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CHAPTER 3

The Fouling Community

The term "fouling" is commonly employed to distinguish the assemblages of animals and plants which grow on artificial structures from those occurring on rocks, stones, and other natural objects. Frequently its use is limited to situations in which the results of the growth may be considered harmful. The concept of fouling is thus based on the practical considerations which have indeed given the subject its importance rather than on any valid biological distinctions. Fouling is, however, a biological phenomenon. If it is to be dealt with effectively from an engineering point of view, it is important that the biological principles which determine its development be understood.

The animals and plants which take part in fouling are primarily the attached, or sessile, forms which occur naturally in the shallower water along the coast. Each of these is adapted to live successfully under some restricted set of environmental conditions which limit the particular places, both on a geographical and local scale, where it may be found. The development of an assemblage of fouling organisms on any structure immersed in the sea depends on the ability of certain members of the natural population locally present to live successfully in the new situations created by man. From the biological point of view, fouling is thus an accident, and of very recent origin.

The development of permanent and massive growths depends on the ability of sessile forms to adhere firmly enough to avoid being washed away. Many free living animals are found among such sessile organisms. They are an integral part of the fouling community and cannot be separated from it on any reasonable grounds. Separation on the basis of freedom of movement or firmness of attachment is difficult, since some sessile forms like the mussel are able to cast off their anchorage and move from place to place, while some motile forms such as the chiton can cling to smooth surfaces with a tenacity which resists the most violent water movements.

The organisms occurring in fouling have been recorded frequently. A few attempts have been made to prepare lists of the species but these have been limited to those found on particular structures. Kirchenpauer compiled a list of 84 species, the majority of them plants, from the navigation buoys of the Elbe (*4*). Hentschel listed about 50 species from ships docking at Hamburg (*3*). Seventy-seven kinds of animals and plants are listed from ships examined in United States waters by Visscher (*11*).

In order to make available the information on the composition of fouling, a comprehensive list has been prepared of species recorded from the principal types of structure affected. This list is presented in Chapter 10. It includes records from structures on which fouling gives rise to problems of some technical interest, i.e., ships, buoys, water conduits and pipe systems, wrecks, telegraph cables, rafts, floats, pontoons, and test panels. Records from wharf piles, piers, quays, jetties, bridge abutments, and similar structures have been omitted.

The following general conclusions are based on the analysis of this list.

Nearly 2,000 species of animals and plants have been reported from fouling. The number of species representing each of the major groups of organisms, listed in Table 1, includes 615 kinds of plants and 1,361 varieties of animals. The list includes 13 of the 17 commonly accepted phyla of animals and all the major groups of marine Thalophytes. The four missing phyla of animals are the Ctenophora, Chaetognatha, Nematoda, and Phoronidea. The two former are pelagic organisms not likely to occur in fouling. The Nematoda are common free living members of fouling communities, but have escaped record because they are difficult to identify. The Phoronidea contain very few species, but may be recorded ultimately since they are sessile forms, partial to crevices in rocks.

Although the number of species reported from fouling is large and is widely distributed among the existing groups of organisms, it actually includes a very small proportion of the known marine species. The proportional representation among the different groups is also very unequal. These facts are brought out by Table 2 in which the total numbers of known marine species are compared with the numbers reported from fouling. It is only among five groups that the species known to foul make up more than 2 or 3 per cent of the recognized species. These are the Barnacles, Tunicates, Hydroids, Marine Plants, and Bryozoa —all groups which are predominantly sessile and

which contribute heavily to fouling. Certain other sessile groups, such as the sponges and corals, are recorded relatively infrequently from fouling.

TABLE 1. Number of Species of the Various Groups Which are Reported from Fouling

Total Plants	614	
Total Animals	1,344	
Total List	1,958	
Plants		*Totals*
Bacteria		37
Fungi		14
Algae		563
Diatoms	111	
Blue green	32	
Green	127	
Brown	88	
Red	205	
Animals		
Protozoa		99
Mastigophora	5	
Foraminifera	43	
Other Sarcodina	3	
Ciliata	39	
Suctoria	9	
Porifera		33
Coelenterata		286
Hydrozoa (Hydroids)	260	
Hydrocorallinae	1	
Alcgonaria	5	
Actinaria (Anemones)	12	
Madreporaria (True Corals)	8	
Platyhelminthes		12
Nemertea		11
Trochelminthes (Rotifers)		5
Bryozoa		139
Brachiopoda		1
Annelida		108
Archiannelids	1	
Polychaeta Errantia	44	
Polychaeta Sedentaria (Tubeworms)	55	
Oligochaeta	4	
Hirudinea (Leeches)	4	
Arthropoda		292
Copepoda	7	
Ostracoda	5	
Lepadomorpha (Goose Barnacles)	50	
Balanomorpha (Acorn Barnacles)	60	
Amphipoda	60	
Isopoda	24	
Decapoda	76	
Pycnogonida	8	
Insecta	2	
Mollusca		212
Amphineura	3	
Nudibranchiata	32	
Pteropoda	4	
Other Gastropoda	59	
Pelecypoda	121	
Echinodermata		19
Crinoidea	3	
Asteroidea	7	
Ophiuroidea	3	
Echinoidea	5	
Holothuroidea	1	
Chordata		127
Tunicata	116	
Pisces	11	

Few species of Pelecypods are recorded although some such as the oysters and mussels are among the most important foulers.

Only 50 to 100 species are commonly encountered in fouling. Those reported most frequently from all types of structures are listed in Table 3. The frequency with which various species were found on the ships examined by Hentschel (*3*) and Visscher (*11*) is recorded in Table 4.

There is little doubt that some differences exist between the assemblages of organisms likely to be found on different types of structure. It is difficult, however, to state very definitely what these differences are, or to justify such statements with quantitative data. The amount of information available from examinations of different structures is very unequal, so that statistical comparisons are impossible. The differences also depend not so much on the character of the structures as

TABLE 2. Comparison of the Total Number of Marine Species Assigned to Various Groups and the Number of Each Group Reported from Fouling. Estimated Totals for Animals from Pratt (*8*), for Plants from ZoBell (*12*)

Group	*Total Marine Species*	*Species in Fouling*	*% in Fouling*
Goose barnacles	200	50	25.0
Acorn barnacles	300	60	20.0
Tunicates	700	116	16.6
Hydroids	3,000	260	8.7
Marine Plants	8,000	614	7.7
Bryozoa	3,000	139	4.6
Nudibranchs	1,000	32	3.2
Polychaetes	3,500	99	2.8
Nemerteans	500	11	2.2
Amphipods	3,000	60	2.0
Pycnogonids	400	8	2.0
Pelecypods	9,000	115	1.3
Anemones	1,000	12	1.2
Sponges	3,000	33	1.1
Decapods	8,000	76	1.0
Isopods	3,000	24	0.8
Gastropods (other than Nudibranchs)	4,900	58	0.8
Echinoderms	4,800	19	0.4
Corals	2,500	8	0.3

TABLE 3. Nineteen Forms Cited More Than 12 Times From Fouling, in Order of Frequency of Citation. (Data from Fouling List, Chapter 10)

Form	*Group*	*Number of Citations*
Mytilus edulis	Pelecypod Molluscs	34
Bugula neritina	Bryozoa	24
Balanus eburneus	Acorn barnacles	23
Balanus crenatus	Acorn barnacles	22
Balanus improvisus	Acorn Barnacles	21
Lepas anatifera	Goose barnacles	20
Balanus tintinnabulum	Acorn barnacles	18
Balanus balanoides	Acorn barnacles	16
Hydroides norvegica	Tubeworms	15
Balanus amphitrite	Acorn barnacles	15
Conchoderma auritum	Goose barnacles	15
Conchoderma virgatum	Goose barnacles	14
Enteromorpha sp.	Green algae	14
Cladophora sp.	Green algae	14
Schizoporella unicornis	Bryozoa	14
Tubularia larynx	Hydroids	14
Ciona intestinalis	Tunicates	13
Tubularia crocea	Hydroids	12
Ectocarpus sp.	Brown algae	11

on the circumstances under which they are exposed and the degree of fouling which is permitted to develop before examination. Navigation buoys, which foul heavily before servicing, support a more mature community of fouling organisms than ships, which are commonly docked before heavy fouling has accumulated. As a result, greater variety is reported from navigation buoys than from ships. Test panels which are commonly inspected after a month's exposure may give a very inaccurate picture of the fouling organisms available, since only the rapidly developing forms are recorded.

TABLE 4. Frequency of Various Forms in Ship Fouling

The numbers indicate the number of ships on which each species was reported by Hentschel (*3*) and Visscher (*11*). The total number of ships examined was 131.

ACORN BARNACLES	
Balanus improvisus	44
Balanus eburneus	34
Balanus amphitrite	27
Balanus tintinnabulum	25
Balanus sp.	25
Balanus crenatus	7
Balanus psittacus	3
Chelonibia patula	2
Balanus perforatus	1
Balanus tulipiformis	1
Chthamalus sp.	1
GOOSE BARNACLES	
Lepas anserifera	5
Conchoderma auritum	4
Conchoderma virgatum	3
Lepas hillii	3
Lepas anatifera	3
Poecilasma crassa	2
HYDROIDS	
Tubularia sp.	30
Campanularia sp.	26
Laomedea sp.	16
Clytia sp.	7
Tubularia crocea	5
Campanularia amphora	3
Eudendrium ramosum	3
Laomedea geniculata	2
Laomedea sargassi	1
Campanularia portium	1
Campanularia vorticellata	1
Bougainvillia carolinensis	1
Perigonimus jonsii	1
Podocoryne sp.	1
Plumularidae (unidentified—5)	1
ANEMONES	
Metridium sp.	8
Sagartia sp.	3
CORALS	
Astrangia sp.	1
BRYOZOA	
Membranipora lacroixii	25
Membranipora sp.	16
Bowerbankia caudata	6
Alcyonidium mytili	5
Alcyonidium gelatinosum	3
Membranipora monostachys	3
Bugula turrita	3
Lepralia pertusa	2
Bugula avicularia	1
Bugula neritina	1
BRYOZOA (cont.)	
Bugula turbinata	1
Watersipora cucullata	1
Callopora lineata	1
Callopora sp.	1
Alcyonidium sp.	1
Membranipora savartii	1
Electra pilosa	1
Schizoporella unicornis	1
Scrupocellaria reptans	1
MOLLUSCS	
Anomia ephippium	31
Mytilus edulis	18
Ostrea elongata	7
Ostrea sp.	4
Mytilus pictus	2
Nudibranchs	2
Ostrea parasitica	1
Anomia fidenas	1
Anomia sp.	1
Teredo navalis	1
ANNELIDS	
Hydroides hexagonis	8
Hydroides norvegica	4
Hydroides sp.	1
Nereis pelagica	1
Nereis sp.	1
(unidentified—11)	
TUNICATES	
Molgula manhattensis	9
Molgula arenata	4
Botryllus schlosseri	1
Ascidiella virginea	1
Diplosoma gelatinosa	1
PROTOZOA	
Vorticellids	10
Folliculina sp.	2
ALGAE	
Enteromorpha intestinalis	39
Enteromorpha sp.	19
Ulva lactuca	8
Cladophora sp.	5
Ulothrix flacca	4
Polysiphonia nigrescens	4
Ectocarpus confervoides	3
Ulva sp.	3
Vaucheria sp.	1
Stigeoclonium sp.	1
Chaetomorpha fibrosa	1
Acrochaetium sp.	1
Syphonales sp.	1
Oscillatoria sp.	1
(unidentified—1)	

TABLE 5. Numbers of Species of Fouling Organisms on Buoys and Ships

	Number of Species per Unit	
Units	*Range*	*Average*
4 Buoys, Plymouth Sound	31–37	34.0
6 Buoys, Estuary	5–19	14.3
All 10 Buoys—Milne (*6*)	5–37	22.4
83 Ships—Visscher (*11*)	1–13	4.18
48 Ships—Hentschel (*3*)	1–12	4.39

Some quantitative differences between the character of the fouling assemblages on ships and buoys are brought out in Tables 5 and 6. Table 5 shows the numbers of species recorded from fouled buoys and ships. The average number of species found on buoys was much greater than on ships. This result reflects the greater complexity of composition in the mature communities found on buoys. Table 6 indicates the percentage of the buoys and of the ships examined on which various groups of fouling organisms were found. Each group occurred more frequently on buoys than on ships, again emphasizing the greater diversity of species represented in the more maturely developed fouling of buoys. The barnacles are the only group that occurs nearly as frequently on ships as on buoys. The great rapidity with which barnacle populations may develop, as well as the firmness of their attachment, may explain their prevalence on ships. Free living organisms associated with the fouling communities, such as errant polychaetes and nudibranchs, are much more generally represented in the buoy fouling.

In a few instances comparisons have been made

TABLE 6. Percentages of Ships and Navigation Buoys Fouled by Various Groups. Ship data from Hentschel and Visscher; Buoy data from American Waters. The Numbers Represent the Per Cent of the Ships or Buoys Examined on which Representatives of Each Group were Found.

	Ships			
Group	*Hentschel (48 ships)*	*Visscher (83 ships)*	*All ships (131)*	*Buoys (373)*
Algae	79	33	50	94
Hydroids	63	49	54	99
Anemones	0	12	12	54
Sedentary Polychaetes	31	11	18	53
Errant Polychaetes	0	2	2	93
Bryozoa	31	45	40	83
Nudibranchs	0	2	2	58
Pelecypods	25	22	23	97
Mytilus	15	16	15	77
Ostrea	10	8	9	17
Others	6	0	6	84
Barnacles	83	89	87	98
Acorn	83	88	86	94
Goose	19	4	9	24
Tunicates	4	16	12	40

between the fouling communities and the naturally occurring populations of a region. MacGinitie found more species on a lighter at Monterey, California, than could be collected in the immediate environs (*5*). In the Suez Canal buoys, barges, beacons, and wharf piles provided far richer collections of species than did the bottom of the Canal (*1*). The poverty of the latter may be due to the frequent dredging of the soft and sandy bottom and the continual scouring attending the passage of ships. These cases do not invalidate the view that the bulk of fouling is composed of a small number of species drawn from a much larger total of coastwise types. They indicate merely that fouling may not necessarily originate from the immediately adjacent natural populations.

Although the bulk of fouling is drawn from members of the natural population, several forms are known only from records of fouling. Certain acorn barnacles, such as the varieties *dorbignyii*, *costatus*, and *plicatus* of *Balanus tintinnabulum*, have been found only on ships. *Balanus crenatus delicatus* is reported only from buoys. A number of goose barnacles of the genera Scalpellum and Megalasma have been collected solely on deep-sea cables. There is no reason to believe that these forms also have not originated from natural populations as yet undiscovered.

Fouling is a way of life to which marine organisms may turn insofar as they are adapted to live under the conditions presented by the surface of an artificial structure. The species adapted to adhere to stones and other hard submerged surfaces most readily take up life on such structures. As they develop, the character of the surface changes, and places are provided where many free living forms may harbor. Thus the possibilities of occurrence are greatly extended and may include creatures quite incapable of acting as independent foulers. The concept of fouling is consequently quite elastic, and the phenomenon is to be understood only by considering, in the most general way, the biological factors which influence the growth and development of marine communities.

FOULING AS A COMMUNITY

Although the fouling on a submerged surface may be described by naming the species and counting their numbers, the assemblages have properties of their own which are additional to those of the separate organisms. Each individual grows at a characteristic rate, attains some ultimate size, and dies after an allotted period. The population may contain organisms of many different ages, and will increase in bulk at a rate which has little apparent relation to the growth of its members. Although the individuals may die, the population as a whole may persist permanently. In addition, the various members of the population influence one another. Crowding may check their growth or modify their form. In communities composed of several species, more complicated relations arise. The presence of one species may favor the growth of another, or a slowly-growing form may crowd out others which became established earlier.

The dominant organism in a community determines, to a large degree, its general character and gives the community its name. Thus the natural assemblages dominated by mussels are known as Mytilus communities. Although no two mussel beds, or parts of the same bed, are exactly alike in the kinds and proportions of other species present, mussel beds in general resemble one another more than they differ and may be recognized as a definite entity. Mytilus communities, as observed in fouling, are essentially similar to natural mussel beds. They display characteristics which make them recognizable as something more than an accidental collection of species.

Buoys along the coast of the northeastern United States are usually fouled by the Mytilus community. Different subordinate species are found associated with the mussels in different regions. Kelp and the barnacle, *Balanus crenatus*, for example, are associated with the mussels north of Cape Cod, while further south the kelp is less prominent and the important barnacle is *Balanus improvisus*.

The character of the communities of the sea bottom has been shown to be governed by the nature of the bottom and its depth (*2*, *7*, *9*, *10*). The communities of mud, sand, gravel, or rock bottoms are each distinctive. Their distribution parallels the distribution of the bottom materials, and tends to fall into depth zones more or less parallel to the shore. In much the same way the communities of fouling depend upon the character of the structures and their conditions of exposure. Thus mussels rarely attach to ships unless these are moored for long periods, and ships are usually fouled by a Balanus community, with algae predominant at the water line. Buoys in bays and estuaries often support a community dominated by *Balanus improvisus* or *Ciona intestinalis*, while

those moored well off shore are fouled with goose barnacles. Buoy anchors often support a community which is different from that on structures suspended directly above the bottom. The Mytilus community is generally confined to the buoy and chain, and is replaced on the anchor by barnacles.

It may be seen that fouling is not a well defined entity. The assemblage of organisms to be found on an exposed structure depends upon the species naturally present at the site of exposure and upon their ability to attach and grow on its surface. The characteristics and the activity of the structure contribute to this selection. In addition the reproductive habits of the different species will determine which organisms appear first on structures exposed at different seasons. The interactions of the various kinds which may appear simultaneously or in succession modify the assemblage and determine the character of the community which finally emerges.

These varied factors, which must be taken into account in order to understand the communities of organisms which are found on artificial structures, will be considered in the chapters which follow.

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