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TECHNICAL REPORT

MARINE BIOLOGICAL FOULING
IN THE APPROACHES TO
CHESAPEAKE BAY

F. M. DAUGHERTY, JR.
Evaluation Branch
Oceanographic Analysis Division

DECEMBER 1961

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ABSTRACT

This report is an analysis of the data of a marine biological fouling program conducted from April 1956 to November 1959 in the approaches to Chesapeake Bay. The data presented in H.O. TR-47 (1958) are incorporated in this report. Curved steel test panels, bottom test cylinders, and steel stakes were used to collect data.

Collateral oceanographic and meteorologic data were taken in conjunction with monthly fouling observations. There were four stations in all, which were occupied as near the midmonth as possible. Thus, a period of one-month is designated as April-May, May-June, etc.

Hydroids, which set in April-May, were the first foulers of the calendar year and the last in December-January. Maximum growth in weight occurred in July-September for the study area. The onset of foulers was governed for the most part by whether water temperatures were above or below approximately 65°F, though some attachment occurred in colder water. There was very little to no set from November-December to March-April; however, growth continued at a slightly reduced rate throughout the cold months.

Twelve-month test panel growth ranged from 31 to 38 ounces per square foot. Barnacles, bryozoans, hydroids, tunicates, calcareous tubeworms, arthropod tubes, and jingle shells predominate in the fouling complex.

ACKNOWLEDGMENTS

Acknowledgment is made of the continued cooperation of the Harbor Defense Unit, Norfolk, Virginia in providing divers and small craft necessary for environmental and fouling data collection. Messrs. Willis S. Glidden, James A. Bruce, and Alfred P. Franceschetti of this Office contributed considerably by their analyses of the fouling test panels, as did the many other oceanographers who conducted the field research.

FOREWORD

This report describes the research methods, results, and conclusions of a cooperative marine biological fouling research program between the U. S. Navy Hydrographic Office and the Harbor Defense Unit, Norfolk, Virginia. The need for such research was established by the Navy's Inshore Survey Program. These data can be of use to the Navy in its maintenance program by furnishing guidance as to timely introduction and removal of equipments from marine waters and in operating ships and equipment more economically. This program provided valuable information not only specific to the approaches to Chesapeake Bay but also pertinent to analogous marine environments elsewhere. Also, it will serve as a prototype for research in other areas.



E. C. STEPHAN
Rear Admiral, U. S. Navy
Hydrogapher

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MARINE BIOLOGICAL FOULING IN THE APPROACHES TO CHESAPEAKE BAY

I. INTRODUCTION

A study of the biological fouling in the approaches to Chesapeake Bay was conducted from April 1956 through April 1957 and reported in H. O. TR-47 by William E. Maloney. The study was then expanded and continued through November 1959. All data from April 1956 through November 1959 are reported herein. This study was directed toward the determination of the biological fouling complex and the seasonal and geographic distribution of organisms. Data analysis was made of the macroscopic sessile organisms of the fouling complex.

The test sites shown in Figure 1 were selected on the basis of accessibility and variability in environments. The sites are characterized as follows:

Site 1--Shallow, near the ship channel, somewhat protected, and strongly influenced by the James and York Rivers.

Site 2--Relatively deep for the approach area, adjacent to the ship channel, very little protection, and influenced by the estuarine nature of Chesapeake Bay.

Sites 3 and 4--Shallow, away from the ship channel, unprotected except from an offshore wind, and greatly influenced by the ocean.

Andrews (1953) discusses the principal foulers of Chesapeake Bay in relation to various environmental factors and presents a list of fouling organisms from the scanty and rather specialized literature pertaining to Chesapeake Bay and nearby marine environments. Maloney (1958) analyzed the findings of the 1956-57 research, determined the materials to be used, methods and procedures, and foulers to be studied.

II. METHODS AND MATERIALS

The methods and materials described by Maloney (1958) were continued in this phase of the problem; consequently, they will receive only cursory treatment in this report except for minor changes or new procedures. New test items were introduced in the form of bottom test

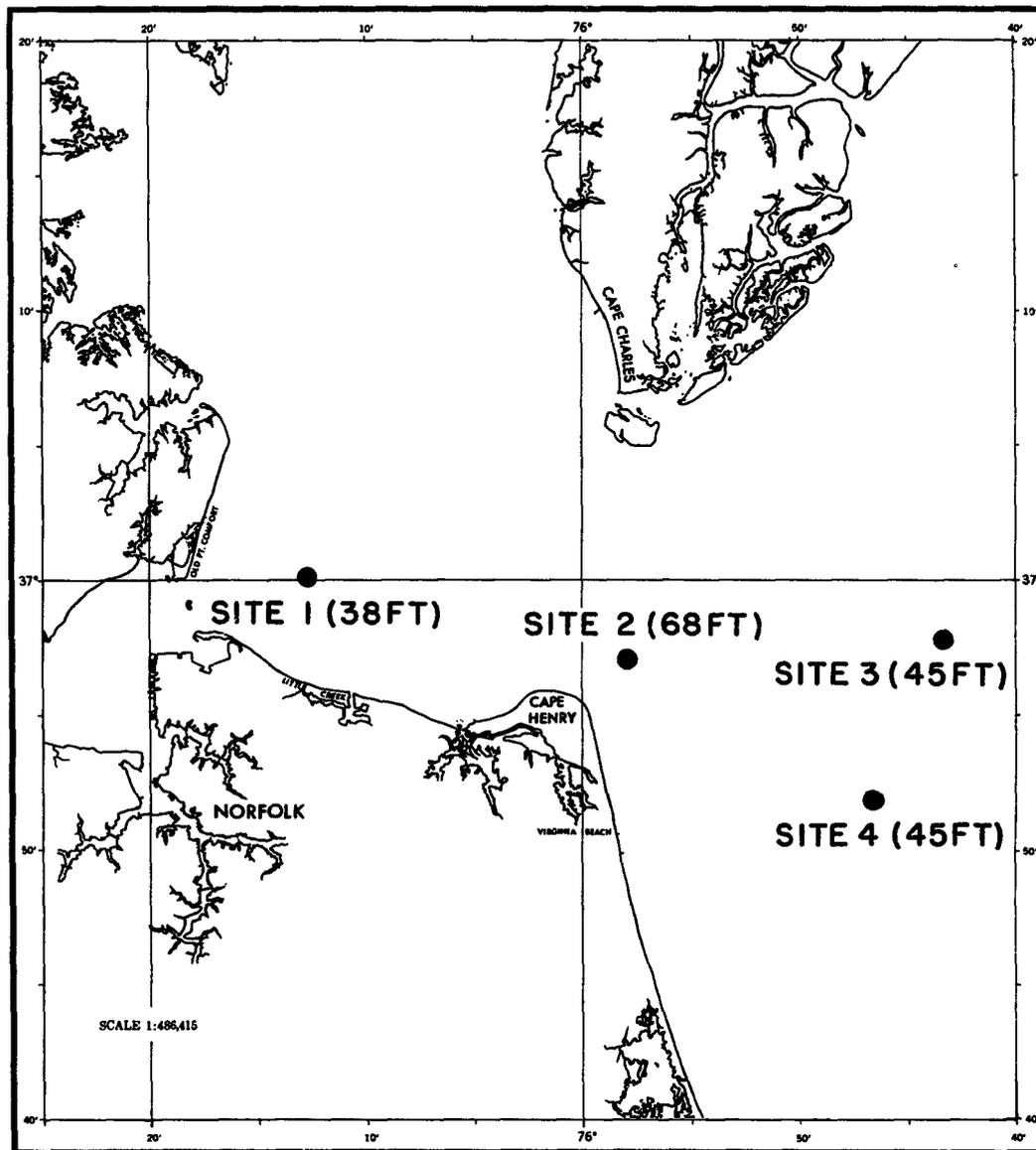


FIGURE 1 FOULING TEST SITES IN THE APPROACHES TO CHESAPEAKE BAY.

cylinders to collect bottom organisms and steel tubular stakes for determination of vertical stratification. Figure 2 shows the basic fouling panel rack and the curved steel panels. The panels measuring 15 1/4 x 8 x 1/8 inches were used in all phases of the problem. Panel introduction and removal schedules are shown in Figures 3, 4, 5, 6, and 7.

The Harbor Defense Unit, Norfolk, Virginia constructed and positioned the racks, provided small boat services, and assigned divers to the project. The sites were occupied at approximately the same time each month, near midmonth, in order to insure the planned continuity of fouling panel series and collateral environmental data. Each 1-month period is referred to as April-May, May-June, etc. Of course, it was not possible to adhere to a firm schedule throughout the study because of inclement weather, equipment failures, and boat nonavailability.

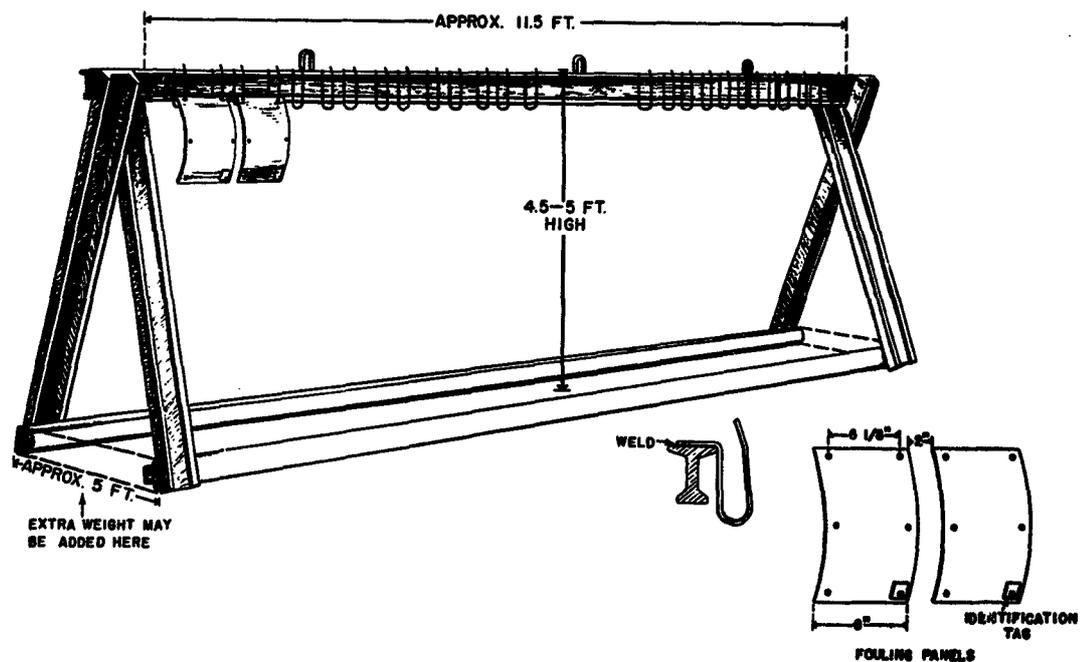


FIGURE 2 FOULING PANELS AND BASIC RACK.

POSITION OF PANELS IN RACK

1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th	DATE
1	2	3	4	5	6	7	8	9	10	11	12	17-IV-56
1												16-V-56
13												19-VI-56
13	2											13-VII-56
14	15											15-VIII-56
14		3										13-IX-56
NoNo		16										14-X-56
NoNo	15		4									13-XI-56
17	18		19									9-XII-56
17				5								9-I-57
20				21								13-II-57
20	18	16			6							19-III-57
22	23	24			25							16-IV-57
22						7						
26							8					
26	23		19									
27	28		29									
27		24						9				
30		31										
30	28			21					10			
35	34											
35										11		
32												
32	34	31	29		25						12	

99	TEST PANEL PLACED IN WATER
99	TEST PANEL REMOVED FROM WATER
NUMBERS IDENTIFY TEST PANELS	

FIGURE 3 SITE 1 FOULING PANEL SCHEDULE 17-IV-56 TO 16-IV-57.

POSITION OF PANELS IN RACK

1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th	DATE
40	41	42	43	44	45	46	47	48	49	50	51	16-IV-57
40												14-V-57
52												18-VI-57
52	41											17-VII-57
53	54											22-X-57
53		42										15-XI-57
55		56										17-XII-57
55	54		43									23-I-58
57	58		59									25-II-58
57				44								27-III-58
60				61								15-IV-58
60	58	56			45							
62	63	64			65							
62						46						
66						67						
66	63		59				47					
68	69		70									
68		64						48				
71		72										
71	69			61					49			
73	74											
73										50		
75												
75	74	72	70		65	67					51	

99	TEST PANEL PLACED IN WATER
99	TEST PANEL REMOVED FROM WATER
NUMBERS IDENTIFY TEST PANELS	

FIGURE 4 SITE 1 FOULING PANEL SCHEDULE 16-IV-57 TO 15-IV-58.

POSITION OF PANELS IN RACK

1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th	DATE
80	81	82	83	84	85	86	87	88	89	90	91	21-VI-57
80												17-VII-57
92												14-VIII-57
92	81											20-IX-57
93	94											22-X-57
93		82										15-XI-57
95		96										18-XII-57
95	94		83									21-I-58
76	98		99									25-II-58
76				84								III-58
100				101								18-IV-58
100	98	96			85							20-V-58
102	103	104			105							17-VI-58
102						86						
106						107						
106	103		99				87					
108	109		110									
	NO PANELS REMOVED											
108	LOST	LOST		101				88	89			
113	114											
113										90		
112												
112	114		110		105	LOST					91	

99	TEST PANEL PLACED IN WATER
99	TEST PANEL REMOVED FROM WATER
NUMBERS IDENTIFY TEST PANELS	

FIGURE 5 SITE 2 FOULING PANEL SCHEDULE 21-VI-57 TO 17-VI-58.

POSITION OF PANELS IN RACK

1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th	DATE	
1	2	3	4	5	6	7	8	9	10	11	12	17-VI-58	
					NO PANELS REMOVED								VII-58
					NO PANELS REMOVED								VIII-58
1	2	3										24-IX-58	
16		17											
16			4									24-X-58	
18	19		20										
18				5								18-XI-58	
21				22									
21	19	17			6							17-XII-58	
23	24	25			26								
23						7						20-I-59	
27						28							
					NO PANELS REMOVED							II-59	
27	24		20				8	9				19-III-59	
32								33					
32		25		22					10			21-IV-59	
34	35												
34										11		27-V-59	
37													
37	35				26	28		33			12	23-VI-59	

99	TEST PANEL PLACED IN WATER
99	TEST PANEL REMOVED FROM WATER
NUMBERS IDENTIFY TEST PANELS	

FIGURE 6 SITE 2 FOULING PANEL SCHEDULE 17-VI-58 TO 23-VI-59.

POSITION OF PANELS IN RACK

1st	2nd	3rd	4th	5th	6th	DATE
13	III	78	79	97	77	27-V-59
13						23-VI-59
14						
	III					21-VII-59
	15					
UNABLE TO LOCATE RACK						VIII-59
		78	79			23-IX-59
		31				
NO REMOVALS SCHEDULED						X-59
				97		12-XI-59
				38		
NO REMOVALS SCHEDULED						XII-59 I-60 II-60 III-60 IV-60
UNABLE TO LOCATE RACK						V-60
UNABLE TO LOCATE RACK						V-60
NOTE: PANELS REMOVED AFTER V-60 ARE NOT APPLICABLE TO THIS DATA SERIES.						

99	TEST PANEL PLACED IN WATER
99	TEST PANEL REMOVED FROM WATER
NUMBERS IDENTIFY TEST PANELS	

FIGURE 7 SITE 4 FOULING PANEL SCHEDULE 27-V-59 TO 12-XI-59.

Analyses of the panels continued as described by Maloney (1958), except for the development of new data sheets that aided in standardizing procedures. Strip templates of 1/10 square foot were used where fouling was severe, and transparent templates marked in squares one centimeter on the side increased accuracy and greatly facilitated calculation of area coverage data.

In the usual procedure, panels were weighed in water and in air both before and after the immersion period. Black and white photographs were made of both convex and concave sides of each panel immediately after removal from water and again after drying. It was necessary to make most analyses in the dry state with photographs of the fresh state for comparison; however, some panels were examined while fresh. Salinity samples, temperatures, Secchi disc readings, currents, and general meteorological data were collected at each introduction and recovery of a panel or other fouling test object.

III. ENVIRONMENT

Maloney (1958) questioned whether the 1956-57 Site 1 period was typical for both environmental factors and biological activity. Representative temperatures derived from the 1956-58 Site 1 and 1957-59 Site 2 data shown in Figure 8 are in relatively close agreement with the 10 years of mean surface temperature data for Old Point Comfort. Salinity comparison indicates that representative salinities are in closer agreement with the mean maximum than with mean salinities for Old Point Comfort. The close relationship between biological activity and water temperature would indicate that the yearly periods involved in this program are basically typical biological periods for the area. The lack of agreement in salinity does not necessarily detract from the possibility of relatively typical biological periods, since mean annual salinity in an estuarine environment is a poor indicator of fouling activity and the local salinity, pollution, and silting inter-relationships create a complicated biological activity situation specific to the area.

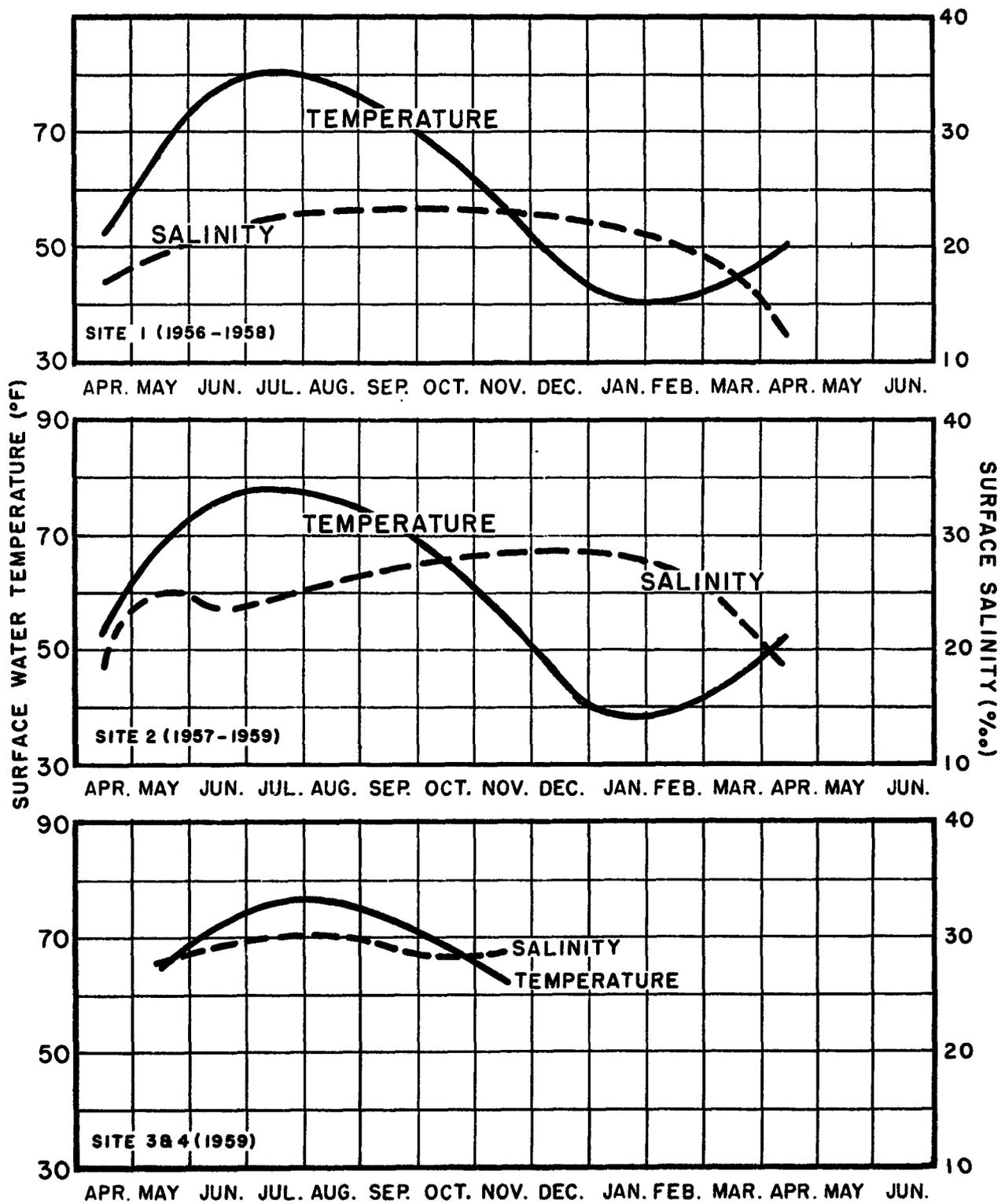


FIGURE 8 REPRESENTATIVE SEA SURFACE TEMPERATURES AND SALINITIES.

IV. FOULING WEIGHT AND COVERAGE

The fouling weight on each panel was determined as wet weight in air. Quantitative determinations were patterned after Maloney (1958) in set and growth relations. Figure 9 presents fouling weights for 1-, 2-, and 3-month periods for Site 1 from April-May 1956 through April-May 1958. This figure, resulting from the compilation of data for 2 years, is in basic agreement with the 1956-57 data for the same site. Maximum set and most rapid growth are exhibited by the 2-month August-October and 3-month July-October panels; minimum set and growth occurred on 1-month panels from October-November through April-May; however, there is no cessation of growth. Figure 11 shows that the growth curve for Site 1 continues to increase during October-November through April-May.

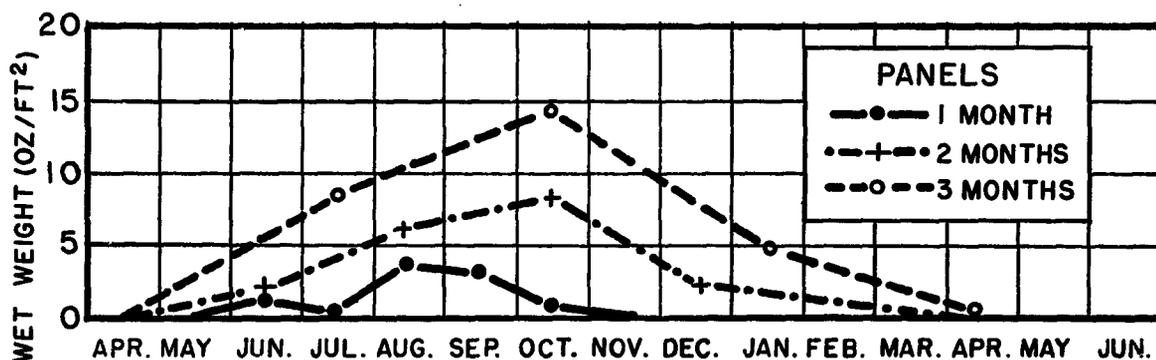


FIGURE 9 SITE 1, TOTAL FOULING COMPLEX WEIGHTS FOR 1-, 2-, AND 3-MONTH PANELS 1956-58.

Site 2 data for 1-, 2-, and 3-month periods are presented in Figure 10. The set-growth trend compares favorably with Site 1 except that the monthly fouling rates are somewhat greater and the maximum 1-month set and growth occurs a month later during August-September. The peak growth in the 3-month period February-March through May-June seems to be rather heavy, even in view of the expected spring bloom. As at Site 1, there is continued growth throughout the winter.

The month-to-month differences in cumulative and monthly set and growth are greater for Site 1 than for Site 2, resulting in a growth factor of greater magnitude (Fig 11).

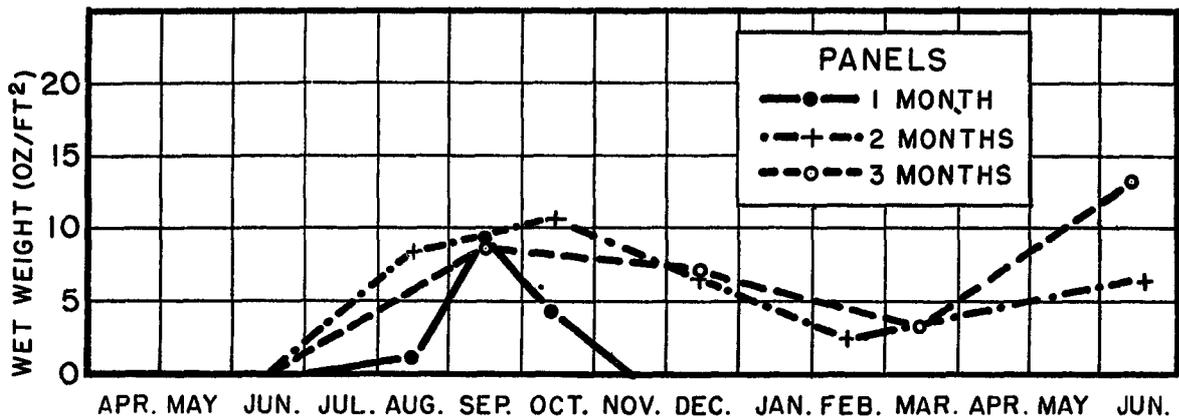


FIGURE 10 SITE 2 TOTAL FOULING COMPLEX WEIGHTS FOR 1-, 2-, AND 3-MONTH PANELS 1957-1959.

Panel analysis included data on the percent of the panel covered by each of several basic groups of sessile macroscopic foulers. Many of the panels are recorded as having coverage in excess of 100 percent, indicating that organisms were literally growing on top of each other or in some panels occupying the same general area (Fig 12). Cumulative and monthly curves for Site 1 are very close, whereas the monthly panel coverage curve for Site 2 exceeds the cumulative curve as much as 250 percent. This fact indicates that a much greater winter decay (natural deaths, loss from foragers, mechanical loss, etc.) of certain foulers or groups of foulers occurs at Site 2.

A summary of the fouling weight per square foot for all Site 1 and Site 2 panels as shown in Figures 3, 4, 5, and 6 is presented in Figure 13 in the form of graphic envelopes. Ultimate set and growth weight was greater, and the rapidity of set and growth was accelerated for Site 2 in comparison to Site 1. The fact that Site 2 panels were always introduced 2 months later in the year probably influenced the magnitude of growth and set because the last 2 months (April-May through May-June) are in the spring onset period, with new set and growth replacing the winter decay and augmenting the carryover to some extent. It is also pertinent that the first few months of Site 2 testing are in a period more conducive to growth than are the first months for Site 1.

The cumulative curve presented in Figure 11 for Site 4 panel data indicates that a 6-month panel had only 5 ounces of fouling per square foot, whereas Sites 1 and 2 had 16 and 8 ounces, respectively, for the same time interval. A bottom test cylinder was fouled only 1.5 ounces

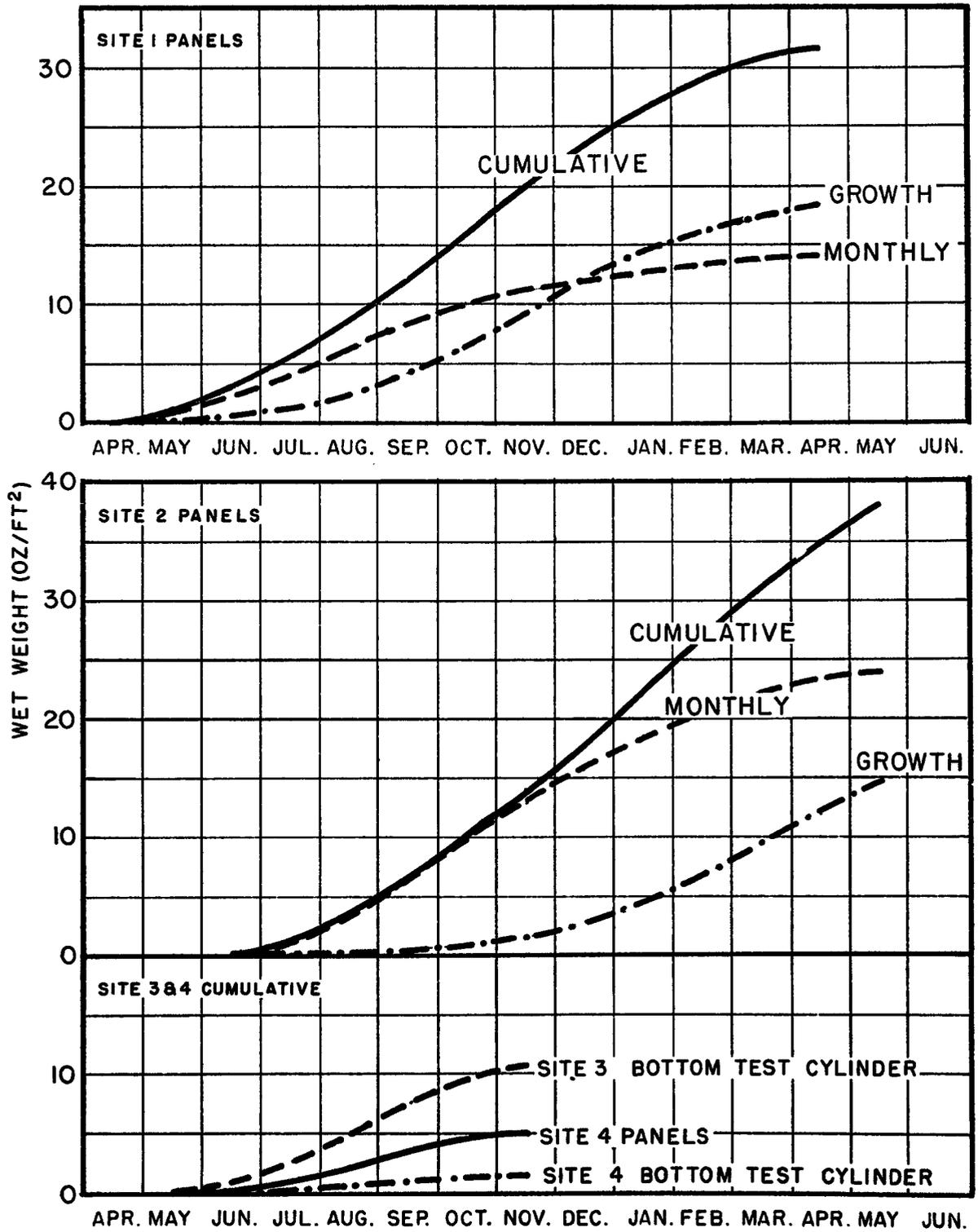


FIGURE 11 CUMULATIVE AND MONTHLY FOULING WEIGHT PER SQUARE FOOT AND GROWTH DETERMINATION.

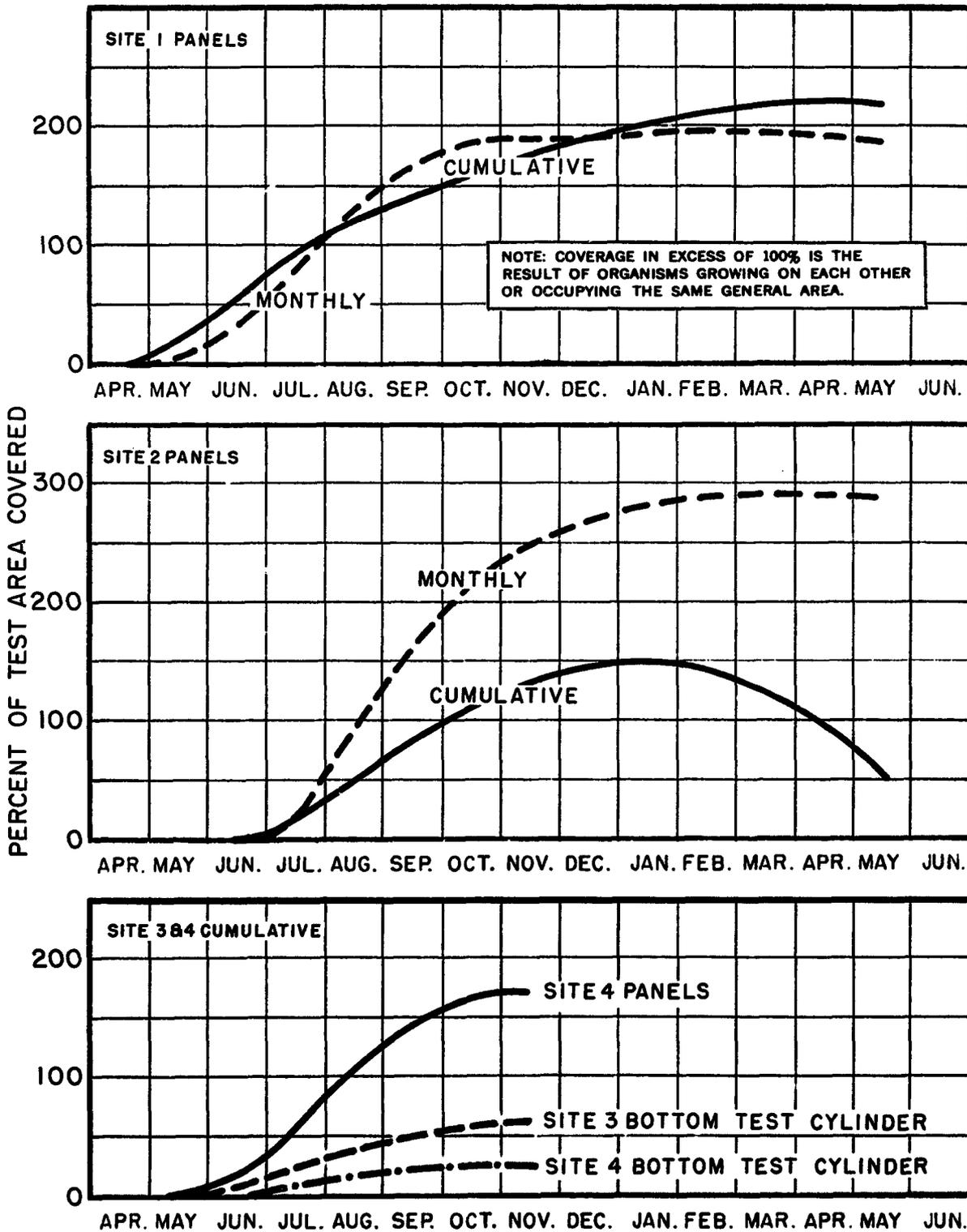


FIGURE 12 PERCENT OF EXPOSED AREA COVERED BY ATTACHMENT FOULERS.

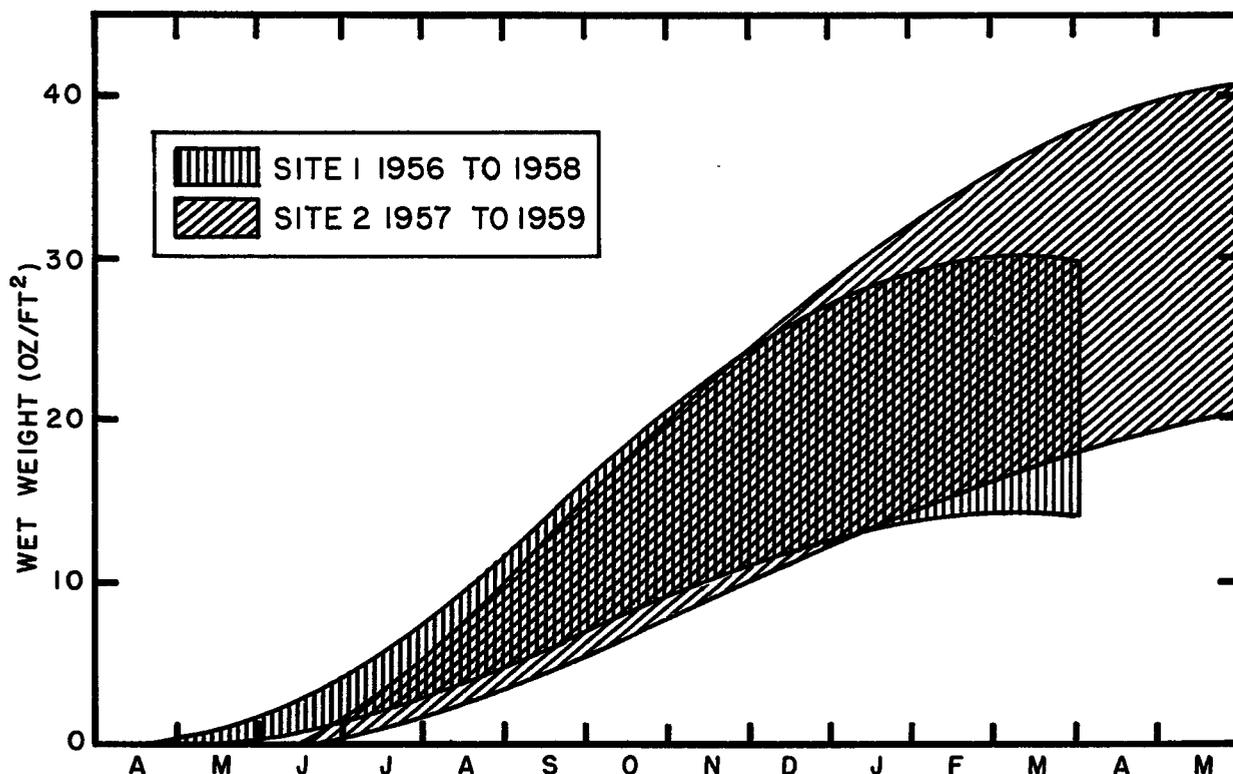


FIGURE 13 COMPARISON OF TOTAL FOULING WEIGHT PER SQUARE FOOT ON STEEL TEST PANELS FOR 1 THROUGH 12-MONTHS DURING 2-YEAR TEST PERIODS.

per square foot during the same 6 months at Site 4, and for approximately the same period Site 3 bottom test cylinders were fouled 10.5 ounces per square foot. Site 4 cumulative panel coverage for 6 months shown in Figure 12 was greater than for comparable panels for Sites 1 and 2 despite the lower weight per square foot relationship in Figure 11. This fact is indicative of variation in local fouling populations and variations in species intensity.

V. ORGANISMS

A. Barnacles

Barnacle fouling occurs as early as April-May in the estuarine-influenced waters of Site 1 and May-June for the less estuarine waters of Site 2 (Fig 14). The first barnacle set during the calendar year for Sites 3 and 4 probably occurs in May-June. Maximum attachment occurs later than the month of onset for all sites. Figure 14 shows peaks in May-June for Site 1, July-August for Site 2, and probably July-August or August-September for Site 4 (Fig 15). As indicated by Maloney (1958), Site 1 has a second peak set in September-

October (Fig 14). Site 2 barnacle set continues strongly though diminishing in August-September and September-October from the July-August maximum; however, it exhibits no second peak set such as occurred at Site 1. No set occurred after October-November for Site 1 nor after November-December for Site 2. No seasonal attachment termination data are available for Sites 3 and 4.

Figure 15 and Table 1 demonstrate that Site 2 cumulative panels for 1 through 12 months retain more barnacles and for longer periods than do Site 1 panels for comparable periods. Organisms on both Site 1 and 2 panels far exceed original set and retention of Site 4 panels.

The use of bottom test cylinders and test stakes (Fig 16 and Table 1) introduced set data differences in relation to shape of test objects, and significant differences in relatively small vertical layering increments above the bottom. Panels immersed as shown in Figure 2 are usually between 36 and 60 inches above the bottom, but may be less depending on how well the bottom supports the rack. The use of bottom test cylinders and stakes, though not specifically designed to collect this

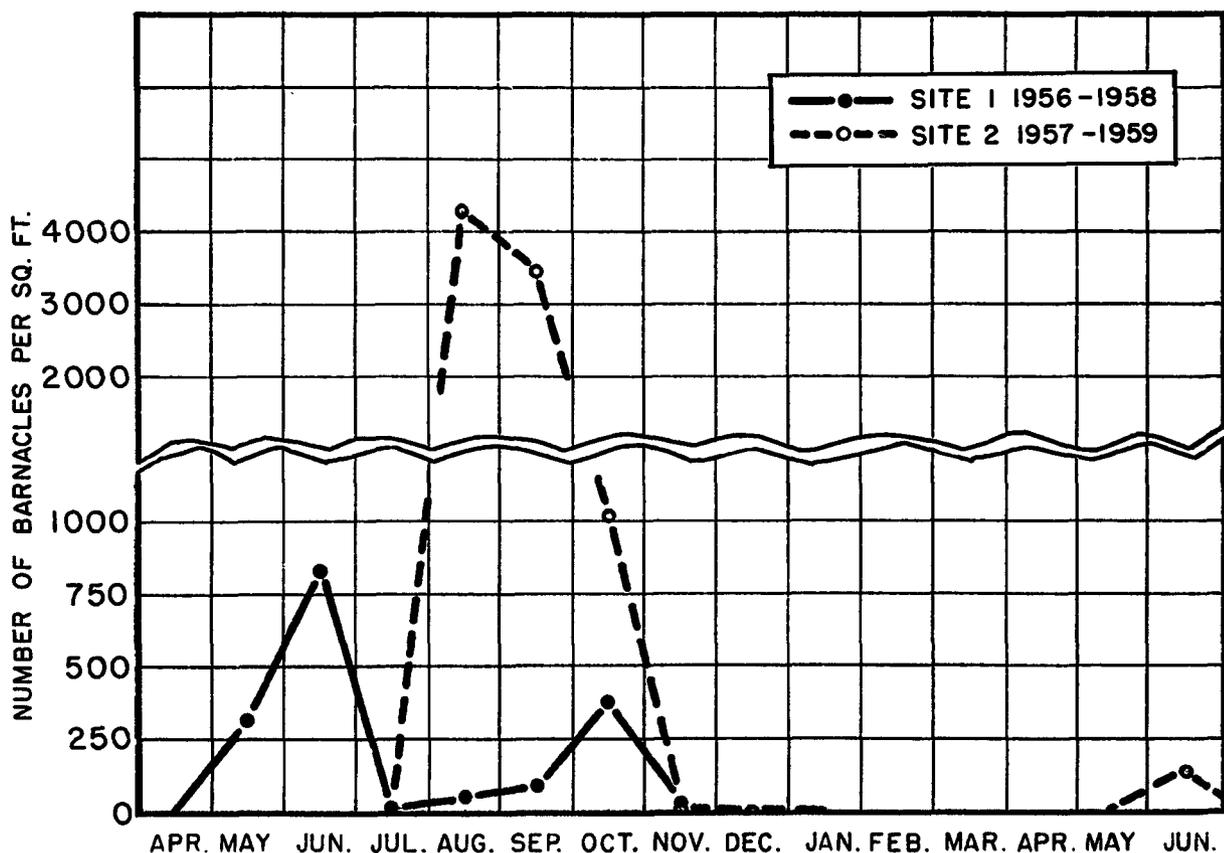


FIGURE 14 COMPARISON OF MONTHLY BARNACLE FOULING FOR SITES 1 & 2.

MONTHS	SITE 1	SITE 2	SITE 3	SITE 3	SITE 4	SITE 4
CUMULATIVE	PANELS	PANELS	BOTTOM CYLINDER	STAKES	PANELS	BOTTOM CYLINDER
1	360	21			30	
2	390	2,085			67	
3	2,505	2,050				
4	1,930	1,800			525	
5	980	1,445	3,065	202		
6	962	968			320	5,060
7	566	1,650				
8	290	1,735				
9	224	1,748				
10	225	1,280				
11	183	1,030				
12	117	1,050				
INTRODUCED	APRIL	JUNE	JUNE	JUNE	MAY	MAY

TABLE 1 COMPARISON OF 1 THROUGH 12 MONTH CUMULATIVE BARNACLE FOULING FOR VARIOUS TEST SURFACES.

information, provided a means of comparing data between the bottom and the height of the test panels. The differences in set in relation to test object shape is very great as shown in the layer 6 inches above the bottom in Figure 16 where barnacle set on the bottom test cylinder is about 70 times as great as that on stakes for Sites 3 and 4, and again at 12 to 18 inches above the bottom where test cylinder barnacle set is only 2.4 times as great as that on the stakes.

Short term fouling tests using bottom cylinders and stakes are presented for comparable periods for Sites 1, 2, and 4 panels in Figure 17. Barnacle fouling was found on all test objects and is presented in the figure in relative magnitude to other foulers. Similarly, barnacles and other predominant foulers are shown in Figure 18 for all panels of 1 through 6 months for Sites 1 and 2.

Periods of barnacle attachment, maximum attachment, and most rapid growth are shown in Figures 19 and 20 for Sites 1 and 2, respectively. The most favorable periods for introducing structures and equipments affected by barnacles are presented in Figures 21 and 22 for Sites 1 and 2, respectively.

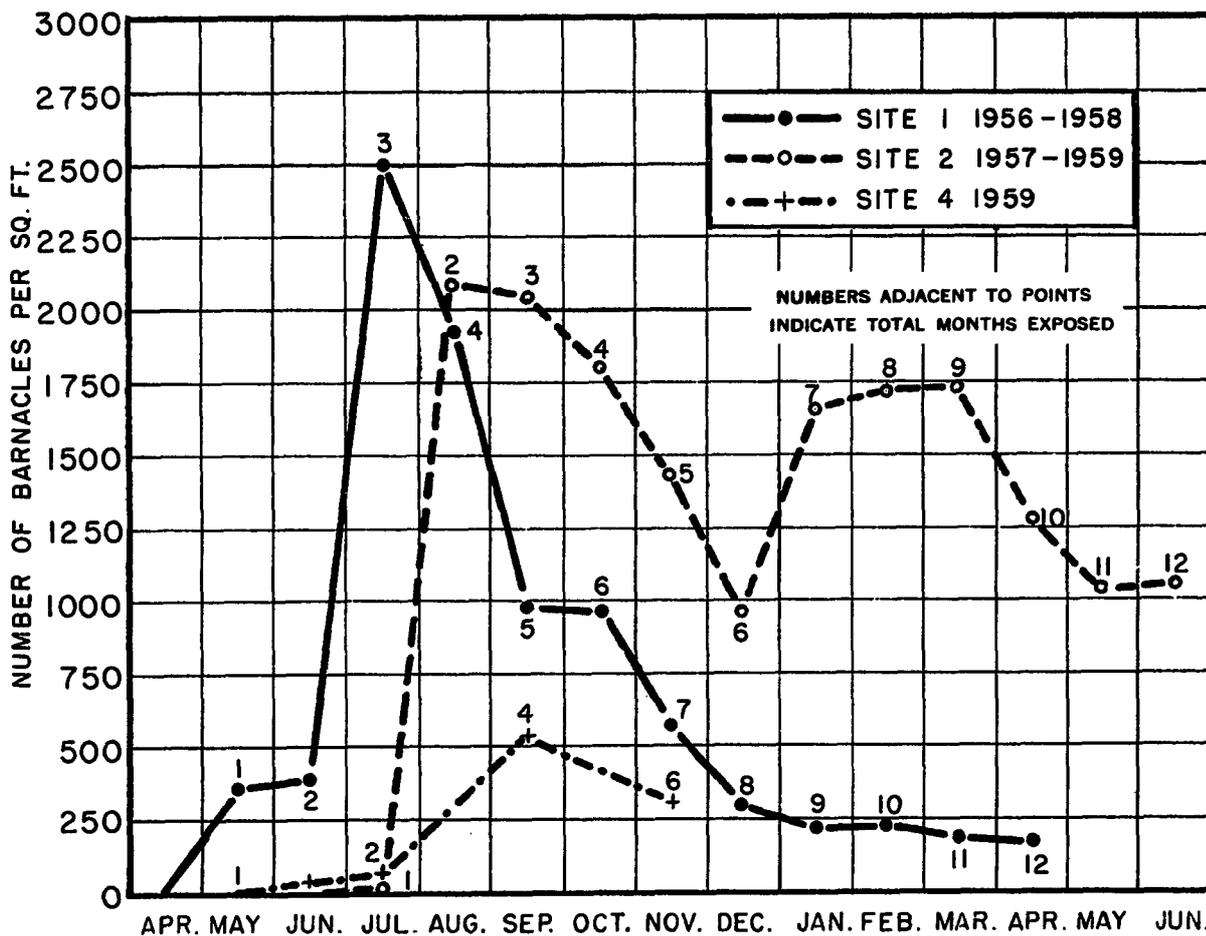


FIGURE 15 COMPARISON OF CUMULATIVE BARNACLE FOULING SITES 1, 2, & 4.

The fact that barnacles survived longer at Site 2 than at Site 1 presents a problem. It may be that the Site 2 panel, introduced 2 months later than the Site 1 panel series and with somewhat lower onset, presented greater and more suitable surfaces for set in later months. It is also possible that there is sufficient environmental variation to cause the observed difference; for example, Site 1 is subjected to less dilute toxic materials and more silt load than Site 2, thus inhibiting Site 1 growth and set. It is also possible that the fouling complex of the 2 sites varies sufficiently to produce this difference. Balanus improvisus and Balanus amphitrite niveus are both known in the area and could be responsible for the difference in the seasonal set for the 4 Sites.

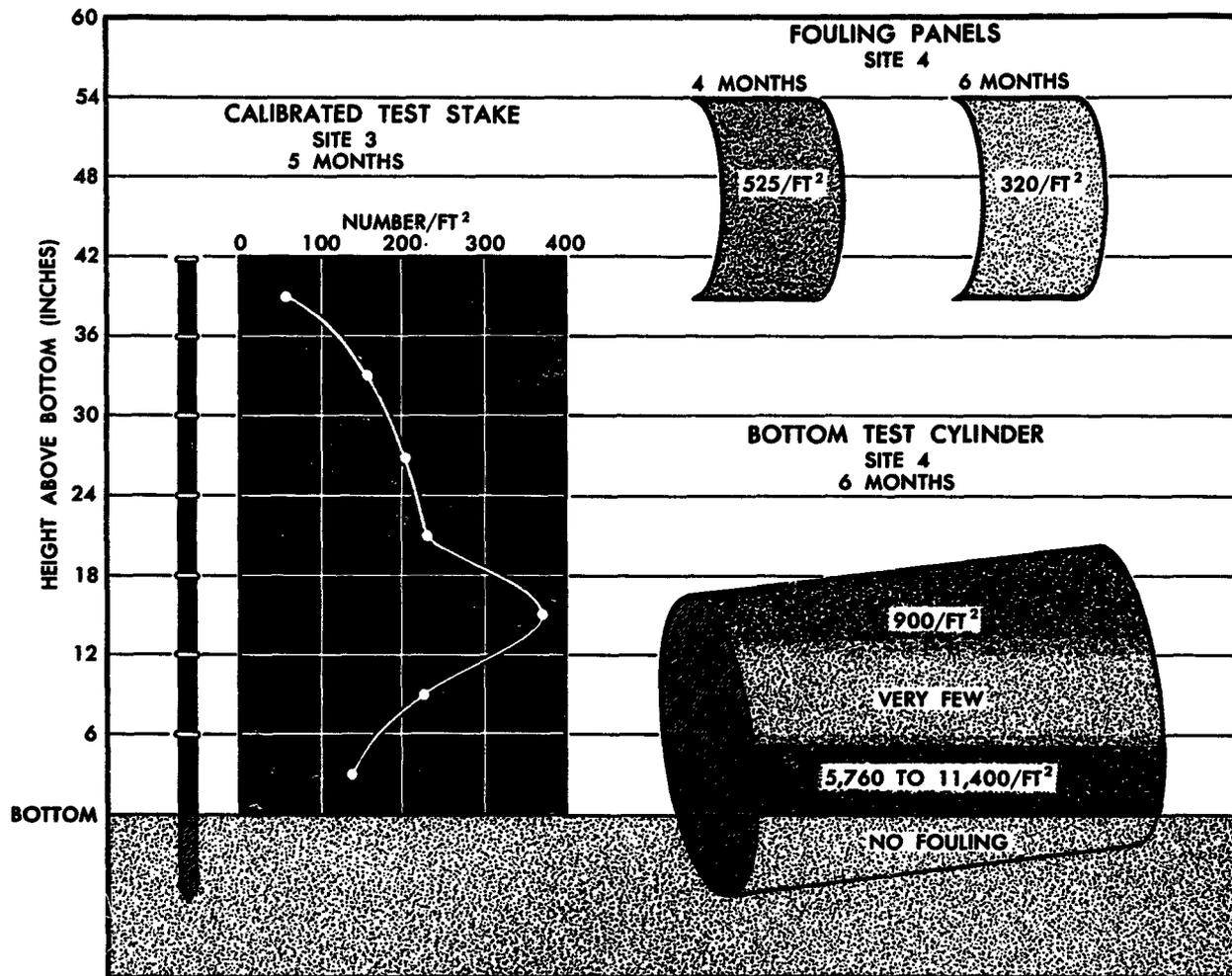
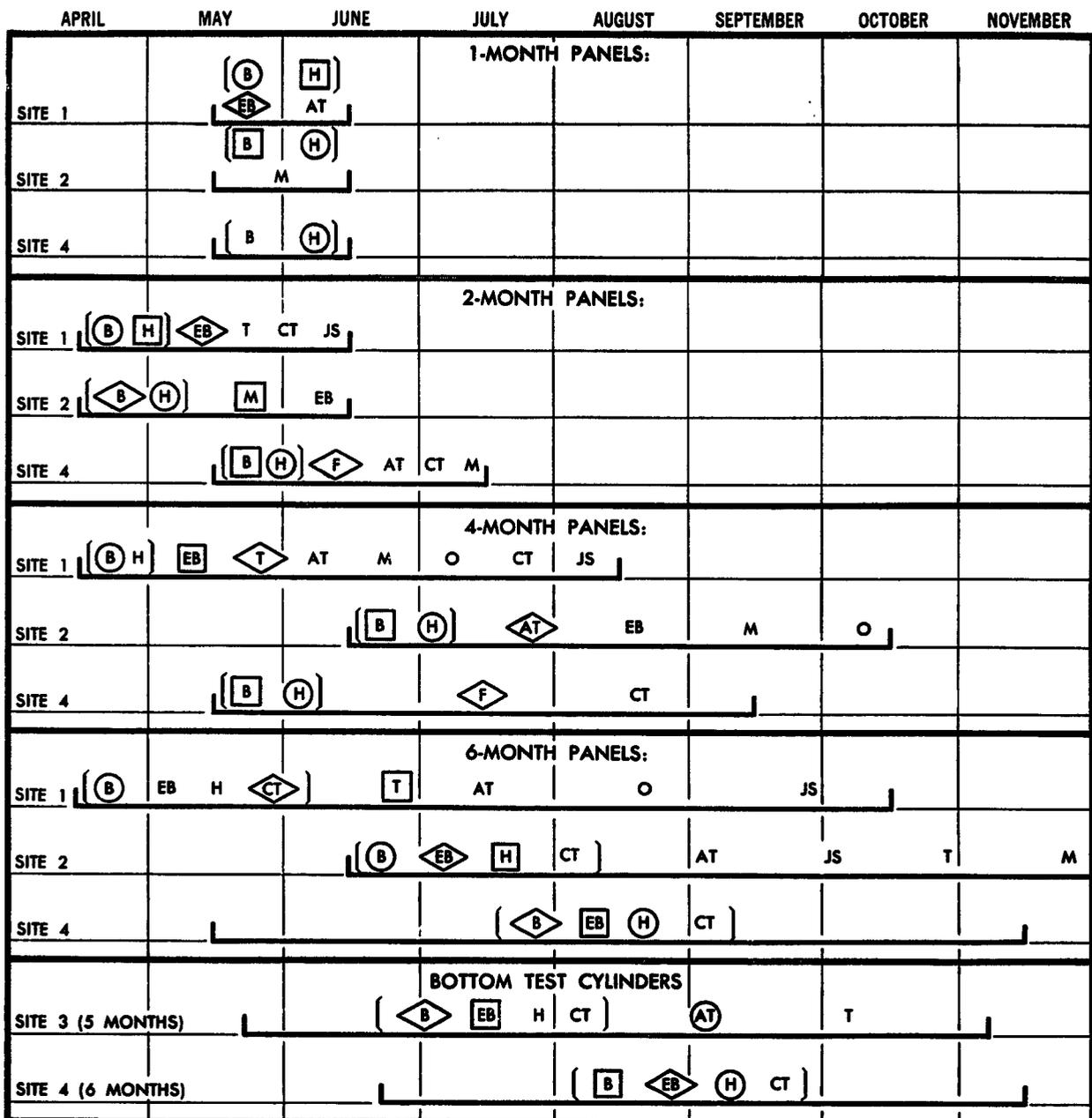


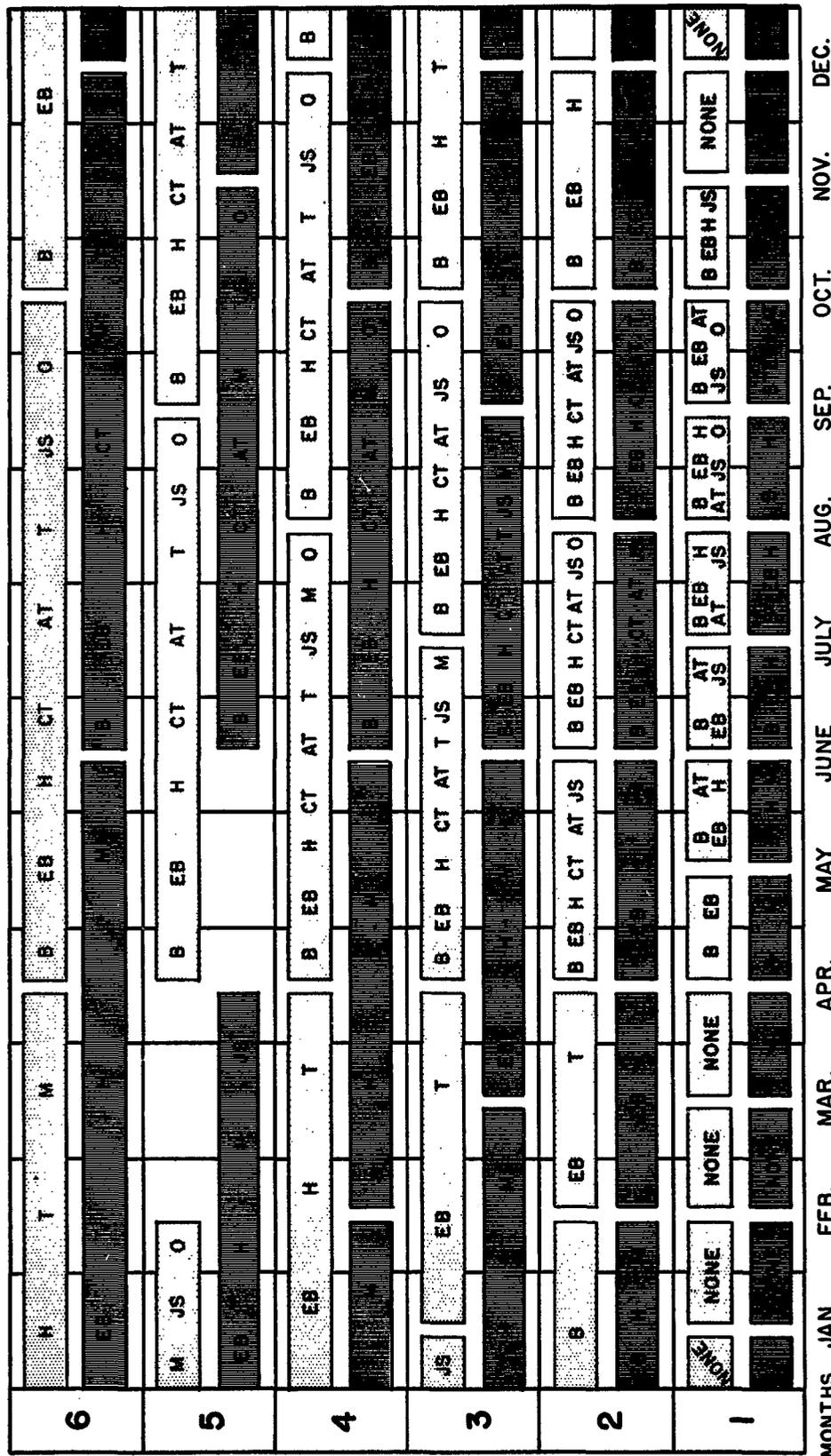
FIGURE 16 BARNACLE FOULING INTENSITY VARIATION (DIFFERENCES IN TEST OBJECT TYPE AND HEIGHT ABOVE THE BOTTOM FOR SITES 3 AND 4).



LEGEND

- | | |
|---|------------------------|
| B _____ BARNACLES | T _____ TUNICATES |
| EB _____ ENCRUSTING BRYOZOA | M _____ MUSSELS |
| H _____ HYDROIDS | JS _____ JINGEL SHELLS |
| AT _____ AMPHIPOD TUBES | O _____ OYSTERS |
| CT _____ CALCAREOUS TUBEWORMS | F _____ FORAMINIFERA |
| [] _____ ORGANISMS COMMON TO ALL SITES FOR COMPARABLE CALENDER INTERVALS | |
| ○ _____ MOST COMMON ORGANISMS | |
| □ _____ SECOND MOST COMMON ORGANISMS | |
| ◇ _____ THIRD MOST COMMON ORGANISMS | |
| LESS COMMON ORGANISMS NOT INDICATED BY SYMBOL | |
| ┌───┐ _____ MONTH (S) EXPOSED | |

FIGURE 17 COMPARISON OF SHORT TERM BOTTOM TEST CYLINDERS AND SITE 4 PANEL DATA WITH LONG TERM SITES 1 & 2 DATA FOR COMPARABLE CALENDAR INTERVALS.



EXPOSURE PERIODS

B-BARNACLES
 EB-ENCrustING BRYOZOANS
 H-HYDROIDS
 CT-CALCAREOUS TUBEWORMS
 AT-AMPHIPOD TUBES
 O-OYSTERS
 T-TUNICATES
 M-MUSSELS
 JS-JINGLE SHELLS

[] SITE 1, APRIL 1956 TO APRIL 1958
 [] SITE 2, JUNE 1957 TO JUNE 1959
FIGURE 18 PREDOMINANT FOULING ORGANISMS OCCURRING ON MONTHLY AND CUMULATIVE TEST PANELS FOR SITES 1 & 2.

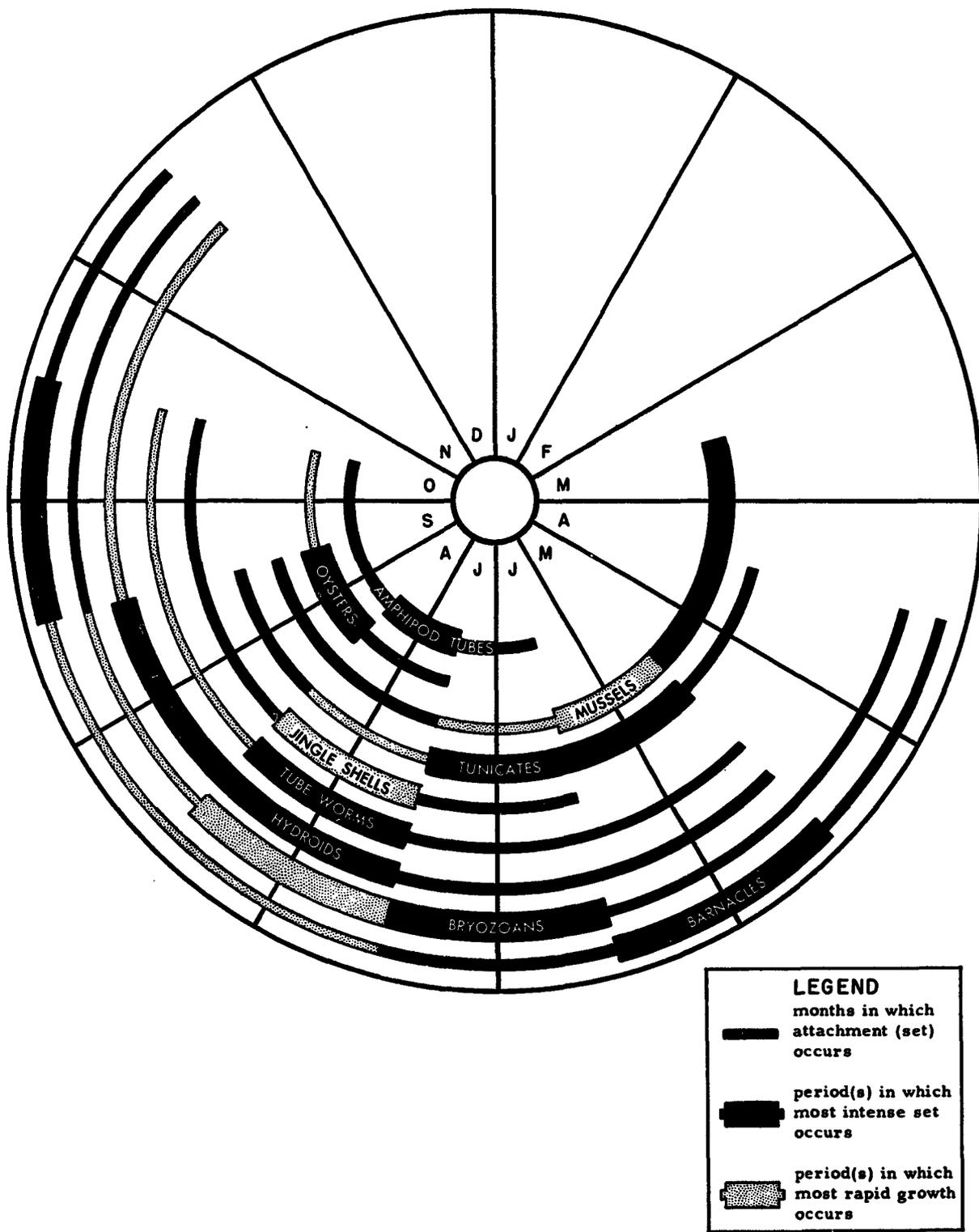


FIGURE 19 SITE 1 FOULING ORGANISMS SHOWING PERIODS OF ATTACHMENT, MAXIMUM ATTACHMENT, AND MOST RAPID GROWTH.

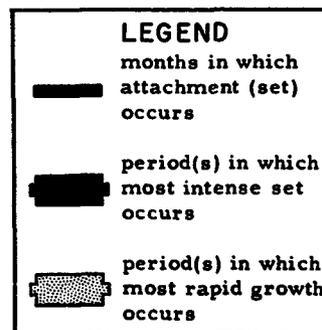
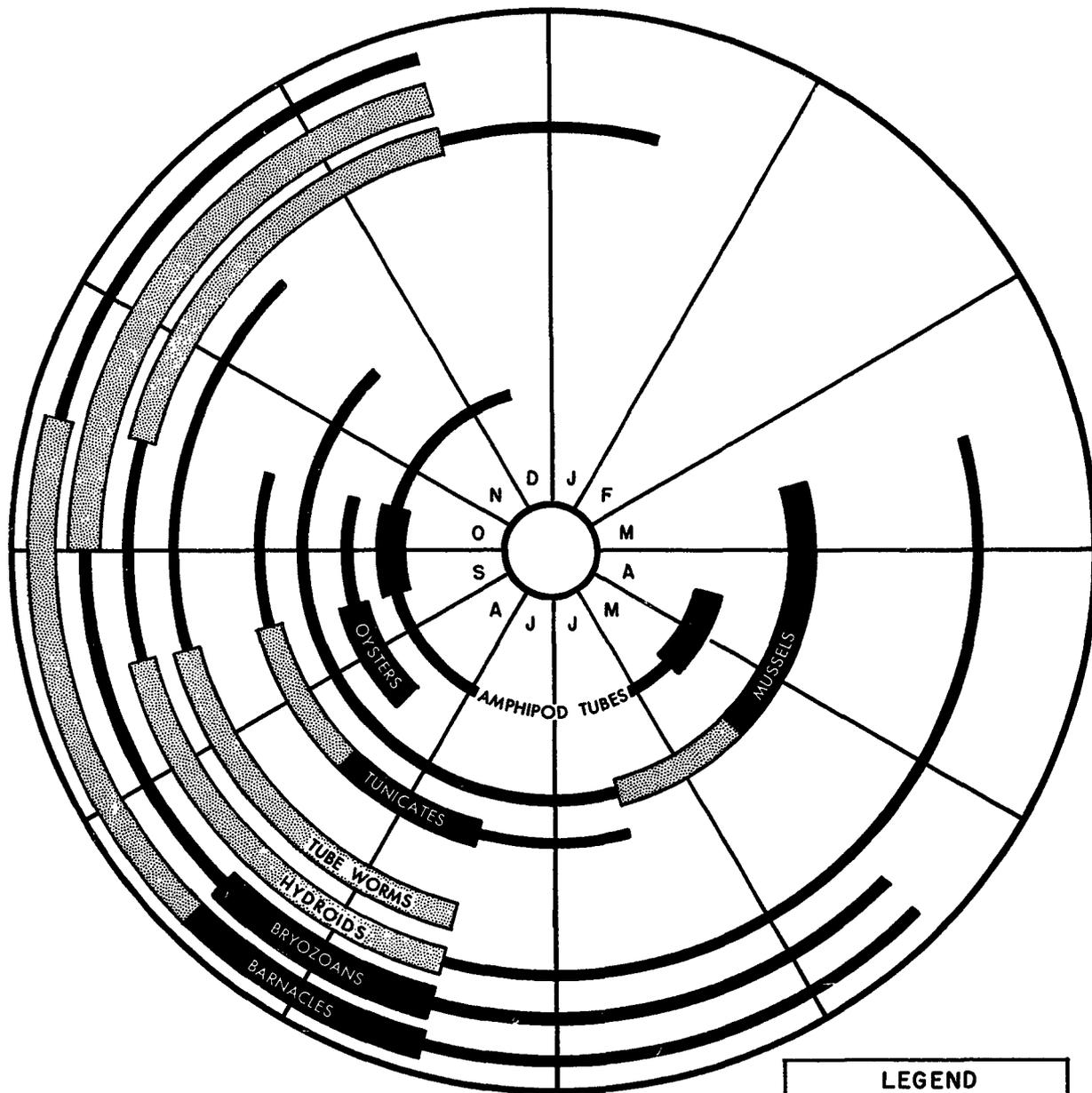


FIGURE 20 SITE 2 FOULING ORGANISMS SHOWING PERIODS OF ATTACHMENT, MAXIMUM ATTACHMENT, AND MOST RAPID GROWTH.

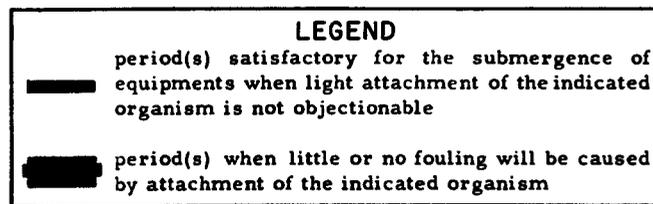
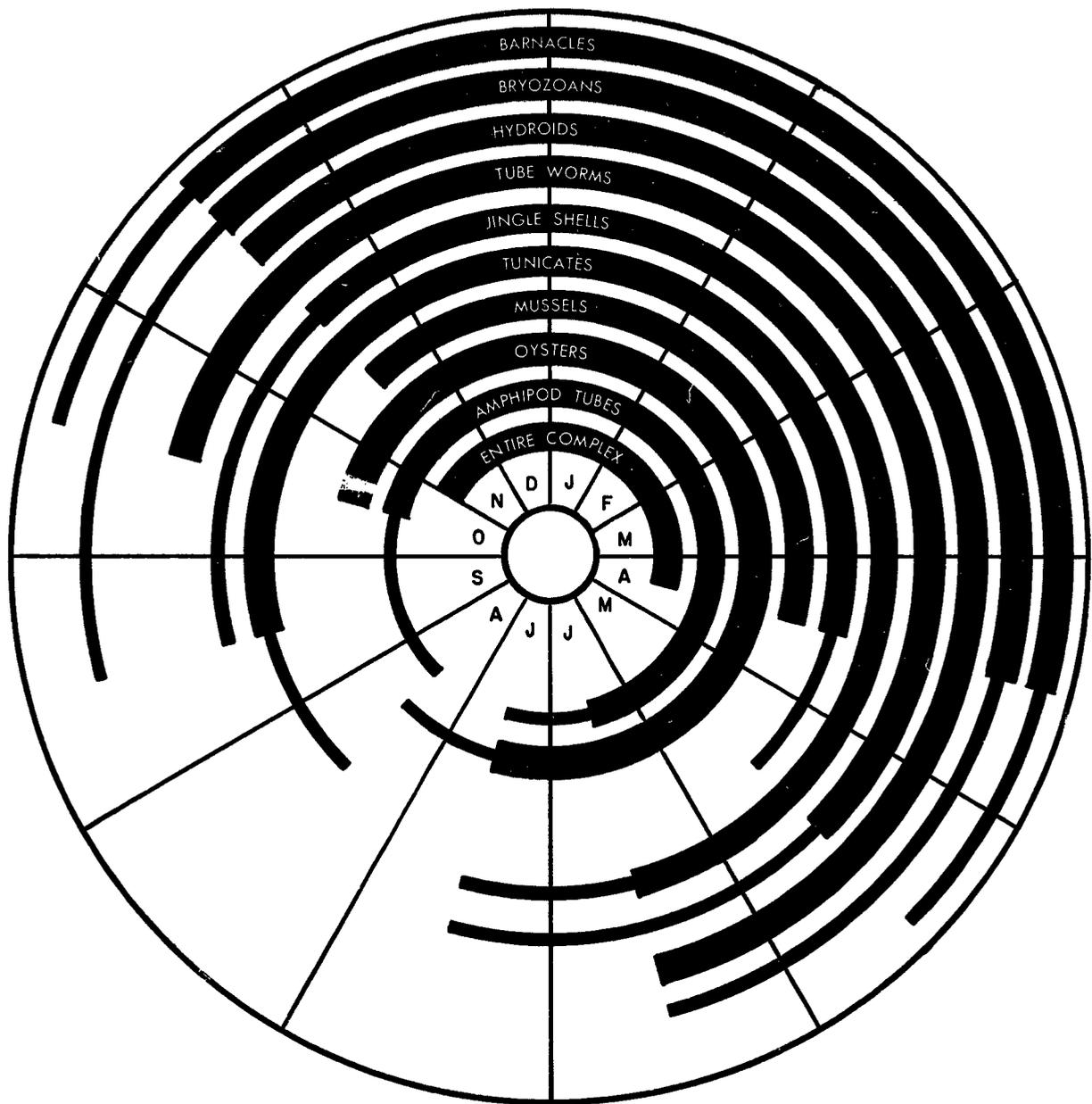
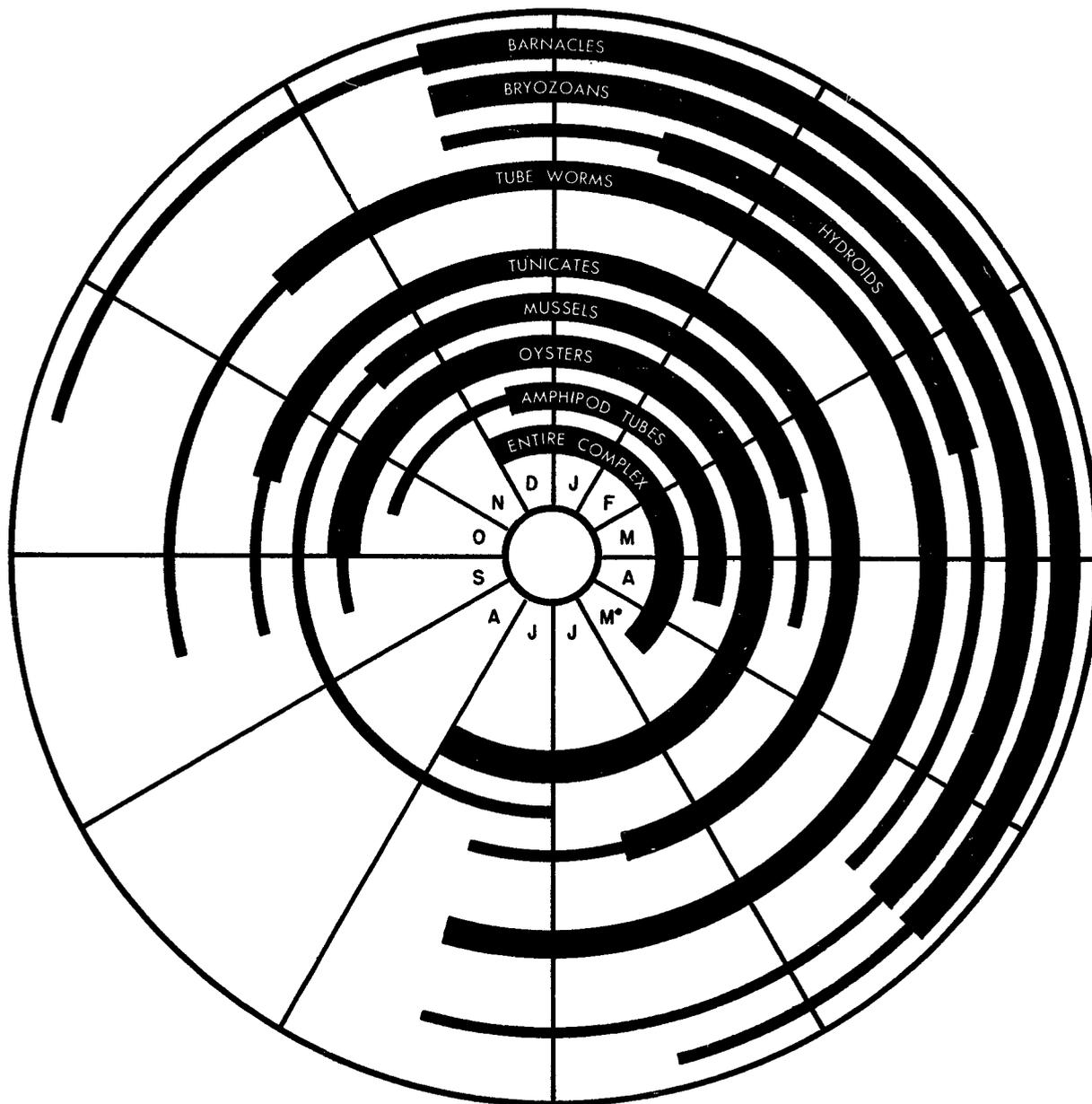


FIGURE 21 SITE 1 MOST FAVORABLE PERIODS FOR PLACING EQUIPMENT IN THE WATER FOR EACH TYPE OF ORGANISM AND FOR THE ENTIRE FOULING COMPLEX. THESE PERIODS ARE BASED ON EQUIPMENT NOT TREATED WITH ANTIFOULING COMPOUNDS.



LEGEND

period(s) satisfactory for the submergence of equipments when light attachment of the indicated organism is not objectionable

period(s) when little or no fouling will be caused by attachment of the indicated organism

FIGURE 22 SITE 2 MOST FAVORABLE PERIODS FOR PLACING EQUIPMENTS IN THE WATER FOR EACH TYPE OF ORGANISM AND FOR THE ENTIRE FOULING COMPLEX. THESE PERIODS ARE BASED ON EQUIPMENTS NOT TREATED WITH ANTIFOULING COMPOUNDS.

B. Colonial Hydroids

Site 1 hydroid data for 1956-57 and 1957-58 were similar. Initial monthly hydroid set for Site 1 occurred in June-July and reached a peak in August-September, after which no set occurred until the following June-July (Fig 23). Site 2 hydroid set started a month earlier than Site 1 set, continued through November-December or 3 months longer than Site 1, but did not occur from December-January to February-March (Fig 23). Most panels were analyzed in the laboratory after drying; consequently, no significance can be placed on hydroid length measurements. In some panels, area coverage data are suspected even though the data were checked against photographs taken immediately after panel removal.

Figure 24 presents cumulative percent coverage hydroid data for Sites 1 and 2, for 1 through 12 months, and for Site 4 for 1 through 6 months. Set, growth, and decay were typical for Site 1, with growth stopping after October-November, then slow decay to February-March, and a more abrupt fall in March-April. Site 2 cumulative hydroid coverage for 1957-58 and 1958-59 is erratic when compared to Site 1. It is possible that this irregularity can be attributed in part to new set occurring through mid-December (Fig 23). The coverage of the 9-month panels far exceeds all others, showing winter growth, the effect of a longer set period, and the possibility of considerable decay in late autumn and early winter along with the late set. Site 4 data indicate initial hydroid fouling in May-June with the possibility of an even earlier beginning (Fig 24). The increase in coverage is much more abrupt than shown in Sites 1 and 2 data, and a slight drop is indicated after August-September. It is not known whether this drop is just an irregularity such as at Site 2 or if it is the actual onset of decay.

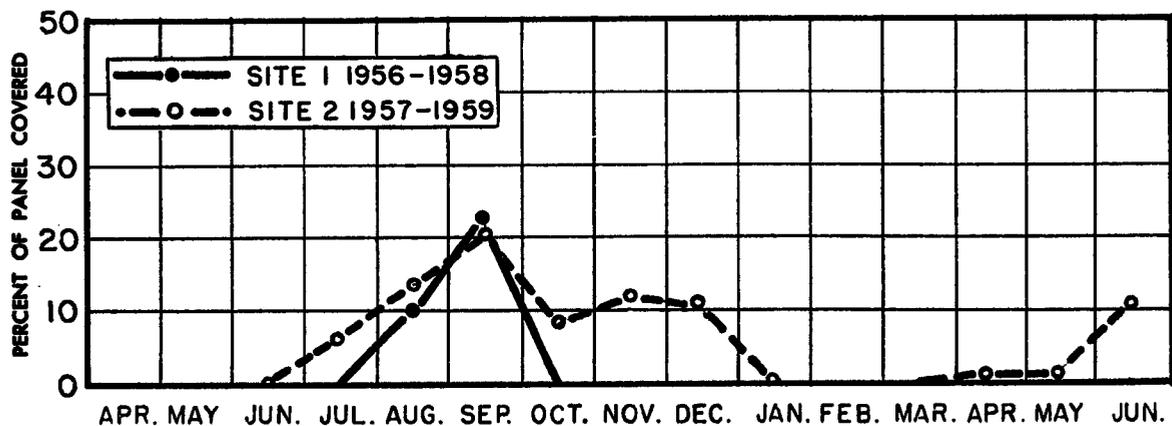


FIGURE 23 HYDROID FOULING, MONTHLY.

Bottom test cylinders from Site 4 were fouled with well-developed colonial hydroids in contrast to the sparse hydroid fouling on Site 3 bottom test cylinders. Site 4 graduated stakes, being bent and leaning, were approximately parallel to, and at the same height as, the bottom test cylinders; consequently were not analyzed. Site 3 stakes, standing upright were fouled with hydroids over about 50 percent of their area, with progressively heavier growth toward the sea surface.

C. Calcareous Tubeworms

Calcareous tubeworms cannot be considered as one of the more important foulers; however, they occur locally in sufficient concentration to affect certain types of equipment adversely.

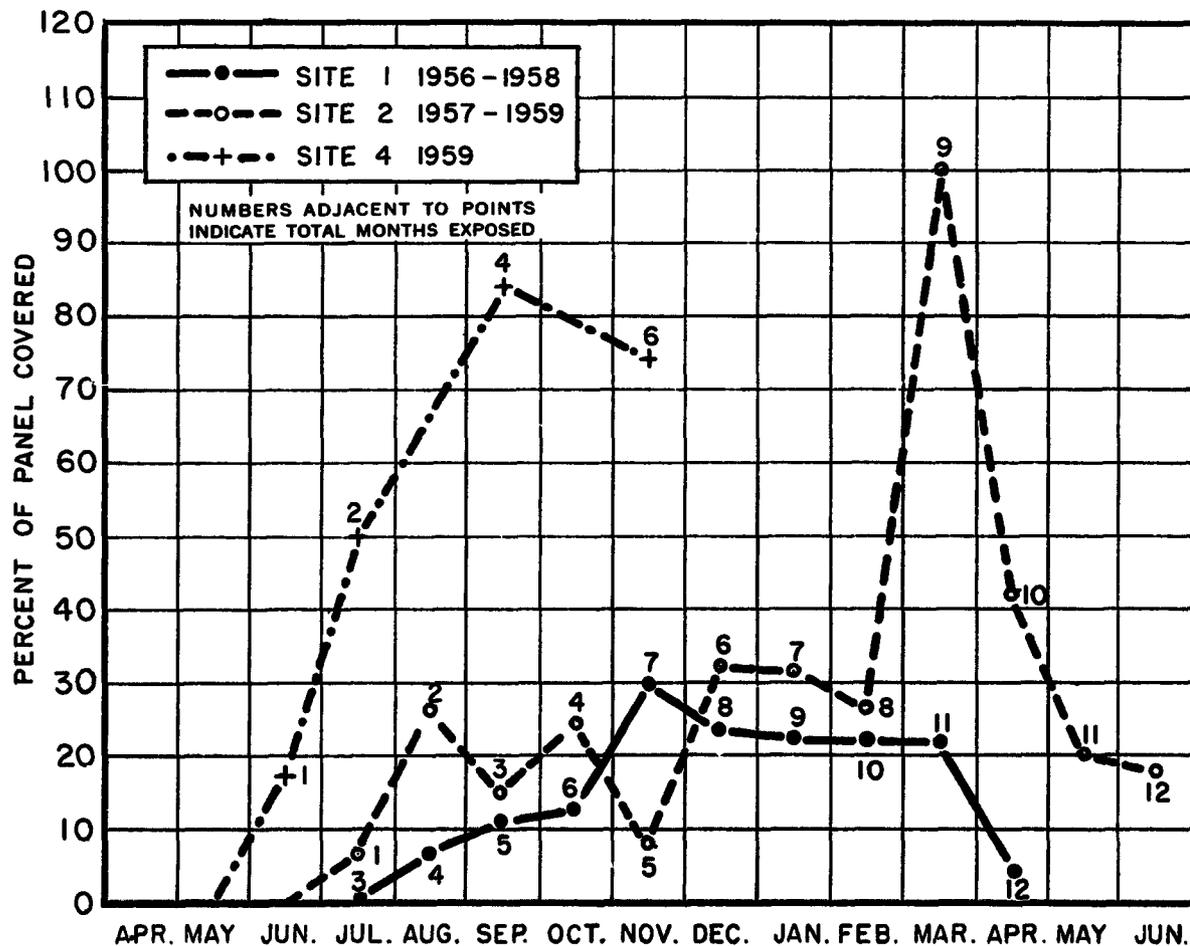


FIGURE 24 HYDROID FOULING, CUMULATIVE, 1 THROUGH 12 MONTHS.

Figure 25 demonstrates the monthly occurrence of these organisms in numbers per square foot for Site 1. Monthly panels from Site 2 were free of calcareous tubeworms. It is probable that very early stages of this organism were lost during drying or were overlooked in the analyses of dried 1-month panels. The earliest appearance of Site 2 calcareous tubeworms was on the 2-month June-August panel (Figs 18 and 26). Similarly, tubeworm fouling was found on the 1-month (May-June) Site 4 panel, but some was present on the 2-month (May-July) panel (Figs 17 and 26). Figure 26 clearly shows the greater and consequently more important calcareous tubeworm occurrence for Site 1. This is substantiated by the comparison of 6-month panels for all sites in Figure 17, which shows calcareous tubeworms as the third most common organism for Site 1. It is evident from Figure 18 that no calcareous tubeworm set occurs later than September-October for either Site 1 or 2; no data are available for this period for Site 4. Cumulative panel data in Figure 26 indicate first peak occurrences for Sites 1 and 4 in August-September and for Site 2 in July-August. Second peaks occurred for Site 1 in November-December and for Site 2 in October-November; no data were available for Site 4. May-November Site 3 and June-November Site 4 bottom test cylinders were fouled with a few well-developed calcareous tubeworms.

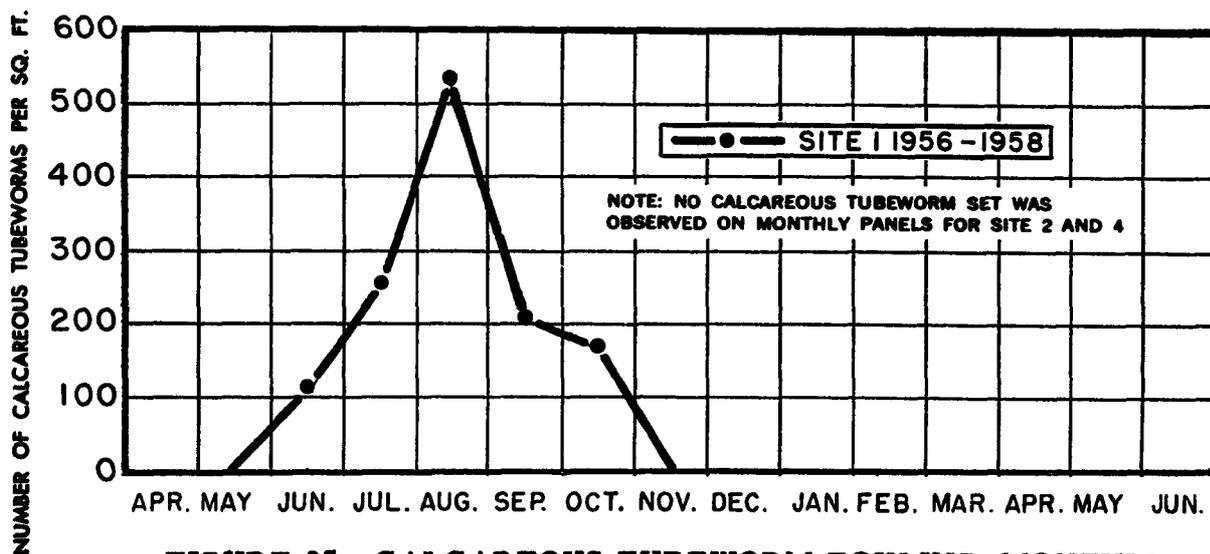


FIGURE 25 CALCAREOUS TUBEWORM FOULING, MONTHLY.

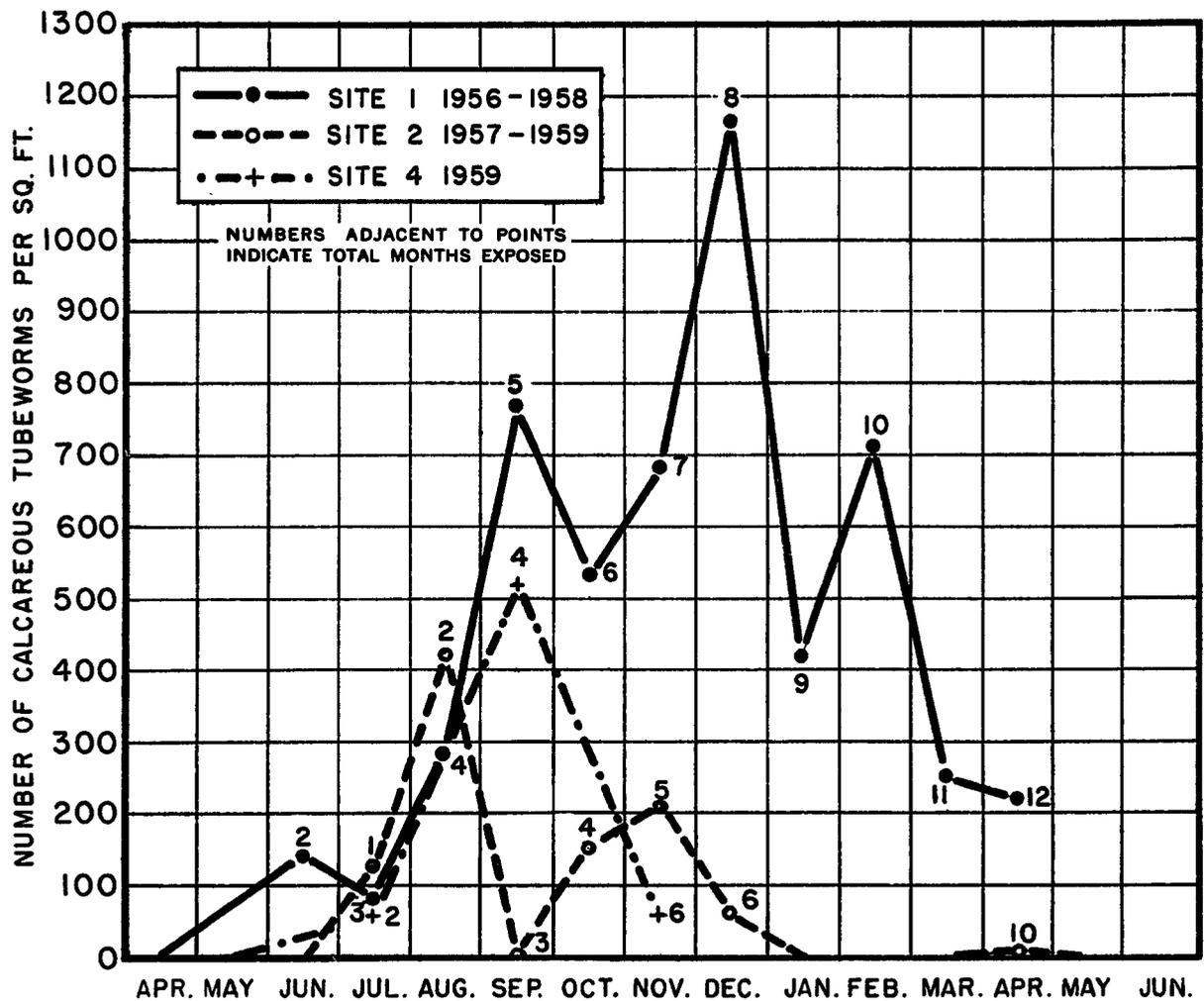


FIGURE 26 CALCAREOUS TUBEWORM FOULING, CUMULATIVE.

D. Encrusting Bryozoa

Site 1 encrusting bryozoan data for 1956-58 did not change significantly from those presented by Maloney (1958) for 1956-57. Monthly encrusting bryozoa set and growth repeated the bimodal peaks which were altered only by an expansion of the June-July peak to include identical set intensity during July-August and a slight set increase in September-October (Fig 27).

Figure 29 shows very little change in the percent of panel coverage pattern. The Site 1 September-October peak set shown in Figure 27 replenished the stock and probably caused the growth increase in the October-November-December cumulative panels after a September-October decay as shown in Figure 30. It should be pointed out that these organisms conform to accepted ideas of productivity potential per unit area. Figure 31 demonstrates this relationship vividly in the

comparison of the numbers of colonies in Figures 27 and 28 and percent of areas covered shown in Figures 29 and 30. For example, the peak numerical set in June-July of the cumulative Site 1 data in relation to area coverage indicates a mean individual colony size of only 0.27 square inch, whereas the relatively low number of colonies per square foot in February-March had a mean individual colony size of 2.9 square inches.

Figure 27 and 29 indicate the occurrence of bryozoa at Site 2 only in November-December and April-May; however, it is probable that early bryozoan stages were overlooked on the monthly panels as were the calcareous tubeworms. This oversight is indicated by the occurrence of encrusting bryozoa on all 2-month panels for Site 2 as shown in Figure 18.

Encrusting bryozoans can contribute appreciably to the fouling complex as demonstrated in Figure 29 on the July-August 1-month panel and in Figure 30 on the April-September 5-month and April-December 8-month panels for Site 1. Figure 30 shows that the percent coverage by encrusting bryozoan fouling on bottom test cylinders was only slightly more than on Site 2 panels, but considerably less than on Site 1 panels for comparable time intervals. Bryozoans of this type effectively cover and kill such organisms as calcareous tubeworms and barnacles. The importance of this fouler in the complex is not particularly significant in coverage, weight, or resistance to current; however, these organisms would be particularly effective in covering sensitive membranes or small mechanisms.

Stolonate bryozoans were recognized on many of the panels. In some panels their light weblike growths covered one-half or more of the panel but were so delicate that they were not considered as significant foulers. Site 2 monthly panels from June-July through September-October 1957 were half or fully covered with weblike colonies. There is evidence that these organisms are capable of holding a silt load.

E. Jingle Shells and Other Attached Molluscs

In the report of Site 1 data for 1956-57, Maloney (1958) treated only the mollusc *Anomia* (jingle shell), but there were sufficient data from Site 1, 1957-58 and Site 2, 1957-59 to justify the inclusion of mussels and oysters in this writing. The combined 1956-58 data for Site 1 are presented in Figure 32.

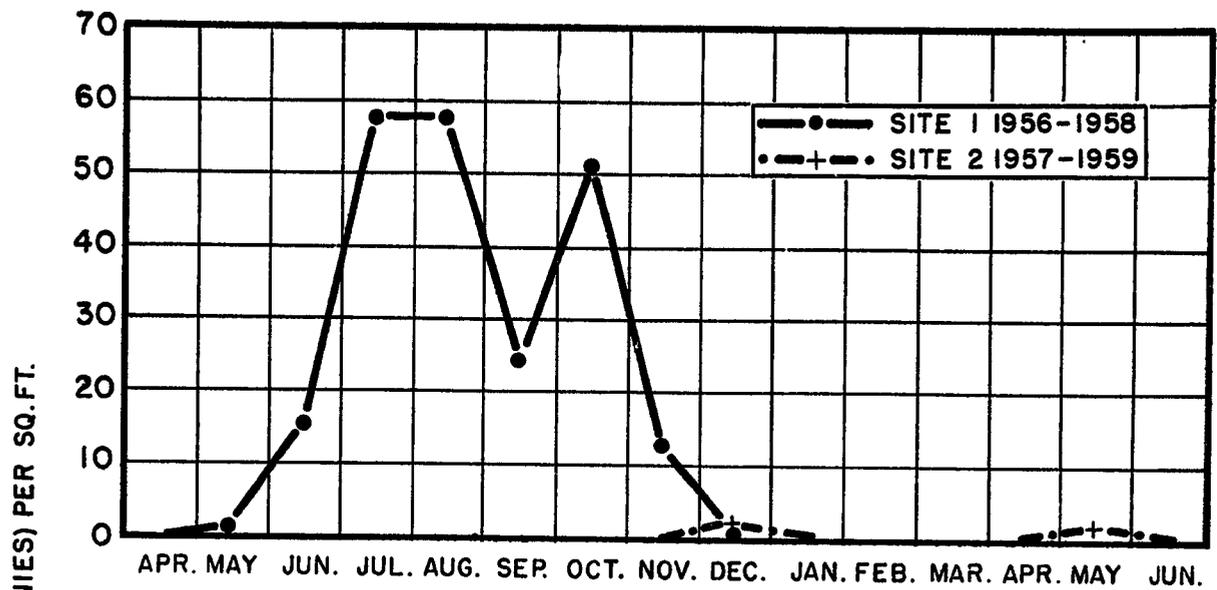


FIGURE 27 ENCRUSTING BRYOZOANS, MONTHLY.

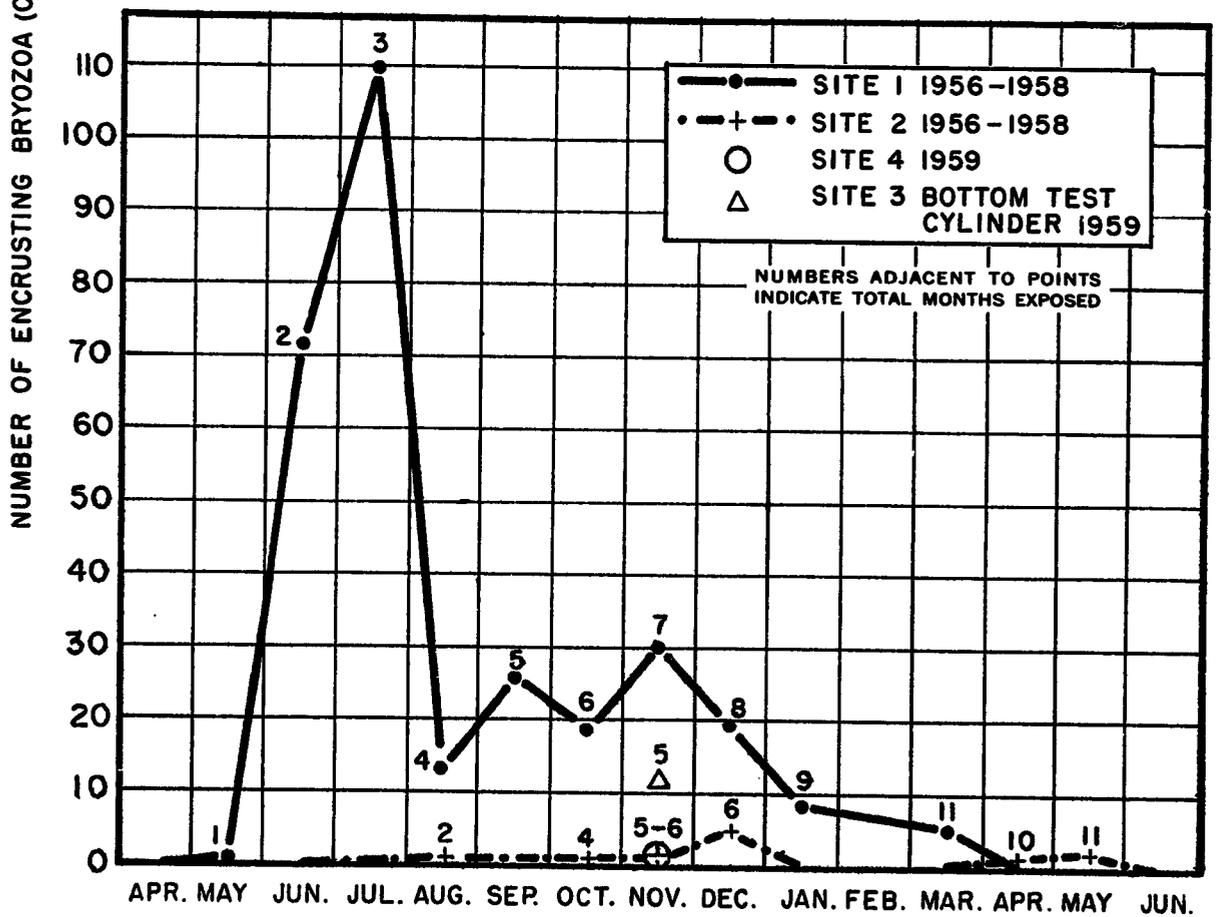


FIGURE 28 ENCRUSTING BRYOZOANS, CUMULATIVE.

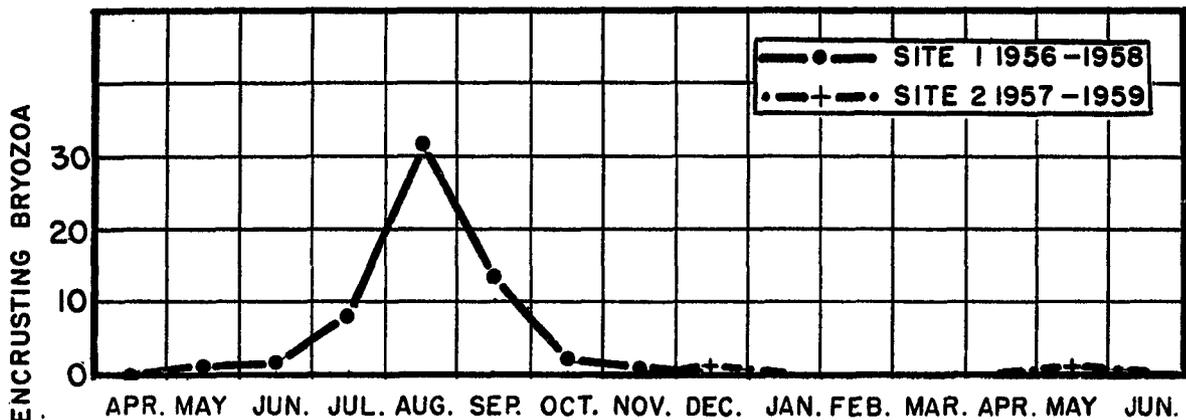


FIGURE 29 ENCRUSTING BRYOZOANS, MONTHLY.

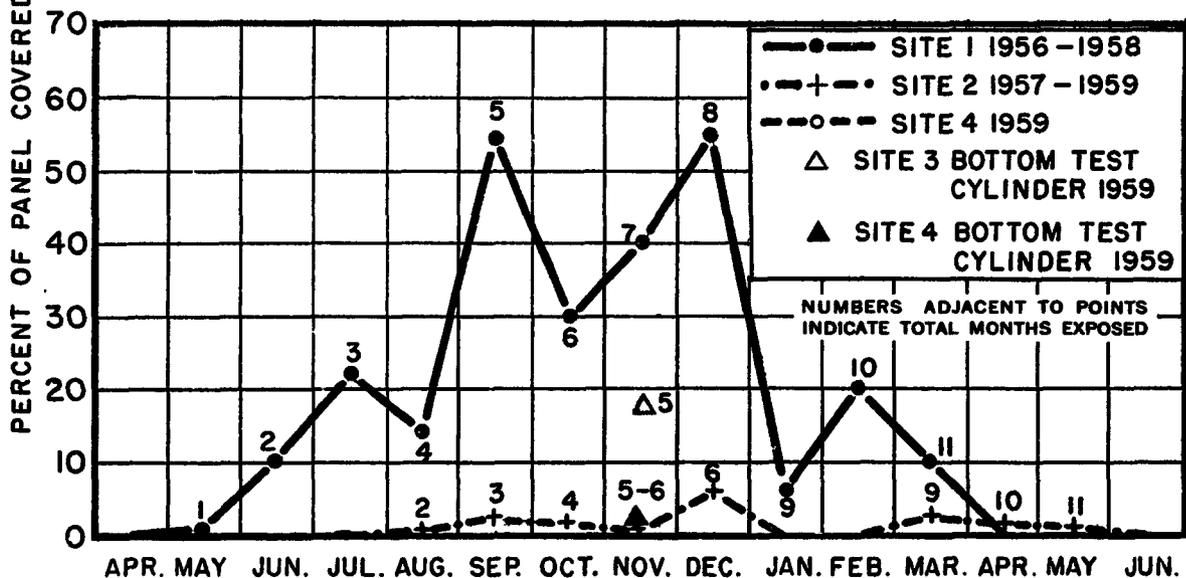


FIGURE 30 ENCRUSTING BRYOZOANS, CUMULATIVE.

Initial jingle shell set at Site 1 occurs in June-July, a month earlier than previously recorded, but terminates at approximately the same time (September-October). No jingle shells occurred on monthly panels from October-November through May-June. August-September was the peak monthly set period with over a hundred jingle shells per square foot. In contrast, no jingle shells occurred on monthly Site 2 panels, or on any Site 4 panels from 1 through 6 months, or bottom test cylinders from Sites 3 and 4 (Fig 17). Jingle shells occurred on Site 1 cumulative 3-month April-July through the 11-month April-March panels (Fig 32), whereas they occurred only on the 2-month June-August and the 5-month June-November Site 2 panels (Fig 33). Site 1 cumulative peak occurred on the 6-month April-October panel. The total lack of jingle shells on the 12-month April-April Site 1 panel for 2 years cannot be explained.

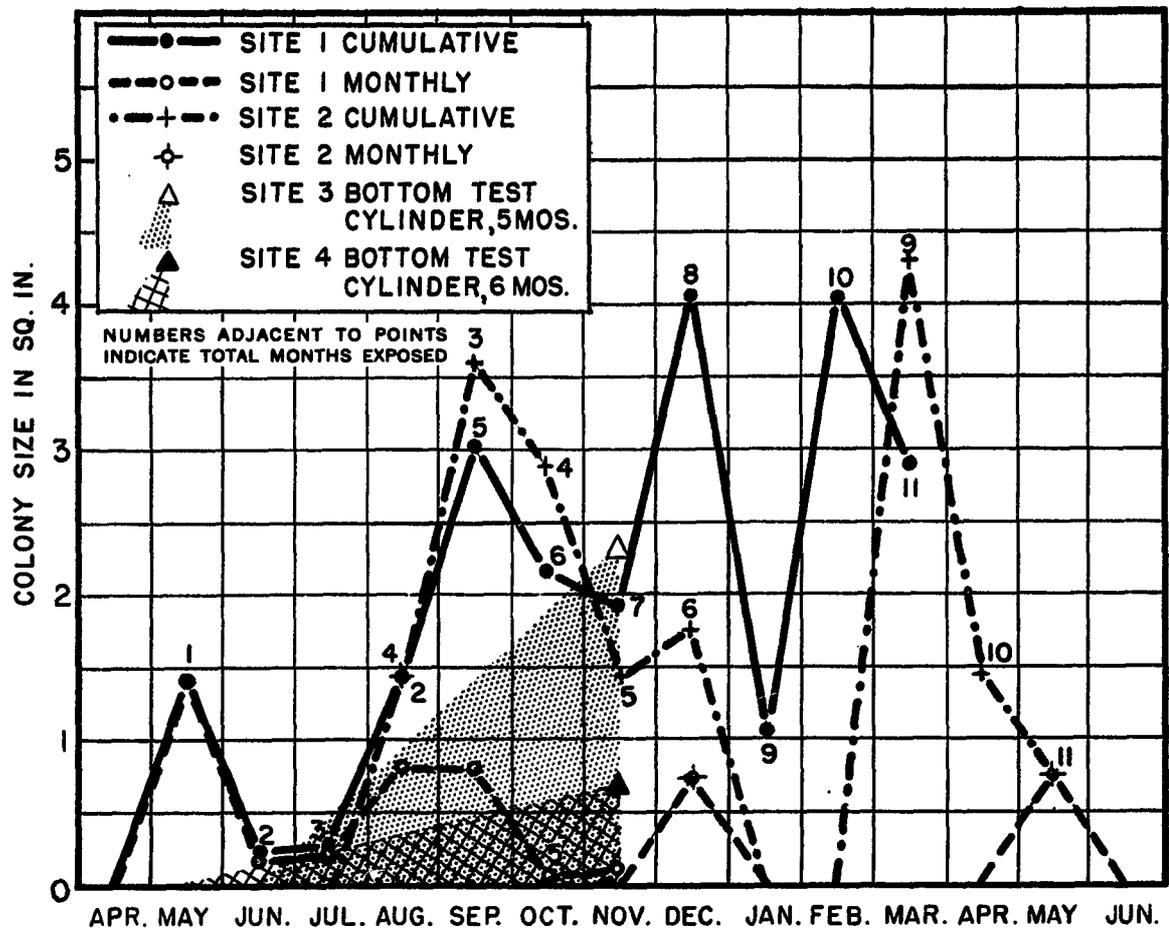


FIGURE 31 ENCRUSTING BRYOZOANS, GROWTH-SET RELATIONS. MEAN COLONY SIZE IN SQUARE INCHES IS USED AS AN INDEX OF INDIVIDUAL COLONY GROWTH FOR A MONTH OR SERIES OF MONTHS (CUMULATIVE). PERCENT PANEL COVERAGE IN ASSOCIATION WITH NUMBERS PER SQUARE FOOT SHOWS OVERALL GROWTH-SET RATE AND INTENSITY PLUS AN INDICATION OF NUMBERS OF COLONIES VERSUS AREA COMPETITION.

No mussels (*Mytilis*) occurred on the Site 1 monthly panels and only small numbers, about 3 per square foot, on April-May and May-June Site 2 panels (Fig 33). Cumulative mussel fouling for both Sites 1 and 2 show somewhat explosive population increases in the spring (particularly in March-April) and early summer months (Figs 32 and 33), demonstrating the importance of seasonal or even more critical timewise introduction of equipments or test objects, and the possible effects of seasonal foragers passing through an area. Mussels occurred on Site 1 3-month and 5-month cumulative panels in very limited numbers and then not again until the 12-month April-April panel with 705 per square foot, mostly in the size range 0-2 mm (Fig 32).

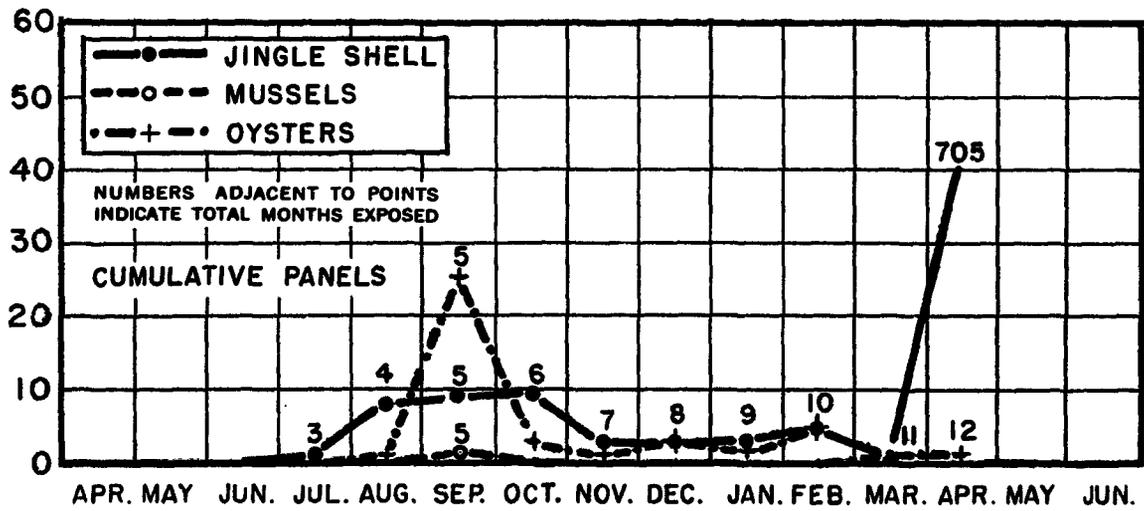
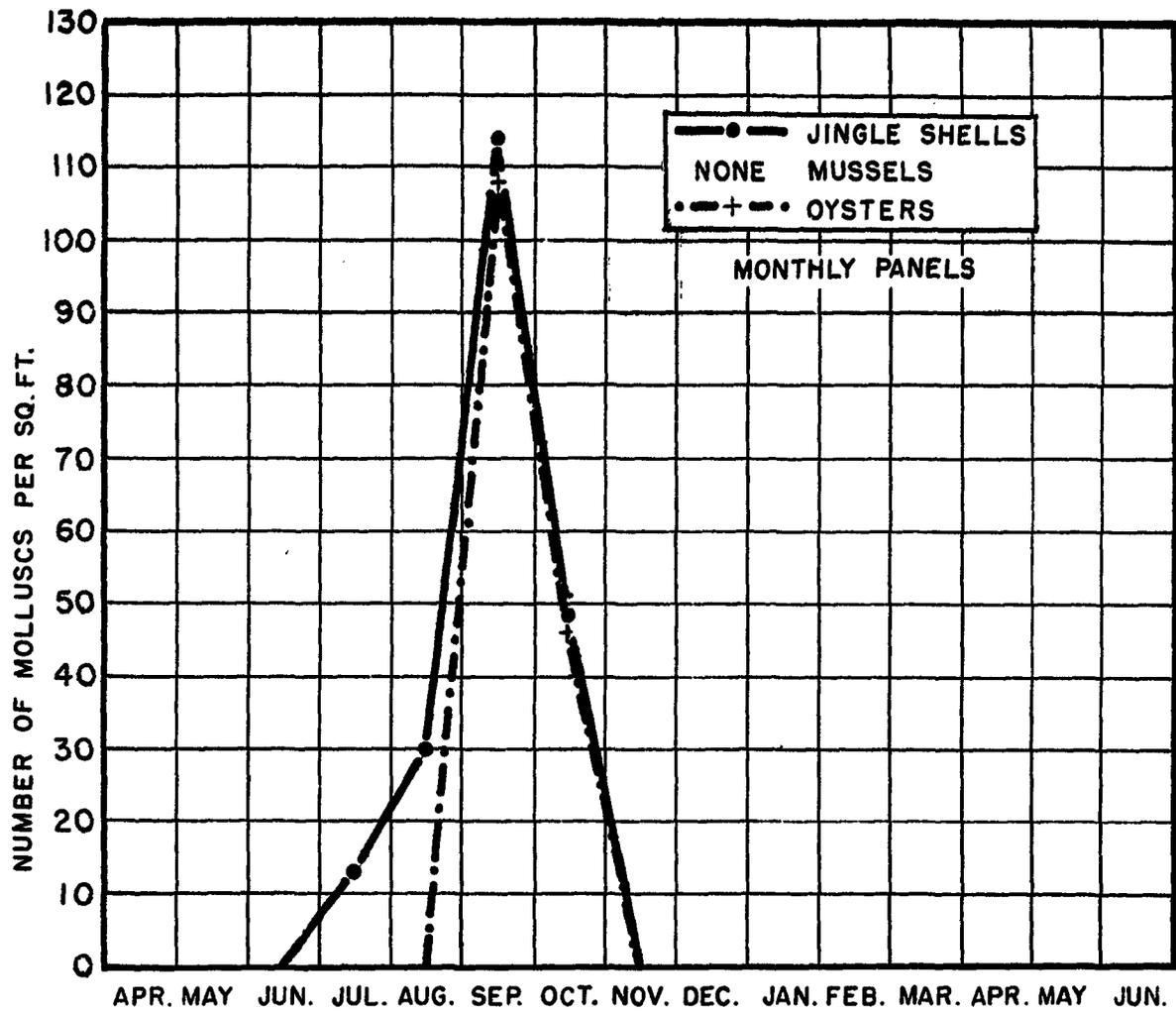


FIGURE 32 SITE 1 MOLLUSCS.

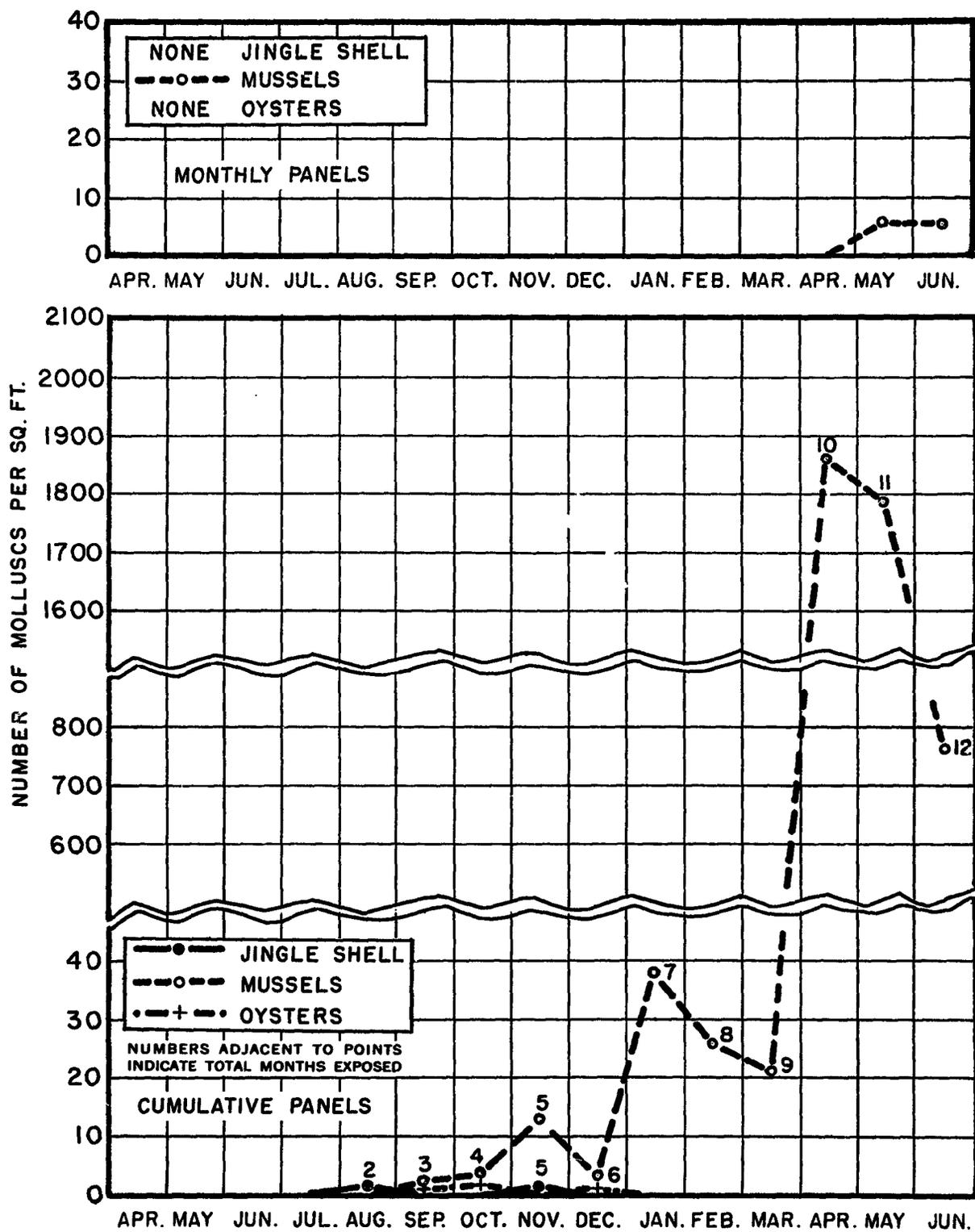


FIGURE 33 SITE 2 MOLLUSCS.

It is apparent that March-April is an important time period, since all Site 1 cumulative panels were introduced in April-May too late for the peak set. Figure 33 shows a cumulative panel trend for Site 2 very similar to previously discussed foulers up to the 9-month June-March panels, with a maximum of 38 per square foot, then in the 10-month June-April panel the mussel population exploded to 1,860 per square foot with most of the organisms in size class 0-2 mm. The 11-month June-May panels show a continuation of the population explosion relatively undiminished, with most organisms in the size range 2-5 mm; in the 12-month June-June panels the population was at the 760-per-square-foot level, with most organisms in the size range 5-10 mm. The initial explosion agreed with that of Site 1 with March-April as the critical month. The decrease in the 12-month Site 2 panels substantiates the possibility of seasonal foraging activity. Mussels occurred only on the 2-month May-July Site 4 panel (Fig 17) and were not present on the bottom test cylinders for either Site 3 or 4.

Oysters occurred on Site 1 monthly panels in the August-September and the September-October month periods but did not appear at all in Site 2 monthly panels (Figs 32 and 33). Site 1 cumulative panels show peak oyster occurrence in the 5-month April-September period after an initial occurrence in the 4-month April-August period. After the peak, oysters appear on all panels through the 12-month April-April period with 1 to 5 per square foot for each panel. Site 2 cumulative panels were fouled by oysters first in the 3-month June-September period, which then increased to a maximum of 2 organisms per square foot in the 4-month June-October period and then declined to none in the 5-month panel and finally one per square foot in the 6-month period June-December (Fig 33). Oysters were not found on the Site 3 bottom test cylinders or on the Site 4 panels (Fig 17).

F. Tunicates

Tunicate fouling was relatively sparse except for the Site 1 cumulative panels (Fig 34). The fact that panels were analyzed in the dry state undoubtedly did much to hinder recognition.

The only occurrence of recognizable tunicates on one month panels was on the Site 2, September-October panels, which were approximately 2 percent covered. The coverage increased on 2-month panels and continued to increase as time intervals increased; for example, the 9-month and 12-month panels for Site 1 were almost completely covered. There is some evidence to support the idea that time in water was required to prepare a suitable surface for tunicate set. Figure 34 indicates that set first occurs in the summer; however, Figure 17 shows that winter set occurs in some of the short period panels. It is evident Site 2 tunicate fouling does not attain the same magnitude as that of Site 1.

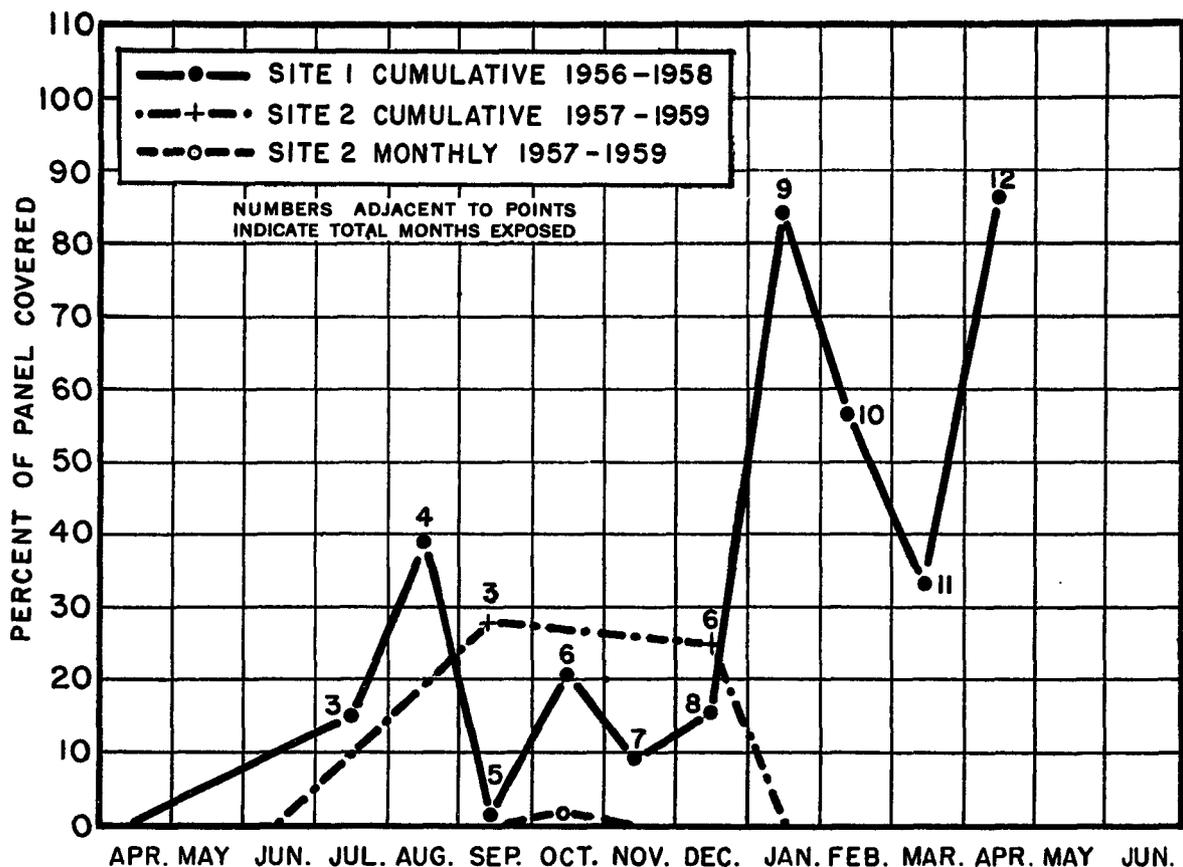


FIGURE 34 INDIVIDUAL AND COLONIAL TUNICATES.

No tunicates were found on Site 4 panels nor on Site 4 bottom test cylinders; however, they were present on Site 3 bottom test cylinders in limited numbers. The presence of tunicates on the 2-, 3- and 4-month panels removed from Site 1 in mid-April indicates that objects introduced earlier in the year than mid-April would have greater tunicate set and growth.

G. Amphipod Tubes

Amphipods were discussed briefly by Maloney (1958), but the dwelling tubes built by some species of this Order were not mentioned. Amphipod tubes or cases are constructed of mud, sand, and any readily available debris cemented by a glandular secretion. An attempt was made throughout the analysis to record amphipod concentrations; however, these data have been disregarded because the nonsessile nature of these crustaceans prevented accurate counts. Data on coverage of exposed area were good for bottom test cylinders but not satisfactory for regular test panels. In a few panels, tubes were readily counted; however, as numbers increased counting became almost impossible, and they were recorded as too numerous to count (Table 2). Numbers of amphipod tubes per square foot are indicated where possible in

MID-MONTH EXPOSURE PERIODS	A	M	J	J	A	A	S	O	N	D	J	F	M	A	M	J	
	M	J	J	A	S	O	N	D	J	F	M	A	M	J			
MONTHLY PANELS																	
SITE 1	1	α	6	14	0	27	5	0	0	0	0	0	0				
SITE 2			0	0	0	22	0	2	0	0	0	NO PANEL	0	α	α		
CUMULATIVE																	
SITE 1	1	2	3	4	5	6	7	8	9	10	11	12					
PANELS	1	α	0	12	(Number of tubes / ft ²)							163	0	α			
SITE 2			1	2	3	4	5	6	7	8	9	10	11	12			
PANELS			0	0	0	α	α	0	α	0	0	5	α	α			
SITE 3										5	(Months exposed)						
BOTTOM TEST CYLINDER										27	(Percent exposed surface covered)						
SITE 4	(Numbers of Months Exposed)																
PANELS		1	2		4	6											
BOTTOM TEST CYLINDER		0	0		9	0											
						0											

α-AMPHIPOD TUBES TOO NUMEROUS TO COUNT
TABLE 2. AMPHIPOD TUBE OCCURRENCE.

Table 2; otherwise, listing may be shown as many, too numerous to count, or as percent coverage as in Site 3 bottom test cylinders.

Monthly data for Sites 1 and 2 indicate that maximum tube development occurs in April-May and May-June. A close examination of Table 2 reveals little pattern or trend except the maximal development mentioned above, which carries over into the cumulative panels for Sites 1 and 2. The heavy mats of tubes covering 27 percent of the exposed surface area of the bottom test cylinders for Site 3 were tightly packed and 3/4 to 1 inch in thickness. The occurrence designation, too numerous to count, in the 11- and 12-month cumulative panels is undoubtedly a product of the April-May and May-June periods of development. A second development peak is indicated in the 5-month June-November and 7-month June-January panels of Site 2 and in the 5-month bottom test cylinders of Site 3. These two development periods could be described as early winter and spring and probably follow movement patterns of the responsible amphipods. The amphipods constructing tubes in this area have been identified as Corophium acherusicum Costa.

VI. CONCLUSIONS

The presentation of the 1956-57 data (Maloney, 1958) established the basic procedures for subsequent research and reporting. First and second year data were relatively consistent for identical sites.

In the approaches to Chesapeake Bay (Fig 1) 12-month accumulations of foulers ranged from 31 to 38 ounces per square foot on curved steel test panels. The predominant macroscopic sessile organisms were barnacles, bryozoans, hydroids, calcareous tubeworms, tunicates, mussels, jingle shells, oysters, and amphipod tubes. As indicated above, this study has been limited to an analysis of the occurrence of readily visible organism. Organisms of less importance and abundance than those mentioned above were listed by Maloney (1958); consequently, they are not included here.

Figure 18 is a revised and expanded presentation similar to Figure 14 of H. O. TR-47 in which organisms occurring on 1-, 2-, 3-, 4-, 5-, and 6-month panels are recorded. The same organisms and several additional ones are shown for the 2-year data from Sites 1 and 2. This presentation is useful for showing initial set, duration of set, and end of set period; for showing the cumulative effect of multiple months of exposure; for indicating the need for conditioning the attachment surface in some panels before set can take place; and for showing the succession of the various organisms.

Periods of attachment, maximum attachment, and most rapid growth of the principal foulers of Sites 1 and 2 are shown on Figures 19 and 20. In Figures 21 and 22 these are interpreted in terms of periods satisfactory for the submergence of equipment, provided light fouling is not objectionable. The data presented here are for surfaces untreated or covered with regular paint; however, they may be used to predict relatively safe periods when antifouling compounds of a known expected effectiveness are used. If the time of introduction or immersion is carefully planned, it is possible to extend the troublefree time as much as 6 months beyond the expected effectiveness of the antifouling compound.

Maloney (1958) presented a series of fouling panel photographs which demonstrate the fouling progression and succession of species for Site 1. These photographs, while not representative of the entire study area, are sufficiently indicative of the succession pattern to obviate additional presentation. Maloney (1958) also presented the possibility of using calcareous tubeworms or jingle shells as immersion time indicator species; however, analysis of the 1956-59 data did not provide sufficient information to establish these or other species as indicators.

This study has served as a prototype for fouling research in other locations of military significance. In addition to determining the macroscopic sessile fouling complex in the approaches to Chesapeake Bay, experience of equal importance was gained in methods of analyzing fouling panels and raw data, in the mechanics of introducing and recovering test objects, in the design and size of test objects, in the planning of introduction and removal schedules, and in the use of personnel for operational work and panel analyses.

No additional fouling research, per se, is contemplated for the area; however, a tentative plan to study the free living stages of the foulers has been formulated. This proposed study would be carried out by means of quantitative and qualitative plankton tows.

This Office is currently conducting fouling surveys similar to this prototype study in other areas under the Inshore Survey Section of the Oceanographic Survey Branch.

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charts, graphs, and figures. (HO TR-96)

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1. Marine Fouling
2. Oceanography
3. Norfolk, Virginia
fouling

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