A STUDY OF MARINE FOULING IN MONTEREY HARBOR

DURWARD BELMONT MOMMSEN, JR.

A STUDY OF MARINE FOULING

IN MONTEREY HARBOR

by

Durward Belmont Mommsen Jr.
Lieutenant, United States Navy
B.S., University of Wisconsin, 1959

[redacted]

Submitted in partial fulfillment
for the degree of

MASTER OF SCIENCE IN OCEANOGRAPHY

from the

UNITED STATES NAVAL POSTGRADUATE SCHOOL
May 1966

ABSTRACT

Observations were made on the marine fouling occuring on test panels in Monterey Harbor during the period January 26 to April 21, 1966. Test panels of various materials were placed at three depths. Observations were made on plywood panels exposed for four weeks, immersed at two week intervals, at just below the mean low tide level to determine the change in rate of attachment of fouling organisms during the test period. Observations were also made on the amount of fouling occuring on different test materials at the same depth and on the same test material at different depths.

The most important short-term fouling organisms in Monterey Harbor were found to be barnacles, bryozoa, serpulids and hydroids. The number of barnacles attaching to test panels reached a peak in early April and then declined. The amount of fouling on the test panels increased with depth. Wood was determined to be the best surface for collecting and observing marine fouling organisms.

TABLE OF CONTENTS

LIST OF TABLES

Table | | Page

LIST OF ILLUSTRATIONS

1. Introduction.

The primary objective of the research described in this paper was to determine the types of marine fouling organisms active in Monterey Harbor and how their intensity varies during the late winter and early spring. Numerous studies of this type made throughout the world show that marine fouling varies greatly with geographical location both in the types of fouling organisms present and in the intensity of their fouling. [6]

Several studies of marine fouling have been made along the West Coast of the United States. These include studies at Friday Harbor, Washington, [1] and in California at Oakland [3], Port Hueneme [10], La Jolla [2] and San Diego [10]. These studies have shown that each area has its own characteristic set of fouling organisms and its own seasonal variations.

As far as can be determined, no systematic study of marine fouling has previously been conducted in Monterey Harbor.

A secondary objective of this research was to show how the fouling in Monterey Harbor varies with depth and type of surface and to observe the growth and change of a fouling community on a test surface.

The site chosen for the study was at Monterey Municipal Wharf #2 about 1000 yards from the shoreline (see Figure 1). This site was selected both for its proximity to the marina and for its inaccessibility to the general public. The depth at the test site was 21 feet at mean low tide. No direct sunlight reached the test site due to the wharf over-head and the pilings on either side. However, due to the fact that the test site was located nearer one side of the wharf than the other, more light reached the test site from that direction than from any other.

The observation period was from January 26 to April 21, 1966.

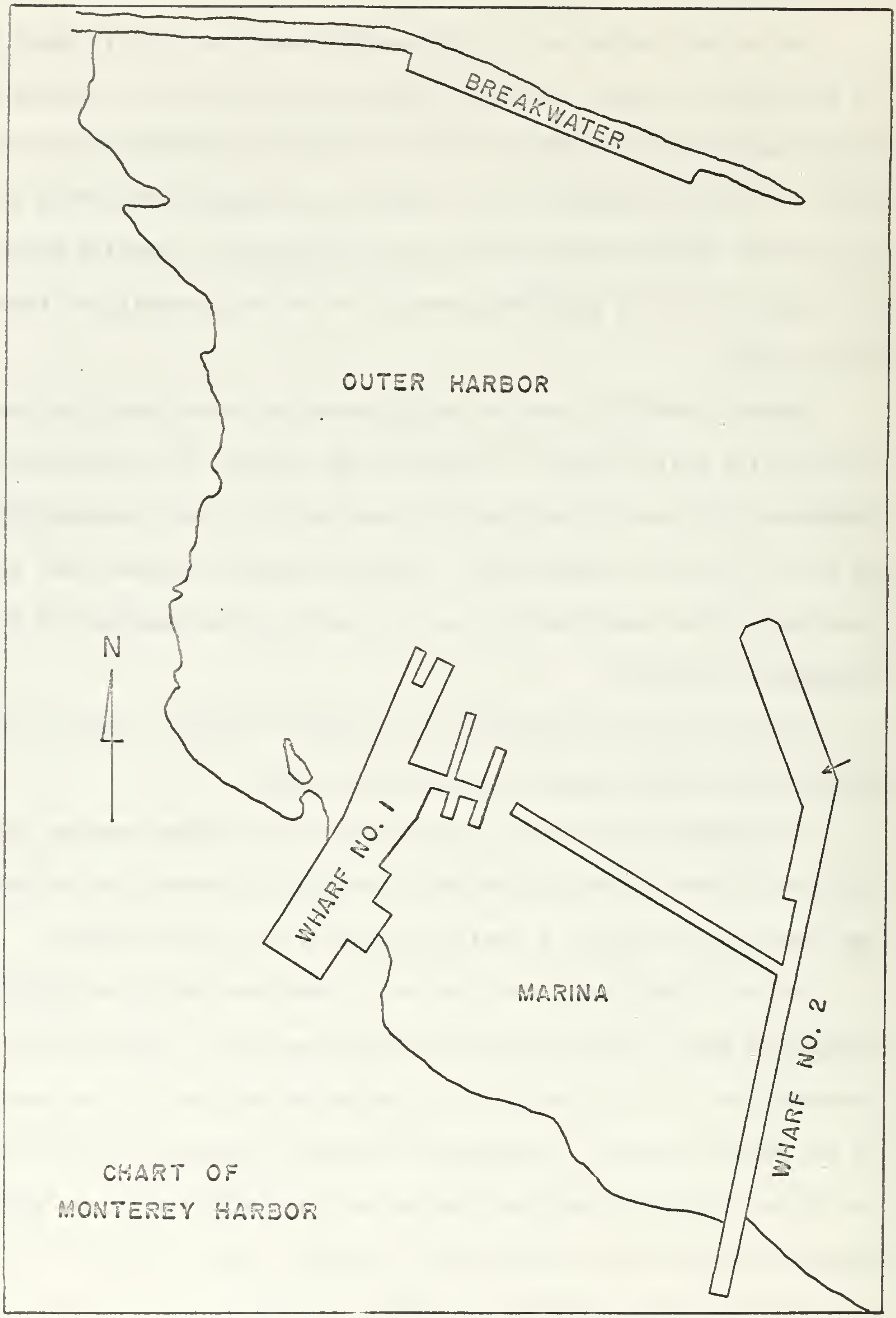

Figure 1. Location of Test Site (denoted by arrow).

2. Equipment.

Three racks were hung from a platform beneath the wharf. Two types of racks were used (see figure 2). Each rack held six 8X10 inch panels spaced at three inch intervals. The wood rack was made of pine and the metal racks of stainless steel. The wood rack was rigged for floating on the sea surface so that its test panels would always be at the water's surface with the upper edge of each panel about two inches above the waterline. Two metal racks were hung by 3/32 inch stainless steel cables to depths of one foot and 15 feet below mean low tide (see figure 3).

The following kinds of 8X10 inch test panels were used: marine plywood, fibreglass, glass, and stainless steel. The fibreglass panels were constructed by using 3/16 inch plywood as a backing with fibreglass on one side only and both sides of the plywood coated with resin. The marine plywood panels had no preservatives or other finishes applied. The surfaces of the glass and stainless steel panels were likewise unfinished.

Each metal rack was hung by two cables in order to restrict its movements. A 1/4 inch nylon line was also attached to each for use in raising and lowering the racks. The floating wood rack was secured to the platform by one 1/4 inch nylon line and to an adjacent piling by another similar nylon line with enough slack to account for the full range of the tide.

The floating rack contained a fibreglass and a plywood panel. It originally also contained a glass panel, but this was lost (presumably due to rough wave action) and was never replaced. The fibreglass and plywood panels were exposed for a period of 54 days from February 14 to April 9.

The shallow rack contained panels of glass, stainless steel

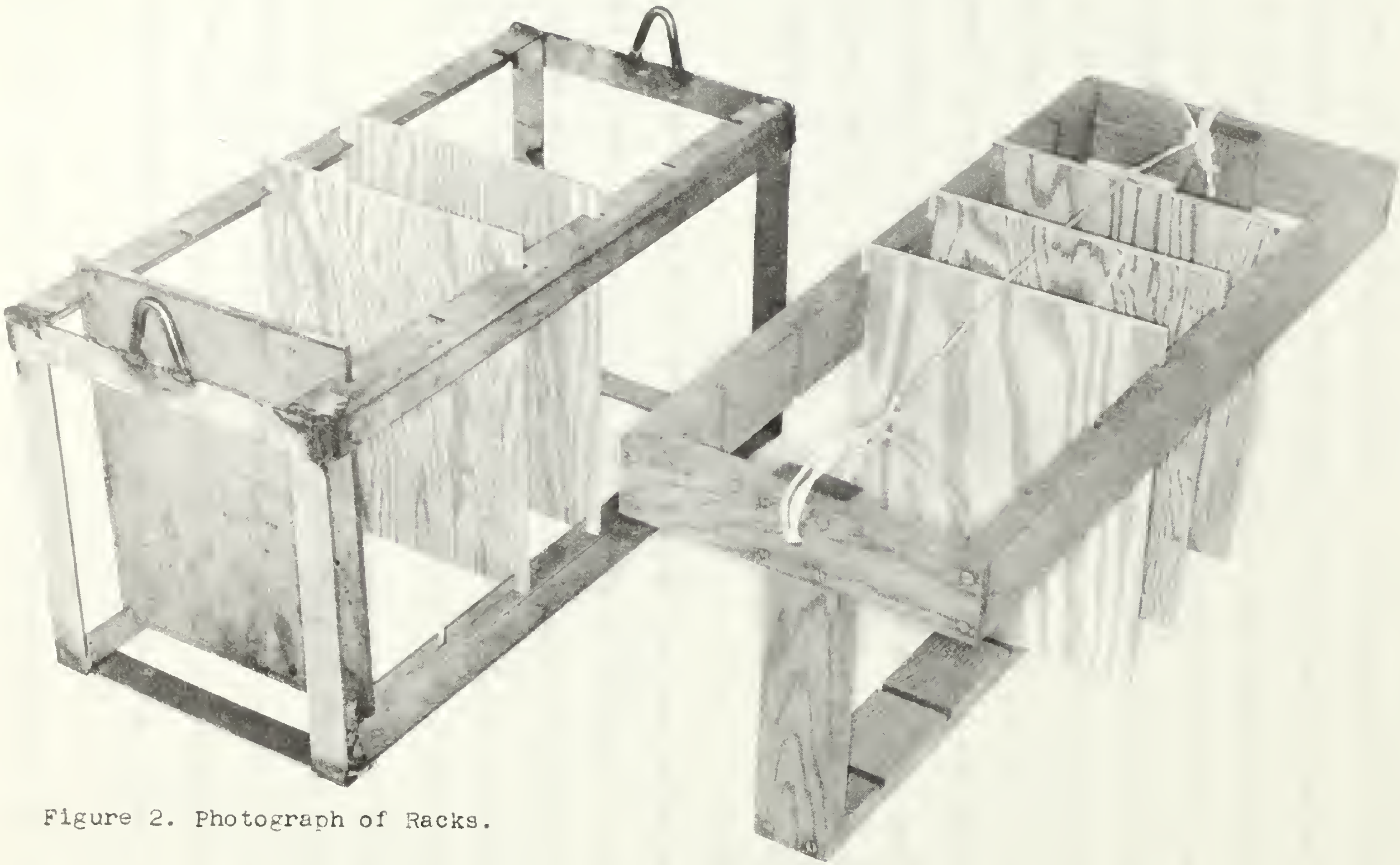

Figure 2. Photograph of Racks.

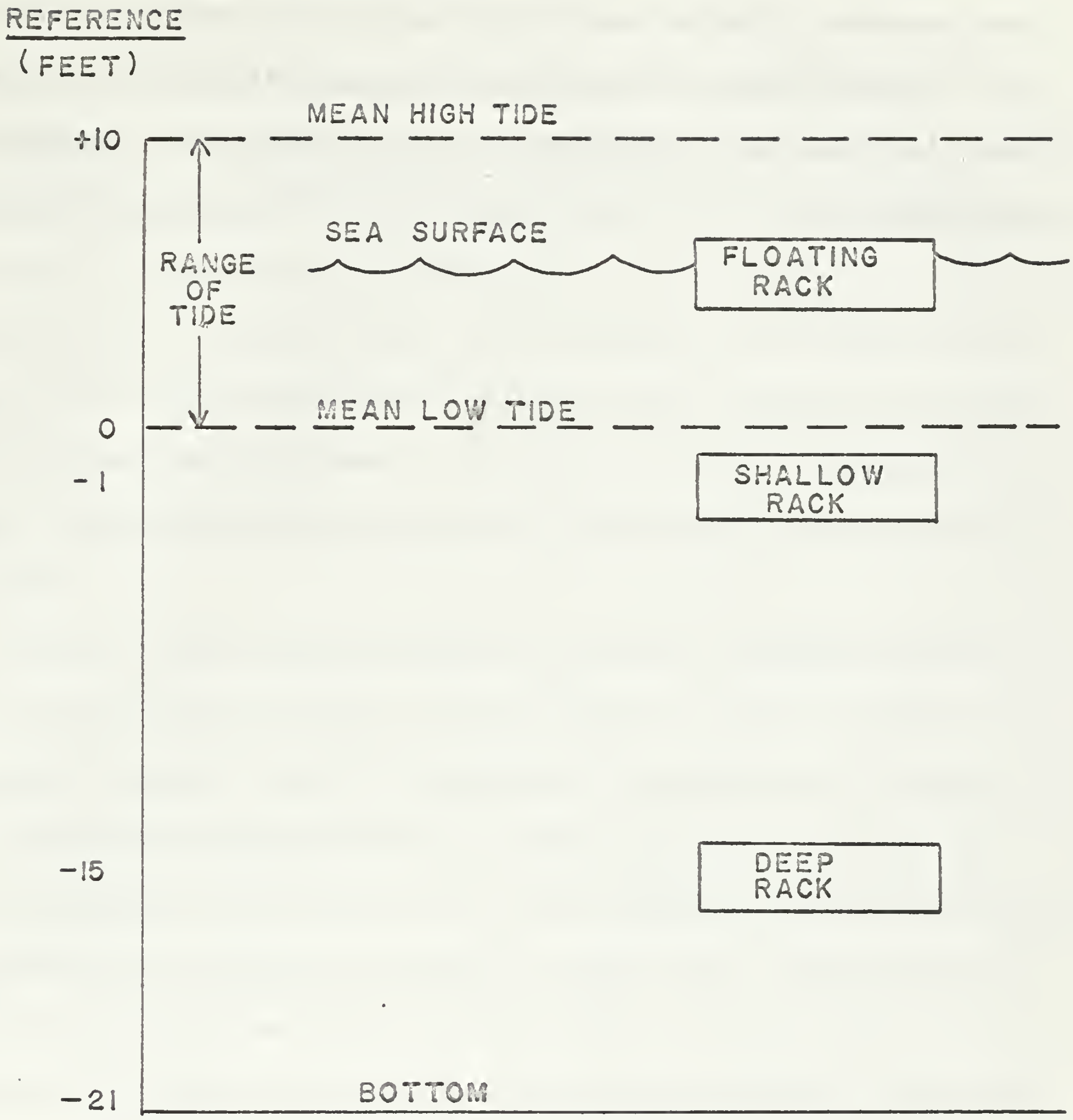

Figure 3. Relationship of Racks to Sea Surface.

and plywood exposed for a period of 55 days from February 14 to April 10. At any particular time this rack also contained two other plywood panels, one new panel being entered every two weeks and removed four weeks later.

The deep rack contained panels of glass, stainless steel, plywood and fibreglass, all exposed for a period of 57 days from February 14 to April 12.

3. Procedures.

In order to determine the change in the rate of attachment of the marine fouling organisms with time new plywood panels were exposed every two weeks during the test period and removed for examination after four weeks exposure. The examination of these panels was done in the biological oceanography laboratory at the U.S. Naval Postgraduate School using a binocular microscope. The panel was kept immersed in a pan of sea water during the examination. The surface of each side of the panel was scanned systematically and the name, size, and location of each organism was recorded on rectangular coordinate paper. The area covered by such organisms as hydroids was recorded and an indication of the density per square inch also noted.

The set of nine, long-term panels, which were exposed continuously for eight weeks, were examined after four weeks and again at the end of the exposure period. The first examination was conducted at the test site by binocular microscope with the panel immersed in a pan of sea water. Each panel was returned to its rack immediately after examination to assure that the organisms suffered no ill effects. Notes were made of the fouling organisms present on each panel. An area, 2-1/2 by 4 inches square, on the plywood panel in the shallow rack was sketched for comparison with the fouling organisms present in that area at the time of the final examination.

The final examination at the end of the eight-week period was conducted in the laboratory at the U.S. Naval Postgraduate School. A more detailed examination could be conducted at that time since the organisms did not have to be kept alive.

The surface water temperature at the test site was taken at two or three day intervals throughout the test period. Starting from March 1 the surface water salinity at the test site was also taken. The temperature of the surface water was determined with a standard Navy bucket thermometer and the salinity with a Kahlsico salinity hydrometer. The mean temperature and salinity was recorded for each week during the test period to give an indication of the change in water conditions at the test site during this period.

4. The Fouling Organisms.

It was possible, since the test panels were examined while immersed in sea water, to observe the fouling organisms *in situ*, thus making identification easier and allowing observation of the ecology of the fouling community.

Complete identification of all the fouling organisms was not attempted. The immaturity of most of the organisms made their identification difficult, if not impossible, and correct identification could be made only by an experienced biologist.

Many of the organisms discussed here are free-living and were not attached directly to the test panel, but when the panel was lifted from the sea and placed in a pail of sea water for transportation to the laboratory they remained with the panel. Therefore, it was assumed that they were closely associated with the life on the panel.

In some cases, such as the flatworm, the free-living organism prefers moving along a surface to swimming in the sea. [4] Some free-living organisms, such as nudibranchs, feed on the attached organisms. [8] Others, such as diatoms, are the food of the attached organisms. Since all of these free-living organisms have some influence on the attached organisms they were considered worth studying in a work on marine fouling.

The marine borer, *Limnoria lignorum*, is not properly considered a fouling organism, but it was found boring into wood panels examined after the first of April and is worth mentioning. The most found on a single panel was three. A seasonal variation in the abundance of these organisms was found at Friday Harbor, but it was present in some numbers all year round. [1] Since this was also true at Oakland [3], it is probably true in Monterey Harbor.

A listing of the fouling organisms observed may be found in Table 1.

TABLE 1

FOULING ORGANISMS RECORDED ON TEST PANELS IN MONTEREY HARBOR

Plants

Diatoms (unidentified)

Animals

Phylum Protozoa
- Foraminifera (unidentified)
- Colonial vorticellids (unidentified)
- *Folliculina* sp.

Phylum Porifera (Sponges)
- One species (unidentified)

Phylum Coelenterata - Class Hydrozoa
- *Obelia gracilis*

Phylum Platyhelminthes (Flatworms)
- *Leptoplana* sp.

Phylum Nemertea (Ribbon Worms)
- One species (unidentified)

Phylum Aschelminthes
- Nematodes (unidentified)

Phylum Annelida (Segmented Worms)
- *Nereis* sp.
- *Spirorbis* sp.
- Spionids (unidentified)

Phylum Arthropoda - Class Crustacea
- *Balanus glandula*
- *Balanus tintinnabulum*
- *Balanus crenatus*
- *Caprella* sp.
- Copepods (unidentified)
- Crabs (unidentified)
- Tube-building amphipods (unidentified)

TABLE 1 (continued)

Phylum Mollusca

- Snail (unidentified)
- Hermissenda crassicornis
- Eubranchus olivacea
- Corambe pacifica
- Mytilus edulis
- Pododesmus macroschisma
- Clams (unidentified)
- Pecten sp.

Phylum Bryozoa

- Barentsia gracilis
- Bugula neritina
- Hippothoa hyalina
- Hippodiplosia insculpta
- Membranipora membranacea
- Tubulipora sp.

Phylum Echinodermata

- Strongylocentrotus sp.

Phylum Chordata

- Two species of tunicates (unidentified)

Plants

Numerous diatoms were observed, but not identified. Masses of diatoms became attached to any projections on the test panel with the hydroids and erect bryozoa being the most frequent collectors.

No algae were observed. This is thought to be the result of the lack of direct sunlight at the test site. [5]

Animals

Many animals were observed and will be discussed by phyla.

Phylum Protozoa

Several unidentified species of foraminifera were observed. Many of the panels had collections of bluish green Folliculina that could be seen with the naked eye as patches of dark specks. All panels observed during April were covered with microscopic colonial vorticellids that recoiled when touched with a dissecting needle. They seemed to attach as readily to the smooth glass panels as to the wood panels.

Phylum Porifera (Sponges)

One species of sponge was found frequently on the long term panels. It belonged to the class Demospongiae, but could not be identified with the intertidal keys available.

Phylum Coelenterata - Class Hydrozoa

The hydroid, Obelia gracilis, was the most important fouling organism on the earlier panels, but as the season progressed only the remains of the stolons and vertical stalks could be found on the panels. Numerous nudibranchs were found on these panels and were apparently the cause of the hydroid demise. Other species of hydroids may have been present earlier in the season, but were not identified.

Phylum Platyhelminthes (Flatworms)

The flatworm, Leptoplana, was found on all but two of the panels and those two panels were those with the least amount of overall fouling.

Flatworms are sensitive to light and avoid it whenever possible. [4] The favorite hiding place of the flatworms on the test panels, which offer a relatively bare environment, was the inside of empty barnacle shells. Almost every empty barnacle shell of sufficient size could be observed to have a flatworm in it. Those flatworms not inside barnacles were most frequently seen lying along-side a living barnacle.

The mouth of a flatworm is about midway along the ventral surface of the worm and in some cases the flatworm could be seen draped over the barnacle with the flatworm's mouth over the opening of the barnacle. In all of these cases observed the barnacle was dead after the flatworm left it. No case was actually observed where the flatworm was able to approach a living barnacle without the barnacle closing up. But flatworms have been known to feed on barnacles [8], and several cases were observed where the flatworms did attempt to gain entry to a living barnacle. Perhaps it is just a matter of patience on the part of the flatworm (and the observer, if he wants to see it) for the flatworm to catch the barnacle unaware.

One panel, which had been exposed for one month, had 191 dead or empty barnacles out of a total of 238. Most of the empty barnacles were too small to offer hiding to the flatworms, but most of the larger empty barnacle shells had flatworms inside.

A few cases on other panels were observed where the barnacle itself lay dead outside its shell while a flatworm was inside.

Although the flatworms are apparently a factor in reducing the population of young barnacles, their affect on the barnacle population as a whole is probably small. It is possible that another organism not observed on the panel, such as a starfish, was responsible for eating the young barnacles.

Phylum Aschelminthes

This phylum includes the nematodes [7], which were numerous on all the panels observed. Nematodes were invariably found in the masses of diatoms and debris on the panels.

Phylum Nemertea (Ribbon Worms)

One species of nemertean worm was observed occasionally but not identified further. These are not considered of great importance in fouling. [6]

Phylum Annelida (Segmented Worms)

A few individuals of _Neries_ were found on the panels. These are known to build mucoid tubes [6], but none were observed.

Numerous tube-building spionids were found on the edges and in cracks in the panels. They appeared to need well protected crevices in order to build their tubes. The edges of the panels, which contained many holes and cracks, seemed to provide the optimum surface for this purpose.

The coiled calcareous tubes of _Spirorbis_ were one of the most frequently observed foulers. These were found on every one of the test panels. Three different tube designs and both sinistral and dextral coiling were observed. A few uncoiled serpulid tubes were also found.

Phylum Arthropoda - Class Crustacea

Copepods were numerous on all the test panels, but no attempt was made to further identify them. Their importance to the fouling community is questionable.

Several young crabs were observed, but not identified. Most of them were heavily covered with diatoms and debris and were difficult to distinguish from the other debris on the panels. They appeared to be eating the detritus attached to the hydroid remains.

Two species of tube-building amphipods became numerous late in the test period. They seemed able to build their tubes on a smooth surface, but preferred building in among crowded barnacles. During some years at San Diego these were found to be the most important summer fouling organism. [2] They undoubtedly would become more important in Monterey Harbor later in the year.

The skeleton shrimp, Caprella, was frequently observed waving back and forth on the remains of the hydroid stalks and on barnacle shells. One was observed attached to a debris-covered crab.

Barnacles were the most significant fouling organism on all but the first panel observed. Three species of barnacles were found. These were Balanus glandula, Balanus crenatus and Balanus tintinnabulum. B. crenatus was the most frequently observed barnacle on the deep and shallow panels, but B. glandula were dominant on the floating panels and numerous on the shallow panels. The most barnacles per panel were of B. crenatus on the deep panels, but the greatest crowding was found of B. glandula within a two inch band on the floating panels.

B. glandula is an intertidal barnacle that prefers periods of relative dryness. The only areas of the test panels used in this investigation that offered such an environment was the splash zone at the waterline of the floating panels and this is where the maximum concentration of this barnacle occurred. Several were also found on the shallow panels and one on a deep panel, but only the larger barnacles could be identified so their exact number could not be determined.

B. crenatus seemed to thrive on the constantly submerged panels and their concentration appeared to increase with depth, or at least to the depth at which this study was conducted.

The pink barnacle, *Balanus tintinnabulum*, was found on two panels in the shallow rack. There were 16 individuals on one side of the stainless steel panel and one individual on the side of the glass panel facing the stainless steel panel. None were found on any of the other test panels. This distribution is not believed to indicate a preference for the stainless steel surface, but rather a chance distribution of a few larvae in the water.

Those *B. tintinnabulum* that were found must have attached in February since they were already quite well developed by the first examination of the panels on March 15. The breeding season of *B. tintinnabulum* at La Jolla does not begin until the water temperature reaches 16 degrees Centigrade, usually in April. [2] If there is a similar temperature dependence in Monterey Harbor, there would not be a significant number of this larvae in the water until much later in the year. It is probable that panels exposed during the summer would pick up a much larger concentration of these barnacles since they are found frequently on pilings and rocks in the area. [9]

The largest barnacle found on the shallow panels after four weeks exposure measured 3.0mm in diameter. After eight weeks exposure the largest found were 5.0mm for *B. glandula*, 7.0mm for *B. crenatus*, and 9.0mm for *B. tintinnabulum.*

Phylum Mollusca

Three species of nudibranchs were found. These were *Hermisseda crassicornis*, *Eubranchus olivacea* and *Corambe pacifica*. *H. crassicornis* and E. olivacea were found on all except the first panel observed and were very likely the cause of the demise of the hydroids in the later panels. Only one individual of C. pacifica was observed and it was found on the lone colony of the bryozoan, Membranipora membranacea, observed on all the test panels. It's habitat is apparently limited to this particular species of bryozoan which it closely resembles by protective coloration. [7]

Only one species of snail was observed and it was found frequently on all but the first panel. It was not possible to identify this snail due to its small size.

Several kinds of pelecypods were observed on the test panels. The only one actually found attached was the rock oyster, Pododesmus macrochisma, which was found on the glass, fibreglass and plywood panels of the deep rack. This species is chiefly subtidal and in spite of its common name prefers pilings to rocks. [9] Several very young Mytilus edulis were observed, but none had yet become attached. They were very numerous in cracks of the plywood panels exposed for two months. Numerous unidentified clams and one Pecten were observed.

Phylum Bryozoa

Circular colonies of encrusting bryozoa were numerous on almost all of the panels observed. They were found least on the floating panels where they were located only on the most deeply submerged part of the panel.

The species of encrusting bryozoa identified were Hippothoa hyalina, Hippodiplosia insculpta, Membranipora membranacea and Tubulipora sp. The distribution of these bryozoa was interesting and will be discussed later. Only one colony of Membranipora was found, but it was the largest of all the bryozoan colonies observed, measuring 26mm in diameter.

Other than the one colony of _Membranipora_ the largest encrusting bryozoan colony found was 11.5mm in diameter. The largest colony found after four weeks exposure was 4.5mm.

Erect bryozoa were frequent on the later panels. The two species identified were _Barentsia gracilis_ and _Bugula neritina_.

Phylum Echinodermata

A few young individuals of the sea urchin, _Strongylocentrotus_, were found on the panels throughout the test period. These measured about 0.5mm in diameter.

Phylum Chordata

Two species of tunicates were observed, but not identified. These tunicates were observed on panels exposed for two months and although they were insignificant in the fouling community at that time, they might have become more important with a longer exposure time.

5. Factors Affecting The Intensity of Fouling.

Six factors were observed to influence the intensity of organisms attaching to the test panels. These factors were length of exposure, season of exposure, type of surface, depth, light and edge effect.

Length of Exposure

In all cases, as can be seen by comparison of Tables 2 and 3, the intensity of the fouling increased with time. The fouling on a 2-1/2 by 4 inch area of the plywood panel in the shallow rack was sketched after 29 days exposure (see Figure 4) and again after 55 days exposure (see Figure 5). It is not difficult to visualize the chronological events that took place on this area of the panel. Within a few days after exposure about six barnacle cyprids landed on the area, attached and began developing into the adult form of barnacle. A couple days later two more attached. After about two weeks hydroids began coming into the area from the edge of the panel. A serpulid came into the area and began secreting its calcareous tube. About the third week eleven new barnacles became attached. Sometime just after the fourth week a bryozoan colony began forming and a barnacle was killed in the center of the area. A few more barnacles attached during the fifth week, but some of the other barnacles were killed. Three more bryozoans began colonies and more serpulids were building their tubes on the area. Some of the barnacles were growing faster than others. Sponges were beginning to appear in the area. By the sixth week the hydroids had reached their maximum growth and were being eaten by nudibranchs coming through the area. Some amphipods built their tubes along-side one of the larger barnacles. Another barnacle was killed and a flatworm took up residence inside. More barnacles became attached during the seventh week and two more of

TABLE 2

RESULTS OF FIRST OBSERVATION ON LONG-TERM PANELS

(Amount of barnacles and serpulids indicated by number of individuals, bryozoa by colonies, and hydroids by square inches of surface area covered.)

FLOATING RACK (29 Days exposure)

	Fibreglass	Wood
Barnacles	131	39
Serpulids	1	2
Bryozoa	0	0
Hydroids	2	3

SHALLOW RACK (29 Days exposure)

	Stainless Steel	Glass	Wood
Barnacles	23	68	82
Serpulids	15	0	27
Bryozoa	1	6	3
Hydroids	2	4	7

DEEP RACK (29 Days exposure)

	Stainless Steel	Fibreglass	Glass	Wood
Barnacles	10	41	200	112
Serpulids	21	15	8	45
Bryozoa				5
Hydroids	2	0	2	1

TABLE 3

RESULTS OF FINAL OBSERVATION ON LONG-TERM PANELS

(Amount of barnacles and serpulids indicated by number of individuals, bryozoa by colonies, and hydroids by square inches of surface area covered.)

FLOATING RACK (54 Days exposure)

	Fibreglass	Wood
Barnacles	1175	1050
Serpulids	2	5
Bryozoa	20	10
Hydroids	5	9

SHALLOW RACK (55 Days exposure)

	Stainless Steel	Glass	Wood
Barnacles	96	551	575
Serpulids	40	26	36
Bryozoa	152	173	158
Hydroids	0	0	0

DEEP RACK (57 Days exposure)

	Stainless Steel	Fibreglass	Glass	Wood
Barnacles	28	5840	6960	4240
Serpulids	74	132	55	73
Bryozoa	77	292	173	331
Hydroids	2	0	0	0

Figure 4. Fouling after 29 Days.

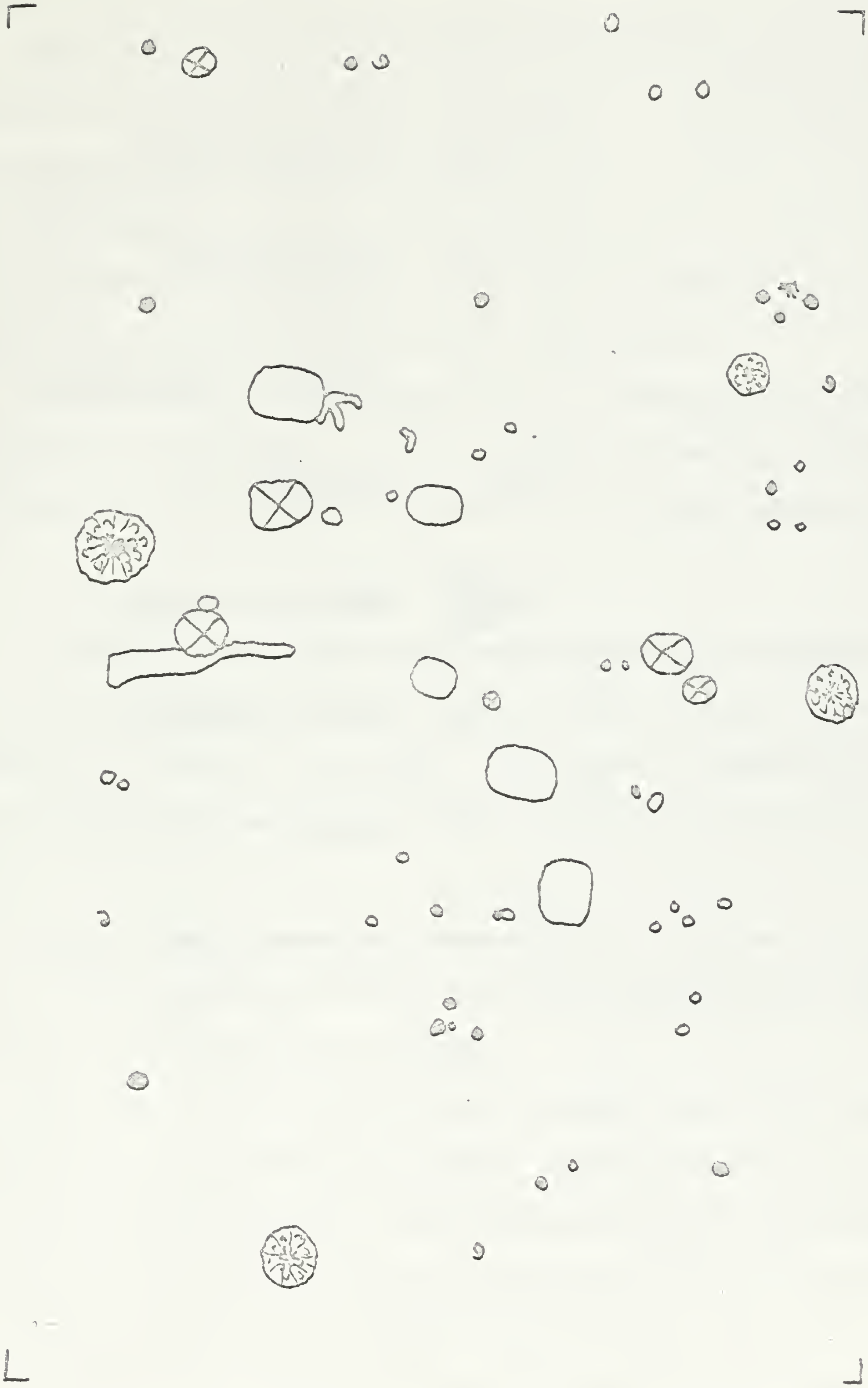

Figure 5. Fouling after 55 Days.

Key to Figures 4 and 5.

 Living barnacle

 Dead barnacle

 Serpulid (*Spirorbis*)

 Hydroid

 Bryozoan colony

 Erect bryozoan

 Sponge

 Tube-building amphipod

the larger barnacles were killed. The hydroids were by now reduced to decaying remains. By the eighth week the area appeared as shown in Figure 5.

There were some indications that with increased exposure time there would be a new dominant organism on the panels. After two months exposure the barnacles were definitely the dominant fouling organism, but already many of the encrusting bryozoan colonies were spreading over the barnacles. The tunicates or the mussels could also become dominant [6], although there was no indication of this in the present study.

Another effect of an increased length of exposure is that even with no increase in the number of fouling organisms the amount of fouling will increase due to the growth of the individual organisms themselves.

Season of Exposure

A series of five plywood panels were exposed in the shallow rack during the late winter and early spring as shown in Figure 6. Each was exposed for a period of four weeks. The changes in abundance of the major fouling organisms attaching during the test period are shown in Figure 7.

As can be seen, the serpulids and bryozoa on each panel increased as the season progressed, whereas the hydroids decreased after being the dominant fouling organisms in February.

The number of barnacles per panel increased from a low of three in February to a high of 238 in early April and then dropped to 21 on the last panel observed in April. This indicates that there was a maximum of barnacle larvae in the water in late March and early April and that the number of these larvae decreased greatly during April.

Similar peaks of barnacle attachment have been found in Puget Sound [illegible] and in San Francisco [illegible]

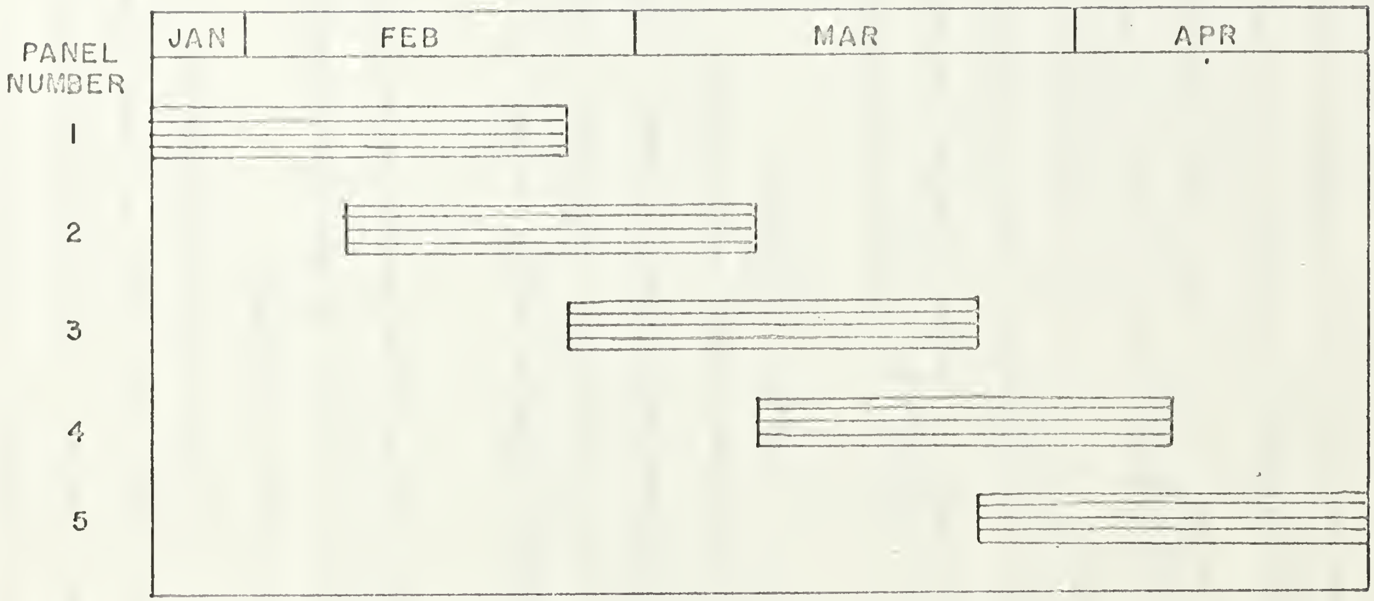

Figure 6. Times of Exposure of Short-term Panels.

Figure 7. Variation of Major Fouling Organisms with Time. (Amount of barnacles and serpulids indicated by individuals, bryozoa by colonies, and hydroids by square inches of surface area covered)

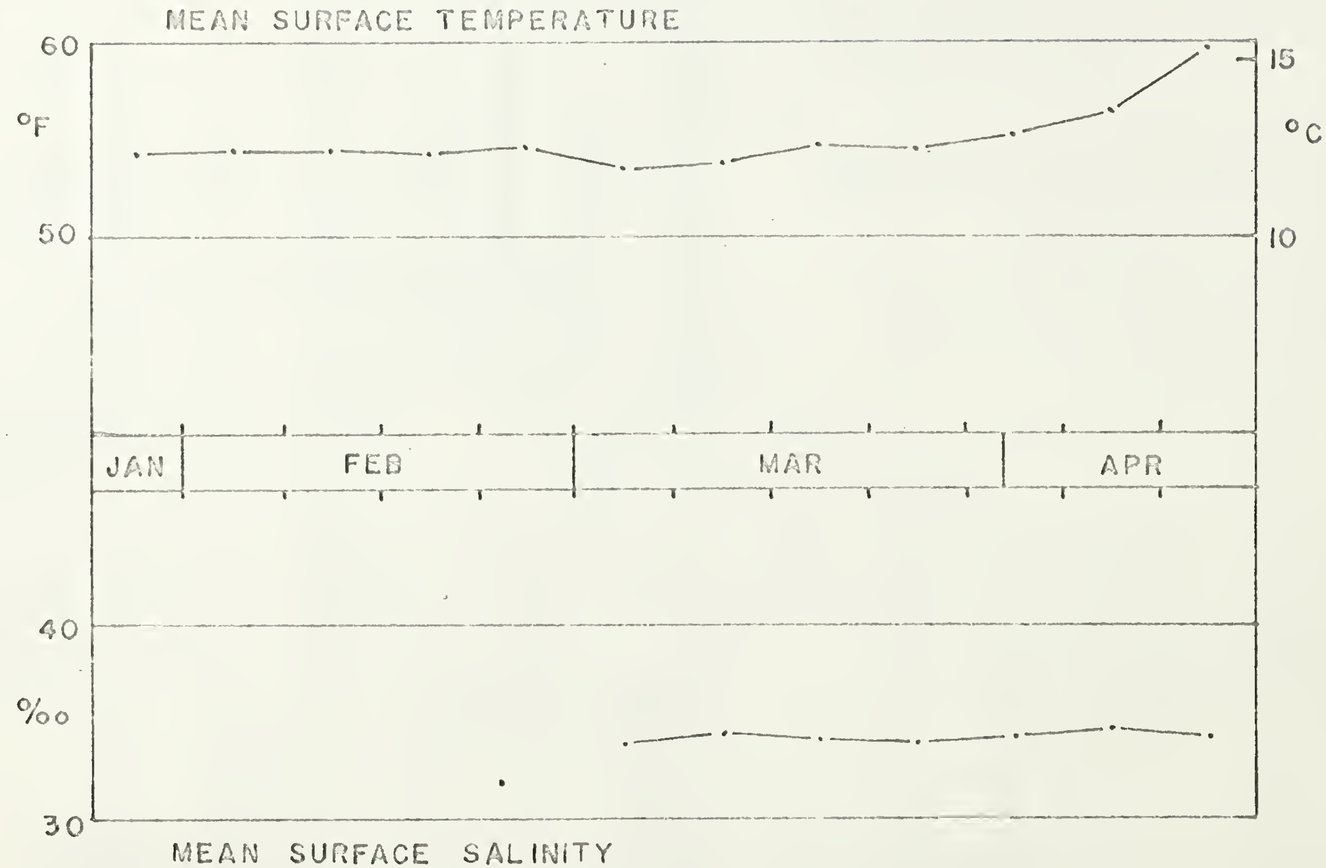

Figure 8. Weekly Mean Temperatures and Salinities.

in May and in San Francisco Bay in April 3 . The peak in Puget Sound was due to Balanus glandula, whereas the peak in San Francisco Bay was due to Balanus improvisus.

It would be interesting to know if the peak in Monterey Harbor represents the maximum abundance of one species of barnacle and, if so, whether there is a peak for the other barnacel species in Monterey Harbor. It was impossible to distinguish between the young of Balanus glandula and Balanus crenatus on the shallow panels, but a time series of panels placed at an intertidal level would pick up predominantly B. glandula and, at the depth of the deep rack, predominantly B. crenatus and thus their time of maximum attachments could be determined.

The weekly mean surface temperatures and salinities during the test period are shown in Figure 8. No apparent correlation with the amount of fouling can be observed during this time period. Most of the organisms seem to have increased in abundance during the period of relatively constant temperature and salinity while the hydroids decreased before the temperature began to rise in April. The peak of barnacle abundance also preceded the rise in water temperature.

A nine year study at La Jolla showed a difference in the seasonal variation of the fouling organisms from year to year 2 . Therefore, observations over several years would probably be necessary to get an adequate picture of the seasonal variation in Monterey Harbor.

Type of Surface

At the time the present study was initiated it was felt that the use of several different surfaces would pick up a more complete set of fouling organisms and also give some insight into the conditions necessary for the attachment of particular organisms. It was not the purpose of this study to test antifouling compounds or surfaces, therefore no antifouling preparations were applied to the panels.

Glass and wood have been used frequently in other studies to collect fouling organisms. [1,2,3,5] Fibreglass and stainless steel were added to give a wider variety of surfaces.

The results of the fouling observed on the nine long-term panels after eight weeks exposure can be seen in Table 3.

No significant differences can be seen of the amount of fouling on the fibreglass and plywood panels in the floating rack. A comparison of the fibreglass and plywood panels in the deep rack shows a slight preference of Balanus crenatus and Spirorbis for the fibreglass surface.

A comparison of the two sides of the fibreglass panels was not possible due to the effect of light which will be discussed later.

The glass and plywood panels showed no significant differences in their fouling at the shallow depth, but at the deeper depth glass accumulated more barnacles and less bryozoa than did plywood.

Since the glass panel in the floating rack was lost before observations were made, glass and fibreglass can be compared only in the deep rack. The glass panel at this depth picked up more barnacles, but the fibreglass panel picked up the greater number of serpulids and bryozoa.

The stainless steel panels showed a significant resistance to fouling compared to the other panels. The difference in barnacle fouling between the stainless steel panel and other panels in the deep rack was especially striking. However, the stainless steel was comparible to plywood in the number of serpulids attached and, in the shallow rack, showed comparable numbers of bryozoan colonies to that of plywood and glass. The stainless steel panel in the deep rack showed hydroid fouling that was not observed on the other panels after two months exposure.

As far as can be determined, there is nothing in stainless steel that is toxic to marine organisms and stainless steel is considered to be in the group of metals which are most likely to foul. [6] Therefore, it must be the character of the stainless steel surface itself that causes less barnacle fouling than the glass surface yet permits serpulids to attach as readily to one as to the other. It may be a difference in the mechanism of attachment of these organisms that affects their ability to attach to the stainless steel surface.

Glass panels have frequently been used to collect fouling organisms when the investigator intends to scrape off the organisms for volume determination. However, for <u>in situ</u> observation and identification of the organisms, wood is the most desirable panel material. It is much easier than glass to examine under the binocular microscope and it is more rugged and inexpensive. Another advantage is that it can also be used to collect marine borers.

Depth

Because of the length of time required to make the final observation of each of the long-term panels it was not possible to examine them all on the same day. Instead, the panels in each rack were examined on a different day. The floating panels were examined after 54 days exposure, the shallow panels after 55 days exposure and the deep panels after 57 days exposure. Since it appeared that very few of the attached organisms could have been attached less than three days, it is assumed that a three day period would not make any significant change in the intensity of the fouling accumulated over a two month period. Therefore, valid assumptions can be made about the fouling at various depths using the data in Table 3. Care must be taken, however, not to make direct comparisons of the number of individual fouling organisms found on the panels in the floating rack and those of the other racks since only about six inches of the floating rack panels were below the waterline.

The intensity of *Spirorbis*, tube-building amphipods, and the one species of sponge observed appeared to increase with depth at the test site. Additional racks placed at intermediate depths would be necessary to determine the exact depths of maximum abundance of these organisms. It may also be that their vertical distribution varies with time depending on the water circulation.

Balanus glandula and possibly the hydroids appeared to be the only fouling organisms decreasing with depth.

The vertical distribution of the barnacles shows two maxima, one at the surface due to *Balanus glandula* and one at depth due to *Balanus crenatus*. At Friday Harbor the maximum abundance of *B. glandula* was found to be at 6.3 feet above mean lower low water [1], but the depth of maximum abundance of this barnacle in Monterey Harbor could not be determined from the three depths considered. This species of barnacle was rarely found on submerged panels at San Diego. [2]

The vertical distribution of the bryozoa depended on the species considered (see Table 4). All species were at a minimum on the floating panels, but *Tubulipora* was far more abundant at the deeper depth while the abundance of *Hippothoa hyalina* and *Hippodiplosia insculpta* varied little between the shallow and deep racks.

The rock oyster, *Pododesmus*, was found only on the deep panels.

Taken as a whole, without regard to type of organism, the amount of fouling was found to increase with depth.

TABLE 4

VERTICAL DISTRIBUTION OF BRYOZOAN SPECIES

	Plywood Panels		
	Floating	Shallow	Deep
Hippothoa hyalina	1	17	21
Hippodiplosia insculpta	4	63	59
Tubulipora sp.	5	75	273

Light

Almost all fouling organisms are negatively phototropic at the time of their attachment. [6] Therefore, if a panel is illuminated more from one side than from the other, there is a tendancy for the fouling organisms to attach more frequently to the shaded side of the panel.

The location of the test site was such that the most illumination was from the southeast, causing the east side of the shallow and deep panels and the south side of the floating panels to be illuminated more. Other factors, however, reduced this light effect. The depth of the deep rack was such that light probably had very little effect on the attachment of fouling organisms. This was borne out by the fact that the intensity of fouling on both sides of the panels were about equal at that depth.

The west side of the plywood and stainless steel shallow panels did usually show an increased amount of fouling over the east side. The 16 *Balanus tintinnabulum* that were found on the stainless steel panel were all on the shaded side. An indication that the increased fouling on the west side was due to light was that the glass panel, which was transparent to light, had about an equal amount of fouling on each side. The light effect on all these panels was probably reduced, however, by the panels being only three inches apart and each shading the panel to the west of it.

The north side of the floating panels had a much larger number of barnacles than the south side.

The most important effect of light in this investigation was undoubtedly the absence of algae due to the lack of direct sunlight at the test site.

Edge Effect

Most of the fouling organisms recorded showed no preference for any particular position on the panel. There was, however, a few notable exceptions.

The few Limnoria observed were boring into the edge of the panels. This observation was also made in the study at Oakland. [3]

All of the hydroid fouling on the panels began at the edge and spread inward and the tube-building spionids showed a preference to build their tubes on the edges of the panels.

But the most interesting example of the edge effect was on the distribution of the encrusting bryozoan, Hippothoa hyalina. On one panel, which was exposed for four weeks in the shallow rack, 30 colonies of H. hyalina were observed. Of these, 26 were found within one inch of the edge of the panel and 24 within a half inch of the edge. The half inch band at the edge of the panel represents less than 22 percent of the total surface area available for attachment, yet 80 percent of these colonies were attached there.

This preference for the edge can probably be explained by the fact that the panels were spaced three inches apart and, with panels on either side, it made the center of the panel less accessible to the larvae than the edges. But no such preference for the edge was noted in the case of Hippodiplosia insculpta. In fact, of the eight colonies of H. insculpta observed on the above panel, none were within an inch of the edge. A similar distribution of these two species of bryozoa was noted on the other test panels, but no exact records of their positions were kept.

6. Conclusions.

The fouling organisms present at the test site during the period January 26 to April 21, 1966, were those as listed in Table 1.

Factors important in determining the type or intensity of the fouling were length and season of exposure, type of surface, depth, light and edge effect.

Hydroids were the dominant fouling organism attaching during the late winter, but barnacles were dominant during the spring. Other important fouling organisms were serpulid worms and bryozoa.

The marine borer, Limnoria lignorum, was found on wood panels in April.

A maximum abundance of barnacle larvae was present in Monterey Harbor in early April 1966 after which the number of larvae decreased.

The amount of fouling in Monterey Harbor increases with depth.

Plywood is the best material for collecting and observing marine fouling and boring organisms. Stainless steel fouls the least of those materials tested.

No correlation of temperature or salinity with the intensity of fouling during the test period could be determined.

Although flatworms are apparently a factor in reducing the population of young barnacles, it is felt that their effect on the barnacle population as a whole is small.

Subjects which can bear further study are the complete annual variation of important fouling organisms in Monterey Harbor, the seasonal and vertical variation of the different barnacle species, a comparison of the fouling in the marina with that in the outer harbor, the distribution of the various species of encrusting bryozoa and serpulids, and the effect of flatworms on a young barnacle population.

7. Acknowledgments.

The encouragement and assistance of Dr. Eugene C. Haderlie during this investigation is gratefully acknowledged. Thanks are due to Commander Donald A. Still, U.S. Navy, for his assistance in providing use of the facilities and much of the equipment.

BIBLIOGRAPHY

1. Johnson, M.W. and R.C. Miller. The Seasonal Settlement of Shipworms, Barnacles, and Other Wharf-pile Organisms at Friday Harbor, Washington. Univ. Wash. Publ. Oceanogr. v. 2, No. 1, March 1935: 1-18.
   A ten year study using wooden blocks.

2. Coe, W.R. and W.E. Allen. Growth of Sedentary Marine Organisms on Experimental Blocks and Plates for Nine Successive Years at the Pier of the Scripps Institution of Oceanography. Bull. Scripps Inst. Oceanogr. tech. ser. v. 4:4, 1937: 101-136.
   A nine year study using cement blocks and glass plates.

3. Graham, H.W. and H. Gay. Season of Attachment and Growth of Sedentary Marine Organisms at Oakland, California. Ecol. 26:4, October 1945: 375-386.
   A fourteen month study using wood panels.

4. Buchsbaum, R. Animals Without Backbones. Univ. of Chicago Press. 1948.
   Contains good discussion on flatworms.

5. Weiss, C.M. The Seasonal Occurance of Sedentary Marine Organisms in Biscayne Bay, Florida. Ecol. V. 29:2, April, 1948: 153-172.
   A four year study using glass panels.

6. Woods Hole Oceanographic Institution. Marine Fouling and Its Prevention. U.S. Naval Institute. 1952
   A basic text on all phases of marine fouling, includes an extensive bibliography up through 1952.

7. Light, S.V. rev. by R.I. Smith, F.A. Pitelka, D.P. Abbott and F.M. Weesner. Intertidal Invertebrates of the Central California Coast. Univ. of Calif. Press. 1954.
   Necessary for identification of marine organisms in this area.

8. Hedgepeth, J.W. Introduction to Seashore Life. Univ. of Calif. Press. 1962.
   Contains discussions of most common marine organisms along California coast.

9. Ricketts, E.F. and J. Calvin, rev. by J.W. Hedgepeth. Between Pacific Tides. Stanford Univ. Press. 1962.
   Contains numerous pictures of marine organisms and a section on wharf-pile organisms.

10. Drisko, R.W. Protection of Mooring Buoys Part III Second Rating Inspection. U.S. Naval Civil Eng. Lab. tech. rep. R-291, 1964.
    Contains lists of fouling organisms collected on test panels at Port Hueneme and San Diego.

INITIAL DISTRIBUTION LIST

		No. Copies
1.	Defense Documentation Center Cameron Station Alexandria, Virginia 22314	20
2.	Library U.S. Naval Postgraduate School Monterey, California 93940	2
3.	Dept. of Meteorology & Oceanography U.S. Naval Postgraduate School Monterey, California 93940	1
4.	Prof. Eugene C. Haderlie Dept. of Meteorology & Oceanography U.S. Naval Postgraduate School Monterey, California 93940	1
5.	LT Durward B. Mommsen Jr., USN 20 E. Humbird St. Rice Lake, Wisconsin 54868	1
6.	Commanding Officer and Director Naval Electronics Laboratory Attn: Code 2230 San Diego, California 92152	1
7.	Environmental Sciences Service Administration U.S. Department of Commerce Washington, D.C.	2
8.	U.S. Naval Oceanographic Office Attn: Division of Oceanography Washington, D.C. 20390	1
9.	Superintendent United States Naval Academy Annapolis, Maryland 21402	1
10.	Office of Naval Research Attn: Biology Branch (Code 446) Department of the Navy Washington, D.C. 20360	1
11.	Director Woods Hole Oceanographic Institution Woods Hole, Massachusetts 02543	1
12.	Dr. James S. Muraoka Materials Division U.S. Naval Civil Engineering Laboratory Port Hueneme, California 93041	1

13. Director 1
Scripps Institution of Oceanography
University of California, San Diego
La Jolla, California

14. Chairman, Department of Oceanography 1
Oregon State University
Corvallis, Oregon 97331

15. Executive Officer 1
Department of Oceanography
University of Washington
Seattle, Washington 98105

Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)* Environmental Sciences Programs U.S. Naval Postgraduate School Monterey, California	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE

A Study of Marine Fouling in Monterey Harbor

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

Thesis

5. AUTHOR(S) *(Last name, first name, initial)*

MOMMSEN, Durward B. Jr.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
May 1966	47	10

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)
b. PROJECT NO.	
c.	9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*
d.	

10. AVAILABILITY/LIMITATION NOTICES

This document has been approved for public release and sale; its distribution is unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	U.S. Naval Oceanographic Office Washington, D.C. 20025

13. ABSTRACT

Observations were made on the marine fouling occuring on test panels in Monterey Harbor during the period January 26 to April 21, 1966. Test panels of various materials were placed at three depths. Observations were made on plywood panels exposed for four weeks, immersed at two week intervals, at just below the mean low tide level to determine the change in rate of attachment of fouling organisms during the test period. Observations were also made on the amount of fouling occuring on different test materials at the same depth and on the same test material at different depths.

The most important short-term fouling organisms in Monterey Harbor were found to be barnacles, bryozoa, serpulids and hydroids. The number of barnacles attaching to test panels reached a peak in early April and then declined. The amount of fouling on the test panels increased with depth. Wood was determined to be the best surface for collecting and observing marine fouling organisms.

DD FORM 1 JAN 64 1473

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Marine fouling						
Fouling						
Biology						

INSTRUCTIONS

1. ORIGINATING ACTIVITY: Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization *(corporate author)* issuing the report.

2*a*. REPORT SECURITY CLASSIFICATION: Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.

2*b*. GROUP: Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.

3. REPORT TITLE: Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all capitals in parenthesis immediately following the title.

4. DESCRIPTIVE NOTES: If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.

5. AUTHOR(S): Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.

6. REPORT DATE: Enter the date of the report as day, month, year; or month, year. If more than one date appears on the report, use date of publication.

7*a*. TOTAL NUMBER OF PAGES: The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7*b*. NUMBER OF REFERENCES: Enter the total number of references cited in the report.

8*a*. CONTRACT OR GRANT NUMBER: If appropriate, enter the applicable number of the contract or grant under which the report was written.

8*b*, 8*c*, & 8*d*. PROJECT NUMBER: Enter the appropriate military department identification, such as project number, subproject number, system numbers, task number, etc.

9*a*. ORIGINATOR'S REPORT NUMBER(S): Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.

9*b*. OTHER REPORT NUMBER(S): If the report has been assigned any other report numbers *(either by the originator or by the sponsor)*, also enter this number(s).

10. AVAILABILITY/LIMITATION NOTICES: Enter any limitations on further dissemination of the report, other than those imposed by security classification, using standard statements such as:

(1) "Qualified requesters may obtain copies of this report from DDC."

(2) "Foreign announcement and dissemination of this report by DDC is not authorized."

(3) "U. S. Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through
____."

(4) "U. S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through
____."

(5) "All distribution of this report is controlled. Qualified DDC users shall request through
____."

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

11. SUPPLEMENTARY NOTES: Use for additional explanatory notes.

12. SPONSORING MILITARY ACTIVITY: Enter the name of the departmental project office or laboratory sponsoring *(paying for)* the research and development. Include address.

13. ABSTRACT: Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as *(TS)*, *(S)*, *(C)*, or *(U)*.

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. KEY WORDS: Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, roles, and weights is optional.

DD FORM 1 JAN 64 1473 (BACK)