The Settling and Growth of Wharf-pile Fauna in Port Nicholson, Wellington, New Zealand.

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ABSTRACT

The investigation extended over a thirteen-month period from April, 1949, to April, 1950. Two series of oregon pine test blocks (long and short term) were used. The established complex community on the wharf piles in the area of the experiment were the common fouling organisms—hydroids, polyzoans, ascidians, barnacles, etc. The pioneer species setting on the blocks in autumn were the hydroids and serpulid worms. The community in winter and spring is dominated by colonial ascidians and polyzoans, and finally in summer and early autumn the slower-growing sponge and algal species gain ascendancy. A thirteen-month period failed to give suitable conditions for growth and development of mussels. Marine borers caused significant damage to the test blocks, and data relating to their setting, development, and growth are recorded.

The fouling of ships, wharf-piling, and similar structures by masses of marine animals and plants is not the outcome of a single event, but results from a long sequence of events culminating in the establishment of a complex community of larger animals and plants. If a clean piece of wood or metal is immersed in the sea, it is first occupied by the settling on it of larval stages of a variety of organisms, few of which are prominent in the final fouling community. These young individuals perish in great numbers, but some survive to grow and to form a pioneer community providing a new environment, which then shelters the young of other individuals, and so the community develops in numbers and variety, changing from one type of community to another until the slower-growing larger organisms settle and survive, producing at last the climax association, a fouling community which continues for many years.

The problem of preventing fouling is accordingly not primarily concerned with direct control of the actual fouling community, but should aim rather at preventing the establishment of pioneer communities. This paper records observations made at Queen's Wharf, Port Nicholson, over a thirteen-month period, using test blocks of oregon pine in such a way as to show the constituents of the pioneer communities, the periods in which the larval stages of these animals settle, and to give information on the nature of the early subsequent communities. These data also provide much information useful as a guide to studies on the life-histories and other aspects of these animals. The study also gives extensive data on the set and development of the wood-destroying marine organisms which are of considerable importance in the damage they do to immersed wooden structures.

Test blocks of Oregon pine (*Pseudotsuga taxifolia*) were chosen because of its straight grain and its greater susceptibility to attack by borers than either Totara (*Podocarpus totara*) or other hard woods frequently used in wharf piles in this country. The use of Oregon has possibly permitted accelerated destruction by borers, but it is unlikely to have falsified appreciably the overall pattern of settling or growth. Each unit (Fig. 1) had two components 12 in. by 12 in. by 1½ in., with one component in the horizontal plane and the other in the vertical. The two were tied together by Tobin bronze wire, which is resistant to marine corrosion. Weights were attached to the bottom of the horizontal component, and the whole test block was suspended about 4 ft. below low-tide level. Two series of units

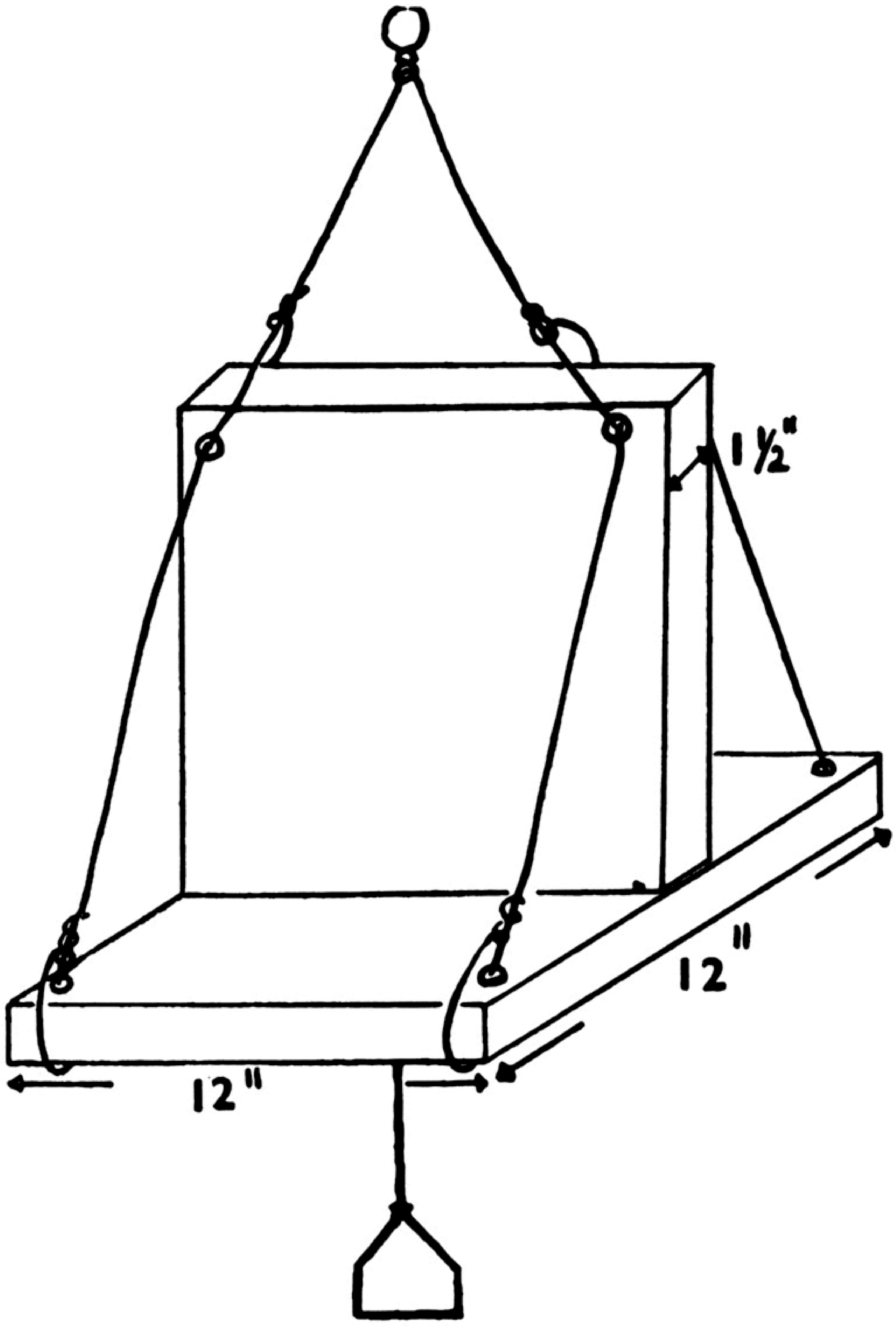

FIG. 1.—Diagram of test block.

were used: firstly, a series of twelve "long term" blocks, all put down on 30th March, 1949. These were raised one each month till 30th April, 1950. Secondly, a series of eleven "short term" blocks, a single one of which was put down at the beginning of each month and raised at the end of the same month. As the first long-term block was down only one month, it also served as the first short-term block. Owing to various difficulties, it was not possible to raise blocks in December, 1949. These were raised at the end of January, 1950. The two-series system was used to demonstrate the monthly larval set (on the short-term blocks) and indicate how the monthly set was modified by animals already established on the long-term blocks. Allen and Ferguson Wood (1950) used a four-weekly series of glass plates in fouling experiments in Australia, and they remark "it is generally at this stage (i.e., four weeks) that the greatest number of specimens are present. Further immersion results in the elimination of many of these, however, particularly in the period three to six months after setting." This is very true in the present experiment, and we have reason to believe a climax association had not been reached on the test blocks even after thirteen months.

We have used diagrammatic presentation of the monthly temperature records to demonstrate the temperature distribution for the month more fully than does the simple graph of average temperatures. The vertical base line of the triangle (Figs. 2 and 3) gives the highest and lowest temperature for the month, and the apex represents the temperature that was most frequently recorded for the month and the number of times it occurred for that month. Thus, not only the highest and lowest temperatures for the month are shown, but also the distribution of daily temperature relative to the two extremes.

The authors wish to extend their thanks to the Wellington Harbour Board, for allowing us ready access to the Queen's Wharf, and to the Harbour Board Engineer, Mr. Hutchinson, for giving us valued assistance in the project; to Mr. P. McLean, the custodian of the Te Aro Salt-water Baths, for his co-operation in taking daily temperature records throughout the period of the experiment; to the late Mr. C. Masters, of Watson Victor Ltd., Wellington, for willing help in taking X-ray photographs of the test blocks; to Professor L. R. Richardson, for helpful advice and assistance; to Miss Beryl Brewin, Dr. D. Brown, Miss S. Jonathan (University of Otago, Dunedin), and Mr. G. Knox (Canterbury University College, Christchurch), and to Miss V. Dellow (Victoria University College), for identifying respectively the Ascidians, Polyzoa, Sponges, Polychaetes, and Algae.

GENERAL SETTLING AND GROWTH ON THE SURFACE OF THE TEST BLOCKS

As stated above, the present system of making use of "short" and "long" term blocks gives an indication of monthly larval sets and also how these are modified by animals already established. Where species of a single class—for example, the Hydroids or the Polyzoa—are involved, the long-term blocks also provided interesting successional studies for that particular group. All the major elements of the well-established association on the wharf piles were at some time present on the test blocks. Prominent species of the complex wharf-pile community at the commencement of the experiment were the gymnoblastic hydroid *Tubularia attenuoides,* the polychaetes *Spirorbis* sp. and *Galeolaria hystrix,* and the barnacle *Elminius modestus.* The three latter species were conspicuous on the shell valves of the mussel *Mytilus planulatus* in the vicinity. Other species in some numbers were a polyzoan *Bugula* sp., the ascidians *Botryllus schlosseri, Asterocarpa cerea,* and *Corella eumyota,* and the sponges *Sycon ornatum* and *Halichondria reticulata.*

Two points were clear almost from the commencement of the experiment. Firstly, the effect the already established species on the long-term units had on the species attempting to settle during the month. Secondly, the very definite if not spectacular change in variety and number of species forming one community after another in fairly rapid succession; although the blocks did not show a climax association even after thirteen months of submergence as evidenced in the fact that mussels, which were an established part of the upper zone of the wharf-pile community at the commencement of the experiment, were scarcely represented on either the short- or long-term blocks. A mussel 2 cm. in length was taken from the last block in April, 1950. This animal had settled and grown on the test block. Other specimens much larger in size (6·0 or 7·0 cm.) were taken from test blocks fairly early in the experiment, but these had obviously fallen from the wharf stringer above. A recent examination (November, 1951) of the wharf piles revealed the interesting fact that practically none of the hydroid, polyzoan, ascidian, or sponge species that were prominent at the commencement of the experiment are now present on the piles—the pile fauna consisting almost entirely of mussels. This indicates in this particular case that mussels dominate the climax association, which takes about three years to come into being.

Any description of settling and growth on the surface of the test blocks falls fairly readily into three sections—viz., a review in general terms demonstrating the salient features of group succession, a month-by-month survey of all the species present on both long- and short-term blocks, and, lastly, notes on the individual species. In general, then (Table 2), the first long-term block showed a dominant hydroid settling. The following month (May), the hydroid element shared equal rank with polyzoan and ascidian elements. This was followed in June with ascidian and dendritic polyzoan elements gaining ascendancy, but in July the hydroid element again appeared and retained equal rank with ascidians and polyzoans till September. In October, the colonial ascidians declined in numbers and importance and two new elements replaced them—namely, algae and sponges. These two groups and a flat crustose polyzoan remained the dominant features of the units till February, when the crustose polyzoans became fewer in number, until in April, 1950 (the last month of the experiment), the algae and sponges were present as the dominant groups. Had the experiment been continued, present indications are that both these groups would have been replaced by mussels.

ATTACHMENT OF SPECIES

Tables 1 and 2 show the seasonal sequence, comparative abundance, and range of species for both the long- and short-term blocks, and also demonstrate that certain elements of the settling fauna persist throughout the investigation on the long-term blocks, but at no time were these a dominant form.

SPECIES PRESENT ON LONG- AND SHORT-TERM BLOCKS

The following systematic account is given so that more detailed comparison of factors involved in settling and growth can be discussed.

PORIFERA

The calcareous species *Sycon ornatum* Kirk was short lived and present in moderate numbers on the long-term blocks in October and November, and was replaced by the siliceous species *Halichondria reticulata* Brondsted for the remaining months of the investigation. This sponge showed greatest coverage and size in March and April, 1950. No evidence of sponges was found on the short-term blocks, indicating that the present two species of Porifera take more than a month to reach identifiable size. Also, the sponges were the last group to settle and become established. This is fairly well in accord with the finding of Allen and Ferguson Wood (1950), where no siliceous sponges appeared on the test plates at all, and the occurrence of calcareous species was mostly confined to *Sycon*-like juveniles up to 1·0 mm. in height on the monthly plates.

HYDROIDA

The hydroids were short lived but quick growing, and showed more clearly evidence of species succession than any of the attaching organisms. The gymnoblast *Tubularia attenuoides* Coughtrey settled very heavily in April, 1949, and again, though less densely, from November to March, but no great bloom comparable to that of April, 1949, was observed the following April. Pyefinch and Downing (1949) found that the presence of a mature colony of *Tubularia larynx* contributed substantially to the amount of successful settling of the species that takes place in the immediate vicinity, and also that *Tubularia* does not settle on a surface covered by long tufts of filamentous algae. We have no information as to the nearness or otherwise of mature *Tubularia* colonies to the April test block, but the alga *Myriogramme denticulata* was dense on the long-term block and of sufficient height (up to 7·3 cm.) to at least limit the set of *Tubularia*. Thus, *T. attenuoides* is an example of a species dominant in the pioneer community (April, 1949), but through changing conditions suppressed in a later community (April, 1950) at a time when a heavy set was anticipated. Of all species, *T. attenuoides* was the most spectacular as far as rapid growth was concerned. The average monthly height was 3·0 cm., but in the warm summer months many colonies grew to

TABLE I.

TABLE I SUMMARY OF ATTACHMENT OF SPECIES ON SHORT TERM BLOCKS.

	SPECIES	MONTHS 1949. APL.	MAY	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC. JAN.	FEB.	MAR.	APL.
PORIFERA	SYCON ORNATUM												
	HALICHONDRIA RETICULATA												
HYDROIDA	TUBULARIA ATTENUOIDES	XXXXX							XX	XX	XX	X	
	CAMPANULINA REPENS									XX		XXXX	XX
	HALECIUM SP.									X			
	SYNCORYNE TENELLA	X										X	X
POLYCHAETA	SPIRORBIS SP.	XX		XXXXX	XX	X		XX	XXX		XXXX		
	GALEOLARIA HYSTRIX	XX	X	X	XX	XX					XX	XX	XXXX
	PODARKE SP.						X	X					
	NEREIS KERGUELENSIS									X			
	PERINEREIS CAMIGUINOIDES									X			
	DORVILLEA AUSTRALIENSIS									X	X		
CIRRIPEDIA	ELMINIUS MODESTUS		XXXXX	XXX									XXX
MOLLUSCA	MYTILUS PLANULATUS									X	X	X	X
POLYZOA	CRYPTOSULA PALLASIANA								XX	XX			
	BUGULA SP.							XXX	XXX	XX			
	B. NERITINA									XX			
ASCIDIA	CNEMIDOCARPA NISIOTIS									XX		XX	
	DIPLOSOMA MACDONALDI									XXXX	XX	XX	
	CORELLA EUMYOTA							XX		XX			
ALGAE	ENTEROMORPHA PROCERA						XX	XX	XX				
	BANGIA VERMICULARIS											X	
	CERAMIUM APICULATUM									XX			

KEY:- X, RARE: XX, MODERATELY COMMON: XXX, COMMON: XXXX, VERY COMMON: XXXXX, ABUNDANT.

TABLE II.

TABLE II SUMMARY OF ATTACHMENT OF SPECIES ON LONG TERM BLOCKS.

	SPECIES	MONTHS 1949. APL.	MAY.	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC. JAN.	FEB.	MAR.	APL.
PORIFERA	SYCON ORNATUM							XX	XX				
	HALICHONDRIA RETICULATA									XX	XXX	XXXX	XXXX
HYDROIDA	Tubularia attenuoides	XXXXX	XXX										
	Campanulina repens			XX	XXXX	XXXX	XX	X			XX		X
	Obelia australis							XXX	X			X	
	Halecium sp.								XXX	XX	XX		
	Syncoryne tenella	X									X		X
	Turritopsis nutricula				X								
POLYCHAETA	SPIRORBIS SP.	XX	XX		XX	XX		XX	XXXX				
	GALEOLARIA HYSTRIX	XX	XX	XX	XX	XX	XXX	XX	XX	XX	XX	XX	XX
	ARMANDIA MACULATA		X	X	X								
	PODARKE SP.		X		X	X			X				
	NEREIS KERGUELENSIS			XX			XX	XX	XX	XX		XX	XX
	CIRRATULUS SP.			X					X				
	NEANTHES CRICOGNATHA				X			X					
	LEPIDONOTUS SP.				X								
	NICOLEA SP.				X							X	
	DORVILLEA AUSTRALIENSIS					X			X				
	MELINNA SP.					X	X	X	X				
	SERPULA SP.					X		X					
	SYLLIS SP.						X						
	AMPHITRITE SP.						X	X		X	X	X	X
	PERINEREIS CAMIGUINOIDES								X				
	AUDOUINIA TENTACULATA									X	X	X	
CIRRIPEDIA	ELMINIUS MODESTUS		XX		XX			XX	XX				X
MOLLUSCA	BANKIA AUSTRALIS		X	X	X	X	X	XX	XXX	XXX	XXXXX	XXXX	XXXX
	MYTILUS PLANULATUS			XX	XX	XX	XX	XX	XX	XX	XX	XX	XX
POLYZOA	CRYPTOSULA PALLASIANA		XX	XX	XX		XXX		XXXX	XXXX	XXXX		
	BUGULA SP.		XXX	XXX	XXX	XXXX	XXXX	XXXX	XXXX	XXX	X	XX	
	B. NERITINA					XXX	XXX						
	BEANIA BILAMINATA		X										
	TUBULIPORA SP.			X									
	IDMONEA SP.			X									
ASCIDIA	DIPLOSOMA MACDONALDI		XXX	XXXXX	XXXXX		X						
	BOTRYLLUS SCHLOSSERI		XXX	XX	XX	XXXX	XXXX		XX	XX	X		X
	CORELLA EUMYOTA			XXX	XXX		XXX	X		X			
	ASTEROCARPA CEREA					XX	X		XX	XX	X	X	X
	CNEMIDOCARPA NISIOTIS		XXX	XX	XX			X					
ALGAE	ECTOCARPUS SP.		XX										
	MYRIOGRAMME DENTICULATA				XX	XXX		XXX	XXX	XXXX	XXXX	XXXXX	XXXX
	CERAMIUM APICULATUM				XXX	XXX	XXX		XXX			XXX	XXX
	BRYOPSIS PLUMOSA					XX	XX						
	ANTITHAMNION SP.						XX						
	LETTERSTEDTIA PETIOLATA								XX				
	ENTEROMORPHA PROCERA									XX			
	DERBESIA NOVAE-ZELANDIAE												X

KEY AS FOR SHORT TERM BLOCKS.

6·0 cm. Some of the polyps of the colony showed mature gonophores after four weeks' growth. In accordance with Corlett's findings for *T. indivisa,* temperature had its effect on maturity in *T. attenuoides*. When temperatures were highest, a greater number of polyps showed ripe gonophores at the end of a month than was the case when temperatures were lower. The life span of *T. attenuoides* is, under local conditions, approximately two months.

Campanulina repens Allman replaced *T. attenuoides* on both series of blocks, and settled in June (long-term blocks) and again in December-January, March, and April, as shown by the short-term blocks. As with *T. attenuoides, Campanulina repens* attains maturity and full height (8·0 mm.) within four weeks. Mainly dead stalks are found on the long-term blocks by the end of October. The reappearance of the species on the short-term blocks in December and January and the long-term block in February suggests that the medusae are sexually mature in three to four months. *C. repens,* in common with other hydroids attempting to become established on the long-term blocks from February onwards, showed little growth compared with previous settlings.

Obelia australis von Lendenfeld replaces *C. repens* as the dominant hydroid element of the long-term block in October and November, and had attained its greatest height (2·5 cm.) within the month when medusae were being shed from the gonophores. The reappearance of the species on the long-term blocks in March suggests that the medusae are sexually mature in about two months. No gonophores were present in March. *O. australis,* like *T. attenuoides,* has, under local conditions, a life span of two months. *Halecium* sp. appeared on the long-term blocks in November, and showed stems 1·5 mm. to 3·0 mm. in height. Those with a stem height of 2·5 mm. to 3·0 mm. had well-developed hydrophores. Smaller stems were without reproductive structures. The spawning period is about one month, as the species appeared on the short-term blocks in December and January. *Halecium* was usually found growing on the polyzoan *Bugula* or on the dead stems of other hydroids.

Syncoryne tenella (Farquhar) was recorded on the first block when stems 16 mm. in height were found and medusae buds were being freely produced. The species seemed seasonal in occurrence and did not appear again until the following autumn on both the short- and long-term blocks. These specimens were much smaller in size (6·0 mm.) than those of the previous autumn and without medusae buds. They may have settled late in the month or found conditions unfavourable for rapid growth and development. *Turritopsis nutricula* McCrady was recorded only once, in July, on the long-term blocks, when stems up to 15·0 mm. were found. Mature medusae and planulae of this species were fairly common in the water in the vicinity of the test blocks at the commencement of the experiment. Four months passed before the species appeared on the blocks, which suggests that few planulae from these medusae survived, as it seems unlikely that planulae would take this length of time to settle and show on the blocks.

POLYCHAETA

Sixteen species of polychaetes were recorded from the test blocks. This is by far the greatest number for any one group in the present investigation, but as at least half of these were errant species, they can only be considered as casual members of the association. The most important species for the present investigation were the two serpulids, *Spirorbis* sp. and *Galeolaria hystrix* Morch., which showed clear evidence of spawning periods and were present for sufficient time to give adequate information for growth rates to be obtained. Both species were present almost constantly on the long-and short-term blocks, indicating that spawning takes place througout the year and that larval life is probably less than one month duration. Some months showed a heavier set than others. *Spirorbis* sp. set heavily in June and again in February, and *G. hystrix* in April, 1950 (Table I). Temperature does not appear to play any part in determining the density of the set, particularly in the case of *Spirorbis* sp., as one heavy set took place in winter and the other when temperatures were highest in the summer. In summary, it can be said of these serpulids that they were present practically throughout the year, but were never a dominant feature. The size range for *G. hystrix* at three-monthly intervals is as follows: one month, 3·0 mm. to 6·0 mm.; three months, 9·0 mm. to 16·0 mm.; six months, 13·0 mm. to 37·0 mm.; twelve months, 61·0 mm. to 80·0 mm.

The following species are errant and mud-dwelling species and appeared only in small numbers and for relatively short time periods on the blocks. The short-term blocks showed the errant *Podarke* sp. present in September and October, and *Nereis kerguelensis* McIntosh, *Perinereis camiguinoides* Augener and *Dorvillea australiensis* (McIntosh) in January. *D. australiensis* appeared again in February. These four species were present on the long-term blocks earlier than on the short-term blocks—i.e., *Podarke* sp. in May, *N. kerguelensis* in June, *D. australiensis* in August, and *P. camiguinoides* in November. Next to *Spirorbis* sp. and *G. hystrix, N. kerguelensis* was the species present for the greatest length of time (seven months) on the long-term blocks. The long-term blocks also showed 10 species over and above those previously enumerated. These were present for varying periods, usually of short duration (Table II).

CIRRIPEDIA

Only one species of barnacle was recorded for the experiment—namely, *Elminius modestus* Darwin. A very heavy set showed on the May short-term block. A count of this block showed 25 animals to the square inch and an estimated total number of 17,750. Less heavy sets occurred in June and April, 1950 (Table I). In all cases, the specimens were large enough to be clearly recognized as *E. modestus*. The barnacles were smaller on the vertical and silted areas of the blocks. The species made only erratic appearances on the long-term blocks, apparently because of failure to survive. At no time was *E. modestus* a very prominent feature of these blocks.

The heavy set during May and the moderately heavy set of June and April, 1950, suggest that the main spawning period of this species is autumn. Work overseas (Corlett, 1948) indicates that settling periods are determined to some extent by temperature. Temperature may not have been so great a factor in determining set in the present instance. For example, in months (October and November) with a temperature range approximating those months when *E. modestus* set heavily, no real indication of the expected set showed on the test blocks. Allen and Ferguson Wood (1950) state that *Balanus trigonus* and two varieties of *B. amphitrite* set fairly heavily from November to March, with smaller settlings in October and April to July. No monthly temperatures are given to allow comparison with *E. modestus*. *E. modestus*, on the short-term blocks, i.e., up to four weeks' growth, showed a diameter ranging from 1·0 mm. to 2·0 mm., with an average of 1·5 mm. By the end of the experiment, specimens up to 6·0 mm. in diameter were present on the long-term blocks, but no estimate of the age of these specimens can be given, as no information as to the settling date is available.

MOLLUSCA

Apart from the molluscan borer *Bankia australis* Calman, the only other mollusc giving data significant for growth and attachment was the mussel *Mytilus planulatus* Lamarck. As stated previously, this species was a well-established member of the upper zone of animals on the wharf piles, but by the time the experiment was ended only one specimen of any appreciable size (2·2 cm.) was found which had set and grown on the test blocks. This was taken from the last block of the long-term series. The long-term block shows that *M. planulatus* spawns throughout the year, but growth appears slow, and in the majority of cases individuals fail *M. planulatus* settled each month on the short-term blocks from December to April. The size range of these individuals was 0·25 mm. to 0·4 mm., with an average of 0·3 mm. A possible explanation of the non-appearance of the species on the short-term blocks before summer is the absence of suitable other species for enmeshing larvae. These were not present until spring. When the rapidly growing hydroids and branching polyzoa appear, mussels were found on the short-term blocks. On the long-term blocks, the size range of the juveniles (0·25 mm. to 0·4 mm.) for June, and September to April, 1950, indicated that they had been present on the units for not more than a month. The greatest size attained by animals surviving for more than a month was 1·75 mm. It would appear that, although sets occur practically all the year round, the species was unable to firmly establish itself on the test blocks, even after they had been in the water thirteen months. Some major factor necessary for the proper growth and development of the mussel must have been lacking. Normally, one would expect a much greater increase in size than was shown over such a time period.

As mentioned above, *M. planulatus* was found entangled in the upright stems of various hydroids and polyzoans. These species are well known for their efficiency in enmeshing settling larvae, but both also are capable of preying on larvae. As the hydroids are in turn food for aeolid nudibranchs (specimens of which were variously found on the blocks) and as each hydroid species flourishes for only a short period, then dies, and is replaced by another, it seems possible that these fairly rapid environmental changes may cause an upset in the normal growth and development of *M. planulatus*. That is, the juveniles do not become sufficiently well established before new factors change the ecological balance, and the young mussels die, or those that survive show little or no growth. It is perhaps noteworthy that those test units from which *M. planulatus* showed evidence of continuous growth for a period exceeding one month were also those blocks where conditions could be said to be fairly stable—i.e., *Bugula* sp. was at its peak for size and coverage, and also there was no replacement of one hydroid species by another, as *C. repens* was present during the whole period. From observations of the surrounding wharf piles, it appears that a full succession of species producing a complex but temporarily stable community must take place before *M. planulatus* can establish to become a dominant member of the wharf-pile community. The latter condition can be seen on the wharf piles at present, three years after the commencement of the experiment. Mussels were but a part of a larger and more varied neighbouring community when the experiment began. At the present time, even their shell valves are almost free of encrusting organisms. Other factors besides rapidly changing conditions no doubt affect the settling and development of *M. planulatus,* but as yet we are unable to offer any hypothesis than that of rapidly changing local environmental conditions causing marked retardation in normal growth and development of the species or even death to fairly large numbers of juvenile individuals.

POLYZOA

The most prominent polyzoan on both series was a species of *Bugula*. *Bugula* sp. was present on all the long-term blocks except in April of both 1949 and 1950. It reached maturity and maximum growth and density in the spring months of August to November, and together with *Cryptosula pallasiana* (Moll.) and *Bugula neritina* (Linnaeus), attached in spring and early summer. *C. pallasiana* paralleled *Bugula* sp. for time range on the long-term blocks, but reached its peak for growth and development in the summer (December to February). Other species showing erratic appearance only on the long-term blocks were *Beania bilaminata* (Hincks) in May, *Tubulipora* sp. (June), and *Idmonea* sp. (June). Quantitatively, the polyzoan species, particularly *Bugula* sp. and *Cryptosula pallasiana*, formed a large proportion of the settling organisms. This was also the situation obtaining in Queensland and New South Wales (Allen and Ferguson Wood, 1950). In Australia, *Bugula neritina* was very prominent, with peaks in November and December. During maximum growth and development, *Bugula* showed a few colonies 9·8 cm. in height, and similarly the flat calcareous *C. pallasiana* reached an area 18·0 cm. by 13·0 cm.

From the evidence of the long-term blocks, it would seem that these species take more than a month to reach identifiable size. The main spawning period for *Cryptosula* and *Bugula*, as indicated from sets on the short-term blocks, was late spring and summer. These blocks were probably principally seeded from animals on the long-term blocks, where they were at maturity and maximum growth at that period. *Cryptosula* and *Bugula* sp. have a life span of approximately nine months. *Beania, Tubulipora*, and *Idmonea* appear on the long-term blocks for a month only. Either these species have a short life span or else for some reason failed to survive.

ASCIDIACEA

The colonial ascidians *Diplosoma macdonaldi* Herdman and *Botryllus schlosseri* (Pallas) were prominent on both long-and short-term blocks. On the long-term blocks, *D. macdonaldi* reached maximum development covering large areas of both horizontal and vertical blocks in the winter months of June and July. Some colonies were 9·5 cm. by 12·0 cm. across at this time. A second heavy set was shown by the short-term blocks to occur in the summer and early autumn. *B. schlosseri* was present to a greater or lesser degree during the whole of the experiment except for the first month. Its peak for surface coverage was early spring, when it replaced *D. macdonaldi*. Colonies up to 7·0 cm. by 5·5 cm. were present at this time. *B. schlosseri* did not develop to an identifiable size on the short-term blocks. Three species of solitary ascidians—namely, *Corella cumyota* Traustedt, *Cnemidocarpa nisiotis* (Sluiter), and *Asterocarpa cerea* (Sluiter) appeared during the experiment. On the short-term blocks, *C. cumyota* was present during October and December-January, and *Cn. nisiotis* in December-January and March. *A. cerea* did not appear on the short-term blocks, but was present in some numbers in late spring and early summer, when it replaced *C. cumyota* as the simple ascidian element on the long-term blocks. By April, 1950, the largest specimen was 6·5 cm. in length. *C. cumyota* was common on the long-term blocks during winter, and a few small animals were present in October, December, and January, reflecting the sets shown for the species on the short-term blocks. *Cn. nisiotis* was at its peak for size and numbers in May, and was present also in June, July, and October, but in much smaller numbers. The evidence indicates that the ascidians, as also the polyzoa, spawn over many months, with a heavy set in spring and summer, and that the species with the longest life span within the group takes approximately four months to attain maturity and maximum growth.

ALGAE

Three species of algae—namely, *Enteromorpha procera* Ahln., *Bangia vermicularis* Harv., and *Ceramium apiculatum* J.Ag., showed on the short-term blocks. *E. procera* settled in spring (September to November), *B. vermicularis* appeared in very small numbers in March, 1950, and *C. apiculatum* in the summer (December-January). The majority of the algal species on the long-term blocks were short lived, more so even than the hydroids—e.g., five species that reached identifiable form appeared on the long-term blocks for one month only. These were *Ectocarpus* sp. (May), *Antithamnion* sp. (September), *Letterstedtia petiolata* J.Ag. (November), *E. procera Ahln.* (December-January), and *Derbesia novae-zelandiae* Chapman (April, 1950). *Bryopsis plumosa* (Huds.) Ag. appeared for two consecutive months. *Myriogramme denticulata* Kylin and *C. apiculatum* are the only species with a life span longer than two months under local conditions, appearing on the blocks for three and more months consecutively.

M. denticulata is first recorded as moderately common in July on the long-term block, but does not appear at all on the short-term block, suggesting that the tetraspores take more than a month to reach identifiable size. This species continues to be present in increasing numbers to the end of the experiment. On the last block of the long-term series, this alga, with the sponge *Halichondria reticulata,* were together the most prominent features of the block. *M. denticulata* seemed one of the few species that was capable of vigorous growth on a silted surface. At the end of the experiment, some specimens had reached a length of 7·3 cm. *C. apiculatum,* the other algal species common from July to April, 1950, showed a second set in December and January on the short-term blocks, which probably signifies a life-cycle of about five months. The length of appearance of the species on the long-term block substantiates this.

OTHER SPECIES ASSOCIATED WITH THE SEDENTARY FORMS ON THE TEST BLOCKS

Species of two other groups of mollusc—viz., the tectibranchiate *Pleurobranchus* sp. and the nudibranch *Aeolidia gracilis* (T. W. Kirk) were found frequently associated with the fixed species of the test blocks. There is little doubt that *A. gracilis* was feeding on the hydroid polyps as sea slugs of this type are known to feed extensively on simple ascidians, and it was probably the presence in some numbers of these animals that caused the appearance of this species on the blocks. The small blennie *Tripterygion varium* (Forster) was twice found browsing among the algae and polyzoans.

DISCUSSION AND COMPARISON WITH SOME OTHER RESULTS IN THE NORTHERN AND SOUTHERN HEMISPHERES

The following paragraphs give a brief comparison of our findings with two recent test experiments on fouling and growth, one from the Northern Hemisphere and one from the Southern. Corlett (1948) describes observations in the Mersey Estuary during 1946 and 1947, using tiles and scallop shells as test units. It should be noted that surface, texture, size, and the time period for immersion differed in our and Corlett's experiments, but the same groups of organisms set in both. However, the most conspicuous groups in Corlett's investigation were not the same as in the present instance. Hydroids, barnacles, and mussels were the most important settling organisms with Corlett, while species of polyzoa, ascidians, and hydroids in that order were dominant organisms in Port Nicholson. The hydroids are important in both investigations. Otherwise, the groups that were most important in the Mersey Estuary were some of the least important in the present experiment. In most groups, a greater number of different species settled in the Northern Hemisphere—e.g., five species of barnacle as against a single species in Port Nicholson. This was also the case with the Australian investigation when compared with our New Zealand tests, and may probably be explained by the fact that in the present experiment the test blocks were confined to one situation of limited area, whereas Corlett, and Allen and Ferguson Wood, had several stations with varying conditions and at points some distance from each other. Species of the genera *Tubularia*, *Mytilus*, and *Enteromorpha* showed in Corlett's and our tests, while the ascidian *B. schlosseri* set at approximately the same season in both hemispheres—namely, early autumn in England and late autumn in New Zealand *B. schlosseri* was not, however, as prominent a species in Corlett's experiment as it was in ours.

Tests carried out in Australia by Allen and Ferguson Wood (1950) are more comparable with our experiment than are Corlett's, as approximately the same time elapsed (30 and 28 days respectively) between the raising of each test block. Also, Allen and Ferguson Wood had long-term units down for three and six months to obtain succession and rates of growth, and short-term units down for seven to fourteen days. The Australian workers, however, used glass plates for test units, thereby obtaining a more rapid check on the settling organisms than could be obtained from the wooden blocks. Their test units were suspended one to two feet below low-tide level, as against our four feet. The following genera, *Ectocarpus*, *Enteromorpha*, *Ceramium*, *Mytilus*, *Sycon*, *Spirorbis*, and the species, *Obelia australis*, *Bugula neritina*, and *Galeolaria hystrix*, were present in both experiments. None of the species of ascidians recorded by Allen and Ferguson Wood was found in the present study.

MARINE BORERS

As far as can be ascertained, the only published work on marine borers in New Zealand waters is a paper by Chilton in 1919. This is a general survey dealing with the systematics and habits of crustacean borers and the damage to wharves in Auckland, Lyttelton, Napier, and Wairoa. So far, in Port Nicholson waters, we have noted four species of borer. Two of them, a nereid, *Nereis kerguelensis*, and the Amphipod *Chelura terebrans,* seem to cause little damage. The burrows of *Chelura terebrans* are, however, very similar to those of *Limnoria quadripunctata* Holthius. It is possible that we have underestimated its damage, and that a greater amount of surface crumbling on some of the test blocks is caused by *Chelura* than is immediately apparent.

The third species of borer is the Isopod, commonly called the "gribble." At the request of Mr. Robert Menzies, of the Pacific Marine Station, California, specimens were sent to him. They were identified by him as *Limnoria quadripunctata,* a species described as new by Holthius in 1949, from Holland, and subsequently reported from Cape Town, Plymouth, and the Central Californian Coast. It had been assumed up to the time of Mr. Menzies' communication that the species present in Port Nicholson was *Limnoria lignorum* Rathke, as this species has been recorded from Auckland, Lyttelton, and Akaroa. Doubt has now arisen as to the correctness of Chilton's diagnosis of specimens from these three latter harbours. Since it is difficult to separate exactly the burrows of *Chelura terebrans* and *Limnoria quadripunctata,* we have referred in general terms to the damage done by these species as "*Limnoria* damage." *Limnoria* is undoubtedly responsible for the greatest visible destruction of the test blocks. The fourth species of borer found in the test blocks is the mollusc *Bankia australis,* commonly called the "ship worm," or "teredo."

Limnoria attacks the surface of the wood. As this becomes riddled with burrows, the surface disintegrates, and an accurate estimate of the attack can readily be made from month to month. *Bankia,* on the other hand, burrows below the surface, the burrows at first running with the grain, but later, as infestation becomes heavier, the burrows twist and turn in all directions. The only indication of "ship worm" in the wood is the presence of numerous small round respiratory holes on the surface. Although a count of these holes gives a fairly true measure of the numbers present, it gives no indication of the overall damage done to the interior of the wood. To obtain a more accurate picture of this damage and to obtain growth measurements, X-ray photographs were taken of the test blocks.

INFESTATION BY CRUSTACEAN BORERS (Fig. 2)

Limnoria numbers were estimated by ruling the test blocks into one-inch squares and counting the number of burrows. These usually follow the grain, and are marked at the surface by a series of respiratory holes. A strong needle run along the line of these respiratory holes will generally expose the tunnel for its full length. The male and female live together at the head of the tunnel, female first, and the young are liberated fully developed from her brood pouch. They commence to burrow on their own account away from the parent tunnel, so that badly infested timber will show branching tunnel systems. As the tunnels eventually become three or four deep, or even more, it becomes impossible to do more than make a very approximate estimate of the number present. This point was reached in the present experiment in about nine months. The short-term blocks rarely showed "*Limnoria* damage," indicating that more than a month's immersion under local conditions on this particular type of test block is necessary before much damage is apparent. Counts on the long-term series show accelerated breeding in October, and again in March, 1950. In both instances, the *Limnoria* population trebled the previous month's total. The first sharp rise in population numbers coincided with rapid temperature rise in spring. The cumulative effect of warm summer water probably accounts for the second increase in autumn. A decrease in numbers in November is shown, and must be due to some unknown factor affecting breeding peculiar to that block. Apart from this one instance, population numbers increased throughout the experiment. The vertical block and the rougher surfaces were consistently more heavily attacked than the horizontal block. The presence of a fairly thick coat of mud on the upper surface of the horizontal block probably accounts for this, since it was observed that where mud had accumulated there was little "*Limnoria* damage."

INFESTATION BY *Bankia australis* Calman (Figs. 3 and 4)

X-ray photographs of the first short-term block proved negative, and the first indication of *Bankia* attack was given by the second-month long-term block, where X-ray photographs revealed a light infestation of young animals ranging in size from 0·3 cm. to 1·8 cm. in length. By a careful comparison of the photograph and the surface of the test block, it was possible to see the minute respiratory holes of these young animals. In all cases, X-ray photographs failed to reveal the presence of *Bankia* in the short-term blocks. Isham, Moore, and Smith (1951) also record that "in panels exposed for only one month ship worms were neither large enough or numerous enough to furnish material adequate for growth rate determination." However, in February, when the long-term blocks clearly indicated a heavy set, it was possible in the present instance, with the aid of a hand lens, to make a fairly accurate count of respiratory holes on the short-term blocks.

Bankia respiratory holes are readily distinguishable from those of *Limnoria*, and counts of the holes give a reasonably accurate estimate of numbers present after the first few months. Counts from X-ray photographs give a check on the numbers obtained from counts of the surface holes. In large specimens of *Bankia australis*, the pallets often protrude slightly from the surface holes, and counting is then easy. The burrows are lined with lime, and usually go a short distance straight into the wood before turning to run with the grain. The fact that the shell valves and pallets are also mainly composed of lime greatly facilitates the count, as these calcareous structures show clearly in X-ray photographs. Accurate measurements of burrow lengths cannot be obtained after about the tenth month because of the number of intimately intertwining burrows.

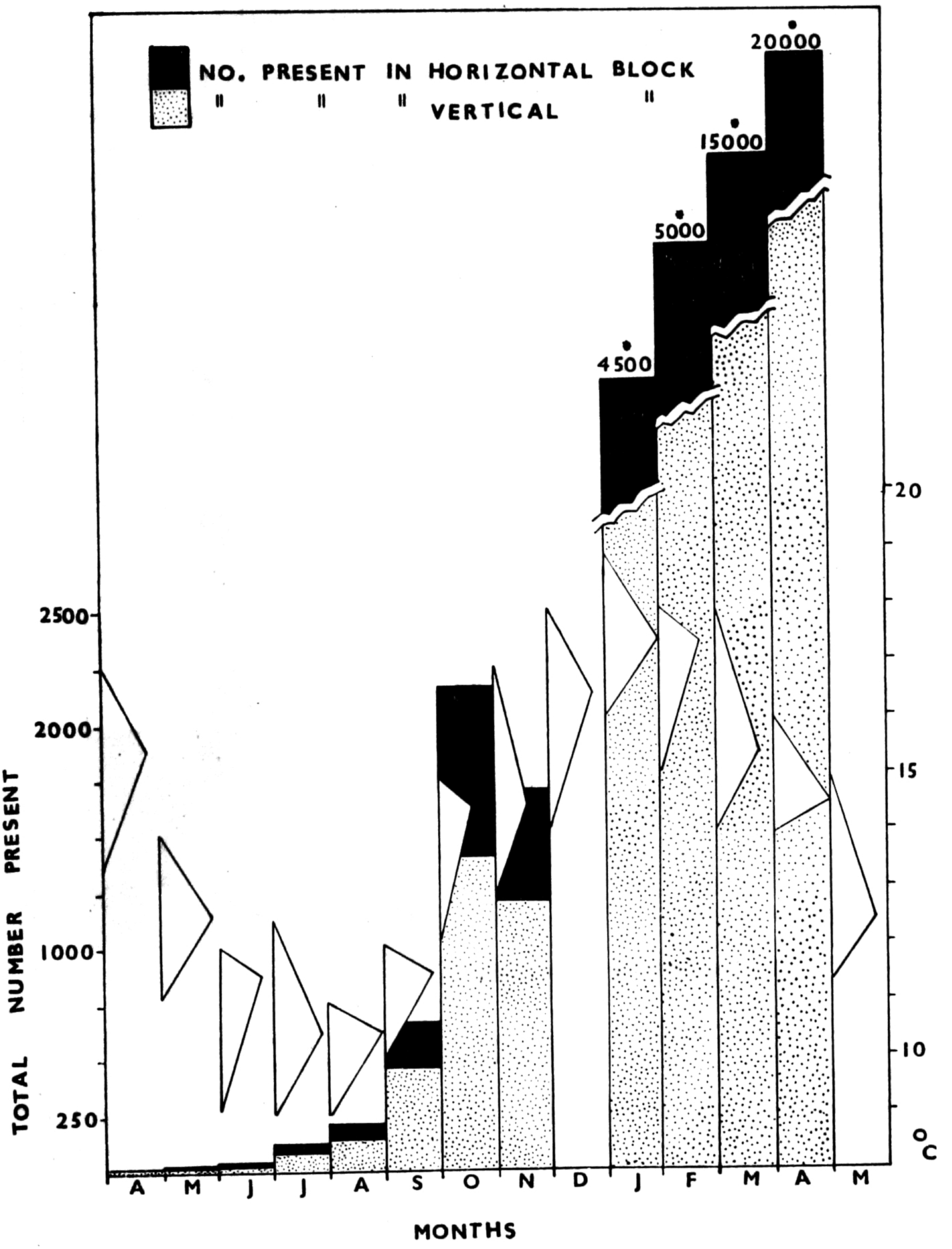

FIG. 2.—Monthly incidence of *Limnoria quadripunctata* Holthius in the long-term test blocks. Temperatures shown by triangles. Full explanation of diagrammatic presentation of monthly temperature records on page 3 of text. *Approximate numbers.

From the second month (May, 1949), *Bankia* was clearly indicated on the X-ray plates. The burrow length for this month was from 0·3 cm. to 1·8 cm. Pallets could not be distinguished in specimens 0·3 cm. in length, were faintly visible in the 0·6 cm. to 0·8 cm., but were distinct in all specimens above this size. The smallest *Bankia australis* recorded on the X-ray plates was 0·3 cm. in length. There appeared to be no significant difference in growth rate between animals in the horizontal and vertical blocks. Over the first nine-month period (April to November, 1949), there were constant small reinvasions of the blocks by larval

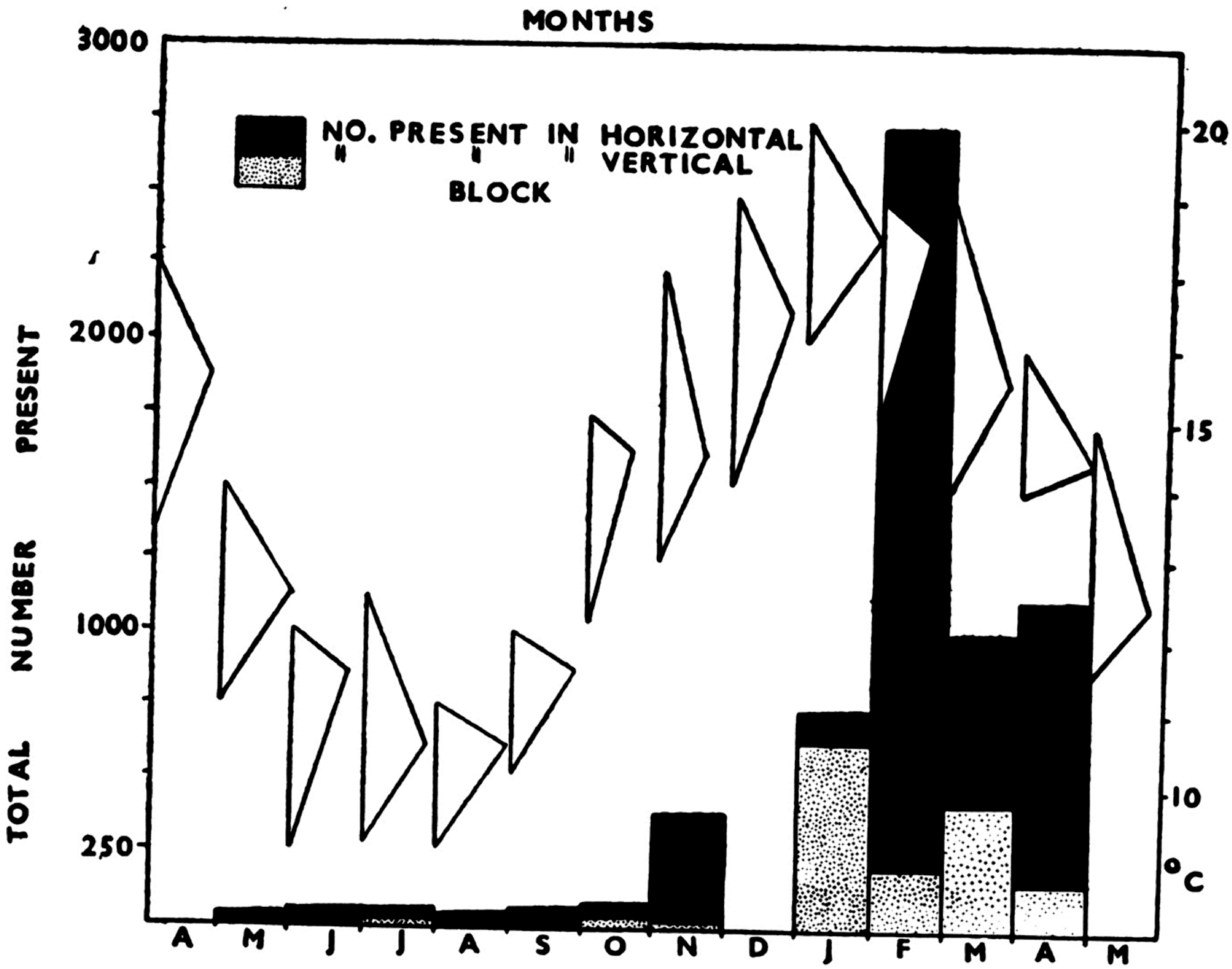

FIG. 3.—Monthly incidence of *Bankia australis* Calman in the long-term test blocks. Water temperatures shown by triangles.

stages. Numbers settling increased markedly from December, 1949, to April, 1950. The peak was February, when approximately 2,000 settled, with another 750 already established.

Figure 4 gives the growth of *B. australis* based on measurement of burrow lengths; the principal curve gives the length of the longest burrow in the block for each month. The other data for each month shows the groupings of the shorter burrows as a vertical line, with the average in each group marked by a filled-in circle. These latter groups are here considered as representing monthly sets, although—e.g., November—there are ten such groups which exceed the number of months and indicate more than one heavy set in some months. The principal curve, in general, is that of an ordinary growth curve, but shows a deceleration of growth rate in September and again in November (i.e., winter and spring). This is also noted by Isham, Moore, and Smith (1951), who have interpreted this as consequent from overcrowding, but in terms of the actual set found on the short-term blocks, the total population is still short of its maximum. In any case, the burrows measured are those of animals which have lived through the period of sharply increasing growth-rate (August and October), and did not benefit to the same degree as did those measured in the September and November blocks. This deviation of the curve accordingly must be considered as due to individual variation and not having the significance of the variation in Isham, Moore, and Smith's curve.

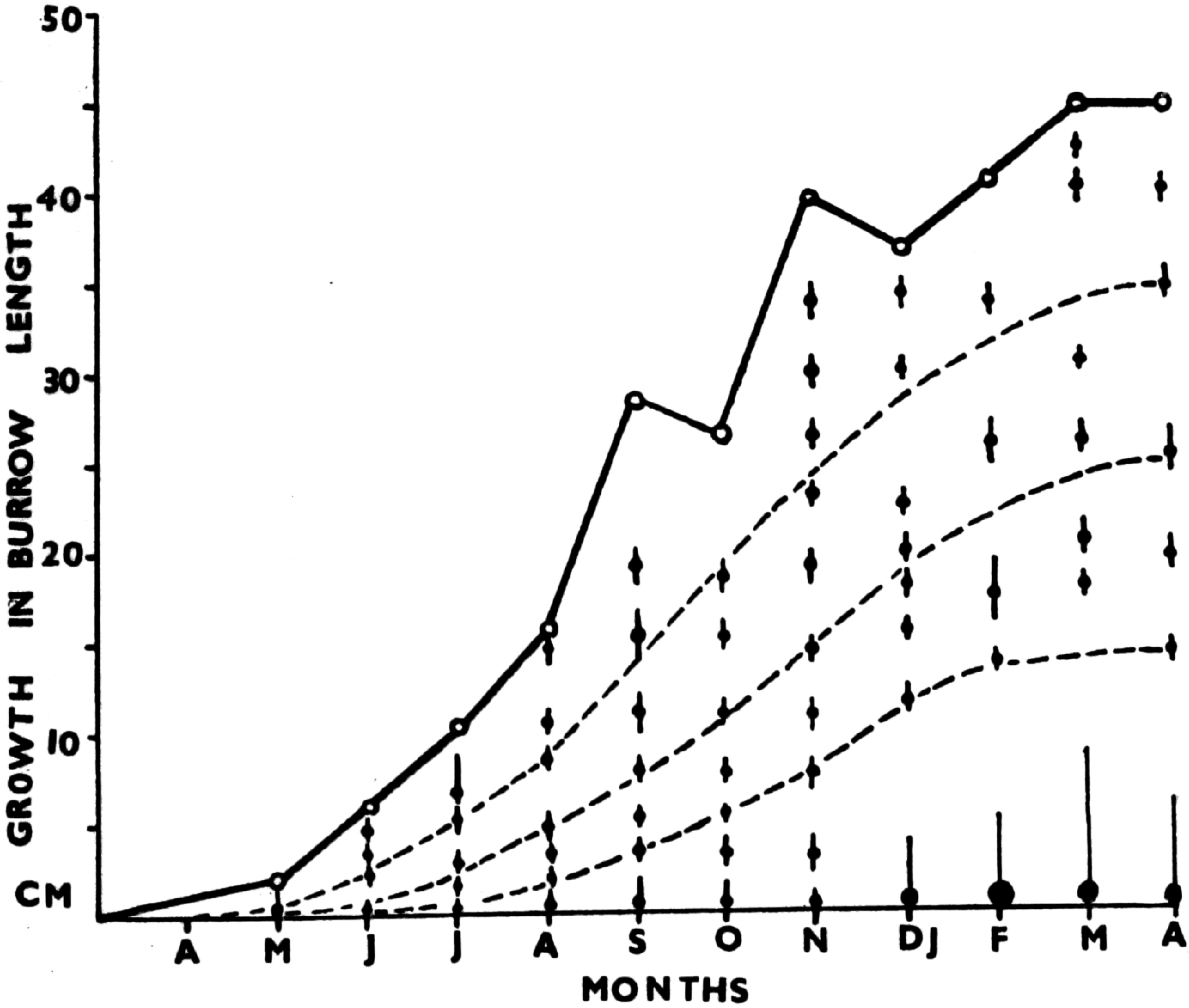

FIG. 4.—Growth curve of *Bankia australis* Calman based on burrow lengths. Principal curve gives lengths of longest burrows. The symbol shows groupings of shorter burrows. Burrows measured at the end of each month.

results are a true indication of the growth and incidence of these borers in Port Nicholson. The sudden rise in numbers in February, followed by a marked decrease in March, is difficult to explain. A steady rise in numbers is more to be expected, with perhaps a flattening-off of the curve of total numbers about March with the decrease in temperature. The March and April, 1950, blocks were exposed to the same heavy settling as the February block as well as later settlings. A possible

The incidence of *Bankia australis* over the thirteen-month period shows one or two unusual features which seem most reasonably to be accounted for by fluctuations in local conditions. Further study is necessary to see if these preliminary

explanation seems to be that the adult *Bankia* in the February block liberated large quantities of spawn, and the resulting larvae settled mainly on that block. There has obviously been a decline in the survival rate, and for some reason spawn liberated in March and April failed to survive in high numbers on these blocks. Calcareous encrustations such as barnacles, oysters, the tubes of marine worms, and encrusting bryozoa form an armour against the entry of borers into wood, especially when their establishment precedes larval lodgement (Watson *et al.*, 1936). This may have been a factor which prevented survival from large settlings on the March and April blocks, as on these other species were well established. However, these species were present also on the February block, and it is hard to see why they failed to reduce the numbers of larvae settling in February if they were one of the chief factors responsible for reduced settlement in March and April.

Several factors are known to influence "ship worm" attack, and different factors are thought to influence different species of "ship worm." Calman (1919) claimed that pollution or muddy water rendered timber less likely to attack. These factors were present to a minor degree only, and seem unlikely to have influenced the numbers of settling larvae in the present experiment. The greater number of animals in the horizontal unit of the test blocks is in accordance with the findings of Shillinglaw and Moore (1947), who report that non-resistant cross and diagonal bracing below mid-tide level are very susceptible to attack. As all the blocks were placed at approximately the same depth, no indication of the vertical working range of *Bankia australis* can be given at the present time. It is generally agreed that, where the substratum is suitable, certain types of fouling organism are indicators of likely areas of borer attack. These include barnacles, hydroids, and mussels (San Francisco Bay Marine Piling Survey, 1923; Watson *et al.*, 1936). Where these animals are already present in an area, borers have usually made their presence obvious also. Species of all the indicator groups enumerated above are present on the wharf piles in the vicinity of the present experiment; and, as indicated by the above description, borers have also made their presence obvious. In an area where barnacles, hydroids, and mussels suddenly make their appearance and where no borer troubles have been previously experienced, then one may expect borers, since salinities and temperatures that suit borers are usually within the ranges of tolerance of these other animals. The sudden appearance of barnacles, hydroids, etc., suggests a change in local salinities and temperature conditions which will suit the borers. Environmental conditions vary within the harbour area, and further experiments are necessary to give a more complete picture of borer activity in Port Nicholson. Most species of *Bankia* show preference for water of high salinity (Watson *et al.*, 1936), and one would predict that *B. australis* may be less active on the eastern side of the harbour near the Petone foreshore, as the movement of the Hutt River water in the harbour on this shore must lower the salinity of the water.

SUMMARY

An account of the species settling, with relative monthly abundance and periods of set are given for the more important species. Results parallel closely those obtained in other countries with non-toxic test units. Sedentary organisms were principally hydroids, polyzoa, ascidians, sponges, and algae. Hydroids, at first dominant, were replaced by sponges and algae. Mussels, an established species on the wharf piles, were only moderately common and of microscopic size on most blocks. The hydroids, and to a lesser degree the algae, grew rapidly and had a short life span. The majority of hydroids attained maximum growth and maturity within four weeks. Other species, notably the serpulids *Spirorbis* sp. and *Galeolaria hystrix,* the mussel *Mytilus planulatus,* and the two borers *Limnoria quadripunctata* and *Bankia australis* grew more slowly and spawned throughout the year. There were further species, chiefly among the polyzoa and ascidians, with a life span of several months but seasonal spawning. *Tubularia attenuoides* grew twice as fast in summer as in autumn, and in the late spring the population doubled in quantity.

The combined attack of the "shipworm" *Bankia australis* and the "gribble" *Limnoria quadripunctata* resulted in marked deterioration of the wooden test blocks. These species stand in contrast in respect to their method of attack. *L. quadripunctata* destroys the immediate surface layer of the timber, while *B. australis* works deeper in the wood. With *L. quadripunctata,* increasing numbers seemed to be largely the result of multiplying stock on the blocks and not the result of repeated invasion from outside sources. There was a sudden rise in population numbers in October and March, and these appeared directly related to increases in temperature. *L. quadripunctata* showed preference for the rougher surfaces, and greatest numbers were found in the vertical blocks. In contrast, *B. australis* vigorously attacked the horizontal blocks. Development of *L. quadripunctata* to an identifiable stage takes more than four weeks, as in general no invasion was recognized on the short-term blocks. In this respect, *B. australis* and *L. quadripunctata* are alike, as no juvenile of the former showed in the X-ray photographs of the short-term blocks. The growth of *B. australis,* based on measurement of burrow lengths is in general represented by an ordinary growth curve.

The double series of blocks have been amply justified, as by this method some estimate can be made of the monthly set and invasions, and of the time taken to reach maturity, etc. It also became evident in the course of the experiment that any future work could be more easily carried out with smaller test blocks and preferably with a smoother surface to facilitate removal and earlier recognition of species. As much fouling under natural conditions takes place on wooden or metal surfaces, we would retain wood as the principal material for future test units. Also, this medium enables a double study to be made—firstly, of attachment and growth of fouling organisms, and, secondly, of borer damage. Much of the value of the present study lies in the interesting problems it brings to light—e.g., the settling and growth of *Mytilus planulatus* and, speaking in more general terms, the history of the community itself—particularly its unstable and transient nature.

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