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Fouling Organisms in Hawaii

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INTRODUCTION

This report on fouling organisms is based primarily upon investigations in Kaneohe Bay, Oahu, which were initiated by C. H. Edmondson in March 1935 and are still in progress. In September 1935, W. M. Ingram began a parallel two-year study of such organisms in Kaneohe Bay and Pearl Harbor. However, the Pearl Harbor station was abandoned after one year because of unsuitable conditions. Studies were then centered in the Kaneohe Bay area, supplemented by casual observations in other localities. Brief preliminary statements on the progress of these investigations were made in 1937 by Edmondson in a published report (13)[1] and by Ingram in an unpublished thesis (19). The present account brings together the most important data and results collected over a period of three years.

The windward shore of Oahu was selected for these studies because most previous observations had been made on the leeward shore, in Pearl Harbor and Honolulu Harbor. The field work was done at the end of a pier extending about 400 yards out from the shore of the Territorial Fish and Game Farm in Kaneohe Bay, a potential harbor on the northeast coast. Here the bottom is muddy and sandy with some outcropping of coral rocks nearby. The water in this general area is about one fathom deep at high tide while a dredged chan-

[1] The numbers in parentheses refer to the Bibliography (p. 290).

nel near the end of the pier increases the depth by several feet, thereby enhancing the value of the locality for experimental purposes. The station is sufficiently isolated to assure a minimum degree of disturbance by marauders which is a factor of no little importance to long-time records.

The primary purpose of the investigations was biological. Special attention was given to the kinds and species of fouling organisms, their seasonal succession, and ecology. Early developmental stages were observed as far as possible, and the rate of growth under varied conditions recorded. Consideration was also given to various experimental and artificial means of preventing or at least discouraging the attachment of sedentary organisms. Methods employed included the use of panels of wood, metal, glass, and composition materials, floated on the surface or suspended in the water to serve as cultch for the organisms. "Masonite" was used extensively, and "Wolmanized" wood was tested for its ability to repel organisms when submerged in sea water. At intervals the panels were lifted temporarily for observation and measurement of affixed forms, or were removed permanently to be photographed and studied more completely.

To study normal fouling the surfaces of panels were untreated. Many non-toxic paints and coatings were utilized to determine the effect of different colors on the settling and attachment of sessile forms. To some of the cheaper non-toxic commercial paints various poisonous chemicals were added, singly or in combination, in order to note the tendency of such mixtures to hinder fouling. Numerous paints recommended by manufacturers as having antifouling properties were tested for their relative efficiency.

Larvae and adults of certain sessile organisms were subjected to laboratory experiments involving desiccation, resistance to dilute sea water and to range of temperature, and their relative capacity to survive when exposed to various toxic agents.

From the earliest period of navigation seafarers have had to contend with conditions similar to those which cause immense economic loss to the shipping industry of today. An early method employed to protect the wooden hulls of ships from sedentary organisms was to sheath the under surfaces with lead fastened by copper nails, or otherwise provide false external bottoms, which when heavily fouled could be removed and replaced. On the introduction of ships with metal hulls, external sheathing became impracticable and an attempt was made to prevent the attachment of organisms by coating the surfaces exposed to sea water with poisonous paints or other toxic preparations. This led to the manufacture of many substances recommended as repellents of marine organisms. Visscher (32) records that Young of England found more than 300 patents had been issued in that country prior to 1867 for antifouling coatings, and Gardner (14) reports that more than 160 such patents had been granted in the United States previous to 1922. The ingredients of these preparations range from garlic to tobacco juice and from arsenic to mercury.

While attempts to discourage fouling have been almost wholly confined to rendering under-water surfaces obnoxious to sedentary organisms, recent biological investigations of the organisms themselves have added valuable information toward a fuller knowledge of the problem if not toward its solution. Studies of the early development, the life cycle, the rate of growth and other biological phases of fouling organisms have contributed much toward an understanding of their behavior both before and after the time of attachment. Such investigations have been conducted in many parts of the world. Data are recorded for European waters by Orton (28), Neu (27), Moore (24, 25), Bassindale (7) and others. On the Atlantic coast of the United States, contributions have been made by Parker (29), Visscher (32, 33), Visscher and Luce (34), Grave (15), Herz (16), and others. These include extensive researches carried on under the direction of the United States Navy. In the Pacific Ocean, Angst (2) and Hilen (17) studied the relation of bacteria to fouling at Seattle, Washington; Johnson and Miller (20) observed the seasonal settlement of sedentary forms at Friday Harbor, Washington; Coe (9) and Coe and Allen (10) determined the seasonal attachment and rate of growth of certain sessile marine organisms at La Jolla, California. A comprehensive study of fouling organisms has been initiated by the Scripps Institution of Oceanography in cooperation with the United States Navy's Bureau of Construction and Repair.

In Hawaiian waters, in addition to observations made by the United States Navy at Pearl Harbor, owners of private yachts and other marine craft have for many years known the constant care required to keep their boats in good condition. J. R. Macauley, Surveyor of the Bureau of Shipping in Honolulu about 15 years ago, experimented on the bottom of the steamer *C. R. Bishop* by painting a 12 foot square area with a solution of white arsenic, zinc, and

Portland cement mixed in boiled linseed oil, the rest of the bottom being painted with a copper paint. The result is quoted from the Bulletin of the American Bureau of Shipping, May-June 1923: "After 9 months the 12 foot square area was as clean as a hound's tooth while the rest of the bottom was covered with an inch of coral."

Lissmann's investigations (21) on fouling organisms initiated in the North Sea were continued in the Red Sea and the Indian Ocean, but the results are unpublished.

In studies of fouling organisms in relation to oyster culture in Japan, Miyazaki (23) suggests that the possible retardation of shellfish growth may be due to masses of sedentary forms on the oyster shells.

Sedentary marine organisms which cause the fouling of ships' bottoms are of similar groups wherever they are found. Although ecological conditions may determine the abundance or prevalence of certain forms and specific variations may occur in different localities, in general the same phyla and even the same genera are represented in waters of both tropical and colder latitudes. Fouling organisms proper include those forms which become attached to the basic surface either directly or indirectly by fixing themselves to other organisms. Frequently a thick mass is formed by organisms piling up on each other, causing the underlying forms to maintain themselves with difficulty or to be completely smothered. A dense coating of barnacles is often covered by a layer of encrusting bryozoans, the tests of the sessile crustaceans being entirely enclosed except for the apices where activity of the branchial processes maintain contact with the water for nutrition and respiration. Over this second encrustation a coating of compound ascidians often develops, spreading as a thin, soft layer or massing into compact colonies several inches in diameter. Interspersed may be colonies of *Bugula,* serpulid worms, bivalve mollusks, algae, and other sedentary forms. Among these, numerous free living organisms find shelter and sustenance, and after a few weeks a highly complex organic association adheres to a submerged panel or the under-water surface of a boat.

DISCUSSION OF FOULING ORGANISMS

In Kaneohe Bay organisms comprising the fouling complex as indicated by test panels included the following species. *Balanus amphitrite* Linnaeus, with two or three varieties, was the most common species of barnacle; isolated specimens of *Chelonibia testudinaria* (Linnaeus), typically attached to turtles, also occurred. Colonial bryozoans included many bushy colonies of the cosmopolitan form, *Bugula neritina* (Linnaeus)[2]; sporadic occurrences of a repent species of *Amathia*; several encrusting forms of which *Schizoporella unicornis* (Johnston) (pl. 1, *C, D*) was the most common sometimes completely covering exposed surfaces, while *Rhynchozoon nudum* Canu and Bassler occasionally settled on wood and metal panels; and the inconspicuous forms, *Aetea truncata* (Landsborough) and *Catenaria lafonti* (Audouin).

Serpulid worms are usually constant and conspicuous members of fouling associations. In Kaneohe Bay, two widely distributed species, *Hydroides norvegica* Gunnerus and *H. lunulifera* (Claparède), were abundant throughout the year (pl. 2, *A, B*). Masses of slender, fragile tubes of *Salmacina dysteri* Huxley (pl. 2, *C*) and at least two undetermined species of serpulid worms occasionally settled on the panels. A species of *Spirorbis* was first observed on panels during the early spring of 1938. Because of its small size and scarcity it had no significant part in the fouling complex.

Among mollusks considered as fouling organisms the most common in this locality was a smooth-shelled oyster, *Ostrea thaanumi* Dall, Bartsch, and Rehder, which was abundant on panels during nearly all months of the year (pl. 3, *A*). A small "pearl oyster", *Pinctada nebulosa* Conrad, which is plentiful in Pearl Harbor and Kaneohe Bay, occasionally adhered to submerged panels. This species, which develops a shell 3 or 4 inches broad, is potentially a significant fouling organism but seldom becomes attached to the bottom of boats in great numbers.

Ascidians, both simple and compound, often comprised a prominent part of the accumulated organic matter on test panels at the Kaneohe Bay station. The rapidly spreading compound forms, of which there are apparently numerous species, may form a superficial layer over barnacles, mollusks, worm tubes, and bryozoa or become clumped into compact, spheroidal masses (pl. 3, *B*). Simple ascidians with transparent tunics frequently attained a length of 18 mm. in 48 days, and specimens from 60 to 70 mm. long have been taken from panels submerged for 14 months. The maximum development

[2] For the determination of Bryozoa mentioned in this report we are indebted to Professor Raymond C. Osburn of Ohio State University, Columbus, Ohio.

of compound ascidians occurred during the spring and summer months although some reproduction and attachment was noted throughout the year.

Two species of amphipods, *Erichthonius disjunctus* Stout[3] and *Lembos concavus* Stout[3] which construct tubular compartments of organic secretion and silt for concealment, were conspicuous members of the sedentary associations, the tubes being attached directly to the panels or to colonies of *Bugula*. During sporadic outbursts of these forms, usually in the winter, the amphipod tubes were especially noticeable. Because of the small size of the tubes, 10 to 15 mm. long, they may be considered of minor importance as fouling organisms.

Sponges are widely distributed in Kaneohe Bay and are abundant bottom dwellers in the vicinity of our field experiments. As few simple or colonial forms became attached to floating or submerged panels during the course of our work, no further consideration is given the group in this report.

Especially during the spring and summer months hydroids were important constituents of fouling associations. Numerous undetermined species, mostly Campanularidae, with colonies usually under 30 mm. high, were common on surface floats from March to August, and occasionally well developed colonies were observed during the winter. Rapidly growing colonies of *Pennaria,* probably *Pennaria tiarella* McCrady, appeared at irregular intervals, being especially prolific during August and September 1937. The species, which is abundant in Kaneohe Bay, developed best on deeply submerged panels rather than floating ones. During 3 years, but one coral colony was observed attached to test panels. It developed on a glass plate in March 1938.

Colonial forms of Infusoria attached to other sessile animals or plants were frequently observed. Alone these colonies of Protozoa are of little consequence as fouling organisms but may add somewhat to the friction of *Bugula,* to the stems and branches of which they often thickly adhere.

In Kaneohe Bay filamentous algae may compete with animals as major fouling organisms, especially in locations with light intensity most favorable to the growth of the plants. In the experimental area algae accumulated more abundantly on floating panels or near the

[3] Specific determinations by Clarence R. Shoemaker of the United States National Museum, Washington, D. C.

upper borders of those completely submerged. Test panels suspended from the side of the pier receiving a maximum of sunlight were soon heavily fouled by the plants, while those a few feet away but in a more shaded position gathered little or no algae. Rapid fouling of panels by algae occurred in the Pearl Harbor area often to the exclusion of animal sedentary forms.

Besides the numerous organisms which become fixed to submerged structures many others, because of their more or less permanent biological associations or because of temporary concealment, may be recognized as a part of the fouling complex. Among crustaceans which find favorable habitats under such conditions are free-living amphipods including caprellids which are parasitic on hydroids and *Bugula*. Many species of crabs, the most common in the areas observed being *Pilumnus oahuensis* Edmondson, find a harbor among the fixed organisms. Swimming crabs of the family Portunidae frequently find a temporary resting place on submerged panels. Numerous isopods, including *Limnoria* which is destructive of submerged wood, were almost always associated with test panels.

Various free-living mollusks commonly frequent habitats offered by masses of sessile organisms. In the Kaneohe Bay area the most common forms of gastropods taken from panels include *Peristerina chlorostoma* Sowerby, *Crepidula aculeata* Gmelin, *Triforis incisus* Pease, *Melanella aciculata* Pease, *Littorina scabra* Linnaeus, and *Atys semistriata* Pease. Nudibranchs also frequently occurred. A member of the family Mytilidae, *Musculus oahuus* Bartsch, was common in this locality, being attached to or buried in the tunics of ascidians. Its relationship seems to be that of a commensal. The bivalve mollusk, *Teredo parksi* Bartsch, which is the common "ship worm" destructive of wood structures in Kaneohe Bay and Pearl Harbor, constantly infested test panels except those of metal and glass during the course of our investigations. Observations on the natural history and destructiveness of this mollusk in Hawaii will be made in a separate report.

Barnacles

In Kaneohe Bay, the barnacles which become attached to floats and submerged panels are representatives of two genera. The most abundant form is a variety of *Balanus amphitrite,* probably *B. amphitrite* forma *hawaiiensis* Broch. Typically the outer plates of the shell of this barnacle are marked by narrow reddish or brownish vertical stripes (pl. 1, *A, B*). At least two other apparent varieties of *B. amphitrite* are numerous in Pearl Harbor but less common in Kaneohe Bay. One grows tall and narrow with a slightly curved beak and the other is more like the typical form of the species but has a white shell. These, however, may be but local growth and color variations.

The genus *Chelonibia* is represented on our test panels by an occasional specimen of *C. testudinaria* (Linnaeus). This species has a low, flat shell with a large aperture and small opercular plates. As a fouling organism it may be considered negligible. In the following discussion, reference to barnacles will signify *Balanus amphitrite,* unless otherwise stated.

Barnacles become readily attached to almost any submerged surface and make rapid growth if conditions are favorable. The normal rate is about 15 mm. in diameter of base in 40 to 60 days, at which time maturity is attained and spawning occurs. An exceptionally rapid growth took place during the fall of 1935 when some barnacles reached a diameter of 15 mm. in 28 days. Spawning has occasionally been observed in individuals with shells but 12 mm. in diameter. At the time of attachment the shell of the young barnacle is 0.5 mm. or less across; growth is rapid during the first two or three weeks then slows to a more gradual increase up to a diameter of about 25 mm. which is attained within the first year (table 1). This is apparently near the maximum size reached by the species, as adult specimens attached to piling near the station vary from 22 to 26 mm. in diameter after a growth of 3 years. Overcrowded individuals are smaller in diameter but taller. Light intensity, food supply, temperature of the water, etc., influence the growth of barnacles.

Table 1. Rate of growth of Balanus amphitrite on unpainted surfaces

Days	Diameter in mm.	Periods of Growth
1	0.5	Aug. 8-9, 1936
6	2	June 17-23, 1937
14	8	Oct. 4-18, 1935
18	10	Nov. 18-Dec. 6, 1936
28	15	Oct. 4-Nov. 1, 1935
73	17	April 16-June 28, 1935
126	18	March 20-July 24, 1935
342	24	Oct. 21, 1935-Sept. 27, 1936

The smaller size reached by barnacles in a given period on toxic surfaces is probably due to delayed attachment rather than to a slower growth rate after affixation (table 2).

Table 2. Rate of growth of Balanus amphitrite on surfaces coated with toxic paints

Days	Diameter in mm.	Nature of coating
54	3	Yacht Green
54	3	Antifouling Germicide
106	12	Copper Red
151	8	Marine Green
164	12	Federal Antifouling
177	17	Cape Cod
383	18	Antifouling Composition

It is a common observation that the under surface of a panel floating horizontally on the surface or just beneath it will collect large numbers of barnacles while the upper surface, although washed by water, may be entirely free of them. That phototropic responses may be concerned with the settling and attachment of many sedentary organisms, including barnacles, is a generally accepted view.

While it is clearly demonstrated that the nauplius stage of the barnacle larva exhibits positive phototropism, Visscher (33) points out that at the time of fixation the cyprids of some barnacles show negative phototropism and are attracted toward the shade rather than toward the light. Although the observations of Herz (16) on the cyprids of *Balanus crenatus* are contrary to this view, it is generally supported by experimental evidence. Unshaded panels suspended vertically in the water usually are about equally fouled by barnacles on both surfaces if they are non-toxic and of similar color. However, if one surface is shaded more than the other the shaded one accumulates more barnacles. Areas contrasted by coats of black and white non-toxic enamels clearly illustrate the relative attraction of light and shade to the cyprid stage of the barnacle. After 57 days a black coated panel supported 772 barnacles, while a white one of similar size supported but 93. Our experiments verify the observations of others that white surfaces are, for a short period of time, less heavily fouled by most sedentary organisms than are dark surfaces (pl. 4, *A*). This is generally true regardless of the composition of the supporting material, provided it be non-toxic.

Although barnacles cause fouling throughout the year in Kaneohe Bay, there are periods when attachment reaches high and low levels. During two weeks beginning November 23, 1937, the number of barnacles affixed to a panel 48 square inches in area was 288 times the number attached to a similar panel during the first two weeks of November of the same year. During the winter months fouling is considerably reduced but not completely inhibited. Fewer barnacles become attached and their growth is slower at this time. Between January and March the surface waters reach a minimum temperature for the year, usually between 20°C. and 21°C., and periods of turbidity and dilution are frequent owing to heavy rains. Less fouling by barnacles during these months is probably due to unfavorable conditions for metamorphosis and attachment. Examination of adult specimens during this period of suppression indicates an abundance of nauplii in the process of development, but relatively few cyprids become affixed. That the growth of barnacles is retarded by one half or more during the winter season is shown by such typical records as 3 mm. in diameter from February 8 to March 2, (22 days), and 6 mm. in diameter from January 26 to March 2, (35 days). (For normal growth during favorable seasons, see table 1.)

Since it is evident that the behavior of barnacles, during both larval and adult stages, is affected by the physical and chemical factors of the environment, a series of laboratory experiments was conducted with nauplii and adults to determine their responses and resistance to changes of temperature, salinity, desiccation, pH, etc.

When active nauplii are suddenly exposed to fresh water they immediately cease to swim and fall to the bottom where slight activity of appendages may be observed for about 5 minutes. On return to normal sea water they resume activity in from 1 to 5 minutes. If the exposure to fresh water is as long as 10 minutes it may require from 25 to 30 minutes for a renewal of activity after the organisms are returned to sea water. After about 1 hour most of the nauplii swim freely. No recovery was observed among nauplii following their exposure to fresh water for periods of 12 to 15 minutes.

When nauplii are suddenly transferred to a mixture of 3 parts of sea water to 1 part of fresh water they exhibit no immediate cessation of movement and the phototropic response remains normal. After 20 hours in this dilution they all swim freely and at the end of 46 hours many are still swimming and all show activity. Nauplii exposed to equal parts of sea water and fresh water exhibit temporary shock, falling to the bottom and swimming about erratically without normal phototropic response. In 10 minutes specimens regain ability to swim and to respond phototropically. After 20 hours nearly all swim and all are active. In 46 hours some still swim and nearly all are active. On placing nauplii in a solution of 1 part sea water and 3 parts fresh water they cease swimming at once and sink to the bottom where feeble movements of appendages are observed. After 10 minutes many have regained the power to swim and within 1 hour nearly all show this activity. Serious injury to the nauplii, however, is evident within 20 hours when most of them have become too weak to swim. After 46 hours a few specimens swim feebly and slight activity of appendages is detected in others. This degree of dilution of sea water is obviously near the limit of endurance of nauplii even for a period of a few hours.

The resistance of barnacles of various sizes and ages to fresh water and to diluted sea water was also determined. One hundred specimens, ranging in diameter of base from less than 1 mm. to 4 mm., the larger ones being from 18 to 20 days old, and all attached close together, were subjected to circulating fresh water. In 24 hours 5 percent of the specimens were dead and in 48 hours 55 percent were dead. At the end of 72 hours 23 percent were still alive, but in 96 hours only 3 of the original specimens had survived. In this group of young barnacles the rapidity of the lethal effect of fresh water had little correlation with age or size. Some of the larger specimens were killed as quickly as some of the smaller ones. Mature barnacles, from 18 to 22 mm. in diameter and from 6 to 12 months old, show a greater resistance to fresh water than do those less than a month old. Some of the adult barnacles tested endured circulating fresh water for a period of 9 days but none survived for 10 days. Visscher (32) reported that specimens of *Balanus amphitrite* were killed by fresh water in 24 hours.

In a solution of 3 parts of sea water to 1 part fresh water adult specimens about 20 mm. in diameter were able to live for at least 58 days, while young specimens up to 8 mm. in diameter lived for at least 53 days. Young and adult specimens lived about equally long in sea water diluted by equal parts of fresh water, and both survived in this solution nearly as long as they did in a solution of 3 parts of sea water. In all dilution tests the animals remained in standing water which was changed daily. Some species of barnacle have become adapted to very dilute sea water. Cowles (12) cites *Balanus eburneus* as typical of brackish water and mentions an undetermined species of the Atlantic coast which flourishes in practically fresh water.

Rapid reduction of the temperature of water containing barnacle nauplii from normal, 25°C., to 0°C. in 32 minutes resulted in no permanent injury to the organisms. Most of the specimens ceased swimming at 13°C. and all were on the bottom at 10°C. Slight activity was still observed in many at 3°C. but all movements ceased at 0°C. The temperature was then reversed and gradually returned to normal. At 6°C. slight activity of the appendages was resumed by the nauplii, and at 17°C. about 50 percent of the specimens began to swim freely. At 20°C. nearly all were swimming with normal phototropic response.

When the temperature of a cooling chamber was rapidly reduced from normal, 26.5°C., to 9.5°C. and maintained at this degree for 1 hour, all specimens ceased swimming but some slight activity of appendages was still observed. Twenty-four hours later with the temperature at 8.5°C. a few nauplii exhibited slight activity and nearly all resumed movements at once when restored to sea water of normal temperature. With the temperature at 8.5°C. for 84 hours a few nauplii still exhibited slight activity of appendages, but after 108 hours no movements were detected. Returned to normal temperature, not more than 10 percent of the specimens showed the slightest activity and none fully recovered. On reducing the temperature from normal to 7°C. slight activity was observed among nauplii after 64 hours. After 84 hours no movement occurred and only about 10 percent recovered on return to normal sea water. No recovery took place after nauplii had been subjected to 7°C. for a period of 108 hours. Nauplii, however, are capable of enduring temperatures much lower than 7°C. for extended periods of time. Water containing active specimens was reduced from normal temperature to -1°C. during 2 hours. Though some individuals survived this low constant temperature for 24 hours, they were near their limit of endurance.

Both young and adult barnacles show considerable resistance to low temperatures. Young specimens with diameters up to 8 mm., are little affected in water at 2°C. for 48 hours, and approximately 25 percent live at this temperature for at least 68 hours. Some smaller individuals, 2 mm. in diameter, are as resistant as many larger ones.

Adult barnacles, averaging 20 mm. in diameter, have lived 72 hours in water at -1°C., with part of the water at this temperature converted into ice, but none of those examined survived this low degree for 96 hours.

In rapidly rising temperature, beginning at 26°C., all nauplii were rendered inactive by the time 41°C. was reached. When restored to normal temperature some regained activity in 15 minutes and within 1 hour 90 percent of them had recovered sufficiently to resume swimming. Under constant temperature, nauplii endured 35°C. for 24 hours at the end of which period about 50 percent of them were still swimming and nearly all were active. After 42 hours at this temperature a few nauplii swam feebly and many exhibited activity of appendages. None, however, survived 60 hours at 35°C.

Adult barnacles submerged in water with the temperature fluctuating between 34°C. and 35°C. survived for 72 hours but did not revive after 86 hours. Numerous tests indicate that young barnacles, up to 8 mm. in diameter, are somewhat more resistant to high constant temperature than are adults.

The resistance of barnacles to desiccation when exposed to the air depends upon the physical condition of the surrounding atmosphere which determines the rapidity at which evaporation takes place. Out of water and in shade, under normal temperature of the laboratory varying between 22°C. and 26°C., adult barnacles lived for 27 days but not for 33 days. Out of water and exposed to the direct rays of the sun, with the air temperature ranging from 30°C. to 35°C., adults lived from 3 to 5 hours. In tests with the air temperature at 45°C. barnacles showed evidences of life after 4 hours but did not recover when returned to normal sea water. Cole (11) states that *Balanus tintinabulum* survived for 12 days out of water in a temperature that at times exceeded 50°C. Evidently this record was taken in alternating shade and sunlight.

Laboratory determinations of the resistance of nauplii to reduced hydrogen ion concentration of sea water were made. On lowering the pH from 8.6 to 7.2, without alteration for salt content, nauplii maintained normal activity for about 22 hours. On a reduction to pH 6 many nauplii ceased swimming in 4 or 5 hours, and after 7 hours activity was observed only in slight movements of appendages.

Transferring marine craft to fresh water when heavily fouled by barnacles has frequently been suggested and put into practice in an attempt to rid the hulls of the organisms. From the foregoing results, it is evident that, with the capacity to endure fresh water which adult barnacles exhibit, it would require considerable time for their destruction. Since only the soft parts and the opercular valves are washed away when the animal dies, scraping the surface would still be essential. The basal and wall plates of the shells would remain firmly attached, for some time at least, and would create almost as much friction in the water as living organisms.

Bryozoa

Members of the group Bryozoa (Polyzoa) are among the most common fouling organisms in Kaneohe Bay. Both upright colonies and encrusting forms are well represented. The tuftlike species, *Bugula neritina,* is especially abundant throughout most of the year. In local waters this widely distributed form may attain a height of about 3 inches in 3 months which is a usual size for full-grown colonies. (See plate 1, *D* and table 3.) The rapid growth of this species during the periods of its greatest development makes it a formidable fouling organism. Reproductive ooecia usually appear on colonies after reaching a height of about 25 mm., which is accomplished in about 2 weeks. The species readily becomes attached to almost any non-toxic surface; even toxic paints frequently show little efficiency in repelling it.

Table 3. Rate of growth of Bugula neritina on unpainted surfaces

Days	Height in mm.	Periods of growth
½	0.25	Aug. 9, 1936 (night)
2	1	Aug. 6-8, 1936
4	2	Aug 8-12, 1936
9	4	July 28-Aug. 6, 1936
14	25	Oct. 18-Nov. 1, 1935
19	40	July 25-Aug. 13, 1936
28	50	April 7-May 5, 1935
50	60	Nov. 1-Dec. 20, 1935
87	70	Nov. 18, 1935-Feb. 13, 1936
127	63	May 2-Sept. 6, 1936
156	65	Mar. 3-Aug. 6, 1936

Observations on the early phases of *Bugula* after affixation indicate that within a few hours after the free-swimming larva has settled the young colony has extended itself above the point of attachment, thus the fast-growing parts are beyond the influence of whatever toxic elements there may have been on the surface. The largest colony observed during our experiments developed on a toxic surface to a height of 100 mm. in 100 days. Monthly records for 3 years show that *Bugula* appears in local waters during all seasons but is less abundant during the winter months, probably due to physical conditions previously mentioned (p. 260). Miyazaki (23) observed that *B. neritina,* in Kanagawa Prefecture, Japan, settled when the temperature of the water remained above 20°C. In successive years our test panels in Kaneohe Bay were lightly infested by *Bugula* during the months of January and February. Its rate of growth was slow—15 mm. from January 28 to February 28. A prolific development, usually begins in March and lasts throughout the rest of the year. Grave (15) states that *B. flabellata* reaches old age in 3 months in the Woods Hole region. Seldom does *B. neritina* live longer than 3 months in Kaneohe Bay.

On toxic surfaces *Bugula* usually shows a more restricted growth in a given period than on an untreated surface (tables 3 and 4). This is probably due to delayed attachment rather than to a slower rate of growth after settling.

Table 4. Rate of growth of Bugula neritina on surfaces coated with toxic paints

Days	Height in mm.	Nature of coating
106	30	Copper Red
140	40	Marine Green
140	35	Federal Antifouling
146	50	Yacht Green
188	30	Cape Cod
188	50	creosote
188	50	varnished over toxic paint

An undetermined species of *Amathia,* developing a soft, flexible colony with zooecia spirally arranged about the stem and branches is occasionally taken on test panels in Kaneohe Bay, and also occurs on the bottom of boats anchored for some time in Pearl Harbor. This form lacks the rigidity of *Bugula* and appears in recumbent masses. Because of its soft consistency *Amathia* is not of major importance as a fouling organism. Even if the species became attached to a boat at rest and developed into a mature colony it would likely be torn to pieces if the craft were moved.

Another branched colony of soft consistency, *Zobotryon pellucidus* Ehrenberg, was taken but once from test panels in Kaneohe Bay, the colony reaching a height of 50 mm. in 56 days. It also has been taken, occasionally, from the bottoms of boats in Pearl Harbor. Like *Amathia* the translucent colony becomes recumbent with age and, because of its infrequent occurrence, may be considered of minor importance as a fouling organism in local waters. Minute species spreading over surfaces by means of stolons are not uncommon. Two of these, *Aetea truncata* (Landsborough) and *Catenaria lafonti* (Audouin), readily attach to wood, metal or glass panels. They are negligible as fouling organisms, however, since their sparse vertical growths usually amount to but 2 or 3 mm.

Encrusting forms of bryozoans are among the most common sedentary organisms in the area of Kaneohe Bay under observation. Because of the rapid spread of colonies and their habit of overgrowing other sessile forms, they greatly increase the thickness and roughness of the fouling association. Two species in local waters have been tentatively identified as *Rhynchozoon nudum* Canu and Bassler and *Schizoporella unicornis* (Johnston). The latter is especially abundant, reproducing throughout the year (pl. 1, *C.*). Early stages may be taken by suspending a panel in the water for but a few hours. In 6 days colonies 2 mm. in diameter with 10 zooecia commonly appear. In 12 days colonies may reach a diameter of 3 mm. and have 16 zooecia. Increase in diameter and number of zooecia now progresses rapidly. An average growth of 1 mm. per day in diameter of colony is not unusual for the first month, after which development is less rapid (table 5). Test panels 12 inches square are often completely coated with crowded colonies of *Schizoporella,* each 50 to 70 mm. in diameter, within a period of 3 months.

An analysis of the rate of growth of this species on surfaces treated with toxic paints suggests that some of the coatings are efficient in delaying the attachment of the organism for some time

Table 5. Rate of growth of colonies of Schizoporella unicornis ? on unpainted surfaces

Days	Diameter in mm.	Periods of growth
6	2	June 17-23, 1937
14	15	Oct. 4-18, 1936
28	25	Dec. 6, 1936-Jan. 3, 1937
34	33	Nov. 1-Dec. 4, 1936
46	45	Nov. 18, 1935-Jan. 3, 1936
69	50	Mar. 20-May 28, 1935
85	62	Mar. 20-June 13, 1935
100	70	Mar. 20-June 28, 1935
132	60	Nov. 28, 1936-April 9, 1937

while others apparently have little influence on attachment (table 6). Like most other sedentary forms observed, *Schizoporella* becomes attached to a dark surface more readily than to a light one, if both be non-toxic. Enameled metal plates, suspended vertically, collected many more colonies on the black surface than on the white one of the same plate. Any panels with dark and light surfaces, both non-toxic, show a similar contrast in number of encrusting bryozoans attached.

Table 6. Rate of growth of colonies of Schizoporella unicornis ? on surfaces coated with toxic paints

Days	Diameter in mm.	Nature of coating
32	30	creosote
46	40	Kress white enamel (copper oleate added)
100	40	Antifouling Composition
100	28	Kress white enamel (mercuric chloride added)
112	40	Yacht Green
432	35	Copper Red

Catches of bryozoans at different periods of the year indicate that *Bugula* becomes affixed as readily during the night as during the day. Observations under natural conditions were verified by laboratory experiments in which larvae of *Bugula* settled on floating panels in the dark as well as in the light. However, *Schizoporella* became attached more readily in the dark and on floating panels rather than on those deeply submerged.

Because of the character of the organisms it is difficult to determine with accuracy the degree of resistance of bryozoans to such ecological factors as dilute sea water, temperature, desiccation, etc. Few experiments of this nature were made with local forms. Tests with colonies of *Bugula neritina* indicate that this species dies in fresh water within 30 minutes.

Serpulid worms

In Kaneohe Bay serpulid worms find attachment on test panels throughout the year, although they are more abundant at irregular intervals. Their coiled and twisted tubes interspersed among other sedentary organisms materially increase the friction of a surface moving through the water. The most prevalent species in Kaneohe Bay and Pearl Harbor is the widely distributed form, *Hydroides norvegica,* although *H. lunulifera* is also abundant. On reaching a length of about 25 mm., the tube of *H. norvegica* often develops two longitudinal ridges on the upper surface (pl. 2, *B*). If the ridges are indistinct, the tube of the species can usually be distinguished from that of *H. lunulifera* by its thinner wall. *H. lunulifera* has a thick walled tube which attains greater diameter and length than that of *H. norvegica.* No longitudinal ridges mark the tube of *H. lunulifera* but with maturity it becomes roughened by circular lines and costae (pl. 2, *A*).

Table 7. Rate of growth of serpulid worm tubes on unpainted surfaces

Days	Length in mm.	Periods of growth
½	3	night of Aug. 24, 1936
6	6	June 11-17, 1937
15	24	July 25-Aug. 9, 1936
30	30	July 10-Aug. 9, 1936
58	32	April 16-June 13, 1935
86	55	April 3-June 28, 1935
104	60	Nov. 28, 1936-April 9, 1937
192	50	April 7-Oct. 16, 1936
322	106[4]	April 7, 1936-Feb. 23, 1937

The cleavage stages, the trochophore, and the early larval phases of *H. norvegica* were observed. A wormlike form with rudimentary

[4] Tube of *Hydroides lunulifera.* Other data in table refer to *H. norvegica.*

branchiae developed in 8 days. This phase doubtless is almost immediately followed by affixation and secretion of a tube, phenomena which were not observed. After attachment of the young worm the secretion of the tube proceeds rapidly. During one night, a period of 11 hours, tubes 3 mm. long developed on wooden panels submerged near the bottom, while tubes 1 mm. long were formed on floating glass panels. In the first month serpulid worm tubes increase in length at an average of about 1 mm. per day after which the rate is reduced. Under favorable conditions in Kaneohe Bay tubes of *H. norvegica* attain a length of 50 to 60 mm. in 3 or 4 months. This is approximately full growth for the species in this locality (table 7). Tubes of *H. lunulifera* 75 mm. long are not uncommon. The largest one observed during our experiments attained a length of 106 mm. in 322 days (table 7). Other species of serpulid worms rarely attached to test panels in this area, although sporadic development of *Salmacina dysteri* occurred, the heaviest growth taking place during the summer and fall months. (See p. 255 and pl. 2, *C*.) The influence of toxic surfaces on the rate of development of serpulid worms was not determined, but antifouling coatings obviously delayed their attachment (table 8).

Table 8. Rate of growth of serpulid worm tubes on surfaces coated with toxic paints

Days	Length in mm.	Nature of coating
99	32	Yacht Green
115	20	Antifouling Composition
151	40	Copper Red
151	30	Marine green
190	40	Antifouling Germicide
376	80[4]	Yacht Green
376	70[4]	Yacht Bottom Enamel
412	50[4]	Copper Red

Our experiments indicated that larvae of serpulid worms prefer to settle on dark surfaces rather than light, although the evidence was not wholly conclusive. Three panels of equal area (27 square inches), one unpainted and two coated with non-toxic enamels, one black and the other white, were submerged in sea water for 8 days. Twenty-

[4] Tubes of *Hydroides lunulifera*. Other data in table refer to *H. norvegica*.

two worms attached to the unpainted surface, 17 to the white area and 100 to the black one. At another time of the year tests with glass panels over a 14 day period indicated that little discrimination was shown by serpulid worms in their attachment to white and blue plates. Large numbers of worms have been known to settle quickly on highly toxic surfaces to the exclusion of other organisms.

Some larvae of serpulid worms and other fouling organisms doubtless possess a high degree of resistance, which enables them to become attached under conditions that would be unfavorable to others. It is suggested that the settling process for all sedimentary forms is indicative of a certain physiological state of the organism and that if this condition does not persist when contact is made with a surface the chances of affixation are slight.

Day and night catches at different times of the year showed that serpulid worms settle during daylight and night with no apparent preference. There is a difference, however, in the number of serpulid worms attached at different levels in the water. While floating panels collect serpulid worm tubes, those suspended low in the water or resting on the bottom usually attract more. Two panels, each having an area of 74 square inches, including both sides, were suspended vertically in the water, the upper border of one 18 inches below the lower border of the other. After exposure for 8 days, 65 worm tubes were attached to the lower panel and 3 to the upper one. Serpulid worms enclosed in their tubes are little injured by prolonged contact with silt-laden water and will endure complete submergence in sand and mud for a considerable period. Since the tubes of serpulid worms are usually found on the under surfaces of stones in their natural shoal water habitat, it is possible that a negative phototropic response explains their preference for lower levels in the water.

That serpulid worms may, at times, constitute the primary fouling organisms in local waters is shown by examination of the hulls of United States Navy craft drydocked at Pearl Harbor. On January 24, 1938, the hull of the submarine *Argonaut* was encrusted with masses of serpulid worms, which chiefly composed the fouling and represented a growth of about 10 months in Pearl Harbor. Heavy fouling, observed on the bottoms of destroyers drydocked in Pearl Harbor on February 23, 1938, consisted mainly of *H. norvegica,* some tubes of which were 55 mm. long. The growth was remarkable, as it represented but 6 weeks of winter fouling. As the tubes of serpulid worms become longer, they tend to rise from the surface of attachment and stand out at a sharp angle from the initial portion. The living animal is thus carried away from toxicants of the coating and is assured more complete aëration.

Laboratory experiments determined the resistance of serpulid worms to fresh water and diluted sea water. When exposed to fresh water adults of *H. norvegica,* in their tubes, usually died in 4 hours. In a mixture of one part of sea water to three parts of fresh water they showed slight response to mechanical stimuli after 9 hours, but all died within 24 hours. In sea water diluted by equal parts of fresh water some lived more than 27 hours, but none for 48 hours. In 3 parts of sea water to 1 part of fresh water, specimens have lived more than 50 days. Fresh water or diluted sea water slightly expands the anterior part of the serpulid worm, causing the branchiae and operculum to be extended from the tube. This results in a more rapid lethal effect on the anterior extremity, the branchiae losing the capacity to respond to stimuli while the posterior portion of the body enclosed in the tube is still active. Pearse (30) observed the ability of numerous marine annelids to endure a mixture of three fourths sea water to one fourth fresh water for a week or two, and concluded that delicate forms lived almost as long as tough ones.

Mollusks

A smooth, thin-shelled oyster, *Ostrea thaanumi* (p. 255; pl. 3, *A*), is the most constant molluscan member of the fouling complex in the Kaneohe Bay area. Heavy infestations of panels usually occur from March to November with a minimum of reproduction and growth during the winter months. Larval forms of the oyster, however, may be taken by towing during all months of the year. Like serpulid worms, *Ostrea* finds most favorable conditions for attachment in the lower levels of the water. Horizontally placed panels with one face directed upward and the other downward collect more oysters on the lower surface. During 10 days in October, 1937, the lower surface of a wood panel 180 square mm. in area and suspended near the bottom collected more than 500 young oysters while less than one tenth of that number became affixed to a similar panel one foot higher in the water. Nelson (26) observed that the larvae of oysters exhibited a strong positive stereotropism just before attachment and with materials at the bottom to serve as cultch the organisms became affixed in that position. Hopkins (18) found that 100 times more larvae of *Ostrea lurida* attached to the under side of a horizontal surface than to a vertical one. He suggests that it is not because of a phototropic response but because the larva swims with its foot directed upward and naturally comes in contact with the lower surface of a support.

At the time of attachment the shell of *O. thaanumi* is about 0.5 mm. in diameter and in 6 days thereafter measures 2 mm. Under favorable conditions it reaches a diameter of 25 mm. in 3 months, after which it grows more slowly. The largest specimen we observed developed a shell 50 mm. across in 322 days. This is probably near the maximum size reached by the species (table 9).

The rate of growth of isolated specimens of the small pearl oyster, *Pinctada nebulosa* (p. 255), is approximate only. Shells 15 mm. across have developed within 49 days and specimens 30 mm. long have reached that size in 105 days. After 414 days, test panels have carried shells 43 mm. across. It may be assumed that the oyster is younger than the exposed period of the panel.

Although the bivalve mollusks, *Ostrea sandvichensis* Sowerby and *Anomia nobilis* Reeve, have not appeared on test panels in Kaneohe Bay, both have, at times, accumulated in great quantity on the bottoms

Table 9. Rate of growth of Ostrea thaanumi on unpainted surfaces

Days	Long diameter in mm.	Periods of growth
6	2	June 17-23, 1937
24	5	July 1-25, 1936
39	10	July 1-Aug. 9, 1936
45	14	July 1-Aug. 15, 1936
65	23	June 19-Aug. 23, 1936
77	25	July 18-Oct. 3, 1936
100	28	March 20-June 28, 1935
174	35	March 3-Aug. 23, 1936
322	50	April 7, 1936-Feb. 23, 1937

of naval craft in Pearl Harbor. On June 1, 1936, the decommissioned U.S.S. *Chicago* was placed in dry dock in Honolulu, after having been at rest in Pearl Harbor for 5 years. The hull was densely covered to a depth of several inches with masses of *O. sandvichensis* almost to the exclusion of other organisms. Following an anchorage in

Pearl Harbor of approximately 3 months (early May to early August, 1937), the hull of the U.S.S. *Chester,* when docked, was found to be heavily fouled by the bivalve mollusk, *Anomia nobilis,* and a coating of serpulid worms, while barnacles were almost negligible.

Few investigations were made to determine the resistance of mollusks to altered environment. On exposure to fresh water young individuals of *O. thaanumi,* 8 mm. in diameter, live for 2 or 3 days, while halfgrown specimens of *Pinctada nebulosa* usually die within 2 days.

EFFECT OF METALS ON FOULING

Sheathing the hulls of wooden craft with copper to prevent fouling was once considered economical, but became generally impractical with iron ships because of the electrolysis which was set up when the two metals came in contact. Numerous investigators who have tested the relative capacity of various metals to repel sedentary organisms agree that copper is quite effective and that other metals with high alloys of copper or other soluble toxins also show this ability. Why some metals have this property to a greater extent than others is explained by Parker (29), who points out that because of their high solubility the ions of copper and zinc develop a poisonous layer next these metals preventing organisms from growing on them. Metals like iron, lead, tin and aluminum have relatively insoluble ions and therefore foul quickly.

In our experiments in Kaneohe Bay, we used iron, tin, galvanized iron, lead, monel, German silver, brass, copper, and zinc panels. They were used separately or coupled together in various combinations. In general, copper and its alloys, brass and German silver were more effective in preventing fouling than other metals. Zinc usually came next in order of merit. Over a period of 13 days, results for 7 metal panels were as follows: iron, tin, lead, and galvanized iron were fouled by barnacles in a descending degree, while copper, brass, and zinc were free of organisms. After 26 days no organisms had settled on copper, brass, or German silver although the other 6 metals used were more or less fouled. Similar results followed tests extending over 43 and 57 day periods. Comparing copper, zinc, tin, and iron over a period of approximately 3 months, copper was found to be fouled only by fine filamentous algae, while the other metals were well covered by barnacles; zinc, however, supported fewer than tin or iron. German silver, consisting of approximately 50 percent copper, 25 percent zinc and 25 percent nickel, frequently was fouled by algae within 40 days, but was quite effective in preventing the attachment of other sedentary organisms over periods of about 3 months, as were brass and copper. Visscher (32) observed that copper was a good repellent of hydroids and algae but not so effective with respect to barnacles, serpulid worms, and bryozoans. Orton (28) found that copper successfully prevented fouling for 14.5 months and that few organisms were attached to zinc during periods of slightly more than 3 months. Gardner (14) quotes the observation of Young that English ships with copper bottoms usually were fouled in 10 months.

Copper and brass panels which are relatively effective in preventing fouling apparently lose this efficiency if removed from the water for a short time, then used again. Copper plates free from organisms after one month in the sea were removed and exposed to the air for 30 days after which they were replaced in the water. Twenty-six days later they were found to be heavily fouled by serpulid worms, *Bugula,* and a few barnacles. The size of the organisms indicated that attachments took place immediately following resubmergence of the panels.

When iron or tin is brought into close contact with copper the copper loses its capacity to repel sedentary organisms and fouls quickly. Parker (29) has shown that if two metals in the electromotive series are in contact, erosion is restricted to the one occupying a superior position in the series. Since iron and tin are on higher planes than copper the latter is incapable of releasing toxic substances and therefore permits the organisms to settle and become attached. Our results were in accord with those of Parker. When iron or tin plates were riveted closely to copper or brass the last two attracted barnacles quite as readily as did the metals with which they were coupled (pl. 4, *B*). Copper plates placed in juxtaposition with iron or tin were found to foul if the interval between the plates was reduced to 20 mm. or less.

THE EFFECT OF PAINTS ON FOULING

With the advent of ocean-going ships with metal hulls about the middle of the nineteenth century, stress began to be placed upon the application of specially prepared paints to surfaces exposed to sea water. The two objectives were, first, the preservation of the metal bottom from corrosive action of the water, and second, the prevention of attachment and development of fouling organisms. Fouling became as important in the economy of ocean traffic as corrosion. In Europe, attention was soon drawn to the loss of time, increased fuel consumption, and repairs necessitated by the rapid growth of organic material on the hulls of marine craft. Early steam-driven iron ships in commerce between England and China frequently lost 2 or 3 months each trip because of fouling, and some became unmanageable and useless after 12 months. Gardner (14) quotes Young as reporting that the Peninsular and Oriental Steamship Line spent £70,000 annually to keep its ships in good condition. Ships of war were likewise affected and were known to lose a mile per hour in speed after 6 to 8 weeks and sometimes were pronounced useless in a few months. Such antifouling paints as were then available apparently proved of little value.

Previous to 1902 the United States Navy used various commercial paints on the hulls of its vessels, each type of craft requiring a different kind of paint. The necessity of keeping large stocks of many kinds of paints at the several navy yards finally became so impracticable that the Navy began to standardize and manufacture its own ship-bottom paints. Following a long series of experiments two types of paints were adopted: one was anticorrosive in function, the other antifouling. The anticorrosive coating was applied directly to the metal bottom and covered by the antifouling composition. This method is still practiced, although several different formulae of antifouling paints, of both foreign and American sources, are now used by the navy.

It is obvious that the best of antifouling compositions are but temporary repellents of sedentary organisms. Conditions other than the nature of the paint must be considered in determining the rapidity of fouling. The reproductive periods of the organisms which vary with latitudes, the temperature of the water through which the boat passes, the speed at which it travels, the length of time at anchorage in harbors, and the location of anchorages are important factors. A report in the American Bureau of Shipping Bulletin for March-April 1924 indicates that while Atlantic Ocean fast passenger ships maintain their speed for 6 or 8 months after being dry-docked, cargo vessels show reduced speed in half that time. The Shipping Board steamer *Hog Island* on the third voyage, after release from dry dock, from the Atlantic coast of the United States to the Mediterranean Sea, lost speed to the extent of 18 percent and fuel consumption increased 29 percent. The boat was painted with Norfolk Navy standard paint.

Neu (*27*), after experimenting in the North Sea, concluded that antifouling paints may delay the settling of larvae for a time but that the toxic elements have no effect on the growth of the organisms after attachment. Neu graded the antifouling compositions, in Germany, for use in different parts of the world. Those designated by him as B, C and D are increasingly poisonous. Paint D is used on ships going into the tropics, paint C on ships in temperate waters, and paint B on ships in colder waters. However, experiments showed that paint D was as heavily fouled, after a given period, as paint B. Fishermen of the North Sea apply the least poisonous paints to their boats, since they cost less and prove to be about as efficient antifoulers as the more toxic and expensive ones.

Although the method of exfoliation, the use of a paint that will wear away with the attached organisms, has been suggested from time to time as a substitute for antifouling coatings, it has received no serious consideration. A chief objection to exfoliation is that erosion of the surface paint does not take place at the same rate in harbors and at sea. Passing from warmer into cooler water or vice versa also has a variable effect on erosion. If exfoliation proceeds rapidly the frequent repainting becomes an economic factor not to be disregarded. Eroding paint does not always carry away with it the sedentary organisms attached to the surface. Frequently cyprids of barnacles bore their way through the paint covering a panel and become fixed to the solid surface. As the young barnacles grow and their plates expand they push up the layer of paint. The tests of adult barnacles may thus acquire external coatings of the paint applied to the surface. Even coatings assumed to be highly toxic are sometimes burrowed through by cyprids, apparently without ill effect. The paint may thus be completely eroded from the surface of the panel while the barnacles remain firmly anchored.

Non-toxic Paints

The colors of commercial non-toxic paints and their effect on fouling have been considered. Most previous investigators agree that light-colored, non-toxic surfaces attract fewer sedentary organisms, during short periods at least, than do darker ones. Phototropic responses of lower organisms which are known to be aroused to maximum activity by different spectral bands are significant. Mast (22) observes that while these forms are not provided with true color vision the photosensitive materials in light-perceiving organs are more sensitive to certain wave lengths than to others.

It has been demonstrated by various investigators that larvae of sessile forms, including barnacles, hydroids, etc., are more active in the blue-green or green bands of the spectrum. A practical application of this knowledge was suggested by Visscher and Luce (34). Their theory is that since cyprids of barnacles are negatively responsive to light just before becoming attached, a green paint should become less fouled than those of darker hues commonly used on the bottoms of boats. Neu (27) found that surfaces coated with green having a wave length of from 543 $\mu\mu$ to 561 $\mu\mu$ were avoided by cyprids of barnacles and collected fewer serpulid worms than did paints of other colors. In experiments at Beaufort, North Carolina, recorded by Williams (35), panels were painted white, yellow, green, blue, and black. In three months the white panels were practically free of organisms, the yellow and green panels slightly fouled, and the blue and black heavily fouled. Williams (35) also cites the results of Mowbray at Bermuda where brown, red, green, and white non-toxic paints were compared for their antifouling properties. In 3 months the green surface was little fouled and in 6 months it supported 75 percent less animal life than any of the other colors, each of which was densely covered with organisms.

In our experiments many non-toxic paints of various colors and shades were utilized. For short periods, up to a month or 6 weeks, surfaces coated with white and green paints were generally more effective in repelling organisms than were those treated with darker colors. White usually showed some antifouling advantage over green. After 2 or 3 months, however, little difference could be detected between colors, all supporting a considerable amount of fouling.

To negate possible effects of the ingredients in the colored paints, parallel experiments were conducted with white, green, red, and blue glass plates, each 24 square inches in area. The results were varied and sometimes contradictory to the above general observation on the effectiveness of white and green surfaces. After colored glass plates were exposed to sea water for 10 days, the white plate had collected

17 organisms of all kinds, the green plate 44, the red plate 85, and the blue plate 130. Before submergence, the green plate showed a maximum transmission at about 540 $\mu\mu$, the red one at about 625 $\mu\mu$ and the blue one at about 460 $\mu\mu$. Under water, however, the accumulation of slime on the surface doubtless alters the transmission property of the glass, and the efficiency of the original color may soon be suppressed. In a 6 weeks' test with colored plates similar to the above, the red and blue plates were 10 percent more heavily fouled than the green ones which accumulated 75 percent more organic matter than did the white plates. Occasionally, however, green plates attracted more organisms than any of the others. During an exposure of 15 days the number of barnacles affixed to both surfaces of the glass plates was as follows: white, 503; blue, 907; red, 1,058; green, 1,152. A comparison of red and green glass plates often revealed little difference in the amount of fouling during periods of 6 to 8 weeks (pl. 5, *A, B*).

The phototropic response of motile organisms at night doubtless varies from that exhibited during the day. Panels, painted and unpainted, were submerged during a night, then examined for affixed organisms and compared with other panels exposed during daylight hours to determine when sessile animals were more readily attached. Daylight tests August 10, 1937 and in the ensuing night showed numerous barnacles, bryozoans, and oysters attached during the day but none at night. During the nights of August 13 and August 19, however, oysters, bryozoans, ascidians, and both cyprids and young barnacles were affixed in considerable numbers to both black and white panels. During the night of August 24, 23 barnacles and 1 serpulid worm became attached to a green painted area of a panel while the unpainted surface of similar area collected 7 barnacles and 1 amphipod tube. During daylight hours of December 22, 1937, an unpainted surface, 20 square inches in area, of a wood panel collected 52 barnacles, 42 colonies of *Schizoporella* and 1 oyster, while an equal area of the same panel, painted black, had attached 26 barnacles, 103 colonies of *Schizoporella,* 45 oysters, and 8 serpulid worms. During the night immediately following, a similar unpainted area had 12 affixed cyprids of barnacles and a black surface of equal area supported 1 barnacle and 1 cyprid.

From the foregoing results which are somewhat conflicting, few definite conclusions can be reached. It seems unlikely that the organisms are capable of discriminating between colors of surfaces in extreme darkness although certain degrees of light intensity may make this possible. Mast (22) points out that not only the maximum stimulating wave bands vary for diffierent organisms but that intensity may modify the results. We suggest that before a specific color is to be considered of major importance in the fouling problem, information is desirable regarding the tropic responses of the larvae of a much wider range of sedentary organisms than is now known and of their behavior under variable light intensity. Though much evidence supports the view that darker colors are more attractive to sessile organisms, Herz (16) has demonstrated that the cyprids of *Balanus crenatus* settle in lighted areas, contrary to the findings of Visscher (33) who worked with different species.

Varnishes, oils, waxes, and creosote have little value in repelling fouling organisms when applied to surfaces. Even toxic paints covered with hard varnishes are soon heavily fouled, probably because the toxic elements of the paint cannot readily enter solution. Creosote, considered to be a good antiseptic but a poor germicide, has little merit in preventing the attachment of sessile animals when applied directly to a surface, as it is quickly diluted by sea water. Fouling occurs on creosoted surfaces about as quickly as on untreated ones (pl. 4, *A*). Panels submerged in creosote for 48 hours before being subjected to sea water prevent fouling for a short time but lose their efficiency even while a strong odor of the compound remains.

Non-toxic Paints with Added Poisons

Investigations were carried on in Kaneohe Bay with commercial non-toxic paints or enamels to which we added poisonous chemicals in an attempt to determine the relative effectiveness of the toxic agents when united with some of the least expensive commercial paints. Compounds of arsenic, cyanide, copper, mercury, and zinc, either singly or in various combinations and amounts, were frequently used.

In general, rapid solution of the chemicals and changes in the paint, on contact with sea water, probably soon wash away or neutralize the toxins to such an extent that sedentary organisms find safe anchorage. While the tests of the added poisons usually indicated some delay in the attachment of organisms, they also disclosed variable results.

Mercuric chloride usually produced the best results. Panels coated with enamels to which mercury was added, either alone or in combination with some of the other poisonous chemicals, frequently reduced or inhibited fouling for 3 or 4 months (pl. 8). The less soluble mercurous chloride was generally inferior to mercuric chloride, probably because it is not dissipated rapidly enough to prevent early attachment of organisms. Once attached, some sessile animals grow rapidly regardless of the nature of the surface to which they are affixed. Laboratory experiments showed that mercuric chloride, both in paint combinations and in solutions, has a more rapid lethal effect on nauplii of barnacles than does mercurous chloride. (See tables 10 and 11.)

Table 10. Effect on barnacle nauplii of solutions of toxic compounds when added to non-toxic enamels (5 grams of poison to 4.74 fluid ounces of enamel) and applied to micro-cover glasses

Toxic compounds	30 mins.	60 mins.	90 mins.	120 mins.
As_2O_3	all swim	nearly all swim all active	as before	95% swim all active
KCN	none swim some active	as before	as before	none swim many active
NaCN	none swim some active	some swim most active	as before	50% swim feebly most active
$HgCl_2$	none active	none active no recovery		
HgCl	all swim	nearly all swim all active	some swim all active	50% swim all active
ZnO_2	all swim	as before	as before	as before
Cu_2O	all swim	as before	all swim some feebly	as before
Cupric oleate	all swim	as before	as before	75% swim all active
Paris green	nearly all swim all active	as before	as before	90% swim all active

Atkins and Purser (4) observed that coal tars with the addition of copper oleate and copper resinate were highly efficient for preserving rope in sea water. Copper oleate served as a lubricant and both copper compounds preserved against bacterial attack. In numerous tests in Kaneohe Bay, copper oleate and copper resinate added to commercial paints had little merit as antifouling agents.

The relative antifouling value of several toxicants when combined with commercial paints or enamels was determined for short periods of time. To each of four quantities of a white enamel was added a toxic compound in the proportion of 1 gram of poison to 4.74 fluid ounces of enamel. Four areas of a wood panel, each 17 square inches, were coated with the enamels, one containing mercurous chloride, one zinc oxide, one Paris green, and the fourth mercuric chloride. An untreated area of similar size on the same panel served as a control. After 14 days in sea water there were 78 barnacles on the area treated with zinc oxide, 26 on that treated with Paris green, 13 on the mercurous chloride area, and only 4 on that treated with mercuric chloride. Many colonies of *Schizoporella* and many amphipod tubes were found on all areas except that containing mercuric chloride where there were only a few amphipod tubes. The unpainted control area supported approximately 400 barnacles. On another panel marked off into equal units, each 15 square inches in area, 5 units were coated with a white commercial enamel, that for each area having added to it a different toxicant, the proportion being 5 grams of the poison to 4.74 fluid ounces of the enamel. The number of barnacles attached to each treated area, after 49 days (December 8, 1936 to January 26, 1937) was: copper oleate, 129; sodium cyanide, 71; copper oxide, 45; zinc oxide, 30; mercurous chloride, 24. Five units of this panel were unpainted. The number of barnacles carried by these areas ranged from 200 to approximately 500.

Under controlled laboratory conditions tests were made to determine the relative effect on nauplii of barnacles of certain toxic compounds when added to commercial non-toxic paints or enamels. Micro-cover glasses 22 mm. square were painted on one side with two coats of white enamel to which had been added 5 grams per 4.74 fluid ounces of enamel of the toxicants listed in table 10. When the coatings were dry each cover glass was placed in a watch glass containing 10 cc. of normal sea water. Many active nauplii were introduced and their behavior noted after periods of 30, 60, 90, and 120 minutes (table 10). Under the conditions of this experiment, mercurous chloride, probably because of its low solubility, does not have the rapid lethal effect shown by mercuric chloride. For similar or other reasons several of the toxic compounds listed in table 10 had little injurious effect on nauplii during the first 2 hours. After 18 hours in these solutions, nauplii showed signs of activity only in those treated with zinc oxide and copper oxide. Inactive specimens under the influence of Paris green for 18 hours exhibited slight activity when returned to normal sea water. None of the nauplii survived for 24 hours in any of the toxic solutions.

Laboratory experiments were also conducted to determine the resistance of nauplii to weak solutions of various toxic compounds in sea water. Solutions of arsenious oxide, copper oxide, mercuric chloride, mercurous chloride, potassium cyanide, sodium cyanide, zinc oxide and Paris green were used in the strength of 1 part to 100,000. The behavior of nauplii subjected to the solutions was noted after periods of 15 minutes, 1, 11 and 18 hours. The results were, in general, parallel to those in which the same toxicants were used in enamels. (Compare tables 10 and 11.) After 36 hours in copper oxide and zinc oxide solutions some activity of nauplii was seen, and some specimens in the cyanide solutions were able to swim. Atwood and Johnson (6)[5], in noting the lethal effects of salts of metals on *Limnoria* and *Bankia,* concluded it made little difference what salt of a metal was used. In rating the toxic values of metals they placed mercury first, copper second, and zinc third.

Analyses of sea water have revealed but traces of zinc, a metal known to be highly toxic to some marine organisms. Atkins (3) who reports Orton as having found less than 0.1 part per million in the waters of the English Channel, records that lobsters confined in a galvanized iron aquarium with a strong current of water died in 4 days, at which time the aquarium water contained 25 parts of zinc per million. It may be assumed that under the conditions of our experiments (table 10) the effect of zinc was negligible during the first 2 hours because little of the metal had entered solution. It is seen, however, that in solutions with a much higher percentage of zinc than contained in normal sea water nauplii were active for at least 18 hours.

Arsenic added to enamel had little effect on nauplii during the first 2 hours (table 10). In solution, it was fatal to the organisms

[5] Investigation by R. H. Carter.

within 18 hours (table 11). That appreciable amounts of arsenic are in sea water chiefly in the form of arsenite, was suggested by Atkins and Wilson (5) and verified later by Rakestraw and Lutz (31). Many marine animals carry arsenic in their tissues apparently without ill effects. Chapman (8) found as much as 174 parts per million in certain prawns. Fishes, lobsters, mollusks, and seaweeds also contain considerable quantities of arsenic.

Table 11. Resistance of nauplii of barnacles to toxic compounds in solutions 1 part to 100,000

Toxic compounds	15 mins.	1 hr.	11 hrs.	18 hrs.
As_2O_3	nearly all swim all active	as before	inactive revive in sea water	inactive no recovery
KCN	inactive revive in sea water	as before	many swim nearly all active	some swim feebly others active
NaCN	inactive revive in sea water	as before	nearly all swim all active	as before
$HgCl_2$	inactive no recovery			
HgCl	all swim	as before	inactive no recovery	
ZnO_2	all swim	nearly all swim all active	as before	some swim many active
Cu_2O	all swim	as before	as before	some swim all active
Paris green	all swim	as before	some swim all active	none swim some active

Paris green added to enamel had little effect on nauplii during the first two hours (table 10). Nor was it highly toxic in solution for a period of 11 hours (table 11). Adamson (1) reports that the United States Navy found Paris green of little value as an antifouler when used alone but efficient when combined with mercury.

It is assumed that some toxic compounds combined with paints enter solution quickly in sea water and are soon expended or neutralized by the action of other ingredients of the paint. In either case fouling organisms are permitted to gain a foothold on the treated surface. To determine the rapidity of solution of some of the poisons used in the preceding test (table 10), a number of micro-cover glasses were coated with poisoned enamel as before but subjected to circulating sea water for 8 days after which experiments were conducted with nauplii as previously described (p. 281). An apparent loss of toxicity was noted for each of the poisons. Nauplii were killed quickly by mercuric chloride in the first experiment but in the second survived 6 hours or more, but did not survive 20 hours. The nauplii resisted the influence of other toxic agents for more than 24 hours, little injury being done by any except potassium cyanide which inhibited the swimming activities of the organisms, though it was not fatal during the period of observation.

Commercial Antifouling Paints

Manufacturers of marine paints have been mindful of the demands of ocean commerce for some relief against fouling organisms. Numerous proprietary paints to which have been ascribed the property of antifouling are available. Some of these have been widely used with varied results. While they are recommended, there is no assurance on the part of the manufacturers that their products are absolute and permanent repellents of sessile organisms. The high cost of some of the antifouling coatings doubtless has limited their use, as the owner of a craft hesitates to buy the higher priced product unless he can be shown that it has increased merit.

Extensive investigations have shown that the most highly recommended antifouling paints are of temporary benefit only. Visscher (32), who observed that organic matter 2 or 3 inches deep often accumulated on the bottoms of ships treated by antifouling coatings after they had been at sea for 6 or 8 months, concluded that none of the toxic paints in use was a successful repellent of fouling organisms for extended periods. The experiments of Neu (p. 276) emphasize this fact, which is the conclusion of all who have carried on similar tests. Orton (28) found that some antifouling preparations were satisfactory for more than 3 years while others were effective for a few weeks only. This investigator pointed out that an antifouling coating should adhere firmly to the surface, resist erosion, and prevent attachment of organisms by reason of its toxic ingredients. Orton also showed that the efficiency of the paint was lost when its toxicity fell below a certain concentration. Neu (27) called attention to the fact that the toxicants used in paints did not take into consideration the variation in susceptibility of different organisms. This biological factor is probably of no little importance and one about which little is known except through restricted laboratory experiments which usually lack natural conditions.

During the course of our observations in Kaneohe Bay, 8 commercial antifouling paints were extensively tested to determine their relative efficiency in repelling sessile organisms. The findings for the several toxic coatings used were drawn from results under conditions of the experiments as performed. There is no implication that if a modified form of application of the paints were employed or the nature of the surfaces of the panels were different the results would be identical. Our method consisted in applying with a brush two thick coats of paint to a panel as evenly as possible. The surface was permitted to dry thoroughly between coats and before being submerged in the water.

The following toxic paints, designated by their trade names, were used in our experiments and applied to panels of many kinds: Yacht Green (Fuller Co.), Marine Green (Fuller Co.), Copper Red (Fuller Co.), Federal Antifouling (Federal Composition and Paint Co.), Antifouling Germicide (International Paint Co.), Cape Cod (American Marine Paint Co.), Yacht Bottom Enamel (Glidden Co.), and Antifouling Composition (Debevoise Co.). Of these the first two are green, as the names indicate, the last two are white and the others are copper colored.

We treated approximately 300 panels with toxic paints, some of them being used more often than others but all given fair and extensive tests during all seasons of the year. Most of the paints tested proved to be effective for periods up to 3 or 4 months, under the conditions of our experiments. Some of them remained free of organisms for 6 months and in exceptioned instances retained sufficient toxicity to resist fouling for more than a year.

Yacht Green rated high among the paints tested. This coating creates a smooth, hard surface and withstands erosion well; panels treated with it come out of the water relatively free from slime and silt. It is usually a dependable repellent of nearly all fouling organisms for periods up to 6 months and often for a longer time (pl. 6, *A, B*). Marine Green also has a good body, unites firmly to a surface, and, in most of our tests, has proved quite as efficient as Yacht Green (pl. 5, *B*).

If the light hue of a surface has any merit in itself in preventing the settling of organisms (p. 277), a white antifouling paint should be especially efficient provided its general qualities, including toxicity, are adequate. Of the white paints used in our tests, Yacht Bottom Enamel was the least effective, usually fouling quickly. Antifouling Composition generally proved to be a good repellent of most organisms for periods of several months (see pls. 7 *A*; 9, *B*). As applied to our panels, however, there was a tendency for this coating to shrink, crack and erode after a few months, resulting in a roughened surface and permitting footholds for sessile organisms.

The four copper-colored paints seem to be about equally efficient as antifoulers. Like other toxic coatings, these copper paints often inhibited fouling for several months, but at other times were effective for only a few weeks. (See pls. 5, *B*; 6, *B*; 7; 9, *A*.) Cape Cod paint, while not always a dependable repellent for extended periods, has occasionally completely inhibited fouling for more than a year (pl. 7, *B*).

As may be inferred, the results of our experiments are by no means uniform. When sudden reproductive outbursts of organisms occur, toxic paints, generally considered most effective, have been fouled almost as quickly and completely as untreated surfaces.

To determine the relative lethal effect on barnacle nauplii of the several antifouling paints under laboratory conditions, experiments were conducted similar to those in which non-toxic paints with added poisons were used. (See p. 279 and table 10.) Micro-cover glasses were coated with the toxic paints and covered by 10 cc. of normal sea water into which were introduced active nauplii. The behavior of the organisms in the various solutions is shown in table 12. Yacht Green, Federal Antifouling, Antifouling Germicide, and Yacht Bottom Enamel were each lethal to nauplii within 3 hours. In the other preparations, some activity of specimens persisted for another hour or two but none survived for 18 hours.

Table 12. Effect on barnacle nauplii of solutions of seven commercial antifouling paints applied to micro-cover glasses

Toxic paints	30 mins.	60 Mins.	90 Mins.	120 Mins.
Yacht Green	few swim all active	no activity	as before no recovery	
Marine Green	all swim	most swim all active	many swim all active	many swim most active
Federal Antifouling	all swim	many swim feebly all active	none swim some active	as before
Cape Cod	all swim	most swim all active	many swim all active	few swim many active
Antifouling Germicide	all swim	most swim all active	few swim many active	few swim feebly many slightly active
Antifouling Composition	all swim	as before	most swim all active	as before
Yacht Bottom Enamel	all swim	most swim all active	some swim feebly all active	none swim some active

To determine the loss of toxicity in commercial antifouling paints on short exposure to sea water, micro-cover glasses were coated with four of the more efficient preparations, Federal Antifouling, Yacht Green, Antifouling Composition, and Cape Cod. They were then submerged in circulating sea water for 8 days after which the resistance of nauplii to each was observed, following the methods of the preceding experiment. Results indicated that all paints had lost considerable toxicity. In the previous test Yacht Green was fatal to nauplii in 90 minutes (table 12), but after 8 days in sea water the lethal properties were reduced to the extent that specimens were able to swim feebly after 4 hours and still showed activity after 8 hours. Federal Antifouling and Cape Cod were reduced in toxicity parallel with that of Yacht Green, activity of nauplii persisting for at least 8 hours. Antifouling Composition failed to inhibit the swimming response in 8 hours and many specimens showed activity after 18 hours.

SUMMARY

This paper presents the results of a biological survey in which the principal fouling organisms of Kaneohe Bay, Oahu, were determined, and their seasons of greatest productivity, their rate of growth and general ecology were investigated. In this locality fouling occurs throughout the year but declines during the months of January and February, probably because of environmental factors such as lower temperature and frequent turbidity and dilution of surface waters by heavy rainfall.

The rate of growth of the principal fouling organisms—barnacles, bryozoans, serpulid worms, oysters, and ascidians—in favorable seasons is usually rapid during the first month then slows to a more steady increase. *Balanus amphitrite* normally matures in from 40 to 60 days, when it reaches about 15 mm. in diameter, but occasionally reaches that state at a smaller size and within 30 days. The species lives in local waters for several years and attains a diameter of from 22 to 26 mm.

Bugula neritina reproduces when about 25 mm. tall and about 2 weeks old. Colonies seldom reach a height of 100 mm. or live more than 3 months. *Schizoporella unicornis* ? increases in diameter about 1 mm. per day for 30 to 40 days and attains a diameter of 60 to 70 mm. in about 3 months. No information on size at maturity or longevity of the species was obtained.

Tubes of serpulid worms were developed to a length of about 30 mm. in as many days, when maturity was reached. *Hydroides norvegica* attains a tube length of 50 to 60 mm. in 3 or 4 months while tubes of *H. lunulifera* have slightly exceeded 100 mm. in length in about 10 months. The duration of life of serpulid worms was not determined.

A thin-shelled oyster, *Ostrea thaanumi,* attained a diameter of 50 mm. in about 10 months. Data on size at maturity or length of life of the species were not obtained.

During spring and summer the spread of compound ascidians over surfaces is rapid. Simple ascidians have reached a length of 70 mm. within 14 months. No information was obtained on the age of these forms at maturity or their duration of life.

The behavior of various organisms under altered conditions was observed in laboratory tests. Resistance, especially of barnacles and serpulid worms, to changes in temperature, to fresh water, to diluted

sea water, to desiccation, etc., was determined. Nauplii of barnacles are less resistant to changes in environment than are adults. Fresh water is fatal to nauplii in 15 minutes while adult barnacles have endured this medium for 9 days. Serpulid worms in tubes and adult barnacles are maintained in a mixture of three fourths sea water and one fourth fresh water for nearly 2 months, and the barnacles endure a half and half mixture of sea water and fresh water for approximately as long. Serpulid worms are more sensitive to this dilution than are barnacles. Adult barnacles live after 3 days in a constant temperature of -1° C. while nauplii endure 8.5° C. for about 4 days. At constant temperature of 35° C. nauplii are slightly less resistant than adult barnacles, the latter living a little over 3 days.

Adult barnacles will live out of water in shade for 27 days with a maximum air temperature of 26° C. Serpulid worms in tubes die out of water in the shade usually within 24 hours. Bright sunlight with air temperature at 45° C. is fatal to adult barnacles in 3 or 4 hours.

Serpulid worms and oysters seem to prefer attachment at lower levels in the water than do other fouling organisms.

Of 9 metals used, copper, brass, German silver, and zinc were more effective than others in repelling sedentary organisms. Copper or brass plates when brought into close contact with iron or tin foul quickly.

Greater fouling on shaded or dark surfaces seems to indicate that negative phototropism on the part of the larvae obtains at the time of attachment. However, settling of organisms occurs as freely at night as during daylight hours, an observation which challenges the view that color of surface is an important factor in fouling. White surfaces have an antifouling advantage over darker ones, for short periods of time. Sometimes green panels repel organisms to a greater degree than red or blue ones if all are non-toxic; often the reverse is true. Spectral colors apparently have little differential value after periods of one or two months.

Poisonous compounds added to non-toxic commercial paints give to the latter slight antifouling properties. Of the toxicants used, mercuric chloride in high concentrations is generally more effective than others. Laboratory experiments to determine the sensitiveness of nauplii of barnacles to 8 poisonous compounds in enamels and in solutions verified the high value of mercuric chloride as a lethal agent.

Eight commercial antifouling paints were tested. Most of them were satisfactory under conditions of our experiments for 3 or 4 months, some for 6 months and occasionally for a longer time. During periods of high productivity of organisms, however, even the coatings usually most effective were often readily fouled.

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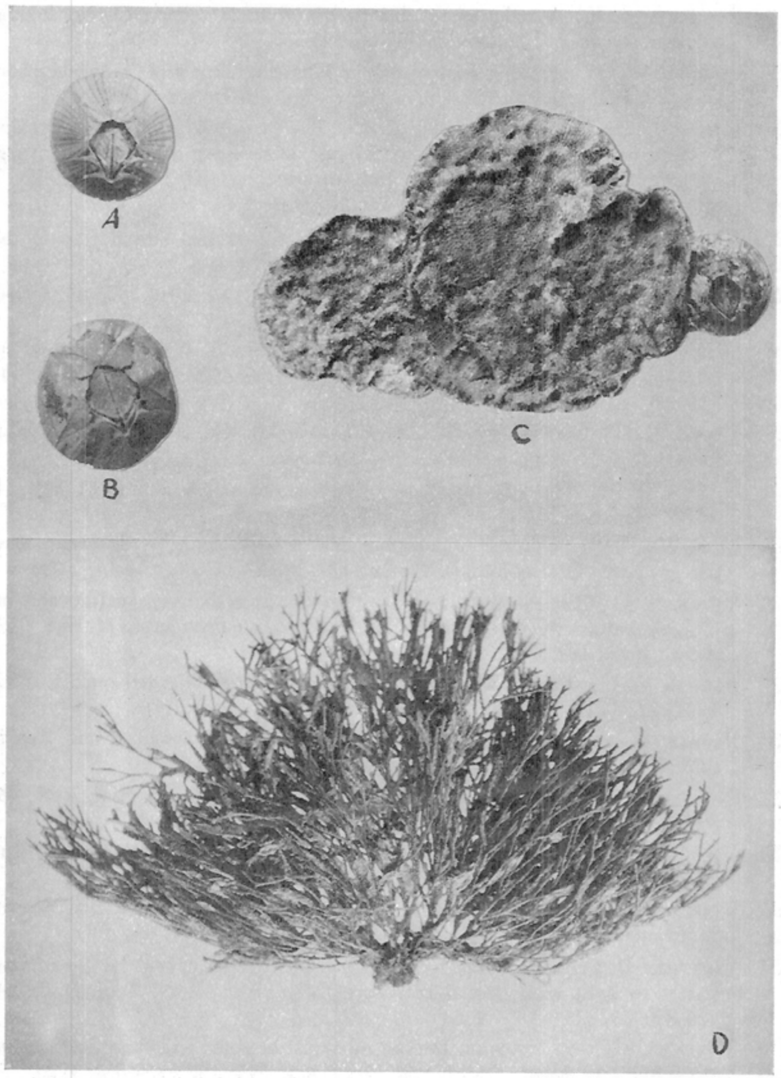


PLATE 1.—Barnacles and bryozoans, natural size. *A, Balanus amphitrite* 126 days old; *B, B. amphritrite* about 3 years old; *C,* fused colonies of *Schizoporella unicornis* ? 35 days old; *D,* colony of *Bugula neritina* 91 days old.

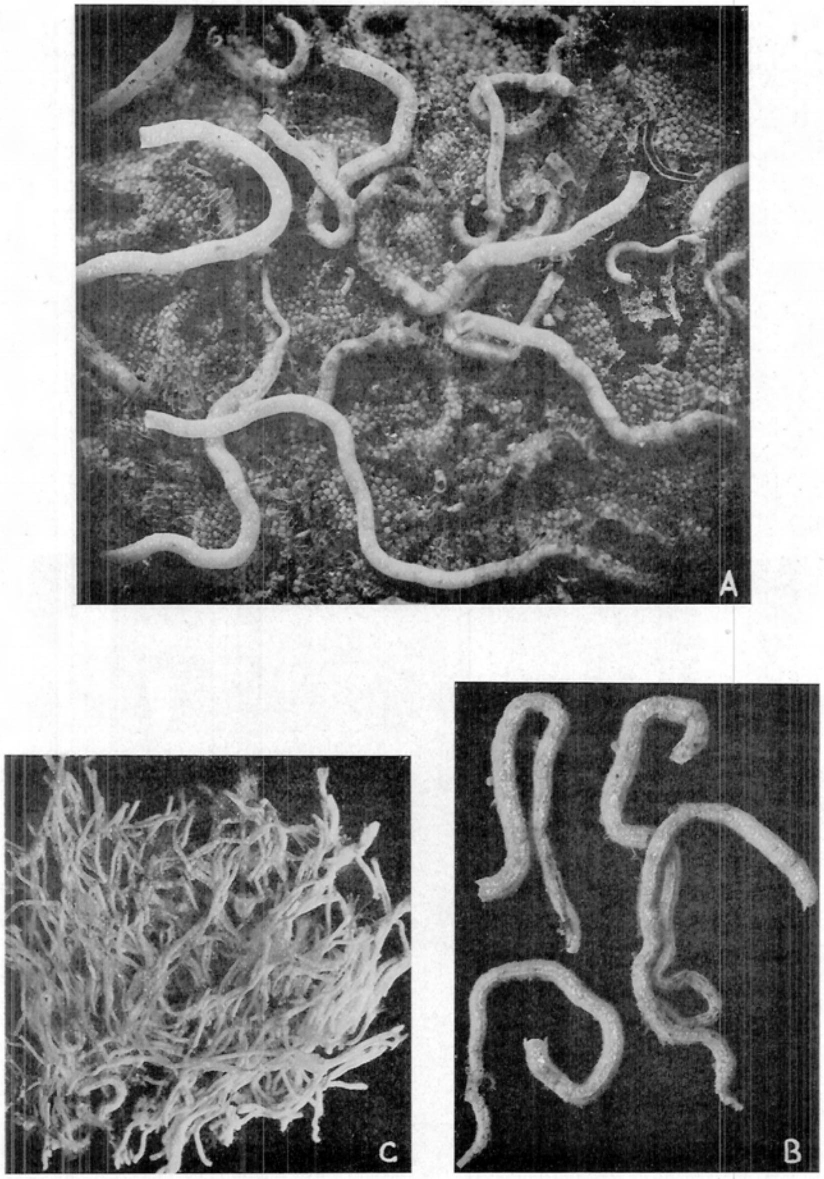


PLATE 2.—Serpulid worm tubes. *A,* group of *Hydroides lunulifera* overlying colonies of encrusting bryozoans; *B,* tubes of *H. norvegica*; *C,* mass of tubes of *Salmacina dysteri.* All × 1.5.

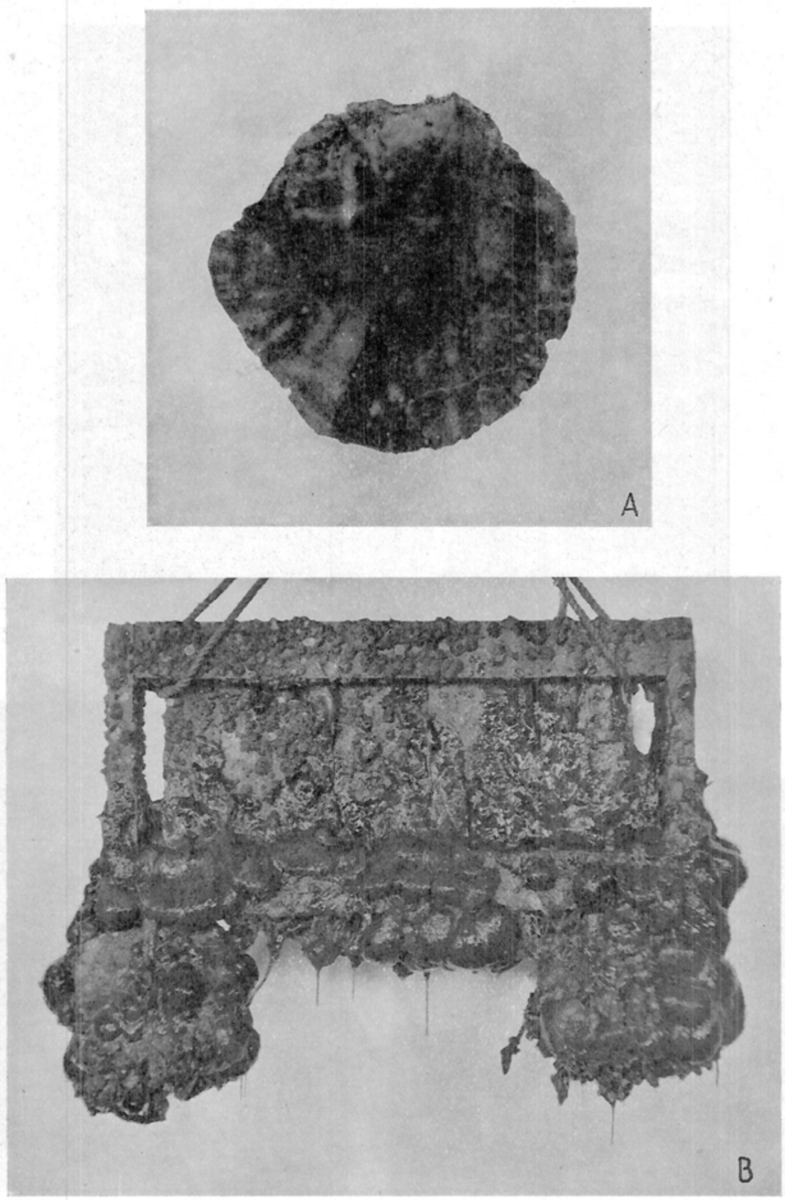


Plate 3.—*A, Ostrea thaanumi,* 322 days old, natural size; *B,* wood frame 19 inches long, supporting glass plates, in sea 69 days. Heavily fouled by compound ascidians.

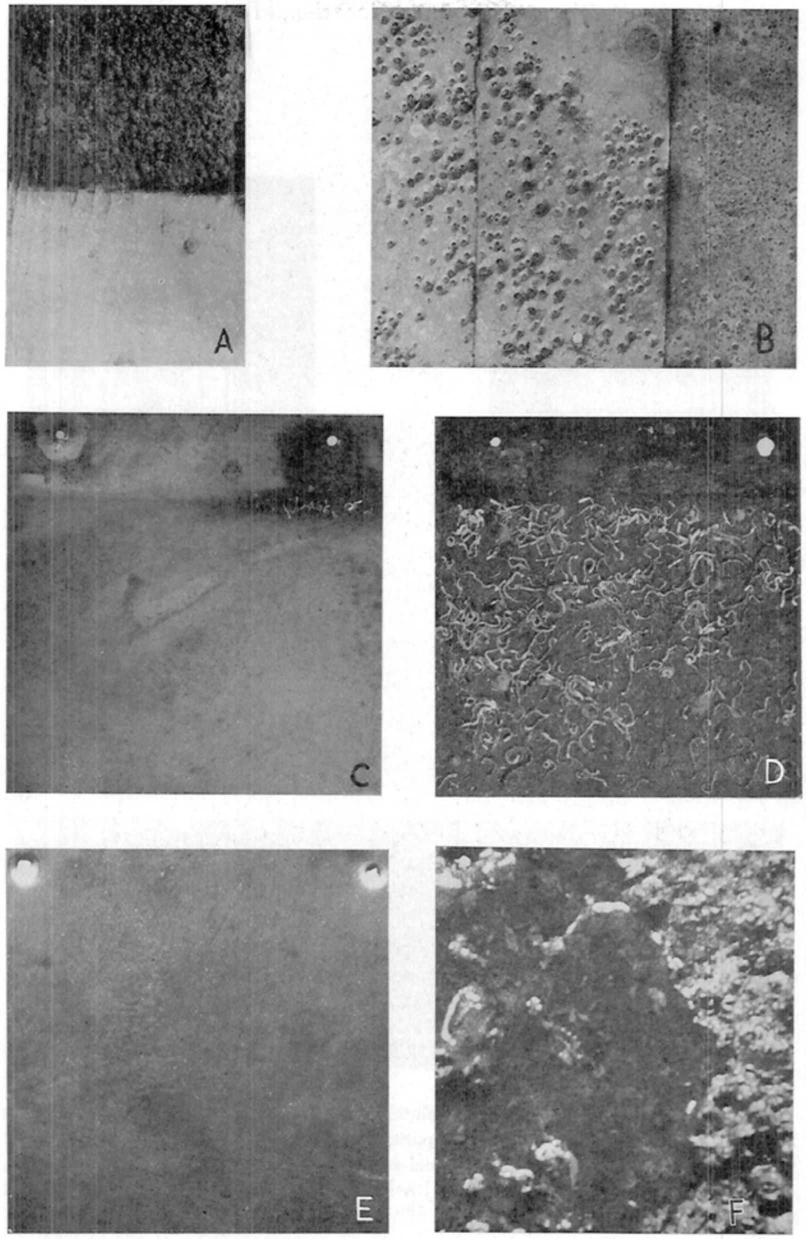


PLATE 4.—*A,* wood panel 6 × 9 inches, in sea 63 days; upper half coated with creosote, lower half with white non-toxic enamel. *B,* tin (left), brass (center), and galvanized iron (right) plates coupled together; brass fouled after 38 days. *C-F,* metal plates 4 × 4 inches, in sea 30 days: *C,* brass; *D,* iron; *E,* copper; *F,* tin; brass and copper unfouled, iron fouled by serpulid worms, tin by barnacles and compound ascidians.

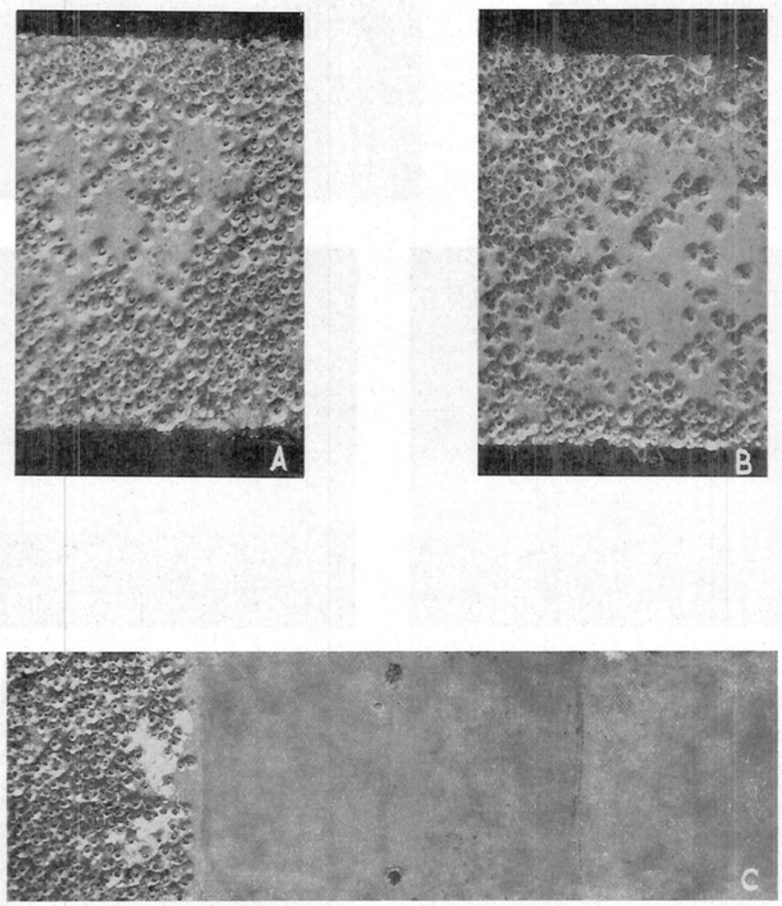


PLATE 5.—*A, B,* colored glass plates 4 × 6 inches, fouled after 48 days in sea: *A,* green; *B,* red. *C,* Masonite panel, 6 × 17.5 inches, in sea 139 days; left section coated with Kress green enamel plus 1 gram $HgCl_2$ per 4.74 fluid ounces, other sections, left to right, coated with Federal Antifouling, Marine Green, and Cape Cod.

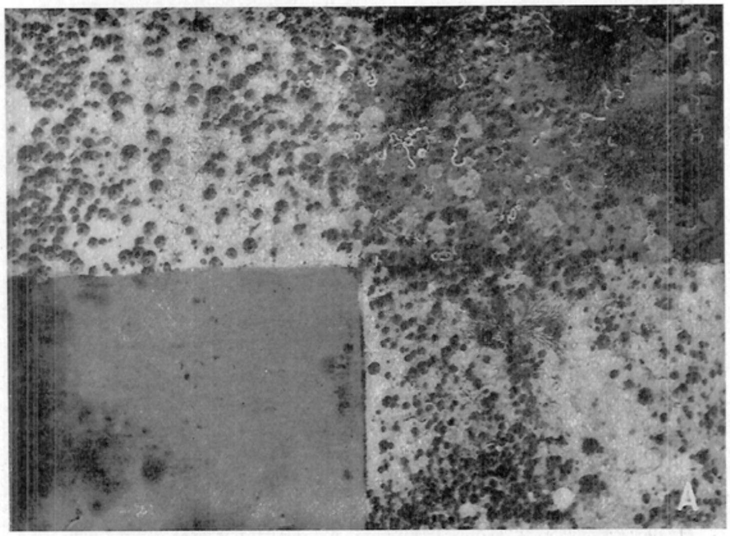
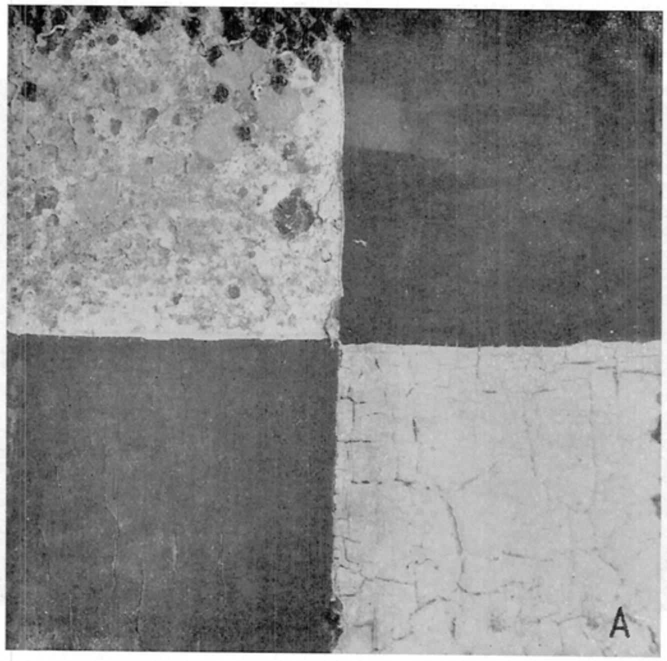


PLATE 6.—*A,* wood panel, 8.5 × 12 inches, in sea 67 days: Areas coated as follows: upper left, Superwhite enamel plus 10 grams Cu_2O, 5 grams As_2O_3 and 5 grams ZnO_2 per 4.74 fluid ounces; upper right, Kress Lettuce Green enamel, normal; lower left, Yacht Green; lower right, Superwhite enamel, normal. *B,* Masonite panel, 8 x 12 inches in sea 9 months and 18 days: coatings as follows: upper left and lower right, Superwhite enamel, normal; upper right, Yacht Green, lower left, Copper Red.



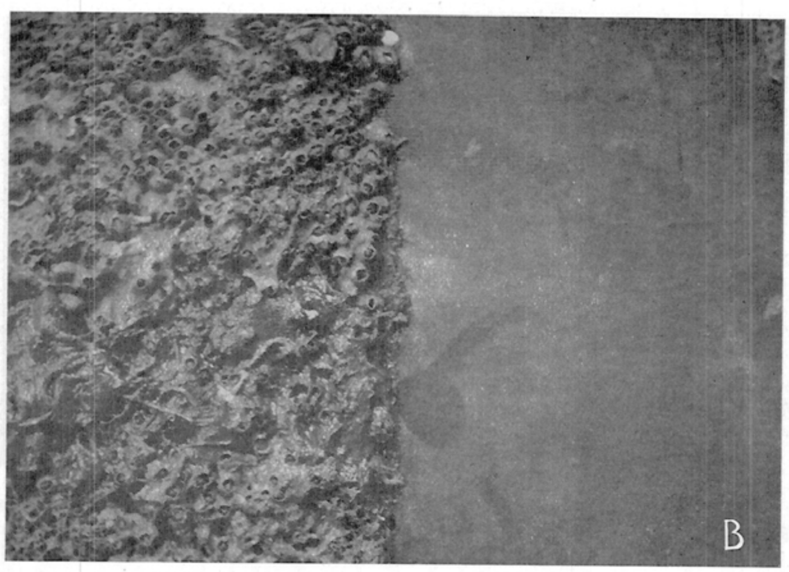
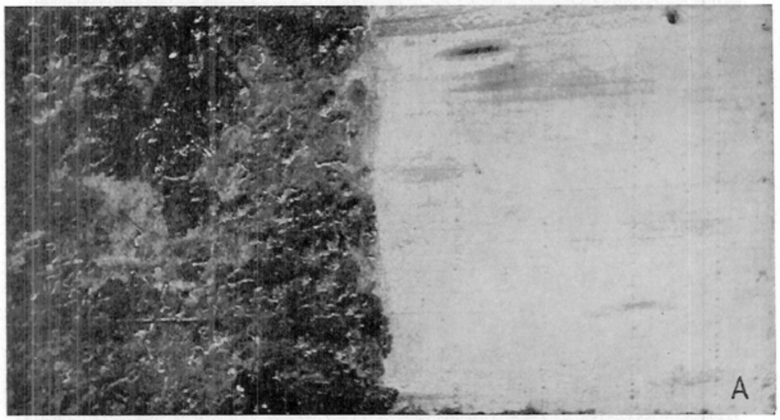


PLATE 7.—*A*, wood panel 12 × 12 inches, in sea 115 days: Coatings as follows: upper left Superwhite enamel plus 5 grams Cu_2O per 4.74 fluid ounces; upper right, Federal Antifouling; lower left, Cape Cod; lower right, Antifouling Composition. *B*, Masonite panel, 8.5 × 12 inches, in sea 383 days. Left half unpainted; right half painted with Cape Cod.



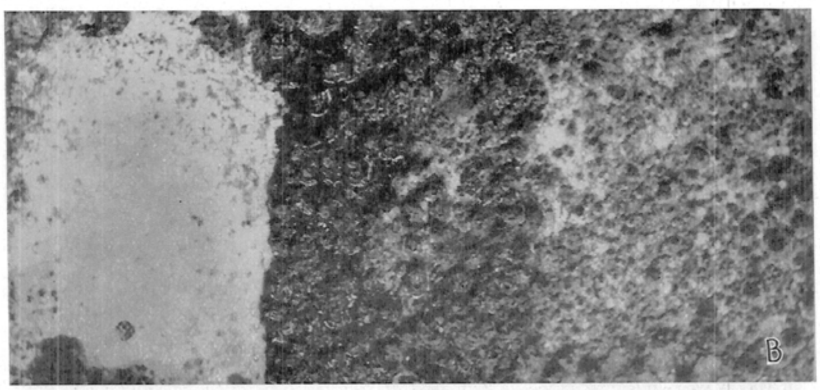
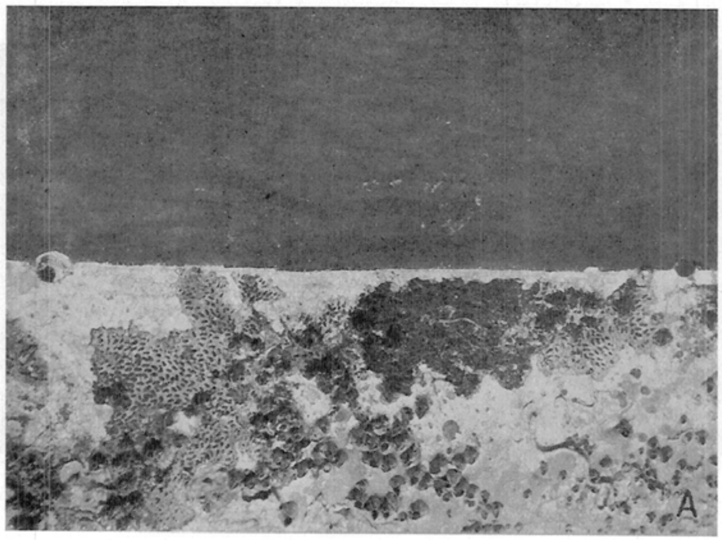


PLATE 8.—*A*, wood panel, 9.5 × 18 inches, in the sea 122 days: Coated with Kress white enamel, left half normal; right half plus 30 grams $HgCl_2$ per 4.74 fluid ounces. *B*, Masonite panel, 6 × 12.5 inches, in sea 3 months and 14 days. Coated with Kress white enamel, left third plus 1 gram $HgCl_2$, right third plus 1 gram Cu_2O and middle third 1 gram KCN, each per 4.74 fluid ounces.



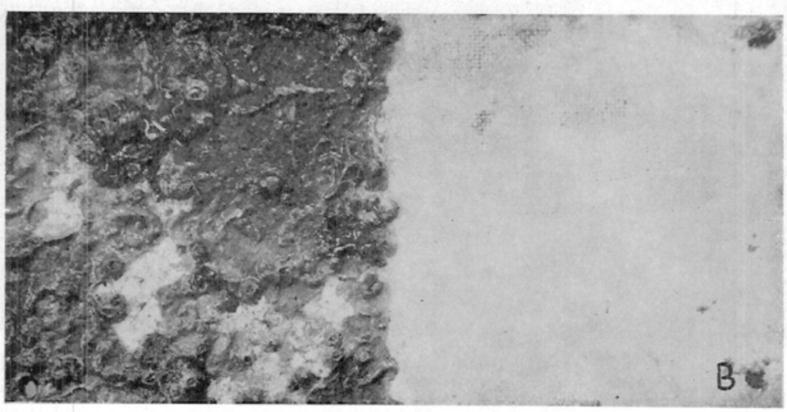


PLATE 9.—*A*, Masonite panel, 9 × 12 inches, in sea 133 days: Upper half coated with Antifouling Germicide, lower half with Superwhite enamel plus 10 grams $HgCl_2$, 5 grams Cu_2O, and 5 grams As_2O_3 per 4.74 fluid ounces; *B*, Masonite panel, 8 × 14 inches, in sea 177 days: Left half coated with Glidden white enamel, normal; right half with Antifouling Composition.