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VERTICAL DISTRIBUTION OF FOULING AND WOODBORING ORGANISMS IN TRONDHEIMSFJORDEN (WESTERN NORWAY)

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VERTICAL DISTRIBUTION OF FOULING AND WOODBORING ORGANISMS IN TRONDHEIMSFJORDEN (WESTERN NORWAY)

by

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ABSTRACT

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The vertical distribution of fouling and woodboring organisms of Trondheimsfjorden at intervals of 3 m from the intertidal level to a depth of 30 m, has been studied based on data collected from two series of panels exposed from 15 March 1977 to 15 July 1977 (Series I) and from 22 July 1977 to 13 March 1979 (Series II). The intensity of fouling generally decreased with increasing depth. Quantitatively fouling was heavier on panels of Series I than on Series II, although species-wise it was more heterogeneous on panels of Series II. The bulk of the fouling was caused by *Balanus crenatus*, *Laomedea* sp., *Mytilus edulis*, *Modiolus* sp., and *Hiatella arctica*. Incidence of borers and the resultant destruction of timber were heaviest on panels of Series II. The influence of the period of exposure on the above pattern of infestation by foulers and borers has been discussed. *Psiloteredo megotara* concentrated at the upper levels down to a depth of 15 m, with most settlement between 3 m and 9 m depth. Although *Xylophaga dorsalis* was present on panels from 3 m to 30 m depth, their intensity abruptly change from 9 m onwards and continued to increase with increasing depth, with maximum number near the mud bottom level at 30 m. Infestation of *Limnoria lignorum* was also heavy at the mud level. On the same panel, while *P. megotara* preferred to settle in greater numbers on the lower surface, *X. dorsalis* preferred the upper silted surface.

The rate of growth of *B. crenatus*, *Laomedea* sp., *P. megotara*, *X. dorsalis* and *X. praestans* in relation to depth has been presented. For *B. crenatus*, rate of growth decreased with increasing depth, while that of *Laomedea* increased with depth up to 12 m and declined thereafter. In accordance with its depth preference, *P. megotara* showed faster growth between 3 and 15 m depth. In the case of *X. dorsalis*, the size of the shell value and burrow increased with increasing depth down to 24-27 m and then showed a slight decline at 30 m. Factors influencing the growth-rate at different levels have been discussed.

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CONTENTS

INTRODUCTION

Pattern of settlement and growth of fouling and wood-boring organisms at different depths in the sea are not only ecologically significant but also economically important to all countries having an expanding shipping and fishing industry. Studies on these aspects from Norwegian waters have been only dealt with in a few papers based on data collected down to a depth of 9.1 m (Dons 1940; Nair 1962; Dybern 1967; Knudsen 1974) and 20 m (Lyngnes 1958). At Trondheim, Dons (1940) observed that the number of *P. megotara* increased with increasing depth, when the vertical range studied was only 3 m. In Dalsfjord, Lyngnes (1958) found greater incidence of *P. megotara* from surface down to a depth of 5 m, with intensity decreasing abruptly below 8 m. Nair (1962) carried out at Bergen a preliminary study on the vertical zonation of plants and animals on a 4.5 m long pile, listing 19 species of animals and nine species of plants. He has also discussed the factors influencing their settlement at different levels. Dybern (1967) also reported the growth of sessile animals on eternite slabs installed down to a depth of 9.1 m at three stations near Bergen and correlated their distribution to the hydrographical conditions of the area. During a survey on the shipworm incidence along the Norwegian coast, Knudsen (1974) observed considerable difference in the vertical distribution of *P. megotara* in various localities. Here again, the maximum depth covered was only 7.5 m. In view of the dearth of information on the depth preference of marine wood-infesting organisms of Norway, especially from Trondheimsfjorden, detailed investigations were carried out during 1977-78 near the Trondhjem Biological Station and the results have been presented in this paper.

MATERIAL AND METHODS

The study was carried out close to Trondhjem biological station located at $63^{o}36'$N, $10^{o}23'$E. Pinewood panels, of 25 x 25 x 4 cm size, were immersed at 11 different levels at an interval of 3 m, starting from the intertidal area down to a depth of 30 m (at low-tide). Ten panels were installed in such a way that the bottom one remained at a depth of 30 m (0.3 m above sea bottom) and the top one 3 m below low-tide level (Fig. 1). An intertidal panel (about 0.3 m above low-tide level) was fixed separately from a rope tied between two piles. Too such sets were immersed, Series I from 15 March 1977 to 15 July 1977 and Series II from 22 July 1977 to 13 March 1978.

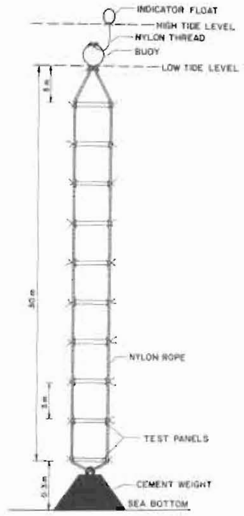

Fig. 1. Method of immersion of timber panels for studying the vertical distribution of boring and fouling organisms.

The salinity and temperature of the water at the test site at an interval of 3 m from surface to 30 m depth were determined once a month using a STD Recorder.

After removal from the site, the panels were put in separate plastic bags and examined in the laboratory under a powerful binocular microscope and data on intensity of various fouling organisms were recorded. In accordance with the relative importance of the various foulers, they were grouped as follows:

For all species other than foraminiferans, folliculinides, hydroids, copepods, *Balanus crenatus*, *M. edulis* and *Modiolus* sp: upto 5 = very rare (VR); 6 to 20 = rare (R); 21 to 40 = moderate (M); 41 to 60 = common (C); 61 to 90 = very common (VC); 91 to 150 = abundant (A); and above 151 = most abundant (MA).

For hydroids (individual colony), *B. crenatus*, *M. edulis* and *Moliolus* sp: upto 25 = very rare; 26 to 50 = rare; 51 to 75 = moderate; 76 to 100 = common; 101 to 150 = very common; 151 to 300 = abundant; and above 301 = most abundant. For protozoans and copepods, the grouping was done by visual assessment. Growth attained by the important foulers was also recorded by measuring the largest 10 individuals or colonies.

After assessing the extent of fouling, the panels were thoroughly cleaned and data on incidence of borers at different levels were collected by counting the number of entry holes. The panels were thereafter cut open and as many borers as possible were collected. The length of the five largest burrows of molluscan borers was measured using a thin iron wire. In the case of *Xylophaga*, the length and height of shell valves of all individuals collected were measured.

RESULTS

The salinity (Tab. I) does not vary appreciably at the various levels except during the months of May to July, when salinities at surface and at 3 m depth are low due to the influx of fresh water from the river Nid after the melting of snow during the late spring. Similarly, range in temperature (Tab. II) at various levels is not considerable except during the period from May to August.

Intensity of various fouling and boring organisms at different depths has been presented in Tables 3 and 4. It can be seen that the intensity of fouling generally decreases with increasing depth and quantitatively fouling was heavier on panels of Series I than on Series II. However, species-wise it was more heterogeneous on panels of Series II.

The general condition of the panels belonging to series I and II was as follows:

Series I (15 March 1977 to 15 July 1977)

Intertidal panel: Here the panel was completely covered on its upper side by juvenile bivalves, predominantly *Mytilus* sp. Its lower surface was fully covered by *Mytilus* and *Laomedea* sp. The bivalves settled in countless numbers on *Laomedea* colonies, the latter collapsing due to the weight of the former. Large number of

Table 1. Salinity from the surface to 30 m depth at the test site (Biological Station) during 1977-78

Months	Salinity (S)										
	Surface	3m	6m	9m	13m	15m	18m	21m	24m	27m	30m
May 77	17.15	25.40	31.30	31.70	32.20	33.10	33.50	33.80	33.80	33.80	33.80
July "	20.25	21.35	26.10	30.75	31.55	32.45	33.00	33.20	33.30	33.40	33.40
Aug. "	28.80	29.30	30.15	31.95	32.55	33.20	33.30	33.70	33.85	33.90	33.40
Sept. "	26.50	27.55	30.90	31.35	31.80	32.75	33.10	33.50	33.60	33.70	33.70
Oct. "	25.41	30.80	31.45	33.20	33.30	33.45	33.40	33.50	33.40	33.40	33.35
Nov. "	29.68	32.40	32.50	32.50	32.60	33.00	33.10	33.10	33.20	33.20	33.20
Dec. "	32.20	33.30	33.30	33.30	33.30	33.30	33.30	33.80	33.90	34.10	34.10
Jan. 78	29.90	31.80	32.80	32.95	33.10	33.10	33.30	33.30	33.35	33.50	33.50
March "	33.65	33.85	33.90	33.80	34.00	34.00	34.20	34.00	34.10	33.90	33.90
April "	26.00	32.05	32.70	33.00	33.50	33.65	33.80	33.90	34.20	34.35	34.55

Table 2. Seawater temperature from the surface to 30 m depth at the test site (Biological Station) during 1977-78

Months		Temperature (°C)										
		Surface	3m	6m	9m	12m	15m	18m	21m	24m	27m	30m
May	77	10.55	8.80	6.20	6.00	5.70	5.25	4.95	4.95	4.90	4.90	4.90
June	"	16.00	14.75	11.25	8.00	7.00	6.40	6.10	5.90	5.75	5.75	5.75
July	"	14.90	14.20	11.90	9.10	8.10	7.10	6.20	6.00	5.90	5.95	5.90
Aug.	"	12.10	11.55	11.00	9.00	8.40	7.80	7.50	7.15	6.90	6.80	7.00
Sept.	"	8.00	8.20	8.70	8.80	8.80	8.80	8.90	9.00	9.00	9.00	8.90
Oct.	"	7.70	7.90	8.10	8.85	8.90	8.90	8.95	8.90	8.95	8.95	8.90
Nov.	"	5.80	5.90	6.00	6.10	6.20	7.30	7.80	7.80	7.70	8.10	8.35
Dec.	"	4.20	5.20	5.20	5.20	5.30	5.25	5.20	6.30	6.30	6.80	6.80
Jan.	78	2.90	3.30	3.90	4.00	4.40	4.40	4.50	4.55	4.70	4.70	4.80
March	"	5.10	5.05	5.00	5.05	5.10	5.10	5.20	5.20	5.25	5.30	5.40
April	"	6.70	5.85	5.70	5.70	5.70	5.65	5.60	5.65	5.70	5.80	5.70

Table 3. Vertical distribution of fouling and wood-boring organisms on panels of series I immersed from 15 march 1977 ot 15 July 1977

Organisms	Intensity of settlement										
	Inter-tidal	3m	6m	9m	12m	15m	18m	21m	24m	27m	30m
Foraminiferans	VR	-	VR	VR	-	VR	VR	VR	VR	VR	VR
Folliculinids	VR	-	-	VR	-	VR	-	VR	VR	VR	VR
Suctorians on hydroids	C	-	-	-	-	-	-	-	-	-	-
Laomedea sp.	MA	MA	MA	MA	MA	MA	MA	MA	MA	A	R
Planarians	A	-	-	-	-	-	-	-	-	-	-
Callopora sp.	-	-	-	-	-	-	-	-	-	VR	-
Polychaetes (*Harmothoe imbricata*, *Capitella capitata* and unidentifiable juveniles)	MA	VC	C	M	R	R	R	R	R	R	M
Serpulids (*Pomatoceros triqueter*, *Hydroides norvegica* and *Spirorbis* spp)	-	-	M	VR	-	VR	VR	VR	-	-	R
Balanus crenatus	VC	MA	MA	MA	A	VC	R	M	VR	R	M
Balanus balanus	-	-	VR	VR	-	-	-	-	-	-	-
Verruca stroemia	-	-	C	C	C	R	R	-	VR	VR	VR
Copepods	M	VR	VR	VR	VR	VR	VR	VR	VR	VR	VR
Amphipods	R	-	-	-	-	-	-	-	-	-	-
Halocarida	MA	-	-	-	-	VR	-	-	-	-	-
Larvae of *Halocladius variabilis*	MA	-	-	-	-	-	-	-	-	-	-
Littorina spp	MA	-	-	-	-	-	-	-	-	-	-
Lacuna sp.	-	-	R	VR	-	-	-	-	-	-	-
Bivalve juveniles (*M. edulis* and *Modiolus* sp.)	MA	MA	MA	MA	MA	MA	MA	MA	M	M	C
Hiatella arctica	-	MA	MA	MA	MA	MA	MA	A	MA	MA	MA
Coryphella verrucosa	M	-	-	-	-	-	-	-	-	-	-
Asterias rubens	MA	A	M	R	-	VR	-	-	-	-	VR
Echinus sp.	R	R	VR	VR	VR	-	-	-	-	-	VR
Psiloteredo megotara	3	-	-	5	4	-	-	-	-	-	2
Xylophaga dorsalis	-	-	-	-	-	-	1	-	1	-	1
Limnoria lignorum	-	-	-	-	-	-	-	-	-	2	1

VR = very rare; R = rare; M = moderate; C = common; VC = very common; A = abundant; MA = most abundant; - = absent.

juvenile *Asterias rubens* and several nudibranchs were also seen on the panel together with young polychaetes, halocarids, gastropods, planarians and chironomid larvae. Profuse growth of algae, although small and covered by bivalves was also observed. Despite its exposure twice daily for a couple of hours, the upper surface of the panel also showed the presence of three larvae of *P. megotara*, of which one with 8 toothed ridges on the shell valves had already produced a tiny pit.

3 m: At this level the panel was completely covered by a thick layer of *B. crenatus* (Fig. 2). *Laomedea* colonies had settled and grown over the barnacles especially on the upper surface. Due to overcrowding on all sides, the barnacles had grown upwards resulting in very tall specimens. Juveniles of polychaetes, *A. rubens* and innumerables bivalves were also seen. Among bivalves young *Hiatella arctica* were also encountered.

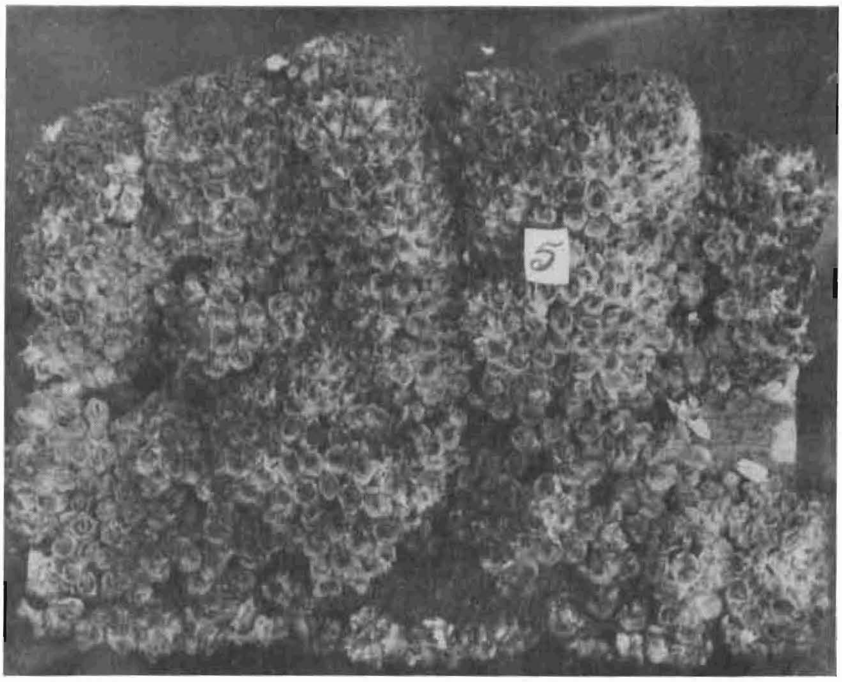

Fig. 2. Panel at 3 m below low tide level, immersed from 15 March 1977 to 15 July 77, showing heavy growth of *Balanus crenatus*.

6 m: Heavy silting was observed on the upper surface. Predominant foulers at this level also were *B. crenatus* and *Laomedea* sp. which had grown to considerable size. Several barnacles were in the recently metamorphosed stage. New entrants to the

fouling community were *Verruca stroemia*, *B. balanus*, *Lacuna* sp., and serpulids, although few in number.

9 m: Composition of the fouling at this level was the same as at 6 m depth. Five pediveligers of *P. megotara* had settled.

12 m: Major fouler at this depth was *Laomedea* sp. The specimens were rather long. A few large *B. crenatus* and *V. stroemia* were also noticed. The bivalves decreased in number. The panel harboured four larvae of *P. megotara*.

15 m: Fouling was essentially the same as in panels at 9 m and 12 m depths except for its reduced intensity.

18 m: The panel showed the presence of numerous *Laomedea* colonies. *B. crenatus* and other foulers were very scarce. One *Xylophaga* larva was found.

21 m, 27 m and 30 m: The panels at these levels were almost clean but for few *B. crenatus*, *Laomedea*, *M. edulis*, and *Modiolus* sp. For the first time, two *Limnoria lignorum* were noticed on panel at 27 m, and their number increased to 13 at 30 m depth. One *Xylophaga* larva was found on each of the panels at 24 m and 30 m, and the latter panel also had two *P. megotara*.

Series II (22 July 1977 to 13 March 1978)

Intertidal: The upper surface of the panel was completely covered by algal fronds and filaments, mainly of *Enteromorpha intestinalis*, *Spongonema tomentosum*, *Fucus* sp. and *Elachista fusicola*. Countless number of small *Laomedea* and some silt also were observed. The lower surface had a complete matting of coelenterate stolons. Enumeration of organisms was rendered difficult due to the heavy growth of algae. Foulers like *Idotea*, *Mytilus*, *Modiolus*, *Littorina* and the halocarids were very few in number.

3 m: Here also the panel was thickly covered by algae, silt, faeces of borers and few dead stumps of *Laomedea*. Foulers present in small numbers were *Mytilus*, *Modiolus*, *Heteranomia squamula*, *Coryphella verrucosa*, *Dendronotus frondosus*, *Electra pilosa*, *Capitella capitata*, halocarids, copepods and folliculinids. Two small *Xylophaga dorsalis* were seen, of which one had formed a pit. The second one having a shell length of 4.4 mm and a burrow length of 14 mm discharged eggs when transferred from the wood to a petri-

Table 4. Vertical distribution of fouling and wood-boring organisms on panels of Series II immersed from 22 m July 1977 to 13 March 1978. Key to symbols same as on Table 3

Organisms	Intensity of settlement										
	Inter-tidal	3m	6m	9m	12m	15m	18m	21m	24m	27m	30m
Foraminiferans	-	-	-	VR	VR	VR	VR	VR	VR	VR	VR
Folliculinids	-	VR	VR	VR	VR	VR	VR	VR	VR	VR	VR
Laomedea sp.	MA	MA	MA	MA	MA	MA	-	-	-	-	-
Tubularia larynx	-	-	R	R	R	R	R	R	M	C	R
Hydractina sp.	-	-	-	R	-	-	-	-	-	-	-
Bryozoans (*Callopora craticula*, *C. dumerili*, *Electra pilosa*, *E. monostachys*, *Crisia* sp., *Cribrilina annulata*, *Plagioecia patina* and *Tubulipora* sp.	-	VR	-	-	VR	VR	VR	-	VR	VR	VR
Harmothoe imbricata	-	-	-	-	-	VR	VR	-	R	R	-
Nereis pelegica	-	VR	-	-	-	VR	VR	VR	-	-	-
Nereimyra punctata	-	-	-	-	VR	-	-	VR	VR	VR	VR
Autolytus prolifer	-	-	-	-	VR	VR	VR	-	-	-	-
Capitella capitata	-	M	R	R	R	R	M	M	VR	R	R
Cirratulus cirratus and *Amphitrite cirrata*	-	-	-	-	-	-	-	VR	VR	-	M
Serpulids (*Pomatoceros triqueter*, *Hydroides norvegica* and *Spirorbis* spp)	-	VR	R	A	M	VC	A	M	A	MA	MA
Larvae of *Halocladius variabilis*	10	-	-	-	-	-	-	-	-	-	-
Idotea sp.	VR	-	-	-	-	-	-	-	-	-	-
Copepods	-	VR	VR	-	VR	VR	VR	-	VR	VR	VR
Halocarida	VR	R	R	VR	VR	VR	VR	VR	VR	VR	VR
Littorina spp	R	-	-	-	-	-	-	-	-	-	-
M. edulis	VR	R	-	VR	VR	VR	VR	-	VR	VR	-
Modiolus sp.	VC	VR	VR	VR	VR	VR	-	-	VR	VR	-
Hiatella arctica	-	-	-	C	VR	R	VR	-	VR	-	-
Heteranomia squamula	-	VR	VR	VR	R	R	VR	VR	VR	VR	VR
Pectenidae sp.	-	-	-	VR	-	R	-	-	VR	-	-
Nudibranchs (*Coryphella verrucosa*, *Dendronotus frondosus*, *Eubranchus pallidus*, and *Cuthona foliata*).	-	R	R	-	VR	-	VR	VR	R	R	-
Asterias rubens	-	-	-	-	-	-	-	-	-	VR	-
Ophiura robusta	-	-	-	-	-	-	VR	-	-	-	-
Ciona intestinalis	-	-	-	-	-	-	-	VR	VR	-	-
Psiloteredo megotara	-	21	28	22	16	9	2	5	-	1	4
Xylophaga dorsalis	-	2	21	126	128	211	220	287	267	315	492
Xylophaga praestans	-	-	-	-	-	-	-	3	1	8	3
Limnoria lignorum	-	-	-	-	-	-	1	1	1	9	418

dish containing sea water. The panel was badly damaged by 21 large *P. megotara*, the largest measuring 242 mm.

6 m: Fouling similar to the panel at 3 m but for the presence of a few *Tubularia larynx*. One *D. frondosus* and *Cuthona foliata* were found on the *Tubularia* colonies. *X. dorsalis* were more numerous and larger than the ones found at 3 m. The numbers of *P. megotara* were also larger resulting in greater destruction of the panel (Fig. 3).

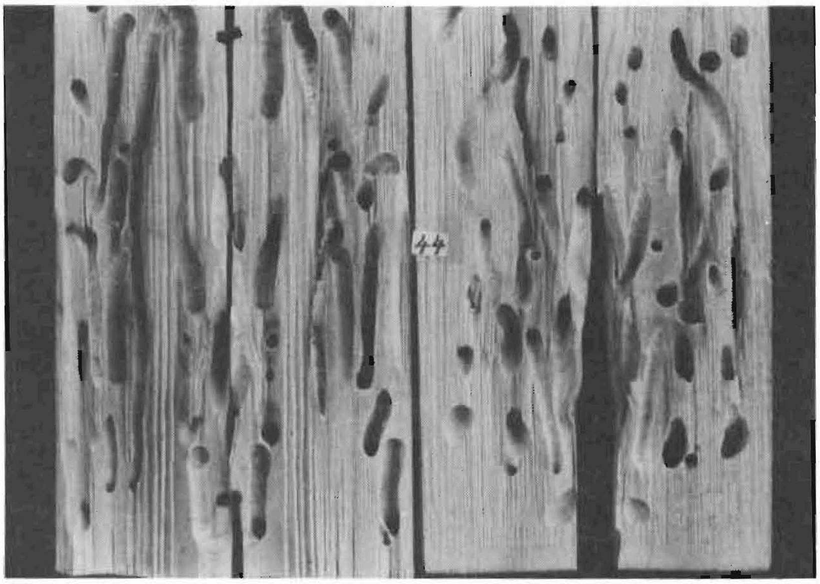

Fig. 3. Panel at 6 m below low tide level, immersed from 22 July 1977 to 13 March 1978, split open to show tunnels of *Psiloteredo megotara*.

9 m: The organisms encountered were almost the same as those at 6 m. New additions were *Pecten* and *Hydractina*. Numbers of *X. dorsalis* had further increased. Quantitatively fouling was scarce. The zigzag tunnels of *P. megotara* hampered their growth.

12 m: Fouling was the same as at 6 m and 9 m. One colony of *Plagioecia patina* and one specimen of *Eubranchus pallidus* and five *Autolytus prolifer* were additional entrants. Destruction was mainly due to large *P. megotara*.

15 m: Nature of fouling the same as on panel at 12 m but for the presence of one colony each of *Callopora craticula* and *C. dumerili* and few juveniles of *Harmothoe imbricata*. Silting was more pronounced. Numbers of *X. dorsalis* had almost doubled (Fig. 4), whereas damage by *P. megotara* had decreased (Fig. 5).

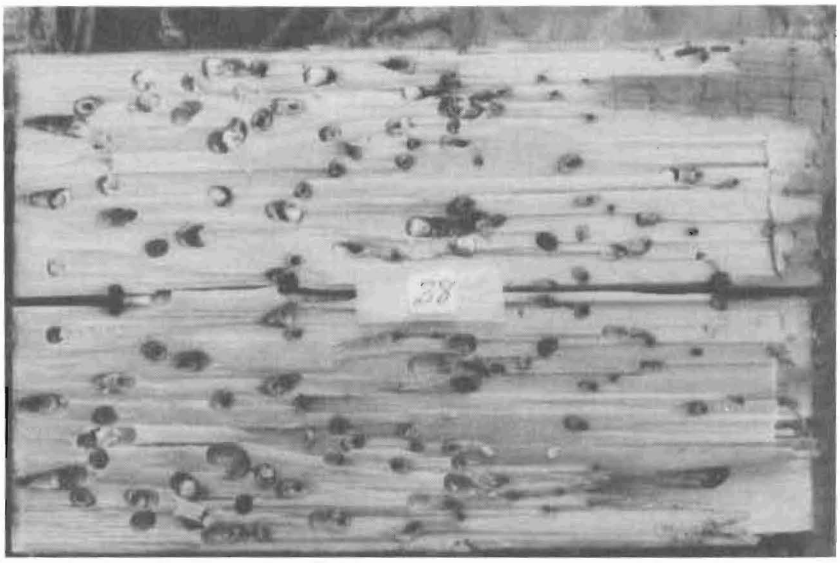

Fig. 4. Panel at 15 m below low tide level, immersed from 22 July 1977 to 13 March 1978, with a thin layer of wood removed from upper surface to show increased activity of *Xylophaga dorsalis*.

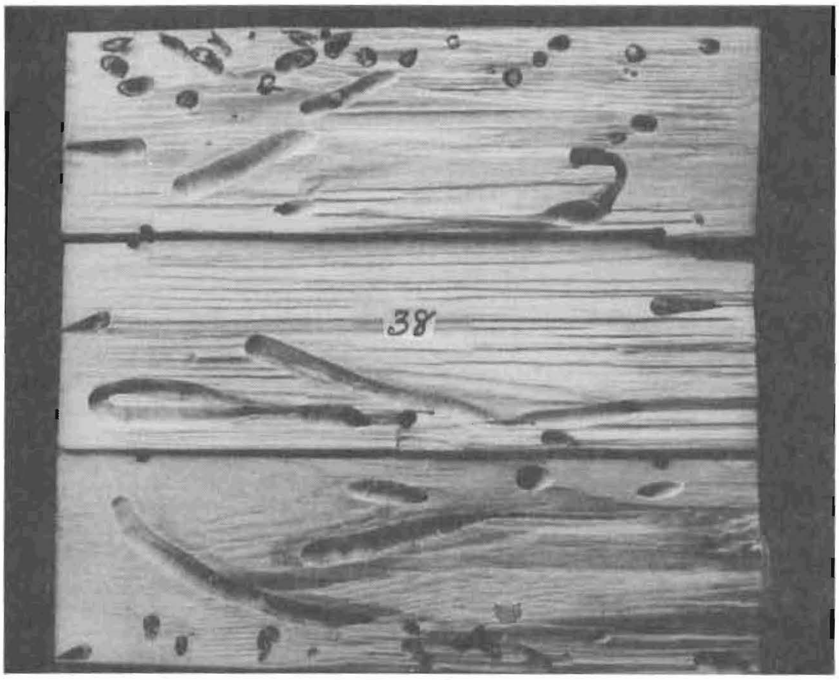

Fig. 5. Panel in Figure 4 split open to show the reduced activity of *Psiloteredo megotara*.

18 m: Fouling essentially the same as in the panel at 15 m depth, except for the increased settlement of serpulids and absence of *Laomedea* even as dead stumps. A new entry to the fouling was the bryozoan *Cribrilina annulata*. There was further decrease in the number of *P. megotara*. One tunnel of *L. lignorum* was observed occupied by a female carrying 26 eggs.

21 m: There was no difference from the panel at 18 m in the fouling composition. The panel, however, had more accumulation of silt. Three specimens of *Ciona intestinalis* were new to the fouling assemblage. For the first time, three large specimens of *X. praestans* were found.

24 m: No variation in the fouling from that at 21 m was observed. Most of the foulers were juveniles. Two colonies of *Crisia* sp. were seen. *P. megotara* was absent.

27 m: The only difference from the panel at 24 m was the comparatively larger number of *L. lignorum*, females of which were carrying developing embryos. *Tubularia*-colonies were mostly without the crowns probably eaten away by *T. foliata* which was present on the panel. Numbers of *X. praestans* had also increased.

30 m: The panel indicated mild silting mixed with faeces of wood-borers. At least five species of bryozoans (*C. craticula*, *C. dumerili*, *P. patina*, *Tubulipora* sp. and *E. monostachys*, of which the last one was a new addition) were noticed. Fouling by *Tubularia* was very slight, but serpulids were seen in large numbers. The polychaete, *C. capitata*, was found emerging from the tunnels of *X. dorsalis*. There was a conspicuous increase in the number of *L. lignorum* and *X. dorsalis*, females of the former carrying embryos. In one female as many as 37 developing eggs were counted in the brood pouch. The upper surface of the panel indicated *Limnoria* tunnels occupied by both male and female. Burrows on the lower surface were small, not enough to cover the borer indicating recent migration. The interior of the panel was completely destroyed by *X. dorsalis* (Fig. 6).

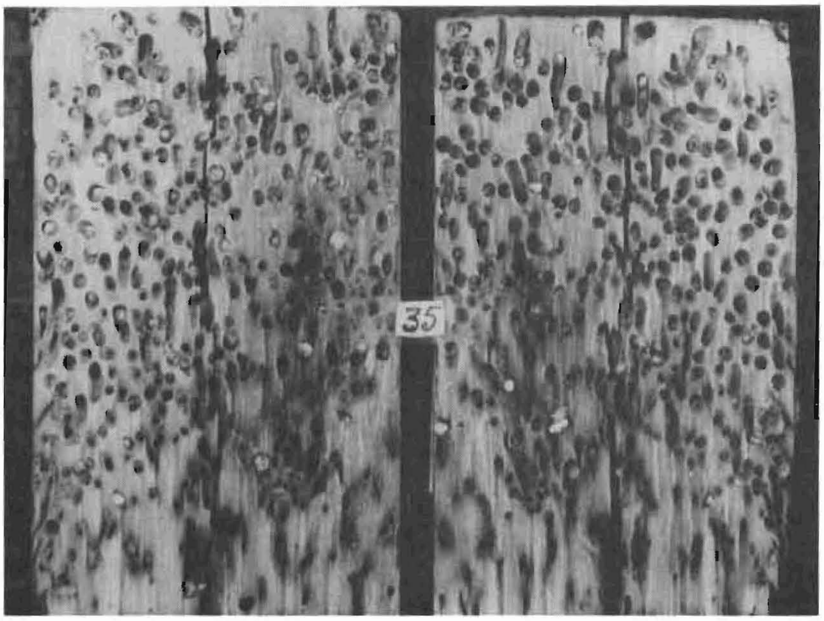

Fig. 6. Panel at 30 m depth split open to show the heavy destruction by *Xylopgaga dorsalis*.

DISCUSSION

The bulk of the fouling on panels of Series I consisted of *B. crenatus*, *Laomedea* sp., *M. edulis*, *Modiolus* sp. and *H. arctica*. These organisms along with polychaetes (*H. imbricata* and *C. capitata*) and copepods were present at all levels. The appearance of juvenile specimens of most of the foulers on the intertidal panel of Series I is natural, as in this series panels were exposed during March to July, when the planktonic larvae are abundant at the sea surface. *B. crenatus*, although present throughout the vertical range covered, was concentrated at 3 m, to such a great extent that growths was only possible vertically resulting in long specimens with an extremely narrow base. Thus, they were maintaining a very precarious footing and could be easily dislodged. Settlement of barnacle spat on panels put out and removed every month during 1977, was first observed on 2 May 1977, and therefore, the reason for their mass settlement at 3 m may have been the low surface salinity in May (Tab. 1) compelling the larvae to sink deeper to more favourable conditions.

On the panel at 3 m, the settlement of *Laomedea* over barnacles was noticed indicating their later attachment.

On Series I panels, halocarids, chironomid larvae, *C. verrucosa* and *Asterias rubens* settled in greater number on the intertidal panel. In fact, chironomid larvae and *C. verrucosa* were seen only on this panel. The echinoderms decreased in number with increasing depth probably due to the fact that the juveniles were present only in the upper water column at the onset of the summer season. The abundant settlement of *Asterias* on the intertidal panel was facilitated by the presence of countless number of juvenile bivalves on which they could feed. Similarly, the good growth of *Laomedea* on this panel might have attracted the nudibranch, *C. verrucosa*.

In Series I, destruction of panels by wood-borers was insignificant, as the incidence was very low. *L. lignorum* settled only at 27 m and 30 m, and *X. dorsalis* at 18 m, 24 m and 30 m. Young *P. megotara* was observed on the intertidal panel and also on panels at 9 m, 12 m and 30 m. This borer usually settles on timber kept in the upper water column down to a depth of 10 to 15 m. Their absence at 3 m and 6 m levels could be due to the influence of foulers, which virtually formed a complete matting on the timber surface denying access to borer larvae (Fig. 2).

Unlike the panels of Series I, *B. crenatus* and *V. stroemia* were totally absent at all levels in Series II, indicating that their period of infestation was already over prior to introducing the panels in late July. Here, the only foulers encountered at all levels were halocarids. Fouling on the intertidal panel by animals was meagre both quantitatively and qualitatively. The profuse growth of algae left no space available for sedentary organisms. Although branching stolons of *Laomedea* and considerable number of small *Modiolus* were noticed on this panel, their contribution to the fouling complex was trivial. The absence of organisms here may also be due to the extremely low air temperature to which the panel is exposed during low tide.

In Series II, *Laomedea* was noticed only down to a depth of 15 m. They were all dead and only long stumps were present. It may be inferred that the individuals settled and grew in large numbers during summer, but were soon eaten away by nudibranchs or killed during the winter months leaving only their dead stumps. Huge colonies of *Tubularia*, which was completely absent on the panels of Series I, were found at all levels from 6 m and down, with maximum intensity at 24 m and 27 m. In most cases, the individuals were devoid of the crown probably eaten by the nudibranchs, of which at least a few species (*C. verrucosa*, *D. frondosus*, *E. pallidus* and *C. foliata*) were observed in sufficient numbers. It may be mentioned that settlement and growth of *Tubularia* were greater on the suspending nylon rope and because of this several specimens of nudibranchs also were encountered on the rope.

Intensity of bivalves on panels of Series II was very much reduced and their occurrence at various levels was also erratic except for *Heteranomia squamula*, a few specimens of which were present at all levels from 3 m and down.

Among polychaetes, only *C. capitata* and serpulids were observed at all depths from 3 m. While *C. capitata* did not indicate any depth preference, the serpulids (especially *P. triqueter* and *H. norvegica*) were more abundant at deeper levels, as was also observed by Nair (1962). Because of the layer of silt and borer faeces, attachment of serpulids was not firm and they could be easily lifted without breaking the tubes. They were also found settling and growing on *Tubularia*.

In accordance with the greater number of borers, panels of Series II, especially from 3 m to 15 m, suffered heavy destruction (Figs 3, 4 and 5). This increased infestation on Series II panels was a result of the different period to which the panels were exposed to settlement. By late July the activity of foulers subsided with the result that settlement of borer larvae on the panel surfaces is not hindered. *L. lignorum* was present very rarely above 15 m with maximum settlement (418 burrows) being found at 30 m. That *Limnoria* infestation decreases in intensity from mud-line upwards in Northern latitudes has also been observed by Nair (1958), who gave experimental evidence to show the influence of low temperature in governing the attack of this borer at different depths. *P. megotara* concentrated at the upper levels down to a depth of 15 m with most settlement between 3 m to 9 m. This is in general agreement with the depth preference reported earlier for this species (Kramp 1927; Lyngnes 1958; Norman 1976). It should be mentioned that considerable variation has been observed in the pattern of vertical distribution of *P. megotara* in various localities (Knudsen 1974). It has been suggested that this difference can be due to the influence of low surface salinity (Norman 1976). Dons (1940) reported an increase in the number of *P. megotara* from 0.5 m to 3 m depth. The data cannot be compared with the present result, as no panels were installed between the surface and 3 m depth during the present investigation.

X. dorsalis was present on the panels of Series II from 3 m to 30 m depth. Although few in number at 3 m and 6 m, their density abruptly changed from 9 m downwards and continued to increase with increasing depth, maximum numbers were registered near the mud-level at 30 m. This species is known to occur from 0 m to 400 m in the Trondheimsfjord (Dons 1929). However, this is the first experimental evidence to show its pattern of distribution in relation to depth. Norman (1976), while studying the vertical distribution of *Teredo navalis*, *P. megotara* and *X. dorsalis* along the Swedish West coast by immersing panels at every 3 m down to a depth of 31 m could find only one or two specimens of *X. dorsalis* between 16 m to 31 m depth during 1971-72, and on six panels at 33 m during 1973, she observed a total of 88 individuals. During 1977-78, an unprecedented activity of *X. dorsalis* in terms of density of settlement and destruction of panels was noticed in Trondheimsfjorden (Santhakumaran 1978) and this accounted for the greater incidence of this borer at different levels sufficient to draw a definite conclusion about their depth preference. The results from both these localities and also from earlier reports on *Xylophaga* (Turner 1973) indicate the heavy concentration of larvae close to the mud-line. From the pattern of incidence on panels belonging to various investigations conducted in Trondheimsfjorden, it is also clear that severity of attack will be greater on a panel installed near the mud-line at a depth of 10 m than on panels at 10 m where the mud-level is at 30 m.

Data on the growth-rate of *B. crenatus* (Fig. 7) show that in four months or less, this species can attain a basal diameter of 17.8 mm on the panel at 3 m, with the average of the 10 biggest individuals being 16.3 mm (only such specimens whose growth was not restricted due to overcrowding were measured). Since, as mentioned earlier, presence of barnacle cyprids was first observed during early May, it is evident *B. crenatus* is a fast growing species reaching a basal diameter of 17.8 mm in about 2 1/2 months. Figure 7 also shows that the growth rate of *B. crenatus*, which is maximum at 3 m level steadily decreased down to a depth of 15 m, remained almost steady at 18 and 21 m levels, thereafter decreasing. At the intertidal level, the size of the individuals was considerably smaller than at 3 m. It may be concluded that first settlement started at higher levels where the planktonic larvae were available in large numbers during the initial stages of the breeding cycle with the earliest attachment occurring at 3 m depth. Thus larvae at higher levels will have a longer period of growth. Infestation to lower levels spread progressively as the breeding continues and when competition for space becomes acute at higher levels. This observation was also supported by the fact that there was a gradual increase in the number of newly attached cyprids and juvenile barnacles on deeper panels.

Corlett (1948) and Nair (1962) recorded a much slower rate of growth for *B. crenatus*. According to Nair (1962), specimens with a basal diameter of 14 mm were observed on the panels only after a period of about four months immersion at Bergen. In the Mersey estuary, Corlett (1948) obtained a maximum value of only 11.5 mm for specimens settled and grown between late April and October. However, the present result is comparable to the growth-rate noted by Pyefinch (1948), according to whom three to four month old barnacles could measure 20 to 22 mm in basal diameter.

Rate of growth of *Laomedea* increased with depth from intertidal level to 12 m depth and thereafter declined gradually down to a depth of 27 m and abruptly decreased at 30 m (Fig. 7). Maximum height of 131.3 mm in about two months was noticed at 12 m depth with average of 10 colonies being 105.8 mm (Monthly panels removed on 2nd May 1977 did not show the presence of *Laomedea*, but the same panels examined on 1st June 1977 indicated the presence of small colonies measuring up to 38 mm. Thus, the settlement of *Laomedea* may have started during the second week of May i.e. a little later than the barnacles. Thus the specimens at 12 m could be about two months old. The reason for this interesting pattern of growth could be that either early settlement started at about 12 m depth and spread upwards and downwards subsequently or that the conditions between 6 m and 18 m depth, with less competition from other foulers, may be more conducive to their growth. Nair (1962) also observed maximum growth and development of hydroids in an area extending from 1 m to 3.5 m above the mud-line, when the vertical range studied was 4.5 m. According to McDougall (1943), hydroids at

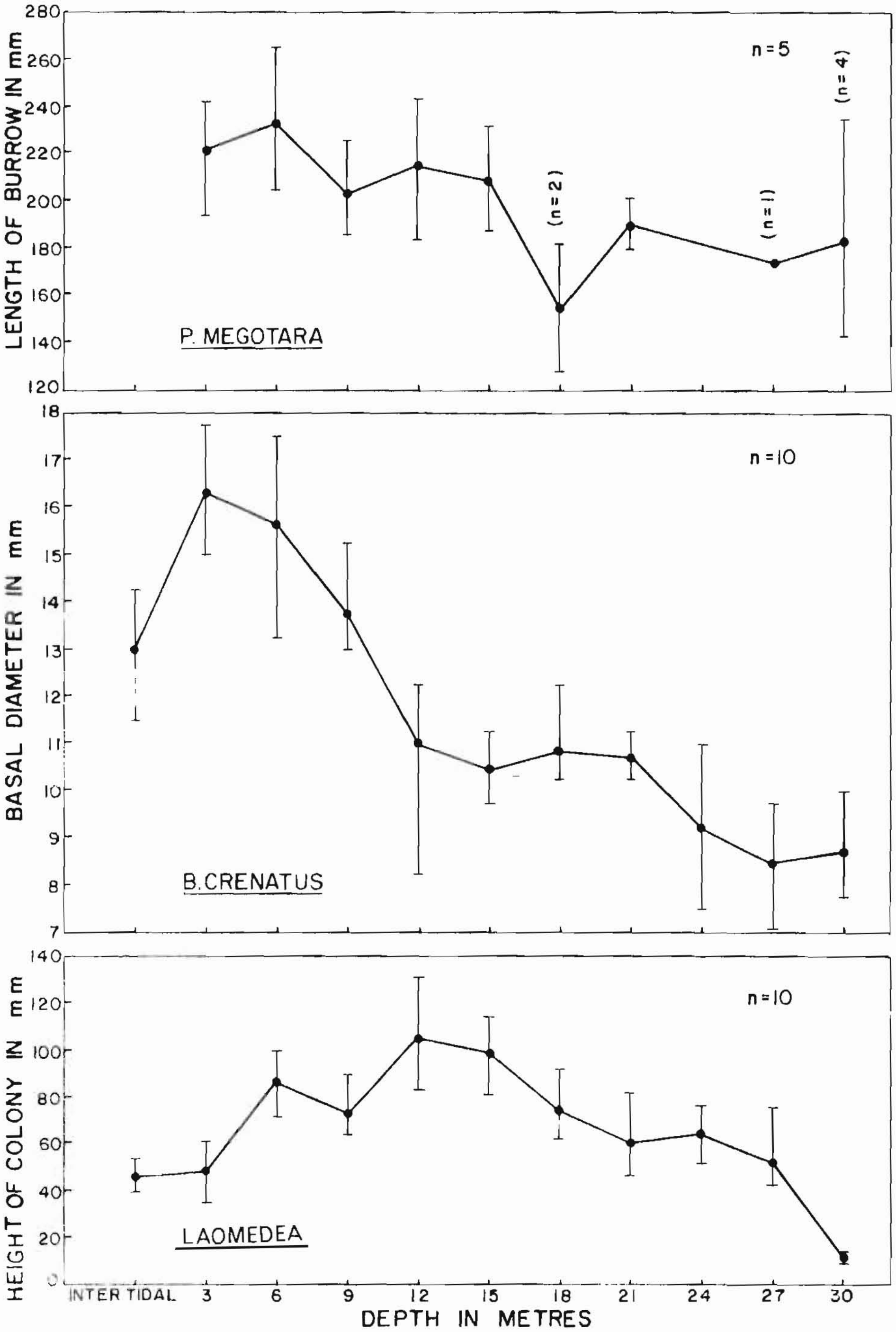

Fig. 7. Growth-rate of *Laomedea* sp. and *Balanus crenatus* on panels of Series I and of *Psiloteredo megotara* in panels of series II at different depths.

the intertidal level would die because of exposure to air and those settled at mud-line as a result of some substances that might diffuse from the mud. Perhaps this might be one of the reasons for the extremely poor growth attained by *Laomedea* at 30 m during the present study. However, on the intertidal panel they were abundant.

Data on the growth of *P. megotara* presented in figure 7 show that, in accordance with its depth preference, the borer registers faster growth between 3 and 15 m depth. Maximum burrow length of 265 mm was observed on the panel at 6 m (average of five tunnels: 232.6 mm) in about 234 days. At depths greater than 18 m, there was considerable reduction in the average also of *P. megotara*. The growth-rate for this species presented in figure 7 is, however, much less than that observed by Nair (1962) at Bergen (286 mm in about 4 1/2 months) and Dons (1945) at Trondheim (420 mm in 8 months). However, it is greater than the values recorded by Kramp (1927) at Hirtshals (160 mm in 8 months) and by Norman (1977) along the Swedish west coast (212 to 245 mm in one year). It may be mentioned here that factors influencing growth at various places differ and even texture, density and size of the test panels can retard or accelerate growth. As pointed out by Nair (1962), the higher values obtained by Dons (1945) might be due to the greater volume of the timber used.

Rate of growth of *X. dorsalis* shows a gradual increase in the length and height of shell valves as the depth increases (Fig. 8). A slight decrease, however, was noticed at 30 m. (The maximum average length of 6.6 mm and height of 6.2 mm recorded at 18 m depth was due to the uniformly large size of the 88 specimens measured.) The length of the burrow also increased progressively down to a depth of 24 m and thereafter decreased at 27 m and 30 m (Fig. 8). Maximum burrow length of 58.5 mm was observed at 24 m. The general decrease in the burrow length at 27 m and 30 m, and size of the shells at 30 m, may be due to the increased number of borers at mud-level and slightly above, leading to competition for space. Further, at these levels, the growth can also be influenced by the mass settlement resulting from the availability of larvaes in large numbers leading to simultaneous growth of several individuals. At levels slightly higher above mud-line, settlement is in batches, as and when the larvae are lifted off the bottom. Therefore, the early settlers, penetrating deeper into the wood, have an unhindered

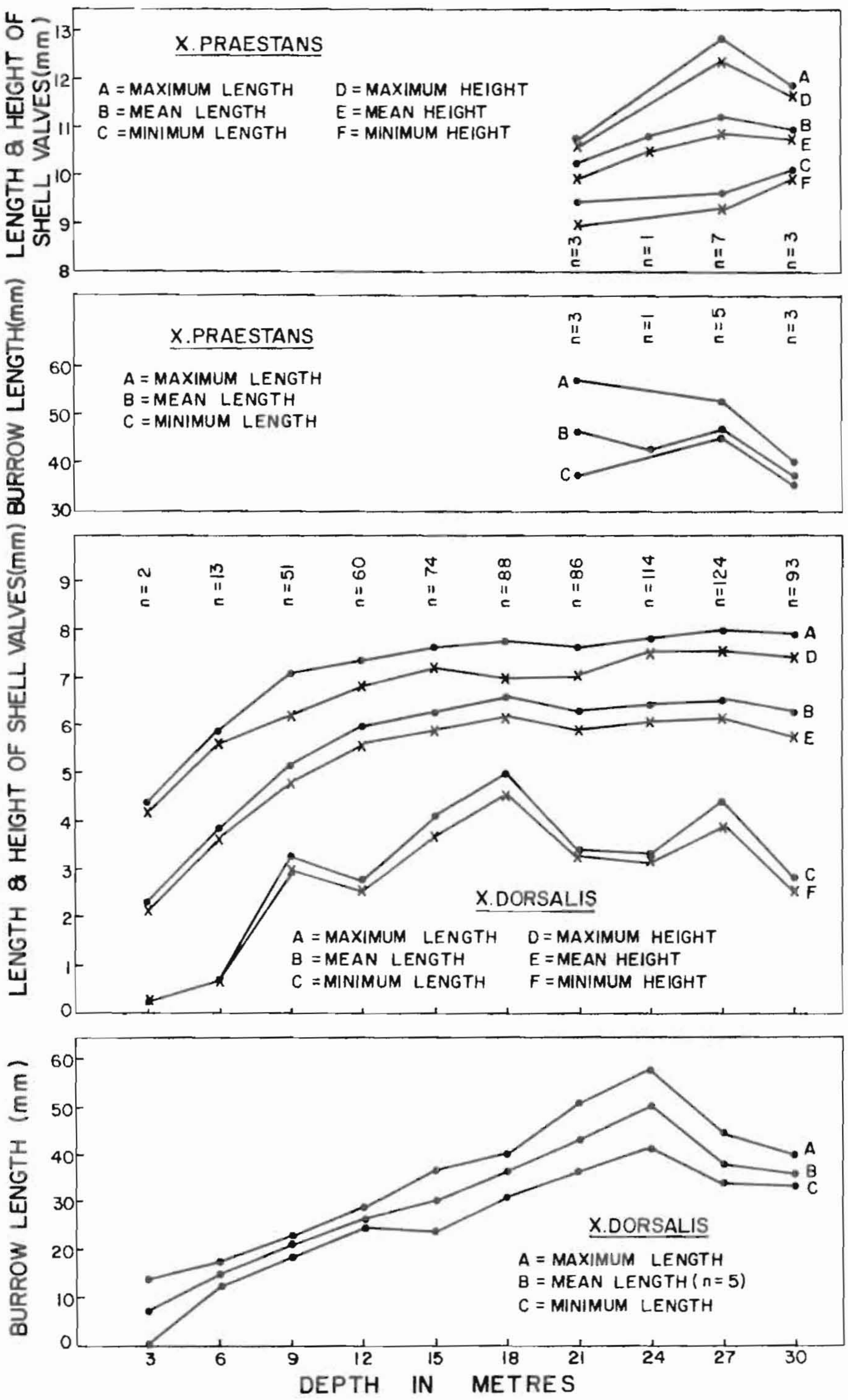

Fig. 8. Growth-rate of *Xylophaga dorsalis* and *X. praestans* in panels of Series II at different depths.

growth and are little influenced by competition. For same reason, panels in the upper water column receive the larval settlement at a later stage, reducing the period of growth and restricting their size.

The maximum burrow length of *X. dorsalis* (58.5 mm, average of five tunnels = 50.4 mm at 24 m depth) obtained during the present study is much greater than that recorded by Dons (1940a: 48 mm in 12 months) and Norman (1977: average length of 11.1 mm in two months). It may be mentioned here that size or age of the individuals has no relation to the length of the burrow.

As can be seen from figure 9, distribution of specimens of various length classes at different depths also follows the same pattern. Individuals in the biggest size groups (shell length 7.6 to 9.0 mm) are predominant in deeper levels (from 24 m to 30 m) only, and those in the next group (6.1 mm to 7.5 mm) are well represented from 12 to 30 m. Following this pattern, the numbers of *X. dorsalis* in smaller size groups are greater at higher levels, with the smallest individuals being encountered at 3 m and 6 m levels.

No clear picture on the growth rate of *X. praestans* emerges from the results, as they are few in number, present on panels at 21 m, 24 m, 27 m and 30 m. Nevertheless, a gradual increase in the size of the shell with depth is discernible (Fig. 8), except at 30 m, where severe competition for space from *X. dorsalis* may be a factor limiting their size as well as their burrow length.

From the condition of the panels, it may be concluded that the destruction of timber could be an economically important problem in Trondheimsfjorden. The selective vertical incidence of the two groups of molluscan borers enables them to share the same habitat with minimal interspecific competition, at the same time posing a threat to any man-made wooden structures in the locality. The extent of cooperation in their destructive activity can also be judged from the fact that even on the same panel while *P. megotara* prefers to settle in greater numbers on the bottom surface, *X. dorsalis* does so on the upper silted surface.

The investigation demonstrate that the potential for fouling and boring in Trondheimsfjorden is so great that it compares well with any tropical locality.

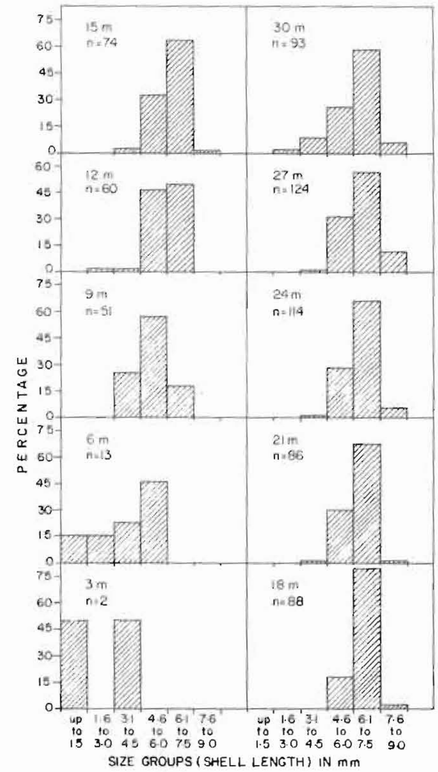

Fig. 9. Percentage distribution of *Xylophaga dorsalis* in various size groups at 3 m to 30 m depth (Period of exposure: 22 July 1977 to 13 June 1978, n = number of specimens measured).

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