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AN ASSESSMENT OF FISH COMMUNITIES OF ARTIFICIAL REEF STRUCTURES IN BRUNEI DARUSSALAM WITH RECOMMENDATIONS FOR MANAGEMENT AND DEVELOPMENT

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CONTENTS

A visual assessment of fish populations around artificial reef structures of Brunei Darussalam indicated that they supported a greater abundance and diversity of food fishes compared to the natural reefs. These artificial reef structures play potentially important roles in contributing to fish production and, in view of the downward trend in the number of artisanal fishermen, can be developed to eventually serve the needs of recreational fishermen. Effective management is important and necessary for long term success. Recommendations for further development of artificial reefs in the country are also given.

INTRODUCTION

Artificial reef structures have been recognised as important management tools to increase the productivity of barren coastal waters[1,2,3].

Brunei Darussalam is endowed with few natural reefs comprising several patch reefs scattered between 5 and 10 km from the coast, and 4 shoals further out at sea (Figure 1). Artificial reefs in Brunei seas consist of constructed tyre reefs and operational petroleum-related structures (drilling platforms and submarine pipelines) which act secondarily as artificial reefs. In addition, two disused oil rigs donated to the Department of Fisheries (DOF) by Brunei Shell Petroleum Company were sunk horizontally at Two Fathom Rock in August 1988[4].

Semi-quantitative surveys of the fish fauna were made at the tyre reef and oil rig/well-jacket (CPWJ No. 30) in 1987, two years after the tyre reef was constructed[5]. These results gave some indication of the function of these artificial structures as fish habitats. This current study represents a more quantitative survey of the fish populations at artificial habitats, with comparisons to natural reefs. Recommendations for management and further development of artificial reefs have also been proposed.

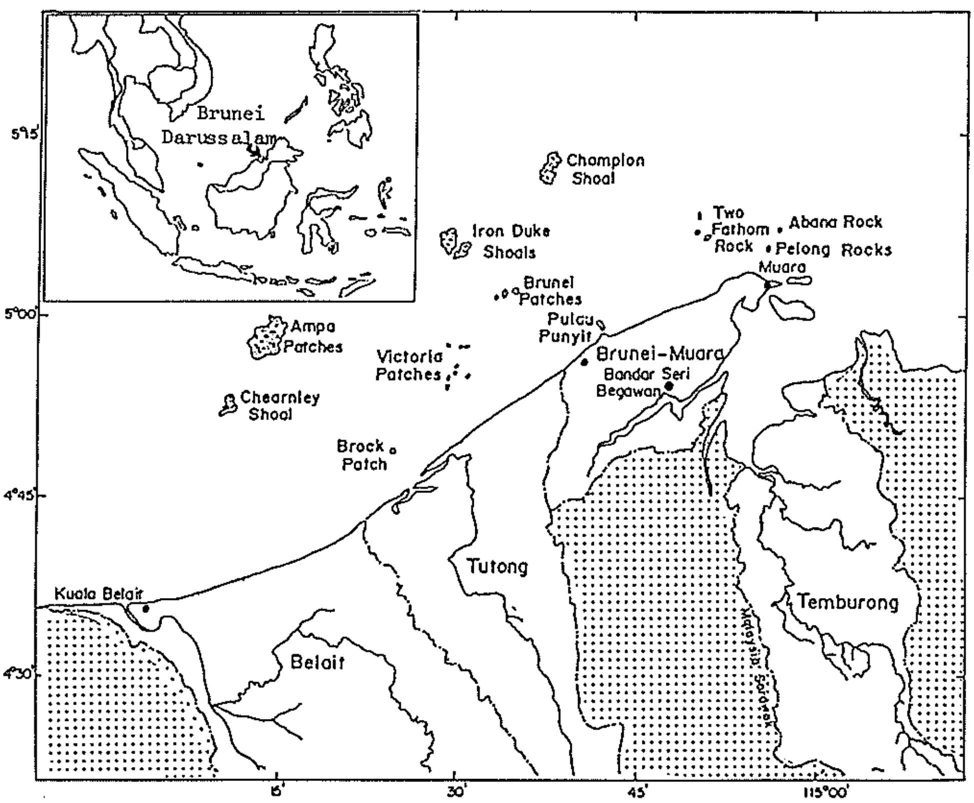

Figure 1 The seas of Brunei Darussalam, showing patch reefs and shoals. (Inset shows the location of Brunei Darussalam in S.E. Asia.)

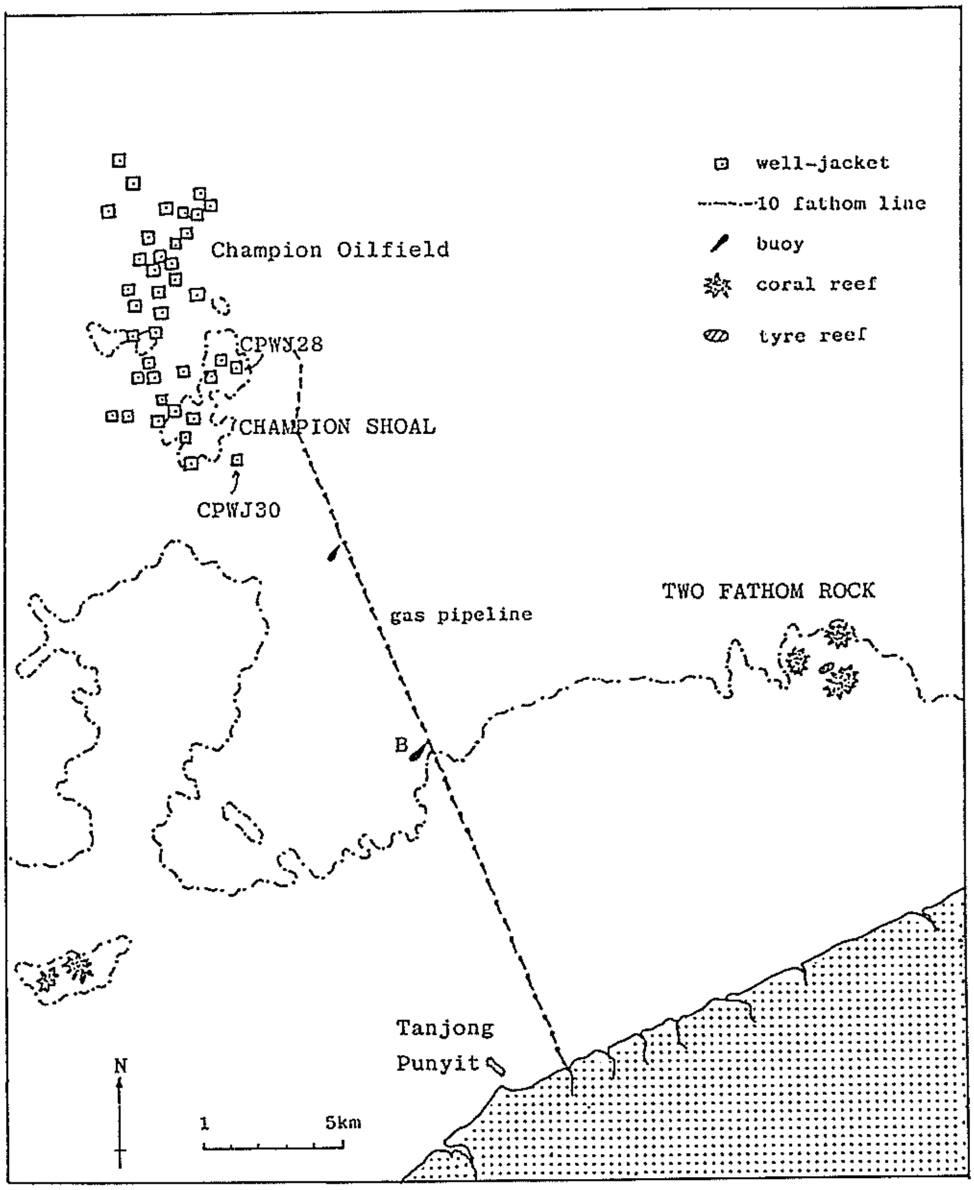

Figure 2 Location of survey sites.

DESCRIPTION OF SURVEY SITES AND METHODOLOGY

This survey was carried out in May 1990 using SCUBA. The nondestructive visual census method was employed and 9 censuses were conducted.

Brunei Darussalam's pilot artificial reef project was a low-profile 5000-tyre reef deposited at the southern portion of the sandy basin of Two Fathom Rock in 1985 (Figure 2). Yearly additions of 5000 tyres have brought the total number to over

16,000 tyres to date, covering an area of approximately 35,000 m^2 at 16.8 m depth. Each tyre module consists of 100 to 300 tyres strung loosely together by a rope running through them and anchored at both ends by concrete blocks. Their random deposition has resulted in units taking up a variety of configurations on the seafloor. The tyres were observed to be lightly encrusted with algae, tunicates, sponges, hydroids and gorgonians; free-living invertebrates (mostly anemones and echinoderms) and several colonies of hard corals (e.g. *Dendrophyllia* sp.). Thermoclines were experienced during two of the transects, 1 to 1.5 m above the seafloor and water in the cooler base-layer was turbid.

Several natural patch reefs, approximately 40–100 m from the tyre reefs in the sandy basin of Two Fathom Rock were surveyed. They were of low and flat profiles, with depths between 8.5 m and 14 m. Live coral cover ranged between 30 and 40%.

Two operational well-jackets of the Champion Oilfields, on Champion Shoal (30 km from shore, Figure 2) were chosen for survey. One of them, CPWJ30 was previously surveyed in 1987[5]. Each well jacket consists of a rectangular tower of tubes (12.5 m × 8 m) reinforced with crossbraces with main shafts of more than 1 m in diameter, and other tubes at 0.5 m in diameter. CPWJ30 stands in deeper waters of 27 m while CPWJ28 is located in shallower waters of 15 m. The shafts and tubes were completely and thickly encrusted with barnacles, hard and soft corals, tunicates, hydroids, sea-fans and algae. Other invertebrates observed on the structure included crinoids, sea-urchins, lobsters and an octopus. The rigs stood on similar substratum of basically coral rubble, with limited growth of hard corals and other reef organisms. Thermoclines were frequently experienced at the deeper oil rig (CPWJ30).

An attempt was made to survey the pipeline running from Champion Oilfields to Tanjong Punyit, but was aborted due to very poor visibility. One of its buoylines (marked 'B' in Figure 2) was surveyed instead. The marker buoy was located in 25 m depth waters and its chain was heavily encrusted with barnacles, hydroids, tunicates and algae. Several crabs and gobies were observed to live among these. A thermocline at 18 m depth reduced visibility of waters below it to less than 1 m. Attempts to locate the 2 disused oil rigs which were sunk horizontally at Two Fathom Rock were unsuccessful.

The tyre reef and natural patch reefs were surveyed using 100 m fish transects. At each reef, three fish transects were carried out. A 100 m measuring tape was laid on the substratum along which the divers would swim. Fish observed within 5 m on either side and above the divers were recorded, corresponding to a sea space of 5000 m^3 of habitat per transect. One of the three transects was a control, and laid over barren substratum adjacent to the reefs.

Vertical fish censuses were conducted for the 2 oil rigs and the marker buoy of the submarine line, with divers gradually ascending from the base of the structures towards the surface. For the oil rigs, fishes found within 5 m of the entire length of the rig structure were recorded while for the buoyline, fishes within 10 m of the line were estimated. This corresponded to a sea space of 8910 m^3 and 6075 m^3 for CPWJ30 and CPWJ28 respectively and approximately 7854 m^3 for the 25 m buoyline.

Actual counts were made for all fishes, except the more numerous families of fishes (e.g. Labridae, Pomacentridae, Caesionidae etc.), for which Log 4 abundance categories[6] were used. Size estimates (total length in cm) were made for target or food important species.

RESULTS

A total of 148 species of fishes from 31 families was recorded for both natural reefs and artificial structures. They comprised 65 target species, 9 indicator species (Chaetodontidae) and 74 species from other families (Table 1). Pomacentridae and Labridae were the most diversified families, with 23 and 22 species respectively. Other well represented families included Serranidae, Lutjanidae, Chaetodontidae, Acanthuridae and Scaridae.

Natural Patch Reefs

One hundred species were recorded from the patch reefs in Two Fathom Rock. The families Pomacentridae and Labridae were dominant, with large numbers of *Chromis* sp., *Pomacentrus* spp., *Thalassoma lunare* and *Halichoeres* spp. Seven chaetodontid species were recorded and food important fishes numbered 33 species. In terms of abundance, high counts were obtained for snapper *Lutjanus madras*, caesionids *Pterocaesio diagramma* and *Caesio teres*, acanthurid *Acanthurus mata*, scarid *Scarus schlegeli*, serranid *Cephalopholis pachycentron* and nemipterid *Scolopsis ciliatus*. The control transect (Visual Census No.2), of which 30 m was laid over a small patch reef and the remaining over sandy substrate, yielded fewer fishes.

Artificial Reef Structures

A combined total of 95 species of reef fishes was recorded for artificial reef structures, of which 46 species (48.4%) were food important species, including many high grade market fishes like groupers, trevallies and snappers.

Fish fauna at natural patch reefs and artificial structures were generally different, although the total number of species recorded at each differed only by 5 species. Among the target species, the families of Carangidae and Haemulidae were more diversified and abundant at the artificial reefs than at natural reefs. Although 9 each of grouper species were recorded for both natural and artificial reefs, those at the artificial reefs comprised larger species (like *Epinephelus* sp). This was also seen for snappers (Lutjanidae). In terms of abundance, schooling fishes were significantly more numerous at the artificial reefs than at the natural reefs. Approximately 55 individuals of the small snapper *Lutjanus madras* were counted at the natural patch reef, while 400–500 were recorded at the oil rigs. The fusilier *Pterocaesio diagramma* numbered 200 at the natural reef, but up to 600 at the oil rigs. In addition, large numbers of *Sphyraena flavicauda* juveniles were observed at the tyre reef, but absent at a nearby patch reef 50 m away.

Although both natural and artificial reefs were dominated by the families Pomacentridae and Labridae, both were more diversified at the natural reefs. Twenty-three

TABLE I

Summary of data from fish visual census for artificial reef structures (values indicate actual counts; estimated length of fishes shown in parenthesis (in cm)).

Habitat type Location Methodology Visual census no.	Natural patch reef Two fathom Rk 100m transects 1	 2 control	 3	Tyre reef Two fathom Rk 100m transects 4	 5 control	 6	Oil rigs CPWJ30 Vertical transects 7	 CPWJ28 8	Buoy line Buoy B1 Vertical transects 9
TARGET (FOOD IMPORTANT) SPECIES									
SERRANIDAE									
Cephalopholis argus	2(15–30)	3							
C. boenack	+	3				1(30)			
C. pachycentron	6(7–10)	3	12(8–15)	2(14, 15)		1(13)	2(15)		
Cephalopholis sp. 1			3(10–15)						
Cromileptes altivelis							1(35)		
Epinephalus caeruleopunctatus				+		1(35)			
E. fasciatus	2		4(15, 20)				2(40)	2(22, 15)	
E. morrhua							2(50)		
E. tauvina?			+	+		1(40)			
Epinephalus sp. 1							1(100)		
Plectropomus maculatus	6(18–30)	1	1(30)				1(40)	4(20–35)	
Labracinus cyclophthalma	2								
L. melanotaenia	3		9						
LUTJANIDAE									
Lutjanus bohar							16(20–45)		
L. carponotatus	1(15)					2(20, 22)			
L. decussatus	4(20)	2(25)	7(15–25)		1(20)			4(30)	
L. ehrengergii?							5(25–30)		
L. fulviflamma		4(40)							
L. johni? (*monostigmata?*)		1(40)				6(20)			
L. kasmira							10		
L. madras		55(15–20)		11(15–20)			400(20)		500+
L. gibbus			+						
Lujanus sp.1		3(30)		1(40)	3(25)	1(30)			

TABLE I (*continued*)

CAESIONIDAE									
Caesio teres	150+	18(25–30)		100+	15(30)	55(14–18)	12	150+	
Pterocaesio diagramma	200+			20+		18(15–20)	600+	300+	100+
P. tile			+						
CARANGIDAE									
Atule mate							1		300+
Caranx sexfasciatus									500+
Carangoides ferdau						+	2(60)		
C. fulvoguttatus					1(60)		1(50)		
Elagatis bipinnulata							6(40)		
Gnathodon speciosus		6(20, 25)					9(50, 60)		
Selaroides leptolepis									200+
SIGANIDAE									
Siganus corallinus		3							
S. guttatus				+		14(20–30)	7(30)		
S. javus							4(25)		
S. virgatus	+	2	4					2(25)	
LATIDAE									
Lates calcarifer				1(15)			1(30)		
SPHYRAENIDAE									
Sphyraena barracuda			1(100)	2(80)			2(80)		
S. flavicauda (juveniles)				700(20–30)					
HAEMULIDAE									
Plectorhynchus diagrammus							2(35)		
P. picus		5(30–35)		9(20–45)		11(20–30)	1(25)	1(40)	
P. pictus						1(30)	16(25–50)	5(30–40)	
NEMIPTERIDAE									
Pentapodus caninus								2	
Scolopsis bilineatus	6		10						
S. ciliatus	6	5	19	2	1	4			
S. dubiosus			4						
S. vosmeri						1			

(*continued on next page*)

TABLE I (continued)

MULLIDAE									
Parupeneus indicus	+								
P. multifasciatus? (*trifasciatus*?)			8				1	2	
P. tragula				+					
Parupeneus sp. 1	1(40)								
POMACANTHIDAE									
Pomacanthus annularis	2	2		1	1				
P. sexstriatus	+	1							
Centropyge vroliki	1								
EPHIPPIDIDAE									
Platax orbicularis							60		10
P. pinnatus							2		
DASYATIDAE									
Taeniura lymma						1(20)			
CARCHARHINIDAE							1		
KYPHOSIDAE									
Kyphosus bigibbus								19(25–30)	
INDICATOR SPECIES									
CHAETODONTIDAE									
Chaetodon baronessa	1								
C. kleinii	3		5						
C. octofasciatus	2	3	1						
C. speculum?			2						
C. trifascialis	1		1						
C. vagabundus								2	
Chelmon rostratus	2	2	3	2		2			
Coradion chrysozonus	2		1	+				3	
Heniochus acuminatus		5		3		1		2	

"+" indicates presence.

TABLE I *(continued)*

Habitat type	Natural patch reef			Tyre reef			Oil rigs		Buoy line
Location	Two fathom Rk			Two fathom Rk			CPWJ30	CPWJ28	Buoy B1
Methodology	100m transects			100m transects			Vertical transects		
Visual census no.	1	2 control	3	4	5 control	6	7	8	9
COMMON FAMILIES									
LABRIDAE									
Anampses melapterus			3*						
Bodianus diana							+	2*	
B. hirsutus	+								
B. mesothorax	2*		3*	+		2*			
Cheilinus diagrammus	1		3*					2*	
C. fasciatus	+								
C. chlorourus	2*		3*					1	
Choerodon anchorago			2*						
C. shoenleinii		2*				3*			
Coris gaimard	1		3*						
Coris variegata			3*				2*		
Gomphosus varius	1		2*						
Halichoeres dussumieri				+					
H. hortulanus			3*				2*	2*	
H. melanochir	3*		4*						
H. melanurus (*hoeveni*)	2*	1	3*	3*		+			
Halichoeres poecilepterus?				6*	+			2*	
Hemigymnus melapterus	3*		2*						
Labroides bicolor	+								
L. dimidiatus	3*	2*	4*	3*	1	2*	3*		
Stethojulis sp. 1				2*					
Thalassoma lunare	4*	3*	6*	3*	1	3*	7*	7*	
POMACENTRIDAE									
Abudefduf bengalensis			1					1	
A. coelestinus								2*	
A. saxatilis		3*						3*	4*
Amblyglyphidodon aureus		2*							
A. leucogaster							3*		
Amphiprion clarkii	2*	3*	3*						
A. ocellaris			2*						
A. perideraion	2*								
Chromis margaritifer	3*	5*	6*						
C. weberi			5*						
Chromis sp. 1	5*	5*		4*					
Chrysiptera cyanea	2*			1					
Dascyllus reticulatus	4*	4*	5*						
D. trimaculatus			2*						
Neopomacentrus taeniurus				6*		5*	7*	7*	
Neopomacentrus spp							7*	7*	3*
Paraglyphidodon melas	3*		4*						
P. nigroris	3*	3*	3*	2*		3*			
Pomacentrus albimaculus	3*	2*	5*	4*		3*			
P. coelestis	4*	4*	5*	+			4*		
P. lepidogenys	3*		2*						
P. littoralis	1								

"*": in log 4 abundance categories; "+" indicates presence.

(*continued*)

TABLE I (*continued*)

Habitat type	Natural patch reef			Tyre reef			Oil rigs		Buoy line
Location	Two fathom Rk			Two fathom Rk			CPWJ30	CPWJ28	Buoy B1
Methodology	100m transects			100m transects			Vertical transects		
Visual census no.	1	2 control	3	4	5 control	6	7	8	9
P. moluccensis	2*	2*	3*						
P. philippinus	+								
unidentified sp. 1	3*	3*							
unidentified sp. 2	4*	3*							
unidentified sp. 3		+							
OTHER FAMILIES									
ACANTHURIDAE									
Acanthurus dussumieri							3		
A. mata		4*		2		5			
A. olivaceus	1								
Ctenochaetus striatus	5		9	5				1	
Naso annulatus		3			7				
Naso brevirostris						7			
APOGONIDAE									
Apogon cyanosoma				+		7			
A. compressus				+		6*			
Cheilodipterus macrodon				+					
Apogon juveniles				4*		6*	+	+	
BALISTIDAE									
Sufflamen chrysoptera		5							
balistid sp.1	+						2	2	
BLENNIDAE									
Meicanthus grammistes			1						
GRAMMISTIDAE									
Diploprion bifasciatus		2							
MONACANTHIDAE									
Aluterus scriptus								1	
MUGILOIDIDAE									
Parapercis sp.	7		4	+		1			
PEMPHERIDAE									
Pempheris sp.	+						+		
SCARIDAE									
Scarus gibbus	+		4				1		
S. ghobban	+					2	1	2	
S. schlegeli	3		11						
S. prasiognathus	+		1			2			
S. bowersi?			2						
Scarus spp.		3							

(*continued*)

TABLE I ***(continued)***

SCOPAENIDAE				
Pterois sp.			1	
SYNODONTIDAE				
Synodus spp.	2	+		
TETRAODONTIDAE				
Arothron stellatus			1	1
A. inconditus?	1			
Canthigaster valentini		1		
ZANCLIDAE				13
Zanclus cornutus				
unidentified juveniles		6*		

"*": in log 4 abundance categories; "+" indicates presence.

Log 4 abundance category	Number of individuals
1	1
2	2 – 4
3	5 – 16
4	17 – 64
5	65 – 256
6	257 – 1024
7	1025 – 4096

species of pomacentrids and 18 species of labrids were recorded at the natural reefs, compared to the 11 species of pomacentrids and 13 species of labrids observed at artificial reefs. Butterflyfishes (Chaetodontidae), angelfishes (Pomacanthidae), surgeonfishes (Acanthuridae) and parrotfishes (Scaridae) were also more abundant and diversified in natural reefs.

Tyre reef Fifty-five fish species were recorded in the tyre reef. Five families which were particularly abundant were Sphyraenidae, Caesionidae, Haemulidae, Pomacentridae and Labridae. There was a significant number of target (food-important) species recorded. Besides the fusiliers and sweetlips, groupers (Serranidae), snappers (Lutjanidae), rabbitfishes (Siganidae) and thread-fin breams (Nemipteridae) were also well represented. The control transect (Visual census No. 5) yielded only 9 species of fishes, all within the first 10 m of the transect line nearest the tyre reef. These were *Caesio teres*, surgeon fishes *Naso annulatus* and snappers *Lutjanus* spp. No fish were reported over the remaining length of the transect.

Oil rigs A combined number of 61 species was recorded for both CPWJ30 and CPWJ28. The fish population at the deeper oil-rig CPWJ30 (41 species) was generally richer than CPWJ28 (25 species). Data collected showed that the deeper rig CPWJ30 supported greater numbers and larger-sized individuals than CPWJ28. Several species of target fishes were common to both rigs, including 2 fusiliers species, 2 haemulids, 1 *Epinephelus* and 1 *Lutjanus* species each. Stratification of fishes was observed only at CPWJ30, with large carangids (*Gnathodon speciosa*, *Carangoides* spp., *Elagatis pinnatulata*), barracudas and 60 batfishes occupying the mid-water column, and groupers, snappers, haemulids, siganids and *Lates calcarifer* occupying the lower water column (up to 12 m above the seafloor). The fish species recorded at CPWJ28 comprised more "reef-associated" species like *Zanclus cornutus*, *Arothron stellatus*, *Siganus virgatus* and smaller-sized species (e.g. groupers, Serranidae and snappers Lutjanidae). In contrast to the large numbers of fishes within and at the oil rigs, the immediate area of the oil rigs were generally much poorer with small labrids and pomacentrids.

Marker buoy line Eight species of fishes observed in mid-water around the chain comprised carangids *Caranx sexfasciatus* (lengths 30 cm), *Atule mate* and *Selaroides leptolepis* (lengths 25 cm); fusiliers *Pterocaesio diagramma* and snappers *Lutjanus madras* (lengths 20–25 cm). The schooling species were observed in large numbers of 300 to 500 for each species and were seen to circle the chain in two distinct layers: an upper layer of largely carangids and a lower layer of snappers. Ten batfishes (*Platax orbicularis*) and pomacentrids *Abudefduf saxatilis* and *Neopomacentrus* spp., were recorded near the surface, associated with the buoy.

DISCUSSION

Fish Diversity and Abundance

The listing of 148 reef fish species from 31 families in Brunei seas, although preliminary, is relatively good compared to the diversity reported in surrounding reefs 174 species on the East Coast of Malaysia[7], 137 in Bali, Indonesia[8]; 168 in Batangas, Philippines[9]; 76 in Singapore[10]. Fish families of Pomacentridae (23 species), Labridae (22 species), Serranidae (13 species) and Chaetodontidae (9 species) were well represented, and in terms of abundance, several species of caesionids, carangids, pomacentrids and labrids, *Lutjanus madras*, and *Sphyraena flavicauda* were significant.

Artificial reef structures in Brunei have increased the productivity of the barren areas in Two Fathom Rock and Champion Shoal. Barren sandy areas of Two Fathom Rock basin (see control transects) have been converted to highly productive areas and poorer fish populations on Champion Shoal enhanced by the oil rig structures.

Fish populations at the natural patch reefs differed from that at artificial structures, with a total of 100 species recorded at the natural reefs and 95 species at the artificial structures. In general, natural reefs supported fish populations with greater diversity and smaller-sized species while artificial reefs supported more food important and larger sized species.

The newly created habitats (tyre reef and oil rigs) situated near/on natural reef seem to attract potential colonisers by its lower competition, new and increasing source of food (as algae grows and other invertebrates establish themselves), ample shelter, thereby augmenting these natural reefs[2]. Comparatively low fishing pressure at Champion oil rigs and Two Fathom Rock may explain the presence of large individuals as the former is a restricted area and the latter being relatively unknown to the public.

This record of more species at the natural reefs than at the artificial reef structures (5 species in this study) was also reported by Fast[11] and Randall[12] in artificial reefs of South Puerto Rico (tyre reef) and Virgin Islands (concrete blocks) respectively. Fast[11], using visual census, recorded 74 species at natural reefs and 56 species at artificial reefs. The difference in species numbers for the natural and concrete reef recorded (rotenone collection) by Randall[12] was more contrasting, with 103 in the natural reef and only 55 species at the artificial reef.

Although comparison of the fish standing crop/biomass with other artificial and natural reefs is not possible in this paper, qualitative observations can be made. The 55 species recorded in the tyre reef during this study, 5 years after its establishment, is below the 81 species recorded in the then 2 year-old tyre reef in Dumagete, Philippines[13]. However, this could possibly be due to the richer fish fauna in that area.

Slight differences were observed in the fish populations of the various artificial reef structures. The oil rigs, especially the deeper rig (CPWJ30), attracted a greater diversity of larger-sized individuals than those at the tyre reefs. An earlier discussion attributed this to the clearer water and the absence of thermoclines[5]. However, a thermocline was present 3 m above the seafloor at CPWJ30 during this survey, indicating that thermoclines may not affect fish abundance as previously thought. It is possible that other factors like the larger shelter space of the rig structure, high productivity (encrusting algae and other invertebrates) and lower fishing pressure have contributed to this. Differences in fish fauna were also seen between the deep and shallow oil rigs (CPWJ30 and CPWJ28). Besides the obvious difference of depth, no inference can be made at this point.

Pelagic fishes have been known to aggregate around drifting objects and mid-water structures[14] and their presence at all the artificial reef structures was not surprising. However, the high biomass of these recorded at the oil rigs and marker buoy was quite unexpected. No conclusions can be made, however, from this one-time observation, but it seems possible that artificial reef structures which extends the whole water column are more attractive to these pelagics. The marker buoy and its anchor-chain evidently serve as an effective fish aggregating device (FAD) although fish diversity was low. Although the surface of the chain was heavily encrusted with barnacles and other invertebrates, these are probably not a source of food, as none of the fishes were seen feeding off the buoy-line. No direct observations were made at the underwater pipelines but large groupers have been reported along the sides of these pipelines (pers. comm. with DOF staff).

The earlier data collected in 1987[5] at the then 5,000 tyre reef and oil rig structure (CPWJ30) permits only superficial and qualitative comparisons to be made. The presence of fishes from all the growth stages from juveniles, semi-adults and adults show a trend towards more stable communities at both the tyre reef and oil rig CPWJ-30. Slight differences in the species composition was observed. In the tyre reef, an evident increase in *Plectorhynchus* species (sweetlips), while lutjanid and siganid species seem to have been replaced by other species of the same family. Fusiliers (Caesionidae), however, remained the most abundant target fishes. At oil rig CPWJ-30, a shift of the dominant group of fishes from pelagics (*Caesio* sp. and carangids) to more permanent species was observed. The diversity and abundance of groupers, sweetlips (size range 20–45 cm) and batfishes (*Platax orbicularis*) have also increased significantly, while snappers, which were not previously recorded, were present in considerable numbers (e.g. *Lutjanus madras*) and in large sizes. Previously recorded species of *Siganus* have been replaced by *Siganus guttatus* and *S. javus*. Continued monitoring is needed to determine whether these slight differences represent seasonal changes or species succession.

Recruitment and Colonization

An important observation in the artificial reefs is the presence of large numbers of juveniles and semi-adults at the tyre reef and oil rigs. These included juveniles of apogonids, *Sphyraena flavicauda*, *Neopomacentrus* and *Thalassoma* and some unidentified species (Table 1). This observation was also reported by Stone *et al.*[2] and Russell *et al.*[15]. Stone[2] attributed it to the reduced competition for unclaimed territories. Ogawa[16] suggested that well-planned artificial reefs do increase survival, growth levels and feeding efficiency of certain juveniles fishes. Juvenile fishes play important roles in the trophic relationship of the artificial reef, as consumers of algae growing on the surfaces of the artificial reef structures and a source of food for other species.

The similarity of some species (14 species) at nearby natural reefs and artificial reefs confirms that coral reefs are a source of colonizers of artificial reefs, either in the emigration of adult fishes or indirectly through the supply of juveniles. However, movement of fishes and consequently their dependency on the artificial structures, especially semi-resident and transient species, is still not established.

From this limited one-time observation, the classification of "resident", "semi-resident" and "transient", similar to that by Russell[15] is suggested. The families that appeared as resident species were the damselfishes (Pomacentridae), wrasses (Labridae), cardinal fishes (Apogonidae), groupers (Serranidae) and seabasses (Latidae). The semi-resident fishes on the artificial reefs are identified by their movement in a larger "territory" which might have included the artificial reef. Most of the target fishes (Lutjanidae, Haemulidae, Mullidae, Siganidae) and others like surgeonfishes (Acanthuridae), parrotfishes (Scaridae), angelfishes (Pomacanthidae), sea-chubs (Kyphosidae) and several species of wrasses (Labridae) are likely to be semi-resident species. Several fishes were observed to swim in and out of the artificial reef area, probably using it as a temporary refuge and/or a point of reference. These included the larger fishes like the barracuda *Sphyraena barracuda*, trevallies (*Caranx* spp., *Carangoides* spp. and *Gnathodon speciosus*) and a shark; and pelagics (*Pterocaesio diagramma*, *Caesio teres*, *Atule mate* and *Elagatis bipinnulata*), batfishes (*Platax* spp.) and snappers (*Lutjanus madras*). It is still unclear if these are semi-residents or transient/nomadic fishes.

Artificial Reef Management and Development

In the initial stages of artificial reef colonisation, the newly deployed structures merely act as FADs, resulting in no actual fish biomass increase in the area. Given a longer term, colonisation and ecological succession of these structures by a variety of encrusting organisms provide the elements for the development of these structures into proper marine habitats serving the needs of fishes for food, shelter and reproduction. Only then can artificial structures contribute significantly towards the generation of fish biomass, as they in effect become fully-established, newly-created marine habitats.

Proper management is important, without which fishery stocks will only be depleted by the increased catchability at initial stages of fish colonisation. With proper management, the artificial reefs deployed and the submarine structures already present will eventually enhance the fish productivity in the coastal waters of Brunei, as they develop towards stable, self-propagating marine communities and can serve as long term management tools.

In view of the declining number of artisanal fishermen, a trend which appears unlikely to be reversed[17], artificial reefs can be developed to serve the needs of recreational fishermen and thereby encourage sport fishing as a recreational activity, in the long term. Since natural reefs are few in the waters of Brunei Darussalam with those currently subjected to fishing pressures having smaller populations of food fish[18], they can be relieved and allowed to develop to retain their high biodiversity. With proper management, they can be conserved as a resource to attract SCUBA divers and tourists.

The present observations should be supported with more data to provide important inputs towards the formulation of an effective management plan. There is a need to know the optimum rate at which fish can be removed from these structures. Data on fish productivity/yield (biomass per unit area/volume), food relationships, recruitment and growth rate, fish movement, seasonal fluctuations, gear efficiencies (hook and line and fish traps) are further necessary information on which a management plan can be developed.

Further development of the tyre reef at Two Fathom Rock is a possibility as there is still a large expanse of seafloor space. Consideration should be given to the use of tyre pyramid modules which provide a higher profile and will extend above the thermoclines. Such tyre reefs can also be developed in other areas with similar features and at the same or even shallower depths of 11 m (6 fathoms) which will bring them closer to shore (average 6 km). New areas to be developed should preferably be located near patch reefs such as at Pelong Rocks, Scout Patches and Victoria Patches, so that they serve as extensions of reef habitat space and in the long term, can also support settlement and growth of hard corals. Other patch reefs further offshore can also be used but cost considerations because of the distance must be taken into account.

Disused oil rigs can be located in depths of 18 m to 22 m and with the broader side resting on the seafloor will extend 8 m above the seafloor. Sites selected will have to be away from navigational channels. Their size and structure allow them to be sited away from existing patch reefs as they are excellent substrata for quick settlement and rich growth of encrusting organisms within a short time, which serve to attract many species of fish. However, it is important to locate and make direct observations on the sunken oil rigs at Two Fathom Rock in order to determine their role in contributing to fish productivity. The present study makes an extrapolation from the standing rigs and may miss out on factors which direct observations can identify. Such information will be important in determining future locations. The placement of disused oil rigs within the 3-mile limit (from shore) from which trawling activities are prohibited, will also discourage errant trawler operators from operating in this zone.

Data from the Department of Fisheries indicate that the great majority of fishermen (both full-time and part-time) operate from the Brunei-Muara District. It would thus be logical to establish artificial reefs closer to this district initially. Site selection studies are required to determine the suitability of identified sites for artificial reef establishment.

Limitations

It must be emphasised that the present study which gives fish abundance and composition data is based on one-time observations and is insufficient to determine fish population dynamics, productivity and stability at artificial reef structures. The fish listing given is a preliminary one, as cryptic and diurnal species may have been omitted due to the inherent bias of the visual census method. Fish biomass/standing stock was not determined from fish transects in this paper as 'k' values of fish species have not been obtained for calculation using the formula $W = kL^3$[19].

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