# MARINE FOULING ORGANISMS IN MONTEREY HARBOR, CALIFORNIA, JUNE THROUGH SEPTEMBER, 1966

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by

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ABSTRACT

Marine fouling organisms occurring on test panels of various substances and at several locations and depths in the Monterey Harbor, California, were studied for identification and significance.

Some panels were immersed for the entire length of the study--June 10 to September 16, 1966; others, mainly plywood, were immersed only for month-long periods throughout the study.

Barnacles, bryozoans, and serpulids were the major fouling organisms in the inner harbor, while hydroids were most significant in the outer harbor. The barnacles reached maximum attachment in June and July, but were covered later by bryozoans. Phoronid worms were abundant in August and September on the shallow panels in the inner harbor.

Fouling increased with depth and distance away from direct sunlight. Fibrous masonite and wood panels were the best collecting surfaces and stainless steel the worst.

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## 1. Introduction.

The primary objective of this study was to continue the type of research begun earlier in the year [10], so as to obtain by systematic test panel experiments a more complete seasonal analysis of the fouling organisms under Monterey Municipal Wharf #2. Data for this study were gathered from June 10 to September 16, 1966.

It has been pointed out by others [2, 12, 16] that a fouling community will vary not only seasonally but yearly. Thus, even though there is now fairly complete seasonal data, it cannot be said that the community will remain unchanged from year to year. However, the fluctuations will most likely be in the relative numbers and not in the species of animals present.

Several other secondary experiments were added to determine such features as: ecological succession; the effect of direct sunlight; and the effect of open, less polluted water on the fouling community. Also, several types of test panel surfaces were used to determine which type was best suited to collection and analysis of fouling organisms. Some panels covered with antifouling compound were used to determine if their surface coating had any effect on nearby panels.

Finally, a comparison was made of the fouling community with temperature and salinity data.

Three sites were chosen for the experiments. The primary site, which had five racks at varying depths and various types of panels, was located approximately 1000 yards from the shoreline under Monterey Municipal Wharf #2 (see Figure 1). No direct sunlight reached the specimens here, and water motion was mostly from tidal action.

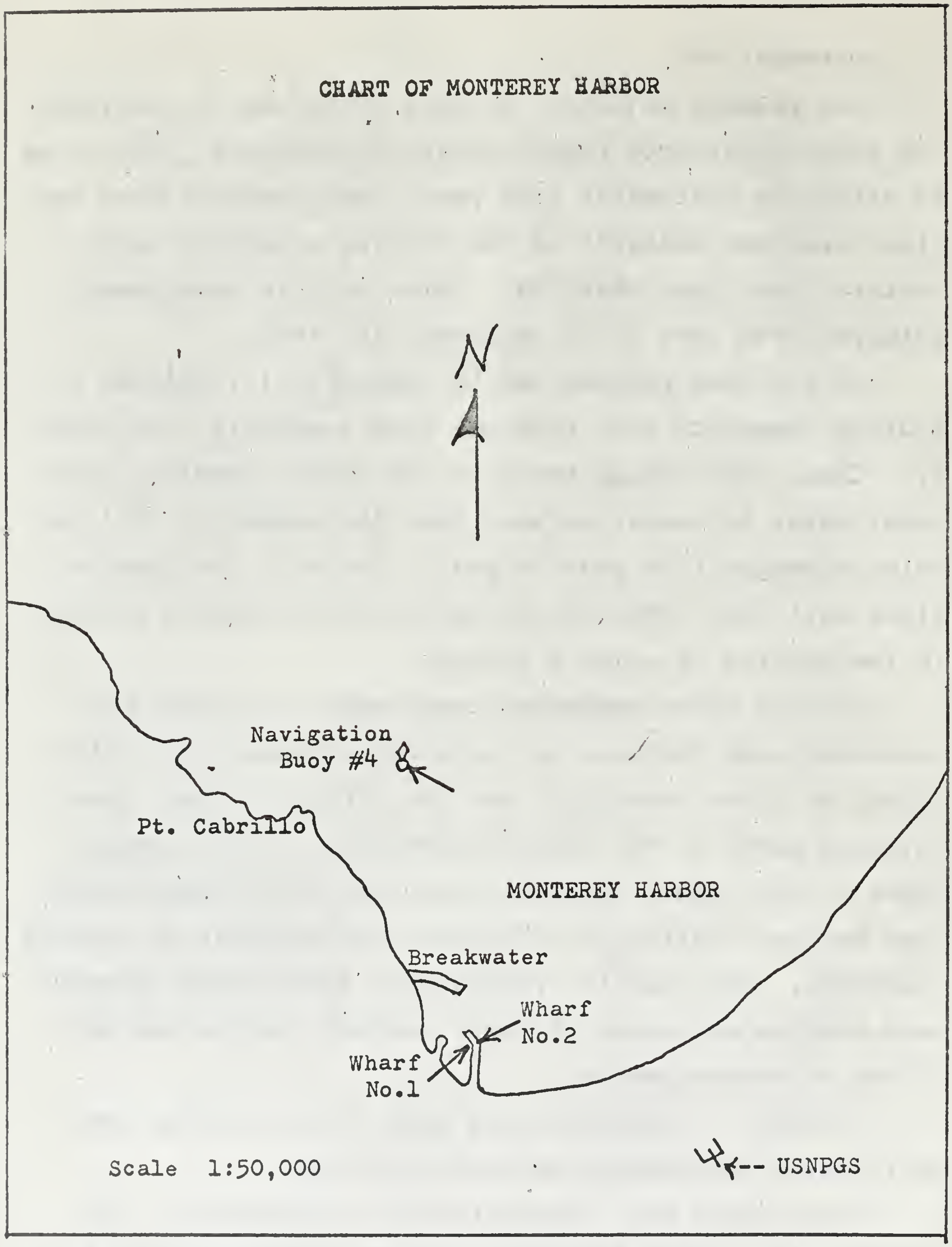


Figure 1. Location of Test Sites (denoted by arrows).

The two secondary sites were principally used for comparison purposes. To investigate the direct sunlight effect, a rack was hung exposed on the west side of the wharf at the same distance from the shore. The third site was Navigation Buoy #4, approximately 1800 yards due north of the west end of the Coast Guard Breakwater. This location was 800 yards from the nearest land, but in more open water than were the two wharf sites.

2. Equipment.

Except for the buoy site, the same types of racks were used in all locations as in the previous study [10].

Four stainless steel racks and two pine wood racks were placed under the wharf at various locations (see Figure 2). Henceforth, the racks under the wharf will be referred to as follows: floating rack--the wooden rack which always remained at the surface; intertidal rack--that metal rack suspended five feet above mean low tide so that it was in the water half of the time and out of the water the other half; shallow rack--that metal rack suspended one foot below mean low tide; deep rack--the metal rack suspended 14 feet below mean low tide; antifouling rack--that wooden rack containing two antifouling paint-coated panels and a glass control panel suspended 14 feet below mean low tide; light rack--that rack suspended from the western side of the wharf to one foot below mean low tide. Each rack was capable of holding six 8X10 inch panels with a three inch space between them (see Figure 2 for a diagram of each rack).

All racks were originally held in location by 3/32 inch stainless steel Bathythermograph wire. However, after about three weeks' exposure, the 5/16 inch hot galvanized steel "U" clamps used to secure the wire to the racks were corroded severely and an additional ¼ inch nylon line had to be added to each rack for extra security.

At first, it was planned to have six kinds of collecting panels, all 8X10X3/16 inches, with glass, stainless steel, and plywood being used as the main collecting surfaces. To give surface variety and to test fouling

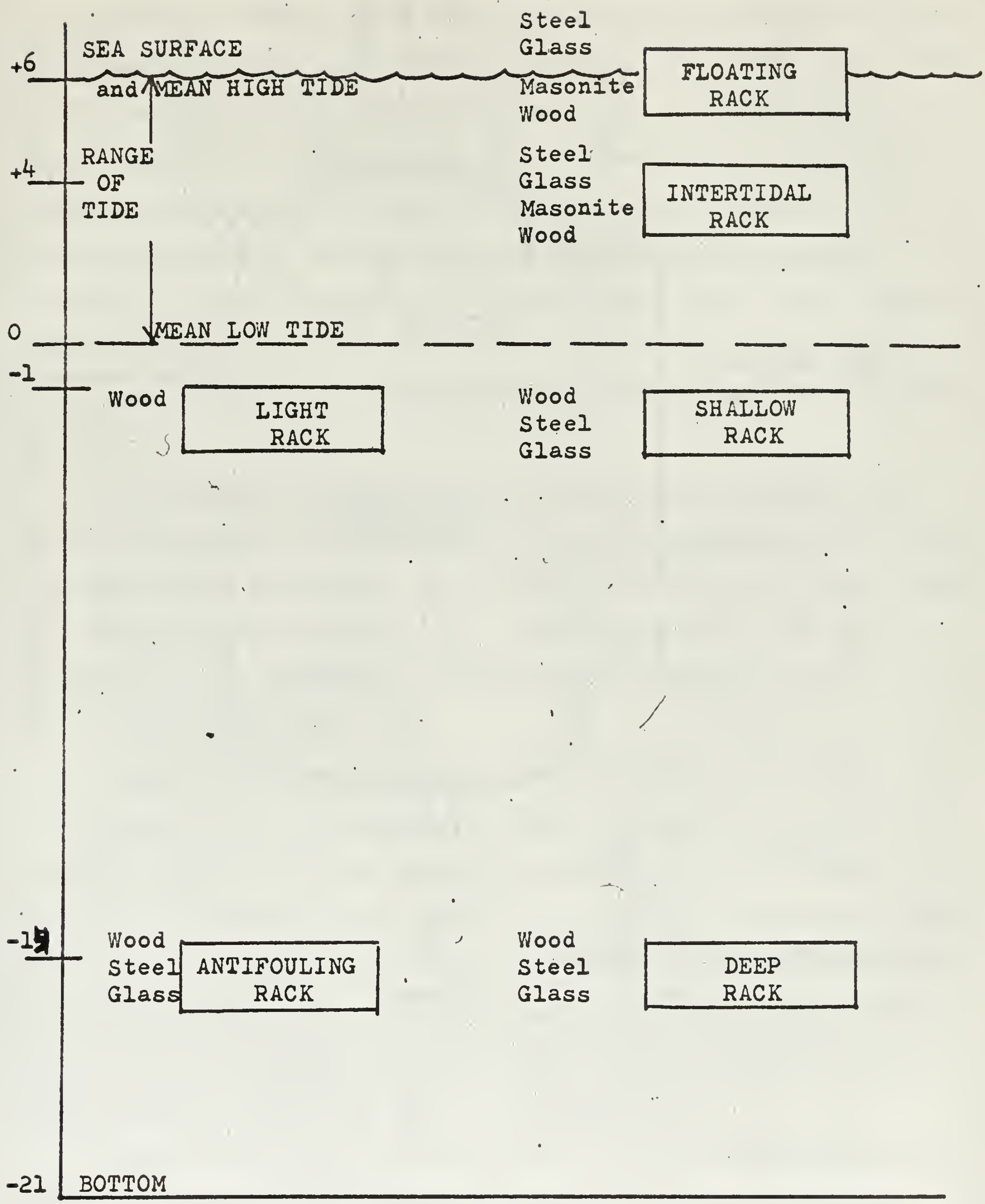


Figure 2. Relationship of Racks to Sea Surface under Wharf #2 and Types of 8X10 Panels Contained in Each.

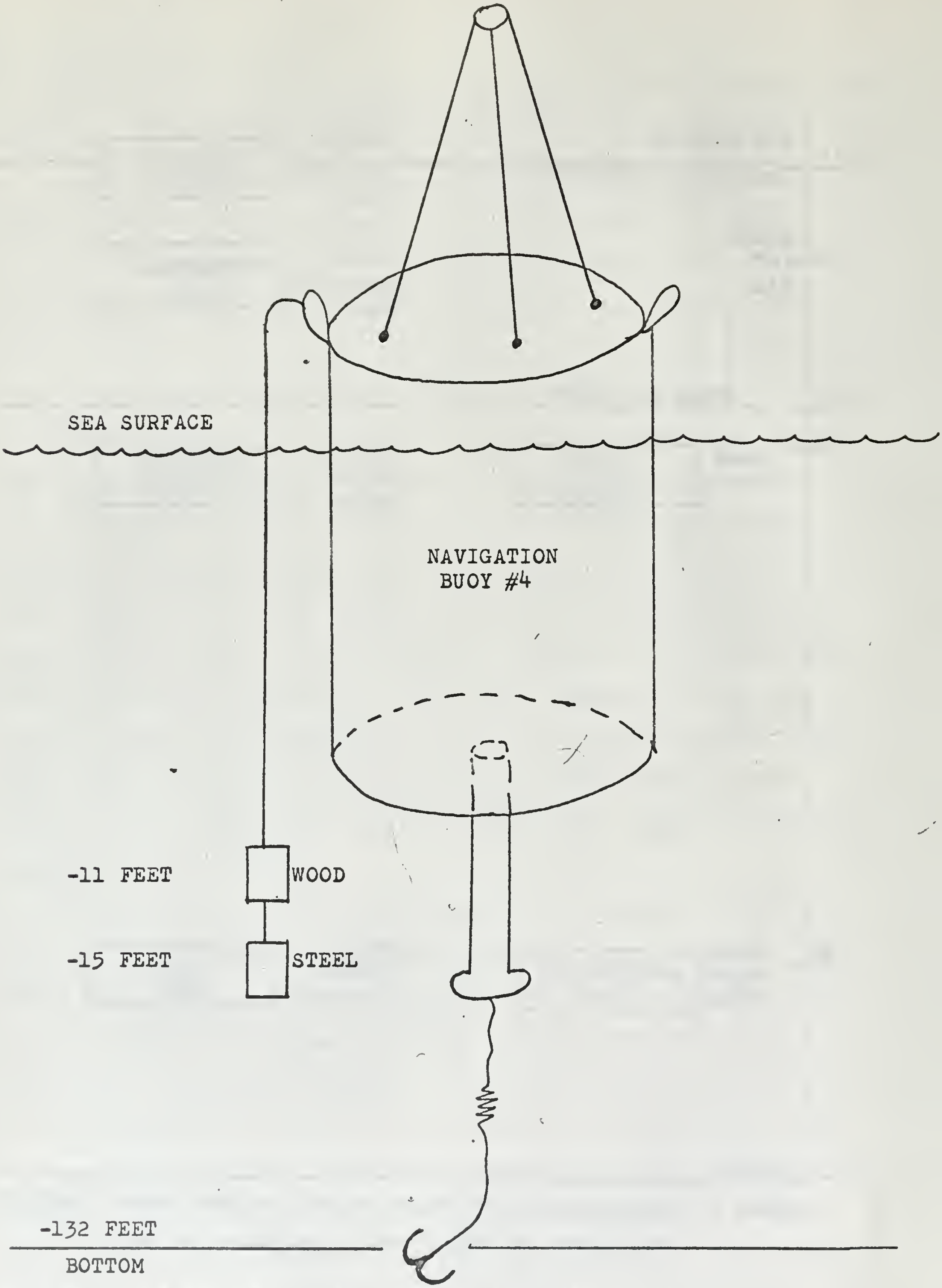


Figure 3. Relationship of Wooden Panel under Navigation Buoy #4 to Sea Surface.

qualities, other secondary materials were used--masonite, and aluminum coated with Teflon. In this last case, the aluminum reacted electrolytically with the steel racks and dissolved within the first month, thus rendering these panels useless. All of the other panels were uncoated except for ball point pen lines which were drawn on the panels to divide the surfaces into one inch squares. Lastly, on July 7, 1966, both a plywood and a steel panel were coated with the U.S. Navy's Formula 105 antifouling hot plastic and then placed in the study area for observation.

The panels suspended from the buoy also were hung originally with the wire. However, the panels were lost and had to be replaced, and in the replacement nylon line was substituted for the wire. The wood panel was suspended 11 feet below the surface and the metal panel 15 feet (see Figure 3).

There were four primary racks. Each contained a glass panel, a plywood panel, and a steel panel which remained in the rack the entire test period of 93 days. In addition, a new plywood panel was added to each rack every two weeks and removed after a month's exposure. Because of the weight of the stainless steel panel, it was necessary to use a counterweight pulley arrangement to keep the floating rack continually at the surface.

Under the wharf, in addition to the above-mentioned racks, there was one wooden rack which contained a wood panel and a stainless steel panel coated with antifouling compound, as well as an uncoated glass control panel. Also, in order to investigate the effect of light on settling fouling organisms, one metal rack was exposed to the maximum afternoon sunlight on the western side of the wharf. This rack originally contained glass, stainless steel, masonite, and three plywood panels. Because of its unprotected location, though, it fell prey to several pilferages and all that could be salvaged was the long-term wood panel; even this panel was lost at the end of 40 days' exposure.

3. Procedures.

Two basic procedures were followed in analyzing the test surfaces under the wharf.

First, to determine any ecological succession within the fouling community and to test the effect of various surfaces on the attachment of fouling organisms, a set of glass, stainless steel, wood, and in some cases masonite panels were placed in each rack and allowed to remain the entire test period of approximately 93 days. For analysis of the organisms, these panels were withdrawn from their racks at the half-way point of the study (or, after 47 days) and again at the end of the study period, but were kept immersed in sea water in order to approximate *in situ* conditions. The panels were examined thoroughly with the aid of a 30X Binocular Microscope. Since the panels had been divided into one inch squares before placement in the water, it was possible to count and record the average number of each species per square inch. Furthermore, each panel was photographed with a Polaroid Model 100 Land Camera with a close-up lens. The purpose of the photographs was to make possible accurate counts of the larger fouling organisms, and to enable accurate comparisons with later photographs taken of the panels at the end of the study. Since the panels were returned to their racks within two to three hours after removal, and since they were continually immersed in sea water during analysis, it is believed that no ill effects befell any of the organisms. All analyses were done at the new aquarium building on the beach of the U. S. Naval Postgraduate School. Since all panels except a plywood one were stolen at the beginning of the study period from the light-exposed rack on the side of the wharf, only that one panel could be examined. As of August 20, even that last panel was lost. Under the wharf, the plywood and stainless steel panels coated with antifouling compound and the glass control panel in the same rack were examined only at the end of their 65-day exposure.

Second, to determine periods and rates of attachment, additional plywood panels were introduced to each rack every two weeks and were withdrawn after one month's exposure. These panels were examined in the same manner as were the long-term panels but, in addition, some were allowed to dry and then each of these was scrutinized carefully. Others were placed in aquaria with fresh but filtered sea water continually bathing them. The purpose here was to try to obtain some estimate of the rates of growth of the organisms without the introduction of new species or individuals.

Similar methods of examination were used in checking the buoy panels of plywood and steel for fouling in the outer harbor. These panels were left in the water for a period of 65 days.

Finally, temperature measurements using a standard Navy bucket thermometer, and salinity measurements using a Kahlisco salinity hydrometer were made at two to three day intervals during the entire period of study. The purpose of this analysis was to determine a possible correlation between the fouling community and the water conditions.

4. The Fouling Organisms.

Essentially the same techniques employed by Mommsen [10] were employed in examining the fouling organisms of this study. All test panels were examined initially while immersed in a pan of sea water, so that an *in situ* environment could be maintained for easier identification and for ecological observations.

Identification was carried as far as possible using the keys [5, 8, 14], but many of the immature specimens would have necessitated observation by an experienced biologist for complete analysis.

Non-attached animals which appeared to be an integral part of the fouling community were also described in this study.

*Limnoria lignorum*, a marine borer, was found in several wood panels throughout the period of this investigation. The abundance was about the same as that found earlier in the year [10], thereby adding evidence to the observation that *Limnoria lignorum* is as continually present in Monterey Harbor as it was at Friday Harbor [7], and at Oakland [4].

There was no evidence of *Teredo* infection in this study.

The fouling organisms observed are listed in Table 1.

### Bacteria

At first, a slime always appeared on the test panels and was especially noticeable on the glass. The slime was undoubtedly due mainly to bacteria [14], although this feature was not examined specifically. According to

TABLE I

FOULING ORGANISMS RECORDED ON
TEST PANELS IN MONTEREY HARBOR,
JUNE THROUGH SEPTEMBER, 1966

Plants

Phylum Thallophyta
- Subphylum Algae
  - Class Chrysophyta - Diatoms (unidentified)
  - Class Phaeophyta - Brown Algae (unidentified)
  - Class Rhodophyta - Red Algae, *Corallina* sp.
  - Class Chlorophyta - Green Algae (unidentified)

Animals

Phylum Protozoa
- Foraminifera (unidentified)
- *Zoothamnium* sp.
- *Folliculina* sp.

Phylum Porifera
- One species (unidentified; numerous spicules)

Phylum Coelenterata - Class Hydrozoa
- *Obelia gracilis*

Phylum Platyhelminthes (Flatworms)
- *Leptoplana* sp.

Phylum Nemertea
- *Tetrastemma nigrifrons*

Phylum Aschelminthes
- Nematodes (unidentified)

Phylum Annelida (Segmented Worms)
- *Nereis vexillosa*
- *Laeospira* sp.
- *Dexiospira* sp.
- Spionids (unidentified)

Phylum Arthropoda - Class Crustacea
- *Balanus crenatus*
- *Balanus glandula*
- *Caprella* sp.
- Copepoda (unidentified)
- Amphipods (unidentified)
- *Limnoria lignorum*

Phylum Mollusca
- Snails (some unidentified; some *Littorina* spp.

TABLE I (continued)

Phylum Mollusca (continued)

- Hermissenda crassicornis
- Dendronotus subramosus
- Doto varians
- Duraucelia festiva
- Triopha grandis
- Austrodoris odhneri
- Mytilus edulis
- Pododesmus macroschisma
- Clams (unidentified)

Phylum Entroprocta

- Pedicellina cernua

Phylum Bryozoa

- Tubulipora sp.
- Membranipora membranacea
- Hippodiplosia insculpta
- Parasmittina collifera
- Hippothoa hyalina
- Tricellaria sp.
- Bugula californica
- Bugula neritina
- Crisia sp.

Phylum Phoronidea

- Phoronis sp.

Phylum Echinodermata

- Pisaster sp.
- Strongylocentrotus sp.

Phylum Chordata

- One species of Tunicate (unidentified)

Zobell [17], this slime not only is always present, but it is also necessary for the subsequent growth of the macroscopic fouling organisms in a marine environment.

## Plants

Diatoms were observed adhering to projections on all of the panels, but they were most obvious on the panels exposed to direct sunlight. None were identified.

Algae were observed only on the light panel and on the long-term panels located under the wharf. Three forms of algae were only identified to major group: red, brown, and green. All forms occurred on the light panels; however, only the red algae, Corallina sp. was found under the wharf and, then, it was found at all depths and on all surfaces.

## Animals

Discussion of the numerous animals will be by phyla.

### Phylum Protozoa

Several of the panels had the dark bottle-shaped protozoans, Folliculina, but these were not as evident as they had been during the first three months of the year [10]. However Zoothamnium, the colonial vorticellid, was present throughout the period on almost all the panels. They appeared to grow best on the deep glass and steel panels.

### Phylum Porifera (Sponges)

The most common evidence of sponges was the numerous tiny needle-like siliceous spicules. Some live specimens were seen on the long-term glass panels at various depths, but they were so limited and so poorly developed that they could not be identified easily. They probably belonged to the class Demospongiae.

### Phylum Coelenterata - Class Hydrozoa

The hydroid, Obelia gracilis, did not appear under the wharf in any significant numbers until the fourth monthly set of panels (July 22 - August 18) was examined; then, it occurred only on the bottom half of the floating and intertidal panels, i.e., not more than a few feet under the surface. The most abundant growth of Obelia gracilis was on the steel and wood panels exposed under Buoy #4. At the end of the 65 days' exposure, this hydroid had developed colonies which were six inches thick on both sides of the panels. When comparing these observations with earlier ones [10], it appears that there are at least two "blooms" of hydroids in the area: one in February and March, and another in July and August. In both periods, the number and size of the nudibranchs (which apparently grazed on the hydroids) increased with the increase in the hydroids.

### Phylum Platyhelminthes (Flatworms)

Several flatworms were observed on early panels containing many barnacles, but no relationship between the flatworms and the barnacles was found [10]. The flatworms did not appear again until the long-term panels were examined, and then they were quite common at all depths. The majority were Leptoplana sp.

## Phylum Aschelminthes

The small transparent nematodes described in Light *et al.* [8] were found on all panels throughout the study period. They were not identified further.

## Phylum Nemertea (Ribbon Worms)

Only one species, *Tetrastemma nigrifrons*, was observed during the study period. The several specimens that were found occurred on the long-term intertidal masonite panels.

## Phylum Annelida (Segmented Worms)

On almost all panels, several species of polychaetes without tubes were observed. One common variety was *Nereis vexillosa*. Other tubeless annelids were not identified further.

Of the tube-building annelids, the white calcareous tubes of the Serpulidae were the most common. Unlike earlier in the year [10], they were found on all panels except the ones in the floating rack and the intertidal rack. Three different tube designs were observed: the sinistrally-coiled *Laeospira*, the dextrally-coiled *Dexiospira*, and a straight or uncoiled species of serpulid [8]. All were equally abundant and became most numerous in September.

Finally, on the long-term panels, several annelids with transparent membranous tubes were observed but were not specifically identified.

## Phylum Arthropoda - Class Crustacea

Several species of free-moving amphipods and copepods were observed on the panels; however, they were not identified further.

The tube-building amphipods were observed only once on the deep panel during the monthly period of July 22 to August 18. No particular pattern was observed.

The gribble, Limnoria lignorum, was seen occasionally at various depths on wood panels throughout the study period.

Balanus crenatus was the most significant fouling organism and the only barnacle (except for two specimens of Balanus glandula) which settled on the panels during the entire test period. Figure 10 shows how the barnacles had settled in great numbers during the first monthly period of June 10 to August 8; Figure 11, a photograph of the second monthly period of June 24 to July 22, shows fewer barnacles, but ones which have grown much larger. The crowded barnacles of the first period, which numbered 40 to 50 per square inch, probably could not get enough food to maintain the large population; Figure 11 shows that the population was reduced to equilibrium with the environment, or, to three or four barnacles per square inch. This finding is in accord with those of Coe [1]. This extreme crowding also was observed on the deep panels at the halfway point of the study. These panels had been covered completely with barnacles in the preceding 49 days but, at observation time, only half of the original barnacles remained. It must be pointed out that some of the missing barnacles might have been removed by grazing starfish rather than by crowded conditions. Very few Balanus crenatus attached after the end of July and, at the end of the study, almost all of the barnacles were covered by bryozoans.

The barnacles grew in basal diameter at the rate of about one millimeter per ten days. This rate agrees with growth measurements taken on Balanus crenatus in the White Sea [15] and elsewhere. The barnacles' attachment rate varied with regard to water depth in the following ways: it increased with depth on all surfaces--that is, there was less barnacle fouling on the shallow, floating, and intertidal racks (except the rough side of the masonite) than on the same surfaces on the deep panels; there were no variations in the surfaces on the deep panels--all were solidly covered; and, later in the study when fewer barnacles were settling, it was noticed that they preferred the sides of the wood panels which were darkest in color and away from the light.

## Phylum Mollusca

Pelecypods were quite numerous throughout the study period and occurred on almost all panels and at all depths. The most common forms were immature specimens of the mussel, Mytilus edulis, which numbered approximately one per square inch. None were attached and most were about one millimeter long. The next most common pelecypod was the rock oyster, Pododesmus macrochisma, which was usually unattached and averaged about half a millimeter in diameter. Later in the season, it was observed that numerous specimens were attached firmly on the long-term shallow and deep panels and that, by the end of the 93 days, some had grown to a diameter of eight millimeters. Several unidentified clams were also observed.

A small snail (one-half to one millimeter) with a greenish translucent shell was seen on several occasions, but could not be identified with the available keys. The same situation occurred regarding a specimen which was white with brown spots and which appeared late in the study period.

The most colorful animals seen during this study were the nudibranchs. *Hermissenda crassicornis* was the most prevalent and was found on almost all panels and at all depths. Although these nudibranchs were present throughout the test period, they became much larger and more numerous when the hydroids, *Obelia gracilis*, became abundant near the first week in August--literally thousands of nudibranch eggs were found on the hydroid-infested buoy panels at the end of the study. Another nudibranch, *Dendronotus subramosus*, was noted on an intertidal panel after 48 days of exposure. During the fifth monthly period (August 5 to September 2), several specimens of a third species, *Doto varians*, were observed on the floating panel. Finally, the long-term panels yielded three other species, *Duvaucelia festiva*, *Triopha grandis*, and *Austrodoris odhneri*.

## Phylum Bryozoa

One of the most plentiful bryozoans was the encrusting form, *Membranipora membranacea*. It was found at all depths and on all panels, and the largest grew to about four millimeters across in a month.

The next most common encrusting species was *Tubulipora* sp.. It was found everywhere, but preferred steel panels. It did not develop as fast as the other encrusting bryozoans.

All long-term panels from under the wharf were 75%

covered with Hippodiplosia insculpta by the end of the study period (see Figure 5). These yellowish, circular, encrusting bryozoan colonies averaged 30.0mm across and were seen covering all previous fouling organisms. They became abundant only in August and September; yet, since they were found only on the long-term panels, other fouling organisms might have to be present on a surface before the Hippodiplosia insculpta will attach. They were particularly heavy where the growth of phoronid worms was most intense.

Other encrusting forms seen occasionally were Tricellaria sp. and Parasmittina collifera.

Finally, there were several bryozoans which were on stalks and were not encrusting. It is believed that these were the early stages in the development of Hippothoa hyalina. These animals preferred attachment along the cracks made by the ball point pen lines on the wood panels. Other stalked bryozoans were Bugula californica and Bugula neritina. These last two species were found only on the long-term panels.

### Phylum Echinodermata

Two small (a half millimeter) immature starfish, Pisaster sp., were observed during the fourth monthly analysis (July 22 to August 19) and were seen on the long-term panels at the end of the study. Also toward the end of this test period, several sea urchins, Strongylocentrotus sp., were observed.

### Phylum Chordata

One species of tunicate was seen but not identified. It was found on the deep panel of the third monthly analysis (July 8 to August 5).

5. Factors Affecting the Type and Rate of Fouling.

The factors which influenced fouling on the test panels in this study were: length of exposure; season of exposure; type of surface; depth; amount of light; edge effect; and geographic location. These factors differ slightly from those examined by others [9, 10, 14], because of the limited scope of this study.

## Length of Exposure

As in observations made earlier in the year at this same location [10] and, indeed, as has been found at many other locations [14], the fouling increased with the length of exposure at all test sites. This point is illustrated in Table II, which summarizes the results of the examination of three macroscopic foulers from the wood, glass, and stainless steel panels in the floating rack, the shallow rack, and the deep rack, respectively; this examination was made at the halfway period of the study, which was approximately the same length of time as the final observations in the earlier study [10]. Table III is a comparison of the same panels at the end of the test period. Care must be exercised in interpreting the number of bryozoans, especially those on the shallow rack, because even though the number of colonies did not increase significantly, the size of the colonies did. For example, the bryozoan *Hippodiplosia insculpta* covered up to 75% of the surface in the case of the wood panel and yet it was not as numerous as the *Tubulipora* sp. and other stalked bryozoans found on the deep panels. Even though this examination was spaced over several days, it is believed that the results will

TABLE II

RESULTS OF FIRST OBSERVATIONS ON LONG-TERM PANELS

(Barnacles and serpulids are indicated by the average number of individuals per side of panel--80 square inches; bryozoans are indicated by the average number of discrete colonies per side of panel.)

FLOATING RACK (48 Days' Exposure)

| | Stainless Steel | Glass | Wood |
|---|---|---|---|
| Barnacles | 6 | 12 | 80 |
| Serpulids | 0 | 0 | 0 |
| Bryozoans | 0 | 0 | 10 |

SHALLOW RACK (47 Days' Exposure)

| | Stainless Steel | Glass | Wood |
|---|---|---|---|
| Barnacles | 1 | 3 | 6 |
| Serpulids | 0 | 0 | 70 |
| Bryozoans | 0 | 50 | 40 |

DEEP RACK (49 Days' Exposure)

| | Stainless Steel | Glass | Wood |
|---|---|---|---|
| Barnacles | 50 | 1200 | 1600 |
| Serpulids | 25 | 6 | 60 |
| Bryozoans | 20 | 80 | 70 |

TABLE III

RESULTS OF FINAL OBSERVATION ON LONG-TERM PANELS

(Barnacles and serpulids are indicated by the average number of individuals per side of panel--80 square inches; bryozoans are indicated by the average number of discrete colonies per side of panel.)

FLOATING RACK (94 Days' Exposure)

| | Stainless Steel | Glass | Wood |
|---|---|---|---|
| Barnacles | 100 | 40 | 60 |
| Serpulids | 0 | 0 | 0 |
| Bryozoans | 10 | 10 | 30 |

SHALLOW RACK (93 Days' Exposure)

| | Stainless Steel | Glass | Wood |
|---|---|---|---|
| Barnacles | 1 | 4 | 6 |
| Serpulids | 80 | 80 | 20 |
| Bryozoans | 50 | 50 | 80 |

DEEP RACK (95 Days' Exposure)

| | Stainless Steel | Glass | Wood |
|---|---|---|---|
| Barnacles | 300 | 1000 | 400 |
| Serpulids | 2000 | 350 | 150 |
| Bryozoans | 350 | 150 | 200 |

Figure 4. Photograph of Fouling on Wood Panel from Shallow Rack after 47 Days Exposure.

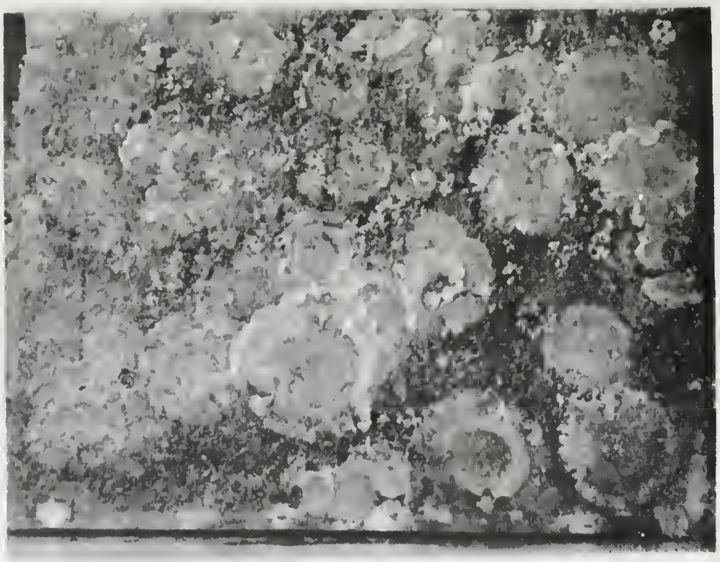

Figure 5. Photograph of Fouling on Wood Panel from Shallow Rack after 93 Days Exposure.

Figure 6. Photograph of Deep Long-Term Wood Panel after 46 Days' Exposure.

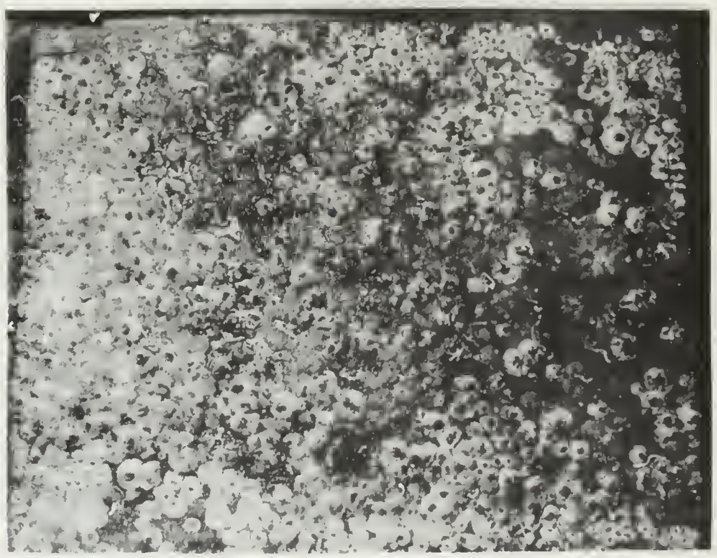

Figure 7. Photograph of Deep Long-Term Wood Panel after 95 Days' Exposure.

be accurate.

Figure 4 shows a photograph of the plywood panel in the shallow rack after 46 days of exposure; Figure 5 shows the same panel after 93 days' exposure. These figures illustrate the point that the encrusting forms of fouling organisms, such as bryozoans, eventually assume an increasingly dominant role. This result agrees with that which was found in Biscayne Bay [12]. However, the evidence is not conclusive and further seasonal studies are required. (The same results can be seen in Figures 6 and 7 which show the wood panel in the deep rack after 46 and after 95 days' exposure respectively.)

Season of Exposure

Every two weeks, a new panel was placed in each of the racks under the wharf. Each was allowed to remain for a period of one month, then it was examined. The periods of exposure are shown in Figure 8. The variation of the major fouling organisms on the shallow panel during these periods is illustrated in Figure 9.

As shown in Figure 9, barnacles are by far the major foulers early in July and then they drop off rapidly in abundance. Balanus crenatus was the only barnacle found in significant numbers during July and August, and, therefore, the peak barnacle attachment earlier in the year [10] must have been caused by Balanus glandula. It remains to be seen if there might be a second maximum attachment in November as was found at Friday Harbor [7].

Figures 10 and 11 are photographs of the deep panels during the first two monthly exposures and they show the sharp decrease in the number of barnacles as the season

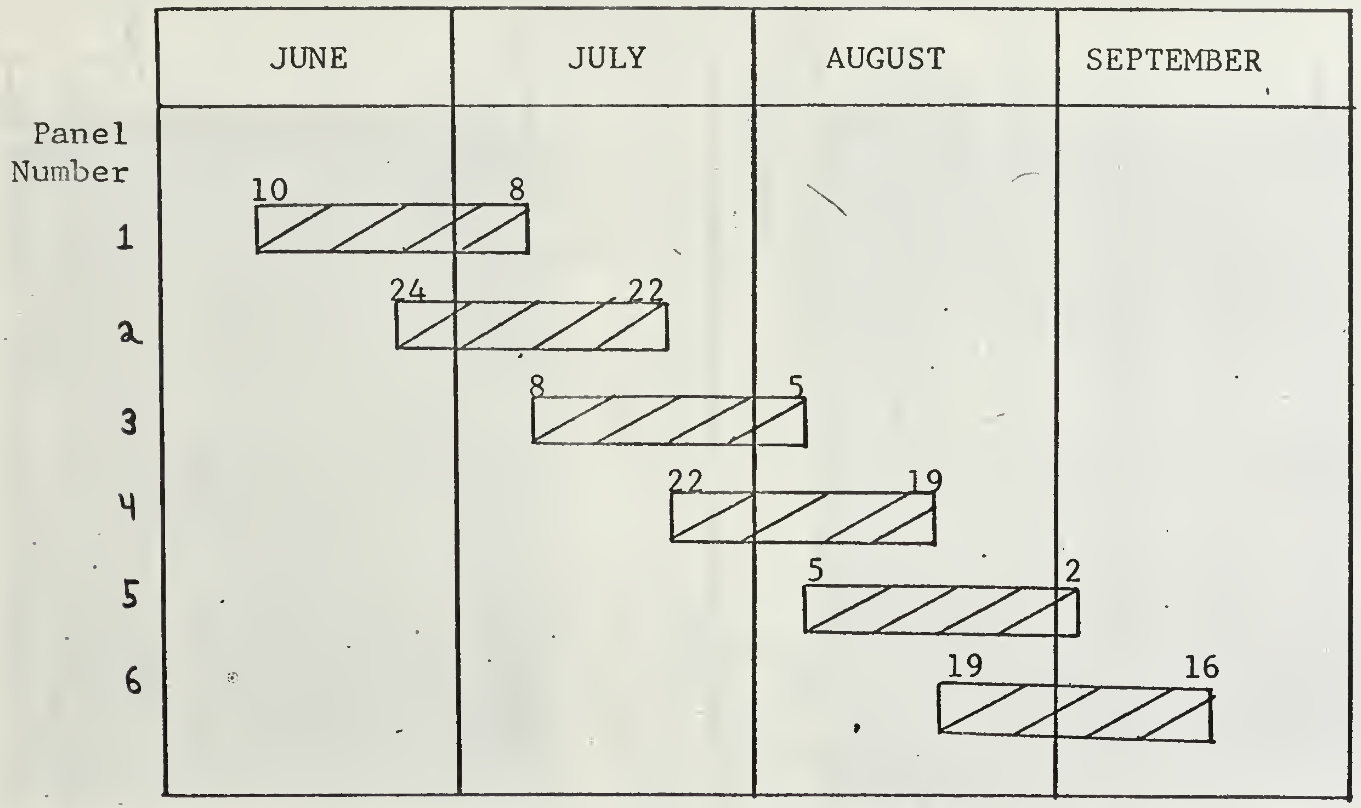


Figure 8. Short-Term Panel Exposure Times.

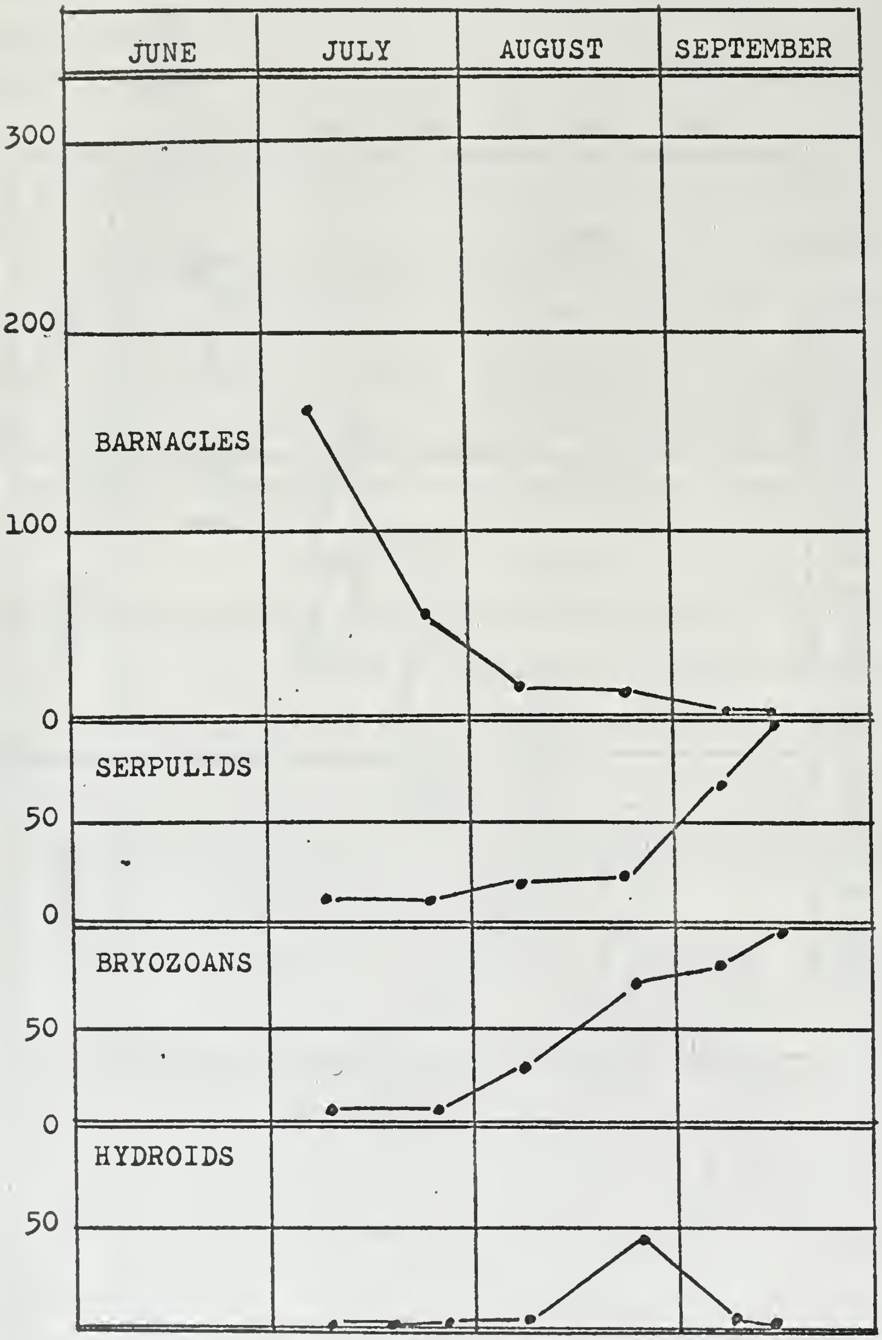


Figure 9. Variation of Major Fouling Organisms with Time on Shallow Wood Panels. (Barnacles and serpulids are indicated by the average number of individuals per side of panel--80 square inches; bryozoans are indicated by the average number of colonies per side of panel.)

Figure 10. Photograph of Fouling on Wood Panel in Deep Rack Exposed between June 10 and August 8.

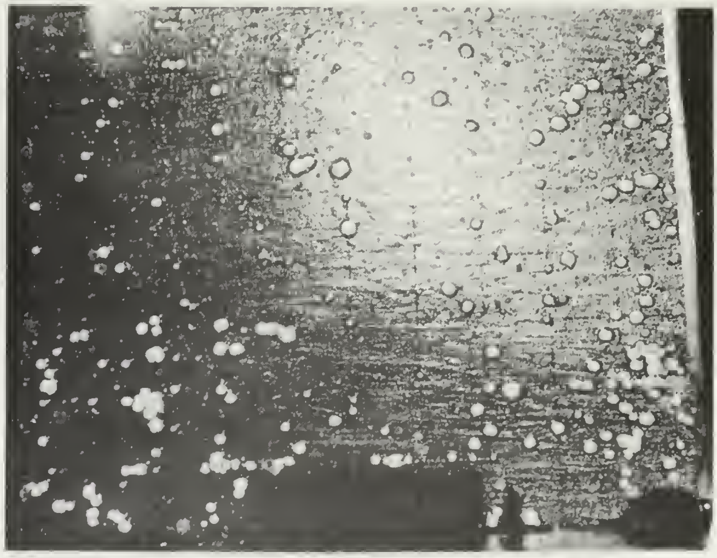

Figure 11. Photograph of Fouling on Wood Panel in Deep Rack Exposed between June 24 and August 22.

progressed.

Serpulid worms and bryozoans increased in number constantly throughout the test period.

Hydroids, which were not present during the early part of the study, suddenly became quite common on the August panels and then, just as suddenly, disappeared from under the wharf in September. Hydroids, though, were very abundant on the buoy panels in September. From data earlier in the year [10], it is seen that there are at least two strong periods of hydroid growth: the first in February and March; the second in August and September.

Maximum fouling at La Jolla [1] occurred in May and June; at Oakland Harbor, it occurred during July and August [4]. Thus, it could be expected that June and July would be most significant at Monterey, and yet this expectation is true only as far as one species of barnacle is concerned. Serpulid worms and bryozoan colonies became more numerous even later in the season. The abundance of these last two fouling organisms could be due to ecological succession processes rather than to seasonal variations.

Figure 12 shows the weekly mean surface temperatures and salinities. No correlation between the attaching fouling organisms and either of these factors was readily apparent. However, the sudden appearance and disappearance of the hydroids in August could have been caused by the rise in temperature during that month. More evidence would be necessary to confirm this inference though.

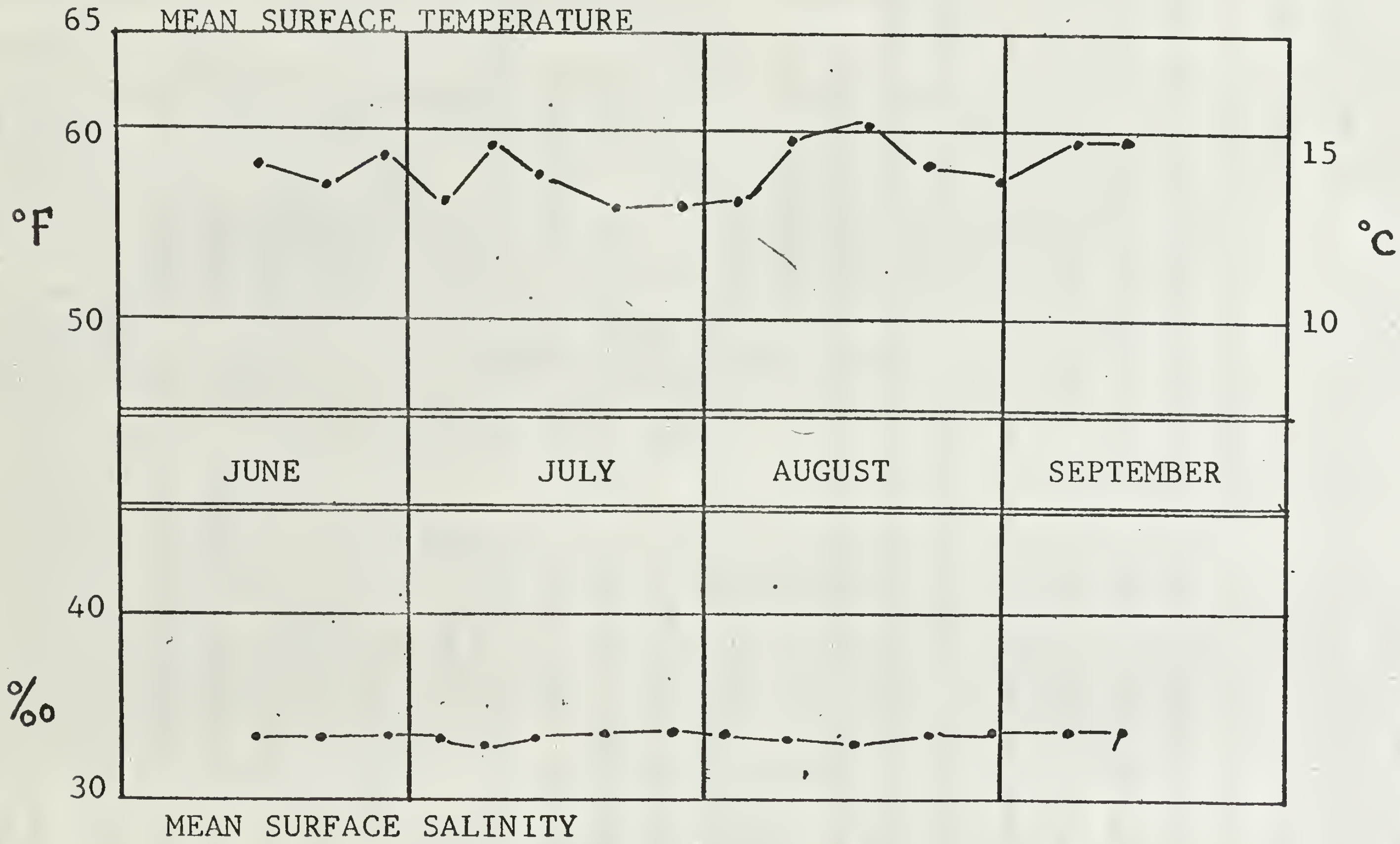


Figure 12. Weekly Mean Temperatures and Salinities.

## Type of Surface

Various types of surfaces were used for the same reasons as given in the earlier study--namely, to give a greater variety of surfaces for attachment and to attempt to gain some insight into the fouling organisms' method of attachment and surface preference.

DePalma [3] and others have discovered that the best collecting surface for fouling organisms is one which is rough, fibrous, and comparatively soft. Asbestos fits these qualifications and is being used at several locations. However, since asbestos is seldom found on submerged surfaces, it is believed that untreated marine plywood, stainless steel, and glass are somewhat more representative of materials likely to be fouled in a marine environment. It must be noted that several masonite panels, which have both a smooth side and a rough side similar to asbestos, were employed with the result that the rough fibrous side collected significantly more fouling organisms.

As mentioned previously, Teflon-faced aluminum panels were used to test a "non-stick," non-toxic surface; however, the electrolytic action dissolved the panels.

As another sidelight, two panels (plywood and stainless steel) were coated with hot plastic antifouling paint. In the same rack but three inches away, a glass panel was inserted to test whether the antifouling paint had any effect on fouling in the immediate vicinity. The result was a confirmation of the earlier results from Biscayne Bay [12] in which it was determined that antifouling paint is effectual when applied to test surfaces, but does not affect "unpainted" surfaces nearby. The painted panels were completely unfouled, but it was noted that the paint on the steel panel chipped off easily after two months' exposure.

Regarding the major part of this study and the evidence from Tables II and III, wood was generally the best all-around collector and stainless steel the worst (compare Figures 5 and 7 with Figures 11 and 12). However, at depth where the fouling was heaviest, it did not matter what the surface was since the majority of the fouling organisms found were represented on all three types of surfaces. Several anomalies were noted: on the deep racks, serpulid worms and the bryozoan *Tubulipora* sp. preferred the steel panels, and barnacles preferred the glass panels; on the shallow and floating panels, phoronid and nemertean worms were common only on the fibrous masonite and wood panels, while sponges were found only on glass panels.

## Depth

As illustrated in Tables II and III and in Figures 13 and 14, the number of fouling organisms attaching to the surfaces definitely varied with depth.

Two striking features were noted regarding the occurrence of serpulid worms: first, they increased in numbers with depth; second, they never occurred on the panels in the intertidal or floating racks.

The significant fouling barnacles consisted of *Balanus crenatus*. The occurrence of this barnacle was greatest at depth and then decreased upward until, near the surface on the intertidal and floating panels, it

Figure 13. Photograph of Fouling on Steel Panel in Floating Rack Exposed for 93 Days.

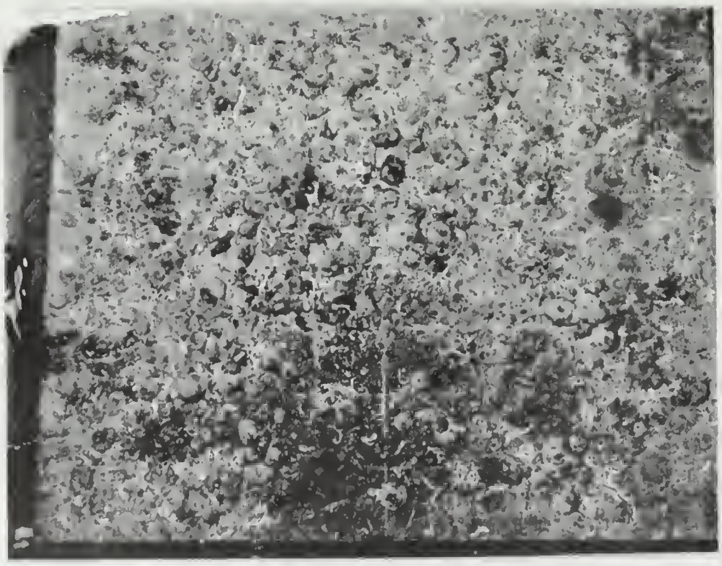

Figure 14. Photograph of Fouling on Steel Panel in Deep Rack Exposed for 90 Days.

increased again. The exact minimum point of occurrence could not be determined from this study.

All species of bryozoans occurred at all depths; *Membranipora membranacea* and *Hippodiplosia insculpta* were most common near the surface, while *Tubulipora* sp. was the major bryozoan at depth.

One significant point is that the intertidal rack and the floating rack were not very different in the number or the species of observed fouling organisms.

Although the species varied seasonally, the conclusion [10] remained unchanged that the amount of fouling increased with depth.

However, the fact that a masonite panel in the shallow rack had almost the same amount of fouling as the wood panel at depth indicates that the type of surface may be as important as the depth.

## Light

One of the primary objectives of this study was to compare the fouling organisms attaching to panels exposed to direct sunlight with the relatively sheltered panels under the wharf. The most significant result was that algae grew on the exposed panels and not on the ones under the wharf, and this lack of algae on the latter is attributed to the absence of direct sunlight [12, 14]. (Some red algae, *Corallina* sp., did occur sparsely under the wharf, however, since it did not require direct sunlight for growth.)

According to some observers [6, 11, 13], the lack of algae on the panels under the wharf would alter or reduce the number of organisms which would settle later on the panels. Moreover, DePalma states [3] that the lack of direct sunlight might make data from the panels under the wharf useless. It must be noted, though, that the majority of fouling organisms are found occurring naturally on the bottom of boats and on wharf pilings where there is no direct sunlight.

It was found in this study that fouling increased with depth and was greatest on the deep rack under the wharf where there was only a small amount of diffused light. Even on the light panels, it was noticed that barnacle fouling was heaviest at the bottom of the panel, furthest away from the light. Thus, it appears that the lack of direct sunlight and the subsequent lack of growth of algae did not inhibit the abundance of other foulers, particularly of barnacles. This result supports the observation [14] that the settling larvae are negatively phototropic and prefer areas with diffused light. It should be noted that the observations on the panels exposed to direct sunlight and the conclusions drawn from them pertained only to the first half of the study, since shortly afterward the exposed rack was lost. It is possible that with longer exposure and with the absence of so many barnacle larvae in the water, the panels exposed to direct sunlight could have obtained more overall fouling.

In the earlier study [10], it was shown that the side of the panels away from the light was most heavily fouled. Since some of the racks in this study were hung so that they could turn freely with the water movements, this light feature could not be investigated in all cases.

However, it was noticed in all cases that, if a wood panel had one side darker than the other, it would show a 25% increase in barnacle fouling over the side lighter in color. It was noted further that, if one side received more light than the other, barnacle fouling was heaviest on the side away from the light regardless of the coloring. On the other hand, bryozoan colonies preferred the side toward the light regardless of the shading in the wood.

## Edge Effect

In general, fouling appeared heaviest within an area one inch from the edge of the panels. However, this distribution was evident only in a few cases and, in these cases, it was caused by one or two species of animals.

Algae grew densest near the edge on the panels exposed to direct sunlight. Hydroids, which became prevalent during August, preferred the edges as a starting point of attachment and also were densest there. This same distribution was true for the bryozoans *Hippothoa hyalina* and *Membranipora membranacea*.

Another type of preference for position was shown by barnacles. They preferred to settle along the etched lines on the glass panels and along the indentations made by a ball point pen when lining the wood panels.

## Geographic Location

There was an attempt to show how the fouling organisms in Monterey Harbor varied at two geographic locations.

The first location, which has been described already in detail, was under the municipal wharf and the second was under the Navigation Buoy #4. What was deduced was that the entire fouling community at the buoy location consisted of hydroids, while hydroids were of no significance under the wharf and many other organisms were common. The evidence is too limited to be conclusive, but it is indicative of the fact that the fouling communities will vary markedly from one location to another even though the actual geographic separation is not great.

6. Conclusions.

Table I lists the fouling organisms present in Monterey Harbor during the period of June 10 to August 16, 1966.

The intensity of fouling was influenced by season of exposure, type of surface, depth, light, edge effect, and geographic location.

The barnacle Balanus crenatus was the most significant fouling organism at all depths during the first half of the study, with the maximum abundance of larvae in early July. The specimens grew at the rate of one millimeter per ten days. Bryozoans and serpulid worms became dominant during the last half of the study (August and September). However, phoronid worms were quite common on the near-surface panels in August and September; hydroids had a minor bloom in August under the wharf but were continually dominant on the buoy panels. Limnoria lignorum was found boring into the wood panels throughout the test period.

On surfaces of the same composition, attached fouling organisms increased with depth and with distance away from direct sunlight.

No fouling was observed on the antifouling panels during their 65 days in the water; the antifouling paint did not influence fouling on nearby surfaces.

At any given depth, fouling was heaviest on the rough fibrous sides of the masonite panels and lightest on the stainless steel panels. An all-around collecting surface was plywood--the fouling intensity here was between those found on the steel and on the rough masonite.

Seasonal succession appeared to be the dominant force which controlled fouling in Monterey Harbor, and yet certain ecological successions also might be significant. (A prime example of the latter was the late bloom of the encrusting bryozoan, *Hippodiplosia insculpta*, which covered all previous foulers and whose appearance seemed strongly influenced by the presence or absence of phoronid worms.)

Temperature and salinity variations were not considered important factors in fouling attachment.

For further study, the following subjects are suggested: a more complete seasonal, yearly, and geographic record of the fouling community; a more detailed study of algae and of the "microfilm" which precede the settlement of the macrofouling organisms; and a study of the interrelationship of the members of the fouling community.

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13. ABSTRACT

Marine fouling organisms occurring on test panels of various substances and at several locations and depths in the Monterey Harbor, California, were studied for identification and significance.

Some panels were immersed for the entire length of the study--June 10 to September 16, 1966; others, mainly plywood, were immersed only for month-long periods throughout the study.

Barnacles, bryozoans, and serpulids were the major fouling organisms in the inner harbor, while hydroids were most significant in the outer harbor. The barnacles reached maximum attachment in June and July, but were covered later by bryozoans. Phoronid worms were abundant in August and September on the shallow panels in the inner harbor.

Fouling increased with depth and distance away from direct sunlight. Fibrous masonite and wood panels were the best collecting surfaces and stainless steel the worst.

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