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EVALUATION OF ARTIFICIAL REEF EFFICIENCY BASED ON THE STUDIES OF MODEL REEF FISH COMMUNITY INSTALLED IN NORTHERN TAIWAN[1,2]

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ABSTRACT

K. H. Chang, S. C. Lee and K. T. Shao (1977). *Evaluation of artificial reef efficiency based on the studies of model reef fish community installed in northern Taiwan.* Bull. Inst. Zool., Academia Sinica, **16**(1): 23-36. The development of a community on artificial reefs has been evaluated from model reef experiment carried out in northern Taiwan during the period from June 1975 to August 1976. From June to August 1975, 4 sets of the concrete multiple disc sampling apparatus (MDSA) and the multiple pyramidal-frustrum sampling apparatus (MPSA) were set on the sea floor at a depth of 10-14 m off Wanli, a fishing village in the northern Taiwan. Periodical visual observations, photographing and collection of fishes were made. Fortyeight species of the fishes in twenty three families were recorded from the model reef area. Among them, 24 species were not the members of the intertidal pools of the Wanli rocky shore. Eighteen species have a commercial value. Both the biomass and the number of species of fishes at the MPSA are higher than those of the MDSA. Isolated model reefs attracted more fishes than the one nearby the natural reefs. The installation of model reef MPSA in the isolated area have completely changed the fish community structure in a year. The possible reasons for the artificial reefs to attract more fishes is discussed.

To improve the fisheries resources around the coastal waters of Formosa (Taiwan) and Pescadores Islands (Penghu), the government of Republic of China has conducted the project on artificial reefs since 1974. Institute of Zoology, Academia Sinica has been granted to take this responsibility for reef site location and assessing efficiency of artificial reefs starting from 1975. As the results of the intensive studies, the concrete blocks lowered to the sea floor between Makung and West Islet of the Pescadores Islands was the most successful in attracting fishes among all casting sites in this country (Chang, 1976[(3)]). The questions arised regarding the artificial reefs were: (1) Selection

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of a suitable location for casting reef? (2) What are the best materials and means of the artificial reef constructions? (3) How does artificial reef attract the fishes? (4) Do fishes really spawn and live around there? (5) Is the artifical reef beneficial or just a huge garbage dump? All these questions stated above have already been discussed by Carlisle (1964)[2], Turner (1969)[13] and Unger (1966)[14]. Besides these, Fast (1974)[5] Kanayama (1973)[6], and Randall (1963)[10] have studied the efficiency of artificial reefs.

The main purpose of this field experiment was to evaluate the efficiency of the artificial reef by the application of the concrete model reef involving the selections of the most suitable type of construction and the best location for attracting more fishes.

MATERIALS AND METHODS

Model reef construction:

The concrete disc (i.e. Multiple disc sampling apparatus or MDSA) and the pyramidal frustrum (i.e., Multiple pyramidal-frustrum sampling apparatus or MPSA) adopted from Pearce (1968)[9] have been prepared by Chang, et al., (1977)[4] initially for the purpose of study on encrusted organisms. Each MDSA has an upper surface area of 0.0415 m^2, and each MPSA has an upper surface and four inclined faces, a total area of 0.1616 m^2. Thus, total surface area of a MPSA set (12 pieces of pyramidal-frustrum) makes up 2.34 times of a MDSA set (20 pieces of discs). Because pyramidal frustrum has concaved space underneath, it could provide more sheltering space for fishes.

The MPSA and MDSA were attached to the heavy weighed steel frames of 160 cm × 120 cm × 150 cm and 178 cm × 117 cm × 152 cm, respectively.

The study area:

The study area is about 100–200 m from Kuei-Hou Fishing Harbor (see Fig. 1) and is about half way between two artificial reefs previously cast in 1974 (Chang, 1976[3]) at the vicinities of Ta-Wu-Lun and Yeh-Liu (Fig. 1). The water at the study area is less polluted and less wave action.

Two sets of MPSA and MDSA was cast respectively at areas A on June 22 and July 31, 1975 and B (Fig. 1, inset) on July 1 and August 11, 1975 on a sandy bottom of 10–14 m deep in a vicinity of natural reef to avoid any disturbances by the local trawlers. A set of MPSA and MDSA at area A is located much

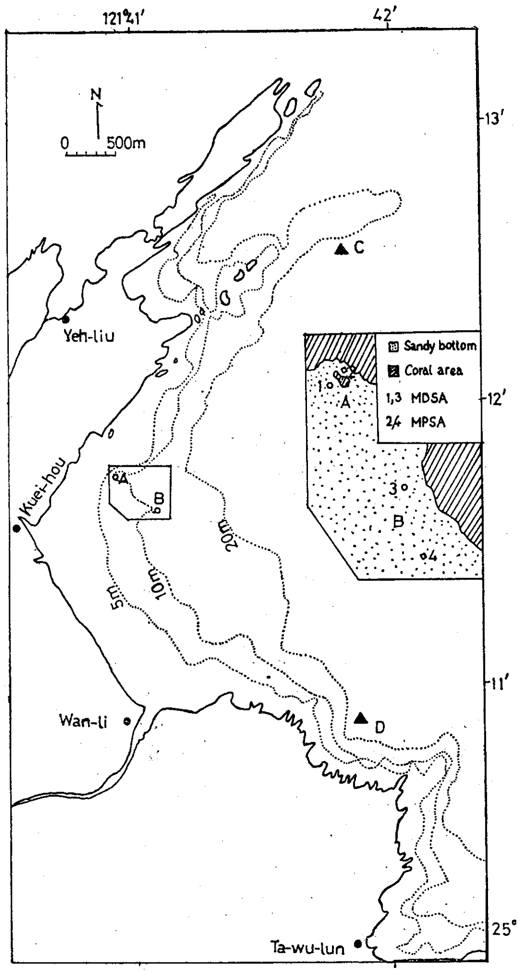

Fig. 1. Map of Wanli area showing the locations of the model reefs installed (A & B) and artificial reef (C & D). cast in 1974.

TABLE 1

Depth, locations, dates of installation and survey

Area	Units	Depth (Mean between high and low tide level, m.)	Distance from the nearest natural reef, ft.)	Installing date	Survey date			
					1	2	3	4
A	MDSA*	10	5	June 22,1975	Aug. 29,1975 (67)***	Oct. 4,1975 (102)	Jun. 24,1976 (367)	Aug. 15,1976 —
	MPSA**	10	6	Jul. 31,1975	Aug. 29,1975 (28)	Oct. 4,1975 (65)	Jun. 24,1976 (330)	Aug. 15,1976 —
B	MDSA	14	17	Jul. 1,1975	Aug. 30,1975 (60)	Oct. 6,1975 (95)	Jun. 20,1976 (355)	Aug. 1,1976 (397)
	MPSA	14	21	Aug. 11,1975	Aug. 30,1975 (29)	Oct. 6,1975 (64)	Jun. 20,1976 (334)	Aug. 1,1976 (376)

* MDSA: Multiple disc sampling apparatus.
** MPSA: Multiple pyramidal frustrum samplıng apparatus.
*** The number in the parenthes is the number of days after the installation of model reefs.

closer to the natural reef than the other set of MPSA and MDSA at area B.

General study method:

The biological observations rely entirely on SCUBA diving technique. The model reef were observed visually during each dive and each set took at least 30 minutes.

Four observations were undertaken during the period from August 29, 1975 to August 15, 1976 (Table 1). Unfortunately, this program was ended due to a diaster caused by typhoon on August 9, 1976 when the model reefs were destroyed.

Underwater observations and sampling included (1) depth, (2) bottom temperature, (3) number of fish species and their behaviors. The depth and bottom temperatures were taken by wrist gauges and horizontal water transparency by vision on every dive. The number and sizes of fish species as well as their behaviors were recorded on an opaque plastic slate. For the purpose of confirming species identification, the fishes were collected by speargun or by ichthyocide, NaCN. The bottom conditions and the creatures observed were photographed with 35 mm Nikonos II camera well as a 8 mm movie camera. The high resolution color films of Kodachrome II and Ektachrome X were being used for photographing.

OBSERVATIONS

Fourty-eight species of fishes were identified during the period of underwater observations. The biological observations are given in Table 2 and Figs. 2–7.

Survey 1:

Very few fishes and benthic invertebrates were found around the model reefs a month after the first submergence. Some Labriidae, Chaetodontidae and Serranidae (perhaps the nearby natural reef dwellers) were found swimming actively around the steel frames and the members of Parapercidae, Synodontidae, Lethrinidae, Mullidae and Pomadasyidae were occasionally seen to feed on smaller benthic invertebrates at the sandy bottom below the model reefs.

The topshells (*Tectus* sp.) were observed on upper surface of the pyramidal frustrum. This molluscan species was the largest invertebrates ever found during this observation. The juvenile *Plectorhynchus pictus* was hiding under the frustrum (Fig. 2) and *Centriscus capito* was pausing vertically along the steel

TABLE 2

Biological data on the fishes occurred around the model reefs MDSA and MPSA at areas A and B during the underwater surveying on August 29–30, October 4, 6, 1975; June 20, 24, August 1, 15, 1976

Species	Fish size (cm)	Species occurred: Area A MDSA	Species occurred: Area A MPSA	Species occurred: Area B MDSA	Species occurred: Area B MPSA	Behaviour noted during the day	Ecological groups
Synodontidae							
*Synodus variegatus**	8–10		R		O	Resting on the sandy bottom, hovering under the model reefs frequently	B
Saurida elongatus	6			R		As above	B
Monacanthidae							
*Navodon modestus**	28				R	A fish hovering through the model reefs	I
Ostraciontidae							
Ostracion cubiceps+	4				R	Hiding among the intersprces of model reef components	Rt
Tetraodontidae							
*Arothron alboreticulatus**	31				R	As above	Rt
*Canthigaster valentini**	2–3				R	As above	Rt
Fistulariidae							
Fistularia petimba+	11–20	R				Aggregating around the model reef frame	S
Centriscidae							
*Centriscus capito**	7				R	Pausing beside the model reef frame	S
Scorpaenidae							
*Dendrochirus zebra**+	8–11				O	Hiding among the model reef crevices	Rt
Scorpaenopsis sp.	13		R			Resting on the sandy bottom under the model reef	I
Platycephalidae							
Onegocia sp.	7				R	As *S. variegatus*	B
Chaetodontidae							
*Heniochus acuminatus**	4–8				C	Sheltering,feeding over and under MPSA	S
*Chaetodon aureus**+	7–9		O			As above	S
Pomacentridae							
*Pomacentrus coelestis**+	1.5–6	C	R			Swam around the model reefs	S
*Chromis notatus**+	3.5–5			R	O	Hover over the top of MPSA	S
*Abudefduf richardsoni**	2.5–3.5				O	As above	S
*A. vaigiensis**+	1–8		R		R	Aggregating over the model reefs when juvenile solitary and territorial when mature,	S

TABLE 2

Biological data on the fishes occured around the model reefs MDSA and MPSA at areas A and B during the underwater surveying on August 29–30, October 4, 6, 1975; June 20, 24, August 1, 15, 1976 (Continued)

Species	Fish size (cm)	Species occurred				Behaviour noted during the day	Ecological groups
		Area A		Area B			
		MDSA	MPSA	MDSA	MPSA		
Mullidae							
*Upeneus moluccensis**+	4–6			R	C	Schooling with damselfish over the model reefs when juvenile, feeding on the sand dwelling organisms under the reef when mature	S
*U. bensasi**	4–6	O			R	As above	S
*U. tragula**+	5–14	O			O	Grubbing the sand	B
Parupeneus indicus+	17–19	R	O	R		As above	B
Apogonidae							
*Apogon doederleini**+	1–3.5			R	O	Sheltering during the day	Rt
Serranidae							
*Plectropomus maculatus**+	12–18		O			Hovering around the model reefs or between the natural reef and the model reefs	S
P. leopardus	22			R		As above	S
*Diploprion bfasciatum**	3–21		R	C	O	Feeding actively under the model reef for a long period	S
*Epinephelus megachir**+	18				R	Eat fishes among natural reef crevices	S
*Cephalopholis pachycentron**	18			R		As above	Rt
Lethrinidae							
Lethrinus sp.	15–17				R	Hovering on the sandy bottom, under the model reef	B
Lutjanidae							
Lutjanus vitta+	5–20			O	R	As above but more abundant	S
Caesionidae							
*Pterocaesio diagramma**	10–12	R		O		Swimming frequently through the model reef	P
Pomadasyidae							
*Plectorhynchus pictus**	15–22			R	C	Sheltering under the model reef while young	S
*Scolopsis monogramma**	6–13	R	R	R	O	Hovering on the sandy bottom, under the model reef	B
S. vosmeri	5–9	R		R		As above	B

TABLE 2

Biological data on the fishes occurred around the model reefs MDSA and MPSA at areas A and B during the underwater surveying on August 29–30, October 4, 6, 1975; June 20, 24, August 1, 15, 1976 (Continued)

Species	Fish size (cm)	Species occurred				Behaviour noted during the day	Ecological groups
		Area A		Area B			
		MDSA	MPSA	MDSA	MPSA		
Echeinidae							
Echeineis sp.	28				R	Two individuals were observed to swim near the model reef	P
Parapercidae							
*Parapercis nebulosa**+	6–14	R	O			Resting on the sandy bottom, hovering under the model reef frequently	B
Blenniidae							
*Ecsenius namiyei**+	4–6			R	R	Resting on the model reef surface	Rt
*Dasson trosulus**	3–5	R	R	R	O	As above	Rt
Gobiidae							
Zonogobius semidoliatus	1.5–2				R	Inhabiting under the concaved side of pyramid frustrum	Rt
Bathygobius fuscus+	6	R				Resting on the model reef surface	Rt
Labriidae							
Halichoeres melanochir+	6–10	R	O	R		Came from the nearby natural reef, feeding around the model reef frame	S
*H. poecilopterus**+	5–14	O			R	As above	S
Stethojulis kalosoma+	5–12			R		As above	S
*Labroides dimidiatus**+	3–6	O	R		R	As above	S
L. bicolor+	3–5			O	R	As above	Rt
*Pseudolabrus japonicus**+	6–11		R		R	As above	S
Choerodon azurio	14–18			O		Hovering on the sandy bottom, under the model reef	B
Acanthuridae							
Acanthurus maculipus+	6–14	R	O	R	C	A school of 10 fish swam across the model reef but left when the diver approached	S
Prionurus microlepidotus+	4–8			R		As above	S

* Specimens collected during the study.
+ Specimens have been collected from the tidal pools in 1974. C, Common; O, Occasion; R, Rare; Rt, Residents; S, Semiresidents; P, Pelagic; B, Benthic; I, Indeterminate.

frames. Both species were using the model reefs as protective covers.

Survey 2:

In general, a slightly decline in the numbers of species and its abundance were observed. However, *Diploprion bifasciatus* and *Pterocaesio diagramma* were perhaps a new colonizers. The place with the highest species diversity was around the MPSA of the area B where the snappers *Lutjanus vitta* swam in the small groups of at least 20 individuals.

Survey 3:

The components of the model reefs were already encrusted with the numerous organisms. The filamentous hydroids were seen on the surface of MPSA at area B. Consequently, this would provide more favourable conditions to attract the juvenile fishes. Schools of the juvenile damselfish and goatfish were observed in the great numbers around the MPSA at area B. They fed on planktons during the day time and hid among the frustrums during the night time. On the other hand, these juvenile fishes were frequently preyed upon by *Epinephelus megachir* and *Dendrochirus zebra* (Fig. 3). It seems that the prey-predator relationship was already established within this new reef community.

Survey 4:

A moderate change in fish species was observed. The dominant species noted previously were replaced by at least 40 individuals of *Heniochus acuminatus* (Fig. 4 a–b) who were hovering over and under the MPSA. Fish fauna observed at the MDSA of the area B (Fig. 5) and both MDSA and MPSA of area A were rather poor (Fig. 6).

Based on Turner (1969)[13], fishes observed or collected from the model reefs were classified into four ecological groups, i. e., true residents, semiresidents of reef associations, pelagic and benthic of non-reef associations (Table 2). The true residents include *Ostraction cubiceps*, *Arothron alboreticulatus*, *Canthigaster valentini*, *Dendrochirus zebra*, *Apogon doederleini*, *Cephalopholis pachycentron*, *Ecsenius namiyei*, *Dasson trosulus*, *Zonogobius semidoliatus*, *Bathygobius fuscus*, *Labroides bicolor*. Semiresidents include *Fistularia petimba*, *Centriscus capito*, *Heniochus acuminatus*, *Chaetodon aureus*, *Pomacentrus coelestis*, *Chromis notatus*, *Abudefduf richardsoni*, *Upeneus moluccensis*, *U. bensasi*, *Plectropomus maculatus*, *P. leopardus*, *Diploprion bifasciatum*, *Epinephelus megachir*, *Lutjanus vitta*, *Plectorhynchus pictus*, *Halichoeres melanochir*, *H. poecilopterus*, *Stethojulis kalosoma*, *Labroides dimidiatus*, *Pseudolabrus japonicus*, *Acanthurus maculipus*

TABLE 3

The number of fish species and its percentages of 4 ecological groups.

Ecological groups	Area A		Area B	
	MDSA	MPSA	MDSA	MPSA
Reef associations:	(60.0%)	(70.6%)	(70.0%)	(76.6%)
Residents	2	3	4	8
Semiresidents	7	9	10	15
Non-reef associations:	(40.0%)	(23.5%)	(30.0%)	(20.0%)
Pelagic	1	0	1	1
Benthic	5	4	5	5
Indeterminates	0	1	0	1
Total species numbers observed	15	17	20	30

TABLE 4

Comparison of the number of fish species and individuals between areas A and B.

Survey date	Area A			Area B		
	MDSA	MPSA	MDSA+MPSA	MDSA	MPSA	MDSA+MPSA
1975, Aug.	11 (29)*	7 (30)	15 (59)	8 (31)	10 (48)	18 (79)
Oct.	5 (7)	7 (14)	11 (21)	8 (14)	6 (35)	12 (49)
1976, Jun.	4 (18)	11 (24)	14 (42)	5 (21)	18 (265)	19 (286)
Aug.	—	—	—	4 (58)	14 (198)	16 (256)
Mean	6.7 (18.0)	8.3 (22.7)	13.3 (40.7)	6.3 (31.0)	12.0 (136.5)	16.3 (167.5)

* Figures in parentheses indicate number of individuals counted.

and *Prionurus microlepidotus*. Pelagic fishes include *Pterocaesio diagramma* and *Echeineis* sp. Benthic fishes include *Synodus variegatus*, *Saurida elongatus*, *Onegocia* sp., *Upeneus tragula*, *Parupeneus indicus*, *Lethrinus* sp., *Scolopsis monogramma*, *S. vosmeri*, *Parapercis nebulosa* and *Choerodon azurio*. Besides the above groups, *Nayodon modestus* and *Scorpaenopsis* sp. are indeterminates Table 3 shows a remarkable efficiency of the model reef at area B in attracting more fishes than those at area A. Particularily, the MPSA of area B attracted 30 species wheareas MDSA of the area A attracted only 15 species during the entire period of observations.

TABLE 5

Comparison of the number of fish species and individuals between the types of model reefs.

Survey date \ Types of reef models	MDSA (total)	MPSA (total)
1975, Aug.	18 (60)*	17 (78)
Oct.	11 (21)	12 (49)
1976, Jun.	10 (39)	26 (289)
Aug.	—	—
Mean	13.0 (40.0)	18.3 (138.7)

* Figures in parentheses indicate number of individuals counted

The correlations among the fish abundance, the types of reef construction and the location of model reefs are given in Tables 4–5. The MPSA of any localities attract more species and numbers than those of MDSA. Both types of MPSA and MDSA at area B had attracted more fish species and more fish individuals than those at area A.

DISCUSSION

By the long range study of model reefs, the artificial reef may serve as a shelter, feeding ground and landmark for the fishes. This agrees with the conclusion of Russel (1976)[11].

The MPSA itself provides a favourable place for the fishes to avoid a strong current and wave action. Furthermore, it could be used to escape from the predators. On the contrary, MDSA does not serve the above goals. In comparison with the observations on the benthic organisms on model reefs (Chang, 1977)[4], the MPSA provided more surfaces for attracting epifauna than that of the MDSA. The MPSA at area B served as a landmark for the fishes (Russel, 1976)[11], even though its range is smaller than the adjacent natural reefs.

The artificial model reef served not only as a landmark for fishes but also as a tem-

Fig. 2. Area B showing juvenile *Plectorhynchus pictus* hovering under the MPSA, about one month after the installation.

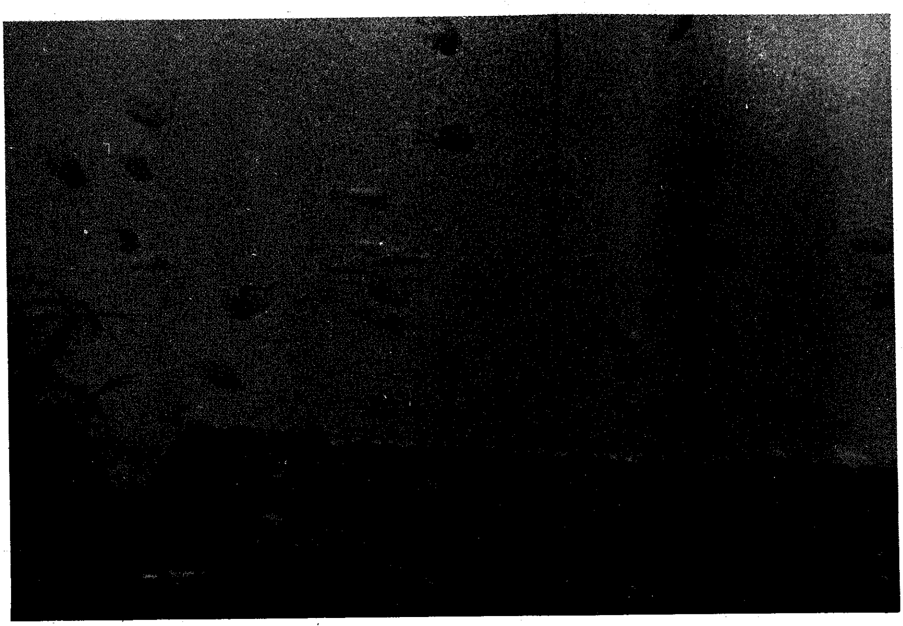

Fig. 3. Area B, showing *Chromis notatus*, *Abudefduf richardsoni*, *Upeneus moluccensis* and *Dasson trosulus* fed on the hydroid over the MPSA, a predator, *Epinephelus megachir*, hid on the reef side, 10 months after the installation.

Fig. 4. a, Area B showing some *Heniochus acuminatus* hovered over and under the MPSA, one year after the installation.

Fig. 4. b, Area B showing some *Heniochus acuminatus* hovered over and under the MPSA, one year after the installation.

Fig. 5. Area B showing a poor attraction of the MDSA, 13 montns after the installation.

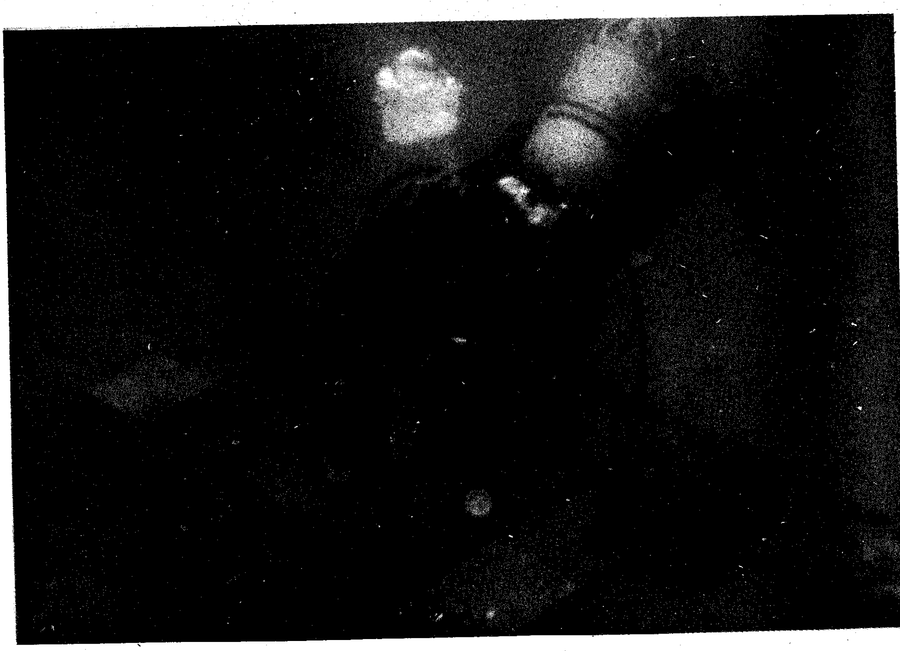

Fig. 6. Area A showing a poor faunal colonization around the MPSA, 11 months after the installation.

Fig. 7. Area B showing egg masses of squid deposited against the frame surfaces of the MPSA.

porary resting place. Some fishes may stay there as the environmental conditions favour them. The absence of the juvenile *Chomis notatus* (3.5–5.0 cm sl.), *Abudefduf richardsoni* 2.5–3.5 cm sl.) and *Upeneus moluccensis* (4.0–6.0 cmsl.) after August 1976 might be linked with their migration toward other larger shelters. Storr (1964)[12] suggested that the small reefs can only provide a space just enough for small fishes while larger shelters are headed for larger fishes to keep away strong wave action. Therefore, the disappearance of the above juveniles may be an action of looking for a larger shelter as they grow.

Ectone usually has a greater number of species and higher population density (Odum, 1971)[8]; therefore, it is easier for the isolated model reef installed at area B to form an ectone (or transition zone) rather than the adjacent natural reef.

Fluctuations in the fish species of model reefs seem to agree with the general patterns reported by Fast (1974)[5], Randall (1963)[10] and Russel (1976)[11]. The fishes appeared around the model reefs for the first time were almost exclusively semi-residents such as butterflyfishes, wrasses, surgeonfishes. These were thereafter gradually replaced by the true residents such as damselfishes, combtooth blennies, cardinalfishes, gobies, triggerfishes, ballonfishes and sea basses. There was no apparent changes in population size of non-reef associations during the whole period.

The spawning behavior of some fishes inhabiting artificial reef were reported by Ahr (1974)[1] and Klima (1971)[7]. Many eggs and larvae of the true residents such as *Apogon doederleini* and *Zonogobius semidoliatus* and juveniles of semiresidents *Diploprion bifasciatus* were collected around the model reefs. Several couples of shrimps (*Stenopus* sp.) and crabs (*Portunus* sp.) were also found mating on the structure of model reefs. Egg masses of squids were found once on the surfaces of the steel frames (Fig. 7). The egg masses of squids, crustaceans and fishes could further attract other species of fishes.

It is concluded that the MPSA is the most effective type of model reef and the model reefs installed farther away from the natural reef was more effective than that of the closer one. The artificial reefs can significantly increase the survival rate of juvenile commercial fishes or other smaller species of fishes and invertebrates and it can serve to conserve the fisheries resources.

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人 工 魚 礁 之 效 果 預 估

根據臺灣北端海岸模型實驗礁臺形成之魚類群社之研究結果

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由 1975 年 6 月～1976 年 8 月間所進行之模型礁臺實驗結果，可預估人工魚礁上動物羣社之發展過程，1975 年 6～8 月間曾安置各二組之水泥質圓盤 (MDSA) 及角錐臺 (MPSA) 於萬里鄉龜吼村附近沿岸水深 10～14 公尺的海底。嗣後經定期潛水觀察，攝影及採集，發現共有 23 科 48 種魚類活動於模型礁臺附近，其中約半數之種類未曾發現於潮間帶，且甚多種類屬經濟魚種。角錐臺所吸引之魚種無論種類及生物量概超越圓盤礁臺，可能是由於前者呈立體狀，俾供魚種有更大藏身之空間。此外尚發現遠離天然礁之模型實驗礁臺較接近者能誘引更多魚類，前者於安置一年後卽形成一個新的動物羣社。由本實驗結果，可推斷人工魚礁確有誘集魚類的效果。