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NATURE AND EXTENT OF FOULING OF SHIPS' BOTTOMS

By J. PAUL VISSCHER

For the Bureau of Construction and Repair, U. S. Navy Department

DEPARTMENT OF COMMERCE

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INTRODUCTION

STATEMENT OF THE PROBLEM

Fouling of ship's bottoms is an accumulation of plant and animal organisms, which attach and grow on both wooden and metal ships. This accumulation of material consists of many species of animals and plants, which find the bottom of a vessel a favorable place of abode. All who have ever been at a seacoast have noted the crowded growths of "seaweed," barnacles, "moss," corals, and the like that frequently cover almost all structures that are either totally or partially submerged and that afford a place of attachment. It is this type of growth, in the main, that attaches to the hulls of boats and causes them to be "fouled." In its broadest usage, this word covers not only the effects of organisms that grow on ships, but also of those that burrow into them (in the case of wooden vessels), and has even been used to include the deleterious effects of corrosion on metal ships. In this paper only the first and original idea of this term will be considered, inasmuch as the effect of marine borers recently has been studied extensively by others (Atwood, 1924), while the problem of corrosion has but little relation to this biological study.

The economic importance of the fouling of ships' bottoms rarely is realized by anyone who is not informed regarding the very special problems relating to the maintenance of ships. The factors that contribute to the importance of this problem may be outlined briefly, as follows:

1. Speed diminished up to 50 per cent.
2. Voyage delayed from 10 to 50 per cent of total time.
3. Increase in fuel consumption up to 40 per cent additional.
4. Increase in wear and tear on machinery.
5. Necessity for dry docking, cleaning, and painting after every six or eight months.
6. Loss of time for above, amounting to about one month out of every year.

It has been estimated conservatively that more than $100,000,000 is spent annually by the shipping interests of the United States alone because of fouling. When one realizes that fouling often increases the resistance of a ship in water, so that the fuel consumption must be increased 30 per cent in order to maintain a given speed, and that for more than half of the time between dry dockings for any vessel that operates at sea, after the first month, such costs probably are increased by a minimum of 10 per cent, the expense due to increased fuel consumption alone assumes large proportions.

It is the practice of most shipping concerns to "clean" the bottoms of their vessels every six or eight months. In order to do this the bottoms are exposed to view, either by the use of dry docks or marine railways. The former are of two types—the graving dry dock and the floating dry dock. Lighter craft frequently are removed from the water by a marine railway. The cost of maintaining and operating such equipment can be charged largely to fouling. The large sums of money involved can be realized when one learns that it costs approximately $100,000 to dry-dock, clean, and paint the bottom of a vessel such as the *Leviathan* or the *Majestic*, for these ships have more than an acre of surface exposed to the action of the sea and which must be cleaned and painted every time these vessels are dry-docked. It must not be forgotten, also, that during the period in dry dock the cost of maintaining the ship and its crew remains constant, while the operating income is reduced to nothing. The time spent in dry dock varies with conditions from three days to three weeks, or more; but for the ships listed in this report the average is seven or eight days. This process of cleaning is illustrated in Figure 1.

In addition to its economic importance, this problem has an important relation to the question of national defense. An able Navy has long been held to be the greatest force for defense that a country such as the United States can possess. Under present conditions, speed of such vessels is of increasing importance. If, then, fouling decreases the speed by as much as 40 per cent, the efficiency of such crafts is lost and critical delays might result.

From a biological point of view, this problem has several interesting aspects. The ecology of the organisms that live at some depth in the ocean has been difficult to study, because it has been impossible to bring them to the surface in sufficient

Fig. 1.—Process of cleaning the hull of a ship after dry-docking. The U. S. S. *Owl* at the Norfolk Navy Yard, June 6, 1925

numbers accurately to determine their relations as life communities. When, however, the bottom of a ship is raised out of water, these communities, in their entirety and uninjured, can be seen and qualitative and quantitative studies can be made. The effect of depth in producing distinct zonations may be studied easily on ships' bottoms, and these special groups of organisms can be studied thus in detail.

The study of this problem also presents data for the solution of the problem of geographical distribution. It has long been a debated question whether a given species of barnacle or other organism attached to the bottom of a boat can survive transportation to another port and continue to live and reproduce its kind. Whether one can explain the mundane distribution of some species of organisms in this manner never has been determined.

Data have been obtained that have a specific bearing on the question of the effect of pollution in our harbors and the ability of some types of organisms to survive. The rate of growth of different kinds of organisms can be studied from these data, as can also the problem of seasonal variation in their abundance. The effects of various poison paints, of sunlight, temperature, salinity, and of tidal currents are all of interest in a biological study of this problem and have been considered wherever possible during this investigation.

The author was assisted in the examination of ships by F. A. Varrelman and in some of the experimental studies by R. H. Luce. To the authorities of the Bureau of Fisheries and of the United States Navy, as well, and especially to Capt. Henry Williams, he is very grateful for many courtesies and continued interest in this work. For the use of laboratory facilities during the course of this investigation he is grateful to the directors of the zoological laboratory of the Johns Hopkins University, of the United States Fisheries laboratories at Woods Hole, Mass., and Beaufort, N. C., and of the biological laboratory of the Western Reserve University at Cleveland, Ohio.

HISTORY OF THE PROBLEM

The problem of fouling growths on the hulls of ships naturally is not a new one, for fouling has occurred ever since ships first were used. We seem to have no record regarding the earliest methods of prevention, but Atheneus (200 B. C.), quoted by Ewbank, informs us that "the ships of Archimedes were fastened everywhere with copper bolts and the entire bottom [of wood] was sheathed with lead." Alberti [in his work on architecture, published in the fifteenth century] tells us that a ship called "Trajans ship" was salvaged from Lake Riccia, where it had been submerged for more than 1,300 years, and that "over all, there was lead, fastened on with copper nails."

Young (1867) records the fact that a Roman ship, sunk in the Lake of Nemi, was found to have been coated with bitumen, over which sheets of lead had been nailed. The seams of the vessel were caulked with "tow and pitch," the hull being made of larch wood. In the reign of Henry VIII (1510 to 1547) vessels were covered with a coating of loose animal hair, attached over pitch, over which a sheathing board about an inch in thickness was fastened to keep the hair in its place. In the reign of Charles II (1660 to 1685) "the *Phoenix* and 20 other of His Majesty's ships were sheathed with lead and fastened with copper nails." That these methods were not satisfactory is seen from the fact that none has persisted, for we find that during the eighteenth century the sheathing generally in use "was a doubling of the skin of a ship with wood, which was kept constantly payed with tar and grease, or mixtures of such compounds."

The prevention of fouling, then, has been a problem persisting through the centuries, which has taxed the skill of ingenious sea captains for hundreds of years; and the fact that it still occurs indicates the extremely difficult nature of its solution. In earlier times it was the general practice for vessels to be cleaned by the scouring action of the surf. A favorable beach was selected and the vessel carefully beached in such a manner that the surf, loaded with sand and broken shells, would scour the sides of the vessel and rid it of its fouling materials. Other vessels were run into fresh water at frequent intervals (a method still employed to a limited extent) and the organisms normally living in salt water would die and in some instances fall off, thus ridding the hull of its fouling. More recently the vessels were beached at flood tide and, allowing the vessel to list as the tide ebbed, were cleaned as the water would leave the vessel high and dry.

It has been the goal all along, however, to prevent the attachment of these organisms. That many people have been interested in this problem is indicated by the fact that in England, previous to 1865, according to Young (1867), more than 300 patents had been issued for antifouling materials; while in America 166 patents were issued prior to 1922, as found by Gardner (1922). The following quotation from his paper (p. 43) will serve to give some idea of the great variety of materials that have been employed within the last century.

> Amongst the many materials for prevention of fouling and corrosion of iron ships which have had patents taken for their use or been experimented with will be found silicates, quicksilver, plumbago, gutta percha, asphalte, shellac, guano, cow dung; now comes a powerful compound consisting of "clay, fat, sawdust, hair, glue, oil, logwood, soot, etc.," mixed, "to be plastered on the ships' bottoms"; then we have "emery, shellac, and castor oil"; next "pitch, tar, and shellac"; next comes another peculiar mixture, "baryta, litharge, arsenious acid, asphaltum, oxide calcium, and creosote"; than another, "Burgundy red earth, grease, lime, unburnt earthenware, chalk, or Roman cement." Next follows a very curious composition consisting of "grease from boiled bones, kitchen stuff, and butter without salt, mixed with poisonous materials." Now we have the grand chef-d'oevre of the whole, which is described thus: "Sugar, muriate of zinc and copper, and the sirup of potatoes or sugar with powdered marble quartz or feldspar." The last one, which will be noticed consists of "asafoetida with pitch, tar resin, and turpentine smeared over the bottom, and then coated with paper or cloth." Who will say, after this, that poisoning and physicking have not had their fair chance?

More modern methods, however, have centered around the idea of poison paints, for with the advent of iron ships the use of metals as sheathing was rendered impossible because of the electrolytic action in sea water and the consequent disintegration of the iron of the ship. Many types of antifouling paints containing posions are offered under various trade names, but none has yet been found which is satisfactory under all conditions. Indicative of the types of many of these paints are the two following, used by the Navy as its standard antifouling compositions in 1922 and 1925, respectively:

1922 NAVY STANDARD ANTIFOULING PAINT (Per gallon of paint)	1925 NAVY STANDARD ANTIFOULING PAINT (Per gallon of paint)
2,248 cubic centimeters denatured ethyl alcohol.	1,196 grams mineral spirits.
355 cubic centimeters pine tar oil.	306 grams pine oil.
355 cubic centimeters turpentine.	564 grams coal tar.
680 grams gum shellac.	923 grams resin.
680 grams zinc oxide, dry.	923 grams zinc oxide.
680 grams iron oxide.	616 grams iron oxide.
336 grams mercuric oxide.	410 grams mercuric oxide.
	515 grams cuprous oxide.
	329 grams silica.

Even before the use of steel ships, methods employed to limit the extent of fouling made use of various paints, many of which contained copper and mercury as poisons. In reviewing the methods followed until recently for the prevention of fouling one can not but be impressed with the fact that these methods have been governed largely by haphazard experiment and rule-of-thumb procedure. Precedence apparently has been relied upon more than any analysis of the factors involved. Progress under these conditions naturally is a matter of tardy development and slow improvement. Consequently, in an attempt to obtain more efficient paints the United States Navy has undertaken an extensive investigation of the entire problem, using a great variety of posions in as many paints. It was soon realized, however, that a careful study of the organisms responsible for the foul condition would be of considerable value, and at the request of the Navy Department, and with its support, this investigation of the fouling agencies has been made under the direction of the United States Bureau of Fisheries.

Although foul conditions on the bottoms of ships have been studied for many years, such studies have related almost entirely to the effects of fouling and to means of preventing it. Thus we find treatises such as that by Young (1867) on "The Fouling and Corrosion of Iron Ships," and many articles, from time to time, in transactions of such organizations as the British Institute of Naval Architecture and the American Society of Naval Architects and Marine Engineers. One of the most recent and comprehensive of such papers is entitled, "Notes on Fouling of Ships' Bottoms, and the Effect on Fuel Consumption," by Capt. Henry Williams, C. C., U. S. N. (1923). Many articles dealing with the effect of fouling, especially with its relation to resistance, have appeared in these journals (McEntee, 1915), but these have not concerned the nature or extent of fouling.

The growths on the bottoms of ships have been studied by many naturalists interested in collecting rare species of organisms and in systematic studies of various groups of animals and plants. Thus, Charles Darwin (1853) and H. Pilsbury (1916), in their respective treatises on barnacles, both record many of their specimens as having been secured from ships' bottoms.

At the time this investigation was begun (September, 1922) no study was known that dealt with the nature and extent of these growths. Since that date, however, two articles by Hentschel, working at Hamburg, have appeared, which deal with "Growths on Marine Vessels." The former (1923) is an ecological study based on the examination of 48 vessels, while the second (1924) is a preliminary study of seasonal distribution of the organisms that cause fouling of ships, made while on board a vessel cruising from Hamburg to the West Indies and Central America.

METHODS

In order to determine adequately the nature and extent of fouling of ships on the Atlantic coast, it was arranged that the author be notified of the proposed dry docking of all the larger naval craft at several of the United States navy yards, and also by the United States Shipping Board regarding many of their vessels. This enabled the author or an assistant to be present at the time of docking of more than 250 vessels. Notations were made in each case of the relative amount of fouling and its distribution on the various parts of the hull. Collections of representative samples were made, which were preserved and carefully examined later in the laboratory. Since the material was frequently in a very poor condition when collected, due, usually, to pollution of the harbor waters and to consequent death and partial decay of the growths, exact determinations were not always possible, especially with hydroids, where one often found only empty "stems." For determination of the total amount of fouling present, known areas were scraped carefully and the material collected, measured, and weighed while wet; and in some cases the relative amounts of each of the fouling agencies were determined. In addition, the itinerary of each vessel was secured whenever possible, and the date of previous docking also was obtained. For the great majority of vessels examined the paint used was the "United States Navy standard" (used by the Shipping Board as well as the Navy), and notation was made of all exceptions. On the data thus obtained the following report is based.

However, in order to determine more accurately the validity of some of the theories that presented themselves during the course of this investigation, considerable experimental work was carried on simultaneously, and the results of these experiments also are included in their appropriate places.

NATURE OF FOULING

As previously stated, the fouling of ships' bottoms is caused by growths of both plants and animals. Among the workers at the dry docks one hears the terms "grass," "moss," and "corals" as describing the types of growths found on ships. It is quite evident that the term "grass" is commonly applied to the stems, or cœnosarcs, of hydroids, and that the term "moss" is applied to the various seaweeds, usually green algæ, which are found so commonly near the water line. The term "shells" includes all shelly growths, such as barnacles, oysters, clams, mussels, and even certain Bryozoa; but more commonly barnacles are recognized as distinct from the other "shells," while the corals so frequently mentioned are probably Byrozoa, for coral itself has been found rarely.

These groups of organisms, then—barnacles, algæ, hydroids, mullusks, Bryozoa, and tunicates—make up the preponderance of the growths that are found on the bottoms of ships. In the determination of the forms collected it has often been quite impossible to ascertain the exact species with finality. This was due to the fact that many of the growths either were dead, and all their soft parts entirely gone, or they were but recently dead and in a putrid condition when the ship was docked and the collections made.

LIST OF THE SPECIES OF ORGANISMS COLLECTED FROM SHIPS' BOTTOMS

Animals:
- Phylum ARTHROPODA—
  - Class CIRRIPEDIA (barnacles)—
    - Balanus improvisus.
    - B. eburneus.
    - B. amphitrite.
    - B. tintinabulum.
    - B. crenatus.
    - B. harmeri.
    - B. tulipiformis.
    - B. perforatus.
    - Balanus sp.?
    - Chthamalus fragilis.
    - Lepas anatifera.
    - L. anserifera.
    - L. hillii.
    - Conchoderma aurita.
    - C. virgatum.
    - Pæcilasma crassa.
- Phylum MOLLUSCA—
  - Class PELECOPODA—
    - Mytilis edulis.
    - M. hamatus.
    - Mya sp.?
    - Ostrea elongata.
    - Anomea ephippium.
    - Anomea sp.?
  - Class GASTEROPODA—
    - Crepidula fornicata.
    - Nudibranchiata sp.?
- Phylum COELENTERATA—
  - Class HYDROZOA (hydroids)—
    - Eudendrium ramosum.
    - Eudendrium sp.?
    - Tubularia crocea.
    - T. couthouyi.
    - Tubularia sp.?
    - Campanularia amphora.
    - C. portium.
    - C. vorticellata.
    - Campanularia sp.?
    - Bougainvillia carolinensis.
    - Obelia commissuralis.
    - O. gelatinosa.
    - Obelia sp.?
    - Perigonimus jonsii.
    - Podocoryne sp.?
  - Class ANTHOZOA—
    - Metridium sp.?
    - Segartia luciæ.
    - Astrangia sp.?
- Phylum PROTOZOA—
  - Class INFUSORIA—
    - Vorticellidæ.
    - Folliculina sp. ?

Animals—Continued.
- Phylum BRYOZOA—
  - Class ECTOPROCTA—
    - Bugula turrita.
    - Bowerbankia caudata.
    - B. gracilis.
    - Anguinella palmeta.
    - Alcyonidium mytili.
    - A. gelatinosum.
    - Membranipora monostachys.
    - M. lacroixii.
    - M. liniata.
    - Membranipora sp.?
    - Lepralia pertusa.
    - Crissia sp.?
- Phylum ANNELIDA (worms)—
  - Class POLYCHÆTA—
    - Hydroides hexagonis.
    - Hydroides sp.?
    - Nereis pelagica.
    - Glycera sp.?
- Phylum CHORDATA—
  - Class TUNICATA (sea squirts)—
    - Molgula manhattensis.
    - M. arenata.
    - Botryllus arenata.
    - B. schlosseri.
    - B. nigrum.
    - Ciona intestinalis.

Plants:
- Division ALGA—
  - Class CYANOPHYCEÆ—
    - Oscillatoria lætevirens.
  - Class CHLOROPHYCEÆ—
    - Cladophora sp.?
    - Enteromorpha intestinalis.
    - E. torta.
    - E. chætomorphoides.
    - E. marginalis.
    - Enteromorpha sp.?
    - Ulothrix flaca.
    - Ulva lactuca.
    - Vaucheria sp.?
    - Acrochætium sp.?
  - Class PHÆOPHYCEÆ—
    - Ectocarpus sp.?
    - Fucus sp.?
  - Class RHODOPHYCEÆ—
    - Polysiphonia nigrescens.
    - P. violacea.
    - Polysiphonia sp.?

In the foregoing list are given the organisms collected from ships' bottoms and identified as far as the condition of the material would permit. By referring to this list it will be seen that 48 species of animals have been found, in addition to 13 types that could be classified only as to genera; while all of the plants found were algæ, of which 16 kinds were recognized.

As will be seen, the largest number of forms is found in the group of barnacles. (Figs. 2 and 3.) These organisms vary greatly in size and shape, many kinds never growing more than one-fourth inch in diameter, and often not so high. Some species, however, notably those that attach on ships in tropical waters, grow to a very considerable size—4 inches in diameter and 6 inches in height. Very frequently they are found growing one upon another, so that the height of a cluster occasionally may reach 8 or even 10 inches. Most barnacles are protected by means of hard calcareous plates, which surround the animal, forming a sort of shell. These plates vary in number, with the kind of barnacle, from four to very many; but the more common forms (Balanus) all have six plates or compartments forming the walls of the shell and two pairs of plates that comprise the top or covering of the shell, and which are arranged like valves. Between these valves the animal extends its thoracic appendages when feeding. (Fig. 4.) This peculiar habit has given rise to a popular description of a barnacle as an "animal which stands on its head and kicks its food into its mouth." Some barnacles, however, do not form heavy calcareous shells and are very much elongated. (Fig. 5.) These are commonly called "gooseneck" barnacles and include the last six species of barnacles listed on page 199. Since the "neck" or stalked portion of this type of barnacle is not protected by shelly structure, such growths fall off upon the death of the organism; but all other types of barnacles leave behind them their shells or houses, which frequently persist for many years if not forcibly removed.

Barnacles have a complicated life history. The eggs are fertilized within the body chamber of the adult and held in lamellar folds until the young are hatched. The almost microscopic larval organism is free-swimming, with three pairs of appendages and a single median eye, and is known as the "nauplius." (Fig. 6 *A*.) After a period varying from 1 to 10 days, or more, these nauplii metamorphose into tiny bivalved forms called the "cyprid" larvæ. (Figs. 6 *B*, *C*, and *D*.) At this time the larval barnacle has six pairs of appendages, like the adult, and two long antennæ with many sensitive hairs or bristles. The median eye is sometimes lost, and paired compound eyes are always present.

These young barnacles, resembling miniature clams, float and swim about for a considerable time, often for two or three months, and finally attach by use of apparently adhesive pads on the tips of the two antennæ. (Figs. 6 *B* and *C*.) After attachment, they metamorphose into the adult stage, miniature at first but growing rapidly to full size. At the time of this radical change the eyes apparently are lost in some forms. It is the study of these cyprid larvæ at the time of attachment, of course, which is of fundamental importance in an investigation of the fouling of ships' bottoms.

It is of interest to note that of the 150 species of barnacles listed by Charles Darwin in his monograph of 1853, only 15 kinds have been found on ships examined for this investigation, and that all of the commonest are typical shore forms, normally inhabiting shallow water (and rarely living at depths in excess of 10 fathoms), such forms as are found in most harbors and sheltered coastal areas.

The hydroids are the next most numerous animal group, with 15 types found during the investigation. Hydroids usually are colonial in their growth and have an even more complicated life history than do the barnacles. These growths begin

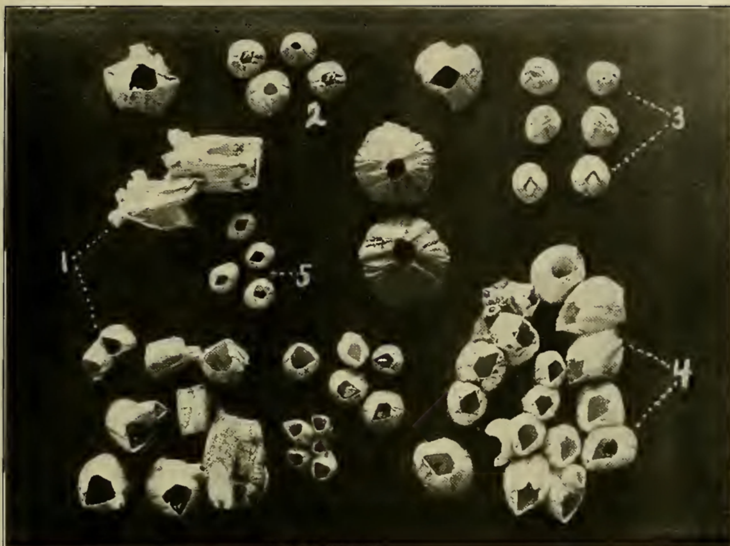


Fig. 2.—Sizes and shapes of sessile barnacles found on ships, bottoms. 1, *Balanus tintinabulum;* 2, *B. crenatus;* 3, *B. improvisus;* 4. *B. eberneus;* 5, *B. amphitrite*

Fig. 3.—Sizes and shapes of sessile barnacles found on ships' bottoms. A cluster of *B. tintinabulum*

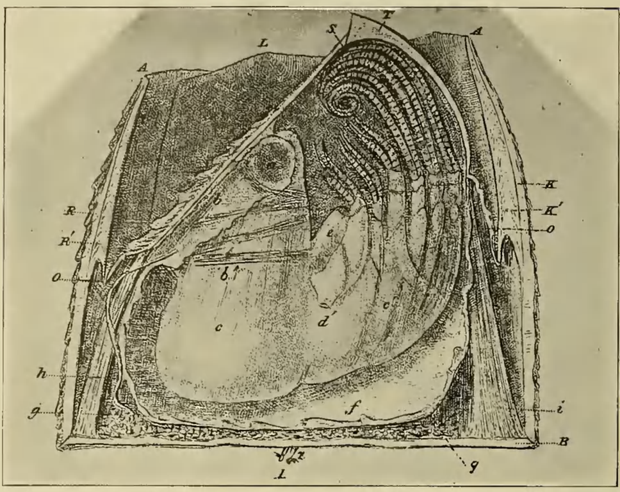


Fig. 4.—Internal structure of a typical sessile barnacle. (After Darwin)

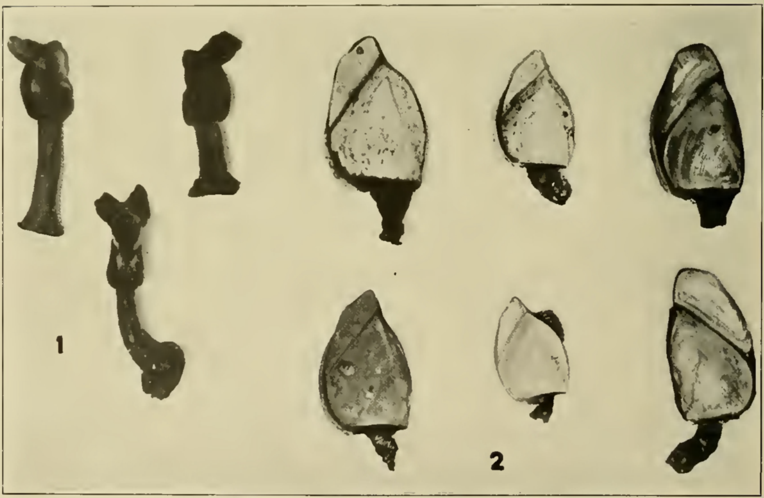


Fig. 5.—Stalked barnacles collected from ships' bottoms. 1, Conchoderma; 2, Lepas

after attachment of a free-swimming larva, which changes its form completely upon fixation and produces a stalked growth or stolon. In many forms this stalk branches profusely and forms a treelike structure, often attaining a length of 6 or 8 inches. (Fig. 7.) Here, too, the living animal is inclosed within a chitinous sheath, which

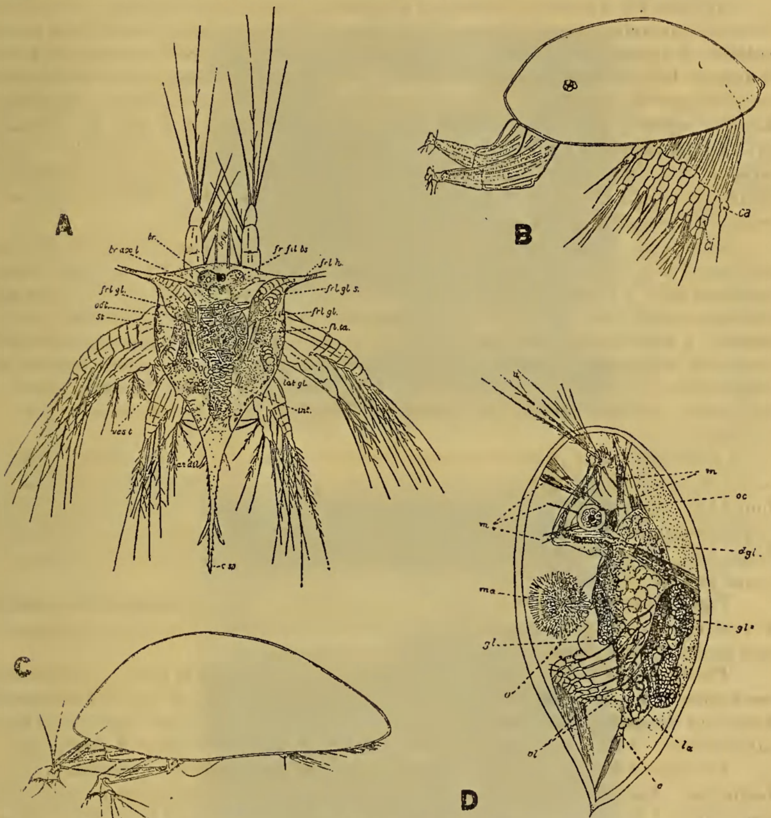


Fig. 6.—Larval stages in the development of barnacles and the condition of the antennæ at the time of attachment. *A*, dorsal view of the nauplian larva of *Balanus perforatus* (after Groom); *B*, cyprid larva of *Tetraclita divisa* (after Nilsson Cantell); *C*, cyprid larva of Scapellum (after Nilsson Cantell); *D*, lateral view of a cyprid of *Lepas fasiculatus*, showing internal anatomy (after Willemoes, as in Hoek)

persists (especially in the case of Tubularia) for many months after the death of the organism. Since these colonial organisms obtain their food by means of feeding polyps, which are situated at the ends of the stalk or its branches, and since all other parts of their bodies are protected by the chitinous *hydrotheca,* it is apparent that after attachment, in the case of these organisms as well as of the barnacle, they are completely resistant to any ingredients of a paint film. The problem of prevention of fouling accordingly resolves itself into one of prevention of attachment of these forms.

Bryozoa are a group of organisms abundantly present on all marine coasts but much less abundant now than in prehistoric times. The great majority of them form colonies of thousands of relatively small individuals, each of which is surrounded by a more or less chitinous or calcareous shell. They may be either aborescent in their form of growth, as Bugula (fig. 8 *A*), or more commonly they form an encrusting lamellar growth, as in the case of Membranipora. (Figs. 8 *B* and *C*.) These growths frequently vary greatly in their form and may produce "sea mats" and coraline structures, which may form growths 6 to 8 inches in height and 12 inches in diameter. Each colony originates from a single minute larva, which has a free-swimming period persisting from one to many hours.

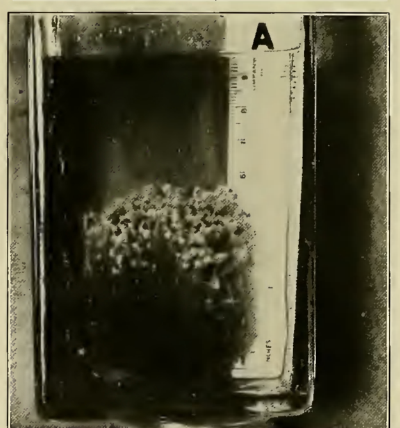
In the case of mollusks, such forms as oysters and anomia attach directly to the surface of the vessel and may grow to considerable size. Thus, oysters have been collected fully 5 inches in length and 3 inches in width. (Fig. 9.) Such forms as Mytilis, on the other hand, attach by means of byssal threads, and although they grow to a very considerable size (fig. 9), upon the death of the organisms the shell drops off, although the byssal threads may still persist for many years, leaving a telltale story of their former presence. These forms, also, at the time they attach, are minute, free-swimming larvæ, which in several cases are known to be sensitive to light.

Of the annelids, only one type occurs at all abundantly, this being the serpulids, which form calcareous, tube-shaped shells. (Fig. 10 *B*.) Hydroides tubes have been found fully 3 inches long, and on a few ships in large numbers. This is the only type of this group that has been found attaching directly to the hull, the other forms listed being only casual inhabitants of the rich growths, both faunal and floral, that are found on some ships.

The Protozoa, unicellular forms, are indicative of the environment in which the ship has been. The Vorticellidæ, in particular, indicate a putrid environment and on some ships were very abundant.

The tunicates, or sea squirts, are both solitary and colonial in type. The former were found more often and frequently grew to large size. (Fig. 10 *A*.) The colonial forms are incrusting types and do not produce as large an amount of growth as the other forms. These, too, are free-swimming organisms at the time of attachment.

The algæ were the most ever-present form, with the possible exception of the barnacles. They frequently formed heavy mats of growth, extending from the water line to from 1 to 8 feet below. Although individual growths might be of little consequence, the large numbers frequently made the mass appear much like a beautiful lawn. In many cases the growths of algæ, especially the Enteromorpha, would attain a length of 7 to 10 inches. It is interesting to note that both the Enteromorpha and Cladophora are remarkable for the fact that many of their species are found indifferently in both salt and fresh water, and that they are characteristic plants of the littoral zone, rarely, if ever, extending into the sublittoral.



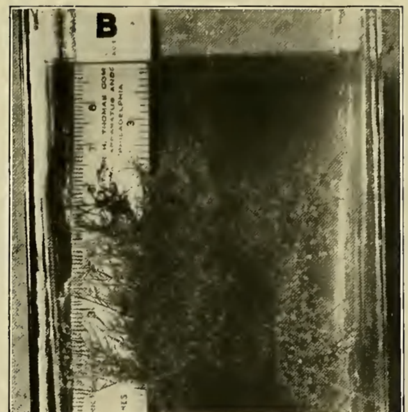
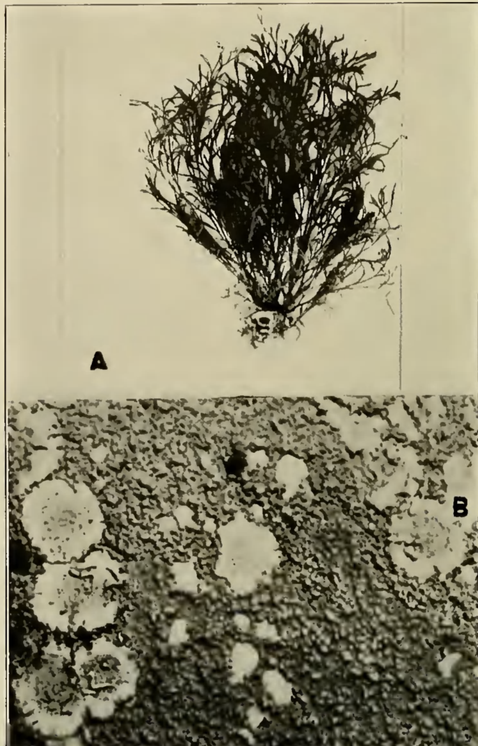


FIG. 7.—Types of hydroids found on ships' bottoms, collected from the U. S. S. *Florida*. A, a cluster of Tubularia; B, a cluster of Eudendrium



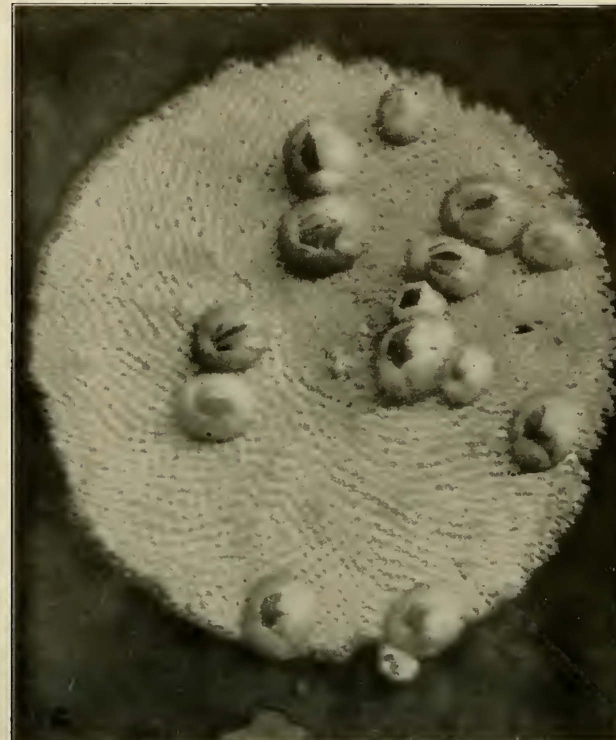


Fig. 8.—Types of Bryozoa (Polyzoa) that cause fouling on ships' bottoms. A, colony of Bugula; B, several colonies of Membranipora from 4 to 6 inches in diameter; C, colony of Membranipora photographed on the hull of the U. S. S. *Texas*, showing *Balanus improvisus* growing upon it

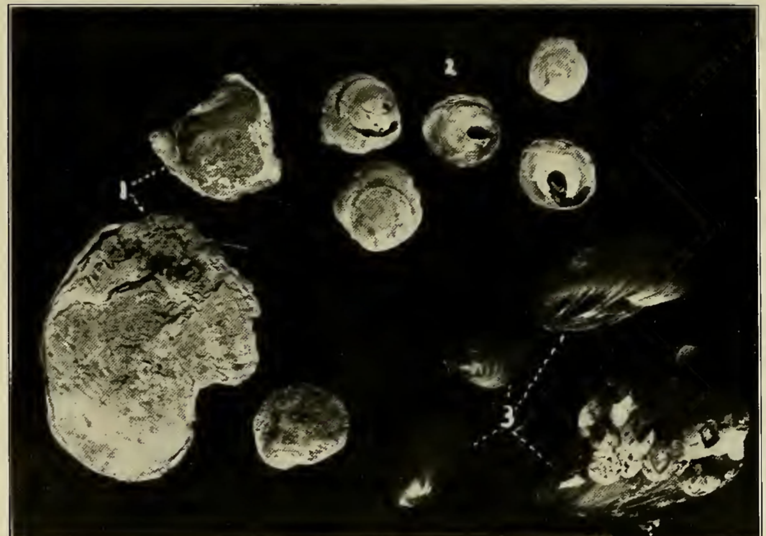
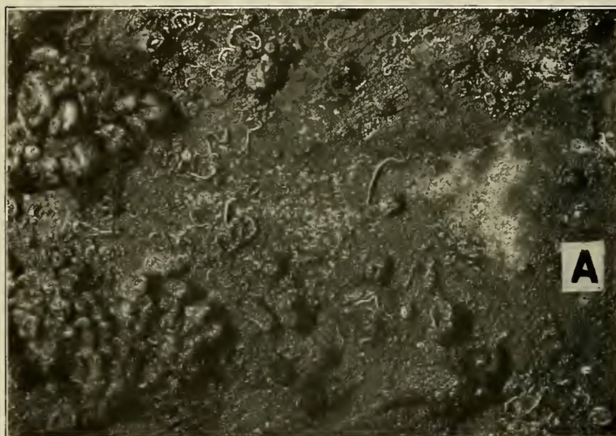


Fig. 9—Types of mollusks found as fouling on ships' bottoms. 1, Ostrea; 2, Anomia; 3, Mytilus



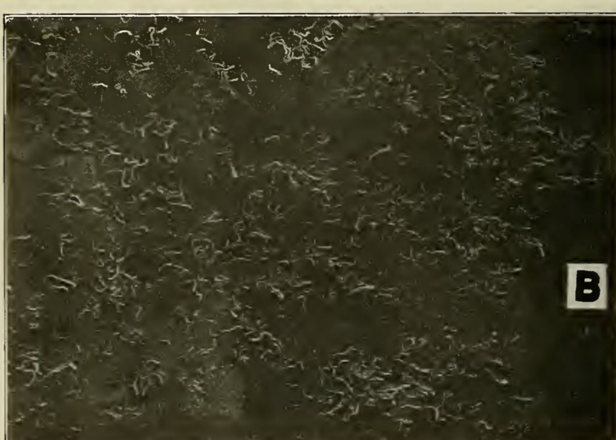


Fig. 10.—Types of fouling. **A,** clusters of the tunicate (sea squirt) Ascidia. **B,** numerous specimens of the serpulid worm Hydroides, showing the calcareous tubes in which they dwell

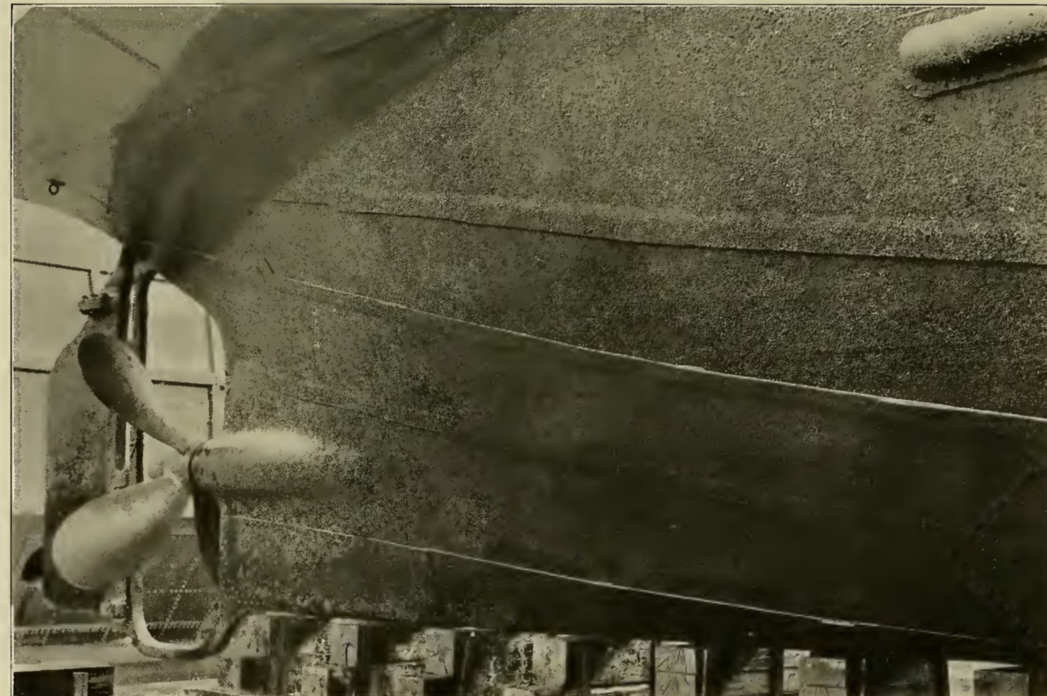


FIG. 11.—Relative amounts of fouling on ships. U. S. S. *Owl* lightly fouled

Fig. 12.—Relative amounts of fouling on ships. A barge at the Norfolk Navy Yard moderately fouled

[Fig. 13.—Relative amounts of fouling on ships. U. S. S. *Chester* heavily fouled

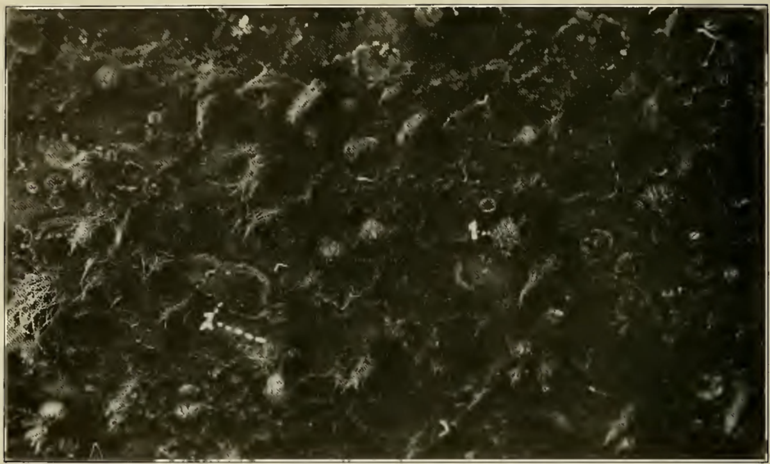


Fig. 14.—Amount and type of fouling. 1. Balanus; 2, Bryozoa; 3, Hydroides

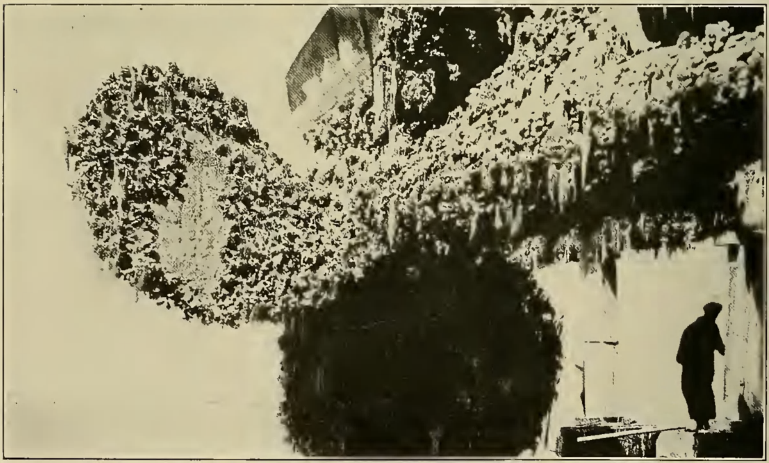


Fig. 15.—Amount and type of fouling. Heavy accumulation of hydroids, tunicates, and barnacles on propeller and struts

EXTENT OF FOULING

The prevalence and amount of fouling is surprising to anyone who witnesses for the first time the docking of marine vessels. In earlier times it was not uncommon for ships to have their entire bottoms incrusted with organisms to a depth varying from 5 to 9 inches, with estimated weights of 300 tons or more. In recent years, due especially to more regular and frequent dry docking, such conditions are experienced but rarely; but even to-day, after vessels have been at sea for 6 or 8 months, they frequently accumulate growths from 2 to 3 inches in depth, and vessels with from 50 to 100 tons of fouling are seen frequently. When one realizes that all ships become foul if submitted to the usual environment, the extent and prevalence of fouling can be realized. In Figures 11, 12, and 13 are shown conditions typical of lightly, moderately, and heavily fouled ships, while in Figures 14 to 19 are seen the kinds of growths contributing to these conditions.

In Table 1 is given a list of all of the vessels examined during this investigation, with notations regarding the amount of fouling on each. By reference to this table it can be seen that there is great variation in the amount of fouling on various ships. The reasons for this will be discussed under separate headings in another section of this paper dealing with the factors that determine fouling.

TABLE 1

Ship	Type	Date examined	Period out of dock (in months)			Waters cruised	Degree of fouling				Predominating type of fouling organism
			Total time	Time cruising	Time in port		Heavy	Moderate	Light	None	
Proteus	Collier	Sept. 28, 1922	11.0	2.0	9.0	Norfolk-Cuban waters	×				Barnacles, hydroids.
Maryland	Battleship	Oct. 12, 1922	2.3	2.0	.3	New York-Brazil			×		Algæ, barnacles.
Fish Hawk	U. S. B. F. vessel	Nov. 7, 1922	17.0	5.0	12.0	New York-Chesapeake		×			Hydroids.
West Virginia	Battleship	Nov. 21, 1922	12.0		12.0	Newport News, Va	×				Barnacles, hydroids.
Parker	Destroyer	Nov. 23, 1922	21.0	1.0	20.0	Charleston, S. C.-Philadelphia, Pa		×			Barnacles, mussels.
O'Brien	do	do	21.0	1.0	20.0	do		×			Oysters, barnacles.
Rail	Mine sweeper	Nov. 28, 1922	11.0	5.0	6.0	Cuban waters-Philadelphia, Pa	×				Algæ, Bryozoa.
Bobolink	do	do	19.0	9.0	10.0	do	×				Do.
Rochester	Cruiser	Dec. 5, 1922	14.0	4.0	10.0	Charleston, S. C.-Philadelphia, Pa		×			Barnacles, hydroids.
Washington	Battleship	Dec. 11, 1922	12.0		12.0	Philadelphia, Pa			×		Algæ.
Wright	Aircraft tender	do	13.0	3.0	10.0	Cuba-Chesapeake-New York		×			Barnacles, hydroids.
Wyoming	Battleship	Dec. 17, 1922	6.0	2.0	4.0	Chesapeake-Cuba-New York	×				Do.
Nevada	do	Jan. 5, 1923	5.0	2.0	3.0	New York-Brazil		×			Barnacles.
Kittery	Cargo ship	Jan. 22, 1923	8.0	5.0	3.0	Cuba-Chesapeake-New York			×		Algæ, barnacles.
Beale	Destroyer	Feb. 2, 1923	46.0	2.0	44.0	Philadelphia Navy Yard			×		Barnacles, hydroids.
Warrington	do	do	43.0		43.0	do			×		Do.
Henderson	Transport	Feb. 12, 1923	9.0	6.0	3.0	Japanese-Cuban via Panama Canal		×			Algæ.
Antares	Auxiliary	do	7.0	1.0	6.0	Chesapeake-New York-Philadelphia	×				Barnacles, hydroids.
America	Passenger	Feb. 24, 1923	7.0	7.0		Transatlantic			×		Algæ.
Eagle 44	Eagle boat	do	(?)	(?)	(?)	North River, New York, Ninety-sixth Street		×			Barnacles.
Eagle 48	do	do	(?)	(?)	(?)	Perth Amboy, N. J		×			Do.
Eagle 51	do	do	(?)	(?)	(?)	North River, New York, Ninety-sixth Street		×			Do.
American Legion	Passenger	Mar. 15, 1923	7.0	7.0		New York-Rio de Janeiro				×	
Denver	Cruiser	do	7.5	7.0	.5	New York-Cuba-Panama			×		Barnacles, hydroids.
Florida	Battleship	do	15.5	4.0	11.5	Boston-New York-Cuba	×				Hydroids.
President Monroe	Passenger	Mar. 22, 1923	6.0	0.0		(?)				×	
S. C. 103	Submarine chaser	do	21.0	3.0	18.0	New Haven, Conn		×			Barnacles.
S. C. 271	do	do	21.0	3.0	18.0	do		×			Barnacles, Bryozoa,
S. C. 143	do	do	24.0	4.0	20.0	North River, New York, Twenty-third Street	×				Barnacles.
Privateer	Naval yacht	do	0.0		0.0	New York Navy Yard				×	
Traffic	Naval tug	do	24.0	12.0	12.0	do				×	
East Wind	Freighter	Apr. 2, 1923	8.0	8.0		Australia-New York			×		Algæ.
Arkansas	Battleship	do	16.0	8.0	8.0	Cuban waters-New York	×				Barnacles.
Argonne	Transport	Apr. 5, 1923	11.0	7.0	4.0	California-Philadelphia via Panama Canal			×		Algæ.
Williamson	Destroyer	do	(?)	(?)	(?)	(?)			×		Barnacles, Bryozoa.
Orion	Collier	do	12.0	7.0	5.0	Chesapeake-Cuban		×			Do.
Cleveland	Cruiser	do	(?)	(?)	(?)	(?)	×				Do.
Eagle 54	Eagle boat	Apr. 14, 1923	(?)	(?)	(?)	North River, New York, Two hundred and twelfth Street.		×			Barnacles, hydroids.
Eagle 15	do	do	(?)	(?)	(?)	New London, Conn		×			Barnacles, Bryozoa.
Ossining	Freighter	do	11.0	10.0	1.0	New York-East coast South America			×		Algæ.
Natirar	do	do	5.5	5.5		New York-North Sea				×	
Maryland	Battleship	Apr. 16, 1923	7.0	2.0	5.0	Chesapeake-Cuban-New York		×			Do.
Reuben James	Destroyer	do	10.5	8.5	2.0	English-Chesapeake-New York		×			Algæ, barnacles.
Camden	Cruiser	Apr. 30, 1923	5.5	2.5	3.0	Seattle-New York via Panama Canal	×				Barnacles, algæ.
Independence	Freighter	do	7.5	5.5	2.0	Round the world via both canals		×			Algæ, barnacles.
St. Paul	Passenger	May 16, 1923	(?)	(?)	(?)	New York Harbor		×			Algæ.
William Penn	Freighter	May 15, 1923	7.0	6.0	1.0	Japanese-Philadelphia via Panama Canal		×			Barnacles.
Leviathan	Passenger	May 18, 1923	50.0		50.0	Newport News and New York	×				Do.
Half Moon	Freighter	May 23, 1923	6.0	5.5	.5	East Indies, via Suez		×			Do.
Surinam	do	June 11, 1923	9.0	9.0		New York-South America				×	
Paul Luckenbach	do	do	12.0	11.5	.5	New York-Portland, via Panama Canal		×			Do.

Azalea	Lightship tender	June 13, 1923	8.0	(?)	(?)	New England waters			×		Algæ, barnacles.
Sinsinawa	Freighter	June 18, 1923	9.0	8.5	.5	New York-Mediterranean			×		Algæ.
Scottsburg	do	June 23, 1923	.7	.5	.2	Pier 88, Brooklyn			×		Cyprids.
Pan America	Passenger	July 14, 1923	2.5	2.5		New York-South America			×		Young barnacles.
Chester	Cruiser	July 25, 1923	30.0		30.0	Boston Navy Yard	×				Mussels, hydroids.
Tacoma	do	do	8.5	8.0	.5	New York-Canal Zone		×			Barnacles, algæ.
Edgemont	Freighter	July 26, 1923	25.0		25.0	Staten Island Sound	×				Do.
Majestic	Passenger	Aug. 4, 1923	9.0	9.0		Transatlantic			×		Algæ, barnacles.
Phalarope	U. S. B. F. vessel	Aug. 14, 1923	12.0	2.0	10.0	Chesapeake-New England			×		Bryozoa, barnacles.
E. A. Morse	Freighter	Aug. 22, 1923	24.0		24.0	New London, Conn	×				Mussels, barnacles.
Nobles	do	do	13.0		13.0	Pier 5, Staten Island	×				Hydroids, barnacles.
Edenton	do	Sept. 11, 1923	24.0		24.0	New Haven, Conn	×				Barnacles, mussels.
Chinook	Dredge	Sept. 20, 1923	18.0	(?)	(?)	Hampton Roads	×				Barnacles, hydroids.
McFarland	Destroyer	do	1.0	1.0		New York-Boston			×		Algæ.
West Nohno	Freighter	Nov. 20, 1923	6.0	6.0		Azores, west coast of Africa	×				Large Barnacles.
Saint Mihiel	Army transport	do	7.5	(?)	(?)	Canal Zone-Hampton Roads		×			Barnacles, algæ.
Goff	Destroyer	Nov. 21, 1923	9.0	7.0	2.0	Constantinople-Norfolk			×		Algæ, barnacles.
Gilmer	do	do	5.0	4.0	1.0	do			×		Do.
S-11	Submarine	do	4.0	1.0	3.0	New England waters		×			Do.
Sands	Destroyer	do	14.0	8.0	6.0	Constantinople-Norfolk			×		Do.
Childs	do	do	(?)	(?)	(?)	Chesapeake			×		Do.
Surinam	Freighter	Nov. 24, 1923	6.0	6.0		Caribbean			×		Barnacles, Bryozoa.
Commack	do	Nov. 27, 1923	8.0	8.0		New York-Argentina			×		Barnacles, algæ.
Reuben James	Destroyer	Nov. 28, 1923	8.0	(?)	(?)	Constantinople			×		Do.
Ourcq	Army transport	Nov. 30, 1923	(?)		(?)	James River, Va	×				Oysters, mussels.
Eastern Leader	Freighter	Dec. 5, 1923	1.0	1.0		Transatlantic				×	
Hopkins	Destroyer	Dec. 7, 1923	9.0	7.0	2.0	Constantinople-Norfolk			×		Algæ, hydroids.
Kane	do	do	9.0	7.0	2.0	do			×		Do.
S-10	Submarine	do	7.0	5.0	2.0	New England coast		×			Do.
Cantigne	Army transport	Dec. 12, 1923	10.5		10.5	James River, Va	×				Mussels.
Independence	Freighter	Dec. 10, 1923	7.5	7.5		Around world via Suez			×		Barnacles, hydroids.
America	Passenger	Dec. 19, 1923	10.0	9.5	.5	Transatlantic			×		Algæ.
Wright	Aircraft tender	Dec. 23, 1923	12.0	6.5	5.5	Canal, Chesapeake-New York	×				Barnacles, algæ.
West Irmo	Freighter	Jan. 7, 1924	7.0	7.0		Caribbean			×		Barnacles.
Angelus	do	do	27.0		27.0	Pauls Island, N. Y	×				Barnacles, hydroids.
Waban	do	do	22.0		22.0	do		×			Do.
William Penn	do	Jan. 9, 1924	7.5	7.0	.5	Around world via Suez			×		Barnacles.
Bird City	do	Jan. 19, 1924	12.5	12.0	.5	New York-East coast of South America			×		Do.
Western Plains	do	Jan. 22, 1924	11.0		11.0	Staten Island Sound		×			Algæ, barnacles.
West Virginia	Battleship	Jan. 27, 1924	16.0	1.0	15.0	Newport News, Va		×			Do.
West Nestleton	Freighter	Feb. 7, 1924	3.0	3.0		West coast of Africa		×			Barnacles, hydroids.
Tulsagas	Tanker	Feb. 13, 1924	4.5	4.5		New York-Canal Zone			×		Barnacles, algæ.
President Garfield	Passenger	Feb. 14, 1924	9.0	9.0		Transatlantic				×	
Argosy	Freighter	Feb. 14, 1924	3.5	3.0	.5	New York-West coast of South America			×		Algæ.
Rapidan	Auxiliary	Feb. 20, 1924	20.0	1.0	19.0	Norfolk-New York	×				Barnacles, oysters.
Chaumont	Army transport	Feb. 23, 1924	10.0	10.0		New York-Seattle, via Panama Canal			×		Algæ, barnacles.
Eastern Tempest	Freighter	do	5.5	5.5		New York-North Sea				×	
Volunteer	do	Feb. 25, 1924	11.5	11.0	.5	New York-China, via Panama Canal			×		Barnacles.
Easterner	do	Feb. 29, 1924	6.0	5.0	1.0	New York-Australia, via Panama Canal			×		Algæ.
Leviathan	do	Mar. 1, 1924	9.0	7.0	2.0	Transatlantic			×		Algæ, barnacles.
West Loquassuck	do	Mar. 7, 1924	6.0	6.0		New York-West coast of Africa			×		Barnacles, Bryozoa.
Western World	do	Mar. 8, 1924	5.5	5.5		New York-South America				×	
Endicott	do	Mar. 15, 1924	7.5	7.5		Around world, via Suez-Panama Canals				×	
Clontarf	do	do	5.5	5.5		New York-Black Sea			×		Barnacles, algæ.
Rochester	Cruiser	Mar. 20, 1924	9.0	9.0		New York-Central America		×			Barnacles, Bryozoa.
Eastern Pilot	Freighter	Mar. 24, 1924	7.0	7.0		New York-Bristol			×		Algæ.
Raleigh	Cruiser	Mar. 25, 1924	3.0		3.0	Newport-Boston				×	
Texas	Battleship	Mar. 26, 1924	5.0	5.0		California-New York, via Panama Canal		×			Algæ, barnacles.
New York	do	Apr. 3, 1924	7.0	6.0	1.0	do		×			Algæ, hydroids.
Stanley	Freighter	Apr. 4, 1924	6.0	6.0		New York-Philippines, via Panama Canal			×		Barnacles, Bryozoa.
Wyoming	Battleship	Apr. 8, 1924	7.0	5.0	2.0	Boston-Canal Zone			×		Barnacles.
Litchfield	Destroyer	Apr. 10, 1924	6.0	1.0	5.0	Mediterranean-New York				×	(Moravian paint.)
Fox	do	do	12.0	3.5	8.5	Mediterranean, Chesapeake-New York			×		Barnacles.
Zarembo	Freighter	Apr. 11, 1924	9.0	9.0		New York-Bordeaux			×		Algæ.

TABLE 1—Continued

Ship	Type	Date examined	Period out of dock (in months)			Waters cruised	Degree of fouling				Predominating type of fouling organism
			Total time	Time cruising	Time in port		Heavy	Moderate	Light	None	
Eastern Sword	Freighter	Apr. 11, 1924	5.5	5.5		New York-Bristol				×	
Nile	do	Apr. 16, 1924	5.5	5.5		New York-East Indies, via Panama Canal			×		Algæ.
Hog Island	do	do	3.5	3.5		New York-Mediterranean		×			Algæ, barnacles.
Pan America	Passenger	Apr. 17, 1924	9.0	9.0		New York-East coast of South America			×		Barnacles.
Haiti	Freighter	Apr. 18, 1924	8.5	8.5		New York-West Indies			×		Algæ, barnacles.
Majestic	Passenger	do	9.5	(?)	(?)	Transatlantic			×		Algæ.
Eastern Glade	Freighter	Apr. 19, 1924	11.0	11.0		Southeast coast of Africa		×			Barnacles.
Sirius	Cargo ship	do	8.5	7.0	1.5	West and east coasts of United States, via Panama Canal.			×		Algæ, hydroids.
King	Destroyer	do	(?)	(?)	(?)	(?)			×		Do.
Arkansas	Battleship	Apr. 22, 1924	4.0	2.0	2.0	New York, Chesapeake-Panama Canal		×			Barnacles.
Relief	Lightship tender	Apr. 26, 1924	12.0	1.0	11.0	New York Harbor	×				Barnacles, hydroids.
West Africa	Freighter	do	6.0	6.0		West coast of Africa	×				Do.
Homestead	do	do	5.5	5.5		New York-India, via Suez			×		Algæ.
West Gotomska	do	do	15.0		15.0	Staten Island Sound	×				Barnacles, hydroids.
Eastern Shore	do	May 2, 1924	33.0		33.0	do	×				Do.
Blue Triangle	do	do	(?)	(?)	(?)	Intercoastal United States ports			×		Algæ.
West Selene	do	May 14, 1924	11.0		11.0	Staten Island Sound		×			Barnacles.
Ballcamp	Tugboat	do	13.0	1.0	12.0	Caldwell, N. Y		×			Barnacles, hydroids.
Trenton	Cruiser	May 26, 1924	6.0	6.0		Newport-New York				×	
Half Moon	Freighter	do	6.0	5.0	1.0	New York-East Indies, via Suez		×			Barnacles, algæ.
Chewink	Mine sweeper	June 2, 1924	15.5	1.5	14.0	New York-Canal Zone			×		Barnacles.
Northend	Lightship	do	10.5	.5	10.0	New York waters	×				Mussels.
Cincinnati	Cruiser	June 3, 1924	3.5	3.0	.5	Seattle-Chili-New York		×			Barnacles.
Western Glen	Freighter	June 4, 1924	4.0	4.0		Southeast coast of Africa			×		Algæ.
Pine	Lightship tender	June 11, 1924	11.5	1.0	10.5	Off Atlantic City		×			Barnacles, hydroids.
Colorado	Cruiser	June 12, 1924	3.0		3.0	New York Navy Yard				×	
West Cawthon	Freighter	June 14, 1924	9.5	9.5		New York-Mediterranean			×		Hydroids, Lepas.
Acme	do	do	7.0	7.0		New York-Mexico-Canal Zone			×		Algæ, barnacles.
Fire Island	Lightship	June 16, 1924	7.0		7.0	Fire Island, N. Y		×			Mussels, hydroids.
District of Columbia	Tanker	June 17, 1924	4.5	4.5		New York-California, via Panama Canal				×	
Kerhonkson	Freighter	June 18, 1924	7.0	7.0		New York-Ireland			×		Algæ
West Calumb	do	June 23, 1924	6.0	6.0		New York-East Indies, via Suez			×		Algæ, Conchoderma.
West Irmo	do	June 28, 1924	5.5	5.5		New York-West coast of Africa		×			Barnacles, hydroids.
Eastern Tempest	do	June 30, 1924	4.0	4.0		New York-North Sea			×		Algæ.
Dochet	do	July 1, 1924	2.5	2.5		New York-Mediterranean			×		Algæ, barnacles.
Eastern Moon	do	July 2, 1924	5.0	4.5	.5	New York-Australia, via Panama Canal		×			Do.
Jennie R. Morse	do	July 7, 1924	6.0	6.0		New York-Japan, via Panama Canal		×			Do.
S-27	Submarine	do	7.0	1.0	6.0	New York-Boston-Cuba		×			Do.
Sagamore	Mine sweeper	July 8, 1924	1.3		1.3	New York Navy Yard			×		Minute barnacles.
Independence	Freighter	July 9, 1924	7.0	6.0	1.0	Around world, via Suez and Panama Canals		×			Algæ, barnacles
Eastern Guide	do	July 11, 1924	6.5	6.0	.5	Transatlantic				×	
Henderson	Transport	do	9.0	5.0	4.0	Philadelphia-Canal Zone-East Indies			×		Minute barnacles.
Sturtevant	Destroyer	July 12, 1924	10.0	6.5	3.5	New York-New England-Cuban	×				Barnacles
West Maximus	Freighter	July 14, 1924	3.5	3.5		New York-North Sea				×	
S-1	Submarine	do	12.0	.5	11.5	New London-New York-Chesapeake			×		Bryozoa, barnacles
Southern Cross	Passenger	July 16, 1924	2.0	2.0		New York-Rio de Janiero				×	
Concord	Cruiser	July 25, 1924	3.0		3.0	New York Navy Yard		×			Barnacles
Eastern Planet	Freighter	July 28, 1924	6.0	4.5	1.5	New York-Australia, via Panama Canal			×		Algæ, barnacles.
West Mahomet	do	July 30, 1924	6.5	6.0	.5	New York-East Indies, via Suez			×		Algæ.
Hampton Roads	do	Aug. 1, 1924	3.5	3.5		New York-San Pedro, via Panama Canal			×		Algæ, barnacles
Sagamore	do	Aug. 5, 1924	7.5	5.5	2.0	New York-Mediterranean		×			Barnacles, algæ.

Scottsburg	do	do	7.0	5.5	1.5	New York-China, via Panama Canal		×			Barnacles.
America	Passenger	Aug. 8, 1924	8.0	8.0		New York-Cherbourg			×		Algæ.
West Hesseltine	Freighter	Aug. 12, 1924	6.0	5.0	1.0	New York-West coast of Africa		×			Barnacles, hydroids.
Overfalls	Lightship	Aug. 22, 1924	(?)	(?)	(?)	New York Harbor	×				Do.
Iuka	Tug	Aug. 19, 1924	(?)	(?)	(?)	New York		×			Barnacles.
West Kedron	Freighter	Sept. 2, 1924	6.0	6.0		New York-Northern South America				×	Algæ.
Cincinnati	Cruiser	Sept. 3, 1924	3.0		3.0	New York Navy Yard		×			Molgula.
Bengula	Freighter	Sept. 4, 1924	5.0	4.0	1.0	New York-West coast of Africa	×				Barnacles, hydroids.
Henley	Destroyer	Sept. 6, 1924	26.0		26.0	New York-Philadelphia				×	Minute barnacles.
Sabotawan	Freighter	Sept. 10, 1924	3.5	3.0	.5	New York-Mediterranean		×			Serpulids.
Childs	Destroyer	do	9.0	3.0	6.0	New York-Central America		×			Barnacles, algæ.
Humphreys	do	Sept. 17, 1924	10.0	3.0	7.0	do		×			Barnacles, tunicates.
Relief No. 16	Lightship	Sept. 27, 1924	9.0	(?)	(?)	New York-Cornfield Point	×				Tunicates, hydroids.
Cathlamet	Freighter	Sept. 29, 1924	6.0	5.0	1.0	New York-West coast of Africa	×				Barnacles, Bryozoa.
Marblehead	Cruiser	Oct. 4, 1924				New York-Philadelphia				×	
Coeur d'Alene	Freighter	Oct. 6, 1924	9.0	5.5	4.5	New York-Mediterranean	×				Barnacles, tunicates.
Teal	Mine sweeper	Oct. 16, 1924	10.0	3.0	7.0	New York-Central America	×				Tunicates, hydroids.
Sands	Destroyer	Oct. 20, 1924	11.0	3.0	8.0	do	×				Tunicates, barnacles.
Western Plains	Freighter	Oct. 22, 1924	5.0	2.0	3.0	New York-Baltic ports		×			Barnacles, hydroids.
Wright	Aircraft tender	Oct. 23, 1924	11.0	4.0	7.0	New York-Central America	×				Barnacles, tunicates.
Falcon	Mine sweeper	Oct. 27, 1924	15.0	7.0	8.0	New York-New England-West Indies		×			Barnacles, oysters.
Pentucket	Tug	Oct. 29, 1924	16.0	16.0		New York Navy Yard and adjacent waters			×		Do.
West Nohno	Freighter	Nov. 6, 1924	6.0	5.5	.5	New York-West coast of Africa	×				Do.
S-29	Submarine	Nov. 15, 1924	4.0	2.0	2.0	New York-New England		×			Barnacles.
Richmond	Cruiser	Nov. 17, 1924	12.0	6.0	6.0	New York-Ireland	×				Molgula.
Relief No. 78	Lightship	Nov. 18, 1924	(?)		(?)	New York-Block Island		×			Hydroids, barnacles.
Hopkins	Destroyer	Nov. 19, 1924	11.5	7.5	4.0	New York-Central America			×		Do.
Sturtevant	do	Nov. 20, 1924	3.0	2.0	1.0	New York-Cuban			×		Barnacles.
Barry	do	Nov. 25, 1924	4.5	1.5	3.0	New York-Labrador			×		Do.
Gilmer	do	Dec. 3, 1924	3.0	1.5	1.5	New York-Norfolk-West Indies			×		Do.
Illinois	Battleship	Dec. 4, 1924	26.0	1.0	25.0	New York Harbor	×				Molgula, barnacles.
Wytheville	Freighter	do	4.5	3.5	1.0	New York-South Africa			×		Minute barnacles.
Hanley	do	Dec. 9, 1924	3.0		3.0	New York-Philadelphia				×	
West Humbaw	do	Dec. 10, 1924	6.0	5.5	.5	New York-West coast of Africa		×			Barnacles.
Beale	Destroyer	Dec. 15, 1924	5.0	3.0	2.0	New York-Philadelphia-Block Island			×		Bryozoa.
Pollock	Lightship	Dec. 24, 1924	6.0			Nantucket Sound	×				Barnacles, Molgula.
Hoven	Tanker	Jan. 6, 1925	8.0	7.0	1.0	New York-West coast of United States, via Panama Canal.			×		Barnacles, algæ.
Eagle 26	Patrol boat	Jan. 29, 1925	24.0	2.0	22.0	New York Harbor, Seventy-second Street	×				Barnacles, mussels.
Eagle 27	do	do	24.0	2.0	22.0	New York Harbor, Ninety-sixth Street	×				Barnacles, Molgula.
West Maximus	Freighter	Jan. 30, 1925	6.5	5.0	1.5	New York-Baltic ports				×	
Abron	do	Jan. 31, 1925	9.0	7.0	2.0	New York-Mediterranean			×		Algæ.
Sapelo	Oiler	Feb. 2, 1925	7.0	5.0	2.0	New York-Texas				×	
Sirius	Cargo ship	do	9.0	5.0	4.0	New York-West coast of United States		×			Barnacles.
Rochester	Cruiser	Feb. 3, 1925	10.0	4.0	6.0	New York-Canal Zone	×				Barnacles, osyters.
McFarland	Destroyer	Feb. 4, 1925	13.0	9.0	4.0	New York-Labrador-Central America			×		Barnacles.
West Kedron	Freighter	Feb. 9, 1925	5.5	4.5	1.0	New York-West coast of Africa			×		Minute barnacles.
Independence	do	Feb. 16, 1925	5.5	5.0	.5	New York-around the world, both canals				×	
Eastern Glade	do	Feb. 17, 1925	6.0	5.0	1.0	New York-South Africa			×		Barnacles, algæ.
Bellhaven	do	Feb. 20, 1925	41.0		41.0	New York-Staten Island	×				Barnacles, hydroids.
Eagle 45	Patrol boat	Feb. 21, 1925	24.0	2.0	22.0	New York Harbor, Bay Ridge	×				Molgula, hydroids.
Eagle 51	do	do	24.0	2.0	22.0	New York Harbor, Fire Island	×				Do.
America	Passenger	Feb. 24, 1925	6.0	5.0	1.0	New York-Cherbourg				×	
Memphis	Cruiser	Mar. 6, 1925	3.0		3.0	New York-Philadelphia				×	
Kearny	Freighter	Mar. 7, 1925	45.0		45.0	New York, Staten Island	×				Barnacles, hydroids.
Westport	do	Mar. 9, 1925	10.0	3.0	7.0	New York-Europe			×		Barnacles.
Hawthorn	Lightship tender	Mar. 10, 1925	8.0		8.0	New York-Block Island-Connecticut River			×		Do.
St. Anthony	Freighter	Mar. 21, 1925	7.0	5.5	1.5	New York-Baltic ports				×	
Cathlamet	do	Mar. 26, 1925	6.0	1.0	5.0	New York-West coast of Africa		×			Do.
Republic	Passenger	Mar. 27, 1925	12.0	11.0	1.0	New York-Translantic			×		Algæ.
Privateer	Naval yacht	Mar. 30, 1925	(?)	(?)		New York Harbor and vicinity					
Homestead	Freighter	Mar. 31, 1925	6.0	5.0	1.0	New York-India, via Suez Canal		×			Algæ, hydroids.
Western World	do	Apr. 3, 1925	7.0	6.5	.5	New York-South America				×	
Lightship	Lightship	Apr. 4, 1925	9.0			Cape May, N. J.		×			Do.

TABLE 1—Continued

Ship	Type	Date examined	Period out of dock (in months)			Waters cruised	Degree of fouling				Predominating type of fouling organism
			Total time	Time cruising	Time in port		Heavy	Mod-erate	Light	None	
Tulip	Lightship tender	Apr. 7, 1925	9.0	8.0	1.0	New York Harbor and vicinity			×		Algæ, hydroids.
Fox	Destroyer	Apr. 13, 1925	12.0	2.0	10.0	New York-Maine		×			Barnacles, Bryozoa.
Aztec	Tanker	Apr. 20, 1925	12.0	11.0	1.0	New York-West Indies			×		Barnacles, algæ.
Arkansas	Battleship	Apr. 22, 1925	4.5	2.5	2.0	New York-Cuban			×		Bryozoa, algæ.
The Lambs	Freighter	Apr. 28, 1925	5.0	4.0	1.0	New York-around the world, both canals			×		Algæ, barnacles.
Vega	Cargo ship	May 2, 1925	7.0	4.0	3.0	New York-West coast of United States			×		Algæ.
Penobscot	Naval tug	May 11, 1925	8.0	1.0	7.0	New York-Washington		×			Barnacles, hydroids.
West Wind	Freighter	May 21, 1925	36.0		36.0	Staten Island Kills	×				Do.
Eastern Light	do	May 25, 1925	24.0		24.0	do	×				Do.
Englewood	do	May 28, 1925	24.0		24.0	do		×			Barnacles, algæ.
Breck	Destroyer	June 2, 1925	2.0	1.5	.5	Norfolk-New York				×	
Belleplaine	Freighter	June 3, 1925	24.0		24.0	Staten Island Kills	×				Barnacles, hydroids.
New Mexico	do	June 19, 1925	5.0	4.5	.5	New York-West Africa		×			Barnacles.
Heffron	do	June 20, 1925	7.0	6.0	1.0	New York-China, via Panama Canal				×	
West Humhaw	do	June 22, 1925	6.0	4.0	2.0	New York-West Africa				×	
Patagonia	do	June 26, 1925	24.0		24.0	Staten Island Kills	×				Barnacles, hydroids.

Fig. 16.—Type and amount of fouling on ships' bottoms. Many small sessile barnacles, some clusters of Bryozoa and hydroids, and numerous conspicuous stalked barnacles (Lepas)

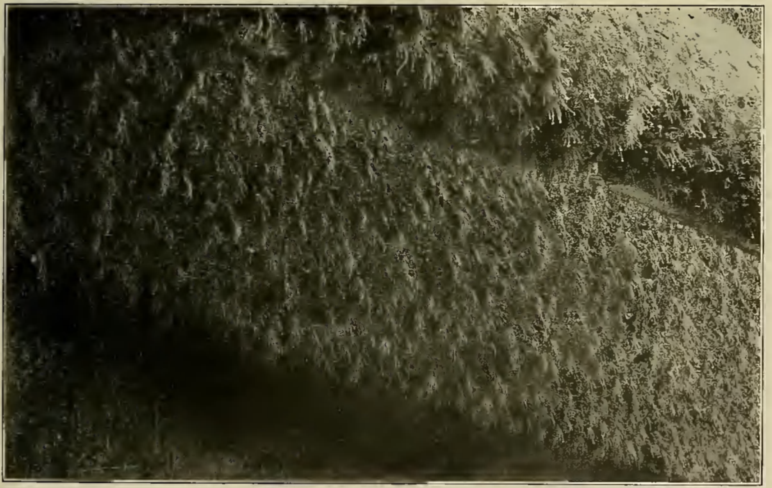


Fig. 17.—Type and amount of fouling on ships' bottoms. A typically dense growth of hydroids

Fig. 18.—Type and amount of fouling on ships' bottoms. Large clusters of tunicates (sea squirts)

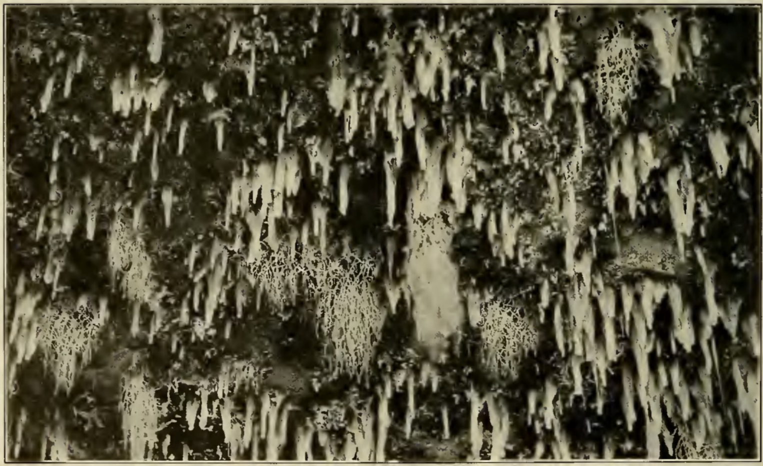


Fig. 19.—Type and amount of fouling on ships' bottoms. Numerous tunicates, typical clusters of hydroids, many small barnacles, and colonies of Bryozoa

By analyzing the data in this table regarding the extent of fouling we find that 87 per cent of all ships were fouled to some extent, and accordingly only 13 per cent were clean. A more detailed analysis of these proportions is given in Figure 20. By referring to this figure it will be seen that while 13 per cent were clean, 39 per cent were lightly fouled, 27 per cent moderately fouled, and 21 per cent heavily fouled.

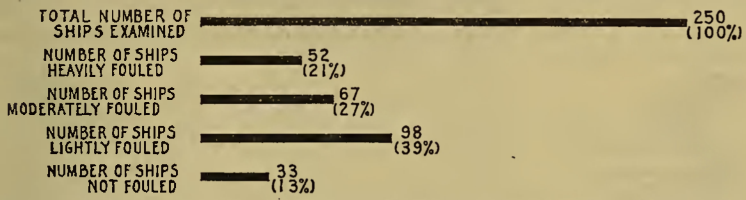


FIG. 20.—Total number of ships examined and relative number in each of the four groups classified according to the amount of fouling on each vessel

TABLE 2.—*Total amount of fouling, by weight*

Ship	Date examined	Length	Width	Draft	Number of areas measured	Size of areas measured	Amount of fouling per area	Total amount	
								Metric	United States
		Feet	*Feet*	*Feet*				*Kilos*	*Tons*
Proteus	Sept. 28, 1922	552.0	62	27.7	4	1 meter wide, water line to keel.	60 kilograms	8,000.0	8.82
Fish Hawk	Nov. 7, 1922	147.0	27	11.0	2	do	5 kilograms	415.0	.46
Wyoming	Dec. 17, 1922	562.0	93	28.5	4	1 square meter	2 kilograms	5,954.0	6.55
West Virginia	Nov. 21, 1922	624.0	97	30.5	3	do	3 kilograms	10,612.5	11.67
Leviathan	May 18, 1923	906.9	100	23.7	4	do	2.5 kilograms	9,987.0	10.98
Do	Mar. 1, 1924	906.9	100	23.7	4	do	3 grams	12.0	.013
America	Feb. 24, 1923	668.0	74	22.8	5	do	10 grams	28.2	.310
Do	Dec. 19, 1923	668.0	74	22.8	5	do	1 gram	2.8	.003

The exact amount of fouling on individual ships has been difficult to determine because of complicating conditions at the time of dry docking. A fairly accurate determination was made, however, for each of the eight ships listed in Table 2. The amount of fouling on each was determined by calculations based upon accurate measurements of the total amounts on limited areas, the sizes of which are indicated for each vessel in the above table. The total amount of fouling on the entire ship was then calculated on the basis of a knowledge of the length, width, and draft of the ship and calculation of its wetted surface. It will be seen by reference to this table that fouling was very severe on ships like the *Proteus*, a collier in the naval transport service; while a passenger ship like the *America* had only a very small amount of fouling. None of the vessels listed in this table indicates the maximum amount of fouling occasionally found on ships. This has been estimated by reliable authorities to exceed 500 tons per vessel occasionally, but fortunately few ships are now permitted to become so foul before redocking, regardless of time intervals.

TABLE 3.—*Distribution and frequency of various organisms on first 100 ships examined*

Fouling material	Proteus 1	Maryland 2	Fish Hawk 3	West Virginia 4	Parker 5	O'Brien 6	Rail 7	Bobolink 8	Rochester 9	Washington 10	Wright 11	Wyoming 12	Nevada 13	Kittery 14	Beale 15	Warrington 16	Henderson 17	Antares 18	America 19	Eagle 44 20	Eagle 48 21	Eagle 51 22	American Legion[1] 23	Denver 24	Florida 25	Sigourney 26	Cole[1] 27	Rowan[1] 28	President Monroe[1] 29	S. C. 103 30	S. C. 271 31	S. C. 143 32	Privateer[1] 33	Traffic[1] 34
Barnacles:																																		
Balanus eburneus	X	--	X	X	X	X	X	X	--	--	X	X	--	--	X	--	--	X	--	X	X	X	--	--	--	X	--	--	--	X	X	X	--	--
improvisus	X	--	--	--	--	--	X	X	X	--	X	X	--	X	--	--	--	X	--	X	X	X	--	X	X	--	--	--	--	X	X	--	--	--
amphitrite	--	X	--	--	--	--	--	--	--	--	--	--	X	--	--	--	X	--	--	--	--	--	--	X	X	--	--	--	--	--	--	--	--	--
tintinabulum	--	--	--	--	--	--	--	--	--	--	--	--	X	--	--	--	X	--	--	--	--	--	--	X	X	--	--	--	--	--	--	--	--	--
crenatus	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	X	--	--	--	--	--	--	--	--	--	--	--	--
Balanus, sp. undetermined	--	--	--	--	--	--	--	--	--	--	--	X	--	--	--	--	X	--	--	--	--	--	--	--	--	X	--	--	--	--	--	--	--	--
Hydroids:																																		
Eudendrium ramosum	--	X	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Tubularia crocea	--	--	X	--	--	--	--	--	X	--	--	--	--	--	--	--	--	X	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
sp., unidentified	--	X	--	--	X	X	--	--	--	--	--	--	--	X	--	--	--	--	--	--	--	--	--	--	X	--	--	--	--	--	--	--	--	--
Campanularia amphora	--	--	--	X	--	--	X	X	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
portium	--	--	--	--	--	--	X	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
vorticellata	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	X	--	--	--	--
sp., unidentified	X	--	--	--	--	--	--	--	X	--	--	--	--	X	X	X	--	X	--	--	--	--	--	--	X	X	--	--	--	--	X	X	--	--
Bougainvillia carolinensis	--	--	--	X	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Perigonimus jonsii	--	--	--	X	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Podocoryne sp., unidentified	--	--	--	X	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Metridium sp., unidentified	X	--	--	X	--	--	--	--	X	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Bryozoa:																																		
Bowerbankia caudata	--	--	--	X	--	--	X	--	X	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	X	--	--
Anguinella palmeta	--	--	--	X	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Alcyonidium mytili	X	--	--	--	--	--	X	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
gelatinosum	--	--	--	--	--	--	--	--	X	--	--	--	--	X	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Membranipora lacroixii	--	--	X	--	--	--	X	X	X	--	--	--	--	X	--	--	--	--	--	--	--	--	--	--	X	--	--	--	--	--	--	--	--	--
sp., unidentified	--	--	--	--	--	--	--	--	--	--	X	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Mollusca:																																		
Ostrea elongata	--	--	--	--	--	X	--	X	--	--	X	--	--	--	--	--	--	--	--	--	--	--	--	--	--	X	--	--	--	--	--	--	--	--
Mytilis edulis	--	--	--	--	X	X	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	X	--	--	--	--
Nudibranchiata sp. ?	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	X	--	--	--	--	--	--	--
Annelida:																																		
Hydroides hexagonis	X	--	X	X	--	X	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	X	--	X	--	--	--	--	--	--	--
Nereis pelagica	--	--	X	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Glycera sp., unidentified	--	--	--	--	X	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Protozoa:																																		
Vorticellidæ	--	--	--	X	X	--	X	X	X	--	X	--	--	--	X	--	--	--	--	--	--	--	--	--	--	--	X	--	--	--	--	--	--	--
Folliculina	--	--	--	--	--	--	--	--	--	--	--	--	--	--	X	--	--	--	--	--	--	--	--	--	--	--	X	--	--	--	--	--	--	--
Tunicates:																																		
Molgula manhattensis	--	X	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	X	--	--	--	--	--	--	--
arenata	--	--	--	X	X	--	--	--	--	X	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Algæ:																																		
Ulva lactuca	--	--	--	X	X	--	X	--	--	X	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Vaucheria sp. ?	--	--	--	X	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Enteromorpha intestinalis	--	--	--	--	--	--	--	--	--	--	--	--	--	--	X	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
sp., unidentified	--	X	--	--	X	--	X	--	--	--	--	--	--	X	--	--	--	--	--	--	X	--	--	--	--	--	X	--	--	--	--	--	--	--
Ulothrix flaca	--	--	--	--	--	--	--	--	X	--	--	--	--	X	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Polysiphonia nigrescens	--	--	--	--	X	--	X	--	--	--	--	--	--	X	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Acrochætium sp., unidentified	--	--	--	--	--	--	X	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Syphonales sp., unidentified	--	--	--	--	--	--	X	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Oscillatoria sp., unidentified	--	--	--	--	--	--	--	--	--	--	--	--	--	X	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--

[1] No record for ship.

TABLE 3.—*Distribution and frequency of various organisms on first 100 ships examined*—Contd.

Fouling material	East Wind	Arkansas	Argonne	Williamson	Orion	Cleveland	Eagle 54	Eagle 15	Ossining [1]	Natirar [1]	Maryland [1]	Reuben James	Camden	Independence [1]	St. Paul [1]	William Penn [1]	Leviathan	Half Moon	Rochester	Surinam [1]	Azalea	Sinsinawa	Scottsburg	Salaam	Manhattan Island	Pan America	Chester	Takoma	Edgemont	Majestic	Phalarope	E. A. Morse	Nobles
	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	56	57	58	59	60	61	62	63	64	65	66	67	68
Barnacles:																																	
Balanus eburneus		X					X	X				X					X				X						X		X		X		X
improvisus		X			X		X	X				X	X				X												X			X	X
amphitrite	X																		X						X	X		X					
tintinabulum																			X									X					
crenatus																																X	
tulipiformis	X																																
Balanus cyprid larvæ																						X	X	X	X	X							
Balanus sp., undetermined																									X					X			
Lepas hillii													X					X															
Conchoderma aurita																		X															
Poecilasma crassa													X												X								
Hydroids:																																	
Eudendrium ramosum																											X				X		
Tubularia crocea																													X		X		
sp., unidentified		X			X								X				X										X					X	X
Campanularia sp., unidentified																	X										X		X			X	X
Metridium sp., unidentified																													X			X	X
Segartia sp., unidentified																	X										X					X	
Astrangia sp., unidentified																	X																
Bryozoa:																																	
Bugula turrita													X															X			X		
Bowerbankia caudata																										X							
Alcyonidium mytili		X																															
Membranipora monastachys													X																				
lacroixii																									X								
sp., unidentified					X		X	X									X		X								X			X			
Mollusca:																																	
Ostrea elongata																	X																
Mytilis edulis																											X		X			X	X
Annelida:																																	
Hydroides hexagonis																																	
sp., unidentified																	X					X											
Protozoa:																																	
Vorticellidæ			X																														X
Tunicates:																																	
Molgula manhattensis			X	X																							X					X	
Algæ:																																	
Ulva lactuca																											X	X	X	X			
Enteromorpha intestinalis			X																								X						
sp., unidentified		X	X							X																	X						
Ulothrix flaca																											X						
Polysiphonia nigrescens																														X			
Cladophora sp., unidentified		X																									X						

[1] No record for ship.

TABLE 3.—*Distribution and frequency of various organisms on first 100 ships examined*—Contd.

Fouling material	Edenton 69	Chinook 70	Neptune 71	McFarland 72	West Nohno 73	Saint Mihiel 74	Goff 75	Gilmer 76	S.-11 77	Sands 78	Childs 79	Surinam 80	Commack 81	Reuben James 82	Oureq 83	Eastern Leader 84	Hopkins 85	Kane 86	S.-10 87	Independence 88	Cantigne 89	Wright 90	West Irmo 91	Angelus 92	Waban 93	William Penn 94	Bird City 95	Western Plains 96	West Virginia 97	West Nestleton 98	Tulsagas 99	President Garfield [1] 100	Total
Barnacles:																																	
Balanus eburneus	X	X	X											X	X							X											34
improvisus	X	X					X	X				X			X				X		X			X	X	X		X	X				38
amphitrita					X															X										X	X		12
tintinabulum					X															X			X							X			9
cranatus									X																								3
tulipiformis																																	1
Balanus cyprid larvæ		X																															6
Balanus sp., undetermined										X	X	X						X	X				X				X						10
Lepas hillii																																	2
Conchoderma aurita																																	1
Poecilasma crassa																																	2
Hydroids:																																	
Eudendrium ramosum																																	3
Tubularia crocea																																	5
sp., unidentified		X													X				X			X		X				X					19
Campanularia amphora																																	3
portium																																	1
vorticellata																																	1
sp., unidentified		X			X		X	X							X		X	X			X							X	X	X			26
Bougainvillia carolinensis																																	1
Perigonimus jonsii																																	1
Podocoryne sp., unidentified																																	1
Metridium sp., unidentified	X	X																															8
Sagartia sp., unidentified																																	3
Astrangia sp., unidentified																																	1
Bryozoa:																																	
Bugula turrita																																	3
Bowerbankia caudata	X																																6
Anguinella palmeta																																	1
Alcyonidium mytili	X														X																		5
gelatinosum		X																															3
Membranipora monostachys																																	1
lacroixii	X	X	X										X				X	X				X											14
sp., unidentified	X	X										X								X		X			X	X		X	X				16
Lepralia partusa							X																										1
Mollusca:																																	
Ostrea elongata		X													X																		7
Mytilis edulis	X	X	X																X		X	X											13
Nudibranchiata sp. ?			X																														2
Annelida:																																	
Hydroides hexagonis																				X													8
sp., unidentified																																	1
Nereis pelagica																																	1
Glycera sp., unidentified																																	1
Protozoa:																																	
Vorticellidæ																																	10
Folliculina																																	2
Tunicates:																																	
Molgula manhattensis		X	X												X																		9
arenata																								X									4
Botryllus schlosseri			X																														1
Algæ:																																	
Ulva lactuca																																	8
Vaucheria sp. ?																																	1
Enteromorpha intestinalis						X												X						X					X				7
sp., unidentified						X	X	X			X						X	X	X					X					X		X		19
Ulothrix flaca																													X				4
Polysiphonia nigrescens																																	4
Acrochætium, sp., unidentified																																	1
Syphonales sp., unidentified																																	1
Cladophora sp., unidentified						X												X															4
Oscillatoria sp., unidentified																																	1

[1] No record for ship.

In Figure 21 is shown a comparison of the relative importance of the various kinds of fouling growths, based upon data given in Table 1. It will be seen that of the 217 vessels that were foul 152 had barnacle growths, 105 were foul with algæ, 91 with hydroids, 87 with Bryozoa, 37 with mollusks, 22 with tunicates, and 17 with Protozoa. It is clearly evident, however, that for most vessels barnacles are the most important fouling agent, while the hydroids and algæ form the next groups, in order of importance. These relations are shown in Table 3, where the occurrence of each kind of organism is tabulated for each of the first 100 ships.

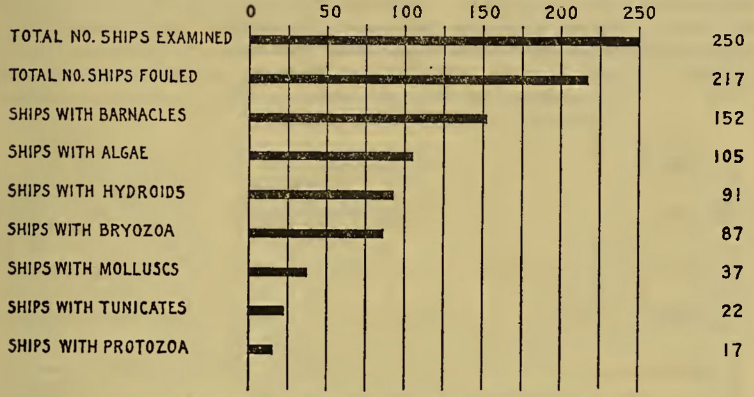


FIG. 21.—Number of ships fouled by each of several groups of organisms

EFFECTS OF FOULING

As Capt. H. Williams has very aptly stated, "considering the fact that frictional resistance is the most important element in the resistance to propulsion of practically all ships, it is surprising that there has been little investigation of the possibility of reducing skin friction to a minimum. Ship owners seem satisfied that everything is accomplished by the present system of docking ships periodically," and the subsequent cleaning of their bottoms and painting with antifouling compositions. He states, further, that "the effort to drive foul ships at full speed has burned many tons of fuel; the normal fuel consumption of ships is in excess of what this consumption would be with clean, freshly painted bottoms. While probably it is not possible to prevent fouling and the consequent increase in fuel consumption, there is room for definite improvement over existing conditions."

A few studies on the effect of fouling, as regards increased resistance, have been made. Thus, McEntee (1915) studied the relation of fouling to increased frictional resistance by submerging, near the navy yard at Norfolk, Va., a series of steel plates, each weighing 10 pounds and measuring 2 by 10 feet. After periods ranging from 1 to 12 months he removed the plates from the water, shipped them to Washington, D. C., and, at the experimental model basin, tested their resistance at speeds ranging from 2 to 8 knots. The maximum increase in resistance was found to be four times as great as when such plates are clean and freshly painted. The amount of fouling was determined in all cases, and the maximum foul condition of these plates would be roughly comparable to the condition listed as slightly less than "moderately fouled" in previous tables and elsewhere in this paper.

Although the author is not aware of any detailed studies on the effect of fouling, as regards increased resistance and consequent increased fuel consumption in ships in actual operation that are moderately or heavily fouled, recent investigations by the Navy Department show a considerable increase in fuel consumption for boats only eight weeks out of dry dock and on which only small amounts of fouling could possibly have accumulated, as the trials were made early in spring in the cold waters near Boston Harbor. The results of tests with a new submarine off Provincetown, Mass., are given in Figure 22, from which it can be seen that the speed attained with a low propeller action was decreased from 9.85 to 9.25 knots; and at high energy input (1,050 kw.) this was reduced from 15 to 14.5 knots. If there is so great a reduction in

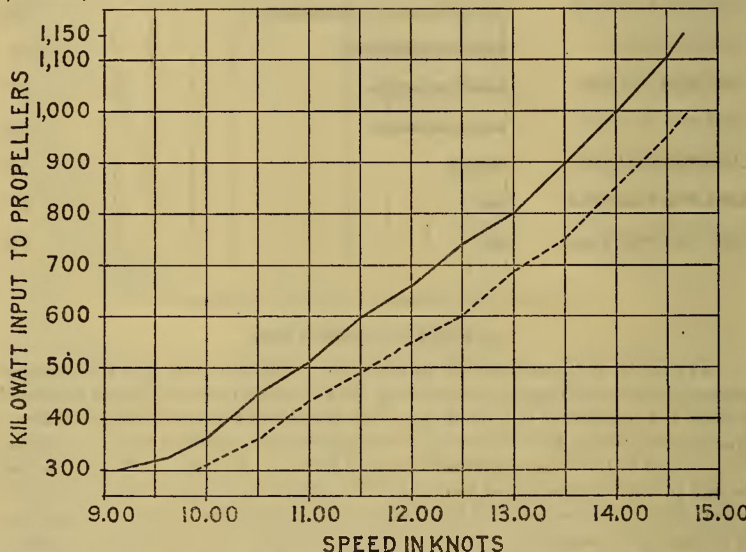


FIG. 22.—U. S. Submarine *S-34*. Standardization trials, measured mile, Provincetown, Mass., May 16–18, 1923. Vessel out of dock 56 days for run with foul bottom. Motor efficiency disregarded as virtually constant. ——— with foul bottom; -------- with clean bottom

speed when the amount of fouling is barely noticeable, the proportionate decrease in the speed of vessels heavily fouled must be very great indeed.

These results are in accord with the observations of McEntee, quoted above, who tested the resistance of recently submerged plates, with no discernible fouling, and yet found a very noticeable increase in resistance, which for the plates used in his experiments he calculated at an increase of almost 2 per cent per day.

That similar results are obtained by actual tests with ships is seen from the statement by Sir Archibald Denny, published as part of the discussions that follow the McEntee paper. Denny states that "at their shipyard on the river Leven, a tributary to the Clyde, they have found an increase in resistance at the rate of nearly one-half of 1 per cent per day for periods as long as three months." This would mean an increase in resistance of almost 50 per cent by the end of this period, while "examination of the bottoms of the vessels in dock revealed no apparent fouling." That such practical tests are fully in accord with theory, as based upon experimental data, is shown by the additional studies of McEntee (1915) on the use of graphite, soaps, and oils as a coating for the wetted surfaces of a model ship. He found that all of these produced greater resistance than a smooth, shellacked surface.

For an analysis of the resistance of ships, the work of Hovgaard (1908) is one of the more recent, while a very excellent bibliography on this subject is given by Rigg (1915).

FACTORS THAT DETERMINE FOULING

The factors that determine the presence and the amount of fouling on a given vessel are very numerous and variable. The major factors, however, may be classified with some degree of accuracy. The season of the year, the weather, and the temperature of the water constitute one group of factors. The condition of the water in various harbors, both as to salt content and pollution, also affects fouling. The contour of the ship, which is correlated with the duty and speed of the vessel, and also the waters cruised, all affect the amount of fouling. The length of time between successive dry dockings and the proportion of this time spent in cruising or in port are very important factors. The nature of the material of which the ship's bottom is made, as well as the paints or other materials that protect it, also are of importance. Inasmuch as life is more abundant and rapid in its growth in tropical regions, it follows that boats that travel in tropical waters become more heavily fouled and in a shorter time than do similar vessels in more temperate latitudes. Likewise, ships in port during the spring and summer show heavier growths than those that are idle in port during the autumn and winter.

It will be impossible to consider all of the factors that condition fouling in all its variations, but the following pages will be devoted to a discussion of some of the major ones, with special reference to the effectiveness of paints, both as regards their poisonous properties and their protective properties from a biological consideration of the reactions to them of the larvæ of the various forms that cause fouling.

We shall discuss the relation of fouling to (1) duty, including the factor of "dry-docking period"; (2) seasons; (3) fresh waters; (4) paints and surface film; and (5) light and color.

RELATION OF DUTY OF SHIP TO FOULING

The "duty" of a ship determines, in large measure, the amount of fouling that will accumulate on its bottom. This is due to several factors, which include the effect of hull contour, of relatively much or little time spent in port, of the ship's speed while cruising, and, finally, the effect of the waters cruised.

By examining Table 1 it will be noted that there is a marked difference in the amount of fouling on ships belonging to different classes; i. e., having different duties. Thus, it was found that passenger ships with regular schedules were by far the least foul of any group. This applies not only to vessels plying between America and Europe, but to those carrying trade from New York to South American ports as well, and can be stated as a general rule.

Freight vessels and most of the active naval vessels form the next class of ships. These ships frequently lie in one port or another from one to three weeks, or even longer, and offer ample opportunity for a dense "set" of fouling growths to take place. The degree to which these organisms continue to grow depends very largely upon the amount of time in excess of 10 days that is spent in any one port and to an equal degree upon the successive ports visited after the acquisition of the original "set." If these ports should be in close proximity, the growths will continue to develop as if the ship were in the original port (with some exceptions), but if considerable distance (500 miles or more) separates them, most, if not all, of the fouling is killed, and if less than 2 weeks old almost all will drop off when dead.

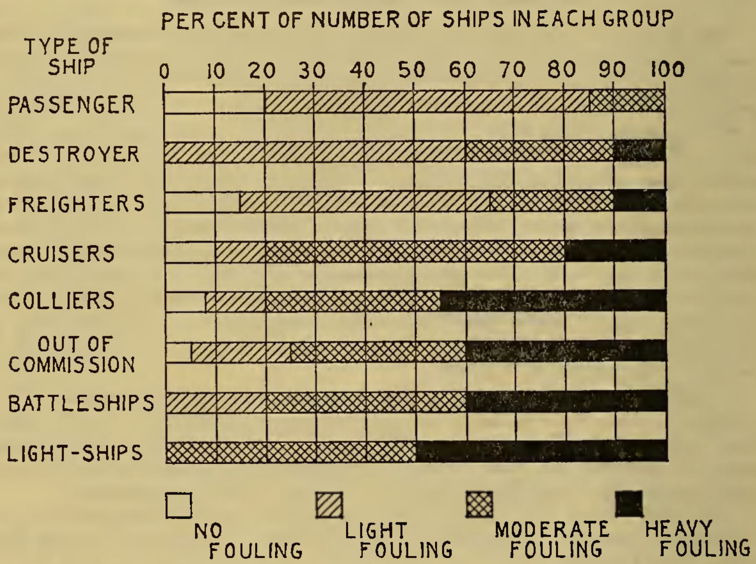


FIG. 23.—Relation between type (and related duty) of a ship and the amount of fouling, disregarding factor of time

Another class of ships, including commercial ships lying idle in port either for overhauling, repairs, or other reasons, as well as many of our naval craft (in peace times), forms the group that is fouled most heavily. This is due largely to the fact that frequently they lie in a given port for from 1 to 6 months, affording ample time for the original set of fouling material to develop and grow, so that all types of sessile marine growths that normally occur in that harbor frequently are found in luxurious growth on the bottoms of such ships.

An analysis of the data in Table 1, as regards the relation of fouling to the above classes of vessels, is given in Figure 23, which shows the percentage of the total number of ships in each of the eight classes, grouped according to the relative amount of fouling on each. It will be seen at a glance that passenger ships average a very light amount of fouling, while lightships and battleships show a very heavy growth. The percentages given for each group do not show an exactly comparable relationship, because data gathered from all the sources are included. If one were able to exclude all data from the Philadelphia Navy Yard, with its polluted, fresh-water harbor, and also omit those ships that enter dry dock after an unusually short interval (because of accident), the relative percentages in each group would show a steady and proportionate increase in amount of fouling.

However, in any chart of this kind more than one factor is represented. The fact that the average docking interval for passenger ships is about 7 months, for freighters about 8 months, for naval craft about 9 months, and for lightships about 11 months, must be taken into consideration. This factor, however, will be discussed separately below. Regardless of many of these complicating factors, the uniform difference in the amount of fouling is of real significance and, as will be shown, is probably related more to the effect of the relative amount of time spent in port than to any other one factor.

Having seen that there is a significant difference in the amount of fouling on ships belonging to the various groups, an analysis of some of the factors that determine this difference will be considered. Since the materials for construction are comparable, the paints usually the same, and the environmental factors, such as seasons, ports, and temperature, are similar in the main, the really significant differences are clearly related to the different duties of these vessels, and this relation to fouling can be analyzed by consideration of four main factors: (1) Hull design, (2) speed of ship while cruising, (3) dry-docking period and use of intervening time, and (4) the routes or waters cruised.

HULL AND CONTOUR OF SHIP

The construction of any ship plays a considerable part in the matter of fouling. The amount of fouling rarely is uniformly dense over the various portions of the hull. This is due not only to differences in structural relations of the various parts of the hull but to specific characteristics of the fouling organisms in attaching in definite zones. Thus, we find that there is a very definite and clearly defined vertical gradation noticeable in growths on ships' bottoms. Certain forms, like Enteromorpha and some varieties of Balanus, are found characteristically in a rather narrow zone around the vessel and extending from the water line to a depth of about 3 feet. Hydroids, ascidians, and the stalked forms of barnacles are found rarely in this zone. This, however, is the zone most commonly fouled, for in almost all classes of lightly fouled vessels this was the only region fouled. Often it is covered with a dense growth of algæ, whose filaments often extend 5 to 6 inches. In such thickets one often finds a bevy of animals, including such forms as amphipods, annelids, isopods, and even canceroid crabs (probably Panopeus). Occasionally this algal zone extended much deeper than usual. On several ships this growth extended from the water line for fully 10 feet, almost to the bilge keels. It has been impossible to correlate these few cases with any seasonal variation as suggested by Hentschel (1923).

Below the algal zone one finds a scattered growth of barnacles and incrusting Bryozoa on almost all ships that are lightly fouled, but on such ships these growths usually are very sparse, especially on the more perpendicular sides of the hull. However, on all parts not so perpendicular as aft (on the "quarter" or near the "run," etc.) these growths often were noticeably more abundant. As previously noted, some ships that were otherwise clean had small amounts of growths only in the seams formed by the overlapping of the steel plates. (See fig. 24.) On most ships barnacles and Bryozoa were found here, if at all. On some, as the *Paul Luckenbach* (June 12, 1924), large clusters of worm tubes (Hydroides) were found in these seams.

The third vertical zone would include those growths that occur on the more horizontal portion of the hull—the true bottom of most ships. In the case of heavily fouled ships, this portion was also the most heavily coated. Hydroids are found in great abundance, while mussels, Ascidia, and often barnacles also are found here in great quantities. In the case of moderately fouled ships, this region is again most heavily coated, as a rule, with sessile barnacles, hydroids, and Bryozoa, and if from certain routes, with stalked or goosenecked barnacles. In the case of but lightly fouled ships, the growths here were of secondary importance to the algal zone but were always most severe in the region directly under the bilge keels and in the "run" of the ship. The factors that determine this distribution are numerous, no doubt, but some may be pointed out at this time, of which several will be discussed under separate headings.

The presence of the algal zone only at the upper limit of growth is determined rather largely by the fact that these organisms are dependent upon sunlight for continued existence and growth. Light also may play a part in determining the activities of the larvæ at the time of setting, and so determine the location of later growths. The distribution of animal life is affected by the factors that determine the place of attachment of the young larval forms as well as by the conditions providing the food necessary for continued growth. The effect of too strong a current of water, as when a vessel is cruising, probably may cause many of the more tender growths to be torn off. This undoubtedly accounts in part for the presence of growths in the seams behind the overlap of the steel plates in vessels that are in constant service. It is a fact that most barnacles, hydroids, and tunicates attach in largest number below the bilge keel and on other shaded parts of the bottom. This would indicate that relative light intensity plays some part in determining the place of attachment on the bottom.

In view of these considerations, it will be seen that the contour of the vessel is an important factor in the matter of fouling. Flat-bottomed ships of shallow draft often are more foul than boats of similar design but greater draft; while vessels designed so as to permit the effective sweep of the water while cruising to play on the entire surface usually are more free from fouling under similar conditions than are vessels with deep "runs."

Directly associated with the type of hull and the contour of the ship is the factor of speed of the ship while cruising. That this factor has some effect on the amount of fouling can not be doubted, but evidence on this point has been very difficult of obtainment without complications. The tremendous pressure exerted on the sides and prow of a vessel as it progresses at the rate of 30 knots undoubtedly

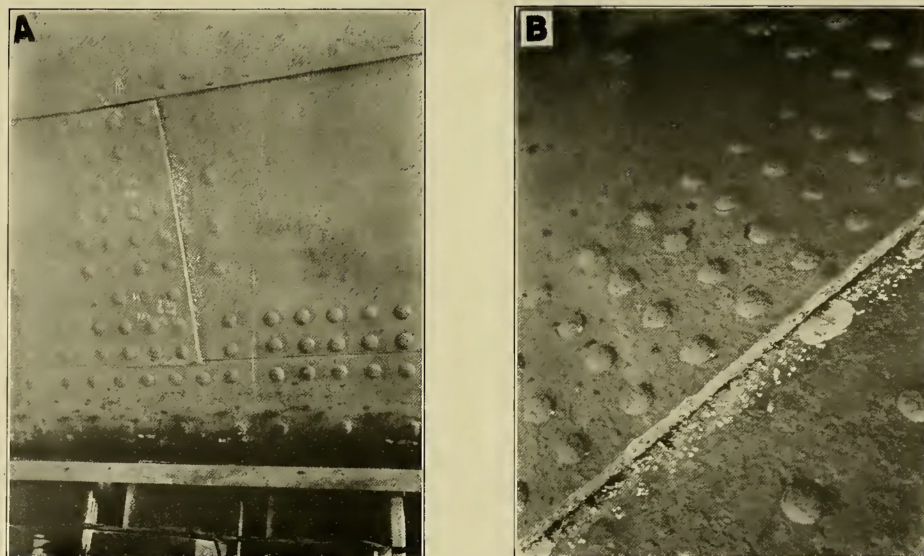


FIG. 24.—Relation between type of hull design and fouling. Views of the *Leviathan* in dry dock at Boston, February 27, 1924. **A**, several steel plates, showing characteristic location of fouling growths. **B**, enlarged view, showing presence of barnacles and Bryozoa in the seam formed by the overlap of the plates

kills most of the living organisms attached to it in exposed places. As indicated previously, the most usual place for fouling to be found on rapidly cruising vessels (passenger ships) was in the groove made by the overlapping of the metal plates of the hull. Here, then, is a case where the effect of friction through water is much reduced or entirely absent, and a merely local growth of fouling results. The noticeable absence of hydroids, tunicates, and other relatively soft-bodied organisms on rapidly cruising vessels indicates that such forms probably can not withstand the pressure, and consequently only shelly growths, such as barnacles and seruplids, are found on such vessels.

LENGTH OF PERIOD BETWEEN DRY DOCKINGS

The amount of time spent in port, in relation to the amount of time spent under way, obviously is related to the duty of the ship. It has long been known

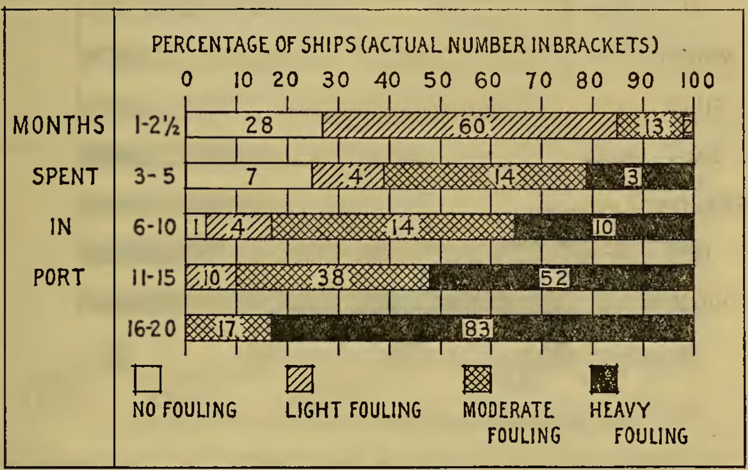


FIG. 25.—Relation between the degree of fouling and the amount of time spent in port between dry dockings

that while idle in port boats frequently accumulate heavy growths of fouling; while similar vessels, on the high seas during an equal period, remain relatively free from fouling. In the past this fact has been associated more with the length of the period that elapsed since the previous dry docking than with the relative amount of cruising done during a given period, a relationship that is of secondary importance only, as will be shown.

From the records of the ships that have been considered in this study, it has been estimated that passenger ships spend more than 60 per cent of their time cruising, while freighters spend an average of about 40 per cent of their time on the high seas. Naval craft vary greatly in this regard, but from the data given in Table 1 it can be seen that destroyers spend about 30 per cent of their time cruising, cruisers about 20 per cent, battleships about 15 per cent, and colliers about 10 per cent, while it will be realized that lightships and "out-of-commission" ships spend virtually none of their time cruising.

That this factor is of great importance can be seen from a careful study of the list of ships, their docking periods, cruising time, and amount of fouling, given in Table 1. It has been considered desirable, however, to present this information more fully and compare it from several points of view.

Accordingly, in Figure 25 the amount of fouling in relation to the time spent in port, regardless of all other factors, is represented in the form of a diagram. As can be seen from this diagram, fouling increases in direct relation to the amount of time spent in port.

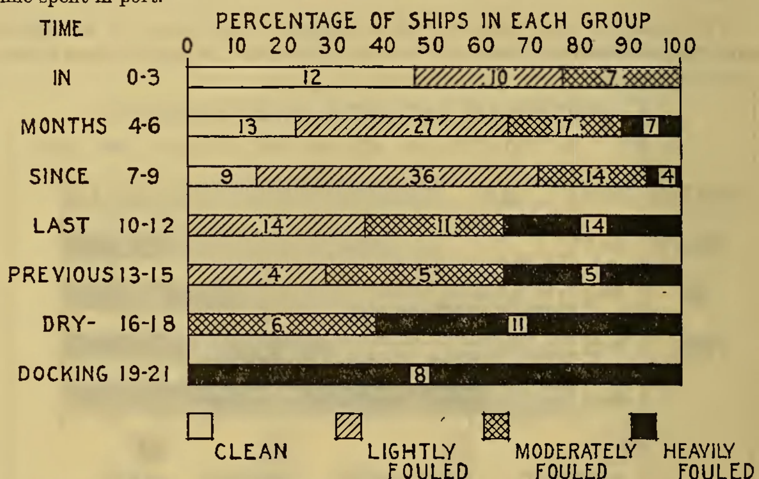


Fig. 26.—Relation between amount of fouling and amount of time between dry dockings

In Figure 26 the amount of fouling in relation to the total period that elapsed since the previous dry docking is shown. It can be seen, by referring to this diagram, that there is a fairly steady increase in the amount of fouling with the lapse of time, regardless of all other factors. Although this diagram presents only relative values, and at best approximate, it shows clearly, however, that the rate of fouling is virtually constant from the moment one dry-docking period ends to the time the next begins. (If the protective paints used have a definite "length of life" for efficiency as an antifouling agent, as is generally maintained, then there should be a marked turn at some point in the diagram, presumably after six or eight months, on the basis of customary dry-docking schedules.)

In Figure 27 is shown the relation of fouling to the amount of time spent cruising. This diagram is the reverse of that shown in Figure 25 and will serve to emphasize the significance of cruising in its effect on fouling. It will be seen that the amount of fouling is decidedly less the longer the period of time spent cruising.

That this is due not so much to the actual effect of cruising as to the fact that such boats are not in harbor sufficiently long to accumulate heavy growths is seen by comparison of this diagram with those given in Figures 25 and 26.

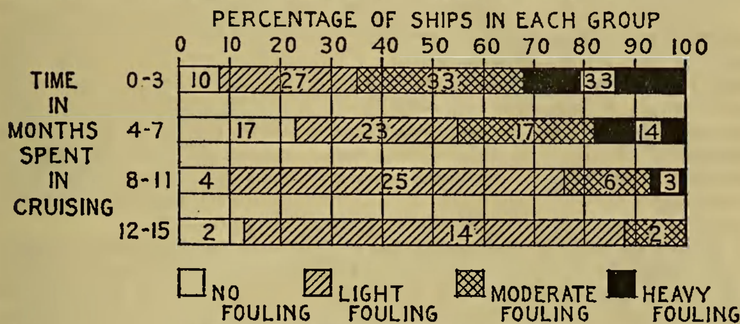


FIG. 27.—Relation between time at sea and amount of fouling

In Figure 28 is shown a combination of Figures 26 and 27, indicating a more accurate relationship between cruising and fouling. As indicated, this table shows

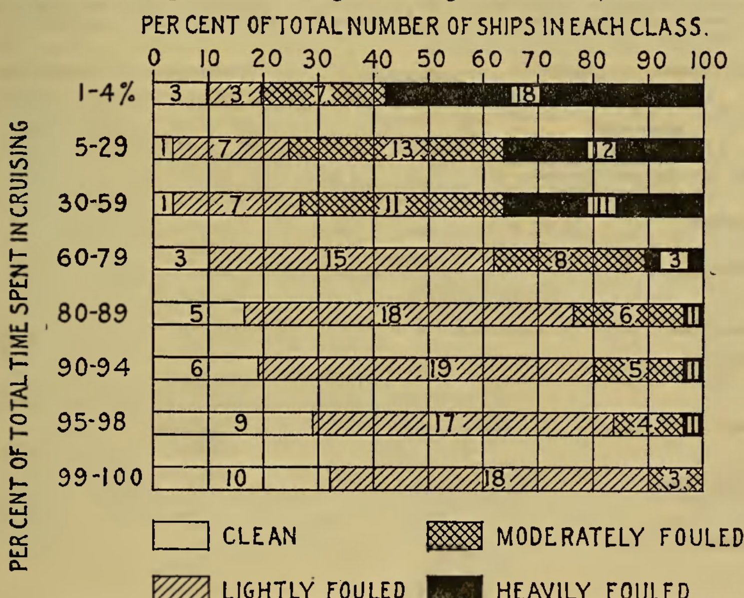


FIG. 28.—Relation between the amount of fouling and the per cent of total time since last dry docking spent in cruising

the relation of the amount of fouling to the amount of time spent at sea. It will be seen easily that this relationship is constant and that the proportions appear to vary inversely as the percentage of time spent cruising.

In Table 4 is shown a classified list of the various types of ships, indicating the number in each group, with their respective amounts of fouling in relation to the length of the last dry-docking period. Of the ships that docked within three months after a previous dry docking it will be seen that in all groups, excepting the battle cruisers, the majority of the ships were clean or only lightly fouled (for those docking), while in the next three months (i. e., from three to six months after previous dry docking) the majority were found to be in the classes of lightly or moderately fouled ships. It is also of interest to note that in columns 6 and 7, the periods longer than 18 months, the preponderance of heavily fouled vessels is very conspicuous, especially in the case of vessels "out of commission."

From these tables it is seen easily that the time between dry-docking periods is of great significance, but the use made of this time, either in cruising or in port, is of even greater importance. It can be seen, in addition, that the amount of fouling increases with the length of time that elapses since the previous dry docking (fig. 26) but becomes proportionately less with any increase in the percentage of time spent cruising. (Fig. 28.)

TABLE 4.—*Analysis of the difference in docking periods for diverse types of ships and the relative amount of fouling on these ships, grouped according to length of time elapsed since previous dry docking*

[H, heavily fouled; M, moderately fouled; L, lightly fouled; N, no fouling; X, aberrant cases, due to putrid waters of the Philadelphia Navy Yard]

Class of vessel	1 to 3 months	3 to 6 months	6 to 9 months	9 to 12 months	12 to 18 months	18 to 24 months	24 months
Colliers and miscellaneous naval craft		2 M	1 H 4 M 2 L	4 H 1 M 3 L	2 M 1 L	1 H	
Battleships	1 L	1 H 3 M	1 M 2 L		2 H		
Destroyers	2 L 1 N	3 L 1 N	1 M 4 L	2 H 3 M 2 L	2 L	1 H	
Passenger vessels	1 L		5 L 3 N	1 L			
Freighters	1 M 2 L 2 N	5 H 10 M 15 L 6 N	1 H 3 M 14 L 2 N	3 M 4 L	1 L		
Cruisers	3 M	2 M 2 N	2 M 1 L	3 H	1 M		
Out of commission	1 L	1 L 1 N		3 H 3 M 1 L	3 H 2 M 1 L	3 H 3 M 1 LX	6 H. 2 LX.
Lightships			1 H 1 M 2 L	3H 1 M			

WATERS CRUISED

Associated directly with the duties of a vessel is the cruising record, indicating by its log where the vessel has been and what ports were visited. Thus, of the boats examined for this report the passenger vessels were on the trans-Atlantic service or the South American or Mediterranean routes, while the freighters had an even wider range of routes. Some of those examined plied regularly between New York and the west coast of South Africa, others between New York and the Mediterranean or New York and our west coast, or even New York and the East Indies.

Naval craft, as a rule, do not have regular definite routes, consequently much of the data in Table 1 is of little use in an analysis of the relation between routes and the amount of fouling.

In those cases, however, where it has been possible to study the effect of different routes traversed by different ships it has proved to be one of the most interesting problems encountered during the entire study. Just as the flora and fauna of the Tropics is different from that of the Arctic regions, and just as the trees of California are different from those found in Maine, so the growths attaching to ships in the China Sea are markedly different from those attaching in the North Atlantic or from those of any other geographic region. In other words, each vessel, if foul, shows at the time of docking, by the growths found on its bottom, a visible record of its cruise.

This report is not the place for a discussion of the geographic range of various species of organisms but a discussion of their effect on fouling will be in order.

One of the effects which was noticed early and was confused on many occasions is that found when a ship fouled in a tropical port arrives in a northern port, or vice versa. On such ships all growths are dead, either in a putrid condition or leaving behind only their skeletons or shelly growths as a reminder of the once abundant life. (*Nevada*, January 5, 1923.) Even ships moving from one port to another 500 miles away usually exhibited a similar state. (*Leviathan*, May 18, 1923, Norfolk to Boston.)

While it can be stated as a general rule that vessels that remain only a few days in one port and then move on to another remain free from fouling, there are certain noticeable exceptions. This is the case with freighters of the United States Shipping Board, which ply between New York and the west coast of Africa. Almost without exception these vessels were found to be heavily fouled, in spite of short dry-docking periods (five to six and one-half months), and in spite of the fact that rarely did they remain in any one port for more than three or four days. By an examination of Figure 29, which indicates the geographical relationship of the routes taken by these ships, it will be seen that although they moved from port to port almost daily yet these ports are very close together and most are in the same latitude; that is, they are in a similar geographical area, with environmental conditions comparable if not identical. It is evident, consequently, that the effect of change of port on growths causing fouling would be very slight, if any, and it is very evident, as seen by the records of examination of such ships, that the barnacles and hydroids that attach

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in these ports continue to grow in the neighboring harbors just as rapidly and luxuriantly as if the vessel had remained in the original port during the entire interval. It is doubtful if a series of ports can be found anywhere else in the world having so similar environmental factors that determine the ecological conditions for rapid growth of fouling organisms.

In contrast with this route, vessels returning from South American ports are frequently clean, or at best only lightly fouled. Vessels in the trans-Atlantic service, whether passenger or freight, rarely show heavy fouling unless delayed in some port for a considerable length of time.

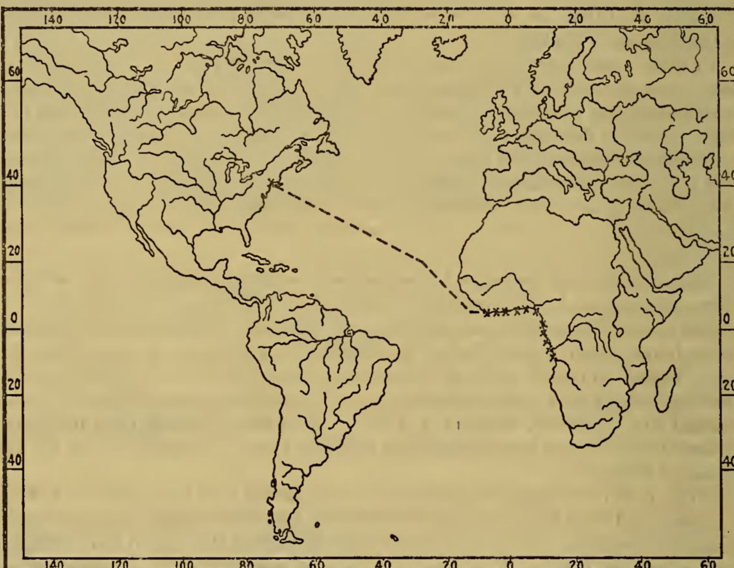

FIG. 29.—Route taken by certain of the freighters operated by the United States Shipping Board. Many of the ports are in the same latitude and all are in a similar geographic area

The type of fouling is very specific for certain routes, or at least for certain waters. Thus, naval vessels that practice in southern drill grounds at Guantanamo Bay, Cuba, West Indies, have characteristically large numbers of *Balanus improvisus*, *B. amphitrite*, and *Membranipora lacroxii*. Vessels that remain in the western Atlantic, north of the Chesapeake, have characteristic growths of *B. eburneus* and Tubularia. Vessels that visit the ports of the east coast of South America usually have growths of *B. tintinabulum* and *B. amphitrite*, although if no extended time was spent in these ports, or if these were river ports, such vessels would have clean bottoms.

It can be stated definitely from all data available that vessels that visit ports in tropical regions usually are more foul than those that ply more temperate zones.

Also, both from an examination of the logs of ships and a study of the organisms found on their bottoms, that ships foul almost entirely while in harbor, and that these growths usually die if the vessel leaves the original port where fouling first attached, provided such movement carries the vessel to a port at some distance from the original one (see *Maryland* and *Nevada*) or into a port with different ecological factors, such as fresh water, polluted water, or any water considerably different in temperature and related salt content, as found in most ports 500 miles or more apart.

It is thus seen that the log of a ship tells in a large measure, to those able to read it, the degree of fouling likely to be found on a ship at any given time, and an examination of the fouling material from the bottom of a vessel shows fairly accurately where the vessel has been and how long it remained in various harbors.

SEASONS AND RATE OF GROWTH

That fouling would occur more severely at certain periods of the year than at others is self-evident to all who study nature's laws. It is a well-known fact that for most animals there is a limited breeding season, occurring, as a rule, but once each year. Similar periodicities are found in most marine organisms, some of which have been carefully studied; as, for example, the oyster (Brooks, 1880), the clam worm, Nereis (Lillie and Just, 1912), and the Chitin (B. H. Grave, 1922). It seems probable that all living organisms that are subject to marked seasonal changes in climate, such as temperature and salt content of the water for marine organisms, as well as to seasonal changes in food, either in kind or amount, have seasonal periodicities related to reproduction. Very little is known, however, regarding the exact details of this question as it applies to those organisms that cause fouling on ships' bottoms. Such knowledge involves a careful study of the breeding periods of many species of these organisms, as well as an accurate knowledge of the habits of the larvæ from the time of hatching to the time when they attach and begin life as sessile organisms.

However, some studies that have a bearing on this problem have been published recently. Caswell Grave (1920 and 1923) has studied the activities of the larvæ of four species of tunicates. He found that all had limited breeding periods during the summer months for the region about Woods Hole, Mass. He was able to demonstrate that in the species studied the larvæ have a relatively short, free-swimming period, varying from 1 to 28 hours. Of this time, during the first portion, in all cases, the organisms reacted toward light and against the influence of gravity; but toward the end of the free-swimming period all reversed these reactions and were negative to light and positive to gravity. At the end of the short, free-swimming period, these organisms become attached, metamorphose, and develop at a rapid rate into the typical adult form.

The recent work of Fish (1925) is also of interest in showing the periodicity in the presence of different types of barnacle larvæ and other fouling agencies in the waters immediately south of Cape Cod. His data show that the larvæ of various barnacles are found for almost 10 months of the year. It is for only about five of these months, however, that the cyprid forms are found. Since of the forms listed only *Balanus crenatus* and *B. eburneus* are serious fouling agents, and since they attach only while in the cyprid stage, it is apparent that fouling by barnacles could occur only from July to late September in this region. Of the three hydroids listed in his report, which are occasionally found on ships' bottoms, it is of interest that the majority are also present as larvæ during the late summer months.

Although a few additional scattered references to similar data could be listed, they are extremely meager, and there are almost no data available on the subject of seasonal distribution and periodicity (especially with reference to the larvæ) that are at all comparable to the complete study of this subject with reference to the boring mollusks (Teredo and Bankia), which so severely attack all marine structures, especially piling, buoys, and wooden vessels. (See Atwood and Johnson, 1924.)

SEASONAL PERIODICITY

During this investigation, while examining the bottoms of more than 250 ships, it has been possible to secure some additional data, but relatively few are of an

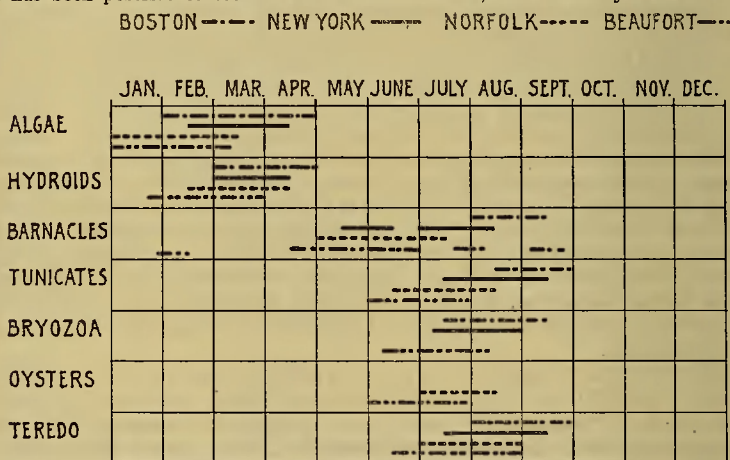

FIG. 30.—Prevalence of the larvæ of organisms that cause fouling at Boston, New York, Norfolk, and Beaufort, N. C. From data gathered from ships' bottoms and test panels

exact nature because few ships are docked within 90 days of their previous docking, consequently it was only on rare occasions that the exact time of attachment for specific organisms could be determined. However, from the few ships that docked within 30 days of their last previous dry docking, as well as from vessels that were in a given port continuously, it has been possible to prepare some incomplete but fairly accurate charts for fouling in the harbors at Boston, New York, and Norfolk, and at Beaufort, N. C. These are given in Figure 30.

By referring to this chart it will be seen that the periods of active fouling vary with the kinds of fouling. Thus, the hydroids and algæ are late winter and early spring forms; while many of the barnacles, the oyster, and the bryozoan Bugula are late spring and summer forms, and some barnacles and the tunicate Molgula are late summer or early autumn forms. Each of these is found earlier in southern waters, as at Beaufort and Norfolk, than in the cooler and more northern waters, as at New York and especially Boston.

It will also be noted that the barnacles and some of the others have a more extended breeding period in warm waters than in those north of New York, where these periods are limited sharply for most organisms. It is apparent, however, that for the barnacles and the more serious types of fouling, measures employed to prevent their attachments should be most effective during the early summer months, varying the date according to the latitude of the locality.

The above data are admittedly not accurate in every detail but serve to indicate the significance of such studies. A more comprehensive study of this problem has been begun by the author, and preliminary results are appended as a preliminary report on seasonal fouling, as determined from panels submerged in various ports by naval vessels.

Early in the course of this investigation it was realized that accurate data for determining the periods of active fouling could not be gathered by a study of ships' bottoms alone, and it was accordingly recommended that such information for various harbors be ascertained by submerging panels from vessels visiting such ports. In conformity with these plans, 10 sets of panels were prepared by the Navy Department (New York and Norfolk yards), and these were issued to as many ships with instructions to submerge a set of two panels in each port visited, provided the vessel remained there three days or longer.

Of these panels only three sets have as yet been received for biological study. Of these one set had but three boards and showed no results. The third set received was likewise small and completely dried out when received so that results were difficult to evaluate. The second set, however, showed definite and significant results. These panels had been submerged by the U. S. S. *Sirius* and represent fouling conditions for limited periods at the San Diego, Mare Island, Bremerton, and New York Navy Yards. The data are tabulated in Table 5. By referring to this table it can be seen that fouling is severe at Mare Island in October, while it is very slight during June. At San Diego growths attach in moderate numbers in June and July, while no fouling, apparently, occurs during November. These data would indicate that at Bremerton, Wash., fouling is moderate in late June, while at the New York yard none occurs during late September. It is interesting that all of the above data substantiate general conclusions drawn from examination of ships' bottoms.

TABLE 5.—*Results obtained, with reference to seasonal fouling, from panels submerged by the "Sirius"*

Panel No.	Date of submersion	Date when removed	Place of submersion	Depth submerged	Current and condition of water	Type of fouling
				Feet		
1	May 31	June 5	San Diego	16	Sluggish, fairly clear	Slimy scum; few barnacles.
2	do	do	do	16	do	Few barnacles and hydroids.
3	do	do	do	16	do	Do.
4	June 10	June 18	Mare Island	16	Fair current, very dirty	Single hydroid.
5	do	do	do	16	do	Few hydroids.
6	do	do	do	16	do	Scum only.
7	June 23	July 11	Bremerton	16	Sluggish, clear	15 minute barnacles.
8	do	do	do	16	do	25 barnacles on panel.
9	do	do	do	16	do	125 barnacles on panel.
10	July 23	July 28	San Diego	16	Sluggish, very clear	Few minute barnacles.
11	do	do	do	16	do	Barnacles and few hydroids.
12	do	do	do	16	do	A single hydroid.
13	Sept. 16	Sept. 23	New York Navy Yard	16	No current, very dirty	Clean.
14	do	do	do	16	do	Slime only.
15	do	do	do	16	do	Do.
16	Oct. 21	Oct. 30	Mare Island	16	Fair current, dirty	500 minute barnacles.
17	do	do	do	16	do	25 barnacles and few minute hydroids.
18	do	do	do	16	do	1,000 minute barnacles and few hydroids.
19	Nov. 22	Nov. 28	San Diego	16	Sluggish, fairly clear	Clean.
20	do	do	do	16	do	Do.
21	do	do	do	16	do	Do.

RATE OF GROWTH

The rate of growth of various organisms is of importance in any study of the factors that determine fouling, because of the fact that organisms become much more resistant to changes in their environment as they grow older (within limits) and as such are not killed off by the moving of a vessel from one port to another as easily as when the growths were young and succulent, and also because of the fact that increase in size increases the resistance of the ship.

It is surprising, perhaps, to learn that barnacles grow to sexual maturity in less than 90 days and often attain large size in less than that time, as can be seen by referring to Figure 31 *F*, which shows the size of some barnacles collected from the *Nevada* after she had spent 60 days in the harbor at Rio de Janiero. Figures 31 *A* to *E*, represent the rate of growth of barnacles at Beaufort, N. C.; and in Figure 32 is shown the amount of fouling that accumulated on a piece of wood at this harbor in 60 days. Very little accurate information is recorded regarding the rate of growth of these forms, although B. H. Grave (1924) has made a recent study of some of the forms that cause fouling, but these results have not been published as yet.

FRESH WATER

HISTORICAL DATA

It is a firmly established belief among mariners that if a "fouled vessel is placed in fresh water the growths on its bottom will be removed and the boat again become clean." When the cruises for vessels were less exactly timed than at present, experienced sea captains often put into a fresh-water harbor for this single purpose; and even to-day ships passing through the Panama Canal are known frequently to spend an extra day or more in the fresh-water lakes, and it is commonly understood that sea captains are anxious to have their vessels in fresh-water ports whenever possible. According to Capt. Henry Williams (1923), however, unfortunately there is no definite information on this subject.

It is known that certain marine organisms can and do survive in fresh water; as, for example, the eel, the salmon, or the shad, all of which spend a part of their lives in fresh water and the remainder in salt water. Similarly, such algæ as Enteromorpha and Cladophora live indifferently in fresh and salt waters; but such forms are very few in number in comparison to the vast number of marine organisms that soon die if placed in fresh water.

Among the organisms that cause fouling, almost all are strictly marine forms with but a small percentage able to survive in brackish waters. There can be no doubt, then, that many of these organisms are killed if the vessel to which they are attached is transferred to fresh water for a period of time sufficient to secure this effect.

DATA FROM SHIPS

During the course of this investigation it was apparent on many occasions that the unusually clean condition of the boat was no doubt explicable on the basis of visits into fresh waters. Thus, in the case of the *Western World* (March 8, 1924) its regular

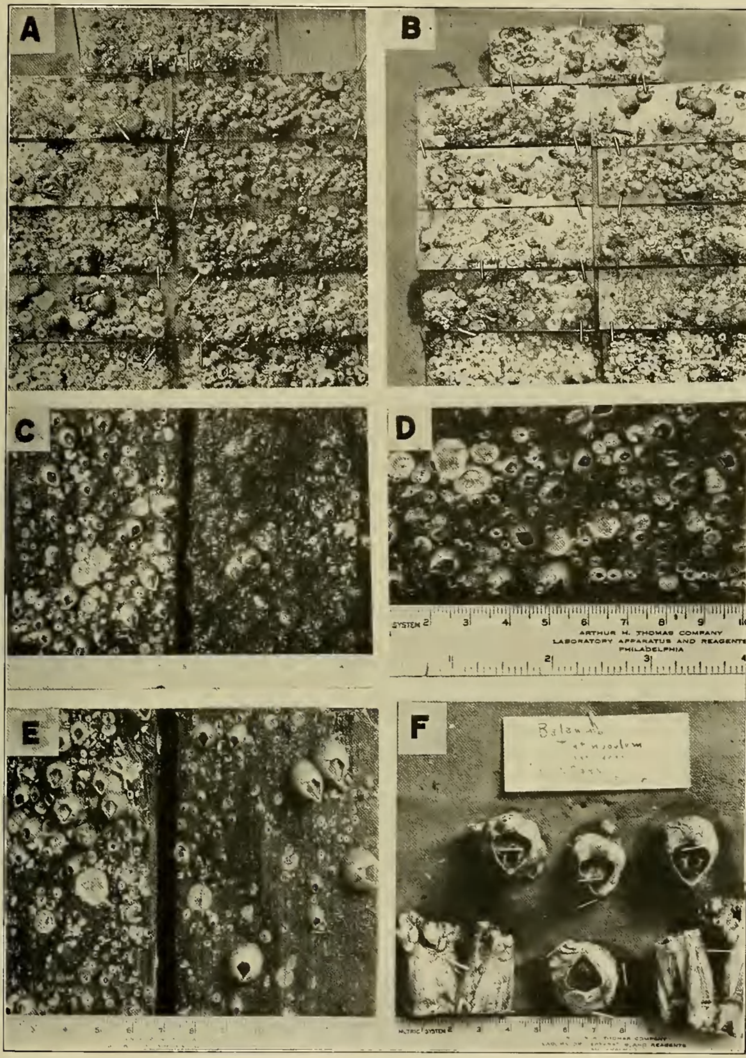

Fig. 31.—Rate of growth for barnacles. **A** and **B**, one month's growth of *Balanus eberneus* on glass slides 3 by 1 inch. June 5 to July 4, 1924, at Beaufort, N. C. **C** and **D**, two months' growth of *B. eberneus* on wood at Beaufort, N. C., May 17 to July 16, 1924. **E**, three months' growth of *B. eberneus*, May 17 to August 17, 1924, at Beaufort, N. C. **F**, approximately three months' growth of *B. tintinabulum* from Rio de Janiero, as collected from the hull of the U. S. S. *Nevada*

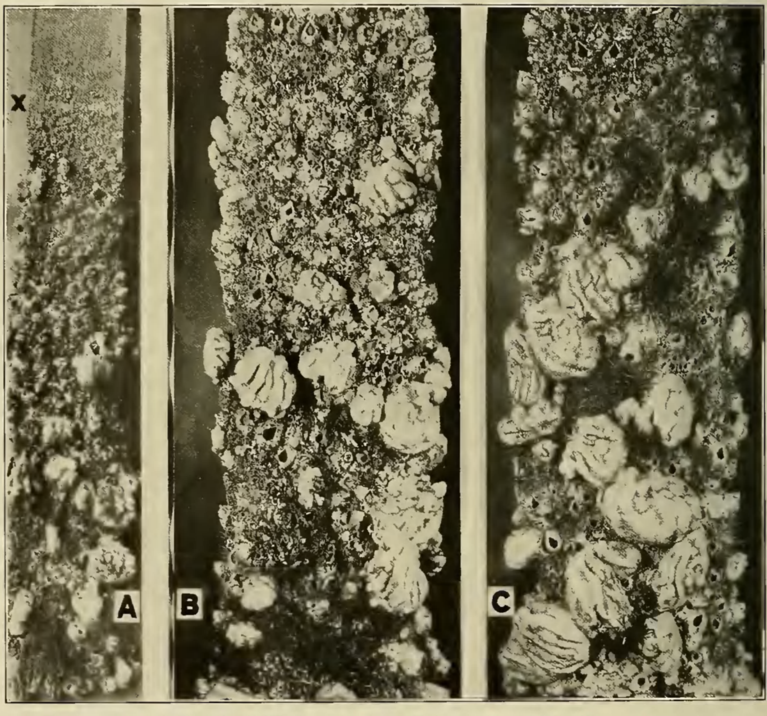

FIG. 32.—Amount of fouling accumulating within 60 days (May 15 to July 15, 1925) on a board 4 inches wide by 1 inch thick and 26 inches long. **A**, entire board, indicating average low tide line (x); **B** and **C**, enlarged views of growths

visit to Sante Fe (Argentina), far up on the Salado River, very probably explains the absence of fouling on this route, while vessels that do not visit fresh-water ports usually acquire heavy fouling. Similar explanations would account for the conditions found on the *Eastern Pilot* (March 25, 1924), the *Zarembo* (April 11, 1924), and also the *Eastern Sword* (April 11, 1924).

The lightship tender *Hawthorne* (March 10, 1925) was found to be almost clean, in marked contrast to most vessels of her group. The fact that she spent considerable time in the Connecticut rivers probably explains this condition, on the basis of the effect of fresh water.

While there can be no doubt that fresh water kills many of the organisms that cause fouling, yet that does not imply in any way the natural conclusion that such ships would then be clean. On the contrary, many ships have been observed where the fouling growths were very probably killed by the entrance of the ship into a fresh-water harbor, but fouling on such ships often remained severe for a considerable period. The shelly growths of barnacles, oysters, Mytilis, and even of Bryozoa, and the chitinous "stems" of hydroids have been seen on ships that had been in the fresh-water harbor of Philadelphia for more than 12 months. The most notable example of this is the case of the destroyers *Parker* and *O'Brien* (November 28, 1922), where many barnacle shells were scraped from their bottoms after more than 20 months in polluted fresh water. It is thus evident that although fresh water kills the growths that cause fouling, it does not remove them or clean the ships unless such growths are succulent or very young, in which cases the entire ship probably is cleaned by this process.

EXPERIMENTAL DATA

In order to ascertain more exactly the period that it is necessary a vessel spend in fresh water in order to secure such desired results, the following experiments were conducted.

Various types of organisms were removed from their normal salt-water habitation and placed in containers, through which a slow current of fresh water passed constantly. A continuous circulation of water was found necessary, both to supply the required oxygen and to prevent putrefaction from affecting the more resistant organisms. Death point was determined if after transfer to normal environment resuscitation did not occur.

In Table 6 is given the list of the organisms tested and the period of exposure necessary to kill. The first column indicates the time at which the first were observed to succumb, and the second column indicates the maximum period during which these organisms were able to live in fresh water. The number of trials is also indicated in each case, many organisms being used in each trial.

It will be seen from this table that many of the organisms that cause fouling can be killed by transfer to fresh water for a period of 24 hours. This is especially true for most larval and young forms. It will be noted, however, that several important organisms such as *Balanus eburneus*, Ostrea, and Enteromorpha, often are not killed in less than four days, although in several tests it was found that the larvæ and younger forms of all but the last of these were killed within that period.

TABLE 6.—*Illustrating the resistance of marine organisms to the effects of fresh water, indicating in hours the length of time that certain forms, common on ship's bottoms, were able to live in circulating fresh water*

Organism	Number of trials	Minimum period	Maximum period
		Hours	*Hours*
Balanus eburneus	4	72	96
B. amphitrite	5	12	24
B. balanoides (1)	4	36	48
Chthamalus stellatus (2)	2	48	60
Tubularia crocea	2	12	24
Eudendrium	2	6	12
Obelia geniculata	1	6	12
Membranipora sp.?	4	12	24
Bowerbankia gracilis	3	6	12
Ostrea elongata	2	48	96
Enteromorpha (3)	3	72	?

NOTE.—(1) and (2) are not common on ship's bottoms but are listed for the sake of comparisons. (3) is a variable, depending upon the previous environmental conditions. Death determined by inability to revive after being returned to original environment.

Accordingly, it can be assumed that much fouling is killed by a stay of one day in fresh water. If the growths present are all young, a larger percentage will be killed and most or all of them will disappear completely. If on the other hand, they are mature forms of more than two or three months, many of such growths may not be killed in less than 72 or 96 hours; and even if killed, their shelly structures will still remain, often for a long period of time. Inasmuch as the resistance to a ship is caused by these structures, whether alive or dead, little benefit will accrue from such visits to fresh water, except that these growths will no longer increase in size. It is accordingly evident that fresh water will kill most forms that cause fouling but will not remove many of the growths already present, unless these are minute and not heavily calcified or chitinized.

POISON PAINTS, METALS, AND SURFACE FILMS

POISON PAINTS

The practice of painting ships' bottoms has been in vogue so long that its value hardly can be questioned. As stated in the introduction, ships probably have been painted since the first ship was launched, but the nature of this paint has varied from time to time. These paints have been utilized as much or even more for the preservation of the wood or metal of which the hull is made than for the prevention of marine growths. Thus, on steel vessels to-day it is the practice to cover the ship first with a coat of "anticorrosive" paint and subsequently with a second coating of some "antifouling" paint. The former is for the preservation of the metal while the latter is applied in the hope of preventing the growth of fouling agencies, and contains the various poisons used for that purpose.

Before metal vessels came into use poison paints were resorted to primarily to prevent the attachment of the marine borers, which, even in recent times, have caused so much destruction to piling and other harbor equipment (see Atwood and Johnson, 1924) and which, until steel ships were first employed, caused even greater damage to the hulls of wooden vessels.

That copper poisons are especially efficacious in preventing the attachment of the young larvæ of these forms, provided the paint has been applied recently, is acknowledged generally. Many copper and mercury salts are extremely toxic to most animal and many plant organisms. It would be supposed, naturally, that these would be effective against those organisms that cause fouling, although no experiments to prove such a contention have been tried, as far as the author can learn, on any of the organisms as they exist at the time of attachment. Recently, Bray (1923) studied the resistance of the earliest larval stage of a single barnacle (*Balanus eburneus*) to various poisons, the results of which study will be considered below.

That the efficacy of poisons has been doubted by many is indicated by the following quotation from Lewes (1889), of the Royal Naval College of Great Britain:

On examining the conditions under which a vessel is put when coated with a composition which relies for its antifouling powers on metallic poisons only, we at once see the reasons which must make such a coating of little or no avail. In the composition we have drastic mineral poisons—probably salts of copper, mercury, or arsenic—which have been worked into a paint by admixture with varnishes of varying composition, and each article of poison is protected from the action of sea water by being entirely coated with this mixture; that this must be so is evident, or the composition would not have sufficient cohesive power to stick on the ship. As a rule, care is taken to select fairly good varnishes, which will resist the action of sea water for, perhaps, two or three months before they get sufficiently disintegrated to allow the sea water to dissolve any of the poison; whilst even with the accidental or intentional use of inferior varnishes, three or four weeks will pass before any solution can take place and any poison liberated to attack the germs. A ship is dry-docked, cleaned, and her antifouling composition having been put on, she goes probably into the basin to take on cargo. Here she is at rest and, with no skin friction or other disturbing causes to prevent it, a slimy deposit of dirt from the water takes place, and this, as a rule, is rich in the ova and germs of all kinds of growth whilst the poisons in her coating are locked up in their restraining varnish and are rendered inactive at the only period during which they could be of any use.

After a more or less protracted period the ship puts to sea, and the varnish being aided by friction of the water the poisonous salts begin to dissolve or wash out of the composition; but the germs have already got a foothold, and with a vessel sweeping at a rate of 10 to 12 knots through the water the amount of poison which can come in contact with their breathing and absorbing organs is evidently so infinitesimally minute that it would be impossible to imagine it having any effect whatever upon their growth. If the poison is soluble, it is at once washed away as it dissolves; if it is insoluble, then it is also washed away, but there is just a chance that a grain or two may become entangled in the organs of some of the forms of life and cause them discomfort. As the surface varnish perishes, the impact of the water during the rapid passage of the vessel through the water quickly dissolves out or washes off the poisonous salts and leaves a perished and porous, but still cohesive, coating of resinous matter, which forms an admirable lodgment for anything that can cling to it; and by the time the vessel lays-to in foreign waters, teeming with every kind of life, the poison which would now again have been of some use is probably all washed away, and a fresh crop of germs is acquired, to be developed on the homeward voyage, and a "bad ship" is reported by the person who looks after her docking. It is evident that a poison, even if it had the power of killing animal and vegetable life in all stages, could only act with the vessel at rest, unless it were of so active a nature as to burn off the roots and attachments of the life rooted to it, and if it did this, what, may I ask, would become of the protective composition and the plates of the vessel? And I think it is also evident that any poison so used must be under conditions in which it is very unlikely to be in a position to act when it might do good.

The practical proof, given by experience, that poisons alone are unable to secure a clean bottom soon led many inquirers to the conviction that it was exfoliation in the case of copper which had acted in giving fairly good results, and in many compositions the attempt has been made to provide a coating which will slowly wash off, and, by losing its original surface, shall at the same time clear away germs and partly developed growths and so expose a continually renewed surface, in this way keeping the bottom of the vessel free from life. There is no doubt that when this is successfully done a most valuable composition will result, but the practical difficulties which beset this class of antifoulers must not be overlooked. In order to secure success, the composition must waste at a fairly uniform rate, when the ship is at rest, and also when she is rushing through the water; and this is the more important in the case of service vessels, as in many cases they spend a large percentage of their time at anchor, or in the basins of our big dockyards. If a composition is made to waste so rapidly that it will keep a vessel clean for months in a basin, then you have a good composition for that purpose; but send the vessel to sea, and under conditions where you have a higher temperature, and the enormous friction caused by her passage through the water exerting its influence upon the composition, and you will find that the coating which did its work so well for six months at rest in the basin will, in the course of one month under these altered conditions, be all washed away, and fouling will be set up. Noting this result, the manufacturer renders his composition more insoluble—less wasting—and so obtains a coating which, when the vessel is in motion, scales just fast enough to prevent fouling, and good results at once follow; the composition is then put on the same or other vessels, and they take a rest in the basin, and bereft of the aid of a higher temperature and the friction of the water, the composition ceases to waste fast enough, and bad results at once have to be recorded. (Gardner, 1922–23, pp. 47 and 48.)

Apparently little consideration has been accorded the fact that all growths that attach to ships have a protective layer of material, frequently of a composition similar to limestone, between their bodies and the film of paint, and that in adult forms, at least, food is taken in from a very considerable distance from the sides of the ship. It is apparent to anyone with knowledge of the structure and habits of the animals that cause fouling that the only time a poison carried in a paint film could possibly be effective must be at the time of attachment.

When it is realized that barnacles (which are, as previously demonstrated, the most serious factor in fouling) attach by means of long antennæ, and that they do not take any food or even have any functional mouth during the period of attachment (that is, until metamorphosis has been completed) it can be seen that the effect of poison must be either as a direct irritant during this process or else the poison must be in such concentration in the surrounding water that the little organism, after attachment and subsequent metamorphosis, is poisoned by it with the food it takes from a distance of at least 1 millimeter from the surface of the paint. The amount of poison necessary to build up a concentration sufficient to be toxic at so great a distance, when submerged in an ocean of water that is usually in motion, and to hold such a concentration for a period of weeks or even months, as is demanded, would probably need to be much greater than the amount used. Even as early as 1867 Charles F. T. Young questioned the efficacy of poison paints, as can be seen from the following quotation (p. 68):

"It has been remarked somewhat dogmatically that for protecting iron vessels against corrosion and the adhesion of barnacles the use of a poisonous paint is in all cases indispensable, and this paint must be slightly soluble in water." But he maintains that "The primary requisite qualification for all paints or patented compositions laid over the bottoms of iron ships is necessarily the 'preservation' of the iron."

It is accordingly apparent that the use of poisons as antifouling agents for steel ships has been based either entirely on a priori evidence, without adequate foundation, or else is a hold over from the custom of painting wooden vessels, and its efficacious use can be legitimately questioned.

The effects of many kinds of commercial paints have been observed during this investigation, but not in sufficient numbers to make it advisable to contrast their effectiveness, except in the comparison with the "Norfolk standard" used by both the Navy and the Shipping Board, whose vessels comprise more than 90 per cent of those examined in this investigation. It can be stated, however, that no paint, with the possible exception of "Moravian" (*Litchfield*, April 10, 1924), has proved to be superior to the "Navy standard." The "amalgamated" was used on the *Benguela* (September 4, 1924), and this vessel was much more severely fouled than the *West Hestleton* (August 12, 1924), both of which, as seen from their records, had similar duties, cruising records, and itineraries, and were operating at almost the same season of the year, a factor that may have had some influence.

The effect of the "Red Hand" paint was seen on such ships as the *Hopkins* and *Kane* (December 7, 1923), *Goff* and *Gilmer* (November 21, 1923), and *Fox* (April 10, 1924), as well as on others; but adequate comparisons could not be made. In several cases, however, similar ships with similar duties but with "Navy standard" paint showed somewhat less fouling than the above.

The "International" paint was used on several lightships and tenders, including the *Relief* (April 24, 1924), *Northend* (June 2, 1924), *Lotus* (August 7, 1924), *Hawthorne* (March 10, 1925), and *Lightship 108* (April 4, 1925), and in most cases these were badly fouled. No comparison could be made, as none were painted with the "Navy standard."

The problem of continued effectiveness of paint is one that has been pondered long. The number of factors that enter into the problem of fouling apparently have clouded any accurate determination of this matter; and even in this investigation with respect to only a few ships could the question be answered positively, as negative data were inconclusive.

In the case of the *Maryland* (October 12, 1922), a heavy set of barnacles had occurred within the 70 days that elapsed after a previous dry docking, and in the case of the *Sturtevant* (November 20, 1924), a similar heavy growth of *Balanus improvisus* occurred during the 90 days after the previous dry docking. In the few other cases of short docking intervals (usually occasioned by some accident to the ship) light fouling, due to algæ, was observed. It is evident, however, from these two cases, as well as from the experimental test plates, that fouling frequently occurs even within 20 days of the time of painting, indicating that the effectiveness of the poisons apparently was lost by that time.

Many steel panels coated with various poison paints have been submerged, both by the Navy Department and by the American Society for Testing Materials, in order to determine the relative efficiency of such paints as antifouling means.

Although the final report on the experiments conducted by the Navy Department has not been seen by the writer, the report of Bray (1923) contains a list of many of the poisons used and the period of exposure when examined. These poisons were used as ingredients of paint films and were employed in concentrations of 4, 8, and 12 per cent. The following selections will give some idea of the range of materials tested: HgO, ZnO, CuO, naphthalene, zinc cyanide, poke root, $NaOH$, cupric oxide, sodamid, thymol, hydroxylamine sulphate, strychnine sulphate, quinine sulphate, uranium nitrate, Portland cement, T. N. T., phenol, capsicum, arsenated bakelite, aluminum sulphate, barium sulphate, sodium silicate, sodium chloride, hexamethylenamine, and copper sulphate. Many of them showed heavy fouling in less than 150 days, although a few, especially the mercury and copper oxides, showed less than the other materials tested. In a tentative report regarding these results Captain Williams (memorandum, July 25, 1923) stated that "of all the different substances tried the most effective are mercuric and cuprous oxides."

The American Society for Testing Materials has appointed a subcommittee (No. 23) for investigating antifouling paints. Five annual reports have been submitted, which include the results of many experiments with submerged panels and some tests on ships' bottoms. One definite result that they record is that "differences in fouling and corrosion are as appreciable in underwater paints by varying the vehicle as they are by varying the pigment." This fact would indicate the relatively minor effect of the toxic agents and the major importance of the condition of the paint film. Their final recommendations to date indicate a conclusion only in regard to the toxic compounds to be employed. They recommend as follows:

Antifouling paints shall contain, in each gallon of paint, copper and mercury in not less than the following amounts for varying service of ship:

Service	Copper	Mercury
	Ounces	*Ounces*
General	14	7
North Temperate waters	25	1.5
South Temperate waters	20	5
Tropical waters	14	14

The compounds of the metals are not specified, excepting that they "shall be present in the form of compounds which are not soluble in distilled water at 20° C. to a greater extent than 1 part per 15,000 parts of water, by weight (0.067 per cent = 0.00067)."

Effect of poison on larval barnacles.—Bray (1923) has studied the effect of various poisons in differing concentrations on the first larval stages of one of the barnacles that causes fouling (*Balanus eburneus*). He collected large numbers of the newly hatched nauplii and tested their resistance to known dilutions of many supposedly poisonous substances. The actions of the nauplii were carefully noted under a microscope, and the time taken to bring about complete cessation of movement was considered to be the amount of time necessary for the given solution to exhibit its toxic effects. In Table 7 the results of some of his experiments are shown. The author states that these data may be "interpreted very diversely, according to the particular conception one has of the fouling process and the time and manner of the action of the toxic agent or the anticorrosive film." While virtually all were effective at saturation, this was not the case for such compounds as cobaltous oxide and carbonate, both of which are fairly soluble in sea water, or for such compounds as antimony trioxide and copper carbonate, which are almost insoluble. "Some are very effective at high concentrations but rapidly lose their toxicity on dilution—e. g., arsenious pentasulphide and calcium fluoride." Others, though but slightly soluble, "seem effective at a great dilution—e. g., copper cyanide, mercury arsenate, phenyl arsenious oxide; and especially worthy of note is clorvinyl-arsenious oxide."

TABLE 7.—*Resistance (in minutes) of larval barnacles (nauplii) to several concentrations of various compounds (from report of A. W. Bray)*

Toxic agent	Percentage strength of solution								
	100	50	25	10	5	1	0.1	0.01	0.001
Mercuric chloride	0	0	0	0	0	0	2	5	60–90
Mercuric oxide	0	-----	-----	5	-----	27	130	280	[1] 24
Mercuric arsenate	1	-----	-----	6	-----	20	84	270	480
Copper O-nitro benzoate	1	-----	-----	5	-----	13	300	-----	-----
Copper P-nitro benzoate	0	-----	-----	14	-----	124	-----	-----	-----
Lead O-nitro benzoate	0	42	89	280	-----	-----	-----	-----	-----
Ferric O-nitro benzoate	0	82	241	-----	-----	-----	-----	-----	-----
Cuprous cyanide	22	-----	-----	-----	-----	-----	-----	-----	-----
Cupric cyanide	10	26	72	94	121	221	372	467	-----
Paris green	64	149	313	316	-----	516	-----	-----	-----
Cupric chloride	0	-----	-----	0	-----	5	8	34	150
Cuprous chloride	0	-----	-----	25	-----	-----	-----	-----	-----
Picric acid	0	-----	0	2	-----	163	-----	-----	-----
Zinc cyanide	0	18	39	220	-----	-----	-----	-----	-----
Barium arsenate	315	-----	-----	-----	-----	-----	-----	-----	-----
Phenyl arsenious oxide	0	0	0	0	-----	3	24	57	-----
Chlor vinyl arsenious oxide	0	0	0	0	-----	2	10	23	90
Diphenyl arsenious oxide	2.5	32	58	270	-----	-----	-----	-----	-----
Diphenyl amine arsenious oxide	56	120	-----	-----	-----	-----	-----	-----	-----
Naptbalene	30	70	-----	105	-----	-----	-----	-----	-----

[1] Hours.

Thus, it is seen that Bray has shown that certain compounds have a very toxic effect on the earliest larval stages of barnacles, provided the concentration is sufficient in the medium surrounding the organism to have its maximum effect. It must be understood at this time that the barnacles attach by means of long antennæ, and that in the case of mercurial compounds a concentration of more than one part per hundred thousand must be maintained in order to have any effect at all. With the entire ocean as a solvent, and less than 14 per cent of an extremely thin film to act upon, it seems questionable if such poisons can build up a concentration sufficient to be lethal for any considerable period of time. Of course, it is remotely possible that chemical action with sea water might have some effect, as suggested by Gardner (1922, p. 55). He states:

> The toxicity of free substances such as mercury and copper compounds to young organisms does not necessarily give a true indication of their toxicity when mixed with other ingredients of a paint, and the influence of the component parts of the sea water upon the toxic substance through longer periods may render it more or less toxic by dilution or by chemical interaction * * *. It is well known that when two substances are mixed together in varying proportions the resulting mixture is frequently more toxic than the same quantity of either component if used separately. The "why" of this action is not known; it is merely an empirical result.

However, this type of speculation has no evidence whatsoever for its support and perhaps is indicative of the methods sometimes employed in the preparation of antifouling paints.

Many paints have been tested by actual application on the bottoms of ships, both by the United States Navy and by the American Society for Testing Materials, through cooperation with the United States Shipping Board. In such tests the vessel to be painted usually was marked off into four divisions, and the forward port quarter and aft stern quarter were painted with the test paint while the other two quarters were painted with the regulation "Navy standard;" or vice versa, as the case might be. In such tests a true comparison of the relative efficiency of the two paints could be determined.

The report of the American Society for Testing Materials, subcommittee No. 23 (1925), records the results with 11 vessels partially or completely covered with test paints, and in addition to these 7 have been examined in the course of this investigation.

From the data given in their report it can be seen that in most cases there was no noticeable difference in amount of fouling, although in almost every case the experimental paint film did not "hold up" as well as the "standard." These data indicate not only the ineffectiveness of poisons but also the very significant effect of the nature of the surface film in the matter of fouling, a subject that will be considered next.

SURFACE FILMS

Since the major importance of the problem of fouling of ships' bottoms centers about the question of frictional resistance of the surface of the ship in passing through the water, the nature of the film covering this surface is of prime importance. It has been recommended by many people that paints of a greasy character would be advantageous, on the theory that there is no adhesion between the films of oil and of water. However, McEntee (1915) maintains, from his experimental data, that the most favorable coating for ships' bottoms, as far as skin friction is concerned, is a paint that offers a permanent, hard, smooth surface.

From a biological point of view, as far as the attachment of larval forms causing fouling is concerned, the nature of the surface film also is of great importance. In the course of the examinations considered in this paper it was noted that fouling was most severe in regions where the surface was not smooth. Thus, in the areas where paint had peeled off, as shown in Figure 33 *A* the growth frequently was heavy, provided corrosion had caused a roughened surface. Frequently the number of barnacles that attached to a colony of Bryozoa (fig. 33 *B*), or even to other barnacles, would be much larger than on the adjoining smooth surface of the ship's hull. In other cases, where the pigment of the paint had not been mixed properly before applying, the resulting rough surface often was fouled more heavily than in regions where the paint offered a smooth surface. (Figs. 33 *C* and *D*.) These observations are confirmed by reference to the report of Adamson (1922), in which he presents data to show that the "problem [of fouling] covers physical properties as well as chemical properties of the paint film."

In the summer of 1922 Bray (1923) made some preliminary tests on the effects of various surfaces in relation to the attachment of barnacles. He set out two sets on separate racks at Beaufort, N. C.; but, he concludes, "unfortunately, the length of time the racks were exposed, due in part to the lack of material and to an accident which caused them to lose rack A, after nearly four weeks exposure, renders any attempt at anything but tentative conclusions of little value."

These tests included such surfaces as glass, beeswax, eseter gum, and shellac, with various types of poisons and combinations. He, however, concludes that "there seems little doubt that a film of a 'waxy' nature is capable of greater retention of the toxic agent than a thinner, harder film." This point is brought up at present, without reference to the question of poison, only to show the superior results obtained with "waxy" surfaces.

The writer has observed barnacles attach to metal surfaces of many sorts, provided no electrolysis was present, to wood, stone, tile, glass, rubber, and shells of more than 30 species of animals—in fact, to everything that is found submerged at

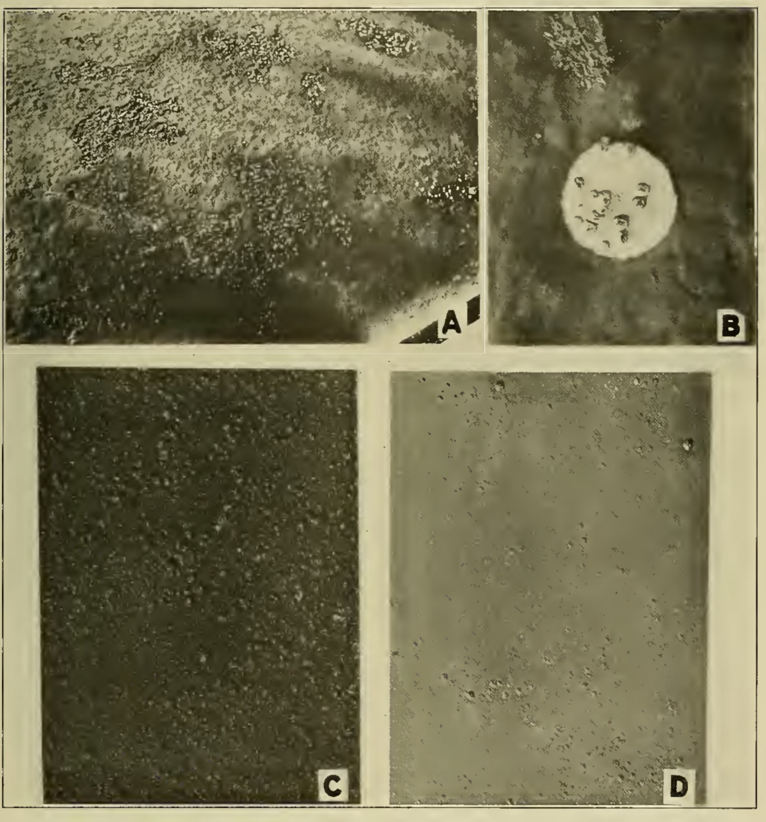

Fig. 33.—Effect of surface film on fouling. **A,** portion of the hull of the U. S. S. *New York* (Norfolk, Va., April 3, 1924), showing heavy set of barnacles where paint had peeled. **B,** also from the *New York*, showing attachment of barnacles on rough surface of a bryozoan colony. **C** and **D,** two test panels submerged at Beaufort, N. C., for identical periods of time, both with poisons but one (C) with a rough surface and the other (D) with a smooth surface

proper seasons and in favorable waters, with the exception of certain algæ. However, not all algæ are free from such attacks. Darwin records the occurrence of a special form of barnacles grown on the southern coast of Africa, and the author has found another variety growing in abundance on the fucus on the breakwater at Beaufort, N. C.

Nevertheless, the question of selective attachment of the larvæ of barnacles has proved a fascinating one for experimental work. Knowing that barnacles attach while in the cyprid stage, by means of an adhesive secretion thrown out from the tip of the antennæ, the possibility of finding some substances to which this "glue" would not adhere presented an interesting phase of the problem.

It has been found that the larvæ of certain barnacles (*Chelonibia testudinaria*) attach only to the backs of turtles; others (*Chelonibia patula*) to the shells of crabs; others (*Dichalaspis mülleri*), again, to the gills and in the gill chamber of certain species of crabs; and that one type of barnacle (*Balanus galeatus*) grows only on a special kind of coral. Likewise, other barnacles are found only *above* low tide line (*Balanus balanoides*), and others, again, only *below* low tide line (*Balanus crenatus*).

Considering these possible factors, and especially the relation of the adhesive substance of the barnacles to the nature of the surface to which it attaches, some experiments have been made, using more than 12 different compounds, including several decoctions made from different marine algæ and which show conclusively that no barnacle can attach to these films (at least within three weeks) during a heavy "setting" period, when all other surfaces were being coated with young barnacles.

It is also of interest in this connection that the presence of a slime film on the experimental panels, as well as on ships' bottoms, has been considered by some to be advantageous in preventing fouling, while others take the opposing view. Recent work done at the University of Washington by Miss Hillen (1923) would indicate that this slime is of bacterial composition, and she even maintains that "without this slime the barnacle would not settle upon the object (test panel) or develop upon it, as the slime is used as food material for the young barnacle in its first development." Further evidence on these points seems to be needed.

METALS

Different metals have been used as a means of preventing fouling since early times, as was described in the introduction to this paper. Copper and zinc were used abundantly on wooden ships, but with the adoption of steel vessels the use of these metals created electrolytic action that proved disastrous to the iron.

That copper has a protective function toward certain growths is seen from the record of the *Denver* (March 16, 1923), *Cleveland* (April 10, 1921), and the *Phalarope* (August 19, 1923), all of which are wooden ships that were partially or completely plated with copper sheathing. On these vessels barnacles were found as abundantly on the copper as elsewhere, but algæ and hydroids were conspicuously absent. Bryozoa and serpulids were present occasionally, but were not nearly so prevalent as on the propeller blades and the struts, which were of alloy composition, probably bronze. This difference was often noted on the propeller blades of iron ships, as on the *Florida* (March 15, 1923), where a very dense growth of hydroids covered the entire bottom but none were present on the propeller blades.

A complete study of the relation of various metals to fouling has been made recently by Parker (1924), who submerged panels of zinc, iron, aluminum, tin, lead, and copper. He found more or less fouling on all of them except the copper, and only a small amount on zinc. He explained this difference on the basis of ionization of these metals in salt water and the solubility of the resulting compounds. Thus, he states:

> The poisonous effects of these metals on marine animal life will depend upon the intrinsic toxicity of their ions, relatively high for all heavy metals, and the solubility of their hydroxides and basic carbonates in sea water. These solubilities in the case of Fe, Sn, and Al are in amounts inappreciable; in other words, these metals in sea water are not surrounded by a layer of poisonous ions, and hence animals may grow upon them. In the case of Zn and Cu, on the other hand, the corresponding compounds are appreciably soluble in sea water, and the poisons thus liberated prevent the growth of animals upon these metals.

His experiments with metal couples, however, have shown results that indicate a means of preventing fouling, even if an impractical method. He found that by coupling copper with metals higher in the electromotive series this metal can be rendered chemically inactive in sea water, and under such circumstances animals will grow freely upon it. Similar results were obtained with other couples, so that Parker concludes that "marine animals will grow upon any heavy metal, provided that metal does not liberate ions or soluble compounds." Conversely, it would accordingly be apparent that any electrolytic action causing ionization would serve to prevent fouling.

LIGHT AND COLORS

During the course of the examination of the second ship observed in dry dock it was observed, as previously noted in this report, that fouling was most severe in the region of the run and beneath the bilge keels of the ship. This increase in amount of fouling on lightly or moderately fouled ships in all areas that might be considered as "shaded" has been one of the most outstanding points noted during the whole investigation. More than 50 per cent of all examinations showed such results very strikingly. Other explanations have been offered to explain this intensification of growth in restricted areas, as, for example, the protection afforded in such locations. The writer, however, has held that the main factor was the influence of light. This contention no doubt was influenced greatly by previous knowledge of various biological studies on related phenomena.

The reaction to light of animals and plant organisms has long been a favorite study of biologists, because of the fact that most organisms react to this stimulus, as well as because of the ease with which the stimulating agent can be controlled. Lord Avesbury (Sir John Lubbock, 1904) was one of the first to demonstrate the fact that animals of many sorts react to light of different colors, finding, for example, that bees "prefer" blue flowers and that the tiny water fleas, Cladocera, gather in the region of the red if given a choice of all the colors of the spectrum.

More recently Mast (1911) and others have shown that reaction to light is a property common to almost all living things, both plant and animal. He showed, among other experiments, that the larvæ of one of the hydroids (Eudendrium) common on ships' bottoms react negatively to light, while the spores of certain plant forms (algæ), also common on ships' bottoms, are positive in their reaction to light. More recently, Caswell Grave (1920 and 1923) and his students have shown that the larvæ of several tunicates (Amaroucium, Perophora, and Botryllus) are positive to light upon liberation from the mantle chamber of the adult, but at the time of attachment all are definitely negative to light. Thus Grave and Woodward found for Botryllus (a tunicate common on our North Atlantic coast) that the free-swimming period for these larvæ persisted for from 1 to 27 hours, and that during this time they react positively to light for a "comparatively long period," and then are indifferent or nonresponsive and finally negative to light for a "period of short duration just before metamorphosis begins."

Some work has been done on the reactions of the barnacle larvæ to light, notably by Jacques Loeb (Groom and Loeb, 1890); but this work was done only on the early larval stages (nauplii) and consequently has little bearing on the problem, as the cyprid stage is the condition in which the barnacles attach to ships' bottoms. In his studies of the "nauplean larvæ" it was found that they were usually positive to light upon liberation from the parent, but that reversal of reaction frequently occurred, probably dependent on environmental factors.

That practical tests have been made on ships' bottoms regarding the effect of colors is recorded by Holzapfel (1923), who concludes that the advantageous effect, if any, is too slight to warrant any serious consideration. However, the report of Captain Macauley (1923) would indicate that not all nautical men would so minimize its practical importance.

As this problem (the effect of light on fouling) seemed one that offered considerable possibilities, and inasmuch as no controlled experimental data were available regarding it, considerable time has been spent on its study. This work has been of four kinds. First, the use of steel plates coated with variously colored paints, submerged in a tidal channel whose waters were heavily infested with fouling organisms; second, the study of the effect of a submerged electric light on the attachment of organisms (the results of this experiment were so inconclusive, due to various difficulties, that they are not presented here); third, the use of colored tiles under similar conditions in order to eliminate the possible effect of the constituents of the paint film, leaving only the effect of light; fourth, laboratory studies of the reactions of the cyprid larvæ of various species of barnacles to light of known intensity and spectral distribution; and finally, as a corollary of this, the study of the actual process of attachment and the effect of light at the time of attachment.

SUBMERGED TEST PANELS

Attachment of fouling growths on steel panels painted with materials of different colors has been studied by several workers. Soon after beginning this investigation a conference of men working on the various aspects of the problem of fouling of ships' bottoms was held at Beaufort, N. C., on October 25, 1922, where large numbers of panels had been submerged to test the effectiveness of as many different paints. Already at this time a series of panels painted with different colored paints had been submerged at the suggestion of H. A. Gardner. As he states in his circular (1922) recording the fact that these were submerged, but without recording any results, these were submerged "to determine the effect of colors upon attachment of barnacles. It is believed that the barnacles might seek, through protective coloration, certain colors and avoid other colors against which they might present a more obvious appearance." However, at the time of the first examination by the author these plates showed results that were quite inexplicable on the basis of adaptive coloration but proved sufficiently interesting from a biological viewpoint so that a preliminary report by the author was submitted at that time (December, 1922), from which the following paragraphs are quoted:

In order to test this hypothesis a series of 12 steel panels had been exposed. All were painted with two coats of standard anticorrosive paint and a third coat which contained the desired pigment. All of the pigments, as well as the paint mixtures used, were nontoxic. (See H. A. Gardner, 1922.) All plates were exposed on the same day, and each panel was suspended separately from a rack built in a tidal channel, where the water flows at between 4 and 6 miles per hour whenever the tide is running. They were submerged in water about 6 feet deep, being held in a vertical position about 12 inches from the bottom. They were arranged in a row, end to end, about 2 or 3 feet from each other and parallel to the water currents in the channel. The plates extended in a line approximately north and south. Both sides of each plate, consequently, received about the same amount of light during the course of the day. Examination was made about two months later. As all of the plates had been treated alike, except for the colored pigments, and as all factors influencing them were the same, it may be concluded that any difference in the amount and nature of the fouling would be dependent on color.

The results obtained are presented in a table (No. 8) and may also be seen in the photographs. (Fig. 34.) The colors of the plates shown in the photographs are as follows: 201, white; 202, yellow; 203, red; 204, green; 205, blue; and 206, black. By referring to the photographs and to the table it will be seen that there was much more fouling on the dark plates than on the lighter colored plates. The contrast between the white and black plates was very marked.

TABLE 8.—*Organisms found on test panels that differed in color of paint*

Color of paint	Clean area	Algæ	Worm tubes	Bryozoa	Hydroids ("grass")	Barnacles
White (201)	Extensive (65 per cent).	Abundant	Very few	0	0	0.
Yellow (202)	Extensive (40 per cent).	Very scattered	Abundant	0	0	0.
Red (203)	Few and small (5 per cent.)	do	Many	Very numerous.	Few	Very few.
Green (204)	Extensive	do	do	Numerous	0	Few.
Blue (205)	Few, medium (15 per cent.)	do	do	do	0	Fairly numerous.
Black (206)	None	(?)	Few (?)	do	Many	Very abundant.

It will be noted that the clean areas were most extensive on the white (65 per cent) and yellow (40 per cent) plates. The growth of very fine algæ was present only on the lighter colored plates and was abundant only on the white plates. It formed almost the only growth present on these plates.

The worm tubes (irregular, slender, white formations seen in the photographs), formed by an annelid worm of the genus Hydroides, appeared very numerous on all the plates except the white and black. The latter may have had as many worm tubes as any other plate, but because it was so densely covered by other growths the appearance of any tubes was obscured.

The Bryozoa (characteristic circular patches seen in the photographs) were noticeably most abundant on the red plates, although all others, except the white and yellow, were also heavily infested. Not a single specimen was found on the white and but a few on the yellow plates.

The hydroids (grass) were absent from all but the red, blue, and black plates, and were abundant only on the last.

The barnacles were the most striking in their distribution. Only on the blue and black plates were many of them found, and they were most abundant on the black.

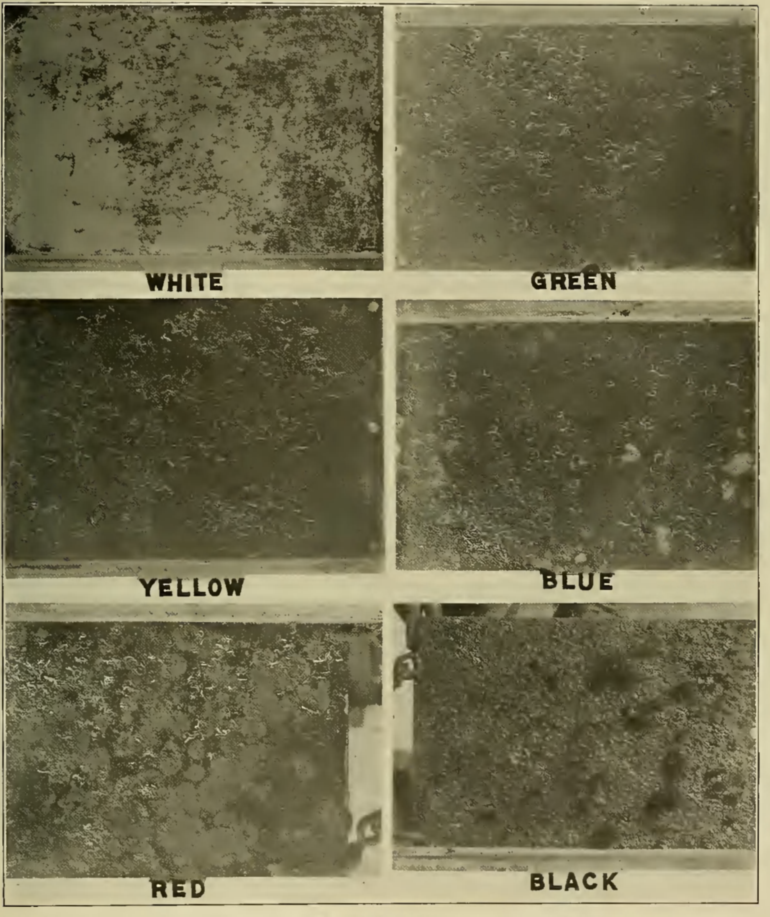

Fig. 34.—Relation of color to amount of fouling. For description see p. 240 of text. Variously colored plates submerged at Beaufort, N. C., for 2½ months, August to October, 1922

It can be seen clearly then that there is a very definite relation between the color of the plates and the kind and amounts of growths on each. The barnacles and hydroids apparently attach only to dark-colored surfaces, while Bryozoa and worms attach to somewhat lighter surfaces as well, but apparently prefer the red and yellow, respectively.

Since the white barnacles were found most abundantly on the black plates, and since neither the barnacles nor the worm tubes, both of which are conspicuously white, were found on the white plates, it would seem that there is no evidence of protective coloration

The apparent selection of the darker surfaces can best be accounted for by a study of the behavior of the larvæ of these organisms. The newly hatched larvæ of almost all sessile marine animals (as well as many others) react positively to light; that is, they swim toward the source of light. This period of positive reaction, however, is of only limited duration. (It appears to be only long enough to carry the young organism to the surface of the water, there to be carried about and distributed by the ocean currents.) Most of these larvæ then become negative to light. It is in this period that they attach and molt into sessile organisms with characters similar to those found in the adult. This fact has been demonstrated experimentally for certain hydroids, annelids, and tunicates. It is also known that lights of different wave lengths have different effects on various organisms. Some go toward red, others toward blue, green, etc., depending on their relative stimulating efficiency on the specific organism.

On this hypothesis one can readily explain the results found on the plates described above. It would seem (from the limited evidence at hand) that barnacles are strongly negative to light at the time of attachment. Hydroids (grass) are likewise so. The Bryozoa, although negative to white light, are apparently "attracted" especially by the red, and the worms (Hydroides) apparently by the yellow-red light waves. It would appear that this selection or "tropism," holds good for the animal forms only, as the algæ were found extensively on the white plates.

As this hypothesis is in accord with observations made on ships' bottoms, where one finds the densest growths in regions least exposed to light, it seems safe to conclude that most organisms commonly found attached to the bottoms of ships become attached there because of a relative decrease in the amount of light given off by such areas.

It was realized that these notes and tentative conclusions were based on very limited evidence, and it was hoped that this problem might be investigated more thoroughly by experiments in which many of the unknown factors would be more definitely controlled. Sources of error in the above experiments were numerous, although probably more or less equal for all. The relative amount of light, the amount reflected from other plates of different colors and composition in the immediate vicinity, are all unknown factors that should be eliminated in future tests. The behavior of pelagic larvæ of different ages was not known for any of the species commonly found on ships' bottoms. It was believed, accordingly, that such studies, with controlled factors, would be of value both from an economic and a purely scientific viewpoint, and a few were carried out subsequently, as described in the following pages.

Although several successive series of panels were submerged, not all presented as clear-cut results as did the series recorded. This lack of differentation was especially noticeable after the plates had been exposed for several months (if in spring or summer months), which, no doubt, can be explained by the fact that once the plate is heavily coated, colors lose their influence, and, consequently, within a relatively short period during the season of the year when fouling is most severe, all of the plates become very heavily fouled, regardless of color. However, as less than 10 per cent of all active vessels become heavily fouled, and those that become moderately foul do so, as a rule, only after a considerable period out of dry dock, it will be realized that under practical conditions the relative influence of colors will be greatly prolonged.

A similar series of panels was exposed in the following summer (1923) at Woods Hole, Mass. (fig. 35), with the results shown in Table 9 in which is shown their relative efficiency on the basis of the area free from fouling. All films were in excellent condition. No corrosion was evident anywhere. Fouling was caused largely by Bugula, with some Alga and a small amount of Obelia. Although no barnacles attached during this period of the year, the same relative differences in amount of fouling are seen here as in the plates at Beaufort.

TABLE 9.—*Results of plates exposed at Woods Hole, Mass., submerged on May 31, examined July 25, 1923, painted with two coats each of the "photographic" color paints, as prepared by Henry A. Gardner*

No.	Plate color	Film	Fouling	Percentage of surface not fouled
8	Black	Good	Heavy	10
7	Dark green	do	do	20
4	Red	do	do	20
5	Chocolate	do	do	20
3	Yellow	do	Medium	30
1	White	do	do	50
6	Light green	do	do	60
2	White	do	Slight	90

It was soon realized, however, that these results were open to various explanations, for the material employed to produce a given color was different in each case, and this factor alone might account for the differences in fouling. Accordingly, other methods of attack on this question were planned. These included, first, a submerged electric light with colored panels on each side; second, a set of colored tiles; and, third, a series of experiments in which the active cyprid larvæ were exposed in the laboratory to light of known wave length and intensity.

SUBMERGED COLORED TILES

Woods Hole, Mass.—During the summer of 1923 a series of colored tiles, with both glazed and unglazed surfaces, were submerged by the author at the biological station of the United States Bureau of Fisheries at Woods Hole, Mass. Tiles were used in these experiments to eliminate all possible effects of any toxic action that might have resulted from the use of pigments needed as coloring matter in the paints employed in the previous experiments with panels. These tiles were submerged in two sets of panels—eight glazed in one panel and five unglazed in the other. The regulation size was 6 by 6 inches, but a few were half size, measuring 3 by 6 inches, and about one-half inch in thickness.

These tiles were submerged on May 13, 1923, and were examined from time to time until July 25. The amount of fouling was noticeably less on the lighter-colored plates. However, there were several apparent inconsistencies, the glazed, black tile having less fouling than any of the others, excepting the two white tiles, whereas the unglazed, black tile was the most heavily fouled. However, the following gradation, from least to most, was noticeable in amount of fouling:

(*a*) Glazed set: White, black, light green, yellow, pink, blue, green, red, and dark green.

(*b*) Unglazed set: White, yellow, red, dark green, and black.

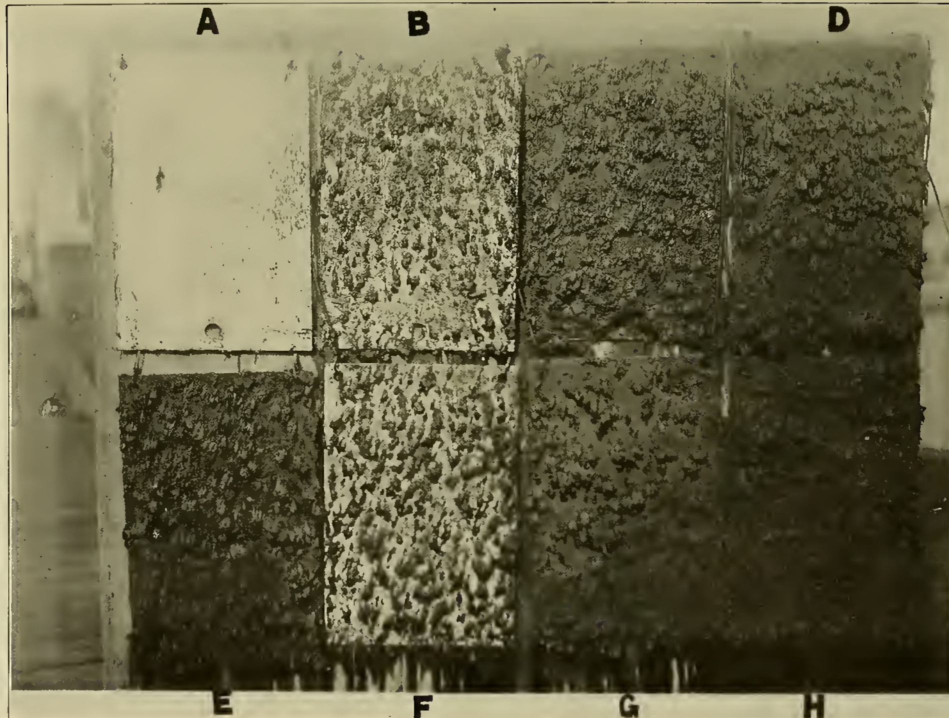

Fig. 35.—Relation of color to amount of fouling. Panels painted with nontoxic paints and submerged from August 4 to September 16, 1923, at Woods Hole, Mass Growths almost wholly of Bryozoa. **A,** white (ZnO); **B,** yellow; **C,** light green; **D,** chocolate; **E,** black; **F,** white (titanox); **G,** dark green; **H,** red

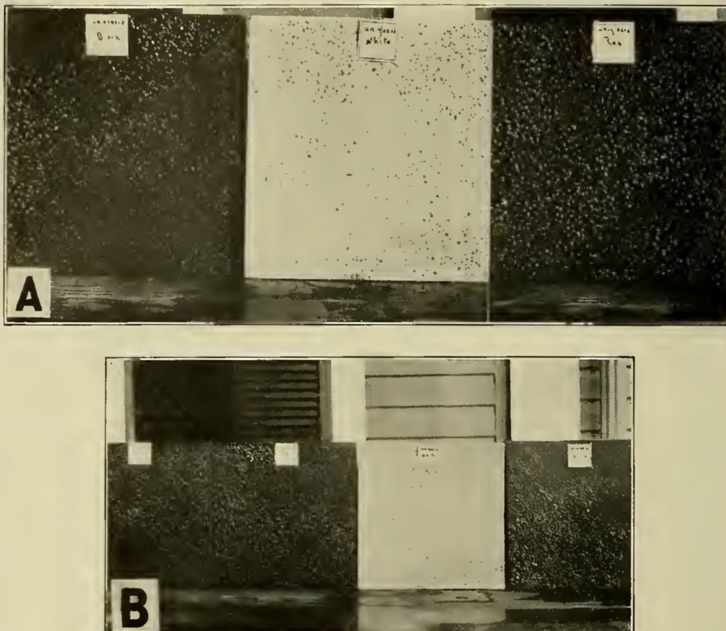

FIG. 36.—Relation between color and fouling, as judged by numbers of barnacles and Bryozoa that attached on colored tiles. **A**, unglazed tiles submerged for one week (July 28 to August 3) at Beaufort, N. C. **B**, another series of unglazed tiles (black, red, white, and green) exposed for 8 days. **C** and **D**, white and black unglazed tiles exposed for 1 month, showing relative amounts of fouling due to Bryozoa (Bugula)

It was noticed that the growths were mostly Bryozoa, with a few hydroids, no barnacles attaching at Woods Hole at this season of the year. As the latter forms are of the greatest significance in the matter of fouling, these tiles were used for tests at Beaufort during the following season, where the summer set of barnacles is very heavy.

Beaufort, N. C.—During the summers of 1924 and 1925 several sets of four or five unglazed tiles were submerged at the Fisheries biological station in a tidal channel, at a uniform distance (about 3 feet) below low water. Unglazed tiles were selected for these experiments, because it had been found that glazed tiles gave conflicting results, because of their "mirror surface" or the reflecting power of such surfaces, as described below. Careful counts of all barnacles that attached, or calculations of the total, based upon accurate counts of several limited areas, were made of all the barnacles attached on each plate during the experiment. These results are given in Table 10.

TABLE 10.—*Number of barnacles that attached daily, one month, on unglazed tiles of different colors at Beaufort, N. C.*

Date, 1925	Total number attached				
	White	Buff	Dark green	Red	Black
June 18	237	570	700	2,840	720
June 19	520	864	672	1,900	884
June 20	680	1,120	1,032	1,800	2,108
June 21	712	1,587	2,068	1,344	2,760
June 22 to 24 [1]					
June 25	128	251	224	240	199
June 26	429	442	809	584	961
June 27 [1]					
June 28	1,164	1,757	1,836	1,491	1,800
June 29	166	760	1,116	916	944
June 30	230	1,040	1,381	1,168	1,900
July 1	750	1,100	1,500	1,800	2,200
July 2	1,400	2,000	2,700	3,000	2,500
July 3	1,800	1,600	2,600	1,800	500
July 4 and 5 [1]					
July 6	1,500	1,900	1,800	1,500	1,700
July 7	280	430	500	564	379
July 8	263	1,130	1,200	1,500	458
July 9	400	713	470	591	520
July 10 to 15 [1]					
July 16	122	212	262	252	300
July 17	40	224	300	448	316
July 18	53	173	190	176	196
Total, 19 days	9,864	18,872	21,150	23,914	21,345
Daily average	419	993	1,113	1,259	1,123

[1] Omitted.

It is evident from this table, which shows the average results of all tests, that the darker the surface the more barnacles are found attached. These results may be seen even more clearly in Figure 36. While a light surface is by no means a cure-all, it will be realized that anything that reduces the fouling 50 per cent is a very important factor. Especially is this true when one realizes that on less than 5 per cent of the ships (on the basis of an examination of 250 vessels) may one find a growth of barnacles at all comparable in number to those obtained at Beaufort in less than one week.

Glazed tiles also were used by the author, but conflicting results were obtained, similar to those recorded in the memorandum report by Perry and Bray of August,

1923. That these results are not valid, because of the varying amounts of light reflected, depending upon the position of the sun and brightness of the day, can be seen easily by referring to Figure 37, which shows photographs of these glazed tiles, taken in front of a south window in bright but diffused light (not direct sunlight).

It will be noticed at once that, optically, there is little difference, under these conditions, between the amount of light reflected from a white or a black surface, as seen in Figure 37, *A* and *B*, and even red is optically almost as "light" as white under these conditions. It is thus evident that any experiments based upon the use of such tiles are of little value in judging the effect of relative light intensities. Accordingly data from unglazed tiles only have been considered of value in these experiments.

REACTIONS OF THE CYPRID LARVÆ OF BARNACLES TO SPECTRAL COLORS

The reactions of the cyprid larvæ of two types of barnacles that cause fouling (*Balanus amphitrite* and *B. improvisus*) were tested by exposure to monochromatic light of known intensity. Light filters were selected that possessed a narrow transmission band and were of known composition and thickness. In Table 11 is given a list of all the filters used, with the limits of light transmissions and the dominant wave length of each filter. A copper sulphate filter was used to cut out the infrared light waves.

TABLE 11.—*List of filters used in experiments on reactions of the cyprid larvæ of barnacles to spectral colors, showing total spectral transmission and dominant wave lengths*

[The letter "C" after a filter denotes a Corning glass filter. The numbers after the Corning glasses refer to the transmission curves shown in Bureau of Standards Technological Paper No. 148. The letter "W" denotes a Wratten filter, and the number refers to the transmission curves found in the booklet "Wratten Filters," published by the Eastman Kodak Co.]

Filter	Total transmission	Dominant wave length	Filter	Total transmission	Dominant wave length
		Mu-mu			*Mu-mu*
Ultra, C 83	315-428 mu-mu and 609 red end.	355	Blue-green, C 56	340-700 mu-mu	505
Purple, C 69	310-485 mu-mu and 690 red end.	370	Green, C 52	425-670 mu-mu	530
Purple, W 35	300-475 and 650-700 mu-mu	420	Green, W 58	485-635 mu-mu	540
Blue, W 49	400-510 mu-mu	440	Yellow, W 16	500-700 mu-mu	590
Blue, C 60	335-640 mu-mu	460	Orange, W 22	545-700 mu-mu	620
Blue, C 59	335-690 mu-mu	480	Orange, C 38	540 red end	640
			Red, C 19	620 red end	700

In order to separate the effect of color from that of intensity it was necessary to determine the total amount of light energy transmitted by each filter. The calibration of these filters was very kindly done by the United States Bureau of Standards. By use of this information the total light energy transmitted through one filter could be balanced by that transmitted through any other filter by moving the source of illumination. By using two beams of light at right angles to each other, and each of equal intensity, the relative effects on large numbers of cyprids were determined for all the filters.

The results of these experiments are summarized in Figure 38, which clearly indicates a great difference in the stimulating efficiency of various spectral colors. In the region of the spectrum between 500 and 600 mu-mu, or from light blue to

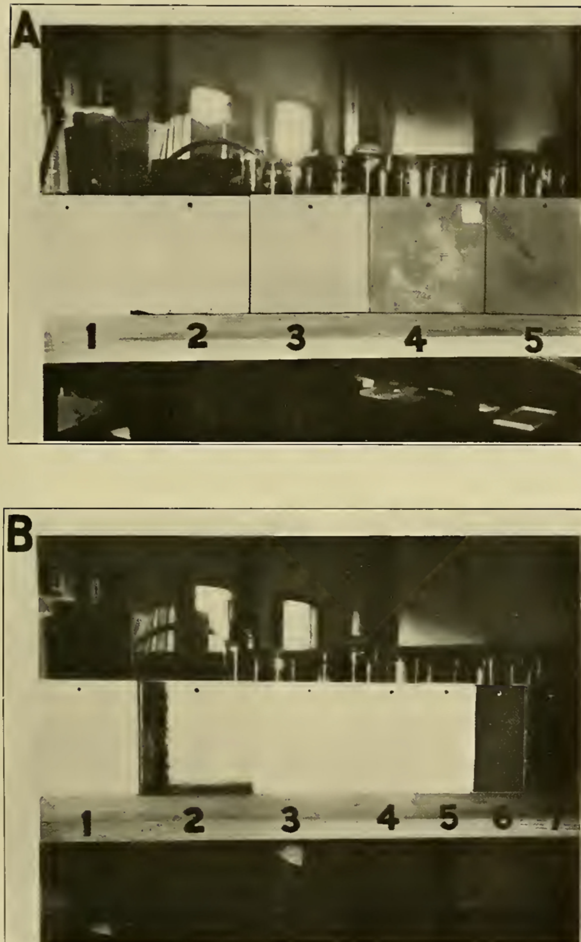

Fig. 37.—Optical effects of glazed tiles, demonstrating their uselessness for these tests. **A.** 1 glazed white; 2, glazed black; 3, unglazed white; 4, unglazed red; 5, unglazed black. **B.** All glazed tiles. 1, white; 2, black; 3, pink; 4, yellow; 5, light green; 6, dark green; 7, red

yellow, the stimulating efficiency is equal to more than 50 per cent that of white light; while between 530 and 545 mu-mu it is more than 90 per cent, or virtually

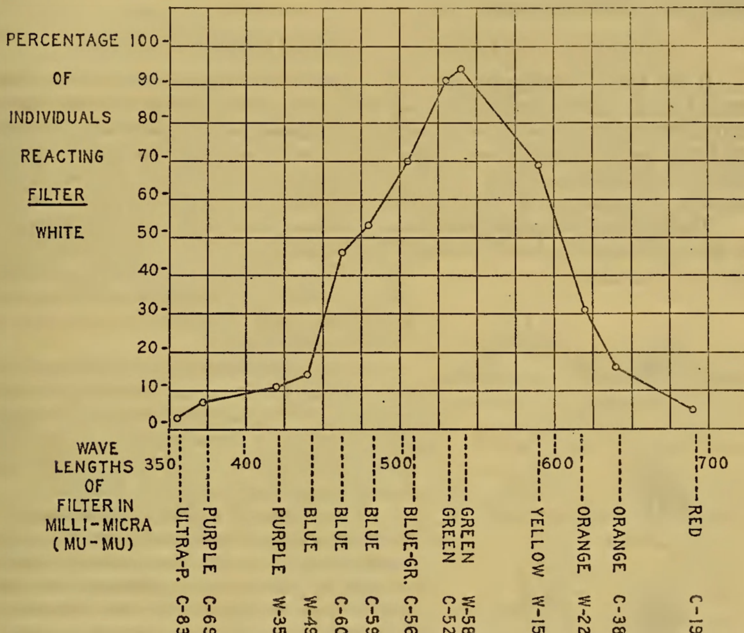

FIG. 38.—Distribution of the stimulating efficiency of equal energy values among the various parts of the spectrum for the cyprid larvæ of certain barnacles

equivalent to white light. On the other hand, light of wave lengths of 700 mu-mu has less than 5 per cent of the efficiency of white light, and likewise at 420 mu-mu

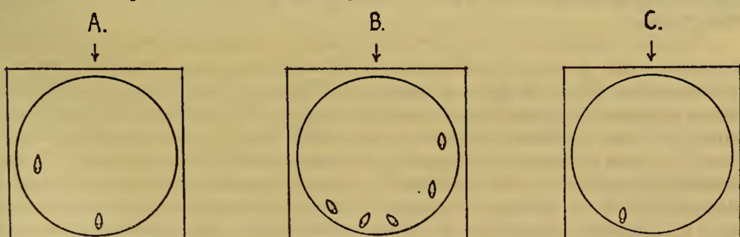

FIG. 39.—Attachment of barnacle larvæ with reference to source of illumination (indicated by arrows)

the stimulating efficiency is very much reduced. For a more complete account of these experiments see Visscher and Luce (1928).

It is evident, therefore, that light rays in the field of blue-green have a much greater effect in activating the cyprid larvæ of barnacles than the light rays in other fields of the visible spectrum.

REACTIONS OF LARVAL BARNACLES TO LIGHT AT TIME OF ATTACHMENT

It has been demonstrated that the larval barnacles are sensitive to light and respond more vigorously to light in the blue-green portion of the spectrum than to light of other color. That these organisms are negative to light at the time of attachment was demonstrated by isolating a number of the cyprids and placing them in small cubical aquaria, which were then covered with black paper on five of their six sides. The uncovered side was exposed to light from a north window.

The results of these experiments, which were repeated on several occasions, can be seen in Figure 39. It will be noted that in each dish the cyprids attached in that half of the container away from the source of light, and that in each case the individuals were so oriented as to be directed away from the source of illumination.

It can be seen clearly from these experiments that for the two types of barnacles that were tested, light is an important factor in determining the point of attachment, and that they orient themselves with their anterior ends directed away from the source of light.

It would appear evident from the results of the submerged colored panels, from the submerged tiles, from the experimental data on reaction of cyprid larvæ to spectral color, and, finally, from the above experiment, in which it is shown that cyprid larvæ become negative to light at the time of attachment, that paints varying from a light blue to yellow would accumulate the least amount of fouling, and that a light green paint probably would be the most efficient, all other factors being equal.

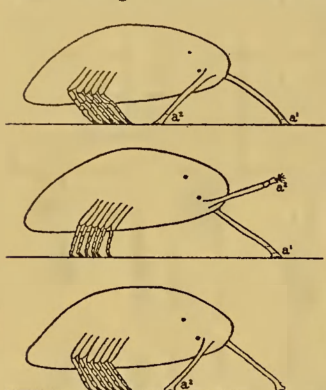

FIG. 40.—Successive movements of a cyprid barnacle larva at the time of "selecting" a place of attachment

Process of attachment of the larvæ of barnacles.—After a free-swimming period of from three days to several weeks, the cyprids attach to some substratum and metamorphose into the adult type of barnacle. When the internal physiological conditions necessary for attachment are present, apparently correlated with the "lipoid" content of the organism, the larvæ have been observed, on many occasions, to "walk" on the substratum, apparently hunting a place for attachment. This remarkable performance is accomplished by alternate attachment and release of the adhesive tips of the antennæ, combined with the relaxation and contraction of the set of appendages, which result in giving the organism a forward movement. (Fig. 40.) In this manner these organisms have been observed to "walk" for considerable distances, and have been seen to "test" various areas for a period of more than an hour before finally attaching.

On several occasions the writer has been fortunate in seeing the actual process of metamorphosis while observing through a microscope. It was observed that after attachment by means of the antennæ the organism would "kick" vigorously for some time, but without effecting release. The animal then appeared to become fixed and metamorphosis followed. The two-valved shell of the cyprid stage was thrown off, as was also the exoskeleton of the appendages and usually the paired eyes as well. From this almost amorphous mass, the young barnacle soon emerges. A secretion continues to be laid down on the formerly ventral surface. and the rudiments of a coating (the future shell) appear around the sides of the mass. Whereas, when attached, the appendages extend downward, they now extend upward, and the mouth parts also have changed their position. A more complete account of this process and related phenomena is given by the author (Visscher, 1928).

It is thus apparent that barnacle larvæ "test" the surface to which they attach, and at no time do the bodies of these organisms come into direct contact with the surface to which they attach.

DISCUSSION AND CONCLUSIONS

From the data presented in this report it is apparent that fouling occurs almost entirely when ships are in port. For this reason passenger ships were found to be almost free from fouling, while ships temporarily out of commission, and battleships, were consistently the most severely fouled. It is accordingly apparent that vessels should be held in port as short a time as possible.

Fouling growths usually are killed if the vessels move from one port to another at a considerable distance. This is due, no doubt, to the differences in temperature, salinity, and dissolved salts of various kinds. However, the death of the organism does not necessarily free the ship from its fouling. Only the living portions are killed and the shells often remain for many months. If, on the other hand, a vessel moves into another port while the fouling growths are still young and succulent, such growths probably die and fall off completely, thus ridding the vessel of all fouling matter.

Fresh water also has been shown to cause the death of most organisms that produce fouling. However, the same results are found here as above; namely, that if heavy calcareous shells have already formed, the fresh water merely stops increase in growth but does not remove most of the material already there, unless it is very young and its parts are still soft.

Metal has been shown to remain free from fouling growths as long as electrolysis takes place and its ions are liberated. As this occurs normally, in sea water, for copper, this material will not foul heavily with most types of organisms unless such ionization is inhibited. It is evident, then, that to be effective it must be in such a condition that it will be wasting away continually, going into solution.

The efficacy of poison paints has been questioned because of biological considerations relating to the activities of the larvæ at time of attachment. It has been shown that the only time when a poison carried in a paint film can be effective is at the time of attachment of the fouling material. Immediately after this a film of calcareous or allied material is deposited by the organism and separates its tissues from the paint. Many vessels and experimental plates have been observed that had become foul within 30 days from the time of painting with an antifouling composition. This would indicate the relative ineffectiveness of such material after a very short period. Much more important is the nature of the surface film in its relation to the method used for attaching the larvæ of the organisms that cause fouling. The beneficial effects of the paints now used very probably can be attributed far more to the nature of the surface (when in water) than to any peculiarly poisonous property that they may possess. It seems probable that undue emphasis has been placed upon the use of poisons in paints on steel ships, which is probably a hold over from their use on wooden vessels, and that the proper nature of the surface film is the desired goal.

Finally, this report presents data that demonstrate clearly the relation between light and the attachment of fouling organisms. The experiments with submerged panels of different colors, with submerged colored tiles, and with the cyprid larvæ exposed to equal energies of spectral colors, all show that barnacles are more sensitive to light colors than to dark, and that at the time of attachment they react away from this stimulus. Inasmuch as red is optically almost as dark as black, it is evident that a worse color could hardly have been selected. Yet red and brown are the colors of more than 90 per cent of the commercial antifouling paints used for steel ships. It is admitted that the red iron oxide so universally used makes an ideally inert "body" for such paints, but if a substance of a lighter color could be found as an adequate substitute, it seems very probable that its use would be advantageous.

SUMMARY

1. The fouling found on ships' bottoms is composed of both plant and animal organisms, with the latter the more important group wherever fouling is at all extensive.

2. Barnacles, hydroids, algæ, tunicates, Bryozoa, mullusks, and Protozoa are all found abundantly and in frequency and abundance usually in the order named.

3. Fouling organisms are almost exclusively those commonly found on rocks and other submerged structures near shore, especially in harbors.

4. Fouling occurs almost entirely while vessels are in port.

5. Passenger ships with regular schedules that permit them to remain for only very brief periods in port are the least foul of any group of vessels.

6. Most ships are moderately fouled after six to eight months from the date of dry docking.

7. Heavily fouled ships frequently carry more than 100 tons of fouling materials and occasionally more than 300 tons.

8. It is conservatively estimated that the annual cost of fouling to the shipping industry of our country is in excess of $100,000,000 per year.

9. Under optimum conditions vessels foul within 30 days of the time of dry docking and the application of poisonous antifouling paints, indicating the hypothetical value of antifouling paints.

10. The time that elapses between dry-docking periods is of great significance, but the use made of this time, whether in cruising or in port, is of even greater importance, for fouling is proportionally more severe as the length of time since previous dry docking is increased, but it is decreasingly heavy in proportion to the time spent cruising.

11. Vessels that are never in port for more than a few days at a time, and whose next port of call is at a considerable distance, rarely if ever accumulate much fouling.

12. Each vessel shows at the time of dry docking the visible record of its cruise by the diverse types of organisms found on her hull.

13. Fresh water kills most of the organisms that cause fouling within 72 hours, but if calcareous or chitinous growths already have been formed, such materials remain and the resistance is not materially lessened.

14. Certain species of barnacles grow at a very rapid rate, attaining a size of 2 inches and becoming sexually mature within 60 days.

15. Fouling can be predicted from a knowledge of seasonal abundance of larval organisms in given ports.

16. Certain barnacles are found attached on certain substances and in limited regions, indicating a relation between attachment and the nature of the surface.

17. Light has been found to be an important factor governing the attachment of the larvæ of the forms that cause fouling.

18. At the time of attachment the larvæ of *Balanus improvisus* and *B. amphitrite* are negative to light. (Most of the forms found on ships' bottoms probably are of a similar nature.)

19. Light in the field of green and blue has been demonstrated to have the maximum stimulating efficiency for the cyprid larvæ of several barnacles.

20. This report indicates the value of an intensive study of seasonal periodicity of fouling organisms, of the relation between fouling organisms at the time of attachment and surface films, and a study of properly prepared paints of lighter colors than those now in general use.

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