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Analysis of Populations of Boring and Fouling Organisms in the Vicinity of the Oyster Creek Nuclear Generating Station with Discussion of Relevant Physical Parameters over the Period Apr. 30-Nov. 30, 1976

by

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3. Salinity in the south branch of Forked River and Oyster Creek equals bay salinity.
4. The middle branch of Forked River retains its estuarine qualities.
5. The silt load in Oyster Creek is higher than at control localities.
6. The shipworm problem in Oyster Creek has diminished over the last year. The most probable cause is some combination of plant shutdown over much of the last 2 winters, reduced operating temperatures, reduction of wood in Oyster Creek, and heavy siltation.
7. The subtropical species Teredo furcifera is still common in the area of the thermal effluent and is also established at Manahawkin.
8. The shipworm problem in the south branch of Forked River is acute. Increased dilution pumping bringing bay water up Forked River may be one reason.
9. There is an outbreak of shipworms at the mouth of Cedar Creek which we cannot attribute to the nuclear generating station.
10. The breeding season of shipworms is still extended in Forked River - Oyster Creek, but numbers of settling larvae are smaller now than 2 years ago. One month panels show evidence of greater growth rate in Oyster Creek.
11. Patterns of fouling organisms indicate that some organisms expected in Oyster Creek on the basis of physical parameters are unable to establish

themselves. We suggest that their larvae may not be able to get into Oyster Creek through the plant's water circulation system.

12. Species turnover is higher in Oyster Creek than at bay or estuarine control localities.
13. Barnacle growth is greater in Oyster Creek than at control localities, but lifespan is shorter.
14. The boring isopod *Limnoria* is present at our 3 southernmost localities, where shipworm infestation is light. *Limnoria* was found once at the mouth of Oyster Creek, but it has not taken hold.
15. We cannot evaluate the effect of any chemicals the plant may use on boring or fouling organisms, because we do not know the schedule of their use.

INTRODUCTION

Severe marine borer infestation is now recognized to have resulted from changes in salinity and temperature in Oyster Creek, New Jersey, caused by the operation of a nuclear generating station. Our previous reports (R.D. Turner, unpublished reports, and 1974) summarized the extent of the infestation at its worst, and detailed such biological phenomena as earlier reproduction in the Spring, later settlement of larvae in the Fall, & greater growth of individual borers within the thermal effluent. We also reported finding 2 semi-tropical species of borers and one tropical flatworm in Oyster Creek and environs.

The N.R.C. ordered J.C.P. & L. to remove untreated wood, which was a breeding ground for shipworms and other borers, from Oyster Creek. This was partially accomplished over the winter, 1975-76. J.C.P. & L. in the last 2 years has increased the rate of pumping water from Forked River to Oyster Creek to dilute the thermal effluent. Finally, the generating station shut down for long periods over the last 2 winters. These factors have affected the size and age structure of populations of boring & fouling organisms. This report details conditions in Oyster Creek over the period Apr. 30-Nov. 30, 1976, & evaluates the effect of plant activities and other physical events on populations of boring & fouling organisms.

METHODS

General Proceedures

Our general proceedures of study are given elsewhere (R.D. Turner, 1974, and unpublished reports; Hoagland & Turner, contract proposal to NRC; Hoagland, legal affidavits, on file with the N.R.C.). Briefly, we have established test stations within and without the thermal effluent and region of altered salinity. At each station, racks containing untreated wood panels are submerged for varying periods of time (1-12 months) and then removed. The fouling organisms are quantitatively analysed by recording the percentage of the surface area covered by each species. The panels are x-rayed and then dissected for removal and identification of marine borers. Physical parameters such as temperature & salinity are recorded at each station. Locations of test stations are shown in Appendix B. Stations 9 and 13 which have not been installed are omitted.

Work Done Prior to Contract (Sept. 1, 1976).

On Apr. 30,1976, five new test stations were established. On the same date, the ten previously established stations were visited. The old test racks were scraped and cleaned, test panels were removed to auxilliary racks, and a full set of new test panels was installed at each station. In this way, the old stations were brought into phase with the new stations. A cement block was deposited at each station for analysis of fouling.

Data collected from May 1 to Sept. 1, 1976, included:

A) Monthly temperature and general weather conditions at each site.

B) Monthly salinity at each site.

C) Monthly semi-quantitative observations of fouling organisms on racks, cement blocks, bulkheadings, and docks (presence-absence data and relative abundances).

D) Observations of shipworm damage to man-made structures in test and control areas, in the general vicinity of our 15 stations (qualitative).

E) Analysis of the fouling community on 1-month panels and cumulative panels: the last of the Sept. 1975 cumulative series and the first of the Apr., 1976 cumulative series. (Space occupied by each species on each panel was calculated.)

F) Analysis of shipworm infestation of 1-month and cumulative panels via X-ray and microscopic examination. (Some panels were dissected; others containing small shipworms were placed in tanks so that the shipworms could grow to a size permitting identification.)

Work Done Under Contract (Sept. 1, 1976-Nov. 30, 1976).

The procedures for data collection established on May 1, 1976, were continued except for the following changes:

A) Since November, monthly temperature & salinity readings have been obtained using a portable Beckman salinometer.

B) Constant recording thermometers were placed on the test racks at Holly Park site 1 (control), Forked River Beach site 8 (to monitor the northerly drift of the thermal plume), Oyster Creek site 11 (to monitor the thermal effluent) and Waretown site 14 (to monitor the southerly drift of the thermal plume).

C) We have negotiated the placement of 2 test sites (#9 & 13) at inflow and outflow channels of the power plant, with assistance from Mr. Bill Campbell, Chairman of the Environmental Commission, Waretown.

D) Panels are weighed at room relative humitity (recorded) prior to their use. After their removal, the surface areas occupied by the various attached fouling organisms are recorded (Sutherland, 1974). Every other month, the attached fouling material is scraped from the panels, dried, weighed, and dissolved in HCl. The residue is dried and weighed, and then combusted in a muffle furnace. The final residue (primarily silt and ash from the organic matter) is weighed. This procedure tells us the relative accumulations of $CaCO_3$, organic matter, and silt being deposited on the panels.

E) All Panels are X-rayed and dissected. Shipworms are separated as to species, and measured (length, width of shell). The shipworms are stored in alcohol. The wood fragments from each dissected panel are air dried and all traces of $CaCO_3$ removed by hand, then with

HCl when necessary. The wood fragments are oven-dried to constant weight, then allowed to come to equilibrium at laboratory relative humidity. They are then weighed, to estimate the percentage of wood lost by shipworm activity.

E) The fouling organisms are divided into 2 categories: those attached to the substrates, and those living and feeding on the substrates but free to move. When each panel is collected in the field, it is washed vigorously in a pan to remove most of the free-living organisms. These are immediately preserved in formalin. They are sorted and counted in the laboratory.

F) Identification to species is being attempted in most cases (notible exceptions: nematodes and gammarid amphipods). This is necessary if we are to find invading tropical or subtropical species. Mollusks, bryozoa, algae, and tunicates have been identified and reference collections established. We are working with polychaete and crustacean experts to identify our material belonging to these important groups. Complete analysis of the fouling community awaits identification of all the invertebrates, so we know positively the number of species we are dealing with.

Deviations from contract.

1. Stations:

Substitution: Proposed site #4 was not possible to establish. The area is shallow and marshy, not accessible by car or foot. There were no structures (eg, bulkheading, buoys, etc.) which we could use to secure a test rack, and no protection from storms or human damage. Most importantly, the area is ecologically quite different from our other test sites and would be difficult to compare, for that reason. There are no permanent wooden structures in the area, as there are at the other sites.

We did check for sites farther north, in the Sunrise Beach area. Preliminary sampling showed negligible temperature influence from the Generating Station plume, so we did not establish a station in the area. Sunrise Beach is very close to our Stout's Creek area. No workers have established sites between Stout's Creek and Forked River, probably for the reasons described above.

Our site #4 that we did establish is at the Mouth of Forked River, and we added site #5 at the lower branch of Forked River (Leilani Drive), to see if warm, saline water is being recirculated and if shipworms are moving up to the branch point.

Omission: Site #9 was not established on May 1, 1976, because: A) we believed that the area would be dredged; B) We feared that the site would be damaged by large barges bringing material up Oyster Creek for construction at the Generating Station and C) We were not able, financially to rent a boat to service the station. Loss of information is minimal, because our site #10 is very close to the proposed site #9.

Delay: The regulatory arm of the NRC promised to try to gain the cooperation of the Generating Station for the establishment of test sites at the inflow and outflow channels of the plant. After waiting 2 months, we contacted the town conservation commission, which helped us to make the necessary arrangements. These sites will be established in January, 1977.

Relocation: Our site #15 had originally been at Carl's Boats, but was moved next door to Liberty Harbor Marina when Carl's dock collapsed last winter. In October, we moved back to a new Carl's Boats dock. The Liberty Harbor site had oil pollution, which we wished to avoid.

2. Yearly panels:

Addition: We are installing these panels by replacing each cumulative panel as it is removed each month, at all test sites rather than only the 5 specified in the contract proposal.

3. Examination of panels for shipworms:

Addition: We find ourselves able to dissect all panels for shipworms and take linear measurements on the identified shipworms. We are able to save all the wood chips from each panel, dry, and weigh this material. Therefore we can determine weight loss for all panels, not just the cumulative series.

4. Examination of fouling organisms:

Addition: We have developed a semi-quantitative method of recording the degree of fouling as racks are removed from the water in the field. Instead of recording "barnacles-abundant; tunicates-rare", we simply list all the common macroscopic fouling organisms in rank order, 1 being most abundant in terms of surface area occupied. There are not more than 10 common organisms per rack, usually only 4 or 5. We have had little difficulty ranking them (2 people do it independently, and rarely have we had conflicts). There is a large gulf between the common and rare fouling organisms (in terms of surface area). Rare organisms are appended in a list.

This procedure is used for the metal racks, stone blocks holding the 4 x 4's, and the 4 x 4's themselves. Panels are analysed quantitatively in the lab.

Addition: We are using photography to compare general appearance of the racks at intervals of 4 months.

Functions of the Stations Established.

The 15 stations now in operation are deployed so that there are at least 2 stations of each experimental type. This allows us to use the pairs of stations as replicates in data analysis. The types of stations and their numbers are in table 1. General physical factors (weather pattern, water depth, tides) are similar for all our stations and cannot be used to explain biotic differences from station to station. The test panels are similarly arranged with respect to currents (1 side facing the current, 1 lee side). However, the estuarine stations necessarily differ from the bay stations by having less severe wave action and greater organic content in the silt which accumulates on and around the test panels.

Table 1: The Stations

Type	Number	Station Name
A. Bay Controls		
1. Mouths of Creeks	1	Holly Park
	2	Cedar Creek (Mouth)
2. Bayside	16	Iggie's
	17	Manahawkin
B. Creek Controls	3	Stout's Creek
	7	Middle Branch, Forked River
C. Forked River, influence of dilution pump (salinity change)		
1. Mouths of Creeks	4	Mouth of Forked River
	8	Bayside Beach Club
2. Creeks	5	Leilani Dr.
	6	Elk's Club
D. Oyster Creek, thermal and salinity effects of power plant	10	Kochman's
	11	Crisman's
	12	Gilmore's
E. Bayside, slight thermal influence	14	Cottrell's (Waretown)
	15	Carl's (Liberty Harbor)

MAJOR PHYSICAL EVENTS

Introduction

In analysing the biological community vs. physical factors, we must remember that there is not a 1:1 correspondence between the physical conditions on a particular day and the biological conditions on the same day. The biological community responds to past physical events cumulatively, and there is a lag between the time of a physical event & its effect on the community. For example, deposition of heavy silt will preceed by days or weeks the elimination of organisms which cannot tolerate silt. Time lags and cumulative effects make it more difficlut to pinpoint cause-and-effect relationships, unless the problem has been studied for more than one year. We will make inferrences in the following discussion based on our 5 year experience working at Oyster Creek, as well as the data from April to November, 1976.

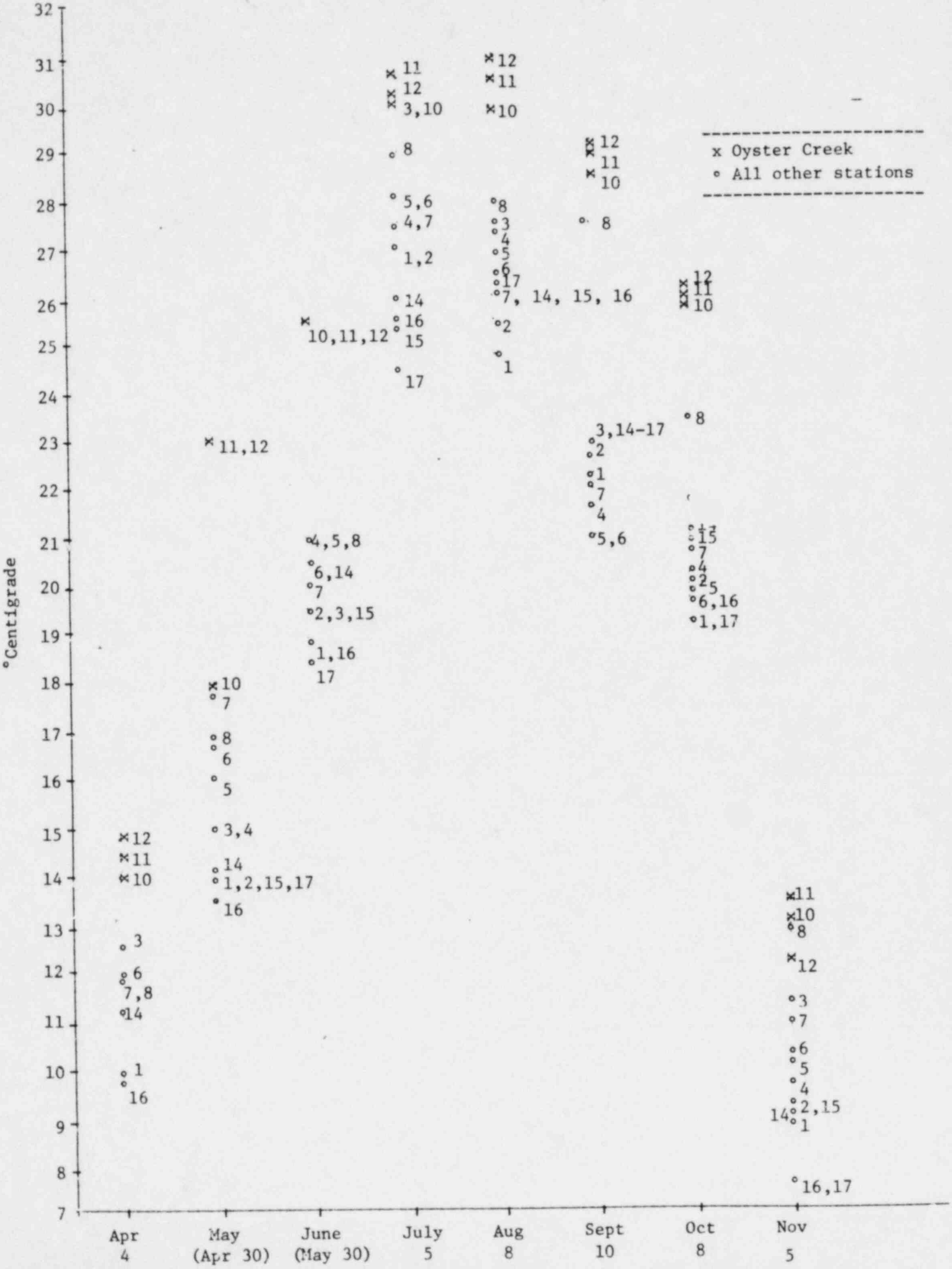
Temperature

Temperature profiles for the months April - November, 1976, are plotted in table 2 and figure 1. The Generating Station was operating during this period. Temperature differentials exist between Oyster Creek and control sites, but the differentials are not as great as those seen in previous years, when a 10°C difference was common during summer months. The greatest differential is 9.5°C. on April 30, 1976, but all others are between 5°-7°C. More interesting is the temperature gradient. The temperature is highest closest to the plant, falling off as one goes down river and continuing to fall off gradually as far away as Liberty Harbor. Some months (eg., July, October) show a temperature gradient extending as far as Manahawkin. Also, there are months when the mouth of Forked River (particularly Bayside Beach Club) is significantly influenced by the thermal effluent (August, September, October, and November, 1976). This indicates that the plant is recirculating

Table 2: Temperature Profiles, in Degrees Centigrade

STATION	Apr. 4	Apr. 30	May 30	July 5	Aug. 8	Sept. 10	Oct. 8-9	Nov. 5	Greatest Differential Within Stations
1	9.9	14.0	19.0	27	24.8	22.3	19.2	8.8	18.2
2	--	14.0	19.5	27	25.5	22.6	20.1	9.2	17.8
3	12.5	15.0	19.5	30	27.5	23.0	21.8	11.3	18.7
4	--	15.0	21.0	27.5	27.3	21.6	20.2	9.6	17.9
5	--	16.0	21.0	28	27.0	21.0	20.0	10.0	18.0
6	12.0	16.8	20.5	28	26.5	21.0	19.9	10.3	17.7
7	11.8	17.8	20.0	27.5	26.0	22.0	20.6	10.8	16.7
8	11.8	17.0	21.0	29	28.0	27.5	23.5	12.7	17.2
10	14.0	18.0	25.5	30	30.0	28.5	25.8	12.9	17.1
11	14.5	23.0	25.5	30.5	30.5	29.0	25.9	13.4	17.1
12	14.8	23.0	25.5	30.3	31.0	29.2	26.0	12.2	18.1
14	11.1	14.1	20.5	26.0	26.0	23.0	21.0	8.9	17.1
15	--	14.0	19.5	25.3	26.0	23.0	20.8	9.2	16.8
16	9.8	13.5	19.0	25.5	26.0	23.0	19.7	7.4	18.6
17	--	14.0	18.5	24.5	26.2	23.0	19.2	7.4	18.9
greatest differential within months	5.0	9.5	7.0	6.0	6.2	6.9	6.8	6.0	

FIGURE 1: MONTHLY TEMPERATUR



a portion of the effluent at some times of year. Biologically, it correlates with the finding of late (Fall) settling shipworm larvae at Forked River Beach (see discussion of shipworms).

The summer-winter temperature differential is between 16.7° and 18.9°C at the 15 stations. A comparison of the mean differential of stations outside the thermal plume vs. those in the plume (excluding the questionable stations 4, 5, & 6) gave a $t = .98$, with 10 degrees of freedom ($p<.50$). Hence the size of the differential is not related to the thermal plume while the plant is running.

One anomaly is the consistently higher temperature at Stout's Creek relative to Holly Park and Cedar Creek. Since our stations are chosen for similar sun-shade exposures, and are sampled consecutively either moving from station 1 to 17 or 17 to 1, we can find no reason for the higher reading, but are investigating further.

Salinity

The salinity data are presented in tables 3 & 4. Stations 1, 2, 3, and 7 show consistently & significantly lower salinities. This is because of fresh water influence from Tom's River, Cedar Creek, Stout's Creek, and the middle branch of Forked River, respectively. The salinity effects of operating the power plant's cooling system are seen by comparing estuarine stations in the south branch of Forked River (#4-6) and Oyster Creek (#10-12) with the other estuarine stations (#1-3 and 7) on the one hand and the bay stations (14-17) on the other. Month-to-month variation is lowest in Oyster Creek and the South Branch of Forked River. Oyster Creek stations tend to be in the midrange of salinities from month to month. There is much more variation at a single bay, Oyster Creek, or Forked River station over the several months than there is between these stations. A one-way analysis of variance considering the months as the treatments & the stations (excluding 1-3 & 7) as replicates gave $F = 76.11$, $df_1 = 7$ and $df_2 = 76$ for a $p<.001$; the same analysis including all stations gave $F = 11.47$, $df_1 = 7$ and $df_2 = 106$, for a $p<.001$. We expect that the salinities of the Oyster Creek and southern Forked River sites should approximate those of the other estuarine sites, hence salinity range should increase, when the plant pumps are not operating to bring bay water into Forked River and Oyster Creek. In fact, our data from past years indicates that this is so (See R. D. Turner's reports, 1971-1975).

Salinity changes from month to month are normal for Barnegat Bay and are due to seasonal and short-term hydrographic & climatic changes. These are not relevant to our study, because they similarly affect all our sites (but the magnitude of the effect in estuaries is greater). Salinities are lower

Table 3: Salinity Profiles, in °/oo

Station	Apr. 4	[May] Apr. 30	[June] May 30	July 5	Aug. 8	Sept. 10	Oct. 8-9	Nov. 5	Greatest differential Within Stations
1	14.47	18.40	13.95	--	26.9	23.8	21.10	18.70	12.95
2	--	19.24	16.73	19.8	26.5	24.9	23.07	19.22	9.77
3	14.47	14.34	14.76	22.5	19.0	23.4	19.92	20.02	9.06
4	--	21.09	23.21	29.0	29.0	28.0	26.61	24.64	7.91
5	--	22.14	23.46	29.0	29.3	28.0	25.58	24.82	7.16
6	21.62	22.68	21.09	28.5	27.5	25.0	24.87	23.58	7.41
7	6.56	12.60	8.06	25.5	16.0	20.5	13.38	20.12	18.94
8	22.94	22.27	23.21	28.5	29.0	28.0	24.95	24.60	6.27
10	21.62	21.87	21.87	28.5	29.0	28.0	24.32	23.88	7.38
11	21.67	21.22	21.87	28.5	29.0	27.0	24.54	24.94	7.78
12	21.62	21.22	21.49	28.0	29.0	27.0	25.55	24.12	7.78
14	22.14	23.3	23.21	30.5	30.5	26.0	25.19	25.15	8.36
15	--	23.08	25.44	30.5	31.0	27.0	25.52	25.45	7.92
16	22.94	22.94	24.52	30.5	33.0	28.5	25.42	24.18	10.06
17	--	19.24	25.32	32.0	31.0	29.4	26.66	24.60	12.76

Table 4: Ranking of Stations by Salinity, Low to high

Rank	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.
1	7	7	7	2	7	7	7	1
2	1,3	3	1	3,7	3	3	3	2
3		1	3		2	1	1	3
4	6,10,12	2,17	2	12	1	2	2	7
5			6	6,8,10,11	6	6	10	6
6		4	12		4,8,10,11,12	14	11	10
7	11	11,12	10,11			11,12,15	6	12
8	14						8	16
9	8,16	10	4,8,14	4,5			14	8,17
10		5				4,5,8,10	16	
11		8		14,15,16	5		15	4
12		6	5		14		12	5
13		16	16		15,17		5	11
14		15	17	17		16	4	14
15		14	15		16	17	17	15

in the spring than in the fall, due to patterns of water run-off from the land.

Biologically, the increased salinity in Oyster Creek and parts of Forked River relative to other creeks alters the biota in favor of bay rather than upper estuarine or even freshwater organisms. We expect this to increase the overall species diversity in these regions, all other factors being equal, because the bay provides a large species pool from which colonization can occur. This change in species diversity is independent of environmental quality per se. Species diversity indices must be interpreted cautiously when the basic parameters of an environment are changed, because wholesale exchanges of species occur. Community equilibrium is impaired, and we would expect in the case of Oyster Creek, for reasons mentioned above, an initial rise in species diversity followed by a decline as community adjustments are made via physiological adjustment, competition, and predation. Therefore, any increase & subsequent decline in species diversity in Oyster Creek and Forked River which might be found is expected from ecological theory. The rise and decline can be explained by time lags in adjustments of organisms to the new regime. This is not to say that a portion of the decline is not due to adverse effects of the power plant. The expected difference in species diversity in Oyster Creek and Forked River from the time before the generating station began operation to equilibrium conditions after operation began, depends partly on the relative sizes of freshwater and brackish versus bay communities in the source area. The negative effects of the power plant on species diversity can be evaluated best by comparing species diversities within Oyster Creek to those in other bay and estuarine sites contemporareously. This will be done in our analysis of the fouling communities. The vagaries of operation of the generating station cause local extinctions (eg, fish kills) and prevent establishment of biotic equilibrium, because both salinity and temperature fluctuate dramatically when the plant turns on and off, which is quite frequent (table 5, supplied by J.C. P. & L.). The natural range of fluctuation of salinities and temperatures in Barnegat Bay is considerable (see tables 2 and 3), but these changes take place over a much longer time interval than do plant-induced changes, hence the biota can adjust. We are evaluating numbers of species colonizations and extinctions versus the length of time salinity conditions are stable in Oyster Creek and Forked River This analysis must run at least a year before results can be given.

Suspended solids

Our qualitative observations indicated that sedimentation was heavier in Oyster Creek than in the other test regions. Using a water sampler which we suspended 1.5 feet below the water surface, we took two water samples at each locality on November 6, 1976, while the power plant was operating. Each sample was shaken and aliquotted; 3 equal-volume subsamples were filtered and the filter paper plus residue dried and weighed. There was virtually no difference in dry weight of subsamples from the same station. A comparison of the 2 replicate samples for each station by means of a 1-way analysis of variance gave an $F = 4.12$; $df_1 = 14$; $df_2 = 15$; $p<.01$. While variation within samples taken from the same station is high, the stations did vary in suspended solids.

Looking at type of environment vs. level of suspended solids (Table 6), we see that the Oyster Creek area (# 10-12) generally has the highest levels.

Table 5

OYSTER CREEK NUCLEAR GENERATING STATION

OUTAGE DATES*

1970

1/31 - 2/12
4/19 - 5/21
10/16 - 10/29

1971

1/25 - 1/28
2/12 - 2/19
3/3 - 3/5
9/18 - 11/11
11/16 - 11/21

1972

1/28 - 2/2
5/1 - 6/20
8/9 - 8/15
11/11 - 11/13
12/29 - 12/31

1973

1/1 - 1/13
4/14 - 6/4
7/21 - 7/25
9/8 - 10/5

1974

1/12 - 1/20
3/7 - 3/11
4/13 - 6/29
10/8 - 10/15
11/11 - 11/15

1975

2/4 - 2/9
3/29 - 5/26
6/13 - 6/15
8/27 - 9/3
9/24 - 10/3
10/5 - 10/6
11/25 - 12/1
12/19 - 12/21
12/27 - 12/31

1976

1/1 - 3/11
7/28 - 7/31

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*From J.C.P. & L.

Table 6: Suspended Solids

Station	Description	Sample 1	Sample 2	Mean
1	Bayside influenced by Mouth of Creek	4.55	9.22	6.89
2	Mouth of Creek	8.75	12.82	10.79
3	Creek - estuarine	5.52	2.42	3.97
4	Mouth of Creek - dilution pump influence weak thermal influence	9.92	8.02	8.97
5	Creek - dilution pump influence	22.52	7.02	14.77
6	creek - dilution pump influence	4.92	5.22	5.07
7	creek - estuarine	7.82	1.22	4.52
8	Mouth of creek - dilution pump influence; weak thermal influence	8.12	5.42	6.77
10	Creek - thermal pump influence	11.62	7.62	9.62
11	Creek - thermal pump influence	34.22	22.12	28.17
12	Creek - thermal pump influence	22.12	14.12	18.12
14	Mouth of Creek - weak thermal influence	13.62	5.12	9.37
15	Bayside - weak thermal influence	3.02	0.82	1.92
16	Bayside	4.62	3.62	4.12
17	Bayside	12.62	19.52	16.07

In most cases, the creeks in the vicinity(#3,7) carry low levels of silt, compared with the more turbulent stations at the mouths of creeks(#1,2,14). The lower Forked River sites(#5,6) also entrained more silt than the control upriver sites. We conclude that entrainment of silt is greater in Oyster Creek than in the surrounding areas, but that it falls off at the mouth of the creek (possibly due to deposition in the widened portion of the creek). We will collect more data on suspended solids in coming months. Silt suspended in the water column may have adverse effects on marine organisms by reducing light penetration; siltation has adverse effects because it interferes with filter-feeding of some sedentary invertebrates such as Bryozoa.

Wood in Oyster Creek

The Jersey Central Power & Light Co. removed untreated marina wood from Oyster Creek over the period Jan.-March, 1976. It was hoped that this removal would reduce the breeding population of shipworms in Oyster Creek. Table 7 gives data compiled by residents of Oyster Creek on the numbers of treated and untreated piles in Oyster Creek as of April 17, 1976,(Crisman, personal communication). According to their figures, J.C.P. & L. removed 44% of the untreated piles, or 37% of the total piles in Oyster Creek. Most of the remaining piles are on private property, and are associated with docks and bulkheading. In addition, there are about 2 acres of trees in standing water below the Generating Station.

The numbers of larval shipworms settling in Oyster Creek and Waretown was lower in 1976 than in previous years, as will be discussed in detail in the shipworm section of this report. There could be several reasons for the decline, but a reduction in the adult breeding population due to wood removal is certainly one likely factor.

Table 7
PILES IN OYSTER CREEK

MARINAS		UNTREATED	TREATED	
Sand Point Marina	134 Boats x 4 piles =	536		
Rules Boat yard	150 Boats x 4 Piles =	600	192	
Briarwood	170 Boats x 4 piles =	680		
Oyster Creek	108 Boats x 4 piles =	432		
		2248	192	
Lagoons 1		751	72	
2		785	121	
3		376	292	
4		329	74	
Upper Creek		556	229	
	Total	5045	980	6025
Removed by JCP+L		2248		
	Total	2797	980	3777*

*Remaining piles

from W. Crisman

Outages

Operation of the Oyster Creek Nuclear Generating Station ceased from Dec. 27, 1975, to March 11, 1976. Because this shutdown occurred over the winter, water temperatures in Oyster Creek, Forked River, and in the Liberty Harbor area reached the normal lows for Barnegat Bay. The plant resumed operation at about the time that the temperature in the bay at large was warming naturally. Therefore the plant effluent did not contribute to an early development of the gonads in marine organisms in the Spring of 1976. Gonadal development and spawning in many marine invertebrates occur when the temperature reaches about 10°C, although these processes also are linked to food supply and indirectly to light intensity and duration, since phytoplankton are dependent upon light.

We anticipated that the winter temperatures would eliminate the semitropical species of shipworms (*T. bartschi* and *T. furcifera*) which had been noted in the Oyster Creek area. *T. bartschi* has not been recorded during 1976, but *T. furcifera* is still present and in fact is more common than the native *T. navalis* in the Oyster Creek area. Therefore, we cannot expect that natural winter temperatures will eliminate all semitropical species which invade Oyster Creek.

Dilution Pumps

Lower maximum temperatures, high salinities, and high silt burden in Oyster Creek in 1975-1976 are explained by increased dilution pumping by the power plant. Table 8 supplied by J.C.P. & L. shows that the average number of pumps operating has increased since the latter part of 1974. It is tempting to correlate a decline in shipworm attack in 1975 and 1976 with this change, but the power plant outages in the winters of 1974-75 and 1975-76, along with removal of marina wood, make it impossible for us to ascribe

Table 8

Average Number of Dilution Pumps Operating at the Oyster Creek Nuclear Generating Station*

Months	P72	P73	P74	P75	P76
1	.07	0	1.1	2	1.9
2	.93	.14	1	1.86	1.86
3	1	0	.94	1.81	1.6
4	1	.4	.57	1.8	1.76
5	.1	.97	.71	1	1.1
6	.27	1	1.4	1.8	1.66
7	1	1	1.39	2	1.8
8	.84	1	1.9	1.9	
9	1	.97	1.33	1.1	
10	1	.87	1.52	1.55	
11	.33	.87	1.6	1.9	
12	0	.97	2	1.71	

*from J.C.P. & L.

a single cause.

Increased dilution pumping has the beneficial result of reduced maximum summer temperature, but it increases the recirculation of water through the plant, increases erosion in Forked River and hence siltation in Oyster Creek (Wicker report to W. Crisman), and could contribute to increases in the number of shipworm larvae brought into Forked River, although it is difficult to test this last hypothesis without knowing the origin of the shipworm larvae.

Chemicals and Detritus

The Nuclear Generating Station is responsible for materials such as chlorine, occasional low-level radioactive wastes, and possibly heavy metals occurring in Oyster Creek from time to time. We are unable to evaluate the biological effect because we do not know the extent or timing of such pollution. We have seen no teratologies in the organisms we have examined from Oyster Creek. We have found sudden decreases in biomass of fouling organisms in Oyster Creek, but these occurred at peak summer temperature, so we have thus far found it unnecessary to invoke chemical causes to explain the phenomenon.

The nuclear generating plant brings a heavy burden of detritus into Oyster Creek, a remnant of the biota which is destroyed in the process of circulating the water through the plant. There is also organic matter in the water which comes from Forked River housing developments (septic tanks), pulled into Oyster Creek by the plant's pumps. Brown organic foam is frequently evident. Its periodic appearance suggests that it coincides with some plant activity such as backwashing. The flow rate and turbulence of Oyster Creek are high enough and the creek is shallow enough that oxygen depletion is not a problem on our test racks, at least. The extent to which estuarine biota utilize detritus is controversial. We do not know which fouling or boring organisms might be able to take advantage of it, either directly or via intermediary organisms such as bacteria. There may be a synergistic effect of heated water and detritus: eg, organisms such as barnacles which grow faster in the heated effluent than elsewhere may be the ones able to utilize detritus whereas organisms unable to profit from it (possibly Mercenaria mercenaria) might be the ones which grow poorly or are eliminated.

SHIPWORMS

Our purpose is to discover the extent of shipworm infestation, the species responsible, and the population dynamics of those species, in the context of the physical parameters within and without the thermal effluent. The data become more quantitative with the August, 1976 samples.

One-Month Panels

The one-month panels show the settlement of shipworm larvae (tables 9 - 10). Settlement occurred between April, 1976, & October, 1976 (November panels were all negative). Settlement occurred first and lasted longest in the vicinity of Oyster Creek, as we have observed in other years, but it was at low levels. Forked River received more spat than Oyster Creek, contrary to our findings in previous years (R.D. Turner, unpublished reports). Most of the settlement (90%) occurred in July & August. Only Bayside beach Club and the mouth of Cedar Creek received heavy settlement. The Cedar Creek settlement was surprising and is as yet unexplained. Control estuarine sites (#3 & 7) recorded no shipworm infestation.

Size of the newly settled larvae after 1 month maximum residence time can be evaluated using the 1 month test panels. In addition to total length (L), we measured the width (W) of the boring shell of each shipworm dissected from the wood. For T. furcifera, the linear relationship between width and length was $L = -34.1 + 19.4 W$, $r^2 = .67$. Standard error of the estimate of L on W was 18.31. While W and L are positively correlated, use of W to predict L is not reliable. A better correlation between L & W is achieved using a nonlinear (exponential) model, but the standard error of the estimate is still large. In this case, $L = 1.78 W^{2.07}$; $r^2 = .77$. For

Table 9: Monthly Shipworm Settlement
(Panels Exposed One Month)

	Collection Date			
Station	Apr. 4	Apr. 30	May 30	July 5
1	0	0	0	0
2	-#	-	0	40
3	0	0	0	0
4	-	-	0	0
5	-	-	0	8
6	0	0	0	7
7	0	0	0	0
8	0	2*	0	2
10	0	**	1	0
11	0	0	0	0
12	0	0	0	0
14	0	5	0	0
15	-	-	0	0
16	0	0	0	0
17	-	-	0	0
Totals	0	7+	1	57

-#station not established

*_T. furcifera_

**newly set larvae, not counted

Table 10: Monthly Shipworm Settlement, Continued
(Panels Exposed One Month)

	Aug. 8				Sept. 10				Oct. 8				Total 1976 Settlement
Station	B.g.	T.f.	T.n.	Total	B.g.	T.f.	T.n.	Total	B.g.	T.f.	T.n.	Total	All Species
1	6	0	2	8	0	0	0	0	0	0	0	0	8
2	28	0	0	28	2	0	0	2	0	0	0	0	70
3	0	0	0	0	0	0	0	0	0	0	0	0	0
4	4	3	0	7	0	0	0	0	0	0	0	0	7
5	2	3	0	5	0	1	0	1	0	0	0	0	14
6	2	0	0	2	0	0	0	0	0	0	0	0	9
7	0	0	0	0	0	0	0	0	0	0	0	0	0
8	11	22	0	37*	3	0	0	3	0	1	0	1	45
10	2	1	0	3	0	0	0	0	0	0	0	0	4(+)
11	3	0	0	3	0	0	0	0	0	0	0	0	3
12	2	0	0	2	0	0	0	0	0	0	0	0	2
14	4	0	0	4	0	0	2	2	0	0	0	0	11
15	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0
17	2	3	0	6*	0	0	0	0	0	0	0	0	6
Totals	66	32	2	105*	5	1	2	8	0	1	0	1	179(+)

*total exceeds sum of species columns because some individuals could not be identified.

B.g. = Bankia gouldi; T.f. = Teredo furcifera; T.n. = Teredo navalis.

B. gouldi, $L = .80\ w^{2.6}$; $r^2 = .85$, but the error of estimate is again high. Therefore it is not possible to accurately estimate L using W.

Length data are in Tables 11 & 12. Numbers in parenthesis give the sample size, which may be less than the number of shipworms from a given locality, due to damaged specimens. Variances are not meaningful with such small samples, and we have opted for using means and ranges rather than presenting all the raw data. Individual measurements are available from the authors. When N>10, we plotted histograms of the size data, and found that the data are unimodal and normally distributed, hence the mean is a useful estimate. The maximum size attained is also biologically significant & can be compared among stations. The specimens in the 1 month panels, unlike those in the cumulative series, are uncrowded and hence their mean & maximum growth rates are more likely to indicate environmental conditions. Of course, we do not know exactly when within the month the shipworms settled. We could make the artificial but simplifying assumption that they all settled midway into the 1-month period. Using this assumption, it appears with the limited data that T. furcifera in the region of the thermal plume (especially station 8) grew faster than those settling elsewhere.

Or, it might be that these shipworms settled earlier, on the average, in the 1-month period. This could happen if bacterial film, which may be necessary for settlement to occur, grew faster on panels in the indicated area. In either case, the result is larger T. furcifera at stations 8 & 10. T. navalis and T. furcifera are similar in adult size and growth rate, while B. gouldi attains a larger size and grows faster. Greatest growth of B. gouldi occurred at stations 11-14, within the thermal plume, although stations 8 and 10 within the plume do not show accelerated growth.

Table 11: Mean Length in mm of Shipworms One Month or Less in Adult Age

	Aug. 8			Sept. 10			Oct. 8
Station	T.n.	T.f.	B.g.	T.n.	T.f.	B.g.	T.f.
1	6.0(2)		7.7(6)				
2			10.0(25)			5.0(2)	
3							
4		7.0(3)	9.8(4)				
5		4.0(3)	10.0(2)		3.0(1)		
6			12.5(2)				
7							
8		13.1(22)	12.6(11)			12.3(3)	2.0(1)
10		10.0(1)	11.5(2)				
11			21.5(2)				
12			46.0(2)				
14			54.3(4)	6.0(2)			
15							
16							
17		3.3(3)	6.5(2)				

Table 12: Ranges of Lengths of Shipworms
One Month or Less in Adult Age (to nearest mm)

	Aug. 8			Sept. 10		
Station	T.n.	T.f.	B.g.	T.n.	T.f.	B.g.
1	5-7		3-11			
2			3-18			3-7
3						
4		4-10	6-14			
5		3-5	9-11		3	
6			10-15			
7						
8		7-22	5-22			4-20
10		10	6-17			
11			16-22			
12			18-74			
14			44-71	4-8		
15						
16						
17		2-5	4-9			

Cumulative Panels, Apr. 30, 1976 Series

Results from the cumulative series of panels begun on Apr. 30, 1976, are presented in table 13. The number of living shipworms is not correlated with the degree of shipworm damage for two reasons: deaths of some shipworms have occurred, and crowding causes size and numbers of shipworms to be inversely correlated. Comparing the numbers within stations over the several months, there are no dramatic trends; in fact, variation from month to month is of the order of magnitude expected if one were to sample different boards at the same locality at the same time. The exception is between the October & November samples. Here, in 11 of 15 cases, the population size declined. This indicates a general trend of mortality. We conclude that the total number of shipworms at all stations combined reaches a steady-state lasting between May and August, with a decline in late October or early November.

Areas with the largest cumulative populations are the mouth of Forked River and its southern branch (#4,5,6,8), and the 2 northern bay controls (#1,2). Cumulative population sizes in Oyster Creek are far reduced from two years ago, before ameliorative actions were taken and before the plant shut down during the winters of 1975 and 1976. Forked River populations, however, remain of concern.

Limnoria tripunctata an isopod which makes shallow tunnels in wood, is abundant at Manahawkin (#17) and Iggie's Marina (#16), and is present in smaller numbers at Liberty Harbor (#15). It has been found occasionally on the wood surface at Kochman's(#10), the mouth of Oyster Creek, but has not damaged the test panels and does not seem to be permanently established. For unknown reasons, *Limnoria* has not invaded the northern half of Barnegat Bay. It is interesting that the southern test region (#15-17) has very light ship-

Table 13: Numbers of Living Shipworms in Cumulative Panels, April 30, 1976 Series

Date collected:	May 30	July 5	Aug. 8				Sept. 10			
Duration:	1 Mo.	2 Mo.	3 Mo.				4 Mo.			
Station			B.g.	T.f.	T.n.	Total	B.g.	T.f.	T.n.	Total
1	0	9	21	0	0	21	29	2	0	31
2	0	27	92	0	4	102*	81	0	0	81
3	0	0	0	0	0	0	0	0	0	0
4	0	11	51	1	0	53	21	1	0	22
5	0	10	21	2	0	25	25	1	0	26
6	0	6	17	1	0	18	28	0	0	28
7	0	0	0	0	0	0	0	0	0	0
8	0	14	42	0	1	43	48	4	0	52
10	1	1	1	13	0	14	1	0	0	1
11	0	8	1	0	0	1	2	0	0	2
12	0	0	3	0	0	3	0	0	0	0
14	0	0	4	0	1	5	6	3	0	9
15	0	0	0	0	0	0	3	0	0	3
16	0	2	1	0	0	1	0	0	0	0
17	0	0	0	3	0	3	0	0	0	0
	1	88	254	20	6	289*	244	11	0	255

*Some specimens could not be identified to species.

Table 13, continued

	Oct. 8 5 Mo.				Nov. 5 6 Mo.			
Station	B.g.	T.f.	T.n.	Total	B.g.	T.f.	T.n.	Total
1	32	0	0	32	21	0	0	21
2	67	2	0	69	48	0	0	48
3	0	0	0	0	1	0	0	1
4	34	6	0	40	32	6	0	38
5	33	3	0	36	29	2	0	31
6	23	0	0	23	15	1	0	16
7	1	0	0	1	0	0	0	0
8	49	2	0	51	24	0	0	24
10	6	0	0	6	6	0	0	6
11	1	0	0	1	5	0	0	5
12	2	0	0	2	1	0	0	1
14	6	4	0	10	3	6	0	9
15	4	0	0	4	6	0	0	6
16	1	0	0	1	2	0	1	3
17	0	0	0	0	0	0	0	0
	259	17	0	276	193	15	1	209

worm attack, but is infested by the wood-boring isopod Limnoria. We have no test area where the 2 types of borer are found sympatrically in large numbers. Our control estuarine sites (#3 & 7) remain nearly free of shipworms.

Maximum sizes of shipworms of maximum age 3 through 6 months are in table 14. Again the data illustrate B. gouldi's greater growth rate. T. furcifera's growth shows no trend between stations, bay vs. upstream or thermal plume vs. control. The stations with the largest and 2nd largest specimens of B. gouldi for each month are stations 4, 5, 8, 10, and 11, all in or near the thermal plume. However, the individuals' sizes are inversely related to crowding. For example, the large specimen at station 11 was living alone. Figure 2 shows this general relationship between population density and size of individuals. The population size (x) and mean shipworm size (y) are plotted for the 6 most populous stations out of each of the October and November cumulative panel series. Numbers are station numbers. One point falls off the line; in this case, many shipworms had already died, hence the panel was more crowded than is indicated by the number of live shipworms. Even though we expect that the thermal plume is causing some increased growth of shipworms, the strong relationship between number of spat (therefore population density) and grow rates of individuals masks the thermal effect. Only by comparing 2 stations with similar density can we unmask the thermal effect. At present, we have insufficient data to make this comparison using the cumulative panels. As previously discussed, the monthly panels do not suffer this problem.

Mean lengths of shipworms from the cumulative panels are meaningless, not only because of the crowding problem, but because the size distributions are bimodal (figs. 3-6). This indicates 2 and maybe 3 concentrated periods

Table 14: Length Ranges of Living Shipworms (in mm), Cumulative Panels, April 30, 1976 Series

Date Collected:	Aug. 8			Sept. 10		Oct. 8		Nov. 5		
Duration:	3 months			4 months		5 months		6 months		
Station	B.g.	T.f	T.n.	B.g.	T.f.	B.g.	T.f.	B.g.	T.f.	T.n.
1	5-59			42-196				31-212		
2	5-93		8-12	15-93	31-74	36-172	40-53	24-156		
3						12-116		140		
4	7-*99*	15		57-*200*	30	31-219	21-80	33-166	33-90	
5	6-65	12		44-139	92	30-*239*	28-53	27-198	42-58	
6	5-65	8		36-139		27-183		72-232		
7						176				
8	5-*116*		2	6-126	13-41	14-141	27-40	36-159		
10	3	4-11		99		120-196		97-*257*		
11	42			187-*198*		*292*		82-*244*		
12	13-81					30-223		231		
14	13-43		15	84-140	6-75	79-214	31-104	18-168	51-173	
15				54-89		154		89-176		
16						167		119-158		16
17		10-14								

Italics: 2 largest specimens of B. gouldi found in each month.

FIGURE 2: SHIPWORM DENSITY VS. SIZE
OF INDIVIDUALS

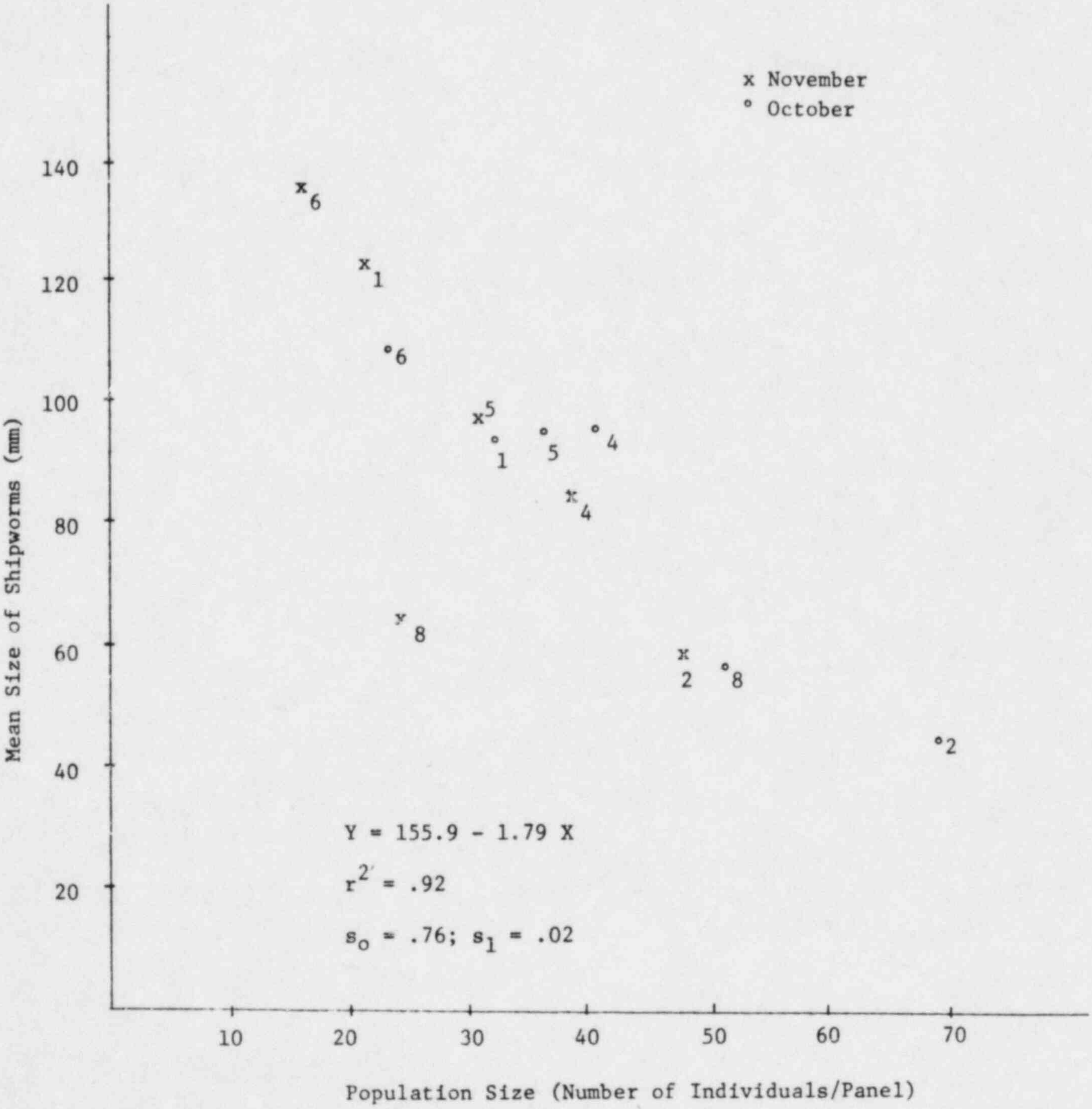


Figure 3: Size Distributions of Shipworms, Apr. 30, 1976 Series

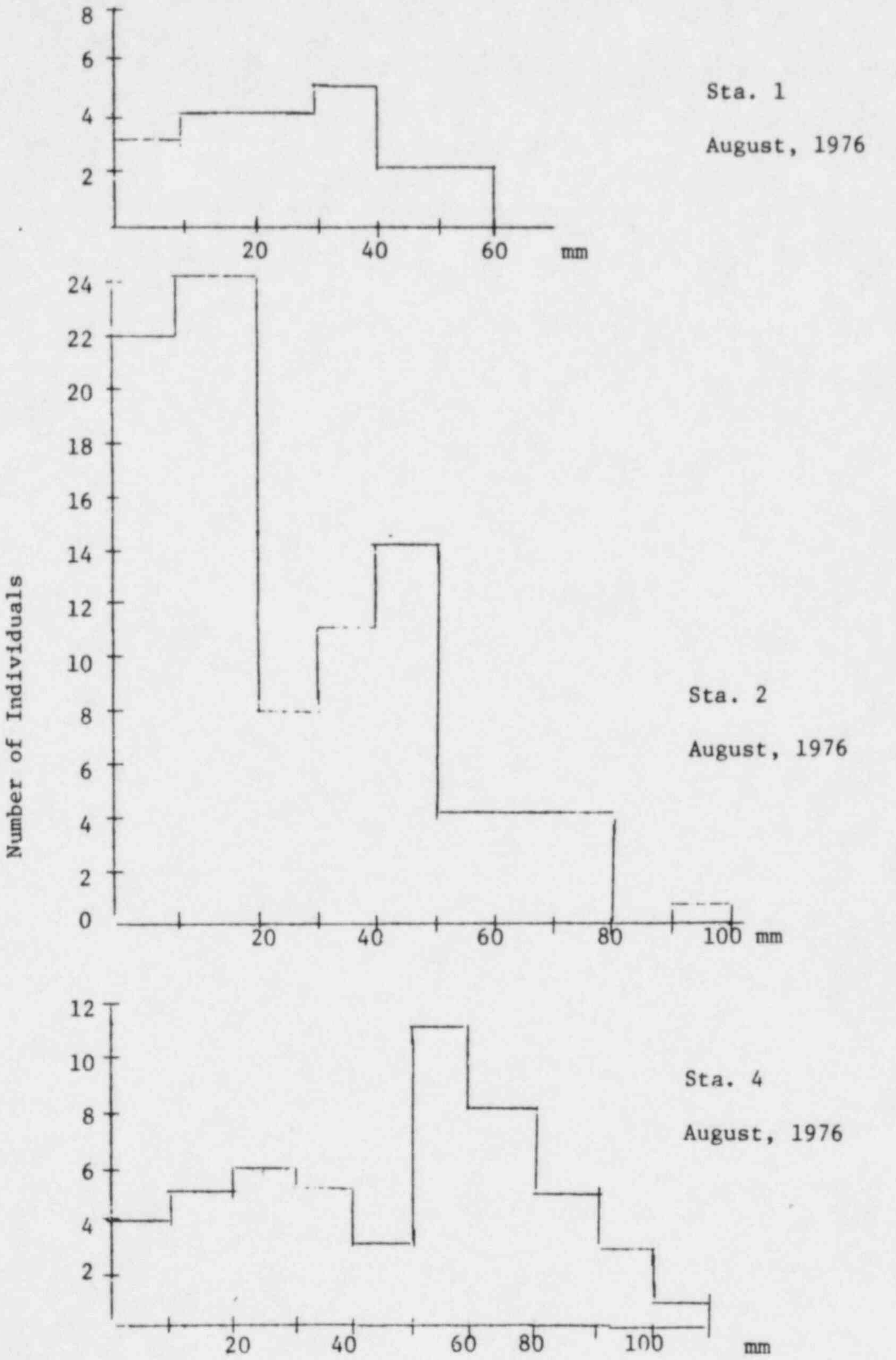


Figure 3: Size Distributions of Shipworms, Apr. 30, 1976 Series

Continued

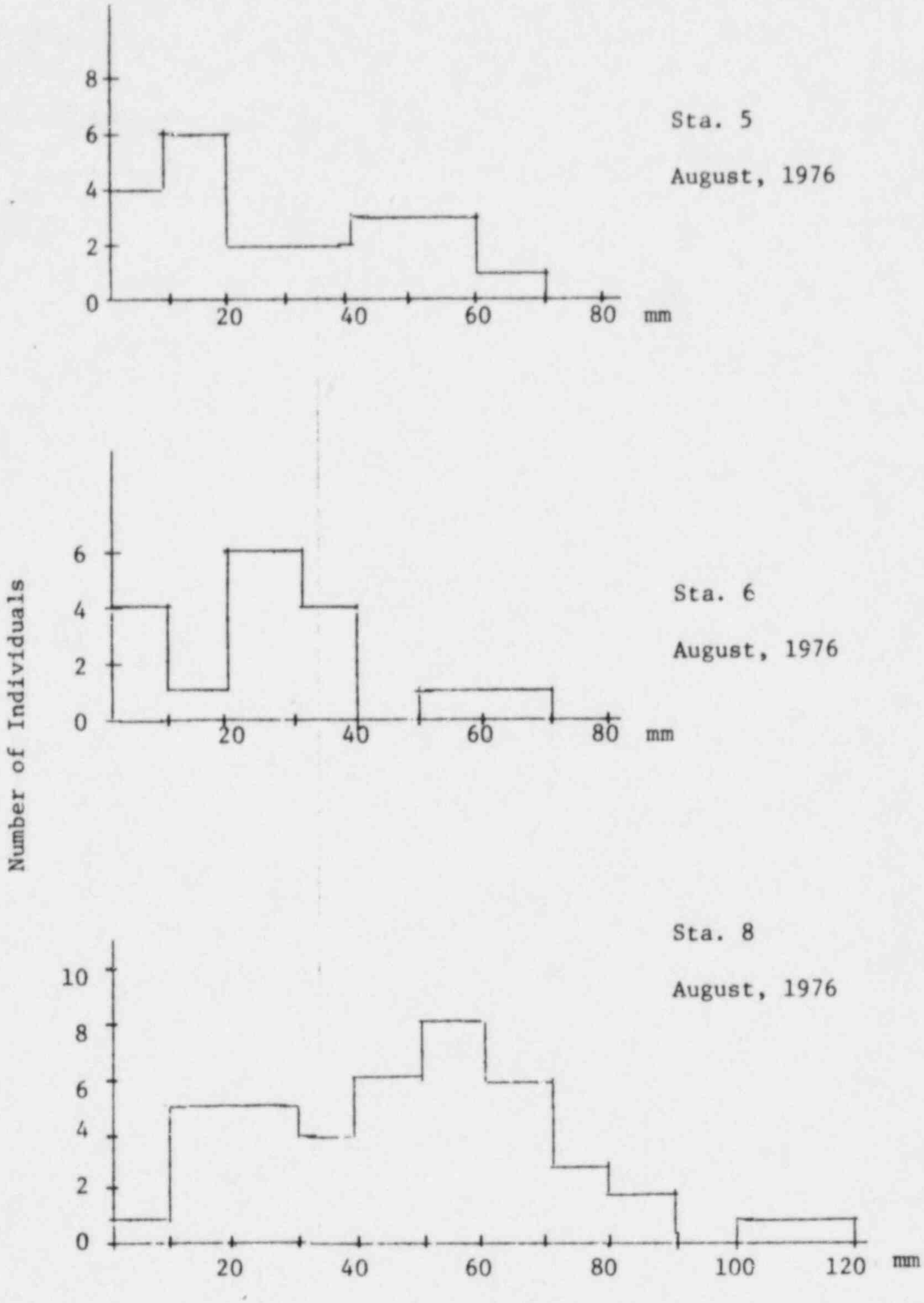


Figure 4: Size Distributions of Shipworms, Apr. 30, 1976 Series

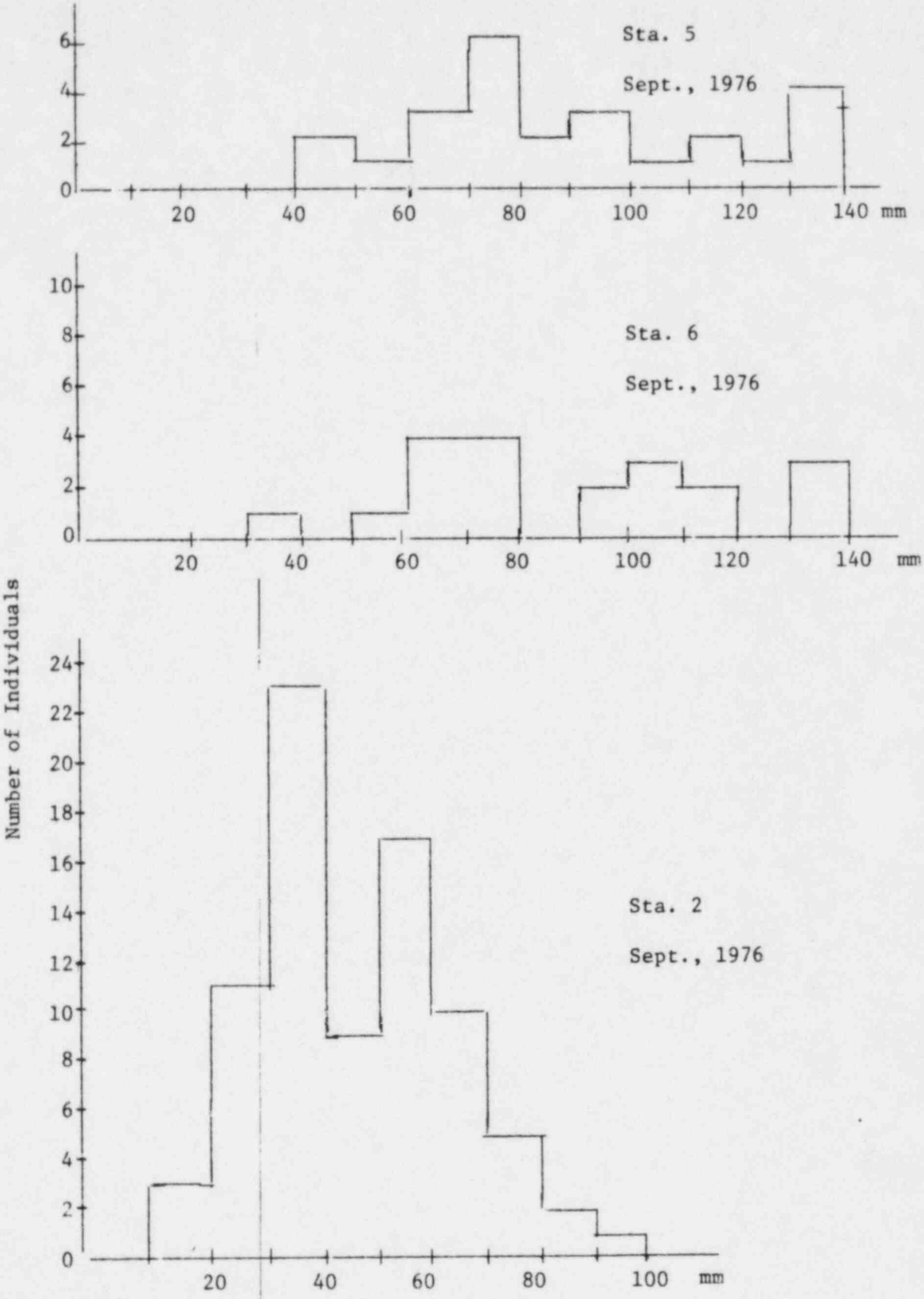


Figure 4: Size Distributions of Shipworms, Apr. 30, 1976 Series
Continued

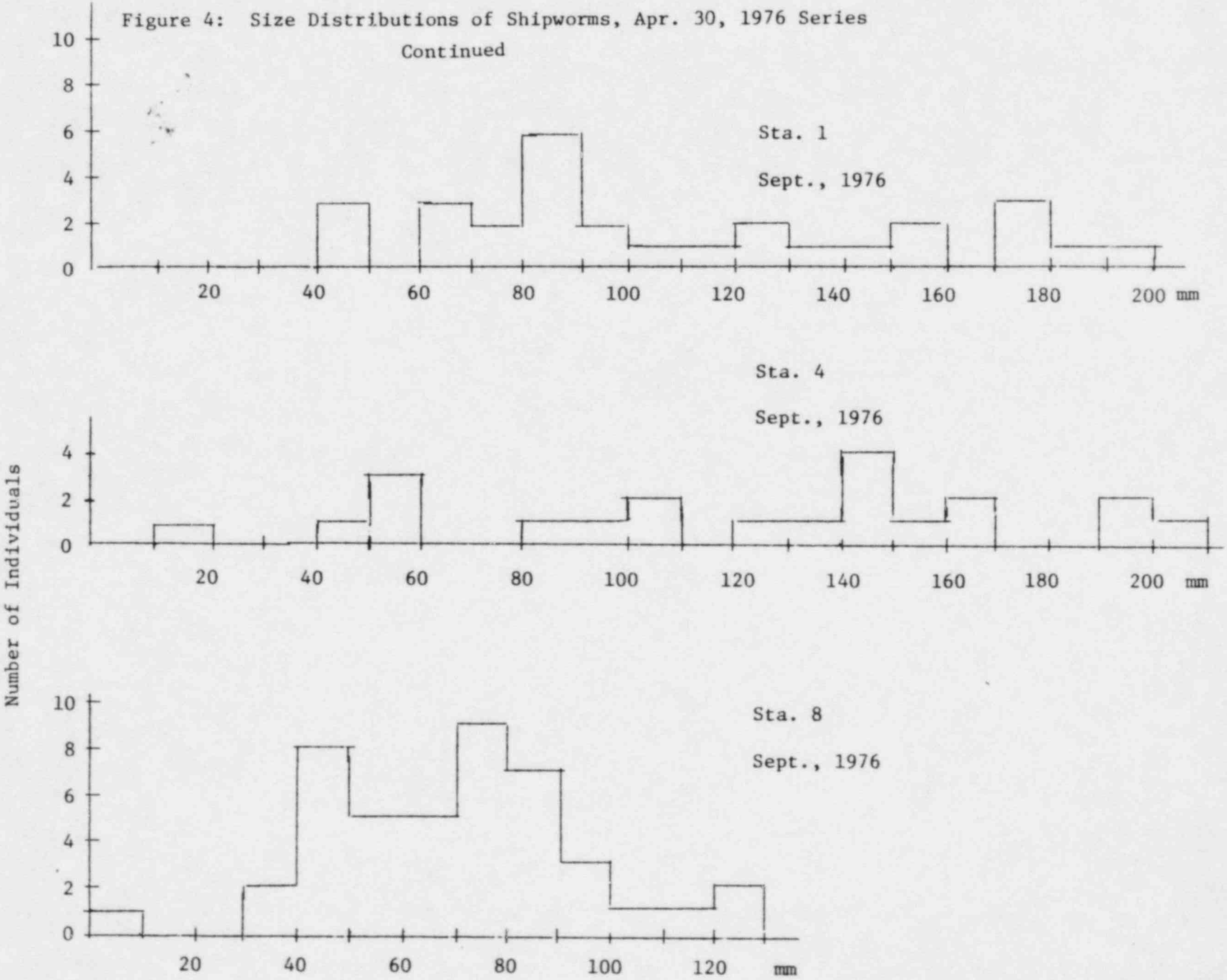


Figure 5: Size Distributions of Shipworms, Apr. 30, 1976 Series

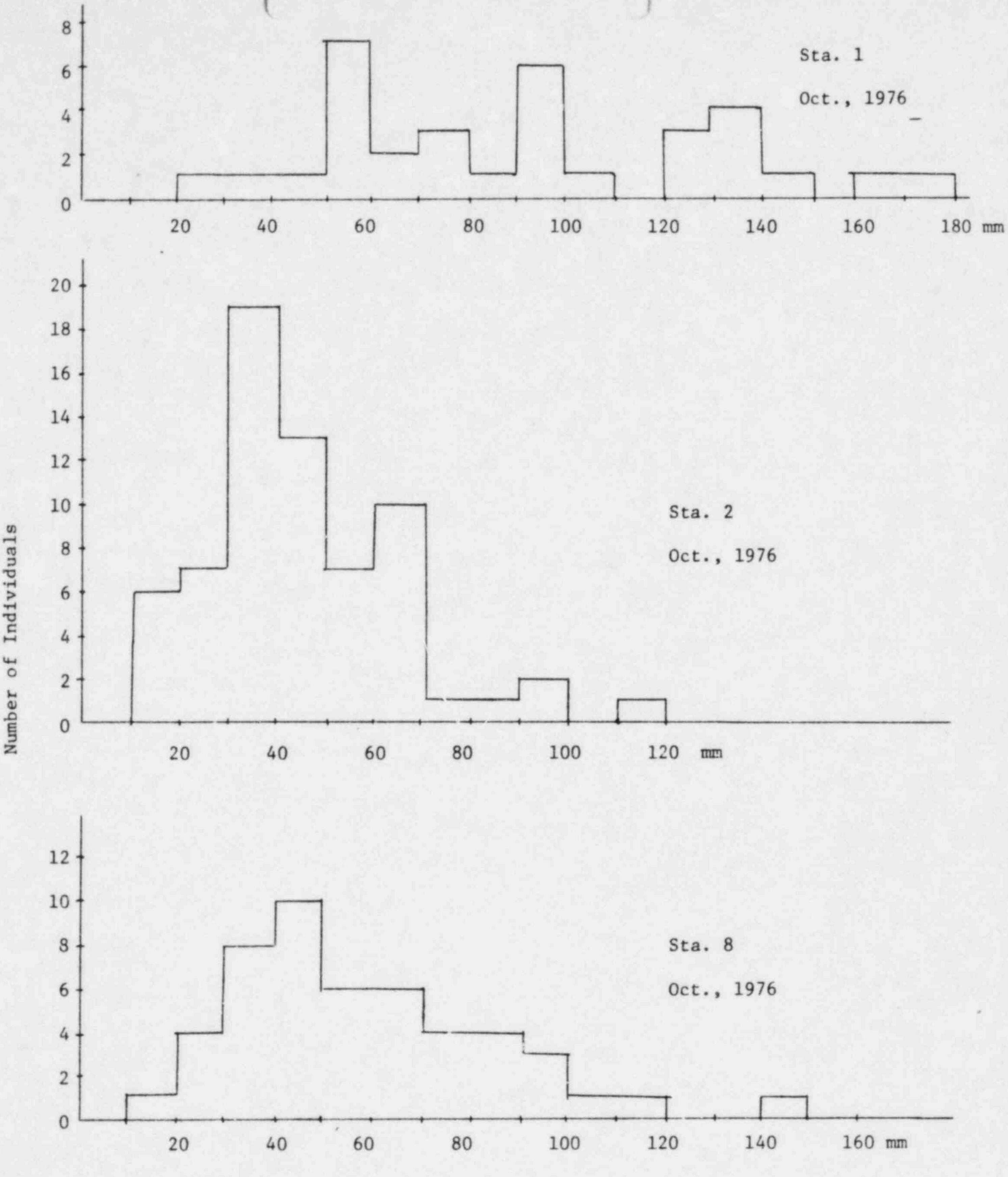


Figure 5: Size Distributions of Shipworms, Apr. 30, 1976 Series Continued

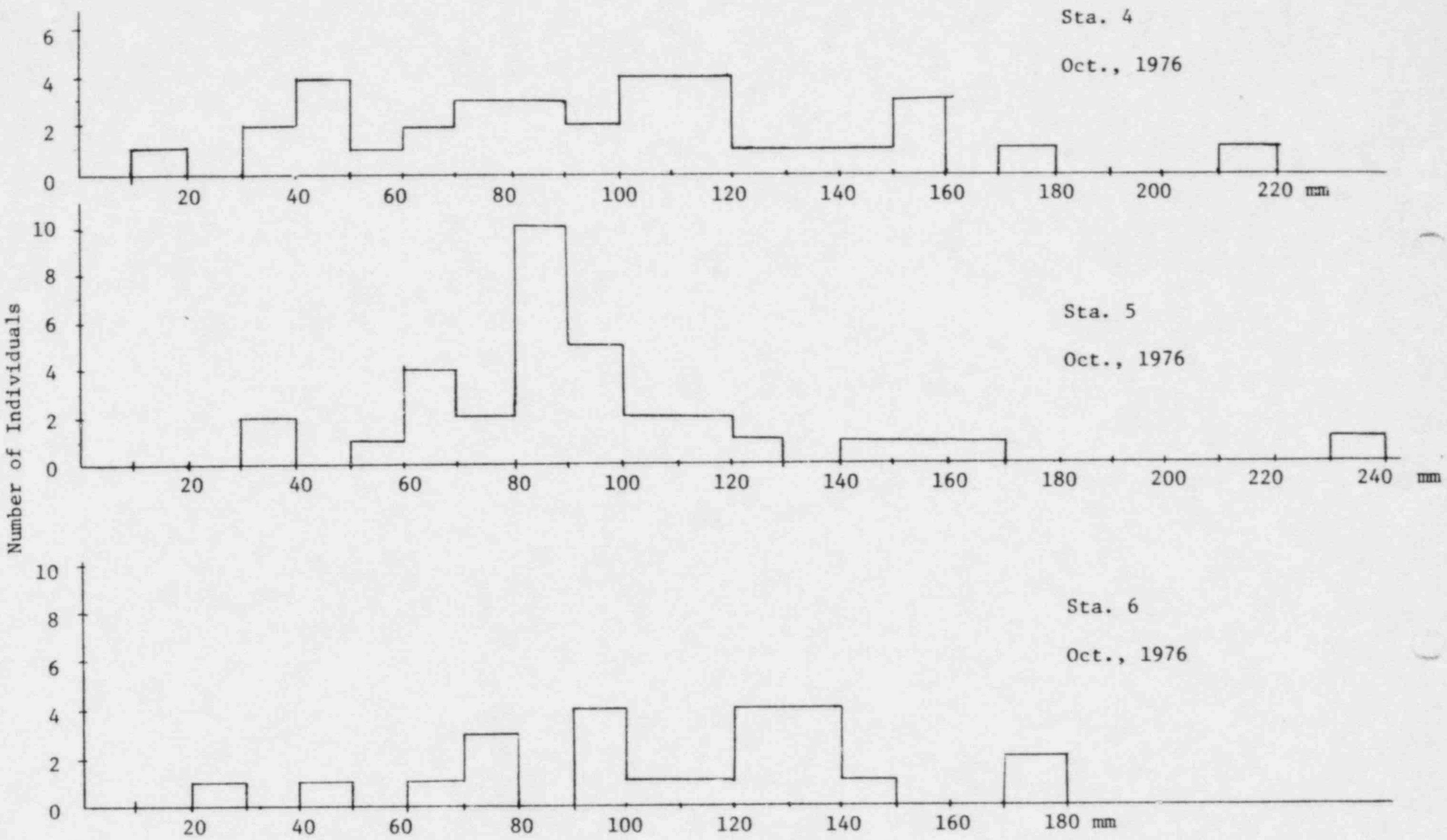


Figure 6: Size Distributions of Shipworms, Apr. 30, 1976 Series

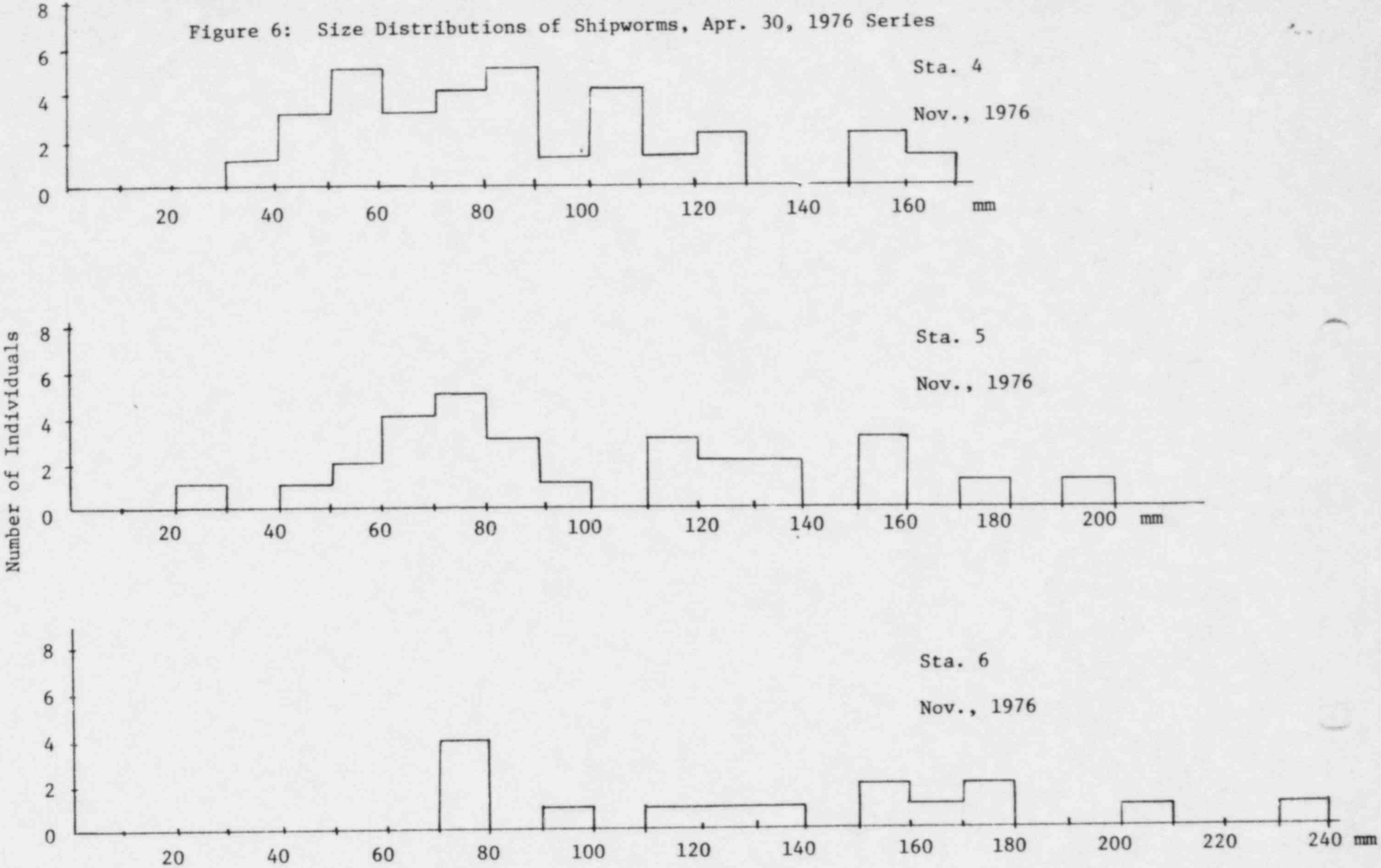
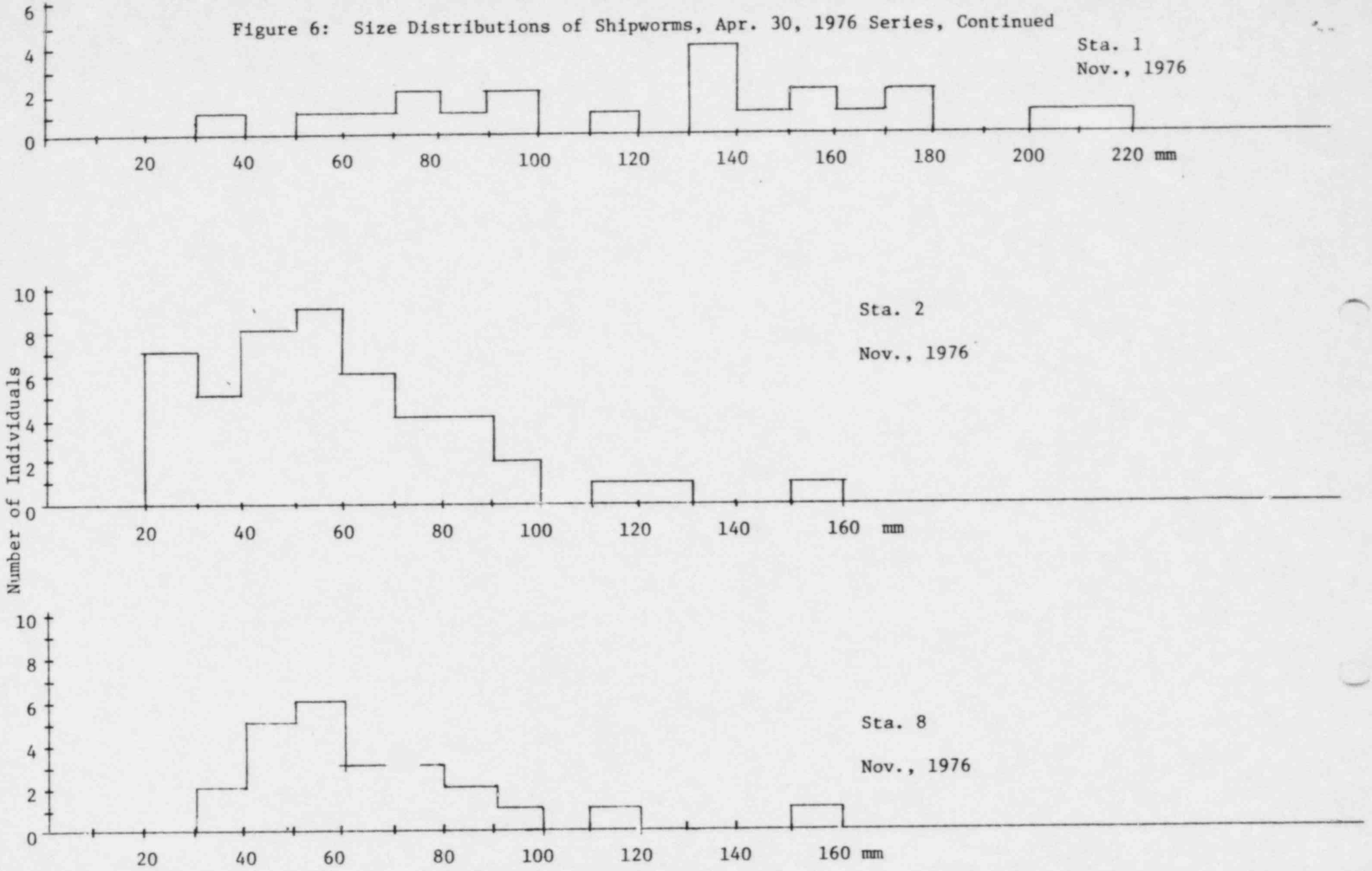


Figure 6: Size Distributions of Shipworms, Apr. 30, 1976 Series, Continued



of spat settlement. Also, the distributions are skewed towards the smaller size classes, because the older spat cohorts have undergone mortality, and perhaps because the later cohorts of spat were larger.

In August (fig. 3), 2 spatfalls are evident at most stations. The more spat, the more clear the bimodality. The tail on station 8 indicates an early settlement, probably mediated by the thermal effluent. Panels from Stations 4 & 8 show larger modal sizes than stations 1, 5, & 6 despite being more dense. Therefore something other than crowding is affecting growth &/or settlement times. Stations 4 & 8 are affected slightly by the thermal effluent, but their being at the mouth of Forked River with strong currents may also be relevant.

In September (fig. 4), there is much greater variation in size in the sparce than in dense populations. Dense populations still have 2 modes. This tells more about variation in population structure in populations with small vs. large founding cohorts, than it does about thermal effects. The shift in the modes between August & September at Station 5 illustrates the growth rate which is possible without excessive crowding.

As time goes on (figs. 5-6), the variation in growth among individuals obliterates the size differences between cohorts, and the populations tend toward unimodality. Rate of growth as represented by shifts in the histograms declines in October & November.

Comparison of the May-July period in tables 9 & 13 show that the 2-month panels picked up more shipworm larvae during June than did one-month panels. It appears that shipworm larvae settle preferentially on the older wood. The reason could be chemical or tactile attraction of spat to shipworms or other organisms (e.g., bacterial film) already present on the older wood. The meaning for our experiments is that our monthly panels underestimate the settlement of shipworm larvae. However, this underestimation occurs equally at all stations.

Looking at species composition, we see from tables 9, 10 & 13 that T. furcifera are still present in Barnegat Bay, having survived the winter. They exist at Oyster Creek and Forked River, Manahawkin out of reach of the thermal plume, and have been tentatively identified at Holly Park (#1) and Cedar Creek (#2) as well. When not containing brooded larvae, T. furcifera can approach T. navalis in the morphological characters used for identification, hence our caution in naming the Holly Park and Cedar Creek specimens. The Manahawkin specimens were unambiguous. Boats formerly kept in Oyster Creek could be responsible for the spread of T. furcifera. We are closely monitoring T. furcifera to see if it can establish breeding populations in regions outside the thermal plume, or if its presence there is due to yearly colonization.

T. navalis, the more oceanic of the 2 native species, was rare in our samples. It is restricted to stations on Barnegat Bay proper. The ratio of the 3 species was, on monthly panels, 22 B. gouldi: 11 T. furcifera: 1 T. navalis. On the cumulative panels, it was, 136 B. gouldi: 9 T. furcifera: 1 T. navalis. This suggests that B. gouldi not only settles in higher numbers, it survives better, as well. Timing of settlement of the 3 species were essentially the same.

Cumulative Panels, Sept. 27, 1975 Series.

Table 15 presents data from a cumulative series of panels begun on Sept. 27, 1975. Some of these panels (Apr. 30, 1976) were kept in laboratory tanks to allow shipworms to reach identifiable size, and are now frozen and awaiting x-ray analysis. Others were riddled and lost. Therefore, the data are incomplete. Because the Nuclear Generating Station was not operating

Table 15: Number of Living Shipworms in Cumulative and One-Month Panels, September 27, 1975, Series

Date Removed:	Oct. 31, '75	Dec. 8, '75	Jan. 25	Feb. 29	Apr. 4	Apr. 30
Mo. Submerged	1 mo	2 mo.	4 mo.	5 mo.	6 mo.	7 mo.
Station						
1	0	0	0	0	0	0
3	0	0	0	0	0	0
6	0	0	0	0	0	missing#
7	0	0	0	0	0	missing#
8	0	0	1*	2*	2	28
10	0	0	11	16	17	missing#
11	0	7	1	2	26	missing#
12	0	4	0	4	0	missing#
14	0	0	0	0	0	1
15	0	0	lost	0	0	0
Total	0	11	13	24	45	29
Mo. Submerged	1 mo.	1 mo.	1 mo.	1 mo.	1 mo.	1 mo.
Station						
1	0	0	0	0	0	0
3	0	0	0	0	0	0
6	0	0	0	0	0	0
7	0	0	0	0	0	0
8	0	0	0	0	0	0
10	0	0	0	2*	0	0
11	0	0	0	0	0	0
12	0	0	0	0	0	0
14	0	0	0	0	0	5
15	0	0	lost	0	0	0
Total	0	0	0	2	0	5

Mo. = months

*boreholes; no animal seen in x-ray

#contained shipworms; panels kept in tanks so that larvae could reach identifiable size.

Table 15 continued

Date Removed:	May 30	July 5	Aug. 8
Mo. Submerged:	8 mo.	9 mo.	10 mo.
Station			
1	20	8	47
3	0	50 spat	0
6	10	10+ spat	8
7	8	12	1
8	7	22	70
10	21	30	missing
11	10	missing	16
12	1	missing	1
14	0	53	28
15	missing	missing	missing
	77	185+	171

Note: these stations and dates overlap the April 30 series; 1 month panels are reported under that series rather than here.

over the winter, this test series gave results similar to the Apr. 30, 1976, series. The plant was off between Dec. 27 and March 11.

Shipworms settled later into the Fall at Oyster Creek and Forked River Beach than elsewhere. Shipworms settled preferentially on wood which had been in the water for longer periods. We see this when we compare tables 13 & 15, especially at Station 3, July 5, 1976. By April 4, a new set of larvae was found in Oyster Creek (Site 11). By Apr. 30, this set extended to Forked River and Waretown. Its restricted location implicates the thermal effluent in bringing an early set. By May 30, 1976, Holly Park was infected. In June, the control site Stout's Creek received a heavy set of larvae. However, these did not survive. Likewise, sets of larvae at sites 6 (south branch) and 7 (middle branch) in Forked River had poor survival. It is not just availability of larvae, but also conditions at the site which determine the degree of shipworm infestation. Sites 1 and 8 were most amenable to shipworm survival, while the largest shipworms were at sites 10 and 11 in July and August, respectively. An early set of larvae is not directly related to intensity of the infestation, but it is related to growth potential of individual shipworms and the timing of their reproduction.

The similarities between the September series and the April series can best be seen by comparing the data for July-August, 1976 (tables 13 & 15). In each series, the between-station distribution of shipworms is similar.

X-ray Evaluations of Total Shipworm Damage.

X-rays allow us not only to count the shipworms, but to see the extent of damage they have caused. Table 16 ranks the cumulative panels from the Sept. 27, 1975, series retrieved in July and in August, according to increasing amount of wood destroyed (qualitative estimation). Table 17 ranks the cumulative panels from the April 30, 1976, series, and Appendix A

Table 16: Ranking of Shipworm Panels
According to Amount of Wood Destroyed. Sept. 27, 1975 Series

Date of Removal Rank	July 5, 1976 Station #	Aug. 8, 1976 Station #
1 (least damage)	1	3
2	7	7
3	3	12
4	6	6
5	8	1
6	14	14
7	10	11
8 (most damage)		8

Table 17: Ranking of Shipworm Panels According to the Amount of Wood Destroyed, Series Begun Apr. 30, 1976

Station Number:

Date of Removal	Aug.	Sept.	Oct.	Nov.
Rank				
1	15 }	3 }	3 } 0	7 } 0
2	16 }	7 }	17 }	17 }
3	7 } 0	12 } 0	7	3
4	3 }	16 }	16	12
5	11	17 }	11	16
6	17	10	15 }	15 }
7	10	15	12 }	14 }
8	14 }	11	14	11 }
9	12 }	14	10	10 }
10	6 }	5 }	6	1
11	5 }	4 }	5 }	6
12	1	1	1 }	5
13	4	6	4	4
14	8 }	8 }	8 }	8 }
15	2 }	2 }	2 }	2 }

(most damage)

Note: brackets indicated ties.

0 = no damage due to shipworms

reproduces the x-rays of some of the panels upon which the rankings were based. All original x-rays are available from the authors.

The growth differential between crowded and isolated shipworms is obvious (Appendix A). We predict that a graph of the damage done vs. the number of shipworms present will look like Fig. 7. The inflection point represents the point where the shipworms begin to interfere with one another, and may be earlier than shown in the figure. We are presently collecting data to test the shape of this curve. If correct, it proves that we cannot estimate damage by counting shipworm boreholes.

Shipworm damage is presently greatest at the Mouth of Forked River (#4,8), the Mouth of Cedar Creek (#2), and the South Branch of Forked River (#5), in that order. Holly Park (#1), which has had a moderately heavy attack for years, remains at that level.

Mortality of Shipworms

X-ray impressions of white rather than grey shipworm tubes represent dead animals (eg, Appendix A, figs. 1-2). The number of dead shipworms increases with crowding, but also with age. Few shipworm spat settle on wood already riddled with shipworms, so we see, by November, many panels containing mostly empty tubes (table 18). The structure of a shipworm population is: highest numbers at the time of larval settlement (early summer), followed by a period of stable numbers (mid summer), and finally a decline (Fall), as deaths outnumber recruitment. A renewable supply of substrate (wood) is necessary to maintain a shipworm population from generation to generation.

Our experiments using 4 x 4 x 12" pieces of untreated wood alongside the thinner & smaller test panels has thus far given similar results. Regardless of the size of the substrate, shipworms move in to occupy the

Figure 7: The Relationship between Density of Shipworms and Damage Done to a Test Panel

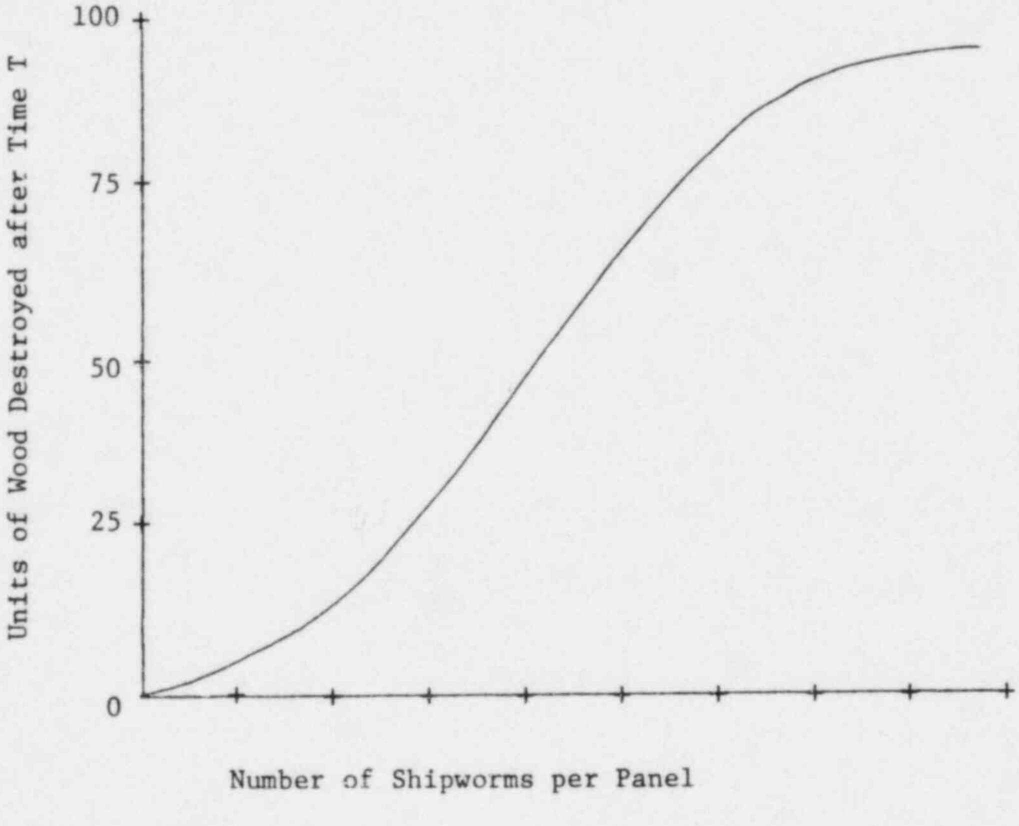


Table 18: List of Panels
Containing Dead Shipworms or Empty Tubes
Panels Submerged Apr. 30, 1976

Removed	Station	Amount of Decay
Sept. 10, 1976	8	4 empty tubes
Oct. 8, 1976	2	20 empty tubes
	4	small amount of decay
	8	much decay
Nov. 5, 1976	1	some decay
	2	much decay
	4	some decay
	5	some decay
	6	some decay
	8	much decay
	15	1 empty tube

entire space within the first year. There is very little interaction between year classes of shipworms. Mortality is high and larval sets are small after the first summer. Hence shipworms are substrate-limited even though they reduce their growth rate when crowded. At heavily infested sites, there are more shipworm larvae than can survive in the available wood. Removal of wood from Oyster Creek was therefore a biologically sound way of reducing the shipworm problem. Had shipworms been shown <u>not</u> to be substrate-limited, wood removal would not have been effective in reducing the number of adult shipworms.

Besides senility and indirect effects of crowding, deaths of shipworms may be due to external causes. Theoretically, heavy encrustment by fouling organisms could harm shipworms, but we have seen no evidence of this. Shipworm mortalities are not greater at stations with heavy encrusting fouling. In Oyster Creek, we have frequently noted deaths of mid-sized shipworms when panels were uncrowded (Appendix A, Fig. 1). This is unusual at our other sites. The cause could be predation, a chemical, temperature shock, or excessive siltation...we cannot give a cause at this time. We have found high mortality in barnacles in Oyster Creek as well. No obvious build-up of predators has been found, although flatworms could go undetected.

The shipworms extracted from the test panels in Oyster Creek and Forked River in the summer of 1976 appeared watery and flaccid, as did clams taken from Barnegat Bay near Waretown in November, 1976. This could be the result of a pathogen, or it could be due to high metabolism without enough food to maintain the body in good condition. Shipworms at the control sites #1 & 2 appeared less flaccid, but more sophisticated analyses are necessary to avoid subjective interpretations. We need to know what chemicals are in Oyster Creek, and organic pollution levels, as well.

FOULING ORGANISMS

Introduction

Prior to August, 1976, fouling data were recorded qualitatively. Since then, we have estimated the surface area occupied by each species found attached to each panel, and we are counting and measuring those organisms not attached but functionally associated with the attached fouling community (eg, Nudibranch mollusks and polychaete worms which eat Bryozoa). Detailed analysis must await species identifications, which are in progress. We are also retrieving presence-absence data on fouling organisms from 1971-1975 to compare with current information.

Early Results

The amount of fouling material deposited over any time interval varies from station to station. This is partly due to the kinds of organisms found at each station. Oyster Creek panels in late summer & early fall have an abundance of a sponge , a hydroid, Enteromorpha, and barnacles, but lower biomass than bay stations, with their masses of worm tubes. The barnacles in Oyster Creek are more extensive than at any other station except station #8. In fact, barnacle settlement in September, 1976, was significant only at stations 10 & 11 (Table 19, October removal date). In August and October, it was significant at stations 8-12 (all influenced by the thermal effluent and high in salinity). Long-term barnacle survival as opposed to settlement is greatest at stations 3 & 7, the estuarine controls. The data indicate that in the vicinity of the power plant there is heavy settlement and rapid growth (note Oct. 9 column) but more rapid mortality (Nov. 5 column) of barnacles.

Tables 20 - 25 record the presence or absence of major components of the fouling community at the 15 stations. The tube worm Hydroides neanthus,

Table 19: Percentage of Surface Area Covered by Barnacles*

	Aug. 8		Sept. 10		Oct. 8		Nov. 5		Dec. 5		Dec. 5#	
Date Removed (1976) / Mo. Submerged	3	1	4	1	5	1	6	1	7	1	7	1
Station												
1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	1	26	2	<1	2	0	0	0	1	0
3	34	1	33	11	41	<1	69	0	46	0	0	1
4	1	1	2	0	1	1	2	2	1	0	0	0
5	5	<1	6	0	17	0	14	0	6	0	0	0
6	8	2	6	1	5	0	4	0	25	0	0	0
7	4	2	19	11	19	0	34	1	30	0	1	0
8	1	0	17	95	57	1	53	100	18D	0	16	0
10	11	2	14	43	40	6	64D	8	66D	0	34	0
11	5	1	11	54	67	30	56D	13	1D	0	85	<1
12	78	11	93	65	100	0	88D	2	24,72D	0	0	0
14	5	1	8	3	12	0	2	<1	11	0	1	0
15	1	2	18	2	14	1	9	0	21D	0	24	<1
16	13	0	1	7	8	0	7	0	14	0	0	0
17	03	1	4	4	11	0	14	0	0	0	1	0

*All were _Balanus_ _eburneus_ except for the last column, indicated by (#).

D: barnacles dead but still occupying space.

Table 20: Distribution of Some Common Fouling Organisms:

Hydroides neanthus, Submerged Apr. 30, 1976

STATION

Date Removed	1	2	3	4	5	6	7	8	10	11	12	14	15	16	17
A)Cumulative															
Aug. 8	X	X		X	X	X	XR	X				X		X	X
Sept. 10	X	X		X	X	X		X				X	X	X	X
Oct. 8	X	X		X	X	X		X				X	X	X	X
Nov. 5	X	X	XR	X	X	X		X				X	X	X	X
Dec. 5	X	X	XR	X	X	X		X				X	X	X	X
B) Monthly															
Aug. 8	X	X		X	X	X		X	X	XR	X	X		X	X
Sept. 10	X	X			X	X	XR					X	X		X
Oct. 8	X	X		X		X		X	X	X	X	X	X		X
Nov. 5	XR			X		XR									
Dec. 5															

X: present

XR: present but rare

Table 21: Distribution of Some Common Fouling Organisms: Electra Crustulenta, Submerged Apr. 30, 1976

	STATION														
Date Removed	1	2	3	4	5	6	7	8	10	11	12	14	15	16	17
Cumulative															
Aug. 8	X	X					X		XR			X		X	X
Sept. 10		X		XR									X	X	XR
Oct. 8	X												X		
Nov. 5	X	X		X	X	X	X	XR			X		X	X	
Dec. 5	X	X		X	X	X	X	X			X			X	
Monthly															
Aug. 8		X		XR										XR	
Sept. 10	X	X			XR	X									
Oct. 8		X								X					X
Nov. 5							XR		X	X	X		X		
Dec. 5	XR	XR									XR		X	X	

Table 22: Distribution of Some Common Fouling Organisms
Botryllus schlosseri Submerged Apr. 30, 1976

Date Removed	STATION 1	2	3	4	5	6	7	8	10	11	12	14	15	16	17
Cumulative															
Aug. 8	X	X						XR				X			
Sept. 10	X	X			X							X	XR		
Oct. 8	X	X			X							X			
Nov. 5	X	X			X			XR				X			
Dec. 5	X	X		X	X			X				X			
Monthly															
Aug. 8	X				XR										
Sept. 10					X										
Oct. 8	X	X		X	X			X				X			
Nov. 5	XR	X	X		X			XR				X?			
Dec. 5		X			X				XR			X		XR	

?: species identification uncertain

Table 23: Distribution of Some Common Fouling Organisms:
Enteromorpha, Submerged Apr. 30, 1976

	STATION														
Date Removed	1	2	3	4	5	6	7	8	10	11	12	14	15	16	17
Cumulative															
Aug. 8															
Sept. 10			X							X					
Oct. 8			X				X	X	X	X			X		
Nov. 5	XR		X		X	XR	X	X	X	X			X	X	
Dec. 5	X	XR?			X				X	X			X		
Monthly															
Aug. 8															
Sept. 10			X							X	X				
Oct. 8			X				X			X			X		
Nov. 5			XR												
Dec. 5				XR											

Table 24: Distribution of Some Common Fouling Organisms: Polysiphonia, Submerged Apr. 30, 1976

	STATION														
Date Removed	1	2	3	4	5	6	7	8	10	11	12	14	15	16	17
Aug. 8															
Sept. 10		X		X	X	X		XR				XR	X		X
Oct. 8		X		X	X	X							X		
Nov. 5	X	X		X	X	X			XR				X	X	XR
Dec. 5					X	X				X	X				
Aug. 8															
Sept. 10		X			X	X								X	X
Oct. 8		X		X	X								X		
Nov. 5					XR	X	XR				XR				
Dec. 5					X						XR		X		

Table 25: Distribution of Some Common Fouling Organisms;
Grantia, Submerged Apr. 30, 1976

Date Removed	STATION 1	2	3	4	5	6	7	8	10	11	12	14	15	16	17
Cumulative															
Aug. 8				X							X				
Sept. 10		XR	X	X	X	X			X		X	X	XR		
Oct. 8		X			X	X		X	X		X				
Nov. 5		X				X					X				
Dec. 5						XR									
Monthly															
Aug. 8															
Sept. 10					X						X				
Oct. 8					X	X			X		X				
Nov. 5															
Dec. 5															

a summer and fall colonizer, is rare at estuarine sites (#3 & 7) as well as in Oyster Creek. This shows that despite changes in temperature and salinity, Oyster Creek still has some characteristics of an estuarine stream. The relevant factor is probably the unidirectional water flow toward the ocean, which reduces the availability of young of this species with a planktonic dispersal stage.

E. crustulenta was found at sites 3 and 10-12 in the September series of panels, but was destroyed by the nudibranch Doridella obscura. It appears that the bryozoan, a winter colonizer, takes longer to recover in the creeks than elsewhere. It never has been abundant at stations 14 and 17.

Botryllus schlosseri is rare at southern stations and in creeks, except for station 5 with its water supply from the bay. It is primarily a fall-winter colonizer. Its planktonic stage does not appear to come into Oyster Creek. Its presence at stations 5 and 8 implies that it is not kept out of Oyster Creek due to temperature, salinity, or organic matter. Its absence from sites 3 & 7 as well as 10-12 indicate that siltation is not the cause of its absence from Oyster Creek. If current strength were the key factor, we would not find it at sites 8 (rough) and 14 (calm) but not at 4 (rough) or 6 (calm).

Enteromorpha sp., a late summer algal species, presents a picture almost the inverse of Hydroides. It does not have a lengthy pelagic dispersal stage. Its presence at sites 10 & 11 and absence at site 12 indicate that Oyster Creek itself is not completely uniform with respect to fouling organisms.

The alga Polysiphonia is most abundant in fall. Again, the Oyster Creek stations align with the estuarine stations (#3, 7) rather than with the South Branch of Forked River and most bay stations. Polysiphonia is rare at all stations within the thermal effluent (#8-14).

The summer and fall sponge Grantia is patchy within Oyster Creek, within bay sites, and within creeks. It is interesting to note its presence at site #12; perhaps it is related to the lack of Enteromorpha there. Such a pattern could have an historical basis; whichever arrived first may be able to exclude the other. We will test this hypothesis in months to come.

Overall, fouling patterns suggest that historical reasons (eg, availability of colonizers) are more important than temperature or salinity in determining fouling community structure. Siltation and possibly organic matter could be relevant, but we have insufficient data to see a pattern using these parameters. Species turnover appears greater in Oyster Creek than elsewhere (this observation incorporates fouling data since 1971 as reported by R. D. Turner). Growth rates of barnacles are greatest in Oyster Creek, but lifespans appear to be shorter.

CONCLUSIONS

Shipworm levels in Oyster Creek have fallen dramatically since the Oyster Creek Nuclear Generating Station shut down in the winters of 1974-1975 and 1975-76, removed untreated marina wood from Oyster Creek, and increased the dilution of (therefore, decreased the temperature of) the warm-water effluent flowing into Oyster Creek. Increased siltation in Oyster Creek probably also had a negative effect on shipworms. All of these factors were involved; none can be singled out. That these factors _did_ decrease shipworm infestation verifies our earlier (R. D. Turner, 1974) contention that the thermal effluent plus salinity changes had turned marina wood in Oyster Creek into a breeding ground for shipworms.

Shipworms, including one subtropical species, still remain in Oyster Creek, hence the problem could return. We do not yet know if removal of the marina wood was a sufficient deterrent. This question will be answered after the generating station operates a full year, including one winter. The deployment of subtropical and/or tropical species of shipworms next summer, as well as the length of the breeding period of shipworms in the affected area & elsewhere, will tell us if the Oyster Creek area is acting as a breeding ground for Barnegat Bay.

The Shipworm infestation in Forked River has not improved as it has in Oyster Creek. The greater extent of the introduced species _T. furcifera_ in Forked River relative to Holly Park & Cedar Creek indicates that the nuclear generating station plays a role in the Forked River shipworm problem. Because the pumping activity causes Forked River to run upstream to the plant most of the time, shipworm larvae from Forked River may contribute to Oyster Creek's population if they survive the trip, but probably will not make a large contribution to Barnegat Bay itself.

Fouling biomass is usually heavier at stations on the bay (eg, #1, 2, 8, 14, 17) than at up-stream sites (eg, #3, 5, 7, 10). High and constant salinity, constant water circulation, and low siltation seem to be important factors: Dominant fouling organisms and the diversity index of the fouling community vary seasonally and from station to station. Boring and fouling organisms are not mutually exclusive; the sites with heaviest borer attack also had heaviest fouling. But shipworms and Limnoria are rarely together in our study area.

RECOMMENDATIONS

For the general health of the biotic community in Oyster Creek, we suggest reduction of the silt load. Botanical methods of bank stabilization should be tried where unsightly artificial methods have not already been used. High rates of dilution pumping should be maintained. Necessary wooden structures should be constructed with treated wood of high quality. Trash wood in the vicinity of the drowned trees should be removed if it can be done without destabilizing the mud bottom & the creek banks.

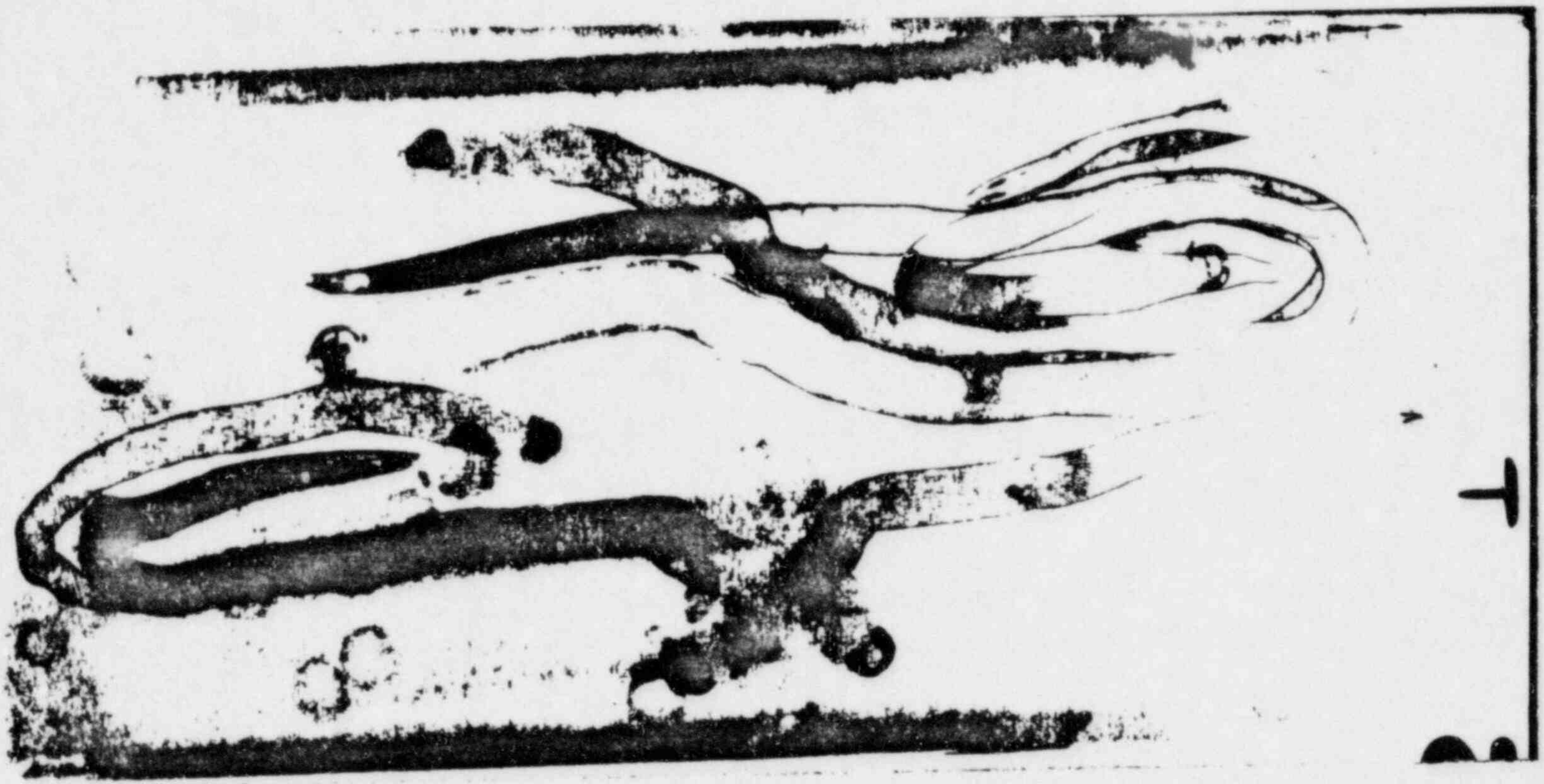
Forked River presents a different problem. Tactics which reduce the problem in Oyster Creek, such as dilution pumping, exaccerbate it in the south branch of Forked River & its lagoons. Here, we recommend removal of trash wood and treatment of all wood structures, including replacement of presently untreated wood. Again, botanical methods of bank stabilization should be tried.

For the future, we warn against activities which could further increase the salinity of Oyster Creek, Forked River, and Barnegat Bay in general. Such changes may increase the attack of bay species such as Teredo navalis, and certainly will increase the geographic extent of shipworm damage and fouling in Forked River.

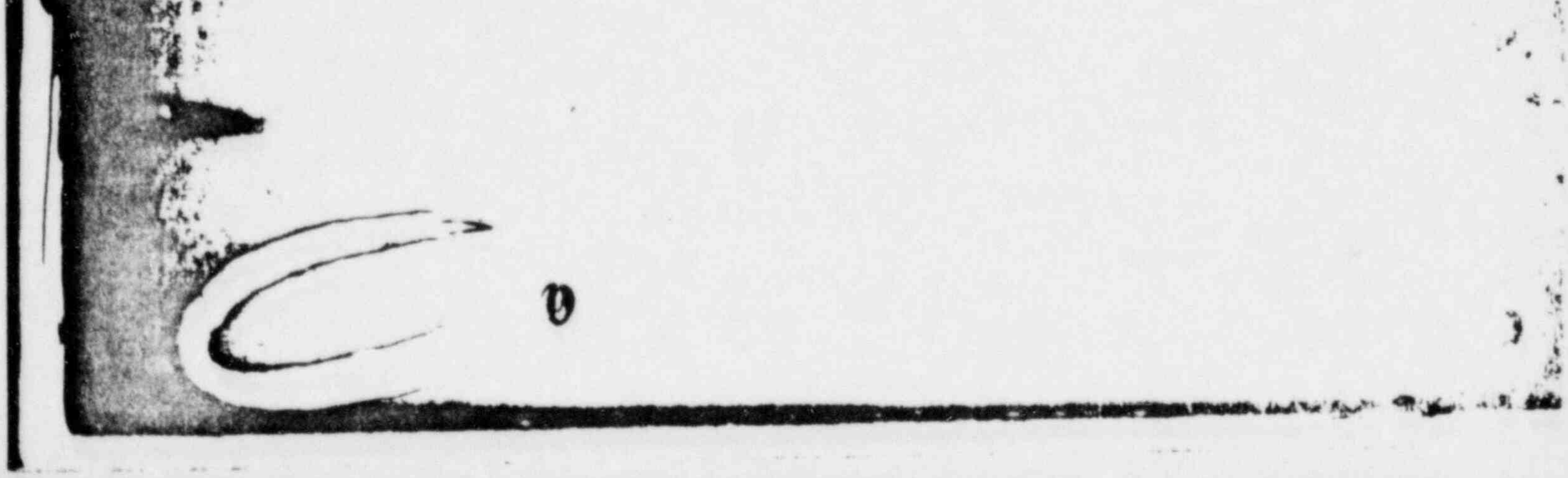
APPENDIX A

X-rays of wooden test panels from Oyster Creek and environs: some sample prints.

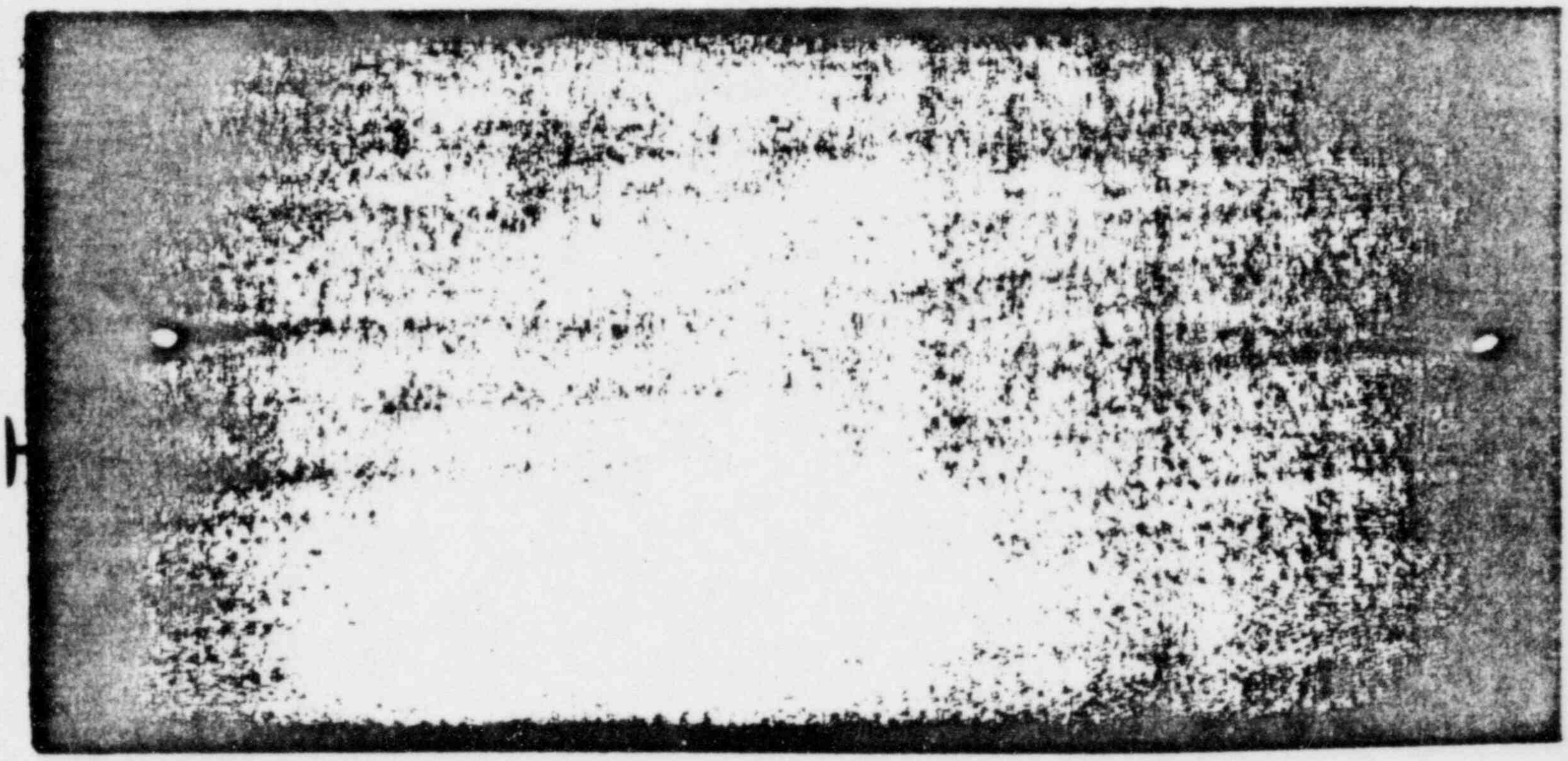
1. Station 11, Oyster Creek, submerged Sept. 27, 1976 - Aug. 8, 1976.



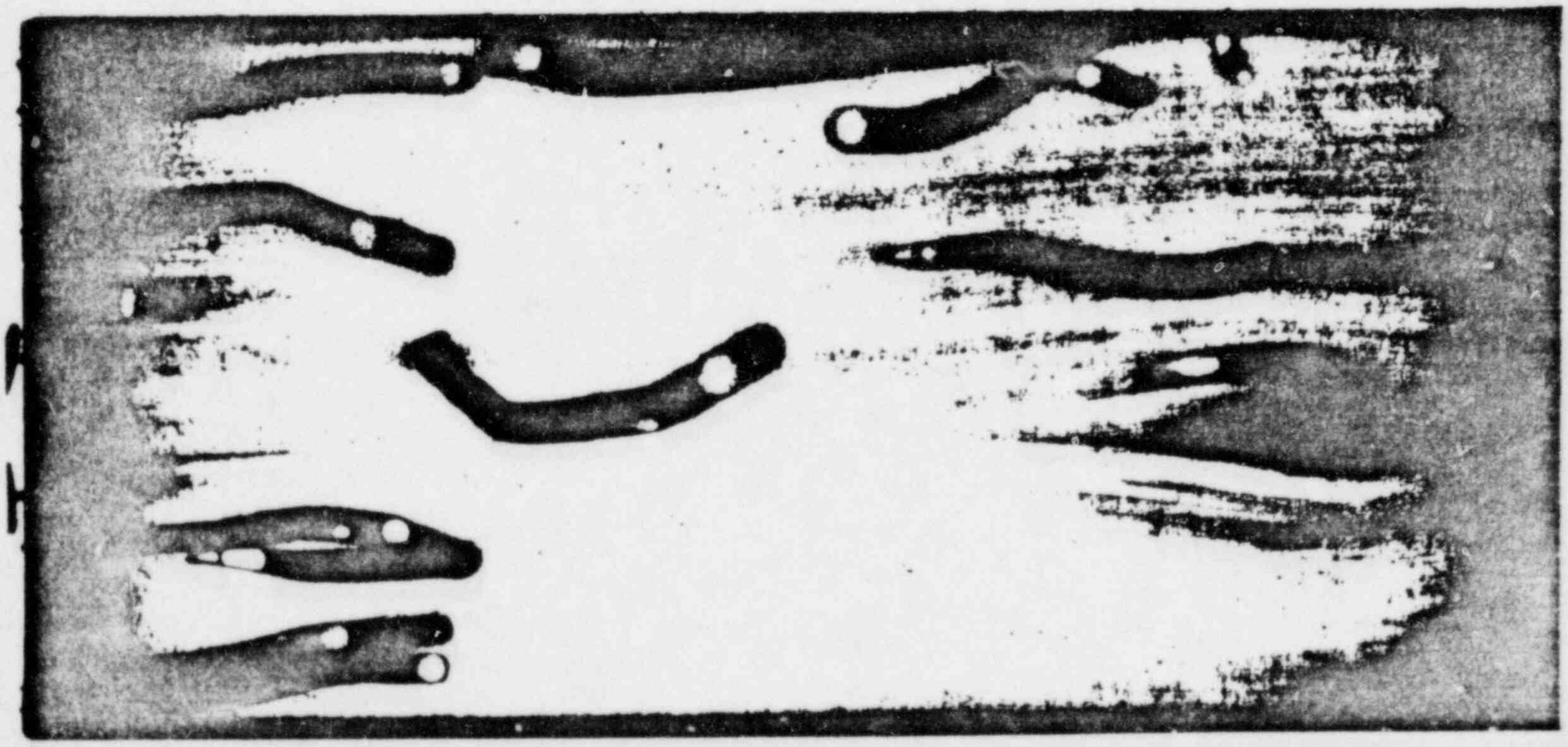
2. Station 12, Oyster Creek, submerged Sept. 27, 1975 - Aug. 8, 1976.



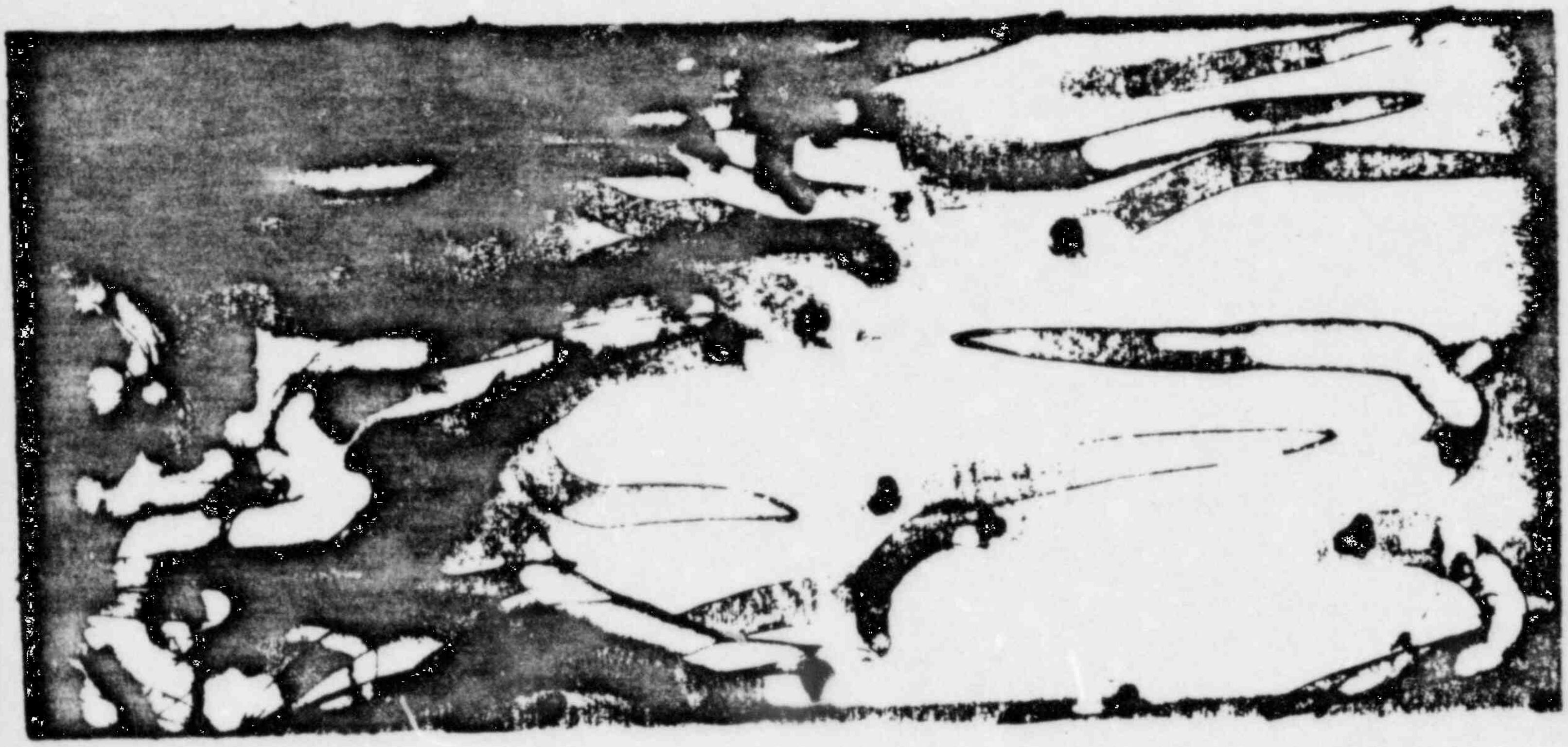
3. Station 3, Stout's Creek, submerged Apr. 30 - Aug. 8, 1976.



4. Station 1, Holly Park, submerged Apr. 30 - Aug. 8, 1976



5. Station 4, Mouth of Forked River, submerged Apr. 30 - Aug. 8, 1976.



6. Station 8, Bayside Beach Club, submerged Apr. 30 - Aug. 8, 1976.

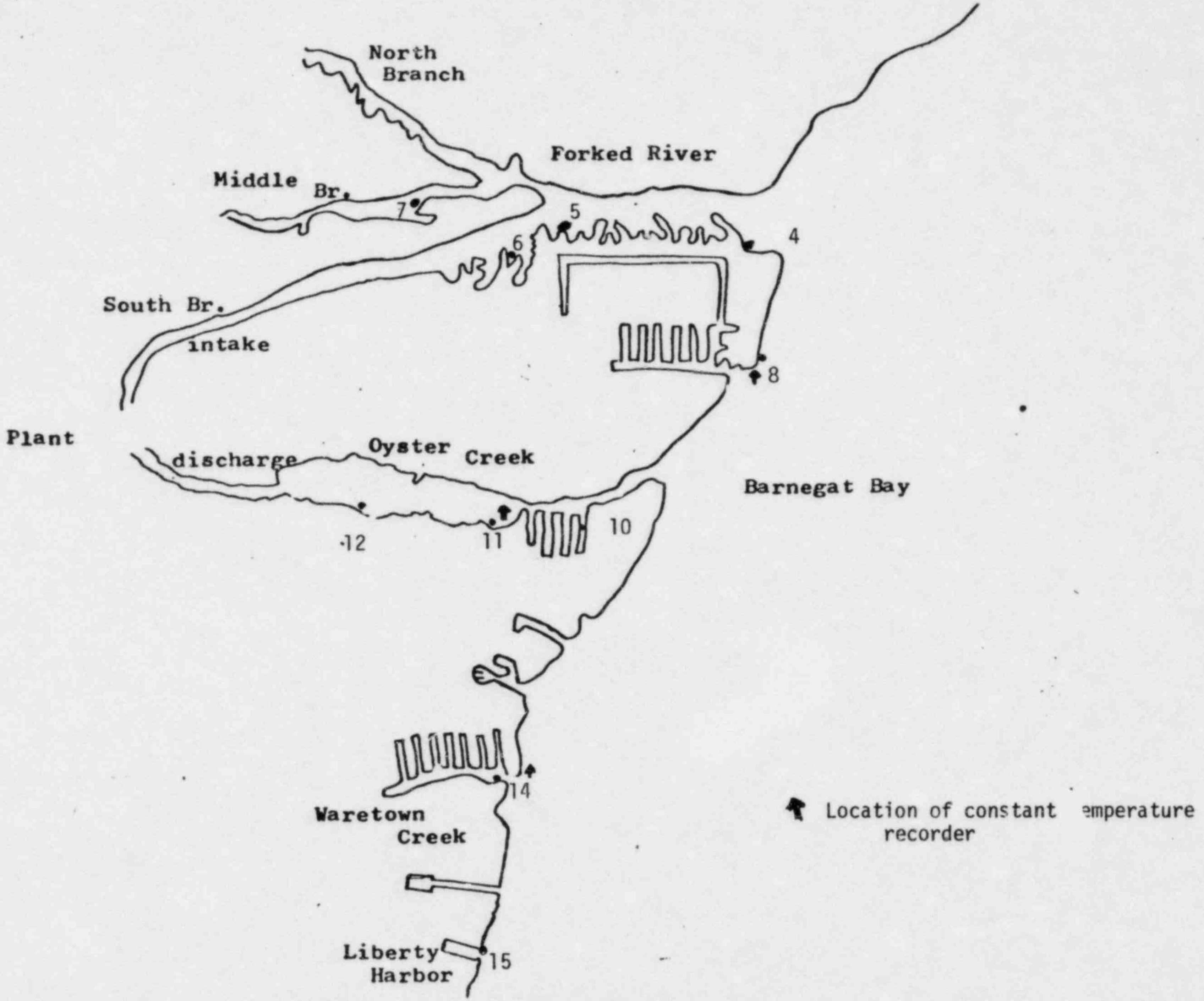
REFERENCES

Sutherland, J. P., 1974. Multiple stable points in natural communities. Amer. Natur. 108: 859-873.

Turner, R. D., 1974. In the path of a warm, saline effluent. American Malacological Union Bulletin for 1973, 39: 36-41.

MAP I

APPENDIX B: SITES OF TEST STATIONS
(Approximate)



MAP 2

APPENDIX B