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Screening and formulation of chemoattractant coatings for artificial reef structures

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Abstract: *This study was carried out to augment the colonization of marine benthic communities on artificial reef structure. Increasing marine pollution along with various natural hazards cause severe damages to marine algae and associated fauna. In recent years, artificial reefs have been deployed in coastal regions of several parts of the world in order to increase the marine productivity. They are mainly built with concrete materials, however, their leachates have considerable impacts on algae. Therefore to increase the algal colonization five chemoattractants such as ferrous sulfate, zinc oxide, ammonium nitrate, sodium phosphate and ferrous lactate were screened against spores of a fouling alga, Ulva pertusa.* $FeSO_4$ */ ZnO (8:2) and ferrous lactate coatings showed the highest spore attachment with* 52 ± 5.2 cm^2 *and* 79.5 ± 10.2 cm^2 *spores respectively (*$p<0.01$*). Furthermore using these chemoattractants, coating formulations were made and their performances were investigated at East coast (Ayajin harbor) and South coast (Meejo harbor) of Korea. A maximum fouling coverage (with green algae 25%, red algae 11.3% and brown algae 63.7%) was estimated from ferrous lactate coatings (*$p<0.01$*). Different composition of coating formulations and their chemoattractive properties were evaluated.*

Key words: *Artificial reef, Chemoattractant coatings, Fouling coverage, Panel immersion test, Ulva pertusa*
PDF of full length paper is available with author ***(*leechungwol@hanmail.net)***

Introduction

The fishing ground is rapidly decreasing in many parts of the world, every country is strengthening its fishery regulations within native economic sea zone by applying the 200 nautical mile Exclusive Economic Zones (EEZ) announcement of UN law of the sea agreement (November, 1994). Modernization of fishery technology with mechanized boats and leaching of toxic antifouling chemicals largely increases marine pollution which causes a decrease in fishing grounds. Because of the liberalization of world trade organization (WTO), increasing marine product import is threatening poorly equipped domestic fishermen. Fishery business is an integral part of the coastal village development so that, management of fishing resources for continuous fish catch is important to raise the production of marine products in order to meet the needs of local demand (Park *et al*., 2000).

There has been an increasing frequency of use, worldwide, of artificial structures in efforts to increase fish abundance and diversity, to improve catch rates of targeted species, to manipulate habitats, and to restore damaged coral reefs (Bohnsack and Sutherland, 1985; Bohnsack, 1990; Bohnsack *et al*., 1991; Seaman, 1997; Spieler *et al*., 2001; Sherman *et al.*, 2002).

In Korea, the sea ranching business that use artificial reef is steadily increasing from 1971 and an amount of 1.8 billion dollars was sanctioned for 306,751 ha of sea ranching area. From which artificial reef structures were laid on the sea floor of an area of 151,649 ha (49.4%). Future plans are in progress to cover the remaining area. Especially, an amount of 1500 million dollars was sanctioned towards sea ranching program at Tongyeong for the period 1998-2010.

The resource cultivation type fishery development is active in Japan since 1963. Since 1980's, a sea ranching program to increase the fishing resources of the offshore in Miyagi prefecture, Japan is in operation with 20 typical rock fish sea ranch units. A huge budget of 350 billion yen/ year was sanctioned towards 12 million ton target for 200 nautical miles in the 2000's. In USA, environment management and fishing resource technology is in near completion phase. The USA and Japan have jointly worked for the sea ranch programs on Pacific Ocean blue fin tuna. China launched a basic study on sea ranching program at Guangdong and Fujian province. In Norway, Norwegian Sea Ranching Program (PUSH, 1990-1997), a coastal resource enhancement and regulation program was established in 2001 (Moksness *et al*., 1998). Many of the maritime countries are now attempting with huge budget for the development of native coastal resources and management programs to enhance fishery resources. Artificial reefs were identified as potential fishery resource management strategy on the west coast of Scotland (Wilding and Sayer, 1996, 2002).

One of the initial colonizers, algae, harbors plenty of benthic marine organisms which ultimately provide a suitable habitat with a continuous supply of feed for fishes. About 90% of the artificial reef is constructed with cement. However, cement has few toxic additives. Algal adhesion on a newly constructed cement artificial reef surface is limited and the colonization process may be delayed. Otherwise algal spore may not prefer to settle on a new cement-concrete surface,

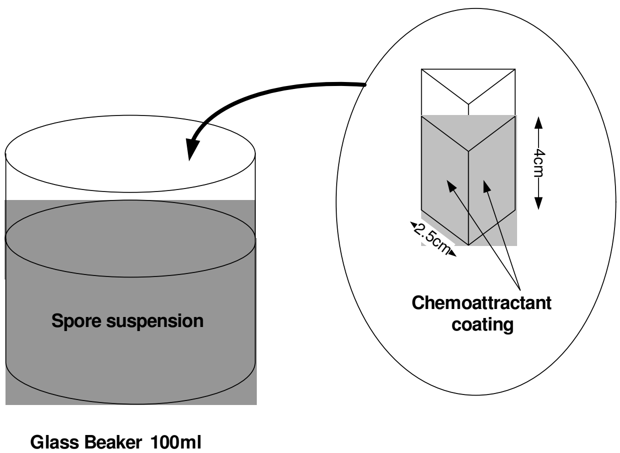

Fig. 1: Experimental setup for the *Ulva pertusa* spore attachment and germination assay

as they have the ability to select surfaces to settle (Callow and Callow, 2000). Inorganic and organic sources of nitrogen, phosphorous and other nutrients induced chemotactic response on spores of macroalgae (Amsler and Neushul, 1989; Amsler and Iken, 2001; Fukuhara *et al*., 2002; Amsler, 2008). Nutrients also induced spore settlement in the kelps, *Pterygophora californica* and *Macrocystis pyrifera* (Amsler and Neushul, 1990). Thus, a coating with suitable chemoattractants may increase the number of algal spore settlement. Active ingredients present in the chemoattractant coatings slowly released from the coating-matrix induce chemotaxis and thereby increase the algal colonization on artificial reef surface, a prerequisite for development of subsequent marine benthic communities.

As spore attachment is a critical stage in algal growth and development it was extensively employed in biofouling /antifouling investigations (Fletcher and Callow, 1992; Hellio *et al*., 2001; Patel *et al*., 2003; Sidharthan *et al*., 2007). In this study also spores of *Ulva pertusa* were used to evaluate the chemoattractants.

It is suggested that, to optimize primary production and enhance the energy flux towards the animal component, the algal species that are most productive in time and space have to be determined, and their establishment on artificial structures should be encouraged by selecting suitable substrate and environmental conditions in relation to the biogeographic region (Falace and Bressan, 2002a). Therefore an attempt has been made to screen and formulate chemoattractant coatings.

Two inorganic pigment and three chemoattractants were initially screened against spore attachment of *Ulva pertusa*. Further, these chemoattractants were incorporated into soluble matrix paint formulation and their performance was investigated at East and South coast of Korea. The main goal of this study is to develop chemoattractant coatings for artificial reefs to enhance macrophytobenthic colonization.

Materials and Methods

Chemoattractants: To evaluate the chemoattractant properties of five algal-chemoattractant candidates such as $FeSO_4$ $7H_2O$ (98%:

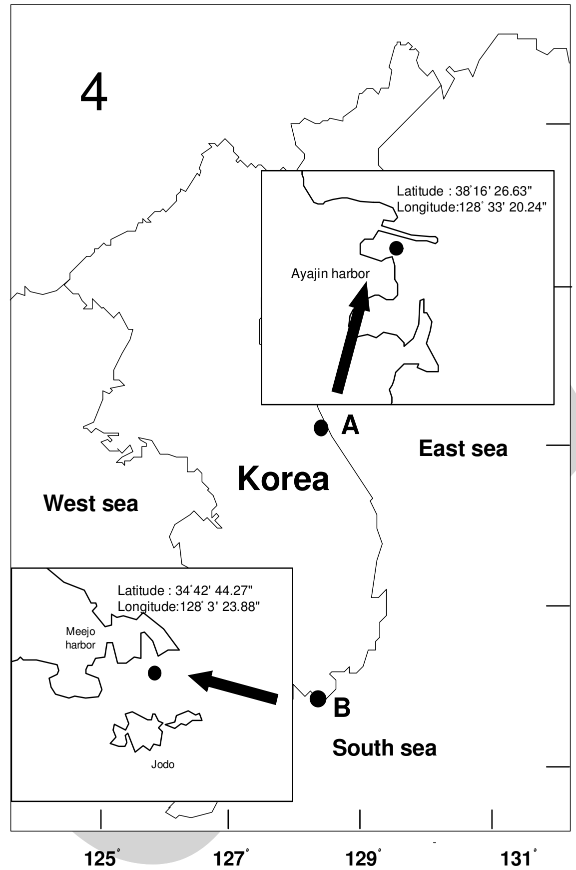

Fig. 2: A map showing panel immersion test sites (A: Ayajin harbor, East coast, B: Meejo harbor, South coast)

Duksan Co., Korea), ZnO (99.8%: Hanil Co., Korea), NH_4NO_3 (99.8%: Samchun Co., Korea), NaH_2PO_4 $2H_2O$ (98%: Duksan Co., Korea), $C_6H_{10}O_6Fe$ $3H_2O$ (98.5%: Ciyun Flavor and Fragrance Co., China) were screened in this study. Pigments ($FeSO_4$ and ZnO) and nutrients (NH_4NO_3 and NaH_2PO_4) are essential trace metals and macronutrients, respectively for algal growth. Ferrous lactate is commonly used for iron fortification and also as food additive. All these are algal growth promoting substances and are nontoxic and environmentally safe. In the light of the results reported from previous experimental studies (Amsler and Neushul, 1989, 1990), five chemoattractant candidates were chosen for this study.

Spore attachment and germination: Fertile plants of *Ulva pertusa* was collected from the East coast of Korea. After removing debris and epiphytes, *Ulva* plants were repeatedly washed in filtered seawater (0.45 µm), spore liberation was facilitated as outlined by Fletcher (1989). Spore suspension was collected in a beaker and the spore density was adjusted to 2.5×10^5 spores ml^{-1} using filtered seawater (0.45 µm).

For preliminary experiments, test coatings were prepared with 5% wood rosin (dissolved in MIBK and xylene) in which chemoattractants were incorporated. Standard microscopic glass slides (75 x 25 x 1 mm: Knittel glaser, Germany) were soaked in

10% HCl for 12 hr and rinsed in distilled water for twice and then dried. One ml of each test coating was applied on acid-cleaned glass slides and allowed to dry at room temperature for 12 hr. Seventy-five ml of spore suspension (2.5×10^5 spores ml^{-1}) was poured into each beaker (100 ml) in which test slides with chemoattractant coatings (1 x 3 slides) were placed and this set up was kept in dark. After 12 hr incubation, slides were carefully removed and spore attachment was observed under microscope (400x; Olympus- CK2, Japan). Thereafter spore suspension containing unattached spores was replaced with PES medium (Provosoli, 1968) and the set up was placed in a culture chamber under fluorescent lamp (39 μmol m^{-2} s^{-1}) with 12:12 LD cycle for 5 days (Fig. 1). At the end only number of spores attached and successfully germinated were examined. Results were expressed as mean number of germlings (cm^{-2}) ±SD.

Preparation of soluble matrix coating: A controlled depletion paint formulation outlined by Sidharthan *et al.* (2006) was slightly modified and employed for the preparation of chemoattractant coatings. Briefly, vinyl resin, wood rosin and solvents (MIBK and xylene) were taken in a 500 ml Teflon container in the ratio 2:1:2 (Table 1), and this mixture was homogenized for 40 min at 800 rpm. Thereafter, additives and pigments were added and homogenized for l hr at 1300 rpm to get a fineness of >80 μm. Finally, chemoattractant was incorporated and further homogenized for 20 min at 1000 rpm. When exposed to seawater (pH~8.2), acidic rosin binder slowly dissolves thereby chemoattractant leaches at the coating surface. Addition of vinyl resin provides suitable mechanical properties to facilitate a minimum dissolution rate. Inorganic pigments are responsible for color, hiding power and improve resistance of coating films. Moreover, they are essential micronutrients for algal growth. Therefore, $FeSO_4$ and ZnO were initially used in five different ratios (10:0, 8:2, 5:5, 2:8 and 0:10) in pigment coatings. Further, an optimum ratio of 5:5 was chosen to make chemoattractant coatings.

Panel set up and immersion test: Surface of the PVC test panel (10 x 10 cm) was roughened with emery paper (#1000). Prepared fouling coatings were separately coated on PVC panels using spray gun (Nozzle: 1.5 mm). Panels were allowed to dry at room temperature for 48 hr. Coated panels were randomly tied on PVC pipes with nylon ties.

Panel immersion tests were conducted during February – March 2007 at East coast (Ayajin harbor) and South coast (Meejo harbor)Fig.2. After 30 and 60 days immersion period, fouling assemblage on each panel was evaluated (ASTM, 1998) to determine the efficiency of newly prepared chemoattractant coatings (Fig. 2). Performance of chemoattractant coatings was continuously monitored up to 90 days.

Means of replicates were subjected to one-way ANOVA followed by Dunnett's test to compare results obtained for control and treatments (*p<0.05, **p<0.01).

Results and Discussion

***Ulva pertusa* spore attachment and germination:** Among the pigments, $FeSO_4$ / ZnO (8:2) coating showed the highest spore

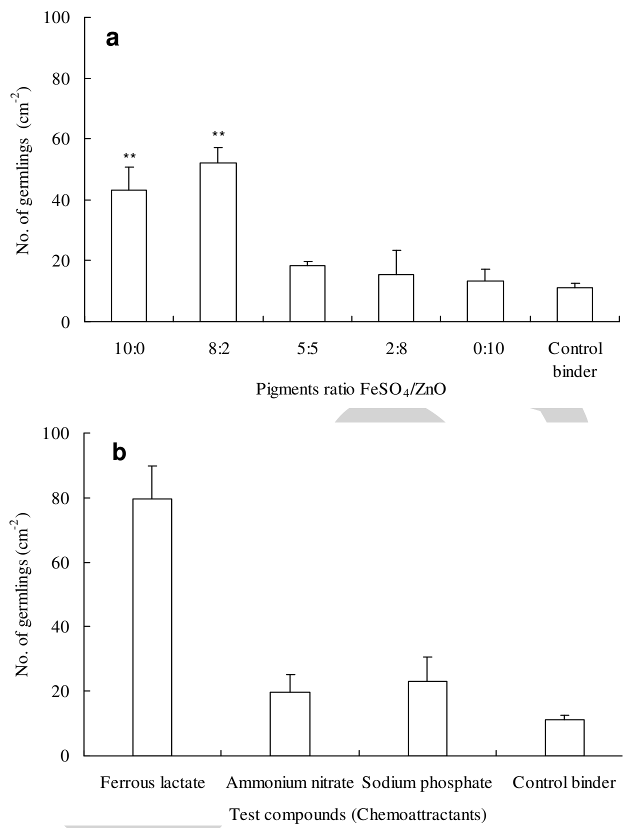

Fig. 3: *Ulva pertusa* spore attachment and subsequent germination on pigment (a) and chemoattractant (b) coatings. One-way ANOVA followed by Dunnett's test indicated a significant increase in number of germlings on chemoattractant coatings compared with respective control. Asterisks indicate significance level (*p< 0.05; **p < 0.01)

attachment with 52 ± 5.2 germlings cm^2 whereas on ZnO coating the lowest value of 13.2 ± 4.2 germlings cm^2 was observed (Fig. 3a). Spore attachment and germination was significantly increased on the ferrous lactate coating with 79.5 ± 10.2 germlings cm^{-2} (p<0.01; Fig. 3b). Spore attachment was found to be less on untreated control surfaces.

Chemoattractive properties of ZnO and $FeSO_4$: After 30 days immersion at Ayajin harbor, East coast, a minimum of 1.7% fouling coverage was observed on ZnO pigment coating (Table 2). On $FeSO_4$ / ZnO combination at 8:2 level, fouling coverage increased to 73.7%. On untreated PVC control panels 66.5% fouling coverage was observed but a minimum of 37% was observed for a negative control, binder coating, however, this difference was not significant (p>0.05).

A similar trend was observed in test panels immersed at South coast (Meejo harbor). Among the pigments, $FeSO_4$ / ZnO (8:2) coatings exhibited a high fouling coverage with 84.7% whereas a minimum fouling coverage was observed for ZnO (11.3%). Both untreated control (PVC) and negative control (binder) showed more or less similar effect (Table 2).

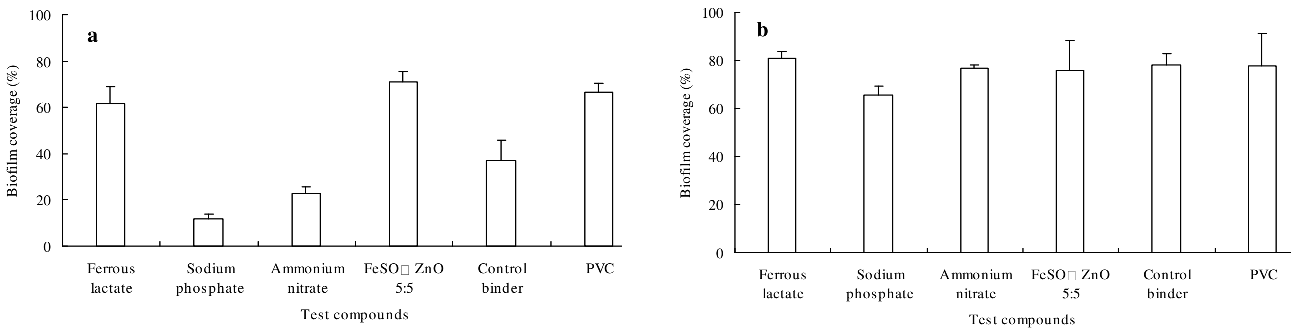

Fig. 4: Influence of pigment and chemoattractant coatings on biofilm coverage (%). Test panels exposed to Ayajin harbor East coast (a), and Meejo harbor South coast (b) for 30 days. One- way ANOVA followed by Dunnett's test indicated a significant increase in macroalgal coverage (%) on chemoattractant coatings. Asterisks indicate significance level ($^*p < 0.05$; $^{**}p < 0.01$)

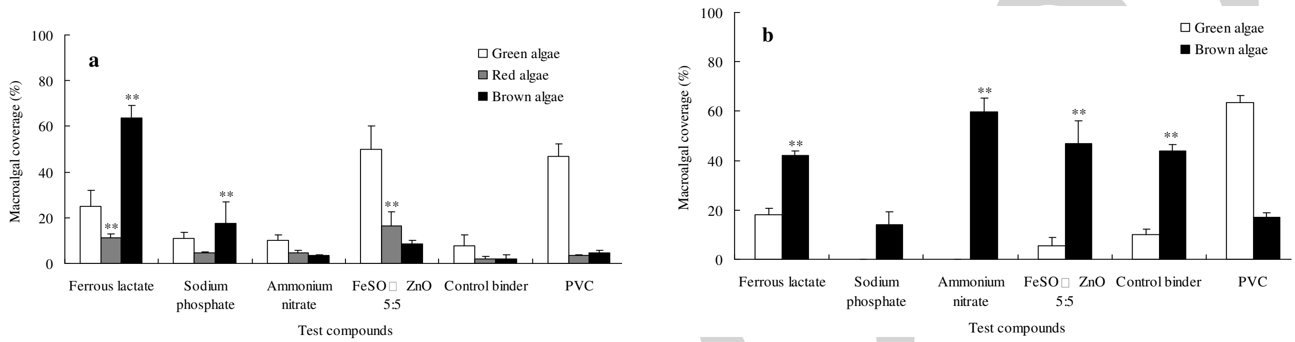

Fig. 5: Influence of pigment and chemoattractant coatings on macroalgal coverage (%). Test panels exposed to Ayajin harbor, East coast (a), and Meejo harbor, South coast (b) for 60 days. One-way ANOVA followed by Dunnett's test indicated a significant increase in macroalgal coverage (%) on chemoattractant coatings. Asterisks indicate significance level ($^*p < 0.05$; $^{**}p < 0.01$)

Influence of pigments on performance of fouling coatings is shown in Table 3. After 60 days exposure to East coast (Ayajin harbor), on panels coated with $FeSO_4$ / ZnO (8:2) exhibited the highest fouling coverage with brown algae (75%; p<0.01), red algae (12.7%; p<0.01) and green algae (9%). On untreated control-PVC panels, fouling coverage was composed of green (47.5%), red (3.5%) and brown (4.5%). Minimum levels of fouling coverage with green (8%), red (2%), and brown (2%) were observed on negative control (binder) coatings. Fouling coverage estimated on ZnO coated panels showed similar levels both after 30 and 60 days exposure to East coast (Ayajin harbor).

At South coast (Meejo harbor), among the pigment coatings, for ZnO coatings a minimum fouling coverage was estimated (Table 3). On the other hand $FeSO_4$ coatings showed a maximum fouling coverage with green (67%) and brown (14%). On untreated control PVC panel surface also fairly high fouling coverage of green algae was seen (63.3%). Comparatively high brown algal coverage was estimated on FeSO4/ZnO (2:8) coating in both harbors (Table 3).

Performance of chemoattractants: After 30 days exposure to Ayajin harbor waters, East coast, the highest biofilm coverage was observed on ferrous lactate coating (61.3%), which predominantly composed of diatoms (East coast: *Navicula elegans, Licmophora abbreviata, Striatella unipunctata, Thalassiosira decipiens* and *Skeleletonema costatum;* South coast: *Thalassiosira* sp*, N. longissima, Amphora coffeaeformis, L. abbreviata, Coscinodiscus* sp) (Fig. 4). For other chemoattractants such as ammonium nitrate and sodium phosphate, 22.7% and 12% biofilm coverage were observed respectively. When these three chemoattractant coatings were exposed to South coast (Meejo harbor), a maximum of 81% biofilm coverage was estimated for ferrous lactate. On the other two chemoattractants, ammonium nitrate and sodium phosphate 76.7% and 65.7% biofilm coverage were observed respectively (Fig. 4).

After 60 days exposure to East coast (Ayajin harbor), the highest macrofouling coverage was observed on ferrous lactate coatings with green algae (25%), red algae (11.3%; p<0.01) and brown algae (63.7%; p<0.01) (Fig. 5a). Similarly, on ferrous lactate coatings exposed to south coast, high macrofouling coverage composed of green algae (18%), brown algae (42%: p<0.01) was observed (Fig. 5b). In both sites, macroalgae assemblages found to be composed of *Ulva pertusa, Colpomenia sinuosa, Undaria pinnatifida, Gracilariopsis chorda, Gelidium amansii, Gloiopeltis furcata* and *Pachymeniopsis elliptica*. Macroalgae coverage on experimental panels after 90 days exposure to harbor waters is shown in Fig. 6.

Artificial reefs are increasingly deployed on the seabed for the purpose of influencing physical biological and socio-economical processes related to promotion of marine resources (Seaman, 1997). Natural hazards (grazing pressure, algal /coral whitening, invasive species, tsunami *etc*.) and anthropogenic perturbations related to the industrialization, pollution, eutrophication, over fishing are the

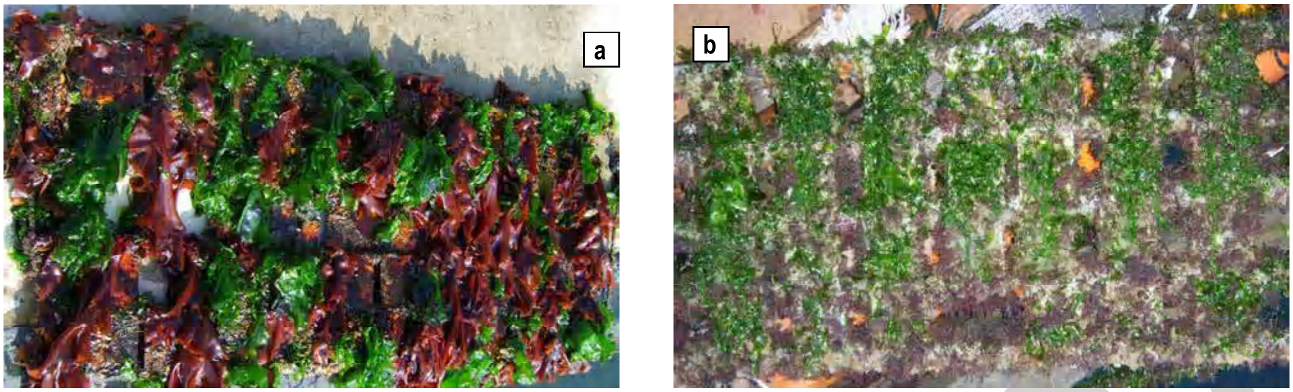

Fig. 6: Macroalgal coverage on experimental panels coated with chemoattractants. Panels exposed to Ayajin harbor, East coast (a), and Meejo harbor, South coast (b) after 90 days

major causes of declining marine resources. Species diversity and abundance of marine organisms are rapidly decreasing in coastal regions in many parts of the world, except few tolerant species.

In the marine ecosystem, algae provide food and shelter to harboring micro- and macrobenthic animal communities. As an initial colonizers algae play an important role in subsequent colonization by other benthic forms, in most of the cases the relationship is positive. However, there are a few specific, exceptions like algal species which possesses deterrent chemicals.

Artificial reefs are used for many purposes, including coastal defense, fisheries protection through fishing effort exclusion, and environmental rehabilitation, and largely for fisheries enhancement (Seaman, 1997; Jensen *et al.*, 2001). Development of macrophytobenthos on artificial structures is a critical stage because of the trophic relationships that may be established during their colonization with edaphic and animal components (Falace and Bressan, 2002a).

In general, grazing is essential for proper survival of corals (Williams and Polunin, 2001). Predatory fishes and herbivorous fishes are known to feed on algae that colonize the surface of the artificial reef structure (Chou, 1997; Williams and Polumin, 2001). Artificial reef acts as a habitat, shelter, nursery and spawning beds for some fishes, abalone and spring lobster, which are valuable fishery resources (Ohno *et al*., 1990; Watanuki and Yamamoto, 1990).

For aquaculture purposes, artificial reef surfaces may be modified by means of inoculation of algal spores or by placing adult thallus in their reproductive phase on specially made structures (Falace and Bressan, 1996, 2002a). The settlement preferences of juvenile stages of various marine benthic organisms are well documented. The ability of motile algal spores to detect and respond to environmental cues is particularly pertinent to their survival and the colonization of new substrata (Callow and Callow, 2000).

During the settlement and attachment processes, algal spores are influenced by several environmental conditions such as surface topography (thigmotactic response), light (phototactic response) and the presence of chemicals (chemotactic response) (Fletcher and Callow, 1992; Callow and Callow, 2000; Sidharthan *et al*., 2007). Zoospores of *Laminaria japonica* exhibited chemotaxis to high concentrations of nitrate-N and phosphate-P (Fukuhara *et al*., 2002). In a previous experimental study, Amsler and and Neushul (1989) showed that algal spores are chemotactically attracted to nutrients ($NH4^{+}$, $NO3^{-}$, $PO4^{3-}$, Fe^{2+} *etc.*). It was reported that nutrient-stimulated spore settlement rates were 150% over unenriched control levels (Amsler and Neushul, 1990). In the present study also a high level of *Ulva* spore attachment with 7 fold increase in germlings cm^{-2} was estimated for ferrous lactate coatings.

Various efforts are in progress to modify the surface characteristics of artificial reefs by adding different base materials for concrete mix, surface microtopography and structural complexity as well as cost-effectiveness to increase colonization of benthic organisms.

Addition of siliceous pozzolans in the concrete mix used for artificial reef construction was reported by Wilding and Sayer (2002). The utilization of granitic by-products in the concrete preparation has 25% and 40% reduction in concrete block production cost. It was demonstrated that granite dust and granite washing plant filter-cake can be combined to reduce cement and fly-ash levels to produce a cost-effective and physically resilient concrete block that is environmentally safe for the construction of artificial reef structures (Wilding and Sayer, 2002).

Several studies suggested that the synergistical interaction and competition among the species of the reef community are presumably conditioned by the limited availability of space to be colonized. Despite the large size of the test panels, colonization dynamics on the panels may not be representative of the natural successional patterns (Falace and Bressan, 2002b). However,

Table - 1: Composition of chemoattractant coatings

Chemoattractant (g)		Binder (g)		Pigment (g)		Additive (g)	Solvent (g)	
		Vinyl resin	Wood rosin	$FeSO_4$	ZnO	Additive	Xylene	MIBK
Pigment	0	30	30	110	0	40	210	180
				88	22			
				55	55			
				22	88			
				0	110			
Ferrous lactate	21	30	30	55	55	40	210	180
Ammonium nitrate	21							
Sodium phosphate	21							

Table - 2: Influence of pigment coatings on biofilm coverage (%). Test panels exposed to Ayajin harbor, East coast (a), and Meejo harbor, South coast (b) for 30 days

Pigments	Ratio	Biofilm coverage (%)	
		Ayajin harbor, East coast	Meejo harbor,South coast
$FeSO_4$: ZnO	10 : 0	68.0 ± 5.3	52.0 ± 9.0
	8 : 2	73.7 ± 7.8	84.7 ± 7.5
	5 : 5	71.0 ± 4.6	76.0 ± 12.2
	2 : 8	75.3 ± 2.5	80.0 ± 8.0
	0 : 10	1.7 ± 1.5	11.3 ± 3.1
Control binder		37.0 ± 12.7	78.0 ± 2.8
PVC		66.5 ± 3.5	77.5 ± 19.1
One-way ANOVA		$p < 0.01$	$p < 0.01$

One-way ANOVA followed by Dunnett's test indicated a significant increase in macroalgal recruitment (%) on pigment coatings. Asterisks indicate significance level (*$p < 0.05$; **$p < 0.01$)

Table - 3: Influence of pigment coatings on macroalgal coverage (%). Test panels exposed to Ayajin harbor, East coast (a), and Meejo harbor, South coast (b) for 60 days

Pigments	Ratio	Fouling coverage (%)				
		Ayajin harbor, East coast			Meejo harbor, South coast	
		Green algae	Red algae	Brown algae	Green algae	Brown algae
$FeSO_4$: ZnO	10 : 0	74.0 ± 2.6**	03.3 ± 0.5	03.7 ± 1.2	67.0 ± 2.6	14.0 ± 3.6
	8 : 2	9.0 ± 2.6	12.7 ± 4.0**	75.0 ± 1.0**	16.5 ± 4.5	41.5 ± 8.5**
	5 : 5	50.0 ± 1.0	16.5 ± 6.0**	8.5 ± 1.5	5.5 ± 3.1	47.0 ± 9.1
	2 : 8	32.5 ± 5.9	07.0 ± 2.6	60.5 ± 9.7**	16.0 ± 2.6	52.0 ± 3.6
	0 : 10	0	0	0	0	0
Control binder		8.0 ± 4.6	2.0 ± 1.0	2.0 ± 1.7	10.0 ± 2.0	44.0 ± 2.6
PVC		47.5 ± 5.5	3.5 ± 0.6	4.5 ± 1.5	63.3 ± 3.2	17.0 ± 1.7
One-way ANOVA		$p < 0.01$	$p < 0.01$	$p < 0.01$	$p < 0.01$	$p < 0.01$

One-way ANOVA followed by Dunnett's test indicated a significant increase in macroalgal coverage (%) on pigment coatings. Asterisks indicate significance level (*$p < 0.05$; **$p < 0.01$)

preliminary panel immersion investigation is the effective technique to estimate the chemoattractive effectiveness of the chemical substances, as demonstrated in the present study. In experiments conducted with coral skeletons, under the influence of nitrogen and phosphorous fertilizers, three times higher algal coverage was observed in Glover's reef, Belize (McClanahan *et al*., 2007). Similarly, nitrate and phosphate coatings increased the algal coverage in the present study.

Growth characteristics of algal vegetation on the reef surfaces are strongly influenced by several environmental factors such as high-sedimentation regime, in which rapid particle deposition and movement takes place (Stewart, 1983; Airoldi and Virgilio, 1998). In eutrophic coastal zones, sediment is considered as an important physical stress that causes reduction or disappearance of macroalgae (Falace and Bressan, 2002b), since sediment largely reduces inputs of light and oxygen (Airoldi *et al*., 1995). Temporal changes in solar irradiance and temperature as well as life history strategies of the different species will have had marked effects on the macroalgal vegetation (Falace and Bressan, 2002a).

Despite the large variations in the productivity of different taxa associated with age structure and environmental conditions, artificial reef apparently may enhance benthic secondary production with two fold increase as evidenced at lower Delaware Bay (Steimle *et al*., 2002). Similar observations with increased macrobenthic colonization on artificial reefs along the southern coast of Portugal were reported (Boaventura *et al*., 2006). These authors suggest that artificial reefs could have an essential role in habitat-loss mitigation efforts.

Seaweed communities developed on the artificial iron reef at Ikata, southern Japan was studied from Feb. 1999 to Aug. 2000 (Choi *et al*., 2006), in which within a month diatoms dominated on all substrata with 100% coverage. Similarly, in the present study 81% biofilm coverage was estimated on ferrous lactate coatings for the same exposure time (Fig. 4). Among the macroalgae, *Enteromorpha intestinalis* and *Colpomenia sinuosa* dominated on the artificial iron reef within three months after the placement in the spring (Choi *et al*., 2006). But they decreased during the summer. In the winter, the seaweed on the reef recovered. *Sargassum* spp., *Ecklonia kurome* and *Padina arborescens* dominated on each substratum after one year (Choi *et al*., 2006). In the present study also on experimental panels exposed to Meejo harbor, South coast, brown algae (*Colpomenia sinuosa, Undaria pinnatifida, Sargassum* sp and *Laminaria* sp) were found to be dominated other groups (Fig. 5b and Fig. 6b). Increase in benthic secondary production was attributed to enhanced fish production (Bond *et al.,* 1999).

Grazing by sea urchins significantly affects the development and evolution of algal communities, on both natural and artificial reef substrates (Andrew, 1994; Falace and Bressan, 2002a). However, a 2-3 fold increase in grazing near the artificial reefs was observed when compared to neighboring natural assemblages (Einbinder *et al*., 2006). Artificial reefs may attract organisms away from natural reefs rather than increase the overall local population. Therefore it is important to examine how epibenthic and epibiotic organisms colonizing reef habitats enhance the availability of benthic invertebrate prey to fishery resources compared to typical endobenthic organisms of the soft sediments in an area (Bohnsack *et al*., 1991; Leewis *et al*., 1997; Steimle *et al*., 2002).

The performance of inorganic pigments and chemoattractant candidates demonstrated in this study clearly indicate their chemotactic effectiveness towards the major groups of macroalgae. These chemoattractants are less expensive and environment-friendly. Application of these chemoattractants is a promising strategy to enhance the fisheries resources for continuous fish catch and better coastal zone management.

However, thorough habitat specific studies are required in order to establish a 'trophic' relationship around artificial reefs to quantify the efficiency of chemoattractive properties of surface coatings. Further studies are in progress using concrete blocks to demonstrate the efficiency of chemoattractant coatings.

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