Marine Biofouling and Fisheries

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Abstract

Marine biofouling occurs on the bottom of boats, fishing gear, nets and the surface of underwater construction materials, as well as on the surface of living and nonliving marine organisms. It causes great damage to marine and fisheries industries. This paper discusses some of the biology of marine biofouling organisms and the relationship between marine biofouling and fisheries. Special attention is given to the damage caused by marine biofouling to the fin–fish cage culture industries of Hong Kong.

At present, approximately 5,000 species of marine biofouling organisms occur in the world, of which 2,000 species are recorded. In the coastal water of China, there are about 700 recorded species. About 250 biofouling organisms are found in Hong Kong. The dominant species are barnacles, bryozoans, polychaetes, sea squirts (ascidians) and bivalves. The main biofouling of fish cages in Hong Kong is caused by the polychaete *Hydroides elegans,* sea squirts *Styela plicata* and *S. canopus,* oyster *Ostrea glomerata,* barnacles *Balanus reticulatus* and *B. trigonus.*

Depending on habitat and sea water temperatures, marine biofouling has obvious seasonal fluctuations in growth and occurrence. Marine fouling organisms occur on the fish cages in Hong Kong all the year round, but April to June is the predominant season of the occurrence of *Hydroides elegans*. During this period, small mesh nets will become completely obstructed by this animal. Oyster *Ostrea* spp., barnacles *Balanus reticulatus* and *B. trigonus* and the sea squirts *Styela plicata* and *S. canopus* occur in the months of June to November. From November to March the main fouling species is the bryozoan *Bugula neritina.*

In Hong Kong because of marine fouling, fish cage nets need to be changed about every 1 – 3 months. The biofouling organisms (such as *H. elegans*) which attack nets, can be sprayed with sea water which will clean the net. But those with calcareous substances such as *Ostrea* and *Balanus* must be cleaned by sunlight and manpower. At present, antifouling paints are being tested on fish cage nets in China, Japan and Hong

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Kong. However, toxic substances such as TBTO and TBTF from these paints may accumulate in the fish with direct or indirect effects on human beings. So their use requires further investigation.

Introduction

Marine fouling organisms include animals, plants and microorganisms which live on ship's bottoms, nets, buoys, tube tunnels or any other man–made materials in the sea.

Marine biofouling organisms always inhibit the normal operation of man–made materials, therefore they constitute a disadvantageous biological environmental factor. Marine fouling organisms can be divided into microfouling organisms and macrofouling organisms. Microfouling organisms such as bacteria, diatoms and protozoa can only be identified under the microscope. Macrofouling organisms include algae and many phyla of marine animals.

Mussels and oysters which are important and valuable cultivated organisms, and barnacles can commonly be seen on rocks along the seashore. These organisms can only be considered as fouling organisms when they are attached to man–made materials or vessels. Some other troublesome organisms such mollusks as *Tereidae* and *Pholadidae* as well as crustacea amphipoda e.g., *Limnoria, Sphaeroma* will not be discussed in this paper.

In the human exploitation of the sea, the two main problems are biofouling, a biological phenomenon, and marine corrosion. These two challenging problems have hindered the exploitation of the seas. Fouling organisms can increase the resistance and lower the speed of a ship, block the tubing of a seawater cooling system, interfere with mariculture, reduce the efficiency of underwater instruments, interfere with the buoys of an underwater mine, or decrease the floating ability of a pier, stimulate the corrosion of metals, etc. (KOOPS, 1971; MILNE, 1975 a, b, 1976; MILNE and POWELL, 1969; LOVEGROVE, 1979; MORING and MORING, 1975; GEFFEN, 1979) The life histories of fouling organisms are complicated and there are many gaps in our knowledge of them.

Biofouling organisms have been studied since 1930 (MAK, 1982). World War I and World War II further stimulated the investigation of fouling problems. Nowadays, all coastal countries are investigating this problem. The first USA investigation report was completed at Woods Hole Oceanographic Institute in 1952. In Japan, scientists have studied the relationship between fouling organisms (ARAKAWA, 1974; UTINOMI, 1966) and bivalve culture (INOUE, 1972) as well as with cage culture (KAZIHARA, 1961;) HISAOKA, etc. 1966; SUGIMOTO, etc. 1966). Marine fouling organisms have also been studied in Malaysia (BERRY, 1966; CHEAH and SHUA, 1979). The marine science laboratories and Far East Science Center of Russia have investigated and surveyed the distribution of fouling organisms in their area (HUANG and GAI, 1983).

China has been investigating fouling problems since 1930 (HUANG and GAI, 1983).

Chinese scientists have concentrated their research on ecology and antifouling methods (HUANG and GAI, 1961). HUANG and GAI have completed an ecological survey of fouling organisms in 40 coastal bays of China, and published a book "Marine Biofouling and its Prevention Vol. 1". Many scientists have studied the effect of marine fouling on cage culture (TSENG and YUEN, 1978; MAK, 1982) and biofouling in Hong Kong (HON, 1978; HUANG, 1980; HUANG and MAK, 1980; HUANG et al, 1983; Huang and Morton, 1983). With the support of COIPM, an International Congress on marine corrosion and fouling has been held every four years. The 6 th meeting will be held in Athens in September 1984. The proceedings of these meetings will be of assistance to those who wish to be familar with the developments in fouling studies. In the southern hemisphere, the main fouling research is being carried out in Australia (BLICK and WISELY, 1964; STRAUGHAN, 1972; WISELY, 1959), New Zealand (FOSTER and WILLIAN, 1979; SKERMAN, 1958; SKERMAN, 1959), Argentina (BASTIDA, 1972; BASTIDA et al, 1980) and Chile (DISALOV, 1980). This report will discuss the fouling organisms of coastal regions of Hong Kong.

Methods and materials

The study was made in the period from June 1978 to August 1983 along the coasts of China (Fig. 1), and from April 1980 to August 1983 in the waters of Hong Kong (Fig. 1).

All the samples and photos were taken and identified, counted and recorded *in situ*. Small amounts of specimens were brought back to the laboratory for further analysis.

A series of 20 × 20 cm PVC plates were hung in water depths of 5 cm, 1 m and 5 m in the studying areas for testing of material preference and attachment sequence, as well as seasonal fluctuations of marine fouling organisms.

Results and discussion

I. Species of Fouling Organisms

In 1947, there were 2,000 species of fouling organisms on the world record (Woods Hole Oceanographic Institute 1952), but now, they have increased to about 5,000 species. There are 700 species in Chinese coastal regions (Huang and Gai, 1983), and 250 species are recorded from Hong Kong (HON, 1978; TSENG and YUEN, 1978; HUANG and MAK, 1980; MAK, 1982). About 150 species which are listed in Table 1 are the dominant species. The boundary line between nothern and southern marine creatures is located at approximately 30° N, roughly in line with the mouth of the Yangtse River. North of this boundary is a cooler region where temperate species are dominant, e. g. *Mytilus edulis*

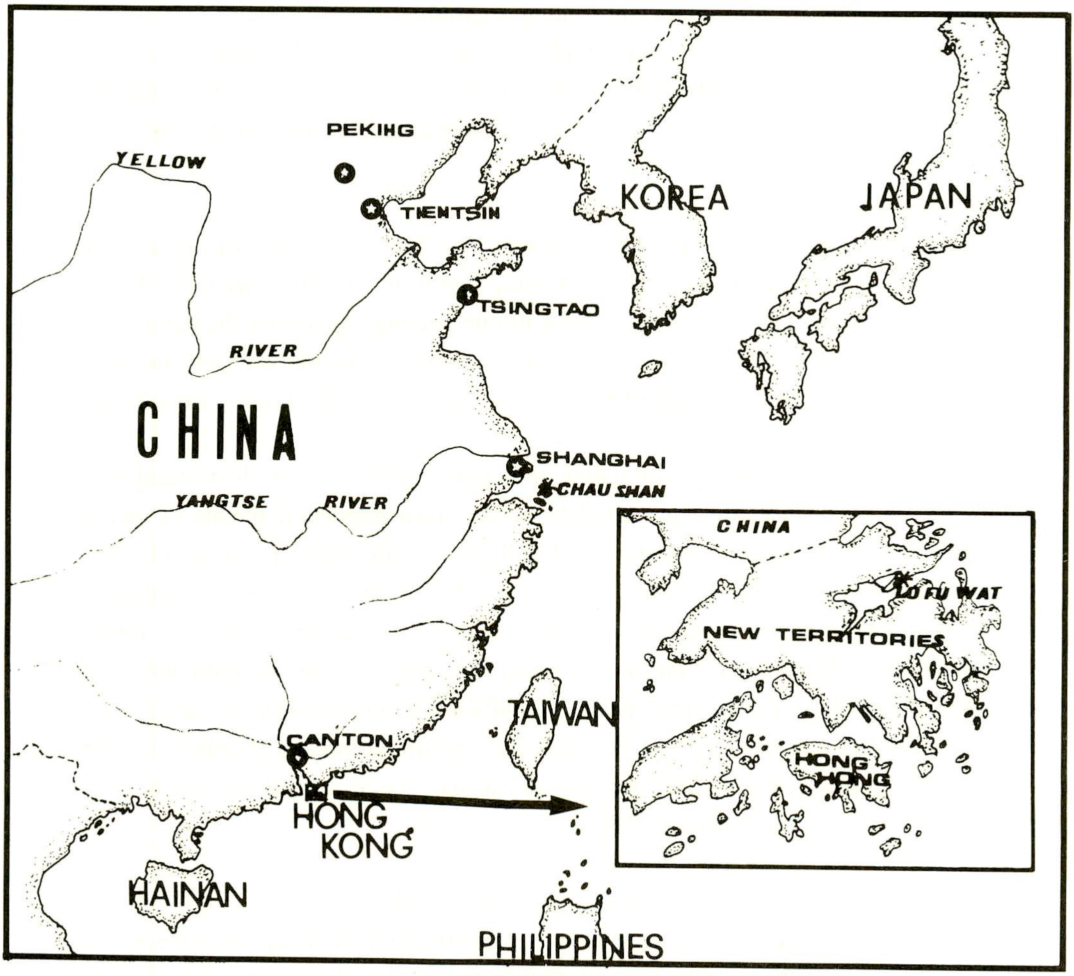

Fig. 1. Maps of China and Hong Kong

and *Styela clava,* which are not be found in the southern region. South of the Yangtse River along the China coast is a sub–tropical region. This southern region includes Taiwan and Hai Nan Islands. Most of the sub–tropical species can not be found north of the Yangtse River, e. g. the 150 species in Table 1. The southern part has 137 species, the northern part 68 species.

Fouling organisms can be divided into 3 categories, depending on their various living style.

1. Solitary life styles

   Solitary living creatures which are non–motile throughout life form the majority of fouling organisms, e. g. *Hydra,* sponges, bryozoans, barnacles as well as the sea squirts.

2. Attached life styles

   Creatures which have byssal threads or basal organs and attach themselves to man-made materials are also important fouling organisms.

Usually, these creatures are non–motile but can move short distances or along with the current, e. g. the Mytiladae which attach themselves to bivalves with byssal threads and sea anemones which attach themselves to man–made materials by means of a pedal disc.

3. Motile life styles

Many motile species live in fouling communities. They may occur on the surfaces of the man–made materials or on other fouling organisms or they may move freely between these two. The number of these motile fouling organisms fluctuates greatly. Thus many carnivorous species of gastropoda, isopoda, amphipoda and decapodean custacea, carnivorous echinoderms as well as fishes form the fouling organisms with this life style.

Most fouling organisms are euryhaline and eurythermal, and are distributed in many regions of the sea. Ships are considered to be the most important means of increasing the distribution of fouling organisms, which adhere to ships hulls. For example the Australian barnacle (*Eliminius modestus*) was carried to Europe by means of warships during the World War Ⅱ and it became a dominant species in Europe (UTINONI, 1966). Oil platforms built in Japan have transplanted many barnacles to New Zealand (FOSTER and WILLUM, 1979). Two gastropoda species *Repidulaonyx* and *Mytilopsis sallei,* orginally lived in California and Central America, but are now found in large numbers in Victoria Harbour, Hong Kong, where they are believed to have been carried by vessels (HUANG et al, 1983; HUANG and MORTON, 1983).

Ⅱ. The period of attachment of fouling organisms (Fig. 2)

The benthic stage of fouling organisms is dependent on their reproductive activities, and this is important information for anti–fouling measures. The benthic stage can be divided into 3 different types depending on how often it occurs.

1. Annual settlement: This is the most usual pattern; the organism settles on man-made materials during the period with the highest water temperatures. This pattern is distributed worldwide in both temperate and sub–tropical regions (barnacles, oysters).
2. Biannual settlement: When organisms have two different settlement seasons during the year, it is known as biannual settlement. These species settle during the periods of mid–range temperatures, spring and autumn, i. e. they will not settle when the water temperatures are high or low *(Tubularia mesembryanthemum, Mytilus edulis, Perna viridis).*
3. Year round settlement: Some organisms can settle anytime throughout the year, but settlement shows conspicuous seasonal fluctuation. These species are mainly found in tropical and sub–tropical regions. *Bugula neritina* and *Hydroides elegans* of Hong Kong can attach to man–made surfaces throughout the year but the peak is

Table 1. The main fouling organisms recorded from the coast of China including Hong Kong

Species	* North	* South	Species	* North	* South
BACILLARIOPHYTA (DIATOMS)			COELENTERATA		
Achnanthes brevipes	++	++	*Eudendeium capillare*	+	+
Cocconeis scutellum	+	+	*Halocordyle disticha*		++
Grammatophora marina	+	+	*Tubularia mesembryanthemum*	+	++
Melosira juergensi		++	*Campanularia denticulata*		+
Nevicula granulata	+	+	*Clytia cylindrca*		++
Nitzschia closterium	+		*C. edwirdsi*	++	+
Staurouеis constricta		++	*Obelia geniculata*	+	++
CHLOROPHYTA			*O. gracilis*	++	++
Cladophora glomerata		+	*Plumlaria seraceoides*		+
Enteromorpha compressa	+	+	*Hydnophora microconos*		+
E. intestinalis	++	+	*Anthopleura pacifica*		++
E. prolifera	+	++	*Haliplanella luciae*		+
E. tubulosa	+	++	ECTOPROCTA		
Ulva lactuca	++	+	*Acanthodesia grandicella*	+	++
U. linza	+	+	*A. lamellosa*	+	+
PHAEOPHYTA			*Bowerbankia imbricata*	+	++
Ectocarpus confervoides		+	*Bugula neritina*	+	++
Endrachne binghamiae		+	*B. californica*	+	+
RHODOPHYTA			*Celleporina costazii*	+	++
Gelidium divaricatum		++	*Conopeum reticulum*	+	+
Polysiphonia urceolata		+	*Cryptosula pallasiana*	++	+
CYANOPHYTA			*Dakaria subovoidae*	+	++
Oscillatoria lutea		++	*Electra anomla*	+	+
Lyngbya confervoides		+	*E. devinensis*	+	+
PROTOZOA			*Lichenopora imperialis*		+
Ephelota gemmipara		+	*Membranipora amoyensis*		++
Vorticella sp.		+	*M. savartii*	+	++
PORIFERA			*Petraliella philippineusis*		++
Cellius toxis		+	*Schizoporella unicornis*	+	++
Halichondria oculum	+		*Scrupocellaria scruspea*	+	
Mycale adhaerens		+	*S. unicornis*		+
Pachychalina variabilis		+	*Tricellaria occidentalis*	+	+
Riniera tubulosa		+	*Steginoporella magnilabris*	+	+
Tethya aurantium		++	*Phylactella collares*		+
			PLATYHELMINTHES		
			Pseudoceros exoptatus	+	+

Species	North	South	Species	North	South
NEMERTUNEA			*Isognomon ephippium*		++
Nemertopsis gracile	+	+	*Pinctada martensii*		+
ANNELIDA (POLYCHAETA)			*P. penguin*		+
Eunice australis		+	*Amonia chinensis*	+	+
Halosydha brevisetosa	+	++	*Chama dunkeri*		+
Harmonthoe imbricata	++		*Ostrea crenulifera*		++
Marphysa sanguinea		+	*O. glomerata*		++
Nereis oyxpoda	++	+	*O. plicata*	++	++
Papilliodorvillea australiensis		+	*O. echinata*	+	++
Syllis gracilis		+	*Trapezium sublaevigatum*	+	+
Hydroides elegans	++	++	ARTHROPODA (CIRRIPEDIA)		
H. ezoensis	++		*Lepas anatifera*		+
H. dirampha		+	*L. anserifera*		+
H. longispinosa		++	*Alepas pacifica*		+
H. lunulifera		+	*Conchoderma virgatum*		+
H. uncinata	+	+	*Euraphia withersi*		++
H. helmatus		+	*Balanus improvisus*	++	
H. inornata		+	*B. amphitrite amphitrite*	++	++
Serpula vermicularis	+	+	*B. reticulatus*		++
Spirobranchus tricornigerus		+	*B. albicostatus*	+	++
Spirorbis foraminosus	++	++	*B. cirratus*	+	+
Pomatoceros triqueter		+	*B. uliginosus*	++	++
P. kraussii		++	*B. trigonus*		++
ANNELIDA (SIPUNCULIDA)			*Megabalanus rosa*		++
Phascolosoma scolops		+	*M. t. tintinnabulum*		++
MOLLUSCA			*M. zebra*		+
Mopalia retifera		+	*Chiroma amaryllis*	+	+
Cellana toreuma		+	*C. tenuis*		+
Crepidula onyx		+	*Tetraclita squamosa squamosa*		++
Thais clavigera		++	ARTHROPODA (ISOPODA)		
Rapana thomasiana	+	+	*Sphaeroma walkerei*		++
Barbatia virescens	++	++	*Paranthura japonica*		+
Mytilopsis sallei		+	*Dynoides dentisinus*		+
Mytilus edulis	++		ARTHROPODA (AMPHIPODA)		
Perna viridis		++	*Caprella equilibra*	++	++
Septifer bilocularis		+	*Coprophium acherusicum*	+	+
Musculus senhousei	+	++	*Ericthonius pugnax*		++
Modiolus barbatus		+			

Species	North	South	Species	North	South
ARTHROPODA (DECAPODA)			*Styela calva*	++	
Alphaeus japonicus	+	+	*S. Plicata*		++
Pisidia serratifrons	+	+	*S. canopus*	+	++
Sphaerozius nitidus		+	*Molgula manhattensis*	++	
Nanosearma minutun		++	*Microcosmus australis*		+
ARTHROPODA (PYCHOGONIDA)			*Ascidia sydneiensis*		+
Lecythorhynchus hilengdorfi			*Botryllus schlosseri*	+	+
ECEINODERMATA			*Botryllides violaceus*	+	
Comanthus parvicirra		+	PISCES		
Asterias versicolor	+		*Dasson japonicus*		++
PROCHORDATA (TUNICATA)			*Petroscirtes kallosoma*		+
Ciona intestinalis	++	+	*Tridentiger obscurus*	+	+
			Total Species	68	137

* North and South represent the northern and southern coasts of China (North and South of Yangtse River).

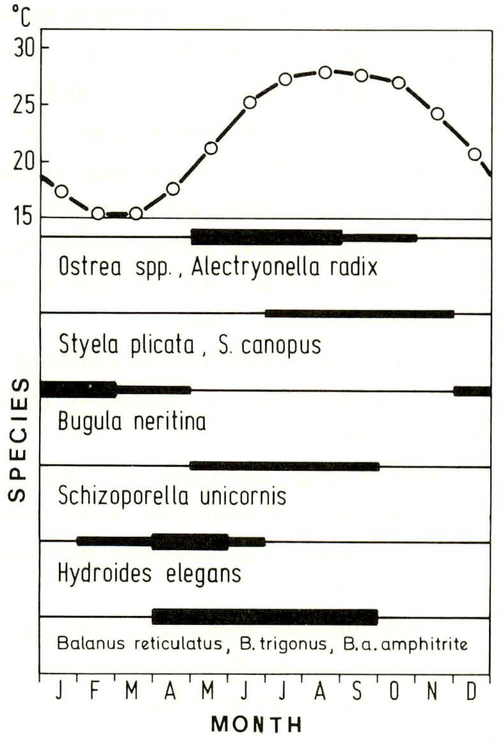

Fig. 2. The period of attachment of main fouling organisms in Hong Kong waters

December – January and April – May respectively.

The internal factor which influences an organism to settle is its reproductive habits, while the external factor is the fluctuation of water temperatures. In Hong Kong, competition between fouling organisms can inhibit the attachment of other fouling organisms. In the peak season, the presence of *Hydroides elegans* and *Bugula neritina* will greatly inhibit other fouling organisms.

According to this study, fouling can occur throughout the year in Hong Kong, but various fouling species have peak settling periods. In spring and winter, *Bugula neritina, Hydroides elegans* are dominant; in summer, *Ostrea* spp, *Balanus* spp and *Styela* spp are dominant.

Ⅲ. The effects of fouling organisms on mariculture especially on cage culture in Hong Kong.

The effects of marine fouling organisms on mariculture are:

1. Competition occurs for the same substrate with cultivated bivalves. The spat of *Ostrea plicata* in China are hindered by the competition for substrate by *Balanus amphitrite*. The same competition also occurs in Porphora cultivation.
2. Fouling organisms can settle on the shell of cultivated bivalves, and compete for food with the host and even smother the host so that the host will die of oxygen deprivation. The annual production of oysters in Hiroshima mainly depends on the extent of the invasion by the barnacles *Hydroides elegans* (ARAKAWA, 1974). An experiment in Lo Fu Wat (H. K.) on hanging oyster culture failed because of excessive amounts of the fouling organism, *Hydroides elegans* (HUANG and MAK, 1980).
3. The fouling of nylon cages directly hinders the exchange of fresh sea water, and decreases the life span of nylon nets. In Hong Kong, nylon nets should be replaced at 0.5 – 1 monthly intervals during the peak fouling season. Normally the net should be replaced every 2 – 3 months. The net cages of scallop culture in Chile are also affected by barnacle invasions (DISALOV, 1980).
4. Beach seine nets and trawling nets of fish ponds are effected by fouling organisms. The beach seine net of Chau Shan, China is blocked by *Tubularia mesembryanthemum* and *Plumularia seraceoides*.

In Hong Kong, with 25,000 fish cages of various sizes, the problem of marine fouling is complex, since the settling times of fouling organisms and the net replacement period vary considerably. Net–cage fouling can be divided into various types:

A. *Hydroides elegans* type (Fig. 3–A)

Hydroides elegans is a white tube–like polychaete, which mass reproduce in April and May. Therefore, it is very commonly seen when replacing nets from May to July. This fouling can be cleared easily by a high–pressure water jet or by being beaten with a wooden rod.

B. *Bugula neritina* type (Fig. 3–B, G)

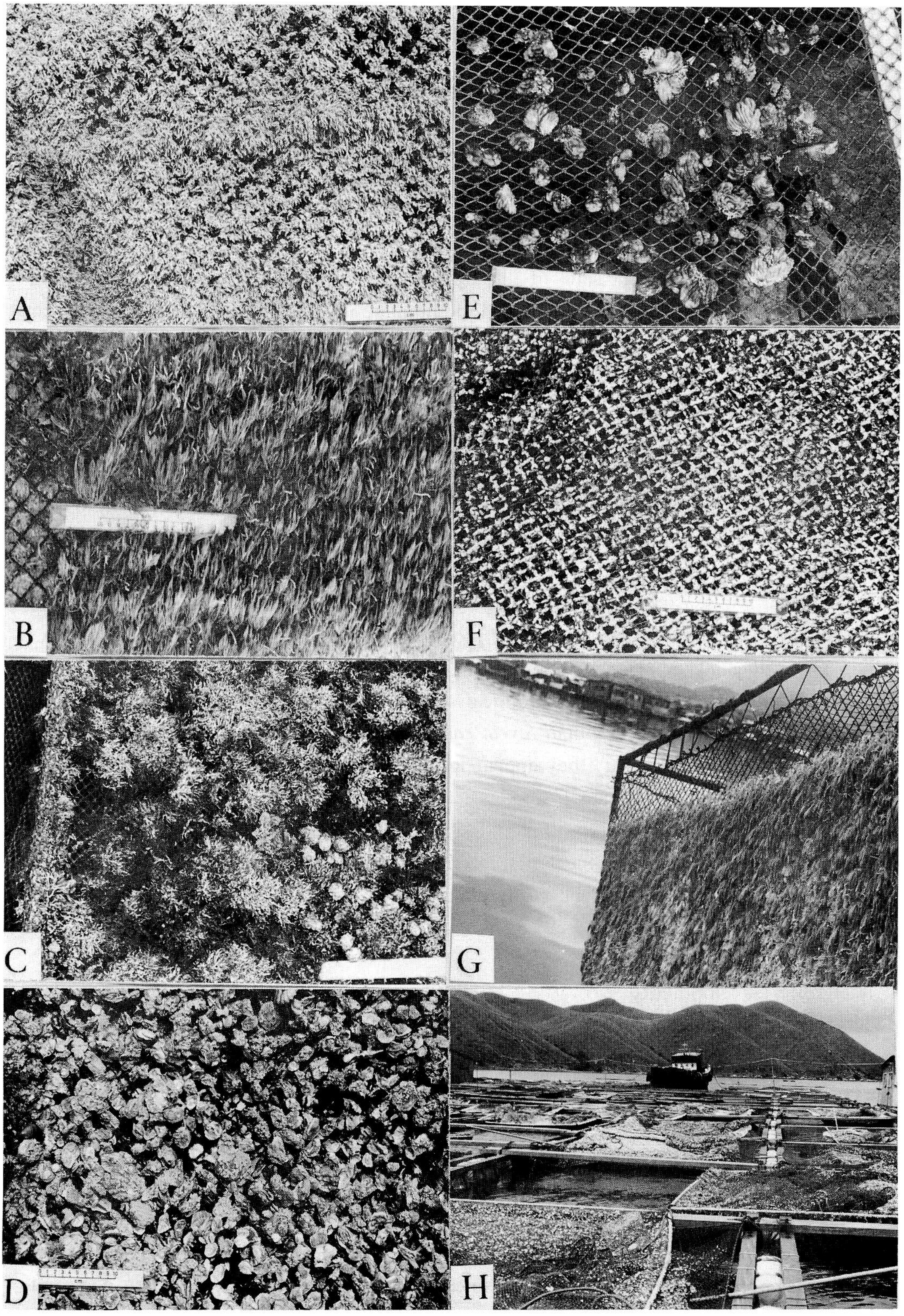

Fig. 3. Some forms of biofoulings on mariculture nets in Hong Kong

Bugula neritina is an erect, brownish coloured ciliated Bryozoan which can mass produce from December to March. This fouling organism can easily be cleared by hand since it attaches to the entire surface of the net just like a carpet.

C. *Hydroides elegans* and *Bugula neritina* mixed type (Fig. 3–C)

Since the growth curve of these two species seems to be in phase, they can be usually found attached on a net together; sometimes the amphipod *Corophium* is attached too.

D. *Alectryonella radix* type (Fig. 3–D, H)

The calcarous external shell of this oyster (left shell) binds to the net tightly and grows around it. Therefore it is hard to eliminate it with high–pressure water jets or by hand. Even after the net is dried in the sun for one to two months, the left shell is still stuck to the net tightly and only the right shell can be cleared. If the shell is beated with a wooden rod or iron bar, the net will tear. This is the most troublesome species of all the fouling organisms. Usually, the oyster settling season is from June to October, the high water temperature season. The life span of this oyster is longer than that of other species, but its growth is quite slow. Therefore, the oyster is attached to the net while the cage is immersed for a long period during high temperature season.

The settling season and characteristics of *B. trigonus* and *B. reticulatus* are similar to those of *A. radix*. However, fouling problems caused by the former are less serious.

E. *Styela plicata* type (Fig. 3–F)

Styela plicata is a white and elliptical ascidian which always appears on cage nets with a small purplish ascidian *Styela canopus*. Although these species attach to the net throughout the year, they appear in only in large quantities if the net has been immersed for a long time.

F. *Schizoporella unicornis* type (Fig. 3–F)

Schizoporella unicornis is a flat Bryozoan which attaches to cage nets. Its weak calcarous external shell can be easily eliminated by beating the net after it has been sun–dried.

Ⅳ. Future Developments

Biofouling is generally a form of natural disaster and a disadvantageous environmental factor in shipping and mariculture. During past centuries, humanity has tried its best to fight against this disaster. Research on biofouling has had considerable success in countries of the northern hemisphere, i. e., Europe, U. S., Russia, Japan and China, and in some countries of the southern hemisphere, Chile (DISALOV, 1980), Argentina (BASTIDA, 1972, 1978), New Zealand (SKERMAN, 1955, 1958; FOSTER et al, 1978), Australia (BLICK et al, 1964; WISELY, 1958). But overall, the southern hemisphere has a long way to go in order to catch up with the northern hemisphere in biofouling research, since many regions have not yet been explored by southern scientists.

The extensive developments in shipping and coastal electricity generating stations have stimulated both biofouling research, and ship and sea water cooling tube systems research. Biofouling on cage culture has been under investigation since the early 1960 s, e. g. in Japan (ARAKAWA, 1974, Hisaoka el al, 1966; INOUE, 1972; SUGIMOTO et al, 1966), in Hong Kong (TSENG, 1978; MAK, 1982), and in East Asia (BERRY, 1966; CHEAH et al, 1979). Although biofouling research is continuing it seems that interest is less when compared with research on shipping and cooling tubes. However as development of mariculture is worldwide the research on biofouling must be increased.

Antifouling paint composed of Cu_2O has been used on ships for hundreds of years. Electrolysis of sea water to produce chlorine and perchloric acid is thought to be capable of preventing fouling in cooling tubes. The use of antifouling paint on cage culture nets is still under investigation. The ideal antifouling paint should possess the following characteristics:

A. High efficiency but low toxicity

Antifouling paint should possess high toxicity to invertebrates but low toxicity to humans and fish. According to reports the toxicity of RSnx 3 is the highest of the 4 different types of organic Sn compounds as TBTC 1 and TBIF. The efficiency diffusion rate of Cu_2O is $10^2/cm^2/day$ but the organic Sn compounds need only $1^2/cm^2/day$. Presently, the commonly used antifouling paint contains an organic Sn compound, and although the efficiency is quite good, the problem is that it is unknown whether its toxicity will accumulate in fish and subsquently affect humans after eating it.

B. Ease of handling and low cost

Since the using of antifouling paint on nets is limited when compared with ships, the production costs are quite high. The mass production of anti–fouling paint is still not well developed. The problem of biofouling organisms on nets is similiar to that of weeds in rice fields. The production and use of the algacides required certain amount of time to spread and develop, and the same is true for antifouling paint.

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