5	
3-10-71	H	26	15	3				25	4
	U	24	4	15					
	J	7	1						
	T	57	20	18				25	
4-07-71	H	18	13	10				1	5
	U	11	1						
	J	3	2	4					
	T	32	16	14				1	
5-04-71	H	22	15	16				27	5
	U	14	3						
	J	7	1	2					
	T	43	19	18				27	
1103 2-02-71	H	14							1
	U	19							
	J	5							
	T	38							
3-10-71	H							4	2
	U	7							
	J	4							
	T	11						4	
4-07-71	H								1
	U	3							
	J								
	T	3							
5-04-71	H								1
	U	7							
	J	5							
	T	12							

LEGEND:

Pen. - Penicillus
Hal. - Halimeda
Acetab. - Acetablaria
Laur. - Laurencia
Rhipo. - Rhipocephalus
Udt. - Udotea
Bat. - Batophora
H - Healthy
U - Unhealthy
J - Juvenile
T - Total

physiological stress to the plants. The oxygen, phosphate, nitrate, light, and temperature regime did not appear markedly different here. Another area (Station 0803) had lowered grass and algae populations and this may also be due to runoff in the wet season. Across Card Bank at Station 1103 the sediment became quite thick (Wanless, 1969) however a relatively low algae population was seen there. This region received little influence from land runoff. Thus, it appears that sediment and lowered salinities may be important for the Thalassia and algae communities.

From diving observations it was determined that the eastern shoreline is similar to the western shoreline although the southeast area has higher abundance of Thalassia than the southwest. This again may suggest a relationship to land runoff.

The stations close to shore in the northwest showed much higher populations of Thalassia (average 3,325 blades/m^2) and macroalgae (average 77.6 g/m^2) than did the shoreline stations near the mouth of the canal. Thalassia averaged 541 blades/m^2 and the macroalgae averaged 62 g/m^2. The stations in the middle of the Bay station lower Thalassia density (average 1,981 blades/m^2)(Figures X-18 and X-19). Station 0104 had 5,875 blades/m^2 and was not close to the mainland shore. This high density was apparently a result of the proximity to a mangrove key. In other words, despite its distance from the mainland shore, it was a "shore-like" station.

There was more flowering Thalassia in Card Sound (Table X-3) than in Turkey Point. On May 3, 1971, Card Sound stations averaged 40 flowers and buds/m^2; whereas, Turkey Point stations averaged 19 flowers and buds/m^2. On May 17, Card Sound had 45 flowers and buds/m^2, while Turkey Point had 16/m^2. Most of the flowers and buds in Biscayne Bay were observed at Station 52, a relatively normal (1.5°C above ambient) station. The part that flowering plays in the total propagation of new Thalassia is not understood. This is an area which must be studied more fully preferably under controlled laboratory conditions.

The Penicillus counts (Figure X-20 and Table X-6) increased at 9 stations, decreased at 4, and decreased during the period February to May, 1971. This demonstrates the typical patchy behavior and year-round growth of these tropical green macroalgae. The grass, which is an angiosperm, recolonizing the sea after long land evolution, would be more likely to show the seasonal cycle typical of both temperate land and marine plants and thus it is not surprising that we see just that. Halimeda abundance declined from February (168 total) to May (149 total) (Figure X-21 and Table X-6) On the other hand, the total number of species per station increased from February to May, although not significantly.

Figures X-20 and X-21 of Penicillus and Halimeda life stages demonstrate the typical turnover rate which occurred during the winter. The number of juveniles of both species was relatively low and there was a substantial percent of each in a scenescent phase. In general, the number of juveniles increase slightly as the spring proceeds, although not as rapidly as Thalassia. The Laurencia cover, as determined by diving and with aerial photographs, was greater in the middle of the north section of the Sound than in the south (Figure X-22). The Laurencia stands could be detected quite well from the photographs. In several of the photographs of the region our buoys could be identified and thus the flora at that point compared with the photographs. Laurencia, was moved by water currents and tended to

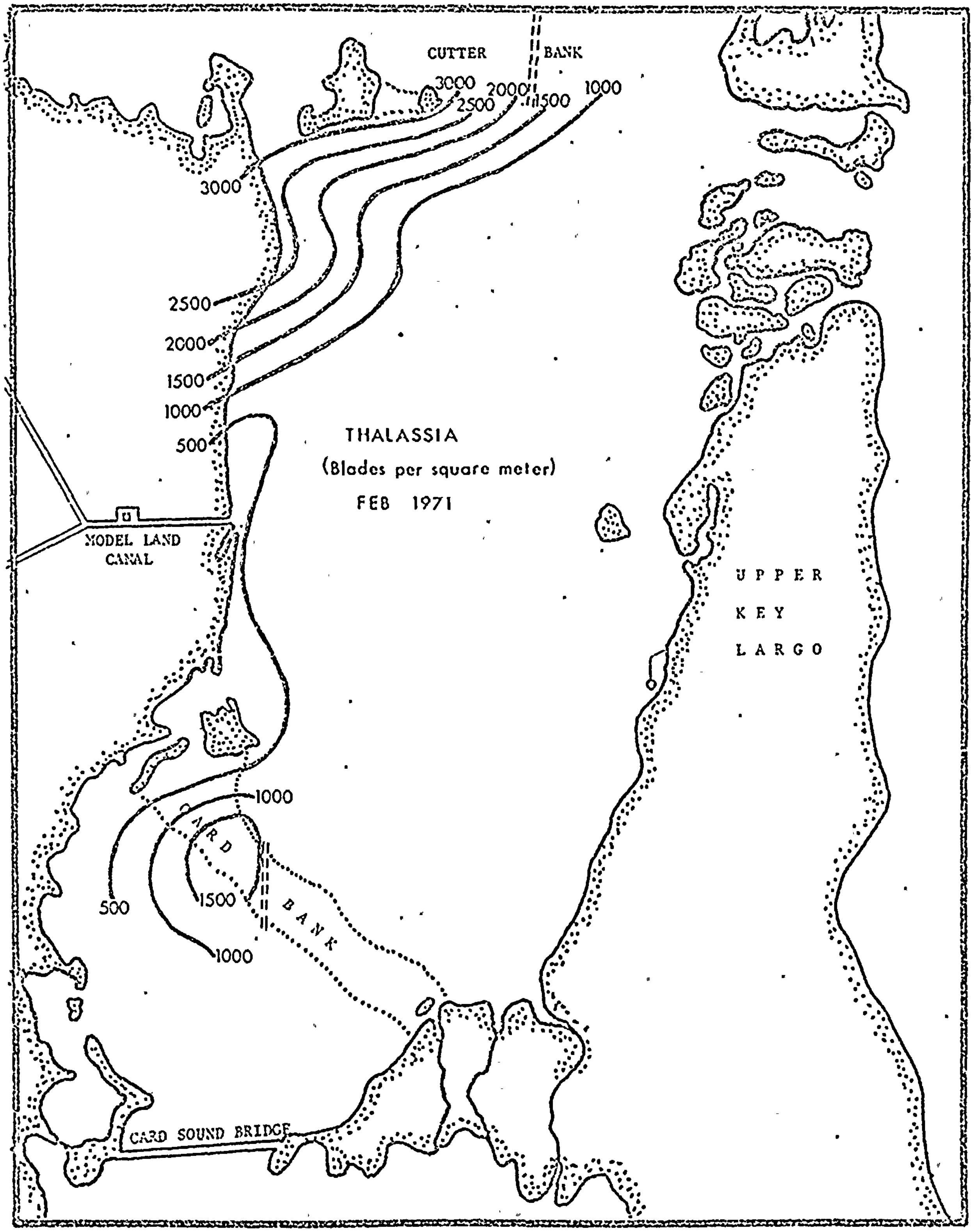

FIGURE X-18 Abundance of Thalassia, blades per square meter, in Card Sound during February, 1971

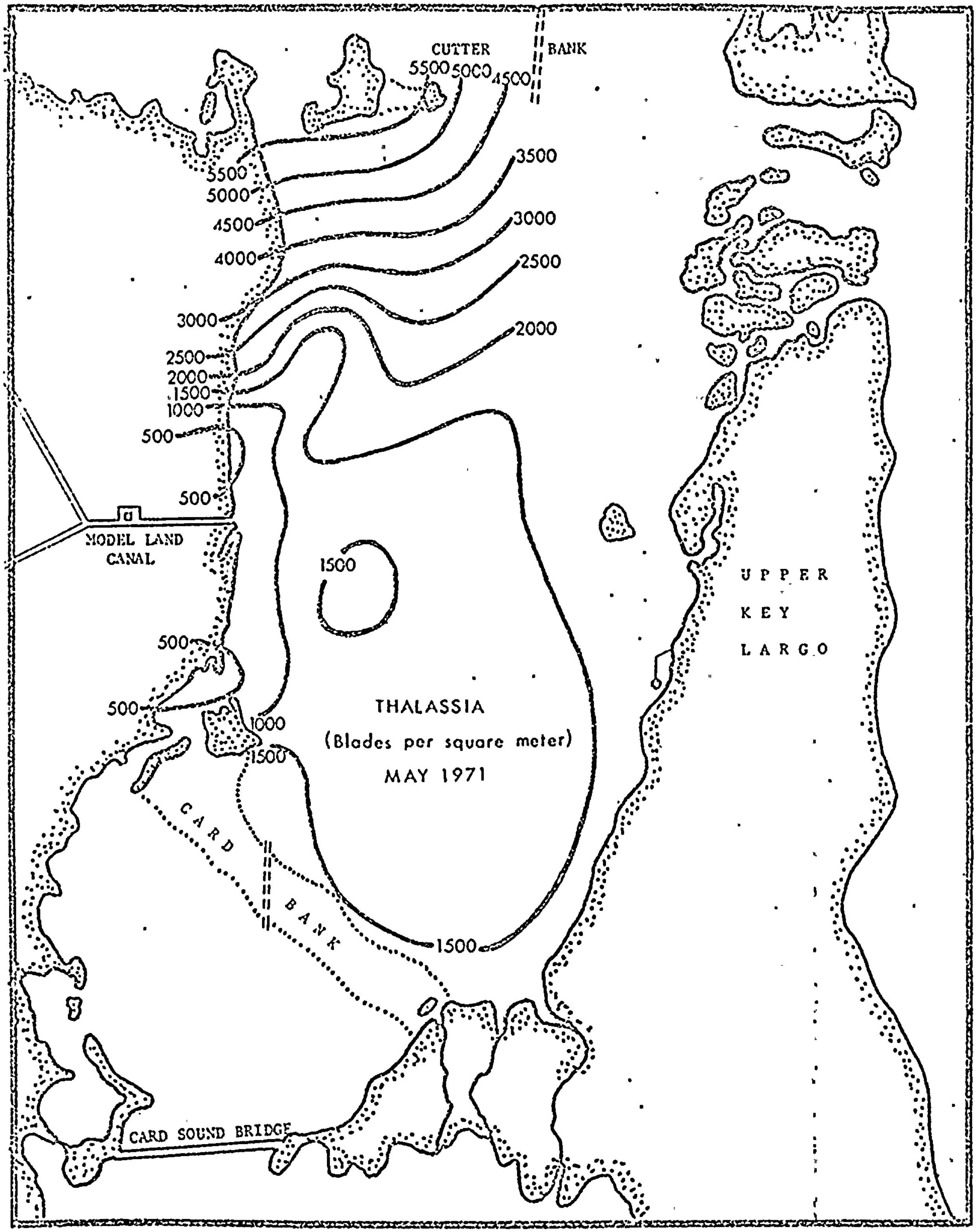

FIGURE X-19 Abundance of Thalassia, blades per square meter, in Card Sound during May, 1971

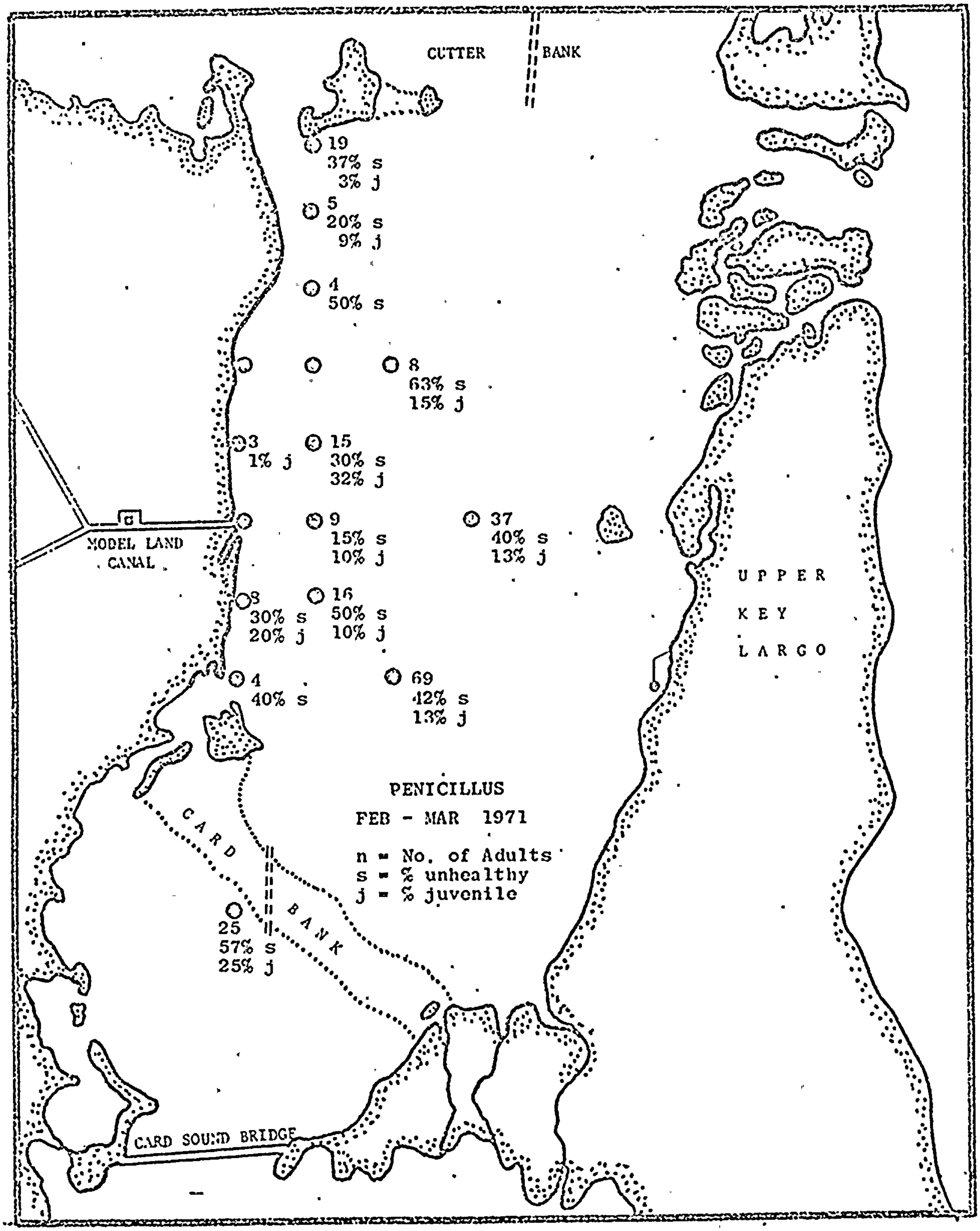

FIGURE X-20 Abundance per square meter of Penicillus capitatus in Card Sound Stations showing per cent unhealthy and per cent juveniles during February and March, 1971

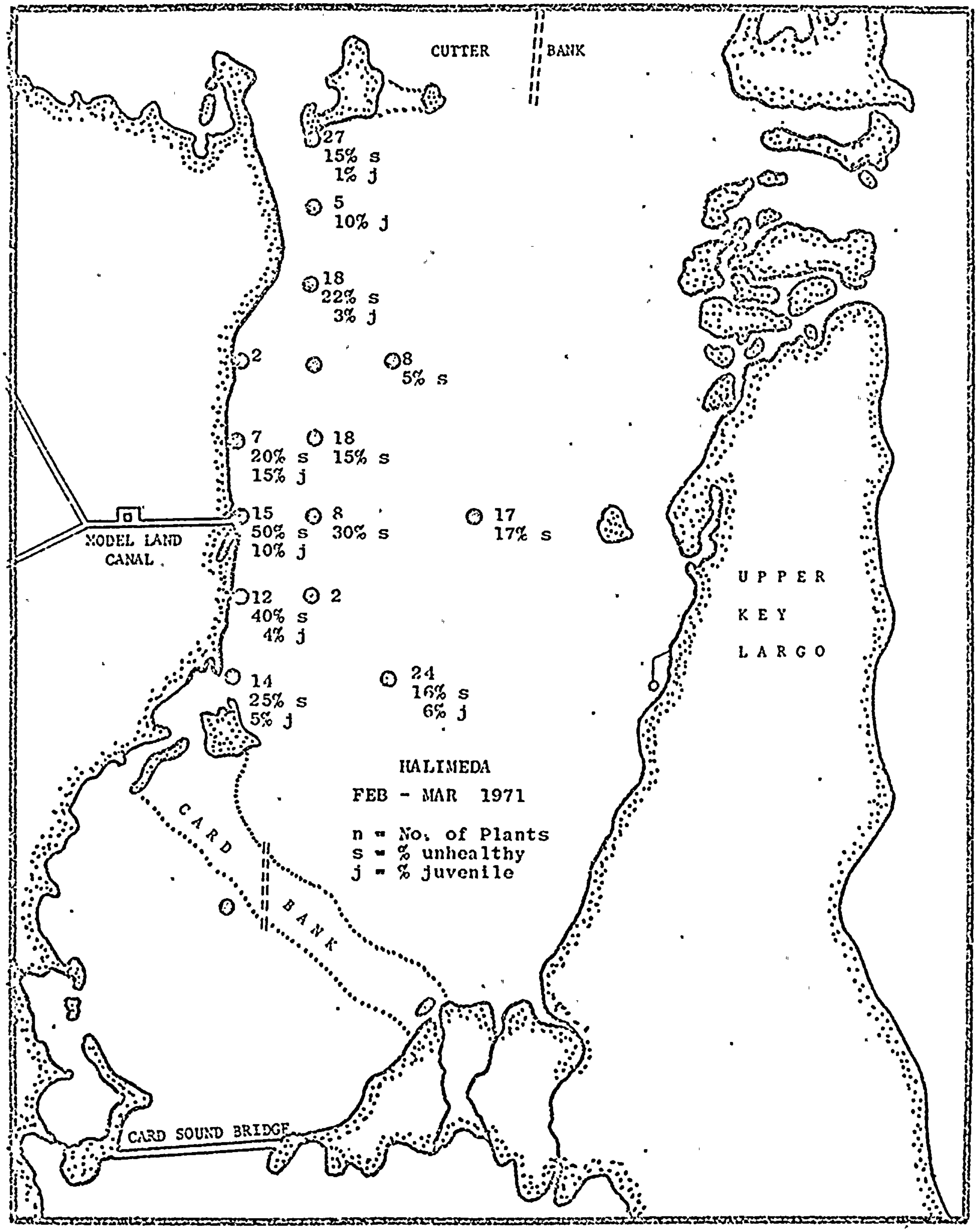

FIGURE X-21 Abundance per square meter of Halimeda incrassata in Card Sound Stations showing per cent unhealthy and per cent juveniles during February and March, 1971

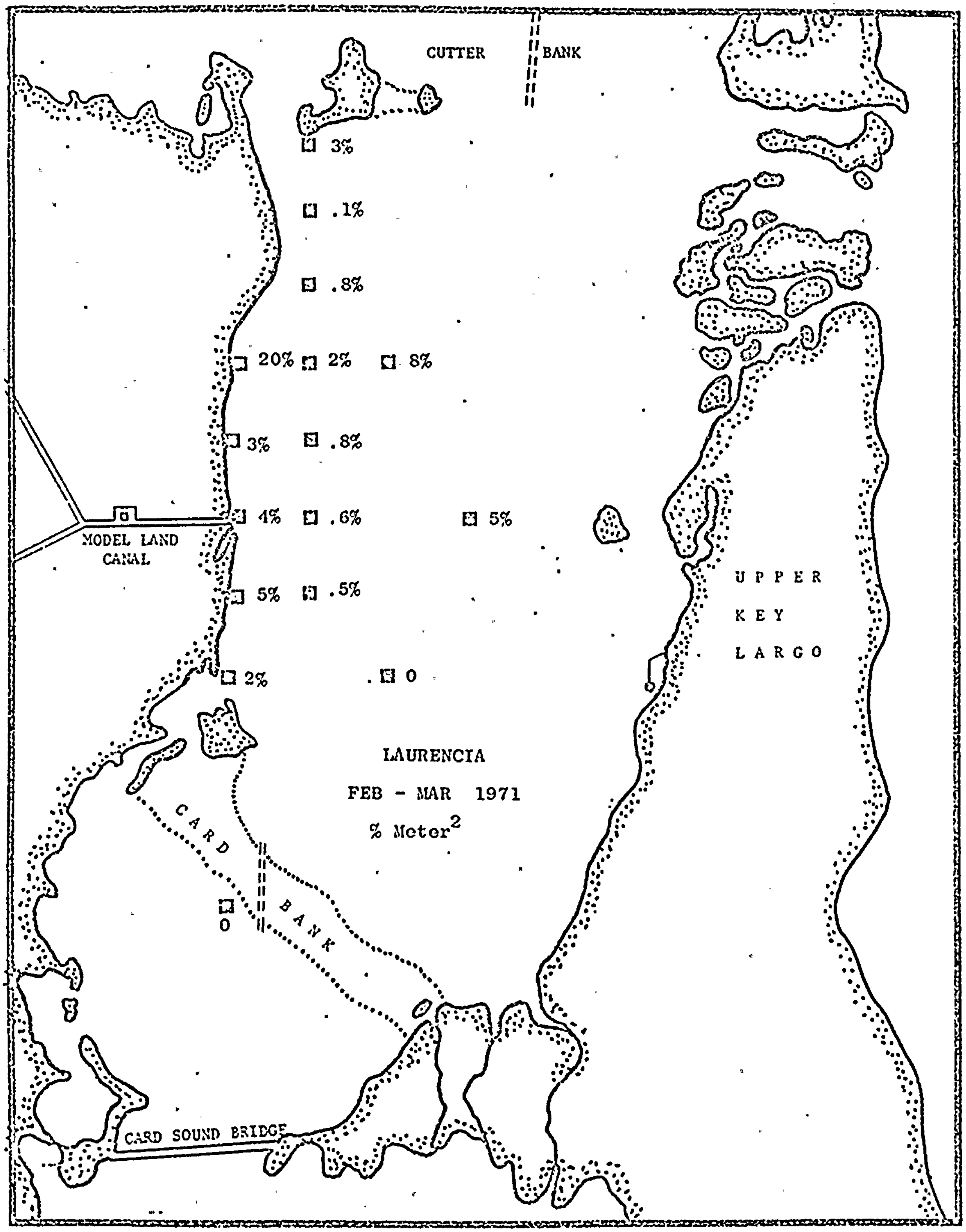

FIGURE X-22 Per cent of cover per square meter of Laurencia poitei in Card Sound Stations during February and March, 1971

Table X 6 Total mean grams dry weight for the predominate algal species in Card Sound stations, with per cent *Thalassia* cover, reproductive stages present, and total number of algae species also included.

CARD SOUND ALGAL BOTTOM COVER *

Date	Station	Pen.	Hal.	Acetab.	Rhipo.	Udt.	Bat.	Total	% Thal.	Repro. Stages	No.	Total Species
2-19-71	0504	36.1	72.0	2.2	13.2	0	5.5	129.0	1			6
3-01-71	0504	24.7	72.0	1.6	11.0	3.0	0	112.3	1			6
4-07-71	0504	28.5	56.0	0	8.8	0	0	93.3	5			7
5-05-71	0504	32.3	48.0	1.4	11.0	7.5	8.5	108.7	10			8.
2-19-71	0603	0	48.0	0.4	4.4	6.0	1.0	59.8	2			7
3-01-71	0603	1.9	72.0	0	8.8	3.0	19.5	105.2	3			8
4-07-71	0603	1.9	72.0	0	15.4	19.5	0	108.8	5			8
5-05-71	0603	9.5	152.0	0.5	22.0	22.5	0	206.5	5			10
2-19-71	0604	15.2	48.0	1.9	8.8	22.5	0	96.4	1			8
3-01-71	0604	17.1	16.0	5.5	6.6	13.5	3.3	62.0	1	Bat.		8
4-07-71	0604	17.1	20.0	10.9	4.4	10.5	12.0	74.9	5	Bat.		7
5-05-71	0604	24.7	24.0	6.0	6.6	9.0	9.0	79.3	15	Bat.		8
2-19-71	0606	77.9	88.0	7.5	6.6	24.0	2.3	206.3	2			7
3-01-71	0606	60.8	48.0	10.0	26.4	6.0	8.0	159.2	5			8
4-07-71	0606	76.0	52.0	6.1	6.6	13.5	4.0	158.2	10			7
5-05-71	0606	112.1	72.0	5.5	6.6	7.5	5.8	209.5	15	Bat.		8
2-19-71	0703	17.1	52.0	0.2	8.8	33.0	0.3	111.4	1			8
3-01-71	0703	13.3	40.0	0	13.2	0	0	66.5	3			6
4-07-71	0703	24.7	52.0	0	11.0	1.5	2.0	91.2	2			9
5-05-71	0703	19.0	48.0	0.1	13.2	1.5	2.8	84.6	5	Bat.		9
2-19-71	0704	24.7	0	7.5	0	3.0	11.0	46.2	10			4
3-01-71	0704	34.2	16.0	10.0	0	1.5	12.5	74.2	15			6
4-07-71	0704	32.3	28.0	7.9	0	1.5	17.0	86.7	35			7
5-05-71	0704	36.1	40.0	7.7	0	0	7.8	91.6	35	Bat.		6
2-19-71	0803	5.7	36.0	0	4.4	3.0	3.5	52.6	10			7
3-01-71	0803	7.6	72.0	0.4	0	0	10.0	90.0	1			8
4-07-71	0803	1.9	72.0	0.2	8.8	0	12.5	95.4	1			8
5-05-71	0803	13.3	24.0	0.5	17.6	10.5	22.5	88.4	2	Bat.		11

CARD SOUND ALGAL BOTTOM COVER

Date	Station	Pen.	Hal.	Acetab.	Rhipo.	Udt.	Bat.	Total	% Thal.	Repro. Stages	No.	Total Species
2-19-71	0104	32.3	128.0	0.1	0	0	0	160.4	70			5
3-01-71	0104	39.9	84.0	0.1	0	6	0.3	130.3	75			7
4-07-71	0104	28.5	80.0	0	0	6	1.5	116.0	75			6
5-05-71	0104	22.8	84.0	0.1	0	1.5	1.9	110.3	85			6
2-19-71	0204	7.6	20.0	0	0	0	15.0	42.6	1			4
3-01-71	0204	11.4	20.0	0.1	0	4.5	11.0	47.0	1	Bat.		8
4-07-71	0204	11.4	20.0	0	0	0	8.5	39.9	1	Bat.		5
5-05-71	0204	19.0	24.0	0	0	0	4.3	47.3	1			5
2-19-71	0304	7.6	72.0	0	15.4	4.5	4.3	103.8	1			6
3-01-71	0304	7.6	68.0	0.2	6.6	3.0	7.5	92.9	1	Bat.		8
4-07-71	0304	7.6	68.0	0.1	8.8	1.5	5.3	91.3	2	Bat.		8
5-05-71	0304	9.5	44.0	0	8.8	3.0	4.8	70.1	3			7
2-19-71	0403	0	8.0	0.1	0	0	80.0	88.1	2			7
3-01-71	0403	0	8.0	0.1	2.2	4.5	90.0	104.8	25	Bat.		9
4-07-71	0403	0	12.0	0.1	2.2	7.5	7.5	29.3	30	Bat.		10
5-05-71	0403	0	8.0	0	2.2	6.0	7.5	23.7	20	Bat.		8
2-19-71	0404	1.9	0	0	35.2	3.0	5.0	45.1	0			6
3-01-71	0404	0	0	0	30.8	1.5	10.0	42.3	0.5	Bat.		6
4-07-71	0404	0	0	0	28.6	1.5	12.0	42.1	1			6
5-05-71	0404	5.7	0	0	28.6	3.0	22.5	59.8	1			7
2-19-71	0405	19.0	20.0	10.5	8.8	48.0	2.8	109.1	2			7
3-01-71	0405	13.3	40.0	14.5	11.0	28.5	6.5	113.8	2	Bat.		8
4-07-71	0405	5.7	52.0	9.4	15.4	22.5	4.8	109.8	15	Bat.		8
5-05-71	0405	0	68.0	6.9	28.6	9.0	4.3	116.8	15	Bat.		7
2-19-71	0503	0	28.0	0.3	0	0	0	28.3	2			4
3-01-71	0503	9.5	28.0	0	8.8	1.5	0.8	48.6	20			7
4-07-71	0503	9.5	36.0	0	8.8	6.0	0.3	60.6	15			7
5-05-71	0503	15.2	36.0	1.1	2.2	10.5	2.0	67.0	15	Bat.	Thal.	8

CARD SOUND ALGAL BOTTOM COVER

Date	Station	Pen.	Hal.	Acetab.	Rhipo.	Udt.	Bat.	Total	% Thal.	Repro. Stages	Total No. Species
2-19-71	0805	153.9	92.0	0	0	1.5	0.3	247.7	5		4
3-01-71	0805	108.3	80.0	1.8	0	0	1.3	191.4	15		4
4-07-71	0805	60.8	64.0	1.4	0	0	0.1	126.3	20		5
5-05-71	0805	81.7	76.0	1.8	0	0	1.4	160.9	35	Bat.	5
2-19-71	1103	72.2	0	0	0	0	0	72.2	2		1
3-01-71	1103	20.9	0	0	0	0	0.2	21.1	0		2
4-07-71	1103	5.7	0	0	0	0	0	5.7	0		1
5-05-71	1103	22.8	0	0	0	0	0	22.8	0		1

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*. (Grams/meter found by multiplying the mean weight of each of the 6 major species by the No. of that species at each station)

** LEGEND:

Pen.	- Penicillus	Udt.	- Udotea
Hal.	- Halimeda	Bat.	- Batophora
Acetab.	- Acetablaria	Thal.	- Thalassia
Rhipo.	- Rhipocephalus		

line up parallel to the shoreline in the western half of the upper and central Sound. In the eastern half Laurencia appeared more-or-less random in alignment. A preliminary interpretation of this was discussed in connection with water circulation and flushing in Section II. Batophora (Figure X-23 and Table X-6) was extremely patchy with 1,700 at one station and 10 at a nearby station. Acetabularia showed a similarly confusing pattern (Figure X-24). Although by number these two appear to be dominant, they are very slender, delicate plants and their biomass seldom approaches that of the previously discussed plants (Table X-6).

The algal diversity (Figure X-25) did not reflect the different types of habitat within Card Sound whereas measures of abundance, health and biomass did indicate differences associated with bottom type, currents, and chemical variables.

The macroalgae which were most abundant were essentially the same algae as found near Turkey Point in Biscayne Bay. Penicillus capitatus, Halimeda opuntia and Laurencia poitei formed the major part of the algal biomass.

CONCLUSIONS

The past year's study of the grasses and macroalgae in Turkey Point and Card Sound resulted in the finding of a strong relation between artificially elevated temperatures in the area of effluent and the distribution and abundance of the grasses and macroalgae. The normal Thalassia community was virtually absent in areas elevated 5°C above ambient. Blue-green algae supplanted the normal Thalassia algae community. It appeared that blue-green algae did not form a suitable food material for most of the normal invertebrates and fishes of Biscayne Bay. The shelter and habitat provided by the large volume of grass and macroalgae was not provided by the blue-green algae because they grew in a very thin layer on the surface of the sediment. The sediment stabilization and accumulation which was previously maintained by the extensive root system of the grass and algal rhizoids disappeared. Thus, some erosion of the area was appearent.

The vegetation in the +4°C zone consisted of a very sparse Thalassia community with a low number of algae species, especially when the temperature was elevated above 32°C in the spring. The growth and vigor (or health) of the plants living here declined markedly in the months when the temperature became elevated above 32 to 33°C. Blue-green algae increased in this area. The field studies of course, did not prove that temperature alone was the cause of this marked decrease at the number, species, growth and vigor of the Thalassia community because there were so many simultaneously varying parameters. The physical, chemical and biological factors affecting the plants are temperature dependent themselves and we are observing the end result or cumulative effect of all of these. However, our laboratory results (Section XI) strongly point to lethal temperature limits for the sublittoral, green macroalgae such as Halimeda, Penicillus and Valonia which are surprisingly close to those observed in the field. This evidence lends strong support to the hypothesis that elevated temperature was the major cause of the observed effect in the areas near the effluent which had temperature elevations of 4-5°C above ambient. It should be pointed out that further work on normal summer populations under lowered and raised salinity conditions with high temperatures must be explored. Other important aspects such as reproductive ability, growth, aging and scenescence versus temperature are being observed in the field and studies have been initiated under controlled laboratory conditions (Section XII).

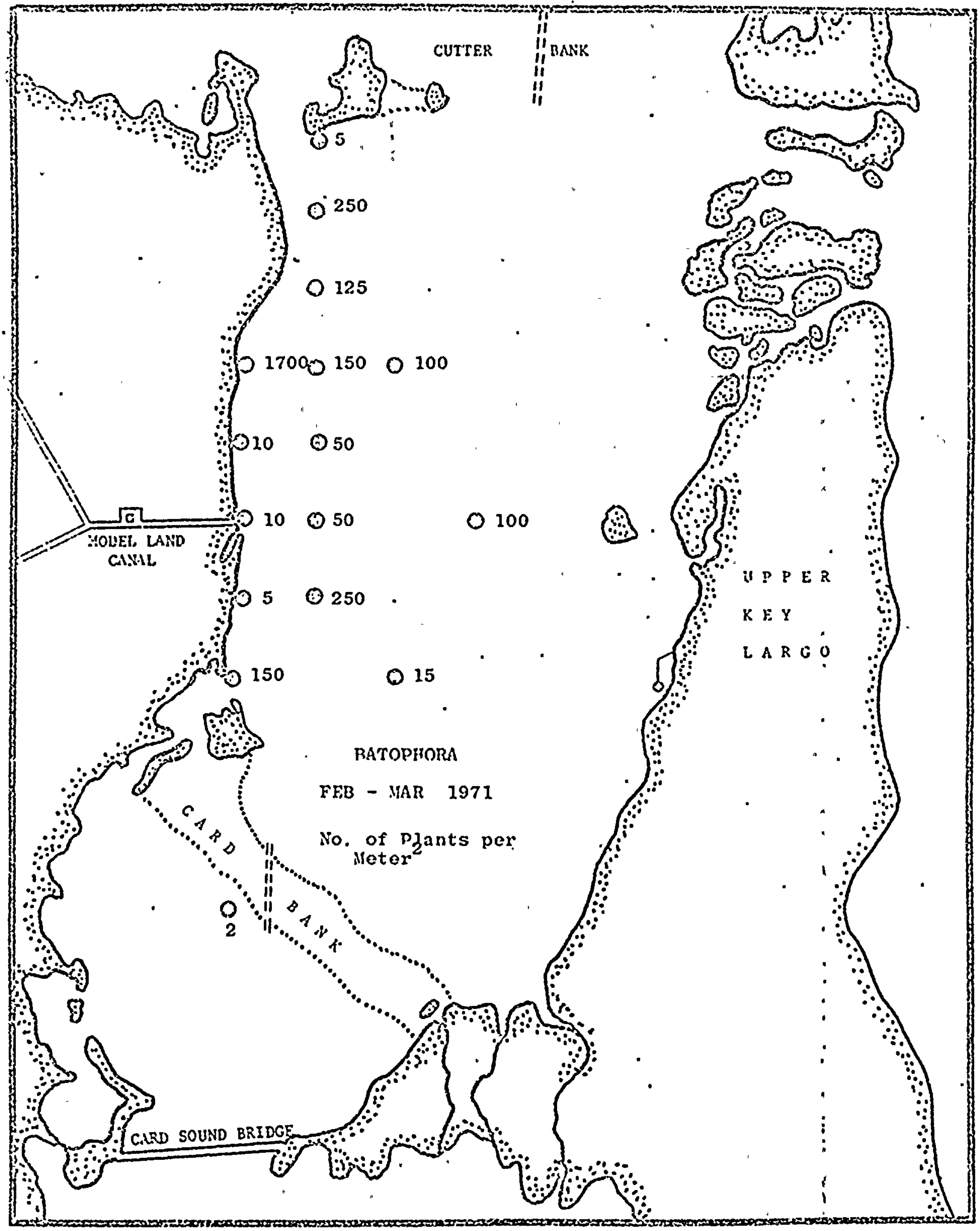

FIGURE X-23 Abundance per square meter of Batophora oerstedii in Card Sound Stations during February and March, 1971

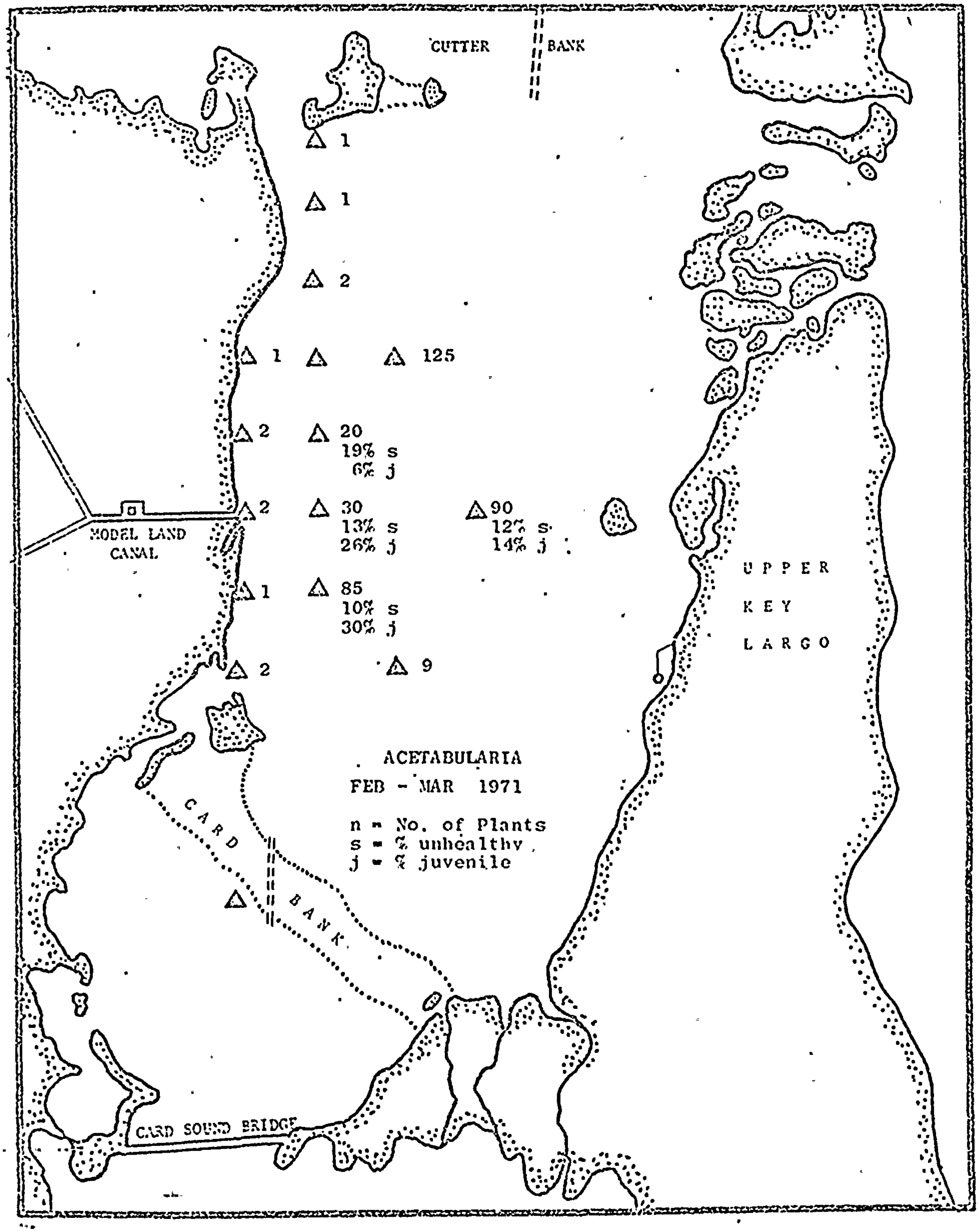

FIGURE X-24 Abundance per square meter of Acetabularia crenulata in Card Sound Stations showing per cent unhealthy and per cent juveniles during February and March, 1971

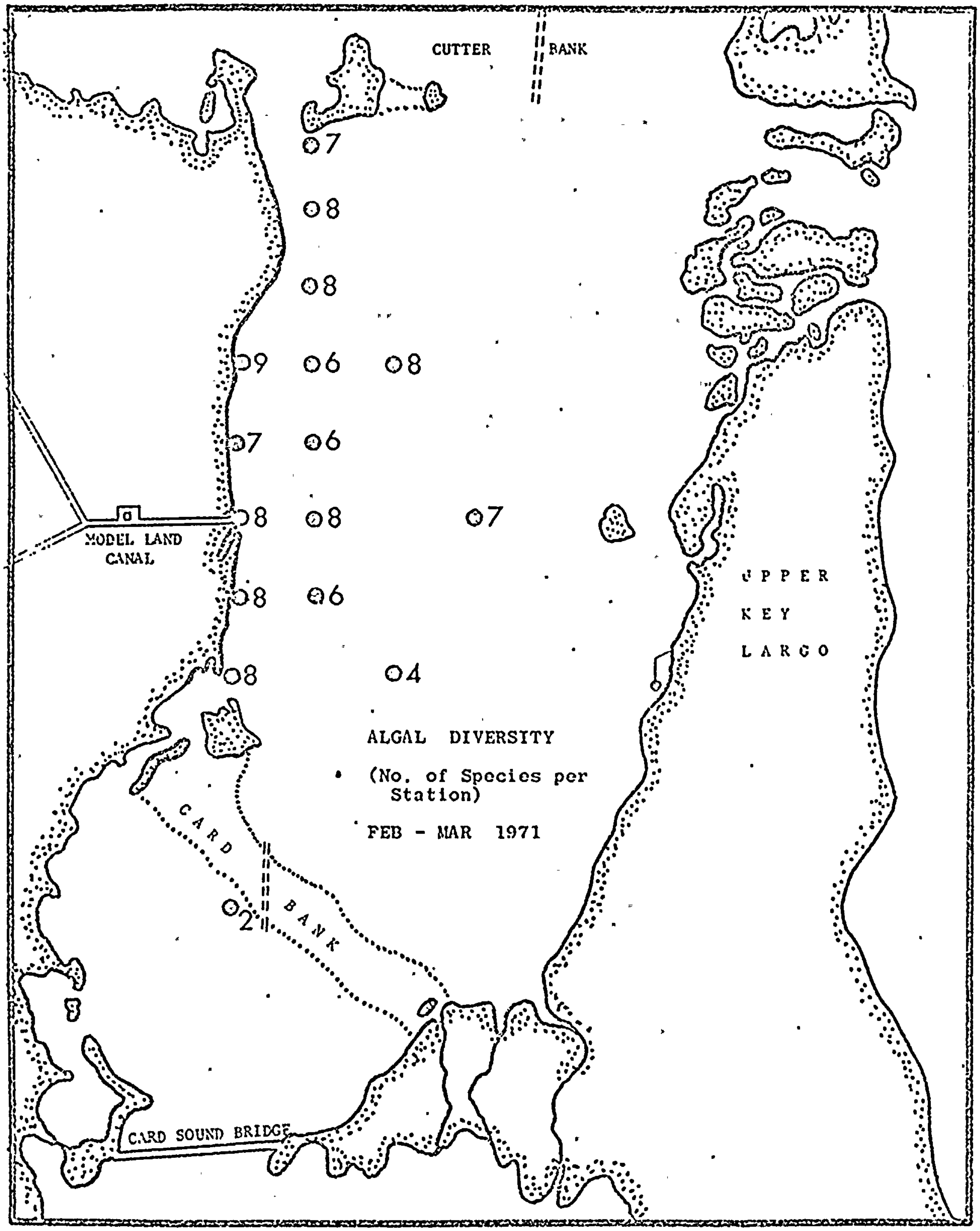

FIGURE X-25 Number of species in a square meter in Card Sound Stations during February and March, 1971

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XI. LABORATORY THERMAL TOLERANCES*

INTRODUCTION

The temperature limits of tropical estuarine organisms have had scant attention in the past. Thus, in order to predict the effects of elevated temperatures on these organisms, either natural or by heated effluents, essential basic information must be obtained. In field conditions many factors are changing simultaneously, making it impossible or difficult to separate out with any degree of accuracy the sole effect of elevated temperature. Also, due to limitations of personnel and time, field sampling was done at relatively widely-spaced time intervals. The chief problem of interpreting these data in terms of heated effluent is the lack of knowledge of the temperature at which heat death occurs to the various organisms. It is not yet clear whether the lethal temperature observed in the field is the mean temperature over a period of time or the highest temperature encountered and the period of exposure to this temperature.

In an effort to help overcome these problems, laboratory investigations were conducted to examine the effect of temperature alone on viability. They were designed to concentrate on important organisms at various trophic levels so that the data could be closely integrated with field information. Investigators in the experimental program were also involved in field studies, thus, field data was directly related to laboratory observations and laboratory experimental designs were constantly improved and directed toward important field observations. In addition, results from the benthic trawling work aided the laboratory studies.

The organisms used in this investigation were selected from the many found living in Biscayne Bay and Card Sound. Over 18,000 individual organisms were examined as to temperature effect on their viability and lethal temperature limits have been determined for 27 different species and life stages. Nine species of plants were studied; _Penicillus capitatus_, _Halimeda incrassata_, _Acetabularia crenulata_, _Laurencia poitei_, and five species of _Valonia._ The early life stages of two commercially important species were also observed under identical laboratory conditions, namely: the stone crab (_Menippe mercenaria_) and the pink shrimp (_Penaeus duorarum_). The caridean shrimp is an important member of the food chain and resides at an intermediate trophic level, thus five species were studied: _Tozeuma carolinense_, _Periclemenes americanus_, _Palaemonetes intermedius_, _Leander tenuicornis_, and _Hippolyte sp_.

It is essential that the test organism to be used in the controlled laboratory experiments be in optimum condition in order to assure that the data is related to the effect of temperature on "healthy" organisms. Thus, great precautions were taken to ensure that only specimens in apparently perfect health were used. For the algae, a preliminary laboratory study of growth and health was conducted (See Section XIII). The fact that growth and reproductive rates did not differ significantly in the field and in the laboratory encourages the belief that normal cells were being used. The crabs and pink shrimp were obtained from the University of Miami Sea Grant mariculture facility with the cooperation of Drs. Yang, Idyll, and Tabb.

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METHODS

The Polythermostat

The basic instrument used in the controlled temperature experiments was an aluminum bar bored to fit glass tubes, heated at one end and cooled at the other to provide the desired temperature. Selected organisms were placed in each tube and held at the observed temperature for the desired time and kept under near constant surveillance. Improvements over similar temperature control devices include the ability to fluctuate the temperature over short or long cycles, providing aeration for adequate oxygen for animal experiments and a constant accurate temperature readout for each tube.

Specifically, the polythermostat is a block of aluminum (6' x 3" x 9") precision bored to fit 24 sets of 19 x 150 mm glass cuvettes. The holes were spaced every 2.5 cm starting 24 cm from both ends of the bar. Twenty-four 3/32 inch thermocouple fittings were also bored in the block 0.5 cm from each tube (permitting temperature monitoring on each set of tubes); ten holes were bored for thermometers. One end of the block was heated with two strip heaters (750 and 400 watts) and the other end cooled by pumping a 50:50 mixture of ethylene glycol and water at -10°C through cooling fins cut into the aluminum bar. A 55-gallon drum containing the glycol-H_2O mixture was cooled by a constant flow portable cooling unit. The mixture was pumped through 1/4 inch copper refrigeration tubing to the cold end of the temperature gradient bar. Both ends of the bar were temperature regulated to $\pm 0.15°C$ by two electric mercury thermoregulators inserted directly into the bar, one at each end. These were, in turn, controlled by a special relay variable transformer circuit. Recording accuracy was better than $\pm 0.05°C$.

Insulation was found to be critical for maintaining the desired temperature gradient in the laboratory. Three inches of styrofoam sheeting was placed on the bottom and sides of the bar and the entire assembly mounted in a wooden casing. Strips of 1/4 inch styrofoam were fitted on the top of the bar. Laboratory air-conditioning was kept at 22°C for best results.

For fluctuating temperature experiments, a tripper switch was hooked into the circuit with the polythermostat. The switch could turn the machine on for a given length of time and then turn off, and the chart recorder would give the thermal history of each set of tubes during the specific time period. Also, the amount of heat produced could be varied and thus, the extremes of the fluctuating temperature regime by resetting the mercury thermoregulators. Fast and slow cycling can thus be accomplished.

Bubbling was supplied with an aquarium pump, with the air passing through as an interconnected system of aquarium gang valves connected by plastic tubing to disposable Pasteur pipettes. The pipettes were inserted through corks and into the cuvettes containing the experimental organisms; penetration into the seawater was controlled. Under rates of bubbling ample to maintain the organisms, using this system, no temperature error or variability was observed.

Using two or three polythermostats at the same time permitted the fine discrimination over a large temperature range, for example one polythermostat could be set from 10 - 40°C; the other from 25 - 35°C also, one broad temperature range and one narrow finely divided one could be observed. In short, many combinations of temperature ranges from 0 - 100°C could be selected; therefore, the system provided a way to set up finely divided and accurate temperature gradients for the purpose of examining the effects of both fluctuating and constant temperatures on living processes.

Plant and Animal Culture

The experiments during the past year were designed to hold the organisms at optimum conditions prior to the experiments and during the experiments at essentially the same conditions while varying the temperature. This required knowledge of the culture methods and physiology of each organism used. For this reason, organisms on which work had already been accomplished were chosen. Since pink shrimp and stone crabs, both important commercial species, have been reared in the University of Miami Sea Grant facilities (Tabb and Yang, personal communication), their tolerances were studied. The caridean shrimp Tozeuma has been kept in culture by Ewald (1965 and 1969) and is an extremely hardy organism. All collected caridean shrimp were handled with great care and those demonstrating any ill effects of captivity or showing damage were discarded.

Single cell green marine alga, Valonia, has been grown for 70 years and its culture conditions are well known. The laboratory growth of the other green and red species was a continuation of earlier work; the methodological details are given in Thorhaug (1965).

Pink Shrimp (Penaeus duorarum) Culture: The basic culture methods used in this investigation were those of Dobkin (1961) as refined by Idyll, et al (1967). Prior to each experiment, seawater (31°/00) was filtered through a Whatman #50 Millipore filter and 17 ml was placed in each of 60 test tubes; these were then put in the polythermostat to attain temperature equilibrium. During this period air bubbling was initiated and all necessary adjustments made to assure proper aeration. The temperature intervals chosen for the experiments were approximately 1°C. The range for the nauplii was 10.0 to 38.0°C; for the protozoea 25.0 to 43.0°C; for the mysis 10.0 to 41.0°C; and for the post-larvae 10.0 to 41.0°C. Replicate tests were run for each stage.

The nauplii were obtained from spawning females collected in the field. The identification of stages of nauplii and protozoea development were taken from Dobkin (1961). The eggs were allowed to hatch under optimum conditions and the most active selected. The more developed stages were obtained from specimens raised at the University of Miami Sea Grant shrimp mariculture facility. They were transported directly to the laboratory in oxygenated water.

Stone Crab (Menippe mercenaria) Culture: Ovigerous females of the species M. mercenaria were kept in 10-gallon glass tanks with flowing seawater at a salinity of 30.0°/00 and a temperature of 27°C. When the larvae were released by the female they were collected and transferred to 4-gallon glass tanks

equipped with air stones. The water was changed daily and the salinity 30.0°/00 and temperature (24.0°C) recorded. The larvae were fed daily with freshly hatched Artemia from San Francisco. Following this phase of their growth which was under the supervision of Dr. Yang of the School of Marine and Atmospheric Sciences, they were transported to the experimental laboratory in 5-gallon plastic jugs and maintained in 15-gallon all glass aquaria. Heaters kept the temperature at 24°C ± 1.0°. The water was changed daily; the salinity during the experimental period averaged 33.9°/00 ± 0.20°/00. After one day in aquaria, ten zoea were removed with a pipette and immediately placed in a test tube containing 17.0 ml of freshly filtered seawater with salinity of 33.9°/00. Nineteen such tubes were then placed in the polythermostat and aerated. No change in salinity was observed in any of the test tubes in the polythermostat during a 24 hour period of monitoring. The temperature of each test tube in the polythermostat was constant to ± 0.10°C. The number of zoea alive in each tube was recorded at four hour intervals. Larval stages were determined according to Porter (1960).

Morphological Criteria of Death

Despite common notions, it is often not too easy to determine when an organism is dead or dying; definitions are vague or non-existent. At times, the transition from the living to the dead is almost imperceptible, in other instances it proceeds slowly but with noticeable clarity and in some cases, as with the sporulation of Valonia, it is shockingly sudden. All species used in this investigation were observed over extended periods under a variety of conditions and the following morphological criteria have been developed.

Halimeda: (1) A color change from deep green to pastel green to pale yellow-green to white. All these may exist in small sections of a completely healthy specimen but when terminal segments are dramatically lighter than proximal ones death is indicated. (2) Individual segments crack easily. (3) Separation of segments on slight touching or shaking of tube. (4) Loss of turgor with a rubbery flexibility to branches, basal stalks, and the entire plant. (5) Care must be taken to note original condition of healthy plants which may be quite pale, with individual dead or damaged terminal segments, broken branches, etc., but with full turgor, and to individually observe changes from this point on.

Penicillus: (1) Color change from a healthy dark green to pale green to yellow green and then white, especially the filaments. (2) Loss of turgor of filaments. (3) Stalk becomes rubbery and then brittle. (4) Actual decay of plant with filaments decaying first, then interior of stipe.

Acetabularia: (1) Loss of color, change from green to white. (2) Sporulation and spores released from cap. (3) Breaking away of cap from stipe and decay of stipe.

Valonia: (1) Outright plasmolysis which is not reversible. (2) The formation of aplanospores. (3) Separation of plasma membrane from outer cellulose membrane forming a gap especially in medium and small cells. (4) The development of patchy grid-like reticulations on the cell wall. (5) Change from a dark green homogenous opaqueness or translucence to a spotty or complete

transparency. (6) Loss of positive turgor; concavity may be introduced on the cell surface by slight pressure. The cells may not have plasmolyzed. (7) A loss of sheen to the cell wall.

Laurencia: (1) The foremost criteria is the condition of the vegetative buds on the tips, including color, shape, and degree of translucency when viewed under low power of a dissecting scope. Death caused the buds to become opaque and lighter in color, and to swell. (2) Secondary indications are color changes on the stem and slightly bloated appearance. When 50% of the buds were dead the entire tip was called dead. Biebl (1962a) used staining techniques and noted that the cells swelled upon thermal death. This is interesting because Valonia cells among others shrink upon thermal death.

Crustaceans: (1) The cessation of swimming or other characteristic motion of a given stage (e.g. "whirring of zoeae) after a two-minute observation. (2) Lack of movement of antennae, antennules and limbs. Occasional twitches must be looked for after the two-minute observation. (3) Lack of movement of appendages associated with respiration and feeding (i.e. mouth parts). (4) No telson flexing; often the last movement of a dying specimen are twitches of the telson. (5) Cessation of heartbeat; this readily observable in nearly all larval stages and sufficiently transparent adult forms. (6) A loss of body translucence; many larvae and some adults turn to opaque white. (7) Gross color change; crustaceans often turn pink rapidly upon thermal death due to carotenoid changes; this is often accompanied by an unnatural curling of the abdomen. (8) The formation of a mucus-like shroud; this is observed mostly in larval forms.

Molluscs: In the snail Nassarius vibex the appearance of death differs for low and high temperatures. (1) When heated, the snails cease to cling to the sides but instead lay in the bottom with their foot, antenna and siphon even more extended than usual. (2) At high temperatures the foot loses its gloss and becomes dull colored and limp and the animal doesn't move when prodded. (3) At less extreme temperatures the animal lies on the bottom extended from shell with only siphon motion observable. (4) At low temperatures death is evidenced by the animals not clinging to the walls of the tubes and pulling back into their shells rather than extending. (5) The operculum cover is closed and the siphon barely visible.

RESULTS AND DISCUSSION

Halimeda incrassata

An earlier investigation (Thorhaug, 1965) showed that Halimeda incrassata could be successfully grown under laboratory conditions with rates of growth close to those in the field. In view of this and the fact that this ubiquitous algae is very abundant in Biscayne Bay and Card Sound it made an excellent experimental plant. Specimens were obtained from the field and gently cleaned to remove epiphytes and debris. The results of three experiments indicated that exposure of eight days at temperatures from 32.9 to 34.8°C caused death (See Table XI-1). Field studies indicated that those stations at which the temperature rose above average daily temperatures of 33°C or a measured mid-day temperature of 32.6°C produced no young Halimeda and the general condition of the

algae began to deteriorate. Temperatures rose to this level in late May and early June, 1971. When the temperature dropped below 30°C, *Halimeda* began to recolonize. Earlier information obtained by Dr. Zieman was not available at this time, but will be used in future comparisons.

Acclimation studies were attempted by holding *Halimeda* in a controlled environment for 2 weeks. One group of plants held at 15°C had upper lethal temperature limits between 33.2 to 34.7°C. A group held at 30°C had upper limits between 32.6 to 34.2°C. Obviously, before valid statements on acclimation can be made, one must investigate various acclimation periods ranging from days to several generations. However, these preliminary results, coupled with experimental data on *Valonia macrophysa* (to be presented later) suggest that little if any acclimation occurs with some tropical algae; if anything those plants held for extended periods close to their upper thermal limits have a lower lethal limit than than those held at lower temperatures. This is different than what was seen in some fishes (Brett, 1956).

Penicillus capitatus

The *Thalassia* community contained an abundance of *Penicillus*. Specimens of *P. capitatus* from the Florida Keys were used in five temperature tolerance experiments that ranged from 3 to 12 days duration (see Figure XI-1 and Table XI-1). As an additional control, *Penicillus* plants were held in the polythermostat at 24°C for 8 weeks; they continued to be in excellent health. Previous laboratory studies demonstrated that specimens and their clones could be held for a year or more (Thorhaug, 1965). The temperature tolerance experiments showed that after 8 days *Penicillus* kept at temperatures below 31.5°C were all alive while those held above 34.7°C were dead. This compared well with the field studies at Turkey Point where *Penicillus* was stressed or non-healthy when the temperature in May and early June rose to 32°C. In June, 1970, 95% of the adults were dead at stations SE 1, 16, 24, 26 and 35. There was growth renewal only after the temperatures fell below 31°C in the fall of 1970; however, stations SEI, 24 and 26 did not attain the previous abundance. This observation was in agreement with laboratory experiments which showed *H. incrassata* withstood temperatures slightly higher than did *Penicillus capitatus*.

Acetabularia crenulata

Specimens were taken from the field attached to small rocks. The rhizoids were carefully detached with needles and held for several days before use in order to insure that the alga was not damaged in handling. When kept under carefully controlled conditions the plants reacted favorably to transplanting and detaching. Thirty replicate tubes each containing 5 specimens of *Acetabularia crenulata* were held at temperatures between 10 and 45°C. Between 38.1 and 39.1°C the specimens were no longer able to survive. One might well expect the lethal temperature of *Acetabularia* to be higher than that seen for any of the other algae since it is an intertidal form. Such plants and animals are well known to be very resistant to many physical stresses including temperature. These data are summarized in Table XI-1.

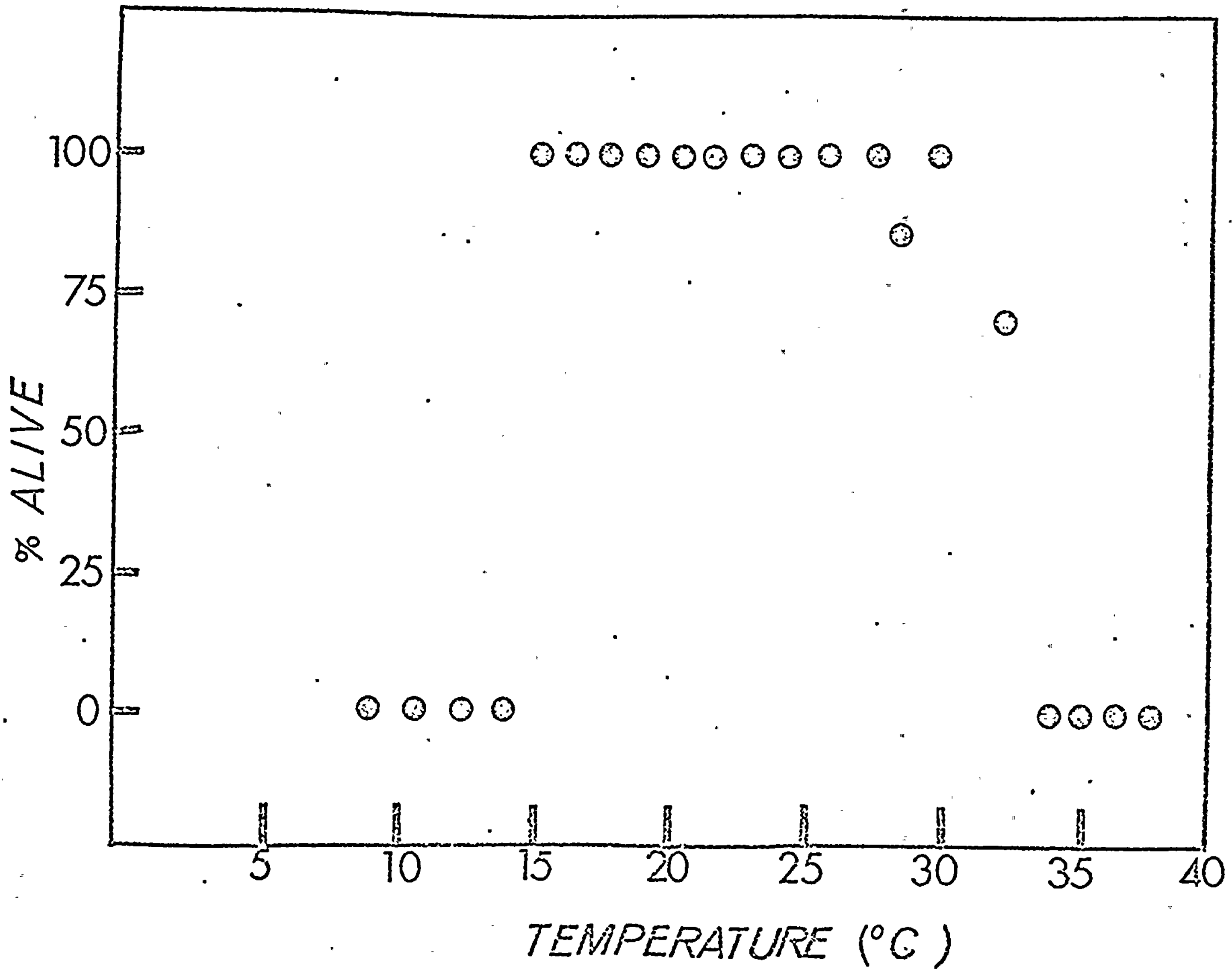

FIGURE XI-1 . Percent alive versus temperature after 8 to 10 days for <u>Penicillus capitatus</u> from the Florida Keys. Each spot represents 10 organisms.

Valonia

Since 1891 when Meyer performed the first physiological experiments with Valonia, it has been used as an indicator of marine algal physiological properties by many investigators. This plant is a large single-celled, tropical benthic green algae found only in the marine environment and can attain a diameter of more than 10 cm. Because of its large size, morphological observations which indicate cell death are relatively easy. Valonia grows in Biscayne Bay, Card Sound and in the waters of the Florida Keys as a part of the abundant green algal community. In addition, Valonia is a member of the Order Siphonales which includes the important estuarine algal families of Caulerpaceae, Codiaceae and Vaucheraceae. These families include most of the major macroalgae in Biscayne Bay and Card Sound (Caulerpa, Avainvillea, Halimeda, Penicillus, Udotea, Rhipocephalus, Chamaedris and Dictosphaera), hence Valonia may provide useful extrapolation.

For these above reasons, it was decided to use Valonia as the tool to study many of the details of thermal stress. It was most thoroughly investigated during this study and many of the findings are applicable to Penicillus, Halimeda, Acetabularia, Laurencia and even Thalassia. The understanding of the gradual process of heat death by observing these giant cells was invaluable for comprehending the events in this field.

One very important consideration in thermal stress studies is the ability of and ease to which an organism can acclimate to changing conditions. In order to investigate this, five species of Valonia from eight locations were used. The organisms were: V. macrophysa, V. ventricosa, V. utricularis, V. ocellata and V. aegrophilia. The cells were collected from Biscayne Bay, the Florida Keys, the Dry Tortugas in the moat at Fort Jefferson, Puerto Rico, (La Parreguera), Jamaica, (Port Royal), Curaçao, (Pescadera Baai), Bermuda, (St. Georges) and Venezuela (Cumaná). They were flown directly to Miami and immediately used in the experiments. Other algae collected locally were maintained in the laboratory under culture conditions resembling the natural habitat in an aquaria outside the laboratory that had continuously running seawater percolating up through the sand and rock on the bottom (Thorhaug, 1965).

Valonia macrophysa: A number of experiments, including all the acclimation studies, were conducted using this species. A summary of the results is given in Figure XI-2 and in Table XI-1.

In one set of experiments different sized cells of each of three species of Valonia (macrophysa, ventricosa and utricularis) were compared to test if there were differences in temperature tolerances between different sizes (age) of cells within a species. We concluded that temperature tolerance was not dependent on cell size in any of the three species. Naturally, as in all these experiments, encrusting growth was removed from the plants and only healthy cells were selected. The cells in the polythermostat were observed at appropriate intervals, the light was kept at less than one foot candle and the light-dark periods were 14 hours and 10 hours, respectively.

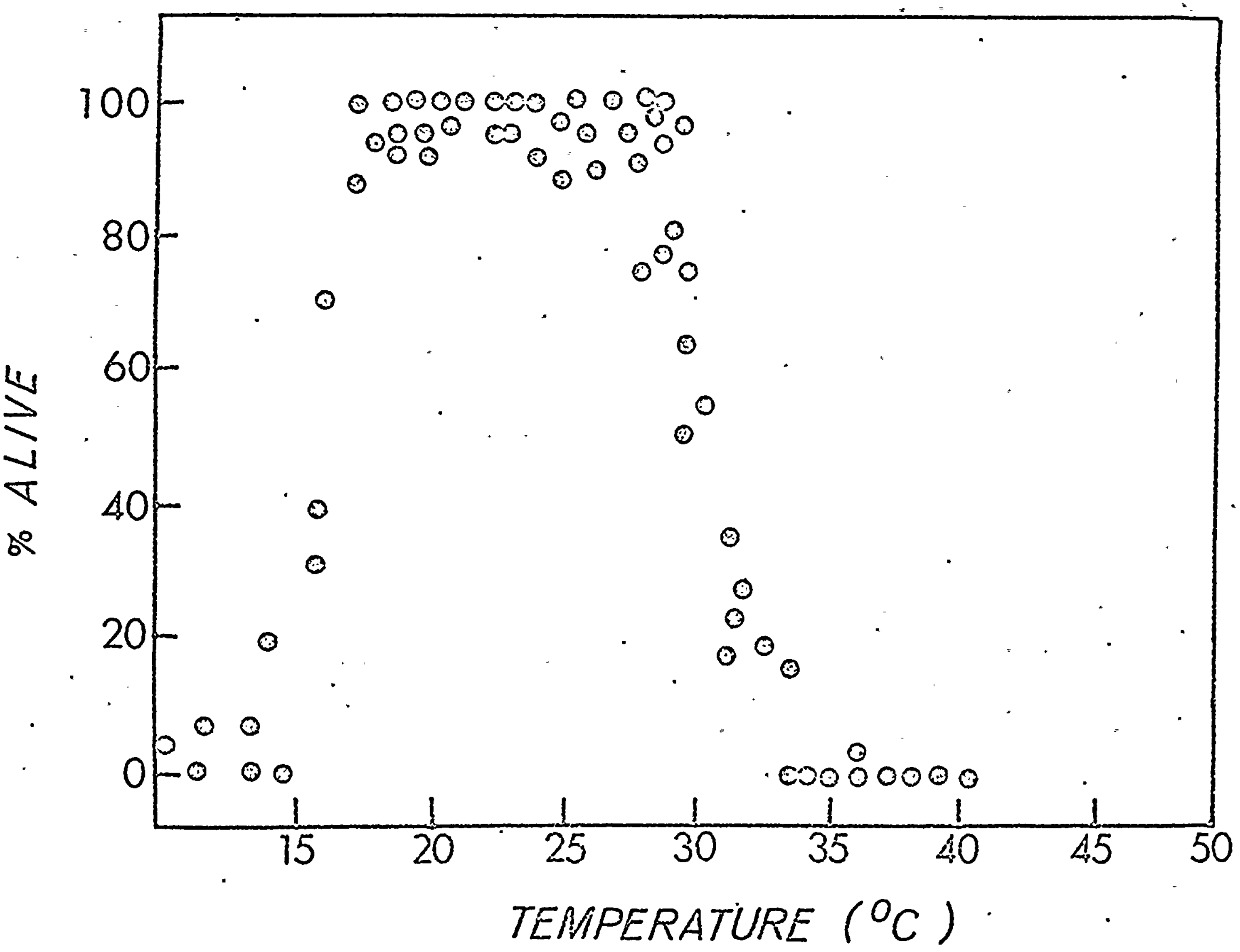

FIGURE XI-2 Irreversible plasmolysis versus temperature after 3 days for Valonia macrophysa cells from various parts of the Eastern American tropics. Each point represents 25 to 100 cells.

Two experiments were conducted using cells from Biscayne Bay and the Florida Keys. The first consisted of two replicates of 19 sets of six cells held at temperatures ranging from 7.0 to 36.6°C for a period of three days, at a salinity of 32°/00. The cells maintained a healthy condition between 15 and 31.5°C. Irreversible plasmolysis occurred abruptly below 14°C and above 33.5°C. Death began at 15°C and 31.5°C. A similar experiment conducted at a lowered salinity (25°/00) gave the same thermal tolerance limits.

Another experiment used 16 cells held at 30 different temperatures ranging from 8.0 to 38.2°C for a period of five days. The temperature interval was 1.1°C, a more closely-spaced interval than used in the previous experiment. During the first 24 hours all cells remained healthy; after 48 hours of exposure above 31.5°C they began to show distress. On the third day, complete irreversible plasmolysis occurred below 15°C and above 33.5°C, partial mortality took place at 13.3 and 31.5°C. No change occurred over a two week period.

To determine if acclimation due to long-term growth at various temperature regimes in the tropics would cause the thermal limits to change, experiments were conducted utilizing V. macrophysa from Puerto Rico where the mean water temperature was 28.5°C. Nineteen sets of 24 cells each were held at temperatures ranging from 7.9 to 38.1°C for 72 hours. Almost all the cells had undergone irreversible plasmolysis at temperatures below 15.6°C and above 29.7°C. Partial mortality was observed between 14.6 and 15.6°C and between 29.7 and 30.7°C. All cells appeared healthy at the intermediate temperatures.

Since acclimation at the warmer temperatures of Puerto Rico did not affect the lethal limits of Valonia the effects of acclimation on cells living in a cooler area were tested using Bermuda specimens where the mean annual temperature was 22.6°C. In one polythermostat, sets of 16 cells each were held at temperatures ranging from 8.0 to 38.0°C at intervals of 1.5°C. The results showed that below 13.9°C and above 33.6°C, all the cells died after three days. In the second polythermostat 30 sets of 13 cells each were placed at 0.33°C intervals between 24 and 34°C. The results show that between 32.0 and 32.6°C more than 50% of the cells died after three days.

Cells from the Dry Tortugas, located at the tip of the Florida Keys and close to Yucutan, where the mean annual temperature is 27.0°C, were examined. In one polythermostat 19 sets of 12 cells each were held between 9.8 and 36.8°C. After five days death occurred in all cells held below 12.3°C and above 32.8°C. In a second trial, four sets of 10 cells were tested in the range of 29.3 to 32.8°C. Between 31.3 and 31.6°C more than 50% of the cells died after five days.

Two final acclimation experiments were run using specimens from Biscayne Bay. Over 500 cells were held for 10 and 14 days at 30° and 15°C. Subsequently, they were placed in a polythermostat and held for 160 hours. One cell of each sample survived at 33.4°C; all cells died above this temperature. At lower temperatures, 14% or less mortality occurred in the 30°C acclimated cells with 1% or less -- occurring in the cell acclimated at 15°C. The critical interval was 32.3 to 33.4°C for those acclimated at 30°C and 33.4 to 34.5°C for those at 15°C. It should be

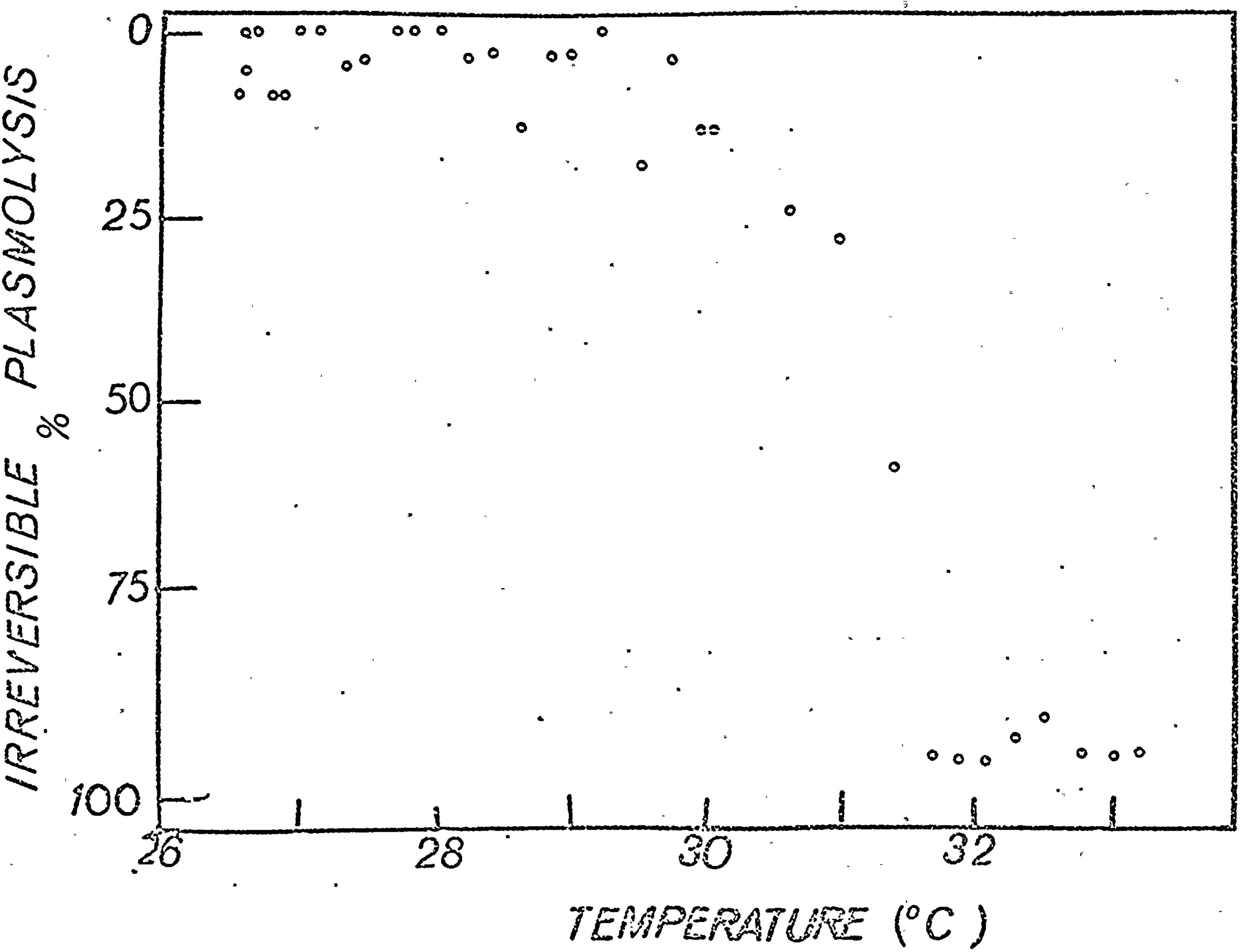

FIGURE XI-3 Irreversible plasmolysis versus temperature for <u>Valonia utricularis</u> after 5 days exposure to the given temperature. Each point represents 25 cells.

observed that those cells held for extended periods (acclimated) at the higher temperature not only had a lower upper thermal limit but also had a much higher mortality at "normal" or "optimal" temperatures. This observation matched that found with the Valonia from Puerto Rico where the mean annual temperature was 28.5°C, the highest for all specimens examined. These results were remarkably close to those using "non-acclimated cells" and suggested that the algal thermal limit was very closely confined with little possibility for acclimation. This, of course, is in variance with what is known about bacteria and fishes. In addition, it strongly indicated that although the thermal limit appeared abruptly, the organisms were under severe thermal stress at temperatures below the death point and that exposure to slightly higher temperatures for short periods will prove fatal.

Valonia utricularis: Comparative experiments were conducted utilizing V. utricularis specimens from two locations, Bermuda and the Florida Keys near Miami. Two sets of 13 cells from Bermuda were held at 30 different temperatures ranging from 8.6 to 37.1°C for five days. The results showed that those cells exposed to temperatures below 13°C and above 31.0°C died within three days. For the Florida Keys specimens, 30 sets of 10 cells each were held at temperatures ranging from 26.6 to 32.7°C. Within the range of 31.0 to 31.4°C there was over 50% mortality after 5 days (see Figure XI-3 and Table XI-1). The similarity of temperature tolerance for cells from the two areas is obvious; there is also good agreement with the thermal tolerance of V. macrophysa.

Valonia ventricosa: Specimens of this third species from the Florida Keys, Curaçao and Jamaica were examined; the results are shown in Figure XI-4 and Table XI-1. For the Florida Keys specimens, 19 sets of six cells each were held at temperature intervals between 7.7 and 38.9°C. After three days of exposure, over 50% of the cells underwent irreversible plasmolysis below 14.3°C and above 33.0°C. Cells from Curaçao, where the mean annual temperature is 24.5°C, were held between 9.7 and 36.9°C in 19 groups of six each. The cells were unable to survive a six day exposure below 12.1°C and above 31.5°C. Three additional trials using Curaçao cells showed that this species had a lower tolerance limit of 14.5°C and an upper limit of 33.0°C with death beginning at 31.5°C. Cells from Cumana, Venezuela had a 100% mortality below 15.5°C after five days. The upper critical limit was between 29.1 and 31.9°C.

Nineteen sets of 17 cells each collected in Jamaican waters, where the mean annual temperature is 27.4°C, were held between 9.7 and 37.0°C. The results showed that below 12.2°C and above 31.5°C more than 50% of the cells were unable to survive after five days. Irreversible plasmolysis began to take place at 13.8 and 29.9°C; cells held between 23 and 26°C for a period of three weeks remained healthy. These limits are very similar to those found for V. ventricosa for Curaçao and only tenths of a degree from the Florida Keys specimens. The striking similarity of the upper death limits of the V. macrophysa, V. ventricosa and V. utricularis is also obvious.

Valonia ocellata: Cells from the Florida Keys were tested over the temperature range of 8.1 to 40°C. After a three day exposure to temperature below 14.7 or above 34.0°C all cells died; those from Curaçao had a very similar limit of 34.6°C. Temperature intolerance began at 32.8°C (see Table XI-1).

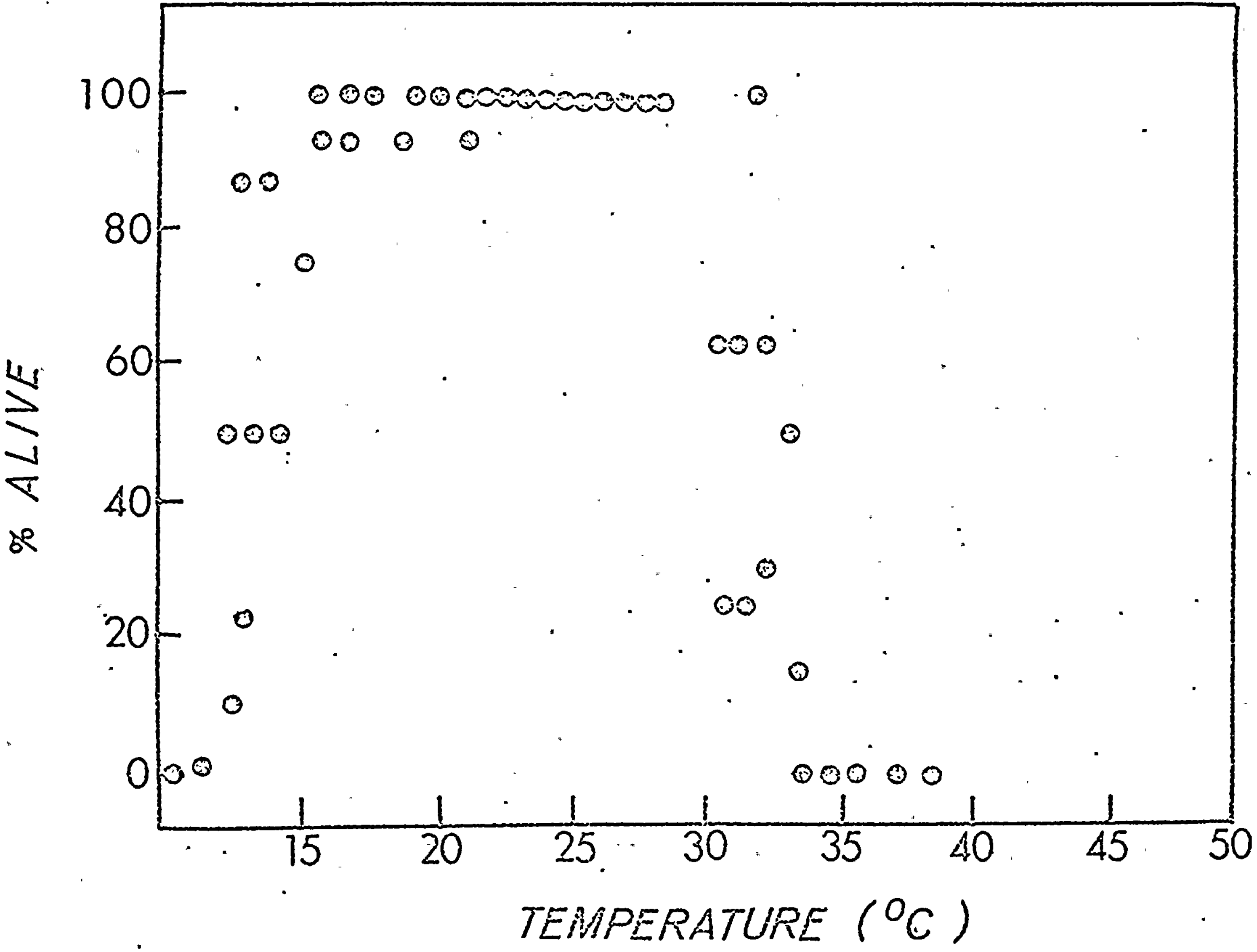

FIGURE XI-4 Percentage survival after 3 days for *Valonia ventricosa* cells from various parts of the Eastern American tropics. Each point represents 25 to 100 cells.

Valonia aegrophilia: This is a very small, relatively rare species collected from the Dry Tortugas. Nineteen Sets of 32 cells each were held between 9.5 and 37.0°C. After three days cells survived ceased below 10.5 and above 33.0°C. The cells began to die at 12.0 and 31.4°C (see Table XI-1).

Laurencia

The red algae, Laurencia poitei, is found in many tropical and subtropical waters and is a dominant species in Biscayne Bay and Card Sound. It exists in non-attached clumps of single strands and masses which move freely with the tide and current except when caught on projections of the bottom. It is not known whether herbivores use it directly as food but it does form a significant portion of the biomass and thus is a major contributor to the bottom detritus. In addition, it provides a substrate for many algae and sessile animals as well as shelter for small fish, polychaetes, molluscs and crustaceans as suggested in Section V, Benthic Biology. The color of the plant ranges from a light yellow to a dark purple-red; in summer it tends towards lighter colors.

The algae were collected by hand from the Card Sound and brought back in large plastic containers equipped with aeration systems. Debris, animals, and other foreign matter were gently removed by mechanical cleaning in running seawater. The plants were held in 5 gallon glass tanks, the water was changed every two days and the salinity, pH, and temperature recorded.

A plant tip (6 to 10 cm) was placed in each of 48 cuvettes containing 20 ml of filtered sea water; the salinity, pH, and appearance of the tip were noted. The temperature gradient used was from 6 to 45°C for a period of 10 days. The tips were examined daily and the water replaced with water of the same temperature. Three trials showed that at the end of 10 days more than 80% of the cells held below 30.1°C were healthy; even those held at 6.3°C were alive. At temperatures from 31.7 to 33.3°C less than 40% of the tips were living and above 34.9°C all were dead. Due to the difficulty in establishing indications of the morphological death point, the upper tolerance can only be expressed as a range of 31.7 to 34.9°C. This information is presented in Figure XI-5 and Table XI-1 and agrees with field data which indicates that no healthy Laurencia occurred above a temperature averaging 33°C for 10 or more days. The benthic biology studies show that the animal populations closely associated with Laurencia became less abundant after sustained periods with average daily temperatures in excess of 33°C. In addition, these values agree with Biebl (1962) for Laurencia poitei held at 32 to 35°C for 12 hours.

Pink Shrimp

The pink shrimp, Penaeus duorarum, is a major member of the animal community of Biscayne Bay and forms one of the most important commercial fisheries in Florida. Juvenile shrimp leave the area and migrate to the spawning grounds, the offspring return as four spine larvae, settle to the bottom and grow to juveniles. Fresh larvae from three different spawning periods were used in these experiments. Nine individuals were placed in each tube for the nauplii experiment, 10 for the protozoea, six for the mysis and 25 to 40 for the postlarval experiments. The data is summarized in Table XI-1.

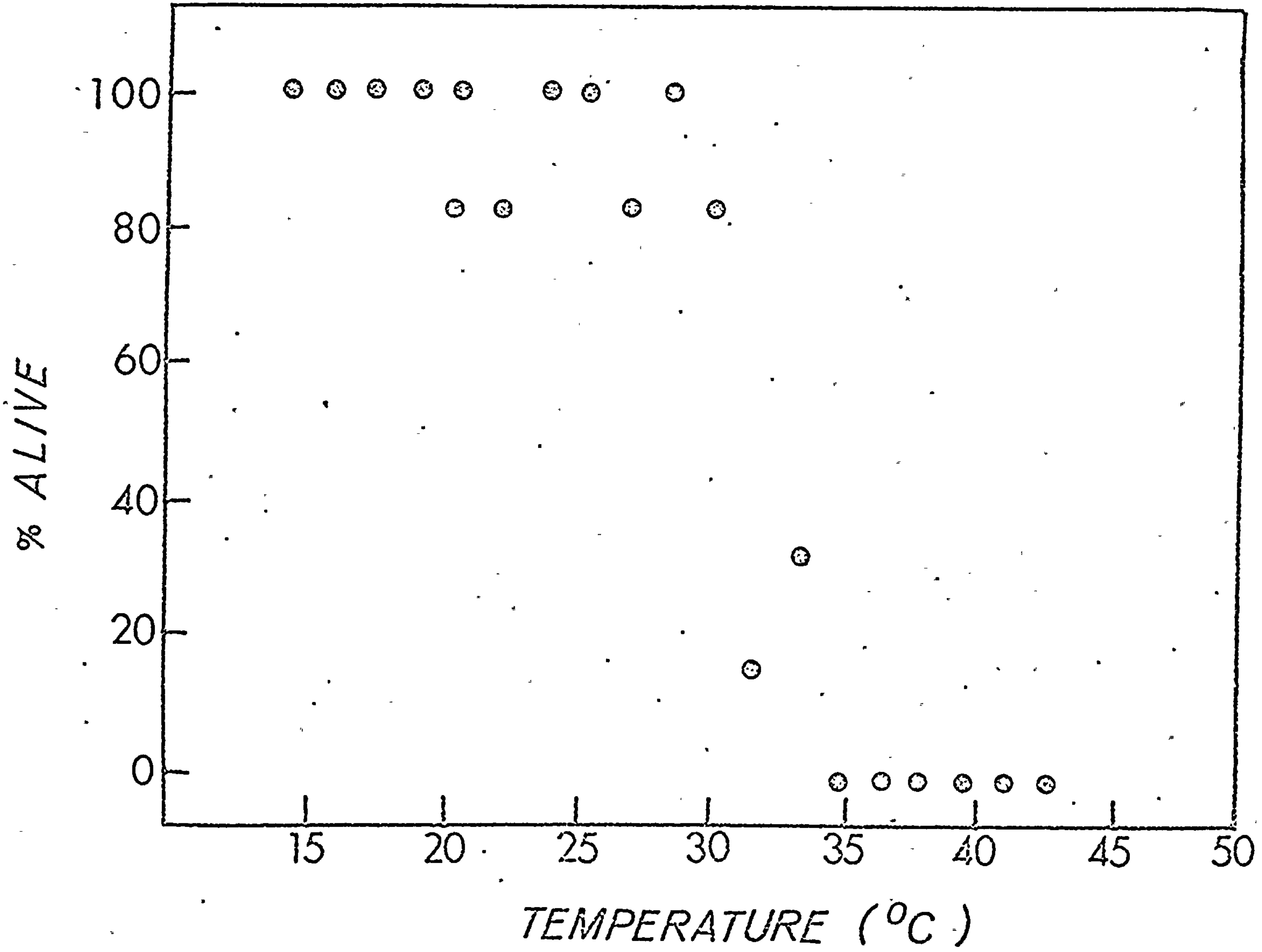

FIGURE XI-5 Percentage survival for Laurencia poitei after 10 days exposure to the given temperature. Each point represents 7 plants.

Nauplii: Over 500 individuals were used in this experiment and exposed to a temperature range of 10 to 38.3°C; the nauplii held below 15°C and above 37°C for 12 hours were unable to survive. Abnormally vigorous swimming activity was observed at 35°C; this may be a response to stress condition. After 18 hours the temperature tolerance was lower, with one exception 50% of the nauplii or less survived at 33.0°C and under 15°C. Between 15 and 23°C many individuals rested on the bottom of the tubes and required prodding to elicit movement. Between 24° and 30°C the organisms swam actively and remained in a healthy condition.

The nauplii metamorphosed into protozoea only between 25.0 and 31.5°C. In the temperature range of 23.0 to 32.6°C the shrimp attained the fifth nauplii stage, above and below these temperatures development was negligible; the ability to develop decreased more rapidly at the hot temperature. This has been discussed in detail by Thorhaug (1970).

First Protozoea: Nineteen tubes, each containing 10 individuals, were held in a temperature gradient of 28 to 42°C for 18 hours. All specimens held above 37.6°C died; death became evident at 37.0°C.

Third Protozoea: Nineteen groups of organisms were subjected to a temperature range of 12-43°C. After 17 hours all specimens kept above 37.7°C were dead. Exposure for 22 hours above 36.7°C caused total mortality; death to individuals began at 35.7°C.

Third Mysis: Nineteen sets of third mysis stage were held in a temperature range of 12.6 to 42.0°C. After 20 hours all specimens held above 36.9°C were dead, while all those below 35.9°C were alive. All individuals remained in the third mysis stage. After 34 hours 100% mortality occurred above 36.9°C, thus preventing development to the first post-larval stage. Death was first observed at 34.9°C.

First Post-Larvae: Nineteen groups of first post-larvae were held between temperatures of 12.6 to 47.0°C for 25 hours. All specimens kept above 37.8°C were dead; all those retained below 33.5°C survived. Survival of 60-70% was attained at 34.9 to 36.3°C.

Second Post-Larvae: Two experiments were conducted; in the first, 7 tubes, each containing 22 second post-larvae were subjected to a temperature range of 36.7 to 41.0°C. After 45 minutes all specimens kept above and at 39.1°C died while the shrimp at 38.5°C and below had 100% survival. An exposure of 128 minutes proved fatal to all individuals maintained at and above 38.5°C, while those at and below 37.9°C remained alive. In the second experiment, 30 post-larvae were placed in 7 tubes ranging from 36.7 to 41.0°C. Temperatures lethal to all individuals were 38.5 and 33.0°C, for exposures of 30 minutes and 2.5 hours respectively. All post-larvae survived 37.2°C.

Juvenile: Young shrimp were aquired from an autumn brood hatched at the University of Miami Sea Grant mariculture faculty at Turkey Point. Because of the large size of the shrimp, only one individual was put in each cuvette. The critical temperature for a two hour exposure was 37.9 to 39.6°C; decreasing to a range of 36.0 to 37.9°C after 16.5 to 24 hours. All specimens kept above 40.7°C died within five minutes and the lower temperature limit has been set tentatively at 12.8°C but this requires further investigation.

Stone Crab

The stone crab, Menippe mercenaria, a shallow water burrowing organism, is a significant contributor to the commercial fisheries of Biscayne Bay. The female carries a spongy mass of eggs which, upon hatching, become planktonic. Larvae settle to the bottom in the megalops stage and thence grow to adults. In addition to comprising a fishery in themselves, they are part of the food chain for many fish. A series of experiments using the polythermostat were conducted using eggs; first, second, and third zoea; megalops and juvenile stages. The results are tabulated in Table XI-1.

Eggs: In the first of a series of experiments 19 tubes containing six eggs each were held at temperatures ranging from 10 to 50°C. After 40 hours of exposure at 29.1 to 36.3°C hatching into the first zoeal stage was observed. No hatching occurred below 29.1°C and eggs failed to survive above 36.3°C. In the temperature range of 23.4 to 36.3°C normal development of the eggs to the first zoea was observed after 70 to 90 hours exposure. The eggs appeared to be tolerant of cold as they remained alive after 280 hours at 12.6°C.

First Zoea: Over 315 individuals, were examined over a temperature range of 29.0 to 50.0°C for 36 hours (see Figure XI-6). After 20 minutes all individuals were dead above 42.8°C; those kept below 40.3°C remained alive. A two hour exposure lowered the upper lethal limit; all zoea above 40.3°C died; 39.1°C proved compatible. The downward trend continued as expected after a 3.5 hour period; no zoea were alive above 38.0°C while those kept below 34.5°C were actively swimming. After 36 hours the lethal temperature decreased to 36.7°C; 100% remained alive under 34.5°C as was the case after only 3.5 hours. A second experiment of nine hours duration showed that temperatures above 37.8°C were fatal while 33.0°C was tolerated for the same time period; the 50% survival point was 34.8°C. A compilation of all data indicates that the upper lethal temperature for Menippe first zoea ranged from 36.1 to 37.4°C.

Second Zoea: Four replicates of 19 tubes with 10 individuals per tube held for 13 hours over a range of 25 to 46°C demonstrated the same general trend as shown for the first zoea. After four minutes all individuals died above 43.8°C; below 42.8°C life was sustained. Twenty six minutes later the lethal temperature was lowered by 1°C. Temperatures over 38.5 and 37.5°C were fatal to all individuals after 3.25 hours and 13 hours respectively; life was sustained at a temperature of 1°C lower. A later 22 hour experiment showed that the second zoea could not tolerate temperatures above 37.3°C for such an extended period; while about 90% could take less than 36.1°C. The 50% survival point was between 36.1 and 37.3°C, almost identical with the first zoea experiment.

Third Zoea: Nineteen tubes each containing 10 third zoea were subjected to temperatures ranging from 28.0 to 46.0°C for 23 hours. After five hours no zoea were alive above 37.6°C; survival was 80% at 36.9°C and 100% at 32.9°C. After 23 hours no third zoea remained alive above 36.7°C. During these experiments an increase in activity apparently related to increased temperatures was noted. Temperatures slightly below the lethal level appeared to increase cannibalistic activity but further behavioral observations are required to define the significance of this phenomenon.

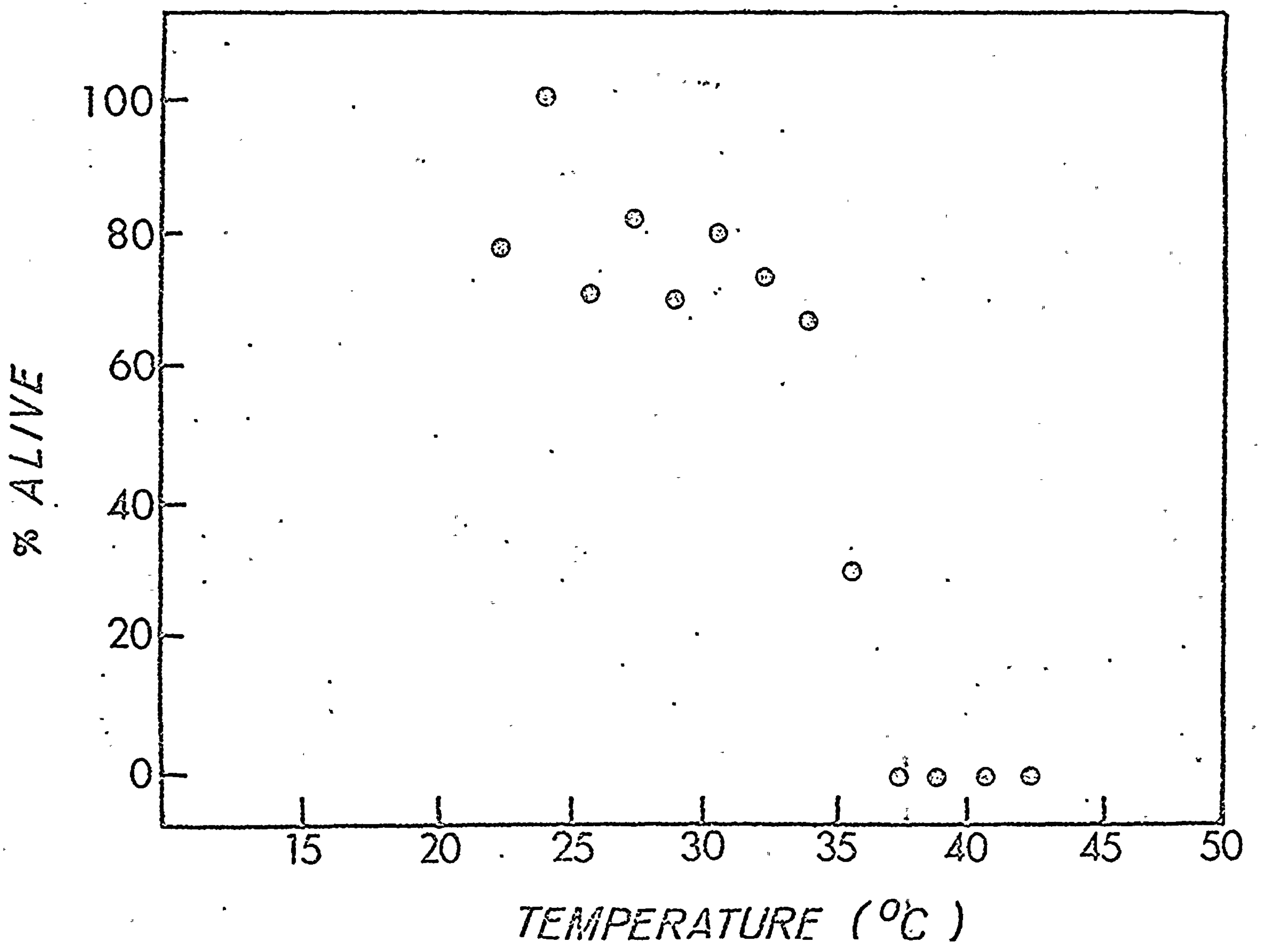

FIGURE XI-6 Percentage survival of Menippe mercenaria first zoea after twenty-four hour survival versus temperature. Each point represents 20 crabs.

Megalops: This stage is by far the most difficult one to raise and to handle experimentally. Although few specimens were observed, the data is quite impressive (see Figure XI-7). The first experiment lasted for 24 hours; fifth zoea were placed in the polythermostat tubes just prior to metamorphosis into megalops. Those individuals maintained in the temperature range of 16.7 to 30.5°C achieved the megalops characteristics. An additional experiment showed that 23 hours above 30.5°C was lethal. It is not known whether death was due directly to temperature or indirectly because the elevated temperature prevented metamorphis.

Juvenile: One experiment was performed using a brood of fully metamorphosed juvenile M. mercenaria, placed singly in cuvettes to avoid damage from hostile behavior. One hundred percent survival was maintained between 12.6 and 37.0°C over a period of 42 hours. Death occurred at 42.7°C within 15 minutes, 41.3°C within 29 minutes, 40.3°C within 44 minutes and at 38.0°C after four hours of exposure.

Caridean Shrimp

As adults these shrimps comprise part of the benthos of Biscayne Bay and as larvae they are important members of the planktonic community. They are reported to live in the Thalassia community which includes macroalgae such as Halimeda, Penicillus and Laurencia. These small shrimp are important members of the food chain, they are eaten by stone crabs and young fish, especially the sciaenids such as sea trout, red drum and silver perch. The results of these experiments are summarized in Table XI-1.

Tozeuma carolenenses: The taxonomy, distribution and ecology of this shrimp treated by Ewald (1969). In an experiment with mostly gravid specimens, those kept at 39.5°C were killed after 20 minutes; after 4 hours 100% mortality was observed at 33.9°C and above. After 48 hours the critical temperature decreased to 32.8°C. In an additional test, all specimens kept at and above 38.7°C died in less than 18 minutes, while after 24.5 hours all shrimp held at 34.3°C were dead. After 128 hours exposure the critical temperature was 32.8°C. Another set of experiments with a 72 hour duration showed that after 47 hours all specimens held at temperature above 33.9°C were dead and only 14% survived between 30.6 and 32.3°C. After 72 hours the critical temperature was the same but stress was evident at lower temperatures. Less than 50% survival was recorded between 29.0 and 32.3°C while below 29.0°C at least 80% of the shrimp survived.

Palaemonetes intermedius: Mature females were obtained from Matheson Hammock Beach during April, May, June and July. They were placed carefully in a 30 gallon plastic container supplied with air from a portable air pump and transported to the laboratory. Before being used as test specimens, they were maintained in a 15 gallon all glass aquaria for 24 hours at 25°C. Control organisms lived for more than two weeks at 25°C. Five experiments were performed, each utilized 19 sets of tubes containing 2 individuals held at temperatures varying from 10.0 to 45.0°C. All animals kept below 36.2°C survived; those above 37.8°C died. No difference in temperature tolerance was observed between the April and July specimens.

Periclimenes species: These shrimp were obtained in Thalassia beds at Bear Cut; the collecting and holding procedures were similar to those used for P. intermedius. The shrimp were conditioned at a salinity of 36.2°/00 over a

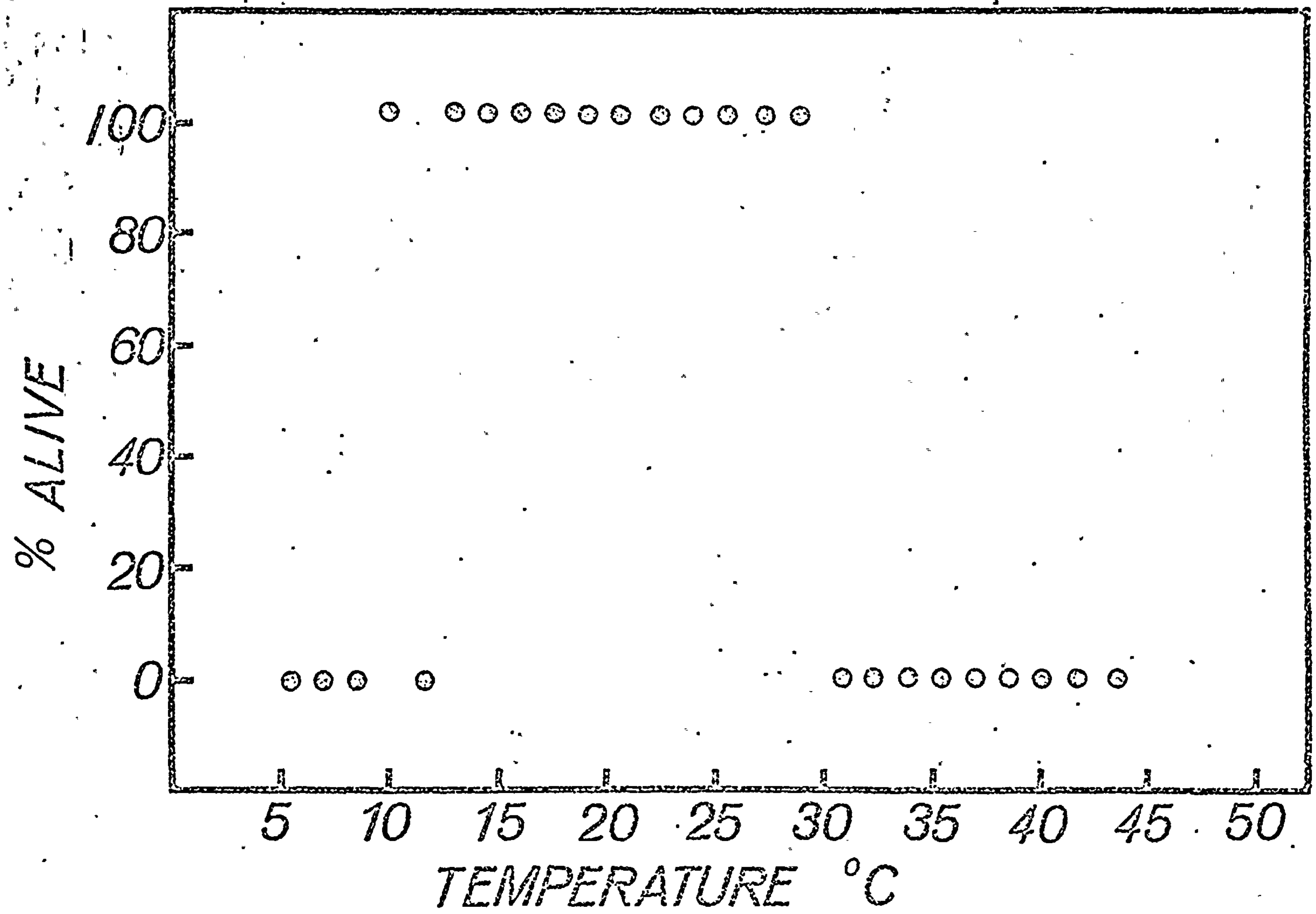

FIGURE XI-7 Percent alive versus temperature after 24 hours for Menippe mercenaria megalopa stage. Each dot represents 2 specimens.

temperature range of 24.0 to 26.0°C and were fed one Oppenheimer pellet per shrimp per day. Under these conditions the control animals lived more than two weeks. For the experiment one shrimp was placed in each of the 38 polythermostat tubes; the temperature range was 1.0 to 45.0°C at 2°C intervals. This experiment was replicated 15 times with freshly obtained specimens in order to obtain statistical significance. The results showed that the animals lived adequately between 14.0 and 35.0°C, but 100% mortality occurred below 14.0°C and above 37.6°C. No difference was observed in the thermal tolerances between individuals collected in April and those in July (see Figure XI-8).

Hippolyte: This is a hitherto undescribed species existing in Biscayne Bay and adjacent waters. Gravid females were collected and handled as described earlier. One experiment showed an upper tolerance limit of 35.5°C after 1 hour and 32.1°C after 5.5 hours. In another run there was 100% mortality in shrimp kept at temperatures above 34.7°C after 90 minutes. An upper critical level was noted at 32.8°C after 48 hours and did not change for the remainder of the 5 day experiment. A lower critical level of 10.0°C was observed but only after 5 days exposure.

Leander tenuicornis: This is a robust, predatory caridean shrimp. Held at temperatures above 38.7°C all individuals died within 15 minutes, those held above 35.5°C were dead within 5.5 hours. Thus Leander may be more temperature tolerant than Hippolyte sp.

Molluscs

The small snail, Nassarius vibex is an important part of the intertidal community. It is a saprotroph, feeds on dead animal tissue, and is equipped with a chemosensory apparatus which enables the sensing of food at great distances. It exists between the high and low tide marks on mud or other suitably soft substrates and spends its time with the shell just beneath the mud and the siphon projecting upward into the water. This species would be expected to have a higher temperature tolerance than open water organisms due to its intertidal adaptation (Newell, 1970).

The snails were collected in mud flat tidal pools at low tide just to the north of the Miami Seaquarium, placed in a mud bottom holding tank and observed for several days. Specimens were then put in cuvettes with 22 mls of filtered seawater (changed twice daily). After one hour in the polythermostat all Nassarius held above 46.7°C were dead. All specimens held above 40.2°C for 24 hours and 37.5°C for 72 hours expired; the lower limit was 8.0°C. Some signs of stress were observed above 32.2°C; however, upon reducing the temperature they became vigorous. This information is similar to that found by Professor H. Moore.

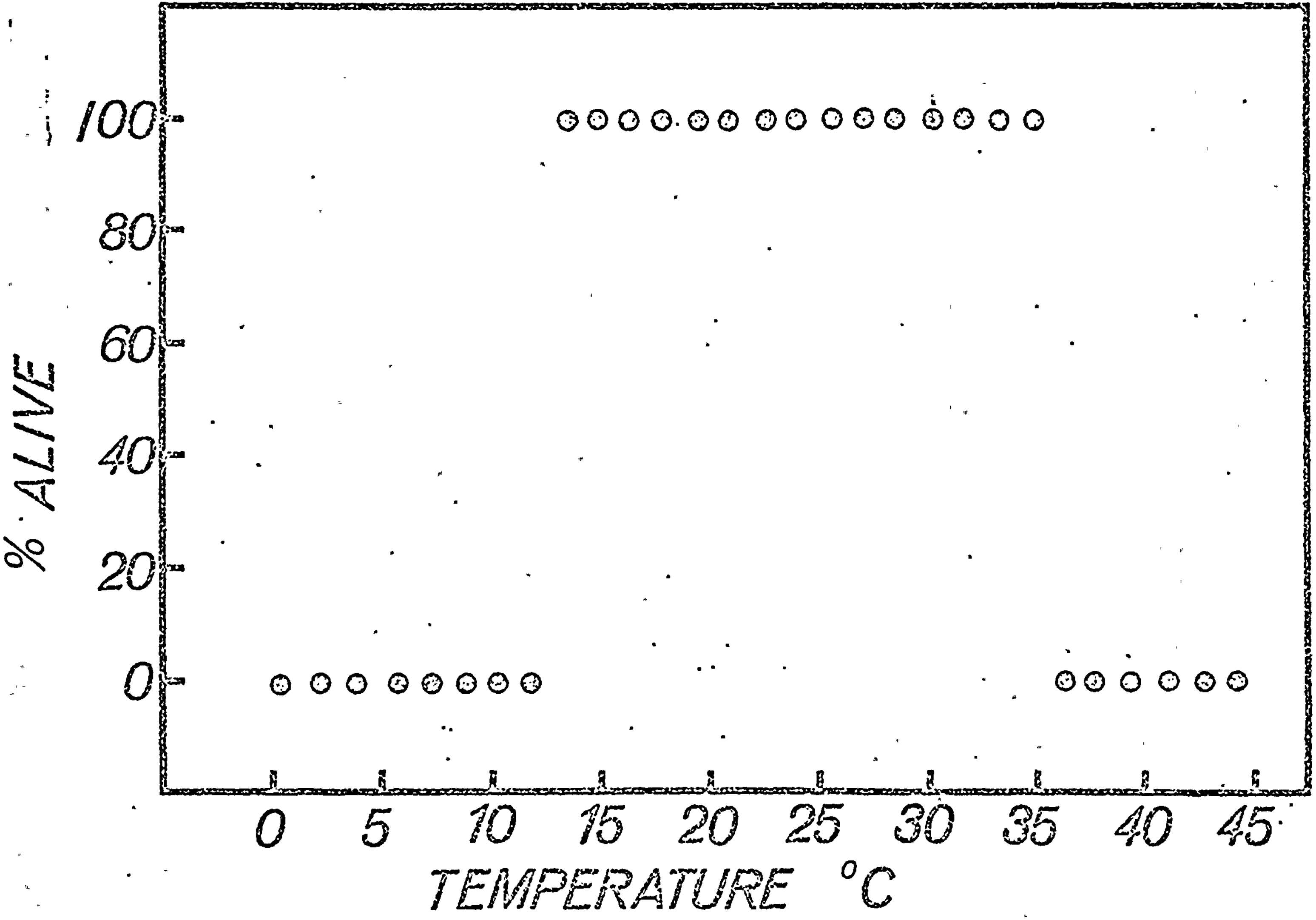

FIGURE XI-8 Percentage survival versus temperature for <u>Periclimenes</u> sp. after 168 hours exposure. Each point represents 6 organisms.

TABLE XI-1

UPPER TEMPERATURE LIMITS OF SELECTED TROPICAL ESTUARINE ORGANISMS IN THE LABORATORY

Organism	Time of Exposure	Upper Lethal Limit in °C	No. of Organisms
I. Plants			
1. *Halimeda incrassata*	8 days	32.9 - 34.8	152
acclimated 15°C	15 days	34.7 - 36.6	41
acclimated 30°C	15 days	32.7 - 34.6	40
2. *Penicillus capitatus*	8 days	31.5 - 34.7	159
3. *Acetabularia crenulata*	4 days	38.1 - 39.1	600
4. Valonia ventricosa	72 hrs.	30.0 - 31.5	
5. *V. macrophysa*	42 hrs.	32.0 - 33.6	
acclimated 30°C	72 hrs.	32.6 - 34.2	9725*
acclimated 15°C	72 hrs.	33.2 - 34.7	
6. *V. utricularis*	120 hrs.	31.0 - 31.4	
7. *V. aegrophilia*	72 hrs.	31.4 - 33.0	
8. *V. ocellata*	72 hrs.	32.8 - 34.0	
9. *Laurencia poitei*	10 days	31.7 - 34.9	144
II. Invertebrate Larvae			
1. *Penaeus duorarum* nauplii	22 hrs.	30.5 - 31.5	2159
2. *P. duorarum* 1st protozoea	18 hrs.	36.0 - 37.6	
3. *P. duorarum* 3rd protozoea	17 hrs.	36.8 - 37.8	
4. *P. duorarum* 3rd mysis	72 hrs.	36.8 - 37.8	
5. *P. duorarum* 1st postlarvae	1 hr.	37.9 - 40.7	
6. *P. duorarum* late juvenile	40 hrs.	36.3 - 38.5	
7. *Menippe mercenaria* eggs	40 hrs.	36.3 - 38.5	3886
8. *M. mercenaria* 1st zoea	24 hrs.	34.4 - 36.0	
9. *M. mercenaria* 2nd zoea	91 hrs.	33.1 - 34.2	
10. *M. mercenaria* 5th zoea	44 hrs.	34.7 - 35.5	
11. *M. mercenaria* megalopa	16 hrs.	36.0 - 37.0	
12. *M. mercenaria* zoea/mega.	24 hrs.	30.5 - 31.4	
13. *M. mercenaria* mega/juve.	24 hrs.	28.9 - 30.5	
III. Caridean Shrimp			
1. *Tozeuma carolenensis*	72 hrs.	32.3 - 33.9	768
2. *Palaemonetes intermedius*	72 hrs.	36.2 - 37.8	570
3. *Paraclimenes* sp.	168 hrs.	36.1 - 37.6	190
4. *Hippolyte* sp.	48 hrs.	31.0 - 32.8	66
5. *Leander tenuicornis*	24 hrs.	34.4 - 35.5	24
IV. Mollusca (intertidal)			
1. *Nassarius vibex*	72 hrs.	37.5 - 40.2	48
		TOTAL	18,572

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*Valonia of all species

Temperature and Salinity Tolerances

Under the direction of Dr. H. B. Moore, Miss Helen Albertson has undertaken a separate laboratory approach to the problem of determining upper lethal temperatures of Biscayne Bay organisms under the support of FWQA (DIWP-01433). The method employed a running seawater system in which the water was replaced at a rate of a liter per minute, thus reducing the build up of metabolic wastes and the lowering of dissolved oxygen. Up to 200 organisms can be tested at one time. Moore and Gray (1968, 1969, 1970) and Albertson and Gray (in preparation) have described the apparatus used. The following method was employed in all tests.. A preliminary test was made to determine the approximate upper lethal temperature; a few specimens were taken from ambient seawater, placed into pre-heated seawater and held at the predetermined temperature for 15 minutes. The animals were then returned directly to ambient conditions to be watched for per cent survival. This preliminary test is repeated at intervals of 5°C. above ambient until an approximate lethal temperature is found.

In the actual test, specimens were placed in the experimental tank and the temperature was raised at a constant rate of 1°C. per hour. As the temperature approached the approximate lethal point as determined by the preliminary run, 25 animals were removed from the tank at 1°C. intervals for a range of 8°C. These organisms were placed in jars filled with water at the temperature at which they were removed and allowed to cool to ambient. The jars were then placed in running seawater where the animals were held 24 hours prior to the determination of per cent survival.

The criterion for the determination of life differs with each taxonomic group; however, it generally involves some form of movement. In echinoderms, for instance, animals are considered alive if they can move their tube feet. A gastropod is considered alive if it moves its foot in response to prodding. For acceptable results all animals removed in the first sample (i.e. at the lowest sample temperature) must be alive and all those from the last sample must be dead.

Any salinity can be maintained in the running seawater system by the apparatus described in Moore and Gray (1970). When this equipment is combined with the temperature programmer, lethal temperature runs can be made at low salinities For these runs, the animals were placed in the test tank and the salinity reduced to the desired value over a period of about 5 hours. The determination of lethal temperature was performed as previously described. When the jars cooled to ambient temperature, they were placed in running seawater of test salinity and then returned to ambient salinity over a period of five hours. As in ambient salinity runs, the animals held for 24 hours before determinating the per cent survival.

Up to the present time, 35 different species have been tested; including 13 gastropods, three echinoderms, three bivalves, four crustaceans, ten cnidarians, and one fish. The upper lethal temperatures of these organisms are shown in Figure XI-9.

Changes in the upper lethal temperature of Nassarius vibex with lowered salinities are seen in Fig. XI-10. As might be expected with the added stress, the lethal temperature is lower at reduced salinities. In addition, the coefficient of variability rises with reduced salinity. Thus as the stress on the animals increases, the variability of individuals of a species becomes greater. Consideration is presently being given to the possibility of using the coefficient of variability as a general index of stress. Upper lethal temperatures have been determined for a few species collected both in summer and in winter. So far there has been little shift of the upper lethal temperature of a species from summer to winter.

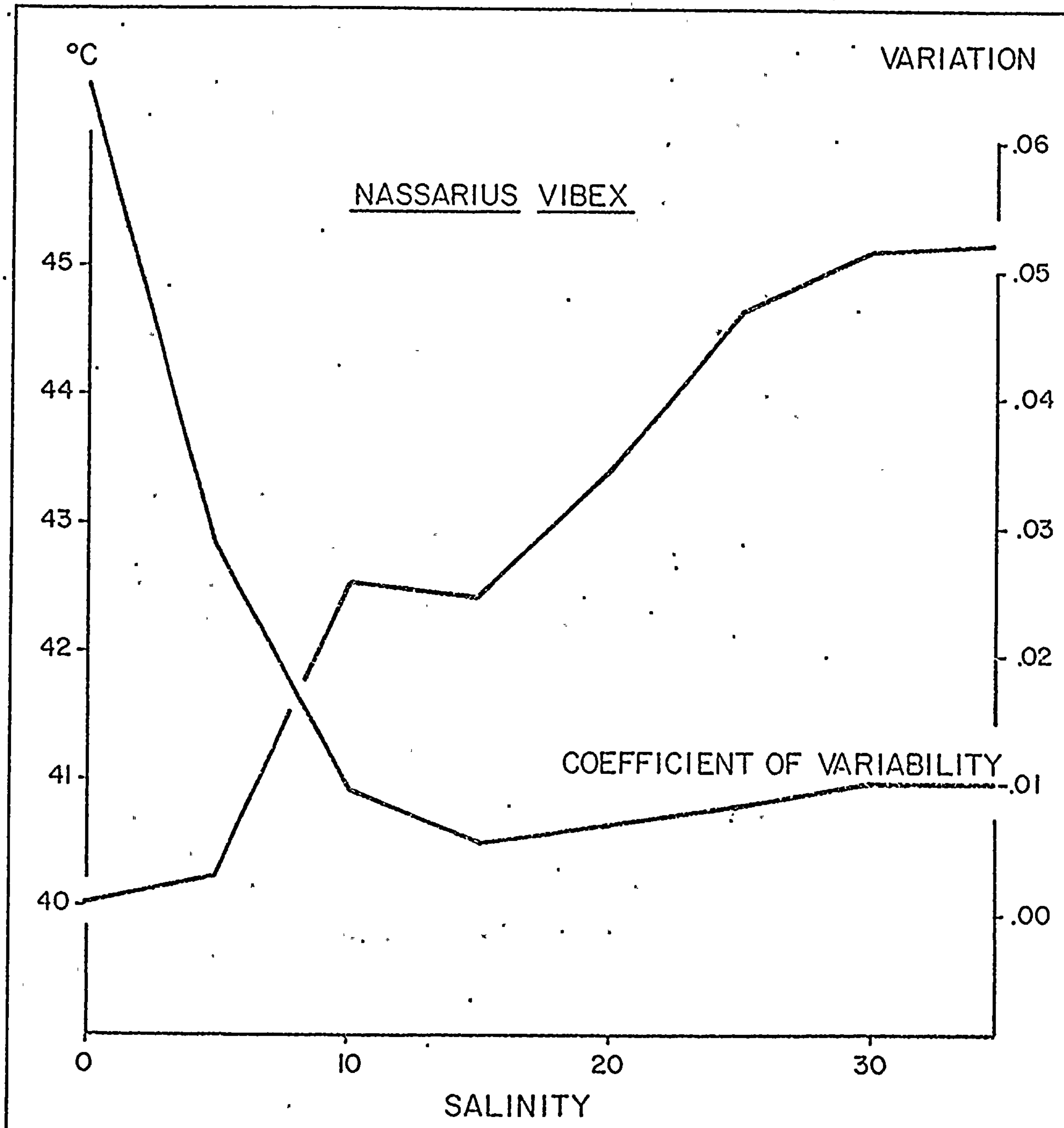

FIGURE XI-10 Changes in the upper lethal temperature and coefficient of variability with lowering salinity in *Nassarius vibex*.

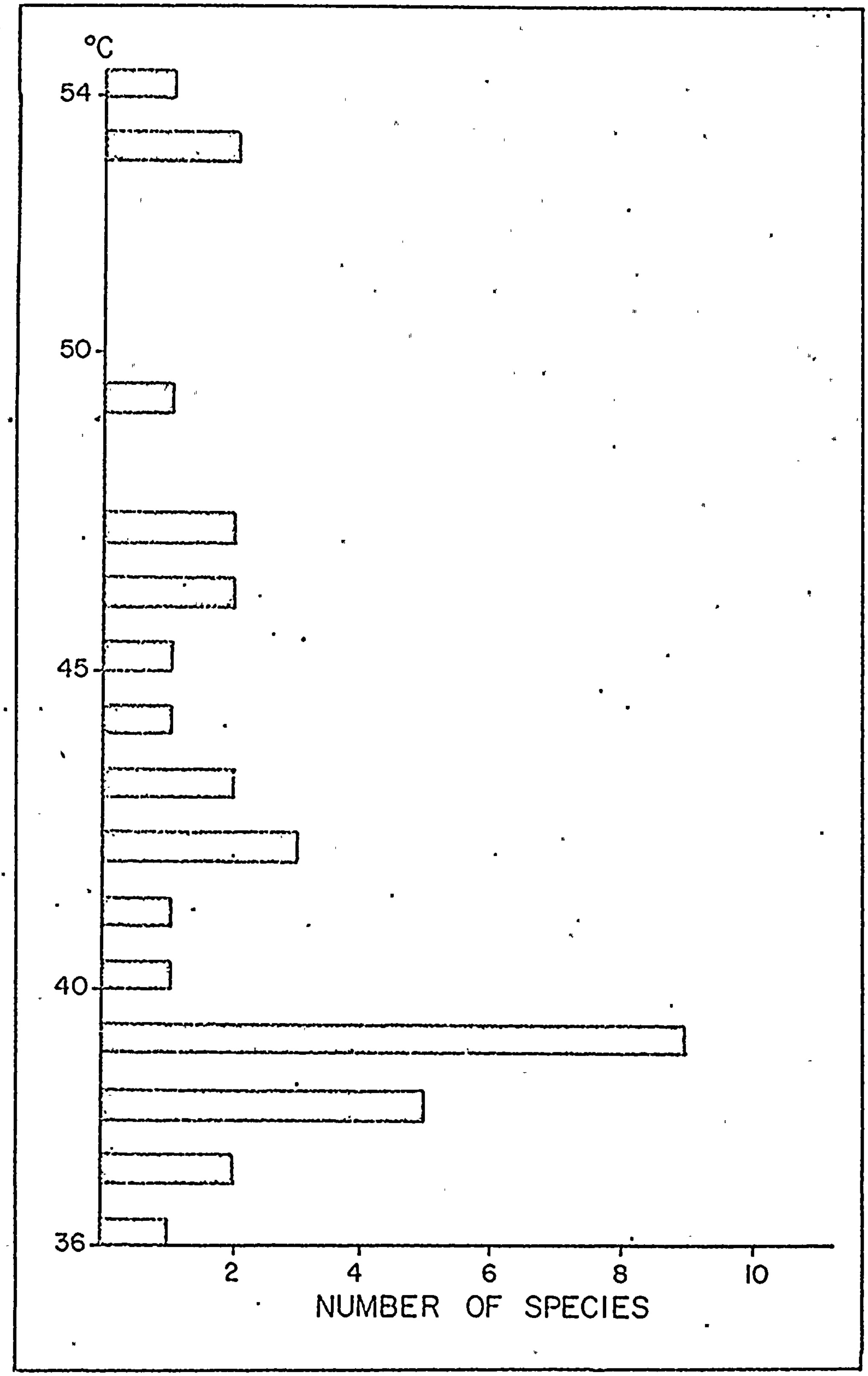

FIGURE XI-9 Upper lethal temperature of the 35 species of Biscayne Bay organisms tested.

In addition to work on upper lethal temperatures, the effects of long term increased and decreased temperatures on the sea urchin, Lytechinus variegatus, have been observed. Urchins were kept for 6 months at four different temperatures in running water aquaria. Growth and gonad volume were greatest in urchins kept at 28°C. (Fig.XI-11) At temperatures both higher and lower than this gonad volume and growth were greatly reduced. Although the upper lethal temperature determined by the previously described laboratory test for L. variegatus was 36°C., it can be seen that a population is threatened at temperatures much below its lethal point. The ability to grow or develop gonads may be lost under the stress of temperatures much below those at which the adults are killed outright.

CONCLUSIONS

One of the most important conclusions from the laboratory data is that tolerance limits obtained in the polythermostat conformed closely to those observed in the field. The laboratory results also aided in the interpretation of the complex field data. The information from the field studies on benthic animals (Section V) and plants (Section X) served to orient the experimental work, thus making the laboratory data compatible with that found in the field. Also, the daily laboratory observations of growth and death of plants proved valuable for the field separation of vigorous mature plants from those scenescent or thermally stressed.

The laboratory experiments, using some 18,000 individuals, have given the most accurate account of thermal tolerances for marine estuarine organisms available to date. The expected Gaussian or skewed curve for lethal thermal limits did not materialize; instead, an abrupt death point occurred often within an interval of 1°C and in many cases within 0.5°C resembling a step function.

The upper temperature limit for many of the plants examined as well as the sensitive stage of the pink shrimp and crab larvae and several of the carideans was 31 to 33°C. This was corroborated in field observations (Section X) where the mean monthly temperature exceeded these limits in areas near the mouth of the effluent canal at Turkey Point. These critical temperatures were only 1 to 3°C above the mean mid-summer temperature encountered under natural conditions. Thus, some of the temperature sensitive tropical organisms appear to live much closer to their upper lethal limit than do either temperate or Arctic species whose limits have been described by Kinne (1970) and Beibl (1971). This is in agreement with the work of Professor H. B. Moore.

The upper lethal temperature limits were time-dependent, but an "equilibrium temperature" was found beyond which prolonged exposure no longer caused death.

In general, the invertebrates examined appeared to have a higher tolerance than the algae, mature pink shrimp, stone crabs and several carideans had limits near 35 to 37.5°C, while most algae had limits of 30 to 33°C. One exception was the intertidal algae, Acetabularia, which had an upper limit between 38 to 39°C; this was expected since organisms living in the inter tidal zone are constantly exposed to extreme thermal stress.

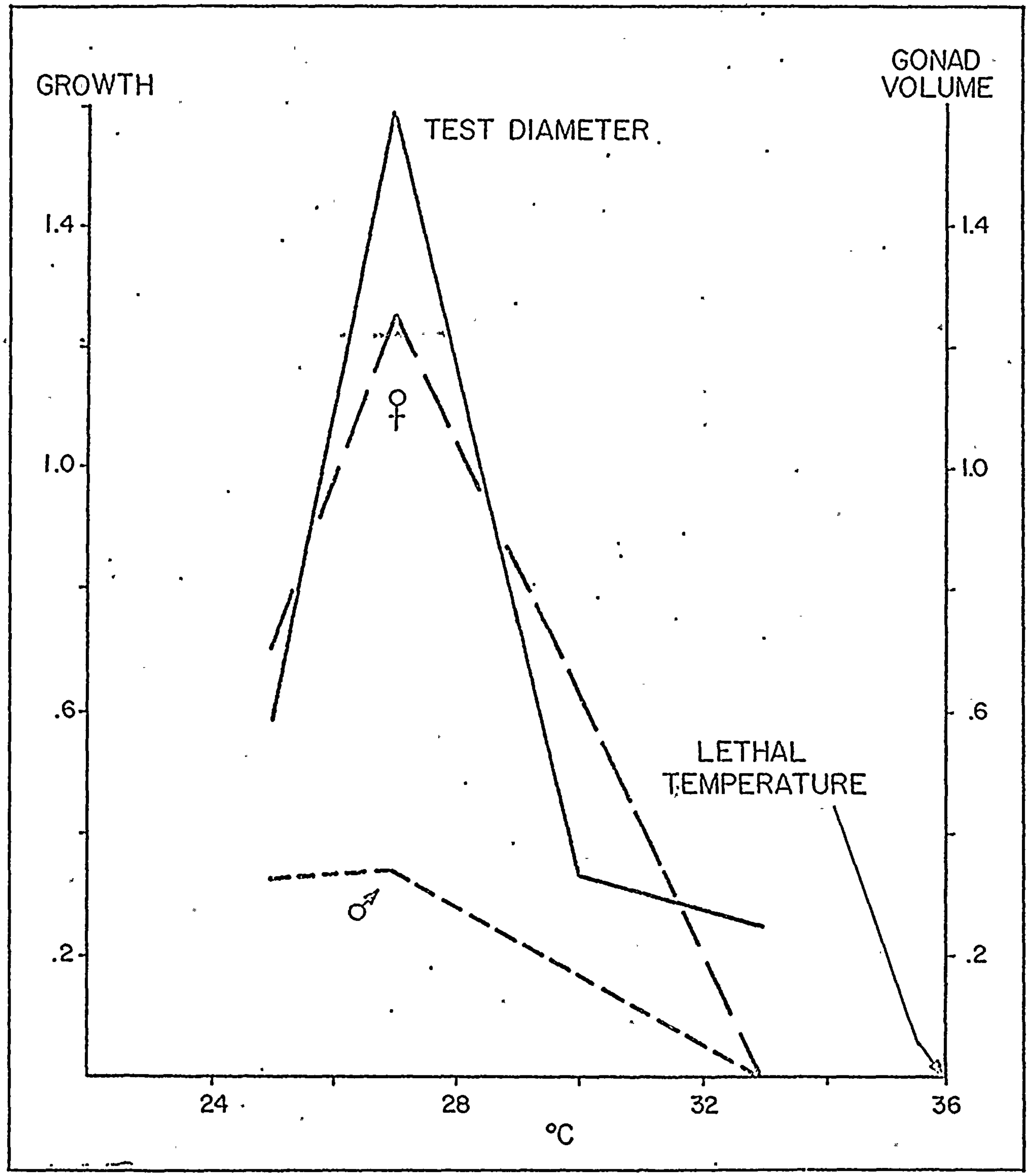

FIGURE XI-11. Growth of the urchin Lytechinus at four controlled temperatures. Whole line - growth of the test, broken lines - growth of the gonads. The experimentally determined upper lethal temperature was 36°C.

The commercial pink shrimp (Penaeus duorarum) had temperature limits near 36 to 37°C in all its life stages. However, the early naupliar stage did not metamorphose to a protozoea at temperatures above 30.5 to 31.5°C. The commercial stone crab (Minippe mercenaria) had upper limits between 36.3 and 37.8°C for eggs and the first larval stage; but, the sensitive megalopa stage had limits near 30°C. Two caridean shrimp (Palaemonetes intermedius and Periclemenes sp.), important to the food web in the Bay, had temperature limits at 36.1 to 37.8°C.

Five species of Valonia collected from six different estuarine regions of the Caribbean and Bermuda had an upper thermal tolerance near 31 to 33.5°C. Acclimation to higher temperature was not demonstrated. Halimeda had slightly higher limits than Penicillus (See Table XI-1). Temperature tolerances for all of the species examined are shown in Figure XI-12.

The information obtained from the snail Nassarius vibex showed that after one hour exposure at 46°C, death occurred to all specimens in the studies by Professor H. B. Moore and in the polythermostat method. After 72 hours exposure, the death point ranged from 37.5 to 40.2°C. The comparison of the two procedures indicates that long-term exposure to thermal stress yields lower lethal temperature limits than short-term exposure (e.g. Professor Moore's experiments of a one degree temperature increase for only one hour). If these two methods of study are to be critically examined, a more thorough investigation is necessary. This is already underway using Valonia macrophysa.

The data presented in Section V show that there are several species of benthic animals with strong temperature responses. It is necessary to explore the temperature limits of these organisms in order to determine whether this dependency is direct or indirect.

The individual variability, a subject of great importance in most physiological studies, appeared amazingly small. The largest error was establishing the criteria for the identification of dead organisms; this had to be empirically defined for each species. Temperature variation due to experimental procedure had no discernable effect, and culture problems were kept to a minimum by working closely with experts for each species.

It must be emphatically stated that if tropical ecosystems are to be effectively managed, a more basic understanding of lethal temperature limits is essential! Tropical organisms live very close to their upper lethal temperature limits and have little tolerance to temperature change. In view of this, it is necessary to employ extremely refined methods in investigating the cause of thermal death at the cellular and subcellular level. During the past year a method for maintaining the intracellular and extracellular temperature at any level between 0 and 50°C (±0.01°C) has been developed and will permit precise determinations of temperature effect and temperature limits on the living cell.

The work by Thorhaug (1970) on temperature controlled perfusion in algal membrane systems addressed itself to and proposed an hypothesis for the cause of heat death. Several investigators have concurred (Brock and Darland, 1970; Daniell et al., 1970; Pierson et al., 1971). This hypothesis basically states that indirect thermal death is caused by the impairment of membrane transport. This may not be the only possible reason for cellular death; but at last it represents a beginning point which may be tested.

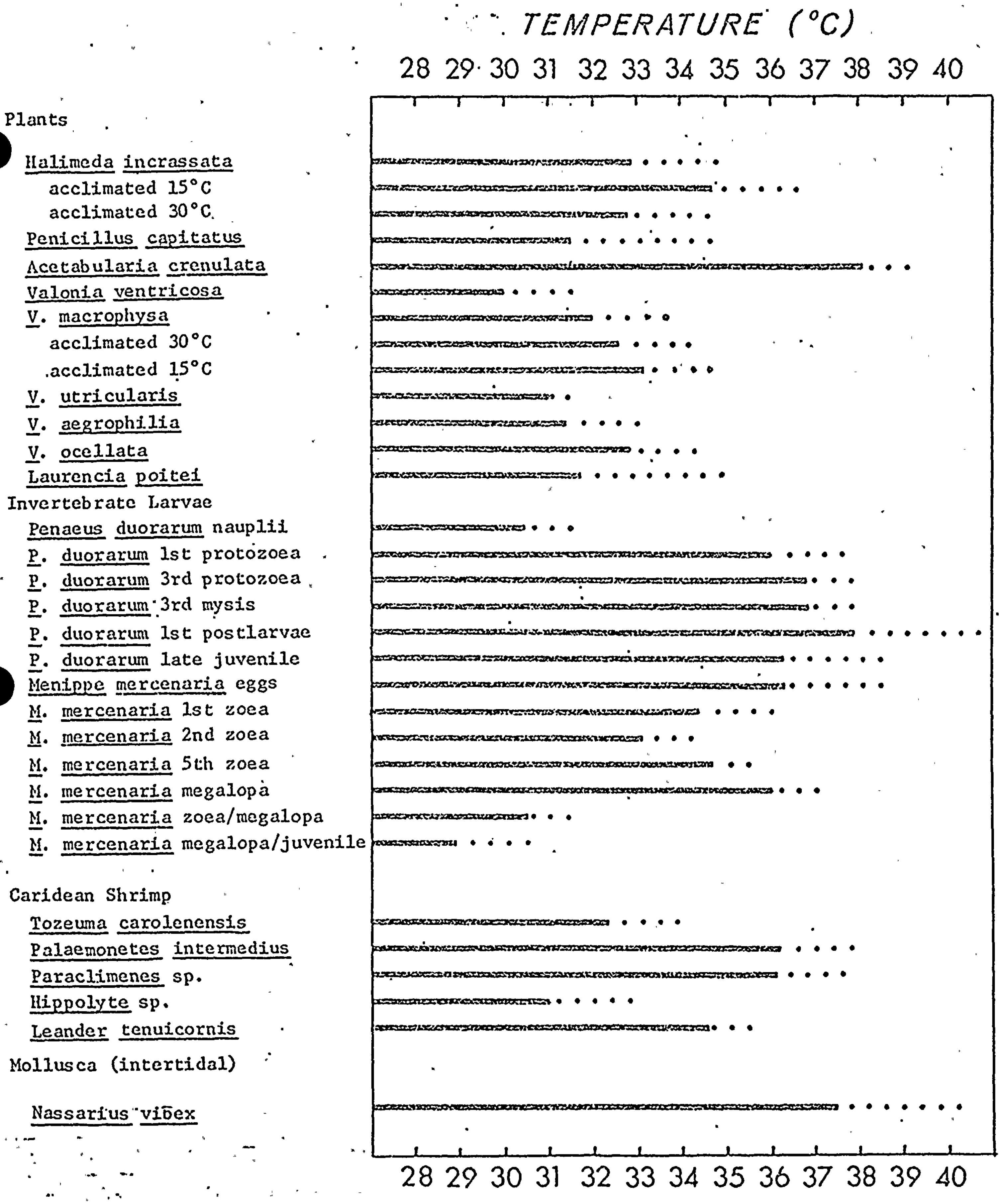

FIGURE XI-12 Upper temperature limits of selected tropical estuarine organisms in laboratory investigations. Black line indicates near 100% survival, dotted line indicates interval to near complete mortality. See Table XI-1 for details of time and numbers of test organisms.

Chemical field studies in the area of thermal discharge at Turkey Point (Section IV) indicate the possibility that thermal stress or death of entrained organisms may be manifested in the release of nutrients, dissolved organic compounds and possibly other chemical species into the water. This indicates a need for controlled laboratory studies of this phenomenon.

Another important area of study is time-temperature relations. The short time period at an elevated temperature may well be more important than any longer time period at a lower temperature, but more data must be accumulated in the area of 29 to 45°C for various organisms before any definitive statement can be made. Fluctuating temperature versus sustained temperature at these elevated levels must also be examined.

Marked changes in the behavioral pattern of crab and shrimp larvae were observed at elevated temperatures. When at ambient temperatures found in Biscayne Bay the organisms live together satisfactorily. However, when exposed to temperatures just under their lethal limit, attack and cannibalism occurred. This represents another possible means whereby the ecological situation of the Bay could be upset. It is essential that the behavioral patterns, and the effect of thermal stress upon these patterns be examined for many forms including fishes.

Under the direction of Dr. H. B. Moore, upper lethal temperatures for 35 species of Biscayne Bay organisms have been determined. Changes in the upper lethal temperatures at low salinities have also been investigated. In these tests, the coefficient of variability of individuals within a species increases with stress. No significant differences were found in upper lethal temperatures within species from summer to winter. Lytechinus variegatus held at different temperatures for 6 months showed pronounced optimal growth and gonad developement at 28°C with significant decreases in both at higher and lower temperatures.

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XII. PLANT COMMUNITY INVESTIGATION*

GENERAL STATEMENT

One of the most important bottom communities in South Biscayne Bay and Card Sound is the wide expanse of the grass Thalassia; thus information from an independent study is included in this report. The work encompasses observations from many areas of southeastern Florida and was conducted in order to better understand the composition of the Thalassia community as well as the growth characteristics, life span, turnover rate and developmental patterns of selected species. Such field information, obtained at many locations from Bear Cut in Biscayne Bay to Key West, makes available data on numerous "typical" communities free of man-made thermal stress. Thalassia and six species of algae were observed, however, most of the effort was devoted to Penicillus and Halimeda, two calcareous green Siphonales that comprise an important part of the tropical estuarine and back reef communities.

A laboratory investigation was also initiated with an immediate objective to raise green calcareous macro-algae in the laboratory in a state of health comparable to that observed in the field. This, of course, is necessary if experimental laboratory results are to be effectively used in conjunction with field observations. Also, measurements such as chlorophyll content were used as preliminary information on investigations of the effect of heat stress.

In addition to contributing significantly to calcareous sediments (Chave, 1965), these two algae, plus Thalassia, are very important to the total ecosystem of South Florida estuaries. Many animals such as forams, micromolluscs, crabs, shrimp, polychaets, adults and larval forms, spend all or much of their life in the rich stands of grass and algae that affords food and protection. For example, the capitulum of the mature Penicillus plants provide food for small organisms. Many types of gastropods such as Astraea phoebia, Bulla striata, Turbo castaneous, and Fasiolaria tulipa have been observed feeding on Penicillus. Also fish such as Holocanthus sp. consumed Penicillus (Thorhaug, 1965).

Besides the early taxonomic literature (summarized in Thorhaug, 1965), very little research has been conducted on these algae. A sexual stage has not been substantiated for Penicillus. Although Ernst (1902) reported sexual reproduction, Fritsch (1956) found it to be an epiphyte, and Thorhaug (1965) observed only asexual reproduction by budding from rhizoids. This same generalization can be made for Udotea and Rhipocephalus. Halimeda, on the other hand, has been observed to reporduce asexually via a rhizoid system as well as via gametes formed in gametangia which are proliferations of the axial filaments.

One of the very few in situ studies on these algae was done by Goreau (1963), who in his work on calcium carbonate deposition measured the rate of photosynthesis. Penicillus was observed to photosynthesize at a rate similar to that of Halimeda but slower than the calcareous reds and faster than lithothamniods. Calcium accretion rate was also measured, and implied to be

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*A. Thorhaug

associated with photosynthesis as with Coccolithophores (Isenberg, 1963). Penicillus has been the subject of geological investigations involving contribution of calcareous algae to sediments. Lowenstam (1955) for example, found that some of the Bahama Bank sediments were of algal origin. In a further effort to ascertain the origin of the sedimentary carbonates of the Bahama Bank, Lowenstam and Epstein (1957) measured the 0-16/0-18 and C-13/C-14 ratios in the sedimentary carbonates and then compared these ratios with those in the algae, oolites and grapestones. They established that the isotope ratios of the sediment were in median range of algal carbonates and were not in the range of either grapestones or oolites. In a similar study, Chave (1965) analyzed the magnesium content of various organisms including Penicillus in the Bahama Banks. These studies and others demonstrate that Penicillus and other algae contributes significantly to the fine calcareous sediments of the Florida estuarine and Bahama regions. However, quantitative yearly contribution and the decay pattern of the organic parts is still unknown.

METHODS

Laboratory Techniques

Specimens of Penicillus capitatus and Halimeda incrassata were successfully grown in plastic coated marine plywood aquaria (4' x 4' x 9") located outside the laboratory in order to expose the plants to normal daily sunlight. Debris was kept out by a screened cover and when necessary a plastic cover was used to exclude excessive rain water.

A subsand filter system was placed on the bottom and covered with a thin layer of fiberglass fibers (glass wool) to prevent clogging of the filter apertures. A three-inch layer of sand was placed on the glass wool. The depth of the sand was sufficient to allow algal hold-fasts and rhizoids to elongate to lengths such as observed in the natural habitat and for plants to send out rhizoids for asexual propagation. A source of continuously-running sea water was connected to the filter system so that the water passed through the subsand filter and percolated from the bottom of the tank upward through the layer of sand creating a deep aerobic layer. The sea water was pumped from Bear Cut in Biscayne Bay through polyvinylchloride (PVC) tubing to an elevated settling tank and finally fed by gravity to the aquarium.

Plants were collected at various locations in Biscayne Bay and Card Sound and transplanted. Healthy plants (P. capitatus and H. incrassata) were dug out so as to retain as much of the rhizoid as possible and quickly brought to the aquarium in large plastic buckets. During transport to the laboratory, the algae were kept submerged in aerated sea water and were planted immediately upon arrival at the laboratory. The holdfast system was set to a depth of about two inches. Specimens and their clones were successfully maintained in this aquarium for periods of more than a year.

Plant growth was carefully followed by tagging with plastic numbers and a record was kept of a number of variables affecting growth. Light intensity in the aquarium was measured by a General Electric exposure meter which was placed at the water surface in the aquarium with the photocell oriented in the direction of the sun. Growth measurements were made by placing one arm of a

new shoots in about a week. These new shoots developed into plants which continued the life cycle by producing rhizoids. A colony was often established around the parent plant in two or three weeks. From daily observation, the pattern of senescence and death was observed. The first sign of decline was the loss of all filaments; they dropped into the sediment and decayed. The organic material in the stipe decayed leaving behind the calcium carbonate deposit. This structure resembled a serpulid worm case and usually remained standing until upended by another plant or an animal. Then it would drop into the sediment and become buried by sand or disintegrate and become incorporated in the sediment. Daily observations of Penicillus in the polythermostat at elevated temperatures indicates that it takes several days to die, the same sequence of events were as readily observed as in stands of Penicillus in the natural environment.

A comparison of the algal growth in the aquarium and in the natural environment was measured from April to October. The primary purpose was to determine if there was any marked difference between field and experimental observations. The growth parameters were: (1) the growth rate of young shoots of the P. capitatus measured while they grew to mature plants (measured in terms of mean rate of growth in cm per week), (2) the mean height of the mature plants, and, (3) the mean longevity of plants from the appearance above the sediment until the plant died.

The mean growth rate of young P. capitatus in the Coral Shoals environment was 0.7 cm per week, with a standard deviation of ±0.4 cm per week. The rate in the aquarium was 1.1 cm per week with a standard deviation of ±0.7 cm per week. The standard error was 0.34. The mean height of the P. capitatus plant in the Coral Shoals sample was 5.7 cm with a standard deviation of ±1.2 cm. In the aquarium the mean height was 4.5 cm with a standard deviation of ±2.0 cm. The standard error was 0.13 for the two mean heights and the critical ratio was 2.31 which shows a definite significance at the 0.05 level. The mean length of life for P. capitatus in the aquarium, excluding those eaten by predators, was approximately 3 months (see Tables XII-3, XII-4, and XII-5).

Halimeda was found to grow more rapidly in an exposed environment than in a calm, sheltered position. The growth rate was fairly rapid, averaging about 1.7 cm/week in exposed areas and 1.2 cm/week in sheltered areas. In culture, the plants grew as in sheltered locations, 1.1 cm/week. A period of rapid growth occurred in the spring. This spring spurt would affirm the work done by Bass-Becking (1933 and 1936), where the nitrogen content (high in actively tissue-building organisms) was shown to be highest in March and April, followed by a second spurt of growth in the summer. Goreau (1961) also has reported growth in spurts of shorter duration - 36 hours.

SUMMARY

The difference in growth rates and mean height of the mature P. capitatus plant in Coral Shoals and in the experimental aquarium indicates that these two environments were somewhat different, however, the experimental plants grew virgorously for generations and reproduced abundantly. The plants in the aquarium grew to a mean mature height of 4.5 cm ±1.3 cm; this approximates field observations. The mean growth of the mermaid shaving brush plants in the natural environment was less than that found for the aquarium studies. (This may be attributed to differences in current, temperature, and turbidity. The Coral Shoals area was subjected to strong tidal currents and high silting and turbidity.

The aquarium water remained clear, flowed steadily and slowly.

It can be concluded from these experiments and observations that at best; some species of algae can exist successfully under controlled laboratory conditions. Thus, they may be used in experiments without the fear that laboratory results are influenced by plant damage.

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TABLE XII-1

DENSITY OF PENICILLUS PLANTS DURING TWO SEASONS (PLANTS/m^2)

LOCATION	SPRING	SUMMER
BEAR CUT	20	45
MATHESON HAMMOCK	9	20
S. W. POINT	0	0
SEWAGE BEACH	7	12
CORAL SHOALS	12	35
SOLDIER KEY	10	15
SAND KEY	30	49
ELLIOT KEY	25	55
UPPER KEY LARGO (Harry Harris Public Park Lagoon)	35	115
LOWER KEY LARGO	8	35
MATECUMBE KEY	-	58
KEY WEST	20	60
WHITEWATER BAY	0	0
EVERGLADES (FLAMINGO)	-	0
SHARK RIVER MOUTH	0	0

TABLE XII-2

ALGAL POPULATIONS IN THREE LOCATIONS (JULY, 1964)

PLANT	BEAR CUT	CORAL SHOALS	KEY WEST
PENICILLUS	45	37	60
THALASSIA	30	55	53
HALIMEDA	7	8	15
SYRINGODIUM	12	6	6
RHIPOCEPHALUS	1	3	6
UDOTEA	2	3	4
DIPLANTHERIA	3	-	-
TOTAL	100	112	144

TABLE XII-3

GROWTH RATE DATA FOR P. CAPITATUS

CORAL SHOALS				AQUARIUM			
PLANT NO.	MEAN RATE	PLANT NO.	MEAN RATE	PLANT NO.	MEAN RATE	PLANT NO.	MEAN RATE
1	1.0	19		1	1.0	19	1.4
2	0.3	20	0.5	2	0.6	20	0.6
3	0.4	21	1.1	3	0.6	42	1.6
4	0.4	22	0.8	4	0.3	51	0.3
5	1.2	23	0.4	5	1.4	55	0.6
6	1.1	24	1.1	6	-	57	2.1
7	1.3	25	0.6	7	-	58	2.2
8	-	26	0.4	8	-	60	0.6
9	-	27	0.8	9	0.7	63	0.1
10	0.5	28	0.4	10	0.7	64	1.4
11	0.8	29	-	11	1.4	65	1.7
12	0.4	30	0.3	12	2.3	69	2.4
13	0.3			13	-	72	1.9
14	0.3			14	-	77	1.5
15	0.6			15	0.2	78	0.4
16	0.4			16	-	79	1.9
17	0.5			17	-	96	0.4
18	0.3			18	-	99	0.3

TABLE XII-4

MEAN HEIGHT DATA FOR PENICILLUS CAPITATUS

CORAL SHOALS		AQUARIUM			
PLANT NO.	HEIGHT	PLANT NO.	HEIGHT	PLANT NO.	HEIGHT
1	6.5	1	3.9	51	3.3
2	6.6	2	2.3	52	-
3	6.2	3	4.9	53	5.2
4	4.1	4	4.0	54	3.5
5	7.6	5	5.3	55	4.2
6	5.3	6	4.4	56	2.4
7	6.2	7	-	57	7.4
8	5.4	8	3.1	58	7.8
9	6.2	9	2.2	59	5.4
10	5.4	10	3.9	60	5.5
11	9.2	11	5.4	61	3.3
12	6.5	12	4.9	62	3.4
13	5.0	13	-	63	3.3
14	7.0	14	2.9	64	7.8
15	5.2	15	5.0	65	7.8
16	6.3	16	1.0	66	5.5
17	6.0	17	1.0	67	4.0
18	6.5	18	3.4	68	-
19	4.6	19	4.9	69	5.8
20	6.9	20	4.5	70	4.8
21	5.0	21	-	71	10.8
22	6.3	22	-	72	6.5
23	7.2	23	-	73	8.0
24	9.0	24	-	74	5.8
25	6.6	25	-	75	5.8
26	6.3	26	-	76	5.4
27	6.9	27	-	77	6.6
28	6.2	28	-	78	6.8
29	5.2	29	-	79	7.7
30	5.4	30	-	80	2.8
31	3.4	31	-	81	4.8
32	4.5	32	-	82	2.9
33	-	33	1.8	83	1.8
34	4.5	34	-	84	-
35	-	35	-	85	-
36	4.9	36	-	86	3.8
37	4.1	37	-	87	4.4
38	4.2	38	-	88	3.1
39	5.0	39	-	89	8.8
40	-	40	-	90	4.0
41	-	41	-	91	4.6
42	4.8	42	4.6	92	3.8
43	3.6	43	3.9	93	3.9
44	-	44	1.4	94	5.3
45	-	45	1.6	95	5.5
46	5.0	46	-	96	7.9
47	4.5	47	-	97	1.7
48	6.4	48	-	98	2.8
49	4.3	49	-	99	2.5
50	6.4	50	-		

TABLE XII-5

HEIGHT AND GROWTH RATE FOR PENICILLUS CAPITATUS

(APRIL, 1964 TO OCTOBER, 1964)

MEASUREMENT	CORAL SHOALS	AQUARIUM
Mean Height of Mature *P. capitatus*	5.7 cm	4.5 cm
Standard Deviation from Mean Height	± 1.3 cm	± 2.0 cm
Standard Error of the two Measurements	0.34	
Mean Growth Rate of Young *P. capitatus*	0.7 cm per week	1.1 cm per week
Standard Deviation from Mean	0.4 cm per week	0.7 cm per week
Standard Error of the two Measurements	0.13	
Mean Life Span (Length of Life) for *P. capitatus*		12.6 weeks or approximately 3 months.

XIII. SUMMARY*

The studies on circulation and flushing indicate the mixing is poor and primarily the result of tidal action. Exchange between Card Sound and the ocean appears to be enhanced by wind stirring. Two types of theoretical models have been developed to evaluate mixing and the extent of the thermal plume. Work is needed to collect adequate data to test these models. The wind records for Homestead Air Force Base should be evaluated to permit the evaluation of the frequency and magnitude of cold front wind systems which would enhance mixing. Further work is also needed to evaluate the effects of engineering design of the effluent canal and discharge shape on the size of the area effected by the thermal anomaly.

The studies on inlets and boundaries has developed a workable model which can be used to predict flow through the various mazes of channels of Ceasars, Broad and Angelfish Creeks. Additional tide and meteorological data as well as current data are needed to further quantify and test this model.

Chemical studies have provided base line values for nutrients, carbon, trace metals and radioactivity levels. There are indications that the chemical species and solubilities in the effluent canal are anomalous: Further work in this region may provide a means of evaluating the effects of the power plant on the planktonic organisms which pass through the cooling system. The sediment chemistry appears to be related to abundance and diversity of algae and sea grasses and this possibility needs further examination. The apparent sink area in southern Card Sound needs further investigation in conjunction with studies on the circulation of the Sound. Radioactivity levels in the dominant organisms and those organisms which may be utilized by people must be measured. In addition, routine sampling must continue as a service to the biologists working on the ecosystem model.

Trawling studies have shown that animals are adversely affected by temperatures above 33°C. An exclusion model has been developed to predict the optimal bay temperature and allows enforcement personnel to calculate the temperature required to protect any fraction of the species deemed advisable. Recommendations are suggested that the level of protection should be near the 50% upper exclusion temperature which is 33°C.

Work should be continued in Biscayne Bay to measure recovery rates when the effluent is moved to Card Sound. The Card Sound studies should be supplemented with samples of the benthic infauna. In addition, food studies are needed to qualitatively evaluate the trophic web. Measurements of weight are needed for evaluation of biomass changes and work should be initiated on carbon-hydrogen-nitrogen analysis to permit later ecosystem modeling.

Zooplankton studies have indicated seasonal cycles are present but larval forms are present in all seasons. Due to the large variation in catches and patchy distribution, it is impossible to relate plankton catches to the thermal discharge. Laboratory studies have shown that the upper tolerance for the copepod Arcatia tonsa is 36°C despite acclimatization to high temperatures. More emphasis must be placed on the entrainment problems. An attempt will be made to improve handling conditions to permit the evaluation of temperature effects on organisms in the intake and discharge canals. The possibility of passing small capsules with organisms inside through the cooling system should be examined.

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Diatom studies have indicated that diatom counts, weight and chlorpohyll-a content is related to the thermal effluent. A cool water form Cocconeis is dominant in winter and replaced by Frustulia which appears heat tolerant over the ranges experienced in Turkey Point. The relative importance of the phytoplankton, benthic microalgae, macroalgae and detritus as a food source must be evaluated for this ecosystem.

The microbiology studies have provided a base line of productivity in Card Sound. The importance of the benthic microbes to the productivity of Card Sound is apparent. A much greater emphasis must be placed on these dynamic studies of productivity. The higher trophic levels must be incorporated into this primary productivity work so that an energy flow model may be developed and the effects of the additional heat energy can be studied to find its effect on productivity. It is important to map this energy flow to try to ensure that it goes to a useable product such as commercial or sport fishes or organisms of aesthetic appeal.

Studies of fungi and nematodes which are important in detritis breakdown have indicated that these organisms may be influenced by elevated temperature. In an estuary which appears to depend on a detritis based food chain the rate of breakdown of detritis under different thermal conditions is essential to proper evaluation of the effects of thermal outfalls.

The sea grass and macroalgae studies have demonstrated that elevated temperatures cause lowered growth or death to most of the plants. In the hottest areas the macroalgae have been replaced by blue-green algae. When the macroalgae and seagrasses die, the associated animals also disappear, more work is needed on the growth of algae and the sublethal effects especially on the flowering and fruiting of Thalassia. Recovery in Biscayne Bay should be investigated when the discharge canal is moved to Card Sound. The grass and algae studies are essential in interpreting animal data since about 60% of the variability in catches of the 15 most common animal species can be explained by weight of vegetation in the catches.

Laboratory studies have demonstrated that many species of algae have an upper thermal limit between 30 to 35°C. Acclimatization on a short-term basis or over many generations does not appreciably change the upper lethal temperature. Animals generally appear more tolerant to elevated temperature. The laboratory determined temperatures of exclusion and death agree very well with field observations indicating that temperature is probably the most significant factor in causing the observed changes at Turkey Point.

In the future, emphasis must be placed on the larger organisms and in particular the sublethal changes in behavior, condition and health must be elevated. The polythermostat work should be directed toward determining the effects of fluctuating temperatures, i.e., a natural cycle as observed in Turkey Point.

Thus, while several questions have been answered by our efforts in South Biscayne Bay and Card Sound, we have really succeeded only in determining the proper questions to ask in order to predict the impact of thermal additions in this subtropical estuary. It is hoped that the hypotheses formulated in this report will be useful throughout the tropics.

The following is a list of manuscripts and publications which indicate the scope of our work so far.

LIST OF REPORTS RESULTING FROM THERMAL POLLUTION STUDIES

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