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by

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In May, 1961, the marine borer Limnoria tripunctata Menzies (also called the gribble or pin worm) was discovered for the first time in British Columbia at Crofton. Until this time its northerly limit of distribution on the Pacific coast of North America was considered to be San Francisco, California. Due to the fact that in California this species is known to attack creosote treated timber, its appearance in British Columbia was viewed with some alarm by the processors of creosoted timber and also by the Federal Department of Public Works which is responsible for the maintenance of an extensive system of public wharves. In order that this department might assess the implications of the occurrence of this species in British Columbia waters relative to creosoted timber, the Fisheries Research Board was requested to investigate the matter. The report on Limnoria is concerned first with the biology, distribution and place of origin, and second, with a test panel study of the three species of wood borers at three stations.

In the course of this study the Atlantic shipworm (Teredo navalis L.) was discovered in Pendrell Sound in northeast Georgia Strait in 1963 and this posed problems similar to those created by the finding of Limnoria tripunctata, but so far it has not been possible to begin the necessary study. This report deals with the occurrence and possible place of origin of T. navalis.

Biology of Limnoria

Gribbles or pinworms are crustaceans belonging to the large crustacean group Isopoda and to the genus Limnoria. The members of this genus are very small animals and in British Columbia waters they seldom exceed a length of 5 millimeters (Figs. 1 and 2). The Limnoria body is made up of three regions: head, thorax and abdomen. The head holds 6 appendages in which are included the mandibles, the main boring organs. The thorax contains 7 segments, each of which bears a pair of jointed legs. In the female brood, pouches for holding eggs and the developing young are formed on the second to fifth sections during the breeding season. The abdomen consists of 6 sections, 5 of which carry flat appendages called pleopods which are used for swimming and respiration. The last segment of the abdomen is the telson on which are located the main identification characteristics.

Reproduction

Usually only one male and one female occurs in each burrow with the latter at the blind end and apparently doing the active burrowing. The same pair may occupy the same burrow for several months. Males are usually the first to migrate and establish new burrows. Only animals of the same species occur together and there is no evidence of interspecific breeding.

After fertilization by copulation large yolky eggs are deposited in the brood pouch formed from plates arising from the inner base of thoracic legs 2 to 5. The eggs develop in this pouch for about 3 to 4 weeks and the young, about one millimetre in length, are released as fully formed animals. Limnoria lignorum produces a maximum of 35 ova with a mean of 22 and L. tripunctata a maximum of 22 ova with a mean of about 7. Several broods may be produced in one season and the minimum ovigerous temperature for L. lignorum is 5°C and for L. tripunctata about 15°C.

Boring

The body is held in position by the legs and claws with those of the first 3 legs directed backwards and those of the other four directed forward. The boring is carried out by the asymmetrical mandibles with which a rasp and file mechanism is suggested. The head can be buried within 24 hours but it may take from 4 to 6 days for the body to be completely enclosed. The depth of the burrow is likely limited by the need for adequate water circulation for respiration and seldom exceeds one inch.

Limnoria is capable, by means of cellulolytic enzymes, of attacking cellulose and is thus able to utilize wood as food, but many aspects of Limnoria nutrition are not well understood.

Limnoria grows most rapidly during the summer months and can grow a millimetre or more during the growth period. It is believed the life span is not greater than about two years.

Migration

Since there is no planktonic larval stages, dispersal must take place through transport by floating wood or by swimming. The migratory stimulus is still not definitely known.

Species identification

The main diagnostic feature separating L. lignorum and L. tripunctata is the shape and tuberculations on the pleotelson (tail segment) as shown in Figs. 1 and 2. The pleotelson of L. lignorum is relatively broad and has a V-shaped tuberculation, whereas L. tripunctata has a pleotelson narrowing markedly on the body side and in this area the edges are markedly toothed. The tuberculations in this species are in the form of three individual ones (Fig. 2). Further details are given in another section.

Limnoria tripunctata

The Limnoria problem was readily divisible into three parts:

(1) The actual distribution of L. tripunctata in British Columbia waters.

(2) To determine whether the species was indigenous or introduced.

(3) The potential destructive capacity, particularly with creosote-treated timber.

Parts one and two became the responsibility of the Fisheries Research Board, while part three became a combined effort between the Fisheries Research Board, Canada Forest Products Laboratory, and the Department of Public Works.

1. Distribution

Until recently the wood boring isopod, Limnoria lignorum (Rathke) was considered to be the sole species of the genus in the northern hemisphere, and Fraser (1923) and Black and Elsey (1948) recorded it from British Columbia. This situation was changed when Holthuis (1949) described Limnoria quadripunctata from Holland. Prior to this, only six other species were recognized. Two years later Menzies (1951) described Limnoria tripunctata with the type locality at Pacific Beach, California. In 1957 the same author revised the family Limnoriidae, re-describing some species and describing a number of new ones. Menzies' only British Columbia record of Limnoria was a single specimen of L. lignorum taken in Departure Bay in 1912. The northern distributional limit of L. tripunctata on the Pacific coast was given as the warmer parts of San Francisco Bay, California at 37°N, with a southward limit at Mazatlan, Mexico (23°N). In addition, it was recorded in the Hawaiian Islands, Japan and the Philippines (Menzies, 1959). On the Atlantic coast of the Americas it is said to occur between Rhode Island (44°N) and Amuay, Venezuela (12°N). In the eastern Atlantic it occurs as far north as the British Isles (51°N), in the Mediterranean and southeast Africa.

To determine the distributional pattern of Limnoria in the northeast Pacific samples of infested wood, both untreated and creosoted, were collected from many areas in British Columbia and from several locations in Washington, Oregon, California and Alaska. Limnoria were picked at random from the wood samples and the proportion of L. tripunctata and L. lignorum was determined by microscope examination of approximately 100 specimens. In the present study over 13,000 specimens in 160 samples have been examined and difficulty in separating the two species has been experienced in less than 1% of the number identified. The conspicuous tubercles on the lateral crests of the pleotelson of L. tripunctata, together with the way in which the lateral crests curve in toward the centre line anteriorly, are very constant and easily observed characteristics. The occurrence of the three punctuations on the pleotelson from which the trivial name is derived is more variable. In the samples examined L. tripunctata was rarely infested with the protozoan Folliculina, whereas L. lignorum was rarely without it. The abdominal appendages of the latter species were very often infested with nematodes, while they were rarely found on the other species.

Origin

Whether or not L. tripunctata is indigenous could have been simply and directly determined by examination of collections from earlier times when all Limnoria in these latitudes were automatically assumed to be L. lignorum. Unfortunately no such collections are available, as far as is known, neither in British Columbia nor in the major museums. It was then necessary to resort to indirect means, based largely on whatever distributional pattern might develop, to determine if it is native to British Columbia.

Results

Tabulated data from the survey are given in Table I and the distributional pattern derived from it is shown in Fig. 3.

This survey has shown that L. tripunctata is distributed along the Pacific coast north of the previously published record at San Francisco Bay, California (37°N), to the upper end of Georgia Strait (50°N). It occurs in Yaquina Bay, Oregon, Willapa and Grays Harbors, Washington, but was not found in Humboldt Bay, California or Coos Bay, Oregon, the only two other bays between San Francisco and Cape Flattery opening into the Pacific. It is widely distributed and well established in lower Puget Sound and in Hood Canal. On the west coast of Vancouver Island it occurs in Sooke Harbour, Barkley Sound and Clayoquot Sound, as well as in Sidney Inlet which is as far as the present survey has extended.

It occurs widely, though not continuously, throughout most of Georgia Strait but has not been found north of this area.

Discussion

The extensive use of soft woods for marine structures, in addition to logging operations on the northern Pacific coast of North America, makes the necessary habitat for Limnoria widely available. Hydrographic factors, together with transport opportunities, may then be considered the possible influences which control the distribution of these animals.

Salinity. Menzies (1957) states that areas having uniformly low salinities (below 10‰) and those having wide ranges of salinity (0.00‰ to 35‰) might be considered as unfavourable for the establishment and development of Limnoria. Eltringham (1958) found the level of limiting salinity (20% survival level) about 11.5‰ after 11 days of exposure for the several species found in Great Britain.

In British Columbia waters a wide range of salinity occurs, from nearly fresh water at the head of inlets, where large rivers enter, to ocean salinities in bays adjoining the open coast. There may also be a wide seasonal range depending on river runoff. Except for the small local areas influenced by rivers, salinity does not appear to be a major influence on Limnoria distribution in these waters.

Temperature. Jones (1960) has shown that in Great Britain the instantaneous minimum lethal temperature for Limnoria lignorum is 3-4°C; for L. quadripunctata, 4-5°C; and for L. tripunctata, 6-7°C. According to Menzies (1957) the reproductive capacity of L. lignorum is impaired at or near 0°C and of L. tripunctata at about 6°C. In Southampton water on the south coast of England where L. lignorum, L. quadripunctata and L. tripunctata all occur together (Eltringham, 1958), the mean monthly temperatures between November and March were from 4-9°C and from April to October between 10°C and 20°C.

In general, Menzies (1957) designates L. lignorum as a species with a boreal distribution, L. quadripunctata as temperate, and L. tripunctata as temperate-tropical. The pertinent data from Menzies' 1957 paper are tabulated in Table II. In Fig. 4 the distribution of the three species is shown graphically according to Menzies and Turner (1956). For purposes of comparison, temperature data from selected areas in British Columbia are shown in Table III (P.O.G., 1963), and for Departure Bay and Crofton in Figs. 5 and 6.

The mean minimum water temperatures in British Columbia in the areas described in Table III are at or above the instantaneous lethal temperatures for all three species as cited by Jones (1960). Minimum ovigerous temperatures are attained for all three species and sufficient time for embryonic development (up to six weeks - Sømme, 1941; Becker, 1959; Jones, 1960) at the necessary temperature levels. That this is so is borne out by the widespread occurrence of L. tripunctata which has the highest temperature requirements.

Limnoria tripunctata in British Columbia. The wide, though not continuous, distribution of L. tripunctata in British Columbia, often occurring in single species populations, indicates the species has been in these waters for a considerable time. The markedly discontinuous distribution would seem to indicate it may not be indigenous. Normally, an indigenous species, presuming the availability of suitable habitat as is the case with Limnoria, tends to have a fairly continuous distribution. For example, in this survey, of the first 150 samples collected, 121 contained L. lignorum and 86 of them contained L. tripunctata, although there has been bias toward sampling areas where that species would likely occur. The discontinuous distribution over short distances in such places as Sooke Harbour and Ucluelet, where L. tripunctata occurs at the head of the harbour but not at the entrance, may also be of significance in this regard.

Sampling northward beyond the limits of Georgia Strait as far as Prince Rupert (54°N) and the Queen Charlotte Islands as well as southeastern Alaska, has shown that only L. lignorum occurs in this region. At the northern end of Georgia Strait are tidal passages (Seymour, Okisollo, Yucultaw) where currents attain speeds up to 13 knots, creating areas of turbulence with resulting low temperatures (Table III, Cape Mudge) which have probably assisted in acting as a barrier to dispersal northward of L. tripunctata. This barrier has also prevented movement of other introduced species such as the lamellibranchs Crassostrea gigas and Venerupis japonica, the parasitic copepod Mytilicola orientalis and other species. The extensive movement of logs in British Columbia, which would be a possible means of transport, is always into and seldom out of Georgia Strait, unless it is to Puget Sound. An area where the possible transport of Limnoria by log booms may have occurred is at Port Moody at the head of Vancouver Harbour.

At the southern end of Georgia Strait the turbulent currents of Rosario Strait and Boundary Pass create a similar low-temperature barrier (Table III, East Point) and L. tripunctata does not occur among the lower and outer Gulf Islands. The species does not occur in the area between the lower end of Saanich Inlet around the southern end of Vancouver Island, and it by-passes Victoria and Esquimalt Harbours, where doubtless suitable temperatures occur, to Sooke Harbour, a distance of about 50 miles. The next blank area stretches from Sooke to Barkley Sound where it occurs widely. In Clayoquot Sound it is found infrequently and only intermittently northward to Sidney Inlet which is as far as the survey has been carried along the west coast of Vancouver Island.

2. Origin of Limnoria tripunctata

Very early in the investigation, a discussion with Dr. D. L. Ray of the University of Washington raised the question of an association between the occurrence of L. tripunctata and the growing areas of the Japanese oyster (C. gigas) which normally occur in protected bays or estuaries where opportunities for relatively high water temperatures occur. As more and more samples were analyzed, the more it appeared that such a correlation might exist. In British Columbia, of 12 areas where Japanese oyster seed has been planted and sampled for the borer, 11 of them held L. tripunctata. In the State of Washington, 8 of 9 planted areas were found with the species. This high correlation not only indicated the two species required similar hydrographic conditions but also suggested a possible common origin.

It should be pointed out that the importation of oyster seed, from both the Atlantic coast of North America and Japan, has been responsible for the introduction of more than a dozen well-established exotic species in British Columbia as recorded by Carl and Guiget (1958).

Most of the Japanese oyster seed exported to North America is grown in Miyagi Prefecture near Sendai, Japan. The seed is collected on strings of shell during the summer months. In autumn it is moved to shallow water to condition it to exposure during the sea voyage across the Pacific. Early in the next year, the seed is packed into wooden cases, each holding approximately two bushels of seed. After packing, the cases are returned to the water for storage until enough are accumulated for a cargo of at least 6,000 cases, which may require several weeks. It is during this period that the wooden seed cases may be attacked by Limnoria. The seed is shipped, usually in April or May, across the Pacific as deck cargo, covered with rice matting which is kept damp during the voyage of about 10 to 12 days. When the seed is received the cases are usually stored on the oyster beds until an opportune time for opening them and planting the seed. It seems there would be ample opportunity for both survival and dispersal of Limnoria.

Japan, then, could well be the origin of the population of L. tripunctata that occur in the oystering areas north of San Francisco Bay. It is of interest to note that a sample of wood from Sendai, the oyster seed-producing area in Japan, contained only Limnoria tripunctata.

The obvious alternative would be a northward route along the Pacific coast from San Francisco Bay. However, the dispersal mechanism is not so obvious and about the only possibility is wooden vessels. In this case a somewhat different distribution than the present one would be expected, with patterns emanating from major ports frequented by shipping.

Further, by the Pacific coast route it would be expected that the temperate L. quadripunctata rather than the temperate-tropical L. tripunctata would be the species to invade the territory of a boreal species. Also, it would be expected to occur in Humboldt Bay, California and Coos Bay, Oregon. By the same token, however, it would be expected to occur in these bays according to the theory of Japanese origin. It may be the sampling in these bays has been inadequate.

Conclusions

(1) In British Columbia L. tripunctata is well established with populations of considerable magnitude throughout Georgia Strait and in several sounds on the west coast of Vancouver Island, thus extending the recorded range northward 13° of latitude.

(2) In Washington the species has been found to occur in Willapa Harbor, Grays Harbor, Lower Puget Sound and Hood Canal. In Oregon it occurs in Yaquina Bay.

(3) There is a correlation between the areas of occurrence and areas of relatively high water temperature which in turn are frequently areas where the Japanese oyster (C. gigas) is grown.

(4) It is suggested that L. tripunctata is not an indigenous species and has been introduced.

(5) It is theorized that the origin of the species is Japan rather than California, and the wooden cases used to carry the seed from Japan to the United States and Canada were the medium of transport.

(6) The tidal passages at the northern and southern end of Georgia Strait have acted as temperature barriers to the farther dispersal of L. tripunctata, as it has for other introduced species.

3. Destructive capacity

In the course of the field sampling program, 37 samples of *Limnoria*-infested creosote-treated wood were collected. In every case there had been a breach in the creosote protection by mechanical failure such as abrasion or fracture, and in no case could the original damage be ascribed to *Limnoria* attack. In 20 of the 37 creosoted samples *Limnoria lignorum* occurred alone, in one sample *L. tripunctata* occurred alone, and in 16 samples both species were found with a ratio of 838 *L. lignorum* to 712 *L. tripunctata*.

Because fracture or abrasion permitted initial attack on the untreated core area, the eroding movement was in part toward the outer creosote zone and both species often occurred in what appeared to be wood with some creosote content.

This may be an indication that *L. tripunctata* may be no more destructive to creosote-treated wood than *L. lignorum* under British Columbia conditions. There is some evidence, however, to indicate untreated wood is being severely attacked by *L. tripunctata* tidal levels above which *L. lignorum* usually occurs. There is also a possibility that in areas where *L. tripunctata* occurs, wooden vessels may suffer more severe attack at the water line by this species than by *L. lignorum* if the anti-fouling protection is lost or weakened.

The destructive capacity was also investigated by means of test panels, a series of which were impregnated with various concentrations of creosote and other chemicals.

Fir sapwood panels, 6" x 4" x 3/8" with a 30-square-inch exposure surface, were placed on racks at four depths, surface (floating), half tide, zero tide, and mud line (20-30 feet below zero), at the government wharves at Cowichan Bay, Crofton, and Commercial Inlet, Nanaimo.

The Forest Products Laboratory assumed responsibility for the test panels, the Department of Public Works for installation and collection of panels and the Fisheries Research Board for analysis of untreated control panels and for species determination on treated panels.

The control panels were arranged in two series. In one series the panels at each location and depth were changed at monthly intervals. In the other series a group of 12 panels were exposed simultaneously and then single panels were removed at monthly intervals to provide an increasing period of exposure up to 12 months.

The cumulative study, started in January, 1963, was unproductive due to a heavy barnacle settlement in late March and to rapid disintegration of panels due to borer activity. The data from the brief period when satisfactory counts could be made confirmed results of the monthly series of panels during similar exposure periods.

Results

The monthly control panel study was conducted during the period from July, 1962, to December, 1964. The basic data for the three wood borer species encountered in the study are given in Tables IV, V, and VI.

Cowichan Bay. No Limnoria tripunctata were found on panels from this area, confirming the results from field sampling. L. lignorum were found only in very small numbers on panels at the mud line although considerable populations occur on boom sticks and "dead heads" in the intertidal area of the bay. It is possible fresh water from the Koksilah and Cowichan Rivers inhibits short-term attack here.

The incidence of Bankia setacea on the panels is also not very high when compared with Crofton or Nanaimo and, as with L. lignorum, the greatest attack was at the mud line.

Crofton. This area showed the heaviest attack of all three areas by L. tripunctata, and as shown in Table VII, virtually all at the surface. This is, of course, where highest water temperatures occur and is the location of attack to be expected from what is described as a temperate-tropical species. The major attack was concentrated in May and June. L. lignorum attacked in approximately the same total numbers as L. tripunctata but the attack was spread throughout the year and apparently some migration is possible in any month of the year. The main concentration occurred at the mud line.

The main attack by B. setacea also occurred at the mud line and the highest intensity of the three stations was located here.

Nanaimo. L. tripunctata attack was very light at this station and is thus not in accord with the large populations of the species in the general area. It may be the particular test location was not suitable. L. lignorum attack was not heavy either, being only about 10% of that at Crofton. Bankia attack was fairly severe although not as great as at Crofton. The attack was nearly equal at the mud line and at the zero tide level with but little at half tide and moderate at the surface.

In summary the results of this study indicate:

(1) L. tripunctata attack occurs mainly at or near the surface with greatest intensity during May and June (Fig. 7). Attack, in the cases of gribbles, however, is essentially a migration and must not be confused with breeding which in British Columbia occurs in July, August and September. The fact that the species does not occur at Cowichan Bay together with a low level short-term attack at the Nanaimo station may indicate a highly selective habitat preference.

(2) L. lignorum attack occurred mainly at the mud line. Both breeding and attack may occur during any month of the year in many localities (Fig. 8). There seemed to be no specific pattern of attack in respect to season of the year in this study.

(3) B. setacea also showed the highest concentration of attack at the mud line at all three stations with pronounced peaks of intensity between August and September but with some attack possible at any time of the year (Fig. 9).

(4) Crofton showed the highest level of attack from all three species.

(5) Preliminary indications are that L. tripunctata may be no more destructive to properly creosote-treated timber than the native L. lignorum under British Columbia conditions.

Teredo navalis L.

In British Columbia it was presumed the sole molluscan wood borer was the shipworm, Bankia setacea, whose general biology was described by Quayle (1956). Further it was long thought the northern limit of the distribution of the Atlantic shipworm, Teredo navalis L., on the Pacific coast of North America was San Francisco Bay (Menzies and Turner, 1956). In 1957 the author found it in Willapa Harbor, Washington (46°N), a northward extension of 9° of latitude. Previously, however, the William F. Clapp Laboratories Inc. (Brown, 1951, 1952, 1954) had reported Teredo, unidentified as to species, on test blocks from Vancouver Harbour and nearby False Creek. The waters of Vancouver Harbour proper are subject to considerable mixing due to tidal passages which attain current speeds up to 6 knots, at each end, 5 miles apart. This mixing holds water temperature levels down to about 14°C at the surface during July, making the area not entirely suitable for the reproduction of T. navalis. The British Columbia Research Council has carried out studies on marine borers with test blocks in Vancouver Harbour from 1950 to the present time and no lamellibranch borer other than Bankia setacea has been recorded. It would be of considerable interest to know the specific identity of the specimens reported by the Clapp Laboratories.

In August, 1963, during the Limnoria survey, a well-established population of T. navalis was found in Pendrell Sound on East Redonda Island (50°N) in the northeast corner of Georgia Strait. A unique set of hydrographic features in this sound (Quayle, 1957) creates conditions for the maintenance of summer surface water temperatures up to 25°C with a level of 20°C being maintained for some time (Table III) and with surface salinities at about 20‰. These conditions make Pendrell Sound the most northerly and probably the most consistent breeding area of the Japanese oyster, C. gigas, on the Pacific coast of North America. These conditions also appear to be near optimum for the breeding activity of T. navalis according to Miller (1926), Hill and Kofoid (1927) and McGonigle (1927).

The occurrence of T. navalis in this area has created problems similar to those posed by L. tripunctata and the actual distribution of the species as well as its destructive potential must be assessed.

It is assumed with reasonable certainty that T. navalis is not indigenous to British Columbia although this may be precipitous in view of the limited information.

It is unlikely T. navalis has as yet a wide distribution, otherwise the test block studies by the British Columbia Research Council at a number of points in Georgia Strait and along the coast would have shown it.

Pendrell Sound is relatively isolated and uninhabited except for occasional small logging camps. Nevertheless there is movement of water-borne logs both into and out of the sound in connection with both logging and oyster seed operations. In recent years it has been visited extensively during July and August by pleasure cruisers, mainly from the State of Washington. Since T. navalis occurs in Willapa Harbor and there is shipping exchange between that bay and Puget Sound, it is likely that a search in lower Puget Sound would locate it there. Likely the species has been carried by wooden vessels from San Francisco Bay to Willapa Harbor, and probably into Puget Sound and from there into Pendrell Sound. More detail on its actual distribution both in the United States and British Columbia might indicate other possibilities. Furthermore the correlation between the occurrence of Japanese oysters and L. tripunctata must not be overlooked.

It is doubtful that T. navalis will become as widely distributed as L. tripunctata, for presumably its breeding temperature requirements are more exacting toward higher levels.

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Table I. Occurrence of two species of Limnoria in treated and untreated wood from British Columbia waters.

No.	Station	Date	Treatment	L. lignorum	L. tripunctata
1	Crofton (oyster bed)	Apr. 25/62	U	50	5
2	Crofton	" 25/62	U	44	8
3	Crofton	" 25/62	C	24	0
4	Crofton	" 25/62	U	24	0
5	Ucluelet	May 4/62	C	50	0
6	Masset	June 3/62	C	50	0
7	Prince Rupert	" 5/62	C	50	0
8	Prince Rupert	" 5/62	U	60	0
9	Nanaimo	" 23/62	C	21	79
10	Nanaimo	" 23/62	U	59	60
11	Nanaimo (Exit Ch.)	" 23/62	C	7	112
12	Victoria	" 19/62	C	103	0
13	Lund	" 26/62	U	0	100
14	Alert Bay	" 1/62	U	100	Nil
15	Comox	" 27/62	U	104	16
16	Henry Bay	" 28/62	U	40	2
17	Crofton (Gov't.)	July 3/62	C	16	104
18	Fulford Harbour	" 4/62	C	100	0
19	Maple Bay	" 3/62	U	113	8
20	Maple Bay	" 4/62	C	67	33
21	Cowichan Bay	" 4/62	C	100	0
22	Fulford Harbour	" 4/62	U	100	0
23	Montagu Harbour	" 5/62	U	100	0
24	Mayne Island	" 5/62	U	100	0
25	Ganges	" 5/62	U	100	0
26	North Galiano	" 5/62	U	100	0
27	Montagu Harbour	" 5/62	C	28	0
28	Fernwood	" 5/62	C	100	0
29	North Galiano	" 5/62	C	97	0
30	Ganges	" 5/62	C	99	1
31	Mayne Island	" 5/62	C	99	3
32	Ladysmith	" 17/62	C	2	98
33	Departure Bay	" 18/62	U	97	0
34	French Creek	" 18/62	C	114	9
35	Nanoose	" 18/62	U	144	7
36	Sidney	" 17/62	C	100	0
37	Nanoose	" 18/62	C	23	77
38	Northwest Bay	" 18/62	C	112	4
39	Union Bay	" 18/62	U	119	5
40	Fanny Bay	" 18/62	C	0	125
41	Nanoose Bay	" 18/62	U	100	0
42	Hope Bay	" 17/62	C	97	0
43	Sidney	" 17/62	U	119	0
44	Lyall Harbour	" 17/62	C	100	0
45	Ladysmith	" 17/62	C	43	3

Table I (cont'd.)

No.	Station	Date	Treatment	L. lignorum	L. tripunctata
46	Pendrell Sound	July 23-62	U	0	100
47	Ladysmith - 164	" 30/62	U	59	41
48	Ladysmith - 164	" 30/62	U	43	57
49	Shannon Bay (QCI)	June 4/62	U	8	0
50	Vancouver (Discovery)	July 26/62	C	100	0
51	Vancouver (Transfer)	" 26/62	C	100	0
52	Vancouver (Lynn Creek Navy)	" 26/62	C	100	0
53	Port Moody	" 27/62	C	74	26
54	Deep Cove	" 27/62	C	74	0
55	Pender Harbour - Popes	" 31/62	C	49	17
56	Halfmoon Bay	" 31/62	C	100	0
57	Pender Harbour - Popes	" 31/62	U	42	58
58	Pender Harbour - Irvines	" 31/62	U	34	66
59	Pender Harbour - Hospital	" 31/62	C	5	53
60	Tofino	" 31/62	C	100	0
61	Tofino	" 31/62	U	100	0
62	Vancouver - Pier A	" 26/62	C	100	0
63	Teakerne Arm	Sep. 11/62	U	95	6
64	Whitney Lagoon (I)	" 18/62	U	3	97
65	Whitney Lagoon (O)	" 18/62	U	8	100
66	Oyster Bay, Washington	" 18/62	U	1	99
67	Nahcotta - beam	" 19/62	U	0	100
68	Nahcotta - dock	" 19/62	U	20	84
69	Willapa - Wildlife River	" 19/62	U	0	100
70	Willapa - Bay Centre	" 19/62	U	0	100
71	Westport, Washington	" 19/62	U	100	0
72	Grays Harbour - Markham	" 20/62	U	0	45
73	Shelton, Washington	" 20/62	U	0	100
74	Oakland Bay	" 20/62	U	0	100
75	Allyn, Washington	" 20/62	U	0	100
76	Poulsbo, Washington	" 20/62	U	99	1
77	Port Townsend, Washington	" 20/62	U	100	0
78	Brentwood	" 21/62	U	1	99
79	Victoria - Fish. Patrol wharf	" 21/62	U	100	0
80	Sooke - Gov't. wharf	" 21/62	U	100	0
81	Sooke - Shell Marina	" 21/62	U	98	2
82	Sooke - B.C.F.P. boom	" 21/62	U	1	112
83	Rayonnier Lab. - Hoodsport	" 24/62	?	20	24
84	Tom Nelson oyster bed stn.	" 18/62	?	64	0
85	Chapmans Cove, Oakland Bay	" 19/62	?	43	7
86	Chemainus	Apr. 25/62	U	85	3
87	Crofton	July 19/62	U	41	40
88	Budd Inlet, Washington	Mar. 1951	U	100	Nil
89	Alert Bay	Jan. 11/63	U	100	Nil

Table I (cont'd.)

No.	Station	Date	Treatment	*L. lignorum*	*L. tripunctata*
90	Blunden Harbour	Jan. 15/63	U	100	Nil
91	Doctor Bay	" 17/63	U	1	100
92	Redonda Bay	" 17/63	U	100	Nil
93	Shoal Bay - Thurlow Island	" 16/63	U	100	Nil
94	Von Donop Creek	" 17/63	U	100	Nil
95	Powell River	" 18/63	U	100	Nil
96	Pendrell - Logging Camp A, Station 9	" 18/63	U	2	76
97	Pendrell - A	" 17/63	U	Nil	100
98	Pendrell - C	" 17/63	U	Nil	100
99	Pendrell - B	" 17/63	U	Nil	86
100	Pendrell - E	" 17/63	U	Nil	60
101	Pendrell - Logging Camp B Station 9	" 17/63	U	Nil	100
102	Little Skookum, Washington	Nov. 26/62	U	65	0
103	Lasqueti Bay	Jan. 18/63	C	100	11
104	Bliss Landing	" 18/63	U	100	Nil
105	Sarita River	Feb. 12/63	U	Nil	100
106	Jordan River (Butler Bros.)	Apr. 2/63	U	89	Nil
107	Cadboro Bay	" 3/63	U	100	Nil
108	Oak Bay - Victoria	" 3/63	U	100	Nil
109	Lasqueti Bay	Jan. 18/63	U	7	69
110	Jordan River	Apr. 2/63	U	94	Nil
111	Denman Wharf	May 27/63	U	Nil	100
112	Ladysmith - New Gov't. Wharf	" 14/63	U	0	100
113	Ladysmith - Old Gov't. Wharf	" 14/63	C	7	82
114	Humboldt Bay - Eureka	Jul. 11/63	U	(100 *L. quadripunctata*)	
115	Humboldt Bay - Buhne Point	" 12/63	U	97 (2 *L. quadripunctata*)	1
116	White Rock	" 16/63	U	99	1
117	Ucluelet - Centre	" 21/63	U	70	30
118	Ucluelet - Head	" 21/63	U	29	71
119	Toquart Mine Wharf	" 22/63	U	0	30
120	Toquart Bay	" 22/63	U	2	98
121	Useless Inlet	" 23/63	U	0	100
122	Ecoole	" 23/63	U	1	99
123	Fatty Basin (Useless)	" 23/63	U	0	100
124	Rainy Bay	" 23/63	U	0	100
125	Bamfield (Cable Station)	" 24/63	U	86	26
126	Bamfield (Head of inlet)	" 24/63	U	2	98
127	Gibralter Island	" 24/63	U	18	82
128	Jacques Island	" 24/63	U	1	99
129	Refuge Cove (Redonda)	Aug. 6/63	U	0	100
130	Cortez Bay	" 6/63	U	100	0
131	Melanie Cove	" 6/63	U	50	50
132	Quathiaski Cove	" 8/63	U	100	0
133	Campbell River (Dock)	" 8/63	U	17	0

Table I (cont'd.)

No.	Station	Date	Treatment	L. lignorum	L. tripunctata
134	Malcolm Island - 33 fath.	Jan. 12/63	U	85	0
135	Coos Bay - Oregon	Mar. 12/63	U	100	0
136	Yaquina Bay No. 1 - Oregon	" 7/63	U	100	0
137	Yaquina Bay No. 2 - Oregon	" 7/63	U	96	0
138	Yaquina Bay No. 3 - Oregon	" 14/63	U	0	75
139	Matilda Creek	" 28/64	U	0	100
140	Dawley Narrows - Clayoquot	" 27/64	U	1	100
141	Air Force Wharf - Grice Bay	" 27/64	U	99	1
142	Matlset Narrows - Clayoquot	" 27/64	U	100	0
143	Hecate Bay - Clayoquot	" 27/64	U	16	0
144	Whiskey Jennie - Shelter Inlet	" 27/64	U	100	0
145	Sidney Inlet	" 27/64	U	0	100
146	Hot Springs Cove	" 28/64	U	117	1
147	Gibson Cove - Herbert Arm	" 28/64	U	26	74
148	Head Herbert Arm	" 28/64	U	16	40
149	Prescott Passage	Apr. 15/64	U	100	0
150	Tee Island - Naden Harbour	" 17/64	U	100	0
151	Datzkoo Bay-Dill Is., Alaska	" 18/64	U	100	0
152	Matsushima Bay - Japan	" 25/64	U	0	100
153	Departure Bay - Old Coal Wharf, 10 ft. level	" 28/64	U	0	50
154	Departure Bay - 4 ft. level	" 28/64	U	50	0
155	Crofton - tide flats	Mar. 16/64	U	40	60
156	Crofton - tide flats	" 16/64	U	43	57
157	Cherry Point - 4 ft. level	May 12/64	U	100	0
158	Cowichan Bay - 8 ft. level	" 12/64	U	100	0
159	Humboldt Bay - Mad River	Mar. 10/63	U	(100 L. quadripunctata)	

Table II. Pacific coast ranges of Limnoria with associated temperature. Data abstracted from Menzies (1957).

	Limit	Area	Mean seasonal water temperature °C			
			Minimum	Maximum	Mean	Minimum ovigerous temperature
L. lignorum (boreal)	northern	Sitka, Alaska	4.2	13.6	8.3	above 7.5
	southern	Point Arena, California	10.0	14.0	11.4	
L. quadripunctata (temperate)	northern	Humboldt, California	11.0	14.0	11.4	above 10.0
	southern	La Jolla, California	13.2	19.4	16.2	
L. tripunctata (temperate-tropical)	northern	San Francisco, California	10.6	15.8	13.0	above 15.0
	southern	Mazatlan, Mexico	24.3	27.8	26.1	

Table III. Mean monthly sea-water temperature (°C) in selected areas in British Columbia. Data from P.O.G. (1963).

Area	Minimum	Maximum	Temperature held for
Cape Mudge	6.7	14.0	above 15°C for 5- to 10-day periods
Chrome Island	6.7	17.6	above 15°C for 2 months
Departure Bay	6.5	17.8	above 15°C for 3 to 4 months
Pendrell Sound	7.2	22.1	above 18°C for 2 months
East Point	7.2	11.6	above 13°C for 2 weeks
Amphitrite	7.5	13.1	short periods above 13°C

. Monthly attack on fir panels, 30 square inches in area, t three stations, July, 1962 to December, 1964.

y	Crofton				Nanaimo			
Mud-line	Surface	Half	Zero	Mud-line	Surface	Half	Zero	Mud-line
1	0	0	0	4	×	0	1	5
1	0	0	0	0	1	0	1	8
0	0	0	0	5	0	0	0	1
0	0	0	0	2	0	0	0	0
0	0	0	0	3	0	0	0	3
2	0	0	0	0	0	0	0	2
5	0	0	0	2	0	0	1	0
9	0	0	3	7	0	0	3	1
7	0	0	0	1	0	0	0	1
12	0	0	0	47	0	0	1	1
1	0	0	0	21	1	0	0	0
5	20	0	0	59	0	0	20	6
0	5	0	0	17	0	0	1	8
0	17	0	0	3	×	0	3	2
8	7	0	0	6	0	0	0	3
1	1	0	79	12	0	0	0	2
11	1	0	2	14	0	0	7	1
2	3	0	0	2	0	0	4	0
0	2	0	0	7	0	0	0	1
3	10	0	0	76	0	0	0	0
6	6	0	1	368	0	0	4	0
5	0	0	0	21	0	0	0	3
0	1	0	0	2	×	0	0	0
0	3	0	0	23	×	0	0	0
0	3	0	0	11	×	0	0	0
1	4	0	0	2	0	0	0	0
0	0	0	1	4	×	0	×	1
4	6	0	3	20	×	0	0	8

Table V. Limnoria tripunctata. Monthly attack on fir panels, 30 square inches in area, at four depths at three stations, July, 1962 to December, 1964.

	Cowichan Bay				Crofton				Nanaimo			
	Surface	Half	Zero	Mud-line	Surface	Half	Zero	Mud-line	Surface	Half	Zero	Mud-line
1962												
July	0	0	0	0	1	0	0	0	×	0	5	3
August	0	0	0	0	0	0	0	0	0	0	0	2
September	0	0	0	0	0	0	0	0	0	0	0	0
October	0	0	0	0	0	0	0	0	0	0	0	0
November	0	0	0	0	0	0	0	0	0	0	0	0
December	0	0	0	0	0	0	0	0	0	0	0	0
1963												
February	0	0	0	0	0	0	0	0	0	0	0	0
March	0	0	0	0	0	0	0	0	0	0	0	0
April	0	0	0	0	2	0	1	0	0	0	0	0
May	0	0	0	0	167	0	0	3	2	0	0	0
June	0	0	0	0	0	0	0	2	0	0	0	0
July	0	0	0	0	1	0	0	1	0	0	0	0
August	0	0	0	0	2	0	0	0	0	0	0	0
September	0	0	0	0	12	0	0	0	×	0	0	0
October	0	0	0	0	2	0	0	0	0	0	0	1
November	0	0	0	0	2	0	0	0	0	0	0	0
December	0	0	0	0	0	0	0	1	0	0	0	0
1964												
January	0	0	0	0	0	0	0	0	0	0	0	0
February	0	0	0	0	0	0	0	0	0	0	0	0
March 2 to April 27	0	0	0	0	0	0	0	0	0	0	0	0
May	0	0	0	0	96	0	1	0	0	0	3	0
June	0	0	0	0	537	0	13	1	0	0	0	1
July	0	0	0	0	1	0	1	1	×	0	0	0
August	0	0	0	0	0	0	0	0	×	0	0	0
September	0	0	0	0	4	0	0	0	×	0	0	0
October	0	0	0	0	1	0	0	1	0	0	0	0
November	0	0	0	0	0	0	0	0	×	0	×	0
December	0	0	0	0	0	0	0	0	×	0	×	0

Table VI. Bankia setacea. Monthly attack on fir panels, 30 square inches in area, at four depths at three stations, July, 1962 to December, 1964.

	Cowichan Bay				Crofton				Nanaimo			
	Surface	Half	Zero	Mud-line	Surface	Half	Zero	Mud-line	Surface	Half	Zero	Mud-line
1962												
July	0	0	0	11	0	0	0	103	×	0	0	0
August	2	0	4	83	0	0	36	650	1	0	308	1097
September	0	0	17	35	0	0	9	205	0	0	147	294
October	0	0	13	55	0	0	102	1490	0	0	386	673
November	0	0	4	52	2	0	34	333	0	0	103	280
December	4	0	0	23	1	0	16	49	0	0	139	58
1963												
February	0	0	0	0	0	0	0	1	0	0	9	12
March	0	0	0	2	0	0	0	20	0	0	12	3
April	0	0	1	2	0	0	0	4	0	0	50	75
May	0	0	0	1	0	0	0	84	0	0	4	1
June	0	0	0	0	0	0	0	11	0	0	0	0
July	0	0	1	25	0	0	1	57	6	0	45	14
August	3	0	18	0	0	0	11	893	24	0	714	196
September	0	2	0	7	160	0	2	789	×	0	425	214
October	0	17	27	114	481	0	92	1126	317	7	443	564
November	0	0	5	212	111	1	0	807	46	0	165	526
December	0	0	6	102	0	0	7	1486	92	0	133	191
1964												
January	0	0	0	1	1	0	4	700	12	0	18	4
February	0	0	0	0	0	0	0	0	0	0	1	0
March												
April	0	0	0	0	0	0	0	85	0	0	0	0
May	0	0	0	1	1	0	0	48	0	0	0	0
June	0	0	0	23	0	0	4	106	×	0	0	2
July	0	0	0	0	0	0	1	0	0	0	0	0
August	0	0	47	58	0	0	51	662	0	0	200	708
September	3	0	34	185	49	0	127	46	×	0	143	77
October	16	0	85	502	100	0	208	471	15	0	147	92
November	22	22	64	187	15	0	37	138	×	0	×	11
December	0	0	48	106	12	0	17	159	×	0	33	33

Table VII. Total attack by marine borers during a 30-month period (July, 1962 to December, 1964) on fir panels exposed at monthly intervals at 4 depths and 3 stations at Cowichan Bay, Crofton and Nanaimo.

Depth	Cowichan	Crofton	Nanaimo	Total
		Bankia setacea		
Surface	50	933	512	1,495
Half	41	1	7	49
Zero	374	759	3,625	4,758
Mud line	1,735	10,523	4,125	16,383
Total	2,100	12,216	8,269	22,685
		Limnoria lignorum		
Surface	0	89	2	91
Half	0	0	0	0
Zero	1	89	46	136
Mud line	84	739	57	880
Total	85	917	105	1,926
		Limnoria tripunctata		
Surface	0	829	2	831
Half	0	0	0	0
Zero	0	16	8	24
Mud line	0	10	7	17
Total	0	855	17	872

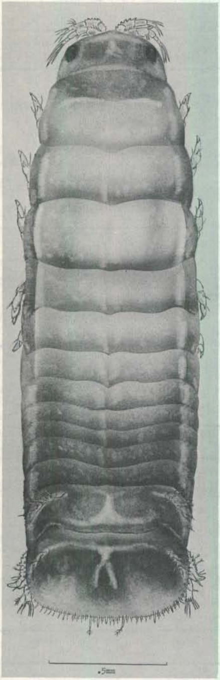

Fig. 1. Limnoria lignorum (Rathke).

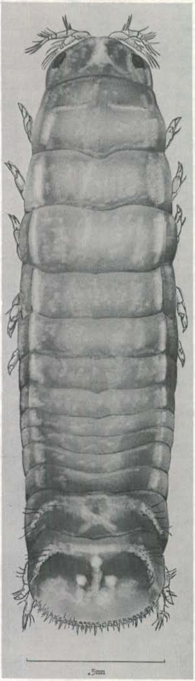

Fig. 2. Limnoria tripunctata Menzies.

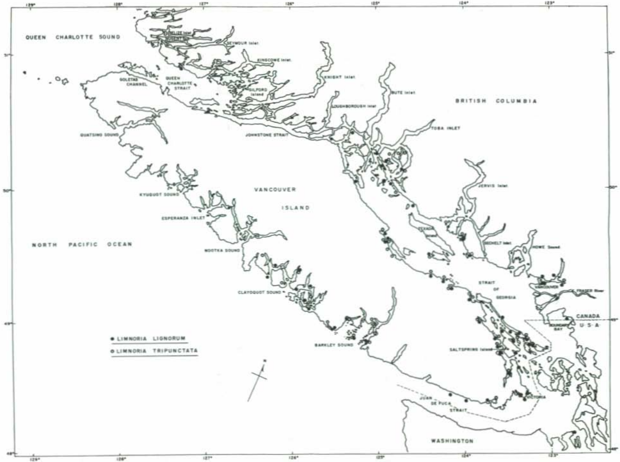

Fig. 3. Map of Vancouver Island showing the distribution of two species of Limnoria.

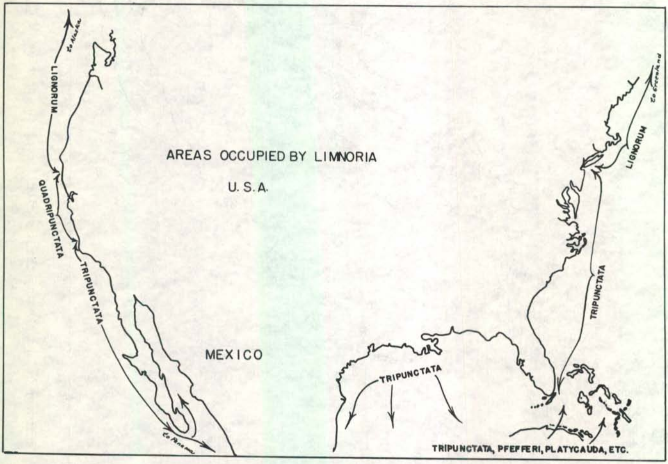

Fig. 4. Distribution of American gribbles. (After Menzies and Turner, 1957.)

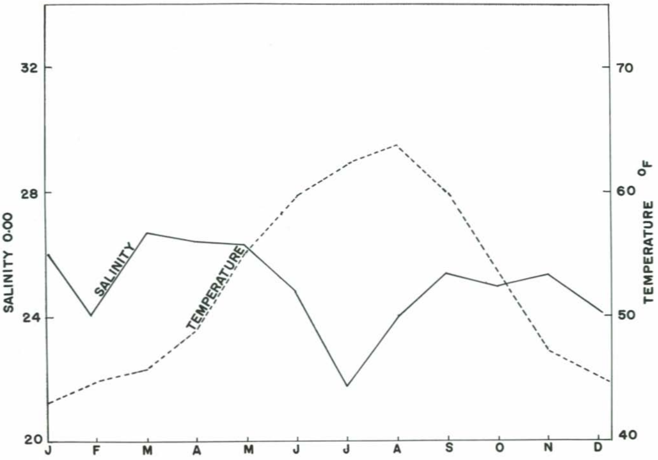

Fig. 5. Mean monthly surface seawater temperature and salinity, Departure Bay, 1963. (Data from POG, 1963.)

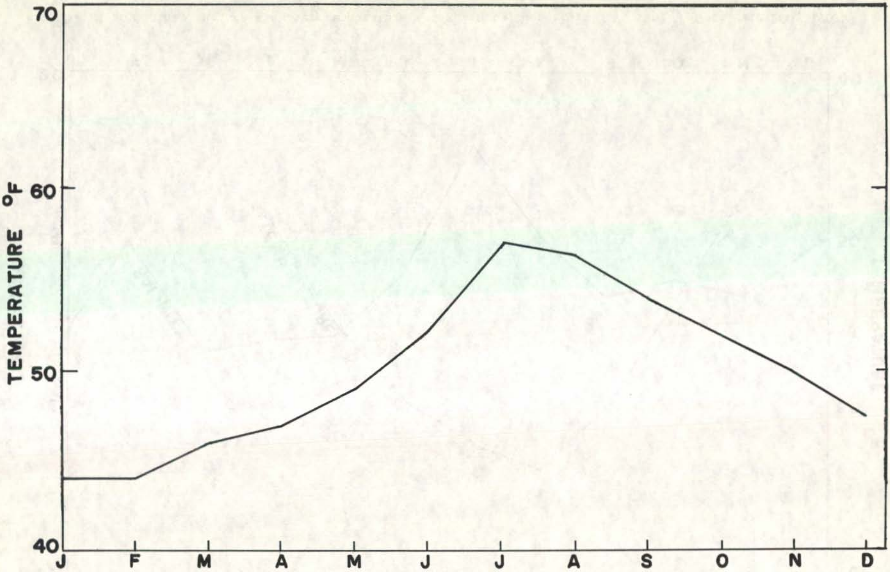

Fig. 6. Mean monthly seawater temperature, Crofton, 1964, from depth 30 feet below zero.

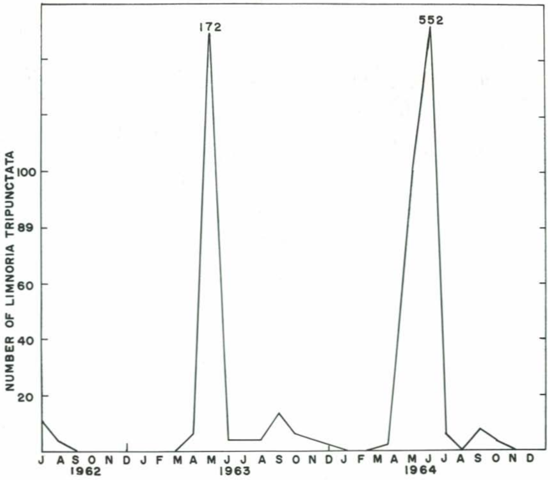

Fig. 7. Seasonal intensity of attack by Limnoria tripunctata on fir panels, 1962-64. Combined data from all depths and all stations, Cowichan, Crofton and Nanaimo.

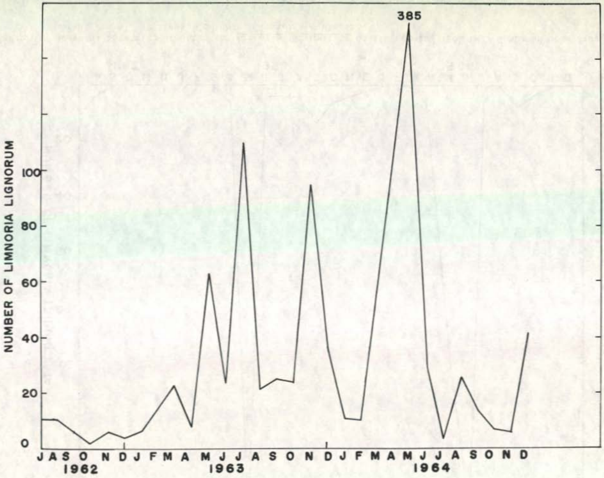

Fig. 8. Seasonal intensity of attack by Limnoria lignorum on fir panels, 1962-64. Combined data from all depths and all stations, Cowichan, Crofton and Nanaimo.

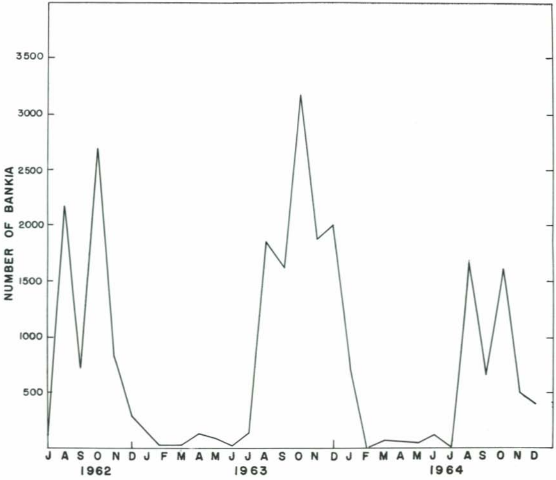

Fig. 9. Seasonal intensity of attack by Bankia setacea on fir panels, 1962-64. Combined data from all depths and all stations, Cowichan, Crofton and Nanaimo.