Tidelines: An Abridged edition authorized by the British Columbia Research Corporation

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Canadian Technical Report of Fisheries and Aquatic Sciences

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Les numéros 1 à 456 de cette série ont été publiés à titre de rapports techniques de l'Office des recherches sur les pêcheries du Canada. Les numéros 457 à 714 sont parus à titre de rapports techniques de la Direction générale de la recherche et du développement, Service des pêches et de la mer, ministère de l'Environnement. Les numéros 715 à 924 ont été publiés à titre de rapports techniques du Service des pêches et de la mer, ministère des Pêches et de l'Environnement. Le nom actuel de la série a été établi lors de la parution du numéro 925.

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edited by

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ABSTRACT

Quayle, D.B. [ed.]. 1992. Tidelines: An abridged edition authorized by the British Columbia Research Corporation. Can. Tech. Rep. Fish. Aquat. Sci. 1902: 136 p.

A series of short articles covering the biology distribution and control mechanisms for British Columbia marine wood borers.

RÉSUMÉ

Quayle, D.B. [ed.]. 1992. Tidelines: An abridged edition authorized by the British Columbia Research Corporation. Can. Tech. Rep. Fish. Aquat. Sci. 1902: 136 p.

Série de courts articles sur la répartition biologique et les moyens d'élimination du xylogphage marin de la Colombie-Britannique.

INTRODUCTION

In 1949 the British Columbia Research Council (now the British Columbia Research Corporation) began a study of marine wood borers as a result of representations from the forest industry regarding the amount of damage and loss of value to saw logs in transit or in salt water storage.

In 1959 the Council began to issue monthly reports on its researches along with forecasts of probable attack level by the borers at a varying number of test sites between Alaska and California. The subsequent monthly attack based on numbers per unit area on test blocks at several depths at these stations was also provided.

The reports, entitled "TIDELINES" were distributed to a limited number of forest industry related firms. The series was discontinued in 1976 after 261 numbers in 18 volumes. Some of the research studies were published in appropriate journals, but there remains a considerable amount of marine wood borer data not generally available.

To remedy this, 113 numbers have been selected and brought together in a sequence according to subject by the Fisheries Research Board of Canada. The forecasts and the actual attack data have been omitted since they have no present day significance.

THE PROBLEM

In 1949, Mr. A.E. Liersch of the Powell River Company approached the Research Council expressing particular concern about the damage inflicted by Bankia setacea on deep-sea ("Davis") rafts of pulp and saw logs towed out of the Queen Charlotte Islands southward along the British Columbia coast. Shortly after, two investigators, Mr. C.O. Fulton and Dr. P.C. Trussell were assigned to the problem of finding ways and means of protecting logs transported and stored in sea water against the ravages of the borers.

A NEW APPROACH

Since only 5-10% of all logs passing into the sea actually suffer damage by Bankia, the most practical approach to the problem was to develop a method for killing borers after they had attacked the logs, but before they had reached destructive size. In this way, only infested rafts would require treatment. This approach, however, was new to borer control, since all efforts in the past had been directed towards preventing attack by the larvae of the Teredo or Bankia. Now it was required that Bankia, after becoming imbedded in wood, be killed. Furthermore, for treatments to be of practical value, all borers had to be eradicated. Even if less than one percent should escape, this might mean that 10-20 borers per sq. ft. of wood surface would continue to consume wood and render it useless for lumber. In peeler stock this would be disastrous, particularly since the sappy, clear portion of the log near the surface is the first area to be damaged.

STALEMATE

A number of possible means of killing imbedded Bankia were considered. It was calculated that, without the Niagara Plant nearby to supply the power, the borers could not be shaken to death by ultrasonics. Electrical shock, although not conspicuously hopeful, was tried. When Bankia, imbedded in small wooden blocks, were exposed to alternating current at 115 volts, no deaths occurred. High voltage discharges of direct current (4500 volts) likewise were without effect.

Attempts to kill Bankia by electrolytic chlorine from sea water also failed. After six seconds of electrolysis at 6 volts d-c enough chlorine was produced to cause the Bankia to "hole up" and the siphons remained withdrawn until the chlorine in the sea water had dissipated.

These were just the first of a series of disappointments.

OUR BORING RELATIONS

The names and distribution of our West Coast marine-borer are shown below:

Teredinidae:

Teredo navalis	San Francisco to San Diego
Teredo diegensis	San Francisco to San Diego
Bankia setacea	Kodiak to San Diego

Isopoda:

Limnoria lignorum	Alaska to Point Arena
L. tripunctata	San Francisco to San Diego
L. quadripunctata	Eureka to San Diego
Sphaeroma pentadon	San Francisco to San Pedro

All members of the teredinidae are often referred to as "teredos" and this term is frequently used in *Tidelines* to cover both *Teredo* and *Bankia*. *Limnoria* are sometimes called "gribbles".

HISTORY

Bankia setacea seems to have been indigenous to the Pacific Coast and was first observed at San Francisco in 1863, following the gold-rush. The next borer discovered on the Pacific Coast was *Limnoria lignorum* described by Hewston in 1874, and also found in San Francisco Bay. This borer had been described by Rathke in Europe as early as 1799 and mentioned in destruction of dykes in Holland as far back as 1731.

The history of *Teredo diegensis* on this coast is rather obscure, but this borer was probably in San Diego Bay before 1900. *Teredo navalis* was undoubtedly imported into San Francisco where it was first observed in 1914 in the Mare Island dykes.

Limnoria quadripunctata was not described until 1949. Holthuis found it in San Francisco Bay where it probably existed with *L. lignorum* unrecognized for many years. Later, in 1951, Menzies singled out yet another species, *L. tripunctata*, which is capable of boring into creosoted wood.

A NEW KIND OF SHIPWORM IN PACIFIC NORTHWEST WATERS

We are indebted to Dr. D.B. Quayle, Pacific Biological Station, Nanaimo, B.C., for the following account of some of his findings concerning the geographical distribution of teredine borers in Pacific Northwest waters.

By now, most people concerned with the marine wood-borer problem in the Pacific Northwest have been conditioned to calling our teredine borer, "*Bankia*". In the future however, confusion may reign, for recently another species of shipworm, *Teredo navalis*, has been found in Pendrell Sound, on East Redonda Island above Powell River.

Teredo navalis is originally an Atlantic species found along the west coast of Europe, the Black Sea, Africa and the east coast of North America between Newfoundland and Florida. It is presumed to have been accidentally introduced into San Francisco Bay where it was discovered in 1914 as a result of piling failures. The heavier attacks in 1917 and the damage estimated at $25,000,000 which occurred between 1919 and 1921 have been attributed to *Teredo navalis*, although *Bankia* and *Limnoria* were also present. However, the structures destroyed were of untreated piling and any treated piling survived the attacks well. Attack was attributed to increases in salinity which allowed *Teredo* to reach wharf areas previously unaccessible to marine organisms.

Until recently *Teredo navalis* had not been found north of San Francisco but in 1957 it was found by the author in Willapa Harbour, in Washington. Northward progress appeared inevitable since hydrographic conditions in certain areas of Georgia Strait and Puget Sound are within the ranges occurring in San Francisco Bay and Willapa Harbour. Any vessel of wooden construction could be the carrier and, in recent years particularly, Pendrell Sound has been well frequented during the summer by yachts from the United States.

Teredo breeds in summer when water temperature is high, whereas Bankia is generally considered to be a low temperature breeder with main periods of settlement during the cooler months; thus wooden structures may now be subject to attack throughout the year.

The breeding method is different in the two species with Bankia discharging eggs and sperms freely into the open water where fertilization and larval development take place. In Teredo however, the female retains the spawned ova in the gill cavities where fertilization (sperms drawn in from outside) occurs and subsequent incubation takes place in brood chambers formed by the gills. The larva spends approximately half of the time between fertilization and settlement in the brood chamber and half in the free-swimming larval stage (like that of Bankia) which is believed to last for two to three weeks.

LOSS IN WEIGHT AND IN LUMBER VALUE OF LOGS BY BANKIA

In the fall of 1960, a Douglas fir and hemlock log was donated by MacMillan, Bloedel & Powell River Company for tests to determine the rate of bankian damage to lumber and pulp logs. Each log, 14 to 16 inches in diameter, was debarked and cut into 16 two-foot lengths. The ends of each log section were given three coats of neoprene paint to prevent marine-borer entry, tagged individually and 14 two-foot pieces of each species were immersed in Burrard Inlet. For each species, seven sections were completely submerged and a corresponding seven sections allowed to float. Two sections of each species were held as unimmersed controls.

At the end of the third month and at monthly intervals thereafter, one floating and one totally submerged log section of each species was removed from the sea. Unfortunately, between the third and fourth month the large float to which the totally submerged log sections were attached was lost in a violent storm and this portion of the experiment was terminated. For the floating sections the loss in lumber value over increasing periods of sea-water immersion is indicated below.

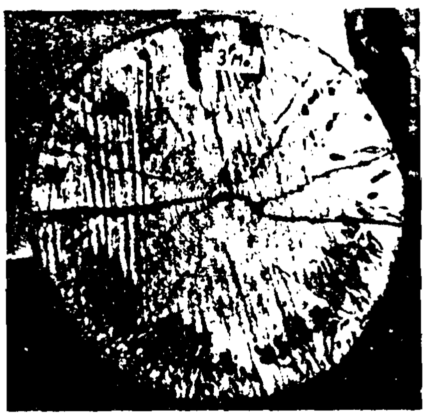
Table: Loss in Lumber Value of Floating Douglas Fir and Hemlock Logs by *Bankia setacea*

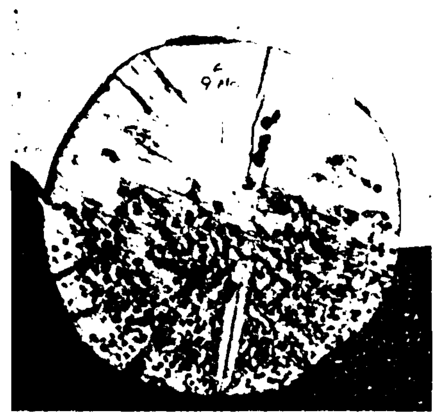
Months immersed in sea	Douglas Fir		Hemlock	
	% Loss Dry Weight	Lumber Shrinkage	% Loss Dry Weight	% Lumber Shrinkage
3	0	10	0	10
4	0	40	0	40
5	0	45	0	55
6	0	50	0	70
7	3	75	5	90
8	9	75	8	100
9	18	100	18	100

Although attack by <u>Bankia</u> larvae was substantial (200 to 450 per square foot of underwater surface), loss in dry weight was not severe until the end of the seventh month. Although the weight loss during the first six months was small, the lumber value dropped rapidly during this period. The lumber value as estimated by inspection, dropped to about 90% in the floating sections in three months, to 60% at the end of the fourth and to 50% at the end of the fifth month. As shown by the centre photograph, only about 1/4 of the clear lumber value was left at the end of seven months. However, it must be appreciated that the position of the teredine tunnels is not the same at all log cross-sections. For this reason the loss in lumber value is likely to be greater than indicated by a single cross-section.

The photograph below shows that the log stored in sea water for nine months had very little practical lumber value.

A Douglas fir section, which had been totally immersed for three months, is shown in the photograph at the left. <u>Bankia</u> had penetrated to a depth of 3.5 inches, had destroyed the sappy clear zone and had penetrated into the heartwood. In this particular log section, probably more than half of the clear lumber value was lost. This substantiates the Council's practice of restricting the storage of lumber logs to about two months during periods of bankian breeding.





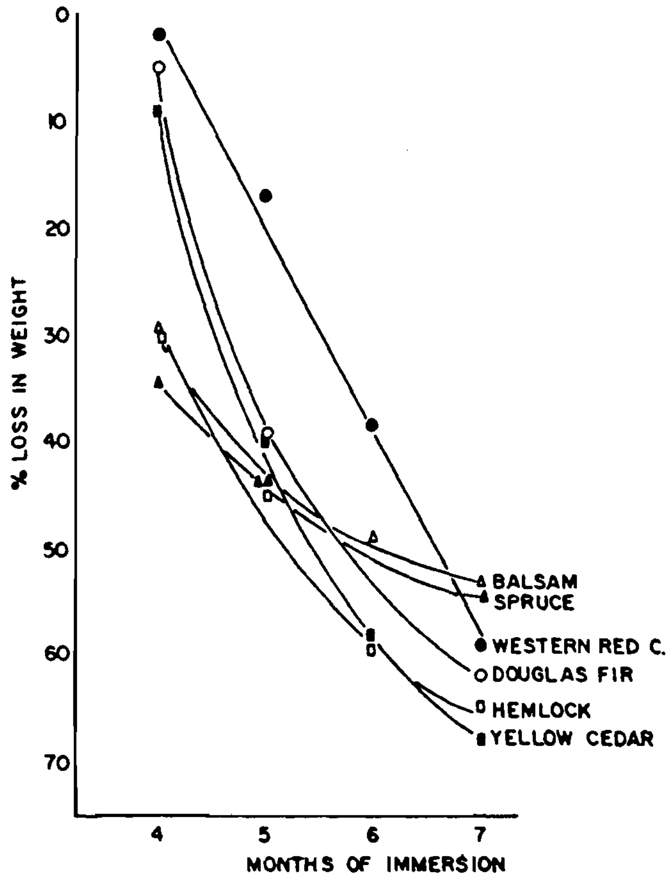
More work will be required to confirm these results and to establish that timber felled in the spring is more susceptible to bankian attack, once the bark is removed, than is timber cut at other times of the year. This information will be of considerable interest to operators transporting and storing logs in the sea.

WEIGHT LOSS OF WOOD SPECIES CAUSED BY <u>BANKIA</u> <u>SETACEA</u>

In the August issue of Tidelines the susceptibility of different wood species to attack by <u>Bankia</u> was described. Although most conifer species were more susceptible to initial bankian settlement than was Douglas fir, particularly for exposure periods of 2 to 5 months, these differences were slight and of small practical significance.

The rate at which wood is demolished by <u>Bankia</u> need not correspond to the rate of initial settlement. Two studies were made, one in the fall of 1959, and the other in the fall of 1960. In both studies 4 x 4 x 12-inch specimens of different wood species were immersed at the 25-foot depth in the water off Burrard Dry Dock, North Vancouver, B.C. and removed at various intervals from 2 to 7 months following immersion.

The rate of dry weight loss of the six coniferous species in the first set of tests is shown in the accompanying figure. At the end of four months, balsam, spruce and hemlock had lost 30-35% weight, whereas western red cedar, Douglas fir and yellow cedar had lost less than 10%. However, with increasing exposure, intra-species differences became less pronounced, so that at the end of seven months all species had lost between 50 and 70% of the dry weight of wood. Hemlock and yellow cedar showed the greatest loss, balsam, spruce and western red cedar the least, and Douglas fir was intermediate.



The results of the second test, which involved hardwoods in addition to coniferous species, are set forth in Table 1. In this second experiment, the rate of weight loss was more rapid, the loss at four months corresponding to that at about five months in the first experiment.

The two hardest species of the series tested, maple and oak, suffered the least weight loss. Although <u>Bankia</u> larvae settled on maple as readily as on Douglas fir, weight loss at the end of five months was only 12%. Balsam, yellow cedar, hemlock and white pine showed rapid early losses. However, by the end of five months all specimens of the conifer species showed between 37 and 53% loss as before. Douglas fir occupied an intermediate position in this range.

Table: Rate of loss of various wood species caused by <u>Bankia</u> 4 x 4 x 12-inch specimens. Loss expressed as percentage of original oven-dry weight.

Species	2 mo.	3 mo.	4 mo.	5 mo.
Maple	0	1.0	13.1	12.2
Oak		2.4	11.6	21.3
W. red cedar		1.6	19.3	37.5
Cottonwood	0.1	3.2	19.1	37.0
Birch	2.5	3.5	28.6	35.2
Douglas fir		4.6	25.1	43.3
Spruce	0	6.6	23.1	47.8
Balsam	0.4	12.3	33.8	48.5
Alder	0	2.3	36.1	52.3
Yellow cedar	0.2	10.2	39.9	52.1
Hemlock	4.9	11.3	41.6	56.1
White Pine	0.5	10.3	46.2	53.4

The number of annual rings per square inch was not correlated with the rate of weight loss. In the first experiment the specimens of yellow cedar had 63 rings per linear inch, and in the second experiment, 38. In both experiments this species underwent severe weight loss, although initial rate of loss was least in the first experiment. In the first study the balsam specimens had only five annual rings per inch and relative to other species these specimens suffered less damage than those balsam specimens in the second experiment which had 14 rings per inch. No correlation with density of wood was apparent: the most dense specimens were the birch, and these suffered greater destruction than the less dense maple and western red cedar specimens.

The foregoing results show that balsam, spruce, hemlock and pine undergo more rapid initial shrinkage than other common conifer species, although after five to seven months' immersion the weight loss among different conifers is much the same. (Theoretically, 75-80% represents the maximum weight loss for 1/4-inch tunnels; for larger tunnels the maximum loss is less.) Western red cedar does lose weight more slowly than other species, but this difference is not great and may not be consistent. Hardwood species, such as maple and oak, lose weight less rapidly than conifer species. However, none of these differences are great enough to be of any practical, commercial value.

LOSSES IN PULP YIELD AND QUALITY CAUSED BY BANKIA

Research on pulp logs stored in sea water has revealed that where teredine attack is heavy, economic loss is sustained when penetrations exceed approximately one inch. Penetrations and corresponding losses increase rapidly thereafter. The effect on pulp recoveries and resulting pulp quality was determined in a series of tests carried out jointly by the British Columbia Forest Products Ltd., Crofton, B.C., and the British Columbia Research Council. Ten-foot balsam log sections were immersed in the sea early during the Bankia settlement season. For immersion times of 16, 24 and 32 weeks, pulp yields and qualities from test logs were compared to similar data from three control logs, stored on dry land.

The following results were obtained:

1. Wood Volume

   Losses in wood volume occur directly. For control logs, percentage recovery of good chips, i.e., +3/8, +5/8, +7/8 inches, ranged from 75.9 to 81.1%. Fine material averaged 16.0% pin chips and 2.9% dust. For the log immersed 16 weeks in sea water, the recovery of good chips was 76.1%, within the same range as the control logs. After 24 weeks' immersion, the test log showed a recovery of 70.6% good chips, with an increase in pin chips and dust to 19.3 and 6.9%, respectively. On the basis of the original wood, i.e., taking into account losses before chipping, recovery of good chips for the logs immersed 16, 24, and 32 weeks were 76.1, 60.5 and 48.5% compared to 78.2% average recovery for the control logs.

2. Pulp Yields

   Recoveries of brownstock pulp, expressed as percentage recovery from chips, were not affected by the previous log immersion. However, total ash analysis of chips produced from the log immersed for 32 weeks gave 9.7% ash, as compared to a range of 0.10-0.14% for normal production values. Subsequent analysis disclosed that this ash was principally calcium, i.e., 5.56% calcium oxide, based on the original dry weight of the chips.

3. Pulp Quality

Although the pulping characteristics of chips derived from teredine infested logs were not affected, when this pulp was made into paper, considerable diminution in quality occurred. Primarily, the paper strength was lessened, as a result of the higher ash content. Calcium carbonate crystals from the Bankia grinders and calcareous tunnel linings were not eliminated during the pulping process and contributed to impoverished paper qualities.

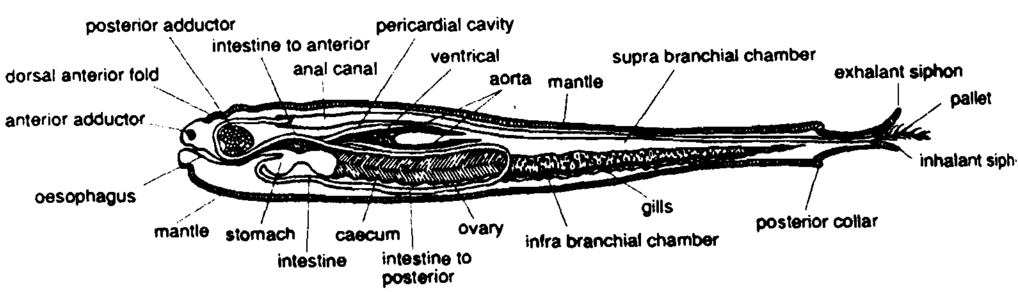
ANATOMY

BANKIA

THE ADULT BORER

Following the larval stage during which the teredine borer is able to move freely about in sea water, the animal attaches itself to wood. Here it transforms into a worm-like creature with a pair of calcareous shells at its front end which it uses to drill deeper and deeper into its new home. The borer is in its adult form and now undergoes very little body change except to increase in size.

The fine puncture a borer makes at the surface of the wood enlarges very little, so that at the end of a year or longer, the diameter of the hole is usually less than 1/8 of an inch. As the borer proceeds inward, usually first at right angles to the grain, and later, if not blocked, parallel to the grain, its body grows to fill the space and it keeps in contact with the water at the surface of the wood by means of two delicate tubes called siphons. The body of the animal is extremely delicate and is encased in a fine envelope known as the mantle. At the front end of the body is the shell which encases both the head and the foot of the animal.



Diagrammatic representation of the anatomy of the British Columbia shipworm (Bankia setacea).

The main organs of the animal - the stomach, intestines, liver, kidney, heart and nerve centres are located in the front third of the worm-like body. Extending throughout the remainder of the body, but not visible from the outside, are the gills. At the back end is located a pair of calcareous feathers, known as pallets.

Because the borer enlarges as it digs deeper into the wood, it not only builds itself a home but also excavates its own grave. It cannot back out through the small opening at the wood surface, so it must spend the remainder of its life in the same place.

A MILESTONE

December, 1959, marks the end of our 10th year of continued research and control against marine borers. Although the years of 1958 and 1959 have seen a vigorous upsurge in borer activity along the Pacific coast, this attack has been well repulsed. Over 35 million board feet of logs, 15 commercial wooden dry docks and miscellaneous wooden structures have been successfully protected.

In response to many queries, this and some following issues of Tidelines will describe the nature of the teredine borer, how he lives, functions and reproduces.

THE GRINDERS

The teredine borers have evolved and adapted specialized anatomical features that enable them to destroy wood in the marine environment. The photograph on the left shows the fine structure of the teredine valves (grinders) under 100 X magnification. The illustration below shows a cross section of a valve mounted vertically in a clear plastic and cut flush to the plastic surface.

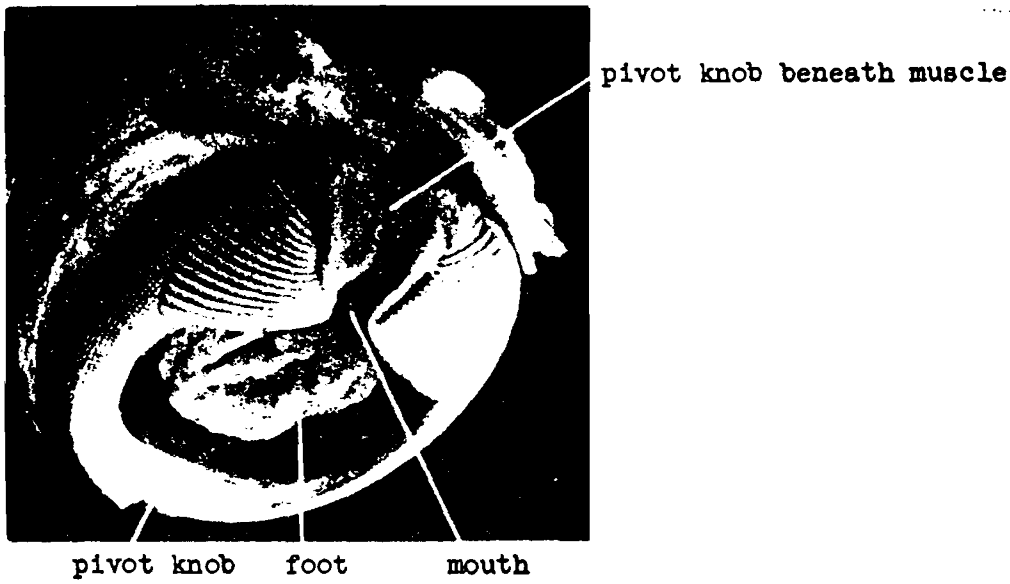
Each valve is composed of three layers. The outer "periostracum" layer covers the cutting ridges that contact the wood during boring. A middle or "prismatic" layer, seen as a dark layer in the photograph, is formed of minute prisms of calcium carbonate. Called "mother-of-pearl" where it occurs in other bivalves, the inner "nacre" layer forms the surface of attachment of the softer teredine tissues, which include two separate sets of muscles.

In the opening between the right and the left valve (above) is a large, muscular foot. When boring, the foot protrudes forwards and acts like a suction disc, to force the valves tightly against the end of the burrow. Alternate contraction and relaxation of the two sets of muscles attached to the valves subsequently cause the cutting ridges of the valves to rasp off fine particles of wood. A slight rotation of the head end of the borer's body aids the abrasion. The rhythmical movement of grinders and body may be repeated many times before the animal rests, creating the remarkable circular sectioned tunnel home that will become its grave when it dies.

TEREDO BICEPS

Although the shipworm can and does cause severe damage to softwoods, and even hardwoods, it has surprisingly few muscles in its body. The most important are those operating the pair of shells. A powerful one, which joins the shells across the front, pulls the two shells together. By the alternate contraction of one muscle and then the other, the shipworm is able to bore deeper into the wood. By turning the head through an angle of

180 degrees it produces a uniformly round burrow.



The shipworm's foot, which is rather like an oversized chin with a sucker-like front, is equipped with three sets of muscles which permit it to be extended, contracted and to grip onto the wood at the front end of the burrow.

A posterior muscle anchors the tail region of the borer to the burrow. In the same general area are a number of highly specialized muscles that manipulate the pallets and the siphons. Besides these discrete muscles, a number of organs contain muscular tissue, such as the heart and the stomach.

The lack of a continuous muscular structure throughout the length of the borer suggests that is must rely on hydrostatic pressure to move its body within the burrow. When a specimen of Bankia setacea is disturbed, its body normally contracts so that its head and shell are drawn back three to four inches from the forward-end of the burrow. Later, by pumping water into its body, it expands itself to fill the full length of the burrow again. This hydrostatic pressure also enables the animal to maintain its body in a fairly rigid position while borrowing into the wood.

OUTSIDE PLUMBING

The only parts of teredine borers that can be seen at the surface of the wood when the borers are active are their pairs of fine tubes known as siphons. These flexible, retractile, translucent tubes can first be seen when Bankia are only one-quarter inch into the wood. In older animals, the siphons are up to 3/16 inches in diameter and 4 to 5 inches long when fully extended.

These siphons are the animal's contact with its water environment. One tube, which is usually much longer than the other, forages for food in the form of small algae and plankton and draws in water from which the animal obtains oxygen. The other tube, which usually extends only a very short distance beyond the surface of the wood, is used to eject waste products, mostly partly-digested wood (frass), and to eject eggs or sperm during the breeding period.

Siphons of Bankia setacea showing piles of excreted wood. Half size.

The respiratory or inhalant siphon bears a number of sensitive tentacles which trigger quick closure and retraction when enemies and injurious materials are near.

BASIC STUDIES ON THE PIGMENTS OF BANKIA

The principal function of this marine borer, like most animals and plants, is to survive long enough to produce young and so carry on the species. He must find a suitable piece of wood, enter this wood and increase in size at a sufficient rate to compete with his companions alongside. His body occupies the entire burrow and apparently grows at a pace determined by the rate at which he can bore and engulf the wood. All of the ground wood the rate at which he can bore and engulf the wood. All of the ground wood produced at the drilling surface of the shell must pass through his intestinal tract and be expelled through the exhalant siphon. For this reason, the marine borer should be easily destroyed by any poison present in the wood since it enters the animal's gut.

In a study of the general biochemistry of Bankia setacea, the Council's investigators were attracted by three of its tissues which are coloured red. These tissues are: (1) the powerful adductor muscle used for providing the grinding motion to the shells, (2) the heart tissue, and (3) the siphons. The siphons pass fresh sea water into the gill area supplying oxygen and pass waste products out. The siphons also serve as an organ of touch and as a means of ejecting eggs and sperm during mating periods.

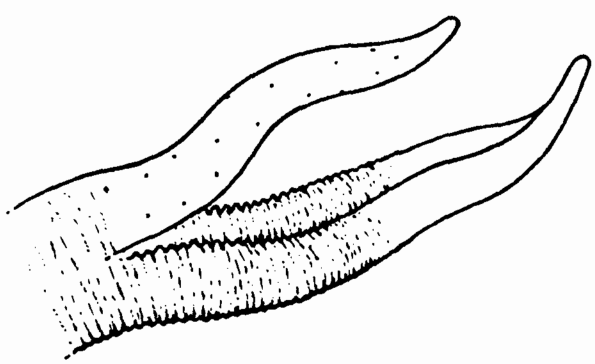
By the use of standard biochemical techniques, the red-pigmented material of the adductor muscle and the heart was found to be myoglobin. This pigment functions in respiration as a store house for oxygen to be used by tissues and cells in the immediate vicinity. Thus, the heart may still beat during low tide when oxygen is not being retrieved from sea water because the Bankia siphons are completely out of water.

Heavily pigmented siphons (marked "X") of the male Bankia.

The pigment isolated from the siphons is even more interesting. This pigment was identified as protoporphyrin which is the immediate chemical precursor to the iron-containing pigment, heme. The protoporphyrin occurs, as shown in photograph I, in patches along the entire length of the siphon.

On sectioning this tissue the pigment can be seen as crystalline material within the cells. The pigment is more prevalent in the exhalant than in the inhalant siphon and in the male animal than in the female. The function of the protoporphyrin is under investigation.

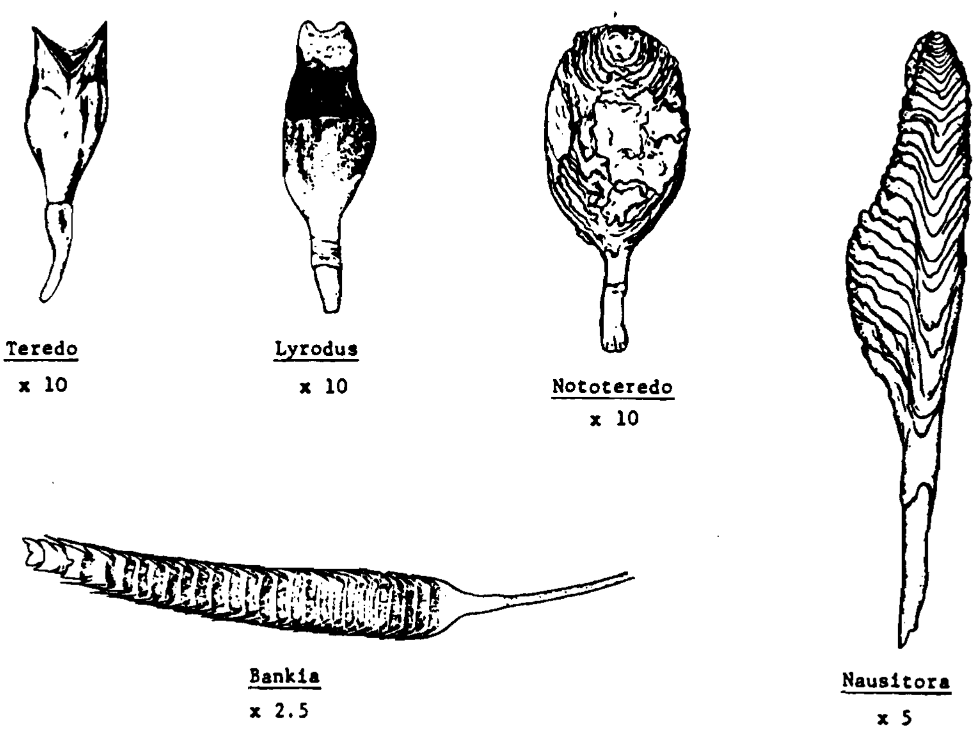
The males can be further differentiated from the females on the basis of siphons. The male siphons tend to be rectangular in cross-section (as seen in the siphon at lower left in the photograph), whereas those of the females are circular and, at least during certain times of the year, the males' siphons have four rows of papillae (small bumps) along their entire length. The papillae cannot be seen on female siphons.



Differentiation of the sexes is not possible at all times because the borers possess the ability to change sex. All Bankia setacea begin adult life as males and, after a short time, approximately half the males change to females. After producing eggs and sperm, they may again change their sex. At times therefore an individual may contain both eggs and sperm. This situation is confusing but presents a challenging problem - what factors cause the sexual phases? Life would be pretty grim for the Bankia if we were to prevent the occurrence of the female phase.

What is the basis for classification of "shipworms" into distinct genera or species such as Bankia, Teredo, Lyrodus or Psiloteredo? As pointed out in an earlier issue of Tidelines (August, 1968), there are approximately 66 currently recognized, different species of teredine borers. These are assigned to 14 different genera by Dr. Ruth Turner in her "Survey and Catalogue of Teredinidae".

PLUMES AND CUPS AND THE CLASSIFICATION OF SHIPWORMS.



The pictures above illustrate typical pallets from five different genera of teredine borers. In addition to certain characteristic anatomical features of the soft tissues, the structure of the pallets vary significantly from one species to the next and is, therefore, used in the classification of mutually exclusive groups of teredine borers.

For example, Bankia setacea has a plume-shaped pallet which is composed of several short segments on a longitudinal stalk. In contrast, the pallets of the Canadian east-coast species, Teredo navalis, are shaped like minute, laterally flattened cups. A Teredo pallet is illustrated above, in 10 times magnification. The much larger Bankia pallet is illustrated in 2.5

times magnification. Generally, all members of the genus Bankia have segmented pallets, whereas all members of the genus Teredo have unsegmented pallets. The genera Bankia and Teredo are regarded as two of the most highly evolved groups of "shipworms". Moreover, these genera are representative of the two major divisions within the family Teredinidae. One of the most important differences between these two divisions, is the difference in pallet segmentation.

LOW SALINITY RESISTANCE

Fresh water intrusion into the surrounding seawater is potentially harmful to most species of "shipworms". Nevertheless, one species of Nausitora was reported from timbers exposed to almost fresh water in a tributary to the river Ganges in India. These borers were discovered 150 miles up river. The genus Nausitora, which has segmented pallets, is regarded as closely related to Bankia.

Another species, with unsegmented pallets and belonging to the genus Psiloteredo, is extremely active in Miraflores Lake in the Panama Canal. In this lake, the salinity rarely goes above 0.5 parts per thousand (ppt), i.e. the salinity is less than one-twentieth of the minimum salinity required for Bankia survival and growth. The same species is also responsible for extensive damage to wood immersed in the brackish Lake Maracaibo in Venezuela.

Fortunately, teredine borers with such high resistance to depressed salinities are mostly confined to the tropics. Although the resistance of Bankia setacea probably varies with temperature or geographic locality, the adult normally requires no less than 12 ppt salinity to maintain regular activity. The larvae of B. setacea need even higher salinity, i.e., over 14 ppt, for unretarded growth and development. The lower salinity limit tolerated by Teredo navalis is normally no less than 9 ppt.

Bankia plugging their burrow entrances

Bankia siphons extended during normal activity

FUNCTION OF THE PALLETS

The teredine pallets, discussed in last month's issue of

"Tidelines", constitute an important part of these borers' mechanism for self-protection against a potentially unfavourable environment. Living entirely inside the wood, the only communication a teredine borer has with the outside world is through a minute pinhole. This hole was initially formed when the free-swimming larvae settled on the wood surface and began to drill into the wood. Once established in the wood, the borer grows steadily larger. Concurrent with the growth of grinders and body tissues, the tunnel also expands in length and width and, as it becomes deeper, obtains the shape of an elongated cone. The smallest tunnel diameter is at the original entrance hole.

Since the body of the growing borer, within a few days after settlement, becomes thicker than the entrance hole, the animal cannot back out and must spend its entire life inside the tunnel. Unlike freely mobile organisms, the teredines cannot, therefore, escape the predicament of an unfavourable environment by physical flight towards a safer habitat and, unlike their phyletic relatives, the oysters, clams, and mussels, they cannot escape by closing the pair of valves. Instead, they have developed highly specialized structures that make it possible for them to plug their tunnels from inside. These structures are the pallets. They are unique to the family Teredinidae. With its pair of pallets, a shipworm can seal itself off from the outside world and thus maintain its own, local environment for a period of up to several weeks.

The East Coast borer, Teredo navalis, has very small pallets that are never visible from the outside, as they fit snugly against the calcareous lining just inside the pinhole end of the tunnel. In contrast, the much larger pallets of Bankia setacea, also forced outwards whenever the animals are disturbed, may protrude beyond the end of the tunnel and the tips of the pallets are then visible as slender, segmented cones. When the animals are left undisturbed, the pallets of either species are retracted into the wider portions of the tunnel. In this position they leave room for the siphons, which must be re-extended before the borer can resume its normal feeding and breathing habits.

As a Bankia setacea grows, the pallets also increase in length and pallet segments become proportionally more numerous. Although the exact measurements and associated number of segments will vary from one individual to the next, these parameters may be of use in a rough estimate of tunnel depth, particularly when the embedded borers are more than a few months old. For instance, where chip sampling of a log produces Bankia pallets, but where the tunnels penetrate inwards and cannot readily be probed, the following table may serve as a guide to assess the approximate tunnel size.

Total Pallet Length	No. of Segments	Approximate Depth of Tunnel
1/2 inch	5	3 inches
3/4 inch	7	7 1/2 inches
1 inch	9	9 1/2 inches
1 1/2 inches	14	15 inches
2 inches	20	20 inches

THIN-SKINNED

The outer skin or envelope which contains the body of the shipworm is called the mantle. In the adult shipworm the mantle forms a very long and delicate tube which is open at the front end for the protrusion of the foot and has two openings at the other end for the inhalent and exhalent siphons. Besides being a wrapper, the mantle may be likened to the cambium layer in a tree and has a secretory function, producing inner layers of the grinding shell and the calcareous lining of the burrow. The calcareous lining is laid down when the borers are quite young and this process is continued as they grow longer and longer. In badly riddled wood, all that remains are the calcareous linings of the original burrows which the shipworms occupied.

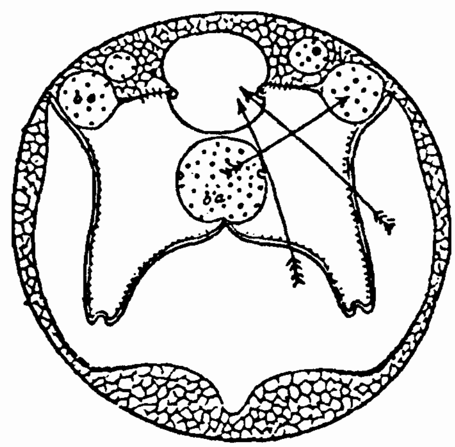
The calcium carbonate residues left in wood by borers may carry through to the final pulp or paper product and reduce its quality. In one case, particles of impurity in a commercial high-grade pulp were identified spectrographically as originating from the teredine shells in the infested logs used by the mill.

THE GILLS

Do teredine borers require oxygen to live? Very definitely. In fact, an amazingly large part of their bodies is occupied by gills - one-half to two-thirds the length. The gills, which are located in a long, hollow tube inside the animal, not only filter oxygen from the sea water, but also convey food to the mouth. The very young shipworm has a continuous series of 75 or more gill filaments, but as the animal becomes longer, the first 10 or 11 filaments become separated from the rest. However, a canal joins the two sets of gills so that food can be carried forward to the mouth.

Water is drawn into the animal by the inhalant siphon, passes through the gills where the oxygen is removed, and then is expelled through a channel connected to the exhalent siphon.

In principle the breathing equipment of the teredo is the same as that of fish, but the teredo has a less compact set of gills and has most of them extended over the posterior half of its body instead of at the back of the head.



Cross-section of teredo showing gills and blood vessels. Arrows indicate direction of blood and water flows.

NERVOUS TENSION

Although the Teredo has not advanced to the stage of possessing a brain, it does have a nervous system composed of ganglia, chains of nerve cells which transmit impulses in one direction only. Ganglia send impulses to the foot, the digestive system and the muscles which operate the shells, the pallets and the siphons. One very significant connection is to the osphradia, which are special sense organs that test the water which passes over the gills. It is possession of these organs which makes chemical poisoning of the adult Teredo so difficult. Successful poisoning demands that the chemical either is not detected by this mechanism or else paralyses its functioning.

Reproduction in the true Teredo has some interesting aspects. During the breeding season the ovaries of the female became greatly enlarged and nearly surround the cavities containing the heart and stomach. Hundreds of separate bunches of densely packed eggs, when ripe, are introduced into the cavity containing the gills. Here fertilization takes place by the sperm which are drawn into the cavity through the respiratory siphon. A special brood pouch is formed in each gill and in these pouches the larvae are retained until they reach a rather advanced stage of development, at which time they are released as minute, free-swimming, clam-like larvae to be distributed by the tides and currents.

As far as is known with Bankia species, the females do not develop brood pouches, but the eggs are dispersed into the water where they depend on chance fertilization and thus the larvae, during their entire development are subject to the hazards of their environment.

SEXUAL CONFUSION

The adult teredine borer has a busy and involved sex life. First he passes through a brief male phase during which he produces a releases sperm into the water, then he assumes a female role during which eggs are produced. In the Teredo species, the sperm are drawn in by the female, and fertilization of the eggs and development of the larvae take place within the parent. Many adults of Teredo navalis repeat the above cycle during their life, and go through a second male and female phase. However, about 10% of the adults which start out as males, manage to retain their masculinity throughout life.

An adult female will lay about 100 million eggs. These vary in size, but have an average diameter less than 0.05 mm. The sperm are much smaller and more numerous than the eggs.

Reproductive patterns for Bankia, particularly Bankia setacea, have received comparatively little study. This species is known to show strong tendency toward changing from male to female functions during life. In contrast to the true Teredo, the females of Bankia species eject eggs into the surrounding waters where fertilization by sperm occurs. The resulting embryos are able to swim within three hours after fertilization.

Water temperatures are one of the controlling factors in reproduction for Teredo. In Samoa, where the water temperature ranges between 77 and 86°F, Teredo attain sexual maturity and produce larvae in 24 days. At Woods Hole, Mass., where the water temperatures are much lower, Teredo navalis reaches sexual maturity in six weeks.

The effect of water temperature on the breeding of teredine borers on the Pacific Coast is not clear-cut. At most points between the Alaskan Panhandle and San Francisco Bay, breeding starts at mid-summer and carries through into early winter. However, in Massett Inlet in the Queen Charlotte Islands and in Puget Sound, breeding is almost continuous throughout the year. To complicate the picture, considerable variation occurs within even short distances, so that other factors may over-ride water temperature.

B.C. Research has compared annual seawater temperature fluctuations along the B.C. coastline with recorded Bankia settlement intensity for a period of fifteen years. The observations have disclosed that the reproductive cycle and intensity of our local teredos are regulated by factors more complex than a simple temperature relationship.

SEX INVERSION IN TEREDINIDAE

As in many other molluscs, changing sexual phases are recognized in the Teredinidae and have been reported in marine-borer literature. In 1926, several hundred Teredo norvegica of various sizes were studied, and it was noted that males were generally smaller than females. Two specimens contained both male and female maturing sex cells. The conclusion of the study was that each individual T. norvegica initially goes through a male sexual phase, then changes into a female.

Subsequent studies on Teredo navalis by other scientists confirmed the presence of an early male phase which, in the majority of individuals examined was followed by a female phase. During the interphase between male and female, many T. navalis proved to be functional hermaphrodites. An individual, during this period in its life cycle, could simultaneously discharge both mature sperm and mature eggs, when environmental conditions were favourable to reproduction. Other individuals remained in their first male phase for a long time or indefinitely. These exceptional individuals were considered the only true males.

A detailed study was undertaken by Nair and Saraswathy in India on the brackish water, tropical species Nausitora hedley. The study demonstrated a preponderance of functional males with developing eggs contained in the gonads (ambisexual males, see Table). With growth, the percentage of females increased, with hermaphrodites appearing in the intermediate size group. A second sex reversal after the female phase was indicated by microscopic examination of the sex glands of female Nausitora. In a number of examined female specimens, developing sperm cells were observed among the mature eggs.

Nausitora hedleyi Condition of the Sex of Specimens

Length (mm)	True Males		Ambisexual Males		Herma-phrodites		Females		Immature		Total No. of Specimens
	No.	%	No.	%	No.	%	No.	%	No.	%	
1-50	4	1.7	128	55.9	-	-	45	19.7	52	22.7	229
50-100	5	4.5	53	48.2	6	5.5	33	30	13	11.8	110
100-200	1	1.4	23	31.4	14	19.2	27	37	8	11	73
150-200	-	-	3	14.3	5	23.8	13	61.9	-	-	21
200-250	-	-	7	43.8	-	-	9	56.2	-	-	16
250-300	-	-	2	20.0	1	10	7	70	-	-	10
Above 300	-	-	2	18.2	-	-	9	81.8	-	-	11

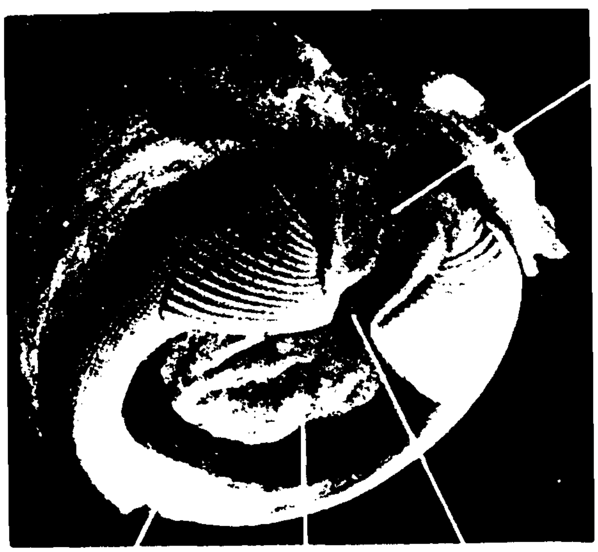
In Bankia setacea, our local North Pacific borer, sexual phases are normally well defined. Hermaphroditism occasionally occurs following the initial male phase but later there is a strong tendency towards rythmical change from one sex to the other, without the hermaphroditic phase. The change can occur several times within the life span of an individual.

DRILLING

BORERS RECORDED

Although much has been written about the basic mechanical techniques used by teredine borers to penetrate wood, little work has been done in describing shell manipulations with respect to the frequency and type of movement involved. A recent study carried out at a marine research station in Scotland has significantly improved understanding of this facet of borer attack.

The adult specimens required for this experiment were obtained by immersing laminated test panels, a technique often used by B.C. Research, in borer-infested waters for approximately one year. The laminated construction allowed adult borers to be removed undamaged from the infested panels, by careful detaching of the individual veneer strips. After removal, the adult specimens were carefully placed in artificial tunnels, which had been previously drilled in seawater-soaked cork panels. All the borers soon resumed normal activity.



The next, and most difficult, phase of the experiment consisted of attaching extremely fine threads to a rear portion of one of each adult borer's drilling shells. The opposite ends of the threads were then connected to a pen recorder, which provided graphical records of each shell movement as the borers continued their tunnelling activity. Painstaking study of these pen tracings provided a much clearer picture of the characteristic shell movements of wood-boring bivalves. The initial step taken in burrow enlargement involves attaching the foot, by means of mucus secretion, to the blind end of the tunnel. It was found that the shell movements which follow are analogous in many respects to those of the Colby crane -- a piece of equipment common to Pacific Northwest pulp mills. Of course, the marine-borer doesn't tear "chunks" of wood from the end of his tunnel like the Colby crane can tear "chunks" of chips from a loaded barge; but, instead, utilizes the serrations on the outer surfaces of his "clam-shells" to wear away adjacent wood surfaces. Several days of observations established a definite tunnelling schedule for the borers. As long as a fresh supply of seawater was kept circulating around the animals, the shell movements consisted of alternating periods of vigorous and slight activity. When the water flow was stopped, activity was either retarded significantly or completely ceased. A slight rotary movement of the borers was also detected from time to time during their tunnelling activity. It is felt that this rotary movement of the shells leads to the almost perfectly circular shape of teredine tunnels.

BORING WITH THE GRAIN

The knowledge and understanding of teredine borers, like that of a myriad other diverse and complex scientific phenomena, has increased by leaps and bounds since the beginning of the Century. Few fields of endeavour have been neglected in exploring the manifold intricacies of ship-worm physiology, anatomy, body chemistry and behaviour. Yet, in spite of all the important breakthroughs in basic "teredo" research, the seemingly simple question of why borers prefer to drill along the longitudinal grain of wood had yet to be conclusively answered.

A research program recently completed in England has done much to finally solve this problem. The experimental procedure, simply stated, consisted of a very exacting and comprehensive x-ray examination of many softwood panels infested by all stages of active teredine borers; as well as an investigation into the nature of water uptake by air-dry softwood. The latter phase was of a corroborative nature and confirmed that water is drawn into air-filled wood at a much more rapid rate in the longitudinal than in the transverse direction. This seems particularly obvious when one considers that at least half (depending on the tree's growth rate) of the longitudinal springwood cells (tracheids), which account for over 90% of a softwood's total volume, were specifically designed as "pipelines" by nature, in order to conduct nutrient-water solutions in the longitudinal direction only. The remaining tracheid cells, known as summerwood (which together with springwood make up one annual ring), were designed to provide structural support, and because of their strong, thick walls do not conduct water with any great success in either the longitudinal or transverse direction.

The primary phase of the program, involving hundreds of x-rays of "teredos" at work, was able to establish, among other things, the following important three factors:

1. When a shipworm retracts his head from the blind end of a tunnel (a relatively frequent movement during drilling), the evacuated area is filled with water or a mixture of air and water.
2. This water or air-water mixture is somehow removed from the head end of the tunnel before drilling resumes.
3. When tunnelling through air-filled wood, an area of water saturation always exists in wood immediately ahead of the borer's shells.

When these three points were considered in light of the previously established fact that a grinding shell was mechanically capable of grinding water-saturated and softened wood only, it led the investigators to an important conclusion. The adult "teredo" overcomes the seemingly inherent difficulties in drilling through air-filled wood by forcing the water or water-air mixture on the head end of its tunnel into the wood ahead, before grinding begins. It now becomes clear that if a teredine attempted to bore across the "pipeline" grain, the water it forced into the wood ahead would escape at right angles to its heading; thus defeating its wood softening technique. When drilling with the grain, however, no problem of this kind develops since the natural porosity of wood in the direction of the borer's travel ensures the presence of a water soaked wood zone in advance of the grinding shells.

STAYING IN THE WOOD

In last month's "Tidelines" we discussed, at some length, a research program recently completed in England which, through the comprehensive analysis of hundreds of X-rays of adult "teredos" at work, did much to clear up the question of why borers prefer to tunnel through wood in the longitudinal, rather than the transverse direction. The "crux" of the matter, in this case, was wood structure and its varying water-permeability properties with respect to grain direction. In this month's issue the phenomenon of "borer navigation", with reference to the avoidance of wood-water interfaces, will be explored.

Interestingly enough, the ability of teredines to avoid leaving their tunnels on arrival at water interfaces is, like boring with the grain, directly linked to changes in wood properties with grain direction. However, for this facet of tunnelling behaviour, the important wood property variation is not water-permeability, but compressive strength. It is generally well known -- through intuition as much as formal training -- that wood is more resistant to crushing in a direction parallel to rather than perpendicular to the grain. For example, few would question the choice of edge grain over flat grain flooring when high resistance to denting or crushing is required.

An understanding of changes in wood hardness with prolonged exposure to seawater is also necessary to account for the behaviour of "teredos" approaching a wood-water interface. Exposure to seawater causes wood to soften as water is taken into the wood. This softening results from the action of both cellulose-destroying bacteria and the swelling of water-saturated cell walls. From last month's discussion of water movement through wood, we can see that softening would proceed at a greater rate in a longitudinal direction (end grain exposure), than in a transverse direction (flat grain exposure). It becomes obvious then, that after a prolonged exposure to seawater, wood specimens will have hardness gradients on all faces, with hardness increasing in a direction away from the seawater contact plane, and with maximum softening penetration adjacent to end grain exposures.

We might now consider the penetration of one of these gradients by a teredine borer tunnelling in the normal longitudinal direction towards a seawater-exposed surface. The shipworm would find that, at some point along the hardness gradient, the opposing pressures exerted as a tunnelling brace by its foot and cephalic (head) hood, would begin to collapse the water softened cell walls around it. The shipworm could improve this situation only by altering its direction such that these horizontally opposed bracing forces were aligned in the direction of greatest compressive strength (i.e., parallel to the grain). In other words, it would begin tunnelling across the grain. The "teredo" would continue this alteration of direction until the area of decreasing hardness was passed, at which time it would resume tunnelling in the longitudinal direction away from the wood-seawater interface. The problem of dry wood lying in advance of tunnel heading when boring across the grain, would not obtain in this case, since the wood being penetrated would be already saturated with seawater.

An interesting validation of the foregoing hypothesis was discovered when the researchers involved compared X-ray photographs of borers approaching flat-grain and end-grain surfaces exposed to the sea for equal lengths of time. As would be expected, the "teredos" nearing end-grain surfaces changed direction earlier than those approaching flat-grain surfaces since, in the former case, the wood softness gradient had penetrated further into the wood.

FOOD

TEREDO PULPING

The digestive system of the teredine borer lies in the front third of the animal's length with most of the digestive glands on the right side, and the stomach to the left. The digestive system includes: mouth, oesophagus, stomach, caecum (posterior stomach), intestines, kidney, liver and anus.

The stomach is always found nearly empty of food. The other parts of the alimentary canal are usually full of wood chips and plankton, indicating that the passage of food through the stomach is relatively rapid. The caecum is relatively large, and is always found full of wood chips and presumably it is here that digestion and absorption of wood takes place. The large size of the caecum allows the wood to remain there for some time since the wood is only digested slowly. Digestive juices are supplied to the tract by a number of livers. The food passes from the caecum to the intestines and then it is expelled through the anus to the exhalant siphon. The faeces of the <u>Teredo</u> (frass) is in the form of fine, white threads, about 0.5 mm in cross-section and 0.5 to 3 or 4 cm long. This white frass at the surface of submerged wood or drifting in adjacent waters, always indicates the presence of live borers.

Siphons of <u>Bankia</u> expelling digested wood (frass)

FENDER PILES

Because fender piles are often untreated, their service life is fairly short. At Sitka, Alaska they are destroyed in 14 months, at Ketchikan in less than two years. In addition to the cost of the new piles, the removal of the "stump" of the destroyed piles presents a problem. The Council is currently developing a simple means of enshrouding such piles so that they can be treated once or twice a year with teredo-killing chemical. It is hoped that this will eliminate one more industrial headache.

WHAT'S IT WORTH?

During the five years 1955 to 1959 inclusive, the estimated value of the Council's marine borer control programs to industry was $1,700,000 in Canada and $3,700,000 in the U.S.

For the year 1959 alone, the estimates were $275,000 and

$1,120,000, respectively. These services meant a saving to the logging and wood manufacturing industries of $75,000 in B.C. and $120,000 in Alaska and Washington. Savings on maintenance costs to dry dock firms were $200,000 in B.C. and over $1,000,000 in the U.S.

ACTIVITY OF <u>BANKIA</u> <u>SETACEA</u> IN THE LABORATORY

In attempts to determine how the activity of <u>Bankia</u> held under laboratory conditions compared with that in the natural sea water environment, animals were collected in Douglas fir sticks, 1/2 inch square by 5 inches long, which had been immersed 3-1/2 months in Burrard Inlet. Three groups of eight sticks, containing 43-56 animals per group, were immersed successively for two week periods in natural sea water enriched with plankton, artificial sea water enriched with plankton, unenriched natural sea water, and in the sea. All salinities were 24‰. During each test period of two weeks, one week was allowed for acclimatization and the frass produced by each group during the following week was collected, dried and weighed. The results are in the following table:

Weight of frass produced by four groups of Bankia specimens

Medium	Algae added	Group I	Group II	Group III	Average
Seawater in the lab	Yes	1.643	1.637	1.873	1.751
Artificial sea water	Yes	1.287	1.249	1.291	1.276
Renewed sea water	No	0.596	0.324	0.333	0.418
Seawater in the sea	No	0.290	0.255	0.262	0.269

Close agreement was found between groups within individual environments. Borers produced the least frass in the sea and the most in the laboratory in natural sea water enriched with plankton. The extra feeding which occurred under laboratory conditions was certainly the most important factor, because even in artificial sea water enriched with plankton, the rate of frass production was 500% greater than in the sea. Even daily changes in the laboratory of unenriched natural sea water resulted in a 50% increase in frass production over the rate in the sea. These data illustrate that non-wood components are important to the diet of <u>Bankia</u> and may be normally in short supply.

Although in the sea, the rate of wood destruction by these borers may be considered extremely rapid, most natural conditions apparently do not permit maximum activity. In reality these results are not too surprising, since most animals will grow more rapidly when their natural habitat is improved.

LAND IRRIGATION AND MARINE-BORER INFESTATIONS

A recent paper by R.I. Ryabchikov and co-workers in Transactions of the Institute of Oceanology (Moscow), 69: 147-155, 1961, describes the invasion of marine borers from the Black Sea into the Sea of Azov, because of increases in salinity over the period 1952 to 1961. The increased salinity from 10-11 parts per thousand (‰) to 12 and more, resulted from the reduced discharge of the Don and Kuban Rivers following the development of a hydraulic network and the withdrawal of a portion of the rivers for irrigation. The borer found most commonly was *Teredo navalis*; a relatively few specimens of *T. pedicellata* were found in some locations. No *Limnoria* were found in either wharf piles or the poles used for staking fishing nets.

Generally, the *T. navalis* borer occurred in two lengths, 1 to 8 cm or 20 to 40 cm. Presumably the small animals belonged to the 1959 generation, the larger ones to the generation of 1958.

Experimental studies demonstrated that *Teredo navalis* are most sensitive to variations in salinity in the free-floating larval stage. Below 12 ‰, normal development of larvae and their penetration of wood is hampered. On the other hand, borers imbedded in wood for 10 to 15 days develop normally and reach sexual maturity in a salinity as low as 10 ‰.

The pattern of borers penetrating into the Sea of Azov is similar to that which occurred into the inner reaches of San Francisco Bay in the early 1900's. Use of the Sacramento and San Joaquin Rivers for irrigation reduced the salinity in the Bay and enabled borers to attack untreated wharf piling, causing the loss of waterfront structures valued at over 20 million dollars in 1918-20.

SUITABILITY OF CARBOHYDRATES FOR ARTIFICIAL CULTURING OF BANKIA

Tests described in last month's issue concerned the artificial culturing of *Bankia* in tubes of bacteriological agar with various additives. Tests with agar in test tubes capped with thin veneer and exposed to borer attack in the waters at North Vancouver in early 1963 showed that at least 4% agar should be used in preparing such media, and possible 7% agar is preferable although it is more difficult to handle and is more opaque. Inclusion of sodium, potassium, calcium and magnesium salts to give a salinity corresponding to that of sea water was found advantageous. Prior adjustment of the pH of the gelled mixtures had little effect since the pH tended to adjust to that of the surrounding sea water. Although some growth occurred in sea water gelled with agar, better growth was obtained when some form of native cellulose, for example, wood flour or cellulose fibre (but no cellulose acetate), was added to the gel. Continuing experiments were undertaken to determine whether similar growth could be obtained when the sugars, which represent the degradation products of cellulose, were added to the gel.

A basal medium comprising 4% agar at a salinity of 24 ‰ and pH 6.3 was used. To this medium were added separately, wood flour, cellulose, cellubiose and glucose, representing the range of the most complex to the simplest form of carbohydrate in wood. Maltose and starch were added to other portions of the basal medium. Ten tubes each of sterilized media containing the above carbohydrates were submerged to the 30-foot depth on January 24 and removed for examination on June 18, 1963. The summarized results are set forth in the table below.

Growth of B. setacea on carbohydrates

Substrate		Maximum depth of penetration, inches
Wood flour	8%	3.0
	4%	3.3
	1%	1.5
Cellulose	3.2%	3.8
Starch	4.8%	1.5
Cellubiose	5.2%	0.1
Glucose	5.4%	0.3
Maltose	5.2%	0.0
Agar alone	(control)	1.5

Growth of Bankia in wood flour, at concentrations of 4% or higher was 3 or more inches. Cellulose is essentially wood less lignin and hemicelluloses and growth of Bankia on the cellulose-agar medium was greater than in the medium containing wood flour. In the 5-month immersion period, the maximum length obtained on cellulose was 3.8 inches and the average length of borers 1.4 in whereas the average length in wood flour was 0.9 in. Although these results on synthetic media are encouraging, the growth over the 5-month period was considerably less than would have occurred in natural wood.

When simpler forms of carbohydrates such as starch, cellubiose, glucose or maltose, were used, the rate and amount of growth was substantially less. Thus the animals were not able to use carbohydrate in the simpler forms.

HEAR THEM BORE

Since Pliny the Elder (23-97 A.D.) first claimed to hear the teredo bore, various investigators have both confirmed and denied the possibility that the rasping of wood by the toothed shells is indeed audible. Using a wide range of listening devices from the simple stethoscope to complex electronic gear, Council scientists have yet to hear 3-inch Bankia in action in test blocks in the laboratory. In the field, detection was impossible against the myriad of both man-made and natural background noises.

HOW DO THE BORERS DIGEST CELLULOSE?

Research has demonstrated the Bankia setacea and other marine borers use cellulose as a source of food. Cellulose, a constituent of the cell walls in wood, is digested by herbivores and wood borers of widely different species. During digestive processes, complex cellulose molecules are split into their component parts by the action of a group of enzymes called cellulases. Even some of the very simple life forms such as certain bacteria, protozoans and fungi produce cellulases and are able to degrade cellulose. When these simple life forms reside in the digestive tract of other species of animals, a symbiotic relationship may be established between the visitor and its host, as the production of cellulases by the simple life forms promote the digestion of the cellulose ingested by the host.

All mammalian herbivores have symbiotic bacteria, protozoans or fungi living in their alimentary canals. Within the entire phylum Chordata, (animals with a backbone or spinal cord), there is no known instance of cellulose digestion independent of symbiotic microorganisms. In the case of invertebrates, cellulose digestion is more diversified and current knowledge of the process is less clear. For example, some termite species use symbiotic protozoans to digest cellulose, others employ molds of bacteria, and it is possible that other termites independently produce their own cellulose-splitting enzymes without the aid of any symbiotic relationship.

The digestion of wood by marine borers (including both teredines and limnorids) has been investigated since the discovery that the animals ingested the wood they rasped off during boring. Analyses of their fecal matter disclosed a depletion of cellulose in the wood during its passage through the borer's alimentary canal. The fecal pellets from Limnoria contained 50% less cellulose than that of the wood in which the experimental animals had lived. But the question of whether cellulose digestion had been aided by symbiotic microorganisms remained unanswered.

With a series of skillfully designed and meticulously executed experiments involving the Limnoria digestive tract, it was discovered that no microorganisms could have provided symbiotic assistance in the digestion of wood. The conclusion generally accepted by physiologists interested in marine borers was that Limnoria self-produced cellulase. In the case of teredine borers, cellulose digestion has been the subject of controversy, mainly because a bacterial flora in the teredine intestine has been difficult to detect. Meticulous microscopic examinations by some workers failed to disclose any microorganisms that could be symbiotic; other workers found that bacteria were present. Attempts at growing bacterial cultures from teredine intestinal smears were equally ambiguous, as results varied depending upon the technique employed. As experimental evidence developed, it was eventually accepted that some teredine borers, including Teredo navalis and Bankia setacea, secrete their own cellulases, and simultaneously serve as hosts to symbiotic cellulose-splitting bacteria. The latest investigations in the field have attempted to determine the relative importance of bacterial versus endogenous cellulases in the breakdown of the ingested cellulose. The results of this study are still controversial.

Among the marine borers, Limnoria is the only one which seems to be capable of making a meal out of cellulose without assistance from other organisms. For Bankia and other teredines, their digestive systems probably require some help.

BREEDING

LARVAL DEVELOPMENT

Following fertilization of the egg, the teredine borer passes through a larval stage at which time it has the appearance of a bi-valved shellfish. This is the only period during its life that it can travel freely from place to place. For the Teredo this is a relatively short period, usually about 72 hours, but for Bankia species, such as the west-coast Bankia setacea, the larval stage lasts about four weeks.

In Bankia setacea, the very young larva is about 0.1 mm in length. It has two tiny shells enclosing its body, and is equipped with an organ, called the veluum, which it protrudes when it wants to swim. Its movements in the sea are largely determined by water currents, and, over a period of thirty days, it can be transported great distances. It feeds on minute organisms in the sea, and grows to a length of 0.25 mm. When ready to settle, it attaches itself onto wood by means of a fine thread called the "byssus". Tiny calcareous teeth form on the outer edges of the shell and the animal is able to completely bury itself in the wood within 24 hours. By the third day the larva has transformed into a shape which grows longer, and is later recognized as a teredine borer.

Teredine borers are classified along with clams and oysters as shellfish. The reason for this is quite obvious when it is appreciated that these borers are nothing more than clam-like animals whose bodies have grown out of the shell. The shell no longer is used as a protective armour for the animal but as a boring tool for drilling into wood.

BEHAVIOUR OF THE TEREDINE LARVAE DURING ITS ATTACK ON WOOD

The first month of its life the minute clam-like teredine larva is free-swimming with feeble powers of locomotion. As this free-swimming stage draws to a close, a special "wood-phase" organ develops.

This structure, known as a foot, extends between the shells and by alternate extension and contraction permits the animal to crawl about and explore the wood surface for a suitable site for attachment.

Several sites may be inspected before choosing one; usually located in springwood, and open resin duct, or on some surface irregularity. After temporarily attaching the foot to the surface with a thread or with mucous, the larva begins the serious job of burrowing. After anchoring one portion of the foot to the wood, the larva uses the remaining portion to clear away and remove debris, surface slime, and soft, poorly attached wood cells. What features decide a potential boring site remain unknown but certainly attack does not occur on newly exposed wood and suggestions are that older wood surfaces must be wet and partially softened.

As the soft outer wood surface is removed by the foot, the way is cleared for the harder shells to be brought into action with a rocking, rasping motion to enlarge and deepen the hole. Several days after attachment the foot undergoes a marked shortening and thickening to assume the sucker-like shape found in the adult borer.

However, if the larva is cultured in the absence of wood, the development of the foot and resulting crawling behaviour in some species may be retarded. A knowledge of the mechanism associated with wood or wood derivatives, which triggers larval development, might hold the key to the ubiquitous problem of teredine-borer control.

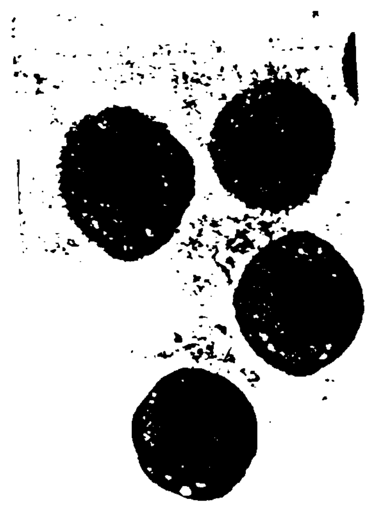
VARIED DIETS

Availability seems to be the keynote determining what material some borers choose for shelter. Although wood is commonly used by all marine borers, teredines (<u>Teredo</u> and <u>Bankia</u>) have been found boring into manila-hemp rope, cork, jute, hard seed pods, reed stems, gutta-percha and man-made cellulose acetate. Pholads ("rock-clams") have bored into low-grade concrete pile jackets, polyvinyl-chloride (PVC) plastic, nylon, silicone rubber and neoprene.

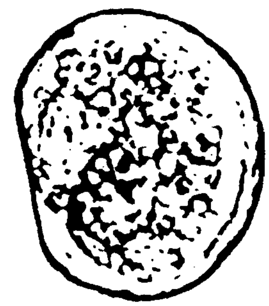
LABORATORY CULTURE OF THE MARINE BORER

Research personnel of the Council have for the past year been raising the shipworm, Bankia setacea, from the fertilized egg to the swimming and migrating larvae. Many millions of these active creatures have been born and raised in the Council's "maternity ward" at will, thus opening new fields, not only for the study of the factors required for producing a mature adult, but also for the study of repellency and attractancy to wood.

I



II



III

Photograph I shows the eggs (large oval cells) and sperm (small elongated dots) of the marine borer at fertilization. From this stage and within a few hours, the single fertilized egg becomes a multi-cellular, free-swimming larva referred to as the trochophore stage shown in photograph II. The larva then quickly develops two shells to become a bivalve, looking at first glance like a very small clam, photograph III.

Untold millions of these larvae are born under natural conditions and carried by currents to unprotected logs and pilings on our sea coast.

In the laboratory, cultured larvae are very sensitive to disease and to environmental conditions. The successful cultivation of the larvae has always required the use of antibiotics to control bacterial disease, particularly during the early stages in their development. The addition of an abnormal nutrient, such as the sugar glucose, to sea water containing larvae causes a sudden change in larval organization. The larvae in the presence of glucose become disoriented; their cells expand, divide and break away. The once organized larvae become a mass of grape-like cell clusters and single dividing cells, some of which show various degrees of specialization. Although the separate cells persist, the larva as an organism disappears.

Under natural conditions in the sea, Bankia setacea larvae may not die from the same conditions which are lethal in the laboratory. In nature many larvae probably do fall victim to predators and to disease. However, we do anticipate that our studies will provide knowledge on which to base improved methods with which to treat wood to repel larvae and thus protect the commercial wood and wood structures exposed to the sea.

BREEDING STUDY METHODS

Many of our readers will be familiar with the strings of settlement blocks immersed at various test locations along the Pacific Coast on a monthly basis. Although these strings of Douglas fir blocks on tarred hempline are simple to prepare and handle, considerable investigation preceded their selection as satisfactory test material.

At the time of the Council's entry into the marine-borer field some thirteen years ago 3/4 by 6- by 12-inch wooden panels were normally used for determining settlement. As some of our readers will recall, these panels were bolted on channel iron or aluminum frames and were both bulky to ship and to handle. At this time experimental studies in the Council laboratories involved the use of "catcher" blocks, 2-inch cubes of wood, strung on a plastic covered wire and immersed at the mudline. These blocks were rapidly attacked by Bankia and their size made them particularly useful for evaluating chemical environments in the laboratory. The greater convenience in the field, particularly for estimating settlement over a range of depths, suggested the use of these blocks for breeding studies.

Catcher block infested with Bankia showing extended siphons and extruded frass

Breeding studies serve to indicate the presence of Bankia larvae or Limnoria in the area and test materials have to be located to give maximum counts at a specific location. Relatively extensive studies showed that the average settlement per square foot on 2-inch cubical Douglas fir blocks was equal to, and in most cases actually greater, than the settlement obtained on the 6- by 12-inch panels. For many purposes the strings of blocks replaced the previous frames of panels and today the Council uses panels only in special circumstances, which are described below.

Use of strings of blocks made it easier to tailor-make immersion material for a specific job. Teredine borer populations concentrate at the mudline and spread upwards. At many industrial locations it is imperative to know the concentration of borers at various depths. For example, a drydock draws water at depths ranging as deep as 35 feet. The logging operator, on the other hand, wants to know the population densities in the zero to 2 feet range for storage of flat rafts and from zero to ten feet for bundle rafts.

Another important question that needed answering was should the strings be immersed from a floating or fixed location. Did tides affect borer populations? Breeding studies over a two-year period showed that tides had no effect and that the number of Bankia decreased linearly from the mudline to the surface, whereas with Limnoria the reverse occurred. Thus for ease of interpretation, where the client is interested in floating material, strings are immersed from floats and where fixed marine structures are involved, fixed strings are used.

Presently a very wide variety of test strings are used for determining Bankia populations. The standard string has the 2-inch cubic blocks stapled at one to two-foot intervals over 20 feet of line. This string is most widely used near logging operations where attack in surface waters is important. For depths below 20 feet the fixed strings with blocks stapled at 5-foot intervals are used.

More recently blocks have been cut to slightly less than 2-inch cubes, so that the total exposed planed surface area is 14.4 square inches. Thus a factor of 10 converts microscopic counts to the number of organisms per square foot.

In some instances accuracies greater than ten organisms per square foot are required. This is particularly true with peeler logs where very light infestation in the outer clear portions results in costly damage. For these storage areas, plywood panels, and one square foot in area on each face, are immersed at 1, 3 and 6 foot depths. These panels are used wherever detection of extremely light levels of infestation is desired.

BLUESTONING

A relatively common industrial procedure, reputed to protect float logs against attack by marine-borers, has been to drill holes at lengthwise intervals, fill them with bluestone (copper sulphate) and plug the holes, before the log is made up into a float. Recently Council staff had the opportunity to examine a log, which had been bluestoned, from a float which had failed in service. The accompanying illustration shows that wood immediately surrounding the "bluestoned" areas and for a short length along the surface grain has been protected but that wood interjacent between the bluestone holes had been completely eroded away and no protection occurred.

USE OF THE TEST BLOCKS FOR DETERMINING MARINE-BORER ATTACK

As most of our clients are aware, marine-borer attack is determined by the monthly exposure of strings to which are stapled cubical wooden blocks. After immersion, each string is forwarded to Council laboratories for microscopic counts of teredine punctures and limnorial tunnels in the blocks. The test blocks are Douglas fir, accurately sized so that each block face has an area of 3.6 sq. inches, giving a total planed area on the four sides of 14.4 sq. inches, or 1/10th of a square foot. Thus, after the borers on four sides have been enumerated, multiplication by a factor of ten gives the settlement of borers per square foot of wood surface.

As described in the February, 1963 issue of "Tidelines", it is important to determine the intensity of attack by borers at various water depths. For this purpose, the blocks are positioned precisely on the marine cord to which they are stapled and the strings are immersed vertically in sea water, by weighting the bottom end of the string.

Where wood or structures at or near the surface are being protected, strings of blocks are hung from a floating location. Blocks are stapled to the string at 1-ft intervals from one to four feet and at 2-ft intervals from six to 20 ft. Where settlement over the entire water depth is of concern, strings are immersed from a fixed structure, such as a wharf, with blocks stapled to the string at 5-ft intervals from zero tide level to the mudline.

The Council has compared blocks and panels as test materials for determining intensity of marine borer attack. Panels have been widely used elsewhere and are usually made of Douglas fir, 12 inches long, 6 inches wide and 1 inch thick. Settlement on the two flat surfaces were counted and compared to the four sides of the Douglas fir cubical blocks. The results are set forth in the accompanying table and show that over a 12 to 18-month period the blocks gave consistently a higher record of attack by teredine borers. In virtually all commercial programs, the purpose of determining settlements is to warn operators of the presence of borers. Thus it is important to use immersion material which gives as early a warning as possible. A later issue of "Tidelines" will present some of the reasons why test blocks give higher counts than panels.

Location	Date	No. Months	No. per sq. ft. at 20 ft. below zero tide level		
			Block	Panel	B/P
Galveston	1954-55	12	87	36	2.41
Seattle	1955	12	122	78	1.56
Seattle	1955-56	18	250	81	3.08
Average	Average	Average	Average		2.35

THE SPRING BREEDING SEASONS

After several years of inactivity during spring months <u>Bankia</u> populations appear on the verge of bursting into a spring breeding season in B.C. coastal waters. Whereas B.C. waters are normally clear of larvae at this time of year, appreciable numbers of organisms have been found this month in sub-surface waters at most test sites. One or two locations, normally quiescent at this time of year, already show heavy settlement in surface waters. If breeding materializes, as these indicators suggest, a long hard year is in prospect for B.C. logging operators.

Further south in San Francisco Bay we have been accustomed to a virtual population explosion of <u>Limnoria</u> in the early spring months. This year settlement was early, appeared to be progressing slowly, then after reaching modest levels in March, has turned down during April. These non-cyclical variations in borer breeding bring out strongly the necessity for the Council's present settlement program now virtually covering the Pacific North American coast. The current lack of knowledge of factors affecting breeding is one gap the Council's basic research program aims to fill.

BAITING THE BORER

Studies using cubical wooden test-blocks attached at intervals along an immersion string serve several purposes towards battling the marine borer. In this battle, monitoring studies are an integral part and, when monitoring with a view to monthly forecasts of teredine activity in the surface waters, it is necessary also to evaluate the occurrence of larvae at greater depths. As outlined in last month's issue of "Tidelines", the sudden appearance of <u>Bankia</u> larvae below log-raft depths frequently signals an infestation, shortly to come, at levels closer to the water surface. The regular floating one-month immersion string, therefore, consists of a hemp or

Figure 1
FLOATING STRING

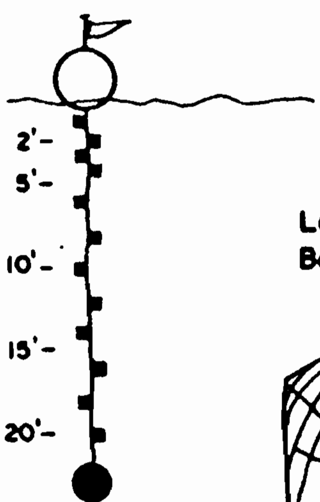


Figure 2

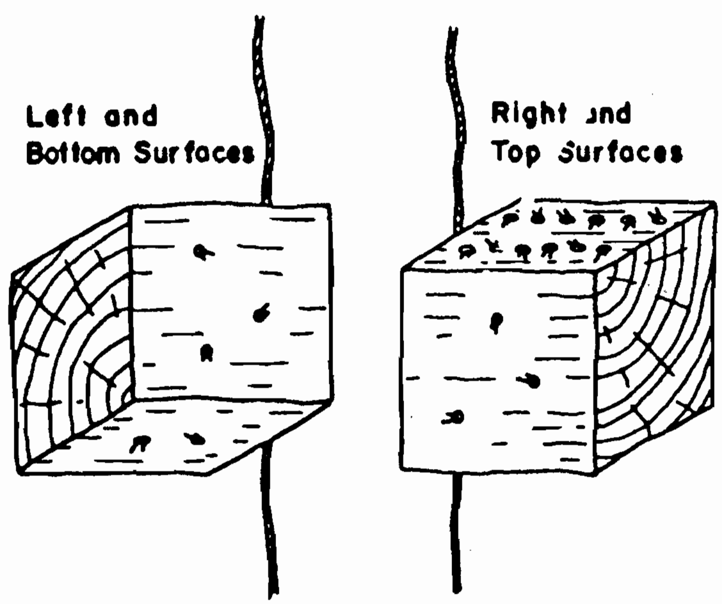
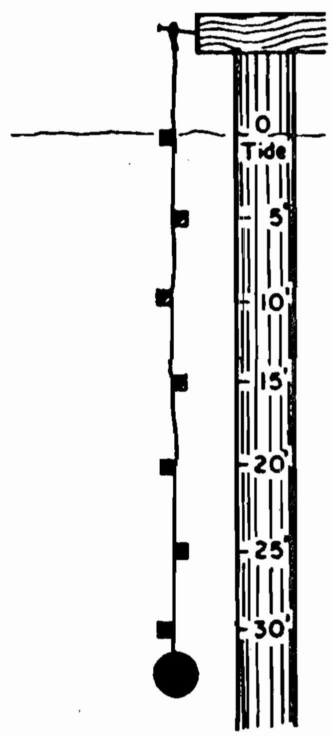


Figure 3
FIXED STRING



nylon line with 12 Douglas fir blocks, approximately 2 x 2 x 2-inches, stapled at intervals from one to 20 feet of depth (Figure 1). In the upper end, four blocks are attached at one-foot intervals; further down, the spacing between each block is two feet. This arrangement of the blocks was accepted for the purpose of minimizing inaccuracies in evaluating borer activity at flat-raft depths and to provide maximum information about current and near-future borer activity at minimal costs. The floating string is securely fastened to a float or floating structure, with the uppermost test block approximately one foot below the water surface. After one month of marine immersion, and with the block faces each sized exactly to one-fortieth of a square foot, the total borer settlement on all the four flat grain face areas of each block equals one-tenth of the monthly settlement per square foot of exposed wood surface at each respective depth.

Borer settlement on a wood surface in the sea is dependent upon the positioning of the exposed surface with respect to the horizontal plane. Comparative studies on the numerical settlement of B. setacea on horizontal versus vertical surfaces have demonstrated a preference for the upper, horizontal surfaces. On a typical test block, where the total settlement on the flat grain surface was 200 larval punctures per square foot, studies showed 60% of the settlement concentrated on the upper surface, 30% on the vertical surfaces, and 10% on the bottom surfaces (Figure 2). When several hundred one-month immersion blocks with a total of 6015 larval punctures were examined, with a view to determining preference of attack, the corresponding average figures were 60.4%, 32.4% and 7.2%. Similar observations on the settlement of Limnoria indicated a reverse preference; the majority of the migrating Limnoria settled on the lower surfaces, a lesser percentage on the vertical sides, with the least on the upper surfaces. With the test blocks attached to the hemp line in such a manner that two flat grain faces remain horizontal and two vertical when the line is positioned in the sea, maximum utilization is obtained towards baiting both teredine and limnorial borers.

For monitoring borer attack on marine piling and other standing structures, the strings extend down to the mudline or to 35 feet of depth, and are attached in a fixed, rather than a floating position (see Figure 3). A fixed string is secured so that the uppermost test block coincides with zero tide level and the remainder of the blocks are spaced at five-foot intervals. Thus, a 30-foot string carries a total of seven test blocks, each test block remaining at a constant distance from the mudline, but not from the water surface, as is the case with the blocks attached to a floating string.

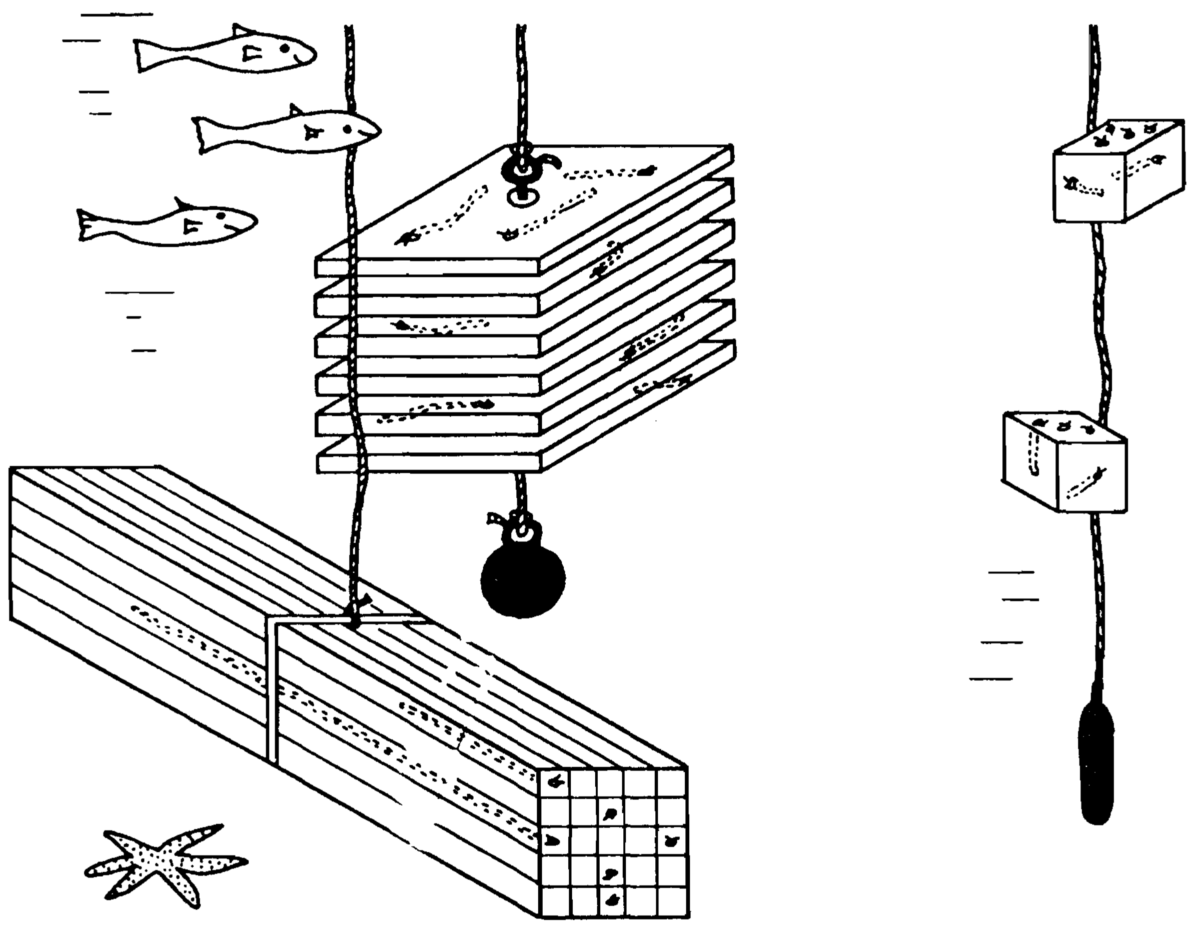
The studies on borer settlement patterns also have proved useful in designing immersion racks for evaluating potential impregnants for wood against marine borers. By mounting the experimental panels in a horizontal position, maximum utilization of B. setacea settlement patterns is achieved by the upper panel surfaces, and of Limnoria settlement patterns on the lower surfaces.

SPECIAL MONITORING TECHNIQUES I

In addition to the regular immersion strings routinely used for monitoring marine-borer settlement at log storage grounds and in the vicinity of dry docks and other marine installations, special monitoring techniques are available for studies where more comprehensive information is desirable.

For instance, it may be important to assess growth rates as a basis for predictions regarding the teredine destructive potential in an unusual or changing environment. Natural estuaries occasionally are modified according to industrial requirements; these modifications may introduce parameters which affect the survival or growth of marine borers. Industrial or agricultural diversion of fresh water away from a river will tend to increase the salinity of the receiving estuary, thereby increasing the growth potential of borer destructivity. The increasing oxygen levels, normally associated with pollution abatement programs, give rise to similar effects, with the return of conditions favourable to a normal marine fauna including marine borers. Although the rates of growth of Bankia setacea are now established for a variety of different localities, special consideration, nevertheless, must be given to situations where a multiplicity of parameters interact and, in particular, if the pertinent species of borer should require detailed study.

For purposes of examining borer growth rates during the first two to three months after settlement, the simplest approach is to use several test strings carrying two-inch cubical blocks which are immersed simultaneously and subsequently withdrawn at intervals for examination of the embedded borers. A more sophisticated technique involves solid metal frames with relatively larger wooden panels or boards horizontally mounted for maximum exposure. In the past, frames carrying six 6-inch by 4-inch by one-half-inch panels have been used for studies on growth rates of teredine borers under special conditions, at a variety of locations from the North Atlantic to the Gulf of Mexico and in the North Pacific.



A limiting factor on the efficacy of the above methods for growth-rate determination frequently is imposed by the sheer numbers of borer larvae present in the environment. Inasmuch as the free-swimming teredine larva is only microscopic in size, a 6-inch by 4-inch panel surface can accommodate literally thousands of these minute animals. When the larvae begin to grow in size as they tunnel inwards into the wood, the majority of them rapidly succumb to starvation and death from overcrowding. Under such circumstances, even the most vigorous ones never will reach their full growth potential, as the available wood soon is depleted through the efforts of their less successful competitors.

The panel method, therefore, is best suited for estuaries and industrial harbours where the total borer population is sparse. The determination of borer growth rates under conditions more favourable to the breeding and settlement of the borers must follow a somewhat different approach. The most successful method currently in use is to immerse bundles of thin wooden sticks which have been specially treated to prevent entry of borer larvae from all sides except from one of the end faces. By limiting the initial penetrations to a very small area, the loss of wood volume due to crowding is largely overcome. Normally, one borer will rapidly establish itself and, in due course, grow almost the full length of the stick. One Bankia in Vancouver Harbor occupied all but the last inch of a four-foot test stick.

Examination of the embedded borers may be carried out by x-ray technique or by manual dissection. The nondestructive x-ray technique permits continued immersion of the same material, whereby the growth of the individual borers may be followed from stage to stage until all the wood is exhausted. Where manual dissection is preferred, several identical wooden blocks, panels or sticks must be immersed initially, as each wood specimen is sacrificed upon removal to the laboratory for examination.

Over the years, B.C. Research has accumulated records of teredine growth rates from a wide variety of localities. On the basis of these studies, it has become possible, with good accuracy, to predict safe limits on marine log storage, the rate of biodeterioration of untreated wooden piling in industrial and modified estuarine environments, and the between-treatment safety periods for marine wooden dry docks and other marine installations.

SPECIAL MONITORING TECHNIQUES II

In order to obtain increased precision in the evaluation of monthly or bi-monthly marine-borer settlement in unusual environments or monitoring situations, B.C. Research utilizes special immersion material in addition to the regular strings of cubical wooden blocks.

As discussed in Tidelines, January 1972, depressed levels of borer settlement frequently are encountered in estuaries and industrial waters. During the colder months of the year, even the open sea and bays, where salinities and the dissolved oxygen content are continuously high, may sustain only limited teredine larval activity. In these situations, the relatively small cubical wooden blocks, while accurately indicating that the level of marine-borer activity is low, after only one month of exposure may fail to distinguish between light, and extremely light, attack.

Each of the regular wooden blocks has an effective surface area of one-tenth of a sq. ft. During examination in the laboratory all the teredine punctures within this area are counted and the value is then converted to the total number of punctures per sq. ft. For example, 100 punctures on one block corresponds to 1,000 per sq. ft.; one puncture to 10 per sq. ft. Although this method provides highly useful results at infestation levels in excess of 50 to 100 larval punctures per sq. ft. per month, alternative methods with larger exposed surface areas may be employed to provide additional information during the assessment of low intensity attack. During periods when the monthly settlement at a given depth is less than one or two punctures per 2 x 2 x 2-in block (i.e., less than 10 to 20 punctures per sq. ft.), the assessment of borer attack is subject to the laws of chance. When the numbers of larvae in waters surrounding test blocks are this few, then if a large number of duplicate test blocks are immersed, some will have as many punctures as four or more, some will have three, some two, others one, but more particularly some will have none. In this situation, to decide from a single test block that all infestation is absent, can be highly dangerous. Obviously, the desirability of increased monitoring to detect these low settlement levels is dependent upon the potential losses of the wood under protection subject to low intensity attack.

In the long-term protection of dry docks and other permanent or semi-permanent marine structures, the regular test-block immersion technique, even at low infestation levels, over a period of several months pinpoints the existing settlement with a high degree of accuracy. Similarly, in the protection of pulp logs, the test block technique offers sufficient sensitivity so as to avoid economic losses and, with the additional information of borer activity below log raft depths, the monthly progression of borer infestation can be correctly followed and evaluated both at the surface and in the subsurface waters.

Special monitoring techniques, therefore, are applicable in unusual circumstances, for instance where the borer breeding season is relatively short and where the settlement is light even at peak activity. For optimum evaluation of the borer infestation in such a situation, 12 x 12-in square plywood panels are available for monthly or bi-monthly immersions. Weighted and placed horizontally at preselected depths, these panels offer at each respective depth level a total exposure surface 20 times in excess of the effective exposure surface of the comparable 2 x 2 x 2-in block. The corresponding increase in monitoring sensitivity amounts to a full order of magnitude.

For extra protection of log rafts, including high quality saw logs and peeler logs, chip samples from the submerged log surfaces provide direct information about borer settlement. This procedure is frequently recommended for rafts subject to transit through potentially infested waters or in storage in waters not covered by a regular borer monitoring program. Another sensitive monitoring technique, particularly useful in the case of bundle rafts where chip sampling may be difficult, consists of immersing from the rafts short sections of bark-free bait logs at depths corresponding to the lower bundle

Bait log, split through the middle to reveal heavy Bankia attack.

raft tiers. Closely simulating the vulnerable log inventory, a one-ft. diameter bait-log section provides an effective exposure surface approximately 47 times the area of a regular cubical test-block surface. The figure shows a bait-log section heavily attacked by Bankia.

Over the years, special monitoring techniques repeatedly have proven useful in solving problems associated with unusual marine-borer environments. Also, log rafts have been protected during transit or storage in waters where regular monitoring results are not available.

INSPECTION PROGRAMS FOR SCHEDULING SAW-LOGS TO AVOID BORER DAMAGE

The Research Council's program for the protection of logs against marine-borer damage involves three phases: a study of the borer breeding in waters in which logs are transported and stored; periodic inspection of the stored logs for borer attack, and preparing disposal schedules for rafts of logs.

Microscopic examination of wood chips for marine borers

An illustration of this type of program is provided by the Council's work for the St. Regis Paper Company in Puget Sound. Previous to 1959, this Company suffered heavy losses annually, amounting to tens-of-thousands of dollars, by borer damage in pulp, lumber and peeler logs. As a first step in bringing this damage under control, the Council set up test stations from which monthly records were obtained of the marine-borer breeding in the main storage grounds used by this Company. This study resulted in the use of one storage area being eliminated because of the presence of borers in almost all months of the year. The study also showed that the remaining storages had longer and more intense breeding periods during a year than any other locations on the Pacific coast. It has been a common observation that the greatest number of the free-swimming larvae occur near the mud-line and it is only during certain months of the year that these larvae are carried to the surface where attack of logs occurs. Most locations have a six month period each year in which surface waters are free from larvae; in the Tacoma-Olympia area this larvae-free period is less than three months. This demanded a very accurate technique for detecting low concentrations of larvae near the surface; and fairly frequent inspections of the logs stored in sea water.

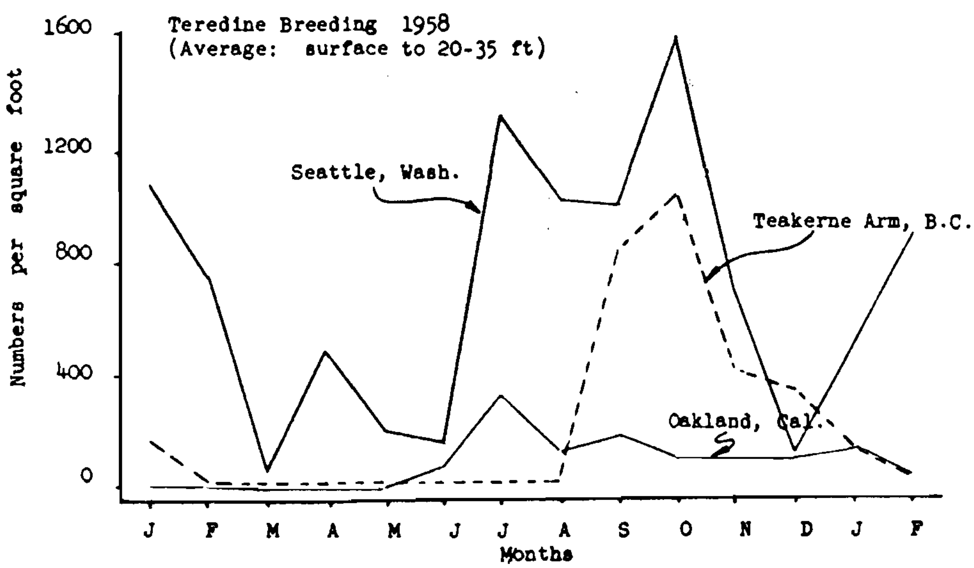
After the rafts containing visible borers had been assigned for immediate use by the mill, inspections were than made on the remaining rafts for the microscopic larval form. The presence of larvae on the logs tells whether visible borers would be present five or six weeks later. Immediately following each field inspection and laboratory examination, the company was issued with priority lists for the use of rafts by the pulp, plywood and lumber divisions.

By acting on the priority lists, the Company has been able to stay ahead of the borers for the last three years, even to the extent of avoiding chemical treatments. On occasion the program has been assisted by moving some rafts into fresh water of the Puyallup River, but even here the storage will accommodate only six rafts at a time, and the river cannot be used during the spring freshet.

If a sudden mill shut-down or a depressed market should interfere with the scheduling of logs, then chemical treatments can be used to arrest the growth of borers before it causes damage. This has been done a number of times in a control program for a B.C. company when withdrawals from sea water inventories have slowed.

The St. Regis control program has also involved studies associated with storage of bundled logs on tidal flats as a means of maintaining a large volume of logs in sea water with minimum borer attack, particulary over the fall of the year when breeding is heaviest.

Geographical differences in teredo breeding rates at three points along the Pacific Coast during 1958 are shown below. The average intensity of settlement was highest at Seattle (9900 per sq. ft. for 12 months), intermediate at Teakerne Arm, B.C. (3000) and lowest at Oakland (1100). Of equal importance in the protection of wooden structures is the length of the breeding periods: essentially continuous at Seattle, nine months at Oakland, six at Teakerne Arm.



Within a specific area the period of breeding is consistent, but considerable variation in numbers can occur over very short distances. Breeding periods do not follow any exact annual pattern. For example, in

January, February and March 1958, settlement at Seattle was decreasing, this year it is increasing.

The above data do not show the vertical distribution in settlement, a very important consideration in borer control on flat and bundle rafts.

A TIMELY EXAMPLE

At this period of peak Bankia breeding and settlement, the following account of a bundle raft, which through litigation could not be cut on schedule, is particularly topical in emphasizing the need for limiting seawater storage of logs during the vulnerable months.

Within a week after dumping in early September, 1965, the raft, comprised of 1661 pieces of bundled salvage logs averaging 15.2 cubic feet and drawing about 6 feet of water, was delivered to the mill where it was held for seven months before a cutting release was obtained. During the seven months, Bankia activity monitored at an adjacent site indicated the following settlement at a depth of 10 feet:

Month	No./sq ft		Month	No./sq ft	
	per month	cumulative		per month	cumulative
September	10	10	January, 1966	3	985
October	930	940	February	4	989
November	35	975	March	0	989
December	7	982	April	0	989

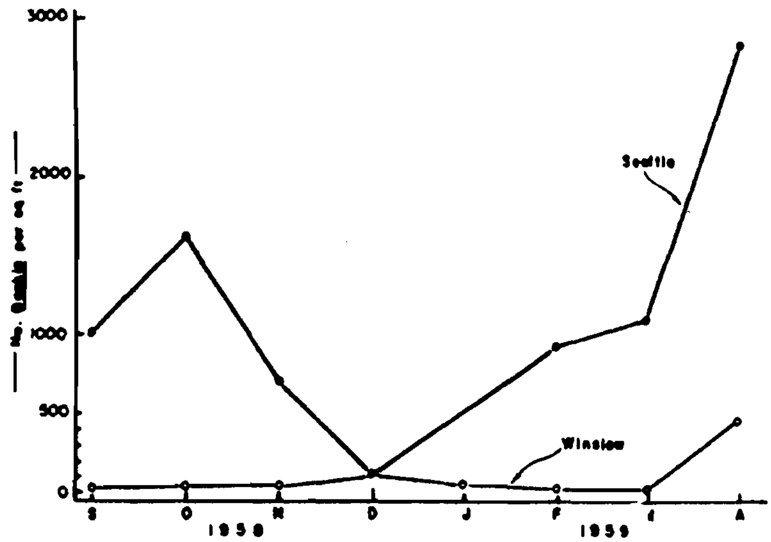
When, upon removal from the water to the log deck, the lower log tiers of the individual bundle disintegrated; safety of personnel and equipment required bundle strapping to be broken in the water and logs fed individually up a jack-ladder to the mill. Some of the logs were so badly Bankia-ridden that they broke up in the hydraulic barker and ultimately became hog fuel. Of the original 1661 pieces, 660 (39.7%) sank, and 1001 pieces were fed into the mill. Bankia damage to half of these 1001 logs amounted to 30%, representing a loss of about 300 individual pieces.

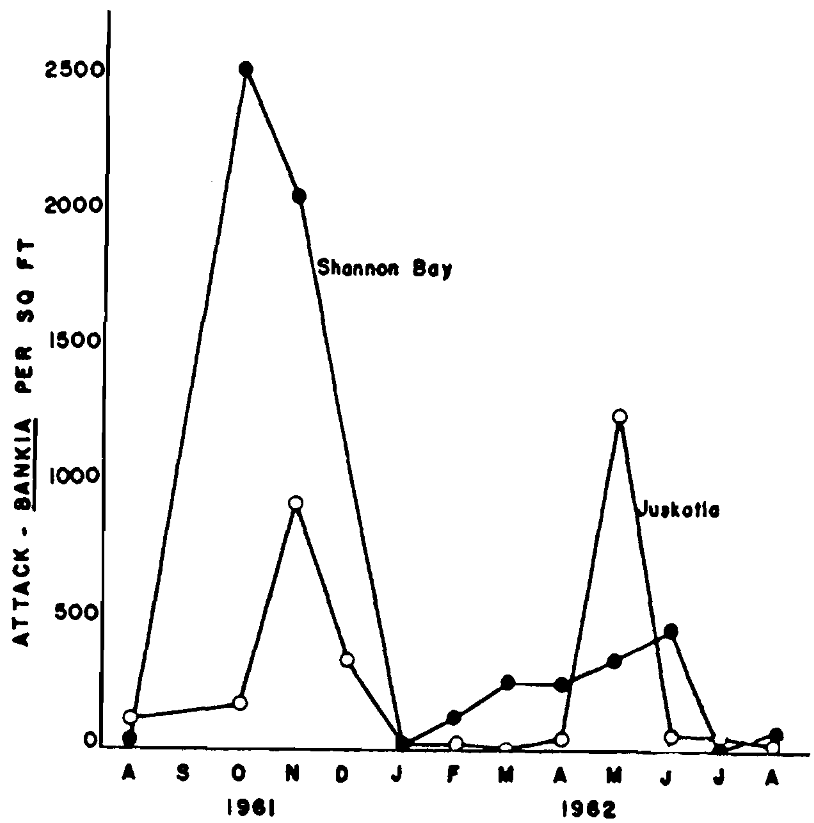
Overall losses produced by a combination of Bankia and log sinkage were almost 58% (14,577 cubic feet, 84,984 FBM), or more than $3,000.

THE BREEDING PUZZLE

Bankia setacea breeding in waters along the Pacific Coast confirms the old saying that nothing is so constant as change. To keep abreast of changes in borer breeding the number of test stations along the coast have had to be increased year after year to provide the information necessary for protecting marine facilities. As with man on land, population explosions of this borer have been taking place under water, particularly during the last decade. Areas which were once free of Bankia, now support substantial adult populations with ever increasing numbers of young larvae being released during the breeding periods each year. In addition, where breeding once lasted only a few months, the borers now exercise less restraint and breed for six or seven months of the year. In still other areas breeding proceeds with gay abandon throughout the year.

The reasons for these year to year variations in the length of breeding periods are not known. At none of the 45 test locations along the coast at which breeding has been followed at different times over the past ten years, has any shortening of the breeding season been observed.





Not only is the length of the breeding season subject to change but considerable variation exists between different locations. This variation with distance may be quite abrupt even over 5 to 10 miles. For example, as in the figure the breeding during 1958-59 at Elliott Bay, Seattle, was moderately heavy from September 1958 to April 1959 whereas at Winslow, only 7 miles away, the breeding was very light. This variation in breeding was likely due to a greater quantity of submerged wood, which provides the habitat for adults, at Seattle than at Winslow. However, this explanation does not fit the data in the figure which shows the breeding at two points in Masset Inlet, Queen Charlotte Islands, one at Shannon Bay and the other at Juskatla over the period August 1961 to August 1962. These locations are only six miles apart, yet their breeding patterns are quite distinct.

A different type of variation in breeding patterns is the shifting of the season from one part of a year to another. This type of change is unusual, although surprising shifts have occurred at certain locations. For example, in the mid-50's the breeding season at Seattle extended from September through January. Gradually this pattern has shifted until in recent years the heaviest breeding occurs from January through April with moderate breeding continuing through to October.

Even in November and December some breeding now occurs so that at no time in the year is this area free from attack at the lower water depths. In fact, at some points in Seattle and Tacoma, breeding at the mud-line has been continuous over the past nine years. What makes these waters of Puget Sound so favourable for breeding? The reasons are not known.

The fourth variation is the numbers of attacking bankian larvae to be found from month to month during a breeding season, and from one breeding season to the next. At no test location serviced by Council biologists, has any consistent decrease in attack been observed as the years roll by. At some locations attack has been steady but in most cases time has brought an increase in intensity of breeding. Often this can be accounted for by an increase in submerged wood, without which no breeding can occur. Probably the most spectacular increases take place when logging operations are expanding to new areas, or at locations in which pollution abatement is undertaken.

Virtually all Council marine-borer protection programs are based on knowledge of borer breeding - whether necessary action involves dispatch of logs to the mill or chemical treatment of dry dock interiors. Because of the breeding puzzle, the reader will appreciate that a basic part of any protection program is an on-site breeding study.

IMPREGNATION STUDIES

Over the past 2-3 years the Council has embarked on a relatively wide study of impregnants for marine timbers and piling. Impregnants include those which are in commercial use elsewhere, such as Boliden salts, impregnants based on copper and zinc formulations and developed at other commercial laboratories, as well as uranium-organic compounds which have been synthesized in Council laboratories. Immersion specimens involve both leached and unleached material (to simulate accelerated testing) and range in size from small wooden coupons to 12-inch diameter logs. Specimens are immersed in both Vancouver and San Francisco harbours to test resistance to Bankia setacea and Limnoria tripunctata respectively. Data to date are interesting, but immersion times are still too short for any conclusive results.

LATE BREEDING

Unless 1973 proves to be very different from all previous years of recorded marine-borer history in B.C., the annual Bankia settlement season is almost upon us. Normally, the month of August sees a heavy outburst of Bankia activity at most B.C. and Alaska locations. However, this year is unusual in that there has been only moderate activity in August, except at the Queen Charlotte Island sites, where the activity throughout the summer has been heavy.

The fall onset of heavy teredine infestation has been recorded by test-blocks since the 1950's. Virtually complete data are available for the six sites shown below since about 1960. Heavy settlement is defined as an average of more than 100 larval punctures per square foot of block surface to a depth of 20 feet.

Month of onset of heavy Bankia settlement at six North Pacific Coast test sites.

	Ward Cove	Teakerne Arm	Crofton	Vancouver*	Earls Cove	Gambier Island
1958	-	-	Aug.	-	-	-
1959	Aug.	Aug.	Aug.	July	-	-
1960	July	July	Aug.	Sept.	-	-
1961	Sept.	Aug.	Aug.	Aug.	-	-
1962	Aug.	July	Aug.	Aug.	Aug.	July
1963	Aug.	July	Aug.	Aug.	July	Aug.
1964	Sept.	I.D.	Aug.	Aug.	Aug.	Aug.
1965	Aug.	Oct.	Aug.	Aug.	Sept.	Aug.
1966	Sept.	Sept.	Aug.	I.D.	Aug.	I.D.
1967	I.D.	Oct.	Aug.	Aug.	Sept.	Aug.
1968	July	Aug.	Aug.	July	Aug.	I.D.
1969	July	I.D.	Aug.	Aug.	Sept.	July
1970	Oct.	Aug.	Aug.	Aug.	Aug.	July
1971	Aug.	**	Sept.	Sept.	Sept.	July
1972	Aug.	Sept.	Sept.	Aug.	Sept.	Aug.

I.D. Incomplete data **Less than heavy all summer *Fixed string

Data for 1973 indicate that there was no heavy Bankia settlement in August at five of the six sites. (No data are available for Ward Cove). This is the first time in 16 years that heavy infestation has not been recorded at any of the sites in July or August. Naturally, we cannot readily expect that the borers will be helpful and gratify the logging industry with their continued absence at log raft depths throughout the fall. That has never happened at any of the listed sites. But, as shown by the table, both 1971 and 1972 were years of relatively late breeding at most sites, and in 1971 the settlement never increased beyond "moderate" at Teakerne Arm. In contrast, during the 12 years of recording at Gambier Island, 1973 is the first year without heavy settlement to 20 ft of depth either in July or August.

There is no doubt that the early 1970's have had delayed borer breeding seasons, as compared to the early 1960's. Ten years ago, in 1963, the breeding season was well under way in July at Teakerne Arm and Earls Cove, and in August at the other four sites. Moreover, Teakerne Arm, Earls Cove and Gambier Island in 1963 had a spring breeding season with averages of over 100 teredine punctures per square foot during at least one of the spring months. No comprehensive explanation for these long-term oscillations in breeding activity has been found.

The irregularities that occur from one year's breeding season to the next, even from one decade to the next, impose on the logging industry a need for continuous vigilance. It is necessary to be alert to sudden changes in the Bankia settlement picture, in order to safeguard against economic losses.

Yearly Settlement of Bankia setacea (Tryon) at Five British Columbia Localities since 1961

By A. Bohn

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[1]The author wishes to express appreciation to Dr. C.C. Walden and to Mr. I.V. Allen for advice and assistance in preparation of the manuscript.

Since the late 1950's, B. C. Research has monitored marine-borer activity at log booming grounds and adjacent to dry docks along the north Pacific Coast from Ketchikan, Alaska, to Ensenada, Mexico. Each month, the teredine settlement on wooden immersion material was utilized as a basis for recommending log rotation schedules, or to predict the rate of reinfestation in wooden dry docks subsequent to borer control treatments. Following initiation of these programs, several sites in British Columbia have been monitored almost continuously.

Immersion material was Douglas fir cubical test blocks, each with a total surface area of 0.10 ft^2 stapled through the end grain to 200-lb test tarred hemp lines. Each immersion string carried twelve blocks, the first four at 1-ft intervals, the rest at 2-ft intervals.

The strings, weighted at one end, were suspended vertically from floating structures with each top block positioned 1 ft below the water surface and the bottom block 20 ft below the water surface. Each string was immersed for one month, then after being replaced by a fresh string, was returned to the laboratory for microscopic examination. The blocks were washed and dried and examined with a stereoscopic microscope at 7 x magnification. All teredine punctures on the flat grain surfaces were counted.

Figure 1 shows the annual settlement during the period from April 1961, to March 31, 1974, at five British Columbia settlement stations: Crofton, Earls Cove, Gambier Island, Teakerne Arm and Vancouver Harbor. Site locations are shown in Figure 2. The Vancouver Harbor records pertained only to immersion depths of 10 ft. The height of each vertical bar in the figure represents the total accumulated monthly _Bankia_ settlement per ft^2 for all sites, during a 12-month period. _Bankia_ breeding along the British Columbia coastline is normally at a minimum in the spring, thus the "_Bankia_ year" represented by each bar is from March 1 to March 31 of the following year. The yearly record from a site occasionally was incomplete, preventing the computation of accumulated settlement at that site for that particular "_Bankia_ year". The bars representing such "_Bankia_ years" (with less than five completed site records) are topped with a bracketed numeral, indicating the number of sites from which the accumulated settlement was available.

Maximum levels of _Bankia_ activity occurred during the periods 1961-1962 and during 1963 - 1964. With minor reversals, the settlement has declined steadily since 1966 - 1967. The total accumulated settlement at all five sites, during 1973 - 1974 was approximately one percent of the corresponding _Bankia_ settlement ten years previously.

Attempts at relating the observed decrease in _Bankia_ activity with any consistent environmental change or changes, have been unsuccessful. To this end, incidences of peak _Bankia_ settlement were compared with the occurrence of above average summer seawater surface temperatures obtained at B.C. shore stations in the general monitoring area (H.J. Hollister and A.M. Sandnes, 1972; H.J. Hollister, 1972 and 1974). No correlation was evident between such temperatures and fluctuations in _Bankia_ activity. The year 1967 had some of the highest temperatures on record at most stations in the area. Other local temperature peaks, particularly during the summers of 1961, 1963, 1965, 1969, 1971 and 1972, were similarly inconsistent with any recorded outbursts of _Bankia_ activity.

The sites monitored at Crofton, Gambier Island and Teakerne Arm have been in continuous use as a log storage grounds since before the onset of _Bankia_ monitoring. In these and other localities, increased use of log bundles, and reduced storage time in the water, have been incorporated in log handling improvements introduced by the forest industry during the last decade. The monitoring site in Vancouver Harbor was adjacent to a log booming ground until 1966, when all logs were removed and this booming ground was permanently closed. The reduced amounts of wood available for marine-borer settlement and proliferation, primarily associated with improved log handling practices, occasionally have been referred to as a possible cause of diminishing Bankia activity.

However, Earl's Cove has not any time been used for log storage, and the closest booming ground is more than ten miles away. Furthermore, information obtained from booming ground personnel asserts that log handling practices at Teakerne Arm do not differ significantly from log handling practices at a sixth Bankia monitoring site, Shannon Bay in the Queen Charlotte Islands, where Bankia activity has not declined since the middle 1960's.

No sources of industrial effluent are located in the general areas of Teakerne Arm or Earl's Cove.

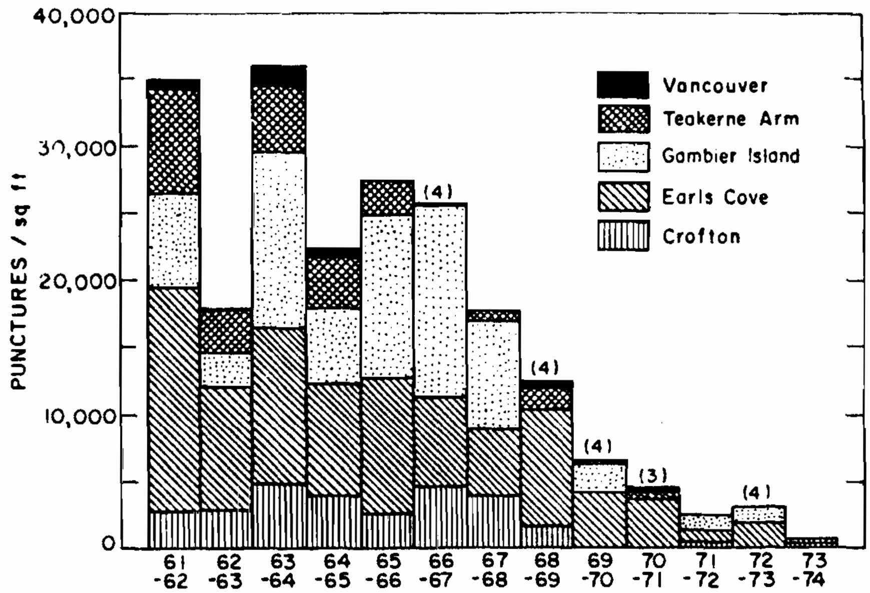


Fig. 1. Accumulated yearly *Bankia* settlement on monthly test blocks at five B. C. localities since April, 1961.

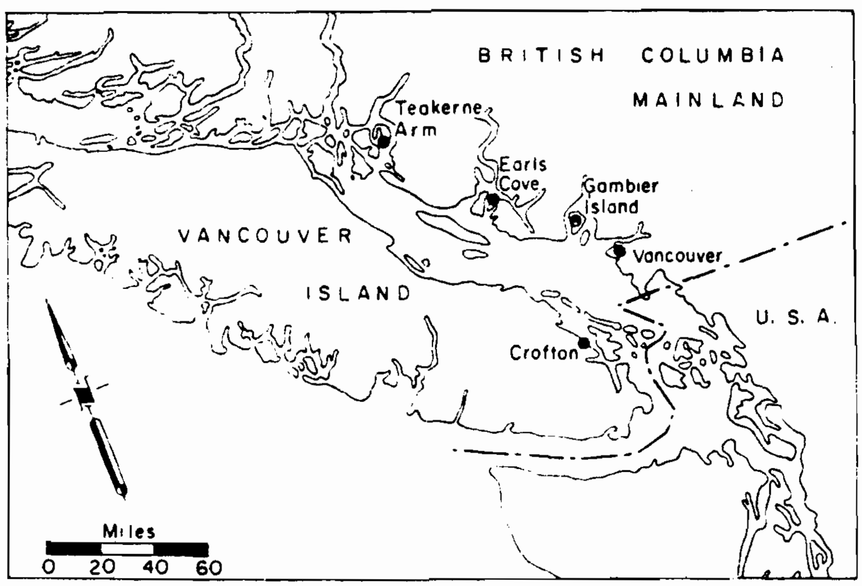


Fig. 2. *Bankia* monitoring sites.

It is, therefore, the conclusion of this study that the observed decreases in Bankia activity along the southern British Columbia coastline cannot at present be satisfactorily explained in terms of any single environmental factor, nor of any simple combination of such factors.

SUMMARY

The settlement of shipworms at five British Columbia (Canada) localities has been monitored since 1961. Settlement peaked in the early 1960's, then declined after 1967. Settlement was less during 1973 than during any earlier year for which data are available.

MARINE-BORER STUDY, PORT OF NEW YORK

During the past 75 years, the pollution in the harbor of New York has suppressed most marine life. However, the current pollution abatement program may stimulate biological growth and activity in the harbor, as a similar abatement program has done over the past ten years in San Francisco Bay. In 1966 the BCRC was commissioned by the Port of New York Authority to project marine-borer activity after the effect of pollution clean up becomes apparent in 1971-72. This study indicated that among other wood borers, *Limnoria tripunctata* -- the creosote-resistant borer -- would find its way into the harbor by that time.

Although *L. tripunctata* has been classified as a warm-water species, BCRC biologists discovered specimens at Crofton, B.C., in 1961, and later studies by Dr. D.B. Quayle, Pacific Biological Station, showed that the species is widespread in waters adjacent to Vancouver Island, both east and west. However, no cases of economic destruction by this species have been reported in temperate waters to date. Studies are expected to be continued for the Port of New York Authority to determine if destruction by *L. tripunctata* will occur to creosoted timbers under the water temperature conditions of New York Harbor.

O, L, M, H -- CLASSIFYING THE INTENSITIES OF MARINE-BORER ATTACKS

Each month's "Tidelines" contains a table of forecasts regarding marine-borer attacks in the near future. The predicted intensities are tabulated using the letter "O" for clear, "L" for light, "M" for moderate, and "H" for heavy. Some of our readers may have wondered what, exactly, do these letters represent in terms of actual numbers. The classification used is as follows:

	Attack per sq. ft.
Clear	None
Light	1 to 9
Moderate	10 to 99
Heavy	100 and up

In one of the coming issues of "Tidelines", we will attempt to illustrate the degree of accuracy achieved in these marine-borer activity forecasts, by comparing the intensities predicted according to the above table with the record of the actual settlements on test blocks in the following months.

WEATHERMAN

How accurate are the marine-borer forecasts issued each month in Tidelines? A random choice from any one of four possibilities (O, L, M, H), such as might be made by throwing of a tetrahedral (four sided) die marked on each of its four faces with a corresponding letter, would tend to predict any sequence of these four events with an accuracy of 25% correct predictions.

Through the judicious use of data compiled over the last decade, combined with existing knowledge of the nature of the Bankia breeding behaviour, scientists at the Council laboratories attempt to forecast coming borer activity. Their degree of success in this matter over the last three years is presented in the following tables.

Table 1. Accuracy of Prediction in One-Month Forecasts.

	1965		1966		1967	
	Forecasts	%	Forecasts	%	Forecasts	%
Right	239	55.6	280	59.1	158	51.7
Wrong	191	44.4	194	40.9	148	48.3
TOTALS	430	100.0	474	100.0	306	100.0

Table 1 compared the predicted settlements for the month immediately following each issue of "Tidelines" with the actual settlement on test blocks for that month (Tabulated in the following "Tidelines" issue); Table 2 covers predictions on settlements two months in advance.

Table 2. Accuracy of Prediction in Two-Month Forecasts

	1965		1966		1967	
	Forecasts	%	Forecasts	%	Forecasts	%
Right	222	52.0	270	57.7	157	51.4
Wrong	205	48.0	198	42.3	149	48.6
TOTALS	427	100.0	468	100.0	306	100.0

The reader will notice that, although being considerably less than perfect, the forecasts in this period of time have accurately predicted the coming borer activity more than twice as often as would be expected from a "hit or miss" method.

The tables do not attempt to differentiate between gross errors and minor errors. Conceivably a "one place" error, as the prediction of a light (L) attack when actually zero (0) or a moderate (M) attack occurs, would be of less consequence to the log operator than would be the forecast of a light attack when actually a heavy (H) attack ensues. A "three-place" error would constitute the expectation of either zero or heavy attack, when exactly the opposite happens.

To demonstrate the degree of error in a series of forecasts, all one-month predictions in 1967 were, therefore, compared with the intensities of corresponding following attacks. The results of this comparison are compiled in the following table.

Table 3. Degree of Accuracy in 1967 Forecasts.

	Forecasts	%	% Expected from Randomness
No error	158	51.7	25
One-place errors	109	35.6	37.5
Two-place errors	38	12.4	25
Three-place errors	1	.3	12.5

The uneven distribution of percentages among the four possible errors, i.e., zero, one-, two- or three-place, to be expected in a strictly random situation, corresponds to limitations in possible errors associated with the original forecast. For example, only "zero" and "heavy" predictions may have three-place errors and are limited also to single one- and two-place errors. "Light" and "moderate" forecasts are associated with no three-place errors, a single two-place but two one-place errors.

While perfect forecasts are only slightly more common than imperfect ones, the occurrence of two-place errors is only half as frequent as what would be expected from chance alone, and three-place errors less than one fortieth.

The factors to be considered in a sound judgment of future borer behaviour have been considered in some detail in earlier issues. Most important is a knowledge of the annual breeding cycle picture at each site. Considerable variability between adjacent localities is often evident. The overall increase from year to year of Bankia activity (also January, 1963) may indicate the existence of long-time population fluctuations superimposed on the annual breeding cycles. Water temperature fluctuations appear to be of importance in larval settlement, and may, therefore, disrupt the temporal regularity of annual breeding cycles, and affect the total intensity of any month's attack. Salinity fluctuations may have the same effect, this question is presently under study at the Council. Other factors to be considered are fluctuations in industrial pollution, as well as the presence or absence of unprotected wood which may serve as Bankia spawning grounds.

Beyond doubt, the continued study of borer activity at a large number of test sites is mandatory to closely delineate the actual marine-borer picture at all times, as well as to keep the forecasts on a sound month-to-month basis.

FORECAST

Tidelines Vol. VII No. 13, January 1965

	February			March		
Station	2 ft	10 ft	20 ft	2 ft	10 ft	20 ft
Ketchikan	O	O	L	O	O	L
Watson Island	O	O	O	O	O	O
Masset Inlet	O	L	M	O	M	H
Call Creek	O	O	L	O	O	L
Teakerne Arm	O	L	L	O	L	L
Fair Harbour	O	L	L	O	O	L
Tahsis	O	L	L	O	L	L
Kildonan	O	M	M	O	L	M
Earl Cove	L	M	M	O	L	L
Burrard Inlet	O	L	M	O	O	L
Crofton	L	M	M	O	L	L
Nitinat Lake	O	O	L	O	O	L
Elliot Bay	L	M	H	M	H	H
Tacoma	L	H	H	M	H	H
Alameda						
(teredines)	O	O	L	O	O	L
(*Limnoria*)	L	M	M	M	M	M

O = Clear   L = Light   M = Moderate   H = Heavy

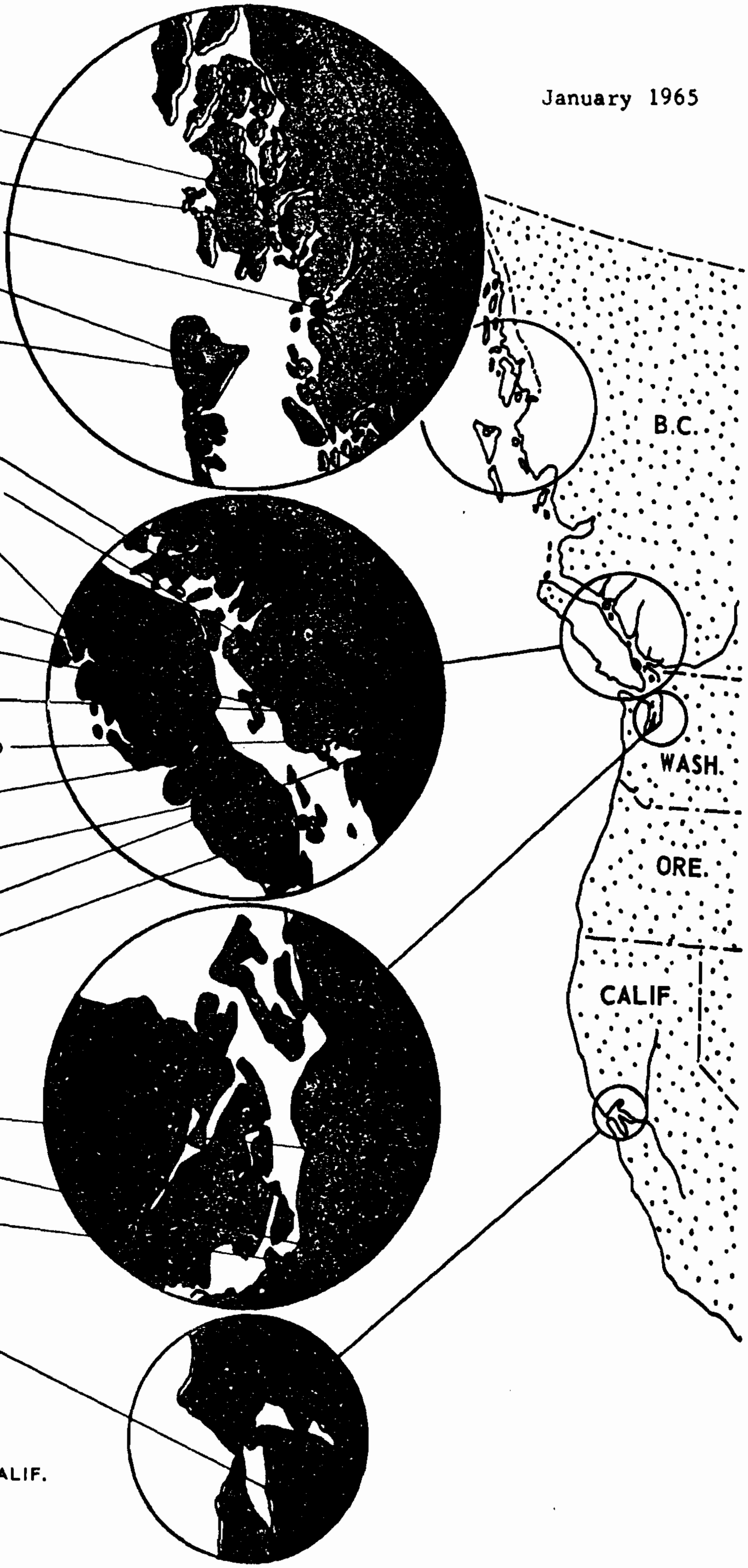
MARINE-BORER BREEDING-PACIFIC COAST

January 1965

NUMBERS PER SQUARE FOOT TO:

2 ft.	10 ft.	20 ft.	
Not received			THORNE BAY
Not received			WARD COVE
0	0	0	WATSON ISLAND
0	876	1238	SHANNON BAY (Dec & Jan)
LOST			JUSTKATLA
0	0	0	CALL CREEK
0	1	6	TEAKERNE ARM
0	6	9	FAIR HARBOUR
0	1	6	TAHSIS
10	16	17	EARL COVE
Not received			BLIND BAY
0	1	22	GAMBIER ISLAND
0	60	176	KILDONAN
0	0	53	NITINAT LAKE
0	3	8	VANCOUVER
0	7	12	CROFTON
30	23	44	SEATTLE
0	100	181	HYLEBOS
10	142	198	TACOMA
0	0	0	ALAMEDA
*10	20	12	LOS ANGELES
Not received			SAN DIEGO
0	0	0	ENSENADA, B. CALIF.

*Limnoria



GROWTH

BORER GROWTH RATES

The last two editions of "Tidelines" have dealt with Bankia penetrations in test blocks immersed at four test sites ranging from Tacoma Harbor to Teakerne Arm (approximately 100 miles northwest of Vancouver, B.C.). Data discussed previously have involved penetrations following two months' immersion subsequent to October 1 and December 1, 1966, and for three months after October 1. Penetrations for three stations for the three months following December 1 are shown in the following table.

Three-month penetrations (inches)

Water Depth Feet	Crofton		Gambier		Teakerne	
	O - D	D - F	O - D	D - F	O - D	D - F
1	.8	.6	--	.05	1.9	.5
2	1.6	.65	.6	.05	.7	.6
3	1.6	.6	.9	.1	1.2	.8
4	1.6	lost	.5	.15	.6	.8
6	1.4	lost	1.8	.3	1.4	.9
8	1.8	lost	1.6	.25	1.0	1.2
10	lost	lost	2.0	.2	1.8	1.2

O - D = October to December D - F = December to February

Unfortunately, test material immersed at Tacoma was lost in a storm--a normal hazard in biological experimentation.

The entire combined data show that, regardless of the time period at which settlement occurred, borer growth rates and penetrations increased with increasing depth. Considering that during settlement periods the number of borers attacking wood also normally increases with increasing depth, this means that logs in the bottom tiers of bundle rafts are subject to much heavier damage than logs nearer the surface or in flat rafts, not only because of heavier settlement but also because of these faster borer-growth rates.

As would be expected, growth rates and penetrations are dependent on the time of the year, presumably associated with water temperatures. In the above table comparing growth rates for three-month periods and for previous corresponding data for two-month immersions, penetrations for the October-November and the October-December periods were greater, with few exceptions, than penetrations for the corresponding two- and three-month periods following December immersion. This means that logs rafted when water temperatures are at a minimum and stored in borer-infested waters have a longer safe period of storage before the onset of economic damage than logs rafted at other times of the year. The variation in growth at different locations, such as Gambier and Teakerne, may be due to water temperatures or to other factors.

Data for both two- and three-month immersion periods re-emphasize previous knowledge that penetrations increase markedly between the second and third month of exposure. For example, at Gambier growth rates during December at 6- to 10-foot depths were about 1-1/2 inches for blocks immersed in October, whereas for blocks immersed in December, corresponding values were only 1/10 inch. However, at Teakerne growth rates during the third month of immersion at the same depths averaged about 1 inch for blocks immersed both in October and in December. Again, the reasons for this difference are not immediately evident, but a difference in penetration rates at different locations is indicated. These data confirm the soundness of a two-month working limit for safe storage of logs in infested water.

BANKIA GROWTH RATES CONFIRMED

Some preliminary data on Bankia growth rates were published in Tidelines, February, 1967. Additional and confirmatory data were obtained during the fall Bankia breeding season in 1967. A total of four strings of test blocks were each immersed at Crofton, Vancouver and Tacoma for two- and three-month periods from October, 1967 to February 1, 1968. The two-month penetrations, covering the October-November and December-January immersion periods are compiled below.

Bankia Penetrations in Inches after Two-month's Exposure

Water Depth Feet	CROFTON	VANCOUVER		TACOMA
	O - N	O - N	D - J	D - J
1	.05	.05	0	0
2	lost	.05	0	0
3	.30	.15	0	0
4	.35	.25	.05	0
6	.20	.40	.05	.05
8	.20	.55	.15	.10
10	.30	.50	.20	.10

O - N = October and November
D - J = December and January

The three-month's immersion data were as follows:

Bankia Penetrations in Inches after Three-month's Exposure

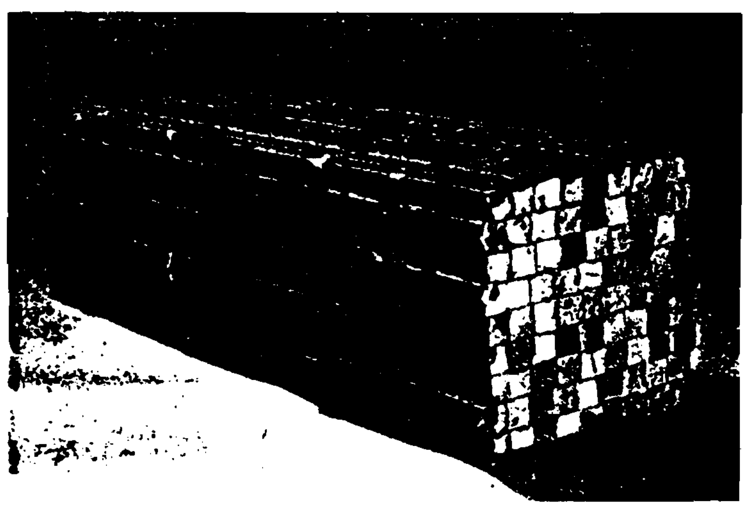
Water Depth Feet	CROFTON	VANCOUVER	TACOMA	
	O - N	O - N	D - J	D - J
1	.05	.85	lost	0
2	1.4	.10	lost	0
3	lost	1.5	.10	0
4	lost	1.7	.25	0
6	lost	2.0	1.6	1.8
8	1.4	1.3	2.0	2.0
10	1.5	1.9	2.0	2.0

D - F = December through February
O - D = October through December

Current results confirm higher penetration rates with increasing depth, although certain exceptions did occur. Also, since the numbers of attacking borer larvae are usually higher at bundle-raft depths than near the surface, the deeper logs in a bundle raft may be expected to sustain more Bankia damage than flat-raft logs when Bankia is present in the water.

In the current results, comparison between the fall and winter penetrations is difficult, because of missing data, associated with the lost strings. At Vancouver, the December to January penetrations were considerably less than for the October to November penetrations. However, at Tacoma, there was little difference between the fall and winter strings after three-month's exposure. In the 1966 experiment, the trend was toward lesser penetrations during the winter months. However, the usefulness of a two-month working limit for safe storage of logs in infested waters is confirmed. Particularly during the early fall, strict adherence to the two-month storage schedule may prevent costly losses to log inventory whenever Bankia is present.

RATE OF GROWTH OF BANKIA SETACEA IN VANCOUVER HARBOR



Just as in the determination of maximum age of Bankia, growth rates and maximum size of individuals can only be determined where overcrowding does not occur. Because only limited data on this Pacific coast species were available, the Council has conducted a number of growth studies. The first tests were undertaken in 1957 using wooden strips packaged as illustrated, with individual strips, 3/4-inch square in cross-section, separated from one another by aluminum foil and the complete package given three coats of neoprene on the four sides and one end. Thus, larval settlement and adult entry on each stick was restricted to the unprotected 3/4-inch square end. Three bundles were prepared, with strips one, two and three feet long respectively, and were submerged at North Vancouver on November 1, 1957.

At eight months borers had reached the end of five of the nine one-foot strips and at twenty-two months, had filled ten of the twelve two-foot strips. At twenty-two months some of the three-foot strips contained borers 34 inches long.

A second series of tests were made using 49, 5-foot strips, immersed on October 1, 1959. In nine of these strips the length of the imbedded borers was determined by X-ray photography after six, seven, eight and nine months immersion. The results are set forth in the accompanying table. Except for strip Nos. 3 and 8, where borers were crowded, the average growth rate between the sixth and ninth months was 7 1/2-inches, or 2 1/2-inches per month. After nine months the largest borer was 22.2 inches long.

Table 1. Rate of growth of Bankia.

Specimen No.	Length (inches) at: 6 mo.	7 mo	8 mo	9 mo	Difference 6-9 mo
1	4.2	6.1	8.2	10.7	6.5
2	9.0	10.7	12.5	15.4	6.4
3*	5.9	6.4	7.8	8.7	2.8
4	12.8	16.0	19.8	20.7	7.9
5	10.3	12.6	14.3	17.2	6.9
6	6.5	9.0	12.0	13.5	7.0
7	13.3	16.2	19.7	22.2	8.9
8*	3.4	-	5.2	5.7	2.3
9	6.1	8.2	11.5	14.7	8.6

*Specimen crowded by other borers in same strip.

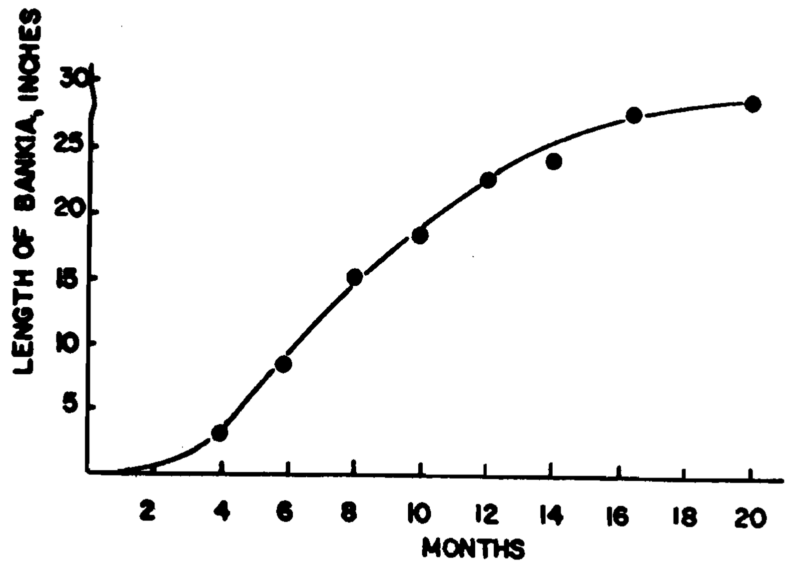
After 21 months, 27 Bankia from 29 other strips of the same group ranged in length from 26.25 to 39.5 inches and averaged 32 inches. At the time of examination most of these were dead although the two longest ones (38 and 39.5 inches) were still alive. Unfortunately storm losses of experimental material terminated the experiment.

A second similar study was undertaken in the fall of 1960, seeking to reduce any possible effect of X-ray radiation on Bankia growth, by using shorter X-ray exposure times and photographing only every two months. From 42 infested strips of 48 immersed, nine were selected for subsequent study. The average lengths of the borers in these nine strips are shown graphically in the accompanying figure.

The average growth rate was 2-3 inches per month between the fourth and 16th month, then declined and virtually stopped after the seventeenth month.

In the above experiments, individual Bankia could grow without interference from one another. This situation rarely occurs in nature.

Settlement of Bankia larvae is usually so heavy, with relation to the timber available, that severe overcrowding begins by the fourth month. Thus, the maximum growth rate of 2 1/2 to 3 inches per month may be realized only over a short period. Even under these conditions, however, a wooden timber or log can be riddled in seven or eight months.



Currently the length of Bankia specimens is being determined by dissecting 12 strips every second month. This procedure is intended to avoid any cumulative effect of X-ray radiation or handling out-of-sea water. The larger number of specimens is expected to give statistically reliable values.

GROWTH RATES

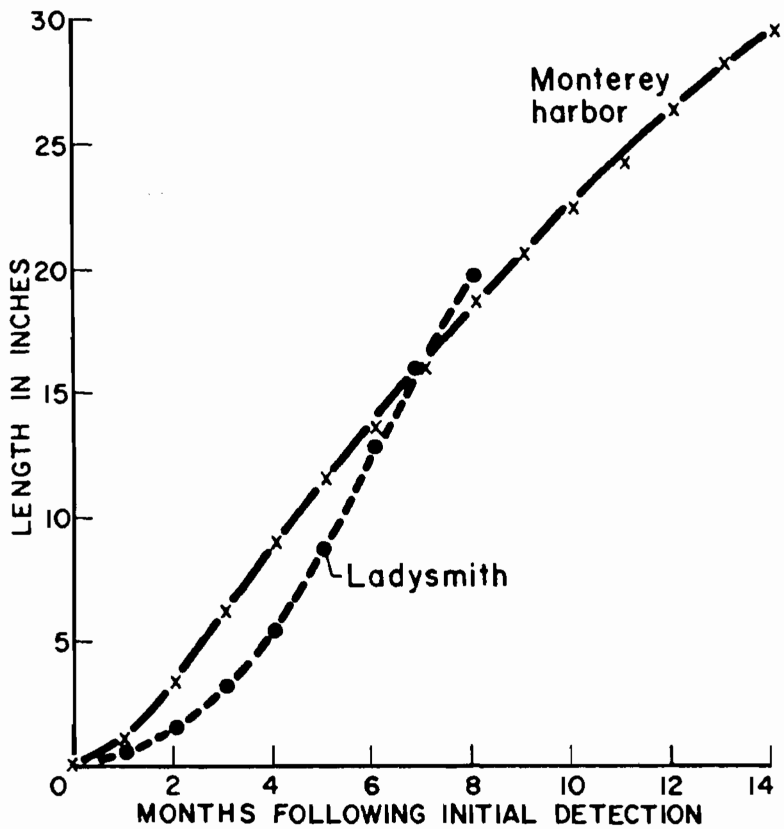
In a recent study by the Department of Oceanography at the Naval Post-graduate School in Monterey, California, the growth rates of Bankia setacea in test panels immersed in Monterey Harbor were evaluated by X-ray photography, over a period of 14 months. The following table summarizes the average for five groups of test panels.

Month to month growth of Bankia setacea in 5 x 13 x 3/4-inch Douglas fir test panels immersed in Monterey Harbor, California

Month No.	Number of individual Bankia measurements	Average length increment (inches)	Average length (inches)
Initial detection	24	.2	.2
1	24	1.1	1.3
2	22	2.2	3.5
3	19	2.9	6.4
4	19	2.8	9.2
5	18	2.7	11.9
6	18	2.0	13.9
7	14	2.4	16.3
8	12	2.6	18.9
9	10	2.0	20.9
10	4	1.7	22.6
11	1	1.9	24.5
12	1	2.0	26.5
13	1	1.9	28.4
14	1	1.3	29.7

The first two groups had floating panels, the other three fixed panels. The floating panels were positioned at the surface and two feet below, the fixed panels at 3, 13 and 23 feet below mean lower low water (MLLW).

Restrictions on growth rates due to crowding of embedded borers were avoided by wrapping the test panels snugly with Seran tape. The tape covered the plane faces of the panels and left only the butt ends open to attack by borer larvae.



In B.C., seven-month Bankia growth rates were studied by Dr. D.B. Quayle at Ladysmith, Vancouver Island, in 1956. His results are compared to the results from Monterey in the figure.

During the first three months, the growth of Bankia at Ladysmith was slower than at Monterey, but from the third to the seventh month the growth at Ladysmith was faster. The lower initial growth rate at Ladysmith coincided with water temperatures lower than those at Monterey. By July, the Bankia at Ladysmith were growing at a faster rate than those at Monterey. This corresponded to a higher water temperature at Ladysmith.

Comparisons between the growth rates in the different panel groups at Monterey demonstrated that B. setacea grow as fast at the surface as at deeper levels down to 23 feet below MLLW. The results obtained by the B.C. Research experiments on growth rates, suggested that Bankia at our latitudes grow slower at the surface than deeper down. Salinity could be an explanation for this apparent discrepancy. In Monterey Harbor, the surface salinity did not go below 32.8 ppt for the entire duration of the experiment. The differences between Bankia growth rates at the surface and in deeper waters here in the Pacific Northwest may be a reflection of the large discharge of fresh water that periodically reduces the surface salinity of the sea in many of our bays and inlets.

LENGTH OF LIFE OF BANKIA SETACEA

The question is often asked "How long do individual Bankia setacea live?" Under natural conditions, where these borers are usually crowded they rarely live longer than one year. However, where the density of settlement on wood is sparse and individual borers can grow without interference from one another, they may live much longer.

On October 1, 1959, fifty wood strips, 3/4 x 3/4 x 60-inches, were strapped together into a single bundle with aluminum foil separating each strip from adjacent strips in the bundle and the four sides and one end of the bundle given three coats of neoprene paint. The bundle was submerged at 25 ft below zero tide at North Vancouver. By treating the strips in the manner described, attack by Bankia could occur only at one end of the strips, and a borer in one strip would be unable to cross the aluminum foil into an adjacent strip. This technique was used to avoid over-crowding of the borers and to permit maximum growth. Because of storm losses, data for only 29 of the 49 strips are available, and for only the first 21 months. Observations for the 12- to 21-month period are set up in the accompanying table.

Length of life of Bankia setacea (45 specimens in test)

Months	Under 12	Between 12-14	Between 14-15	Between 15-16	Between 16-17	Between 17-21	Over 21
% died, each interval	0	12	7	16	7	30	28
% of total alive	100	88	81	65	58	28	

None of the borers died in less than 12 months. The greatest proportion (30%) died between 17 and 21 months, but more than 25% lived beyond 21 months. Had the experiment continued, some borers probably would have reached an age of two years.

Attempts have been made to determine how long Bankia setacea will live in wood removed from sea-water. Tests made as far back as 1949 showed that when blocks infested with Bankia were removed from the sea and covered by a sack during moist winter temperatures (not freezing), many of the borers remained alive for four weeks and then resumed their activity when the blocks were placed back in the sea. More recent tests made in 1960 showed that only about 2 percent of borers survived a four week period of land storage. During the period out of water, the animal is living on his food reserves (glycogen). Thus this test actually measures the time it takes to starve the animals to death. Understandably the rate of starvation is affected by a number of factors, including the age of the animal and the temperature of his surroundings.

During exposure of infested wood to air between high and low tides, borers suffer no damage unless temperatures are low enough to freeze the animals in the intervening period. In fact, during severe winters, this method has been used to reduce or eliminate the borers in infested logs in Alaska.

NEW IMPREGNANTS

In the Council's continuing search for new wood impregnants to repel the creosote-resistant _Limnoria_ _tripunctata_, three classes of compounds show promise. Organo-lead compounds show a high degree of initial resistance. These compounds are similar in structure to the organo-tin series which has attracted considerable attention in this field. Certain combinations of chlorinated aromatic hydrocarbons have provided complete protection for panels over the first year's immersion. Inorganic uranium oxide, colloidally dispersed within wooden panels, has also proven very toxic to _L_. _tripunctata_. Further studies are planned on these three groups of compounds.

BLOCK PENETRATIONS

Monthly test block counts provide salient information on the population pressures of _Bankia_, closely delineating the zonation, intensity, and season of attack. Since blocks are serviced on a monthly basis, embedded "larvae" must be examined microscopically, and thus no indication of subsequent survival is available. Rates of growth which, in turn, determine recommended economic storage periods of log inventories and timing for chemical treatments for permanent marine wood structures, previously have been calculated from published data or by experiment in Vancouver Harbor.

Following reports of excessive short-time _Bankia_ penetrations in logs in both B.C. and Washington, a preliminary experiment was conducted at four regular test stations representing major log-holding areas: Tacoma Harbor, Vancouver Harbor, Gambier Island, and Teakerne Arm.

Four strings, comprising regular 2-inch cubical blocks stapled to nylon line at 1-, 2-, 3-, 4-, 6-, 8- and 10-foot intervals were immersed at each station on October 1, 1966. At the end of November (two months) two strings were removed and shipped to the Council for examination. Similarly, at the end of December (three months' immersion), the remaining two strings were shipped. Observations in the laboratory included regular counts together with depths of penetration of embedded _Bankia_ as determined by splitting and probing.

Penetrations--inches

Water Depth Feet	Tacoma		Vancouver		Gambier		Teakerne	
	2 mo	3 mo	2 mo	3 mo	2 mo	3 mo	2 mo	3 mo
1	0	0	0	0.2	0	0.28	.08	.02
2	0	0	0	0.9	0.04	0.6	.04	0.7
3	0	0.2	0.43	0.8	0.08	0.87	.08	1.2
4	0.2	0.43	0.3	1.1	0.35	0.51	.08	0.6
6	0.2	1.2	0.4	1.4	0.35	1.8	.08	1.4
8	0.3	2.0	0.3	1.8	0.43	1.6	.47	1.0
10	0.3	2.0	1.0	2.0	0.43	2.0	.43	1.8

As the table above shows, zones recording no attack at two months extended to 1, 2 and 3 feet at Gambier Island, Vancouver and Tacoma, respectively, whereas attack occurred at all levels in Teakerne Arm. Penetrations, which generally increased with depth, ranged from 0.04 inches at the 2-foot levels at Teakerne and Gambier to a maximum of 1 inch at 10 feet (Vancouver). At all sites except Vancouver, growth rates were of the same order of magnitude with penetrations of less than one-half inch.

Three-month results illustrated the sound basis for limiting log storage to this maximum period and tended to smooth differences in penetration amongst test sites. At flat raft log levels (2 ft) borer lengths ranged from 0.02 to 0.9 inches at Teakerne and Vancouver respectively; at bundle raft levels (8 ft) penetrations of 1 to 2 inches were recorded; and at 10 feet below the water surface, 2-inch borers occurred at all sites.

Since populations at all sites were sufficiently dense to produce maximum economic damage, the following index based on summed penetrations to 2 feet for flat rafts and to 8 feet for bundles, provides a rough basis for comparison of sites; the lower the number, the less total wood shrinkage.

Raft Type	Tacoma		Vancouver		Gambier		Teakerne	
	2 mo	3 mo	2 mo	3 mo	2 mo	3 mo	2 mo	3 mo
Flat	0	0	0	1.1	0.04	0.88	0.12	0.72
Bundle	0.7	3.83	2.43	6.2	1.25	5.66	.83	5.1

Thus, for three-month flat raft storage, Tacoma appears to the most advantage, Vancouver the least, with the remaining sites only slightly better than Vancouver. For bundle rafts storage in Tacoma again appears to be more desirable, followed in order by Teakerne, Gambier, and Vancouver.

In most cases growth rates were less than the maximum observed elsewhere in the literature and experimentally in previous years but similar to that in adjacent logs at Gambier. With further testing in 1967, the block technique may prove a useful tool in the simple detection and evaluation of Bankia survival and growth throughout log zones.

GROWTH OF BANKIA IN ARTIFICIAL SUBSTRATES

For many research studies, wood is an unsatisfactory material in which to grow *Bankia*. A transparent material would be far more useful, and one of simple and known composition would be desirable for nutritional studies. Accordingly, exploratory attempts were made during 1962 to find substances other than wood in which *Bankia* would grow.

The first attempts involved wood flour bonded with phenolformaldehyde resin, wood flour packed in test tubes faced with a veneer disc and wood flour incorporated in thermoplastic "Lucite", an acrylic resin. Bankian larvae failed to establish themselves and grow in these materials.

Another substance tested was 4% bacteriological agar gel into which was mixed various percentages of wood flour, cellulose pulp or cellulose acetate prepared in test tubes and faced with cork or veneer discs. These were submerged in the sea during the breeding season in the fall of 1962.

Bankian larvae did not grow in the cork discs, but many attacked the veneer discs and in many cases the adult penetrated into the agar beneath. None of the borers penetrated agar-distilled water gels further than 0.25 in. However, when sea water was used in place of distilled water, the *Bankia* penetrated to a maximum depth of 0.5 in. This penetration was extended to 1.5 inches when wood flour was incorporated in the agar-sea-water gel. The largest specimens, 2.5 in. long, were obtained using agar in sea water with cellulose. On the other hand, cellulose acetate gave poor results.

Although the size of *Bankia* grown in this manner has been limited, these experiments demonstrated for the first time that *Bankia* can be grown in material other than wood or other natural cellulose fibres. Under natural conditions in the sea various authors have found *Teredo* growing in natural fibre rope, certain seed pods, and hard nut shells.

LABORATORY-REARED BANKIA

Attempts to rear *Bankia* throughout their life cycle in the laboratory have met with considerable difficulties. Adult *Bankia* can be maintained, will breed and produce fertilized ova. However, the small free-swimming bivalved larvae only live about 15 days before dying and no successful attachments on wood have been observed to date. Considerable effort is being expended to bridge this gap in the cycle since the ability to rear the animal completely in the laboratory would facilitate both our applied and basic research considerably.

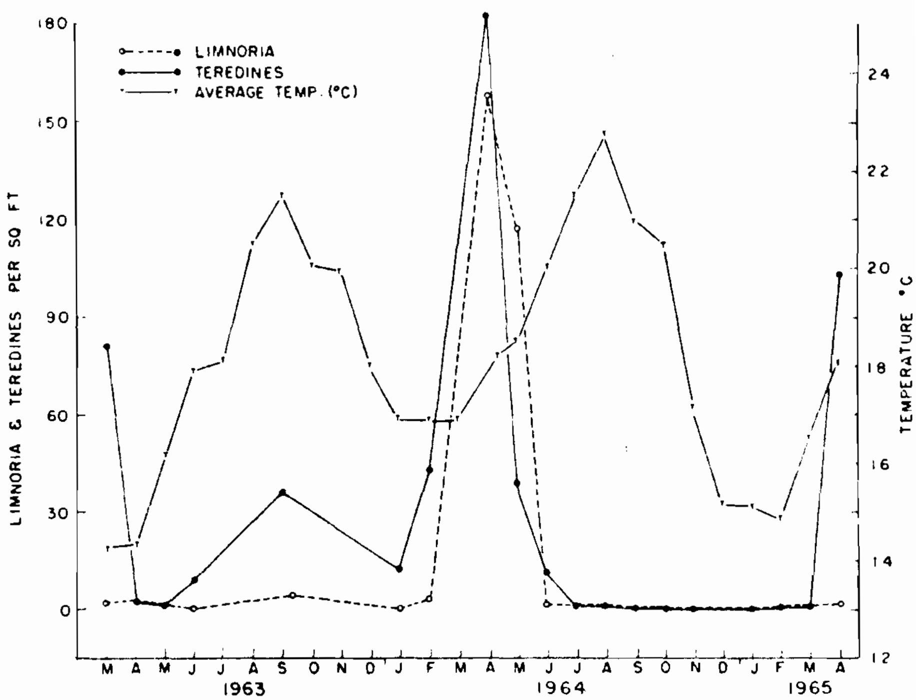
ECOLOGY

TEMPERATURE AND ATTACK

Readers will recall the table below which first appeared in "Tidelines" Vol. VI, No. 1, January 1964, and illustrated the relationship between water temperature and bankian attack. Maximum-minimum water temperatures were obtained once monthly at a depth of 10 ft. and the salient characteristic was that, in each instance, borer settlement was activated by an increase in water temperature and depressed by cooling waters.

Location	Temperatures to Start Attack	Stop Attack
Sitka, Alaska	12.5°C	7°C
Ketchikan	12.5°C	7°C
Teakerne Arm	18.5°-21°C	7°C
Vancouver	12.5°-15.5°C	7°C
Crofton	15.5°C	7°C
Seattle	above 7°C	7°C
Alameda	18.5°-21°C	12.5°C
Ensenada, Mexico	15°-17°C	18°C

The last entry was made possible through the courtesy of Dr. Pedro Mercado S ., Director of the School of Marine Sciences, University of Baja California, Ensenada, Mexico, and his associate Dr. G. V. Ferrer, who supplied temperature data which are obtained four times daily at a number of harbour locations and depths.



As shown in the graph above it has been possible to correlate both teredine and limnorial activity with temperature variations during the two-year period from March 1963 to April 1965. In Ensenada's semi-tropical waters, cooling temperatures (15°-17°) are required to trigger teredine settlement and limnorial migrations, both of which seem to be depressed by following temperature increases above 18°C.

RELATION BETWEEN WATER TEMPERATURE AND BANKIA ATTACK

Possible correlation between water temperature and bankian breeding and attack is being studied on a continuous basis at seven stations extending from Sitka, Alaska to Alameda, California. Records at each location cover at least four years, and at one location, Seattle, over nine years. A similar study made many years ago by Black and Elsey (Fisheries Research Board of Canada, Bull. No. 80, 1948), failed to show any relationship between water temperature and the settlement of the larvae on wood.

At each location monthly maximum and minimum temperatures have been recorded and attack by Bankia has been determined with test blocks. Since the readings were made only at the end of each month, the data do not indicate temperature fluctuations within the monthly periods. In addition, settlement records are a measure of larval attack, not of production of sperm and eggs or of formation of larvae. Further, Quayle ("The Larva of Bankia setacea Tryon, Province of B.C.", Provincial Dept. of Fisheries Report, 1951, pp 89-91) has found that these larvae may move about in water up to a month before settling on wood. Thus it should be appreciated that this study does not relate water temperature to breeding, but to settlement of larvae, and that the relatively long, free-swimming period of the larvae precludes an exact relation between water temperature and settlement.

The water temperatures were taken ten feet below water surface and Bankia settlement was recorded from one to 20 ft deep. The accompanying table shows the relation between water temperature and bankian attack. For the same location the onset of attack was fairly consistent with water temperature each year. Bankian attack begins at lower water temperatures in the more cooler, northern waters, starting at 55°F at Sitka and Ketchikan, and at 55-60°F at Vancouver. During the summer, waters at Teakerne Arm and at Crofton are considerably warmer than at Vancouver and the onset of attack at these two points occurs at distinctively higher temperatures. On the other hand, water temperatures at Seattle show the least variation of all seven stations, and the yearly range usually does not exceed 10°F. Here borer attack has been continuous as far back as September, 1953; the lowest values were obtained in February and March, 1956 when the water temperature was between 44 and 45°F. At Alameda, where the waters are the warmest of all test locations, the water temperature must reach 65-70°F before attack commences.

At all stations from Sitka to Seattle, attack stops when the temperatures drop to 45 or lower. At Alameda, bankian attack ceases when the temperature drops to 55°F.

As can be seen from the table, start of attack by Bankia is not associated with one absolute temperature, the same for all locations, but appears to be related to the water temperature characteristics at a specific location.

The rate of water temperature increase seems to trigger teredine breeding. The peak attack usually follows one to two months, occasionally three months after the maximum water temperature for the year.

Relation Between Water Temperature and Bankian Attack

	Temperature of	
Location	Start Attack	Stop Attack
Sitka, Alaska	55	45
Ketchikan	55	45
Teakerne Arm	65-70	45
Vancouver	55-60	45
Crofton	60	45
Seattle	above 45	45
Alameda	65-70	55

AND STILL LARGER

A single Bankia removed from Vancouver Harbour in early February measured 46 inches long and almost filled the 3/4 inch square test stick at the terminal or head end. The animal had reached these dimensions in less than 17 months in relatively quiescent waters.

EFFECT OF LOWERED SALT CONCENTRATION ON BANKIA SETACEA

For studying the effect of lowered salt concentration, clear sticks of Douglas fir, 1/2-inch square in cross-section by 5 inches long were completely coated with a mixture of epoxy resin and glass powder, except for a 1/4-inch diameter circle near one end of each stick. The epoxy coating minimized uptake of sea water by the wood and the glass powder limited settlement of larvae to the unprotected 1/4-inch circle during immersion in Vancouver Harbor.

After they had become infested with Bankia, the wooden sticks were returned to the laboratory and divided into groups containing 25-30 animals each. One group was immersed in natural sea water at different salinities, another group in a similar range of salinities of artificial sea water (distilled water plus salts). The water was maintained at 15°C and was exchanged daily. Bankia activity was noted by the number of extended siphons and the presence of frass (excreted wood material) in the surrounding water. After a number of days in the test solutions the animals were returned to natural sea water for two days for recovery prior to checking their activity.

			In test solution		After Recovery	
Sea Water	Salinity ‰ (parts per thousand)	Days immersed	% siphons extended	Frass formed	% siphons extended	Frass formed
Natural	23	20	95	++	100	++
	13	20	100	++	100	++
	12	20	70	+	95	++
	11	10	40	-	85	++
	9	1	10	-	95	++
Artificial	25	20	100	++	100	++
	14	20	90	++	90	++
	13	10	30	+	95	++
	12	10	0	-	65	+

The summary of results in the accompanying table show that in natural sea water, Bankia extended their siphons and produced frass in salinities down to 12 ‰. At 11 ‰ over half the siphons were retracted and no frass was produced; at 9 ‰ only 10% of the siphons were visible. On returning the Bankia to normal sea water, virtually full activity was resumed by animals which had been held at 12 ‰ or higher for 20 days. Ten days at 11 ‰ resulted in some decrease in later activity, although one day at 9 ‰ had little continuing effect.

These results obtained with Bankia setacea correspond with those published by the Russian worker, Soldatova (1961) for Teredo navalis. Kudinova and Pastionab (1960) have shown that T. navalis requires a salinity of 12‰ for normal development of larvae.

The Bankia detected little difference between natural and artificial sea water until salinities became limiting. In artificial sea water the activity, both by siphon count and frass production, dropped sharply as the salinity was reduced from 14 to 13‰ and ceased entirely at 12‰. However, in recovery solutions the only Bankia failing to show complete return to normal were those immersed 10 days in 12‰ artificial sea water.

The natural sea water used in these experiments came from Burrard Inlet, where normal salinity is 23‰. In the open sea a more usual value is 30-35‰.

IMPROVED PILE INSPECTION FACILITIES

Miniaturization of electronic components and engineering re-design of underwater equipment will facilitate the performance of the Council's team for underwater non-destructive testing of piling. Although the basic principles of the sonic technique remain unchanged, inspection will now be possible, independent of a 110-volt power supply. Re-design of equipment is expected to reduce diver and observer fatigue, at the same time enhancing the overall speed and accuracy of inspection. The demand for pile inspection services is constantly growing and the desirability of licensing suitable firms to perform these services in other world areas is being examined.

EFFECT OF SUBSTITUTING SALTS IN SEA WATER ON BANKIA SETACEA

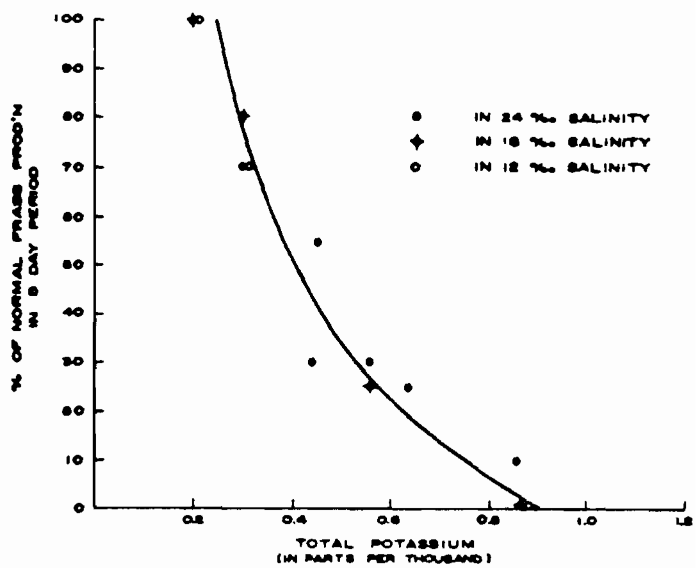
Experiments described in the previous issue of "Tidelines" showed that Bankia setacea requires a salt (salinity) concentration of 12 parts per thousand (‰) in the surrounding water to carry on wood-boring activity. The question now arises, what is the effect of the concentration and proportion of the principal salts in sea water on the boring habit of Bankia? To answer this question, first a sample of sea water from Vancouver Harbour, with a salinity of 23.2‰, was analyzed for metallic ions.

Composition of sea water, Vancouver Harbour (23.2‰ salinity)

Metal ion	% by weight	Ratio Na to:	Concn ‰
Sodium	29.6		6.875
Magnesium	4.0	7.4:1	0.930
Calcium	1.06	28:1	0.245
Potassium	0.87	34:1	0.203

The sodium ion made up about 30% of the weight of salt in this sample of sea water, the magnesium 4%, calcium about 1% and potassium less than 1%. Although the total salt concentration regulates the osmotic pressure to which Bankia is subjected in the sea, the individual concentrations of ions, in the case of most animals, have important physiological effects. The effect on Bankia of small increases in concentration of some metals was observed. Individual additions of less than 1‰ magnesium, 0.5‰ calcium, and 0.2‰ potassium stopped the animals from boring. The effect in most cases was temporary, and the animals appeared to function normally when returned to sea water of natural composition.

Experiments were conducted to determine whether the absolute or the relative amounts of these metallic ions were responsible for the decreased <u>Bankia</u> activity. Natural sea water (24‰) was diluted to 12 and 16‰ salinity, and potassium salts were added to portions of the three salinities to give a number of solutions at each salinity whose total potassium concentration ranged up to 0.9‰. Using 25-30 test animals, the percent of normal frass production over a five-day period was determined in each test solution. Results are plotted in the accompanying graph.



Although the animals in sea water of greater salinity tended to show slightly more activity at the same potassium concentration than those animals in sea water of lesser salinity, differences were extremely small. <u>Bankia</u> is sensitive to the absolute amount of potassium ion in sea water and 0.9‰ effectively inhibits all boring. Low potassium ion concentrations also inhibit borer activity. In the complete absence of potassium salts, a German investigator (F. Roch, 1932) noted that <u>Teredo</u> <u>navalis</u> retracted their siphons and "holed up" for as long as six weeks. On return to natural sea water, most animals recovered within 12 to 24 hours.

GEOGRAPHICAL DIFFERENCES IN BANKIA ATTACK

For reasons not completely understood, attack by <u>Bankia</u> larvae varies considerably for the same location from year to year and for different locations during the same year. As the first table following shows, yearly total counts to a depth of 20 feet for five selected locations from Alaska to San Francisco Bay ranged from 90 to 4403 per square foot in 1960 and in 1964 from 1435 to 4742. In each year maximum and minimum attack occurred at the mid-B.C. Coast site and at San Francisco Bay. Difference in yearly totals was not marked at the mid-B.C. Coast site, whereas the pronounced increase in attack at San Francisco, from 1960 to 1964, may be attributed in part to the improvement of the marine environment by reduction of the pollution load being discharged into harbour waters.

In comparing counts for all five locations during the first six months of 1960, only the Puget Sound area recorded heavy attack. During the same period in 1964, attack was heavy both at Puget Sound and at the mid-B.C. Coast site.

During the summer and fall months, the normal period of breeding in northerly waters, the 1960 counts were particularly heavy at the B.C. and Alaska locations, with lesser numbers at Puget Sound and San Francisco. This tendency for counts to decrease progressively, southward along the coast, was also evident in 1964, when overall counts were much higher than in 1960. Variation between years in intensity of attack is evident in that only at the Alaska location did maximum attack occur in September of both years. Peak attack in 1960 and 1964 occurred at the mid-B.C. Coast location in August and November, at the lower B.C. Coast in November and September, at Puget Sound in February and April, and at San Francisco in October and July. Even at the two B.C. coastal locations, where breeding patterns are considered essentially similar, the peaks did not coincide in either year and their order in time was interchanged between 1960 and 1964.

Although average larval counts to the 20-foot depth monitor Bankia activity of concern in the protection of permanent waterfront structures and dry docks, of more paramount importance in the protection of log inventories and floating structures is the attack in the floating zone, i.e., over the depths from 0 to 8 feet.

As shown in the second table following, for three areas where protection of log inventories is a problem, Bankia larval attack to the two-foot depth also varies with time and geographical location. In Alaska logs in flat-raft formation were attacked during September and October of 1960, but waters to this depth were entirely safe throughout 1964. At the mid-B.C. Coast site safe storage was available for five months in 1960 and six months in 1964. Moreover in 1960, waters were free of larvae in January and not in 1964, whereas the reverse was true for the month of July in the two respective years.

Geographical differences in Limnoria attack between 1960 and 1964

MONTH	Alaska		Mid-B.C. Coast		Lower B.C. Coast		Puget Sound		San Francisco Bay	
	1960	1964	1960	1964	1960	1964	1960	1964	1960	1964
Jan.	0	1	14	8	6	0	0	1	1	0
Feb.	2	3	7	17	2	0	0	1	24	8
Mar.	5	0	43	58	12	1	2	8	344	53
Apr.	34	9	15	198	14	0	0	4	2263	388
May	11	12	27	233	12	0	0	4	285	181
June	0	2	29	389	6*	0	6	0	73	84
July	0	0	14	294	4	0	1	0	11	4
Aug.	0	1	32	100*	8	0	4	0	52	38
Sept.	0	1	24	17	18	0	5	0	170	10
Oct.	0	2*	11	14	3	1	1	0	285	13
Nov.	0	3*	20	25	2	0	0	1	1	1
Dec.	2	10	11	10	3	0	3	4	19	0
TOTALS	54	44	247	1363	90	2	22	15	3528	772

*=Estimated

Attack at Flat-Raft Log Levels, 1960 and 1964

Month	Alaska 1960	Alaska 1964	Mid-B.C. Coast 1960	Mid-B.C. Coast 1964	Puget Sound 1960	Puget Sound 1964
January	O	O	O	X	O	O
February	O	O	O	O	O	O
March	O	O	O	O	X	O
April	O	O	O	O	X	O
May	O	O	X	O	O	O
June	O	O	O	O	O	O
July	O	O	X	O	O	O
August	O	O	X	-	X	O
September	X	O	X	X	O	O
October	X	O	X	X	X	X
November	O	O	X	X	O	X
December	O	O	X	X	O	O
TOTAL MONTHS OF ATTACK	2	0	7	5	4	2

X = attack O = no attack - = no record

PARASITES

PARASITES AND PREDATORS AND THE PROBLEM OF BIOLOGICAL CONTROL OF SHIPWORMS

Much effort has been exerted over the years to find effective control measures against the ravage of shipworms. Charring the wooden hulls of boats, impregnating wood for marine use with chemical toxicants, wrapping wooden piling in copper-based or plastic sheathing, scupper nailing and concrete encasement of piling, are only some of the many methods used to prevent attackby the borer larvae. Established borers have been eradicated with varying degree of success, by poisons, blasting, high voltage currents, drying, encasements and protective wraps.

Possibly certain parasites or predators could be utilized for more effective and economic control than the nonbiological measures utilized to date. Surprisingly, no detailed study has been carried out on the parasites and predators of marine borers. Part of the reason for this may be that biological agents have not appeared to hold much promise as a potential means of shipworm control. Shipworm parasites were discovered in the last century, and later accounts have confirmed that the naturally occurring host-parasite relationships do not usually have any serious detrimental effects on the shipworm host.

Recently, a wide variety of shipworm parasites have been described. The majority of these have been unicellular animals, frequently infesting the gill tissues of the host. The growth of the infested shipworms was occasionally retarded, but otherwise they were only slightly affected. Other parasites of shipworms belong to the same group of animals as sea-anemonae and corals. These hydroid parasites infested nearly all shipworms collected during the period of December to March, on the southwest coast of India. However, as in the case of the unicellular parasites, the host specimens appeared healthy and quite normal. Parasites belonging to the phyla of flat worms and crustaceans, and to the small phylum Acanthocephala also have been found to infest shipworms.

Shipworm larvae have many enemies. Like other free-swimming marine larval organisms, they are the prey of small fishes and a great number of pelagic and bottom dwelling invertebrates. Off the coast of New Jersey, during 1921-1923, a relationship was discovered between the abundance of ctenophores (comb jellies) and the intensity of shipworm infestation. When the incidence of ctenophores was high, shipworm infestation was correspondingly low. Predators of adult, embedded shipworms are less well documented, although carnivorous and scavenging bristle worms (polychaetes) have been discovered to live in empty shipworm tunnels. Published discussions on the subject disagree on the role played by the bristle worms. The view that they are able to attack and feed on live, embedded shipworms, has not been widely substantiated. Some fishes will feed on shipworm siphons protruding from infested wood, but there is no evidence to indicate that the affected shipworms suffered more than a brief slow-down in their rate of boring.

TEREDICOLA TYPICUS--A PARASITE ON SHIPWORMS

The November, 1972, Tidelines article on parasites and predators on shipworms indicated that parasites on shipworms are of common occurrence, and that they range in structural complexity from simple, unicellular organisms to members of the more highly developed phyla.

Teredicola typicus is an example of a shipworm parasite that has been described in some detail in the literature. Genetically classified as a copepod, (phylum Arthropoda), it lives in the mantle cavity of shipworms and may reach a size of up to 5.9 mm (slightly less than one-quarter inch). In the mature female parasite, two external egg sacs, which may be nearly as long as the body, are attached near the tail and protrude past the hind end of the parasite. _T. typicus_ was first discovered in 1939, in specimens of the shipworm, _Teredo milleri_, collected from Honolulu Harbor, Hawaii. Seventy-five percent of the collected _T. milleri_ specimens were infested.

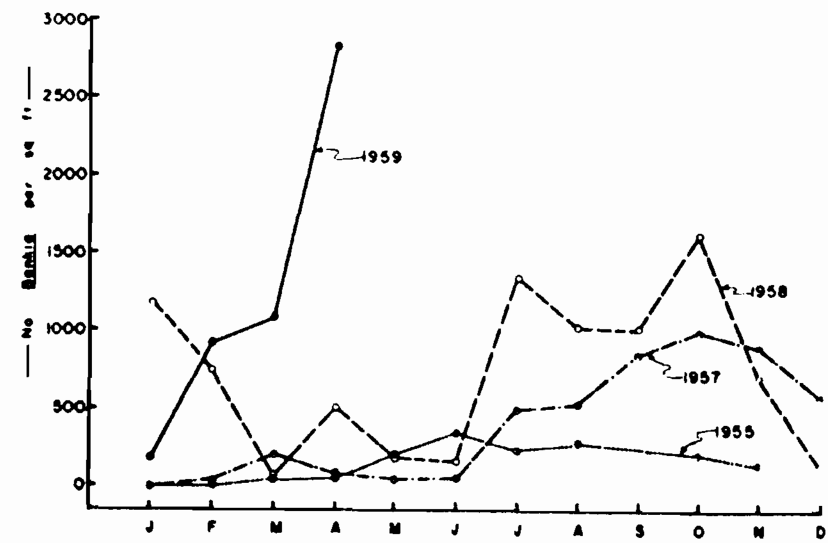
Five other Hawaiian shipworm species also serve as hosts to _T. typicus_: three of the genus _Teredo_, one _Bankia_ and one _Lyrodus_. The growth of the infested shipworms appeared to be retarded, otherwise no ill effects on the host organisms were evident.

In 1972, _T. typicus_ was discovered at eight different localities in Australia and two in New Zealand in specimens of _Bankia australis_ and _Teredo fragilis_. In Auckland Harbor, 56 percent of the examined shipworms were infested. In the Wade River estuary, also in New Zealand, 23 percent were infested. The parasite has also been observed in four specimens of _Lyrodus pedicellatus_ from Otomi, Japan. No injurious effects on the host organisms were reported.

Although probably widespread in the tropical and subtropical Pacific Ocean, _T. typicus_ has not been reported from the American coast, or from any oceans outside the Pacific. It has not been observed in _Bankia setacea_, the common species of shipworm along the west coast of Canada. It is, therefore, unlikely that it may be of use to control shipworm infestation at B.C. booming grounds.

POLLUTION

THE EFFECT OF POLLUTION ON BORERS



All higher animal forms, including both teredine and limnorial borers, require atmospheric oxygen to live. Marine life depends on the 10 parts per million of oxygen dissolved in unpolluted sea-water. In polluted waters the build-up of bacterial populations uses most or all the oxygen so that higher forms of life cannot survive. The activities of marine borers have been completely suppressed in many of the large ports on this continent for this reason. What happens when pollution abatement regulations are enacted has been demonstrated in San Francisco Bay. Following World War II, regulations were enforced severely curtailing the release of domestic and industrial wastes into San Francisco Bay and by 1955, the oxygen content of the water in the Oakland-Alameda area increased to a point which permitted the growth of increasing numbers of marine borers. The figure shows the monthly count of Bankia near the mud-line at Alameda for the years 1955, 1957, 1958 and for the first four months of 1959. Between 1955 and 1958 a steady increase in Bankia occurred, particularly between the months of July and November. By 1959, however, conditions for these borers had so improved that their numbers approached 3000 per sq. ft. of wood surface.

Even more striking was the increase in limnorial activity. By the spring of 1959 the attack of limnorial borers near the water surface had exceeded 10,000 per sq. ft. of wood surface. Since 1959, attack of Limnoria each spring has exceeded 10,000 per sq. ft. and the organisms are so numerous that the larvae of teredine borers have found no place to settle. Only during the summer months, when the breeding of Limnoria recedes, does teredine attack become appreciable. This heavy limnorial infestation is particularly disturbing since most of these organisms are Limnoria tripunctata, a species capable of attacking creosoted timber.

Indications are that the now critical marine-borer situation in San Francisco will be repeated in other ports as pollution is reduced. The Limnoria, which can tolerate lower oxygen levels than teredine borers, are usually the first to appear. In the San Pedro - Wilmington area, near Los Angeles, the Limnoria have been attacking piling near the mud-line (instead of in the intertidal zone, which is more common) for some years. Pollution in surface waters has forced these borers into sub-surface waters. In the last two or three years, the Limnoria have been moving further into the inner harbour and teredine borers have also appeared. Again, these Limnoria are of the creosote-resistant, tripunctata species.

The effect of pollution in suppressing marine-borer activity should not be confused with the reduction of salinity by dilution with fresh river water. In the second case, marine-borer activity is not reduced if the salt concentration is above 20 parts per thousand. In fact, more commonly brackish water appears to promote the breeding and activity of the borers.

SELECTION OF LOG STORAGE AREAS

Freedom from bankian attack is one of the major considerations in selecting a storage area in sea-water. In many cases fresh water outfalls provide some protection, depending on the volume and the extent that the fresh water overlays the salt water. In evaluating the suitability of a new storage area a Council biologist selects both water sampling points and locations for immersing test blocks. Over the breeding season Company personnel take water samples at 0, 5 and 10-foot depths and exchange test blocks on a monthly basis. Salinities and larval punctures are determined in Council laboratories on the water samples and test blocks respectively.

The likelihood of bankian attack at log storage depths is estimated from salinity values and confirmed by test-block data. If salinities are adequate for Bankia and if attack is present, frequent inspections for larval attack must be made during the breeding season. Attack is normally low in unused waters, but after 2-3 years the accumulation of sunken logs supports a much larger permanent bankian population.

DETECTION

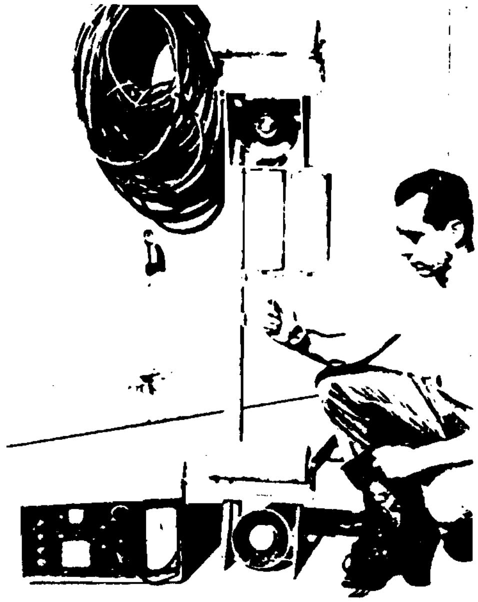
INSPECTION OF PILING FOR MARINE-BORER DAMAGE

The development of a non-destructive method for determining the presence of borer damage under the surface of piling has been a challenging research problem. The Council initiated a program on this problem in 1955 and it was not until after pursuing a number of unproductive ideas that promising results were first obtained in 1960. By early 1961, after the expenditure of $20,000, the first field unit was produced.

The principle of this testing device is that sound waves, when transmitted through borer-damaged wood, are reduced in velocity and strength. After transmission through wood, the sonic signal is picked up and read on an oscilloscope. One unique feature of the testing unit is that intimate contact of the transmitting and receiving transducers with the piling is not required. This means that it is not necessary to remove normal amounts of marine growth from the piling before testing.

Initially it had been planned to design a unit which could be manipulated from above the water surface. However, because of the variety of obstructions that are often present on piling, and because of the value of supplementing results from the sonic unit with a visual report, it has proven desirable to use a diver.

The unit is held in place on the piling by two sets of spring loaded rollers which permit it to be moved up or down or around a pile, as the examining diver wishes. The diver is in constant telephone communication with the "upstairs" member of the team, who is reading the oscilloscope. For practical purposes the amount of damage is expressed in percent of residual



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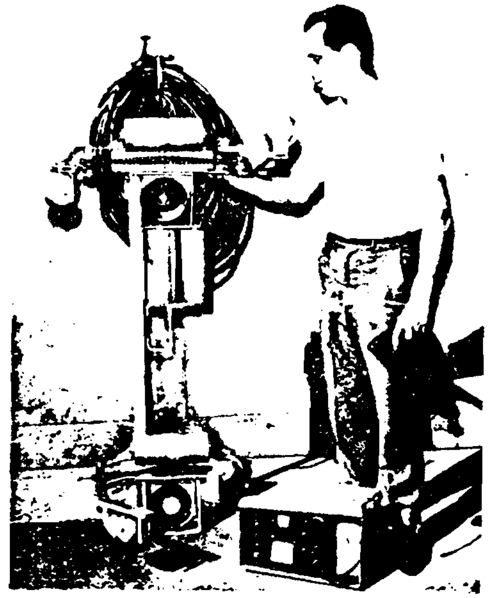


II

Sonic testing equipment: I - with side-rollers removed, for testing flat surface; II - with side-rollers for testing piling.

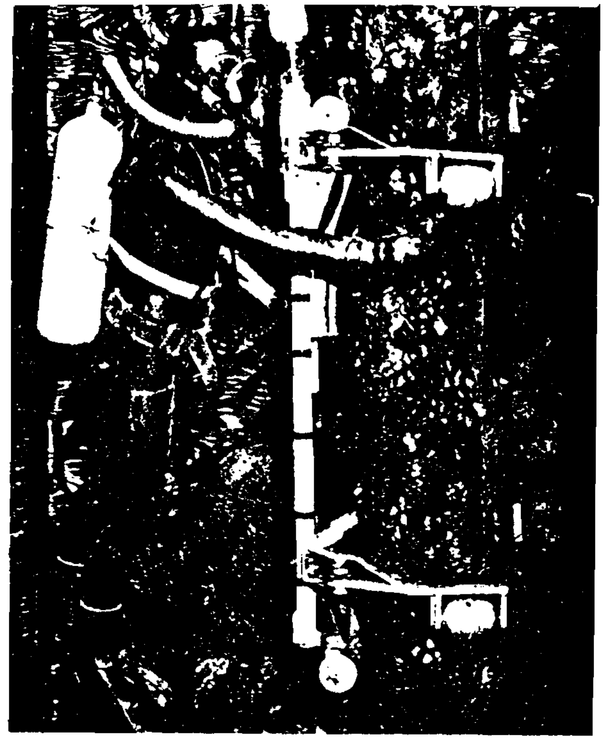
bearing strength retained by the piling. The relationship between reduction in oscilloscope signal and residual strength was determined by measuring signal strength on piling with a variety of damage, then cutting the piling into short sections and determining the compressive breaking strength in a 100-ton hydraulic press. The testing unit is amazingly accurate, being able to detect as few as 3-6 bankian tunnels in a single pile. Previously no numerical evaluation of piling strength had been possible. In fact teredine damage had been exceedingly difficult to detect at all, particularly where damage had been only partial.

The rate at which the inspection team can examine piling depends on a variety of factors: accessibility of the piling, their underwater length and exposure to unfavourable elements such as cold water, strong currents or muddy water. Normally where only 20 to 30 percent of total piling in a wharf are being examined and considerable movement of the crew is necessary, 50 to 85 piles per day are examined. Where all piling are being inspected, the rate per day is greater.

Inspection results are submitted in an individually prepared report, showing by plan drawing and by table the location, zone and residual strength of each damaged piling. This reporting is being extremely well received by engineers supervising wharf maintenance programs.

Over the past year and one half the inspection unit has been used to test over 5,000 piles in wharves in the State of Washington and along the B.C. Coast.

TEN YEARS OF TESTING



Illustrated is a B.C. Research diver using our patented sonic-inspection apparatus to determine, nondestructively the condition of a marine pile with respect to both borer damage (teredine and limnorial) and residual strength. This ultrasonic pulse apparatus is now entering its eleventh year of successful commercial operation since being developed by B.C. Research scientists. Under favourable conditions an inspection team, which normally consists of two men alternating duties between surface instrument reading and underwater manipulation of the probe, can test approximately 100 piles per day.

A standard sonic inspection job involves the minute visual and sonic inspection of each pile, from mudline to pile cap. Results are then tabulated and presented to the client in a final report containing tables, listing the residual strength and extent and type of damage in each pile, as well as a piling plan, showing the residual strength and location of each pile in the structure. The above factors are analyzed in the body of the report, and the client is advised both on maintenance procedures required and the present strength and condition of the piling, as related to anticipated service life of the structure. The client can then determine the overall loading capacity of the structure by utilizing the data provided, and implement any remedial action deemed necessary.

Piles examined to date now total approximately 85,000, representing 80 different firms and 190 individual projects. During 1970, our last full year of operation, 10,000 piles were tested at 25 locations. Projects have been carried out for both government and industry throughout North America and even as far afield as Hawaii. In North America piles have been tested from Alaska to California on the West Coast, and at Quebec, New York and South Carolina on the East Coast. Extensive testing has been carried out at New Orleans, as well.

The sonic inspection method continues to remain the most satisfactory, nondestructive means of determining strength in underwater piling.

Mr. Ken Jurgens, American Wood Preservers Institute, reported the following on Quality Marked Marine Piles:

> "AWPI has developed three (3) standards for timber piling for marine use. Select the standard most appropriate and you will receive the best treatment for the most economical cost. Our manual 'AWPI Quality Mark Marine Piling' contains the three standards. Each standard stipulates the types and quantities of preservatives to be used and the penetrations required to protect timber piling from decay, insects and marine borer attack.

Standard AWPI-MP-1: Standard for dual treatment of timber piling pressure-treated with water-borne preservatives and creosote--for use in marine waters of extreme borer hazard. (*Limnoria tripunctata* are extremely active or where oil slicks in harbors contribute to marine-borer attack).

Standard AWPI-MP-2: Standard for timber piling pressure treated with creosote--for use in marine waters of severe borer hazard.

Standard AWPI-MP-3: Standard for timber piling pressure-treated with creosote--for use in marine waters of moderate borer hazard."

Mr. Jurgens then reviewed the history of a number of marine structures constructed throughout the world with double-treated marine piling. The piling, treated according to AWPI Standard MP-1, had, in all cases, stood up well to borer attack. The longest service period reported was seven years in Pearl Harbor, Hawaii, with no damage yet reported.

INFORMATION PLEASE

Inevitably, and for a variety of reasons, impregnated wooden piling fail in service. Apart from mechanical causes, marine-borers can inflict damage resulting in extensive loss of wood volume and a corresponding decrease in strength. Because of the above reasons, B.C. Research developed nondestructive electronic methods for detecting marine-borer damage and evaluating residual strength of in-place piling. This method does not require the removal of fouling and does not hamper the normal operation of the pier.

Owners of marine structures containing wooden piling must keep a continuous vigilance for marine-borer infestation in order to prevent weakening or destruction of their facility. The B.C. Research sonic-inspection service provides the client with all the information necessary to keep ahead of the borer, and to implement remedial action before serious damage results.

The sonic-inspection service consists of a comprehensive visual and sonic examination of piling from mudline to cap. A visual examination of the super-structure members is also carried out. The results are presented in a final report and include the following points.

1. An accurate piling plan showing the residual strength and location of each pile in the structure
2. Tables listing the residual strength, the extent and type of damage in each pile.
3. Type of wood, treatment and treatment retention (if requested).
4. Pile lengths and circumferences (if requested).

The above factors are analyzed in the report and three relevant areas of information are provided.

1. Present strength and condition of piling.
2. Anticipated service life of the piling.
3. Recommendations for maintenance.

This information allows a determination of the present overall bearing capacity of a structure and construction necessary for any possible increase in loading demands.

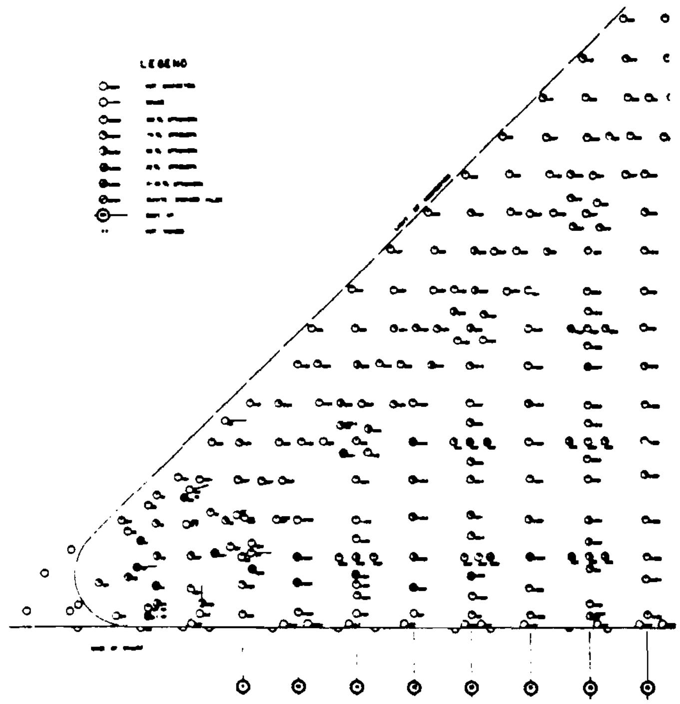
The inspection is normally carried out at a rate of 100 piles per day. Interim field reports are issued for large projects and a final report is submitted at the completion of the field work.

INTERTIDAL EXPOSURE

BANKIA SURVIVAL OUT OF WATER

As reported earlier in "Tidelines", (February, 1959), Bankia in logs stored on tidal flats may stay alive even without direct contact with tidal movements, and resume their boring when the logs are reintroduced into the sea. New experiments on Bankia survival in moist, stored, Douglas fir blocks at the Council confirm these borers' ability to survive for weeks after removal from the sea. In these experiments, the longest survival recorded for Bankia out of water was 41 days. Although most of the borers were dead within the first month, those remaining alive gradually began to show signs of active boring upon re-immersion into sea water.

Initially, 2 x 2 x 12-inch Douglas fir blocks were introduced into the sea during the Bankia breeding season. Two blocks were removed after two months, two after three months, and two after four months of immersion. After removal, the blocks were placed inside containers cooled to 50°F, and loosely covered with wetted burlap to retain a humid atmosphere. Inspection for live borers was undertaken at two-week intervals.



Sonic Inspection Piling Plan Showing Residual Strength of Piles

		Survival after					
		2 weeks		4 weeks		6 weeks	
		No. of B	%	No. of B	%	No. of B	%
Two-months immersion	Live	1		0			
	Dead	100+		100+			
	Uncertain	5		0			
	Total			100			
Three-months immersion	Live	300*	55	160	29	2	.4
	Dead	225	41	385	70	548	99.6
	Uncertain	25	5	5	1	0	
	Total	550	100	550	100	550	100
Four-months immersion	Live	680	68	10	1	0	
	Dead	160	16	980	98	1000	100
	Uncertain	160	16	10	1	0	
	Total	1000	100	1000	100	1000	100

*All numbers over 5 are approximate to ± 5 per cent.

The two-months immersion data are based on microscopic examination for live and dead borers. The three- and four-months data, however, are based on reimmersion of the blocks in sea water for a period of 24 hours, and counting the extended siphons. The latter method was found to be the most reliable, although with this technique the borers were permitted a 24-hour period of recuperation every two weeks which may have tended to somewhat prolong their total period of survival.

The highest survival rate was found for borers inhabiting the three-months immersion blocks. As indicated in the table, these blocks contained approximately 550 borers each, whereas the four-months blocks contained approximately 1000 borers each. As the two four-months blocks not only contained more but also considerably larger borers than the other two sets, the heavy evolution of hydrogen sulfide and other noxious decomposition products from dead borers in these two blocks, as well as the effects of overcrowding may have contributed to the shorter average lifespans of their respective *Bankia* inhabitants. Unpublished observations by Council workers indicate variations with age or crowding in the glycogen content of teredine tissues. Glycogen, being a chief source of reserve fuel in many animals including *Bankia*, will permit the survival of these organisms if deprived of food, depending upon the amount of glycogen present. As *Bankia* cannot drill and obtain cellulose for nutrition when removed from water, presumably its survival period is correlated with tissue glycogen content.

Future biochemical experiments may further elucidate the age dependency of *Bankia* glycogen content, and thereby enhance our understanding of *Bankia* survival with age.

SAN FRANCISCO BAY

Curtailing the release of industrial and domestic wastes into the Bay during the last few years is resulting in an increase in borers. Our records show that teredine borers have increased three-fold in the last two years; *Limnoria tripunctata*, a creosote-resistant species, is now causing serious erosion of creosoted piles.

UNDERWATER TRACKAGE

In 1958 a method was developed by Council for treating the wooden supports of tracks for a Crandall Cradle at one of the Vancouver shipyards. These tracks are now being given two treatments per year which should extend their life considerably.

EFFECT OF BEACHING LOGS ON TIDAL FLATS

Logs that run dry once or twice each day may become freshly infested if lying on mud (due to formation of depressions under the logs which hold water at low tides); if logs rest on navijack and drainage is good, the logs will not show infestation.

In logs that are infested already, teredos grow at a reduced rate. In a study off Point Grey (Vancouver) in 1953, the rate of boring on tidal flats was found to be 40% of normal.

ABILITY OF TEREDOS TO LIVE OUT OF WATER

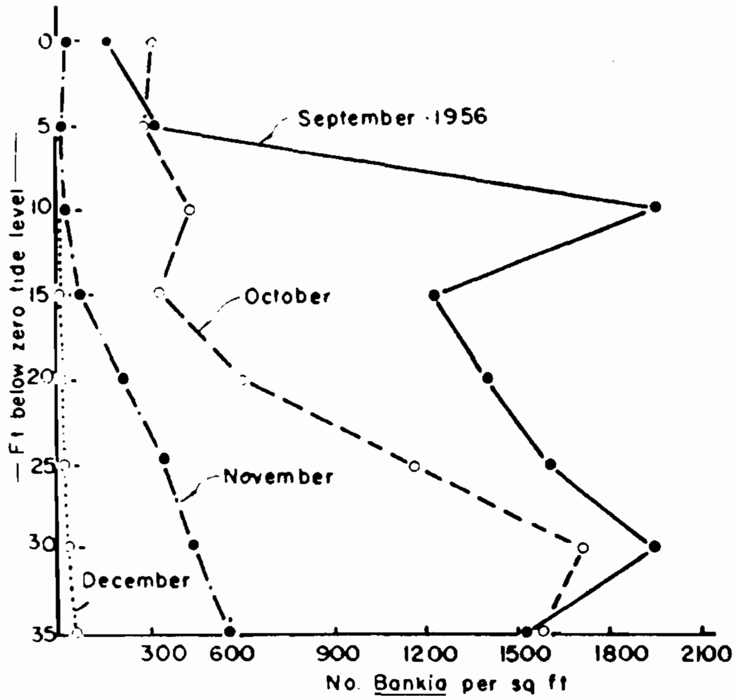
Merely taking infested wood out of water does not kill teredos and, so long as the wood does not dry out or the water in the wood does not freeze, the teredos will live for weeks. At the Council, Bankia have been kept alive experimentally for 35 days out of water - probably they can stay alive for two or three months.

Last week one of our men encountered a sawmill which was about to spend hundreds of dollars to install equipment to periodically lift the end of a jack ladder out of the salt water. We pass this item along now so that others might not be making futile and expensive outlays to combat teredos.

VARIATION IN INTENSITY OF ATTACK BY BANKIA AT DIFFERENT WATER DEPTHS

For the operator who is interested in protecting a structure that floats or is near the water surface, the distribution of the young, attaching borer with water depth is very important. Since most submerged wood containing adult borers lies on the sea floor, newly hatched larvae are found first near the mudline. As the breeding season progresses, and the density of larvae increases, they move towards the surface and, as the weeks pass, floating wooden structures are subject to attack. Eventually, the larvae become fairly uniformly distributed from the mud-line to the water surface.

After the peak of the breeding season, the distribution trend reverses and the larvae become less numerous and disappear from the surface. As time proceeds, the larvae finally disappear from the vicinity of the mud-line. The accompanying graph illustrates the distribution of larvae at the peak of breeding in September, 1956 at Seattle, and during October, November and December during which breeding steadily decreased. In September, the breeding from the minus 5-ft level to the mud line was uniformly heavy, between 1200 and 2000 per sq ft. By October the breeding to the 15-ft depth had dropped to 300 per sq ft; at 30 to 35 ft between 1600 - 1700 per sq ft remained. By November larval concentration was very light in the first ten feet but was still 600 per sq ft at the 35-ft depth. In December essentially no larvae were present above the 25-ft depth.



For the measurement of this gradation in larval concentration with water depth, the Research Council uses strings of test blocks positioned at fixed, known intervals. Also, because of this stratification of larval concentration at different periods of the year, a true picture of breeding can be obtained only if attack at various depths is examined over successive (monthly) periods. These data reveal a trend in the breeding. For example, in the above graph, when the records for September and October are known, together with preceding site history, a forecast can be made for diminished attack in November and December.

Successive monthly records to establish a trend are extremely useful, particularly during a period that breeding is on the increase. It is partly on this basis that forecasts of breeding are made in each issue of "Tidelines".

PENETRATION BY BANKIA ABOVE LOW TIDE LEVEL

A frequent question asked about Bankia with regard to wharves and piling, is how high above the low tide level will Bankia attack. Because Bankia retract their siphons when out of water it is often assumed that they attack only wood surfaces which are continually immersed. This is not so. During certain periods of the year and depending on tidal movements in specific locations, wooden surfaces one or more feet above mean low-tide level may be above water long enough to be attacked by bankian larvae. The ability of adult Bankia to survive out of water for protracted periods is well known. The Council is currently studying the survival of the larvae on wet wood out of water. Results of this study are expected to provide quantitative data which will permit more precise estimation of possible damage to the intertidal area of permanent marine structures.

Another point to keep in mind on bankian damage in the intertidal zone is that the adult Bankia, after entering a timber, tend to turn and burrow with the grain of the wood. Thus, internal damage can occur up to 2-3 feet above the point of entry.

BANKIA ATTACK AT THE MUDLINE

Marine structures in waters with stream runoff or low dissolved oxygen levels at the surface may show no marine-borer attack visible from the surface, but heavy attack near the mudline. Untreated wharf piling at Steveston Harbor originally driven in relatively shallow water in the Fraser River, several years after driving, were dredged around the base to provide greater depth of vessel moorage. Subsequent to dredging, tidal intrusion in the dredging channel created a seawater wedge around the piling near the bottom. This permitted teredine borers to gain entry into the piling base, resulting in the subsequent attack and destruction.

Another example comes from a northern B.C. pulp mill, where mill effluent depressed oxygen levels around the loading wharf, maintaining an environment hostile to marine borers. Nevertheless, tidal flushing supplied sufficient oxygenated water to permit Bankia attack at the mudline.

DRYING TO KILL

Since ancient times teredine control by removal of infested timbers and boats from the water has been attempted with varying success by many peoples. William Dampier, in his "A New Voyage Round the World" (1697), described waters of Mindinao in the Philippine Islands, as a "horrid place for the worms" where the natives "are so sensible of these destructive Insects that, whenever they come in from the Sea, they immediately hail their ship into a dry Dock, and burn her bottom, and there let her lie dry till they are ready to go to sea again".

An 1864 paper by E.P Wright described a control method used on the Comer, a branch of the river Ganges of northern India. To kill a fresh-water teredinid, Nausitora dunlopei, the Hindu fishermen removed the boat from the water, suspended if from two upright poles, and dried and charred the bottom planks by means of a fire.

Through the years, opinions on the survival of adult teredines in boats and timbers removed from the water, but not fire-dried, have varied: i.e., 24-36 hours, two or three days four days, five to 10 days, two weeks, 24 days, six weeks, and two months in Boston, U.S.A., Britain, Hawaii, USSR and Australia, respectively. Unfortunately, records of drying conditions (temperature, humidity, air circulation) are not available for these locations.

Out-of-water survival of Bankia setacea along the north Pacific coast is of particular importance to the log export industry. Logs for export to Japan are normally loaded into the ship's hold or on deck from floating rafts. During the 14- to 21-day journey, infested logs in the hold may be kept wetted, though not submerged by a considerable amount of contained water and those logs stored on deck, saturated occasionally by sea spray. Upon arrival in Japan, logs are off-loaded into the sea. Examples of the ability of the established borer to survive the ocean trip "out of water" and to continue active boring in Japanese waters are many and costly.

Among the plans for coming applied research at the B.C. Research Council is a project to closely delineate the drying conditions under which borers of varying sizes may be controlled in logs and timbers of economic importance.

VERTICAL DISTRIBUTION

SUSCEPTIBILITY OF HORIZONTAL AND VERTICAL SURFACES TO ATTACK BY BORERS

In monitoring borer attack in marine waters, it is important to know whether borers prefer wood surfaces in the vertical or horizontal plane. Both teredine and limnorial borers were investigated in this respect.

Over a period of four to six months, the top, bottom and two side faces of individual blocks from two sampling strings in the Tacoma area and two in the Seattle area were counted separately for Bankia punctures. The two strings of blocks exposed at Tacoma were of the "floating" type moving up and down with the tides; the two at Seattle were "fixed" strings exposed from zero tide level to near the mud line. A total of 184 blocks were examined with total counts on individual blocks ranging between 95 and 1158. Bankia found on the different faces of the test blocks from the four locations are expressed as percent of the total.

Attack on different faces of test blocks by Bankia.

Location	No. Monthly Test Strings	Percentage of Attack on: Top	Side 1	Side 2	Bottom
Tacoma I	4	67.5	15.9	11.7	5.0
Tacoma II	6	55.1	20.0	19.5	5.3
Seattle I	4	75.0	10.4	11.1	3.6
Seattle II	4	53.8	26.5	14.9	5.7
Averages		62.9	17.9	14.3	4.9

The greatest percentage, 62.9%, attacked the top surface of the blocks, and the smallest 4.9%, the bottom surfaces of the blocks. Combined attack on the two sides of the blocks accounted for 32.2% of the total. These results show that Bankia larvae prefer to settle on the upper face of horizontal surfaces and avoid the underside of horizontal surfaces.

Further data on the preference of borers for top and bottom surfaces have been obtained with one-foot square wooden veneer panels exposed horizontally in surface waters in the Tacoma area. These panels are used to detect low concentrations of borers in water that are used for storage of mill logs. Settlement data for both Bankia and Limnoria borers on the top and bottom surfaces of these panels over a 30-month period are summarized in

Period	Bankia		Limnoria	
March 1960 to August 1962	Top	Bottom	Top	Bottom
Total attack, No./sq ft	26,986	936	20	667
Percentage of total attack	77	23	3	97

Again Bankia preferred the top surface, 77% of the 34,922 Bankia attacked the top surface of the panels during the period, 23% the underside. With Limnoria the situation was reverse; 3% attacked the top surface, 97% the underside. Since all panels were floating within 6 ft of the water surface and attached to floating structures, the effect of light intensity as a controlling factor should be considered. Although Limnoria may attack the undersides of panels to avoid light, Bankia probably do not prefer the top surface because of light intensity, since they showed the same preference even near the mud line in Seattle where light intensity was low at both top and bottom surfaces.

Since Bankia prefer to settle on the top side of horizontal surfaces and Limnoria on the underside, suitable wooded test specimens should provide both. This is one reason why cubical test blocks were selected for our monitoring studies.

CHOICE SURFACES

Although marine borers attack virtually all North American wood species, the borer actually is reasonably discerning in selecting a suitable site to establish a burrow. Equipped with a motile foot, the larval Bankia and Teredo can explore the wood surface in search of a location soft enough to permit the fragile, toothed shells to penetrate under rotation. More motile, the migrating Limnoria can explore larger wood surfaces at will, using seven pairs of legs.

Past experiences with test material has revealed a 70% preference by Bankia larvae for the upper surface of a cubical test block and a definite avoidance (5%) of the lower surface. Limnoria, on the other hand, displays a sensitivity to light and avoids upper surfaces. It concentrates 97% of its activities on the lower, shaded face of the test material.

Whereas a one to two-week period of softening enhances Bankia larval settlement on new wood surfaces, wood that is leached for a month, dried, then re-exposed, suffers only half the attack of fresh wood.

Although sapwood and heartwood of Douglas fir are equally susceptible to attack, springwood is preferred to the harder summerwood unless massive numbers of Bankia larvae are present, when both are utilized.

B.C. Research experiments, using natural wood chips with one smooth side (as found on the outer face of the log) and the other rough, confirmed the work of H.C. Redeke in Hamburg, who showed that teredine attack in test boards attached to fishing vessels was always heavier on the rough surfaces than on those smooth-planed.

A knowledge of surfaces most likely to be attacked is valuable in examining logs, where samples are most likely to show Bankia damage if taken from areas free of bark, fouling, sap-rot, knots, and having a slightly 'weathered' appearance. Areas where surfaces are abraded, broken, or otherwise roughened are also desirable for sampling. Certain weak points, vulnerable to attack by both Bankia and Limnoria, may exist in even well-treated creosoted wooden piling. Choice surfaces include such man-made openings as bolt, dog, and picaroon holes as well as untreated cuts exposing heartwood. Knots and surrounding compression-wood are often a means of limited ingress for the borer. In very old, leached and poorly treated piling, even without manmade openings, the borer reverts to the preference displayed in untreated wood, choosing slightly roughened surfaces or edges of cracks.

Untreated timbers comprising the internal framework and support of floating drydocks are generally exposed only periodically to marine borers during the course of flooding operations. The wood surface is characteristically leached and softened, with a 'weathered' appearance. However, flooding waters wash the softened surface, exposing 'fresh' wood to provide the choice ingress for both Bankia and Limnoria. An experiment carried out in Vancouver Harbor showed that, over a period of seven months, no protection is provided by the 'weathered' surface of a drydock timber exposed to water currents and the heavy populations of Bankia outside the dock - the specimen was completely destroyed.

OF WOOD AND WINE

As the taste of wine to the connoisseur improves with the passing of time, so also does wood become tastier with age to that great connoisseur of wood, Bankia setacea.

As most log operators are aware, logs freshly immersed in the marine environment will remain relatively free of marine-borer attack for a period of one to three weeks. An interesting confirmation of this was recently obtained at the Council, using a technique on age determination of young Bankia developed by Dr. D. B. Quayle at the Pacific Biological Station in Nanaimo, B.C. The technique measures only the time since larval puncture (dissoconch stage).

In test blocks immersed for one month at both Crofton on Vancouver Island and Shannon Bay in the Queen Charlotte Islands, the following settlement pattern was recorded:

Numerical Settlement on Crofton Test Blocks One-month Immersion, October

Days	2 feet		10 feet		20 feet	
from puncture	No.	%	No.	%	No.	%
1 - 3	25	44.7	36	21.4	23	7.4
3 - 8	8	14.3	26	15.5	42	13.5
8 - 10	12	21.4	31	18.4	76	27.3
10 - 30	11	19.6	75	44.7	171	54.8
Totals	56	100.0	168	100.0	312	100.0

Numerical Settlement on Shannon Bay Test Blocks One-month Immersion, October

Days	2 feet		10 feet		20 feet	
from puncture	No.	%	No.	%	No.	%
1 - 3	2	18.1	15	30.6	18	41.9
3 - 8	3	27.3	2	4.1	2	4.6
8 - 10	3	27.3	14	28.5	11	25.6
10 - 30	3	27.3	18	36.8	12	27.9
Totals	11	100.0	49	100.0	43	100.0

On the average, 60% of all larvae present in the Crofton test blocks after one month were less than ten days old. In the Shannon Bay blocks, 70% of the observed Bankia larvae had settled in the last ten days. That is, during the four weeks of immersion, only about one-third of the total bankian attack occurred during the first three weeks.

Why is the wood more attractive to Bankia larvae within increasing immersion time during the first month? This question is not completely resolved, but some probable answers are forthcoming from recent experiments. These will be discussed in a future issue of Tidelines.

HIGH COUNTS

The October settlement of Bankia on test blocks immersed near Stoney Creek, a few miles south of Squamish, B.C., gave the highest count we have ever recorded. The average count on the 12 blocks was 14,037 per sq ft with a maximum of 28,860 per sq ft on the single 16-foot block. The infestation was entirely confined to depths below 4 feet, probably due to a fresh water overlay, and thus flat rafts at this location will have escaped attack.

The previous record was from Shannon Bay in October, 1963, with an average of 12,397 punctures per sq ft.

COMPARISON OF ATTACK ON TEST BLOCKS AND LOGS

Comparative data collected from test blocks and floating test logs exposed in the same location over the period September 1, 1963 to June 1, 1964 are presented in the table below. The test blocks were immersed for one-month periods, the individual logs continuously for the indicated exposure periods up to 36 weeks.

	Test Blocks			Test Logs (Sections)			
	No. of larvae/sq ft		Exposure Period (weeks)	No. of Bankia per sq ft			
Month	Monthly	Cumulative		Larval*	Young Adults	Older Adults*	Total
September 1963	50	50	2				
October	130	180	6				
November	590	770	11				
December	200	970	16	1100	330	310	1740
January 1964	100	1070	20	720	470	370	1560
February	10	1080	24	600	160	470	1230
March	0	1080	28	680	230	590	1500
April	0	1080	32	560	370	980	1910
May	0	1080	36	530	130	760	1420

*Approximate size ranges: larvae, 0 to 4 mm; young adults, 4 to 22 mm; older adults, 22 mm up to 362 mm in last month of immersion.

Bankian attack on the test blocks in substantial numbers continued through January when the cumulative count was 1070 per sq ft. On the logs, the larval count (cumulative) in December was 1100. Together with the young adults and older adults, this gave a total attack of 1740.

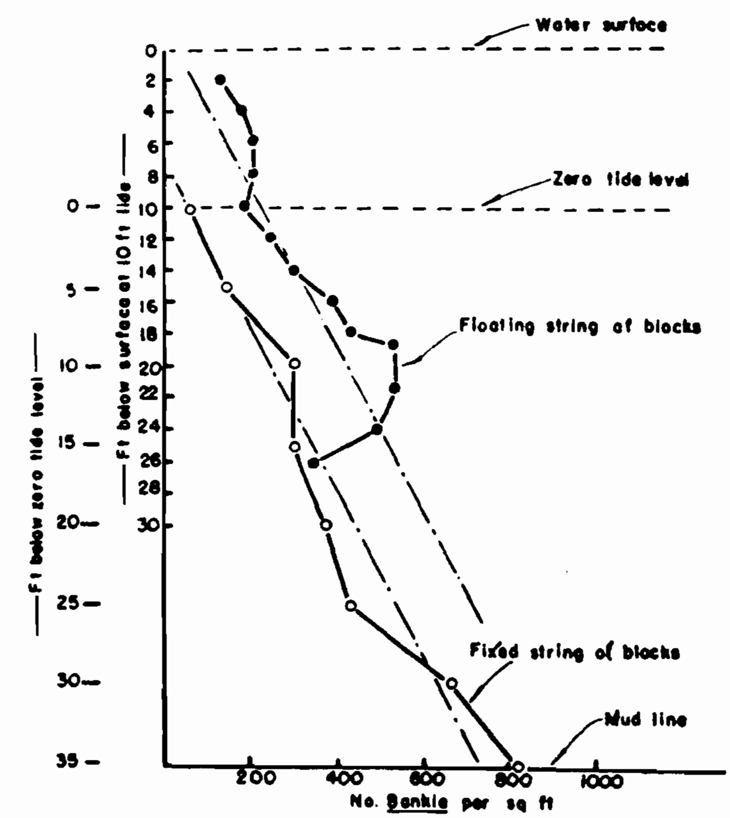
During the following five months the total counts on the logs ranged between 1230 and 1910, indicating that the seasonal bankian attack had been completed by December - January. The average count for the five logs was 1560 Bankia per sq ft, about 50% higher than the cumulative count obtained with test blocks.

In the test logs about half the larvae which attacked and metamorphosed to the juvenile stage failed to reach the young adult stage. Thus, in all the test logs an average of 860 Bankia matured to the adult stage. Roughly one-third of the adults did not live beyond the young adult stage (22 mm).

In general terms, The counts from the test blocks gave a closer indication of the number of borers reaching the adult stage in the logs, than of the total number of borers attacking the logs.

"FLOATING" VS "FIXED" STRINGS

At most sites along the Pacific coast where monthly tests are made for borer breeding strings of blocks are attached to floating structures. These strings of blocks move up and down with the tides and are referred to as "floating strings". In some cases, however, the strings of blocks are attached to fixed structures and these are referred to as "fixed strings". The floating strings are used where the marine-borer records are to be used in protection programs for floating equipment, whereas the fixed strings usually involve dry docks which draw water into their pontoons from well below the surface. The question arises, "How do the data from the two types of strings compare?".



The accompanying figure indicates the average attack found on blocks attached to floating and fixed strings at Elliot Bay, Seattle from June 1955 to December 1956. Each point on each curve is an average of 18 monthly values.

It is interesting to note that the slope of the lines, or gradient of borer attack with increasing depth, was the same for each type of string. Furthermore, if the position of the floating string is reduced by the mean tidal shift (about 6 - 8 ft), then the two graphs virtually coincide. From this it may be concluded that both types of strings produce very similar data.

TIDAL CURRENTS

Periodically the Council is asked how fast water currents must be to prevent borer attack. At the Marine Laboratory, University of Miami, Dr. F. G. Walton-Smith determined this experimentally by drawing water through a tapering square wooden tube to produce a range of internal velocities from 0.1 to 2.2 knots. Current speeds of 1.4 - 1.8 and 1.5 - 1.9 knots prevented the settlement of _Teredo pedicillata_ and _Limnoria lignorum_ respectively.

On the North American Pacific coast few safe log storage areas have currents which consistently exceed these values. In some locations such as the Yuculta Rapids in B.C. water velocities up to 7 knots occur but even here turbulent flow patterns can produce small 'dead-water' pockets which allow larvae to attack. Once established the borer is relatively unaffected and indeed may thrive more heartily than in calm waters.

Currents may be detrimental to the protection of standing and floating wooden installations. In infested waters increased water movement can bring more borer larvae into contact with the wood than occurs in quiescent locations. With impregnated poles and timbers increased leaching of wood preservatives occurs and operators of such vulnerable structures are advised to maintain a periodic inspection program.

DEEP DIVERS

In last month's "Tidelines", we discussed some _Limnoria_-oriented results of a study conducted by the U.S. Naval Civil Engineering Laboratory on deep ocean biodeterioration of engineering materials. The study involved placement, and subsequent periodic examination, of numerous test materials in 5,640 feet of water off the southern California coast. As the reader is well aware, no study on marine deterioration seems complete without mention of a boring mollusc of some kind and, in spite of the great depths involved, this program was no exception.

After four months' immersion, one of the two submersible test units was recovered and each of the 1,324 attached test specimens, representing 492 materials, was minutely examined for marine-related change. Teredine activity was described as follows:

> "When the wood test panels were examined under a microscope aboard ship, young, immature, Teredo-like boring molluscs (_Xylophaga washingtona_ Bartsch), were discovered. Some had just started to penetrate the wood; others had already penetrated more than 1/16 inch. There was an average of 25 borers per square inch of surface on wood panels exposed approximately 0.5 to 1 feet above the mud. But 3 to 4 feet above the mud, the average dropped to one borer per square inch. Manila hemp rope was also attacked by these Teredo-like borers. They were found in small quantity throughout a 4-foot-long rope, in various stages of boring activity. Some had penetrated deep into the rope, completely severing four to six fibers. But the borers did not attack the cotton, nylon, or polypropylene rope."

These results corroborate an earlier "Tidelines" report, which described _Bankia_ infestations in underwater cables at depths of up to 7,200 feet. In these earlier cases, the materials involved hemp and jute fibers, as well as gutta percha (an insulator coating made from the condensed sap of various Malayan trees).

CHIP SAMPLES

Logging operators are reminded that the main purpose of test-block studies is to delineate the periods and intensity of settlement of *Bankia* larvae.

Since test blocks remaining in the water for only one month cannot determine rates of growth over longer periods, it is essential for the operator to make periodic inspections of log inventories during and subsequent to periods of *Bankia* breeding. Flat-rafted logs can be turned for axe-checking; bundles may be parbuckled or sampled by removing a log and underwater with a long saw. Should monthly test blocks be lost, send chip samples from any suspect rafts in the area to B.C. Research for microscopic examination.

WOOD SPECIES RESISTANCE

BANKIAN ATTACK ON DIFFERENT WOOD SPECIES

Only a few wood species, not indigenous to North America (Greenheart, Manbarklak and some varieties of Australian eucalyptus), are not attacked by marine borers. At the Research Council the relative susceptibility of West Coast species to the most common teredine borer of the region, *Bankia setacea*, has been determined.

Results of studies with two-inch cubical blocks immersed at Burrard Dry Dock, North Vancouver during November and December 1959 and January 1960 are shown in Table 1. Compared to attack on Douglas fir the three-month percentage averages show that western red cedar, spruce, balsam and hemlock are attacked at about the same rate, but yellow cedar at about only half the rate.

Table 1. Monthly attack on Different Wood Species Test I). Rate of Attack on Douglas Fir = 100.

	Comparative bankian attack			
	November 1959	December 1959	January 1960	Average
Western Red Cedar	96	135	128	120
Yellow Cedar	19	58	45	41
Spruce	75	99	69	81
Balsam	77	101	75	84
Hemlock	93	89	91	91

A second test made at the same location the next fall, involved seven local coniferous species, including Douglas fir, and four hardwoods (cottonwood, birch, alder and eastern maple). Except for the hardwoods, where insufficient specimens were available, ten two-inch cubical blocks of each species were immersed each month. Only 5-7 blocks of birch and maple were used and a full schedule of testing for the hardwoods could not be carried out. The results in Table 2 show that although the average attacks on the six local coniferous species, particularly white pine, are all higher than that on Douglas fir. The results for the individual months vary so considerably that any consistent difference cannot be considered proven. Similarly, the data on the four hardwood species only suggest an attack equivalent to Douglas fir. Yellow cedar failed to show the reduced susceptibility to attack indicated by the data in Table 1. These data fail to show that western red cedar is less readily attacked than Douglas fir, or that yellow cedar is more readily attacked by Bankia, contrary to widely held popular opinion.

Table 2. Monthly attack on Different Wood Species (Test II). Rate of Attack on Douglas Fir = 100.

	Comparative bankian attack			
	Nov. 1959	Dec. 1959	Jan. 1960	Average
Western Red Cedar	128	264	79	157
Yellow Cedar	167	134	55	119
Spruce	199	147	60	135
Balsam	165	106	45	105
Hemlock	194	99	99	131
White Pine	309	173	82	188
Cottonwood	88			88
Birch	288		60	174
Alder	95			95
Maple	202		73	138

A more complete test with 4 x 4 x 12-inch wood specimens submerged at 25 ft below zero tide level at the Burrard Dry Dock, North Vancouver, B.C., was initiated in early November 1959, about halfway through the breeding season. The same seven common commercial conifer and five hardwood species were included. Specimens were removed after two, three, four and five months and all side faces examined microscopically for bankian attack. The results are compared to attack on Douglas fir in Table 3.

Table 3. Cumulative Attack on Different Wood Species (Test III). Attack on Douglas Fir = 100.

	2 mo	3 mo	4 mo	5 mo	Avg.
Western Red Cedar	132	100	97	122	113
Yellow Cedar	209	82	95	125	128
Spruce	133	79	70	97	95
Balsam	250	105	102	81	135
Hemlock	180	76	139	133	130
Cottonwood	203	82	93	170	137
White Pine	164	116	159	97	134
Alder	238	138	170	141	172
Birch	265	86	212	131	173
Maple	266	137	165	90	165
Oak	258	68	155	74	139

Western red cedar, yellow cedar, balsam and hemlock all showed higher cumulative attack than did Douglas fir, particularly those specimens which were removed after two months' exposure. The results of this third test, more than those of the second, indicate that, excepting spruce, Douglas fir is not as readily attacked as are the other conifer species. The deciduous species, alder, birch, maple and oak, showed unexpectedly high susceptibility to attack.

TIMBER WITH NATURAL RESISTANCE TO MARINE BORERS

The August, 1971 issue of Tidelines discussed a U.S. Navy study on the resistance of tropical wood test panels to marine borers in the Panama Canal Zone. In this study, only three out of the 115 different woods tested proved to have good resistance against all species of marine borers infesting the three test sites.

The marine durability of other tropical wood species from Africa, Asia and the Americas have also been evaluated. Several interesting points have arisen from the studies.

1. High resistance to one or two groups of borers (teredines, pholads, limnorids) does not necessarily imply resistance to borers belonging to other groups.

2. High resistance to teredine borers in one locality may not be equalled in another locality where different teredine species dominate. In the Panama Canal Zone, 70 tropical woods showed good resistance in full-strength seawater at Fort Amador on the Pacific Coast, whereas the majority of the woods soon failed in the brackish waters of Miraflores Lake.

3. In many tropical wood species, resistance against teredine borers is correlated with the amount of particulate silicate present in the wood. At more than 0.50% silica, wood generally is resistant to teredines, presumably due to the abrasive effect of the silica on the teredine

valves or "grinders". The abrasive quality of high silica timbers is easily seen by the rapid wear they exert on steel wood-working tools.

4. The silica content and associated resistance to destruction in the sea of a species of wood may vary considerably between trees grown in different localities. It may even vary between two different pieces of wood from the same tree.

5. Tropical woods may show resistance to marine-borer attack despite a low silica content. In these species, durability in the marine environment is attributed to toxic, organic compounds present in the wood. The chemistry of these compounds is far from completely known. Greenheart, a Central American species with good marine-borer resistance under several different test conditions, contains little silica and its borer resistance is attributed to the content of a toxic alkaloid.

6. In the tropics, the hazard to wood and wooden installations may frequently be greater in brackish waters than along the open coast where the water salinity is higher.

7. Generally, the marine-borer hazard to wood is more serious in tropical than in temperate waters. Nonresistant woods are more rapidly destroyed and the durability of resistant species is comparatively less.

TROPICAL INVASION

Though no woods have been demonstrated to be indefinitely immune to the destructive activity of marine borers under severe conditions, some are known to possess a higher degree of resistance than others. Certain tropical woods have great durability in sea water. Natural substance such as oils, silica, tannins, resins and gums may serve as deterrent agents.

The density of wood is not necessarily a controlling factor in borer resistance. However, hard, dense woods are generally more resistant to all borers than the less dense species. Highly silicated woods are generally effective in resisting ocean teredos, but silicate content seems to have little influence on resistance to pholads (rock clams) and Limnoria.

In a study recently completed by the U.S. Navy, 115 different species of wood were exposed for periods of up to 90 months in three different tropical marine-borer environments. Sites were located in the Panama Canal Zone at these locations: The Pacific Ocean, the Caribbean Sea and a brackish water lake, Miraflores Lake. All samples were evaluated for resistance to three principal borers: Teredo, Limnoria and pholads.

Two types of control woods, Douglas fir and southern yellow pine were both found to be very susceptible to all three borers. Only a few of the woods tested were found to be resistant to one or more of the borer types. Before 90 months had elapsed, 96% of all the exposed wood specimens had been highly damaged by one or more species of borer. The most resistant to all classes of borers was cocobolo (Dalbergia retusa), whose oily extract seemed to prevent borer attack.

Wood from the cocobolo tree would be unsuitable for marine construction timbers because of its irregular shape and size. However, this high-density, low-silica wood is naturally impregnated with an oily substance which, after identification, might be synthesized for use in the treatment of other, more suitable and less costly timbers. Many of the woods were selectively resistant to certain species of borers, and should be very good for specific installations. Two such woods were Cordia allio ora (laurel) and Bombacopsis quinata (cedro espino). Both are excellent structural woods of medium density and exhibit high resistance to all marine borers except pholads.

The use of exotic woods for local construction is not unknown to old-timers in B.C. In the late nineteenth and early twentieth century, before creosoting came into practice in this province, great quantities of blue gum eucalyptus (Eucalyptus globulus) were imported from Australia. The Canadian Pacific Railway Pier A and Kitsilano trestle in Vancouver were constructed on eucalyptus piling, and the Department of Public Works used eucalyptus in several provincial wharves. Eucalyptus piling from the Canadian Pacific's Nanaimo wharf, built in 1911, was still in good condition 38 years later and salvaged for use in the company's Kootenay Division.

No member of the Australian eucalyptus woods was included in the Panama Canal Zone test series, and a direct comparison with the best performers in the above study is not readily available. However, in temperate waters where pholads are not a problem, these woods could be excellent for marine construction materials.

Currently, creosote impregnation has the most extensively proven record for protecting wood exposed to teredine attack from a cost versus performance point of view. Nevertheless, in area where the creosote resistant Limnoria tripunctata predominates, supplementary methods must be considered to obtain better protection of wood. Natural impregnants which occur in tropical woods, or the woods themselves, could be the supplement required to obtain this added protection.

EUCALYPTUS VS. TEREDO

Though no woods have been demonstrated to be indefinitely immune to the destructive activity of marine borers under severe conditions, some are known to posses a much higher degree of resistance than others. Certain tropical woods, for example, are accredited with great durability in seawater. It is assumed that various natural substances -- such as silica, oils, resins and gums, tannins, alkaloids or other elements within the woody structure -- may serve as deterrents to borer attack.

Several species of the tropical wood, Eucalyptus are used for marine construction. The State Marine Service of Australia recommends the use of Eucalyptus paniculata, E. crebra, E. hemiphloria, E. capitella, E. canaldulensis, and E. globulus, as suitable for use in marine structures.

The numerous species of Eucalyptus differ from each other with respect to physical characteristics and all vary substantially from the coniferous North American woods such as Douglas fir. The Eucalyptus has a sense interlocked grain with distinct growth rings owing to denser late wood bands. The sapwood is usually one and a half to two inches in width and remains constant for the length of the tree.

In addition to a species difference, similar species from different geographical locations, possess varying degrees of resistance to marine-borer attack. The Australian species of Eucalyptus are felt to be resistant to borer damage because of their high silica content. Similar species found in Hawaii contain up to 90% less silica and, consequently, have much less resistance to borer attack. The species inconsistency with respect to borer resistance is well illustrated by E. tereticornus which was considered to be one of the most durable Eucalyptus. And yet, piling of this species used in Los Angeles and San Diego failed after periods of two and one-half and ten years, respectively.

Observations made by B.C. Research staff at two locations in B.C.

indicated that Eucalyptus piling had sustained extensive Bankia damage. In one case, the damage was restricted primarily to the sapwood area; however, in the second location, penetration of the entire pile was observed. Extensive Limnoria infestation was noted in fir piling at both locations; nevertheless, the Eucalyptus had sustained only Bankia setacea attack.

Apart from the marine-borer damage, extensive checking, cracking and splitting of the Eucalyptus piles was noted. This may be a result of the dense, brittle nature of the wood.

The indication is that generalizations regarding the resistance of Eucalyptus to marine-borer attack cannot be made and that no Eucalyptus is universally immune to the marine-borer. For structural use, treated wood and other materials will still have priority, with Eucalyptus being used in less critical areas such as fender piles and bumper logs.

SPRING AND SUMMER WOOD IN RELATION TO ATTACK BY BANKIA

Spring growth in a tree is rapid and produces fairly large thin-walled cells whereas when growth slows during the summer, the width of the cells is considerably less and the cell layers are closely compacted. These compacted layers of cells are also more highly lignified and tougher than the spring cells. The alternate layers of spring and summer cells are clearly defined in the cross section of a tree as the annual rings. Microscopic examination of test blocks used for routine settlement studies has shown that Bankia larvae invariably attack the spring wood and avoid the summer wood. This observation raises an interesting speculation: is a log cut during the spring more vulnerable to bankian attack than one cut in the late summer, fall or winter? That is, does it depend on whether the large soft spring wood cells or the harder tougher summerwood cells are immediately under the bark?

Bankian settlement on planed and natural surfaces of wood chips.

Chip No.	No. of Bankia per sq. ft.		Chip No.	No. of Bankia per sq. ft.	
	Planed surface	Natural surface		Planed surface	Natural surface
1	29	14	14	124	9
2	139	0	15	58	29
3	99	12	16	96	0
4	141	0	17	62	7
5	19	28	18	151	7
6	39	0	19	0	9
7	113	13	20	39	23
8	15	0	21	46	0
9	93	5	22	29	0
10	40	30	23	394	0
11	140	0			
12	91	0	Avg.	92.6	8.4
13	175	9	Percent	92	8

To determine relative settlement of Bankia on spring and summer wood, log chips were obtained from Douglas fir and hemlock logs, felled in the late summer. Bark was removed, baring the natural summerwood on one side of the chip; the other side was planed smooth exposing a surface of both spring wood and summer wood. Immersion data in the accompanying table show that in 21 out of 23 chips, bankian attack was greatest on the planed surfaces where the bankian larvae had access to both spring and summer wood, with 92% of the over-all settlement occurring on the planed surfaces.

SYNTHETICS, BEWARE

While continuing to be alarmed by the depredations of marine borers, operators of marine waterfront structures are at least cognizant of the potential damage that may occur to virtually anything made of unprotected wood immersed in the open sea. Less well known are the types of damage which various borers can wreak on non-wooden materials. A recent issue of Tidelines indicated how the Pholadidae, or rock-boring clams, can burrow into marble, sandstone and mortar-grade concrete. Another similar man-made material subject to attack by these organisms is unglazed brick.

Rather more intriguing is the variety of materials which are attacked under natural conditions by a spectrum of borers, particularly the teredines. Although bark can be presumed to provide some protection to the underlying wood, penetration by _Bankia_ has been observed frequently by Council biologists. Similarly cork (usually derived from the bark of the Spanish oak), and floats and buoys made from there, are subject to attack. Various plant products, particularly the shells of hard nuts and the water-borne seed pods of certain plants also are attacked by teredine borers.

The communications industry is one which has been plagued with the problem of protecting its underwater cables from teredine damage. Hemp and jute fibers, widely used for mechanical protection of the core, are readily attacked. Gutta percha insulator coatings also suffer severe damage. One interesting feature in the problem of cable protection is that depth of immersion is of no assistance, one instance of severe damage being recorded at 1200 fathoms. Even lead sheathing can fail to protect and for many years protective measures were based largely on the use of twin copper tapes and flooding of jute or hemp coatings with coal tar. The recent advent of a variety of synthetic plastics has been of considerably assistance, although these synthetics are by no means all resistant to attack.

Present indications are that polyethylene is largely impervious to borer attack, as are a variety of other synthetics including the epoxies and polyesters in combination with glass mats. The fibreglass boat, of course, is well known and one of its advantages is resistance to marine borers. Penetration of nylon by pholads has been observed and polyvinyl chlorides are particularly susceptible to attack by these organisms. Some of the rubbers can be damaged, i.e., silicones, and Council scientists have demonstrated that neoprene stops teredine larvae very effectively but fails to prevent entry of the adult from an adjoining bait piece of wood. Cellulose acetate, a man-derived material, is especially susceptible to attack. In fact, Council biologists have attempted to use this material as a food source for the laboratory rearing of _Bankia_ _setacea_.

Although one of the promising aspects of the commercially available synthetic materials has been their resistance to biological degradation, particularly microbial activity, many materials which are otherwise inert, are subject to marine-borer action.

CHOICE SURFACES

Although marine borers attack virtually all North American wood species, when immersed in the sea, the borer actually is reasonably discerning in selecting a suitable site to establish a burrow. Equipped with a motile foot, the larval Bankia and Teredo can explore the wood surface in search of a location soft enough to permit the fragile, toothed shells to penetrate under rotation. More motile, the migrating Limnoria can explore larger wood surfaces at will, using seven pairs of legs.

Past experiences with test material has revealed a 70% preference by Bankia larvae for the upper surface of a cubical test block and a definite avoidance (5%) of the lower surface. Limnoria, on the other hand, displays a sensitivity to light and avoids upper surfaces and concentrates 97% of its activities on the lower, shaded face of the test material.

Whereas a one to two-week period of softening enhances Bankia larval settlement on new wood surfaces, wood that is leached for a month, dried, then re-exposed, suffers only half the attack of fresh wood.

Although sapwood and heartwood of Douglas fir are equally susceptible to attack, springwood is preferred to the harder summerwood unless massive numbers of Bankia larvae are present, when both are utilized.

B.C. Research experiments, using natural wood chips with one smooth side (as found on the outer face of the log) and the other rough, confirmed the work of H.C. Redeke in Hamburg, who showed that teredine attack in test boards attached to fishing vessels was always heavier on the rough surfaces than those on smooth-planed.

For centuries, heavy, hard marine fouling has been known to exclude wood surfaces mechanically from borer attack, but still unexplained is the preference for Teredo attack on wooden surfaces with a southerly exposure, as reported in 1940 by Carl Dons of Norway.

A knowledge of surfaces most likely to be attacked is invaluable in the testing of potential wood preservatives and the detection of marine borers in commercially important logs and wooden structures. Particularly where impregnated test material is exposed to creosote-resistant Limnoria tripunctata, wooden panels are always exposed in a horizontal position to take maximum advantage of the organisms preference for the shaded underside surfaces.

In examining logs, samples are most likely to show Bankia damage if taken from areas free of bark, fouling, sap-rot, knots, and having a slightly 'weathered' appearance. Areas where surfaces are abraded, broken, or otherwise roughened are also desirable for sampling. Certain weak points, vulnerable to attack by both Bankia and Limnoria, may exist in even well-treated creosoted wooden piling. Choice surfaces include such man-made openings as bolt, dog, and picaroon holes as well as untreated cuts exposing heartwood. Knots and surrounding compression-wood are often a means of limited ingress for the borer. In very old, leached and poorly treated piling, even without man-made openings, the borer reverts to the preference displayed in untreated wood, choosing slightly roughened surfaces or edges of cracks.

Untreated timbers comprising the internal framework and support of floating drydocks are generally exposed only periodically to marine borers during the course of flooding operations. The wood surface is characteristically leached and softened, with a 'weathered' appearance. However, flooding waters wash the softened surface, exposing 'fresh' wood to provide the choice ingress for both Bankia and Limnoria. An experiment carried out in Vancouver Harbor showed that, over a period of seven months, no protection is provided by the 'weathered' surface of a drydock timber exposed to water currents and the heavy populations of Bankia outside the dock - the specimen was completely destroyed.

COMPARISON OF BANKIAN ATTACK ON NEW AND LEACHED WOOD

Differences in rates of attack have suggested that natural wood may contain substances which directly or indirectly favour bankian settlement. If these substances should be water soluble, then wood not previously immersed in sea water should be attacked more readily than wood which has been immersed.

An initial study of this question involved the exposure in seawater at North Vancouver of unleached and leached strings of blocks for monthly periods from July to December 1959. All the leached blocks had been previously submerged in the sea for one month. Each comparative test string contained twelve blocks exposed at depths of from 1 to 20 ft below the water surface. After each month of exposure, an unleached and leached string of blocks were examined microscopically for bankian attack. During the six-month period, the total attack on the unleached wood was 593 Bankia per square foot, on the leached wood 318. In all cases the leached blocks showed substantially less attack than the unleached blocks, and the average attack on the leached blocks was only 54% of that on the unleached.

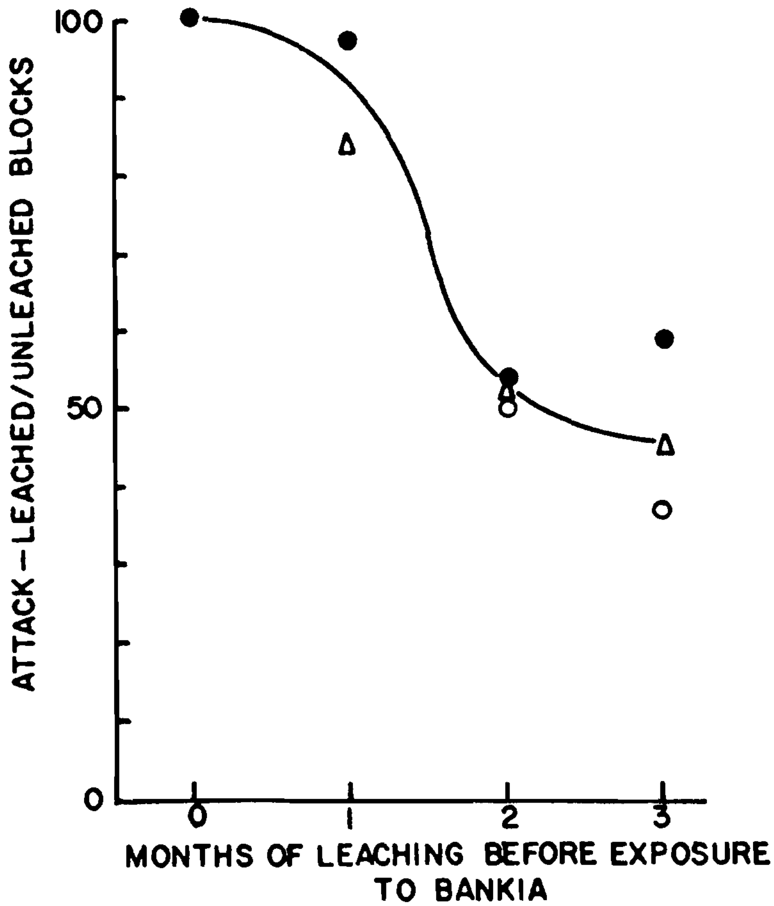
Attach on Leached and Unleached blocks by Bankia

	Bankian attack, No./sq. ft.		
Month	Unleached	Leached	% Leached
July	54	32	59
August	199	105	53
September	121	53	44
October	106	58	55
November	62	49	79
December	41	21	51
Average	593	318	54

During the breeding season in this same area the following year (1960), strings of blocks which had been leached 1, 2 and 3 months in the sea were exposed along with unleached blocks during the months of October, November and December. Again the attack on the leached blocks was less than on the unleached, and the blocks which had been leached the longest showed the least attack. The results of this second study are shown in the accompanying figure. Solid circles, empty circles and triangles correspond to data obtained from blocks immersed during October, November and December respectively of 1960.

These preliminary studies may explain, in part, why some wood is less readily attacked than other wood. For example, within the same storage area some rafts of logs are much more severely attacked than others. Differences may be due to different lengths of time in the water before the breeding season, or to a difference in leaching rates between different wood species, or both.

Leaching may be of significance in reducing the susceptibility of wood surface to attack by borers. However, for long term storage the value of a leaching process is not promising, since attack is only reduced, not eliminated.



Leaching may explain the apparent protection, observed by Council personnel, of green piling, initially driven in polluted waters, which were unattacked some 30 years later when the source of pollution was removed and teredine borers re-entered the area. However, such protection is not considered well enough documented, as yet, to draw general conclusions.

Somewhat removed, yet of a similar nature, is the apparent protection provided by weathering of logs prior to immersion in sea water. Weathering actually corresponds to bacterial action on the cellulosic fraction of the wood. In the field, "punky" or sap rotted logs seldom suffer attack.

PLYWOOD BORERS

Plywood, as a marine engineering material, has become of increased importance over the past few years. It is now used as sheathing in both boat and floating dry-dock construction and repair; with effectiveness varying with wood species involved, and degree of prior protection provided. In boat construction, sheathing plywood is usually protected by a conventional paint, varnish, or special antifouling finish. Loss of this protective coating through either mechanical abrasion or simple leaching often leads to exposure of the underlying plywood to the ravages of teredine and/or limnorial infestation. On the advice of B.C. Research, most dry-dock owners on the northern Pacific Coast of North America now utilize full-cell pressure creosoted Douglas fir plywood for all underwater sheathing repair. Results to date have been excellent with exposure times approaching 15 years in some locations. Another solution to marine-borer attack on plywood, involving the incorporation of fine grains of silica in the glue lines, was tested by B.C. Research over ten years ago. Although this material provided an all-borer barrier of relative permanence, large-scale manufacture has not been undertaken to date.

A study on both the natural resistance of certain plywoods and the effectiveness of three treatments -- designed to inhibit borer attack -- has recently been completed in England. This work was an extension of an earlier appraisal of the natural marine-borer resistance of 95 different timber species, as reported in the March, 1970 issue of "Tidelines". The plywood study involved the three-year marine exposure of nine types of plywood representing six timber species, two preservative treatments and one type of surface overlay -- all tested without surface treatment. An excerpt describing the performance of overlay and preservatives follows:

> "Plywood impregnated with copper/chrome waterborne preservative to give 29.3 kg/m^3 (1.83 lbs/cu ft) net dry salt retention was 28 times more resistant than untreated veneers of the same species, in terms of area attacked by Limnoria. Veneers impregnated with the preservative to give 13.6 kg/m^3 (0.85 lb/cu ft) n.d.s.r. showed 7 times more resistance than untreated veneers. Plywood with phenol-formaldehyde resin impregnated paper overlay to improve its surface properties gave complete protection from direct face attack by borers. Other aspects of the performance of this type of overlaid material in the marine environment were not however investigated in the present test and further evaluation will be necessary to determine whether it possesses sufficient advantages over conventional marine grade plywood to justify its use in boat-building".

Assessment of Limnoria damage to the test panels involved the visual estimation of surface area attacked. The extent of Teredo damage was determined by counting the number of animals per panel, using X ray techniques. The performance of the six unprotected and untreated plywoods tested is summarized in the following table in order of decreasing natural resistance to marine borers.

	LIMNORIA			TEREDO		
Plywood	1 year	2 years	3 years	1 year	2 years	3 years
Makore	very slight	slight	moderate	none	none	none
Utile	very slight	moderate	heavy	very slight	slight	slight
Red Seraya	very slight	moderate	heavy	none	none	none
African Mahogany	moderate	heavy	very heavy	very slight	very slight	very slight
Birch	heavy	heavy	very heavy	none	none	very slight
Gaboon	heavy	heavy	very heavy	very slight	very slight	very slight

The excellent durability so far of Makore plywood in this test suggests some promise for North American waters. Whether costs and service could compete with the creosoted, silica glued, or preservative salt-treated plywood mentioned previously remains doubtful.

SILICATED PLYWOOD

Sometimes, even after the basic problem has been solved, many years are required to bring the results of research to fruition. Silicated plywood is a case in point. As far back as 1949, protection against marine borers has been conceived using this principle, and resistance of experimental silicated plywood had been proven by sea water immersion tests. However, because plywood production is geared to mass marketing, marine applications have received a minimum of attention and commercial development of the product has been stalled.

The principle behind the resistance of this plywood is very simple. Instead of the usual extenders for plywood glue, fine silica dust is used so that an impervious barrier of silica is incorporated in each glue line as the boards are formed. The outside surface is protected by an external coat of silicated glue with the press platens being protected during pressing by a sheet of kraft paper.

Industrial glass powders were used in preparing experimental boards, although suitable silica (sand) powders would be cheaper for commercial production. Microscopic examination was used to confirm that no teredine larvae or adult could get through the glue line without encountering pieces of fine glass or sand. Since both glass and silica are appreciably harder than the calcium carbonate of the teredine grinder, the prospects for protection seemed excellent.

The effectiveness of fine silica in the glue line is illustrated by the photographs above. The panel on the left contained no silica, the one on the right did. The non-silicated board suffered severe attack on the outside veneer, considerable attack passing through the glue line to the adjacent layer, with some penetration of the third layer. This penetration is normal for the immersion period involved, indicating that the glue line normally provides no protection. On the other hand, attack on the silicated panel occurred only on the unprotected outer ply. With this panel no attempt had been made to protect the surface with a film of silica and glue.

Table 2. Attack on Faces of Plywood Panels by Bankia and Limnoria.

Period	Bankia		Limnoria	
March 1960 to August 1962	Top	Bottom	Top	Bottom
Total attack, No./sq. ft.	26,986	936	20	667
Percentage of total attack	77	23	3	97

Again Bankia preferred the top surface; 77% of the 34,922 Bankia attacked the top surface of the panels during the period, 23% the underside. With Limnoria the situation was reverse; 3% attacked the top surface, 97% the underside. Since all panels were floating within 6 ft of the water surface and attached to floating structures, the effect of light intensity as a controlling factor should be considered. Although Limnoria may attack the undersides of panels to avoid light, Bankia probably do not prefer the top surface because of light intensity, since data obtained with the fixed strings of blocks at Seattle (Table 1) showed the same preference even near the mud-line.

Since Bankia prefer to settle on the top side of horizontal surfaces and Limnoria on the under side, wooden test specimens should provide both these surfaces. For this reason cubical test blocks which permit counts on top, bottom and two side surfaces, give a more reliable estimate of borer attack than do flat wooden panels in the vertical plane. Undoubtedly this is the main reason why blocks give higher counts than do panels (April 1963).

The initial purpose of developing silicated plywood was for sheathing the outside of wooden drydocks, particularly those in waters containing Limnoria tripunctata, the creosote-resistant borer found along the coast in many parts of North America. Tests made in Galveston, Texas, demonstrated that silicated plywood resists all wood borers whereas creosoted panels were badly attacked by L. tripunctata after six months exposure.

The inclusion of silica in the glue lines of plywood adds little to the weight or cost of the plywood. Its principal disadvantage is the abrasive effect on cutting tools, such as the trim saws in plywood plants. Despite the technical excellence of this product, plywood manufacturers have not entered into its production, principally because of limited markets. We should appreciate receiving comments from our readers, concerning expanded markets or potential manufacturers.

COATING MATERIAL FOR PILING

Since early 1963, Council chemists have been attempting to develop a mastic formulation which could be applied to creosoted and untreated piling in and below the intertidal zone and which would set to a firm, hard but non-brittle texture. Current formulations have reached the field testing stages and various properties also are being evaluated in the laboratory by physical tests, including accelerated weathering. The outlook is very promising for a cheap practical coating to protect those creosoted piles which are now being destroyed by Limnoria tripunctata. Although damage occurring to these piles prompted development of the coating material, many other applications are foreseen, such as coating of metals in the splash zone to prevent corrosion.

DISCONTINUATION OF PILE WRAPPING MACHINE

Concurrent with promising results for a protective coating for marine piles, attempts to develop an automated tape wrapping system have been discontinued. This program, undertaken jointly with Caproco Corrosion Prevention Ltd., encountered several serious difficulties. Although adequate bonding of tape under water was achieved and equipment design was progressing favorably, the economics of providing sufficient protection in the intertidal zone appeared impractical. In addition, the problem of brace piling and underwater obstructions interfered seriously with any automated wrapping device.

MAINTENANCE

MAINTENANCE METHODS

When marine piles are damaged to the extent that loss of bearing capacity results, remedial action must be taken in order to maintain structural integrity. Often economic or structural considerations make the replacement of damaged or destroyed piling impractical. In such cases various types of pile barriers can be used.

Pile barriers fall into two main categories: those which protect damaged piles from further damage and those which restore strength in severely damaged piling.

Pile protection is achieved by encasing the piling with protective material. Of the nonmetallic wraps, polyvinyl-chloride ensheathing of the pile appears to be one of the most effective methods. Sections of PVC sheeting are prepared on land and then wrapped around the piling, creating a watertight fit. The principle of the method is to protect piles against borer activity by cutting off water circulation, and thereby restricting the supply of oxygen to the borers, below survival levels. Over 200,000 lineal feet of piling have been wrapped by this method.

Numerous other methods have been tried with various degrees of success. One port encased piles with fibreglass prior to driving and apparently the wrap withstood both the driving and considerable lateral bending while in place. However, three weeks after driving, one-quarter of the fibreglass casings developed vertical splits due to swelling of the piling as they absorbed water.

Metallic barriers have been used for a number of years as an effective means of protecting piles. More recently, however, application and material costs have made the use of metal prohibitive other than for patching localized cavities.

Various methods have been employed to restore strength to severely damaged or destroyed piling. Three of these methods use concrete as the primary construction material.

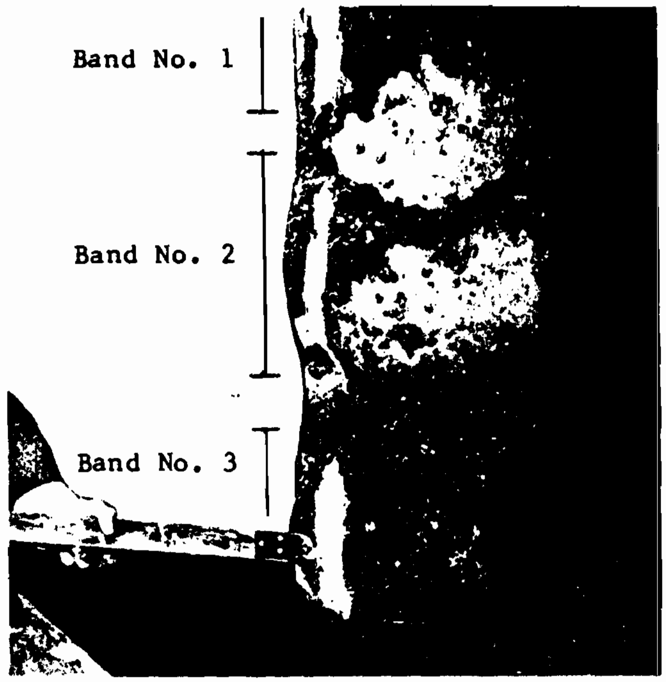
"Pile Renu" has been used when 20% or more of a pile cross section is damaged or lost. A fabric "sock" is installed, as a mould, around the length of a damaged pile, reinforcing mesh or rods are placed around the pile inside the sock and the sock is pumped full of concrete.

The "Colby Method" has been used to "stub" piles. The damaged section is removed and a new reinforced concrete pile is poured between the remaining sound stumps at the mudline and cap. Specially developed attachments are used to connect the mould to the cap to insure adequate support by the new concrete pile section.

The "Oil Drum Method" is also used to stub piles or to splice piles where the damaged section is replaced with a new treated wood pile. Forty-five-gallon oil drums are cut to fit around a pile and are filled with concrete. Reinforcing can be placed inside the drums and the drums can be left in place for added protection.

Another approach has been to develop a mastic which could be applied as a coating to piling under water and which would set to a firm but not brittle covering. Coating material filling this specification has been developed by the Division of Chemistry. It has excellent adhesive properties for wet creosoted or uncreosoted wood and is highly resilient to physical impact. The nature of the coating permits it to flex with the piling without cracking.

Test piles coated with this material are under observation in Vancouver harbor. To date, the results are very good and the prospects for protection now look encouraging. As shown in the illustration, three separate circular bands of coating (delineated by the white vertical strips revealed by scraping away fouling and the surface layer of mastic) have remained intact, even at the edges, for more than one year in the intertidal zone at an industrial location where wood debris has been unusually heavy. Preliminary estimates indicate that the cost of the coating will be about $1.25 per lineal foot, or $75.00 for the average full length pile.



ORGANO-LEAD COMPOUNDS

The first stage of the laboratory investigation sponsored by the International Lead Zinc Research Organization into the use of organo-lead compounds as marine-borer repellents has been completed. Triphenyllead chloride, tributyllead acetate and hexaphenyldilead all showed good resistance to accelerated leaching in the laboratory. Leached and unleached panels, both with and without creosote, have been immersed in Burrard Inlet, Vancouver, B.C., to evaluate repellency to marine borers. A similar set is scheduled for immersion at Oakland, California, in April.

ECONOMICS OF MARINE PILE REPLACEMENT

Although the costs of placing, testing, repairing and replacing a marine pile vary considerably with the nature of the pile and the geographic factors involved, figures pertinent to the Vancouver area are illustrative of the relative economics involved.

	Piling Cost (No. 14, 65-ft. pile)	
	Per lineal ft.	Per pile
Green pile	$ 0.65	$ 42.00
Impregnation (creosote)	1.26	82.00
Shipping		25.00
Driving		25.00
Decking		25.00 - 75.00
Total installed cost		$200 - $250
Underwater inspection	$ 0.10	$ 4.25
Pile barriers		
PVC	5.50	220.00
Cupro Nickel	8.00	320.00
Concrete	13.00 (?)	
Pile replacement		
Stub		200.00
Normal replacement		$222 - $272
Decking removal		10.00
Pulling pile		12.00
New pile		200 - 250
Difficult replacement		400 - 500

The above figures are approximate only and refer to the use of No. 14 piles (14 inches in butt diameter), 65 feet long.

For new installations the cost of the green pile is only about 20% of the original structural cost, expressed on a per pile basis. Correspondingly, impregnation costs are about 40%, half of these representing the costs of the impregnant. Transportation costs to site can vary tremendously and even driving costs vary somewhat with the driving equipment necessary under differing conditions. Since wharf superstructures vary so greatly, even the range quoted here is only approximate. Nevertheless, total wharf costs, on a pile basis, run $200.00 to $250.00.

The major cause of marine wharf failure is biological corrosion and up to 5% of the piling may fail in the two years after installation, due to a variety of causes. Subsequent failure rates are extremely slow and for satisfactory installations service lives in excess of 40 years are common. Assessment of wharf condition and necessary protective maintenance can be determined only by underwater inspection, for which the Council's ultrasonic device is essential for detection of teredine damage.

Although wharf deck repairs may be made in many instances without severe dislocation of the structure or its uses, extension of pile service life is accomplished chiefly through use of pile barriers. Polyvinyl chloride and cupro nickel wraps are given frequent consideration, although the cost of protecting the 40 feet of pile length exposed to the marine environment is equivalent to or greater than original installation costs. Method research is expected to reduce costs of concrete barriers to competitive levels.

Where sectional loss is greater than 25%, pile replacement is considered desirable. Although piles can be stubbed into place, using the technique devised by Mr. H. A. Hertzog of Fisher Flouring Mills, Seattle, loss of lateral flexural capacity is a severe handicap. Where accessibility through the deck is not difficult, pile replacement costs still must consider removal of the decking and the old pile. Where added difficulties include removal of complex structures, machinery, jack hammering concrete decks, or working in limited space with restricted driving equipment, then pile replacement costs become simply horrendous.

With biological corrosion as the major cause of pile failure and with the impregnation as the only protective process, money spent in rejecting unfit piling at this stage obviously is well spent, before additional costs for shipping and installation of pile and decking have been incurred. This is even more vital when costs of protective maintenance and pile replacement are considered. Although the value of correct construction practices cannot be discounted, intensive inspection procedures following impregnation will reduce the probability of inadequate piles coming into service. For example, a wharf was constructed in 1955 on Vancouver Island where six core samples from each pile were taken in a spiral course over the surfaces to be exposed in the marine environment and no retreated piles were accepted. On inspection of this wharf ultrasonically in March 21, 1961, not one pile had suffered loss of structural strength.

Less expensive pile barriers undoubtedly would extend the usefulness of this technique, even in those situations where pile replacement is comparable to the cost of new installations. Where replacement is difficult, their use unquestionably is warranted. In either case, the cost of pile replacement or pile barriers, together with the safety of the wharf, merits periodic inspection.

SERVICE LIFE

The time period between driving of marine piling and the stage where general deterioration begins will depend upon several factors. These include: the quality of the creosote treatment, driving methods, construction practices, water quality, floating debris, marine fouling coverage and, of course, the type and intensity of marine-borer settlement.

During construction mechanically induced breaches may occur in the protective creosote layer of piles. This type of damage will provide access to marine-borers and can result in the complete destruction of a pile. Our experience has been that, even in new structures, up to 10% of the piles can break down in the first few years after construction, because of mechanical damage resulting in marine-borer damage. After the initial period of one or two years, the remaining properly-treated piles may last for several years before widespread marine-borer attack becomes evident.

With the increasing age of a pile, the probability of marine-borer attack also increases. <u>Bankia</u>, as well as <u>Limnoria</u>, may gain entry through physically damaged areas of a pile or, in undamaged piles, <u>Bankia</u> attack may occur through knots where the creosote retention is low enough to be tolerated by the <u>Bankia</u> larvae. If no mechanical or physical weak points exist in a pile, <u>Bankia</u> attack is usually repelled until the process of creosote leaching has reduced retention below <u>Bankia</u> tolerance levels. Piles exposed to the creosote-resistant borer, <u>Limnoria tripunctata</u>, are, of course, constantly vulnerable to attack.

In view of the above observations, a sonic inspection of piling should be carried out within five years of construction. Initially 25-30% of the piles can be examined. This sampling has proved to be very accurate in predicting the total amount of damage existing in a structure. If the sampling inspection indicates widespread and extensive damage, a full-scale inspection of all piling should be carried out. This is essential in order to locate destroyed piling and to pinpoint dangerously weakened areas of a pier. Periodic reinspections are also essential in determining the rate of deterioration of piling and in projecting the anticipated service life of a structure.

Bankia attack through a knot resulting in extensive damage to the pile.

PILE BARRIER MEETING

On October 31, 1968, a meeting of the West Coast Committee on In-Place Marine Wood Pile Barriers was held at the University of British Columbia in Vancouver with the B.C. Research Council acting as hosts. The Committee is an informal group concerned with efficient and economic methods of protecting in-place marine piles against biological deterioration and mechanical damage. The agenda covered three main areas: the detection of damage and residual strength evaluation of piling, protection of damaged piling retaining adequate residual bearing strength, and restoration of bearing strength of in-place piling by methods other than redriving. The following is a résumé of the day's discussion. In northern waters where the corrosion caused by teredine borers (Bankia and Teredo) is of major concern, detection of internal damage in wooded piling is extremely difficult. In ideal circumstances, a visual inspection may reveal borer damage; however, the problem of evaluating the remaining strength of a damaged pile still remains. Consequently, at the present time, the B.C. Research Council sonic inspection system is still the most satisfactory method of evaluating borer damage and determining the residual bearing strength of in-place wooden piling. Not only is sonic testing more accurate than visual inspection, but it is considerably more expedient. Under relatively normal water conditions, as many as 100 piling can be sonically tested in one day.

An adequate visual inspection would require the removal of all fouling from the pile, a meticulous visual examination of the pile surface and the taking of pile core samples and the patching of the holes, resulting from such sampling. All of the above activities are, of course, quite difficult to perform underwater and would result in only about 10 - 15 piles being examined in any one day. In addition, a mere visual inspection of a pile still leaves the problem of a meaningful strength evaluation.

In southern waters where Limnoria damage is of prime concern, frequently a visual inspection is satisfactory. However, factors such as poor underwater visibility and heavy marine fouling can make a satisfactory visual examination difficult; consequently, the sonic inspection method is a valuable diagnostic tool even in southern waters. In any case, sonic and/or visual inspections of marine wood installations should be carried out within five years after construction and repeated at approximately five-year intervals thereafter.

Creosoting of wooden marine piling has, of course, been the major method of protecting piles against marine-borer attack. Borer damage results because of possible flaws in the creosote layers or due to attack by the creosote-resistant borer, *Limnoria tripunctata*. Subsequent to the damage and strength evaluation, remedial measures must be applied. Where the damaged piling still retain adequate bearing strength, some form of pile protection can be installed to prolong the service life of a structure.

Metal and concrete protective methods have been used successfully for several years. However, because of the relatively high cost of this type of protection, plastic pile barriers have been developed over the past decade. One of these is polyvinyl chloride sheathing (PVC), which has been used commercially to wrap wooden marine piling over the past ten years. Experience in testing and commercial use indicates that this type of wrap establishes a layer of low oxygen content seawater between the pile and the wrap. This, in turn, kills the existing borers in a pile, prevents future borer infestation and helps to maintain the pile at the bearing strength remaining at the time of wrapping. At the present time, tests are being carried out for use of PVC wrap on marine structures other than piling.

Currently, tests are also being carried out with spray-on or paint-on coatings developed by the B.C. Research Council. These coatings bond directly to wood or metal structures both above and below water. Below water, they protect wooden piling from marine-borer damage, and metal piling from oxidative corrosion and destructive electrolytic reactions. On dry land, a third coating acts as a fire retardant and prevents fungal deterioration in wooden structures.

Tests on both the coatings and application methods are continuing with commercial availability anticipated within six months. In-place costs are expected to be approximately one-half of the epoxy-resin coatings presently available.

When a piling is damaged to the extent that it does not retain sufficient bearing strength, it must be replaced. Replacement can be carried out by the redriving of new piling. However, in some structures this remedy can be extremely expensive or virtually impossible. In such cases, a strength restoring method must be employed.

Restoring strength to a piling is usually achieved by either stubbing with concrete or wood or by coating the existing damaged pile with a reinforced layer of concrete.

Stubbing is carried out by removing the weakened section of a pile and replacing this with a treated wood section and coating the joints with concrete. Alternatively, as in the Colby method, the damaged section of a pile is removed and a reinforced concrete section is poured in place, extending from the sound stump remaining below the mudline up to the cap.

Another relatively new method of restoring pile strength is the Fibriform Process. In this case, a zipper-enclosed cloth "sleeve" is installed around metal reinforcing surrounding a damaged pile. Subsequent to this, concrete is poured into the sleeve. When the concrete is set, the sleeve is removed and the process is repeated on another pile.

LET'S BLAST 'EM

Many years ago, the Olympic Forest Products Company at Port Angeles, Washington, tested the use of dynamite and following these experiments, recommended that "shooting" of piles should be done within three months of being driven, and subsequently every three months for the first year and once a year thereafter. Later a number of logging companies in British Columbia adopted this method for protecting untreated piling and dolphins. The treatment was considered to be more effective against the young Bankia, and the frequency of blasting was generally once every two months during the breeding season. Usually two to five sticks of 60% blasting powder were set off five to eight feet from the piling. In none of these tests was a subsurface examination made to determine the effectiveness of the blasting.

Following a severe Teredo infestation of the Queen's dock at Swansea, South Wales, in 1945, blasting procedures patterned after those used along the B.C. coast were employed for control of the infestation and partly favorable results were reported. Nevertheless, Teredo attack and damage had been so severe that complete reconstruction in reinforced concrete was necessitated. In an attempt to find a means of killing Bankia in flat rafts in open water, the Council undertook a study using dynamite in early 1956.

Initial studies were made at North Vancouver in water depths of about 35 feet; later experiments were made at Teakerne Arm in water depths from 20 to more than 100 ft. A special ditching dynamite (50%) was used. This powder had a high water-resistance, high shock-wave velocity, and a high sensitivity which permitted self-propagation. Preliminary tests showed that one-half pound charges could be detonated no closer to logs than six feet without causing serious damage and at this depth charges could be separated by no more than ten feet if they were to propagate each other. With one-pound charges the minimum depth to avoid excessive log damage, was ten feet and the maximum propagation distance also ten feet. The minimum safe depth for a two-and-a-half pound charge was 12 feet.

In the table below are shown the results obtained when one-half and two-and-a-half pound charges were released beneath infested logs in flat rafts. The number of Bankia infesting the logs initially averaged about 100 per sq ft. In the area immediately above and surrounding the individual blast, at least a quarter of the borers were found alone and active 24 hours later. No difference in susceptibility was noted between borers of 1.25 and 8 inches in length. Even in log surfaces that had been badly splintered by blasts, pulsating bankian siphons were surprisingly plentiful a day later.

As shown in the following table, the radius of the partial kill for each individual charge was only 4 to 10 feet. Thus, to produce only a partial kill of Bankia in a section (65 x 65 ft) of logs, sixteen 2.5 lb charges would be required. From this it appears quite impractical to use dynamiting for control of borers in log rafts. Such a means of control would cause as much destruction to the logs as the borers themselves.

Effectiveness of dynamite for killing Bankia in floating logs.

Test No.	Size of charge (lb)	Depth of charge (ft)	Borer penetration (inches)	Kill of Bankia		Radius of partial kill (ft)
				Log shoulder	Log bottom	
1	0.5	6	2	partial	partial	6
2	2.5	12	1.25	partial	partial	-
3	2.5	12	1.5	partial	partial	4
4	2.5	12	1.5	partial	partial	-
5	2.5	12	1.5	partial	partial	-
6	2.5	12	2	partial	partial	-
7	2.5	12	3	partial	partial	6-8
8	2.5	12	3	partial	partial	6-8
9	2.5	12	3	partial	partial	6-8
10	2.5	12	8	partial	partial	10

AN UNWELCOME VISITOR

During May, specimens of Limnoria tripunctata the creosote-resistant borer, was identified in a sample of creosoted piling sent to the Council laboratory from Crofton by Mr. Ian Rennie of B.C. Forest Products Ltd. Identification of the borer was confirmed by Mr. Menzies of Los Angeles, the investigator who originally described and named this species.

If this visitor decides to stay and multiply in B.C. waters, we can expect trouble. And the creosoting industry will need to look to its laurels.

SEARCH FOR A POISON

At the beginning of 1949, the Applied Biology Division at the Council undertook a program to find a poison effective against teredine borers. For this work the following method was developed to test borers against chemicals in the laboratory. Two-inch cubical Douglas fir blocks were exposed in the sea for three to four months during the breeding season and then the infested blocks submerged in various chemical solutions. At certain times of the year when no breeding was occurring locally, it was necessary to ship infested blocks by air from the Queen Charlotte Islands. After the infested blocks had been exposed to the chemicals, the blocks were put back in the sea for four or five days. An effective poison was considered to be one that would kill all borers in 18 hours at a concentration of not more than 200 parts per million (0.02%).

NOT SO SIMPLE

Initially it was considered a simple matter to find a poison which would kill imbedded teredine borers. However, it was soon found that the relatively primitive organisms have a surprisingly keen sense of taste. When a poison is present they readily sense it, withdraw their inhalant and exhalant tubes at the surface of the wood and plug the hole with their pallets. In this way, they could reside in their galleries for many days without using the poisonous water surrounding the wood. Some chemicals, such as a number of substituted dinitrophenols, were effective in killing borers at low concentrations, but when the concentration of the chemical was increased, more borers became aware of its presence and shut themselves off. In this way, the total kill decreased as the concentration of the poison was increased.

After testing essentially all of the common poisons, only one, sodium arsenite, was effective in killing imbedded borers. The results obtained with some of the common poisons of normally high biological activity are shown below.

Chemical	Concentration tested, ppm*	Sensed by borers	Kill after 18 hours
Copper sulphate	60-200	yes	none
Copper arsenite	60-200	yes	none
Mercuric chloride	60-200	yes	none
Sodium arsenate	60-200	yes	none
Sodium fluoride	60-200	yes	none
Copper-8-quinolinolate	60-200	yes	none
Copper naphthenate	60-200	yes	none
Phenol	60-200	yes	none
Pentachlorophenol	60-200	yes	none
Phenyl mercuric acetate	60-200	yes	none
Strychnine	60-200	yes	none
Sodium arsenite	12.5-10,000	no	complete

*ppm - per million by weight.

NEW POISONS

Besides testing well-known poisons, toxicants under development by commercial chemical companies were submitted to this testing program from many commercial laboratories in an attempt to find a poison which would be more selective in its action on borers than sodium arsenite. Ideally, a chemical was sought which would be toxic to borers but not to fish. In this program scores of chemicals were tested. Although some chemicals were effective in partially killing a population of borers, none was effective in killing the whole population.

THE EFFECTIVENESS OF SODIUM ARSENITE

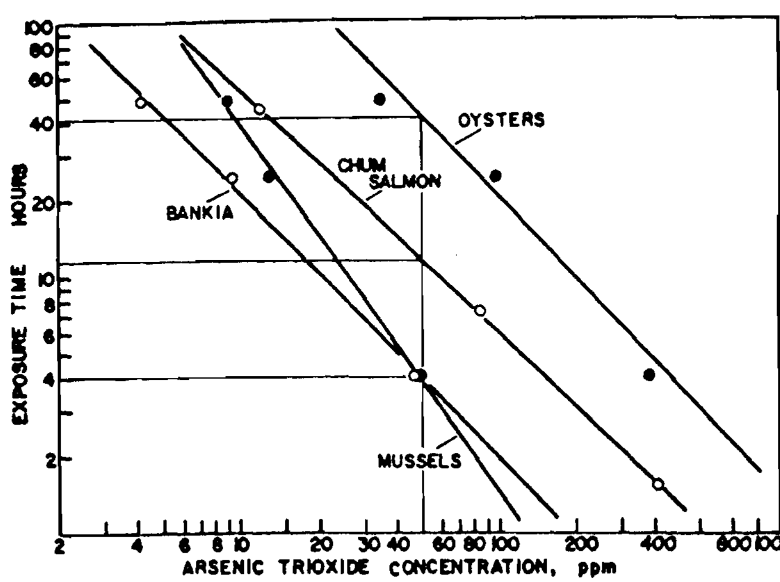
The action of sodium arsenite on teredine borers is unique. The borers are unable to recognize its presence in relatively high concentrations, 1% (10,000 ppm), and yet may be killed by as little as 6-10 ppm. The actual quantity required to kill is dependent upon the time that the borers are exposed to the chemical. The table below shows a concentration of 1,000 ppm will kill all borers in 30 minutes, whereas 25 ppm require an exposure time of 12 hours. In most commercial operations, it is advantageous to have a long exposure period and use a relatively low concentration of chemical. This is not only advisable from the standpoint of cost, but also because it reduces the hazard to valuable species of marine life.

Concentration sodium arsenite (As_2O_3, ppm)	Minimum lethal time
1000	10 min
200	90 min
100	3 hours
50	6 hours
25	12 hours
12.5	18 hours

Separate tests have shown that the two Limnoria species, lignorum and the creosote-resistant tripunctata are equally sensitive as teredine borers to sodium arsenite.

SENSITIVITY OF MARINE FORMS TO SODIUM ARSENITE

After it was discovered that sodium arsenite is an effective poison for imbedded borers such as Teredo or Bankia, it became important to know the toxicity of this chemical for other forms of marine life. In measuring toxicity against organisms, the concentration of poison required to kill half the test population is usually determined (minimum lethal dose for 50% kill) since this value can be determined more accurately than the concentration required to wipe out the entire population. The concentrations of sodium arsenite required to kill 50% of the test population in 4-, 24- and 48-hour periods of exposure were determined for Bankia setacea, the local mussel (Mytalus edulis) and the Pacific oyster (Crassostrea gigas). These tests were carried out in the Council laboratories. Similar tests were carried out by Drs. J. R. Brett



and D. F. Alderdice of the Fisheries Research Board, Nanaimo, B.C. using chum salmon fry (Oncorhynchus keta). Many months were required to complete this work. The results are shown graphically and have been condensed in tabular form below.

Bankia and mussels are about equally sensitive to sodium arsenite. Chum salmon are about three times as resistant as Bankia, and oysters about nine times.

The two economically-important forms of marine life, chum salmon and oysters, are more resistant than Bankia to sodium arsenite. The salmon, like other fish, have an advantage over the mussels and oysters in that they are free-swimming forms and can pass through and out of localized concentrations of chemical. However, because the margin of difference in toxicity is not really large, it is necessary to consider the possibility of hazard to commercial fisheries wherever sodium arsenite is applied against teredine or limnorial borers. Thus, all applications of sodium arsenite to sea water come under the surveillance of fisheries and pollution control authorities and industrial treatments are permitted by these agencies only when carried out under technical supervision.

Hours of exposure	Concentration of arsenic trioxide (parts per million by weight of sea water) required to kill 50% (MLD_{50}) of the population			
	Bankia	Mussels	Chum salmon	Oysters
4	50	48	150	450
24	9	13	24	82
48	5	9	11	44

This poison is no longer available or permitted as a control measure.

FULL CELL CREOSOTE TREATMENT AS A MARINE IMPREGNANT

Creosote is the impregnant most widely used to protect wood in the marine environment against biological corrosion. The manner in which it protects wood over service lives of 40-60 years and its deficiencies in certain situations have been the subject of many researches over the years. However, only in recent years have these researchers yielded a logical pattern of creosote protection, consistent with field observations. A summary of these studies, together with some original observations, was presented by Dr. Harry Hochman of the U.S. Naval Civil Engineering Laboratory at the spring meeting of the American Wood Preservers' Association. Following is a brief summary of this interesting review of creosote action.

One of the most persistent ideas about creosoted piles was that, as long as rough handling or later abrasion by floating logs did not break through the protective layer of wood, only the quantity and quality of creosote in the pile determined its service life. Often this idea persisted even in harbors where consistently poor service life was demonstrated by top quality creosoted piling, much to the financial detriment of wharf operators. The answer, of course, as many of our southern wharf operators realize is Limnoria tripunctata, the creosote resistant "gribble" which has variously been reported as destroying piling in 7, 12 or 17 years. The variation in time to destroy piling, depends upon the population of this borer, which in turn depends largely upon water temperature. For instance, in Port Hueneme, California, a rise in average water temperature between 1956 and 1958 from 57.8°F to 61.1°F caused an approximate 18-fold increase in the L. tripunctata population causing an accompanying increase in the rate of biological deterioration to standing creosoted piling.

A second commonly held idea about creosoted piling was that when creosote was placed in the water, it began to leach out of the pile and until the creosote level went below a certain threshold level, borers would be repelled. After this level had been reached borers would begin to penetrate the pile.

Actually, when a pile is first placed in the water, an oily slick of creosote appears on the water; something which should not occur if the creosote was being leached (dissolved) out of the wood. What occurs to the pile when it is placed in the water is that its fibres absorb water and swell, thereby both expelling some creosote and driving some into the heartwood. As much as 30 to 40 percent of the creosote lost is expelled within the first six months after which very little more is lost. Analysis of creosote left in the pile at the end of this expulsion has shown a change of composition which continues to increase after the expulsion process is over. It appears that on top of this expulsion process is superimposed a selective leaching which removes the lighter more soluble fraction of the creosote, leaving the heavier less soluble portion behind. The lighter more soluble fraction of the creosote is most poisonous since it can dissolve in the aqueous fraction of the animals body while the heavier fraction is less toxic. Therefore, even though the creosote level in the pile may be high, its composition has been detoxified by leaching, it may not still be poisonous to borers. Because of this, a threshold level of creosote which will repel marine borers can not be defined.

A third idea which ties in with the selective leaching process is that, if one could incorporate into creosote a hydrocarbon in which the toxic fraction was soluble, this hydrocarbon would keep the toxic portion of the creosote in the pile and kill the borers when they ingested it rather than exhausting its toxic properties by dissolving in the water and repelling the settling borer. The first part of this idea works admirably with the addition of common motor oil and the toxic portion of the creosote is largely retained in the pile. However, the resistance of the creosote to borers is greatly reduced. It followed that the oil was holding the toxic portion of the creosote so well that it passed through the borers digestive tract without poisoning them.

Thus, three facts about creosote piling emerge:

1. The best creosoted piling will not resist borer damage in subtropical waters where _L. tripunctata_ exists.

2. Whole creosote is first expelled from creosoted piling after which selective leaching continues to remove the lighter more toxic portions of the creosote.

3. Hydrocarbon additives decrease the toxic properties of creosote by holding the toxic portion of the creosote and not releasing it into the aqueous phase in the digestive tract of the borer.

"AWPI has developed three (3) standards for timber piling for marine use. Select the standard most appropriate and you will receive the best treatment for the most economical cost. Our manual 'AWPI Quality Mark Marine Piling' contains the three standards. Each standard stipulates the types and quantities of preservatives to be used and the penetrations required to protect timber piling from decay, insects and marine borer attack.

Standard AWPI-MP-1: Standard for dual treatment of timber piling pressure-treated with water-borne preservatives and creosote--for use in marine waters of _extreme_ borer hazard. (_Limnoria_ _tripunctata_ are extremely active or where oil slicks in harbors contribute to marine-borer attack).

Standard AWPI-MP-2: Standard for timber piling pressure treated with creosote--for use in marine waters of _severe_ borer hazard.

Standard AWPI-MP-3: Standard for timber piling pressure treated with creosote--for use in marine waters of _moderate_ borer hazard."

OPEN INVITATIONS

In northern waters, well-driven wooden piling with adequate full-cell pressure creosote treatment provide excellent protection against attack by marine borers. Where the creosoted sapwood shell of the piling remains intact, a minimum service life of 35 years can be expected.

The engineer, familiar with the well-known ability of the borer to broach any vulnerable wood available, designs a structure which, if built exactly to specifications, will produce the expected service life. However, during construction of most wharf structures some compromise with unexpected field situations is affected, which involves departure from the construction drawings, (as attested by the necessity of the Council's sonic testing group to may many wharves on the basis of what actually exists).

A number of construction malpractices contribute to the early failure of marine piling structures. Recently Council staff observed a failure due to inadequate treatment of underwater pile cutoffs; the second such instance in their experience. An underwater ramp, built on a pile foundation, was severely weakened because of poor fitting of the pile caps with the result that the untreated heartwood of the pile has been exposed and destroyed by _Bankia_ below the low tide level.

The first instance, a number of years ago, involved a shipway where the core of piling cutoffs to a level five feet above zero tide were similarly riddled. Damage could have been avoided in both cases by the installation of a copper or concrete shield covering the exposed heartwood after the structure had been completed. A simple prevention--a costly cure.

Fender and bearing pile cutoffs are continuously exposed to air and, if not treated, may suffer from another type of biodegradation--fungal decay, or heart rot. Again, the untreated heartwood is vulnerable and, as decay progresses, a cup-like cavity becomes a trap for the water required to maintain the fungal activity which moves progressively downward in the pile heartwood.

Amongst the proven preventatives for fungal decay in this situation are: the application of hot creosote or waterproofing the cutoff face. Some techniques involve gang drilling 3/4-inch holes and filling with hot creosote; several applications of hot creosote over the intact pile cutoff; capping with copper, aluminum, or lead sheeting; or sealing by several coats of asphalt or other waterproofing compound.

Other construction abuses involve the use of pike poles, axes, and other sharp tools in handling treated wood in vulnerable areas. As an excellent compromise to accommodate the easy handling of material, the Canada Department of Public Works permits the use of sharp tools within 3 ft of either end of the creosoted pile, since the bottom end is most likely to be buried during driving and the upper end will be cut off after driving has been completed.

Exposing untreated wood in creosoted piling by cutting and boring notches and holes also should be avoided. Where holes are unavoidable, bolts used should be 1/16-inch oversize. Ideally, though not often practical, all cuts should be made prior to installation and treatment.

Creosote protects only against Bankia larvae, not against the adult. Many instances of Bankia becoming established in untreated wood, developing and entering adjacent treated wood, have been reported both in the literature and elsewhere. Thus, the use of untreated timber, affixed or in close contact with the creosoted wood is inadvisable, certainly below the tidal level.

Occasionally, where the bearing material for piles is inadequate, crushed rock is used to increase stability, Quarried rock, having sharp edges, is particularly undesirable since the creosoted shell of the pile is often broached, exposing to the ever-ready borer the vulnerable unprotected heart of the pile.

A common wharf maintenance problem encountered by the Council's sonic testing crews is the abrasion of treated piling by fender logs (designed to prevent intrusion of floating material) and the floating material which penetrates the fender log defence. Both act to abrade the protective shell of the piling, thus opening the way for marine-borer attack in the unprotected heart of the piling. The solution lies in adequate metal sheathing of piles adjacent to fender logs and periodic removal of intruding drift material from under the wharf.

From the standpoint of biodeterioration of wharf structures, it follows that, like much pollution control, the solution often resolves itself into people control.

PILE PATCHING

In wharves where expensive decking (laminated wood, concrete, asphalt) or superstructures such as processing plants or warehouses virtually prohibit replacement of weakened piling, the installation of pile jackets or barriers, in "patches" or in "toto" may provide the most satisfactory and most economic solution to safe wharf maintenance. However, at no time has this procedure been considered as an alternative to standard impregnation methods, but rather as a supplement to extend pile service life, particularly in waters infested with Limnoria tripunctata.

As with the origin of most technical organizations, some 4-1/2 years ago, a group of engineers, contractors, suppliers and researchers, recognizing the value of the unrestricted co-operative exchange of information, formed the West Coast Committee on In-Place Marine Wood Pile Barriers which meets semi-annually. At its most recent meeting on April 11, 1967, hosted by the Port of Oakland, the Committee decided to expand its terms of reference to include methods and techniques for protecting not only wooden piling, but also all waterfront structures. Thus, it seems appropriate to review progress in the pile-protection area, with particular reference to findings reported at the recent Oakland meeting.

Maintenance procedures for in-place marine wood piles logically fall into two categories; those used to protect and to extend the service life of piles which have suffered some marine-borer attack but which retain a high proportion of their original load bearing capacity, and those which are used to reinforce or to replace badly weakened or destroyed pile sections. This issue of TIDELINES deals with those procedures developed to protect piles retaining appreciable strength, whereas the remaining category will be dealt with in next month's issue.

Plastics

The only plastic barrier installation with a long-term service history is polyvinylchloride (PVC), at the Port of Los Angeles, California. After 22 years exposure, Mr. Caroll Wakeman, Port Testing Engineer, has been able to detect in the plastic wraps no decrease in tensile strength and only limited decrease in tear strength, and similar correspondingly small changes in solubility of plasticizers and water uptake. At the same time, protection against Limnoria attack has been absolute in pile zones from the mudline to the intertidal area. In over 80,000 installed lineal feet no abrasion damage has occurred.

As yet PVC wraps are not in common use in B.C., although after five years' testing at Port Alberni, Nanaimo, Crofton and Chemainus, wraps are still in good condition. In a recent 1000 lineal foot installation at Powell River, B.C., coverage has extended to 6 ft above zero tide level in order to guard against Bankia attack. Negotiations are in progress for further installations on piles in Vancouver Harbor, selected on the basis of sonic testing by the British Columbia Research Council.

PILE PATCHING II

Last month's "Tidelines" dealt with materials used to extend the service life of piling which, although weakened by marine borers, still retain a high proportion of their load-bearing capacity. Where elaborate superstructures or expensive decking precludes economical conventional redriving, several other techniques are being used to replace or reinforce badly weakened sections. These latter methods all employ concrete in some form and their applicability depends upon two factors; the normal over-design of wooden pile structures which permits adjoining piling to bear the load temporarily, and a 30-foot length limitation on the pile to be replaced.

For replacement of relatively short pile sections in the intertidal zone (up to 12 1/2 lineal feet), a system was devised by Roy A. Clark, Port Supervising Engineer with the Port of Oakland, which involves sawing out and removing the damaged section. Before replacing it with a sound section exactly matching the length of that removed, oil drums with the bottoms cut out are slipped over the sound stub and lowered. After the sound replacement section is in place, weld-wire mesh is wrapped to overlap the joint and provide reinforcement. The oil drums are raised into position, the bottom of the lowest one sealed and then pumped full of grout. Metal clips are used to join the drums which are left in place after completion of the operation.

The maximum number of drums installed on one pile has been nine, and total costs, which do not vary directly as the length of repair, are about $7.50 per lineal foot. This figure is based on using Port Authority maintenance personnel during normal working hours and charging labor costs to the job only when the men are actually doing any repair work.

Mr. Harold Herzog, Manager of Research and Promotion, Fisher Flouring Mills, Seattle, has developed a method of replacing whole piling in areas under a large warehouse where conventional redriving would involve expensive dismantling and disruption of normal business.

Suitable for piling up to 30 feet long, the method involves excavating mud surrounding the base of the destroyed pile and then cutting it off to leave a 3-foot stump. Accuracy of the cut off should be of the order of 5° to insure even bearing. The new pile is cut to length, weighted to float vertically into place and secured with a turn-buckle system to center directly over the stump. The top of the pile is then attached to the pile cap with steel straps.

After a two-week period to permit the new pile to soak up water, the underwater section is surrounded with a cage of reinforcing wire. A form is applied around this cage and it is then pumped full of concrete to complete the repair. Costs per pile for this replacement method average $50 more than conventional redriving.

FOULING PROTECTION

Although no marine organisms have been found which prey on either Bankia or Limnoria, some fouling organisms -- notably mussels and barnacles -- appear to foil the borers by mechanically covering the exposed wood surface, thus excluding larval attack. In addition, fouling organisms are plankton feeders, i.e., they feed on the plankton filtered out of the sea water which they pump over their gill system. Teredine larvae are classified as zooplankton and as they approach a wood surface harboring these fouling organisms, they constitute a natural food source. Thus, in addition to creating a mechanical barrier, mussels and barnacles actually may reduce larval concentrations in the environs of the wood surfaces. As early as 1841 Lehman in Denmark observed that "wood [on piling] covered with colonies of the mussel Mytilus edulis (our common blue coastal species) is not attacked by shipworms". He assumed that the protection is a mechanical one, provided by the byssal threads which attach the mussel to the wood by means of a small disc. He noted that wood not protected by Mytilus edulis was infested within five years with borers measuring 12 inches. It is interesting that this rate of attack, recorded well over a century ago, is considerably less than the rate of destruction normal on the west coast of North America where it is not uncommon for damage of this order to occur in less than 12 months.

Test block experiments by Weiss in 1948 and Redfield in 1952, both in Miami, Florida, showed that, whereas regularly cleaned blocks showed heavy teredine and limnorial damage after one year's immersion, similar blocks which were not cleaned and which were heavily fouled showed negligible attack. More recently in November, 1964, a group of log rafts which had been regularly inspected by the B.C. Research Council staff showed much lighter borer damage when cut than anticipated from test block data from the storage area. These rafts were immersed during a period of heavy barnacle settlement and this freedom from attack was associated with the heavy barnacle fouling.

Thus, documentation is extensive that marine fouling can reduce considerably the settlement of marine borers. However, one interesting aspect concerning which no information is available is whether fouling organisms will settle on surfaced already attacked by marine borers, and if so whether mechanical blockage or the competition for food will slow down or eliminate borer attack. This subject is included in the Council's investigative program for the coming breeding season.

Copper-Based Wraps

The modern cupro-nickel alloys, which have undergone extensive testing in southern waters, are not yet in common use. With costs approximately 1-1/2 times that of plastics, Cu-Ni alloy sheets have the added advantage of generating toxic concentrations of copper ion in the microenvironment between the wrap and the pile surface. Striking documentation of this type of protection involves the Evans, Coleman and Evans wharf in Vancouver Harbor, built in 1896 on green piles sheathed with Muntz metal (60% copper; 40% zinc) which showed no damage to the alloy-covered areas when some piles were removed in 1949. Even where this old-type allo sheet was cut or torn, copper ions absorbed into the pile surfaces, prevented marine-borer attack.

Concrete-Based Coatings

Gunited and cementitous coatings, when properly applied in 1- to 4-inch thicknesses, have given satisfactory service for many years at a number of widely dispersed locations along the Pacific Coast. Although costs have been generally higher than for alternative materials, these may be reduced by improved application techniques now under study by several organizations.

Potential Materials

Now under test are a number of barrier wraps including chemically impregnated paper-based tubes and nylon-reinforced plastics. Commercial trials, involving the special coating developed in Council laboratories, will be undertaken as soon as underwater application equipment, now under development, is completed.

GROWING PAINS

The activities of marine-borers, as they affect the service life of individual standing piles in permanent marine foreshore structures, always have represented one of the information areas under constant review in "Tidelines". At various times we have discussed commercial techniques of impregnation, construction and continuing maintenance necessary to prevent or control structural loss due to marine-borer attack. One technical aspect of vital importance in wharf longevity, not previously discussed, is the effect of the natural variability of wood as a biological material. Just as an engineer working with steel must choose the right alloy for the job, so must an engineer working with steel must choose the right alloy for the job, so must an engineer involved in designing a marine pier ensure that the quality of piling he uses meets specifications previously demonstrated to provide adequate service.

The three natural defects developed most often in the standing tree with pile potential are spiral grain, shakes and knots. Spiral grain is defined as a condition where, instead of a vertical arrangement of wood fibre about the bole of a tree, the fibers are spirally aligned. This growth phenomenon is frequently difficult to identify in unseasoned piling, but is made readily apparent in well seasoned wood by the presence of sloping checks on the outer surface. Rare is the tree that has no spirality of grain, but present standards define those situations where problems may be expected. The pile specifications of the Canadian Standards Association do not permit a spirality greater than a one-half turn in any 20-foot section. The reduction of strength exhibited by spiral-grained piling results from the relatively low strength properties of wood perpendicular to the grain, as compared to wood strength parallel to the grain. A spiral arrangement of fibers changes the nature of axial loading from a parallel to a perpendicular fibre stress.

Shakes are commonly found in both seasoned and unseasoned wood. They are defined as separations of the wood along the grain, parallel to the growth rings and frequently occurring between rings of unequal width. Internal stress resulting from wind action and tree growth is generally blamed for this defect. The effect of shakes on piling strength have been summarized as follows:

Tension--little or no effect in direct tension parallel to the grain. A reduction in strength in tension perpendicular to the grain.

Compression--a reduction due to unequal distribution of stresses across the cross-section.

Shear--a reduction in proportion to the reduction of the area resisting the shear stress.

Except when occurring in clusters, knots are usually not an important factor in reducing the strength of piling. In fact, in piles of over 50 feet in length, knots of up to 5 inches in diameter are permitted between the mid-length and the tip. Strength properties are largely affected by grain distortion around knots and, neither the size of a knot cluster nor the size of individual knots within the cluster can be directly related to the size of the resultant strength-reducing grain distortion. As a result, knot clusters are prohibited by the C.S.A. The strength-retarding properties of a single knot depend upon its size, location and the resultant degree of grain distortion. Tensile strength is always more seriously affected than compressive strength, and stiffness properties escape significant change.

In a future issue we will discuss post-harvesting defects and their effect on the marine-borer resistance of treated piling.

NEW PROTECTIVE COATING FOR UNDERWATER APPLICATION TO WOOD AND METAL

In recent years a creosote-resistant borer, _Limnoria tripunctata_, has become of increasing importance to operators of industrial marine wooden structures. Until about 1960, this borer appeared to be limited to areas extending from Boston to the Gulf of Mexico on the east coast and along the Pacific Coast north to Point Arenas, California. However, recent field studies by Dr. D. B. Quayle, Fisheries Research Board of Canada, have shown that this borer is widely distributed in southern British Columbia waters.

Not only is the geographical area increasing over which the borer is distributed, but also its population density, particularly in some major ports of the United States in which pollution abatement programs have permitted re-establishment of marine fauna. For some years, this species has been the predominant _Limnoria_ in the Oakland-Alameda waters of San Francisco Bay and year by year it is encroaching further into the inner reaches of the harbors at San Pedro and Wilmington, California. The species is well established in waters along the Atlantic seaboard and can be expected to raise havoc with creosoted structures in east coast seaports when pollution is controlled and oxygen levels increase. Two major problems arise in the continuing use of wooden structures in _L. tripunctata_-infested waters; first, a new impregnant is needed for use in new installations to protect them against this borer; secondly, some method of protecting the millions of dollars worth of existing installations is urgently required.

For some years, members of the Division of Applied Biology have been aware of this mounting industrial problem and have been studying methods for protecting piling already in place. In conjunction with Caproco Corrosion Prevention Limited, the Council attempted to develop a mechanical wrapping device for applying tape to piling under water. Although underwater bonding of the tape was successful, the approach was abandoned because the variety of underwater obstructions tended to make tape application to piles impractical.

NATURAL BARRIERS

In relatively clean ocean waters unprotected wood has always been vulnerable to attack where populations of marine borers exist. Over the centuries, man's efforts to provide physical or chemical barriers for wood have met with varying success but all have increased costs of the original installation. Entirely apart from the intrinsic properties of naturally-resistant woods and tightly-adhering bark in more vulnerable species, fouling organisms--primarily barnacles and mussels--frequently provide protection against teredine and limnorial borers.

This protection probably occurs in two ways: mechanically, by excluding the borer with an 'armor-plate' continuously covering the wood surface or possibly with the larger foulers using the planktonic larval teredine as food.

Considerable recognition of the relationship between fouling and marine-borer attack has been given over the years, but perhaps the earliest was in Danish waters in 1841 where Lehman observed that untreated piling completely covered by blue mussels suffered no borer attack. As a solution to future pile protection, Lehman proposed planting mussels on piling surfaces. Presumably costs for underwater work would be much lower in those days even if the mussels cooperated by remaining in an unfavorable zone at the bottom of deep piles.

Today, unexpected benefits sometimes accrue to pulp mill operators forced to maintain log inventories for extensive periods in sea water. In rafts where a dense barnacle 'set' occurs before the major onset of larval Bankia attack, the resultant wood shrinkage frequently is a fraction of that in logs entering the water several months later but remaining relatively clear of fouling.

Two months' penetration - inches

	Tacoma		Crofton		Gambier		Teakerne	
Water Depth	O-N	D-J	O-N	D-J	O-N	D-J	O-N	D-J
1 ft	0	0	0.14	1	0	1	0.08	0.1
2 ft	0	0	0.2	0.1	0.04	1	0.04	0.15
3 ft	0	0	0.7	0.15	0.08	1	0.08	0.15
4 ft	0.2	0	0.2	0.15	0.35	0.1	0.08	0.17
6 ft	0.2	1	0.12	0.15	0.35	0.1	0.08	0.2
8 ft	0.3	0.2	0.43	0.15	0.43	0.1	0.47	0.2
10 ft	0.3	0.3	0.40	0.15	0.43	0.1	0.43	0.2

O-N = October-November
D-J = December-January

As the above table shows, in two months, Bankia growth rates in test blocks vary considerably with the month of initial immersion. A summary of three months' results will be presented in next month's Tidelines.

FOULING PROTECTION

Although no marine organisms have been found which regularly prey on either Bankia or Limnoria, some fouling organisms--notably mussels and barnacles--appear to foil the borers by mechanically covering the exposed wood surface, thus excluding larval attack.

Fouling organisms are plankton feeders, i.e., they feed on the plankton filtered out of the sea water which they pump over their gill system. Teredine larvae are classified as zooplankton and as they approach a wood surface harboring these fouling organisms, they constitute a natural food source. Thus, in addition to creating a mechanical barrier, mussels and barnacles actually may reduce larval concentrations in the environs of the wood surfaces. As early as 1841 Leman in Denmark observed that "wood (on piling) covered with colonies of the mussel Mytilus edulis (our common blue coastal species) is not attacked by shipworms". He assumed that the protection is a mechanical one, provided by the byssal threads which attach the mussel to the wood by means of a small disc. He noted that wood not protected by Mytilus edulis was infested within five years with borers measuring 12 inches.

It is interesting that this rate of attack, recorded well over a century ago, is considerably less than the rate of destruction normal on the west coast of North America where it is not uncommon for damage of this order to occur in less than 12 months.

Test block experiments by Weiss in 1948 and Redfield in 1952, both in Miami, Florida, showed that, whereas regularly cleaned blocks showed heavy teredine and limnorial damage after one year's immersion, similar blocks which were not cleaned and which were heavily fouled showed negligible attack. In November, 1964, a group of log rafts which had been regularly inspected by the B.C. Research Council staff showed much lighter borer damage when cut than anticipated from test block data from the storage area. These rafts were immersed during a period of heavy barnacle settlement and this freedom from attack was associated with the heavy barnacle fouling.

Thus, documentation is extensive that marine fouling can reduce considerably the settlement of marine borers.

TWENTY-YEAR STICKS

A continuing problem to the operator concerned with the maintenance of floating boomsticks, log floats, and fender or camel-log systems is the need for periodic replacement of marine-borer damaged material. For some structures in areas of heavy Bankia attack, the total effective service life can be as little as two years.

Two approaches toward increasing service life are available: periodic eradication of infesting borer populations before significant strength and flotation-reducing qualities are diminished, and total prevention of attack by prior pressure impregnation with a water borne preservative.

Periodic eradication can be accomplished "naturally" by rotating floats or boomsticks at three-month intervals to fresh water but, in most instances, either the demand for continuous use of the structures or the high cost of towing long distances to a suitable fresh-water body preclude the use of this method.

Alternatively, periodic in-place chemical treatment with sodium arsenite can be used to prolong the service life of floating log structures considerably. Here, all material to be treated may be rafted together in flat-raft formation and sprinkled with a one-percent sodium arsenite solution for a period of four hours. Individual floats may be enrobed with polyethylene sheet to form a water-filled bath to which the chemical is added, effecting an overnight kill of embedded borers.

Full-cell pressure impregnation of logs with a water-borne chemical salt such as copper-chrome-arsenate prior to immersion in the sea is a relatively new approach for the permanent protection of floating installations but one which holds considerable promise for maintenance-free operation.

Unlike creosote which, at the minimum required retention levels of 12 lb/cu ft, greatly reduces the floating quality of the log, water-borne salt treatments provide protection at a one-pound or less per cu ft (on a dry salt basis) and alter the buoyancy of the wood very little.

Conditions for suitable treatment with copper-chrome-arsenate vary considerably with raw log history. In all cases, log species should be coastal Douglas fir with as large as possible a sap ring. To bring the moisture content to the required 20 - 25%, as little as one month is needed for logs not previously immersed. For those previously floated in the sea, six to eight months may ensue before successful treatment can be accomplished. All logs should be peeled and chain holes drilled in boomsticks before treatment.

HELPFUL HINTS

In timber structures, various construction practices can result in mechanical damage which ultimately leads to marine-borer infestation and destruction of piling.

Marine-borer attack is often found in the area where a brace timber is attached to a pile. This is usually a result of borers gaining access into a pile through the bolt hole by which the two members are joined. Borer attack occurs if the bolt is loose in the hole, thereby allowing an influx of water and marine-borer larvae. Often, when bracing is removed or replaced, old bolt holes are left open. This type of breach in the protective creosote layer invariably results in marine-borer damage. A significant problem with this type of damage is that both Bankia and Limnoria attack inside the bolt hole is impossible to detect visually, until the pile has been completely destroyed. To avoid this type of damage, bolts should be checked and tightened if loose. All open bolt holes should be filled with grout and patched.

Another problem in the intertidal zone can result from the attachment of a piece of untreated wood to a treated pile. This practice can lead to infestation of the pile, since adult borers can penetrate treated wood from a piece of untreated wood attached to it.

Two practices which can result in borer attack at the mudline are: the placement of rip-rap around the base of the piles after driving, and driving piles through rip-rap or large sharp rocks. In both cases, the rock can penetrate the creosoted layer of the pile and allow marine-borer entry. Inspection of the piles below the rip-rap is impossible and this type of damage is often not detected until structural failure occurs.

Piling located in areas of heavy silting or shifting mudline should be checked regularly to insure that any possible marine-borer damage is not covered by a raised mudline.

Often piles are damaged during driving either by overdriving or impact with other piling or bottom debris. Even in a new structure, a cursory underwater visual examination is recommended immediately after construction, followed by a sonic-inspection within five years. Both are carried out to locate mechanically damaged areas before marine-borer infestation can cause serious loss of bearing strength.

Avoiding the above problem areas can increase the overall service life of a structure significantly.

GOOD HOUSEKEEPING

Every summer, along the Pacific Coast from Alaska to Vancouver, environmental factors trigger the onset of a new annual borer-breeding season. With this, fresh hordes of microscopic-sized borer larvae are formed and ready to attack logs, rafts and floats, piling, unprotected wooden vessels and other commercially important wooden structures. Where do they all come from?

Well, the answer is simple enough--they come from other borers. Each multicellular life of the animal kingdom springs from a parent generation; in the case of the wood-boring molluscs, larval development is initiated after the fusion of a sperm cell and an ovum, respectively produced by a male and a female borer of the same species. In the complete absence of sexually mature adult borers, no second generation would be produced, no free-floating pelagic <u>Bankia</u> larvae would be available to attack and destroy unprotected and valuable wood, and the life expectancy of deadheads and sinker logs would also be greatly extended. In the delicate balance of nature's housekeeping, the rapid degradation of wood in the sea constitutes one link in the ecological chain of events which serve to maintain the continuous recycling of nutritional chemicals. Modern-day environmentalists have realized that many of the great "pests" to mankind are really very important in the overall harmony of the environment we live in. Nevertheless, the activities of man sometimes contribute to making the somewhat noxious species more numerous, and then it becomes desirable that the trend should be halted, and perhaps even to some extent reversed.

In the case of artificially accumulated wood, a nucleus <u>Bankia</u> population initially would form after the pelagic larvae had arrived by current transport, or from a piece of wind-blown driftwood. When the nucleus population reached maturity and procreation towards a next generation wold begin, larval arrival into the surrounding waters no longer would be restricted to pelagic communication over relatively long distances. On-site production of large swarms of larvae would quite overshadow the more limited supply from outside sources. If enough exposed wood were readily available to further attack in the immediate vicinity, population growth from the initial size of the nucleus population would tend to be exponential; i.e., each new generation of established borers would be many times more numerous than the immediately preceding generation. With the final destruction of all of the available wood, this tend would reverse as a consequence of the population collapsing. Alternatively, a continuous supply of fresh bait wood in the form of drift logs or sinkers would serve to maintain this new borer breeding ground, and to ensure continued high-level larval activity in the surrounding waters. This level, under the circumstances, would correlate to the supply of the bait wood: the more wood supplied, the more borers would survive and further increase the larval density during the next breeding period.

Good housekeeping practices of logging operators, therefore, would demand keeping at a minimum the supply of bait wood adjacent to log boom storage grounds, so as to avoid the above type of submarine population explosion and its economic consequences. In the absence of data on bait wood supply, a numerical evaluation is difficult. Nevertheless, the tendency towards increased counts, from year to year, has been evident at several monitoring stations where other environmental factors have remained relatively unchanged. Prevention of sinkage, and the removal and isolation of infested logs and rafts before the embedded borers reach the spawning stage, would help to reduce reinfestation. Permanently or semipermanently immersed structures, where economically feasible, might be made from suitable materials not susceptible to borer attack. In the case of standing structures, creosoted wood is borer resistant and durable north of the 38th parallel; floating structures resting on styrofoam, hollow metal containers, concrete or constructed of logs pressure treated with a toxic metallic salt, similarly do not contribute to maintaining high levels of borer incidence.

Wherever feasible, housekeeping with a view to restricting borer bait-wood supply and existing breeding grounds would pay off, as established breeding populations gradually would diminish.

LIMNORIA

CRUSTACEAN WOOD-BORERS

Previous issues of "Tidelines" (August 1959 to September 1960) have described the molluscan borers: *Teredo*, *Bankia*, *Martesia* and the pholads. The next series will be devoted to the crustacean borers: the *Limnoria* ("gribbles") *Sphaeroma* and *Chelura*.

Unlike the molluscs which are relatively stationary, the crustaceans are able to move about quite freely. The most destructive crustacean borer is the *Limnoria*. *L. lignorum*, the most common species, is found north of the Arctic Circle in Norway and as far south as the Falkland Islands, South Africa, Australia and New Zealand. This borer was first noted on the Pacific coast by Hewiston in 1874 at San Francisco Bay. In 1949, a second species, *L. quadripunctata*, was described by Dr. L. B. Holthuis and in 1951, a third species, *L. tripunctata*, by Dr. R. J. Menzies in California.

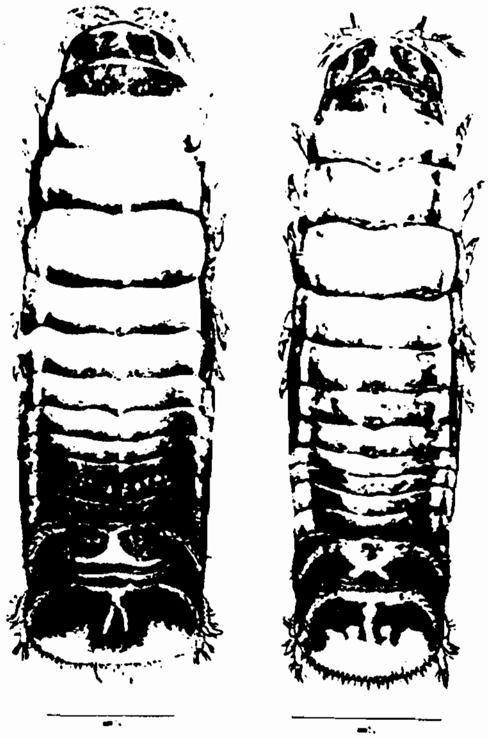
The *Limnoria* predominate in the inter-tidal zone, although they are commonly found to depths of 40 ft or more. They are very small - scarcely 1/8 - inch long - and hundreds per square inch may be found in heavily-infested wood.

Limnoria slowly erode the surface of the wood. The animals form networks of fine channels and, as the finely honeycombed pieces of wood slough away, newly-exposed surfaces are attacked. Although the damage caused by individual borers is small, by virtue of tremendous numbers, particularly in the warmer surface waters of California and further south, they completely destroy one-inch test-panels in three of four months. One of the more disquieting features is that one species, *Limnoria tripunctata*, attacks creosoted wood and no commercial protection is currently available.

THE LIMNORIA - AN INSIDE LOOK

On the evolutionary scale, the *Limnoria* are considerably further advanced than the *Teredo*. For example, the *Limnoria* possesses a brain from which nerve connections are made to various parts of the head and abdomen.

The circulatory organs consist of the heart and a system of connecting blood vessels. The heart, which is almost half the length of the body, lies across the back of the animal. The oblique strands surrounding the wall of the heart are contractile fibres. Breathing takes place at the five plate-like discs (pleopods) on the underside.



Dorsal view of the two gribble species found in British Columbia. Left, Limnoria lignorum (Rathke). Right, Limnoria tripunctata Menzies.

The digestive tract of Limnoria consists of an oesophagus, a stomach containing a gastric mill, an intestine and anus. The gastric mill is liberally supplied with muscles and its purpose is to thoroughly grind the ingested wood. Just beyond this mill, two liver ducts open into the digestive tube. The liver secretes a yellow crystalline substance which can be readily seen through the body of the animal in the form of a letter H. The function of this material is not known.

The reproductive organs in the female consist of two large ovaries; relatively few eggs, usually not more than 30, are produced per brood. The female carries the young in a brood-pouch and they are able to fend for themselves when released. Temperature greatly influences reproduction; for L. tripunctata the breeding peak is between 63 - 66°F contrasted with about 50°F for L. lignorum.

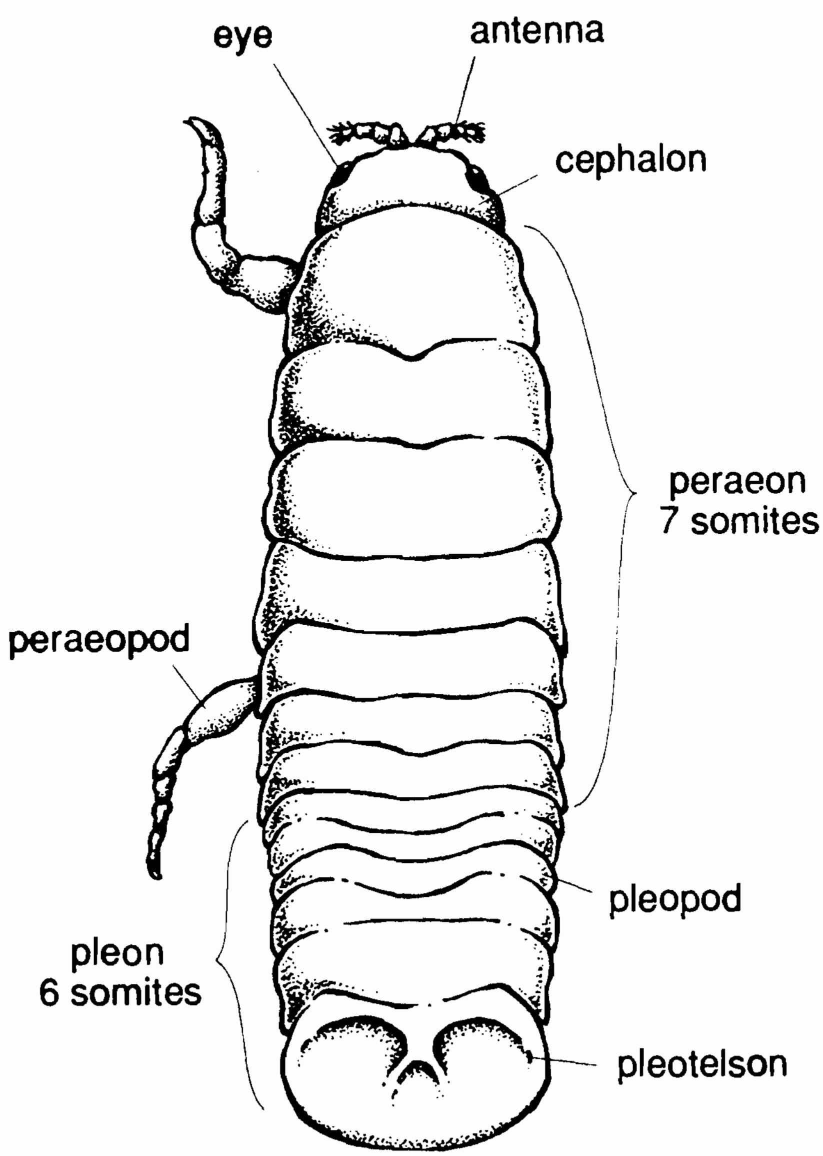
EXOTIC TASTE

The African hardwood species, Azobe, has been regarded by many investigators as resistant to marine borers. At the end of one year's immersion at Puget Sound Bridge and Dry Dock Co., Seattle, an Azobe panel picked up only external fouling. At the end of the second year, however, Bankia had penetrated eight inches.

THE LIMNORIA - AN OUTSIDE LOOK

In structure the Limnoria resembles the lobster to which it is related. Its body is composed of three parts, the head, thorax and abdomen which are intimately connected so that the over-all appearance is a stubby cylinder rounded at the ends. The head contains two sets of feelers (antennae), a pair of prominent eyes and a rather complex mouth which has parts for grinding, collecting and ingesting wood particles.

The Limnoria is equipped with seven pairs of legs which enables it to move across the surface of wood and back and forth in the tunnels which it excavates. Also found on the under-side of the body are five sets of platelets (uropods) which are used for swimming and respiration. Its swimming movements are very erratic. It swims in a straight, darting fashion for one or two feet, then stops and sinks for a few seconds. After resting, it moves another couple of feet in a different direction, much like a drunken sailor.



The plate at the tail is known as the telson, and it is of importance in distinguishing the different species. Limnoria lignorum has no bumps (tubercles) on the upper surface of its telson, L. tripunctata has three and L. quadripunctata has four. Even with the aid of a microscope these small tubercles are difficult to distinguish.

In contrast to the complicated sex pattern of the teredine borers, that of Limnoria is comparatively simple. The sexes are separate and fixed.

LIMNORIAL ETCHINGS

In contrast to the teredine borers which drill deeply into wood, Limnoria form delicate networks of channels near the surface. Limnoria operate in pairs, male and female, each pair excavating its own network of channels.

When starting to drill at the surface of wood, the wood is gripped firmly by the animal's seven legs, the front three of which have toes that point backwards and the back four with toes that point forward. The boring is done by the pointed tips of the mandible which grind the wood, the particles of which are swept into the mouth. The antennae are apparently not used during boring but are laid back across the head. The boring continues day in and day out, with only occasional stops. If the animal is disturbed, it will either go into the deepest part of its burrow, or else crawl to the surface of the wood and sometimes roll into a ball.

After *Limnoria* has settled on wood it requires from four to six days to bury itself completely. The burrows generally do not extend more than one-half inch below the surface of the wood. This limitation of depth is probably set by oxygen concentration in the water. Marine bacteria and other microscopic forms of life consume oxygen in these channels so that the *Limnoria*, to maintain an adequate supply of oxygen for themselves, drill holes at frequent intervals along the channels to the surface. As the outer parts of the wood become perforated by the *Limnoria*, these parts slough away and the borers continue to work deeper.

LIMNORIA TRIPUNCTATA - PRESENT STATUS IN THE NORTHWEST

The June, 1961 issue of "Tidelines" reported the presence of the creosote-resistant borer, *Limnoria tripunctata*, in wharf piling at Crofton, B.C. This observation gave rise to the question as to whether this borer might be more widely distributed in northern Washington and British Columbia than heretofore realized. Also, since the taxonomy of *Limnoria* has been investigated in detail only recently, there was the possibility that it might be a native species.

Dr. D. B. Quayle, Pacific Biological Station, Nanaimo, B.C. has identified recently 7,800 individual animals contained in 85 samples taken from along the coast between Willapa Harbor, Washington and Masset in the Queen Charlotte Islands and has found *Limnoria tripunctata* in 47 of the samples. The species was found to occur in inland sheltered waters between Willapa Harbor in the South and Teakerne Arm (North-east Georgia Strait) in the North. The occurrence of *L. tripunctata* is fairly closely associated with relatively high water temperatures for the general area. The species was found in 22 different localities and eight samples contained only *L. tripunctata* and no *L. lignorum*.

Dr. Quayle states that, as shown by both its distribution and by direct observation, the species can breed well under the water temperature conditions in some areas of British Columbia. Both *L. lignorum* and *L. tripunctata* occurred either singly or together in both untreated and creosoted timbers. Preliminary observations in this study by Dr. Quayle indicate neither species is more destructive than the other under similar temperature conditions but detailed quantitative research will be required for a definite answer to this question.

The discontinuous distribution would lead to the suggestion that *L. tripunctata* is an introduced species and its wide distribution and abundance in some areas would indicate it has been in B.C. waters for some years. The earliest authentic record is from Port Moody in 1958.

LIMNORIA IN GREAT BRITAIN

An excellent account of the physiology and biology of various limnorial species encountered in Great Britain, has been published in the September 1962 issue of the Journal of the Institute of Wood Science by the Research Laboratories of the Timber Research and Development Association Ltd. of Tylers Green, England. This article is an excellent review source of much of the information that is currently known about this species.

BORERS WITHOUT WOOD

An interesting sidelight of the Council's basic research program on marine borers has been the growth of adult Bankia in glass tubes filled with agar (a hard setting high temperature gel extracted from sea weed) and capped with plugs of Douglas fir veneer. When either sawdust or cellulose (a purified wood constituent) is incorporated into the agar, borer larvae settling on the wooden plug grow into the agar at much the same rate as they grow in wood. Present borers are 1 to 2 inches long and are thriving in the laboratory. Even though the agar is considerably softer than wood, it is possible to see the grinding action of the two calcareous shells at the head of the animal.

LIMNORIAL PULPING

Wood appears to be the only substance used as food by the Limnoria. The Teredo uses diatoms and other plankton, but Limnoria have no means for filtering out these small organisms. However, recent studies carried out by Dr. C. E. Lane at the Marine Laboratory, University of Miami, indicate that marine fungi may supplement the wood diet of Limnoria, and that these fungi are essential for continued growth and activity. The utilization of fungi as a source of nitrogen by Limnoria have a supplementary source of this element.

If Limnoria are deprived of wood but given a liberal supply of sea-water containing natural flora, 80% of them die in 60 days and the remainder in the third month. Examination of the internal organs shows evidence of starvation.

In place of wood, Limnoria have been successfully maintained on cellulose in the form of high-grade filter paper. In some parts of California Limnoria bore into the hold-fasts and stalks of kelp and presumably use this material to meet their carbohydrate demand.

GO IT ALONE

Most wood-eating species of termites are entirely dependent on protozoa in their gut for breaking down wood. These protozoa contain the enzyme cellulase which dissolves cellulose. On the other hand, the outstanding work of Dr. Dixy Lee Ray of the University of Washington (Seattle) has demonstrated that no bacteria or protozoa exist in the entire alimentary tract of Limnoria. From this it has been concluded that Limnoria produce their own digestive enzymes and operate independently of microbes.

WHAT'S MISSING?

Dr. Ray has studied the activity of 1320 Limnoria acting on 76 separate specimens of Douglas fir for two months. The average weight loss of the specimens was 45%. An analysis of the excreted wood pellets together with that of the original wood is given below.

	Average Composition of:	
	Douglas fir	Pellets
α cellulose	36.0%	33.6%
polyuronide hemicelluloses	15.5	0.2
noncellulosic polysaccharides	12.0	0.8
lignin	29.0	63.2

Thus Limnoria are able to remove essentially all the polyuronide hemicelluloses and non-cellulosic carbohydrates and about half the cellulose. The lignin is relatively indigestible.

PROTECTIVE BARRIERS FOR MARINE PILES

Previous issues of Tidelines have described the failure of creosoted piling in southern waters due to the attack by the creosote-resistant Limnoria tripunctata. Although piles can fail in 8 to 12 years, often the process takes longer due to the slow erosion of the outer protective shell. Mr. C. M. Schillmoller of the International Nickel Company has studied the rates of piling erosion and states that the cross-sectional loss of a pile should not exceed 15 percent for the pile to be worth saving.

A number of attempts are being made to protect piles against L. tripunctata by the use of barriers. Two of the most common barriers being used at present are polyvinyl chloride sheathing and a 90-10 alloy of copper-nickel. The borers entrapped by the sheathing are killed by "stagnation" or lack of oxygen in the water. In addition, the metal alloy wrap supplies copper ions which are toxic to the borers. Some of the characteristics of these two types of barriers are shown below:

	PVC Sheathing	90-10 Copper-Nickel Alloy
Thickness	20-60 mil	20 mil
Life expectancy	25 years	30 years
Abrasion resistance	Low	High
Fastenings used	Cupro-nickel bands or monel nails and washer	Monel nails
Costs (U.S.) per lineal foot installed	$5.35	$7.00-$9.00

From the above data it may be seen that the cost of wrapping 35 linear feet of piling runs between $180.00 and $315.00. Currently, the BCRC is experimenting with a mastic coating which sets up under water. It is hoped that the cost of treating a pile with this coating will be under $100.00.

Service records, presented at a recent meeting of the Committee on In-place Wood Pile Barriers held in Oakland, California, indicated that pile barriers have proven extremely effective to date. Of several thousand piling under test in southern California over the past four years, not a single failure has occurred. The evidence documents the availability of adequate technical know-how and equipment to protect in-place piling against the ravages of L. tripunctata. The relatively high cost of existing barriers may limit their use to certain locations, such as under buildings, warehouses, and other waterfront structures where re-driving costs are exceptionally high.

Regardless of whether continuing wharf maintenance involves barriers or pile replacement, accurate assessment of present pile conditions is paramount. Since teredine species co-exist in virtually all L. tripunctata-infested waters, the only accurate means of detecting internal pile condition is with the Council's sonic inspection equipment. Thus, sonic inspection should precede any proposed rebuilding or protection program.

Proper visual inspection by hard hat or SCUBA divers, without sonic equipment, involves finding the smaller entry holes left by the teredine borers. In the fouling zone, pile surfaces must be scrubbed to remove fouling. Inevitably this means that proper visual inspection is considerably slower than sonic inspection. A more rapid visual inspection necessarily means a less intensive search for teredine borers, with increasing hazard of missing damaged areas. Even though thorough visual inspection may locate all damaged areas, no accurate estimate of loss in pile strength can be made as can be done by sonic inspection.

GEOGRAPHICAL DIFFERENCES IN LIMNORIA MIGRATIONS

Last month's Tidelines described the wide variation in Bankia attack with both time and geographical location, and emphasized the need for continuous monitoring of each of the 69 stations now being serviced by the Council's marine-borer protection program. As seen in the following table, similar variations occur in migrations of Limnoria, the crustacean borer associated with large scale destruction of wharf piling and unprotected marine wood structures.

For five selected locations, from Alaska to San Francisco Bay, average counts, to a depth of 20 feet, ranged from 22 to 3528 per square foot in 1960 and in 1964, from 2 to 1363. Unlike Bankia attack, which in 1960 and 1964 was heaviest and lightest at mid-B.C. and San Francisco sites, respectively, Limnoria migrations were heaviest at San Francisco in 1960 and at the mid-B.C. site in 1964. Similarly, the lowest migrational activity for both years occurred at the lower B.C. Coast and Puget Sound testing sites.

For 1960, in both Alaska and San Francisco, migrations peaked in the spring months, whereas elsewhere, activity was relatively uniform throughout the year.

Curiously, in 1964, Alaskan waters produced active migration over a ten-month period (five in 1960) but, further south, test material revealed activity only during two and six months at the lower B.C. Coast and Puget Sound sites, respectively.

At least three species of Limnoria were involved at all five sites: L. quadripunctata, L. lignorum and L. tripunctata. At both the mid-

B.C. Coast and San Francisco Bay locations, L. tripunctata, the creosote-resistant species, predominated and perhaps it is more than sheer coincidence that these sites recorded the heaviest overall migrations.

SURVIVAL OF LIMNORIA TRIPUNCTATA AT LOW TEMPERATURES

In order to evaluate the survivability of Limnoria tripunctata at winter seawater temperatures, typical along the temperate coasts of North America, three mixed populations of Limnoria lignorum and L. tripunctata were exposed to seawater temperatures of 29.4°F, 35.0°F and 41.2°F, respectively. Each concurrent exposure lasted for a period of three months, in a controlled environment laboratory at B.C. Research.

Originally, the Limnoria were collected from infested piling by a B.C. Research SCUBA diver. Before subdivision into the three sample populations, the ratio of L. tripunctata to L. lignorum was determined to be almost exactly 1 to 9. The following results were obtained:

1. L. tripunctata survived the three-month exposure period equally well as L. lignorum.

2. The difference between the temperature regimes of 29.4 to 41.2°F did not favour the survival of L. tripunctata at the higher temperatures as compared to the survival of the cold water species, L. lignorum.

Temperature	Total Counted	L. lignorum		L. tripunctata		Unknown	
		Numbers	Percent of Total	Numbers	Percent of Total	Numbers	Percent of Total
41.2°F	232	176	75.9	41	17.7	15	6.4
35.0°F	217	172	79.3	35	16.1	10	4.6
29.4°F	311	240	77.2	62	19.9	9	2.9

Although L. lignorum was nine times more numerous than L. tripunctata, according to the initial count, after exposure, the L. tripunctata fraction in all three sample populations was over 15%.

The experiment demonstrated that the low winter temperatures per se did not curtail the survival of L. tripunctata as compared to that of L. lignorum. Further experiments have suggested that, where summer winter temperatures rise above 70°F, freshly creosoted wood will be attacked by L. tripunctata.

ORGANISMS ASSOCIATED WITH LIMNORIA

A recently published study from Duxbury, Massachusetts, disclosed that a variety of small, invertebrate organisms were closely associated with Limnoria. However, none of these appeared to have any detrimental effects upon the well being of the Limnoria population. None were parasitic.

Instead, all the small organisms were scavengers, utilizing faecal matter, dead Limnoria, and various forms of other detritus for food. The most important of the scavengers were nematodes and copepods.

The authors of the publication concluded that "the burrows of L. tripunctata offer a good source of protection and a variety of niches to all the associated organisms, while the waste products of Limnoria offer a readily available food source, as well as a substrate for bacteria, fungi, diatoms and protozoa".

FELLOW TRAVELLERS

The numerous tiny creatures, who call the "Pacific gribble" home, can be designated, depending upon their relationship with the host, as either parasites or commensals of Limnoria. Parasitism refers to an association between two living organisms in which one benefits and the other is harmed by the relationship; while commensalism describes an association in which one of the partners benefits while the other is neither benefited nor harmed.

Sessile or "fixed" protozoa make up the commensal population of Limnoria; while a species of nematode or "roundworm", and an unidentified trematode or "flatworm" have been described as parasites of this crustacean. The phylum Protozoa contains the myriad one-celled organisms of the animal kingdom and, in the case of the relatively gigantic "gribble", commonly contributes at least five distinct minuscule species as "hangers-on". The scientific names of these "fearless five" follow: Folliculina, Spirochona, Epistylis, Opercularia and Cothurnia. These protozoan species are classed as commensals because, although they are attached to the epidermis or "outer skin" of their host by a sticky secretion at their bases, no penetration of the host's body takes place.

The exterior of Limnoria is often "carpeted" by these harmless intruders, with few body parts escaping activity. Points of attachment are commonly provided by the telson, the basal joints of the legs, the mouth parts, the pleopods, the bases of the antennae, and the lamellae of the brood pouch. It has been reported that the characteristic dark-green tubes of Folliculina are found on up to 80 per cent of individuals examined. This organism is most frequently found on the posterior segments of the abdomen and on the telson, which is often completely covered.

The nematodes occurring on Limnoria have been classed as parasitic because of their presence in the brood-cavity of the female. It has been deduced that these "foreign organisms exist by utilizing the enclosed fluid as nourishment. The presence of nematodes on Limnoria, however, does not always signal parasitism. The fold of hard body covering or chitin located between the first segment and the head of Limnoria practically never escapes invasion by great numbers of these microscopic "pests". But in this instance their presence does not appear to be detrimental and thus can be regarded as commensal.

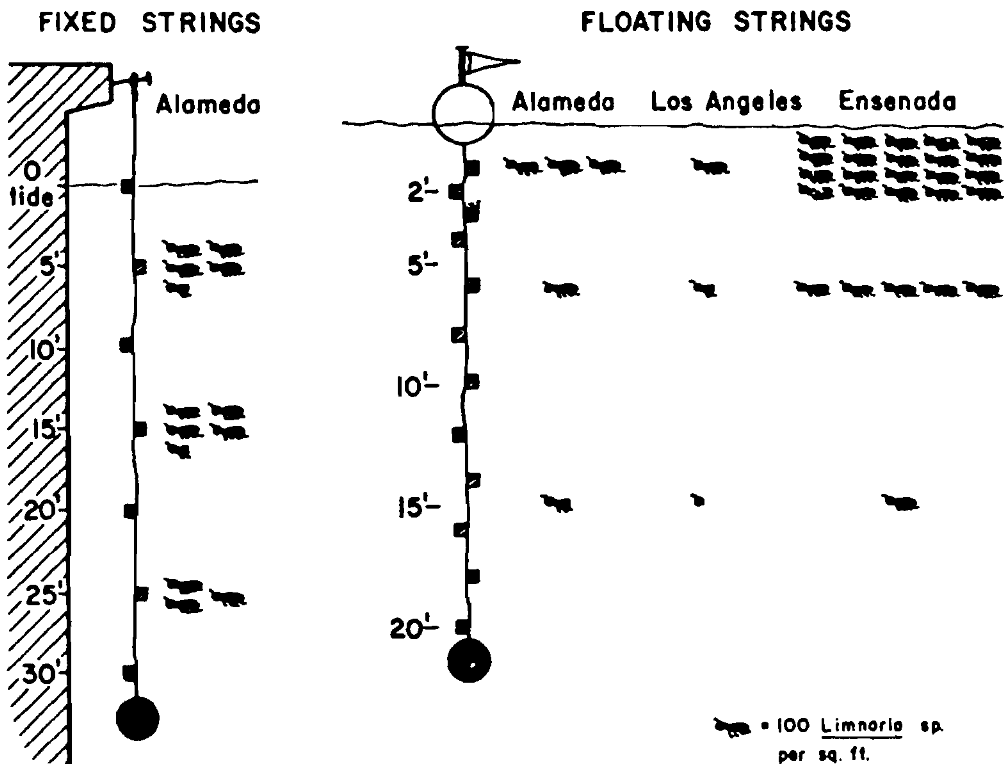
The other organism reported as being injurious to Limnoria has not been found in the active state and has yet to be positively identified. Its existence is suggested by the discovery of a round cyst near the inner portion of the thin, plate-like appendages known as pleopods. Although no definite structures have been detected, it has been suggested that it may be a trematode.

In any event, it is not likely that parasitic control of Limnoria holds much promise in supplanting present chemical control methods.

WHERE LIMNORIA TRIPUNCTATA ATTACKS

The rule of thumb in estimating the zone of maximum destructivity of marine borers, is that Bankia and the other teredine borers usually attack at peak intensity near the mudline, whereas the various species of Limnoria generally concentrate in the intertidal zone.

If, however, this rule of thumb is taken literally to mean that either group of borers confidently can be expected to confine themselves entirely to any particular zone, then unpleasant surprises may result. For three locations along the California and Baja California coast, where L. tripunctata are rampant, the two-year (1966-67) average monthly settlement of Limnoria on test blocks is shown in the histogram.



Since creosoted wood is not resistant to L. tripunctata and because these organisms can broach a creosoted pile interior in relatively short time periods, wharf engineers should be aware of their true settlement patterns. Economic wharf maintenance often includes the installation of protective wraps or other barriers where superficial borer attack is evident, but where the piling still maintains most of its structural integrity. The installation of such barriers in the intertidal zone alone as protection against L. tripunctata undoubtedly prolongs the creosoted piling service life. However, the optimum long-term cost evaluation should also consider the slower limnorial erosion which is likely to occur down to the deepest levels of documented limnorial attack.

DEEP DIVERS

The ability of various limnorial species to withstand, without ill effect, extreme variations in both diet and environment has been demonstrated in many ways over the years. The search for "gribble-proof" impregnants has been hastened, for example, by the ability of L. tripunctata to rapidly destroy marine piling and timber structures in spite of heavy impregnation destroy marine piling and timber structures in spite of heavy impregnation with creosote.

The amazing durability of this marine pest has been further demonstrated by the U.S. Navy Civil Engineering Laboratory in their continuing study on the deep ocean biodeterioration of materials. As part of a program to determine the effects of deep ocean environment on various engineering materials, a test site was established on the ocean floor in 5,640 feet of water off the southern California coast. The study involves the bottom placement of test units loaded with hundreds of test specimens for varying lengths of time, followed by recovery and detailed examinations of each material under test.

A relevant excerpt from the Phase 1 program report follows:

> "During one of the oceanographic data-collecting cruises to Test Site 1, *Limnoria tripunctata* (a marine-boring organism found on creosoted pilings in Port Hueneme Harbor) were lowered to a depth of 5,580 feet to see if these borers could survive the high hydrostatic pressures and the low water temperature. Forty-five borers were placed in a 150-ml translucent plastic bottle with tiny holes punctured in the upper half of the bottle for circulation of sea water. Two small pieces of wood were also placed in the bottle as food for the animals. The bottle with the animals was then locked inside a small pocket on one side of a scoop sampler, and the sampler was lowered to a depth of 5,580 feet, at a rate of 200 feet per minute. The animals remained at this depth for five minutes, and were then raised to the surface at a rate of 250 feet per minute. Immediately after recovery, all the borers were on the bottom of the plastic bottle, as if stunned or dead. But two hours later, the majority of them were either swimming actively or feeding on the wood pieces.
>
> This experiment was duplicated in the laboratory to see if the temporary disabling effects were caused by the cold water or the high hydrostatic pressure. Another group of these borers (in a plastic bottle with wood pieces) was placed in sea water in a 9-inch-ID pressure vessel and subjected to a hydrostatic pressure of 2,500 psi (equivalent to about a 5,700-foot depth). The hydrostatic pressure was applied and released in the pressure vessel at rates corresponding to descent and ascent at sea. But the water temperature was higher; 25°C instead of the average 2.53°C on the bottom at the test site. Immediately after recovery from the pressure vessel, all borers were actively feeding on the wood pieces, and it was concluded that temperature change was more significant than pressure change on *Limnoria tripunctata*"; another entry in the lengthening list of "gritty" performances by the indefatigable Pacific gribble.

MISCELLANEA

NOTHING NEW UNDER THE SUN

"For as the ship by hidden shipworm spoil'd;
Or as the rock by briny wavelet mines;
Or as the wrested sword by rust is soil'd;
Or book unread the tiny moth unbind;
So gnawed and nibbled, without hope of rest,
By cares unceasing, is my tortured breast."

- Publius Ovidius Naso, 43 B.C.-17 A.D.

But teredine borers undoubtedly far outdated the Romans. Fossils of tertiary species have been found in Italy and England and two of the species occurring in England in recent times were present there in the post-Pleistocene period.

In modern times teredos were first mentioned as an economic problem in Holland where they were responsible for destruction of piling and dykes in the 18th and 19th centuries. Andre Delandes, in 1722, described both the borers and their destruction of timber in Brittany (NW France). Rousset in 1733 states that teredos had been a problem at least fifty years previous to that date in Holland. An optimist, Job Baster, writes of the shipworm problem in Holland as of 1739:

"But the Divine Clemency has already so far destroyed these pernicious Insects, which multiplied so prodigiously for eight or nine years past, that there is great room for Hope, that our Country will in a short time be entirely freed from them."

It can now be reported 130 years later that we are having to use a little more than Hope to keep ahead of the "pernicious Insects".

DID YOU KNOW

a. That when Bankia settles on wood, it is only 1/100 inch in diameter, or about half the diameter of the period at the end of this sentence.

b. That Bankia and other teredine borers do not settle below 600 ft of depth, but that marine-borer attach by specialized deep sea pholads has been observed in wood recovered from depths of up to 18,000 ft, or about 3 1/2 miles.

c. That a certain kind of petrified Teredo wood in 1967 was designated as the state stone of North Dakota, and that this particular stone is presently known only from the Cannonball fossil formation in North Dakota where Nototeredo globosa left behind thoroughly riddled chunks of wood about 60 million years ago.

d. That the so-called rock clams (Pholads) cannot bore into materials harder than 2.5 on Moh's mineral hardness scale.

ALMOST AS OLD AS THE HILLS

The animals living today are only a part of the vast and continuing population that has inhabited the earth through millions of years. Evidence of these former organisms is provided by fossils and, indeed, many present-day species of animals occur also as fossils, showing that they had lived in earlier geological times.

Although they may have existed 155 million years ago, the first definite fossil records suggest that members of the 'teredo' family arose during the Cretaceous or "Chalk" Period of the Age of Reptiles or about 120 million years ago. During this period, the Rocky Mountains and the Andes were forming, great swamps covered much of the earth, and cooling climates added to the rise of flowering plants, small primitive mammals, the first snakes, modern fish and invertebrates.

In fossilized wood, originating from such diversified sources as India, Texas, and Japan, teredine tubes and valves (shells) have been examined by various investigators who described as many as 26 different species. However, recent examination by the authority on the Teredinidae, Dr. Ruth Turner, Harvard University, suggests that only the family grouping is valid for material of the Cretaceous Period.

The 70-million-year-old forerunner of our Bankia of North America has been described recently from material from the Age of Mammals, during which the continents were mainly above the seas, the Alps, Himalayas, and other mountains were rising, the climate was warm but gradually cooling, and modern plants were established. Amongst those modern plants were the progenitors of our forests, the wood which today finds manifest application in the marine environment--boats, dry docks, scows, wharf piling, floats and log rafts. It is small wonder that today's West Coast Bankia is such an effective boring organism--he's had at least 70 million years' practice.

BORERS WITHOUT BURROWS

Attempts have been made at various times, without success, to extract adult Bankia from their wooden habitat and maintain them alive in Council laboratories. More recently an adult Bankia, 6 inches in length has been kept alive for 15 days and is still living at the time of this reporting. Although he has no wooden burrow, he has begun slowly to secrete a new calcareous cover for his body, starting at the siphons and growing towards the grinder. This animal, after extraction from his burrow, has been kept in aerated sea water at 52°F and fed a diet of sawdust and algae.

PENETRATION OF BARK

Tree bark is usually regarded as a protective armour against borers, at least among coniferous species. This may be accepted as fact for most commercial situations. However, in field operations at Crofton in April, borers were found which had established themselves on Balsam bark as larvae and had penetrated the bark to the wood itself. It is to be hoped these cases remain rare.

FULL-SPEED AHEAD

Usually Bankia setacea live so close together they crowd themselves out of existence before they have a chance to grow to maximum length. In a specially-designed catcher exposed in Vancouver Harbor, Bankia have achieved a length of 36 inches in 18 months and are still pushing onwards.

RESISTANCE OF WOOD SPECIES

In contrast to a few Central and South American, Australian and African species, the North American commercial wood species are all readily attacked and destroyed by marine borers. West coast conifers are about equally palatable to borers, although yellow cedar seems to disappear more readily than some of the other woods.

For settlement studies the Council uses only one species, Douglas fir. Its selection is predicted on its wide acceptance as a structural wood.

A NEW BATTLEGROUND

Control on the release of waste into the Port of Los Angeles is making this area increasingly vulnerable to borer attack. The effects here are expected to be similar to those which had occurred during the last two years in San Francisco Bay following clamp-down on waste disposal into the sea. In the Oakland-Alameda area, attack on submerged wood increased from a few hundred borers per sq ft for past years to monthly peak attacks of 2800 teredos at the mud-line and over 10,000 Limnoria near the surface during 1959. The most devastating feature about both San Francisco and Los Angeles is the predominance of Limnoria tripunctata, the creosote-resistant borer.

THOSE PERSISTENT LIMNORIA

A recent examination of untreated Douglas fir timbers supporting the rails of a Crandall Cradle shipway revealed attack by live Limnoria lignorum eight to twelve inches below the mudline and 10 ft above zero tide. Fill material adjacent to the attacked wood was coarse sand and gravel which provided good drainage or "pipes" surrounding the timbers. The borers may have gained access to temporarily exposed timbers during the washing operation involved in cleaning wooden ships and scows immediately above the rails and free tidal circulation of water through the porous fill provided the necessary dissolved oxygen to maintain life.

TEST BLOCK LOSSES

Despite the best precautions in any continuing program involving periodic immersion of test material, losses are bound to occur. With test strings, the most frequent cause of loss is mechanical--by ship activity or abrasion, followed by vandalism in exposed locations. Recently, a new type of loss was discovered in San Diego Harbor--destruction of the tarred hemp line by Limnoria tripunctata, the very organisms the test blocks were designed to collect. The problem was solved by replacing test strings with nylon cord which can withstand biological corrosion for a number of years.

TWENTY YEARS OF MONITORING

In B.C., Bankia settlement has also declined steadily over the last decade. As a result, the average settlement on five B.C. monitoring station in 1973 was only 2.3% of the corresponding settlement in 1963. Perhaps this justifies a similar "Hope". However, experience with biological population cycles has advanced since 1739, making it advisable to restrain our own optimism until later. Records from other parts of the world have demonstrated that large fluctuations in marine-borer activity are not at all common.

HOW RESISTANT IS CREOSOTE?

The ability of *Limnoria tripunctata*, the warm-water species, to attack creosoted wood is well authenticated. Now the evidence is mounting that *Limnoria lignorum*, the species found in the cooler waters extending through Washington, British Columbia and Alaska, also may be able to attack creosoted wood.

During the past year, Council biologists have found *L. lignorum* attacking creosoted piling at a number of points on Vancouver Island. More recently *L. lignorum* has been observed boring into creosoted piles in Alaska.

The protection provided by creosote appears to be one of degree. Although full-cell retentions to 1-inch in depth may stop *L. lignorum* initially, the lesser retentions and penetrations brought about by leaching during service, fail to repel *L. lignorum*, while still repelling *Bankia* larvae. This is particularly true where large populations of *L. lignorum* are thriving nearby on untreated wood. However, instances have been observed of *L. lignorum* attacking creosoted piles after only two years in the sea. Further careful investigation is required of creosote characteristics, retention and penetration in those creosoted piles showing attack by *L. lignorum*.

WATER TEMPERATURES AND BREEDING OF *BANKIA*

Compilation of water temperature records at the Council for a number of our breeding stations is bringing forth much interesting data. In most locations larval settlement, which is what is actually recorded, begins 1-3 months after maximum water temperatures are reached. In warmer waters where this pattern is not followed certain temperature levels or temperature changes precede settlement. In Puget Sound where breeding is more or less continuous water temperature variation on an annual basis, is the least. These data confirm the predominant role of temperature in breeding of the species *Bankia*. Little is known about the role of other interrelating factors.

THE ODD ONES

Since our primary interest is the protection of commercially important wood in the sea, we have come to regard marine borers as a group active only in wood. However, lesser known, but occasionally economically significant, organisms bore into other materials harder than wood, notably shells, coral, limestone, and even basalt.

A group of such organisms are the rock-boring clams, the pholads, which penetrate materials softer than 2.5 on the diamond scale (lead, plastics, stone material, including shale and low-grade cement mortar and cordage).

A much lesser known borer, belonging to the Bryozoa (moss animals, common fouling organisms) has been reported, from both the United Kingdom and Portugal, to burrow in both snail and bivalve shells. Actual erosion of the shell is purported to be by a combination of mechanical and chemical agents.

Another borer related to the common barnacle but confined to tropical waters penetrates the coral limestone of Australia's Great Barrier Reef by mechanical means only, according to one authority. Attack in the shells of tropical snails, insists another writer, occurs solely by chemical dissolution.

A relative of the starfish, the spiny sea urchin, has been implicated in attack in coral, basalt, limestone and even steel piles in such widely scattered locations as Britain, France, Australia and the southern Pacific Coast of North America. Apparently, only the intertidal and not the deep water European species of sea urchin burrow in rocks solely for protection from heavy wave action and, at low tides, from desiccation. Except where the rocky tunnel is very deep, the borer emerges at night to feed. Each burrow may serve successive generations of urchins.

In 1953, about half of the steel piles in a California oil well pier were found to be damaged at their bases. In some instances three-eighth-inch plates were completely perforated but the majority of damage consisted of deep pits. A sea urchin was found in each pit, the bottom of which was bare and bright. Apparently the continuous scraping of the spines and movement of the tube feet kept the steel exposed to the corrosive action of the sea water.

A sea-going distant relative of the earthworm, a polychaete worm entirely unrelated to _Teredo_ or _Bankia_, has been found burrowing by mechanical, and possibly chemical, action in limestone and oyster shells on the Pacific Coast and in Holland. Generally, the oyster shell is not perforated but where penetration threatens, the oyster lays down a layer of protective material, effectively blocking the borer's progress. Unfortunately, the oyster suffers some loss in market value as a result of the barrier building.

FASTER THAN YOU THINK

Preliminary tests have demonstrated that the rate of weight loss of most western species of wood by _Bankia_ is the same. Five months after 4- x 4- x 12-inch sections were completely submerged in the sea, red cedar had lost 17% by weight, Douglas fir 39%, yellow cedar 40% and spruce, balsam and hemlock, 43%. The weight losses for hemlock, fir and spruce are particularly significant because of the large quantities of these pulp species which are stored in sea water.

HEAT TREATMENT

One of the first recorded instances of using heat to kill embedded borers is found in the 1864 transactions of the Linnean Society London "On a new genus of Teredinidae". The author, E. P. Wright, described the method used by the Hindu fishermen to control attack by a fresh water 'Teredo' (Nausitora dunlopi) as "suspending the boat infested across two upright poles and to light a fire beneath it, which in a short time destroys all the mollusks, and by slightly charring the timber, hinders for some time a second attack". Today, more than one hundred years later, wooden planked scows which have figured prominently in B.C.'s marine commerce, are treated in a basically similar fashion in local shipyards. The only differences are that marine shipways replace the upright poles, blowtorches replace the wood fire, and copper paint, the charring.

A patent granted to Frank Batter in 1891 proposed a method for the periodical treatment of piles exposed to marine borers. "The pile is enclosed in a removable sectional casing and steam is applied to displace the water at the inside of the casing and to heat the surface of the pile. This treatment is followed by the application of a preservative solution such as tobacco juice (sic), corrosive sublimate, or other suitable material." No records are available to confirm the effectiveness of this technique.

Reporting in the Bulletin of the Sea Horse Institute, Mr. A. P. Richards (1953) described the results of experiments in an exposure laboratory at Wrightsville Beach, North Carolina in which elevations of sea water temperatures to 110°F for 30 minutes per week prevented new Bankia attack and halted the activities of mature Bankia present in wood. Limnoria lignorum appeared to be less sensitive to high temperatures than Bankia.

KILLING BORERS WITH FRESH WATER

Wherever possible, log rafts have been moored in rivers and river estuaries for the current logging shut-down in B.C. This practice will kill all borers if the salinity is low enough. Council studies have shown that Bankia setacea are killed within 16 days at salinities below 1.0%. Between 1.0 and 1.4% adult Bankia grow at a reduced rate, but do not reproduce. Above 1.4% bankian activities are normal. If the salt concentration in a booming area is not known, it is a relatively simple matter to collect and analyze water samples. The salinity of normal sea water is 3.0%.

STORAGE ON TIDAL FLATS

Log operators are reminded that storage of logs on tidal flats will not kill adult Bankia. Council studies have shown that new infestation rarely occurs in well drained tidal flats and is limited to the bottoms of logs which are continually immersed in tidal pools or depressions. However adult Bankia infesting logs continue to grind wood during periods when the logs they infest are immersed in sea water. Growth rates are thus only 30-40% of the normal, but nevertheless very damaging. Inventories that are intended for storage on tidal flats should be towed there immediately after dumping. Any appreciable delay, which permits bankian attack, defeats the purpose of tidal flat storage. A number of Companies have been burnt in this manner, this past season.