Studies on the Shipworms III
Pattern of Vertical Settlement of Shipworms

Kunio TSUNODA* and Koichi NISHIMOTO*

Abstract——Test wood blocks (*Pinus sylvestris* LINNAEUS, 4×4 cm in section and 30 cm in length) were suspended vertically in the sea at the sea water log storage area, Takahama, Fukui Pref. The test blocks were connected by a rope and submerged at 0.3, 0.8 and 1.3 m below the water surface, and at regular intervals of 1 m from 2 m to the bottom level (about 23 m). The blocks were removed and replaced every month for examining monthly settlement of shipworms on the surfaces of the blocks.

The heavier settlement of shipworms was generally observed in deeper regions, particularly at the bottom. This tendency was prominent in the months when the furious shipworm settlement was noticed. The patterns of monthly vertical settlement of shipworms on wood surfaces were divided into the following 4 types:

(1) The intensity of settlement of shipworms increases proportionally with water depth so that the maximum settlement is recorded at the deepest level (September, 1975 and August, 1976).

(2) The heaviest settlement is observed at the deepest level with the second peak at about 10 m depth (July and October, 1976).

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

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

The effect of light intensity and water temperature gradient with water depths would partly account for the different patterns of monthly vertical settlement of shipworms. And the active vertical locomotion of shipworms might help shipworms concentrate at deeper levels. The results suggest that the sunken logs at the bottom are the important reproductive sources of shipworms. It is therefore helpful to remove not only riddled floating wood and logs but also sunken logs for reducing shipworm attack in the sea water log storage areas.

Introduction

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[1~8]. Both limnorial borers and shipworms are significant for the destruction of marine wooden structures. However, only shipworms play an important role in the matter of the deterioration of the logs stored in the sea water log storage sites[9,10].

Only a few papers have dealt with the pattern of vertical settlement of shipworms[4,11~16]. They showed that the intensity of shipworm attack generally increased with depths in shallow waters. If these results are true for the sea water

* Division of Wood Biology.

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.

Experimental

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[10].

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 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.

Results and Discussion

1. Series I during the period from June 1, 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 at least down to about 10 m, as shown in Figs. 1 and 2. This phenomenon was also demonstrated at other parts of the world: Manati Bay, Cuba[11,17], San Francisco Bay[15], Beaufort, North Carolina[18], Loch Ryan, Scotland[13], Ladysmith Harbor, British Columbia[16], Shirahama, Wakayama Pref.[6], Cochin Harbor, India[14], Monterey Bay, California[19].

In September the intensity of shipworm infestation typically increased with the increase in water depth down to the bottom (see Fig. 2). The extent of infestation increased abruptly with increasing depth down to 12 m and 10 m levels

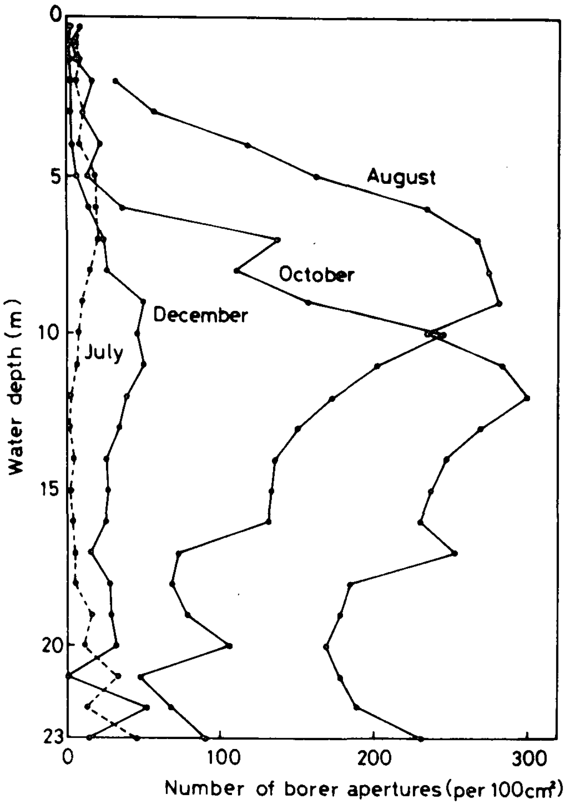

Fig. 1. Patterns of vertical settlement of shipworms at Takahama in July, August, October and December, 1975.

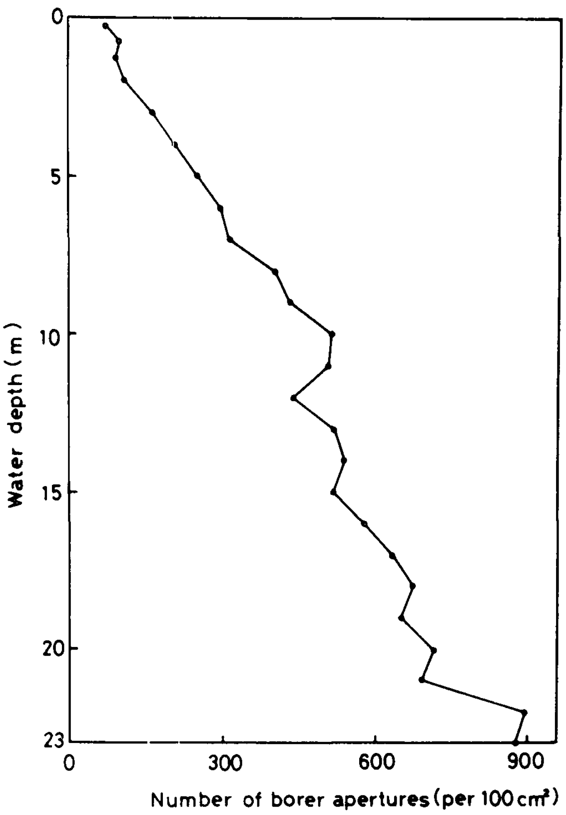

Fig. 2. Pattern of vertical settlement of shipworms at Takahama in September, 1975.

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. 1. 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[20,21]. The larvae of *Teredo pedicellata* DE QUATREFAGES* preferably settled and bored into wood under conditions of illumination of 166 ft candles[20]. In addition, the larvae tended to sink downwards whenever ciliary activity ceases because of the higher specific density of the animals than that of sea water[22]. It, therefore, also possibly takes part in the tendency of vertical settlement especially in September. The larvae can actively move horizontally and vertically over a long distance.

* Isham et al. called the specimens which they studied *Teredo pedicellata* DE QUATREFAGES. But that was misidentification. Their specimens are *Teredo bartschi* CLAPP after Turner[23].

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 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. The increase in the extent of shipworm infestation observed from 20 m depth to the deepest level would be reflected by the abundance of shipworms 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 1).

Of the horizontal surfaces, the upper surfaces were infested more severely than the lower ones. This tendency was also conspicuous in deeper regions as shown

Table 1. 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)	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 2. 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)	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

in Table 2. The tendency of which the upper surfaces suffer severer infestation than any other surfaces; and number of borers settling on the upper surfaces increases proportionally with water depths would demonstrate the settling behavior of shipworms that they selectively settle when they go downwards.

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 settlement 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 generally occurred in the deepest zone as shown in Figs. 3 and 4. 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 cm²). In August, 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

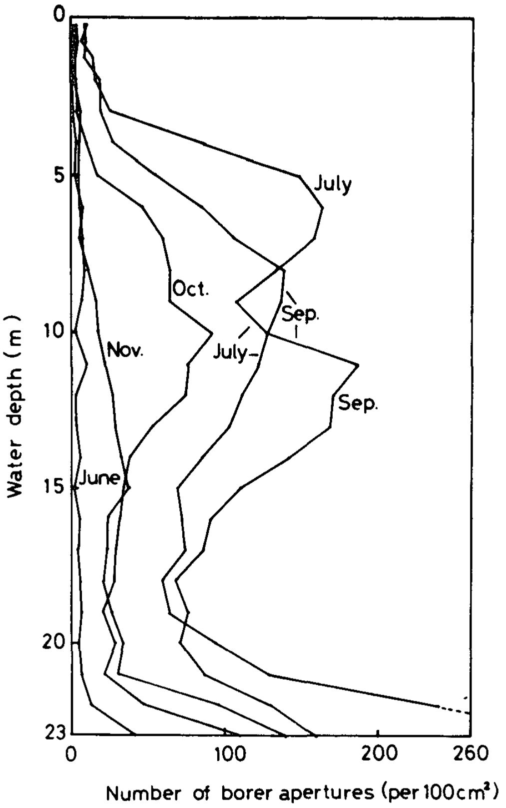

Fig. 3. Patterns of vertical settlement of shipworms at Takahama in June, July, September, October and November, 1976.

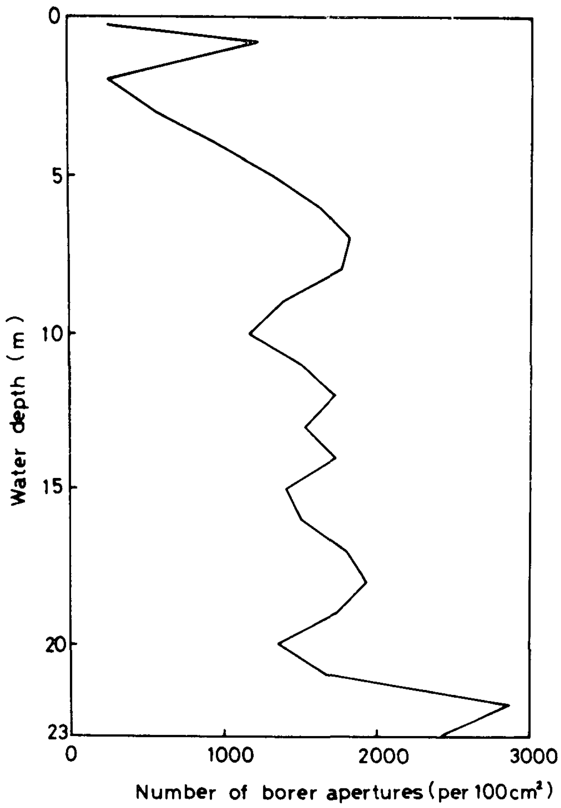

Fig. 4. Pattern of vertical settlement of shipworms at Takakama in August, 1976.

Table 3. 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)	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
19	90	53	63	60	63	48	25
23	82	67	62	46	60	73	50

Table 4. 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)	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

II are figured in Figs. 3 and 4.

The horizontal surfaces suffered severer infestation than the vertical ones as shown in Table 3, but the ratios were comparatively lower than those in Series I. The upper horizontal surfaces were generally infested more severely than the lower and lateral surfaces (Table 4).

Though the pattern of vertical settlement of shipworms may possibly be affected by illumination[20,21], water temperature gradient with depths obviously restricts the vertical distribution of shipworms[24]. 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[25]. Cimbination 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 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 most heavily 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 for such the case of sea water log storage area as the test site in the present investigation.

References

1) W. J. ATWOOD and A. A. JOHNSON, Marine structures — their destruction and prevention, Nat. Res. Council, Washington, D. C., 534 pp. (1924).
2) R. A. JOHNSON et al., Destruction of timber by marine organisms in the Port of Sydney, Supplementary Rep. No. 1, Maritime Service Board of N. S. Wales, 99 pp. (1936).
3) C. H. EDMONDSON, Occ. Paper Bernice P. Bishop Mus., **17**: 97 (1942).
4) C. H. EDMONDSON, Nautilus, **58**, 55 (1944).
5) S. MAWATARI, Studies on the aquatic animals (in Japanese), Tokyo, **1**, (1) 45 (1950).
6) S. MORI, (in) Attack on wooden ships and timbers by marine borers and its prevention, Y. K. Okada ed., Japan Society for the Promotion of Science, 75 (1958).
7) M. SARAWATHY and N. B. NAIR, Jour. Ker. Acad. Biol., **1**, 3 (1969).
8) L. F. FUNG and B. MORTON, Proc. 4th Int. Cong. Mar. Corr. Foul., 187 (1976).
9) P. C. TRUSSELL, et al., Pulp and paper magazine of Canada, Feb. 67 (1956).
10) K. TSUNODA and K. NISHIMOTO, Wood Research, **53**, 1 (1972).
11) C. H. JOHNSON, Engng. News Rec., **81**, 773 (1918).
12) C. J. J. WATSON, et al., Destruction of timber by marine organisms in the Port of Brisbane, For. Bull. Queensland, **12**, 107 pp. (1936).
13) G. OWEN, Nature, London, **171**, 484 (1953).
15) C. A. KOFOID, et al., (in) Marine borers and their relation to marine construction on the Pacific coast, Biological section, C. L. Hill and C. A. Kofoid ed., 188 (1927).
16) D. B. QUAYLE, Rep. prov. Dep. Fish. British Columbia for 1951, 88 (1953).
17) A. S. HOBBY, Engng. News Rec., **81**, 551 (1918).
18) K. D. McDOUGALL, Ecol. Monogr., **13**, 321 (1943).
19) E. C. HADERLIE and J. C. MELLOR, The Veliger, **15**, 265 (1973).
20) L. B. ISHAM, et al., Bull. mar. Sci. Gulf Caribb., **1**, 46 (1951).
21) R. NAGABHUSHANAM, Proc. 1st All India Cong. Zool., 30 (1959).
22) L. B. ISHAM and J. Q. TIERNEY, Bull mar. Sci. Gulf Caribb., **2**, 574 (1953).
23) R. D. TURNER, A survey and illustrated catalogue of the Teredinidae, Mus. Comp. Zool., Harvard Univ., 265 pp. (1966).

24) E. NORMAN, Material und Organismen, **11**, 303 (1976).
25) N. B. NAIR and M. SARAWATHY, (in) Advances in Marine Biology, Vol. 9, F. S. Russell and M. Yonge ed., Academic Press, London and New York, 335 (1971).