Asian Fisheries Science 6(1993):99-116.
Asian Fisheries Society, Manila, Philippines

https://doi.org/10.33997/j.afs.1993.6.1.010

Biofouling and its Possible Modes of Control at Fish Farms in Penang, Malaysia

HOI-CHAW LAI, ADRIAN OSWALD KESSLER and LIAN-EE KHOO

School of Biological Sciences and
School of Chemical Sciences
Universiti Sains Malaysia
Penang, Malaysia

Abstract

Biofouling by 13 selected organisms was monitored with regard to their settlement patterns and their suppression by three types of chemicals. Their settlement patterns over a period of 180 days within a depth range of 1.5 m can generally be divided into three types. The early settlers colonized the substrata within the first two months of submergence and disappeared towards the end of the experiment. The sec- ond type also reached a peak density sometime during the first or second month, but declined slightly at the end. The late settlers started to appear only on the second or third month and their numbers were mostly sustained till the end. However, the distribution of all the organisms except barnacles and tunicates was random within the depth range studied. Biofouling was also significantly associated with the types of substrata.

The three chemicals used, namely antifouling paint, formulated *bis*-tributyltin oxide and tannin extract effected various degrees of suppression on fouling. The effects of *bis*-tributyltin oxide was similar to that of antifouling paint in suppressing most of the 13 foulers studied except mobile molluscs. But the degree of suppression by the former was milder as measured by the mean weight of the foulers at 42.3 g against 20.1 g of the latter. Tannin extract was least effective and suppression was only restricted to a few groups such as sea anemones, serpulid polychaetes, bryozoans and sessile molluscs.

Introduction

Fouling organisms belong to nearly all invertebrate phyla. Many attach to the substrata by calcareous secretions from the cement glands, while others cling with special byssal threads. Invasion by mobile invertebrates such as amphipods, isopods and polychaetes follow, with transient settlement by macroalgae on the rough surfaces. Grazing on the fouling organisms by other animals may occur to a certain extent (Neushul et al. 1976), but this process by itself is not sufficient to remove the encrustations.

When biofouling occurs on the polyethylene nets used for fish culture, the solid submerged canopy of fouling organisms may cut off the free exchange of the water current and creates an anoxic environment inside the net, especially during low tide. The rugged surfaces of the encrustation may scratch the cultured fish, resulting in open wounds for bacterial and viral infections. Fish culturists in Malaysia have to clean, maintain and replace fouled nets every one or two months.

When cotton nets were used, local fishers soaked them in tannin from the bark of mangrove trees (*Rhizophora* sp.) to prolong their useful life. However, modern synthetic netting is relatively nonabsorbant.

Antifouling paints may have to be considered. Many of these paints contained organotin compounds, particularly tributyl- and triphenyl-derivatives which possessed antifouling effects on a wide spectrum of organisms including fungus, bacteria and wood borer (Zedler 1964) without lasting harmful impacts on the environment (Evans and Smith 1975).

However, recent findings have disputed this claim that organotin compounds have little environmental impact (Alzieu and Heral 1984 in Stebbing 1985; Beaumont and Budd 1984). Waldock and Thain (1983) reported that tributyltin oxide (TBTO) drastically reduced growth in the Pacific oyster *Crassostrea gigas*. Stebbing (1985) was of the opinion that even if TBTOs are chemically undetectable in the aquatic environment, they are nonetheless biologically significant. This is because molluscs and a number of other organisms can bioaccumulate heavy metals including TBTOs to a value well above the actual environmental concentration (Tugrul et al. 1983). Schweinfurth and his coworkers (in Langston 1988) also clearly stated that gastropods and bivalves were most susceptible to TBTO, followed by crustaceans, algae and fish. The threshold lethality of TBTO thus depends largely on the types of animals chosen for study. The extent of the environmental impact posed by TBTO is also determined by the type and leaching rates of the antifouling paints (Stebbing 1985). This leaching rate in turn varies depending very much on the nature of the bonding of the polymer backbone (Salem 1986). As a result of its adverse effects on the environment, antifouling paints have been banned in several European countries.

The use of antifouling paints and tributyltin compounds in this study is more of standards and comparison rather than an outright encouragement for their use.

This article presents some results on the antifouling effect, within a limited depth range, of organotin and other modified compounds when coated on the surfaces of polyethylene nets and on wooden frames. The experiments were conducted in Malaysia, mainly at a floating cage fish farm at Baru Maung (100° 17'E, 5° 15.7'N). Occasional trials were conducted for comparison at a fish farm across the Penang Straits at Permatang Pauh, Butterworth. The tidal range at the study site was about 1.8 m.

Materials and Methods

Preparation of Nets for Immersion

Low density polyethylene (PE) nets commonly used for fish culture were cut into two sizes, large and small. Each piece was mounted onto a wooden frame and vertically suspended in the sea. All the nets were hung from a floating cage platform outside the existing fish nets and completely sumberged.

(1) *Large Nets*

Large nets were used to determine whether there was any difference in the distribution of the fouling organisms with respect to substratum, depth and period of submergence.

Pieces of net, each measuring 0.3 m (width) and 1.5 m (depth) with a mesh size of 10 mm, were used. Each net was divided into 45 grids measuring 0.1 m by 0.1 m with colored nylon threads. Each grid was given a code number corresponding to the depth of submergence from the water surface, e.g., 2A, 2B and 2C represented the three adjacent grids at the 0.2 m depth. Counting and monitoring of the fouling organisms was restricted to 15 random grids but covered the entire depth of 1.5 m. Only 13 major foulers were monitored to facilitate statistical analysis, although Cheah and Chua (1979) reported a total of 34 types of active fouling organisms on similar fish nets. Counting was done five times throughout a period of six months and each time the same 15 grids were used.

Apart from the untreated controls, each wooden frame and PE net was treated with either antifouling paints or tannin extract so that five types of substratum were obtained, namely, untreated wooden frame (control 1), wood surface with antifouling paint, untreated PE net (control 2), PE net with antifouling paint, and PE net with tannin. Three replicates were set up for each type of substratum.

Colonial animals such as soft coral and sea anemones were enumerated based on the per cent surface of each grid occupied. If 10% of the grid surface was occupied, then a value of 10 was accorded for that animal.

Altogether the effects of five variables on fouling were analyzed, i.e., types of substratum (variable 1, n=5), depth (variable 2, n=15), period of submergence (variable 3, n=5), replicates (variable 4, n=3) and the number of each type of fouler per grid (variable 5, n=13). A total of 1,125 readings were written into the active file of the SPSS (Statistical Package for Social Sciences, SPSS Inc., Chicago, Illinois) program for chi-square analysis.

(2) Small Nets

The objective of this experiment was to determine the effects of different concentrations of an organotin compound and the mesh size of the PE nets on fouling.

Nets, each measuring 0.3 m by 0.3 m and with mesh size 1 mm, were coated with 50% (by weight) of the paraffin-cum-TBTO mixture. Nets with 10-mm mesh size were treated with either the same concentration of TBTO-cum-paraffin preparation or full strength antifouling paint. The treated nets were each weighed before mounting on the untreated wooden frames. Duplicate sets of nets were suspended at two depths, 0.5 m and 1.5 m, respectively. The weights of the net together with the fouling organisms were monitored on nine occasions over a period of 140 days. During each weighing, the fouled nets were removed from their wooden frames and allowed to drain for five minutes before their weights were recorded. For comparison, the respective fouling by the organisms as measured by their weight increases over 140 days on the 10-mm mesh control net was designated as Grp 4, TBTO-cum-paraffin-coated net as Grp 2, and antifouling paint-coated net as Grp 1. Similarly, the weight increase on the 1-mm mesh control net was referred to as Grp 5 and that on the TBTO-cum-paraffin-coated net as Grp 3.

Another set of experiments was similarly done using various concentrations of TBTO with nonmarine commercial paint as binder. Different pieces of net with mesh size 10 mm were painted with 0 (control), 500, 1,000 and 2,000 ppm preparations of TBTO. One set of nets treated to each level of concentration was suspended at a depth of 0.5 m and the other at a depth of 1.5 m. Fouling was estimated by weighing the nets as described above.

The results were analyzed statistically by the Scheffe multiple comparison test using the SPSS program.

PREPARATION AND COATING OF ANTIFOULANTS ON THE NETS

(1) *Organotin Compound*

The organotin compound, *bis*-tributyltin oxide (TBTO) was separately mixed with two types of binder. When paraffin was the binder, 50 g of it was first dissolved in 300 ml of chloroform before 50 g of TBTO was added to give a final concentration of approximately 50% by weight. The final product was a colorless, opaque and gluey mixture into which the small experimental PE nets were soaked for two days. These nets were then allowed to dry for two days at room temperature before they were taken to the field for biofouling trials.

When a nonmarine commercial paint (Berger Super Gloss Green 14C39) was the binder, 0, 0.5, 1.0 and 2.0 g of TBTO were separately mixed with 1 liter of the paint to give a final concentration of 0, 500, 1,000 and 2,000 ppm (w/v), respectively. The mixture was immediately painted onto other small PE nets and allowed to dry at room temperature for 2 days before field trials. This nonmarine paint did not contain any tributyltin or cuprous oxides.

(2) *Tannin*

Tannin was extracted from the bark peeled off live *Rhizophora mucronata* trees. Approximately 710 g of the bark was ground in a blender and soaked in distilled water in the ratio of approximately 1:1.5 (w/w) for seven days in a hot-air oven at temperatures of 53-

67°C. Evaporated water was replaced to allow the extraction to continue uninterrupted. The debris (circa 220 g) was removed by filtering and the extract was allowed to evaporate further to a thick, gluey, dark brown mixture (circa 215 ml). To this mixture was added sodium hydroxide (4N) and formaldehyde (40%) in the ratio of 7:1.5:1 (w/w/w) similar to that reported by Mohamed Nor and Abdul Razak (1987). The mixture was allowed to settle for two hours and its pH adjusted to neutral with concentrated sulfuric acid. The large PE nets were submeged in tannin extract for two hours and air-dried at room temperature for seven days. This process of immersion and drying of nets was done twice before they were used for the biofouling experiment.

Freshly ground powder from the same mangrove bark was sieved through a 2-mm sieve; 2.5 g of it was dissolved in 50 ml distilled water and refluxed at 50-60°C for one hour. One ml of the extract was added and mixed with 75 ml distilled water, 5 ml folin-Denis's reagent and 10 ml saturated sodium carbonate similar to that described by Miyato (1987). The volume of this mixture was topped up to 100 ml with distilled water and stood for 30 minutes before it was read spectrophotometrically at 400 nm and determined with a standard curve prepared from pure tannic acid powder (Merck Art 771).

(3) *Antifouling Paint*

The antifouling paint 200 (Nippon Paint 13AM1F5Y) was purchased from retailers and is commonly used by fishers for painting their boats.

DETERMINATION OF ORGANOTIN

Two pieces of PE fish net of 14 x 14 cm each were painted with TBTO-paraffin mixture with a net concentration of 50,000 ppm organotin. The treated fish nets were immersed in a beaker containing 800 ml seawater and left on a shaker (Gallenkamp Orbital Shaker) at a speed of 110 rpm. Every month the seawater in one beaker was siphoned out and extracted to determine its TBTO level by using a graphite furnace atomic absorption spectrophotometer (Perkin-Elmer Model HGA 300) similar to the procedure reported by Pillay et al. (1989).

The seawater in the vicinity of the fish farm was similarly treated to determine its TBTO level.

Results and Discussion

Types and Distribution of Fouling Organisms

In the vicinity of the fish farm, the common foulers (Table 1) on the nets were barnacles (*Balanus striata*), serpulid polychaetes (*Pomatoceros* sp.), and tunicates (*Botrylloides* sp.) Green (*Bryopsis* sp.) and red algae (*Gracilaria* sp.) constituted the transient settlers. Other invertebrates such as the sea anemone, soft coral and molluscs (*Littorina* sp., *Perna* sp. and *Thais* sp.) occurred only in small numbers on the treated nets or the treated wooden frames.

Table 1. The main fouling organisms monitored during the experiment.

1.	Phyllum Coelenterata Class Anthozoa Subclass Zooantharia Sea anemone	8.	Phyllum Mollusca Class Bivalvia Family Pholadida *Martesia striata*
2.	Phylum Coelenterata Class Anthozoa Subclass Alcyxonaria Soft coral	9.	Phylum Mollusca Class Bivalvia Family Mytilidae *Perna viridis*
3.	Phylum Arthropoda Class Crustacea Subclass Cirripedia *Balanus* sp.	10.	Phylum Mollusca Class Bivalvia Family Pteriidae *Pinctada* spp.
4.	Phylum Annelida Class Polychaeta Subclass Sedentaria *Pomatoceros* sp.	11.	Phylum Chordata Subphylum Tunicata Class Ascidiacea *Botrylloides* sp.
5.	Phylum Bryozoa Class Gymnolaemata Order Ctenostoma *Bowerbankia* sp.	12.	Division Chlorophyta Class Chlorophyceae *Bryopsis* sp.
6.	Phylum Mollusca Class Gastropoda Family Littorinidae *Littorina scabra*	13.	Division Rhodophyta Class Rhodophycease *Gracilaria* sp.
7.	Phylum Mollusca Class Gastropoda Family Muricidae *Thais* sp.		

The cross-tabulated chi-square (χ^2) analysis showed various degrees of association between any of the variables tested with a selected type of fouler and also provided some indication of the strength of their association. A low probability from the χ^2 test indicated there was some association and the strength of significance was marked with either two or three asterisks in Table 2.

Table 2. Chi-square (χ^2) analysis on the effects of some variables on fouling ofnets and wood frames by different types of invertebrated and algae.

Organisms	Variables						
	Substrata (a)	Depth (b)	Period of submer-gence (c)	df1	Replicate (d)	df2	SS #
1. Sea anemone	(***)	(*)	(***)	12	(**)	6	iii
2. Soft	(***)	(*)	(***)	12	(**)	6	i
3. *Balanus*	(***)	(***)	(***)	16	(*)	8	ii
4. *Pomatoceros*	(***)	(*)	(***)	12	(*)	6	iii
5. *Bowerbankia*	(***)	(*)	(***)	8	(*)	4	i
6. *Littorina*	(*)	(*)	(*)	16	(*)	8	?
7. *Thais*	(***)	(*)	(*)	9	(*)	4	?
8. *Martesia*	(***)	(**)	(***)	16	(*)	8	iii
9. *Perna*	(*)	(*)	(*)	4	(*)	2	?
10. *Pinctada*	(***)	(*)	(***)	4	(**)	2	iii
11. *Botrylloides*	(***)	(***)	(***)	8	(***)	4	iii
12. *Bryopsis*	(***)	(**)	(***)	8	(*)	4	i
13. *Gracilaria*	(***)	(*)	(***)	12	(*)	6	ii

* No significant association ($P > 0.05$)
** Significant association ($P < 0.05$)
*** Highly significant association ($P < 0.01$)

Degrees of freedom: df1 for parameters a, b and c; df2 for d; SS# = Settlement sequence.

The analysis revealed that the extent of biofouling was signficiantly associated ($P<0.01$) with the types of substratum, except for *Littorina* and *Perna* (organisms 6 and 9, respectively, in Table 2). More barnacles settled on the wooden frames than on the PE nets but both substrata with antifouling paint had less barnacles than untreated ones. The wood borer *Martesia* sp. exclusively attacked the wooden frames but was effectively controlled by the antifouling paint. It is likely this paint had prevented their settlement rather than curbed their boring into the wood as the settling phase of many molluscs, especially *Martesia*, was found to depend largely on their byssus glands and the organic environment; the boring phase is entirely mechanical (Purchon 1977; Morton 1979). Sea anemones and soft corals tended to foul both untreated control wooden frames and nets but they were considerably suppressed by the antifouling paint. Red algae and tunicates were generally more abundant on untreated control and tannin-treated nets. Serpulid polychaetes *Pomatoceros* sp. were less abundant on wooden frames and PE nets treated with antifouling paint than on the respective untreated controls, but tannin was only moderately effective. The bryozoan *Bowerbankia* sp. grew mainly on untreated nets and tannin was effective in preventing their settlement.

Most of the control nets were heavily clogged with fouling organisms at the end of the experiment. Some of the wooden frames had broken up due to the weight of encrustation on the nets, boring by *Martesia* sp. and strong wave action (C2 in Fig. 1a). Nets treated with antifouling paint or organotin preparations were relatively free from fouling except for sporadic settlement by barnacles. Even their wooden frames treated with antifouling paint, though heavily fouled, remained intact under the battering of waves (P2 in Fig. 1b). Nets treated with tannin were relatively unclogged (Fig. 1c) but their wooden frames were later broken probably because they were untreated.

The distribution of foulers and associated organisms with respect to the prescribed water depth of this study was random ($P>0.05$), except in the case of barnacles, the wood borer *Martesia* sp., tunicates and the green alga *Bryopsis* (organisms 3, 8, 11 and 12, respectively, in Table 2). The output of the χ^2 analysis revealed that the majority of barnacles attached on the wood submerged in depths below 1 m; while tunicates tended to settle on nets above 0.5 m ($P<0.01$). The random distribution of most of the other foulers could be related to the limited depth (1.5 m) of the wooden frame.

With a few exceptions, like the mobile molluscs (organisms 6, 7 and 9 in Table 2), the foulers roughly fall into three groups with respect to their time sequence of settlement on the substrata. The first group of biofoulers (labelled *i* in column 5 of Table 2) showed significant initial settlement ($P<0.01$) within the first two months

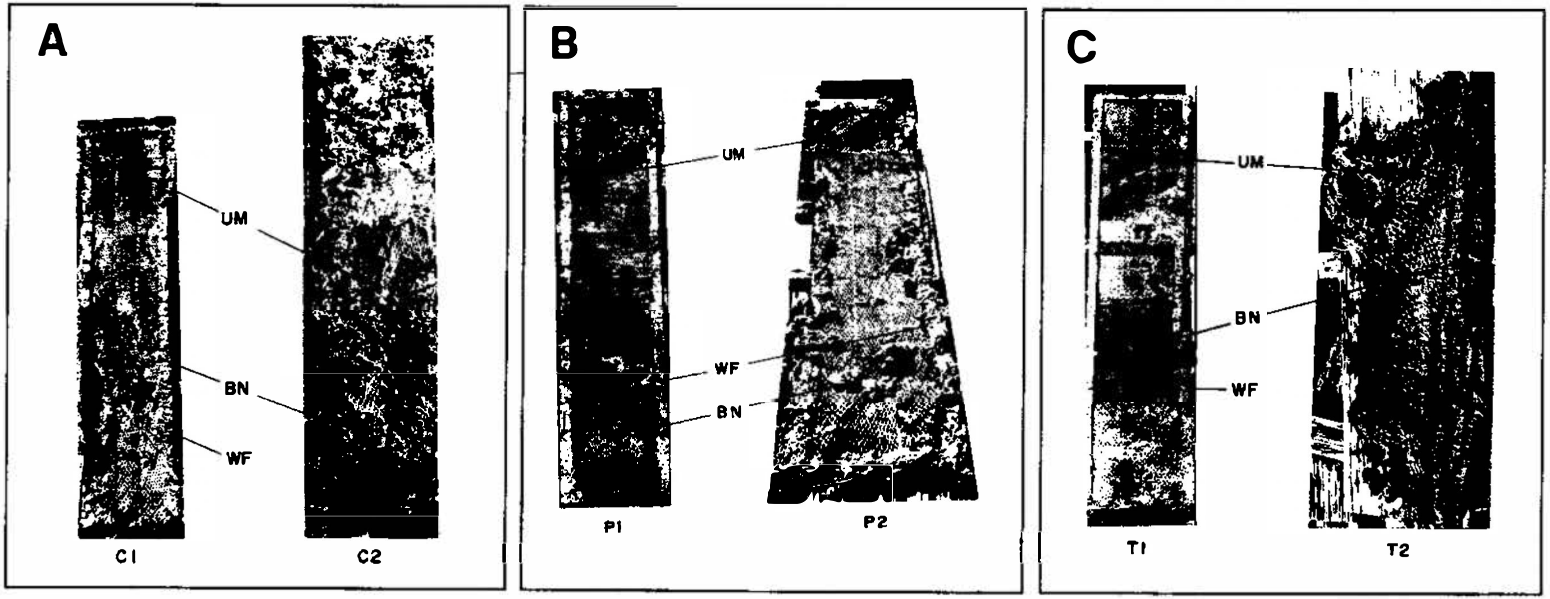


Fig. 1. A) Photographs of the control large polyethylene (PE) nets. (C1): 117 days; (C2): 414 days; BN = barnacles; WF = wooden frame; UM = unclogged mesh. B) Photographs of the large PE nets coated with antifouling paint (P1):117 days; (P2): 414 days; BN = barnacles; WF = wooden frame; UM = unclogged mesh. C) Photographs of the large PE nets coated with tannin extract. (T1):117 days; (T2): 414 days; BN = barnacles; WF = wooden frame; UM = unclogged mesh.

but were later wiped out from the nets and wooden frames. These early foulers were represented by soft coral, bryozoan *Bowerbankia* sp. and green alga *Bryopsis* sp. The second group (labelled *ii* in column 5 of Table 2) consisted of barnacles and red alga which peaked in abundance during the first or second month ($P<0.01$) but decreased slightly toward the end of the experiment. The third group or the late-arriving foulers (labelled *iii* in column 5 of Table 2), such as sea anemones, serpulid polychaetes *Pomatoceros* sp., pearl oysters *Pinctada* sp. and tunicates *Botrylloides* sp., began to settle after two or three months of submergence ($P<0.01$) and were sustained or nearly so until the end of the experiment. The wood borer *Martesia* sp. also started to settle during the second or third month of submergence which coincided with the settlement of the third group of foulers.

Whether these settlement patterns reflect the seasonalities of fouling or the result of spatial competition among foulers is a matter of conjecture. It is interesting to note that the competitive displacement of the bryozoan *Bowerbankia* sp. by the serpulid polychaete *Pomatoceros* sp. on nets was similarly reported by Rubin (1985); both of these organisms were highly selective of their substrata. Once settled, the bryozoans were slowly replaced by serpulid polychaetes. Jin and Zhou (1983) observed that growth of the pearl oyster *Pinctada fucata* was partly hindered by other foulers, in particular the two species of *Balanus* barnacles during their abundance peak in July and August in Liusha Bay, South China. The same settling sequence for these two genera was also observed in this study.

Counts from the different replicates were highly variable and each replicate could be considered independent ($P>0.05$) from the others for 9 out of 13 foulers (column 6 in Table 2.)

Comparison of Fouling on Various Types of Substratum

For nets of 10-mm mesh size, the effect of TBTO (Grp 2) in suppressing fouling was approximately midway between the untreated control (Grp 4) and those treated with antifouling paint (Grp 1) as shown by the distribution of the respective curves over a submergence period of about 4.5 months (Fig. 2a). The weights of the fouling organisms for the control nets increased from 20-30 g at day 10 to 110-120 g towards the end of the experiment. In comparison the organotin-coated nets showed weight increases from the initial

10 g to over 80 g during the same period. The antifouling paint, as the name implies, was most effective in suppressing biofouling and the final weight recorded was only about 40 g.

There were hardly any detectable differences in weight of foulers (Fig. 2b) between the untreated control nets (Grp 5) of 1-mm mesh size and those treated with the organotin compound (Grp 3). The weight increases in both groups fluctuated only slightly throughout the entire period of submergence. In fact, most of the time these nets were covered with a layer of shifting mud and silt which may have limited the settlement of many foulers.

The results of the Scheffe multiple comparison test (Table 3) showed that the degree of fouling (Fig. 2) may be divided into three subsets. The first subset was the nets of 10 mm mesh size coated with antifouling paint (Grp 1 in Fig. 2a) with a mean weight of 20.98 g over a period of 4.5 months. The second subset included the organotin-coated net of 1-mm mesh size (Grp 3), organotin-coated net of 10-mm mesh size (Grp 2), and the control net of 1-mm mesh size (Grp 5) with mean weights of 39.6 g, 42.3 g and 43.4 g, respectively. The third subset was represented by the most heavily fouled untreated control net of 10-mm mesh size (Grp 4) with a mean

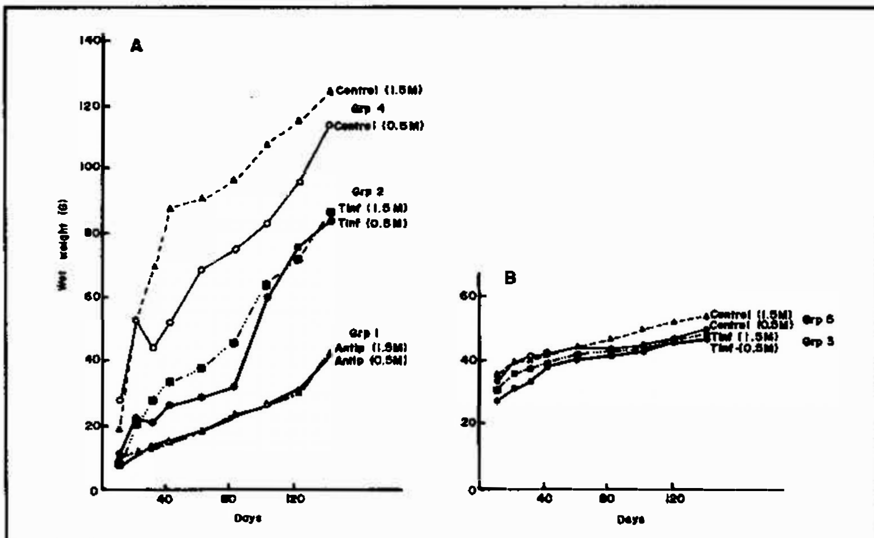


Fig. 2. Weight increase with time of the small (0.1 m^2) PE nets. a: 10 mm mesh size. b: 1 mm mesh size. Control: untreated net. Tinf: coated with organotin formulation. Antip: coated with antifouling paint. Values in brackets refer to depths at which the nets were suspended.

Table 3. Scheffe multiple comparison test relating the weight of foulers to various types of substratum.

		Subsets				
		1	2			3
Mean weight of foulers (g)	Group	Grp 1	Grp 3	Grp 2	Grp 5	Grp 4
20.98	Grp 1					
39.61	Grp 3	*				
42.32	Grp 2	*				
43.41	Grp 5	*				
76.86	Grp 4	*	*	*	*	

Grp 1 = antifouling paint-coated 10 mm PE net
Grp 2 = TBTO-cum-paraffin coated 10 mm PE net
Grp 3 = TBTO-cum-paraffin coated 1 mm PE net
Grp 4 = 10 mm control PE net
Grp 5 = 1 mm control PE net

weight of 76.86 g. It is of special interest to note the enormous difference in weights of foulers between the untreated control nets of 1-mm (Grp 5) and 10-mm (Grp 4) mesh sizes. The former were usually clogged by silt and mud while the latter were not. Hence in future tests, only nets of 10-mm mesh should be used so as not to mask the real effects of the various antifoulants under study.

Antifouling Effects of Various Concentrations of Organotins

In this experiment weight increases due to fouling over 4.5 months were shown as regression lines. Approximately 140 g of fouling organisms were recorded on the surface of the untreated control net towards the end of the experiment (line A in Fig. 3), while those coated with nonmarine Berger paint showed a weight increase of slightly over 60 g (line B). Nets with 500, 1,000 and 2,000 ppm of the TBTO preparations were slightly less fouled as represented by Lines C, D and E. Lines A, B, C, D and E can be described respectively by the following regression equations:

$$y = -3.13 + 1.17x \quad (n=8,\ r=0.976)$$
$$y = 2.00 + 0.47x \quad (n=8,\ r=0.946)$$
$$y = 0.48 + 0.46x \quad (n=8,\ r=0.976)$$
$$y = 1.72 + 0.38x \quad (n=8,\ r=0.958)$$
$$y = 0.27 + 0.36x \quad (n=8,\ r=0.976)$$

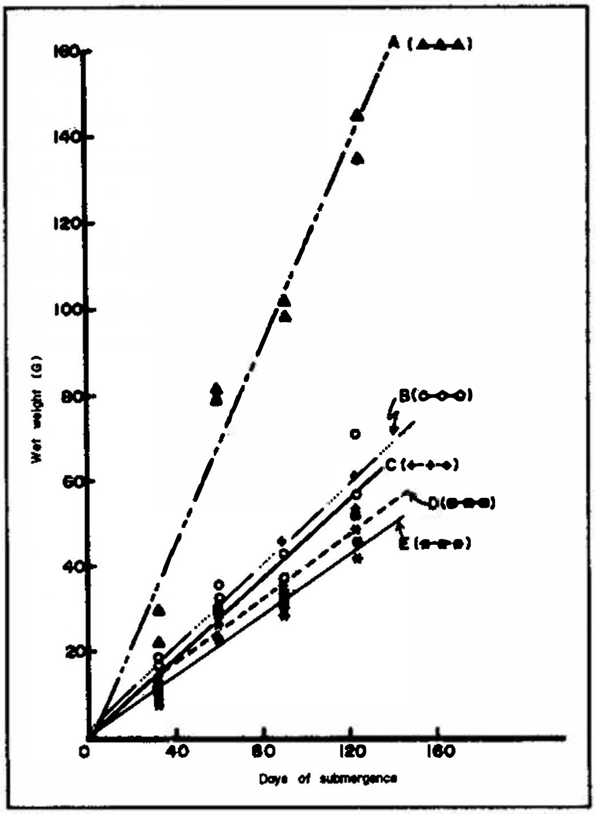


Fig. 3. Weight increase with time of the small (0.1 m^2) PE nets coated with various concentrations of organotin using nonmarine paint as a binder. Line A: untreated control net. Line B: coated with nonmarine paint only. Line C: 500 ppm organotin. Line D: 1000 ppm organotin. Line E: 2000 ppm organotin.

The significant differences between these lines were elucidated by *t*-tests which showed that the weight increase of the fouling organisms on the control net (line A) was significantly different from those treated with TBTO (lines C, D and E). However the effects of the three concentrations with nonmarine paint as binder were not significantly different ($P>0.05$). The mean weight of foulers at 500 ppm, 1,000 ppm and 2,000 ppm TBTO (nonmarine paint as binder) were 36.08 g, 31.05 g and 27.39 g, respectively, all of which were less than the mean weight of 42.3 g obtained for the 50% TBTO preparation (paraffin as binder). It is possible that the amount of TBTO that leached into the sea was minimal when nonmarine paint was used as a binder. Hence a lower concentration of the active ingredient was already effective. For this reason most of our subsequent experiments were based on formulations with TBTO concentrations less than 500 ppm.

The action of paraffin in the presence of chloroform on the surface of PE nets and on TBTO is uncertain at this stage. It is possible that it has structurally modified the TBTO and rendered it less toxic to the foulers thereby resulting in more fouling. It is unlikely that the TBTO leached out or was washed away because preliminary leaching rates were estimated to be 0.4-34 $ng \cdot cm^{-2} \cdot day^{-1}$ under laboratory conditions. The higher leaching rate represented that of the TBTO-coated PE net while the lower value was that of the TBTO-exuded PP lines. This range of leaching rates was well below that of the critical leaching rate of <0.1 $\mu g \cdot cm^{-2} \cdot day^{-1}$ (Evans and Smith 1975). The states of Virginia and Maryland, USA, permit the sale of antifouling paints with leaching rates below 5 $\mu g \cdot cm^{-2} \cdot day^{-1}$ (Hall 1988).

Generally, the total weight increase on untreated control nets due to fouling at the study site was estimated to be about 1,400 $g \cdot m^{-2}$ for a submergence period of about 4.5 months. This is comparable to the 1,490 $g \cdot m^{-2}$ recorded by Cheah and Chua (1979) at another cage culture site about 12 km away with fairly similar environmental factors in terms of salinity, organic matter, etc. (Ong 1981). This total weight due to fouling exceeds those in subtropical waters by more than 50% (Jin and Zhou 1983).

For monitoring fouling, weight measurement is more reliable than counting as organisms that settle on the nets increase in weight as they grow. Counting may show more variation because the remaining organisms, although they continue to grow, are monitored only in numbers *per se*. Hence the count may decrease with the progress of submergence, if the settlers are later washed away or grazed upon by predators. In the present study, barnacles increased from about 60/grid in the first month to about 130/grid in the second month and thereafter levelled off to about 70-90/grid, though they formed the bulk of the fouling organisms. Such fluctuations in count can be avoided by weighing the encrusted nets (Figs. 2 and 3) once the major foulers are identified for a particular location (Tables 1 and 2).

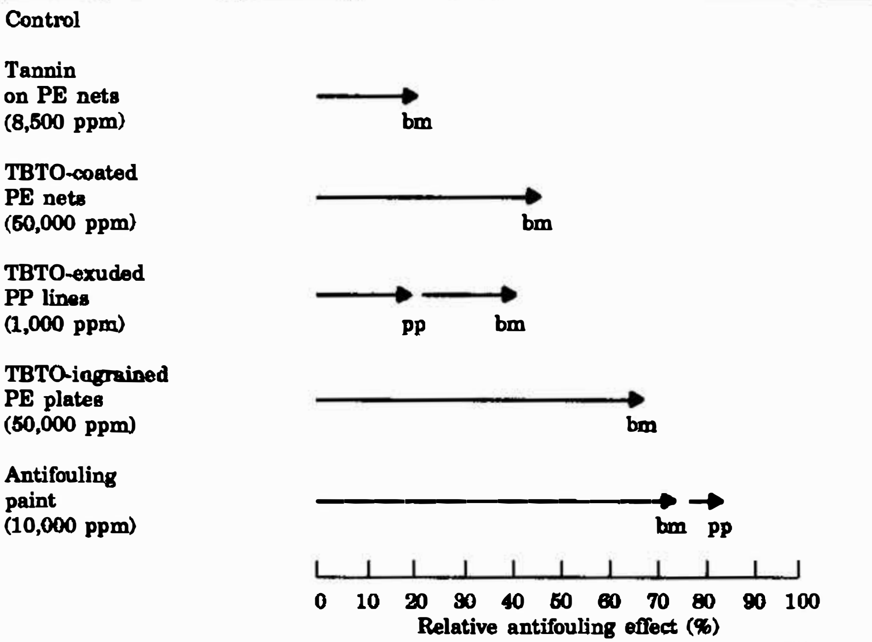
The use of antifouling paint by local fishers to protect their fishing boats is widespread, notwithstanding its reported harmful effects to some molluscs such as the Pacific oysters in European waters. The level of TBTO in seawater samples collected during low and high tides at a fish-rearing site at Batu Maung was less than 2 $ng \cdot l^{-1}$ (Pillay et al. 1989) though there were more than 200 fishing vessels plying the area and they were frequently painted and maintained. This background level of organotin is close to the detection limit of the graphite furnace atomic absorption spectrophotometer (Pang et al. 1991) or two to three orders of magnitude lower than the British standard of 2 $\mu g \cdot l^{-1}$ where the use of antifouling paint for smaller boats is prohibited. The use of antifouling paint on vessels smaller than 25 m is also banned in France. In the USA, rather than an outright legislative ban, the use of antifouling paints with certain leaching rates is restricted or the products are regulated by the Federal Insecticide, Fungicide and Rodenticide Act (see Mar. Poll. Bull. 18, 427).

There is a suggestion that floating net cages used in fish culture be sprayed with antifoulants to reduce labor costs (>15%) arising from the frequent changes of the fouled nets. There was evidence in Ireland, however, that organotins might affect scallop recruitment (Michin et al. 1987). The use of tributyltin compounds to preserve wood is quite common because of their moderate toxicities on rodents at 0.15-1.64 ppm (Crowe et al. 1979). Tannin may have potential if it can be firmly bound to the surface of the PE net. It was about 20% better than the control, while the antifouling paints showed 70-80% effectiveness (Table 4).

Conclusion

Various antifoulants such as organotin compounds and ordinary paint without TBTO showed some antifouling effect for up to six months of submergence. The leaching rates of TBTO-containing formulations were well below the permissible standards. In general, antifouling paint was found effective, based on weight increases and actual counts, in suppressing the settlement of most foulers, except molluscs, both on wood and PE nets. The formulated TBTO showed some similarity with the antifouling paint in suppressing the settlement of foulers particularly sea anemones, soft corals, serpulid polychaetes and tunicates. The types of foulers suppressed by tannin were restricted to sea anemones, serpulid polychaetes, bryozoans

Table 4. Comparative effects of various antifouling formulations.



bm = experiment carried out at Batu Maung
pp = experiment carried out at Permatang Pauh

and oysters, and its efficacy was less than the others. All the antifouling agents tested had only slight effects on mobile species like molluscs and green algae.

Acknowledgements

The authors express their gratitude to the Universiti Sains Malaysia for a research grant (No. 131/0240/0370/1000) and R & D funding (No. 123/3101/2401) in support of this project. The help of Dr. Quah Soon Hoe in the usage of the SPSS/PC package is gratefully acknowledged. Thanks are also due to Miss Bessie Ong for her critical reviews and comments of the manuscript.

References

Beaumont, A.R. and M.D. Budd. 1984. High mortality of the larvae of the common mussel at low concentrations of tributyltin. Mar. Poll. Bull. 15:402-405.

Cheah, S.H. and T.E. Chua. 1979. A preliminary study of the tropical marine fouling organisms on floating net cages. Mal. Nat. J. 33:39-48.

Crowe, A.J., R. Hill, P.J. Smith and T.R.G. Gox. 1979. Laboratory evaluations of tributyltin compounds as wood preservatives. Int. J. Wood Preserv. 1:119-124.

Evans, C.J. and P.J. Smith. 1975. Organotin-based antifouling systems. J. Oil. Col. Chem. Assoc. 58:160-168.

Hall, L.W. 1988. Tribyltin environmental studies in Chesapeake Bay. Mar. Poll. Bull. 19:431-438.

Jin, Q.Z. and B.C. Zhou. 1983. Studies on prevention and elimination of fouling organisms on the pearl oyster, *Pinctada fucata* G. 1. Effects of fouling organisms on the survival and growth of pearl oysters. Tropic Oceanog. 2:141-148.

Langston, W.J. 1988. Organotin reviewed. Mar. Poll. Bull. 19:297-298.

Michin, D., C.B. Duggan and E. King. 1987. Possible effects of organotins on scallop recruitment. Mar. Poll. Bull. 18:604-608.

Miyato, H. 1987. Studies on the new analytical method of mangrove tannins and the utilization of mangrove wood and seed, p. 160-225. *In* U. Kokpol (ed.) Proceedings of the Unesco Regional Seminar on the Chemistry of Mangrove Plants. Chulalongkorn University, Bangkok, Thailand. 12-16 January 1987.

Mohamed Nor Mohd Yusof and Abdul Razak Mohd Ali. 1987. Utilization of mangrove bark, p. 287-295. *In* Proceedings of Unesco Regional Seminar on the Chemistry of Mangrove Plants. Chulalongkorn University, Bangkok, Thailand. 12-16 January 1987.

Morton, J.E. 1979. Molluscs. Hutchinson and Co., London.

Neushul, M., M.S. Foster, D.A. Coon, J.W. Woessner and B.W.W. Harger. 1976. An *in situ* study of recruitment, growth and survival of subtidal marine algae: techniques and preliminary results. J. Phycol. 12:397-408.

Ong, T.L. 1981. Ecology of cockle culture bed and its relationship to the growth of *Anadara granosa* (L). Universiti Sains Malaysia, Malaysia. M.S. thesis.

Pang, F.Y., Y.L. Ng and S.L. Tong. 1991. Determination of total tin and tributyltin in biological tissues. Paper presented at the Regional Seminar on Ecology and Conservation of Southeast Asain Marine and Freshwater Environments including Wetlands. 4-6 November 1991, Institute for Advanced Studies, University of Malaya, Kuala Lumpur.

Pillay, N.R., K.T. Wong, S.L. Tong and H.C. Lai. 1989. Determination of tributyltin in Malaysian coastal waters. Paper presented at The International Chemical Conference on Silicone and Tin. 23-26 October 1989, Kuala Lumpur.

Purchon, R.D. 1977. The biology of Mollusca. Second edition. Pergamon Press, Oxford.

Rubin, J.A. 1985. Mortality and avoidance of competitive overgrowth in encrusting Bryozoa. Mar. Ecol. 23:291-299.

Salem, S. Al-Diab. 1986. Synthesis of novel organotin copolymers. J. Chem. Res. (S). 1986:306-307.

Stebbing, A.R.D. 1985. Organotins and water quality - some lessons to be learned. Mar. Poll. Bull. 16:383-390.

Tugrul, S., T. Balkas and E.D. Goldberg. 1983. Methyltins in the marine environment. Mar. Poll. Bull. 14:297-303.

Waldock, M.J. and J.E. Thain. 1983. Shell thickening in *Crassotrea gigas*: Organotin antifouling or sediment induced? Mar. Poll. Bull. 14:411-415.

Zedler, R.J. 1964. Organotin compounds as antifouling ingredients and marine wood preservatives, p. 401-405. *In* Congres Internacional de la Corrosion Marine et des Salissures. Centre de Recherches et d'Etudes Oceanographiques, Paris.

Manuscript received 15 January 1992; accepted 26 March 1993.