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AN EXPERIMENT ON THE EVALUATION OF ARTIFICIAL REEFS WITH INVERTEBRATE COMMUNITY[1,2]

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ABSTRACT

K.H. Chang, C.P. Chen, H.L. Hsieh and K.T. Shao (1977). *An experiment on the evaluation of artificial reefs with invertebrate community.* Bull. Inst. Zool., Academia Sinica, 16(1): 37-48. Four sets of multiple discs or pyramidal frustums sampling apparatus were placed on two kinds of sandy sea-floor, one near natural reefs, the other far off natural reefs, to study which attracts more passing organisms. The results revealed from one year's study show that the pyramidal frustums sampling apparatus attracted more organisms than the discs. The sampling apparatus far off natural reefs is more effective than the ones near natural reefs. Refering to the results, the casting of artificial reefs and its mechanisms were also discussed.

The casting of artificial reefs underwater to improve fishing has been applied in many years[1,3,11]. However, the studies of artificial reefs during the past have mainly focused on increasing the fish population[7,10] and a few on the analysis of benthic algal community[9].

There are two kinds of attracting "forces" existing in submerged artificial reefs. The first derives from the construction of the reef which provides shelter from wave action and holes in which to hide. The second comes from the organisms living on artificial reefs. Those organisms are food for other organisms and they also modify the habitat to other organisms as homes, spawning grounds, etc. The second attracting force seems more efficient than the first one. Since the organisms living on artificial reefs vary with construction materials, casting sites and time, large scale artificial reef construction must be predicted on a scientific basis.

The field experiment described here is an attempt to understand the developing invertebrate community on submerged artificial reefs in offshore area of Taiwan.

MATERIALS AND METHODS

Pearce's multiple disc sampling apparatus (MDSA) was slightly modified for this study[6]. Two sets of the MDSA were placed in different sea-floor located off Kuei-hou in northern Taiwan. As shown on Fig. 1, station A has a depth of 10 m, with a sandy bottom and nearby natural reefs; station B has a depth of 14 m and sandy bottom, but is located farther from natural reefs. All of the discs are made of concrete, the most suitable material for constructing artificial reefs in Taiwan at present.[1] Concrete discs are approximately 23 cm in dia-

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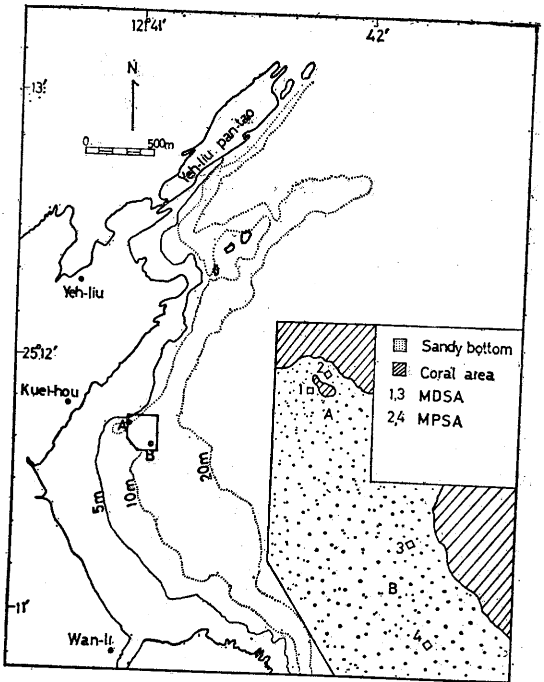


Fig. 1. The map and artist's drawing of casting area for the sampling apparatus.

meter and 3 cm in depth. The tops of the discs are covered with five strips raised above the disc surface. Each strip is 2.5 cm in width and 0.5 cm in height (Fig. 2). The bottoms of the discs are flat (Fig. 3). Using nylon threads, 24 discs were attached to a heavy weighted iron frame (178 × 117 × 152 cm).

The discs were collected by SCUBA diving techniques. In each diving, biologistdivers Dr. Chang and Mr. Shao observed and recorded the number of fish near the MDSA for a period of 30 minutes and then replaced certain discs which were selected at random. The sampled discs were placed in plastic bags and then examined carefully with a dissecting microscope in the laboratory.

After a few field work experiences, concrete pyramidal frustums were created to correct two defects in the MDSA experiment. First, it took too much time to unfasten and fasten the nylon thread for collecting and replacing discs in the water. Second, we could not detect with the discs whether sea currents had affected the encrusting of the organisms. The pyramidal frustums have a large internal cavity and are 16 cm in upper margin, 24 cm in base and 17 cm in height. There is a 5 × 1.5 cm slot in each inclined surface (Fig. 4, 5). The slots make the pyramidal frustums easy to attach and release from the frame (160 × 120 × 150 cm).

The two sets of sampling apparatus (MPSA), each with 12 pyramidal frustums, placed near stations A and B respectively, were studied.

For comparing the biomass attracted by each sampling apparatus, the amount per unit of vertical projective area is cited as a suitable critical value. The vertical area in MPSA is 1.4 times of that of MDSA.

The first MDSA was set at station A on June 22, 1975, and the second MDSA at station B eight days later. The MPSA were placed at stations A and B on July 31, 1975 and August 11, 1975, respectively. Seven samples with 28 units were collected at about one and a half month intervals over one year period*. Because of difficulties in identification of small organisms, the materials will be treated in large units, such as sponges, flat worms, polychaetes, etc.

RESULTS

I. Encrusting invertebrates:

As shown in Table 1 and Fig. 2-5, most of the encrusting organisms, i. e., sponges, sea anemones, ectoprocts, polychaetes, barnacles, bivalves and sea squirts, prefer the bottom of the discs or inside the pyramidal frustums. The amount of most organisms are varied considerably difference between stations A and B. In both MDSA and MPSA, sponges, sea anemones, ectoprocts and single sea squrits in station B outnumbered those at station A, which only

* Note: the sampling apparatus were destroyed by the heavy currents during a strong typhoon on August 9, 1976.

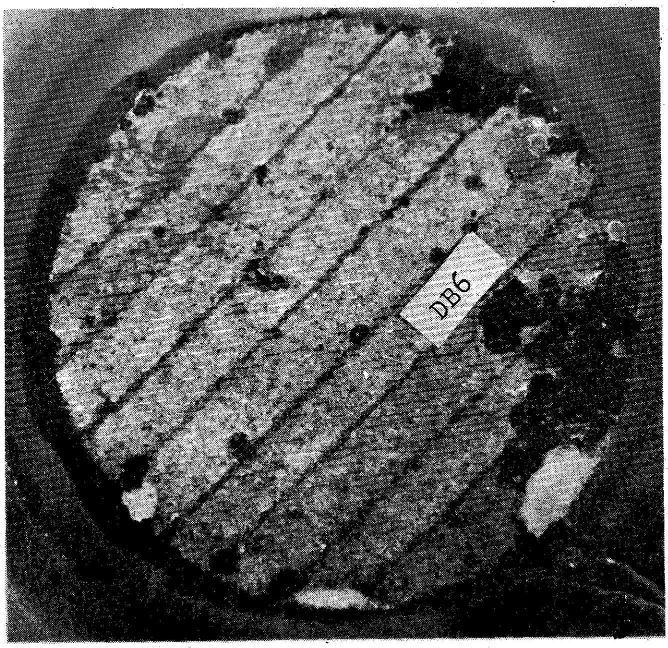


Fig. 2. Creatures found in small numbers on the disc-tops.

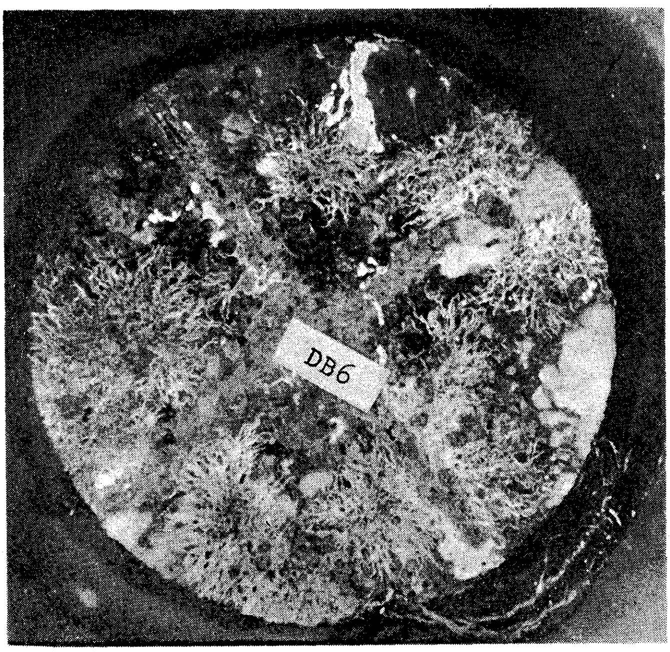
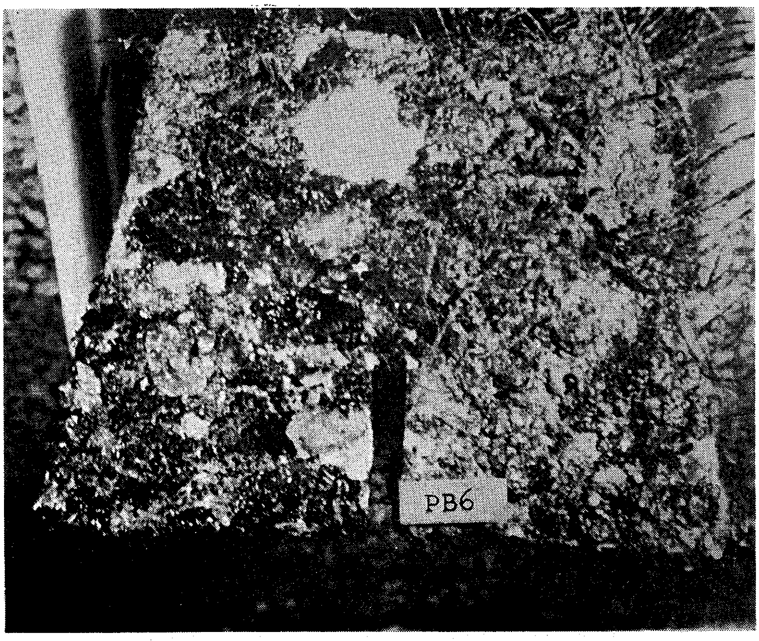


Fig. 3 Marine life found in abundance on the bottom of discs.



Fg. 4. The outside of pyramidal frustums.

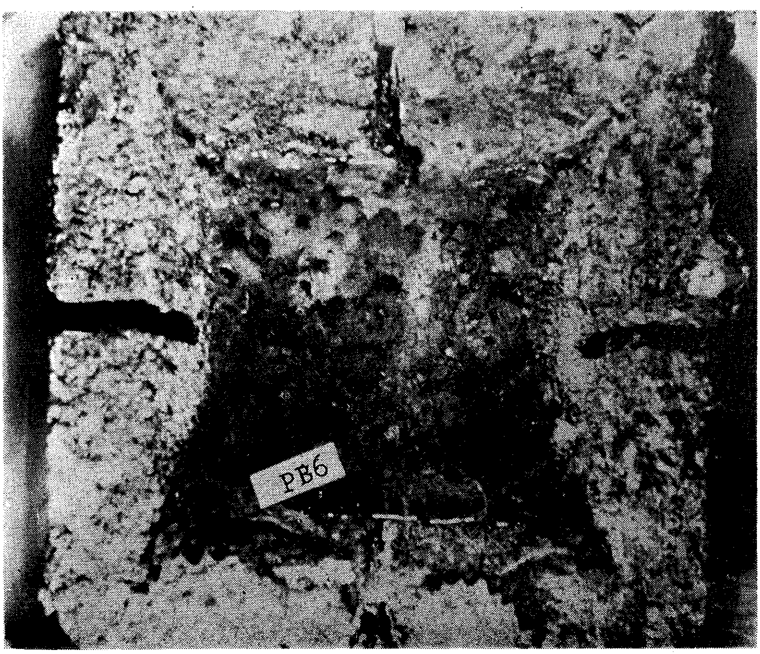


Fig. 5. The inside of pyramidal frustums.

TABLE 1

The number of invertebrates encrusted on the top and bottom of the discs (MDSA) and the outside and inside of the pyramidal frustums (MPSA) cast at stations A and B. The data has been pooled from all seven samples

Sampling apparatus	MDSA				MPSA			
Stations	A		B		A		B	
Positions	Top	Bottom	Top	Bottom	Outside	Inside	Outside	Inside
Sponges*	.5	20.7	.8	33.5	.6	2.7	32.0	42.2
Sea anemones	33	212	42	326	4	10	29	13
Stony corals*	5.8	.7	4.1	0	19.0	0	5.4	0
Ectoprocts*	41.8	712.3	45.2	781.4	364.9	493.8	974.0	355.4
Polychaetes	48	1319	87	1664	480	2521	906	1902
Barnacles	126	1238	19	148	97	661	597	320
Bivalves	46	342	98	301	299	954	582	870
Sea squirts						18		
Single	0	177	2	531	0		10	276
Colony*	0	60.6	0	95.2	1.1	39.9	2.1	1.3

* the unit is 1 cm²

stony corals were more numerous at station A. As for polychaetes, barnacles, bivalves and colonial sea squirts, although no distinct pattern between stations A and B of MDSA or MPSA was evident, the total amounts added from MDSA and MPSA revealed that the barnacles were greater at station A, while polychaetes, bivalves and colonial sea squirts were almost equal in both stations. As regards the biomass concentrated in MDSA and MPSA with the amount per unit of vertical projective area, Table 1 shows that stony corals, polychaetes and bivalves were more abundant in the MPSA than in the MDSA, while only sea anemones and colonial sea squirts were evident in greater numbers in the MDSA.

Table 2 presents the distribuion of the encrusting invertebrates on different outside surfaces of the pyramidal frustums. Only the stony corals preferred the top surface, the other organisms clustered on the side surfaces. Most organisms seems appeared in greatest numbers on the northern surface.

The fluctuations of biomass of invertebrates encrusted on each sample are shown on Fig. 6. All of the encrusted invertebrates increased numerously in the early submerged stage, and the numbers of most organism fluctuated greatly later on. However, some continued to increased i. e., the sea anemones of MDSA at station B and ectoprocts of MPSA at station A.

Table 3 represents the greatest size of invertebrates encrusted on the discs or pyramidal frustums in each sample. By Sign test[4], it was revealed that both sea anemones and sea squirts grew larger on the bottom and inside of the discs and pyramidal frustums, but barnacles grew larger on the outside of the pyramidal frustum. The other organisms showed no significant difference in their growth in respect to the different positions.

The growth rates of those organisms between stations A and B also varied. Sea squirts of both MDSA and MPSA grew more rapidly at station B than at station A, but barnacles of MPSA grew more quickly at station B. Other

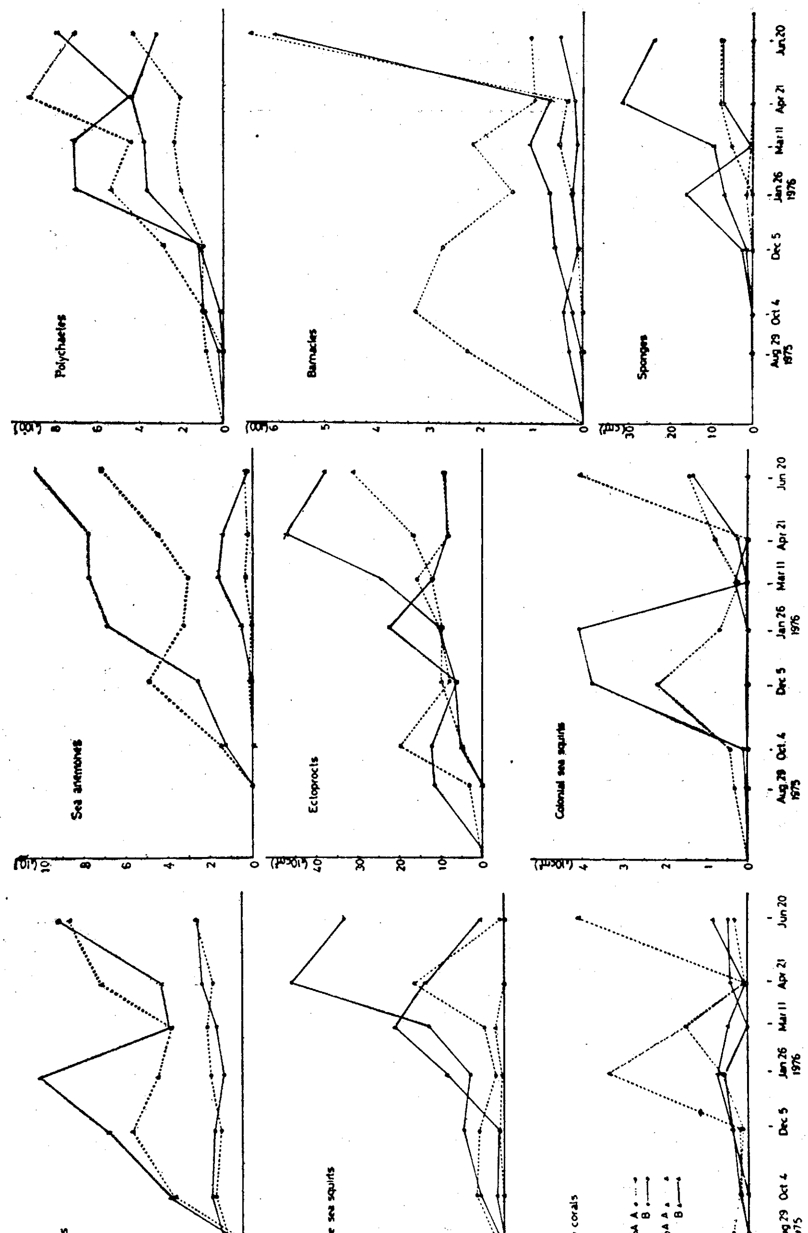


Fig. 6. The temporal fluctuation of the number of individuals in various invertebrates.

TABLE 2

Comparison among the numbers of invertebrates encrusted on different directional surfaces on pyramidal frustums. The data has been pooled only from samples with clearly-marked directions in stations A and B, i. e., the 2nd, 3rd, 6th and 7th samples

Directions		TOP	NE	SE	SW	NW
Sponges*	A	0	0	0	0	0
	B	.1	1.1	4.1	10.0	7.2
Stony corals*	A	5.4	.2	.1	.1	3.4
	B	1.5	.1	1.3	.0	.0
Ectoprocts*	A	2.1	87.9	59.3	68.4	80.8
	B	26.6	153.0	203.1	114.6	240.4
Polychaetes	A	13	81	46	47	58
	B	38	92	96	102	151
Barnacles	A	2	17	13	6	3
	B	4	59	53	54	293†
Bivalves	A	19	44	45	52	59
	B	14	104	58	87	102

* the unit is 1 cm^2.
† 273 small individuals appeared at the 7th sample.

TABLE 3

The largest size invertebrates encrusted on the MDSA orMPSA+

Sampling apparatus		MDSA							MPSA				
		'75			'76				'75	'76			
Samples		Aug.	Oct.	Dec.	Jan.	Mar.	Apr.	Jun.	Dec.	Jan.	Mar.	Apr.	Jun.
Sea anemones	A	—	—	5	6*	5	5	5♯	4	4	8	4	5
	B	—	—	5	6	9	5	6♯	0	3	6	5*	5
Polychaetes	A	3	4	3	6	4♯	3	4*	4	7*	4*	5*	5
	B	2	3	2	3	2	4*	5*	3*	5*	6*	6*	5*
Barnacles	A	3*	5*	3*	3	4*	4	4*	3	7*	8♯	10*	5
	B	3*	4	2	3*	2	2	5	9	10*	12*	10*	9*
Bivalves	A	4	7	19	9*	6	10	22*	19	16	19	11*	32
	B	10	15	6*	13*	4*	16*	14*	14*	23	33	28	45
Single sea squirts	A	2	27	10	19	8	13	10	15	22	35	0	0
	B	22	29	25	11	12	40	12	30	25	20	24	58

†: Size was measured in units of 1 mm.
*: The largest sizes appeared on top of the discs and outside of the pyramidal frustums.
♯: The largest sizes appeared both on top and bottom of the discs and both outside and inside of the pyramidal frustums.
—: missing data.

TABLE 4

The temporal fluctuation of free-living invertebrates on MDSA.

Stations	A							B						
Samples	'75			'76				'75			'76			
	Aug.	Oct.	Dec.	Jan.	Mar.	Apr.	Jun.	Aug.	Oct.	Dec.	Jan.	Mar.	A pr.	Jun.
Sipunculids	4	6	1	3	3	0	5	3	2	4	2	4	0	1
Polychaetes	16	32	15	59	73	51	127	20	40	22	40	37	45	124
Sea spiders	1	1	0	0	0	0	1	0	5	1	2	1	3	0
Acarinas	—	—	6	87	178	59	48	—	0	0	81	204	45	24
Clam shrimps	—	—	0	13	139	19	56	—	0	0	16	56	5	27
Copepods	—	—	123	4082	5830	2469	2930	—	1	100	3015	6133	1952	1736
Cumaceans	0	0	90	30	253	83	28	3	2	25	30	81	37	29
Tanaidaceans	1	0	23	238	1020	488	743	1	71	6	203	771	412	204
Isopods	—	—	25	349	528	283	138	—	3	13	132	37	145	77
Amphipods	—	2	44	96	588	258	123	—	7	22	67	154	145	32
Decapods	15	3	1	2	3	9	113	24	20	1	25	6	54	51
Chitons	0	0	0	5	3	5	18	0	0	0	1	3	2	19
Snails	6	30	3	4	52	43	328	8	14	1	11	5	11	412
Slugs	5	1	3	8	5	5	5	0	2	0	2	0	0	3
Sea cucumbers	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sea urchins	0	0	0	0	0	0	3	0	0	0	0	0	0	3

Note: A small jellyfish and a juvenile fish appeared at station B on Jan. 26, '76 and Aug. 27, '75 respectively.

organisms showed no significant difference in individual size between stations A and B.

II. Free-living invertebrates

The amount of free-living invertebrates on MDSA and MPSA fluctuated with seasonal change (Table 4, 5). Isopods, amphipods and molluscks appeared in greater volume during the summer. The temporal fluctuation of the number of copepods appearing on the sampling apparatus also showed marked variations. In MDSA, copepods increased quickly from late winter to spring, and then decreased; but copepods of MPSA appeared in large numbers earlier in winter than those of MDSA and showed no significant numerical decrease later on. Table 4 & 5 also shows that the productivity of the MPSA at station B was higher than that at station A, but there was no distinct pattern between the productivity of MDSA at stations A and B. In general, the MPSA Produced greater biomass than the MDSA for most organisms, while the only exceptions belong polychaetes and tanaidaceans. The largest sized organisms for all types appeared at MPSA (not shown).

III. Immigrating pattern

The patterns of organisms immigrating into the MDSA and MPSA at stations A and B are similar. Pioneers were those invertebrates with hard calcareous shells or tubes capable of being cemented to the surface of the submerged artificial reefs, such as polychaetes, barnacles, ectoprocts and stony corals; then free-living invertebrates with high self-protective ability.

TABLE 5

The temporal fluctuation of free-living invertebrates on MPSA

Stations	A							B						
Samples	'75			'76				'75			'76			
	Aug.	Oct.	Dec.	Jan.	Mar.	Apr.	Jun.	Aug.	Oct.	Dec.	Jan.	Mar.	Apr.	Jun.
Sipunculid	0	1	0	2	1	0	19	0	16	0	4	1	4	11
Polychaetes	3	23	16	38	96	24	89	0	17	52	33	49	57	129
Sea spiders	0	0	0	0	1	0	0	0	0	30	8	8	13	0
Acarinas	—	—	37	111	261	237	149	—	—	33	300	245	157	334
Clam shrimps	—	0	0	3	91	3	175	—	48	13	34	77	37	211
Copepods	—	—	1581	2125	6713	4194	5331	—	—	1311	3952	6617	2861	5075
Cumaceans	—	—	88	51	263	48	118	—	1	184	139	258	90	11
Tanaidaceans	—	3	46	57	181	72	1135	—	2	36	226	631	721	644
Isopods	1	6	78	199	394	250	110	—	6	123	310	349	540	189
Amphipods	—	7	54	67	1926	441	104	—	7	82	252	1254	1204	287
Decapods	15	29	4	19	5	38	223	2	25	9	5	144	29	298
Chitons	0	0	2	14	19	31	27	0	0	1	6	9	8	46
Snails	2	26	13	26	48	53	268	1	18	5	13	12	80	391
Slugs	0	0	0	5	6	3	6	0	4	4	12	15	3	6
Sea cucumbers	0	0	0	0	0	0	0	0	0	5	0	0	0	0
Sea urchins	0	0	0	0	0	2	2	0	0	0	0	5	5	7

Note: 1. At station B, six and one flat worms appeared on Oct. 4, '75 and Jan. 26, '76 respectively.
2. The total numbers of juvenile fish occurred at station A and B are four and one respectively.

i. e., crabs and gastropods followed. Gradually, more encrusting invertebrates with less protective ability settled, for example single and colonial sea squirts and sponges. At about the same time, shrimps, soft sea slugs, sea cucumber, amphipods, isopods, clam shrimps, flat worms and sea urchins appeared.

DISCUSSION

Although the patterns of organisms immigrating into the sampling apparatus were similar, the MPSA attracted greater biomass than the MDSA and the sampling apparatus in station B concentrated more organisms than those of station A. Therefore, the number and size of organisms appearing on MPSA at station B were greater than those of the other three sampling apparatus (Fig. 7, 8). From those facts, two basic concepts about artificial reefs can be deduced. First, artificial reefs must be in stereo-construction with internal cavities and second, cast far off natural reefs.

The fish community around the sampling apparatus also support these two basic concepts[2]. Near the MDSA or MPSA in station A or B, 48 species of fish were observed. Among them, many small fishes schooled around the sampling apparatus to feed or hide. The sampling apparatus also attracted some larger carnivorous fishes. The MPSA at station B attracted most of them, i. e., 30 species of fish, and the MDSA at station A attracted only 15 species of fish.

Having made intensive studies on coral reefs,

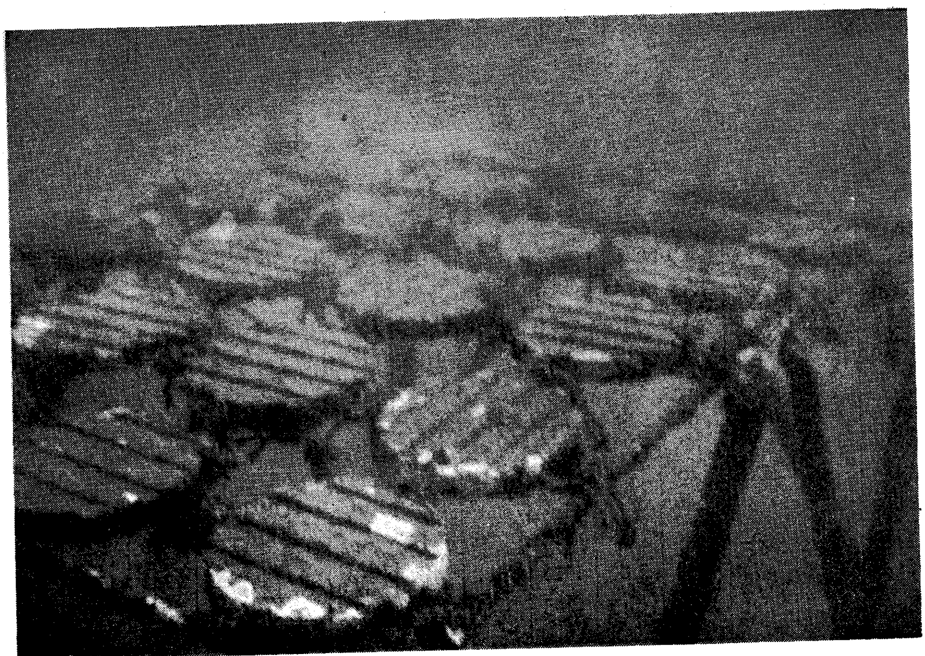


Fig. 7. Monotonous scenes found around the disc sampling apparatus.

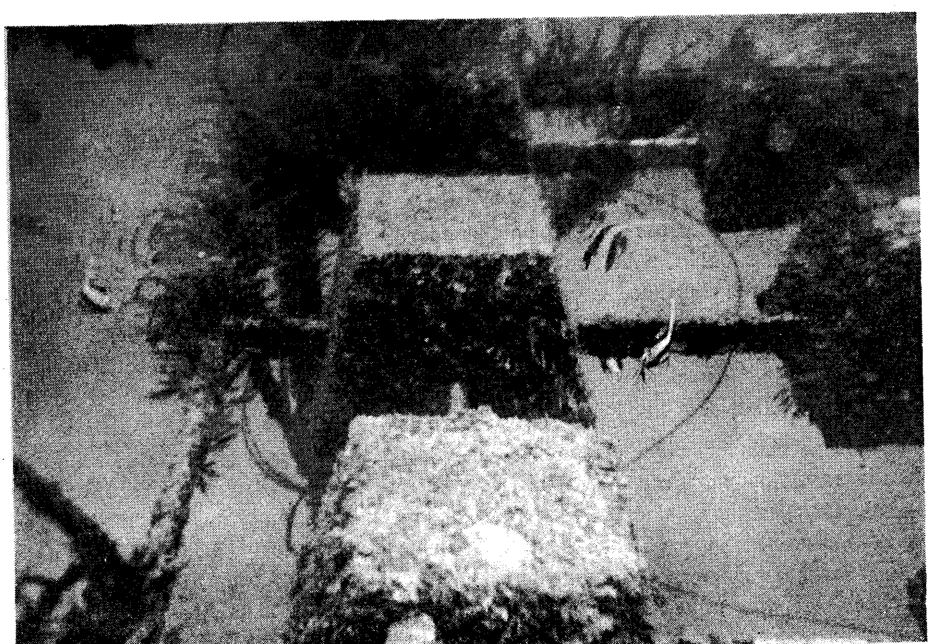


Fig. 8. Lively community created in pyramidal frustums sampling apparatus.

Storr suggested that certain physical characteristics of the successful natural reefs be duplicated in artificial reef designs[8]. In natural reefs there are small hiding places suitable to protect small fishes from predators and large places to protect larger fishes from wave activity. Artificial reefs, therefore, should probably be constructed to form both small caves and larger passages ways. In this study, we confirm Storr's ideas as the MPSA with its greater number of small hiding places attracted more marine animals than the MDSA.

The results of casting artificial reefs far off natural reefs revealed that this study agrees with those of Turner, *et al.*[10] They summarized that reefs should be constructed at a considerable distance (1/2 mile or more) from natural reefs.

Why do artificial reefs cast far off natural reefs attract more marine fauna? Turner, *et al.* believed that the ectone effect between the artificial reefs and sea bottom provides the explanation. In Fager's experiment, with the nitrogen analyses of various encrusting materials taken from the boxes placed on a sandy bottom at 12-14 m depth off La Jolla at different ages, he found that in this marine community there was some primary production on the boxes but most of the energy used by the community came from plankton collected by barnacles, anemones, ectoprocts, etc[5]. Therefore we may assume that as too many creatures often feed on plankton on natural reefs, invertebrates encrusted on artificial reefs cast on a sandy bottom far off natural reefs will have more to feed on and greater amounts of energy will be transferred to the larger animals than those organisms encrusted on artificial reefs cast near natural reefs.

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以無脊椎動物群聚評估人工魚礁的實驗

張崑雄 陳章波 謝蕙蓮 邵廣昭

在臺灣北端龜吼外海，水深 10～14 公尺之臨近天然礁及遠離天然礁之海底上，分別投放圓盤及角錐台採集架計四座。據此比較不同投放地點及礁體類別所聚集之無脊椎動物群聚。一年後發現角錐台比圓盤更能聚集更多的生物量又遠離天然礁者比臨近天然礁者更能誘引生物。本文並論及這些現象在人工魚礁的應用。