Ecological Studies of Shipworm Attack on Wood in the Sea Water Log Storage Site

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Introduction

The wood-boring bivalve molluscs of the family Teredinidae, commonly called "shipworm", have been well known to man since antiquity.

The shipworms appeared on the earth relatively early, and they are found in fossil wood in marine or brackish water sediments[1~4]. Therefore, it is easily presumable that the attempts to prevent shipworm attack began in the ancient time

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when man first used wooden rafts and boats.

The catastrophic ravage occurred in the Netherlands in 1730. This disaster stimulated scientists to study shipworms from various points of view.

More recently, *Teredo navalis* LINNAEUS gave a great deal of damage to the coastal structures in San Francisco Bay, California, U. S. A. in 1914. The San Francisco Bay Marine Piling Committee was established in 1921 to investigate the marine borer problem comprehensively. HILL and KOFOID[5] afterwards summarized the papers in the book entitled "Marine borers and their relation to marine constructions on the Pacific coast" as the final report of the committee.

In addition, test board operation supported by the U. S. Navy was initiated in 1920's under the directorship of W. F. CLAPP and the National Research Council.

The scientific interest in marine borer attack on wood was intensely stimulated about the time of World War II in several countries including Japan.

In Japan, the prevention of shipworm attack became a matter of importance with the increased use of wooden ships during World War II, though investigations on the Teredinidae had already begun in the early 20th century. Before World War II, only several investigators[6~12] were concerned with the Japanese shipworms. The 22nd Special Committee for the prevention of marine borer attack was organized by the Japan Society for the Promotion of Science in November, 1943 to accelerate the pace of the research on the problem. The results of this committee were published in the book edited by OKADA[13], "Attack on wooden ships and timbers by marine borers and its prevention". Unfortunately, the Society did not continue support of the committee after the war. Since that time, only a few papers which relate to the Japanese Teredinidae have appeared.

The interest was mainly centered on marine wooden constructions and ships before and during World War II. A lot of work has been done to eradicate shipworms or to prevent their attacks. However, the shipworms have been one of the most serious marine pests in the world domestically and internationally for the last few hundred years.

In present-day Japan, the shipworm problem is characterized by the fact that the more attention should be paid to the damage of imported logs stored in the sea water rather than to marine wooden installations or ships because of the increase of replacing them by concrete, steel and plastic materials. Only a few papers have so far discussed the problem involved in protecting logs stored in the sea[14~16].

The first step to restrain the shipworm attack on timber and logs in sea water is to supply basic biological and ecological informations.

This article is divided into 5 parts. The 1st part is related to the distribution of the shipworms along the coasts of Japan with a brief historical survey of the literature on the Japanese shipworms. The 2nd part refers to the season of settlement of shipworms at various localities in Japan. The 3rd part discusses the pattern of vertical settlement of shipworms in the sea water log storage site. The 4th part is concerned with the rates of growth of the shipworm, *Teredo navalis* LINNAEUS, the commonest species in Japanese waters as well as in the world. In the 5th part, the rate of shipworm attack on wood is discussed as it is directly related to the damage of wood including the logs stored in the sea.

1. Distribution of the shipworms along the coasts of Japan[17]

This part includes the review of the early works dealing with the classification of shipworms found in Japan according to TURNER's systematics[18,19]. Moreover, the distribution of the Japanese shipworms is discussed together with the locality records in the literature.

1.1 Historical survey on the Japanese shipworms

Because of a number of all named Japanese forms in the early papers are definitely synonymous forms of known species, they should be briefly reviewed before going to discussing the classification and distribution of the Japanese shipworms so that one can avoid confusing species.

With the advance of investigations, the number of species that have appeared in papers increased, and amounted to about 40 up to the present. However, only 25 species can be recognized in Japan today. Table 1 shows the catalogue of the Japanese shipworms with synonyms arranged by the new systematics[19] that is widely accepted in the world at present: 4 species each in *Teredo* and *Lyrodus,* 9 in *Bankia,* 2 in *Teredothyra* and one each in *Kuphus, Nototeredo, Uperotus, Teredora, Zachsia* and *Bactronophorus.* Two of them are still questionable because of the lack of sufficient description and illustrations of Japanese materials: *Teredora aurita* (HEDLEY)[20] and *Zachsia zenkewitschi* BULATOFF and RJABTSCHIKOFF[20]. Moreover, *Bankia inoi* HABE[21] and *Bactronophorus philippinensis* (BARTSCH)[20] are nude names.

MOLL[26] considered *Lyrodus (Teredo) yatsui* MOLL and *Lyrodus (Teredo) hibicola* KURONUMA as synonyms of *Lyrodus siamensis* BARTSCH (=a synonym of *Lyrodus pedicellatus* (QUATREFAGES) after TURNER[18]), and also *Bankia nakazawai* KURONUMA as identical to *Bankia kuronunii* ROCH (=a synonym of *Bankia carinata* (GRAY) after TURNER[18]). TAKI and HABE[20] regarded *Bankia kuronunii* ROCH and *Bankia nakazawai* KURONUMA as synonyms of *Bankia oryzaformis* SIVICKIS (=a synonym of *Bankia carinata* (GRAY) after TURNER[18]). They[27] also included *Nausitora kamiyai* ROCH in a synonymous form of *Bankia (Nausitora) orientalis* ROCH, but both are young *Bankia carinata* (GRAY). On the basis of growth stages in the pallets of *Bankia carinata* (GRAY)[18], these 2 are surely the same.

Table 1. Japanese shipworms with synonyms found in the early works.

Specific name	Synonyms
1. *Teredo navalis* LINNAEUS	*Teredo japonica* CLESSIN
2. *Teredo triangularis* EDMONDSON	*Kuphus teredoides* TAKI and HABE*
3. *Teredo mindanensis* BARTSCH	*Coeloteredo mindanensis* BARTSCH
4. *Teredo furcifera* VON MARTENS	*Teredo parksi* BARTSCH
5. *Lyrodus pedicellatus* (QUATREFAGES)	*Teredo yatsui* MOLL *Teredo hibicola* KURONUMA *Teredo tateyamensis* KURONUMA *Teredo taiwanensis* TAKI and HABE *Teredo diegensis* BARTSCH
6. *Lyrodus takanoshimensis* (ROCH)	*Teredo takanoshimensis* ROCH
7. *Lyrodus affinis* (DESHAYES)	*Teredo milleri* DALL, BARTSCH and REHDER
8. *Lyrodus massa* (LAMY)	*Teredo massa* LAMY
9. *Bankia carinata* (GRAY)	*Nausitora orientalis* ROCH* *Nausitora kamiyai* ROCH* *Bankia nakazawai* KURONUMA *Bankia oryzaformis* SIVICKIS *Bankia kuronunii* ROCH *Bankia orientalis* (ROCH)
10. *Bankia bipalmulata* (LAMARCK)	*Bankia rubra* SIVICKIS
11. *Bankia bipennata* (TURTON)	*Bankia kingyokuensis* ROCH
12. *Bankia setacea* (GRAY)	
13. *Bankia rochi* (MOLL)	*Bankia komaii* TAKI and HABE*
14. *Bankia philippinensis* BARTSCH	*Bankia tenuis* SIVICKIS
15. *Bankia johnsoni* BARTSCH	*Bankia osumiensis* MAWATARI and KITAMURA*
16. *Bankia campanellata* MOLL and ROCH	
17. *Bankia fimbriatula* MOLL and ROCH	
18. *Teredothyra smithi* (BARTSCH)	*Kuphus kiiensis* TAKI and HABE *Kuphus smithi* (BARTSCH) *Teredo radclifei* BARTSCH
19. *Teredothyra matocotana* (BARTSCH)	*Kuphus matocotana* (BARTSCH)
20. *Kuphus polythalamia* (LINNAEUS)	*Dicyathifer polythalamia* (LINNAEUS)
21. *Nototeredo edax* (HEDLEY)	*Psiloteredo pentagonalis* TAKI and HABE* *Psiloteredo hydei* SIVICKIS *Psiloteredo kirai* TAKI and HABE *Psiloteredo yakushimae* HABE* *Psiloteredo septa* MAWATARI and KITAMURA*
22. *Uperotus clavus* (GMELIN)	*Glumebra shionomisakiensis* TAKI*
23. *Teredora princesae* (SIVICKIS)	*Teredora aurita* (HEDLEY)* *Teredora sparcki* (ROCH)
24. *Zachsia zenkewitschi* BULATOFF and RJABTSCHIKOFF	
25. *Bactronophorus thoracites* (GOULD)	*Bactronophorus philippinensis* (BARTSCH)

* Questionable, further examination is needed.

CLENCH and TURNER[28], TAKI and HABE[20], and HABE[21] regarded *Bankia kingyokuensis* ROCH as a synonym of *Bankia bipalmulata* (LAMARCK), but TURNER[18] who examined the type specimen afterwards confirmed that *Bankia kingyokuensis* ROCH is a synonym of *Bankia bipennata* (TURTON).

TAKI and HABE[20] listed *Teredora aurita* (HEDLEY), and HABE[21] considered *Teredo gazettae* ROCH (error for *gazellae* ROCH) and *Teredo diederichseni* ROCH as synonyms of *Teredora aurita* (HEDLEY). These are all synonymous forms of *Teredora princesae* (SIVICKIS)[18]. However, HEDLEY[29] described *Nausitora aurita* HEDLEY on the basis of shells only, and HABE[21] gave no description of it. Likewise, *Bactronophorus philippinensis* (BARTSCH)[20] and *Bankia inoi* HABE[21] were mentioned without any description and illustration. HABE[21] later gave an illustration of the former species. From his illustration this is distinctly *Bactronophorus thoracites* (GOULD). The pallets of *Zachsia zenkewitschi* BULATOFF and RJABTSCHIKOFF measured 1.8 mm in length for specimens from Matsunaga Bay, Hiroshima Pref., Japan[27]. No further details was given. This might be a malformed or stenomorphic form of a known species.

Bankia osumiensis MAWATARI and KITAMURA[24] differs obviously from *Bankia setacea* (TRYON) and *Bankia bipalmulata* (LAMARCK) since serrations of cones are distinct at least on the outer margin. This is probably a synonym of *Bankia johnsoni* BARTSCH, although it is not definite until the type specimen is examined.

As the adults of shipworms can survive a wide range of salinities and water temperatures, the records which are not based on the test panel method would be invalid. It means that newly introduced species by drift timber into Japanese waters can live and occasionally reproduce when the environmental conditions become suitable for fertilization and spawning of the offsprings. Therefore, the test panel method must be used to ascertain the existence of shipworm species at a given locality.

Only 10 species of the shipworms listed in Table 1 were certainly found in test panels submerged in Japanese waters: *Teredo navalis* LINNAEUS, *Teredo furcifera* VON MARTENS, *Teredo triangularis* EDMONDSON, *Lyrodus pericellatus* (QUATREFAGES), *Lyrodus takanoshimensis* (ROCH), *Lyrodus massa* (LAMY), *Bankia campanellata* MOLL and ROCH, *Bankia carinata* (GRAY), *Bankia bipalmulata* (LAMARCK), *Teredothyra smithi* (BARTSCH). Further investigation would consequently be required for other species.

1.2 Distribution of the shipworms found in test panels submerged in Japanese waters[30]

Test panels (*Pinus densiflora* SIEB. et ZUCC., 5×2 cm in section and 20 cm in length) were exposed to shipworm attack for at least a month to 4 months at 33 test localities in Japan during the period from May, 1974 through November, 1976. The panels were then brought back to the laboratory to identify shipworm specimens.

In the present investigation 9 species were found as shown in Table 2.

Table 2. Shipworms found along the coasts of Japan (○: species found, —: not found).

Locality \ Species[a]	1	2	3	4	5	6	7	8	9
1. Muroran, Hokkaido	—	—	—	—	—	—	—	—	—
2. Hakodate, Hokkaido	—	—	—	—	—	—	—	—	—
3. Onagawa, Miyagi	○	—	—	—	—	—	—	—	—
4. Sado, Niigata	○	—	—	○	—	—	—	—	—
5. Noto, Ishikawa	○	○	○	—	—	—	—	—	—
6. Kawasaki, Kanagawa	—	—	—	—	—	—	—	—	—
7. Oppama, Kanagawa	○	—	—	—	—	—	—	—	—
8. Aburatsubo, Kanagawa	○	—	—	—	○	—	—	—	—
9. Shimizu, Shizuoka	—	—	—	—	—	—	—	—	—
10. Nagoya, Aichi	—	—	—	—	—	—	—	—	—
11. Yokkaichi, Mie	○	—	—	—	—	—	—	—	—
12. Toba, Mie	○	—	○	—	—	—	—	—	—
13. Tatoku Island, Mie	○	—	○	○	—	—	—	—	—
14. Takahama, Fukui	○	—	○	○	—	—	—	—	○
15. Maizuru, Kyoto	○	—	○	—	—	—	—	—	—
16. Sakai, Osaka	—	—	—	—	—	—	—	—	—
17. Wakayama, Wakayama	○	—	—	—	—	—	—	—	—
18. Kainan, Wakayama	—	—	—	—	—	—	—	—	—
19. Arita, Wakayama	○	—	○	○	—	—	—	○	—
20. Yura, Hyogo	○	—	—	○	—	—	—	—	—
21. Aioi, Hyogo	○	—	—	—	—	—	—	—	—
22. Naruto, Tokushima	○	○	○	—	○	—	—	—	—
23. Sakaide, Kagawa	○	—	○	—	—	—	—	—	—
24. Uno, Okayama	○	—	○	—	—	—	—	—	—
25. Mizushima, Okayama	○	—	○	—	—	—	—	—	—
26. Kure, Hiroshima	○	—	—	—	—	—	—	—	—
27. Miyajima, Hiroshima	○	—	○	—	—	—	—	—	—
28. Shimonoseki, Yamaguchi	○	—	○	—	—	—	—	—	—
29. Kokura, Fukuoka	○	—	—	—	—	—	—	—	—
30. Tobata, Fukuoka	—	—	—	—	—	—	—	—	—
31. Nagasaki, Nagasaki	○	—	○	—	—	—	—	—	—
32. Koniya, Kagoshima	—	—	○	○	—	○	○	—	—
33. Naha, Okinawa	—	○	○	—	—	—	○	—	—

a) 1: *Teredo navalis* LINNAEUS, 2: *Teredo furcifera* VON MARTENS, 3: *Lyrodus pedicellatus* (QUATREFAGES), 4: *Bankia carinata* (GRAY), 5: *Bankia campanellata* MOLL and ROCH, 6: *Bankia johnsoni* BARTSCH, 7: *Bankia bipennata* (TURTON), 8: *Teredora princesae* (SIVICKIS), 9: *Nototeredo edax* (HEDLEY).

Teredo navalis LINNAEUS is widely distributed in Japanese waters, and found at 23 localities this time as shown in Fig. 1 (see also Table 2) with early locality records in the literature. When the species appeared as a single species at 7 localities (i.e. Onagawa, Oppama, Yokkaichi, Wakayama, Aioi, Kure, and Kokura), the number

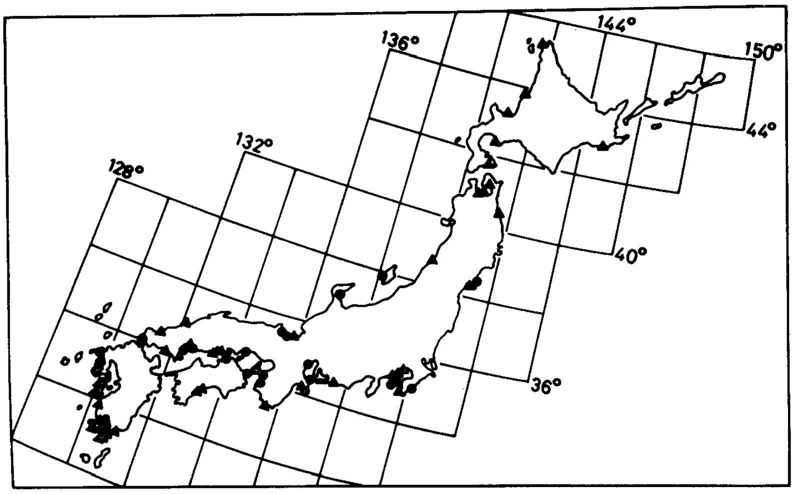


Fig. 1. Distribution of *Teredo navalis* LINNAEUS along the coasts of Japan (●: Specimens seen, ▲: Literature).

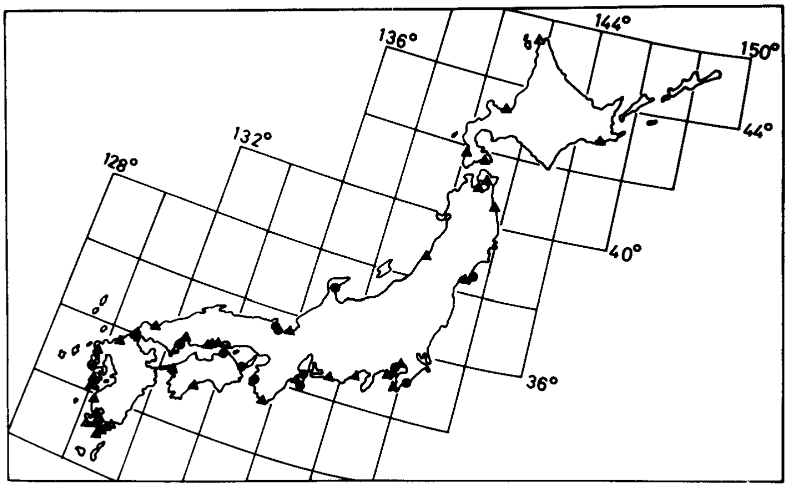


Fig. 2. Distribution of *Lyrodus pedicellatus* (QUATREFAGES) along the coasts of Japan (●: Specimens seen, ▲: Literature).

of animals obtained from test panels was quite few without any exception.

Distribution of the second commonest species *Lyrodus pedicellatus* (QUATREFAGES) almost overlaps that of the above species, but locality records are a little scantier (Fig. 2). This species, a long-term larviparous, retains larvae until the pediveliger stage, and the larvae have a short free-swimming period. It therefore appears that the larvae of *Lyrodus pedicellatus* (QUATREFAGES) can not travel over a long distance in their larval life but settle on new wood in the vicinity of attacked wood in which the adults live.

Of other species present, *Bankia carinata* (GRAY) is relatively common along the coasts of Japan. The distribution of the species is restricted to the the west of Tokyo and to the south of Sado as shown in Fig. 3.

On the basis of the early locality records, *Teredo furcifera* VON MARTENS is found

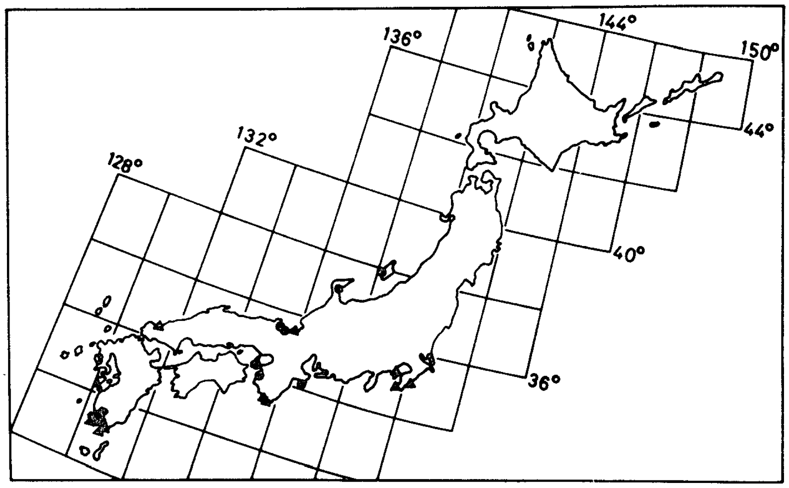


Fig. 3. Distribution of *Bankia carinata* (GRAY) along the coasts of Japan (●: Speciments seen, ▲: Literature).

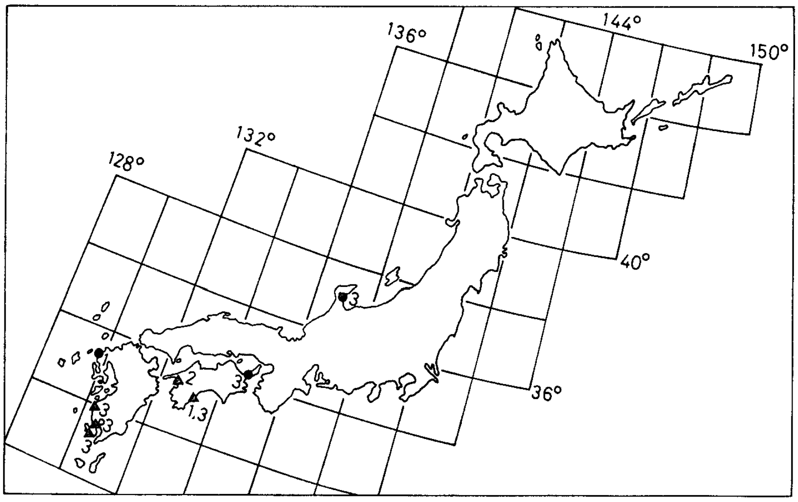


Fig. 4. Distribution of 3 *Tredo* species (1: *T. triangularis* EDMONDSON; 2: *T. mindanensis* BARTSCH; 3: *T. furcifera* VON MARTENS) along the coasts of Japan (●: Specimens seen, ▲: Latcrature) *T. furcifera* were seen at Koniya.

only in Shikoku and Kyushu, but the present results show that this species is found even at Noto (see Fig. 4).

Bankia campanellata MOLL and ROCH, which may possibly be confused with *Bankia carinata* (GRAY), was newly recorded at Aburatsubo and Naruto, and the species was not abundant in number.

Bankia johnsoni BARTSCH, *Bankia bipennata* (TURTON), *Teredora princesae* (SIVICKIS) and *Nototeredo edax* (HEDLEY) were occasionally found among the predominant species such as *Teredo navalis* LINNAEUS and *Lyrodus pedicellatus* (QUATREFAGES). The tendency of distribution of these minor species, together with the early records, is summarized as follows: *Bankia johnsoni* BARTSCH is limitted only in Kagoshima Pref.; *Bankia bipennata*

(TURTON) in Chiba Pref., Kagoshima Pref. and Okinawa Pref.; *Teredora princesae* (SIVICKIS) in Wakayama Pref. and Kagoshima Pref.; *Nototeredo edax* (HEDLEY) in Wakayama Pref., Fukui Pref., Nagasaki Pref. and Kagoshima Pref. These are all tropical species as demonstrated by the locality records in the world[18,31] and MCZ* collection.

For the species not found this time but collected before (see Tables 1 and 2), previous locality records and MCZ collection indicate that *Lyrodus takanoshimensis* (ROCH) and *Bankia bipalmulata* (LAMARCK) are found along the southern Pacific coasts of Honshu and Kyushu, *Uperotus clavus* (GMELIN) and *Teredothyra smithi* (BARTSCH) in Wakayama Pref., *Lyrodus affinis* (DESHAYES), *Bankia philippinensis* BARTSCH and *Lyrodus massa* (LAMY) in Kyushu, *Teredo mindanensis* BARTSCH and *Bankia rochi* (MOLL) in Shikoku, *Teredo triangularis* EDMONDSON in Shikoku and Kyushu, *Teredothyra motocotana* (BARTSCH) in Shikoku and Wakayama Pref., *Bankia setacea* (TRYON) in Hokkaido, *Kuphus polythalamia* (LINNAEUS) and *Bactronophorus thoracites* (GOULD) in Taiwan**, and *Bankia fimbriatula* MOLL and ROCH in Sagami Bay. Unfortunately, the scant locality records of the above 15 species, in addition to the absence of them in the present investigation, make it impossible to discuss their patterns of distribution at present (see also Figs. 4～7). However, *Kuphus polythalamia* (LINNAEUS) and *Bactronophorus thoracites* (GOULD) must be removed from the Japanese shipworms (see footnote). Judging from the locality records in a world-wide basis, the incidence of 5 species, i.e. *Uperotus clavus* (GMELIN), *Lyrodus affinis* (DESHAYES), *Bankia philippinensis* BARTSCH, *Bankia rochi* (MOLL) and *Teredo mindanensis* BARTSCH is fairly doubtful in Japanese

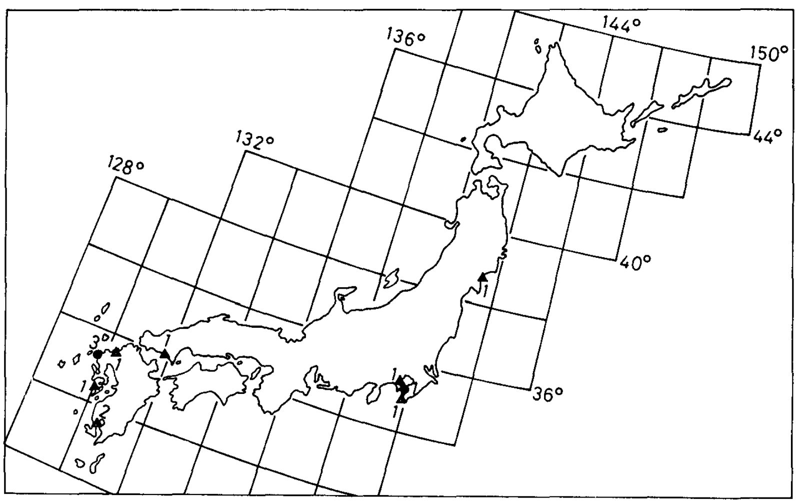


Fig. 5. Distribution of 3 *Lyrodus* species (1: *L. takanoshimensis* (ROSH); 2: *L. affinis* (DESHAYES); 3: *L. massa* (LAMY)) along the coasts of Japan (●: Specimens seen, ▲: Literature).

* Museum of Comparative Zoology at Harvard University, Cambridge, Massachusetts, U.S.A.
** Taiwan was a part of Japan when study[20] was made.

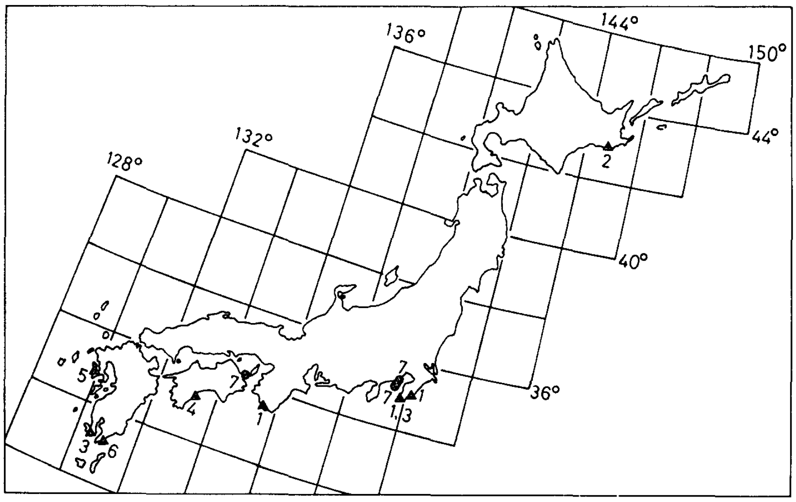


Fig. 6. Distribution of 7 *Bankia* species (1: *B. bipalmulata* (LAMARCK); 2: *B. setasea* (TRYON); 3: *B. bipennata* (TURTON); 4: *B. rochi* (MOLL); 5: *B. philippinensis* BARTSCH; 6: *B. johnsoni* BARTSCH, 7: *B. campanellata* MOLL and ROCH) along the coasts of Japan. (●: Specimens seen, ▲: Literature) *B. bipennats* specimens were seen at Koniya and Naka; *B. johnsoni* and *B. bipalmulata* at Koniya.

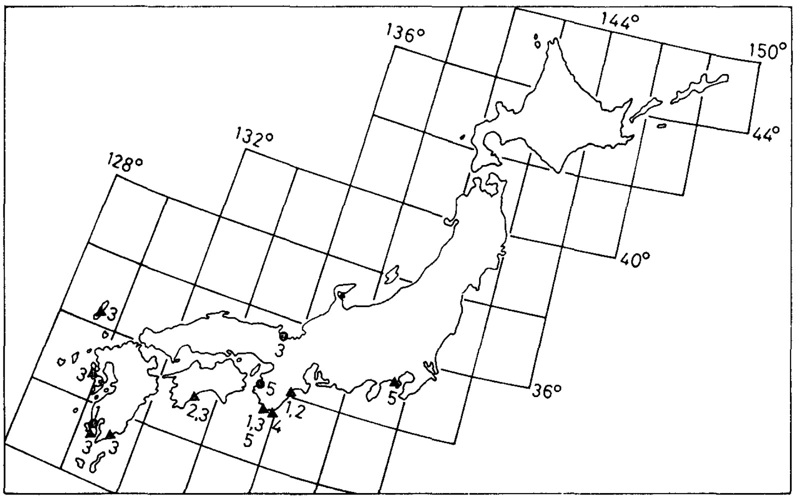


Fig. 7. Distribution of 5 species of shipworms (1: *Teredothyra smith* (BARTSCH); 2: *Teredothyra matocotana* (BARTSCH); 3: *Nototeredo edax* (HEDLEY); 4: *Uperotus elavus* (GMELIN); 5: *Teredora princesae* (SIVICKIS)) along the coasts of Japan (●: Specimens seen, ▲: Literature).

waters. *Zachsia zenkewitschi* BULATOFF and RJABTSCHIKOFF will also be excluded until the type specimen is examined. Accordingly, the species which are probably found in Japanese waters other than 9 species confirmed in the present investigation are *Teredo triangularis* EDMONDSON, *Lyrodus takanoshimensis* (ROCH), *Lyrodus massa* (LAMY), *Bankia setacea* (TRYON), *Bankia bipalmulata* (LAMARCK), *Bankia fimbriatula* MOLL and ROCH, *Teredothyra smithi* (BARTSCH) and *Teredothyra matocotana* (BARTSCH).

Table 3. Geographic distribution of the shipworms in Japan.

Shipworm species	Hokkaido	Honshu[a)] South	Honshu[a)] North	Shikoku	Kyushu
1. *Teredo navalis*	L	P	P	P	P
2. *Teredo triangularis*	—	—	—	L	P
3. *Teredo mindanensis**	—	—	—	L	—
4. *Teredo furcifera*	—	L	P	P	P
5. *Lyrodus pedicellatus*	L	P	P	P	P
6. *Lyrodus takanoshimensis*	—	P**	L**	—	P
7. *Lyrodus affinis**	—	—	—	—	L
8. *Lyrodus massa*	—	—	—	—	P
9. *Bankia carinata*	—	P	P	—	P
10. *Bankia bipalmulata*	—	L**	—	—	P
11. *Bankia setacea*	L	—	—	—	—
12. *Bankia rochi**	—	—	—	L	—
13. *Bankia johnsoni*	—	—	—	—	P
14. *Bankia campanellata*	—	P**	—	P	—
15. *Bankia philippinensis**	—	—	—	—	L
16. *Bankia bipennata*	—	L**	—	—	P
17. *Bankia fimbriatula*	—	L**	—	—	—
18. *Teredothyra smithi*	—	L**	—	—	P
19. *Teredothyra matocotana*	—	L**	—	L	—
20. *Teredora princesae*	—	P**	—	—	—
21. *Uperotus clavus**	—	—	—	L	—
22. *Nototeredo edax*	—	P**	—	L	L

a) Boundary between South and North is 36°N.
*: Occurrence is questionable in Japanese waters.
**: Locality records are restricted in the Pacific coast.
P: Specimens seen or finding the species in test panels is specified in the literature.
L: Literature; no specification is given if the species is found in test panels or drift timber or attacked wooden hull. —: Not found.

As discussed above, the distribution of each species of the shipworms along the coasts of Japan requires further work, but it can be summarized anyhow as shown in Table 3.

2. Season of settlement

The amount of imported logs occupies more than 60% of Japan's total supply of wood. The imported logs are transported by ships into about 100 international trading ports along the coasts of Japan.

The logs are generally stored in sea water for classification, inspection and plant quarantine, and at least 10 to 20 days are required for these operations. Some logs are occasionally stored in the sea for one month to 6 months at the longest.

During the period of storing logs in sea water, the logs are inevitably exposed to marine borers, especially to shipworms. The longer storage of logs in summer results in some economic loss caused by shipworms. Shipworm attack distinctly results in the loss in not only lumber yield but also in pulp yield and quality[32].

In 1969, a great economic loss was caused by shipworms in the sea water log storage area at Uchiura Port in Fukui Pref. as the occurrence and settling season of shipworms were unknown at that time. Consequently, it is desirable to investigate the season of settlement of shipworm larvae in relation to the species of shipworms present at specified localities.

In this part, monthly settlement of shipworms is discussed. That was determined by the test panel method in consideration of water temperature and salinity at 14 test localities along the coasts of Japan.

2.1 Investigations during the period from May, 1974 to April, 1975

A test panel (sapwood of *Pinus densiflora* SIEB. et ZUCC., 5×2 cm in section and 20 cm in length) with a hole at the center for rope penetration was employed. Three test panels constituted a test string for obtaining the precise information on the monthly

Table 4. Monthly settlement of shipworms at Onagawa (number of borer apertures per 100 cm²).

Month	Wood surface		Water temperature (°C)
	Upper	Lower	
May, 1974	0	0	11.0
June	0	0	15.5
July	0	0	18.4
Aug.	0	0	21.5
Sep.	6	2	21.2
Oct.	1	1	18.7
Nov.	0	0	14.5
Dec.	0	0	10.1
Jan., 1975	0	0	7.1
Feb.	0	0	6.4
Mar.	0	0	5.8
Apr.	0	0	6.6

Table 5. Monthly settlement of shipworms at Sado (number of borer apertures per 100 cm²).

Wood surface	Month											
	M 1974	J	J	A	S	O	N	D	J 1975	F	M	A
Upper	0	1	2	40	31	1	1	1	1	0	0	0
Lower	0	1	1	32	17	1	2	2	0	0	0	0

Table 6. Monthly settlement of shipworms at Oppama (number of borer apertures per 100 cm^2).

Month	Wood surface		Water temperature (°C)	Salinity (‰)
	Upper	Lower		
May, 1974	0	0	22.0	30.72
June	1	0	22.0	30.72
July	3	1	24.0	32.80
Aug.	13	1	26.0	32.88
Sep.	1	1	22.0	35.35
Oct.	1	0	18.5	29.54
Nov.	1	1	17.0	31.70
Dec.	0	0	11.0	32.08
Jan., 1975	0	0	10.0	33.17
Feb.	0	0	9.0	31.12
Mar.	0	0	13.0	32.53
Apr.	0	0	18.5	30.86

Table 7. Monthly settlement of shipworms at Aburatsubo (number of borer apertures per 100 cm^2).

Wood surface	Month											
	M 1974	J	J	A	S	O	N	D	J 1975	F	M	A
Upper	0	5	1	0	3	1	0	1	0	0	0	0
Lower	0	1	3	0	18	6	1	0	0	0	0	0

Table 8. Monthly settlement of shipworms at Noto (number of borer apertures per 100 cm^2).

Month	Wood surface		Water temperature* (°C)	Salinity* (‰)
	Upper	Lower		
May, 1974	0	0	17.4	35
June	4	5	21.8	37
July	6	9	24.4	36
Aug.	59	372	26.0	36
Sep.	223	1097	23.2	35
Oct.	31	232	21.3	36
Nov.	18	189	15.6	34
Dec.	3	25	11.8	33
Jan., 1975	1	7	10.7	33
Feb.	0	1	10.5	34
Mar.	0	0	10.6	34
Apr.	0	0	14.6	33

*: Water temperature and salinity were measured at the surface level once a month at replacing a test string.

Table 9. Monthly settlement of shipworms at Tatoku Is. (number of borer apertures per 100 cm²).

Month	Wood surface		Water temperature (°C)
	Upper	Lower	
May, 1974	0	0	19.5
June	1	0	23.8
July	5	3	26.0
Aug.	5	3	29.1
Sep.	4	0	26.6
Oct.	3	3	22.5
Nov.	0	1	17.9
Dec.	0	0	12.8
Jan., 1975	0	0	12.9*
Feb.	0	0	11.7
Mar.	0	0	10.3
Apr.	0	0	14.6

*: Measurement was made only twice in the period.

Table 10. Monthly settlement of shipworms at Aioi (number of borer apertures per 100 cm²).

Month	Wood surface		Water temperature* (°C)	Salinity* (‰)
	Upper	Lower		
May, 1974	0	0	19.0	29.7
June	0	0	25.5	28.2
July	54	34	28.0	26.4
Aug.	4	8	29.0	25.7
Sep.	Lost		24.3	28.0
Oct.	12	9	20.8	28.4
Nov.	6	2	12.5	28.4
Dec.	1	0	9.2	28.9
Jan., 1975	0	0	7.0	27.5
Feb.	0	0	7.6	29.0
Mar.	0	0	10.1	30.3
Apr.	0	0	16.2	23.3

*: Measurement was made only once in the period at removing test panels.

Table 11. Monthly settlement of shipworms at Uno (number of borer apertures per 100 cm²).

Wood surface	Month											
	M 1974	J	J	A	S	O	N	D	J 1975	F	M	A
Upper	0	1	208		Lost		31	1	0	0	0	0
Lower	0	2	44				44	0	0	0	0	0

Table 12. Monthly settlement of shipworms at Miyajima (number of borer apertures per 100 cm²).

Month	Wood surface		Water temperature (°C)	Salinity (‰)
	Upper	Lower		
May, 1974	0	0	19.0	31.8
June	5	5	21.0	30.4
July	0	0	23.0	23.1
Aug.	36	46	26.0	29.1
Sep.	163	70	24.0	34.3
Oct.	11	6	20.0	34.3
Nov.	0	0	21.0	37.2
Dec.	0	0	11.0	31.6
Jan., 1975	0	0	7.8	30.9
Feb.	0	0	7.6	31.8
Mar.	0	0	12.0	31.8
Apr.	0	0	9.5	35.9

Table 13. Monthly settlement of shipworms at Shimonoseki (number of borer apertures per 100 cm²).

Month	Wood surface		Water temperature (°C)	Salinity (‰)
	Upper	Lower		
May, 1974	0	0	—*	—*
June	0	0	—	—
July	5	3	—	—
Aug.	12	18	—	—
Sep.	7	16	24.1	32.5
Oct.	0	1	20.0	30.5
Nov.	1	2	15.7	32.1
Dec.	0	0	12.9	33.7
Jan., 1975	0	0	11.8	34.4
Feb.	0	0	10.8	27.9**
Mar.	0	0	13.3	33.6
Apr.	0	0	17.2	32.5

*: No measurement was made. **: Noctilucae occurred abnormally in the period.

settlement. The test string was submerged vertically in the sea from an experimental raft or some other floating structures, as 3 panels were between 30 and 100 cm below the surface of the water. The test string was renewed every month to examine the monthly settlement of shipworms for a year from May, 1974 to April, 1975 at 12 test localities.

After removal of the test panels, surface debris and fouling organisms were scraped

Table 14. Monthly settlement of shipworms at Nagasaki (number of borer apertures per 100 cm^2).

Month	Wood surface		Water temperature* (°C)	Salinity** (‰)
	Upper	Lower		
May, 1974	0	0	20.5	31.8
June	0	0	22.5	32.3
July	1	0	24.0	23.1**
Aug.	5	1	26.0	31.8
Sep.	70	9	25.0	39.4
Oct.	55	90	23.0	38.7
Nov.	17	72	21.0	39.4
Dec.	0	1	16.0	41.5
Jan., 1975	0	0	13.0	34.1
Feb.	0	0	10.3	31.1
Mar.	0	0	14.0	36.7
Apr.	0	0	22.5	31.6

*: Measurement was made only once in the period at removing test panels.
**: Low salinity possibly depended on a lot of rainfall.

Table 15. Monthly settlement of shipworms at Naha (number of borer apertures per 100 cm^2).

Wood surface	Month										
	J 1974	J	A	S	O	N	D	J 1975	F	M	A
Upper	0	0	2	1	14	3	1	Lost	0	—	—
Lower	0	1	7	5	16	7	0		0	—	—

off for counting the number of shipworm apertures on both upper and lower surfaces under a binocular stereoscopic microscope. The results are shown as the average number of borer apertures per 100 cm^2 of the surfaces of 3 test panels removed at the same time. Brief results are given in Tables 4～15.

2.2 Investigations at Naruto

Investigations were carried out at Naruto (34°12′30″N, 134°36′27″E) for the period from June, 1973 through May, 1976.

Western hemlock (*Tsuga heterophylla* SARGENT) test block (4×4 cm in section and 30 cm in length) with a center hole for rope penetration was employed in the experiment. Two test blocks were suspended vertically from an experimental raft every month, as the blocks were at 30 and 130 cm respectively below the surface of the water. In the first year (1973), an additional test block was submerged at 80 cm every month.

After removal of the test blocks, surface debris and fouling organisms were scraped

Table 16. Species of shipworms at Naruto and their occurrence during the period from June 1, 1973 to January 27, 1974.

Immersion date	Removal date							
	July 1	July 31	Aug. 30	Sep. 29	Oct. 29	Nov. 28	Dec. 28	Jan. 27
June 1	A	T	T	T	T			
July 1		T	T, L	T	T, L			
July 31			A	T	T, L			
Aug. 30				T, B	T			
Sep. 29					T, B			
Oct. 29						A		
Nov. 28							A	
Dec. 28								A

A: Borers apertures found but unidentified.
T: *Teredo navalis* LINNAEUS present.
L: *Lyrodus pedicellatus* (QUATREFAGES) present.
B: *Bankia campanellata* MOLL and ROCH present.

off so that number of borer punctures on the wood surfaces (upper, lower and side surfaces) could be counted under a binocular stereoscopic microscope. Number of borer apertures was taken as the criterion of monthly settlement of shipworms.

Teredo navalis LINNAEUS and *Bankia campanellata* MOLL and ROCH were found in the test blocks. *Lyrodus pedicellatus* (QUATREFAGES) was also present in test blocks submerged for a longer period as shown in Table 16. In addition, *Teredo furcifera* VON MARTENS was first collected from a drift timber, and occasionally found later in the test blocks in 1975 and 1976. Of 4 species present, *Teredo navalis* LINNAEUS was the predominant species at the test site.

As seen in Table 16, *Teredo navalis* LINNAEUS was first confirmed in July and found through the period of settlement. *Lyrodus pedicellatus* (QUATREFAGES) appeared only in warmer season (August and October). In September and October, the settlement of *Bankia campanellata* MOLL and ROCH was demonstrated. The submerging length of only a month seemed to be too short to identify the animals found in a test block, though it was possible to do in July, September and October surely because of favorable conditions for the growth of shipworms.

Number of borer punctures per 100 cm^2 on the wood surfaces is calculated and tabulated below (Table 17) with mean monthly water temperatures. The results at testing depths 30 and 130 cm are averaged and shown in the table. The results at 80 cm obtained from June, 1973 to May, 1974 are given in Table 18. No conspicuous difference was perceived among depths.

On the basis of the results given in Tables 17 and 18, settlement of shipworms

Table 17. Monthly settlement of shipworms (number of borer apertures per 100 cm^2) and monthly mean water temperatures (°C) at Naruto. Water temperatures are given in the brackets.

Month \ Year	1973	1974	1975	1976
Jan.		0 (9.0)	0 (10.9)	2 (9.7)
Feb.		0 (8.3)	0 (8.8)	0 (7.7)
Mar.		0 (9.5)	0 (10.3)	0 (9.8)
Apr.		0 (14.8)	0 (14.0)	0 (13.4)
May		0 (18.7)	0 (17.5)	0 (17.7)
June	15 (22.9)	6 (22.2)	28 (21.9)	0 (—)[a]
July	25 (27.1)	14 (25.5)	22 (25.4)	1 (—)
Aug.	3 (28.0)	7 (28.4)	27 (27.3)	2 (—)
Sep.	71 (26.7)	116 (26.6)	128 (27.9)	2 (—)
Oct.	154 (23.6)	494 (24.3)	314 (23.9)	13 (—)
Nov.	30 (19.6)	161 (19.2)	135 (19.2)	25 (—)
Dec.	2 (13.9)	18 (14.3)	111 (15.1)	1 (—)

a) not measured.

Table 18. Monthly settlement of shipworms at 80 cm depth for the period from June, 1973 to May, 1974 (number of borer apertures per 100 cm^2)[a].

June	July	Aug.	Sep.	Oct.	Nov.	Dec.
17	25	1	59	139	29	1

a) No settlement occurred from January to May, 1974.

began in June when water temperatures were over 20°C, and ended in December with water temperatures of 14°~15°C. A conspicuous peak was recorded in October. Larval settlement was occasionally observed in January. When water temperatures began to go down after August, the number of borer apertures found on the wood surfaces suddenly increased. The dominant species at the test site, *Teredo navalis* LINNAEUS releases the larvae at straight-hinge stage. The larvae spend 20 to 30 days in free-swimming stage before settling, though the duration of free-swimming stage might be varied with environmental factors such as water temperature and salinity[18,33,34]. Subsequently, the larvae which succeeded in penetrating into wood in the fall (September, October and November) had been discharged in August, September and October. The peak in October therefore seemed to have resulted from the advent of sexual maturity of shipworms which burrowed into wood in June, July and August.

Heavier borer's infestation was generally found on the horizontal surfaces than on the vertical ones. Of horizontal surfaces, the upper surfaces were liable to be attacked more severely than the lower surfaces. Similarity was obtained by other investigators[35]. Blocks immersed for longer periods confirmatively support the tendency. As an example, a test block immersed at 130 cm depth for 2 months (September and October) suffered 304 shipworm apertures per 100 cm^2 on the upper surface, whereas 61 on the lower one and 95 on the side one.

Difference of shipworm attack with water depths was not demonstrated apparently in the present investigation. However, much heavier infestation was sometimes observed at 130 cm level (e.g. October, 1974).

Longer immersion periods are expected to result naturally in the severer attack as a rule, if the attack is simply interpreted on the basis of the number of borer apertures on the wood surfaces, but the adverse phenomenon was exceptionally noticed (Table 19). Comparison of the results with the cumulative data calculated from Table 17 points out that shipworms which settled on the surfaces of wood would not increase in number proportionally with the increase in the period of immersion. That also suggests that fouling organisms and/or debris accumulated on the surfaces play an important role in preventing the shipworms from settling by reducing potential areas for shipworms' settlement[36].

Nevertheless, the attack by shipworms develops day by day because the animals

Table 19. Settlement of shipworms on the wood surfaces of test blocks submerged at 80 cm depth for longer periods (number of borer apertures per 100 cm^2).

Period of immersion (month)	Number of borer apertures	Cumulative data[a]
2 (June～July, 1973)	36	42 (17)[b]
3 (June～Aug., 1973)	28	43 (17)
4 (June～Sep., 1973)	47	102 (17)
5 (June～Oct., 1973)	40	241 (17)
6 (June～Nov., 1973)	52	270 (17)
2 (July～Aug., 1973)	25	26 (25)
3 (July～Sep., 1973)	24	85 (25)
4 (July～Oct., 1973)	33	224 (25)
5 (July～Nov., 1973)	36	253 (25)
2 (Aug.～Sep., 1973)	12	60 (1)
3 (Aug.～Oct., 1973)	10	199 (1)
2 (Sep.～Oct., 1973)	110	198 (59)
3 (Sep.～Nov., 1973)	83	227 (59)
2 (Oct.～Nov., 1973)	180	168 (139)
3 (Oct.～Dec., 1973)	44	169 (139)

a) Data were calculated from the test blocks immersed monthly (see Table 17).
b) Number of borer apertures in the first month of immersion-period is shown in the brackets.

keep growing just after initial boring into wood. Therefore, the longer immersion periods finally result in the severer damage.

2.3 Investigations at Takahama

Investigations were carried out in the sea water log storage area at Uchiura Port, Fukui Pref. The geographic location of the test site should be referred to the previous paper[36].

Scotch pine (*Pinus sylvestris* LINNAEUS) test block (4×4 cm in section and 30 cm in length) was employed to examine monthly settlement of shipworms. Three test blocks were vertically submerged in the sea at 30, 80 and 130 cm, respectively below the surface of the water at 4 test stations in the area. The test blocks were replaced every month, and were served to count the borer punctures on the wood surfaces under a binocular stereoscopic microscope at low magnification. Number of borer apertures was taken as the index of the settlement of shipworms.

On the basis of the examination of test blocks, 3 species of shipworms were identified: *Teredo navalis* LINNAEUS, *Lyrodus pedicellatus* (QUATREFAGES) and *Bankia carinata* (GRAY). *Nototeredo edax* (HEDLEY) was additionally found in a sinker of western red cedar (*Thuja plicata* D. DON) which had been previously imported from the Pacific coast of U.S.A.

Of 4 species present at the test site, *Teredo navalis* LINNAEUS was by far the commonest. When the damage was discovered in 1975 and 1976, the population density of the species seemed to become relatively higher than usual. Therefore, short-term larviparous species such as *Teredo navalis* LINNAEUS, or oviparous species could explosively disperse their posterity and gametes into the surrounding water.

Table 20. Monthly settlement of shipworms at Takahama during the period from April, 1975 to March, 1977 (number of borer apertures per 100 cm^2)[a].

Test sta.	May 1975	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Jan. 1976
A	1	1	7	65	140	14	7	1	0
B	2	1	7	—[b]	88	7	16	3	1
C	2	4	7	53	163	5	7	1	0
D	1	1	4	55	162	6	7	2	0
		June 1976	July	Aug.	Sep.	Oct.	Nov.	Dec.	
A		1	8	300	13	2	1	1	
B		1	10	745	8	3	1	1	
C		0	8	141	15	4	2	1	
D		0	8	277	10	3	1	1	

a) Months with no settlement of shipworms are omitted. b) Test blocks lost.

In accordance with the same procedures of estimation at Naruto, the results are tabulated below (Table 20). Data in the tabulation are the average of 3 test blocks submerged at 30, 80 and 130 cm depth, respectively.

In the first series from April, 1975 to March, 1976, the larval settlement was observed for 9 months from May, 1975 through January, 1976 with a prominent peak in September. The data in Table 20 assume that after September, when water temperatures fell continuously, the decline in sexual activities agreed with the decrease of larval settlement. There was no settlement in April, 1975, February and March, 1976.

The similar phenomenon was noticed in the second series from April, 1976 to March, 1977, but the settlement began in June and terminated in December.

As shown above, salinity did not seem to be a prevailing hydrographic factor in relation to the settlement of shipworms at the test area, though NAGABHUSHANAM[37] who investigated the occurrence of shipworms in Visakhapatnam, India testified that the density of settlement was directly related to temperature and salinity. On the other hand, the water temperatures ranged from 8°C in February to 30°C in August with an annual variation of 22°C.

Settlement of shipworms was determined by the regular monthly replacement of test panels or blocks at 14 localities along the coasts of Japan. Borer apertures on the wood surfaces were taken as the index of shipworm settlement.

Summing up the results, the following figure is obtained with the species present, and the range of water temperature and salinity in which settlement of shipworms

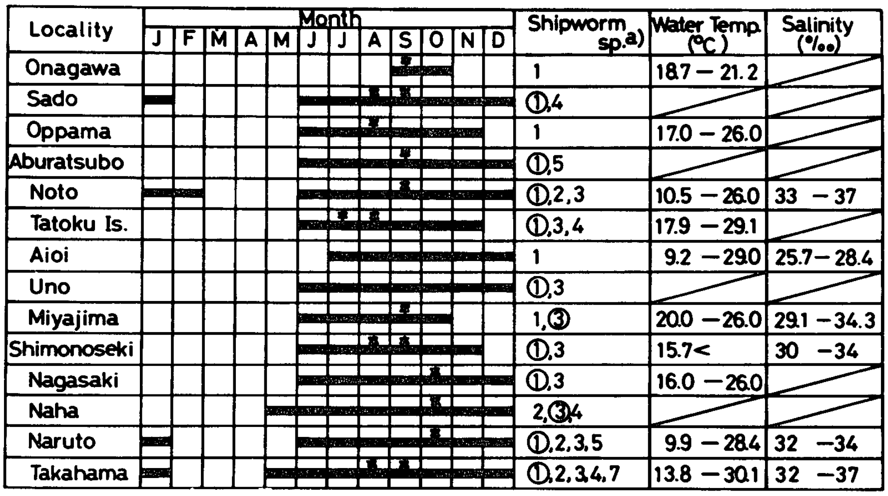


Fig. 8. Summarized data on monthly settlement of shipworms at 14 test localities along the coasts of Japan.
a) 1: *Teredo navalis* LINNAEUS, 2: *Teredo furcifera* VON MARTENS, 3: *Lyrodus pedicellatus* (QUATREFAGES), 4: *Bankia carinata* (GRAY), 5: *Bankia campanellata* MOLL and ROCH, 6: *Bankia bipennata* (TURTON), 7: *Nototeredo edax* (HEDLEY).

was observed. The peak, if it is conspicuous, is marked by an asterisk (*) in the figure (Fig. 8). The dominant species at each locality is also circled.

In Japanese waters, the settlement of shipworms generally began at water temperatures above 20°C and terminated at the lower temperatures than those of beginning, though the range of water temperatures in which settlement occurred was varied with localities.

The period of settlement was relatively long (usually from June to December) but depended mainly on water temperature and the amount of attacked wood at the tested sites. The peak of settlement generally coincided with rather the transition stage of water temperature in September or October when water temperature began to fall than the highest temperature in August. A few exceptions were noticed at Oppama and Tatoku Island where the number of borer apertures on the wood surfaces was quite small.

3. Pattern of vertical settlement of shipworms[38]

The depth preference of marine wood borers is ecologically significant since the degree of attack on marine wooden constructions varies with the depth of water together with environmental factors and competition with fouling communities[39~46]. Both limnorial borers and shipworms are significant for the destruction of marine wooden structures. However, only shipworms play an important role in deteriorating the logs stored in the sea water log storage sites[14,36].

Only a few papers have dealt with the pattern of vertical settlement of shipworms[42,47~50]. They showed that the intensity of shipworm attack generally increased with depths in shallow waters[41,51,52].

The sea water log storage areas are usually established in shallow waters. If the former results are also true for the sea water log storage areas, sunken logs which are present inevitably at the bottom in the storage areas may help shipworms go downwards, and finally contribute to the reproduction of shipworms. Therefore, it is necessary to investigate the pattern of vertical settlement of shipworms in the sea water log storage sites.

The investigations were carried out in the sea water log storage area, Takahama, Fukui Pref. for 2 years from June 1, 1975. Water depth at the test station is around 23 m. The geographic location of the test area should be referred to the previous paper[36].

A monthly test string consisted of Scotch pine (*Pinus sylvestris* LINNAEUS) test blocks (4×4 cm in section and 30 cm in length). The test blocks were connected by a rope and were submerged vertically from the floating structure at 0.3, 0.8 and 1.3 m below the water surface and at regular intervals of 1 m from 2 m depth to the bottom level. The test string was renewed every month to examine the monthly settlement of shipworms.

After removal of the test blocks, they were cleaned off fouling organisms and debris, and then subjected to the close inspection of borer apertures on the surfaces of the blocks under a binocular stereoscopic microscope. Therefore, the number of borer punctures was taken as the single criterion of shipworm settlement.

Water temperatures and salinities at different depths of water were not measured but only at the surface level.

3.1 Series I during the period from June, 1975 through May, 1976

Shipworm attack continued for 9 months from June to February with a marked peak in September. The number of borer punctures on the wood surfaces was few in June, January and February. Particularly in February, only 2 borer holes were detected on the horizontal upper surface of a test block immersed at 23 m depth. Unfortunately the test string was lost in November.

The heavier infestation generally occurred at deeper levels as shown in Figs. 9 and 10. This phenomenon was also demonstrated at other parts of the world: Manati Bay, Cuba[47,53], San Francisco Bay[51], Beaufort, North Carolina[54], Loch Ryan,

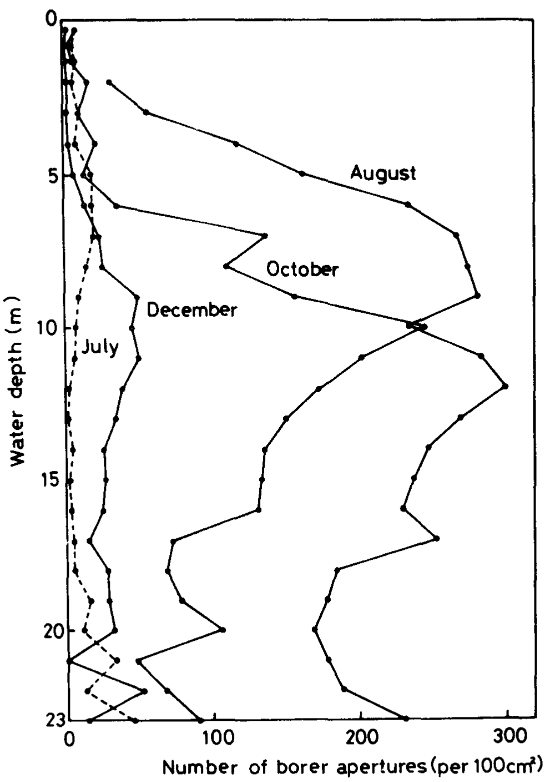


Fig. 9. Patterns of vertical settlement of shipworms in July, August, October and December, 1975.

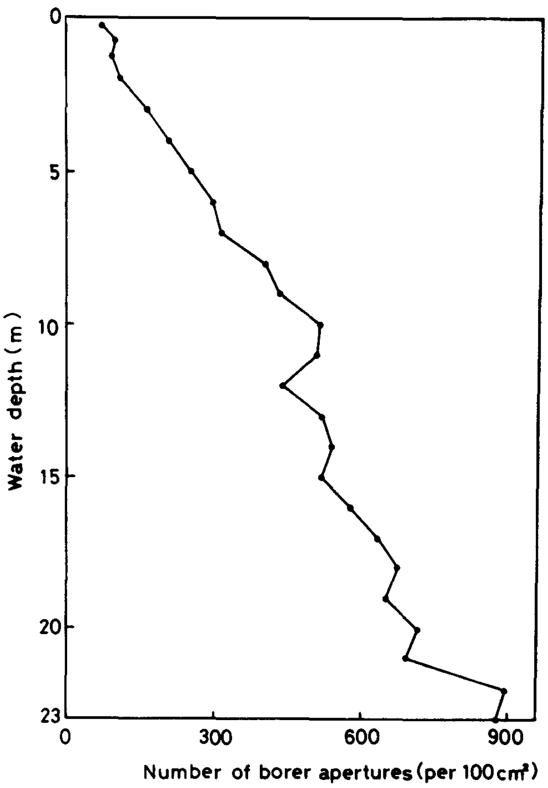


Fig. 10. Pattern of vertical settlement of shipworms in September, 1975.

Scotland[49], Ladysmith Harbor, British Columbia[52], Shirahama, Wakayama Pref.[44], Cochin Harbor, India[50], Monterey Bay, California[55].

In September the intensity of shipworm infestation typically increased with the increase in water depth down to the bottom (see Fig. 10). The extent of infestation increased abruptly with increasing depth down to 12 m and 10 m levels in August and October respectively. And it was followed by the sharp decrease at deeper levels up to approximately 20 m depth, and then it increased slightly as shown in Fig. 9. The resultant peaks of shipworm infestation along the water column were observed at around 10 m depth in August and October. In July and December slight shipworm attack was found, and the number of borer apertures relatively showed the even vertical distribution from 0.3 m depth to the bottom.

Pattern of vertical settlement of shipworms in September would be well explained by the effect of light: the maximum infestation is expected to occur in the dim regions[56,57]. The larvae of *Teredo pedicellata* DE QUATREFAGES* preferably settled and bored into wood under conditions of illumination of 166 ft candles[56]. In addition, the larvae tended to sink downwards whenever ciliary activity ceases, which is due to the higher specific density of the animals than that of sea water[57]. It, therefore, also possibly takes part in the tendency of vertical settlement in September. The larvae can actively move horizontally and vertically over a long distance. They are also transported by the current of water and the passive movement of water caused by the passage of boats. Consequently, combination of the above factors would force the shipworm larvae to move either upwards or downwards looking for the more favorable zone along the water column, and finally the larvae would tend to concentrate at deeper levels. However, the results in August and October did not testify to the above explanations: 2 peaks of shipworm settlement were observed along the water column. The increase in the extent of shipworm infestation observed from 20 m depth to the deepest level would be reflected by the abundance of shipworm mainly due to the presence of riddled sunken logs at the bottom.

Examination of the surface preference of shipworms showed that the animals preferably settled on the horizontal surfaces at all the depths, particularly at deeper levels. In August the ratios of borer's population on the horizontal surfaces to the total number of shipworms found on the overall surfaces of blocks were 55% at 2 m depth, 62% at 6 m depth, 68% at 10 m depth, 76% at 14 m depth, 70% at 18 m depth and 85% at 23 m depth. The ratios of shipworm population on the horizontal surfaces in July, September, October and December are tabulated below (Table 21).

Of the horizontal surfaces, the upper surfaces were infested more severely than

* ISHAM *et al.* called the specimens which they studied *Teredo pedicellata* DE QUATREFAGES. But that was misidentification. The species is a synonym of *Teredo bartschi* CLAPP after TURNER[18].

Table 21. Ratios of shipworm population (%) on the horizontal surfaces to the total number of shipworms found on the overall surfaces of the blocks at selected depths.

Depth (m)	Month			
	July	Sep.	Oct.	Dec.
2	42	57	53	20
6	70	58	56	53
10	63	73	78	59
14	44	64	58	61
18	60	79	74	80
23	85	81	72	64

Table 22. Ratios of shipworm population (%) on the upper surfaces to the total number of shipworms found on the overall surfaces of the blocks at selected depths.

Depth (m)	Month				
	July	Aug.	Sep.	Oct.	Dec.
2	33	8	23	22	10
6	53	32	38	38	25
10	48	48	67	63	52
14	22	63	52	52	55
18	53	62	69	65	75
23	75	78	75	66	53

the lower ones. This tendency was also conspicuous in deeper regions as shown in Table 22. Shipworms would selectively settle on wood when they go downwards since the upper surfaces generally suffer the severest infestation of the shipworms. The fact that the number of settling shipworms on the upper surfaces increases proportionally with water depths would also demonstrate the settling behavior of the shipworms.

3.2 Series II during the period from June, 1976 through May, 1977

Shipworm attack was observed for 8 months from June to January. A remarkable peak was recorded in August when monthly mean water temperature at the surface level was the highest (28.7°C) in the year. Monthly mean water temperatures in Series II were lower by 0.5°~1.3°C than those in Series I.

The heaviest infestation approximately occurred in the deepest zone as shown in Figs. 11 and 12. The number of borers increased with the increase in depth down to 5~10 m regions. The surface zone between 0.3 m and 1.3 m depths was very slightly attacked by the animals (fewer than 20 apertures per 100 cm^2). In August,

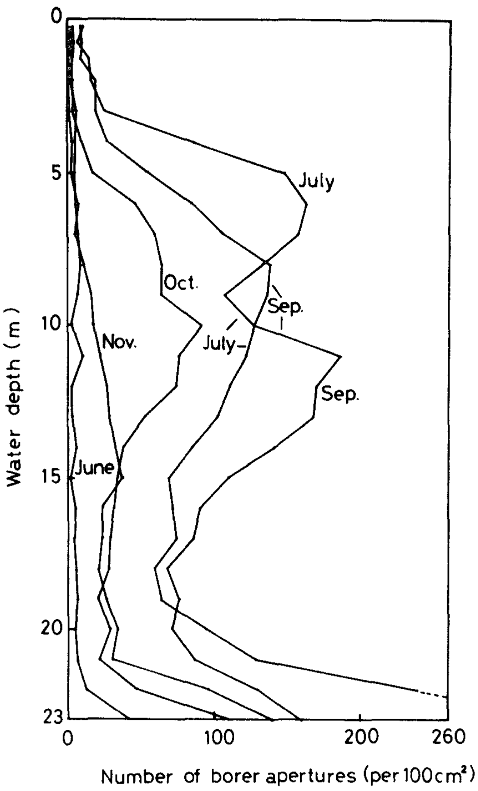


Fig. 11. Patterns of vertical settlement of shipworms in June, July, September, October and November, 1976.

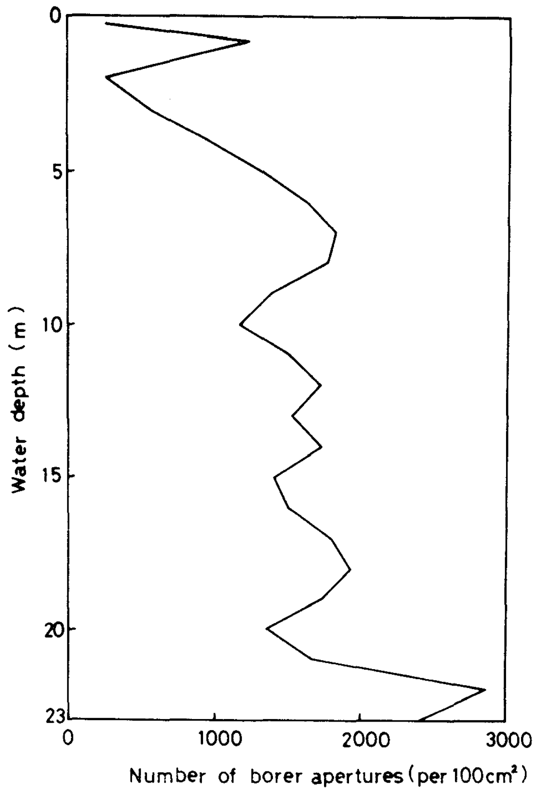


Fig. 12. Pattern of vertical settlement of shipworms in August, 1976.

however, much severer attack emerged even at 0.8 m depth, and the extent of infestation increased almost proportionally with water depth, though there found a great variation. Patterns of monthly vertical settlement of shipworms in Series II are figured in Figs. 11 and 12.

The horizontal surfaces suffered severer infestation than the vertical ones as shown in Table 23, but the ratios were comparatively lower than those in Series I. The upper areas of the horizontal surfaces were generally infested more severely

Table 23. Ratios of shipworm population (%) on the horizontal surfaces to the total number of shipworms found on the overall surfaces of the blocks at selected depths.

Depth (m)	Month						
	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
2	0	44	53	64	50	0	0
6	67	55	60	71	40	50	25
10	50	56	64	61	57	59	0
14	60	57	62	56	66	48	33
18	90	53	63	60	63	48	25
23	82	67	62	46	60	73	50

Table 24. Ratios of shipworm population (%) on the upper surfaces to the total number of shipworms found on the overall surfaces of the blocks at selected depths.

Depth (m)	Month						
	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
2	0	16	26	51	29	0	0
6	60	45	47	62	29	35	0
10	67	49	42	53	30	34	0
14	61	40	44	48	40	41	17
18	86	48	54	34	54	25	0
23	74	50	55	30	37	55	13

than the lower and lateral surfaces (Table 24).

Though the pattern of vertical settlement of shipworms may possibly be affected by illumination[56,58], water temperature gradient with depths obviously restricts the vertical distribution of shipworms[59]. Therefore, the shipworms would be liable to move to the favorable light and temperature zones. For instance, the shipworm larvae are likely to concentrate on the wood at the surface level during the night, whereas they tend to settle on wood at deeper levels in the daytime[31]. Combination of these factors could produce the different types of monthly vertical settlement of shipworms as indicated in the present investigations.

Based on the results of Series I and II, the patterns of monthly vertical settlement of shipworms are assorted into the following 4 types:

(1) The intensity of infestation increases with the increase in water depth so that the peak is recorded at the deepest region — September, 1975 and August, 1976.

(2) The heaviest infestation, as same as the above, is observed at the deepest level with the second peak at approximately 10 m depth — July and October, 1976.

(3) The heaviest infestation is observed at about 10 m depth; the extent of infestation increases in proportion to depths down to 10 m level and then decreases adversely, but rises again at depths between 20 m and 23 m — August and October, 1975 and September, 1976.

(4) The infestation occurs very slightly and relatively evenly along the water column — June, July and December, 1975 and June, November and December, 1976.

The heaviest-infested months, September, 1975 and August, 1976 truly belong to the type (1). And the months before and after the severest months undoubtedly represent 2 peaks at around 10 m and 23 m levels, belonging to the type (2) or (3).

As the results demonstrated that the shipworms can locomote vertically throughout the depths from the surface to the bottom, it is consequently important to remove not only the riddled floating wood but also the sunken logs especially in July, August, September and October for the purpose of reducing shipworm attack. This is principally significant to such the case of sea water log storage area as the test site in the present investigation.

4. Growth rates of the shipworm, *Teredo navalis* LINNAEUS[60]

Difficulties in determining the rates of growth of shipworms are due to the fact that the shipworms are hidden in wood habitat just after initial boring.

Formerly, test panels infested with shipworms of known age were periodically sectioned to measure body length, diameter of burrow and burrowing volume, but this method could not follow the same individuals afterwards[61~64].

The X-ray technique can, however, satisfactorily be used for the determination of the rates of growth. The advantage of this method is that it does not destroy the wood habitat and the animals and renders possible the repeated measurement of individuals over long periods. The possibility to use the X-ray technique for the study of the growth rates of shipworms was first indicated in 1924[39].

Several investigators[14,55,65~68] have so far employed the X-ray technique for growth studies. The technique can also be applied for the estimation of the progressive shipworm attack of untreated or treated wood with the length of immersion[69~71].

In the present investigation the X-ray technique was employed for the determination of the growth rates of *Teredo navalis* LINNAEUS, a representative species in Japanese waters as well as in other temperate parts of the world.

The investigations were carried out at Uchinoumi, Naruto, Tokushima Pref. (34°12′30″N, 134°36′27″E).

The rates of growth of shipworms were estimated directly from the lengths of burrows on the X-ray photographs.

All the shipworm specimens examined here were the commonest shipworm species *Teredo navalis* LINNAEUS.

Length measurements included 3 series from August, 1973 as follows:

Series I —August 19, 1973-May 19, 1974

Series II —September 10, 1974-September 10, 1975

Series III—September 10, 1975-September 10, 1976

Douglas fir blocks which were covered with plastic sheets except for the ends were submerged in the sea from the experimental rafts, as the blocks were positioned between 30 and 100 cm below the surface of the water. Shipworm attack was therefore restricted only to the ends, and the animals had to grow parallel to the grain.

The size of blocks was 2×6×30 cm in Series I, and changed to 2×6×28 cm in Series II and III simply because X-ray photographs could be taken more conveniently from this size.

The blocks were removed at monthly intervals for applying X-rays and then returned to the water to permit continuous development of the animals.

4.1 Series I

Of 3 test blocks submerged on August 19, 1973 and first X-rayed on October 22, 1973 (64 days after immersion in the sea), only one block was infested with 2 borers (A and B in Table 25). Their rates of growth were repeatedly followed. On November 19, another specimen (C in Table 25) appeared on the X-ray photograph, and it measured 4mm long. In addition, one more specimen (D in Table 25) was found on January 19, 1974. This animal possibly succeeded in penetrating into the test block in late December or early January when water temperatures were below 14°C.

As expected, all the animals grew almost straight along the grain, and the longer ones (A and B) attained a length of about 200 mm within 5 months. They, however, were found dead on May 19, 1974 at the age of 9 months as shown by the deposition of the valves and pallets on the X-ray photograph. The younger specimens C and D had grown up to 59 mm and 29 mm respectively until May 19 when they were at least 6 months and 4 months old (Table 25). Consecutive growth of the animals is shown in Fig. 13.

Table 25. Body lengths (mm) of shipworms at Naruto during the period from August 19, 1973 to May 19, 1974.

Specimens	Oct. 22 1973	Nov. 19	Dec. 19	Jan. 19 1974	Feb. 19	Mar. 19	Apr. 19	May 19
A	99	155	194	220	241	252	270	Dead
B	97	152	180	195	207	223	241	Dead
C	—	4	9	17	25	31	43	59
D	—	—	—	3	8	12	18	29
Water temp. (°C)*	23.6	19.6	13.9	9.0	8.3	9.5	14.8	18.7
Salinity**	32∼34							

*: Monthly mean water temperature at the surface level.

**: Salinity ranged between 32 and 34‰ through the investigation.

On the basis of the monthly increment of body length, the rates of growth were high during the period with high water temperatures above 20°C as shown in Fig. 14, and dropped remarkably below 15°C although the animals continue burrowing. Moreover, each individual that showed similar growing pattern for the first few months as seen in A and B, gradually changed the pace of burrowing (Fig. 14), and attained different body lengths at last.

4.2 Series II

Six test blocks were submerged on September 10, 1974. The first X-ray photographs of them taken on October 10, 1974 revealed an infestation of shipworms in

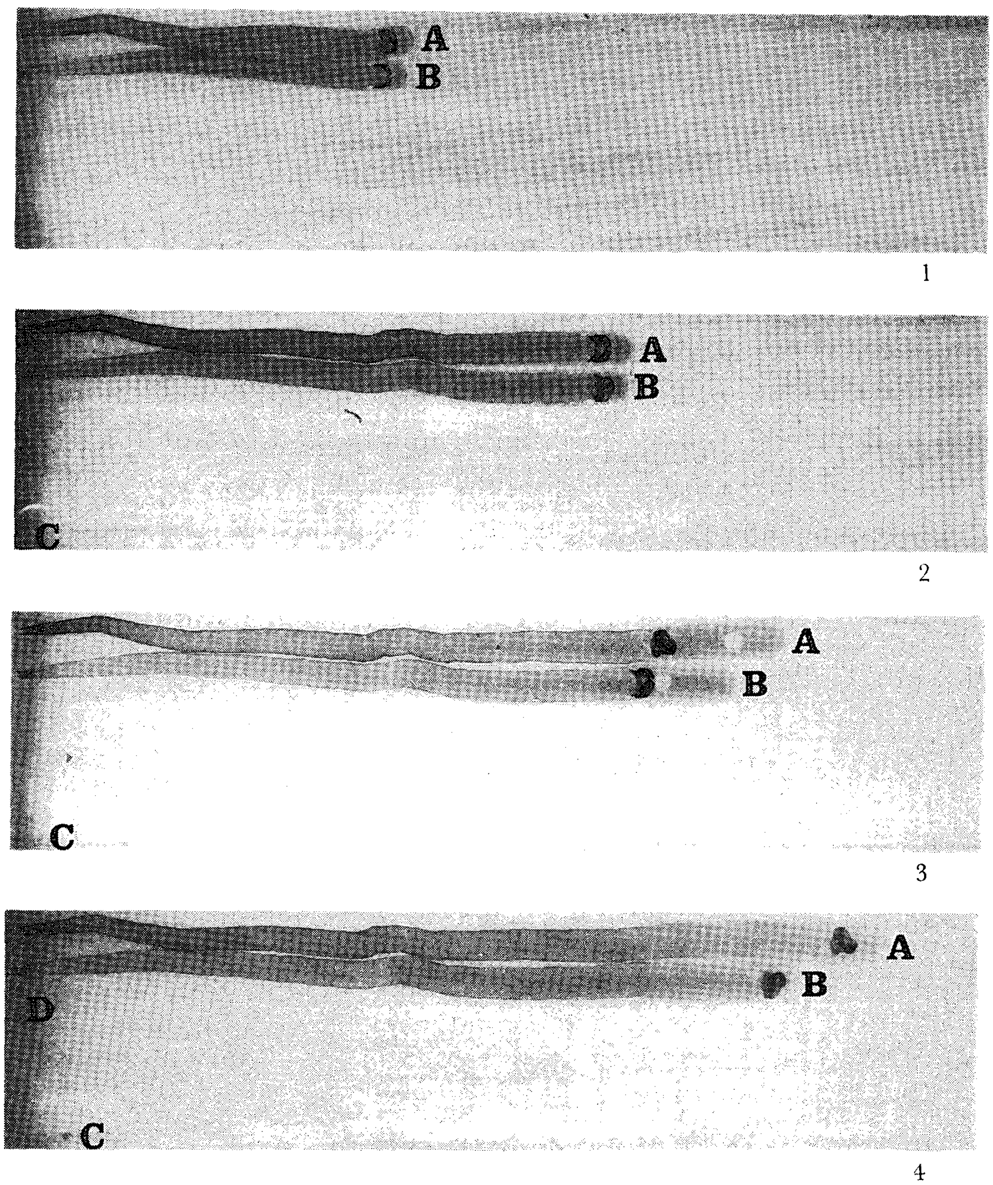


Fig. 13-A. Consecutive growth of *Teredo navalis* LINNAEUS at Naruto. Douglas fir test block (2 × 6 × 30 cm) was submerged in the sea on August 19, 1973.
1: About 2 months after submergence (body length—A=99 mm, B=97 mm)
2: Three months after submergence; specimen C first appeared (body length —A=155 mm, B=152 mm, C=4 mm)
3: Four months after submergence (body length—A=194 mm, B=180 mm, C=9 mm)
4: Five months after submergence; another specimens D appeared (body length—A=220 mm, B=195 mm, C=17 mm, D=3 mm)

5 test blocks. Nine specimens were distinguished and their rates of growth were followed. The measurements showed average rates ranging from 13 mm for one month old specimens to 38 mm per month for 3 months old ones. Results of length measurements are shown in Table 26 together with average lengths. The largest

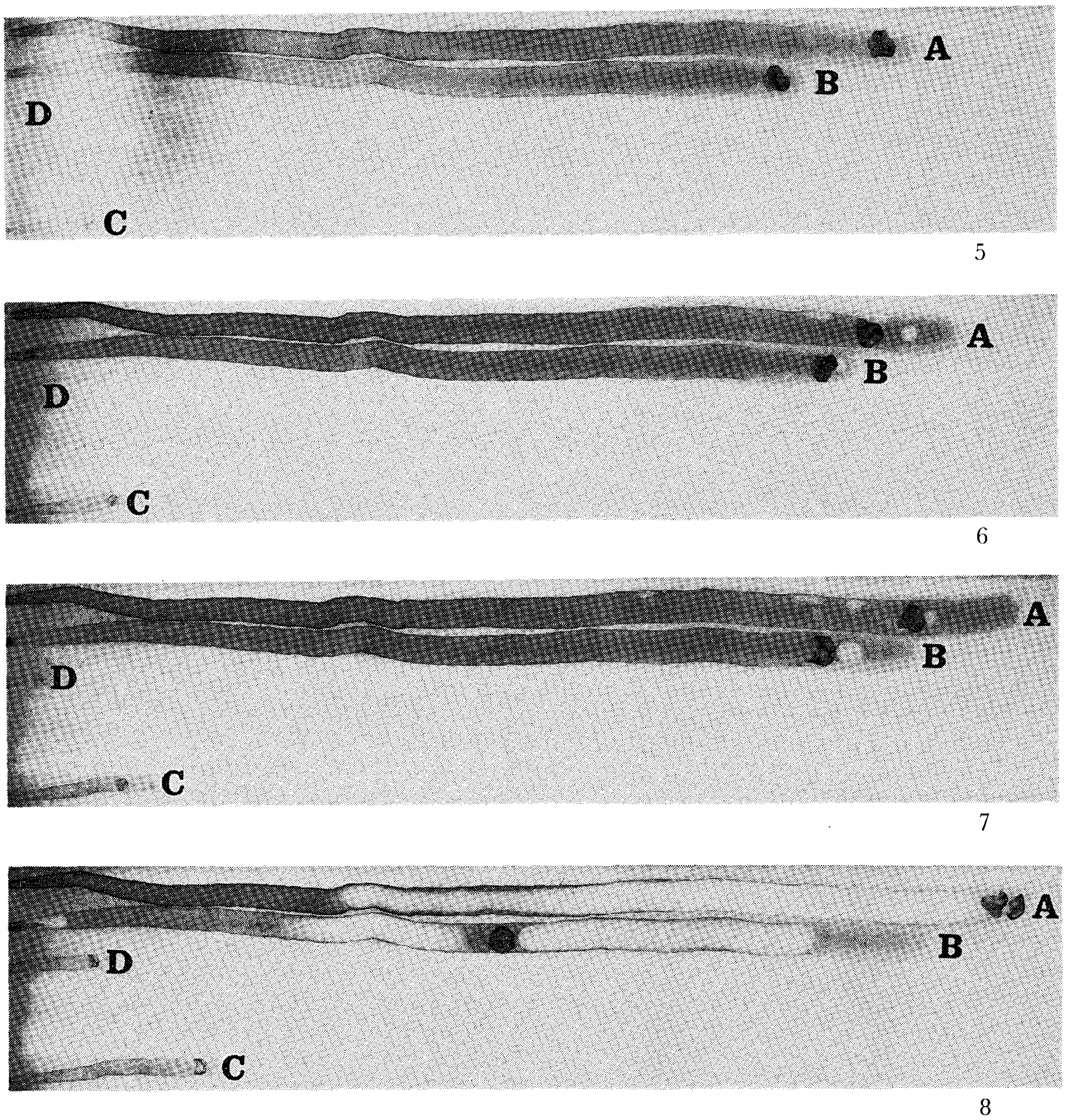


Fig. 13-B. Consecutive growth of *Teredo navalis* LINNAEUS at Naruto.
5: Six month after submergence (body length—A=241 mm, B=207 mm, C=25 mm, D=8 mm)
6: Seven months after submergence (body length—A=252 mm, B=223 mm, C=31 mm, D=12 mm)
7: Eight months after submergence (body length—A=270 mm, B=241 mm, C=43 mm, D=18 mm)
8: Nine months after submergence (body length—A, B=dead, C=59 mm, D=29 mm)

specimens H and I were longer as compared with the 2 specimens A and B of Series I at the same age. They extended their burrows over the whole length of a test block (28 cm) within 8 months.

Three animals which appeared on the X-ray photographs of November 10 were

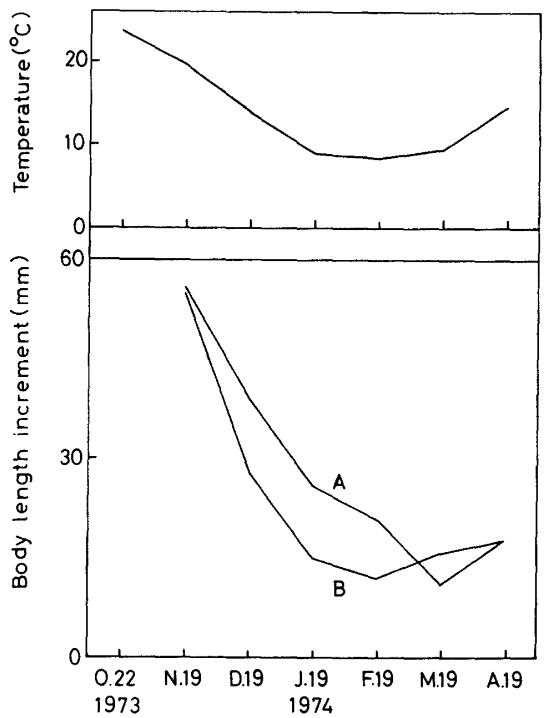


Fig. 14. Monthly body length increment of 2 specimens of *Teredo navalis* LINNAEUS (A and B in Table 25) at Naruto.

Table 26. Body lengths (mm) of shipworms at Naruto during the period from September 10, 1974 to July 10, 1975*.

Specimens	Oct. 10 1974	Nov. 10	Dec. 10	Jan. 10 1975	Feb. 10	Mar. 10	Apr. 10	May 10	June 10	July 10
E	3	32	66	88	90	100	108	Dead		
F	5	47	95	132	152	170	185	205	Dead	
G	17	51	104	126	142	155	171	200	247	**
H	21	104	173	209	232	248	271	280	**	
I	19	103	174	207	231	248	270	278	**	
J	33	115	132	149	164	174	196	200	**	
K	11	82	123	148	158	161	168	190	**	
L	4	21	43	64	81	93	112	144	**	
M	5	62	123	160	182	192	211	243	280	Dead
Average***	13	69	115	143	159	171	188	218	—	—
Water temp. (°C)****	24.3	19.2	14.3	10.9	8.8	10.3	14.0	17.5	21.9	25.4

*: Test blocks were X-rayed until September 10, 1975.

**: Impossible to measure body lengths because of crowding or complicated turning of the burrows.

***: Average body length (mm) of the animals.

****: Monthly mean water temperature at the surface level.

Table 27. Body lengths (mm) of 3 specimens which appeared first on November 10, 1974 at Naruto.

Specimens	Nov. 10 1974	Dec. 10	Jan. 10 1975	Feb. 10	Mar. 10	Apr. 10	May 10	June 10	July 10
N	30	88	134	165	190	227	257	*	
O	26	82	120	142	156	178	208	255	*
P	30	79	121	148	173	200	224	273	*
Average**	29	83	125	152	173	202	230	—	—

*: Impossible to measure body lengths because of crowding or complicated turning of the burrows.
**: Average body length (mm) of the animals.

also measured and the results are shown in Table 27.

4.3 Series III

Seven shipworm specimens in 3 test blocks submerged on September 10, 1975 were detected on the first X-ray photographs taken on October 10, 1975. On the basis of the results of length measurements in Table 28, the average rates ranged from 12 mm for one month old specimens to 55 mm per month for 3 months old ones. The largest monthly growth, however, was obtained in the second month (over 80 mm on an average) as true for Series II, though the animals of Series III grew somewhat more rapidly than those of Series II. The largest specimen T reached 280 mm in length within just 5 months.

Table 28. Body lengths (mm) of shipworms at Naruto during the period from September 10, 1975 to July 10, 1976*.

Specimens	Oct. 10 1975	Nov. 10	Dec. 10	Jan. 10 1976	Feb. 10	Mar. 10	Apr. 10	May 10	June 10	July 10
Q	13	92	152	200	229	230	241	260	264	Dead
R	14	108	161	207	241	267	**			
S	11	78	143	183	207	232	252	**		
T	10	110	191	247	280	Dead				
U	8	71	135	173	188	202	Dead			
V	17	113	188	239	Dead					
W	10	97	181	245	**					
Average***	12	96	165	212	233	—	—	—	—	—
Water temp. (°C)****	23.9	19.2	15.1	9.9	9.6	11.1	13.4	17.9	21.4	24.4

*: Test blocks were X-rayed until September 10, 1976.
**: Impossible to measure body lengths because of crowding or complicated turning of the burrows.
***: Average body length (mm) of the animals.
****: Monthly mean water temperature at the surface level.

Table 29. Average rates of growth (mm) per month compiled from the results of Series I, II and III.

Age (month)	1	2	3	4	5	6	7	8
Average growth per month (mm)	13	44	48	46	40	33	31	30

As shown in Table 29, the average growth rates per month are statistically estimated from all the results despite the great variations observed among individuals.

The results obtained herein appear to coincide with Grave's[61] on the whole, but not with IMAI and other's[63].

Teredo furcillatus MILLER (a synonym of *Teredo furcifera* VON MARTENS after TURNER[18]), allied to the tested materials here, showed that the maximum increment of body length (29 mm) corresponded to the highest water temperature of 30.9°C in May. And all the animals were dead in October when water temperature was still high (30°C) enough for surviving. That was due to the sudden drop of salinity from about 26.5‰ to 4.63‰[64].

Accordingly, the growth of shipworms should be considered by the interrelation of environmental factors such as salinity and water temperature. Salinities at Naruto remained at 32~34‰ throughout the investigations and resulted in an insignificant effect on the growth of shipworms.

The growth of shipworms, however, is undoubtedly affected by water temperature, and additionally by the rate of crowding and the difference of activities among individuals. The mere values of water temperature influence shipworms' growth, but the fluctuations of the temperature throughout the year seem to play the more important role in boring virility of the animals. Dependence of shipworm growth on water temperature is also demonstrated by the abrupt decrease in winter with temperature below 10°C.

The decrease in growth with the fall of water temperatures in winter time (Tables 25, 26, 27 and 28), and the fact that individuals separately keep lengthening their burrows would mean that the growth rates vary not only seasonally but also individually (see specimens C and D in Table 25, and N, O and P in Table 27).

Favorable temperatures for shipworm boring consequently seem to lie between 15° and 25°C at the test site. Moreover, the rapid growth for the first few months during September, October, November and December testifies the temperature preference of the shipworms as shown in Fig. 15.

As the shipworms were forced to grow parallel to the grain this time, which could be the most favorable condition for their boring, they grew more quickly than those who usually have to bore across the grain.

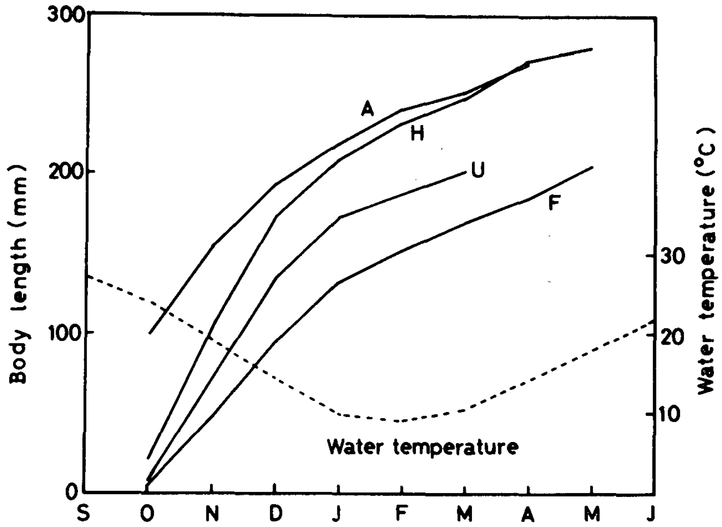


Fig. 15. Increase in body lengths of the 4 selected specimens (A, F, H and U) at Naruto.

During his inspections the author has rarely found shipworms longer than 300 mm in attacked logs stored in sea water along Japanese coast lines for 6 months because the individuals can not burrow straight along the grain undisturbedly by others.

When the growth rates of *Teredo navalis* LINNAEUS are compared with other shipworm species such as *Bankia setacea* (TRYON)[55,68], the latter, possibly preferring a different water temperature, shows higher growth rates than the former. The difference in growth rates of these 2 species is probably species-specific.

As shown above, the body lengths of shipworms are not directly determined by the age, but the animals can reach sexual maturity within a relatively short time. The youngest *Teredo navalis* LINNAEUS which can spawn are just 6 weeks old, and 38 mm in length[61]. Therefore, we have to take the removal of attacked timber into consideration as a possibility to prevent deterioration. That is particularly true for the sea water log storing areas which are located along the coasts of Japan seriously infested with shipworms.

5. Effect of the time and the length of immersion on the rates of shipworm attack on wood[72]

As the import of logs into Japan has been increasing recently, the shipworm attack on the logs stored in sea water is becoming a great economic concern in present-day Japan.

In practical problems of protecting wood against shipworm attack, the rate of attack becomes a matter of importance: the variation of the extent of shipworm attack on wood with the time or the length of immersion should be taken into consideration.

The number of shipworm tunnels[16], area reduction of cross section[13,36,55] and weight loss[73] have been converted into a shipworm attack rating. Of these criteria, area reduction seems to be the best if measurement can be done easily and accurately. However, the use of X-ray[74] would be the most available when it is necessary to estimate the progress of shipworm attack on wood and the growth rates of shipworms with the length of immersion since the X-ray technique can follow the same wood blocks at regular intervals for a given period without destruction of wood blocks and animals.

In the present investigation, the rate of shipworm attack on wood blocks was expressed as the reduction of cross sectional area, and was discussed in relation to the effect of the time and the length of submergence.

The investigations were conducted at the sea water log storage area, Takahama, Fukui Pref. The geographic locality of the test site should be referred to the previous paper[36].

Scotch pine (*Pinus sylvestris* LINNAEUS) test block measuring 4×4 cm in section and 30 cm in length with a center hole for rope penetration was employed. A test string that consisted of 3 test wood blocks was vertically submerged with a rope in the sea so that 3 test blocks might be respectively at 30, 80 and 130 cm below the surface of the water.

The test strings were immersed for a month to 7 months at the longest during the periods from June 1 to December 28, 1975 and from June 1 to December 29, 1976 being coincided with the season of settlement at the test site[36].

After removal of the strings, foulers and surface debris were washed off. And then the test blocks were dried before cutting 5 slices (1 or 2 mm in thickness) at intervals of about 5 cm from the end of each block for measuring area reduction of cross section caused by shipworm attack. The measuring device employed was an automatic area meter, Hayashi Denko AMM-5 Type, accurate to the nearest square millimeter. The extent of shipworm attack on test wood blocks is consequently expressed as the mean value of the percentage of cross sectional area reduction measured for all the slices that are obtained from 3 test blocks removed at the same time. As the slices thicker than 3 mm are rejected by the automatic area meter, the maximum limit of potential measurement is defined to 35%. Because the measurable slices are unobtainable from severely attacked wood blocks. The slices with over 35% of cross sectional area reduction mean that they are riddled too heavily to be subjected to cutting into slices thinner than 3 mm.

The duration of the present investigation was determined on the basis of the previous results on the season of settlement of shipworms under floating condition at the same test site during the period from February, 1971 to January, 1972.[36]

In addition, the present results on the monthly settlement of shipworms at the test site (see 2.3) also support that the test duration is appropriate for the present purpose.

The first series of the investigation was performed from June 1 to December 28, 1975. Many of the test blocks were unfortunately lost because of the raid of typhoon in August, 1975. The results are consequently quite insufficient, but will be briefly mentioned below. Test blocks submerged on August 1, 1975 were riddled so seriously that the rate of attack attained to the severe cross sectional area reduction over 35% until November 1, 1975. Favorable high water temperatures in the period obviously appeared to contribute to the rapid destruction. When the test blocks submerged on September 1, 1975 are compared with the above instance, they suffered much lower boring damage. Area reductions were below 1% for a month, 12% for 2 months, 25% for 3 months and 33% for 4 months. Reduction in cross sectional area of all the blocks immersed on October 1 and November 1, 1975 never exceeded 5% after 2 month submersion. The results additionally showed that the blocks exposed on June 1 and July 1, 1975 underwent over 35% cross sectional area reduction respectively after 6 and 5 month submergence.

From June 1 to December 29, 1976 the same series was conducted, and the results are shown in Table 30.

Shipworm attack on wood blocks naturally tended to become serious with the increase in the length of submergence, though the rate of increase in severity varied with the time of immersion. The first month of submergence generally did no conspicuous damage below 1% to the test blocks as shown in Table 30, but an exception was perceived in August, 1976, namely 2% loss in cross section of the blocks was recorded depending on the enormous settlement of shipworms in the month. The relatively large increment in the rate of shipworm attack on test blocks was currently

Table 30. Percentage of cross sectional area reduction of test wood blocks at Takahama during the period from June 1 to December 29, 1976.

Immersion date	Removal date						
	July 1	Aug. 1	Sep. 1	Oct. 1	Nov. 1	Dec. 1	Dec. 29
June 1	<1[a]	<1	5	22	>35[b]	Lost	Lost
July 1		<1	7	21	>35	>35	>35
Aug. 1			2	25	>35	>35	>35
Sep. 1				<1	< 1	11	20
Oct. 1					0	< 1	4
Nov. 1						0	0
Dec. 1							0

a) below 1%, b) above 35%.

Table 31. Percentage of cross sectional area reduction of test wood blocks and number of borer apertures per 100 cm² at Naruto during the period from June 1 to December 28, 1973. Number of borer apertures is given in the brackets.

Immersion date	Removal date						
	July 1	July 31	Aug. 30	Sep. 29	Oct. 29	Nov. 28	Dec. 28
June 1	<1[a] (16)	4 (41)	15 (36)	22 (56)	21 (59)	>35[b] (47)	
July 1		<1 (22)	7 (28)	12 (34)	14 (37)	30 (30)	
July 31			<1 (2)	<1 (13)	<1 (8)	Lost	
Aug. 30				1 (67)	9 (125)	15 (80)	
Sep. 29					<1 (138)	25 (206)	
Oct. 29						<1 (29)	4 (37)
Nov. 28							0 (1)

a) below 1%, b) above 35%.

observed in the second and the third month after submergence. That meant that the shipworms acceleratedly lengthened their burrows after the initial penetration into wood, which was suggested by the studies of growth rates of shipworms[60].

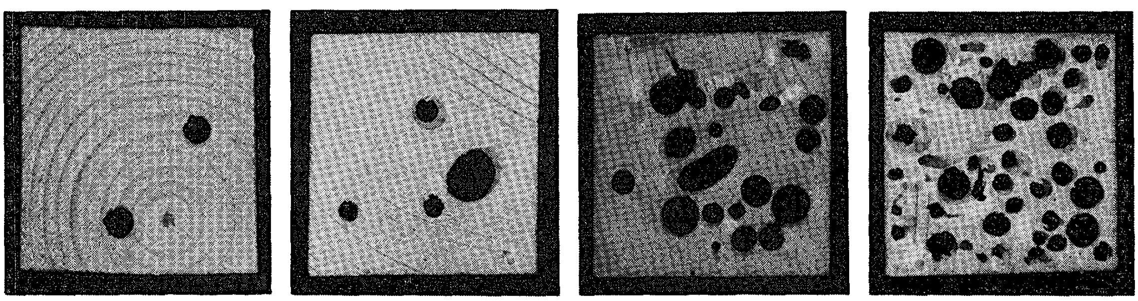
The similar investigation was carried out at Naruto, and the supplemented data are shown in Table 31. The results at Naruto also suggested that the pace of shipworm attack on test wood blocks was relatively rapid in the second and the third month after immersion.

The blocks submerged on July 1 and August 1, 1976 sustained over 20% area reduction in cross section at the end of 3 month submergence. Contrary to expectation, a few extreme exceptions of which the cross sectional area reductions did not surpass 1% within 2 month immersing period were found. At Takahama the immersion of blocks on June 1, September 1 and October 1, 1976 did not seem to be harmful, and at Naruto the blocks suffered the slight loss in cross section when the immersion started on July 31, 1973. The fact is possibly explained by the scant occurrence of shipworms at the incipient stage of immersion (Tables 30 and 31). The more distinct examples were therefore noticed for the blocks submerged in the late period of the season of shipworm settlement. Furthermore, the fouler's covering and the accumulation of debris on the wood surfaces might partly reduce the potential area for the later setlement of the shipworms on wood blocks.

At Takahama the season of settlement of shipworms indicated the typical one peak pattern in 1976. The enormous settlement of shipworms occurred in August.

The blocks which were suspended on August 1, 1976 and were exposed to the peak of settlement of shipworms suffered the rapid destruction with the severest loss in cross section (23%) in the second month after submersion. Immersion which started on September 29, 1973 at Naruto similarly did the heaviest damage to the wood blocks during the second month after submergence. On the other hand, the blocks submerged on September 1, 1975 at Takahama sustained only 12% reduction in cross section within 2 months. There is no satisfactory explanation for the difference and/or fluctuation observed at separated localities, though the heavy settlement of shipworms definitely acted the important role in the rapid destruction.

It is moreover noticeable that at Takahama a marked increment in the extent of shipworm attack on wood blocks was found in September, 1976 for the blocks which were submerged on June 1 and July 1, 1976 as can be seen in Table 30. Fig. 16 shows a series of cross sections of the test wood blocks submerged at 80 cm below the surface of the water on June 1, 1976. With the increase in immersing period, the number of shipworm tunnels increases in cross sections as well demonstrated in the figure.



(a) two months after submergence (b) three months after submergence (c) four months after submergence (d) five months after submergence

Fig. 16. Cross sections (4×4 cm) obtained from test wood blocks which were submerged at 80 cm below the surface of the water on June 1, 1976.

As described before, the heavy infestation of shipworms in test wood blocks caused the wood blocks to receive the severe extent of attack within a short time. However, the number of shipworm apertures on the surfaces of wood blocks does not always seem to be the direct reliable measure when the progress of shipworm attack on the blocks is assessed[36]. Because the number of borer punctures is not likely to increase in proportion to the length of immersion. Therefore, the time and the length of immersion must be considered with caution to protect wood against shipworm attack.

There is a widely accepted circulation among wood dealers that the logs stored in sea water get into dangerous condition against shipworm attack if they are kept in the sea for 45 days or longer during the season of settlement of shipworms. However, a few exceptions of which the longer immersion of wood blocks in the sea does not always lead to the heavier damage are found in the present investigation as seen in Table 30. That suggests that the time of immersion is meaningful in helping shipworms do damage to wood. Practically, much attention should be paid to the imported logs stored in sea water along the coasts of Japan since Japanese waters are seriously infested with shipworms. When the storage sets in and how long the logs are stored in the sea may be particularly significant if the storing period includes August, September and October. In the case of the storage which starts in November and December, it would be unnecessary to remove the logs onto the land even when the logs are kept in the sea for a longer period. In addition, the storage which starts in the period without shipworm settlement (from January to May at Takahama) may be less harmful to the logs even if the storage is prolonged over months, for microbial films and fouler's covering on the surfaces of logs prevent the shipworm from settling and penetrating afterwards. In conclusion, it is desirable to avoid the sea water storage of the imported logs for a period longer than 2 months during the season of furious shipworm settlement extending over a considerable period, possibly from June to October at the present test site.

Conclusions

The coasts of Japan are seriously infested with wood-boring bivalves belonging to family Teredinidae as evidenced in part 1. The most important species in Japanese waters are *Teredo navalis* LINNAEUS and *Lyrodus pedicellatus* (QUATREFAGES). *Bankia* species are occasionally found at some localities. Though the animals of genus *Bankia* are not abundant in number, they can be deserving of special caution because of the possibility of rapid growth.

Season of settlement of shipworms has been investigated at various localities in the world because the informations on the subject could give the first step to understand the shipworm problem. Shipworms breed for 7 months or so from June through December along the coasts of Japan as described in part 2. At a few localities the settlement of shipworms is noticed even in January and extremely in February. The peak of settlement is observed in August or September or October varying with localities, which may be caused by the differences of species present, the fluctuations of water temperatures through the year, the amount of wood available for the borers, the activities of fouling communities and so forth. Consequently, in the sea water log storage areas the logs are exposed to shipworm attack for a relatively long period in some cases so that the time of removing logs onto the land before the damage is detected becomes a matter of importance.

The logs are generally stored in the form of a bundle raft or a flat raft in the zone between 0 m and 2 m below the surface of the water. However, shipworms tend to attack wood located all through the water column, and the intensity of settlement is definitely severer in deeper regions than in surface ones (part 3). It is effective to remove not only floating riddled wood but also the sinkers at the bottom for the purpose of reducing and preventing the economic damage on the basis of the knowledge of settling season.

The shipworms, inconveniently to the logs stored in sea water, grow acceleratedly for the incipient few months just after initial boring. Based on the growth studies, the shipworms can lengthen their burrows up to over 5 cm within 2 months (part 4). The pace of growth is evidently influenced by environmental factors. Sudden and extreme change in the principal factors such as water temperature and salinity might result in the death of the animals, though the shipworms are known to be both eurythermal and euryhaline.

The fact that almost all the early attempts for preventing shipworm attack have been unsuccessful in practical use suggests that eradicating the adult borers in wood and the larvae is very difficult. Accordingly the most reliable way to protect logs against shipworm attack seems to land them within 60 days after the start of storage if the logs have to be stored in the season of serious settlement, particularly in July, August, September and October. The results on the rates of shipworm attack on wood also support the counterplan (part 5). However, the logs are actually covered with bark which is expected to be a natural chemical and/or physical barrier. The propagation of fouling organisms and the accumulation of debris on the wood surfaces must counteract the settlement of shipworms and the growth of them. Therefore, the time of landing logs would be a little later in practical cases, if the data on the season of settlement, the rates of growth, and the rates of attack on wood permit the longer storage of logs in the sea at given localities.

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