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ECOLOGICAL FACTORS RELATED TO THE DISTRIBUTION OF *Bankia gouldi* BARTSCH IN CHESAPEAKE BAY

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May, 1954
Publication No. 100

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Solomons Island, Maryland

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ECOLOGICAL FACTORS RELATED TO THE DISTRIBUTION OF *Bankia gouldi* BARTSCH IN CHESAPEAKE BAY

INTRODUCTION

The family Teredinidae is a group of marine bivalve molluscs which is cosmopolitan in its distribution. The molluscan character of the group was first recognized by the Dutch zoologist G. Snellius in 1773. Extensive damage to wooden structures in marine waters has made the teredinids the subject of considerable study throughout the world. Many of these studies have been coincident with sudden and severe destruction to marine installations. Between the years 1919 and 1921, the sudden spread of *Teredo navalis* Linnaeus in San Francisco Bay caused damage estimated in excess of fifteen million dollars (Kofoid and Miller 1927). Clapp (1946) estimated an annual loss of 55 million dollars to waterfront structures in the United States alone.

The predominant form of shipworm in Chesapeake Bay is Gould's shipworm, *Bankia gouldi* Bartsch. The natural history and morphology of this species was extensively studied by Sigerfoos (1907). Geographical limits of the species extend from the New Jersey Coast to the West Indies, including the Gulf of Mexico and southward to Brazil (Clench and Turner 1946). The distribution of the teredinids in Chesapeake Bay as here described was studied during the period extending from May 1950 to May 1953.

METHODS AND MATERIALS

Organisms were collected on test panels, six inch lengths of dressed two by four inch pine, suspended in the water in a vertical position as described by Turner (1947). The panels were usually located at some convenient structure such as a dock-piling or sea-wall. Except where otherwise indicated by the data, the samples were collected from each station once a month between May 1950 and May 1953. During the three year period, seven hundred and nineteen panels were submerged in Chesapeake Bay. Approximately 14,000 organisms were encountered on these panels of which 20% or approximately 3,000 organisms could be identified from the dried pallets. Preliminary notes on the extent of fouling were made in the field after which the samples were removed to the laboratory for further study.

During the fall of 1953, collections were made from pilings and stakes at selected locations throughout the bay and its tributary rivers in order to better delineate the distribution of the teredinids in the Chesapeake Bay estuarine system.

Salinity and temperature determinations were made each month at both the surface and bottom at the time the panels were collected. Water samples were obtained with a Kemmerer water sampler and were returned to the laboratory in citrate of magnesia bottles where salinity determinations were made either by titration with silver nitrate or from densities obtained with a hydrometer standardized by the U. S. Bureau of Standards. Salinities are reported to the nearest tenth of a part per thousand (o/oo). Temperatures were determined with a reversing thermometer and are given to the nearest tenth of a degree centigrade.

The panels were examined in the laboratory to determine the extent of fouling by barnacles, serpulids and sedentary molluscs, and were then scraped clean with a knife. Examination for shipworms was done under a binocular dissecting microscope at magnifications of 8.4 and 24 X. The entire surface of the panels was examined and all burrow openings were counted. In those cases where the pallets extended from the opening of the burrow, the species was determined and recorded. It was possible by this method to count and identify small specimens of 2 mm. in length. Most of the test panels were dry when examined. This was necessary because of the time which unavoidably elapsed between the collection of samples and their examination. In many instances, therefore, the number of organisms actually living when the panels were removed from the water could not be determined.

On most of the early test panels, the lengths of the organisms were estimated by measuring the length of their burrow. This was done by splitting each panel lengthwise with the grain into several thin sections, and then measuring the length of the various sections of each burrow with a piece of fine wire. These measurements were discontinued during the summer of 1952 and 1953.

Sample specimens from each station studied have been deposited in the U. S. National Museum, Washington, D. C. (Catalog numbers 605188 through 605194) and in the Museum of Comparative Zoology, Harvard University, Cambridge, Massachusetts. The location of the test panel stations is shown in figure 1.

DESCRIPTION OF THE AREA

The Chesapeake Bay is a coastal plain estuary and is the largest inland body of water along the Atlantic coast of the United States. It is formed from the drowned river valley of the Susquehanna River (Shattuck *et al.* 1906, Carter 1952). As may be seen in figure 1, the coastline of the estuary is very irregular and many rivers or secondary estuaries contribute to the Chesapeake Bay system. The Bay extends in a north-south direction for approximately 306 kilometers from Havre de Grace, at the mouth of the Susquehanna River, to the Virginia Capes where it opens into the Atlantic Ocean in an eastwardly direction between Cape Charles and Cape Henry.

The physical features and hydrography of Chesapeake Bay are described by Cowles (1930) and more recently by Pritchard (1952c). Hydrographic data from the Chesapeake Bay have been routinely collected by the Chesapeake Bay Institute, the Johns Hopkins University, since 1949 and have recently been graphically summarized by Whaley and Hopkins (1952). The typical surface salinity distribution as shown in figure 1 has been extensively discussed by Pritchard (1952a, 1952b, 1952c). Beaven (1946) has indicated that the Susquehanna River contributes 85 percent of the fresh-water inflow in the upper Chesapeake Bay (above the Potomac River) and has shown that variations in the Susquehanna River flow have marked effects on the salinities of the upper bay. The seasonal differences in temperature

TABLE I

DESCRIPTION OF TEST PANEL STATIONS

Location	Depth (M)	Salinity [1] Range o/oo	Mean [2] Salinity o/oo	Principle Fouling Organisms [4]	Approximate Percent of Total Area Covered by Fouling [4]
MARYLAND					
Patapsco River, mouth of Middle Branch, Baltimore	1.6	0.5-12.7	7.9	*Balanus eburneus* Gould *Victorella pavida* S. Kent	*B. eburneus* covering 20% at intertidal to 80% just below intertidal area.
Wall Cove, Rock Creek	2.0	2.9-11.7	7.4*		
Gibson Island, Sillery Bay	2.0	3.4-14.9	7.9*	*Balanus eburneus* *Corophium lucustre* Vanhöffen	*Balanus* covering from 50 to 85% of surface. Entire remaining surface usually covered with mud tubes of *C. lucustre.*
Kent Narrows	1.2	5.6-14.8	9.9*	*Enteromorpha sp.* *Ulva sp.* *Molgula manhattensis* Dekay	
Spa Creek, at mouth Annapolis	1.6	3.3-15.6	9.3	*Corophium lucustre* *Balanus eburneus*	*C. lucustre* most abundant covering usually the entire surface of panel in autumn.
Choptank River, Cambridge	1.8	5.1-14.5	9.2	*Balanus eburneus* *Victorella pavida*	15% of surface covered with *B. eburneus.*
Patuxent River, Solomons Island	1.8	6.0-17.9	13.6	*Balanus eburneus* *Membranipora crustulenta* (Pallas) *Acanthodesia tenuis* (Desor) *Cylista leucolena* Andres *Molgula manhattensis*	10%-80% *B. eburneus* on surface of panels. Most abundant one half meter off bottom.

Little Annemessex River, Crisfield	2.0	12.7-19.2	15.9*	*Balanus eburneus*, *Molgula manhattensis*, *Membranipora crustulenta*, *Cylista leucolena*, *Ulva sp.*, *Enteromorpha sp.*	*B. eburneus* covered 20% of panels in intertidal area.
VIRGINIA					
Pungoteague Creek, Harborton	1.0	13.2-19.9[3]	16.6	*Molgula manhattensis* *Hydroides sp.* *Balanus sp.* *Crassostrea sp.*	*M. manhattensis* and *Hydroides sp.* covered most of panels. *Balanus sp.* covered 50% of panel at 10 cm. off bottom.
Gloucester Point	1.0	26.3-15.2	19.6	*Hydroides hexagones* Bosc., *Anomia simplex* Orbigny	50% of surface covered with *H. hexagones* on panels near surface.

[1] Maximum and minimum salinities recorded from monthly samples taken between May 1950 and May 1953.

[2] Mean annual salinity taken from data of Coast and Geodetic Survey except figures with asterisks (*) which are calculated from samples taken once a month between July 1951 and July 1952. Data from Baltimore is annual mean for 1950.

[3] Data from monthly samples taken between April and October 1952.

[4] Observations based on data for summer of 1952 (April through October).

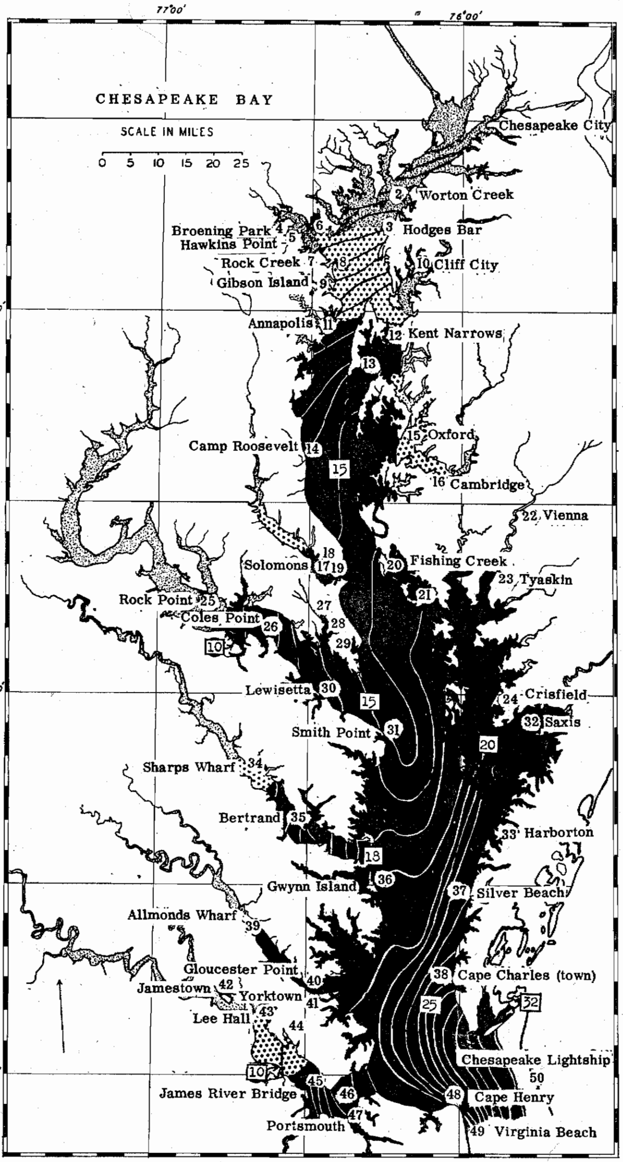

FIGURE 1. Distribution of *Bankia gouldi* Bartsch in Chesapeake Bay. The darkened portion of chart indicates area where Bankia is normally always encountered. Large stippling indicates the area in which Bankia has occasionally been reported. Areas from which Bankia has never been reported are indicated by fine stippling. Isohalines indicate typical salinity distribution during summer months. (Salinity distribution after Pritchard 1952 c). The numbers in the figure indicate points of collection (*), test panel stations (†), and records from the literature (see Appendix I). Numbers in squares indicate salinity in parts per thousand.

and salinity as these relate to the setting and distribution of *Bankia gouldi* are discussed below. Table I indicates the hydrographic and fouling characteristics of each test panel station.

RESULTS

Species represented in Chesapeake Bay

The only species of teredinid encountered from panels examined in this study was *Bankia gouldi* Bartsch, although specimens of *Teredo navalis* (Linnaeus) were collected during the autumn of 1953 from a piling at Cape Henry, Virginia. Brown (1952) has reported *Teredo bartschi* Clapp in the Elizabeth River at Portsmouth, Virginia, while *Teredo navalis, Teredo megotara* Hanley and *Teredo sigerfoosi* Bartsch have been identified from test panels exposed from the Chesapeake lightship (36° 59′ N. Lat.–75° 42′ W. Long.). The only other species recorded from the Chesapeake Bay region is *Teredo morsei* Bartsch in the collection of the U. S. National Museum, Washington, D. C. (U.S.N.M. 348124), but unfortunately the specimen has deteriorated beyond recognition. It was collected from Lambert Point, Norfolk, Virginia, on November 10, 1922. This species is probably a stenomorph of *Teredo navalis* and in any case the record is of little value since the specimen is not intact. *Bankia gouldi* is the only species that previously has been reported north of the York River and appears to be by far the most important species in the Chesapeake Bay.

Distribution

Bankia gouldi is distributed in Chesapeake Bay from the mouth of the Bay northward to Annapolis, Maryland, and occasionally extends as far up the estuary as the entrance of the Patapsco River. It is found in the more saline regions of the many tributary rivers of the Chesapeake Bay. The upper limits of distribution vary somewhat from one year to the next and depend largely on numerous ecological conditions which at present are difficult to define. These limiting conditions may possibly include variations in salt water intrusion up the estuary and differences in the transport of larvae within the estuary. The horizontal distribution of *Bankia gouldi* Bartsch in Chesapeake Bay, as determined by collections in the field, panel data, records in various museums, and from the literature, is indicated in figure 1.

The vertical distribution of set by Bankia was examined on panels submerged at various depths during the summer of 1952. Only stations where data for the complete vertical column were available have been considered. An examination of the profiles shown in figure 2 seems to indicate that the largest proportion of the total number of organisms appear in the lower half of the vertical column. Observations made in the field have generally indicated that the strike is greater below the intertidal area in Chesapeake Bay. Kofoid and Miller (1927), Johnson and Miller (1935), Edmondson (1942), Black and Elsey (1948), and Greenfield (1952) have made observations on the vertical distribution of teredinids in various areas and have found that in conditions of shallow water the strike increases with depth. Quayle (1951) has recently studied the vertical distribution of larvae from *Bankia setacea* Tryon in British Columbia waters and has shown that at a relatively shallow station (6.1 meters) at Ladysmith Harbor the number of larvae increases with depth. Sixty-four percent of the total number of larvae in the vertical column were found on the bottom. Data from Black and Elsey (1948) indicate that on surface and bottom test panels exposed between July 1933 and January 1936 at Ladysmith Harbor, British Columbia, 85 percent of the set occurred on the bottom panels. In this instance there appears to be good agreement betwen the observed vertical distribution of larvae and set. A

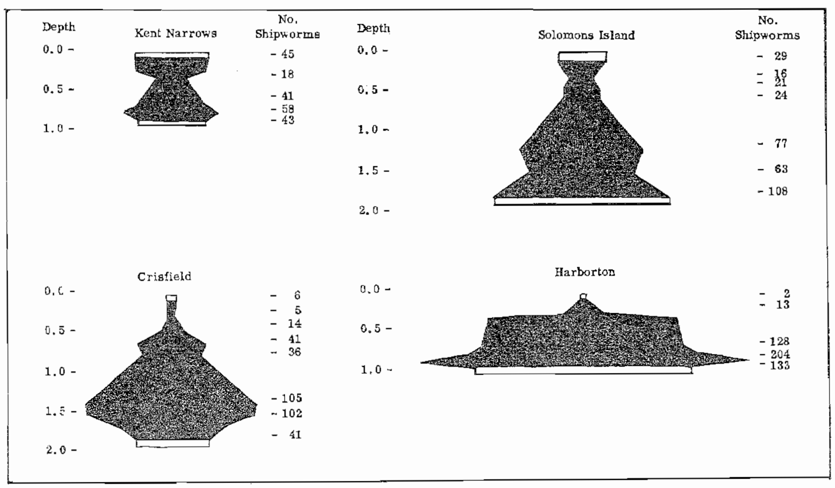

FIGURE 2. Vertical distribution of set at four stations in Chesapeake Bay during the summer of 1952. The numbers at the left of each profile indicate the depth in meters. Figures at the right of each profile indicate the number of Bankia per test panel at the depth indicated by the dash. All profiles indicate a series from surface to bottom.

more satisfactory study on the vertical distribution of *Bankia gouldi* in Chesapeake Bay depends upon the description of the larvae, a knowledge of their vertical distribution, and on a more extensive series of data from test panels.

Period of setting

Attacks of *Bankia gouldi* in Chesapeake Bay occur between the beginning of June and the end of October. The period during which the set of *Bankia* occurs closely coincides with that of the oyster *Crassostrea virginica* Gmelin in Chesapeake Bay, but the heaviest attack usually occurs somewhat later. This may possibly be related to a longer larval life of Bankia. The relative magnitude of the strike for each month during the period between May 1950 and May 1953 is given in Table II. An examination of this table indicates that the heaviest attack in most areas of the bay occurred during the month of July. This is more clearly seen in figure 3 which shows the magnitude of strike for each month in the lower Chesapeake Bay stations during the summer of 1952. The peak strike may however sometimes occur during the month of August. This is seen in figure 4 which shows data taken for three consecutive years at Gloucester Point, Virginia.

The period of maximum strike apparently may vary in different areas of the bay during the same year. The reasons for this difference can not easily be understood but certainly does not appear to be related to horizontal differences in temperature since these variations are small and are primarily related to meteorological phenomena (Pritchard 1952c). Maximum surface water temperatures of about 27-28° C are usually attained in the open bay during August.

No direct evidence was obtained to estimate the time at which spawning commences. The length of the planktonic existence of *Bankia gouldi* is not known; however, Quayle (1951), on the basis of size frequency of larvae, has estimated the pelagic life of the west coast, cold water form, *Bankia setacea* Tryon to be about four weeks at 12° C. to 15° C. in Ladysmith Harbor, British Columbia. Sigerfoos (1907) estimated planktonic life of *Bankia gouldi* to be approximately four weeks. On the basis of Sigerfoos' estimate, the spawning of *Bankia gouldi* must then probably begin in late May and certainly by early June when surface water temperatures in Chesapeake Bay are between 16° and 20° C. (60° to 68° F.).

Growth

The number of organisms which entered test panels varied markedly at different locations within the estuary. The amount of destruction caused by the organisms however can not be accurately judged from

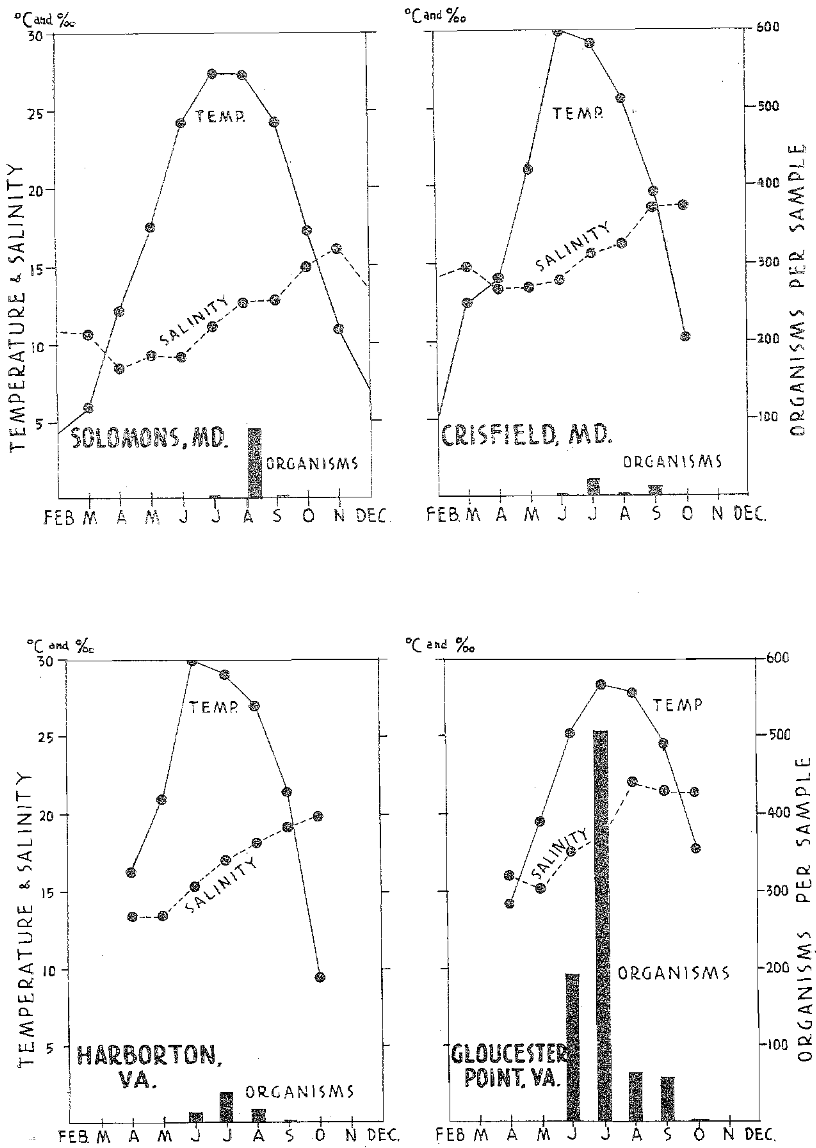

FIGURE 3. Monthly strike of *Bankia gouldi* Bartsch at four stations in Chesapeake Bay (1952). The temperature and salinity data at Solomons, Maryland, and Gloucester Point, Virginia, are means for the month from daily measurements. Similar data from Crisfield, Maryland, and Harborton, Virginia, is based on single measurements taken once a month at the time test panels were removed.

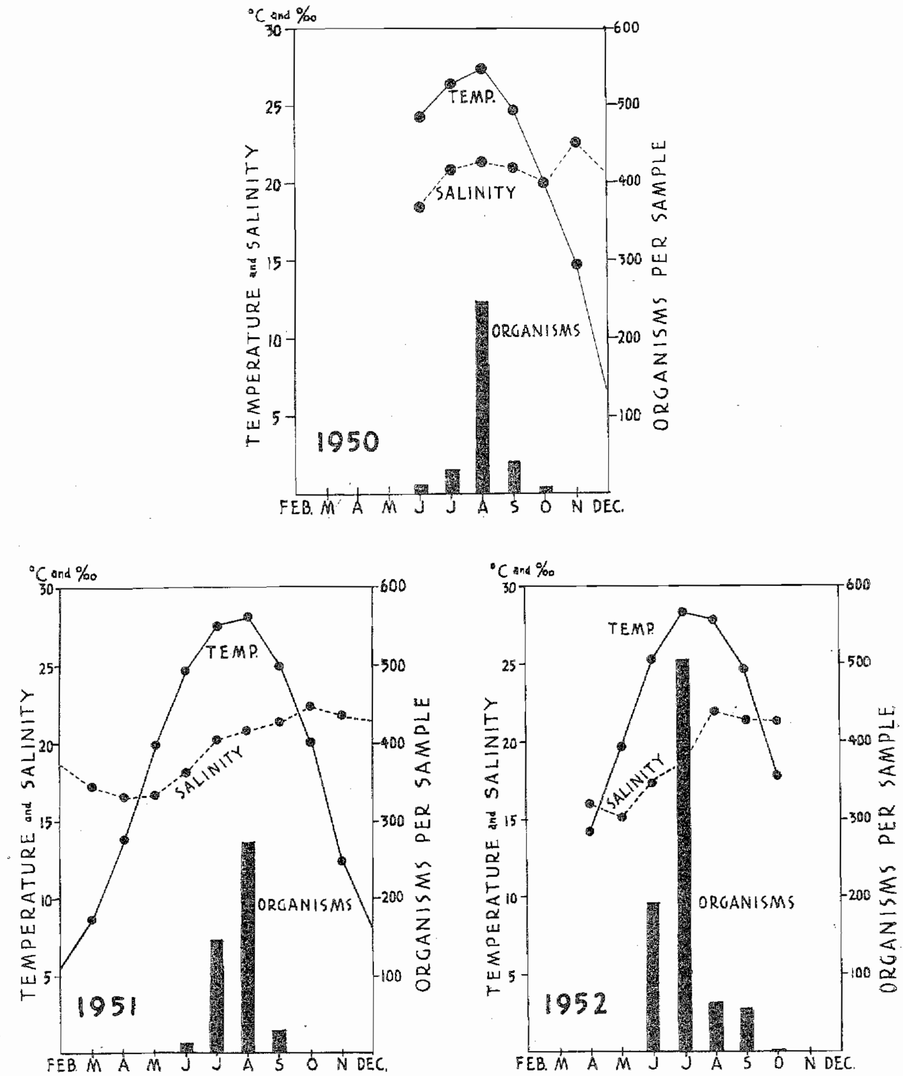

FIGURE 4. Strike of *Bankia gouldi* Bartsch by month for three consecutive years at Gloucester Point, Virginia. The temperature and salinity data are means for each month as determined from daily measurements.

TABLE II

SUMMARY OF MAGNITUDE OF SET BY MONTH OF *Bankia gouldi* BARTSCH
CHESAPEAKE BAY 1950-1953

DATE *From*	DATE *To*	Number of Shipworms Per Panel
Patapsco River, mouth of Middle Branch, Baltimore		
V-5-50	X-28-52	None
Gibson Island, Sillery Bay		
V- -50	X-28-52	None
* X-28-52	V-24-53	None
Kent Narrows		
V- -50	XI-8-50	None
XI-8-50	IV-2-51	No Data
IV-2-51	VII-2-51	None
VII-2-51	VIII-1-51	3
VIII-1-51	VI-28-52	None
VI-28-52	VII-26-53	11
VII-26-52	VIII-29-52	1
VIII-29-52	IX-27-52	2
IX-27-52	X-28-52	None
* X-28-52	V-24-53	None
Patuxent River, Solomons		
VII-31-50	IX-5-50	1
IX-5-50	X-17-50	4
X-17-50	XI-30-50	No Data
XI-30-50	V-10-51	None
V-10-51	VIII-7-51	26
VIII-7-51	IX-19-51	None
IX-19-51	X-24-51	2
X-24-51	VII-4-52	None
VII-4-52	VII-28-52	3
VII-28-52	IX-13-52	90
IX-13-52	X-15-52	2
X-15-52	XI-11-52	None
* XI-11-52	VI-20-53	None
Pungoteague Creek, Harborton		
IV-28-52	V-31-52	None
V-31-52	VI-29-52	13
VI-29-52	VII-27-52	49
VII-27-52	VIII-29-52	18
VIII-29-52	IX-28-52	1
IX-28-52	X-30-52	None
Wall Cove, Rock Creek (Patapsco River)		
V- -50	VI-30-52	None
Spa Creek (Severn River), Annapolis		
V- -50	VII-3-51	None
VII-3-51	VIII-3-51	2
VIII-3-51	VI-30-52	None
VI-30-52	VII-26-52	1
VII-26-52	VIII-28-52	None
VIII-28-52	X-1-52	1
X-1-52	X-28-52	None
Choptank River, Cambridge		
V- -50	VI-30-50	None
VI-30-50	IX-3-50	No Data
IX-3-50	X-6-50	1
X-6-50	VIII-1-51	None
VIII-1-51	I-29-52	No Data
I-29-52	VII-26-52	None
VII-26-52	IX-27-52	7
IX-27-52	X-30-52	None
* X-30-52	V-24-53	None
Little Annemessex River, Crisfield		
IV-2-51	VII-2-51	None
VII-2-51	VIII-1-51	6
VIII-1-51	IX-6-51	3
IX-6-51	X-1-51	2
X-1-51	V-31-52	None
V-31-52	VI-29-52	1
VI-29-52	VII-26-52	25
VII-26-52	VIII-29-52	1
VIII-29-52	IX-28-52	10
IX-28-52	X-29-52	None
* X-29-52	V-24-53	None
York River, Gloucester Point		
VI-10-50	VII-10-50	11
VII-10-50	VIII-3-50	32
VIII-3-50	VIII-30-50	245
VIII-30-50	X-2-50	40
X-2-50	XI-1-50	9
XI-1-50	VI-10-51	None
VI-10-51	VII-9-51	13
VII-9-51	VIII-4-51	148
VIII-4-51	IX-15-51	274
IX-15-51	X-15-51	31
X-15-51	XI-23-51	None
XI-23-51	IV-12-52	No Data
IV-12-52	VI-4-52	None
VI-4-52	VII-2-52	234
VII-2-52	VIII-1-52	521
VIII-1-52	IX-1-52	73
IX-1-52	X-1-52	59
X-1-52	XI-1-52	2

* Panels submerged continuously during period indicated.

the numbers present within a panel. This may be seen in figure 5 which shows two panels taken from different regions in Chesapeake Bay. The lower panel in figure 5 was submerged at Gloucester Point, Virginia, through the summer of 1950 and demonstrates the destruction resulting from hundreds of specimens of *Bankia gouldi*. The upper panel in figure 5 was submerged during the same period at Solomons,

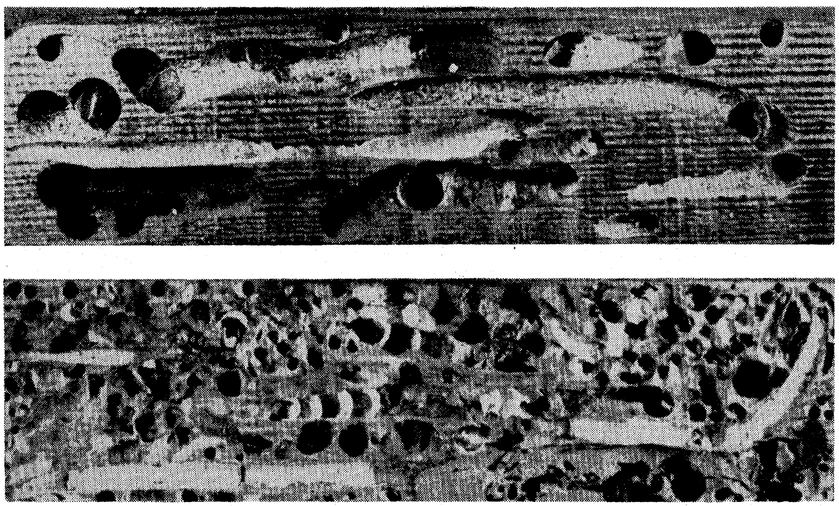

FIGURE 5. *Upper*—Panel submerged at Solomons, Maryland, from May 4, 1950, to February 5, 1951. Five hundred and seventy-seven specimens Bartsch were found in this panel.

Lower—Panel submerged at Gloucester Point, Virginia, from June 10, 1950 to February 5, 1951. Five hundred and seventy-seven specimens of *Bankia gouldi* were found on this panel. Note the larger diameter and length of the organisms in the upper panel. (⅔ actual size).

Maryland, and contained only twenty-five specimens. Obviously the growth rate of the organisms in the panels from Solomons was considerably greater than that of the shipworms found in the panels from Gloucester Point. Thus Needler and Needler (1940) comment, "A heavy attack . . . amounting at times to over one hundred individuals per square cm., would be serious even with very slow growth, but the rate of growth governs the damage when the shipworms are not crowded in the wood . . . ". Great differences in the size of sexually mature individuals are often found within a single species of shipworm. Decreased growth rates are believed to be due principally to over-crowding of the organisms within the substrata. The term stenomorph has been suggested by Bartsch (1923) to include those individuals whose growth has been affected in this way. The studies of Isham *et al.* (1951) on the growth rate of *Teredo pedicellata* De Quatrefages at Miami Beach, Florida, demonstrate that on panels exposed for more than two months, the summer rate of growth is reduced as a result of over-crowding, due to the heavy summer attack rate.

The difficulties encountered in growth studies on shipworms are clearly apparent in the last mentioned paper (Isham *et al.* 1951). Briefly these may be summarized as follows:

(1) *Difficulty in determining the age of individuals from submerged panels.* It is not possible to know the exact date any particular organism entered the wood. This makes it necessary to choose arbitrarily a sample from the largest organisms present in the panel, the assumption being that the largest organisms present were the first to set.

(2) *Difficulty in finding a measurement which is a reliable index of growth.* Burrow length does not appear to be a very reliable index. We have often observed in our samples that the organisms need not occupy the entire length of the burrow. In many cases the burrows of *Bankia gouldi* were found to be bifurcate.

(3) *Difficulty in eliminating the effect of crowding.* This problem may be more or less overcome by using large panels or by leaving only a small area of the panel exposed. This may be accomplished by painting part of the surface with an antifouling paint (Needler and Needler 1940).

(4) *Difficulty in the actual mechanics of making measurements.* This difficulty possibly may be partially overcome by making use of stereoscopic x-ray photographs (Crisp *et al.*, 1953). An advantage of this method is that it makes it possible to follow the growth of the same individuals over an extended period of time.

From a practical point of view, it is not the growth which concerns us, but rather the rate of boring. In Table III are summarized data on the rate of boring from three widely separated areas in Chesapeake Bay. The column "mean length Cm." indicates the mean length of the ten longest organisms except where the total number is small and where it appears that certain individuals in the panel are obviously much "younger". The column "apparent rate of growth"

TABLE III

RATE OF BORING: *Bankia gouldi* Bartsch
CHESAPEAKE BAY 1950-1951

Date Submerged From	Date Submerged To	No. Months Submerged	Total No. Shipworms	Maximum Length Cm.	Mean Length Cm.	Apparent Rate of Boring (Cm.)
			Kent Narrows			
VII-2-51	VIII-1-51	1	3	3.1	2.7	
						0.5
XII-8-50	VIII-1-51	9 (2)	3	4.2	3.2	
						15.3
XII-8-50	IX-6-51	9 (3)	8	18.2	18.5	
						6.3
XII-8-50	XI-29-51	12 (6)	10	28.7	24.8	
						5.2
XII-8-50	I-4-52	13 (7)	9	30.0	....	
						....
IX-3-50	XI-5-51	14	5	31.7	....	
						1.1
VI-30-50	XI-5-51	16	2	35.0	31.1	
VI-30-50	XI-5-51	16	8	34.2		
VI-30-50	XI-5-51	16	2	29.7		
VI-30-50	XI-5-51	16	5	34.1		
			Amphibious Training Base, Solomons			
VII-6-51	VIII-7-51	1	1	2.1	2.1	
						2.1
V-5-50	VIII-31-50	3 (2)	4	5.5	4.2	
						10.2
V-5-50	IX-9-50	4 (3)	14	23.4	14.4	
						10.7
V-5-50	XII-27-50	8 (7)	15	29.6	24.8	
V-5-50	XII-27-50	8 (7)	5	27.8	22.1	
V-5-50	XII-27-50	8 (7)	4	18.2	15.7	
						2.8
V-5-50	III-17-51	10.5 (9.5)	6	29.1	27.3	
V-5-50	III-17-51	10.5 (9.5)	6	27.8	23.2	
V-5-50	III-17-51	10.5 (9.5)	9	25.4	20.5	
						2.9
V-5-50	IV-25-51	12 (11)	4	33.2	26.6	
			Crisfield			
VII-2-51	VIII-1-51	1	6	5.9	3.5	
						13.3
IV-4-51	VIII-6-51	5 (2)	19	20.1	16.2	
						1.7
IV-4-51	X-1-51	6 (3)	16	25.5	17.9	
						6.4
IV-4-51	XI-5-51	7 (4)	20	28.4	24.3	

Figures in parentheses ( ) indicate probable age of organism.

indicates the differences between mean length from one month to the next. Thus it may readily be seen that the greatest rate of boring occurs during the first few months. After this initial growth the rate of boring declines. Whether this is the result of reduced activity during the winter months or an intrinsic characteristic of the organism is not shown by the data. It is possible that the reduced rate in boring in the panels submerged for greater lengths of time may have been due in part to overcrowding.

DISCUSSION

Annual fluctuation of strike

The magnitude of strike may vary substantially from one year to the next. Table IV shows the difference in set at test panel stations during three consecutive summers. It may be seen that the strike was most intense and extended further up the bay during the year 1952. The two preceding years showed considerably lighter strikes.

Differences in the magnitude of set occurring during successive years can be demonstrated in almost all marine invertebrate organisms, and the reasons for these fluctuations are difficult to determine. Perhaps a partial explanation may be found by a consideration of the physical structure, circulation and mixing of an estuary, and its relationship to the distribution of larvae.

An upstream bottom flow in Chesapeake Bay was first described by Cowles (1930) from a limited number of current measurements. Newcombe, Horne and Lang (1939) deduced from the vertical salinity distribution in the Patuxent River that denser water must move upstream along the bottom. The recent investigations of Pritchard (1952a, 1952c), based on extensive field observations, have more clearly defined the circulation in Chesapeake Bay.

Essentially the circulation in Chesapeake Bay closely resembles that of an ocean basin in which there is an inflow across the sill and where precipitation and stream flow exceed evaporation. The transport of water along the bottom of such a basin is described by Sverdrup *et al.* (1942) using the relationship

$$T_L = D \frac{\bar{S}_U}{(\bar{S}_L - \bar{S}_U)}$$

where T_L is the transport in the lower stratum, D is the difference

TABLE IV

Comparison of Intensity of Set, *Bankia gouldi* Bartsch for Three Consecutive Years at Various Locations in Chesapeake Bay

Location	Date		Depth of Panel (Meters)	Total Number of Shipworms/Panel
		1950		
MARYLAND				
Patapsco River, Baltimore	V-5-50	XI-6-50	.9-1.0	None
Rock Creek	V-5-50	XI-6-50	.9-1.0	None
Gibson Island	V-5-50	XI-6-50	.9-1.0	None
Annapolis	V-5-50	XI-6-50	.9-1.0	None
Cambridge	...	...	...	...
Kent Narrows	V-5-50	XI-6-50	.4- .5	None
Laboratory Pier, Solomons	V-4-50	III-23-51	.9-1.3	25
Crisfield	...	...	...	...
VIRGINIA				
Harborton	...	...	...	...
Gloucester Point	VI-10-50	X-2-50	...	557
		1951		
MARYLAND				
Patapsco River, Baltimore	IX-4-50	XI-29-51	1.3	None
Rock Creek	VIII-1-50	X-5-51	1.8	None
Gibson Island	VIII-5-50	XI-6-51	1.6	None
Annapolis	VII-3-51	IV-30-52	1.9	4
Cambridge	XI-8-50	VIII-1-51	1.0-1.2	None [1]
Kent Narrows	V-7-51	I-28-52	.3	12
Laboratory Pier, Solomons	V-10-51	VIII-7-51	1.0	26 [1]
Crisfield	VII-2-51	XI-30-51	.7	26
VIRGINIA				
Harborton	...	...	...	...
Gloucester Point	III-10-51	XI-23-51	...	483
		1952		
MARYLAND				
Patapsco River, Baltimore	IV-30-52	X-28-52	All to 1.8	None
Rock Creek	...	...	...	...
Gibson Island	IV-30-52	X-28-52	All to 1.8	None
Annapolis	IV-30-52	X-28-52	1.5	2
Cambridge	IV-30-52	X-30-52	.6	7
Kent Narrows	IV-30-52	X-28-52	.7	58
Laboratory Pier, Solomons	V-11-52	XI-7-52	1.8	108
Crisfield	IV-29-52	X-29-52	1.3	105
VIRGINIA				
Harborton	IV-28-52	X-30-52	.8	204
Gloucester Point	IV-12-52	XI-1-52	...	528

[1] Data for complete summer not available.

between river flow and precipitation over evaporation, $\bar{S}_U$ is the mean salinity in the surface water, and $\bar{S}_L$ is the mean salinity at the bottom. If we apply this relationship to Chesapeake Bay using salinity data collected by the Chesapeake Bay Institute (Stations 848-I, 848-H, 848-G, 848-E) and if we neglect the effect of precipitation and evaporation it can be shown that the mean volume of water in second-feet passing upstream along the bottom through a transect of Chesapeake Bay at latitude 38°40′ was approximately 60 percent greater during the month of July 1950 over the same month in 1949.

It seems reasonable to assume that larval zooplankton forms may be transported up the estuary by the net upstream movement of water along the bottom. Wallace (1940) has demonstrated that this actually occurs and has shown that the eggs and larvae of the Croaker, *Micropogon undulatus* (L.) are transported up the Chesapeake Bay estuary by the net upstream movement of bottom water.

If we consider the magnitude of strike in the upper bay largely the result of transport of larvae up the estuary, then it would appear, other factors being equal, that we might expect a greater strike during years with summer months of greater stream flow, providing of course that the larvae are found in the bottom stratum. The available evidence indicates that the larvae of shipworms are in fact found near the bottom in shallow waters and that they do not exhibit diurnal movement (Quayle 1951). A more satisfactory explanation of the annual fluctuation of strike of *Bankia gouldi* awaits the description of the larvae, an investigation of their distribution under various conditions over numerous years, and a better knowledge of the factors that effect a successful set.

Relation of Salinity to Distribution

The difference in the magnitude of the strike of *Bankia gouldi* as one proceeds northward from the mouth of the estuary is apparent in figure 6. It may readily be seen that the highest incidence of attack occurs near the mouth of the Bay and diminishes markedly as one proceeds up the estuary.

Since many of the physical and biological properties of the Bay water vary with the distance up the estuary, it is difficult to determine precisely which of these factors may be important in determining the success of spawning, larval survival, and setting of Bankia. The most obvious physical factor which varies in this way is salinity.

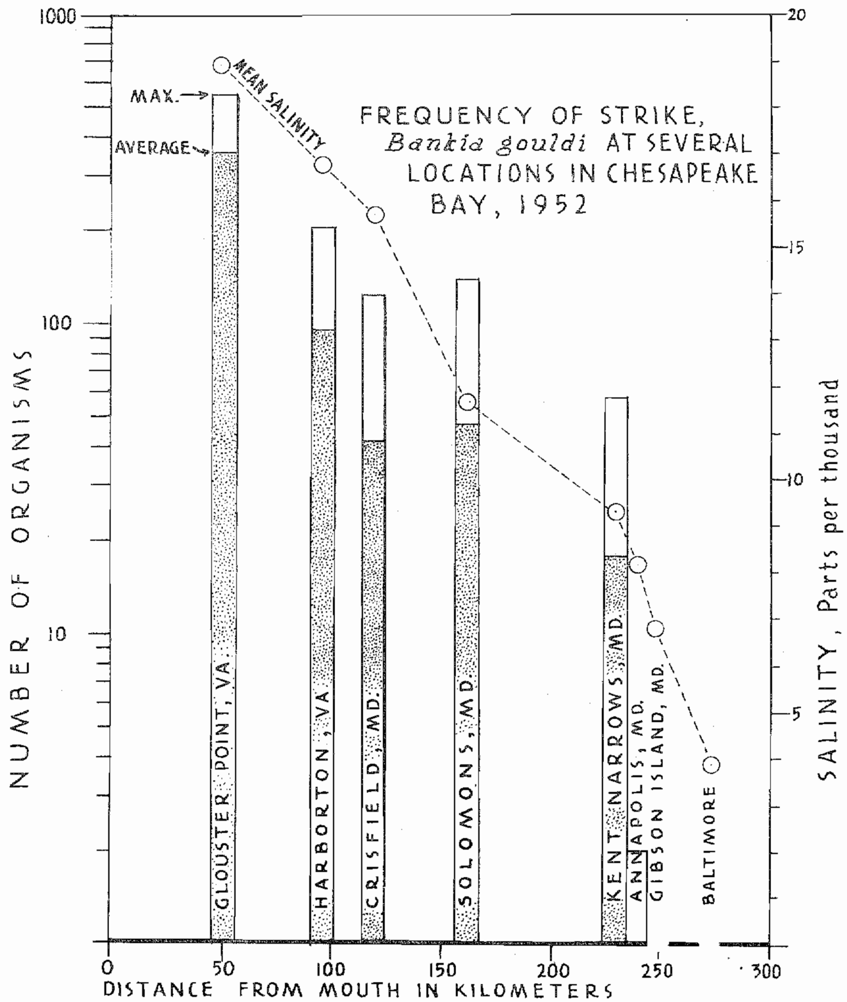

FIGURE 6. For explanation see text.

A.—Review of Previous Work.

Numerous attempts have been made to show the effect of salinity on the distribution of teredinids. Blum's (1922) experimental observations on the activity of *Teredo navalis* as manifested by the extension of the siphons, indicate that this organism is normally active in salinities as low as 9 o/oo. At salinities below 7 o/oo, the proportion of active individuals decreased very rapidly until at 3 o/oo no activity was noted. The average lethal salinity was determined to be 5 o/oo.

White (1929a) working with *Bankia setacea* Tryon states that "at salinities of less than 7.5 gm. NaCl/L death ensues within one hour; at 10 within 6 hours and at 13.7 within 12 hours."

Edmondson (1942) in his treatise on the Teredinidae of Hawaii found that *Teredo milleri* Dall, Bartsch and Rehder would survive but two days in fresh water, while specimens of *Teredo bartschi* 30 mm. long showed some activity at the end of three days. Smaller specimens survived a shorter time. Specimens of *Bankia hawaiiensis* Edmondson and *Teredo trulliformis* Miller were dead within three days. In a mixture of seawater diluted by an equal portion of fresh water, specimens of *T. milleri, Teredo diegensis* Bartsch, *T. bartschi, T. trulliformis* and *Bankia hawaiiensis* survived 12 days but "in a state of nature under comparable salinity values, all of these species would doubtless maintain normal activity indefinitely if properly nourished."

Miller (1926) reporting on the ecology of wood boring organisms in San Francisco Bay remarks: ". . . *Bankia setacea* are limited to areas where the average annual salinity is not much below 16 o/oo, *Teredo navalis* will thrive in salinities as low as 9 o/oo and can survive long periods in practically fresh water providing a salinity of 5 o/oo or above is attained once a month."

White (1929b) concluded that the breeding season of *Bankia setacea* in Departure Bay, British Columbia was related to low temperature and high salinities in October and March. He regarded salinities as the most important limiting factor.

Black and Elsey (1948) working in the same area found a salinity range between 9 and 23 o/oo to be optimum for *Bankia setacea*. Panels in salinities between 23 o/oo and 31 o/oo showed consistently lower strike.

Watson, McNeill, Johnson and Iredale (1936) report heavy attacks from a species of Bankia (subgenus Nausitora) in the Brisbane River where the salinity is less than 1 o/oo and noticed reduced activity of shipworms in salinities above 15 o/oo. Johnson, McNeill, and Iredale (1936) observed species of the subgenus Nausitoria in the upper George River, New South Wales, where the salinity was found to be as low as 1.5 o/oo. Our data indicate that *Bankia gouldi* is found quite frequently in waters with a mean salinity of approximately 9.3 o/oo (range 3.3 to 15.6 o/oo) at Annapolis, Maryland.

Although most of the above data were not obtained under controlled conditions, it is apparent that species of shipworms vary markedly in their tolerance to reduced salinity. It also appears that most species studied are euryhaline; that is, they tolerate a wide range of salinities. A better understanding of the part played by salinity in the distribution of the teredinids will require a more extensive knowledge of the physiology of osmoregulation in these forms.

Prosser *et al.* (1950) briefly review osmoregulation in molluscs and indicates that most marine forms studied appear to be poikilosmotic; that is, these organisms adjust osmotically to the surrounding medium rather than maintain body fluids at any given concentration. Scheer (1948) indicates that there appears to be little difference between the internal and external medium of marine molluscs as shown by freezing point depression of the body fluids and the external environment. Little is known of the osmoregulatory mechanism in teredinids.

It is of interest to note the difference in distribution with respect to salinity which apparently occurs within genera and even within species. *Teredo navalis* in San Francisco Bay is found at salinities as low as 5 o/oo (Miller 1926) while observations in Chesapeake Bay indicate that this same species has never been recorded north of the York River where salinities range between 15 and 26 o/oo. Yet this species is known to occur along the entire western Atlantic Coast (Brown 1953)! *Bankia setacea* is seldom found below 16 o/oo in San Francisco Bay (Miller 1926) while the same species has an optimum salinity range between 9 and 23 o/oo in Departure Bay, British Columbia (Black and Elsey 1948). Some of these apparent anomalies reported in the literature may be explained by (1) differences in water temperature, (2) differences in the transport of water masses, (3) differences in other unknown ecological factors within the estuaries in which these studies were made or perhaps (4) differences in salinity tolerances in different populations of the same genus or species.

The tolerance to reduced salinities by adult organisms is probably most important during the spring months when low salinities may possibly reduce the population of potential spawning adults or perhaps affect the ability of adults to spawn normally. In the oviparous forms such as *Bankia gouldi*, the ability of larvae to withstand lower salinities also should be considered as important in determining the uppermost distribution in the estuary.

Little is known regarding the salinity tolerance of most shipworm larvae. M'Gonigle (1926) demonstrated that salinities below 10 o/oo were detrimental to the larvae of *Teredo navalis* while the optimum temperature for development was 73° F. (22.8° C.). Nelson (1924) found shipworm larvae (*T. navalis* and *B. gouldi*) in salinities of 18 to 32 o/oo in Barnegat Bay, New Jersey although he does not distinguish between the larvae of the two species. Edmondson (1942) obtained some data on the comparative resistance to fresh water of larvae from several Hawaiian species. The larvae of most species with which he worked lived only a short time in fresh water (less than one hour) but specimens of *T. bartschi* and *T. diegensis* survived for 10 days in water of approximately 15 o/oo. It is noteworthy that the larvae of the larviparous form of *T. milleri*, confined within the body of the parent which was embedded in wood, survived in fresh water for more than two days.

B.—Relation Of Salinity To Distribution In Chesapeake Bay.

It should be recognized that correlations of ecological factors such as salinities with quantitative distributional data do not establish a cause and effect relationship. However, such a correlation may have some practical value in defining the distributional limits of a species and success of strike in an area such as the Chesapeake Bay. Figure 6 illustrates the frequency or intensity of strike of *Bankia gouldi* with respect to the mean salinity at several locations in Chesapeake Bay. Along the left hand ordinate the log of the number of shipworms per panel at each station is given while the abcissa indicates the distance of each station in kilometers from the mouth of the estuary. The right hand ordinate indicates the salinity in parts per thousand. The salinity values shown at each station are mean values for the summer of 1952, during which period the panels were submerged. The bars of the histogram are marked to indicate the mean number and maximum number of shipworms found in a vertical section at each of the stations.

If the log values of the number of shipworms per panel were plotted against the mean salinity for each station, the resulting graph would reveal an approximate exponential relationship between these two sets of data. We do not feel that any great significance may be attached to this fact, but, for practical purposes, the relationship does give a rough method for estimating from the salinity, the attack of shipworms which might be expected in various points in Chesapeake Bay when other data are not available. It should be recognized, however, that approximately the same type of relationship would emerge if one plotted the distance from the mouth of the bay against the number of shipworms per panel. Doubtlessly, other factors could be correlated in this fashion.

SUMMARY

1. The most abundant species of teredinid in Chesapeake Bay is *Bankia gouldi* Bartsch. This species occurs in Chesapeake Bay from Annapolis, Maryland, to the mouth of the bay. It is occasionally found as far north as the mouth of the Patapsco River.

2. The available evidence on vertical distribution indicates that the largest portion of the total number of Bankia is usually found in the lower half of the vertical column.

3. The strike of *Bankia gouldi* in Chesapeake Bay is continuous from the beginning of June to the end of October. The peak of strike usually occurs in July although some variation may occur between different areas and during successive summers. Spawning probably begins in May when the water temperature in Chesapeake Bay is between 16-20° C (60-68° F.).

4. The rate of boring determined at three widely separated areas in Chesapeake Bay indicates that boring activity is greatest during the first few months after set. The organisms continue to bore at reduced rates throughout the winter following the set.

5. Annual fluctuations in the intensity of strike occur in Chesapeake Bay. It is believed that these fluctuations may be related in part to differences in the volume of water transported up the estuary along the bottom during different years.

6. *Bankia gouldi* in Chesapeake Bay is found at salinities between 9 and 30 o/oo. The magnitude of strike decreases with decreasing salinity. No cause and effect relationship may be established from the data. The mean salinity is considered of practical value in defining the distribution and the success of strike.

ACKNOWLEDGMENTS

It is a pleasure to acknowledge the generous assistance and encouragement from many organizations and individuals. Especially helpful was the staff of the Virginia Fisheries Laboratory. Dr. J. L. McHugh, the Director, graciously gave permission for placing panels at the laboratory pier and Mr. Dexter Haven collected samples at monthly intervals at this location. Many of the salinity samples were titrated by members of the staff of the Chesapeake Bay Institute. Dr. C. R. Shoemaker of the U. S. National Museum kindly identified some amphipods. Dr. H. A. Rehder, curator of molluscs, U. S. National Museum, checked the identification of some shipworm specimens. Dr. W. F. Clapp gave valuable suggestions and encouragement. Miss Grace Jensen and Mrs. J. R. Longwell assisted in the preliminary examination of a large number of panels. Various members of the staff of the Chesapeake Biological Laboratory were helpful, especially Capt. H. Mister who assisted in the field work, Mr. H. Elser who was instrumental in making some of the graphs and charts, and Mr. T. Sweetland and Mr. R. D. Van Deusen who assisted in the photographic work. Mr. R. Mansueti accompanied the senior author in making collections during the fall of 1953. We are indebted to Dr. Jay D. Andrews for reading the manuscript and for his helpful suggestions.

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APPENDIX I

(See Figure 1)

1. Chesapeake City, Maryland, U. S. Coast Guard, Chesapeake and Delaware Canal Depot. Panel station operated from May 1, 1948 through 1950. No shipworms reported in this area (Rhoads 1951).

2. Worton Creek, Worton, Maryland. Panel station 1928-1929. No shipworms reported in this area (Weiss 1950).

3. Hodges Bar, Tolchester, Maryland. "Low strike" reported from panel station 1928-1929. *Bankia gouldi* (?) (Weiss 1950).

†4. Broening Park, Baltimore, Maryland (Upper Patapsco River). Panel station 1928-1929. No shipworms reported (Weiss 1950). Panel station 1950-1952. No shipworms encountered.

5. Hawkins Point Pier, Thomas Cove (Patapsco River), Maryland. Panel station January 14, 1948-1950. No shipworms reported (Rhoads 1951).

6. Sparrows Point (Patapsco River) 1917—"Light attack on a pile bridge over Bear Creek . . . affected ten percent of 100 piles" (Weiss 1950). Pier Number 4. Panel station 1938-1951—"a single 13 mm. specimen of *Bankia gouldi* from a set in 1941". (Brown 1953).

†7. Rock Creek (Lower Patapsco River), Maryland. Panel station 1950-1951. No shipworms encountered.

8. Seven-foot-knoll, Maryland—Panel station 1928-1929. No shipworms reported in 1928. "Heavy strike" reported in 1929. *Bankia gouldi* (?). No detailed quantitative data given (Weiss 1950).

†9. Gibson Island, Maryland (Inner Harbor)—Panel station from May 1950-May 1953. No shipworms encountered. Several specimens of *Bankia gouldi* were collected by Mr. John Sherwood from a section of rope, August 1941 (U.S.N.M.—160761).

*10. Cliff City, Maryland—October 26, 1953 (Chester River). Several pilings and a crab float examined. No evidence of shipworms—salinity 10.6 o/oo.

†11. Annapolis, Maryland (Severn River)—U. S. Naval Small Craft Facility—Panel station from September 1948 - 1952. "The attack rated as slight in 1949, 1950 and 1952 and moderate in 1951. Specimens of *Bankia gouldi* . . . were observed." (Brown 1953).

†12. Kent Narrows, Maryland—Panel station 1950 through 1952 *Bankia gouldi* encountered in 1951 and 1952.

*13. Romancoke, Maryland—October 26, 1953. Several large specimens of *Bankia gouldi* from pilings of ferry landing.

14. Camp Roosevelt (Smith Point)—Specimens of *Bankia gouldi* deposited with U. S. National Museum, Washington, D. C. (U.S.N.M. 95467). Date unknown (Weiss 1950).

*15. Oxford, Maryland (Tred Avon—Town Creek) October 26, 1953. A few small specimens of *Bankia gouldi* from crab float submerged during the summer of 1953.

†16. Cambridge, Maryland (Choptank River). Panel station 1950 through 1952—*Bankia gouldi* encountered in 1950 and 1952.

†17. Solomons, Maryland—Laboratory Pier (Patuxent River) Panel station 1950 through 1952. *Bankia gouldi* encountered 1950, 1951, 1952.

†18. Amphibious Training Base (Mill Creek), Solomons, Maryland. Panel station 1950 through 1952. *Bankia gouldi* encountered 1950, 1951, 1952.

†19. Upper Mill Creek, Solomons, Maryland. Panel station 1950. *Bankia gouldi* encountered.

*20. Fishing Creek, Hooper Island. October 27, 1953. Several specimens of *Bankia gouldi* collected from 2″ x 8″ fender on dock.

*21. Hoopersville, Maryland. October 27, 1953. Old sea wall collapsed from shipworm activity. Species—*Bankia gouldi* (sight record).

*22. Vienna, Maryland (Nanticoke River) October 27, 1953. No evidence of Teredinidae on wooden structures examined. Salinity 3.3. o/oo.

*23. Tyaskin, Maryland (Nanticoke River). October 27, 1953. Specimens of *Bankia gouldi* collected from base of small piling.

†24. Crisfield, Maryland (Little Annemessex River) Panel station 1951 through 1952. *Bankia gouldi* encountered in 1951 and 1952.

*25. Rock Point, Maryland (Potomac River) October 30, 1953. No indication of shipworms on stake examined in laboratory. Salinity—12.4 o/oo.

*26. Coles Point, Virginia. (Potomac River) October 30, 1953. Several specimens of *Bankia gouldi* collected.

*27. Martins Point, Maryland (St. Mary's River) November 12, 1953. Several specimens of *Bankia gouldi* collected from stake on bottom along shore.

*28. Seminary Pier, St. Mary's City, Maryland (St. Mary's River) November 12, 1953. Several specimens of *Bankia gouldi* collected from fouling collector submerged over the summer of 1953.

*29. Molls Cove, St. Inigoes Creek, Maryland (St. Mary's River) November 12, 1953. Several specimens of *Bankia gouldi* collected from stake.

*30. Lewisetta, Virginia (Potomac River) October 30, 1953. Several specimens of *Bankia gouldi* collected from stake.

31. Smith Point, Virginia (Potomac River) *Bankia gouldi* in collection of the U. S. National Museum, collected by R. D. Evans, August 17, 1883, several specimens in good condition (U.S.N.M. 203912).

*32. Saxis, Virginia. (Pocomoke River) October 28, 1953. Several specimens of *Bankia gouldi* collected from small piling near Fishing Creek Island.

†33. Harborton, Virginia (Pungoteague Creek) Panel station in summer of 1952. *Bankia gouldi* encountered.

*34. Sharps Wharf, Virginia (Rappahannock River) October 30, 1953. Evidence of Teredinidae but no living specimens were found in stake collected. Salinity 12.7 o/oo.

*35. Bertrand, Virginia (Rappahannock River) October 30, 1953. Several specimens of *Bankia gouldi* collected from stake at White House Creek.

*36. Gwynn Island, Virginia. October 29, 1953. Several specimens of *Bankia gouldi* collected from stake.

*37. Silver Beach, Virginia. October 28, 1953. Several specimens of *Bankia gouldi* collected from stake.

*38. Cape Charles (Town), Virginia. October 29, 1953. Several specimens of *Bankia gouldi* collected from small piling.

*39. Allmonds Wharf, Virginia (York River) October 29, 1953. Several specimens of *Bankia gouldi* collected from stake.

†40. Gloucester Point, Virginia (York River) Panel station 1950-1952 *Bankia gouldi* encountered 1950, 1951 and 1952.

41. Yorktown, Virginia (York River) Panel station June 15, 1949 through 1952. "Heavy" sets of Teredinidae occurred during 1949, 1950, 1951 and 1952. Species present were *Teredo navalis* and *Bankia gouldi* (Brown 1953).

*42. Jamestown, Virginia (James River) October 29, 1953. No evidence of Teredinidae was found in examination of various wooden structures. Salinity—6.7 o/oo.

43. Lee Hall, Virginia. U. S. Maritime Commission's James River Reserve Fleet, Old Pier Head. Panel station January 1948 through 1952. ". . . No evidence of marine borers until 1952 when a moderately heavy attack occurred." Species encountered was *Bankia gouldi* (Brown 1953).

*44. Two miles west of Denbigh (James River). October 29, 1953. A few small specimens of *Bankia gouldi* collected from stake on Warwick River.

*45. One half mile north of James River Bridge (James River) October 29, 1953. Several specimens of *Bankia gouldi* from portion of dead tree fallen from embankment.

46. Norfolk, Virginia (Elizabeth River). U. S. Naval Operating Base. Panel Station 1944 through 1952. Usually "very heavy" attacks. Species encountered were *Bankia gouldi* and *Teredo navalis* (Brown 1953).

47. Portsmouth, Virginia (Elizabeth River). Panel station 1944 through 1952. Attacks from "light" to "very heavy". Species encountered were *Teredo bartschi* Clapp, *Teredo navalis* and *Bankia gouldi* (Brown 1953). A specimen of *Teredo (Teredo) morsei* Bartsch (1922) was collected at Lambert Point Warehouse No. 2 on November 10, 1922. U. S. National Museum Collection (U.S.N.M. 348124).

*48. Cape Henry, Virginia. October 29, 1953. Opposite Cape Henry Light. Specimens of *Bankia gouldi* and *Teredo navalis* collected from 20 feet below mean low tide mark on piling drifted ashore. *Bankia gouldi* in the collection of the U. S. National Museum. Specimen collected by H. P. Agersborg. No date (U.S.N.M. 407775).

*49. Virginia Beach (Atlantic Ocean) October 29, 1953. Specimens of *Teredo navalis* and *Bankia gouldi* from stake located in small inlet.

50. Chesapeake Lightship—15 nautical miles northeast of Cape Henry. Panel station from April 1949 through February 1952 showed "heavy" to "medium heavy" attack by Teredinidae. The species encountered were *Teredo navalis, Teredo megotara* Hanley and *Teredo sigerfoosi* Bartsch. (Brown 1952) *Bankia gouldi* apparently was not encountered.