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Ecological Studies of Wood-Boring Bivalves in the Vicinity of the Oyster Creek Nuclear Generating Station

Progress Report
June - August 1981

Prepared by K. E. Hoagland, L. Crocket

Wetlands Institute
Lehigh University

Prepared for
U.S. Nuclear Regulatory Commission

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PREVIOUS REPORTS

Twelve reports have been prepared under Contract AT(49-24)-0347 (=NRC-04-76-347) during three years of funding from the U. S. Nuclear Regulatory Commission, 1976-1979, under the title:

Analysis of Populations of boring and fouling organisms in the vicinity of the Oyster Creek Nuclear Generating Station with discussion of relevant physical parameters.

Those reports with NTIS numbers are:

NUREG/CR-0223 Dec. 1, 1977-Feb. 28, 1978
NUREG/CR-0380 Mar. 1, 1978-May 31, 1978
NUREG/CR-0634 Sept. 1, 1977-Aug. 31, 1978
NUREG/CR-0812 Sept. 1, 1978-Nov. 30, 1978
NUREG/CR-0896 Dec. 1, 1978-Feb. 28, 1979
NUREG/CR-1015 Mar. 1, 1979-May 31, 1979
NUREG/CR-1209 June 1, 1979-Aug. 31, 1979

Five reports have been published in this current series:

Ecological studies of wood-boring bivalves in the vicinity of the Oyster Creek Nuclear Generating Station.

NUREG/CR-1517	Sept. 1, 1979-Feb. 28, 1980, 65 pp.		
NUREG/CR-1795	March 1-May 31, 1980, 31 pp.		
NUREG/CR-1855	June 1-Aug. 31, 1980, 48 pp.		
NUREG/CR-1939	Vol. 1	Sept. 1, 1980-Nov. 30, 1980,	36 pp.
	Vol. 2	Dec. 1, 1980-Feb. 28, 1981,	41 pp.
	Vol. 3	March 1, 1981-May 31, 1981,	38 pp.

ABSTRACT

The species composition, distribution, and population dynamics of wood-boring bivalves are being studied in the vicinity of the Oyster Creek Nuclear Generating Station, Barnegat Bay, New Jersey. Untreated wood test panels are used to collect organisms at 12 stations. Physiological tolerances of 3 species are also under investigation in the laboratory. Competition among the species is being analyzed. In the summer of 1981, *Teredo bartschi* occurred in large numbers at one station in Oyster Creek, but did not appear in significant numbers in Forked River. The ΔT in Oyster Creek was about +4° C. Both *Teredo bartschi* and *T. navalis* settled, matured, and produced offspring in less than 3 months in Oyster Creek. Specimens of *T. navalis* brooding young were more frequent in Oyster Creek than at control stations. Laboratory experiments indicated that *T. bartschi* pediveligers do not prefer to settle on wood containing adults.

SUMMARY OF FINDINGS

The purpose of this investigation is to understand the population dynamics and competitive interactions of shipworms in the vicinity of the Oyster Creek Nuclear Generating Station (OCNGS) and at control stations outside the influence of the station. The relative importance of the introduced species *Teredo bartschi* in causing damage, and physiological tolerances of all species, are being assessed. On a monthly basis, wood panels are added and removed for analysis of population dynamics and to obtain live animals for the lab studies. We also record temperature, salinity, and we estimate siltation levels at each station.

1. The generating station was operating during most of the period of this report, except for the last two weeks of August.

2. The ΔT was about +4 to 4.5° C in Oyster Creek during these summer months. The salinity in Oyster Creek and Forked River was similar to that of nearby portions of Barnegat Bay. It was more stable than that of Stout's Creek, which dropped to 7 ‰ during part of the summer, explaining the lack of shipworms there.

3. *Teredo bartschi* was found only at stations 4 (Forked River), 11, and 12 (Oyster Creek).

4. Adult *T. bartschi* suffered very heavy mortality in June, 1981.

5. Heavy shipworm attack occurred at station 12 (Oyster Creek). *Teredo bartschi* was the most numerous shipworm found in the panels at station 12, by an order of magnitude. Attack at all other stations was light.

6. New shipworms were found to settle on the monthly panels during July and August. *Teredo navalis* settled earlier than *T. bartschi* and *Bankia gouldi*.

7. *Teredo bartschi* and *Teredo navalis* suffered more mortality than *Bankia gouldi* in panels of the same age.

8. Mature specimens of both *Teredo* species produced larvae after less than 3 months in the wood.

9. All three species were found at no single station, although all three were found in Oyster Creek as a whole.

10. In several panels, all of the specimens of _Teredo bartschi_ were females brooding young.

11. Shipworm larvae were found in Oyster Creek, Forked River, and Holly Park on July 2, 1981.

12. _Teredo bartschi_ withdraws its siphons in turbid water, but re-extends them while the water is still turbid.

13. Pediveligers of _Teredo bartschi_ seem to prefer to bore into fresh wood rather than wood containing adults.

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ACKNOWLEDGMENTS

We thank the many residents of Oyster Creek who have cooperated in our field work. James Selman provided technical assistance. Eugenia Böhlke of the Academy of Natural Sciences of Philadelphia served as X-ray technologist. J.C.P. & L. Co. provided data on the operation of the Generating Station.

ECOLOGICAL STUDIES OF WOOD-BORING BIVALVES

IN THE VICINITY OF THE OYSTER CREEK

NUCLEAR GENERATING STATION

June 1 - August 31, 1981

INTRODUCTION

Previous studies have shown a direct causal relationship between the effluent of the Oyster Creek Nuclear Generating Station and the proliferation of shipworms (Teredinidae) in Oyster Creek and adjacent portions of Barnegat Bay, New Jersey (Turner, 1974; Hoagland et al., 1977; Hoagland et al., 1978; Hoagland and Crocket, 1979; Hoagland and Turner, 1980; Hoagland et al., 1980). The effluent adds heat to the receiving waters, which extends the breeding season of teredinids, increases their growth rates, and reduces their winter mortality rates. It has allowed the establishment of a tropical-subtropical shipworm, Teredo bartschi, in Oyster Creek and Forked River. The design of the generating station's cooling system, taking salt water from Barnegat Bay up Forked River, through the plant, and out into Oyster Creek, has increased the salinity of these two creeks. Shipworms now can reside in these creeks, which previously were unsuitable in salinity level and constancy for the establishment of actively breeding shipworm populations.

The populations of Teredo bartschi compared with the native species in Oyster Creek and Forked River are the focus of current studies. This report summarizes an ongoing collection of data on physical parameters of Barnegat Bay, as well as species composition, distribution, growth, mortality, and reproduction of teredinids. We assess the degree of shipworm damage occurring at each station. We also report on physiological studies comparing the native and introduced shipworms with regard to temperature and salinity tolerances.

We summarize the conclusions from work accomplished between Sept. 1, 1980, and August 31, 1981, and compare our results with those of the Battelle laboratories and others working on the relationship of thermal effluents to bivalve population biology.

METHODS

Stations

Over the first three years of our study, 20 stations were established in Barnegat Bay to monitor boring and fouling organisms. In September, 1979, the number was reduced to 12. The stations are shown in Hoagland and Turner, 1980, and are listed in the appendix. The station numbers are not contiguous because some have been discontinued.

Station 1 is a northern control station on Barnegat Bay outside the influence of the heated effluent. Some shipworms, primarily *Bankia gouldi*, are traditionally found there. Station 3 is a control station in a tidal creek outside the influence of the effluent. Shipworms are rarely found there. Stations 4, 5, and 6 are in Forked River, influenced by the plant's water intake system. There is some recirculation of heated water that affects these stations, but the main influence is that the salinity is essentially that of the bay. Station 6 is sampled on a reduced schedule, only 4 times a year.

Station 8 is on the bay between Oyster Creek and Forked River. Stations 10-12 are in Oyster Creek, influenced directly by heat, increased (and constant) salinity, and other components of the effluent (heavy metals, silt, increased flow rate, etc.). Since JCP & L calculates average values of heavy metal input per month, exact data necessary to characterize the effluent completely are not available.

Stations 14 and 15 are at or near the southern limit of the thermal plume, on Barnegat Bay. Station 15, like Station 6, is being sampled on a reduced schedule. Station 18 on Long Beach Island is being used only as a reliable source of *Teredo navalis* for laboratory experiments.

Field Work

Once each month, the water temperature and salinity are measured at each station. Air temperature and time of day are also recorded. The amount of silt settling on wood panels submerged for one month is estimated as trace, light, moderate, or heavy. At stations 1, 5, 11, and 14, records of temperature and salinity are kept by means of constant recording instruments that are serviced once a month.

White pine panels, approximately 3/4" x 4" x 8", are used to obtain shipworms for study. There are three panel series: 1) Each month, a panel that has been in the water for 1 month is removed and replaced. In this way data on monthly settlement and early growth of borers are obtained. 2) Each month, a panel that has been in the water for 12 months is removed and replaced. It provides data on timing of reproduction, species and age structure of established borer communities, and other population data. 3) Each May, a series of 12 panels is deployed. These panels are removed one per month. They provide information on the cumulative growth and maturation of individual borers as well as development of the boring and fouling communities. The cumulative monthly amount of wood destruction can be evaluated. These three panel series are called M, Y, and C, respectively. The Y and C series are replicated at some stations, as indicated in the data tables to follow. Replication is not possible at all stations because of limited space where the water is deep enough to submerge a series of shipworm panels.

Panels are presoaked for 2 weeks, then set on aluminum frame racks against bulkheading or off finger docks. They rest about 6" above the water-sediment interface.

On July 2, plankton tows were taken to look for shipworm larvae in the vicinity of the test stations.

Laboratory Work

Panels are examined for pediveliger shipworm larvae and boring isopods, scraped, and X-rayed to locate the shipworms and provide a permanent record of damage. It is possible to count and often to identify shipworms from the X-rays in uncrowded panels, but X-rays do not provide quantitative data in most cases. Therefore, using the X-rays as guides, the panels are dissected. All the shipworms are removed, identified, examined for larvae in the gills, and measured (length only). They are preserved in 75% buffered alcohol. Identifications are first made by technicians, but all *Teredo* spp. are checked by one of the senior investigators.

Wood fragments from the dissected panels are saved. Calcareous tubes and other debris left by the shipworms are removed with HCℓ. The wood is washed in fresh water, then dried to constant weight, allowed to cool to room temperature, and weighed. The panels are also weighed before going into the water. The weight difference is a measure of wood destruction due to boring organisms.

During dissection of the wood panels, we estimate the percentage of empty tubes, which indicate mortality. If pallets are still present in the empty tubes, we can record the species of the dead shipworm.

Shipworms from the replicate 12-month panels are not preserved but are kept alive and allowed to spawn in tanks containing filtered sea water (22‰ salinity) and new pine panels. In this way, we have established pure laboratory populations of *Teredo bartschi*. Individuals of *B. gouldi* and *T. navalis* from the field are being maintained in the laboratory. These stocks are used for temperature and salinity tolerance experiments. Attempts are underway to establish breeding colonies of *Teredo navalis*.

Larvae are being fed cultures of Monochrysis lutheri and Isochrysis galbana. Both algae and larvae are maintained in an incubator at 22° C. The procedures for culturing shipworm larvae are those of Culliney, Boyle and Turner (1975) and Turner and Johnson (1971).

Physiological Ecology

Pediveliger larvae released from animals that had themselves been raised in the laboratory were collected from an aquarium maintained at about 18° C. Ten pediveligers were placed in each of 6 finger bowls containing artificial seawater at 20-22° C and salinity of 22 ‰.

A sliver of fresh white pine presoaked for 7 days in filtered seawater was placed in each of two bowls. Two bowls contained slivers of white pine that had been in the field for several months but contained no shipworms. The last two bowls contained slivers of white pine containing adult lab-reared Teredo bartschi. The purpose of the experiment was to see if the pediveligers had a preference for settlement on wood containing organisms. The behavior of the pediveligers was observed over a period of 8 days, then the experiment was repeated over a period of 5 days.

The behavioral categories included actively swimming with velum extended, actively crawling on wood with foot extended, attached to surface film, probing the wood as if to begin burrowing, crawling on the glass bottom, swimming slowly with foot extended near the bottom, lying open on the bottom, and lying closed on the bottom. The temperature was kept at 20-21.5° C.

Turbidity

To test the theory that teredinids are unable to filter in turbid water, observations were made on a panel containing over 100 adult Teredo bartschi in a finger bowl with 22 ‰ ocean water, to which enough suspended fine silt was then added for the water to become distinctly turbid. In a second finger bowl was a panel also containing adult T. bartschi, to which clear seawater without silt was added. The two panels were observed for 30 minutes at room temperature and light aeration on June 17, 1981.

The experiment was repeated two months later with 2 test panels. Once the animals were filtering actively in water of 22 ‰, silt was added.

RESULTS AND DISCUSSION

Physical Factors

The temperature elevation in Oyster Creek was about 4 to 4.5° C during the summer of 1981 (Tables 1 and 2). The temperature exceeded 31° C at station 11 in parts of July and August. The maximum temperature elsewhere was 30.2° C, briefly in July, at station 14 (Waretown). There is some indication of the presence of heated water in Forked River during early August (Table 1). The plant was not operating at the end of June and during the last half of August (Table 5), hence the lack of evidence of a thermal effluent on July 2 (Table 1) and during much of August (Table 2). Some problems with the instruments are noted in footnotes to Table 2.

The instability of the salinity in small tidal creeks is shown by the July reading of only 7 °/₀₀ at Stout's Creek, station 3 (Table 3). This periodic low salinity explains the rarity of shipworms at that station. The salinity in Oyster Creek is less than or equal to that in Forked River, indicating that some fresh water does enter Oyster Creek. The salinity in Forked River (stations 4 and 5) is equal to that along the inner bay, e.g., station 14 (Tables 3 and 4).

The circulation of water into Forked River and Oyster Creek from Barnegat Bay depends on the operation level of the plant. Because there was a 2-week outage in August, much less water circulated (Table 5). This event reduced the likelihood of pediveligers of *Teredo bartschi* being transported from Oyster Creek to Forked River in late August, when pediveligers were being released. The other factors involved in the transport of larvae are the surface-water currents, controlled in part by the winds, and the presence of wooden boats. Our laboratory studies show that *Teredo bartschi* can successfully penetrate wood after as long as 3 weeks in the pediveliger state at 20-22° C.

Table 6 shows that there was no ongoing severe drought during the summer of 1981 that would affect the salinity and hence the survival of shipworms in tidal creeks.

Shipworm Populations

The first shipworms to settle on monthly panels in 1981 were found in early July. *Teredo navalis* occurred at station 8, between Oyster Creek and Forked River, and a teredinid sp. was found at several other stations (Table 7). In all likelihood, these were *T. navalis* (compare Table 11). In early August, a panel containing *Teredo bartschi* was found in Oyster Creek, and *Bankia gouldi* joined *T. navalis* at station 8. As has been the pattern over several years, *T. bartschi* first appeared at station 12. There was some mortality of the settling shipworms, particularly at stations 8 and 11, as can be seen in Tables 8 and 9. The largest of the settling shipworms was the specimen of *Teredo bartschi* in Oyster Creek, which grew 10 mm in less than one month (Table 10).

Table 1

Temperature Profiles in °C
June-August 1981

Station	June 8	July 2	Aug. 4	Differential among months
1	24.0	25.6	25.6	1.6
3	26.0	25.0	27.8	2.8
4	24.5	23.3	26.1	2.8
5	25.0	23.6	27.2	3.6
8	23.0[b]	26.1[a]	28.9[a]	5.9
10	27.0[a]	24.4	28.9[a]	4.5
11	27.0[a]	25.0	28.9[a]	3.9
12	27.0[a]	25.0	28.9[a]	3.9
14	23.5	22.1[b]	24.4[b]	2.3
Differential among stations	4.0	4.0	4.5	

[a] highest value

[b] lowest value

Table 2

Continuous Temperature Recorder Data (°C) for June 8-Sept. 3, 1981

I. Temperature at 1:00 PM

	June 8-July 2				July 2-Aug 4				Aug 4-Sept 3			
	1	5	11[b]	14	1[a]	5[a]	11[b]	14	1[a]	5[c]	11	14[d]
Mean Daily Temp. at 1PM	24.3	27.2		24.6				26.5		23.0	25.5	26.1
Standard deviation	1.4	1.5		1.5				1.4		1.8	3.2	1.1
Highest value of Temp. at 1 PM	26.6	29.5	>30.9	28.0			>30.9	29.2		26.4	>30.9	28.0
Lowest value of Temp. at 1 PM	21.3	24.5	23.6	22.0			27.5	23.3		20.6	21.3	24.7
Monthly Temp. Range at 1 PM	5.3	5.0	>7.3	6.0			>3.4	5.9		5.8	9.6	3.3

II. Maximum Daily Temperature

	June 8-July 2				July 2-Aug 4				Aug 4-Sept 3			
	1	5	11	14	1	5	11	14	1	5	11	14
Mean value of Max. Daily Temp.	24.9	27.4		25.6				27.4		23.7	25.9	26.8
Standard deviation	1.2	1.4		1.4				1.5		1.8	3.2	1.1
Highest value of Max. Daily Temp.	27.2	29.6	>30.9	28.6			>30.9	30.2		27.5	>30.9	28.5
Lowest value of Max. Daily Temp.	22.1	24.5	24.1	23.8			28.0	23.6		21.8	21.7	25.2
Monthly Range of Max. Daily Temp.	5.1	5.1	>6.8	4.8			>2.9	6.6		5.7	9.2	3.3

Table 2, continued

III. Minimum Daily Temperature

	June 8-July 2				July 2-Aug 4				Aug 4-Sept 3			
	1	5	11	14	1*	5*	11	14	1*	5[b]	11	14[c]
Mean value of Min. Daily Temp.	23.3	25.2	26.0	23.4			28.3	25.6		22.1	23.7	25.2
Standard Deviation	1.3	1.1	2.7	1.3			1.1	1.3		1.7	3.5	1.1
Highest value of Min. Daily Temp.	25.8	27.0	30.2	25.9			30.1	28.3		25.7	29.4	27.0
Lowest value of Min. Daily Temp.	21.0	23.4	21.7	21.4			25.5	23.0		19.7	19.3	23.5
Monthly Range of Min. Daily Temp.	4.8	3.6	8.5	4.5			4.6	5.3		6.0	10.1	3.5

IV. Daily Temperature Range

	June 8-July 2				July 2-Aug 4				Aug 4-Sept 3			
	1	5	11	14	1*	5*	11[a]	14	1*	5[b]	11	14[c]
Mean Daily ΔT	1.6	2.2		2.2				1.8		1.6	2.2	1.5
Standard Deviation	0.6	0.7		0.8				0.6		0.7	1.1	0.7
Largest Daily ΔT for one month	2.5	3.3		4.4				2.9		3.5	5.7	2.9
Smallest Daily ΔT for one month	0.5	0.8	1.2	0.8			0.8	0.4		0.8	0.8	0.9

a Technical difficulties

b Range of machine not adequate to complete calculations

c Last 22 days of cycle

d First 11 days of cycle

Table 3

Salinity Profiles in $^{\circ}/_{\circ\circ}$
June-August 1981

Station	June 8	July 2	Aug. 4	Differential among months
1	20[b]	15	20[b]	5
3	20[b]	7[b]	20[b]	13
4	27.5	23[a]	27[a]	4.5
5	28[a]	23[a]	26	5
8	26	23[a]	26	3
10	25.5	21	26	5
11	26	21	26	5
12	24	20	26	6
14	27	23[a]	26	4
Differential among stations	8	16	7	

[a] highest value

[b] lowest value

Table 4

Continuously Recording Salinometer Data[a] in °/₀₀, May 7-August 4, 1981

Date	Statistic	Sta. 1	Sta. 5	Sta. 14
May 7-June 8	N	22	6	15
	$\bar{x}$	19.6	23.6	23.5
	S_x	1.6	1.1	0.8
June 8-July 2	N	23	21	0
	$\bar{x}$	18.7	24.4	
	S_x	1.5	2.1	
July 2-Aug. 4	N	0	18	0
	$\bar{x}$		24.2	
	S_x		1.0	

[a] Data represent readings taken at 12:00 Noon, EST

[b] N, Number of days recorded, indicates extent of missing data.

$\bar{x}$ = Mean; S_x = Standard deviation.

Table 5

Oyster Creek Nuclear Generating Station Outages, Circulation and Dilution Flow in gal. x 10^6 for June-August, 1981

	Total Water Flow (gal. x 10^6)	Outage Dates
June	38,040	June 27-30, 1981
July	43,060	None
August	24,544	August 15-31, 1981

Table 6

Average Temperature and Precipitation in New Jersey, Deviation from Normal. June-August, 1981

	Temperature (° F)	Precipitation (inches)
June	+0.6°	+1.0"
July	+1.1°	-0.93"
August	-1.0°	-1.96"

Table 7

Numbers of Living Shipworms in Monthly Panels

Date Removed:	June 8, 1981	July 2, 1981						Aug. 4, 1981				
Station	Total	B.g.	T.n.	T.b.	T.sp.	Teredinid sp.	Total	B.g.	T.n.	T.b.	Teredinid sp.	Total
1	0	0	0	0	0	1[a]	1	0	0	0	5	5
3	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	2	2
5	0	0	0	0	0	2[a]	2	0	0	0	0	0
8	0	0	2	0	2	0	4	1	0	0	3	4
10	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	1	0	1
14	0	0	0	0	0	5[a]	5	0	0	0	0	0
Total	0	0	2	0	2	8	12	1	0	1	10	12

[a] probably *T. navalis*

B.g. = *Bankia gouldi*

T.n. = *Teredo navalis*

T.b. = *Teredo bartschi*

T.sp.= Teredo unidentified species

Table 8

Numbers of Living Shipworms Plus Empty Tubes in Monthly Panels

Date Removed:	June 8, 1981	July 2, 1981						Aug. 4, 1981				
Station	Total	*B.g.*	*T.n.*	*T.b.*	*T.* sp.	Teredinid sp.	Total	*B.g.*	*T.n.*	*T.b.*	Teredinid sp.	Total
1	0	0	0	0	0	1	1	0	0	0	5	5
3	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	2	2
5	0	0	0	0	0	2	2	0	0	0	0	0
8	0	0	3	0	2	0	5	1	0	0	3	4
10	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	3	3
12	0	0	0	0	0	0	0	0	0	1	0	1
14	0	0	0	0	0	5	5	0	0	0	0	0
Total	0	0	3	0	2	8	13	1	0	1	13	15

Table 9

Percentage of Specimens that were Alive when Collected, Monthly Panels

Month Collected:	July 2, 1981			Aug. 4, 1981		
Station	Number Living Specimens	Total No. Tubes Observed	% Alive	Number Living Specimens	Total No. Tubes Observed	% Alive
1	1	1	100	5	5	100
3	0	0	-	0	0	-
4	0	0	-	2	2	100
5	2	2	100	0	0	-
8	4	5	80	4	4	100
10	0	0	-	0	0	-
11	0	0	-	0	3	0
12	0	0	-	1	1	100
14	5	5	100	0	0	-
Total	12	13	92	12	15	80

Table 10

Length Ranges of Shipworms in mm, Monthly Panels

Date Removed:	July 2, 1981		Aug. 4, 1981
Station	*T. navalis*	Teredinid sp.	*T. bartschi*
1		1	
3			
4			
5		5	
8	4-7 *		
10			
11			
12			10 *
14		1-2	

* Largest specimen each species, each month

Table 11

Numbers of Living Shipworms in Cumulative Panels Submerged May 7, 1981

Date Removed:	July 2, 1981						Aug. 4, 1981				
Station	B.g.	T.n.	T.b.	T.sp.	Teredinid sp.	Total	B.g.	T.n.	T.b.	Teredinid sp.	Total
1	0	3	0	0	3[a]	6	13	9	0	5[a]	27
3	0	0	0	0	0	0	0	0	0	0	0
4	0	3	1	1	0	5	1	5	0	0	6
5	0	1	0	0	0	1	0	2	0	0	2
8	0	8	0	2	0	10	2	5	0	0	7
10	0	0	0	0	0	0	0	0	0	0	0
11	0	2	0	0	1	3	0	3	4	0	7
12	0	2	0	0	0	2	0	1	33	0	34
14	0	1	0	0	0	1	0	1	0	0	1
Total	0	20	1	3	4	28	16	26	37	5	84
1 Rep.	0	0	0	0	2	2	15	1	0	0	16
4 Rep.	0	0	0	1	1	2	0	2	0	0	2
8 Rep.	0	5	0	0	0	5	2	4	0	0	6
11 Rep.	0	0	0	0	1	1	0	0	4	0	4

Rep. = Replicate panel

[a] probably T. navalis

The cumulative panels, submerged in May, began to harbor shipworms by early July. The most interesting find was one Teredo bartschi in July at the mouth of Forked River (station 4), although no T. bartschi have been found there since. Teredo navalis was the dominant species settling prior to July 2. It was most abundant between Oyster Creek and Forked River (station 8). A comparison of the data from 1- and 2-month panels removed on July 2 (Tables 7 and 11) shows that there were more specimens infecting more stations in the 2-month data set. We attribute this to earlier settlement on the panels submerged in May, even though that settlement probably did not begin until June. The replicate pairs of panels at stations 1, 4, 8, and 11 were in agreement with one another.

By August 4, Bankia gouldi had begun to settle. It was most abundant at Holly Park (station 1), although it also settled in the Forked River area (stations 4 and 8). Teredo navalis occurred at the greatest number of stations, while T. bartschi was restricted to stations 11 and 12 in Oyster Creek. The heaviest attack at any station was that of T. bartschi at station 12. This is consistent with the pattern established in past years, as we have reported in past progress reports.

Tables 12 and 13 show that there was considerable shipworm mortality in the cumulative panels. Because of their small size, most of the dead shipworms fell out of their tubes, hence the species could not be determined. In those cases where an identification could be made, the dead specimens were Teredo navalis or T. bartschi. There was no pattern detected relative to the stations at which mortality occurred, nor was mortality related to the degree of crowding of the young shipworms.

The growth of the shipworms in the cumulative panels can be deduced from data in Table 14. One Bankia gouldi reached a length of 79 mm in less than 3 months, while one T. navalis reached 111 mm. Because no shipworms were observed to settle in May, these lengths were probably attained in closer to 2 months. In the panels removed in July, by far the largest shipworm was found in Oyster Creek. It either settled earlier or grew faster than those settling elsewhere.

The yearly panels (Table 15) approach the composition of a natural assemblage of shipworms. Table 15 is important because it shows the availability of spawning adults from which the next generation is produced. There is a striking difference between June and July, 1981 in Oyster Creek (Table 15). The number of living specimens of Teredo bartschi declined precipitously. Examination of Tables 16 (total number of tubes) and 17 (percent living specimens) clearly shows that significant mortality occurred between June 8 and July 2. A wave of mortality also occurred in Forked River at the same time, but to a lesser extent. The numbers of living specimens in the July and August panels were similar; Teredo navalis was twice as abundant as the other two species. Living specimens of all 3 species were found at no single station. In past summers, all three did occur in Oyster Creek and at the mouth of Forked River. A comparison of Table 15 with Tables 7 and 11 (monthly and cumulative panels) confirms the presence of only 2 species at any one station. For example, there were no Bankia gouldi in Oyster Creek except at station 10, where Teredo bartschi was absent. Ninety-two of the 146 shipworms alive in the yearly panels (63%) were Teredo bartschi.

The impact of the introduced species Teredo bartschi can best be seen in Table 16 where dead as well as living specimens were counted. T. bartschi dominated at station 12 in Oyster Creek, but was absent a few meters away at station 11 (Appendix). This patchiness is due to the type of larval development: T. bartschi releases pediveligers that are competent to settle adjacent to the parent. But the pattern of species abundance at the various stations was similar in panels deployed in June, July, and August of 1980.

Only station 12 had a heavy attack of shipworms in the summer of 1981, although the Forked River area (stations 5 and 8) and Waretown (station 14) consistently had two species present that became large enough (Table 18) to cause considerable damage. Bankia gouldi and Teredo navalis were both scattered over all stations except station 3, the creek control station that had no shipworms.

Mortality was 16% of the specimens of Bankia gouldi settling in the yearly panels, while 26% of the Teredo navalis and 62% of the T. bartschi in the same panels died (Tables 15 and 16).

The largest specimens Bankia gouldi were at station 11 in all three months. The largest specimens of Teredo navalis were at stations 8 and 14. No newly-settled shipworms appeared on the yearly panels in June, except for numerous T. bartschi at station 12. Even on the July and August panels, there was no evidence of recruitment at stations 4, 10, and 11.

Table 12

Numbers of Living Shipworms Plus Empty Tubes, Cumulative Panels

Date Removed:	July 2, 1981						Aug. 4, 1981				
Station	B.g.	T.n.	T.b.	T.sp.	Teredinid sp.	Total	B.g.	T.n.	T.b.	Teredinid sp.	Total
1	0	3	0	0	4	7	13	9	0	6	28
3	0	0	0	0	0	0	0	0	0	0	0
4	0	4	1	1	2	8	1	5	0	0	6
5	0	1	0	0	0	1	0	3	0	0	3
8	0	8	0	2	1	11	2	6	0	0	8
10	0	0	0	0	0	0	0	0	0	0	0
11	0	2	0	0	2	4	0	3	4	3	10
12	0	2	0	0	0	2	0	1	35	9	45
14	0	1	0	0	0	1	0	1	0	0	1
Total	0	21	1	3	6	31	16	28	39	18	101
1 Rep.	0	0	0	0	2	2	15	1	0	0	16
4 Rep.	0	0	0	0	2	2	0	2	0	0	2
8 Rep.	0	5	0	0	0	5	2	5	0	2	9
11 Rep.	0	0	0	0	1	1	0	0	5	2	7

Rep. = Replicate panel

Table 13

Percentage of Specimens that were Alive when Collected, Cumulative Panels

Month Collected:	July 2, 1981			Aug. 4, 1981		
Station	Number Living Specimens	Total No. Tubes Observed	% Alive	Number Living Specimens	Total No. Tubes Observed	% Alive
1	6	7	86	27	28	96
3	0	0	-	0	0	-
4	5	8	63	6	6	100
5	1	1	100	2	3	67
8	10	11	91	7	8	88
10	0	0	-	0	0	-
11	3	4	75	7	10	70
12	2	2	100	34	45	76
14	1	1	100	1	1	100
Total	28	34	88	84	101	83
1 Rep.	0	2	0	16	16	100
4 Rep.	1	1	100	2	2	100
8 Rep.	5	5	100	6	9	67
11 Rep.	1	1	100	4	7	57

Rep. - Replicate panel

Table 14

Length Ranges of Shipworms, in mm, Cumulative Panels Submerged May 7, 1981

Date Removed:	July 2, 1981				Aug. 4, 1981		
Station	T.n.	T.b.	T.sp.	Teredinid sp.	B.g.	T.n.	T.b.
1	4-7			2-3	2-63	23-111*	
3							
4	5-9	12*			7	34-79	
5	4				44-79*		
8	3-16				2-3	30-71	
10							
11	12-22						
12	20-36*					93	0.5-35
14	8					12	
1 Rep.	3-6			3-6	1-5	42	
4 Rep.			2			70-77	
8 Rep.	5-10				2-3	36-82	
11 Rep.				4			29-43*

* Largest specimen each species, each month

Rep. = Replicate panel

Table 15

Numbers of Living Shipworms in Yearly Panels

Date Removed:	June 8, 1981				July 2, 1981				Aug. 4, 1981			
Station	B.g.	T.n.	T.b.	Total	B.g.	T.n.	T.b.	Total	B.g.	T.n.	T.b.	Total
1	1	0	0	1	0	0	0	0	1	0	0	1
3	0	0	0	0	0	0	0	0	0	0	0	0
4	2	0	0	2	1	0	0	1	0	0	0	0
5	2	2	0	4	0	1	0	1	1	8	0	9
8	5	4	0	9	0	4	0	4	4	3	0	7
10	0	0	0	0	1	1	0	2	2	1	0	3
11	1	0	0	1	3	2	0	5	0	1	0	1
12	1	0	68	69	0	0	3	3	0	0	8	8
14	1	7	0	8	0	5	0	5	0	2	0	2
Total	13	13	68	94	5	13	3	21	8	15	8	31
1 Rep.	0	0	0	0	1	0	0	1	0	1	0	1
11 Rep.	3	0	0	3	1	0	0	1	0	0	0	0
14 Rep.	0	5	0	5	0	4	0	4	0	1	0	1

Table 16

Numbers of Living Shipworms Plus Empty Tubes in Yearly Panels

Date Removed:	June 8, 1981					July 2, 1981				Aug. 4, 1981				
Station	B.g.	T.n.	T.b.	Teredinid sp.	Total	B.g.	T.n.	T.b.	Total	B.g.	T.n.	T.b.	Teredinid sp.	Total
1	1	0	0	0	1	0	0	0	0	1	0	0	4	5
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	2	0	0	0	2	3	0	0	3	0	0	0	0	0
5	3	2	0	0	5	1	5	0	6	1	8	0	1	10
8	5	4	0	1	10	0	5	0	5	4	8	0	1	13
10	0	0	0	0	0	1	1	0	2	2	1	0	0	3
11	1	0	0	0	1	3	2	0	5	1	1	0	0	2
12	1	0	93	0	94	0	0	80	80	0	0	35	0	35
14	1	8	0	0	9	0	5	0	5	0	6	0	0	6
Total	14	14	93	1	122	8	18	80	106	9	24	35	6	74
1 Rep.	0	0	0	0	0	1	0	0	1	0	1	0	0	1
11 Rep.	3	0	0	0	3	2	0	0	2	0	0	0	0	0
14 Rep.	0	5	0	0	5	0	5	0	5	0	3	0	0	3

Table 17

Percentage of Specimens that were Alive when Collected, Yearly Panels

Date Removed:	June 8, 1981			July 2, 1981			Aug. 4, 1981		
Station	Number Living Specimens	Total No. Tubes Observed	% Alive	Number Living Specimens	Total No. Tubes Observed	% Alive	Number Living Specimens	Total No. Tubes Observed	% Alive
1	1	1	100	0	0	-	1	5	20
3	0	0	-	0	0	-	0	0	-
4	2	2	100	1	3	33	0	0	-
5	4	5	80	1	6	17	9	10	90
8	9	10	90	4	5	80	7	13	54
10	0	0	-	2	2	100	3	3	100
11	1	1	100	5	5	100	1	2	50
12	69	94	73	3	80	4	8	35	23
14	8	9	89	5	5	100	2	6	33
Total	94	122	77	21	106	20	31	74	42
1 Rep.	0	0	-	1	1	100	1	1	100
11 Rep.	3	3	100	1	2	50	0	0	-
14 Rep.	5	5	100	4	5	80	1	3	33

Table 18

Length Ranges of Shipworms in Yearly Panels

Date Removed:	June 8, 1981			July 2, 1981			Aug. 4, 1981			
Station	B.g.	T.n.	T.b.	B.g.	T.n.	T.b.	B.g.	T.n.	T.b.	Teredinid sp.
1	75						319			1-4
3										
4	180-355			230-365						
5	192-265	40-165		320	8-300		250	25-96		
8	10-282	26-50			5-100		2-3	32-315*		
10				450	180		325-375	60		
11	445*			210-300	145-185		400*	91		
12	430		2-90*			2-85*			2-91*	
14	195	20-185*			55-130			28-210		
1 Rep.				215				11		
11 Rep.	155-310			390-515*						
14 Rep.		20-140			5-234*			21-241		

* Largest specimen each species, each month

Tables 19 and 20 reveal that damage of wood due to borers was not greatest at station 12, as might have been expected. The relatively small Teredo bartschi did not consume as much wood as the larger species. At station 10, 2 specimens of Bankia gouldi and one T. navalis consumed almost 24% of the wood of the August, 1981, yearly panel. The percent destruction of the yearly panels was less than in other summers we have reported upon. All of the panels with the greatest damage for a particular month were from Oyster Creek or Forked River.

The 18 adult specimens of Teredo bartschi collected in August were all brooding larvae (Table 21). The smallest of these specimens was 9 mm in length. However, the one adult of T. bartschi collected in the July yearly panels, and only 2 of 20 collected in the June yearly panels, carried larvae. Compared with Teredo bartschi, a lower percentage of adult Teredo navalis from any one panel were brooding larvae. None were brooding in June. From the size range of the animals not brooding, it is clear that many were large enough to be females. The population appears to be less synchronized than that of T. bartschi. Histological examination of gonadal material has been initiated to determine if these two presumed protandrous species of shipworms might have different sequences of sexuality. There is an obvious difference in the minimum size of brooding females of the two species, shown in Table 21 and in similar tables in our previous reports. There seems to be no correlation of station or type of panel (cumulative or yearly) with the percentage of adult T. navalis that were brooding larvae.

It is important to observe that the cumulative panels submerged in May and retrieved in August already contained brooding adults of T. navalis at the Oyster Creek and Forked River stations where T. navalis settled. However, T. navalis from control stations (stations 1 and 14) did not contain larvae, although specimens at station 1 were certainly large enough (Table 14). No breeding at all was observed at station 1. Teredo bartschi, like T. navalis, reached female maturity by August, although data from monthly panels indicate that it began boring into test panels later in the summer than T. navalis.

Although our monthly and cumulative panels revealed relatively few shipworms that had successfully penetrated the wood by July, our plankton tows taken on July 2, 1981, did yield shipworm larvae (Table 22). Also extremely abundant were ctenophores, which can eat shipworm larvae and other zooplankton, and have been thought to be capable of reducing shipworm populations (Nelson, 1923). Although our plankton tows were not quantitative, the ctenophores were clearly most abundant at stations 11 and 12 in Oyster Creek.

Table 19

Percentage of Wood Weight Lost by Cumulative Panels Submerged May 7, 1981

Station	July 2	August 4
1	4.8	8.3
3	0.0	0.0
4	4.4	7.4
5	0.0	12.6 *
8	5.3	8.2
10	0.0	0.0
11	6.5 *	7.3
12	6.2	6.0
14	6.2	6.5
1 Rep.	0.0	7.1
4 Rep.	0.0	7.0
8 Rep.	0.0	8.0
11 Rep.	0.0	7.1

* Greatest damage for the month

Rep. = Replicate panel

Table 20

Percentage of Wood Weight Lost by Yearly Panels

Date Removed: Station	June 8, 1981	July 2, 1981	Aug. 4, 1981
1	9.3	0.0	14.3
3	0.0	0.0	0.0
4	22.2	22.6	0.0
5	23.4	24.4	15.7
8	29.9 *	13.1	18.6
10	0.0	19.6	23.9 *
11	12.7	27.5	17.6
12	19.7	12.4	14.7
14	22.0	11.9	16.0
1 Rep.	0.0	14.4	11.1
11 Rep.	27.0	28.5*	0.0
14 Rep.	13.8	22.4	6.6

* Greatest damage for the month

Rep. = Replicate panel

Table 21

Percentage of Living <u>Teredo</u> Carrying Larvae in the Gills

	Mo. Submerged	Max.Length of ship-worms with Larvae (mm)	Min.Length of ship-worms with Larvae (mm)	Max.Length of ship-worms without Larvae (mm)	Min.Length of ship-worms without Larvae (mm)	% of Adult shipworms with Larvae	Sample Size
<u>Teredo bartschi</u>							
12 June	12	60	50	90	2	10	20
11 August	3	32	27	5	4	100	2
11 August	3	43	29	-	-	100	4
12 August	3	35	9	8	1	100	4
12 August	12	41	11	-	-	100	8
<u>Teredo navalis</u>							
12 July	12	36	-	25	-	50	2
4 August	3	71	-	79	41	25	4
4 August	3	77	-	70	-	50	2
8 August	3	71	56	38	30	40	5
8 August	3	70	-	82	53	25	4
11 August	3	68	-	95	40	33	3
5 August	12	96	45	33	25	75	8
8 August	12	95	-	66	32	33	3
11 August	12	91	-	-	-	100	1
14 August	12	50	-	47	-	50	3

Table 22

Contents of Plankton Samples Collected July 2, 1981

Station 1

Teredo navalis pediveligers. Common
Straight-hinge larvae, teredinid sp., probably *Bankia gouldi*. Abundant
Barnacle nauplii
Harpacticoid copepods

Station 4

Straight-hinge larvae, teredinid sp. Rare
Barnacle nauplii
Ctenophores
Marine mite
Nematodes
Harpacticoid copepods
Bryozoans
Fragments of *Enteromorpha*
Wood fragments

Station 8

Barnacle nauplii
Idotea (isopod)
Several species of copepods (mostly harpacticoids)

Station 11

Teredo bartschi pediveligers. Abundant
Juvenile polychaetes
Harpacticoid copepods
Chironomid midges
Hydroid medusae
Nematodes
Ctenophores. Abundant
Idotea (isopod)
Crab zoea
Crustacean nauplii
Gastropod veliger (probably *Anachris avera*)
Wood fragments

Station 12

Gastropod veliger (probably *Anachris avera*)
Harpacticoid copepods
Barnacle nauplii
Ctenophores. Abundant
Chaetognath eggs
Juvenile copepods - Calanoid
Juvenile polychaetes
Nematodes
Idotea (isopod)
Wood fragments

Shipworm Physiological Ecology

The experiment which tested the behavior of Teredo bartschi pediveligers on three types of substrates gave surprising results. We predicted, on the basis of field results, that the pediveligers would prefer to settle on "old" wood containing bacteria and other biological material, and especially on wood already containing adults. However, the pediveligers in the bowl with the new wood were the earliest and most active burrowers (Table 23). It was not realistic to give the same animals a simultaneous choice of wood types, because any chemical from one piece would diffuse into the surrounding water. But the pediveligers used in the experiment were all of the same age and genetic stock.

When the experiment was repeated, there was no pattern in boring activity. The majority of the pediveligers in each bowl were inactive. The aeration of the tanks was intermittent overnight due to a faulty pump; our data were probably affected by loss of vitality of the pediveligers.

Observations on the Effect of Turbidity

When silt was added to the water, the adult Teredo bartschi withdrew their siphons until only the tips were extended. However, some filtration appeared to occur. After 15 minutes, the siphons were partially extended, about half as long as the siphons of the control experiment.

When the experiment was repeated, similar results were obtained. The siphons were initially withdrawn. After 7 minutes, they had re-extended, although the water was still so turbid that one could not see from one side of the finger bowl to the other. After 15 minutes, the water was stirred up, and the siphons retracted again, reappearing after 5 minutes. The animals appeared oblivious to a thick (~3 mm) layer of silt that settled on the panels.

Control panels containing Teredo bartschi in filtered seawater extended their siphons throughout the period of observation.

Other Laboratory Observations

In September, 1979, pediveligers of Teredo bartschi were induced to settle on fresh wood in the laboratory. These specimens were used as breeding stock and for physiological experiments in the following months. We also observed the growth and mortality of some of the original individuals. The lifespan of these individuals can now be described. In the spring of 1981, many of the original animals were dead. The last of them were dead by the end of August, 1981. Hence the lifespan of these specimens, kept at 22-24 ‰ salinity and approximately 20° (winter) - 30° C (summer), was

Table 23

Behavior of Pediveligers of _Teredo bartschi_
Exposed to three Treatments of Wood

Behavior	With Adults	With Adults	Old Wood	Old Wood	New Wood	New Wood
			Type of Wood			
A. Initial Observation (after 30 minutes)						
Closed on bottom	2	5	2	2	2	2
Crawling on glass	2	0	0	0	0	0
Swimming	4	2	6	5	0	0
Burrowing or probing wood	2	0	0	1	7	6
Gaping on bottom	0	1	0	1	0	0
Not seen	0	2	2	1	1	2
B. After 3 hours						
Closed on bottom	0	2	0	1	2	4
Crawling on glass	0	0	1	0	0	0
Swimming	10	6	4	4	1	0
Burrowing or probing wood	0	0	0	0	7	6
Gaping on bottom	0	0	0	0	0	0
Not seen	0	2	5	5	0	0
C. After 4 days						
Closed on bottom	*	*	1	3	0	0
Crawling on glass	*	*	0	0	0	0
Swimming	*	*	0	1	0	0
Burrowing or probing wood	0	0	0	0	4	5
Gaping on bottom	0	0	5	1	0	0
Not seen	*	*	4	5	6	5

* Adults in the wood released pediveligers.
The original 10 pediveligers could not be identified.

about 24 months or less. These animals produced pediveligers almost continuously during their lives, although production of the pediveligers tended to peak in one 2 or 3 week period, followed by an equal period in which few offspring were released.

Studies of the freshwater clam *Corbicula* (Dreier and Tranquilli, 1980) showed that caged specimens grew significantly more in a thermal discharge than in a plant intake area. The season of growth was extended. These results are in accordance with ours for the teredinid clams.

In prior reports for 1980-81, we did not include full data on the percentage of adult *Teredo* sp. carrying larvae in the gills. These data are now reported (Table 24) in order to compare with the data from the current quarter (Table 21). It is evident that very little reproductive activity occurred after December in *Teredo bartschi*. *T. navalis* showed no sign of brooding from December to April, with the exception of one specimen in March. We can conclude that while neither species bred all year, *T. bartschi* was active for a longer period.

Table 24

Presence of Brooded Larvae in Specimens Removed in Winter and Spring, 1980-81

Species Date Station	Mo. Submerged	Max.Length of ship-worms with Larvae (mm)	Min.Length of ship-worms with Larvae (mm)	Max.Length of ship-worms without Larvae (mm)	Min.Length of ship-worms without Larvae (mm)	% of Adult shipworms with Larvae	Sample Size
<u>Teredo</u> <u>bartschi</u>							
December, 1980							
Sta. 12	7	90	20	70	0.5	48	130
Sta. 12	12	82	10	40	1.0	61	122
Sta. 8	12	72	36	-	-	100	2
January, 1981							
Sta. 12	7	75	18	46	0.5	40	50
	12	34	18	35	2.0	27	11
February, 1981							
No brooded larvae							
March, 1981							
Sta. 8	10	50	-	-	-	100	1
April, 1981							
Sta. 8	11	Ten empty tubes contained larvae					
May, 1981							
Sta. 8	12	One empty tube contained larvae					
<u>T.</u> <u>navalis</u>							
March, 1981							
Sta. 14	10	175	-	-	-	100	1
May, 1981							
Sta. 14	12	190	-	170	2.0	20	5

GENERAL DISCUSSION

The elevation of temperature caused by the operation of the plant was within tolerable biological limits for most of the summer of 1981. A ΔT of 4 to 5° C in July and August does occasionally cause the temperature to exceed 30° C by several degrees, and hence to cause stress and even mortality in some local species. The ΔT is lower than it was prior to 1974 when fewer dilution pumps were operated. It appears that the reduced ΔT could have been one of the factors in reducing the breeding of *Teredo bartschi*. However, it has not eliminated the introduced species, and outbreaks still occur.

There has been some controversy about the salinity of Oyster Creek prior to the operation of the plant. It is clear from the data in 1980-1981 that the present salinity from the bay to the plant is close to that of Barnegat Bay. We asked NOAA for all available climatic data for the Oyster Creek-Barnegat Bay region prior to the operation of the Oyster Creek Nuclear Generating Station. The computer printout that we received shows that, for the period May 10, 1967 - April 10, 1968, salinity in the lower portion of Oyster Creek ranged from 9.2 to 27.5 in G/L (conductivity). For comparison, stations in Barnegat Bay over the period never recorded a salinity lower than 17 G/L. The salinity in Forked River varied between 16.2 and 25.6 G/L conductivity from May 10, 1967 - April 10, 1968. Therefore it seems that the salinity in Oyster Creek was at times much lower than that in the bay. However, we cannot be sure exactly where the conductivity was measured in all cases. The values of G/L conductivity are approximately the same in ‰ salinity.

Our data for 1980-81 continue to show greater individual shipworm growth in Oyster Creek and Forked River than at other stations, although the data are confounded by the effects of crowding. The greater growth may be due to higher and more constant salinity than at station 1 (Holly Park). Discounting this argument is the fact that station 14 (Waretown) does have constant salinity yet usually has slower growth than the Oyster Creek stations.

Two other factors could account for the rapid growth: higher temperatures and greater food supply. For *Bankia gouldi* and *Teredo navalis*, which are thought to require plankton as well as wood during adult life, the greater currents in Oyster Creek and Forked River could contribute to better nutrition. For all shipworm species, currents improve access to micro-nutrients and remove toxic materials. Areas of moderate to fast currents have greater settlement of juveniles and much better survival of the juveniles as they begin boring into wood (see our earlier reports dealing with station 18 versus 19). An example of the effect of currents is the difference between station 10 in a lagoon with poor circulation off Oyster Creek, and station 11 nearby. Recruitment of shipworms to station 10 is poor. Yet shipworms do grow rapidly and reach large sizes at station 10, suggesting that temperature is the most important growth factor.

Blake et al. (1981) of the Battelle Laboratories have made findings and drawn conclusions quite similar to ours. Their agreement with us is all the more significant because their study was commissioned by the operators of the Oyster Creek Nuclear Generating Station. Their study included gonad analysis that complements our own work.

M. Kennish of Jersey Central Power and Light Company estimated for Blake et al. (1981) that recirculation of the heated effluent into Forked River occurs as much as 22% of the time; this is in accord with our data in 1976-1981 on water temperatures at stations 4, 5, and 8 and with the Blake et al. data (1981, p. C-50). Shipworm damage was reported to be higher in 1979-80 than in 1980-81, and higher in Oyster Creek and at the mouth of Forked River than other inner Barnegat Bay stations. Teredo bartschi was found only in areas influenced by the thermal effluent, that is, Oyster Creek, Forked River, and the portion of Barnegat Bay between the two creeks. This introduced species was responsible for most of the damage to the Battelle Laboratories panels.

The finding by Blake et al. (1981) of Teredo spp. with ripe gonads in winter is interesting but ambiguous. Neither Battelle Laboratories nor our research group has found larvae settling on newly deployed panels in winter. However, both research groups have found 1-2 mm specimens of Teredo bartschi in panels submerged during the previous spring and removed in winter. Either the pediveligers are attracted to old wood, or they fail to grow once they settle in November. We believe that both explanations are valid, but that the latter explanation is more important for Teredo navalis, based on our experience with both species in the laboratory. We have no evidence that T. navalis actually spawns in January, and neither does Battelle Laboratories.

Blake et al. (1981) contend that the nuclear generating station is not affecting the populations of Teredo navalis and Bankia gouldi. We agree that in 1980-81, the numbers of these species were not higher in Oyster Creek than at some other stations in Barnegat Bay. But this is the wrong comparison. There are two factors to consider: A) What would be the abundance of the two species in Oyster Creek and Forked River if the station didn't exist? In other words, we must compare the abundances not to Barnegat Bay populations but to tidal creek populations. The Battelle Laboratory has not disproven that populations of T. navalis and B. gouldi are enhanced by the thermal effluent. B) What would be the abundances of the two native species in Oyster Creek if Teredo bartschi was not competing for wood? Our results before and after T. bartschi was introduced suggest that indeed, the native populations are lower with the presence of the third species.

We agree with Blake et al. (1981) that Teredo bartschi probably reproduces throughout the year in its native state. Specimens collected in Florida in May, June, October, and November all contained larvae in the gills.

However, in Oyster Creek, most of the young are held in the gills during winter and not released.

Blake *et al*. (1981, p. A-17) agree with our finding of a delay in settlement of larvae in 1980 until August. Like us, they attributed the delay in settlement as well as the decline in *Teredo bartschi* to the outage of the generating station that lasted from January to July, 1980. The Battelle Laboratories research group also admits that the generating station influences the areas of Waretown and Forked River, due to the location of the thermal plume.

One other nuclear generating station is known to have mediated the introduction of *Teredo bartschi*. At the Millstone plant in Connecticut, *T. bartschi* occurs only at the test station within the discharge area. There, cumulative panels removed in November show little damage due to *T. bartschi*, but by February, the effluent panels have the greatest destruction of all the test panels (D. Morgan, undated and unpublished report). This can be explained by the fact that *T. bartschi* settles in the fall at Millstone, after the native species. Yet it continues to grow in the effluent while native species become nearly inactive. The same phenomenon occurs in Oyster Creek and Barnegat Bay.

Hillman (1978) and Blake *et al*. (1981) believe that the parasite *Minchinia* could be a factor causing oscillations in numbers of *Teredo* species in Barnegat Bay. We concur in this possibility and believe that the theory should be tested in as rigorous a manner as possible. Predictions should be made of the effect of the parasite on populations of various densities and age compositions, based on the preliminary data. Future histological work should include data from enough individuals and months to test the theory. The observed correlation of the outages of the generating station and the population crashes and lags of *Teredo bartschi* remains, despite the *Minchinia* theory. Perhaps *Minchinia* is in some way correlated with plant operations.

CONCLUSIONS

The key factor controlling the size of shipworm populations in Oyster Creek is the success of recruitment of *Teredo bartschi*. It is not directly related to the number of adults surviving the winter. The best way to reduce the teredinid population in Oyster Creek and Forked River is to perform a thorough clean-up in the area of station 12, where a residual population has survived each winter. This cleanup should be performed in early April, 1982, before the 1982 release of pediveligers.

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* Available for purchase from the NRC/GPO Sales Program, U. S. Nuclear Regulatory Commission, Washington, D. C. 20555, and the National Technical Information Service, Springfield, VA 22161.

APPENDIX: STATION LOCALITIES

STATION NUMBER	NAME	DESCRIPTION	COORDINATES
1	Holly Park	Dick's Landing Island Drive Bayville, N.J. Bay control	Lat. 39° 54' N Lon. 74° 8' W
3	Stout's Creek	End of Raleigh Drive Gustav Walters' residence Estuarine control	39° 50.7' N 74° 9' W
4	Mouth of Forked River	South Shore Developed property Possible temperature increase increased oceanic influence due to reverse flow	39° 49.6' N 74° 9.8' W
5	Leilani Drive	At branch point of Forked River	39° 49.6' N 74° 10.5' W
6	Elk's Club	South Branch Forked River Increase in salinity due to plant intake canal	39° 49.4' N 74° 10.9' W
8	Bayside Beach Club	On bay between Oyster Creek and Forked River across from 1815 Beach Blvd., Forked River, N.J. Temperature increase since plant operation.	39° 49.0' N 74° 9.7' W
10	Kochman's Residence	End of Compass Rd. on #1 Lagoon, Oyster Creek Waretown, N.J. Temperature, salinity siltation increase	39° 48.5' N 74° 10.6' W

STATION NUMBER	NAME	DESCRIPTION	COORDINATES	
11	Crisman's Residence	Dock Ave. on Oyster Creek, Waretown, N.J. Temperature, salinity, siltation increase	39° 48.5' 74° 11.0'	N W
12	Gilmore's Residence	20 Dock Ave. on Oyster Creek Waretown, N.J. Temperature, salinity, siltation increase	39° 48.5' 74° 11.3'	N W
14	Cottrell's Clam Factory	End of North Harbor Rd. Waretown, N.J. (Mouth of Waretown Creek) Within but near limits of reported thermal plume	39° 47.7' 74° 10.9'	N W
15	Carl's Boats	Washington & Liberty Sts. Waretown, N.J. (on the bay)	39° 47' 74° 11'	N W
18	Barnegat Light	Marina adjacent to Coast Guard Station	39° 45.8' 74° 6.5'	N W

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The species composition, distribution, and population dynamics of wood-boring bivalves are being studied in the vicinity of the Oyster Creek Nuclear Generating Station, Barnegat Bay, New Jersey. Untreated wood test panels are used to collect organisms at 12 stations. Physiological tolerances of 3 species are also under investigation in the laboratory. Competition among the species is being analyzed. In the summer of 1981, *Teredo bartschi* occurred in large numbers at one station in Oyster Creek, but did not appear in significant numbers in Forked River. The ΔT in Oyster Creek was about +4° C. Both *Teredo bartschi* and *T. navalis* settled, matured, and produced offspring in less than 3 months in Oyster Creek. Specimens of *T. navalis* brooding young were more frequent in Oyster Creek than at control stations. Laboratory experiments indicated that *T. bartschi* pediveligers do not prefer to settle on wood containing adults.

17. KEY WORDS AND DOCUMENT ANALYSIS

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