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PREVENTION AND REMOVAL OF FOULING ON CULTURED OYSTERS: A HANDBOOK FOR GROWERS

KOHMAN Y. ARAKAWA, D.Sc.

translated by
REGINALD B. GILLMOR

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PREVENTION AND REMOVAL OF FOULING ON CULTURED OYSTERS
A HANDBOOK FOR GROWERS

Kohman Y. Arakawa, D. Sc.
Hiroshima Fisheries Experimental Station
Ondo-cho, Aki-gun, Hiroshima-ken, Japan 737-12

Translated by Reginald B. Gillmor
Department of Oceanography, Ira C. Darling Center
University of Maine at Orono, Walpole, Maine 04573

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TRANSLATOR'S PREFACE

Biofouling interferes with a variety of human activities in the marine environment, mariculture among them. In suspension oyster culture, unchecked fouling will result in reduced growth, inferior shell quality, and, in the extreme, morbidity and mortality of stock. The control of fouling can be quite laborious and time-consuming – in a word, expensive – and may be regarded as a major problem hindering the more widespread use of suspension techniques in U.S. oyster culture.

Fouling control is especially critical in the case of cultchless oyster grow-out. Cultchless oysters grown in suspension must be contained within enclosures – nets, bags, trays, baskets, etc. – which can not unduly impede the flow of water to the oysters they hold. Unfortunately, most mesh materials currently in use make excellent settling substrates for a variety of fouling organisms (see Milne, P.H. 1972. Fish Farming International, 2(3): 15-19; and 2(4): 18-21). A lush growth of fouling on a stack of trays or a lantern net will greatly restrict water exchange around the oysters within, and stock growth will suffer accordingly. Moreover, fouled gear is considerably heavier than unfouled gear, and puts strains on retrieval and suspension systems. In Maine, where suspension techniques for cultchless grow-out predominate, whole long lines holding upwards of a hundred modules have gone to the bottom for want of timely fouling removal.

An adequate program of fouling control should, then, be a prime consideration during the planning phase of any oyster culture venture. As indicated in the title of this handbook, methods of fouling control may be divided into two broad categories: those dealing with prevention, avoiding the problem in the first place; and those for removal, getting rid of it once you have it. Dr. Arakawa, closely connected with the Japanese oyster industry for many years and its leading authority on biofouling, has in this work, first published in Japan in 1973, detailed all of the various methods of prevention and elimination tried or considered by oyster growers in his country. The rationale for the publication of this translation is to provide English-speaking workers a useful guide and starting point for devising their own programs of control.

I wish to emphasize that the techniques described should not be adopted before careful testing has established their validity for the species and conditions encountered in any particular culture situation. That is, this handbook should be used as a guide only: what works in Japan with Japanese oysters and the fouling organisms found there may or may not work in other places, where different organisms are encountered and different oysters are grown.

Several sections of the text are particularly relevant to the fouling problems encountered by Maine oyster growers. I wish to draw attention to these by noting a few observations on the Maine situation derived from my experience in the industry. First, in the area of fouling prevention, the importance of careful site selection can not be stressed enough. Certain sites, for hydrographic or other reasons, have substantially less fouling than others yet support adequate oyster growth. The reduced fouling may be the result of pollution by toxic agents, in which case oyster grow-out would be ill-advised. If this is not the case, the site in question should be considered a prime candidate for oystering operations. The time saved by not having to deal with extensive fouling could easily cut labor costs in half. A savings of this magnitude would more than justify any extra time and money spent on the site-selection process.

A second method of fouling avoidance which could be readily exploited in Maine waters is deep suspension of stock. As will be discussed more fully in the text, many of the most troublesome fouling organisms often set more heavily higher up in the water column. Were culture units to be hung more deeply during the fall, for example, when a mussel set is underway, the worst of the fouling could be avoided. Also, for stock that has been put down for the winter — at or near the bottom — it is recommended that it be left down until the spring barnacle set has mostly passed sometime in April. Not only does the lower water-column position of the stock expose it to fewer settling barnacle larvae, but those that do find their way there are discouraged from attaching by the layer of silt that has accumulated over the winter.

During the warmer months, sea strawberries (Tubularia) and various sea squirts are quite common and often contribute greatly to the fouling problem. At this time of the year, standard practice in the industry is to retrieve gear and stock for periodic cleaning using spray-down equipment of the portable-fire-pump variety (100-140 GPM capacity). This generally succeeds quite well in removing most of the attached organisms and probably contributes to shell quality as well by regularly knocking off new growth shoots. As useful as this practice is, however, it often leaves behind many individuals or clumps which can spread relatively rapidly once returned to the water. This difficulty can be alleviated by allowing gear and stock to air-dry from one to several hours (except when very small oysters are involved — these should not be overly stressed). Sea squirts and strawberries are particularly susceptible to this method of elimination. Treatment need not be applied every time gear is pulled for servicing — that would be overkill. However, this is a useful weapon to have in the arsenal, especially when fouling is severe, and such a capability could be considered when designing the culture system.

A related alternative is to raise oysters on intertidal racks where periodic exposure to air is a matter of course. Elsewhere in the world oyster growers have made extensive use of the intertidal zone during various phases of the grow-out cycle, the stick-and-rack culture of rock oysters in Australia and New Zealand being a notable example. Maine's cold winters pose an obstacle to exercising this option, though, as stock would have to be removed to submerged locations in order to survive; equipment, too, would have to be removed or else risk ice damage. Nevertheless, the potential savings in labor during the warmer months is substantial, and would seem to justify some preliminary trials, at least. (Much work directed towards the biological aspects of intertidal grow-out has been pursued at the Darling Center's Aquaculture Facility during the past few years; results will be published separately [Gillmor, R.B. (in preparation)]).

Finally, Dr. Arakawa makes much of the potential of biological control in antifouling programs. In this regard, mention can be made of a recently completed experiment (Hidu, H., C. Conary, and S.R. Chapman. 1980. Aquaculture [In press]) which demonstrates the potential of rock crabs as net tenders, keeping cultured oysters free from mussel fouling. The study was devised after a tray of overwintered yearling oysters, surprisingly free of fouling and siltation after months of neglect, was found to contain an entrapped crab. Such findings, fortuitous though this one was, serve to underscore the many interesting possibilities for the biological control of fouling.

It is my pleasure to acknowledge several individuals who have assisted me during the translation of this handbook: the author, Dr. Kohman Y. Arakawa, provided much help and encouragement; Takaharu Hoshino, Mukaishima Marine Biological Station, Hiroshima University, contributed to the project in various ways; William Shaw, Office of Sea Grant, kindly read and commented upon a draft of the manuscript; Phyllis Coggins and Martha Beall, Sea Grant Publications, University of Maine, have been most helpful and supportive in readying material for publication. I further wish to note that this project was begun during the tenure of a research scholarship awarded to me by the Japanese Ministry of Education, and completed while receiving support from various grants (NOAA, Office of Sea Grant) given to Dr. Herbert Hidu, University of Maine. Both sources are gratefully acknowledged.

Reginald B. Gillmor
Walpole, Maine
April, 1980

FOREWORD

In 1969 an unprecedented outbreak of fanworms (*Hydroides elegans*) occurred in Hiroshima Bay, center of Japan's largest oyster culture fishery. Nearly 6,000 oyster rafts were affected and production dropped by some 60%. In recent years various fouling organisms — mussels, sea squirts, barnacles, and others — have been the cause of considerable damage to the cultured oyster crop. The increasing seriousness of the fouling problem appears to be related to a deterioration of water quality in the culture areas. Deterioration has not been sudden and dramatic; rather, it has resulted from the cumulative effects of various long-term, slow-acting influences. These go unnoticed until reaching the level where serious economic consequences begin to be felt.

Growth rates of oysters under culture have, in recent years, declined rather rapidly, a fact reflected in the quantities of oysters ready for harvest after being in culture for one year or less. First-year oysters, as these are termed, previously accounted for nearly 60% of Hiroshima's production; at present virtually no first-year oysters are harvested. Various reasons for the decline in growth rates have been advanced: deterioration in culture conditions, the increasing intensiveness of suspension culture, delays in spawning, pollution and others. There can be little doubt, however, that the proliferation of fouling organisms has had a considerable impact on oyster performance. This proliferation may, in part, be the result of the increasing organic pollution (and consequent eutrophication) in coastal areas.

When the patent law was enacted in Japan some seventy years ago, the very first application was for a hull paint with antifouling qualities. There have been more than two-hundred patents of a related nature since, though truly epoch-making techniques have yet to be devised. In any event, the problem of marine fouling is not one limited to the oyster, pearl and other culture fisheries. It is one of major concern to those who use the oceans for other commercial and military purposes as well. Accordingly, there exists a long history of investigative efforts mounted on a grand scale involving many researchers and large sums of money. For example, the locating of power plants in coastal areas has generated much interest in the development of equipment and techniques for the prevention of fouling in saltwater cooling systems.

Different users of the marine environment, therefore, face a common problem. The results of research undertaken by one may be expected to be of benefit to another. Differences in desired ends and permissible means may, however, be reflected in the kinds of research undertaken. In the case of naval transport or power plants, it is sufficient to devise techniques that prevent or eliminate all fouling indiscriminately. But in aquaculture the aim is to remove only the attached organisms and not the cultured animals themselves. Moreover, the methods employed must not have a harmful effect on the food value of the cultured crop or on water quality. Considerations of this sort complicate the fouling problem in oyster culture. Notwithstanding, included in this handbook are results of relevant research undertaken in fields other than fisheries.

In addition to covering such practical matters as the nature of fouling damage and actual methods for dealing with it, I have also tried to include much basic information on the biology and ecology of the major fouling organisms. Furthermore, areas toward which future research might best be directed are indicated. Finally, as fouling organisms might possibly be put to some good use, ideas along these lines not previously considered are also presented.

ECOLOGY OF FOULING ORGANISMS

What species occur

Fanworms, mussels, barnacles and sea squirts are among the more conspicuous fouling organisms. Considering the harm done to cultured oysters they do indeed head the list, but in view of the many kinds of fouling organisms which occur, they merely represent the tip of the iceberg. The list (see Table 1) extends from micro-organisms such as bacteria and diatoms, which form slime, to a variety of plant and animal groups. Oysters themselves, under certain circumstances, can be considered as fouling organisms.

Equally varied are the ways in which these plants and animals come to be attached to the oysters. Many spend their whole lives adhering to the oyster's shell using one or another form of attachment mechanism, including mucus, cement, byssal threads, and other devices. Such species are referred to as primary fouling organisms. Other species, called secondary fouling organisms (examples indicated in Fig. 1), arrive after the establishment of the primary fouling community. These organisms are able to move about freely and feed on the smaller attached forms, the cumulative biodeposits, etc. In this booklet I shall be using the term "fouling" in the broad sense to include both groups.

Living habits and life histories

"Know your enemy" is a good expression to keep in mind when considering ways of dealing with fouling. Effective means of prevention and removal must be based on a knowledge of the biology and ecology of the species in question.

When fouling occurs (Breeding season, time of settlement)

The time and duration of reproductive effort for coastal marine organisms is generally dependent upon water temperature and other sea or weather conditions. These will vary from year to year so that breeding seasons can not be definitely fixed. However, on the basis of past experience the limits of the breeding seasons of various fouling animals may be roughly determined, as well as the times of heaviest activity (Figs. 2 and 3). The sea squirt, *Ciona intestinalis*, for example, is reproductively active from spring until the onset of winter; setting (i.e., attaching to oysters and other suitable surfaces) occurs most heavily during the four-month period from June to October. Barnacles (*Balanus* spp.) are active from June or July until about mid-September. This overlaps to a considerable degree the spawning season of oysters and it is not hard to see how this would pose a problem for spat collection.

Mussels (*Mytilus* cf. *edulis*) have their breeding season one or two months before oyster setting begins, so they do not present any difficulties to spat collection. But since this is the time when second-year oysters are transferred to offshore culture areas, they are a potential problem and must be watched closely. The fanworm (*Hydroides elegans*) gradually enters a period of increased breeding activity sometime around the middle of September. Breeding may be intense throughout October, although this will differ from year to year.

Table 1. Blacklist of the major fouling organisms occurring on cultured oysters in the Hiroshima area. Asterick (*) indicates secondary fouling organisms (See Fig. 20 EST)

Plants

Bacteria (slime-forming)
Diatoms (slime-forming)

Green algae (Chlorophyceae)
Codium fragile (Fig. 1A), *Enteromorpha linza* (Fig. 1B), *Ulva pertusa* (Fig. 1C), *Monostroma, Cladophora*

Brown algae (Phaeophyceae)
Colpomenia sinuosa, Hydroclathrus clathratus, Scytosiphon lomentaria, Eisenia bicyclis

Red algae (Rhodophyceae)
Grateloupia filicina, Gracilaria verrucosa, Polysiphonia

Animals

Sponges (Porifera)
Haliclona permollis, Halichondria panicea (Fig. 1D)

Cnidarians (Cnidaria)
Tubularia mesembryanthemum (Fig. 1S), *Halecium flexile, Haliplanella luciae* (Fig. 1E).

Flatworms (Turbellaria)
**Stylochus ijimai* (Fig. 1G), **Thysanozoan brocchii*, **Notoplana humilis*

Molluscs (Mollusca)
Anomia lischkei, Mytilus cf. *edulis* (Fig. 1N), *M. coruscus, Hiatella orientalis*

Polychaetes (Polychaeta)
Hydroides elegans (Fig. 10P), *Serpula foraminosus, Spirobranchus giganteus*, **Polydora* spp.

Crustaceans (Crustacea)
Balanus amphitrite hawaiiensis (Fig. 1H), *B. reticulatus* (Fig. 1I), *B. albicostatus albicostatus, B. amphitrite krugeri, B. eburneus, B. trigonum, B. tintinnabulum rosa*, **Leander serrifer* (Fig. 1L), **Heptacarpus rectirostris*, **Hemigrapus penicillatus* (Fig. 1K), **H. sanguineus*

Bryozoans (Bryozoa)
Bugula neritina (Fig. 1F), *Tricellaria occidentalis, Dakaria subovoidea*

Sea squirts (Ascidacea)
Ciona intestinalis (Fig. 1Q), *Styela clava* (Fig. 1R), *S. plicata* (Fig. 1T), *Leptoclinum mitsukurii, Botrylloides aurantium, Didemnum moseleyi*

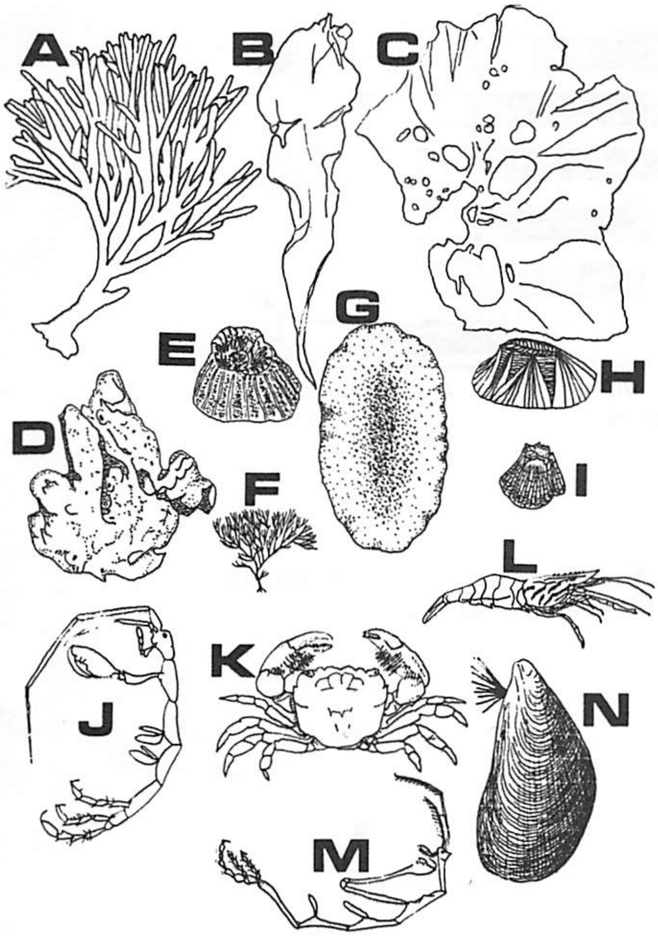
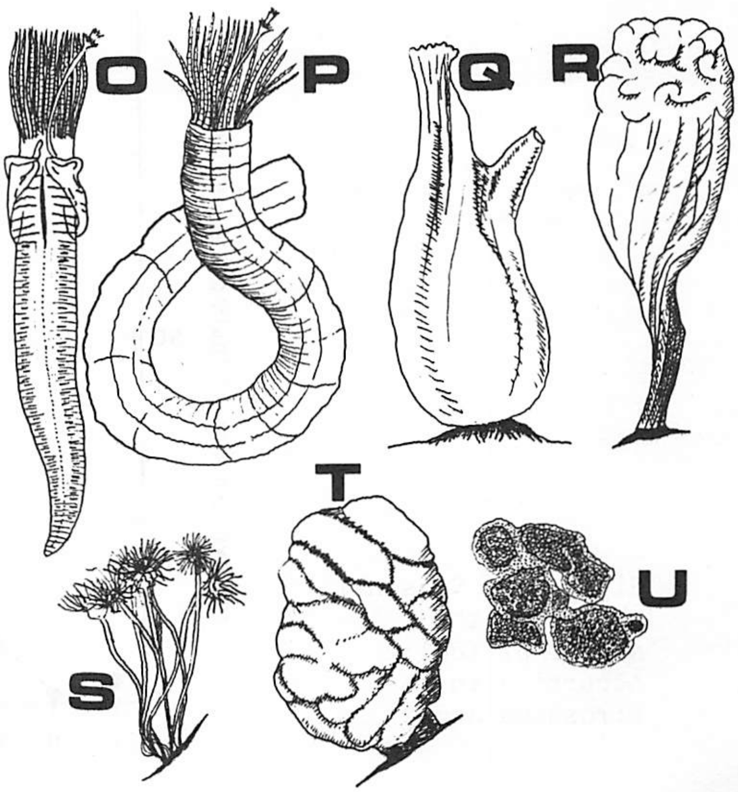


Figure 1. Typical Fouling Organisms
A, *Codium fragile* (green alga); B, *Enteromorpha linza* (green alga); C, *Ulva pertusa* (green alga); D, *Halichondria panicea* (sponge); E, *Diadumene luciae* (sea anemone); F, *Bugula neritina* (bryozoan); G, *Stylochus ijimai* (flatworm); H, *Balanus amphitrite hawaiiensis* (barnacle); I, *Balanus reticulatus* (barnacle); J, *Protella gracilis* (skeleton shrimp); K, *Hemigraspus penicillatus* (crab); L, *Leander serrifer* (shrimp); M, *Caprella gigantochir* (skeleton shrimp); N, *Mytilus* cf. *edulis* (mussel); O, *Hydroides elegans* (fanworm, shell removed); P, *H. elegans* (in shell); Q, *Ciona intestinalis* (sea squirt); R, *Styela clava* (sea squirt); S, *Tubularia mesembryanthemum* (sea strawberries); T, *Styela plicata* (sea squirt); U, *Botryllus schlosseri* (a colonial sea squirt).

G and J through M are secondary fouling organisms; the others are primary foulers.



After the Illustrated Encyclopedia of the Fauna of Japan, 1952.

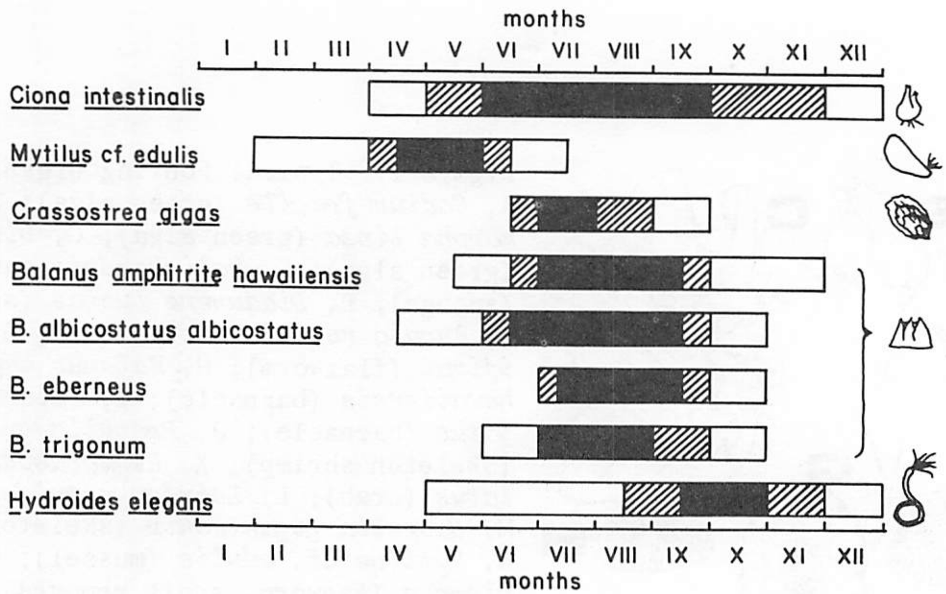


Figure 2. Breeding seasons (times of settlement) of the major fouling organisms in the Hiroshima area.

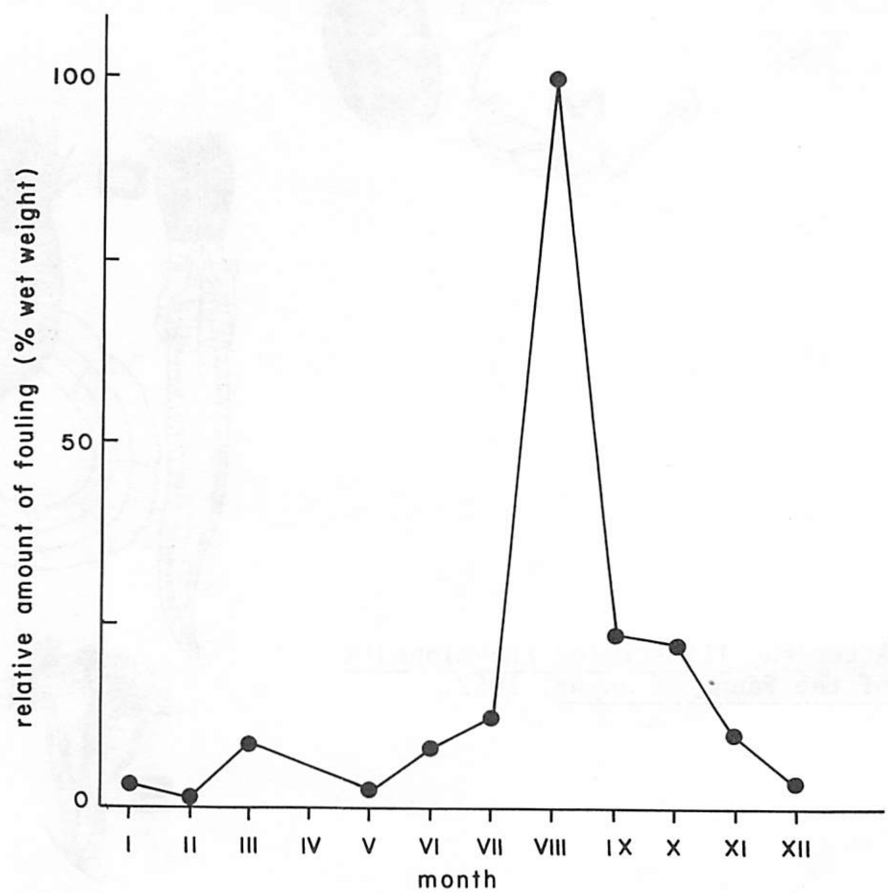


Figure 3. Seasonal change in the amount of fouling occurring in the Hiroshima area.

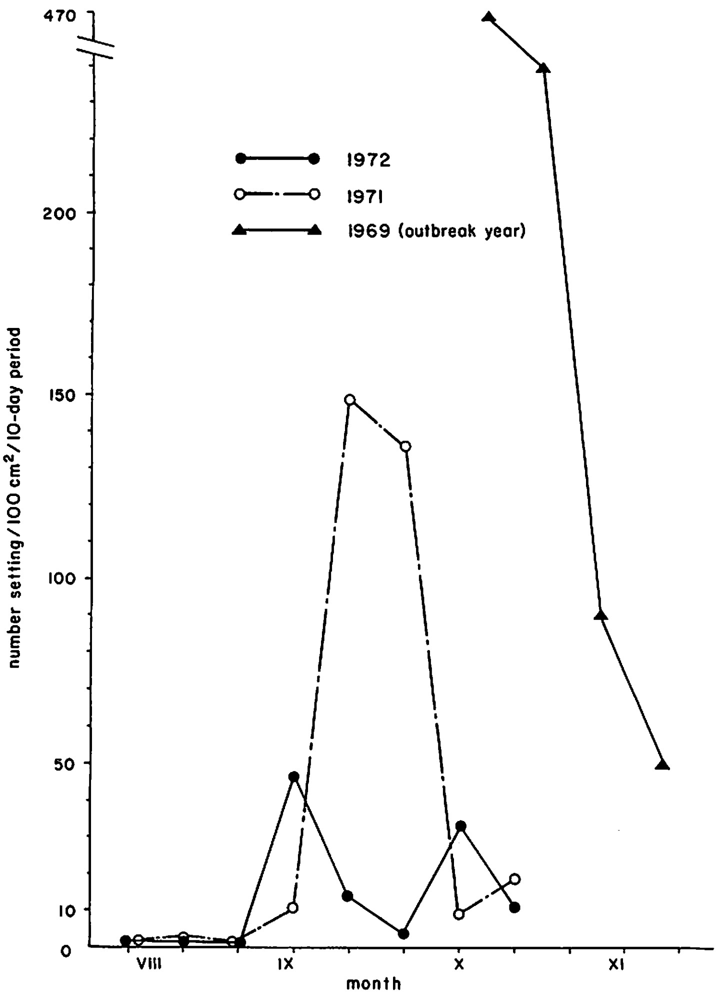


Figure 4. Setting intensity of *Hydroides elegans* during several different years.

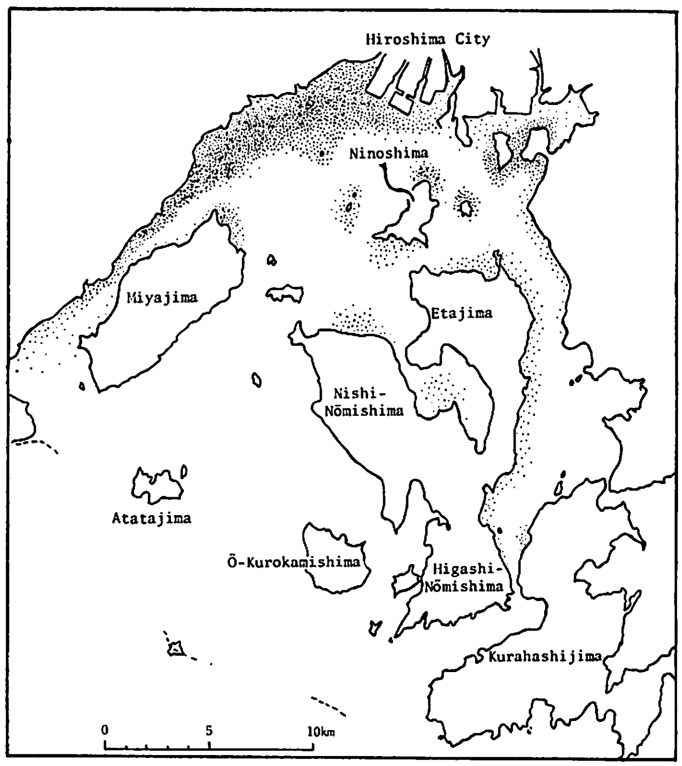


Figure 5. Distribution of *Hydroides elegans* after the outbreak of 1969.

From these observations on the breeding seasons of major fouling organisms, it can be seen that a program for the removal of fouling may be reasonably divided into two phases: the first will occur during early to mid-June and be aimed primarily at mussels; the second will be in the middle of October and deal with the summer/fall pests — barnacles, fanworms, sea squirts, etc. Of course, if mussel set has been avoided through the use of deep suspension (see p. 25, para. 2) or some such method, the first phase may be omitted. As for the second phase, operations should not be put off until fanworms have finished setting. To do so would interfere with the all-important oyster fattening period (October-December). Therefore, measures taken against fouling during the second phase should be completed by the end of October at the latest.

We will conclude this section by considering the seasonal breakdown of fouling intensity (Fig. 3). In Hiroshima Bay fouling is very light from December until May, begins to increase during June and reaches a peak in July and August. Levels decline in September, continue to fall off during October, November and December, finally reaching a minimum in February.

Where fouling occurs (distribution)

Where a particular fouling organism occurs depends upon its species-specific behavior and a number of environmental factors. Different species will live in different places and occur at different depths. As water characteristics and hydrographic conditions in any given area may vary somewhat from year to year, different locations within an area will be subject to varying levels of fouling from one year to the next.

Fanworms, for example, will generally occur noticeably in only a few areas around Hiroshima Bay. Outbreaks can arise, though, and when they do the worms become widespread throughout the Bay (Fig. 5). Mussels usually set most heavily around the island of Ijima but, again, depending upon the year, may occur profusely in the entire Bay area.

Barnacles enjoy a wide distribution: some (e.g., *Balanus amphitrite hawaiiensis*) occur predominately in inshore areas; others (e.g., *B. albicostatus* and *B. eburneus*) may be found offshore as well. Similarly, the sea squirt *Ciona intestinalis* is distributed along the coast while *Styela plicata* is more of an open-water species.

When we consider distribution as a function of depth, different groupings occur. Mussels and barnacles tend to set more heavily in the upper 3 m of water, fanworms from 3 to 6 m, and sea squirts (*Ciona*) from about 5 to 10 m. During outbreaks, however, a species may be found firmly established at all levels in the water column. Nevertheless, by exploiting a knowledge of the normal distributional patterns of these animals, culture gear may be skillfully manipulated so as to minimize fouling and the damage it causes.

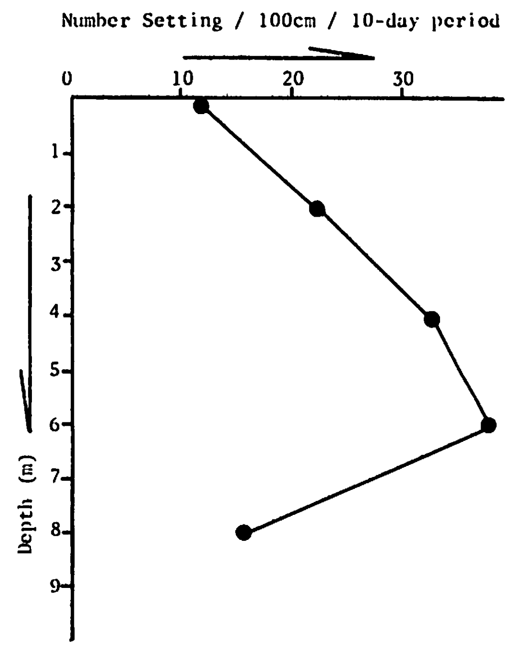


Figure 6. Vertical distribution of *Hydroides elegans* set.

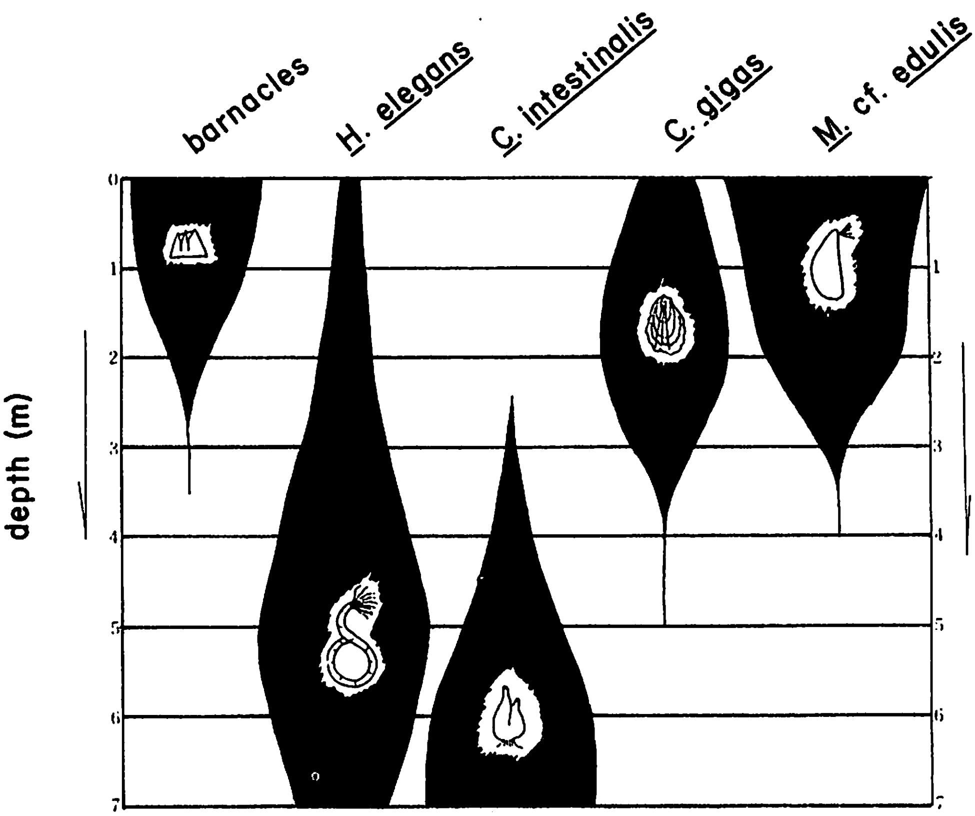


Figure 7. Occurrence of the major attaching forms as a function of depth.

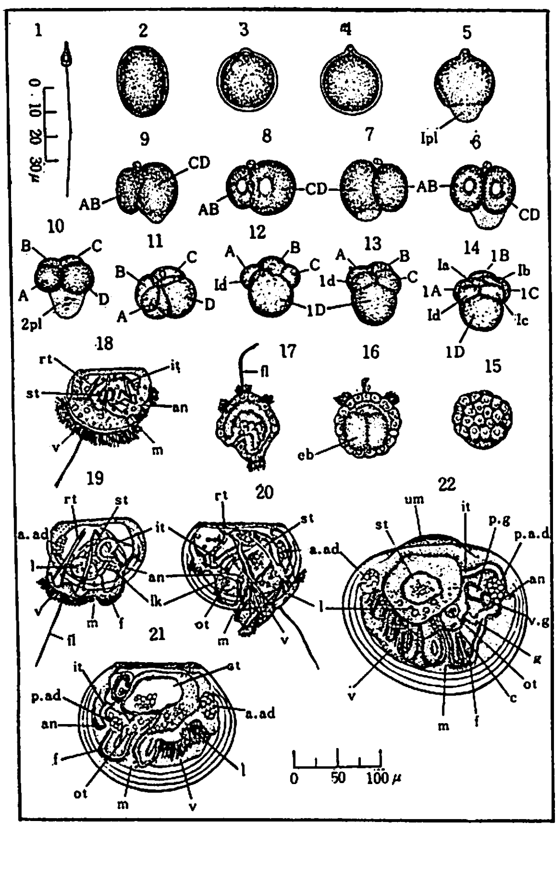


Figure 8. Development in *Mytilus* cf. *edulis*. 1, sperm; 2-15, cleavage; 16, early trochophore; 17, fully developed trochophore; 18-21, straight-hinge veliger; 22, late umbo larva (pediveliger). (From Miyazaki, 1932).

From egg to adult

Mussels

Sea mussels (*Mytilus* cf. *edulis*) are believed to have been indigenous to northern Europe but presently enjoy a cosmopolitan distribution. These bivalves may have come to Japan attached to the hulls of Dutch ships that called here during the Edo Period (1600-1867) of Japanese history. The coming and going of foreign vessels was restricted primarily to the Port of Nagasaki, and the distribution of mussels centered in Nagasaki until about fifty years ago. Since that time they have become more widespread along our shores.

In the Hiroshima area mussels spawn from March until June. The early larval stages — trochophores and straight-hinge larvae (see Fig. 8) — lead a free-swimming, planktonic existence. In about a month from hatching the larvae mature and achieve a length of 0.3-0.4 mm. When this stage is reached setting begins. The mussel attaches itself to some natural object by a strong, cord-like byssus which originates in the base of the foot (Fig. 8:22,f). After primary settlement, mussels will often release their byssal attachments and move to other, presumably more suitable, locations and once again attach themselves.

Growth rates differ according to location, but generally mussels reach a size (length) of approximately 1 cm a month after setting. After two months they will be about 4 cm, and in four or five months 12-13 cm. Sexual maturity is reached in about a year, at which time they are capable of spawning.

Fanworms

The fanworm (*Hydroides elegans*) is a tube-dwelling relative of the sandworm. Its head is topped by a crown of feather-like appendages, the fine projections of which form a sieving network for filtering and concentrating suspended organic material upon which the animal feeds. This is very similar in principle to the ways in which oysters, mussels and other filter-feeders acquire their food.

Spawning occurs in Hiroshima Bay from May to December but is most intense during September and October. Trochophore larvae (Fig. 9) appear about 24 hours after hatching and live in the plankton for approximately a week. The larvae then enter a benthic (bottom-living) nektochaete stage and attach to submerged objects. Subsequently certain areas on the head of the nektochaete larva enlarge to form a number of club-shaped protuberances from which the finer outgrowths develop. After branching and development of the finer appendages is completed the whole apparatus comes to resemble the "Gorgon head" of Greek mythology. Large eyespots appear during the trochophore stage but degenerate with further growth and are completely absent in the adult.

The calcareous tube develops from an initially glutinous substance secreted by tissue in the worm's neck region; the substance solidifies into a hard tube. Roughly three months are believed to elapse from the time of settlement to the appearance of the adult form. The tube appears earlier and one month after

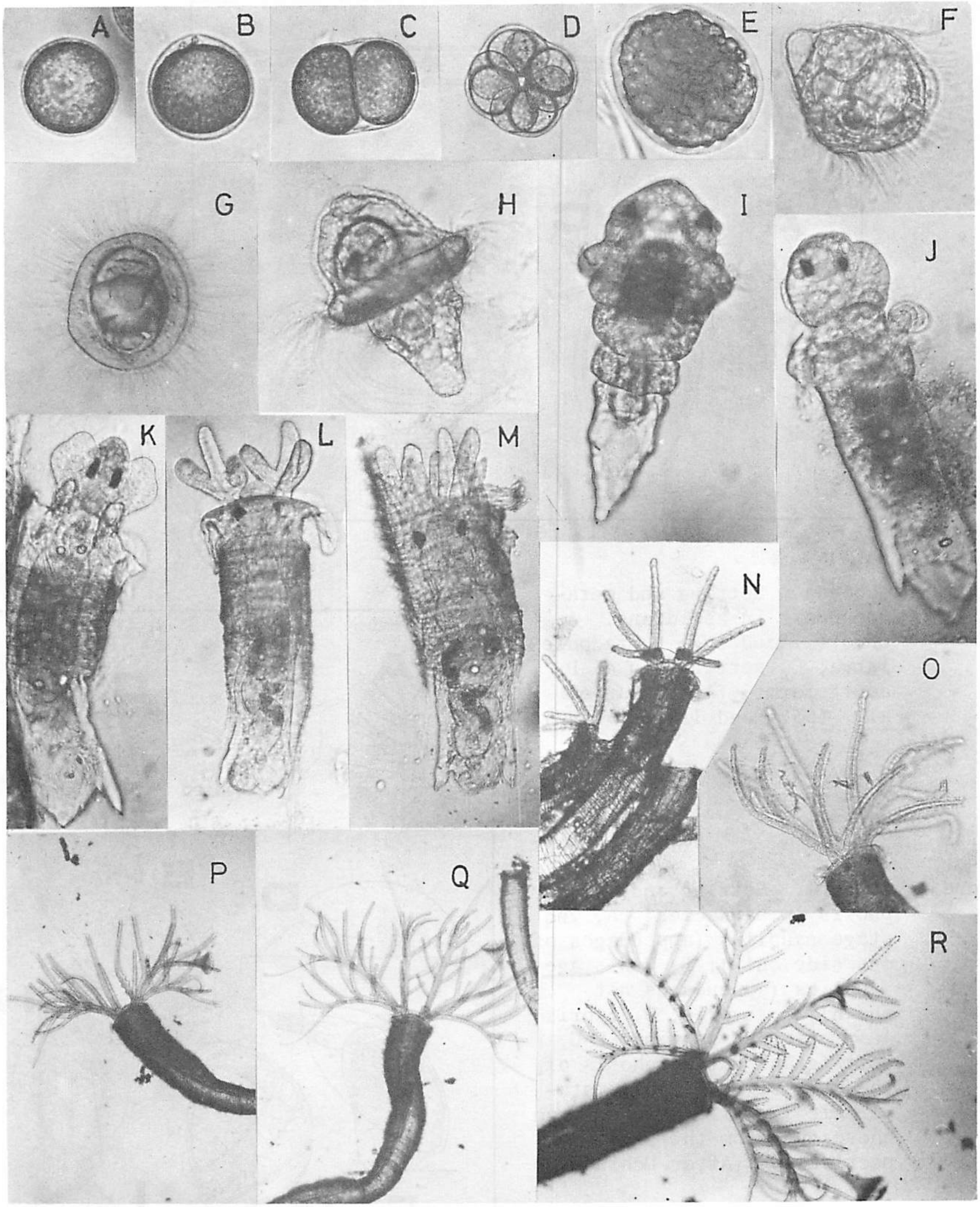


Figure 9. Development in *Hydroides elegans*. A, fertilized egg; B, polar body formation; C, 2-cell stage; D, 8-cell stage; E, morula; F-H, protrochophore; I, metatrochophore; J-M, nektochaete larva; N-R, post-settlement juvenile development. (From Arakawa, 1971).

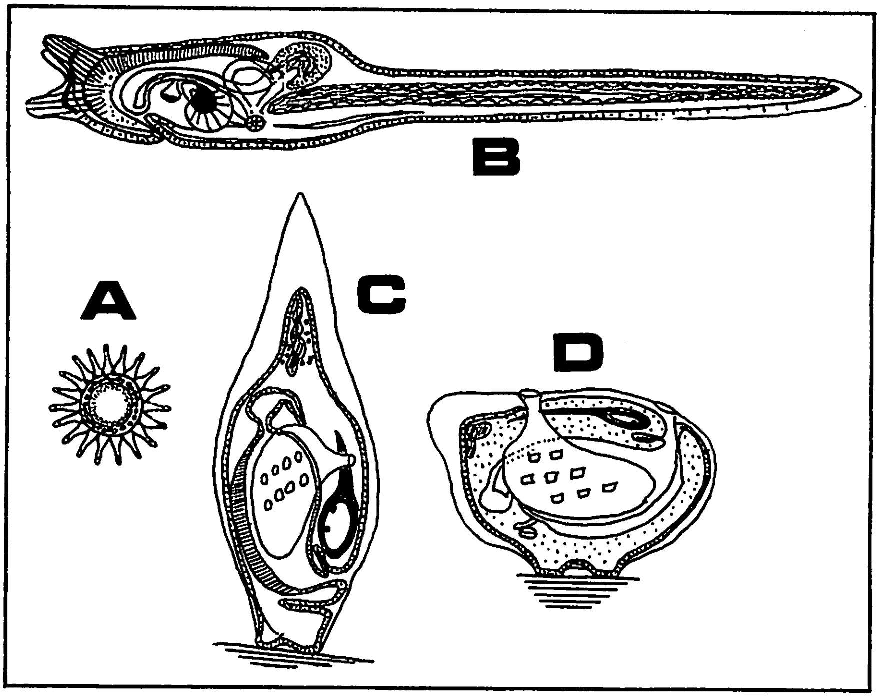


Figure 10 (above). Setting and metamorphosis in ascidians. A, unfertilized egg; B, tadpole larva; C, setting larva; D, adult form. (After Dan et al., 1957, and Iijima, 1927).

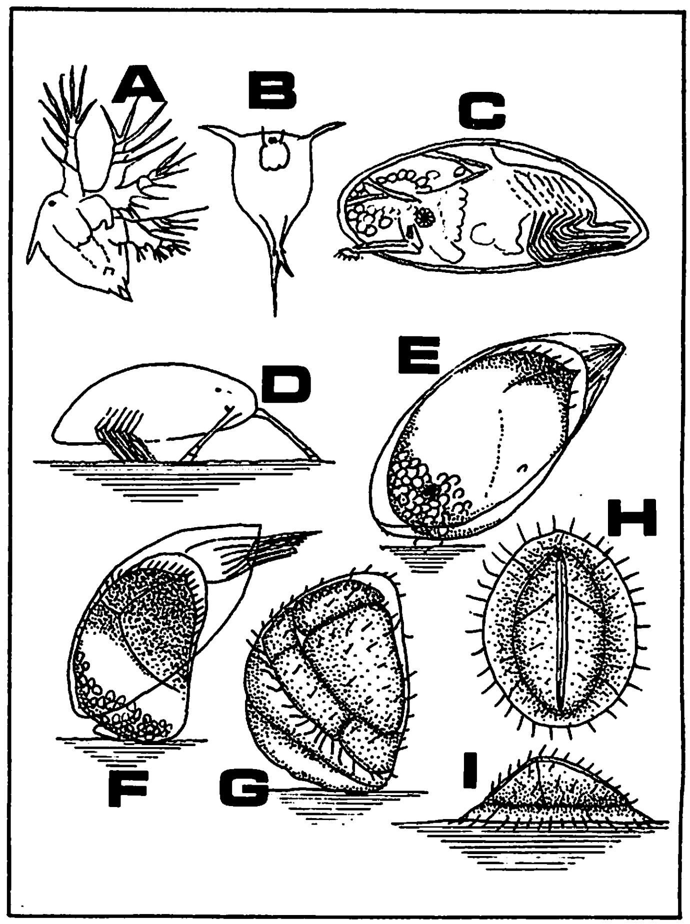


Figure 11 (right). Setting and metamorphosis in barnacles. A, 2nd stage nauplius (appendages of one side only); B, 7th-stage nauplius (appendages not shown); C, cypris; D, cypris just prior to setting; E-G, setting and metamorphosis of the cypris; H, I, post-metamorphic juvenile, viewed from above and from the side, respectively. (After Uchinomi, 1947.)

settlement is approximately 0.5 mm in diameter. In three months time it will be between 1.0 and 1.5 mm, and in four months over 1.5 mm. For individuals a year or more in age the maximum diameter of the tube is about 3 mm.

Hydroides elegans prefers estuarine or inner-bay areas, more specifically, turbid areas of low salinity, and areas where the current is slack. It is unable to set when current velocity exceeds 1.8 knots or survive widely fluctuating salinities. Outbreaks are known to occur and seem to coincide with years of exceptional organic pollution — we may probably designate fanworms as a pollution-indicator species for inner-bay areas (see p. 29, para. 4).

Sea squirts

Sea squirts (ascidians) may occur singly or form colonies depending on the species. Water enters and exits the animal at two separate sites (the buccal and atrial siphons, respectively) in forms living singly. The life-history information that follows applies to *Ciona intestinalis* (Fig. 10), a species of solitary tunicate capable of causing considerable damage. We might note that this species also has a worldwide distribution.

Sexually mature individuals in the Hiroshima region will spawn sometime between April and December, though the greatest activity will be from June to September. From a spawned and fertilized egg develops a tailed larva resembling a tadpole. This requires only one or two days, and the larva is free-swimming. After about a week of pelagic life the larva searches out some hard, submerged object to which it attaches itself. This it does using three nipple-like appendages on its head referred to as fixation papillae. Attachment, therefore, is effected with the head against the substratum.

Once firmly anchored, the larval tail is resorbed and the entire body gradually acquires a sack-like appearance. During this time the mouth migrates from what had been the head to the opposite end; when this is complete the form is essentially that of an adult.

Barnacles

Barnacles possess a tough, calcareous shell and, like oysters, may be found adhering to rocks, pilings and other submerged objects. Barnacles are not related to oysters or clams, however, but belong instead among the crustaceans, a group including shrimp and crabs. One can better appreciate the reasons for this after examining barnacle development, for their early larval stages are very similar to those of many other crustaceans.

Our example will be a species of *Balanus (B. amphitrite hawaiiensis)*, a very common genus (Fig. 11). Larvae develop from eggs about 0.15 mm in diameter. The just-hatched larva is called a first-stage nauplius and is virtually identical to other crustacean nauplii. Growth is by a series of molts, generally eight, after which the larva will be ready to set. Larvae at this stage possess thin transparent shells and are referred to as cypris larvae. Approximately two weeks are required to attain the cypris stage, although this will vary somewhat depending on temperature and food availability. Once the cypris stage is reached, some two or three days elapse before the larva sets. Attachment is achieved by the secretion of a sticky substance from a special organ, the cement gland.

Various physical factors will influence where barnacles set. For example, current velocity is important. In an experiment where current was varied from 0.0 to 0.1 knot, it was found that setting was heaviest at the lowest velocities.

Adult barnacles possess ten fine, whip-like appendages, called cirri, which can be extended through an aperture in the top of the shell. When extended and spread out, the cirri are manipulated like a net to gather suspended matter in the water which they use for food.

Why outbreaks occur

An unusual proliferation of a living organism may arise for various reasons. In certain cases outbreaks occur when the "normal balance" of a living community is disrupted or collapses; such disruptions may result from cyclical processes or be irregular in occurrence. In other instances changes in meteorologic, oceanographic or other environmental conditions allow outbreaks to occur. They may also occur when organisms enter new territories where competitors or predators are few or absent.

It is strongly believed that the 1969-70 outbreak of fanworms in Hiroshima Bay resulted from environmental conditions which impeded the dispersion of large amounts of pollutants high in nitrogen (see Fig. 12). A 1970 outbreak of hydroids was also clearly the result of environmental change.

In the summer of 1971 swarms of jellyfish plagued Tokyo Bay in such numbers that the cooling systems of coastal power stations became completely clogged. This produced power outages and much turmoil in the shore areas. Concurrent with the Tokyo outbreak of jellyfish, which, by the way, are closely related to the hydroids that had created problems in Hiroshima, there occurred what, in effect, was an outbreak of a pea crab (*Tritodynamia horvathi*) all over the Inland Sea. (Pea crabs live commensally with various invertebrates, oysters included; *T. horvathi* usually associates with the mudworm, *Loimia medusa*, but leaves its host when mature.) Outbreaks of this organism had previously been confined to Tokyo Bay, the Ariake Sea, and a few other areas; this was the first occurrence of an outbreak in the Inland Sea. These developments heightened the feeling that the severity of pollution in the Inland Sea was fast approaching that of Tokyo Bay.

The occurrence of unusually large numbers of predatory flatworms has also been linked to variations in environmental conditions. In this case it has been noted that damage to oysters under culture at offshore sites is more likely to occur during years when rainfall has been slight, producing higher water temperatures and salinities than usual (Fig. 13).

In the case of outbreaks whose occurrence may be traced to unnatural environmental change (i.e., pollution), I feel that merely dealing with the fouling after it occurs falls far short of what is really needed. We must stop pollution at its source; strict laws are necessary.

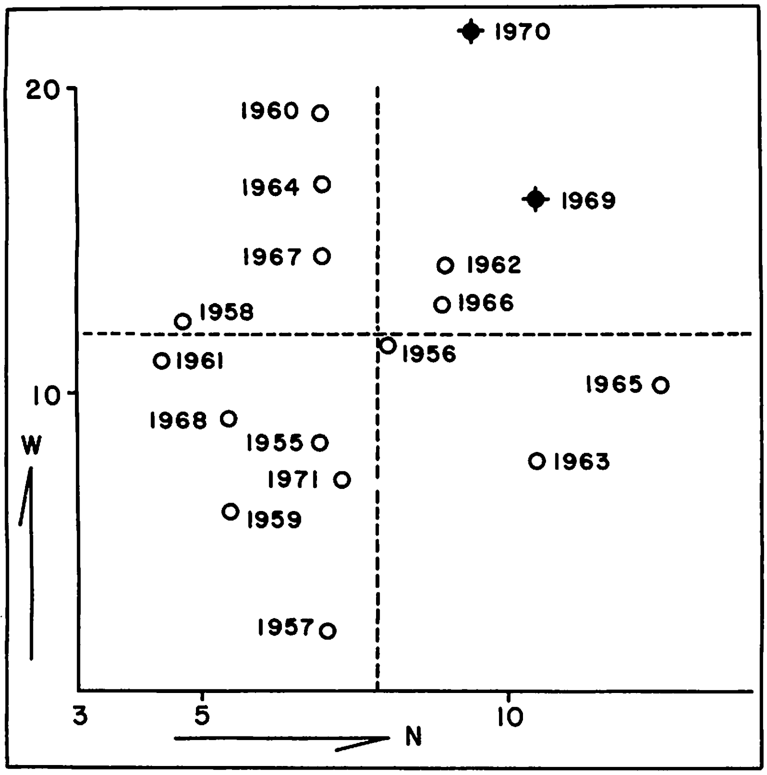


Figure 12. Comparison of *Hydroides elegans* outbreaks and occurrences of red tide with environmental conditions. X-axis (N): Nitrogen entering Hiroshima Bay during June and July (tons/day). Y-axis (W): Number of days during the latter part of July and beginning of August for which the mean air temperature exceeded 27°C and either the mean wind velocity was below 2.3m/sec or wind direction was from the SSE-SW. Outbreak years indicated by solid circles. (From Kimura, 1972.)

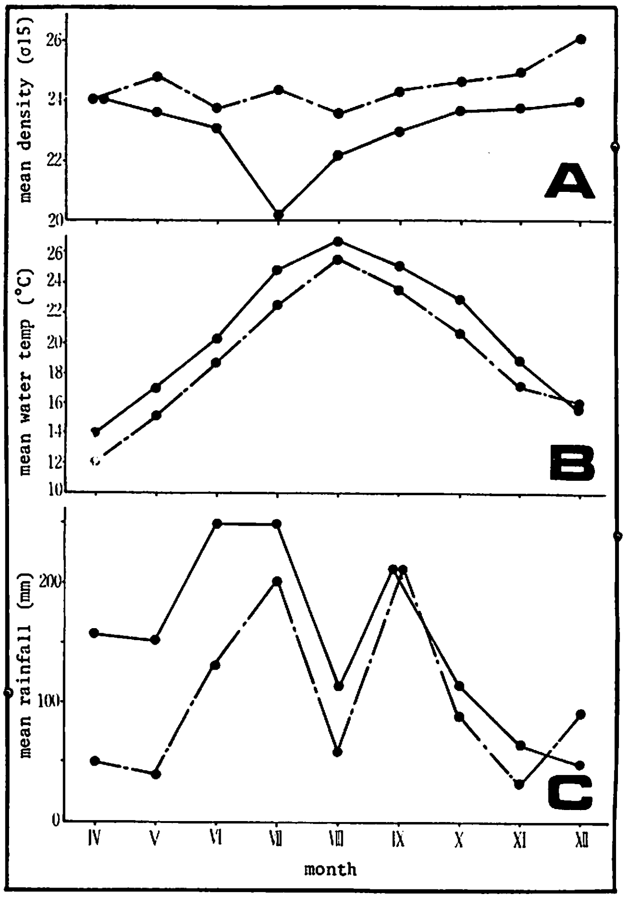


Figure 13. Comparison of *Stylochus ijimai* (secondary fouling organism) outbreaks with environmental conditions. A, density; B, water temperature; C, rainfall. Solid lines indicate conditions during an average year, while the broken lines are for an outbreak year. (From Arakawa, 1970.)

Finally, we have also witnessed outbreaks developing from the introduction of new species. Recently the plant, *Solidago altissima*, originally from America, has received much attention as a rapidly spreading weed. Another North American import, which in this case is largely unknown to the general public yet has been proliferating furiously in Hiroshima Bay since about 1966, is a species of barnacle, *Balanus eburneus*.

DAMAGE CAUSED BY FOULING ORGANISMS

Generally an intensely competitive struggle arises among oysters and fouling organisms for living space and food. Sometimes, through sheer proliferative power, one or more fouling organisms flourish and out-compete the oysters. When this happens oyster growth is suppressed; if especially severe, oysters may be smothered and die.

During spat collection the time at which the collectors are set out is very important. If the timing of oyster setting is predicted incorrectly and the collectors are set out prematurely, not only will they acquire a set of ascidians and barnacles, but will also be covered with a thin film of slime. This slime, a product of attaching bacteria and diatoms, will hinder oyster set, and the longer it has to get established the greater the decrease in setting. According to experimental evidence, collectors put out six to nine days prior to the commencement of oyster setting will collect spat at 60-70% the rate that occurs on fresh collectors; those left out for twelve to fifteen days will acquire set at 40-60% that rate.

The extent to which mussels will adversely affect offshore oyster growth is a question that has also been investigated. Research indicates that when fouling is at an average of three mussels per oyster, growth will be reduced by nearly 20% of that attained by unfouled oysters. When the ratio of mussels to oysters is 7:1, the reduction in growth will be closer to 40%. As the average oyster raft produces 3 metric tons of shucked meats, a 40% reduction amounts to 1.2 tons. In monetary terms this represents a potential loss of some $3,500.

A good example of the harm that fouling organisms can inflict is provided by the 1969-70 outbreak of fanworms in Hiroshima Bay. Approximately 60%, or 6,000, of the oyster rafts in the bay were affected and losses totalled $12-15 million.

In the pearl culture industry the damage done by blisterworms (*Polydora*) can be considerable. These worms live in the shell of the pearl oyster and cause an inferior pearl to be produced. Every year much time and expense is invested in efforts to prevent and eliminate these fouling organisms.

Freighters, tankers and other merchant ships sustain losses due to the fouling of their hulls. Consequently, much effort has been devoted to countermeasures in this area also. If fouling is neglected speed may drop to one half or less. In order to maintain a constant speed, therefore, fuel consumption may have to increase by more than 40%; to traverse a given distance may require 10-50% more time because of fouling.

Such considerations are potentially of critical importance in the military realm. It is not generally well known, but the crushing defeat of the Russian Baltic fleet at Tsushima during the Russo-Japanese War (1904-5) is attributed by naval historians to "hull oysters", that is, fouling. The specialists point out that more than half a year elapsed between the departure of the Russian fleet from its home base and its arrival in the vicinity of Tsushima, an island between Korea and Japan. During the transit their speed, because of fouling, had fallen off by 20-30%. By the time of the battle the Russian ships were not capable of more than 12-13 knots, and were outmaneuvered by the swifter Japanese vessels.

From the above considerations, then, we should no longer be surprised when fouling organisms, although largely unnoticed, have such major impacts on our affairs.

PREVENTION AND REMOVAL OF FOULING

In this section we shall be concerned with the prevention and removal of fouling, introducing in a concrete manner those methods which have been tried so far and attempting to indicate their comparative merits and drawbacks.

Physical methods

Burning

This is a method of killing organisms attached to the outer surfaces of oysters by flaming them with an oil burner or large torch (Fig. 17). The culture strings are suspended using the oyster boat's derrick. After most of the water is carefully whisked away, the flame is passed repeatedly over the strings so as to contact every surface. This treatment is best done on a calm, windless day when the flame will not be dispersed. Also, I should point out that it requires a bit of a knack to moderate the flame such that the fouling is eliminated without harming the oysters.

The flame method is effective against mussels, fanworms, sea squirts, barnacles and all other fouling organisms. Sea squirts are especially susceptible, any contact with the flame being sufficient – in several days or a week they will all be dead.

Recommending this method is the observation that after treatment oyster growth improves substantially. Whether this is a direct consequence of the extermination of the attached organisms or, rather, an indirect effect on oyster growth caused by the heating, is not yet well understood.

Air-drying (sun-drying)

This method makes use of the radiant heat of the sun and its drying action (Figs. 14, 15 and 17B & C). It is effective against nearly all fouling organisms and useful both for inshore spat-collecting (or hardening) strings and offshore culture strings. Take the mussel, for example. Death occurs when its internal temperature

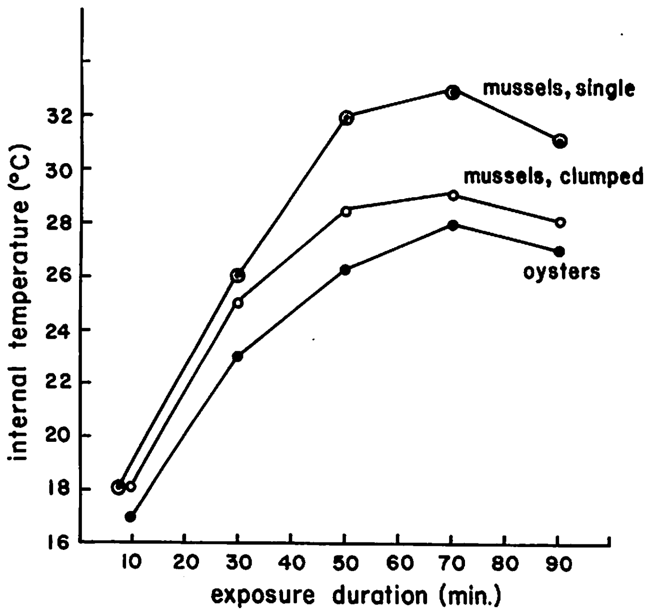


Figure 14. Internal temperatures of oysters (*Crassostrea gigas*) and mussels (*Mytlius* cf. *edulis*) exposed to the sun.

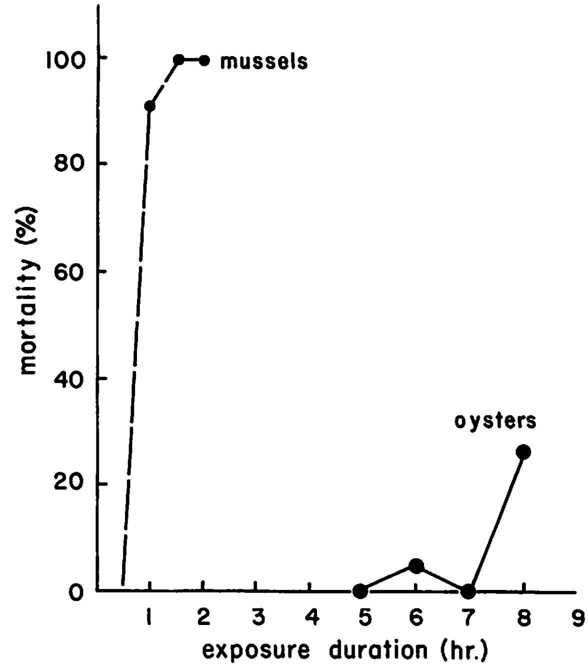
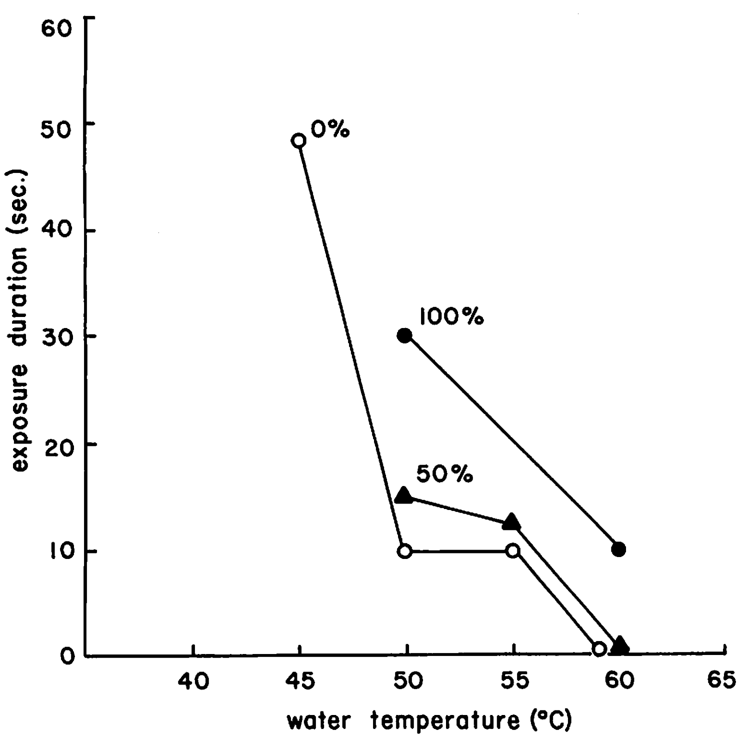


Figure 15. Comparative resistance of oysters (*Crassostrea gigas*) and mussels (*Mytilus* cf. *edulis*) to sun exposure.



Figures 14-16 from Data on Oyster Countermeasures, 1964.

Figure 16. Resistance (per cent mortality) of mussels (*Mytilus* cf. *edulis*) to hot water treatment.

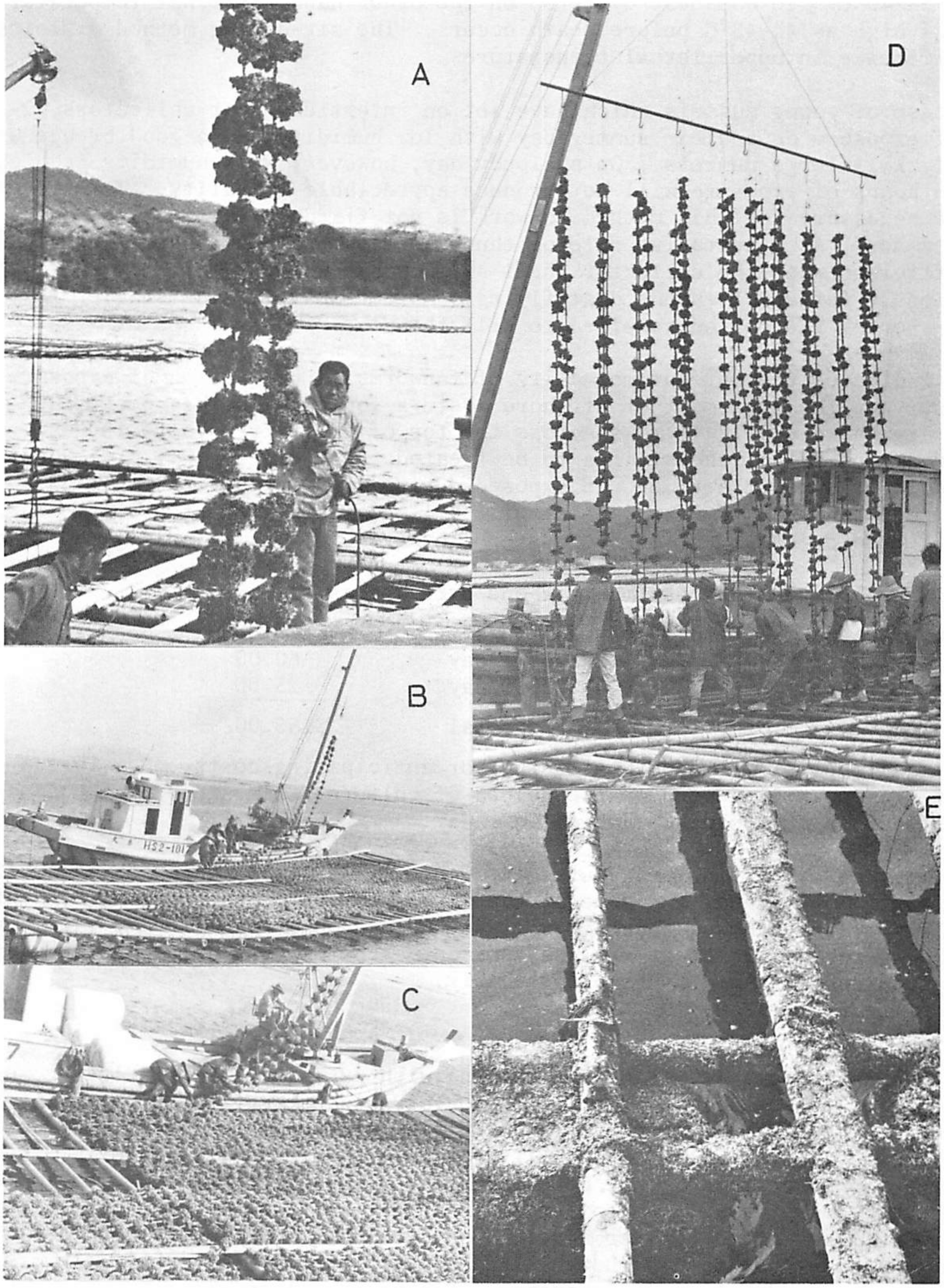


Figure 17. Removal of *Hydroides elegans* from cultured oysters. A, burning; B-C, air-drying; D, scraping; E, broken fanworm shells which have fallen on the culture raft. (from Arakawa, 1971.)

reaches 38-40°C. In Japanese oysters, on the other hand, internal temperatures may go as high as 44-48°C before death occurs. The air-drying method exploits this difference in upper lethal temperatures.

In the case of young mussels which have set on intertidal spat collectors, 2-3 hours of exposure on a clear summer day with low humidity and a good breeze will generally kill large numbers. On a cloudy day, however, when humidity is high, even 5-6 hours of exposure will not produce appreciable mortality. Therefore, the time necessary for this method to work is not fixed but a function of the day's weather. As a tentative rule of thumb we might say that exposure has been sufficient when the collector shell surface has whitened with drying and blowing on it forcefully sends dust flying. As for mussels, the smaller they are the shorter the period required to kill them.

Table 2 indicates the percent mortality of fanworms as a function of exposure duration. For the treatment of offshore oysters fouled with this pest, the culture strings are laid in rows across the top of the raft. There is not enough room for all of the strings to be treated together, so only a third of them should be done at a time. If exposed during fair weather in the middle of fall, one or two days of treatment will kill nearly all the fanworms. There will be little or no effect on the oysters, however.

Expenses involved in the treatment of one raft are as follows:

Labor:	Male,	2 @ $35.00/day	$ 70.00
	Female,	4 @ $15.00/day	60.00
Boat Expense:		1 @ $25.00/day	25.00
		Total	$155.00

This itemization will, I hope, be useful for anticipating costs. How fast a raft can be done will depend on the number of culture strings per raft. Generally a raft of 600 strings can be handled in a day.

After using the air-drying procedure, it might not at first appear to have killed the sea squirts, seaweeds and some of the other members of the fouling community. Gradually, however, these organisms will begin to drop off and in 4-7 days the real effects of the treatment will be apparent. Furthermore, if properly carried out, oyster growth should improve noticeably.

Hot-water bath

This method is especially useful for dealing with juvenile forms including mussels, barnacles, etc., found attached to collector strings not yet transferred offshore (Fig. 16). A few strings at a time are entirely submerged for 10-15 seconds in a large kettle — a 55-gallon drum will do nicely — filled with water at 55-60°C. After immersion the strings must be immediately returned to sea water at ambient temperature. Young mussels up to 1-2 cm in height will nearly all be killed with no adverse effects on the oyster spat. A word of caution is again in order: it sometimes happens that both principal and interest are lost by carelessly mistaking the temperature or duration of immersion. Please pay close attention.

Table 3 summarizes the effects of the hot-water bath on juvenile oysters and mussels according to size, temperature and duration of exposure. Please go over this material carefully so there will not be any mistakes during the actual treatment.

Fresh-water immersion

Immersion of marine fouling organisms in fresh water produces osmotic stress and, eventually, death. Nearly all of the attaching forms discussed so far can be removed effectively using this technique. In practice this calls for the transfer of entire oyster rafts to the mouth of a river. Alternatively, culture strings could be suspended from racks set up along the banks of a river, or some similar scheme could be devised.

The time required in order for the treatment to be effective will be a function of various factors. When dealing with mussels, for example, a period of fifty hours is needed if water temperature is 15-20°C but only thirty hours at 20-25°C. The mortality of fanworms follows the time course indicated in Table 4. It should be noted that flowing water is thought to be more efficacious than standing water.

Brine bath

This treatment also subjects fouling organisms to osmotic stress, but in a direction opposite to that of the previous method. In this case a bath is prepared of NaCl-saturated water, that is, seawater into which as much table salt as will go into solution has been added. The method is used with good results by pearl culturists to destroy blisterworms infesting the shells of pearl oysters.

In the grow-out of Japanese oysters, however, the culture strings are very long and it is only with much trouble and expense that the brine technique may be employed. Consequently it is not thought to be a terribly practical method compared with some of the others. Nonetheless it is effective against the usual array of fouling pests — sea squirts, mussels and most of the rest. Extermination of fanworms takes place as indicated in Table 5.

Scraping and brushing

Fouling can be removed by scraping or the use of a wire brush. In order to do this the culture strings are first strung at fixed intervals from a horizontal bar which is then lifted in the air by the oyster boat derrick (Fig. 17). About thirty strings can be hoisted at one time and five or six people can work on them simultaneously. As with the similar shell-cleaning process in pearl culture, there exists the potential for the organisms so painstakingly removed to reproduce themselves if allowed to fall back into the water. This should be prevented.

The expenses involved for the treating of one raft are roughly as follows:

Labor:	Male,	1 @ $35.00/day	$ 35.00	
	Female,	5-6 @ $15.00/day	75.00 -	90.00
Boat Expense:		1 @ $25.00/day	25.00	
			$135.00 -	$150.00

Table 2. Resistance of *Hydroides elegans* to air-drying

Exposure (hrs)*	Mortality (%)
1	17.5
3	92.0
4	92.0
6	96.2

*These results are experimental and were obtained on a clear winter day after the fanworms had been removed from the rafts and spread out over an exposed surface. For practical use it is felt that the treatment period should be extended by a factor of 3-4 (i.e., 9-24 hrs.).

Table 3. Comparative resistance of oysters (*Crassostrea gigas*) and mussels (*Mytilus* cf. *edulis*) to high water temperature

Temperature	50°C			55°C			60°C		
	Mussels		Oysters	Mussels		Oysters	Mussels		Oysters
Exposure (sec)	1-2cm	4-5cm	1-2.5cm	1-2cm	4-5cm	1-2.5cm	1-2cm	4-5cm	1-2.5cm
1	--%	--%	--%	--%	--%	--%	0%	0%	0%
3	--	--	--	--	--	--	70	0	0
5	0	0	0	0	0	0	100	0	0
10	0	0	0	60	0	0	100	0	0
15	10	0	0	100	0	0	100	20	8
20	30	0	0	100	0	0	100	30	13
30	100	0	0	100	10	0	100	60	20
60	100	0	0	100	20	10	100	100	60

(From Koganezawa, 1972)

Table 4. Resistance of *Hydroides elegans* to fresh water

Exposure (min)*	Mortality (%)
30	8.7
60	44.6
120	64.9

*As these results were obtained under controlled experimental conditio it is recommended that exposures be 3-4 times longer (i.e., 6-8 hours` practical applications.

Table 5. Resistance of *Hydroides elegans* to saturated salt solution

Exposure (min)*	Mortality (%)
20	59.4
30	52.9
60	59.4

*Once more, these are experimental results and it is advised that actual treatment periods be increased to 5 or 6 times the durations shown.

Spraying

Pearl growers use a machine for washing their culture nets and this can be adapted to our purposes. As in the previous method the culture strings are suspended using a derrick. A 3-5 HP diesel-powered pumping unit is used to provide jets of water at about 28 kg/cm^2 pressure to spray off the attached fouling. Tests have been made on the elimination of fanworms by this method and in many instances only the front ends of their tubes were removed. The worms, taking refuge in the portions of the tubes that remained, survived and were able to reestablish themselves. Consequently, the treatment did not have much effect. Moreover, there is once more the concern that worms sprayed off completely and falling into the water might reproduce.

Towing

Using a large oyster boat with a 105 HP engine the oyster raft is towed at maximum speed for approximately three hours in an offshore area. The pressure of the passing water on the culture strings will remove some of the fouling. During trials of this method, again aimed primarily at fanworms, many oysters were lost and on those that remained the removal of fouling organisms was only partially accomplished. In any event, normally two boats are used to pull two rafts simultaneously, the expense per raft amounting to $65-70.

Other methods

In addition to the techniques already described, others have been tested by various users of the marine environment. For example, experiments have been conducted on the feasibility of applying low frequency electric shocks to micro-screens as a method of killing the larvae of fouling animals. These would be used in conjunction with seawater cooling systems. Other research has focused on the prevention of hull fouling by ultrasonically irritating settling larvae to impede attachment. Development of both of these techniques has only recently begun, however, and has not yet advanced to the point where they could be put into use.

Chemical methods

Pesticides

The general effectiveness of various insecticides against fouling organisms, barnacle larvae in particular, has been experimentally examined. DDT, BHC, EPN, lindane, sumithian, malathion, kelthane, phenakaton, dipterex, parathion, diazine, endrin and others were tested. Of these DDT (1%) was shown to be the most effective. BHC also produced promising results. Trailing these were dipterex and a few others. The remaining chemicals had very limited or no effect.

Pesticides such as DDT and BHC could be used effectively against barnacles, the oysters' chief competitors during spat collecting time. An emulsion is made which is diluted with water (DDT to 1%, BHC to 3-4%). Collector strings are prepared by spraying with the chemical solution and allowing them to dry. Virtually no barnacles will set on collectors treated in this manner, yet setting oysters will be unaffected.

The use of agricultural chemicals can not be recommended, however. Were many hundreds of millions of collectors to be treated and put into the sea, potentially dangerous concentrations of the toxic materials would accumulate not only in oysters, but possibly in other marine resources as well. These, then, would find their way into our own bodies and perhaps cause irreparable harm. At present the use of such agents as DDT is banned in many of the world's nations.

Other chemicals

Besides pesticides, compounds of chlorine have been tested, mostly at electric power plants. These are prepared by dissolving chlorine in water which produces hydrochloric and hypochlorous acids. The latter is a strong oxidizing agent with the ability to destroy organic matter. Although this treatment deals adequately with bacteria, diatoms and other microorganisms, it has no effect on mature mussels, barnacles, etc.; nor is it likely to be of much use against the larvae of these species. In a test using barnacle larvae, 100% of third-stage nauplii died in 20 min. at a concentration of 3 ppm; the kill rate of cyprids at the same concentration for 30 min. was only about 60%. As for the adults, an exposure to 20 ppm for 48 hr. had no effect whatsoever. We might conclude, therefore, that since chlorine is highly toxic and difficult to handle, and is not very effective except at very high concentrations, it is not well suited for use as an antifouling agent in marine culture fisheries.

Power companies have looked into the feasibility of using certain other compounds — copper sulfate, ferric chloride and pentachlorophenyl-NaCl among them. Tests of their helpfulness in the prevention of fouling revealed pentachlorophenyl-NaCl to be of great value, having an effect like that of chlorine though apparently more toxic. Of mussels placed in a 20 ppm solution for 15 min., 20-40% died. Copper sulfate and ferric chloride failed to prove themselves unequivocally effective even at concentrations of 10-100 ppm.

In the field of marine transport the aim has been to produce an effective antifouling hull paint. Powdered copper, compounds of copper, compounds of mercury, arsenate compounds, blueing agents, napthalene, alkaloids and other poisonous chemicals have been tried. Mercury and copper in particular have long been used, and their effectiveness is apparent. As with pesticides, however, the use of these chemicals in aquaculture could pose a serious health problem and we can not very well recommend them.

To conclude this section it must be said that at present no chemical exists which is economical, does not pose a pollution hazard, and at the same time exhibits a selective ability to knock out fouling but not affect oysters or other non-target organisms.

Biological methods

A number of techniques for the prevention and elimination of fouling are possible through understanding and exploiting the unique biological features of the various organisms — their ecology, life histories, feeding habits, etc. Compared with

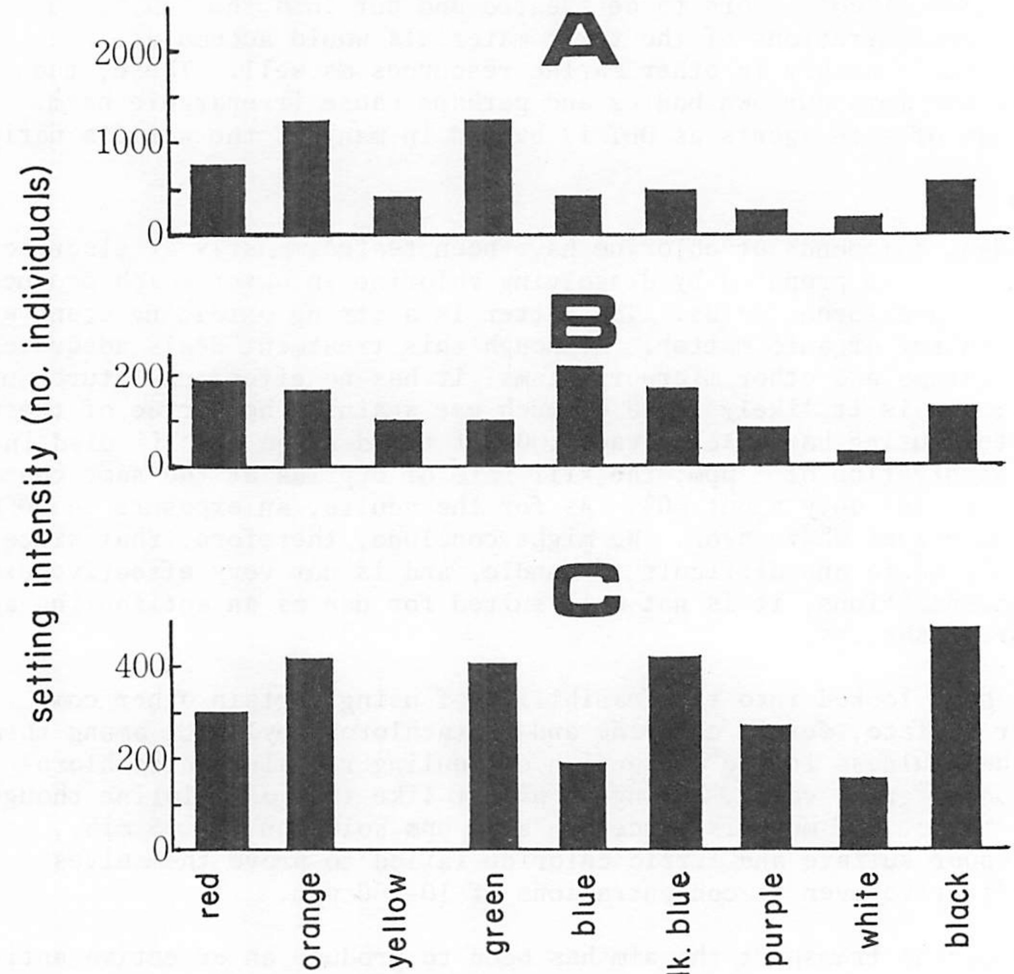
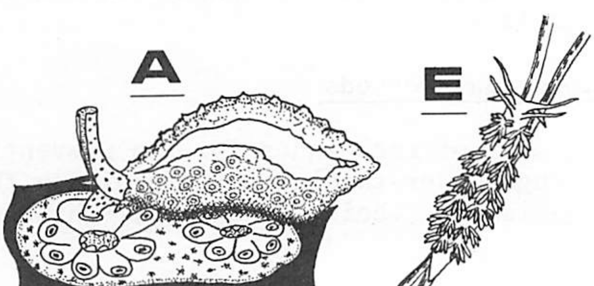


Figure 18. Setting intensity as a function of substrate color in several fouling organisms. A, *Balanus reticulatus* (June): B, *Hydroides elegans* (August); C, *Botrylloides tuberatus* (June). (After Mawatori <u>et</u> <u>al</u>., 1953).

Figure 19. A, cypraeid snail feeding on a colonial ascidian (*Botrylloides tuberatus*) (After Fretter, 1951); E, *Sakuraeolis enoshimensis* (nudibranch), a natural enemy of hydroides (sea strawberries, for example).



the chemical means of control just discussed, biological methods would appear to have much greater promise in the field of aquaculture since secondary effects such as pollution would be less of a problem.

Predicting when fouling will occur

Based on a knowledge of the life history, spawning habits and larval ecology of any given fouling organism, an appropriate monitoring program can be developed which will allow the time and extent of setting to be forecast. By modification of the culture routine, the provision of refuge or other measures, potential damage can be avoided from the start. Currently, promising results are being obtained by the use of these measures against mussels, barnacles, and fanworms.

Deep suspension of culture strings

As was touched upon in the section on the distribution of fouling organisms, the depths at which these forms live is more or less fixed for each species. The culture strings may be temporarily suspended more deeply than usual in order to avoid water layers where attachment is occurring most heavily. In relatively shallow areas the strings are folded in half twice, gathered together, and suspended in two or three bunches — this makes for economy of time and space.

Decoy or throw-away strings

This technique provides a means for the prevention of set by utilizing differences in larval settlement behavior with respect to substrate color. In experiments it has been noted that the mature larvae of certain barnacles, for example, prefer dark surfaces (red, orange, or black) and display a definite avoidance of light (negative phototaxis). Mature oyster larvae, on the other hand, prefer light colors and bright areas and are attracted to light (positive phototaxis). Oyster spat collectors are therefore constructed using the light-colored (left) valves of Japanese scallops. These strings are then alternated with or surrounded by ones made up of the dark-colored lid (right) valves. Other dark shells such as those of the mussel could also be used. Barnacles will be lured toward these decoy strings and thereby kept away from the spat collectors. Decoy or throw-away strings may also be constructed from the rounded scallop shells, which for this purpose must be strung one on top of the other without intervening spacers. This forms a denser stack with many shaded areas between the shells and produces much the same effect as if the shells were darkly colored.

Using natural enemies (biological control)

The environmental damage caused by agricultural chemicals became apparent quite some time ago, and much effort has gone into the testing and dissemination of the natural enemies of various farm pests to preclude the necessity of using insecticides. The use of natural enemies, referred to as biological control, is not yet employed in aquaculture. Examples must therefore be taken from agriculture. One such example concerns the eradication of an insect, *Pseudococcus comstocki* (Hemiptera), causing serious harm to apples. This was brought about by introducing a species of wasp, *Allotrona burrelli* (Hymenoptera), naturally parasitic on *P. comstocki*. Successes have also been achieved against houseflies, dung flies, green bottle flies and others by mixing a pathogenic bacterium, *Bacillus moritai*, into manure.

Because methods of biological control, as opposed to chemical control, do not produce unwanted side effects such as pollution and the development of pesticide resistance, they would seem to offer great promise in the elimination of fouling organisms attached to cultured oysters. I feel it desirable to pursue research along these lines in the future. In this connection it is possible to mention several species as candidates for biological control agents. First, sea strawberries (*Tubularia mesembryanthemum*) are known to be selectively grazed by a species of nudibranch (*Sakuraeolis enoshimensis*) as well as by a skeleton shrimp (*Protella*). Also we know of some small snails in the families Cypraeidae and Lamellariidae and certain crabs which preferentially feed on *Botrylloides violaceus*, *B. schlosseri* and other colonial ascidians (Fig. 19). Finally, we might mention that close to thirty species of mussel parasites are known — protozoans, trematodes, crustaceans, etc. These might be skillfully employed to eliminate mussels as a pest.

Other methods

One method of avoiding barnacle set on spat collectors entails the covering of the strings with straw matting — the barnacle cyprids are attracted to the straw. This method is used primarily in the Kumamoto area of Kyushu. Collector strings are suspended horizontally about 20 cm above the tidal flat and straw mats are suspended about 30 cm above the collectors in a single layer. Collectors protected experimentally in this way caught about twelve oyster larvae and ten barnacles per shell (average of fifty strings), versus four oysters and eighty-nine barnacles on unprotected collectors.

MAKING USE OF FOULING ORGANISMS

Up to now we have been concerned only with the negative aspects of fouling organisms and could be accused of having ignored any points in their favor. Looked at differently, all animals have good qualities as well as bad. Wouldn't there be some merit in now considering the other side of the question, namely, how might these organisms be of some value? This is not to say that we shouldn't continue in our efforts to rid ourselves of fouling organisms and the damage fouling can cause, but if in the process we could take advantage of any useful qualities they may possess, this would be a real countermeasure!

As food

In the Hiroshima area mussels are used at most for cultured shrimp feed. In Europe, though, mussels along with oysters have been widely and long used as food. Rich in vitamins and minerals, mussels are prepared and served in a variety of ways — raw, stewed, fried, pickled, and others. In fact *Mytilus edulis* is the object of a prosperous culture fishery in Europe. This is especially true in Holland where an aquaculture program is being pursued on a national scale.

According to some recent statistics on European mussel production, Spain heads the list at 110,000 tons (in shell); Holland is second with 100,000 tons, followed by France, England, Germany, and Portugal. The mussel industry contributes substantially to the foreign currency earnings of some of these nations; this is particularly important for Holland which ships some two-thirds of its production to other European countries.

Mussels grow naturally in nearly all of Japan's harbors and oyster culture areas, from Hokkaido's Lake Saroma in the north to Kyushu's Ariake Sea in the south. The production of mussels can be phenomenal. One acre (4,047 m^2) of land will yield a mere 0.07 tons of beef per year, but beneath the same area of sea surface 4.54 tons of mussels, fully sixty-five times as much protein, can be produced. The greater efficiency of mussels is readily apparent, and one would expect suspension culture using rafts, which is relatively simple, to produce by far the highest yields.

Mussels were at one time exported to China where they were not only consumed directly but were also used as fresh feed for cultured fish and shellfish – shrimp (*Penaeus japonicus*), for example. For this purpose they are superior to Manila clams (*Tapes philippinarum*) or coarse fishes. At present there is still some demand for mussels. If appropriate marketing outlets could be developed, a potentially sizable industry might emerge as a side line to oyster culture. It would be gratifying to see this valuable yet unutilized resource put to good use in the future.

As chum

Various fish assemblages gather around the oyster rafts which are thereby useful as a kind of artificial reef, enhancing to some extent local fish populations. Fish are attracted to the rafts not merely for the shelter they afford or their potential as spawning areas but, more important, for the feeding opportunities offered by the fouling community. In other words our oyster raft is, to a fish, a first-rate cafeteria; and to a fisherman it is a good place to drop a line.

The species of fish which collect around the rafts will vary according to season and stage of growth. In general, 20-30 different kinds of fish are known to live in culture areas and to depend directly or indirectly on the rafts for at least part of their sustenance. These include the following: horse mackerel (*Trachurus japonicus*), sea bass (*Lateolabrax japonicus*), greenling (*Agrammus agrammus*), parrot bass (*Oplegnathus fasciatus*), rock-trout (*Hexagrammos otakii*), black rock fish (*Sebastes inermis*), black sea bream (*Acanthopagrus schlegelii*), red sea bream (*Pagrus major*), leather fish (*Stephanolepis cirrhifer*), sea perch (*Ditrema temmincki*), filefish (*Navodan modestus*), and mojarra (*Leiognathus nuchalis*).

The feeding habits of many of these fish have been investigated. We know, therefore, which fouling organisms are being eaten by which species. For example, sea bass will feed on *Leander* (Fig. 1L), *Hemigrapsus* (Fig. 1K), and *Tridentiger bifaciatus*, among other organisms; black sea bream on *Leptoclinum mitsukurii* (ascidian), *Protella* (Fig. 1J), *Caprella* (Fig. 1M), *Hemigrapsus* and *Leander*; parrot bass and various species of leatherfish will concentrate more on *Halichondria* (Fig. 1D), and *Balanus* (Fig. 1E); and sea perch, black rock fish, greenling and rock-trout will utilize *Caprella*, *Hemigrapsus*, gammarids and other amphipods.

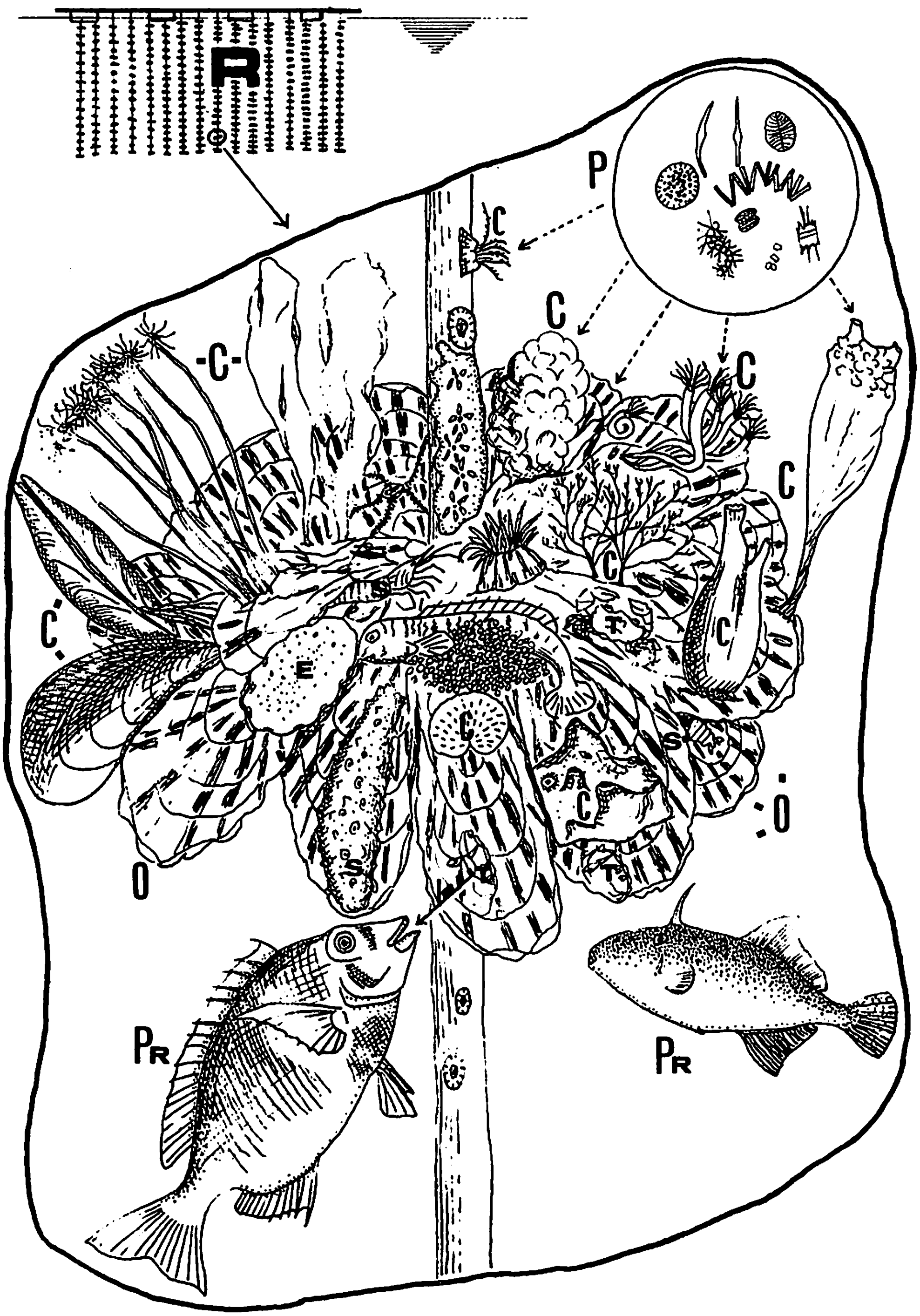


Figure 20. The living community beneath an oyster raft. R, raft; P, plankton (food for suspension-feeding animals); O, oysters; C, primary fouling organisms (oyster competitors); E, S, T, secondary fouling organisms: E, predatory flatworm (preys on oysters); S, crustacean feeding on biodeposits; T, forms feeding on the primary foulers; Pr, predators utilizing both the primary and secondary fouling organisms

As indicator species

Assaying site potential for oyster culture

Among the main factors controlling the kinds and intensity of fouling are such things as water turbidity, salinity, etc. — this was discussed in the section on distribution. The nature of the fouling present in any given area will therefore correspond to the biological and other characteristics of that area. Coastal bay areas may be usefully categorized by the degree to which they are estuarine in character, that is, by the extent they are influenced by fresh-water input. Such a scheme follows:

a. Mouth area (weak to medium-weak estuarine character) — Organisms found: *Balanus tintinnabulum rosa, B. trigonus, Lepas anatifera.*

b. Central bay area (medium estuarine character) — Organisms found: *Styela plicatus* (Fig. 1T), *Balanus reticulatus* (Fig. 1I), *Dakaria subovoidea* (Bryozoa), *Bugula neritina* (Fig. 1F), *Mytilus* cf. *edulis* (Fig. 1N), *Hydroides elegans* (Fig. 1O, O & P), *and Serpula vermicularis.*

c. Inner bay area (medium to strong estuarine character) — Organisms found: *Ciona intestinalis* (Fig. 1O), *M.* cf. *edulis, H. elegans, B. amphitrite hawaiiensis* (Fig. 1H), *Bugula californica,* and *Musculus senhausia.*

Generally there is good reason to believe that an area with many fouling organisms will also be an area suitable for raising oysters. Furthermore, growers with long experience regard some fouling by fanworms and sea squirts as a harbinger of good oyster production and are, therefore, glad to see it. This is because fouling along the margin of the shell stimulates growth which both increases yield and produces an oyster easier to shuck. This is a matter of degree, however. If the oysters are overwhelmed by a luxuriant growth of fouling, as during an outbreak, the disadvantages are many and the advantages none. One can not, therefore, regard without qualification the occurrence of fouling as a good omen.

From the research done on the distribution of fouling and its correlation with oyster growth, it is generally thought that an area of medium to medium-strong estuarine character (i.e., between b. and c. above) will be most suitable for oyster culture. It is my feeling that the most effective strategy would be to make use of various sites within the general area where the industry is located. In particular, oysters should be cultured in places with limited fouling (a. to b. above) during the season when it is most likely to occur, i.e., early summer to the beginning of fall. Then, around October when the oysters enter a period of active growth (fattening), the rafts should be transferred to more productive areas (b. to c.) so that this growth might be maximized. However, since it is sometimes easy (depending on the year) to suffer damage from flatworms (*Stylochus*) and other pests in offshore, high-salinity waters, please make transfers only after a thorough investigation and consideration of all the pros and cons.

Assaying water quality

In addition to the physical parameters which influence the occurrence of fouling organisms, there is a close link also with water quality, organic pollution in particular. We have already mentioned that fanworm outbreaks are most likely at times when high-nitrogen municipal and industrial wastes accumulate more than usual. Another example concerns barnacles: before the war, when our waters were comparatively clean, only two barnacles, *Balanus albiscostatus albiocostatus* and *B. amphitrite krügeri*, were observed in coastal areas. With the severe pollution of recent years a new assemblage has arisen – *B. reticulatus*, *B. amphitrite hawaiiensis*, *B. tintinnabulum rosa*, *B. eburneus*, and others. Barnacle distribution is now a more complex matter. Also, *Mytilus* was formerly found primarily in the eastern part of Hiroshima Bay and there limited to the upper 3 m of the water column. At present mussels are distributed throughout the Bay and can be seen at all depths. These and other pronounced changes have occurred.

Some understanding of the conditions prevailing in organically polluted waters can be gained from analyses of such parameters as dissolved oxygen, chemical oxygen demand (COD), organic nitrogen, transparency and so forth. Unfortunately, the results of such measurements will vary over a considerable range due to tidal and other currents and various transient phenomena. The members of the fouling community, however, have been subjected to conditions in the water averaged over a period of time. By conducting studies that compare the qualitative and quantitative occurrence of fouling organisms with chemical parameters of water quality we might be able to gauge more precisely the state of pollution in any given area. Fouling organisms may in this way serve as valuable "barometers" indicating the extent of eutrophication in the culture areas. For this reason please do not neglect to make such observations during spare moments while tending your oysters.

POSTSCRIPT

Oyster farming in Hiroshima, which has a history spanning nearly four centuries, may be approaching a major turning point. During the postwar transition to a period of relative calm and prosperity, there has been a tremendous increase in urban population and industrial growth. A consequence of the rapid change in modern social conditions is the despoliation of the natural environment. Around Hiroshima Bay the effects of land reclamation, pollution and other abuses are now showing up in poorer oyster growth, delays in spawning, outbreaks of harmful fouling organisms, and similar phenomena. The oyster industry is currently in the position of having to devote a great deal of its efforts to various countermeasures.

Suspending oysters from rafts as a method of cultivation was originally introduced by Prof. Hidemi Seno and Mr. Juzo Hori in 1927. The technique has been improved upon considerably since then and after the war quickly became popular throughout the Hiroshima area. At present this culture method has attained a reasonably high level of development. But because of the increasing abuse to which the culture areas are being subjected, perhaps attributable in part to the reckless promotion of the GNP standard which tends to ignore any consideration of quality, this kind of oyster farming shows signs of coming to an end. Recently culture operations have been moved to sites further offshore, outside of Hiroshima Bay, to take advantage of the cleaner waters there. This activity has gone under the heading of "offshore expansion" but might more accurately be thought of as a forced retreat.

Japanese oysters naturally occur and prosper best in estuarine situations where fresh and salt waters are well mixed and food is abundant; and it is in such areas where the highly prized "Hiroshima Oyster" acquires its distinctive flavor. Even if a retreat is possible from the estuarine areas of the inner bay to the middle and outer portions of the bay and, finally, outside the bay altogether, one must realize that the Inland Sea itself is nothing more than a small body of water bounded by land masses. Where, then, shall Hiroshima oyster culture find refuge when pollution overtakes the entire Inland Sea?

The renowned English malacologist, C.M. Yonge, touches upon these matters in a discussion on the future of oyster culture in the first chapter of his book, Oysters. A great many oyster producing grounds have been lost through the thoughtless destruction of the environment by industrial activity. We should regard the disappearance of a large number of oyster beds along North Atlantic shores in both Europe and America as a harsh warning. Given the realities of today's society we have no guarantee that our own oyster fishery will not also play out the same sad scenario.

Our ancestors have cultivated oysters in Hiroshima waters for 400 years. Let us not allow this fine tradition to end in ruin through indolence or neglect. Let us try to preserve this heritage and constantly strive to improve our methods to meet the demands of a changing age, that we, too, might pass on a rich legacy.

For this handbook I have kindly been allowed to draw upon valuable graphs and tables appearing in a number of published and unpublished sources. Because of the nature of this book, I have refrained from citing each reference, but to the authors of these materials I wish to here express my heartfelt gratitude. I further wish to acknowledge my indebtedness to my dear friends and fellow staff members at the Hiroshima Fisheries Experimental Station.

SELECTED BIBLIOGRAPHY

Adam, F., and E. Leloup. 1934. Sur la présence du gastéropod Crepidula fornicata (Linne, 1758) sur la Côte Belge. Bull. Mus. R. Hist. Nat. Belg. 10.

Allen, E.J. 1914. Polychaeta of Plymouth and South Devon coast including a list of the archiannelida. Jour. Mar. Biol. Assoc. U.K. 10: 592-646.

Arakawa, K.Y. 1971a. Notes on unusual outbreak of hydroids in oyster culture beds of Hiroshima Bay. The Collecting and Breeding 33(8): 195-196.

__________. 1971b. Notes on a serious damage to cultured oyster crops in Hiroshima caused by a unique and unprecedented outbreak of a serpulid worm, Hydroides norvegica (Gunnerus) in 1969. Venus 30(2): 75-82.

__________. 1971c. Hiroshima wan no kaki yōshoku ni ijō hassei shita kasane-kanzashi — sono higai to taisaku [Outbreak of fanworms in the oyster growing areas of Hiroshima Bay — damage and countermeasures]. Yōshoku, 1971(4): 114-119.

__________. 1973a. Biological studies on prevention and extermination of fouling organisms attached to cultured oysters. II. Early life history of Hydroides norvegica (Gunnerus) (Polychaeta: Annelida). Bull. Hiroshima Fish. Exp. Sta. 4: 19-27.

__________. 1973b. Biological studies on prevention and extermination of fouling organisms attached to cultured oysters. III. Tolerances of fresh water, saturated salt water and sun-drying by Hydroides norvegica (Gunnerus) (Polychaeta: Annelida). Bull. Hiroshima Fish. Exp. Sta. 4: 26-33.

__________. 1973c. Kaki gaiteki taisaku kenkyū [Research on countermeasures against organisms harmful to oysters]. Hiroshima Shigotohō 47: 46-47.

__________. 1973d. Aspects of eutrophication in Hiroshima Bay viewed from transition of cultured oyster production and succession of marine biotic communities. La Mer:Bull. Soc. Franco-Japon. Ocenogr. 11(2): 72-77.

__________. 1974a. Notes on damage to cultured oyster crop in the vicinity of Ondo, Hiroshima, caused by keen competition with blue mussel, Mytilus edulis galloprovincialis Lmk. Bull. Hiroshima Fish. Exp. Sta. 5: 35-37.

__________. 1974b. On damages to fishing industry sustained by competition from fouling organisms. Marine Sciences 6(4): 42-48.

__________. 1975. Kaki gaiteki taisaku kenkyū [Research on countermeasures against organisms harmful to oyster]. Hiroshima Shigotohō 48: 54-55.

__________, and M. Hotta. 1972. Kaki gaiteki taisaku kenkyū (Yōshoku higai taisaku) [Research on countermeasures against organisms harmful to oysters (countermeasures against aquaculture damage)]. Hiroshima Shigotohō 46: 4-5.

__________, and H. Kubota. 1973. Biological studies on prevention and extermination of fouling organsism attached to cultured oysters. I. Distribution and seasonal settlement of Hydroides norvegica (Gunnerus) (Polychaeta: Annelida) in Hiroshima Bay. Bull. Hiroshima Fish. Exp. Sta. 4: 13-17.

__________, A. Mizokami, M. Hotta, T. Hoshimoto, Y. Kusumoki, and T. Kimura. 1970. Kyōgō (fuchaku) seibutsu [Competitor (fouling) organisms]. Hiroshima-ken Hiroshima wan chiku gyojō kaihatsu jigyō chōsa hokokusho (Shōwa 42-44 nendo sokatsuhen): 37-45.

Auzot, M. 1665. Shining worms in oysters. Philosoph. Trans. 12: 203-206.

Bartsch, P., and H.A. Rehder. 1945. The west Atlantic boring mollusks of the genus Martesia. Smithsonian Misc. Coll. 104(11): 1-16.

Belcher, T.E. 1922. Crepidula fornicata (Linne) in Dorset. Jour. Conch. Leeds 16: 312.

Berkeley, E., and C. Berkeley. 1936. Notes on polychaeta from the coast of western Canada. I. Spionidae. Ann. Mag. Nat. Hist. Ser. 1, 18: 468-478.

Burton, E. St., Jr. 1930. The distribution of the slipper limpet in Britain. Proc. Bournemouth nat. Sci. Soc. 22.

Cameron, B. 1969. Paleozoic shell-boring annelids and their trace fossils. Amer. Zoologists 9: 689-704.

Carazzi, D. 1893. Rēvisione del genere Polydora Bosc e cénni su du specie che vivo no sulleostriche. Mitth. Zool. Sta. Neaple 2(1/2): 4-45.

Cole, H.A., and R.H. Baird. 1935. The American slipper limpet (Crepidula fornicata) in Milford Haven. Nature 172(4380): 687.

__________, and D.A. Hancock. 1955. Odostomia eulimoides (Hanley) chrysallida obtusa. Jour. Mar. Biol. Assoc. U.K. 34: 25.

Conklin, E.G. 1891. Preliminary note on the embryology of Crepidula fornicata and of Urosalpinx cinerea. Johns Hopkins Univ. Circ. 10(88): 89-90.

Fischer, P.-H. 1930. Association occasionelle du Purpura lapillus L. avec une annélide (Polydora hoplura Clapacédè). Jour. Conch. 74: 35-38.

Fujita, S., T. Fujita, and M. Itō. 1966. Iwate-ken Miyako wan ni okeru kaki yōshoku suika ren ni fuchaku shita murasaki-igai no jōkyō. II [On mussels attached to hanging oyster culture strings in Miyako Bay, Iwate Prefecture. II]. Suisan Zōshoku 14(1): 47-50.

Gould, Harley N. 1952. Studies on sex in the hermaphrodite mollusk Crepidula plana. Jour. Exp. Zool. 119: 93-164.

Haigler, S. 1969. Boring Mechanism of Polydora websteri inhabiting Crassostrea virginica. Amer. Zoologists 9: 821-828.

Hiroshima, Suisan Shikenjō. 1937. Suika-shiki ren chakusei seibutsu chōsa [Investigation of the fouling organism on hanging-culture strings]. Hirosui-shihō 16: 237.

________. 1958. Kaki — Fujitsubo no fuchaku in tsuite (Tōsha) [On the fouling of oysters by barnacles (Mimeograph)]. Suishi Dayori 63: 3-4.

________. 1959a. Murasaki-igai ni tsuite (1) (Tōsha) [On mussels (1) (Mimeograph)]. Suishi Dayori 69: 2.

________. 1959b. Murasaki-igai ni tsuite (2) (Tōsha) [On mussels (2) (Mimeograph)]. Suishi Dayori 74: 1.

________. 1961. Murasaki-igai no fuchaku seiki ni tsuite (Tōsha) [On the time of heavy mussel settlement (Mimeograph)]. Suishi Dayori 94: 4.

________. 1962. Fujitsubo no fuchaku ni tsuite (Tōsha) [On the settlement of barnacles (Mimeograph)]. Suishi Dayori 102: 1-2.

________. 1963. Murasaki-igai ni tsuite — Ninensei kaki ishoku jiki to no kankei (Tōsha) [On mussels — relation to the time of transfer of second-year oysters (Mimeograph)]. Suishi Dayori 115: 3-4.

________. 1964a. Kaki no heishi to higai seibutsu no fuchaku jōkyō ni tsuite (Showa 38 nendō) (Tōsha) [On the settlement of organisms causing damage and mortality to oysters (1963) (Mimeograph)]. Suishi Dayori 125: 3-4.

________. 1964b. Kaki no higai ni tsuite [On damage to oysters]. Showa 39 nendō kaki taisaku shiryō (Hiroshima-ken — kaki ren) bessatsu: 9-13.

________. 1964c. Kinnen no murasaki-igai fuchaku jōkyō [On the settlement of mussels in recent years]. Suishi Dayori 128: 3-4.

________. 1965. Hoya ni tsuite [On sea squirts]. Suishi Dayori 138: 3-4.

________. 1970. Kasanekanzashi ni tsuite [On fanworms]. Showa 45 nendō kaki shukka taisaku shiryō: 17-18.

Hopkins, S.H. 1958. The planktonic larvae of Polydora websteri Hartman (Annelida, Polychaete) and their settling on oysters. Bull. Mar. Sci. Gulf Caribb. 8: 268-277.

Imai, T., S. Itō, C. Nakamura, and H. Onodera. 1957. Kessenuma wan kaki yōshokujō no seitaigakuteki kenkyū [Ecological research on the oyster culture grounds in Kessenuma Bay]. Kessennuma wan kaihatsu kenkyūkai: 1-39.

J., C.W. 1921. Crepidula fornicata in the British Isles. Nautilus 35: 62-64.

Kavanaugh, L.D. 1940. Mud blisters in Japanese oysters imported to Louisiana. La Conserv. 1940: 31-34.

Kikuchi, S., and S. Tanita. 1961. Tanegaki saibyōhin no fuchaku seibutsu ni yoru osen to kaki chigai no fuchaku-ritsu [Fouling of oyster seed collectors caused by attached organisms and the rate of oyster settlement]. Tōhoku Suikenpō, 19: 149-153.

Knight, E.W. 1948. Elminius modestus, another imported pest of east coast oyster beds. Nature 161: 201-202.

Koganezawa, A. 1972. Higai seibutsu no seitai to sono bōjo. III. Murasaki-igai [Ecology and prevention of fouling organsism. III. Mussels]. Yōshoku, 1972(5): 72-74.

Korringa, P. 1949. Nieuwe aanwijzingen voor de bestrijding van slipper en schelpziekte. Visserij-Nieuws, Nr. 8.

__________. 1951a. Crepidula fornicata as an oyster-pest. Rapports et proces-verbaux des reunions, conseil permanent international pour l'exploration de la mer. Vol. 128. Contributions to special scientific meetings 1949. Part II. Shellfish Investigations: 55-59.

__________. 1951b. The shell of Ostrea edulis as a habitat: observations on the epifauna of oysters living in the Oosterschelde, Holland, with some notes on polychaete worms occurring there in other habits. Archives néerlandaise de Zoologie, 10(1): 32-135.

Kusunoki, Y. 1960. Murasaki-igai no fuchaku jōkyō ni tsuite [On settlement in mussels]. Hirosuishihō, 21(2): 9-15.

__________. 1963. Murasaki-igai no fuchaku yohō ni kansuru kenkyū [Research concerning prediction of settlement in mussels]. Hirosuishihō, 23(2): 1-7.

__________. 1964. Nōyaku ni yoru fujitsubo no fuchaku bōjo ni tsuite. I. [On the prevention of settlement in barnacles by agricultural chemicals. I.]. Hirosuishihō, 24(2): 47-56.

__________. 1967. Satchūzai toku ni DDT ni yoru fujitsubo no fuchaku bōjo shiken [Experiments on the prevention of settlement in barnacles by insecticides, especially DDT]. Suisan Zōshoku, 15(3): 63-72.

Loosanoff, V.L., and J.B. Engle. 1943. Polydora in oysters suspended in the water. Biol. Bull. 85: 69-78.

Lunz, G.R., Jr. 1941. Polydora, a pest in South Carolina oysters. J. Elisha Mitchell Scient. So3, 57: 273-283.

Mackensie, T., and L.W. Shearer. 1961. Chemical Control of Polydora websteri and other annelids inhabiting oyster shells. Proc. natn. Shellfish. Ass. 50: 105-111.

Mackin, J.G., and F.F. Cauthron. 1952. Effect of heavy infestations of Polydora websteri Hartman on Crassostrea virginica (Gmelin) in Louisiana. Conv. Addr. Nat. Shellf. Assoc. 1952: 14-24.

Marteil, L. 1960. Elminius modestus Darwin, nouveau compétiteur des huîtres et moules du Morbihan (France). I.C.E.S. Meeting, 1960.

Matsui, Y., K. Uchihashi, and M. Yamaguchi. 1944. Murasaki-igai Mytilus edulis no fuchaku bōjo ni kansuru kenkyū (Dai-ippō) [Research concerning the prevention of settlement in mussels, Mytilus edulis (First report)]. Bull. Fish. Exp. Sta. Hyogo-ken 5: 15-20.

Medcof, J.G. 1946. The mud-blister worm Polydora in Canadian oysters. J. Fish Res. Bd Can. 6: 498-505.

Miyagi Fisheries Experimental Station. 1959. Jūyō seibutsu seitai chōsa (Kaki to igai seitai kankei) [Investigations on the ecology of important species (Ecological relations between oysters and mussels)]. Iwate Gyogyō Shūyaku Keiei Chōsa Hōkokusho (Dai-ni Nendo): 357-368.

Miyazaki, I. 1934. Kanezawa jisshūjō ni okeru suika kaki chakuseibutsu ni tsuite. I. [On organisms attaching to suspended oysters at the Kanezawa Training Center. I.]. Yōshoku Kaishi 4(11/12): 207-214.

__________. 1938. On fouling organisms in the oyster farm. Bull. Jap. Soc. Sci. Fish. 6(5): 223-232.

Murie, J. 1911. "Slipper limpet" or "boat shell" (Crepidula fornicata): its introduction and influence on Kent and Essex oyster beds. The Zoologist 15(4): 401-415.

Orton, J.H. 1909. On the occurrence of protandric hermaphroditism in the mollusc Crepidula fornicata. Proc. Roy. Soc. London 81B: 488-494.

__________. 1912a. The mode of feeding of Crepidula, etc. Jour. Mar. Biol. Assoc. U.K. 9: 444-478.

__________. 1912b. An account of the natural history of the slipper-limpet (Crepidula fornicata) with some remarks on its occurrence on the oyster grounds of the Essex coast. Jour. Mar. Biol. Assoc. U.K. 9(3): 437-443.

__________. 1915. On the extension of the distribution of the American slipper-limpet (Crepidula fornicata) in the English coastal waters. Proc. malac. Soc. Lond. 11: 190-191.

_________. 1926. Is the American slipper-limpet (Crepidula fornicata) an oyster pest? Nature 117: 324.

_________. 1945. Utilization of the slipper-limpet (Crepidula fornicata) as food as an aid to the recovery of oyster culture in the Thames estuary. Nature 156: 665.

Robson, G.C. 1915. On the extension of the range of the American slipper-limpet on the east coast of England. Ann. Mag. Nat. Hist. London, Ser. 8, 16: 496-499.

_________. 1929. On the dispersal of the American slipper limpet in English waters 1915-29. Proc. malac. Soc. Lond. 18.

Sato, S., and T. Takeda. 1952. Suika yōshoku kaki no fuchakubutsu ni kansuru kenkyū 1, murasaki-igai no kujo ni tsuite [Research concerning fouling organisms on oysters in suspension culture. 1. On the extermination of mussels]. Tōhokusuikenpo 1: 56-66.

Sparck, R. 1935. On the occurrence of Crepidula fornicata (L.) in the Limfjord. Rept. Dan. Biol. Sta. 40(4): 43-44.

Spicer, J.L. 1923. The slipper-limpet, an enemy of the oyster. J. Dep. Agrig. tech. Instruct. Ire. 23: 35-37.

Tanita, S. 1958. Sponges collected from oyster-rafts in Matsushima Bay and its adjacent waters. Bull. Tohoku Fish. Res. Lab. 11: 127-143.

_________, and S. Kikuchi. 1961a. Suika yōshoku kaki no fuchakubutsu ni kansuru kenkyū Dai-nippō Kisetsu henka [Research concerning fouling organisms on oysters in suspension culture. Second report: Seasonal changes]. Tōhokusuikenpō 2: 56-66.

_________, and _________. 1961b. Suika yōshoku kaki no fuchakubutsu ni kansuru kenkyū Dai-sanpō Kaki no seichō, mi-iri ni oyobosu eikyō [Research concerning fouling organisms on oysters in suspension culture. Third report: Influence exerted on oyster growth and meat content]. Tōhokusuikenpō 2: 142-148.

Werner, B. 1948a. Über den Laichvorgang der Amerikanischen Pantoufleschnecke, Crepidula fornicata L. Verh. dt. Zool. Ges. 1948: 262-270.

_________. 1948b. Die Amerikanische Pantoufleschnecke Crepidula fornicata L. im nordfriesischen Wattenmeer. Zool. Jb., Abt. 1, 77: 449-488.

_________. 1951. Über die Bedeutung der Wasserstromerzeugung und Wasserstromfiltration für die Nahrungsaufnahme der ortsgebundenen Meeresschnecke Crepidula fornicata L. (Gastropoda, Prosobranchia). Zool. Anz. 146: 97-113.

Whitelege, T. 1890. Report on the worm disease affecting the oysters on the coast of New South Wales. Rec. Aust. Mus. 1: 41-54.

Yamada, M. 1951. Kaki ni fuchaku no muhi hidoromushi ni tsuite [On athecate hydroids attaching to oysters]. Dōzō 60(1/2): 32.

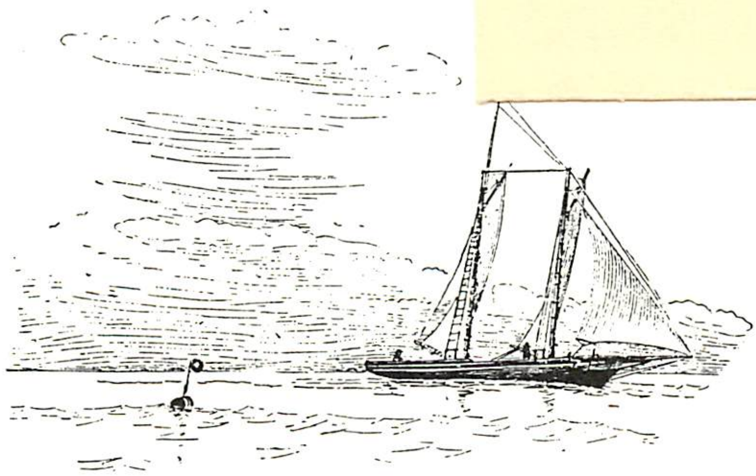
Yokota, T. 1936. Suika yōshoku kaki no chakusei seibutsu kujo ni tsuite [On the extermination of organisms fouling suspension-cultured oysters]. Yōshoku Kaishi 6(1): 19-22.

Yonge, C.M. 1966. Oysters. (2nd ed.). Collins, London, 209 pp.

Young, L.Y., and R. Mitchell. 1973. The role of microorganisms in marine fouling. Intern. Biodetn. Bull. 9(4): 105-109.

Zottoli, R.A., and M.R. Carriker. 1974a. External release of protease by stationary burrow-dwelling polychaetes. Jour. Mar. Res. 32(3): 331-342.

________, and ________. 1974b. Burrow morphology, tube formation and microarchitecture of shell dissolution by the spinoid polychaete *Polydora websteri*. Marine Biology 27: 307-316.



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