CHAPTER III

RESULTS

1. Description of the 1991 Bleaching Event

1.1 Extent of the Event

Following the onset of bleaching in late May 1991 and subsequent establishment of field survey in Phuket, Phangnga, and Krabi provinces, the spreading area of this phenomenon was evidently shown. The survey revealed synchronous and conspicuous bleaching of coral reefs along the Andaman coast of Thailand. Estimation of the area affected was at least within the 3,000 square kilometers. Neither the initial time nor total area of bleaching were exactly known. It was strongly believed, however, that the area affected was more widespread.

On 26 May 1991, prior to the first notice of bleaching in Phuket, but within roughly the same period, an extensive bleaching was noticed in one coral community developed in the vicinity of a seagrass and mangrove area at Ko Ra, Ranong province (Fig 1: site 14). In this case, at first, it was believed that the corals could be stressed and vulnerable to bleaching by the discharge of fresh water, as it happened in the rainy season. However, the seawater temperature measured during flood tide around that area was uniformly and abnormally high (32 ^{0}C), whereas the salinity measured at the same time was normal (31 ppt.). The abnormally high temperature was the same as that recorded elsewhere within bleached reefs of Phuket, Phang-nga and Krabi provinces, ranging from 30^{0}C to 32^{0}C (Table 1). Even though, up to this time, no information confirmed whether bleaching had occurred throughout various reefs (i.e. Surin Islands group and Similan Islands group) in Ranong province. Notwithstanding, if bleaching at Ko Ra was assumed to coincide with the event in Phuket-Krabi

Table 1 Records of 1991 bleaching at some selected sites along the Andaman coast of Thailand.

Date	Reef sites	Depth (m.)	Temperature (C)	Visual estimation of % affected	Remark	
20 May	Maithon Is.	3-15	nd	-	no bleaching observed	
26 May	Ra Is.	1-3	32	20-30%	-	
30 May	PMBC	0	nd	40-50%	-	
25 June	Bon Is.	3-8	31.7	30-40%	-	
25 June	Kacow Is.	3-6	31.5	20-30%	-	
25 June	Hae Is./N	1-5	31.8	40-50%	-	
25 June	Hae Is./S	3-6	31.7	30-40%	-	
25 June	Loan Is./E	1-4	31.8	30-40%	-	
25 June	Loan Is./S	2-4	31.7	30-40%	-	
25 June	PMBC/W	1-5	31.5	60-70%	-	
26 June	Ell Is/N	2-6	31.5	40-50%	-	
26 June	Ell Is/NW	1-6	31.5	40-50%	-	
26 June	Racha Yai Is./N	3-10	31.5	10-20%	-	
26 June	Racha Yai Is./E	3-8	31.7	10-20%	-	
28 June	Maithon Is./W	3-10	31.7	20-30%	-	
28 June	Maithon Is./E	3-7	31.7	10-20%	-	
28 June	Dokmai Is.	4-25	31.7	30-40%	-	
28 June	Khai Nok Is.	2-4	31.7	60-70%	recently dead	Acropora
5 July	Racha Yai Is./E	6	31.5	10-20%	-	
8 July	Phi Phi Don Is.	5	31.5	40-50%	-	
8 July	Phai Is.	2-6	31.5	20-40%	-	
9 July	Damkwan Is.	1-4	31.5	20-30%	-	
10 July	Hong Is.	4	31.7	40-50%	-	
11 July	PMBC/W	0	nd	40-50%	-	
16 July	Hae Is./N	2-3	30.2	40-50%	-	
19 July	PMBC/S	1-3	30.8	30-40%	recently dead	Acropora
29 July	PMBC/W	1-4	30.6	30-40%	recently dead	Acropora
31 July	Loan Is./E	2-3	30.5	20-30%	recently dead	Acropora
1 August	Maithon Is./W	3-6	30.5	20-30%	-	
1 August	Maithon Is./E	3	30.5	10-20%	-	
1 August	Dokmai Is.	4-25	30.5-30.2	30-40%	-	

then the expected range of bleaching could span approximately 1.7 degrees of latitude (187 kilometers).

Records of bleaching encompassed a wide range of environments, ranging from shallow nearshore fringing reefs in highly turbid neritic water to deeper offshore reefs (up to 25 meters) in slightly clear oceanic water.

1.2 Severity of Bleaching and Species Affected

The response of corals to the bleaching event was found to be of all degree of bleaching, for instances completely bleached, partially bleached, and normal. The bleached appearance as faint shades of brown or stark white, is due to the underlying white calcareous skeleton becoming visible through the translucent tissues (Plates I-V).

The amount of bleaching observed on different reefs varied considerably. By visual estimation, the percentage of living coral bleached ranged between 10 to 70 per cent of the total living coral covering on reefs (Table 1). This may be site-specific, depending in part on the community structure and sensitivity of the dominant coral species in the community.

Reef cnidarians affected by bleaching during the summer of 1991 included scleractinians, hydrocorals, octocorals, zoanthids and sea anemones. A total of 94 taxa from 105 of these organisms were recorded to have bleached conditions (Table 2). Since, identification was sometimes not possible beyond the genus level, the actual number of species subjected to bleaching might be substantially higher.

The major bleached species, list in Table 2, included the most frequently affected species at the sites. Among these, *Acropora* spp. were found to be the most susceptible species between sites while the others, such as *Pectinia* spp., *Montipora* spp., *Fungia* spp., *Pavona* spp., *Pocillopora* spp. and favids were found more affected at certain sites (Fig. 4).

Table . Record of responses to bleaching of corals and other reef biota during bleaching in the summer of 1991 along the Andam coast of Thailand. The data were derived from 10 line transect assessment within 8 locations including PMBC reef site, Loan Is., Hae Is., Racha Yai Is., Dokmai Is. ,Phi-Phi Don Is., Damkwan Is., and Hong Is. The additional records of other bleached species (*) were derived from field observation. The different degree of response of corals to bleaching included normal (N), partially bleached (PB), and completely bleached (CB).

Taxa	Number of Colonies	Responses N (%)	PB (%)	CB (%)	Total Affected (%)
Scleractinian corals					
Pocillopora damicornis	51	49.0	13.7	37.3	51.0
* *P. eydouxi*	-	-	-	x	-
* *P. meandrina*	-	-	-	x	-
P. verrucosa	9	0	33.3	66.7	100
Acropora aspera	3	66.7	0	33.3	33.3
A. austera	12	33.3	16.7	50.0	66.7
A. clathrata	2	0	0	100	100
A. divaricata	21	19.0	28.6	52.4	81.0
A. florida	36	5.5	80.6	13.9	94.5
A. formosa	161	23.0	11.2	65.8	77.0
A. humilis	13	23.0	38.5	38.5	77.0
A. hyacinthus	40	22.5	42.5	35.0	77.5
A. nasuta	4	50.0	0	50.0	50.0
A. nobilis	18	22.2	16.7	61.1	77.8
A. palifera	14	35.7	28.6	35.7	64.3
* *A. pulchra*	-	-	x	-	-
A. sarmentosa	3	66.7	0	33.3	33.3
A. squarrosa	4	0	50.0	50.0	100
A. subulata	3	0	33.3	66.7	100
Acropora spp.(branching)	38	28.9	29.0	42.1	71.1
Acropora spp. (colymbose)	17	11.8	5.8	82.4	88.2
Acropora spp. (tabulate)	7	14.3	14.3	71.4	85.7
* *Astreopora spp.*	-	-	-	x	-
* *Montipora crassituberculata*	-	-	-	x	-
* *M. digitata*	-	-	x	x	-
* *M. efflorescens*	-	-	-	x	-
Montipora spp. (encrusting)	40	67.5	17.5	15.0	32.5
Montipora spp. (foliaceous)	149	71.8	12.1	16.1	28.2
Montipora spp. (massive)	3	33.3	0	66.7	66.7
Montipora spp.(mixed forms)	28	64.3	32.1	3.6	35.7

Table 2 (continued)

Taxa	Number of Colonies	Responses N (%)	PB (%)	CB (%)	Total Affected (%)
Coeloseris mayeri	31	87.1	12.9	0.0	12.9
* *Gardineroseris planulata*	-	-	-	x	-
Pachyseris spp.	7	42.9	42.9	14.2	57.1
Pavona cactus	8	100	0	0	0
P. clavus	16	6.2	43.8	50.0	93.8
P. decussata	28	85.7	14.3	0	14.3
P. explanulata	13	76.9	0	23.1	23.1
P. varians	7	57.1	42.9	0	42.9
P. venosa	3	33.3	66.7	0	66.7
Pavona sp.	2	100	0	0	0
Psammocora digitata	3	0	0	100	100
Psammocora spp.	23	87.0	13.0	0	13.0
Fungia echinata	2	50.0	0	50.0	50.0
Fungia spp.	46	32.6	13.0	54.4	67.4
Herpolitha limax	6	0	0	100	100
Polyphyllia sp.	2	50.0	0	50.0	50.0
Lithophyllon edwardsi	2	50.0	0	50.0	50.0
Podabacia crustacea	7	100	0	0	0
Stylocoeniella sp.	1	0	0	100	100
* *Alveopora sp.*	1	100	x	x	0
Goniopora spp.	23	60.9	26.1	13.0	39.1
Porites annae	3	100	0	0	0
P. cylindrica	1	100	0	0	0
* *P. lobata*	4	100	x	x	0
P. lutea	262	75.2	19.5	5.3	24.8
P. nigrescens	60	33.3	33.3	33.4	66.7
Porites spp. (massive)	19	15.8	21.0	63.2	84.2
Porites sp. (encrusting)	1	0	0	100	100
Porites sp. (branching)	1	100	0	0	0
Synaraea rus	98	53.1	25.5	21.4	46.9
Cyphastrea spp.	21	47.6	23.8	28.6	52.4
Echinopora gemmacea	5	60.0	0	40.0	40.0
Echinopora sp.	2	50.0	50.0	0	50.0
Diploastrea heliopora	9	100	0	0	0
Favia stelligera	3	0	33.3	66.7	100
Favia spp.	14	28.5	28.6	42.9	71.5
Favites abdita	11	18.1	45.5	36.4	81.9
Favites spp.	19	31.6	57.9	10.5	68.4
Goniastrea pectinata	16	18.8	25.0	56.2	81.2
G. retiformis	2	0	0	100	100
Goniastrea spp.	4	25.0	50.0	25.0	75.0

Table 2 (continued)

Taxa	Number of Colonies	Responses N (%)	PB (%)	CB (%)	Total Affected (%)
Leptastrea spp.	5	100	0	0	0
Leptoria phrygia	1	0	100	0	100
Montrastrea spp.	5	60	20	20	40
Platygyra spp.	10	40.0	30.0	30.0	60.0
* *Oulophyllia crispa*	-	-	-	x	-
Galaxea astreata	1	0	0	100	100
G. fascicularis	11	72.7	0	27.3	27.3
Hydnophora exesa	2	50.0	50.0	0	50.0
H. microconos	5	20.0	40.0	40.0	80.0
H. rigida	15	20.0	53.3	26.7	80.0
Merulina ampliata	21	0	33.3	66.7	100
Acanthastrea sp.	1	0	0	100	100
* *Australomussa rowleyensis*	-	-	-	x	-
Lobophyllia spp.	8	0	62.5	37.5	100
Symphyllia spp.	9	33.0	33.0	34.0	67.0
Echinophyllia spp.	8	25.0	25.0	50.0	66.7
Mycedium elephantotus	3	0	0	100	100
* *Oxypora spp.*	-	-	x	x	-
Pectinia spp.	40	5.0	47.5	47.5	95.0
Euphyllia glabrescens	1	0	0	100	100
Physogyra lichtensteini	1	0	0	100	100
Plerogyra sinuosa	2	50.0	0	50.0	50.0
Turbinaria sp.	2	50.0	50.0	0	50.0
<u>Hydrocorals</u>					
Millepora sp. (branching)	2	50.0	0	50.0	50.0
Millepora sp. (columnar)	3	100	0	0	0
<u>Octocorals</u>					
Heliopora coerulea	6	100	0	0	0
Lobophytum sp.	21	52.4	47.6	x	47.6
Sarcophyton sp.	3	0	0	100	100
* *Sinularia spp.*	-	-	-	x	-
Nephthea sp.	5	100	0	0	0
Dendronephthya sp.	1	100	0	0	0
Xenia sp.	1	100	0	0	0
Subergorgia sp.	1	100	0	0	0
* *Rhumphella sp.*	-	-	x	-	-
Junceella sp. (whip form)	11	100	x	x	0
<u>Zooanthids</u>					
* Palythoa sp.	1	100	0	x	0
<u>Sea anemone</u>					
* Entacmaea quadricolor	-	-	-	x	-
<u>Sponges</u>	24	100	0	0	0
Total	1692	48.8	22.3	28.9	51.2

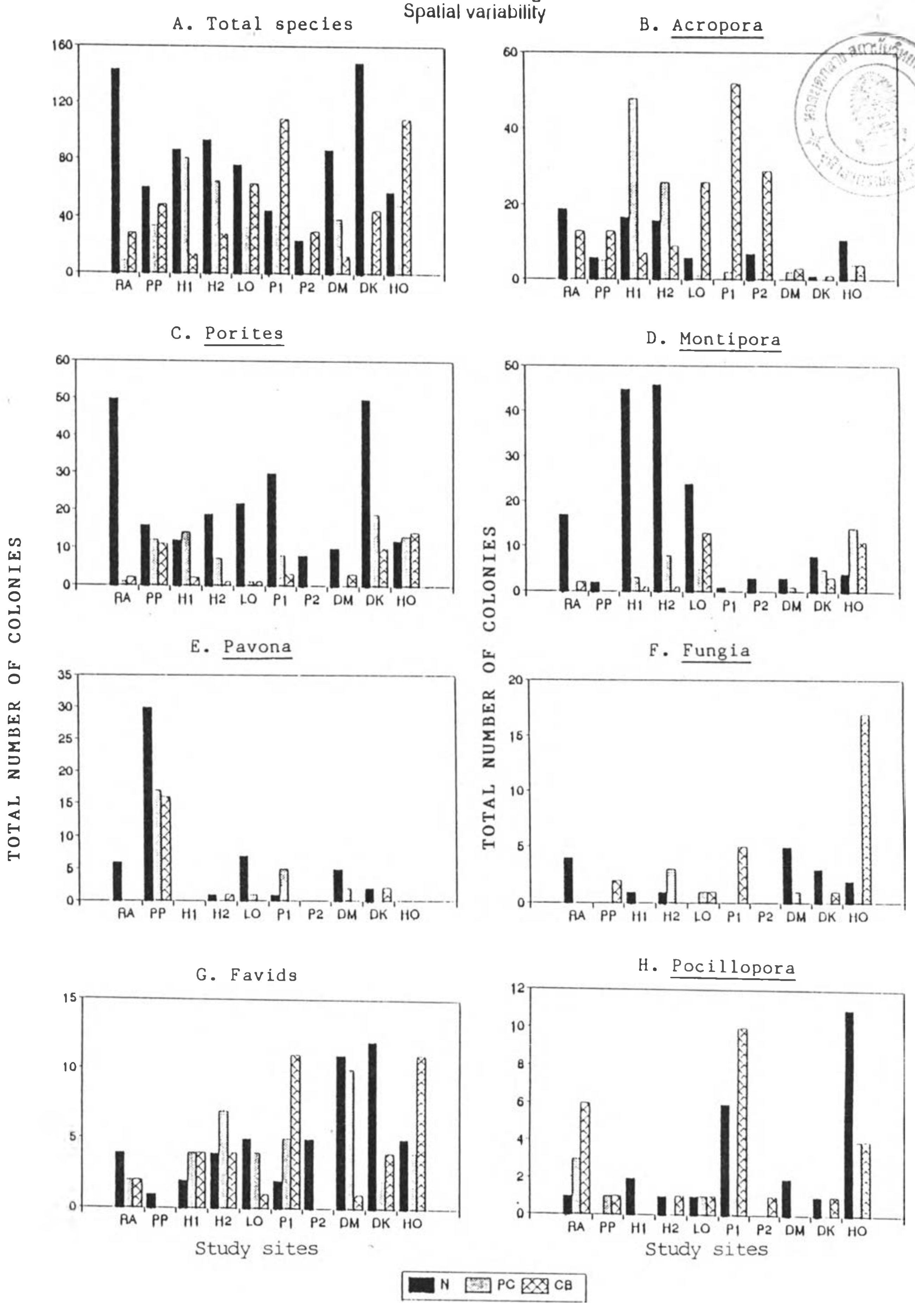


Fig. 4. Spatial variation of bleaching responses: normal (N), partial bleaching (PB), and complete bleaching (CB), A) total coral species and B-H) major taxa concerned.

Bleaching in different coral species was extremely variable; the response might even vary over an individual colony. Some species, no consistent pattern of bleaching response between locations and/or colonies were found. The prominent case, in *Porites lutea*, partially bleached, completely bleached and unbleached colonies were usually found together in one location, even side by side, and the proportion of each bleaching pattern among locations showed markedly different.

In almost all cases, it was noticed that partially bleached corals had lost coloration only on the upper surface and not where they were shaded. For instance, in partially bleached branching corals, such as *Acropora* spp., *Pocillopora* spp. or foliaceous corals such as *Montipora* spp., *Pavona* spp., the under surface of branches and leaves retained their normal color. On the uppermost surfaces, differences of responses were also recognized. Obviously, in partially bleached massive *Porites* spp., the downward curved surfaces or ridges were white while the nearby upward curved surfaces or grooves remained normal or slightly pale.

Considerable coral mortality was observed during the resurvey of some reefs within only one and a half months after the onset of bleaching. This was obviously evidenced for the sensitive branching species of genus *Acropora* and *Pocillopora*. At the same time, the sign of recovery was also observed in some coral species, particularly in the partially bleached massive colonies of the genus *Porites*. Dead zones observed over several coral colonies were patchy distributed. Shaded or less exposed surfaces usually found recovered among the dead zones of exposed surfaces.

Quantitative assessment of corals at 10 selected reef sites revealed spatial variation of bleaching responses (Table 3). The assessments were varied by 2-3 months after the onset of bleaching in late May. The coverage of live corals affected by partial bleaching and complete bleaching ranged from 2.3% to 37.8% and from 1.8% to 30.1%, respectively. The recently dead corals caused by the event varied from 0-31.5 % of coverage.

Table 3 Coverage and responses of corals following bleaching event at selected reef sites in the Andaman Sea. Data were assessed on 100 meters trasect length except those from Dokmai Is. and PMBC (South) sites which an assessment was performed on 37 and 15 meters transect, respectively. Figures in parenthesis show number of coral colonies. (data was mainly supplied by Niphon Phongsuwan)

Location	Date	Bleaching Responses				Pre-bleaching condition		
		Normal corals	Partially bleached corals (%	Completel bleached corals (%)	Dead bleached corals (%)	Dead corals (%)	*Living corals (%)	Dominant corals
Racha Is.	5/7/91	31.88 (144)	2.69 (9)	6.11 (29)	0.00 (0)	27.44	40.68	*Acropora spp., Porites lutea*
Phi Phi Is.	8/7/91	29.12 (61)	14.00 (34)	23.27 (40)	2.65 (9)	30.96	69.04	*Synaraea rus, Acropora spp. Porites nigrescens*
Damkwan Is	9/7/91	43.60 (149)	12.35 (32)	4.43 (33)	2.95 (12)	35.17	63.33	*Porites lutea, Acropora spp.*
Hong Is.	10/7/91	15.79 (58)	18.95 (49)	25.28 (87)	8.34 (22)	31.24	68.36	*Acropora spp., Porites lutea*
Hae Is. (upper zone	16/7/91	41.22 (87)	37.83 (81)	1.85 (8)	1.85 (6)	17.25	82.75	*Montipora spp., Acropora spp*
Hae Is. (lower zone)	16/7/91	36.96 (94)	32.00 (65)	4.21 (20)	2.63 (8)	24.20	75.80	*Acropora spp., Porites lutea, Montipora spp.*
PMBC (west)	19/7/91	16.00 (24)	2.27 (2)	30.13 (15)	22.06 (15)	27.87	70.46	*Acropora spp.*
PMBC (south)	29/7/91	15.42 (45)	7.17 (34)	11.92 (51)	31.47 (58)	30.17	65.98	*Acropora spp., Porites lutea*
Loan Is.	31/7/91	30.12 (76)	8.06 (33)	5.07 (26)	15.67 (37)	40.48	58.92	*Acropora spp., Porites lutea*
Dokmai Is.	2/8/91	23.94 (83)	17.72 (39)	12.60 (10)	1.10 (3)	44.40	55.36	*Mixed species, Galaxea spp., Favites sp., Porites spp., Goniopora sp, Octocorals*

*Remark: Percentage live-coral cover during pre-bleaching period was predicted by summing up the coverage values of normal, partially bleached, completely bleached, and dead bleached corals.

1.3 Causative Factors

In situ temperature measurements at various localities during the field survey in June 1991 showed consistently abnormally high temperatures ranging from 30^{0}C to 32^{0}C (Table 1). Seawater temperature was also consistently high along a depth gradient from near surface down to at least 25 meters depth.

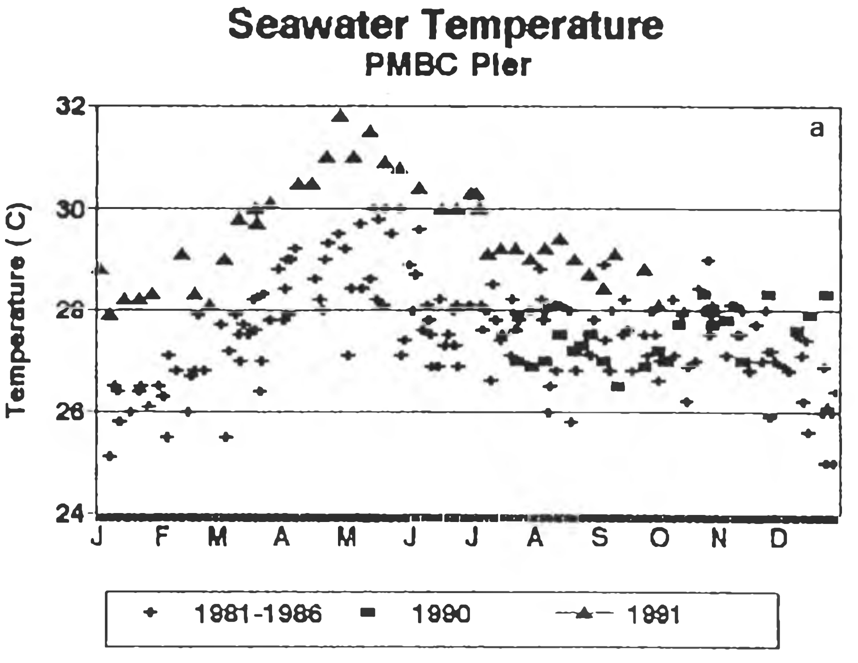
Examination of available seawater temperature data at the PMBC pier showed obvious anomalies prior to and during the summer of 1991 compared with the normal trend of 1981-1986 (Fig. 5). In 1990, after September, rather than normal decrease, records showed that temperature tended to be higher than the records of the former six-years data and even clearly evidenced of higher records in 1991 (Fig. 5b).

The mean local summer maxima during April and May in 1981-1986 was 29.4 ^{0}C (SD = 0.59, n = 6) and the average normal summer ambient within the same period of years was 28.76 ^{0}C (SD = 0.812, n = 27). In 1991, corals experienced elevated seawater temperatures of 0.4 ^{0}C to 2.4 ^{0}C above mean summer maxima (29.4 ^{0}C) for two and a half months before the onset of bleaching in late May. Or put another way, they experienced elevated temperatures of 1 ^{0}C to 3 ^{0}C above the average normal summer ambient (28.76 ^{0}C) within the same period. After that the temperature dropped but still remained about 0.8 ^{0}C above the previous records until approaching the same level as the previous records in October.

2. Coral Community Responses

2.1 Tagging Assessment

Tagging was restricted to the prolonged bleaching of corals that remained after early mortality. The results of 295 tagged corals from 31 taxa, with 3 successive monitoring, were recorded in Table 4. Any loss of tags was restricted to branching and ramose colonies due to breakage by strong wind and wave action during the period. Tagging of the soft coral,



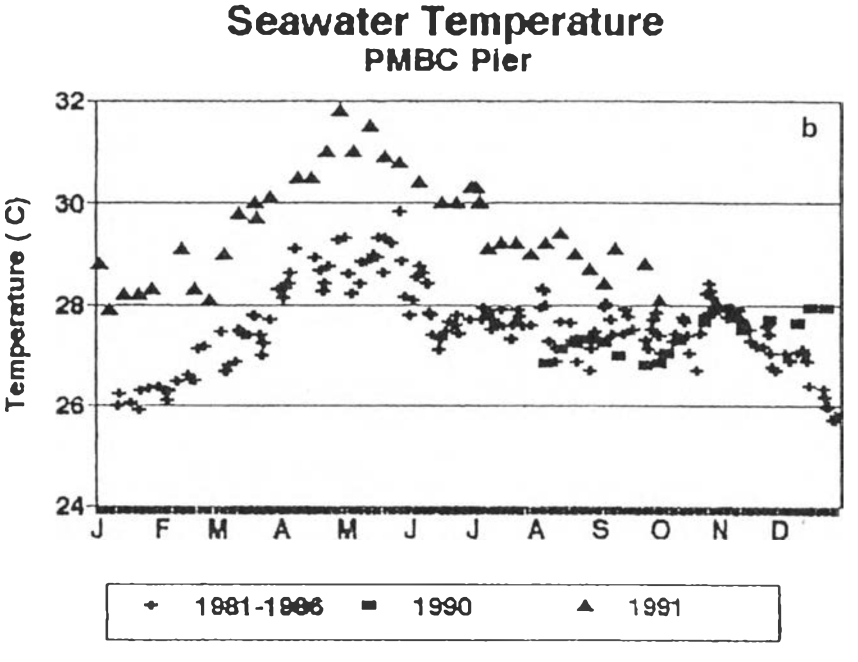


Fig. 5. Seawater temperatures (C) recorded at 1 meter depth at PMBC pier, 1981-1986, July to December 1990, and January to October 1991. (Unpublished data provided by Woodhichai Janekarn)..

a.) normal plotting

b.) smoothing for 1981 to 1986 and July to December 1990 by moving average (n=3).

Table 4. Results of three successive monitoring on tagged corals which responded to bleaching on the PMBC reef in 1991.

Corals	Date	Number of colony									
		PB	B	B/PD	B/R	B/R/PD	N	N/PD	D	L	Total
Scleractinian corals											
Family Thamnasteriidae											
Psammocora digitata	Aug. 7		5		8	4					17
	Sep. 12				1	4	7	5			17
	Dec. 15							15		2	17
Family Pocilloporidae											
Pocillopora damicornis	Aug. 7					1					1
	Sep. 12					1					1
	Dec. 15							1			1
Family Acroporidae											
Acropora hyacinthus	Aug. 7				1						1
	Sep. 12							1			1
	Dec. 15							1			1
Acropora nobilis	Aug. 7		7								7
	Sep. 12				1				6		7
	Dec. 15							1	6		7
Acropora squarosa	Aug. 7	5			1						6
	Sep. 12				1		4	1			6
	Dec. 15						5	1			6
Acropora humilis	Aug. 7				1						1
	Sep. 12						1				1
	Dec. 15						1				1
Acropora (colymbose)	Aug. 7	1			1						2
	Sep. 12					1		1			2
	Dec. 15							2			2
Acropora spp.(branching)	Aug. 7		2								2
	Sep. 12								2		2
	Dec. 15								2		2
Family Faviidae											
Favia sp.	Aug. 7		9	3	4						16
	Sep. 12				6	6	1	1	2		16
	Dec. 15						5	9	2		16
Favites abdita	Aug. 7		2								2
	Sep. 12		1						1		2
	Dec. 15							1	1		2
Platygyra sp.	Aug. 7		1		1						2
	Sep. 12						2				2
	Dec. 15						2				2
Family Poritidae											
Porites lutea	Aug. 7	3				5					8
	Sep. 12					1	3	4			8
	Dec. 15						3	5			8

Table 4 (continued)

Corals	Date	PB	B	B/PD	B/R	B/R/PD	N	N/PD	D	L	Total
Synaraea rus	Aug. 7			2							2
	Sep. 12					2					2
	Dec. 15							2			2
Family Agariciidae											
Pachyseris sp.	Aug. 7		3		1						4
	Sep. 12				2		2				4
	Dec. 15						3	1			4
Family Fungiidae											
Fungia echinata	Aug. 7		2		1						3
	Sep. 12				1		2				3
	Dec. 15						2			1	3
Fungia sp.	Aug. 7				4						4
	Sep. 12				2		2				4
	Dec. 15						2			2	4
Herpolitha limax	Aug. 7		2		5						7
	Sep. 12				2		5				7
	Dec. 15						7				7
Lithophyllon edwardsi	Aug. 7		3		1						4
	Sep. 12		1		2		1				4
	Dec. 15						3	1			4
Family Oculinidae											
Galaxea sp.	Aug. 7		1	1							2
	Sep. 12					1			1		2
	Dec. 15							1	1		2
Family Merulinidae											
Merulina ampliata	Aug. 7		3		7						10
	Sep. 12		1		1		2	4	2		10
	Dec. 15						3	4	2	1	10
Hydnophora microconos	Aug. 7				1						1
	Sep. 12							1			1
	Dec. 15							1			1
Hydnophora rigida	Aug. 7			2							2
	Sep. 12								1	1	2
	Dec. 15								1	1	2
Family Mussidae											
Lobophyllia sp.	Aug. 7		2								2
	Sep. 12					1			1		2
	Dec. 15								2		2
Symphyllia sp.	Aug. 7				4						4
	Sep. 12				1		3				4
	Dec. 15						3	1			4

Table 4 (continued)

Corals	Date	Number of colony									
		PB	B	B/PD	B/R	B/R/PD	N	N/PD	D	L	Total
Australomussa rowleyensis	Aug. 7		2								2
	Sep. 12				2						2
	Dec. 15						1	1			2
Family Pectiniidae											
Pectinia spp.	Aug. 7		14		5	2					21
	Sep. 12		2		7	3			9		21
	Dec. 15						2	4	9	6	21
Mycedium elephantotus	Aug. 7		4		5						9
	Sep. 12				4		2		1	2	9
	Dec. 15						4	1	1	3	9
Echinophyllia sp.	Aug. 7		1								1
	Sep. 12				1						1
	Dec. 15						1				1
Family Caryophylliidae											
Physogyra lichtensteini	Aug. 7				2						2
	Sep. 12				2						2
	Dec. 15						2				2
Soft corals											
Family Alcyoniidae											
Sarcophyton sp.	Aug. 7		8	140							148
	Sep. 12		1	51					96		148
	Dec. 15								148		148
Sinularia sp.	Aug. 7		1	1							2
	Sep. 12								2		2
	Dec. 15								2		2

Remarks

PB = Partially bleached colony
B = Completely bleached colony
B/PD = Bleached colony with some dead parts
B/R = Bleached colony which begin to recover
B/R/PD = Bleached colony with some dead and/or recovery parts
N = Normal colony
N/PD = Normal colony with some dead parts
D = Dead colony
L = Lost colony

Sarcophyton sp., was restricted to a single patch of its assemblages. The result showed that the corals responded to the bleaching agent were different. Soft coral of the genus *Sarcophyton* was among the most severely affected regarding to fully bleached response which resulted in total death. During bleaching response, all *Sarcophyton* colonies were gradually reduced in size and most of their polyps were in contracted condition. Some dead parts of their basal stalks were detached from the substratum until the whole colony was completely removed. The last survey revealed total lost of *Sarcophyton* sp. from the site.

Those corals susceptible to full bleaching were confined to several corals of the Family Acroporidae, Faviidae, Fungiidae, Pectiniidae, Merulinidae, and Agariciidae (Table 4). Among these, *Fungia* spp., *Herpolitha limax*, *Physogyra lichtenstenii*, *Mycedium elephantotus*, and *Lithophyllon edwardsi* were more or less resistant which lead to recovery afterwards. While, *Favia* sp., *Pectinia* spp, *Acropora squarosa*, and *Psammocora digitata* were less resistant, even though they could be recovered, but partial death of colonies could be observed. *Galaxea fascicularis*, *Hydnophora rigida*, *Lobophyllia* sp. were the least resistant forms and almost all of them died afterwards.

Diploastrea heliopora and *Goniopora* sp. colonies were never been observed to have bleached at the study site. However, bleached *Goniopora* spp.were sometimes observed elsewhere but scarcely.

Porites lutea was intermediate both in resistance to bleaching and in the degree of recovery. Non-bleached and partial bleached colonies were found together at the study site. The partial bleached specimens were observed to be rapidly recovered to normal.

In general from field observations, recovery of bleached colonies tended to increase in the following months until late November, excluding *Sarcophyton* sp., which 22.2% of dead colonies were assessed after the bleaching event with the successfully recovered colonies and partial death colonies (see Plate VI) of 38.5% and 39.3%, respectively (Fig. 6).

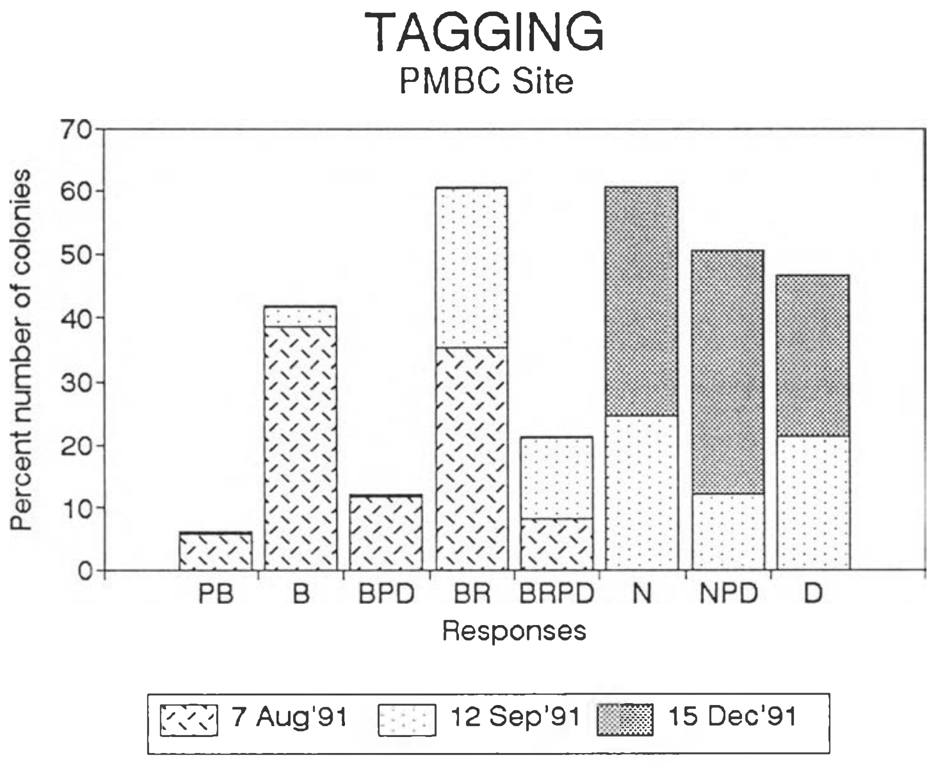


Fig. 6. Changes in bleaching responses of tagged corals during recovery.

PB = partially bleached colonies
B = completely bleached colonies
BPD= bleached colonies with dead parts
BR = bleached colonies which beginning to recover
BRPD= bleached colonies with some dead and/or recovered parts
N = Normal colonies
NPD= normal colonies with some dead parts
D = dead colonies

2.2 Line Transect Assessment

On 29 July 1991, 2 months after the onset of bleaching, the percentage of living coral cover declined markedly when compared with the expected value of benthic cover for the pre-bleaching period, with recorded decrease in total living cover from 65.88% to 34.41% (Table 5). The major decline in coral cover was due to decline in branching *Acropora*, in particular *A. formosa*. Coverage of *Acropora* corals decreased from 35.5% to 6.01%, which is a 83.1% decrease. Only a few *Acropora* colonies survived after the bleaching event. Most non-*Acropora* corals, predominated by *Porites lutea*, were lesser affected, with only a 6.6% decrease (Fig. 7).

In the repetitive survey of the transect following 10 months after the bleaching event, live coverage still tended to decrease. Total living corals cover showed a 45.2% decrease from July 1991, which was the result of mortality in some prolonged bleaching species (Table 5). The major decrease (32.5%) was shared by non-*Acropora* death.

The bleaching event not only significantly reduced the percentage living coral cover but also the number of species and colonies (Table 6). Within 10 months after the bleaching, the decreases in number of coral species and colonies on the transect were 25.7% and 52.4%, respectively.

Subsequently, a semi-quantitative survey in July 1992 revealed marked abundance of new-recruits of corals. At least 1 coral recruit per square meter was estimated (Table 7). The most common species observed included fungids, *Pectinia* sp., *Turbinaria* sp., favids and *Acropora* spp. of which composing about 82% of total individuals recorded.

Another significant change on coral community is the average colony size (Table 8). The average colony diameter decreased from about 35 cm during pre-bleaching period in 1991 to about 21 cm for assessment in 1992 (Fig. 8,9).

Table 5 Total number occurrences (OC) and percentage cover (% COV) of corals on 100 meters line transect at the PMBC reef during bleaching period (July 1991) and after the event (March 1992 and April 1993).

TAXA	July 1991								March 1992		April 1993	
	Normal corals		Partially bleached corals		Completely bleached corals		Dead bleached corals		Recovered corals		Recovered corals	
	OC	% COV	OC	% COV	OC	% COV	OC	% COV	OC	% COV	OC	% COV
Acropora hyacinthus							3	1.15	1	0.07	1	0.08
A. divaricata							1	0.35				
A. formosa					6	3.80	28	25.95				
A. squarosa			2	0.28			1	0.19	1	0.10		
Acropora (branching)					3	1.55			1	0.10	1	0.08
Acropora spp. (colymbose)					2	0.38	8	1.85			2	0.18
Acropora sp. (juvenile)									1	0.03	1	0.03
Montipora verrucosa											1	0.05
Montipora sp. (encrusting)											2	0.13
Montipora sp. (foliaceous)	1	0.02										
Montipora sp. (massive)									1	0.05	1	0.06
Favia sp.					3	0.25	1	0.10	2	0.25	7	0.37
Favites abdita			3	0.34	1	0.15			4	0.37	4	0.18
Diploastrea heliopora	1	0.25							2	0.20	1	0.25
Montastrea sp.	1	0.01									3	0.13
Cyphastrea microphthalma					3	0.30			1	0.10	1	0.14
Goniastrea pectinata			1	0.03			2	0.14				
Platygyra sp.			1	0.11	1	0.12			2	0.13	2	0.06
Merulina ampliata			3	0.50							2	0.12
Goniopora sp.	2	1.20							1	0.20	1	0.06
Porites lutea	30	13.15	7	2.80	1	0.41			31	12.29	41	16.52
Porite nigrescens			1	0.10	2	0.22			1	0.15	2	0.36
Synaraea rus	1	0.08	5	0.92			2	0.25	5	1.05	12	1.75
Symphyllia sp.									1	0.10	1	0.13
Pectinia alcicornis	1	0.03	5	0.87	6	2.20	2	0.52	8	1.36	8	1.81
Hydnophora microconos					1	0.25						
H. rigida							2	0.25				
Mycedium elephantotus					2	0.10			1	0.07	2	0.12
Echinophyllia sp.					2	0.35			1	0.15	2	0.09
Galaxea fascicularis					2	0.20	1	0.14	2	0.14	2	0.08
Psammocora sp.			2	0.45								
Pocillopora damicornis	6	0.41	2	0.24	3	0.32	7	0.58	6	0.52	11	0.85
Pavona decussata	1	0.14	2	0.53								
P. explanulata					1	0.14			2	0.50	3	0.57
Podabacia crustacea											1	0.05
Pachyseris speciosa					1	0.17			1	0.20	2	0.31
Lithophyllon edwardsi											4	0.35
Fungia spp.					5	0.35			10	0.56	2	0.08
Herpolitha limax					3	0.22			2	0.16		
Turbinaria sp.											1	0.03
Sarcophyton sp.					3	0.34						
sponge (vast)	1	0.13							1	0.07	2	0.47
sponge (encrust)											1	0.03
mud		3.85								4.03		1.90
Subtotal												
Acropora	-	-	2	0.28	11	5.73	41	29.49	4	0.30	5	0.37
Non-Acropora	44	15.29	32	6.89	37	5.75	17	1.98	84	18.55	119	24.65
Other fauna	1	0.13	-	-	3	0.34	-	-	1	0.07	3	0.50
Abiotic	-	3.85	-	-	-	-	-	-	-	4.03		1.90

Summary	*Pre-bleaching		July 1991		March 1992		April 1993	
	OC	% COV	OC	% COV	OC	% COV	OC	% COV
Acropora	54	35.50	13	6.01	4	0.30	5	0.37
Non-Acropora	130	29.91	113	27.93	84	18.55	119	24.45
Other fauna	4	0.47	4	0.47	1	0.07	3	0.50
Abiotic	-	3.85	-	3.85	-	4.03	-	1.90
Dead corals	-	30.27	-	59.74	-	77.05	-	72.58
Live cover	188	65.88	130	34.41	89	18.92	127	25.52

* Remark; Benthic coverage of the pre-bleaching year can be estimated by taking the bleached dead corals into accounted.

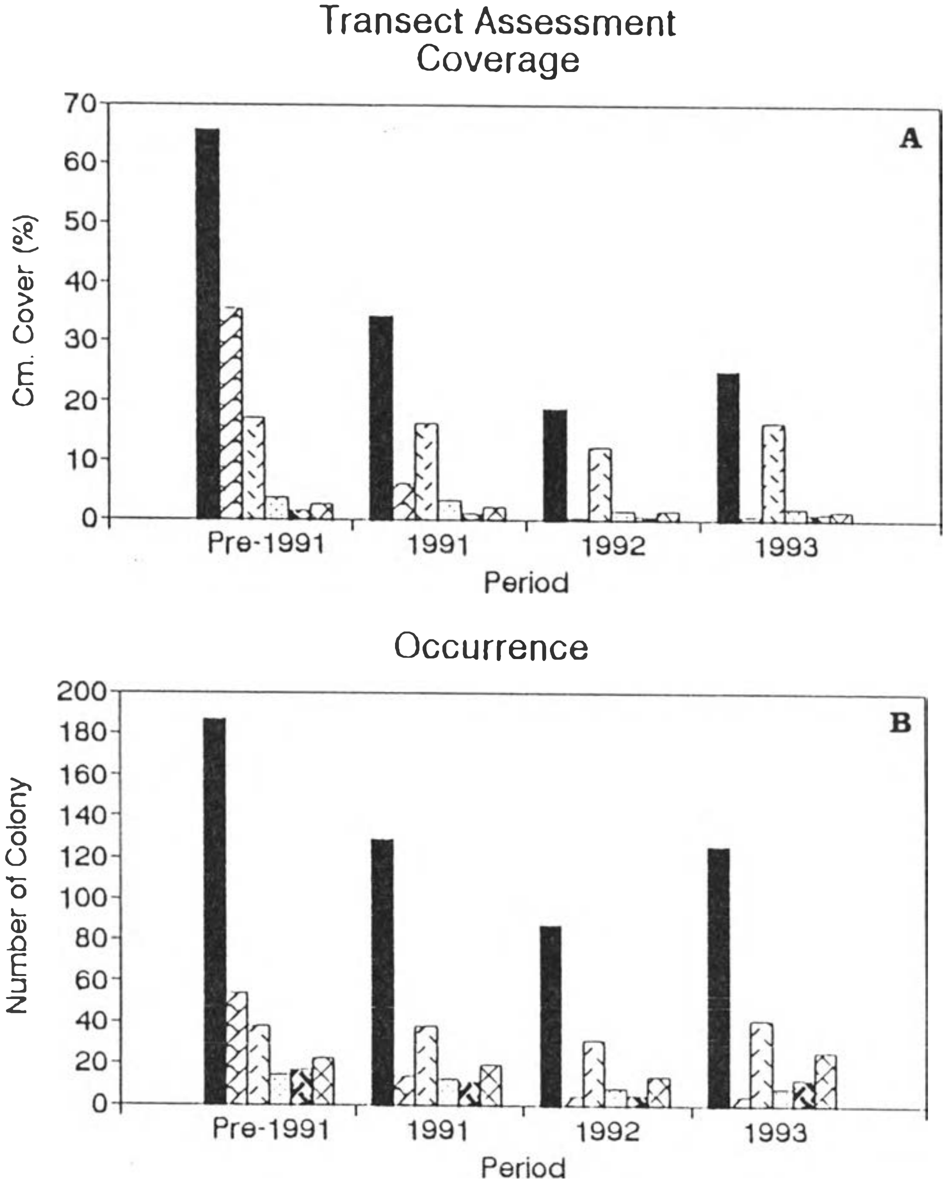


Fig. 7. Changes in coverage (A) and occurrence (B) of corals at the PMBC reef site.

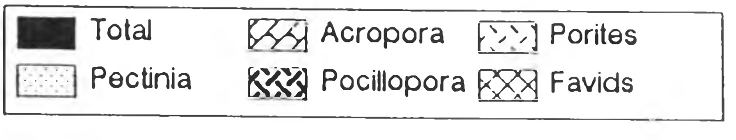


Table 6. Summary of ecological parameters of coral community at the PMBC site. The parameters of *pre-bleaching period were the expected value (see remark in table 4.).

TL = transect length (cm.)
COV = coverage of live coral colonies in centimeter
Nn = number of colonies recorded on the transect
Ns = number of species recorded on the transect
H'c = Shannon-Weiner diversity index (based on centimeter coverage of colonies)
H'n = Shannon-Weiner diversity index (based on number of colonies)
J'c = evenness values based on H'c
J'n = evenness values based on H'n

Period	Parameters							
	TL	COV	Nn	Ns	H'c	H'n	J'c	J'n
*Pre-bleaching	1000	6588	188	34	1.952	2.840	0.554	0.805
July 1991	1000	3441	130	31	2.144	2.814	0.624	0.819
March 1992	1000	1892	89	25	1.594	2.480	0.495	0.770
April 1993	1000	2552	127	32	1.617	2.705	0.466	0.781

Table 7 Observation on new coral recruits within approximated survey tract (2x40 m.) along the reef slope at the PMBC reef site on 3 July 1992.

Taxa	Number of individual counted	Approximate size (cm.)
:Scleractinian corals		
Acropora spp.	11	2-5
Pocillopora damicornis	3	<3
Porites sp.	4	<1
Cyphastrea sp.	2	<1
Favids	12	<2
Lobophyllia sp.	1	<2
Pectinia sp.	14	1-2
Merulina sp.	5	2-5
Fungids	27	<5
Turbinaria sp.	14	<1
:Soft corals		
Cladiella sp.	2	<1
Total	95	

Table 8. Comparision of descriptive statistic data for the projected length of corals (colony size (cm.)) on the monitoring transect-lines at the PMBC reef site before and after the bleaching event.

Measures	Pre-bleaching	1991	1992	1993
Sample size	188	130	89	127
Average	35.06	26.48	21.26	19.63
Median	15	15	10	10
Mode	10	10	10	5
Variance	2681.40	986.79	878.99	906.62
Standard deviation	51.87	31.41	29.65	30.11
Minimum	1	1	1	1
Maximum	320	180	210	224

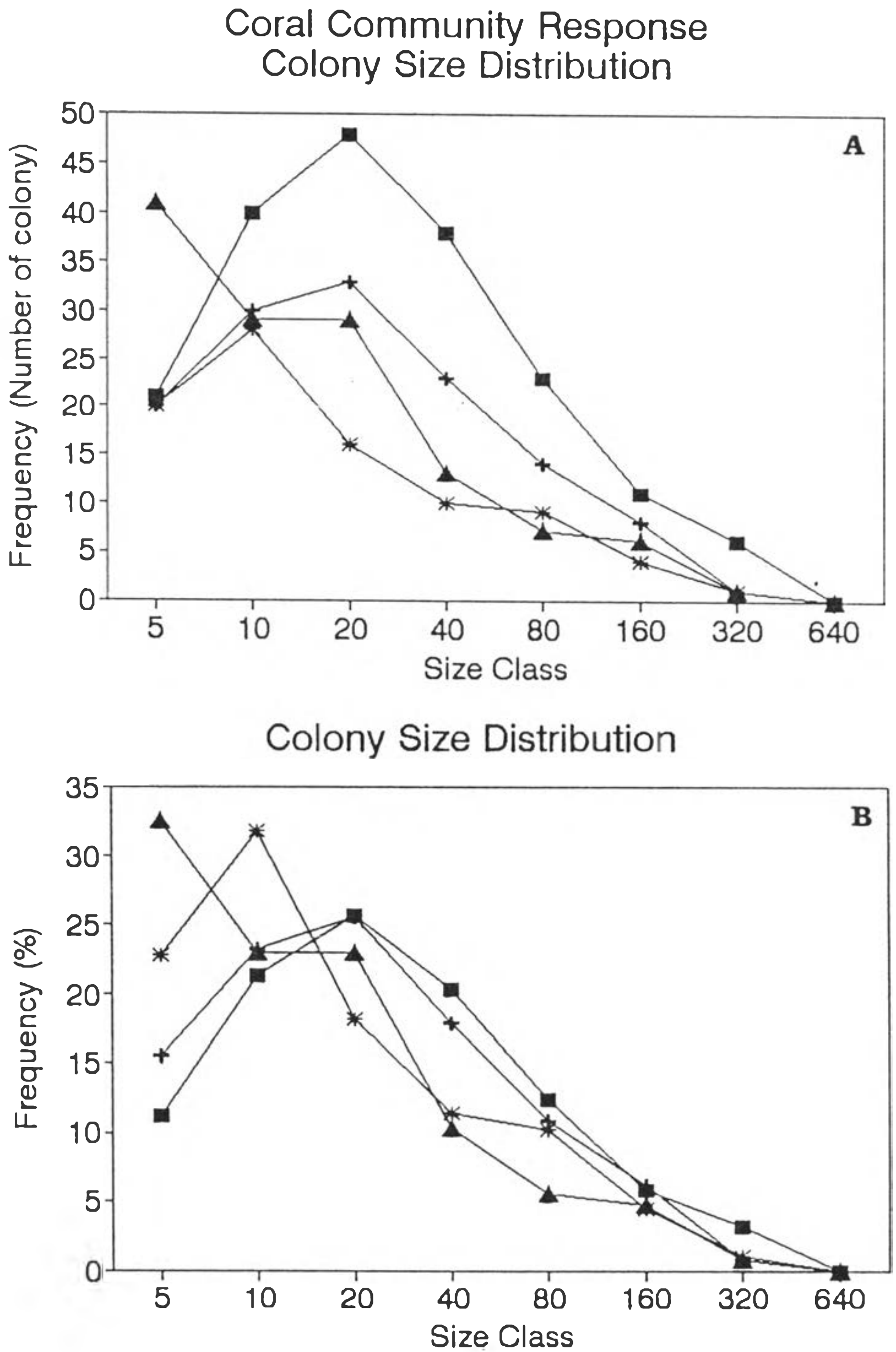
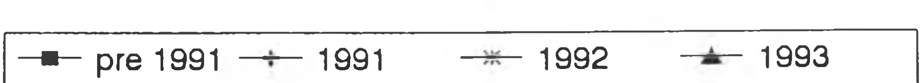


Fig. 8. Changes in coral colony size distribution at the PMBC reef site: A) total, B) relative frequency.



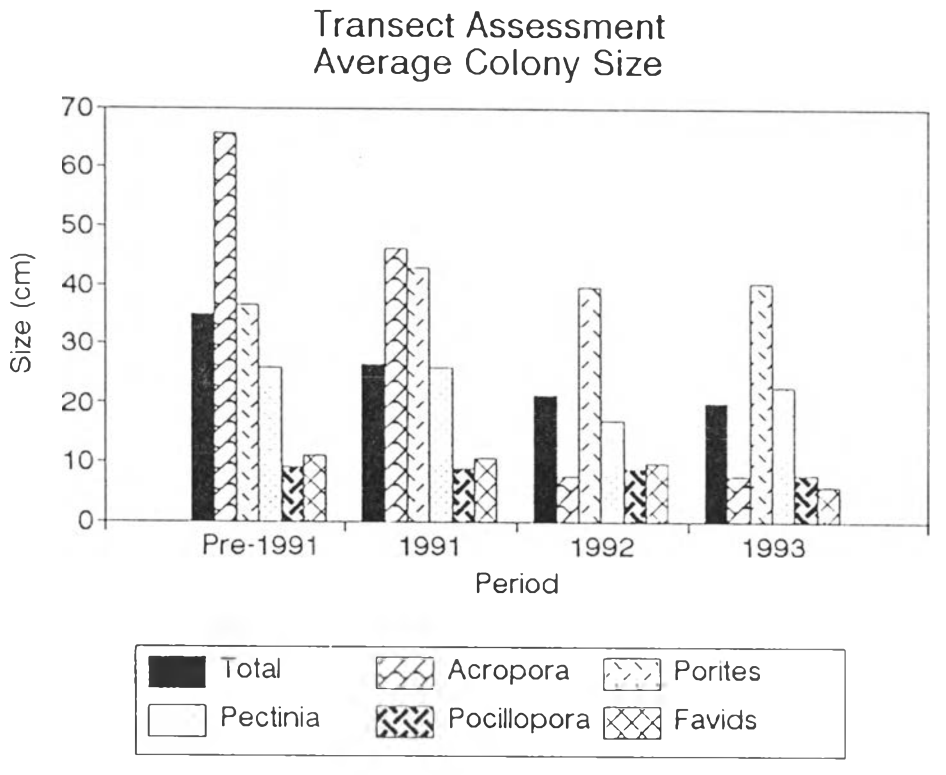


Fig. 9. Changes in colony size distribution of some selected major taxa of the PMBC reef.

There were also marked differences in coral diversity (H'c and H'n) during the pre-bleaching period to 1992 (Table 6). All measures of diversity in 1992 was lower than it was in the pre-bleaching period, which directly reflect decreases in both coral species and coverage on the transect.

The result from the transect assessment in April 1993, for approximately 2 years after bleaching, revealed a tendency of recovery of the coral community at the PMBC site. All parameters significantly increased when compare with those in the former year. The coral cover, number of colonies and number of species assessed on the transect were increased approximately 1.4 times (Table 6.).

3. Coral Colony Responses

Analyses on zooxanthellae population density, chlorophyll content, and protein content were made according to nine time-matched collections of coral samples. Date and approximated weeks related to the onset of bleaching in late May are presented in Table 9.

3.1 Zooxanthellae Population Density

The mean zooxanthellae densities expressed as cells per square centimeter of surface area for each of five coral species for each sampling times were summarized in Fig. 10. By the 15th week, after onset of bleaching in late May, 1991, the population densities of zooxanthellae for all coral species were very low ranging from 0.16×10^6 cells/cm^2, for *M. ampliata* to 0.57×10^6 cells/cm^2, for *M. elephantotus*. The zooxanthellae density at the 17th week for *L. edwardsi*, *M. ampliata*, and *P. alcicornis* were still consistently low while those in *P. digitata* and *M. elephantotus* began to increase. The week of approaching stability: the week when there are no more significantly changes as compared to the following weeks, basing on ANOVA; Multiple Range Test (Appendix D-I), was variable among

Table 9. List of sampling times for coral samples collection.

Sampling time	Date	Weeks after onset of bleaching event
1	13 Sep. 91	15
2	27 Sep. 91	17
3	15 Oct. 91	19
4	26 Oct. 91	21
5	10 Nov. 91	23
6	8 Dec. 91	27
7	28 Dec. 91	30
8	18 Jan. 92	33
9	28 Feb. 92	39

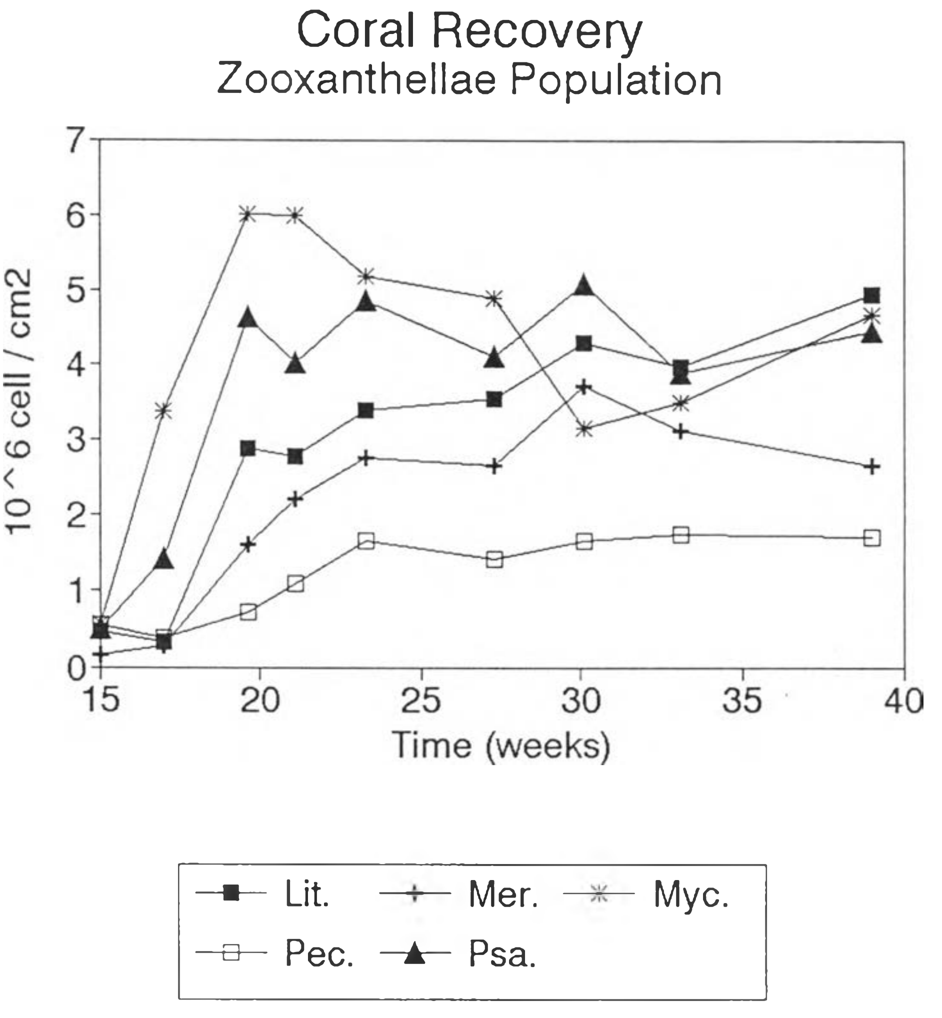


Fig. 10. Average densities of zooxanthellae in time-matched samples of coral tissues.

Lit.= Lithophyllon edwardsi, Mer.= Merulina ampliata, Myc.= Mycedium elephantotus, Pec.= Pectinia alcicornis, Psa.= Psammocora digitata.

coral species. Firstly, *M. elephantotus* approached stability by the 17th week, followed by *L. edwardsi* and *P. digitata* by the 19th week and late on the 21st week by *M. ampliata* and *P. alcicornis*.

The zooxanthellae density values for each coral species from the week of approaching stability through the last sampling week (39th) were averaged and compared with those of the 15th-week values as presented in Table 10. The descendent ranking of zooxanthellae density among recovered coral species was as follow; *M. elephantotus* and *P. digitata*, *L. edwardsi*, *M. ampliata*, and *P. alcicornis*. Among those recovered corals, the percent increments of zooxanthellae abundance were 64% to 95% related to the bleached coral (15th week).

3.2 <u>Chlorophyll Content</u>

Changes in chlorophyll-a content, expressed both per square meter of surface area and per algal cell, with time for each bleached coral species were presented in Fig. 11. When started sampling, 15 weeks after onset of bleaching in late May 1991, the amount of chlorophyll-a per surface area for all coral species (Fig. 11a) was very low ranging from 0.07 ug/cm^2 (for *M. ampliata*) to 1.0 ug/cm^2 (for *L. edwardsi*). The contents in *M. elephantotus* and *P. digitata* were markedly increased at the 17th week, while those in *L. edwardsi*, *M. ampliata*, and *P. alcicornis* were still consistently low. After the 17th week, all corals except *M. elephantotus*, had increased in chlorophyll-a content until approaching the stability. The 20th, 23rd, and 27th weeks where the week of approaching stability for *P. digitata*, *M. ampliata* and *P. alcicornis*, and *L. edwardsi*, respectively (Appendix D-II; ANOVA, Multiple Range Test). For *M. elephantotus*, the chlorophyll-a content at the 17th week was not markedly different from the following week, but varied.

The pattern of changes in chlorophyll-a per algal cell with time for *L. edwardsi*, *M. ampliata* and *P. alcicornis* were similar to that of chlorophyll- a per surface area (Fig. 11b). Obviously, the chlorophyll-a per algal cell for both *M. elephantotus* and *P. digitata* were variable

Table 10 Comparison of zooxanthellae density during the first sampling time and recovery period for each coral species.
Values in parentheses are number of replicates.

Coral Species	Zooxanthellae Density (cells x 10 ^ 6/cm ^ 2)				Increment (%)
	First sampling time		Recovery period		
	Avg.	Std.	Avg.	Std.	
Lithophyllon edwardsi	0.469 (3)	0.120	3.688 (20)	1.276	87.2
Merulina ampliata	0.156 (3)	0.011	2.855 (18)	0.729	94.5
Mycedium elephantotus	0.565 (3)	0.166	4.601 * (24)	1.576	87.7
Pectinia alcicornis	0.564 (3)	0.411	1.554 (18)	0.405	63.7
Psammocora digitata	0.492 (3)	0.219	4.437 * (20)	0.715	88.9

* denotes statistically equal mean value (ANOVA, multiple range test: LSD method)

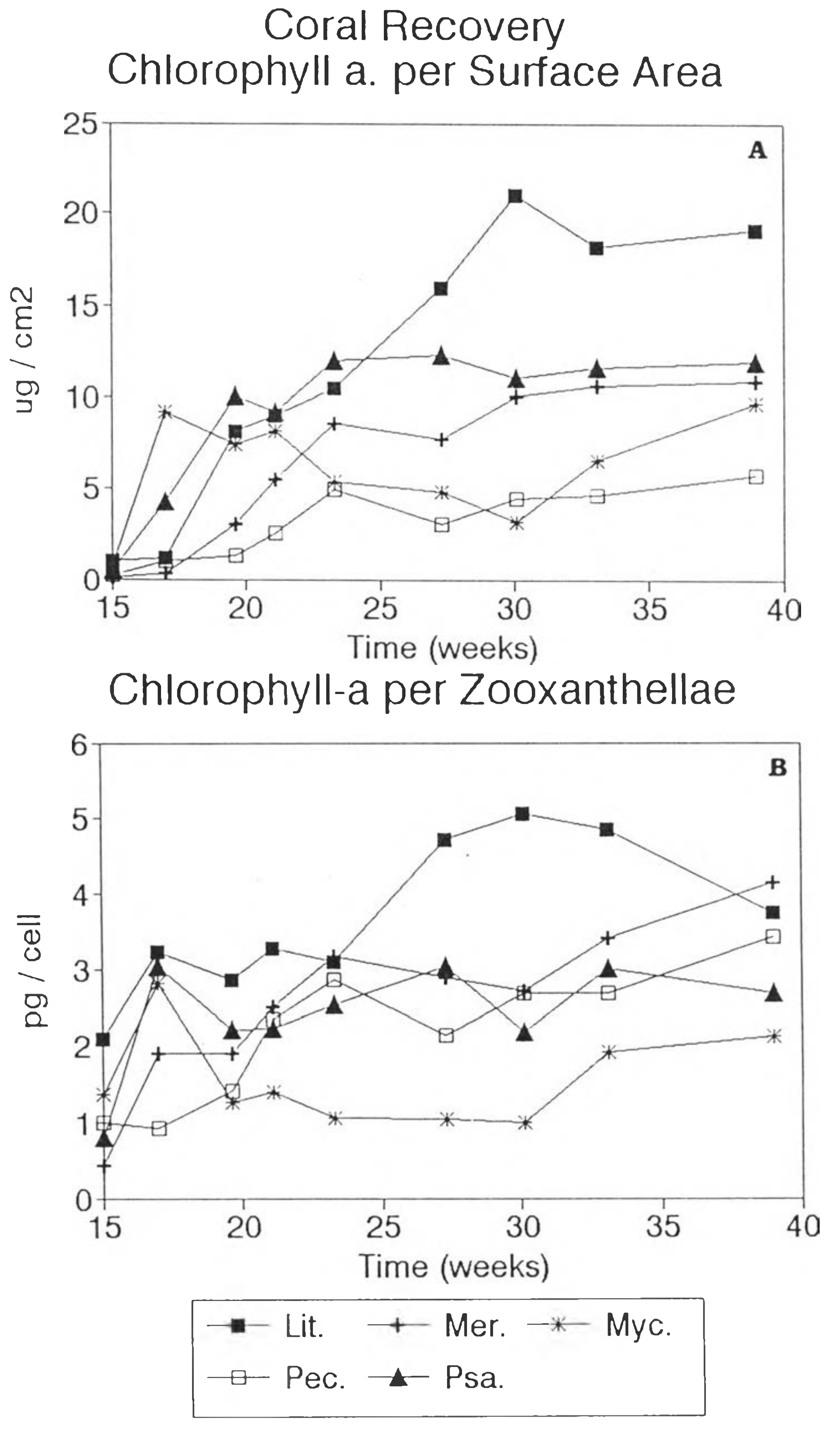


Fig. 11. Average chlorophyll-a contents in time-matched samples of coral tissues: A) chlorophyll-a/surface area, B) chlorophyll-a/zooxanthellae cell.
Lit.= Lithophyllon edwardsi, Mer.= Merulina ampliata, Myc.= Mycedium elephantotus, Pec.= Pectinia alcicornis, Psa.= Psammocora digitata.

but within a relatively consistent level through time.

The average values for chlorophyll-a both per surface area and per algal cell during constant maintaining period for all coral species were compared with the values at the first sampling week (15th) as presented in Table 11 and 12, respectively. The chlorophyll per surface area in recovered corals were different among species with descending ranks as follows; *L. edwardsi, P. digitata* and *M. ampliata, M. elephantotus* and *P. alcicornis*. In terms of chlorophyll per algal cell the ranks were as follows; *L. edwardsi, M. ampliata, P. alcicornis* and *Psammocora digitata*, and *M. elephantotus.* The relative increment of chlorophyll-a content in recovered corals were 89% to 99% compared to bleached corals whereas the increment values of chlorophyll-a per zooxanthellae were ranged lower (ie. 54% to 86%).

Except for M. elephantotus, not only did bleached coral contained fewer zooxanthellae but also the zooxanthellae of bleached coral contained less pigment. Further assumed that measures of pigment content in corals at the first sampling time and during recovered period were representative for bleached and normal conditions, respectively. The determination of two contributary loss factors, including loss of zooxanthellae from coral and loss of pigment from zooxanthellae, was presented in Table 13. The analysis was adopted the formulation provided by Kleppel et al.,1989. The proportional contributions of loss of zooxanthellae, c, and loss of pigment per zooxanthellae, p, were related by

$$p = Wc \qquad \text{.......................(1)}$$

where W is a ratio relating the ratios of pigment content per zooxanthellae in normal : bleached corals and of zooxanthellae cm^{-2} in normal : bleached corals (Table 13). Then the quantity of pigment lost, ^ Q, during bleaching is;

$$\triangle Q = p\triangle Q + c\triangle Q \qquad \text{................(2)}$$

substituting Wc for p,

Table 11 Comparison of chlorophyll-a concentration during the first sampling time and recovery period for each coral species. Values in parentheses are number of replicates.

Coral Species	Chlorophyll-a Concentration (ug/cm ^ 2)				Increment (%)
	First sampling time		Recovery period		
	Avg.	Std.	Avg.	Std.	
Lithophyllon edwardsi	0.996 (3)	0.291	18.569 (12)	5.527	94.6
Merulina ampliata	0.070 (3)	0.036	9.588 * (15)	1.920	99.3
Mycedium elephantotus	0.769 (3)	0.226	6.807 (24)	2.612	88.7
Pectinia alcicornis	0.189 (3)	0.129	4.554 (15)	1.504	95.8
Psammocora digitata	0.490 (3)	0.444	11.178 * (20)	1.798	95.6

* denotes statistically equal mean value (ANOVA; Multiple range test: LSD method)

Table 12 Comparison of chlorophyll-a content per zooxanthellae cell during the first sampling time and recovery period for each coral species. Values in parentheses are number of replicates.

Coral Species	Chlorophyll-a Concentration (pg/cell)				Increment (%)
	First sampling time		Recovery period		
	Avg.	Std.	Avg.	Std.	
Lithophyllon edwardsi	2.100 (3)	0.154	4.594 (12)	0.971	54.3
Merulina ampliata	0.438 (3)	0.193	3.141 (18)	3.141	86.1
Mycedium elephantotus	1.366 (3)	0.062	1.552 (28)	1.552	ND.**
Pectinia alcicornis	1.006 (3)	1.056	2.692 * (18)	2.692	62.6
Psammocora digitata	0.810 (3)	0.434	2.616 * (24)	2.616	69.0

* denotes statistically equal mean value (ANOVA; Multiple range test: LSD method).

** ND.; not permit to determine since the multiple range test showed no different mean values among time-matched samples.

Table 13. A. Ratios of mean pigment content zooxanthellae^{-1} (pg cell^{-1}) and mear pigment content cm^{-2} in normal (N) and bleached (B) corals, and weighting factor, W.

B. Analysis of pigment loss including total loss and losses associated with contributary processe .

Lit.= *Lithophyllon edwardsi*, Mer.= *Merulina ampliata*

Myc.= *Mycedium elephantotus*, Pec.= *Pectinia alcicornis*

Psa.= *Psammocora digitata.*

	Coral Species				
	Lit.	Mer.	Myc.	Pec.	Psa.
A. Ratios					
Pigment zooxanthellae^{-1}					
N:B ratio	2.19	7.17	1.14	2.68	3.23
Zooxanthellae cm^{-2}					
N:B ratio	7.68	18.30	8.14	2.76	9.02
*W	0.28	0.39	0.14	0.97	0.36
B. Analysis of pigment loss					
Total loss (ug cm^{-2})	17.57	9.52	6.04	4.37	10.69
Contribution to pigment loss					
1. loss of zooxanthellae (c)					
%c	78	72	(100)	51	74
ug cm^{-2}	13.70	6.85	6.04	2.23	7.91
2. loss of pigment zooxanthellae (p)					
%p	22	28	(0)	49	26
ug cm^{-2}	3.87	2.67	-	2.14	2.7

*W = N:B ratio of pigment zooxanthellae^{-1} / N:B ratio of zooxanthellae cm^{-2}.

** In respect to an ANOVA; multiple range test, the total pigment loss in *M. elephantotus* could be solely contributed by loss of zooxanthellae (%c = 100, %p = 0).

$$\triangle Q = Wc \triangle Q + c \triangle Q \text{ ....(3)}$$

and

$$C = 1 / (W + 1) \text{ ....(4)}$$

The result showed that the pigment loss in bleached coral was contributed majorly by loss of zooxanthellae, of about 50%-80% reduction, and that loss of loss of pigment zooxanthellae were lower, of about 20%-50% reduction.

3.3 Protein Content

The coral tissue protein contents (coral including zooxanthellae) for each coral species during each sampling weeks were measured (Fig. 12). At the first sampling week (15th) the protein contents among coral species were still low ranging from 0.5 mg/cm^2 (for *P. alcicornis*) to 1.7 mg/cm^2 (for *L. edwardsi*). Recovery in protein contents varied among coral species. *M. elephantotus* was among the first that had recovered the protein content by the week of 17th, followed by *M. ampliata*, *P. alcicornis P. digitata* by the 21st, and late until the 27th by *L. edwardsi* (Appendix D-4; ANOVA, Multiple Range Test).

Average values of protein contents in recovered corals were compared with the bleached corals at the 15th week as presented in Table 14. Descending ranks for protein content among recovered corals were as follows; *L. edwardsi, P. digitata, M. ampliata, M. elephantotus*, and *P. alcicornis*. Increments in protein content of recovered corals were 43% to 74% related to bleached ones.

Recovery period of each tissue components for each coral species were summarized in Table 15. Variations of recovered time for each tissue components were found both within and among coral species. In general, population density of zooxanthellae in coral tissues were first recovered and followed by chlorophyll-a concentrations, either per cell or per square centimeter, and last for protein content. Rate of recovery of

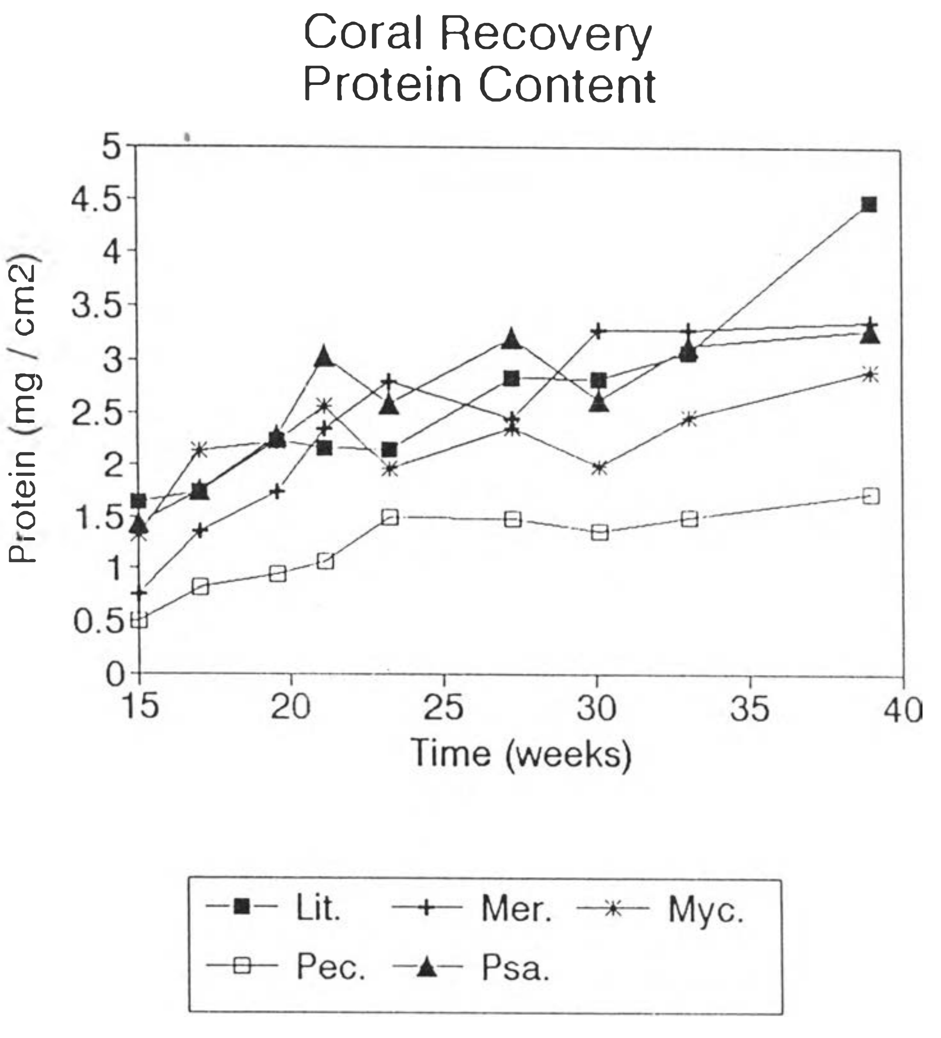


Fig. 12. Average protein contents in time-matched samples of coral tissues.

Lit.= Lithophyllon edwardsi, Mer.= Merulina ampliata, Myc.= Mycedium elephantotus, Pec.= Pectinia alcicornis, Psa.= Psammocora digitata.

Table 14 Comparison of protein content during the first sampling time and recovery period for each coral species. Values in parentheses are number of replicates.

Coral Species	Protein Content (mg/cm ^ 2)				Increment (%)
	First sampling time		Recovery period		
	Avg.	Std.	Avg.	Std.	
Lithophyllon edwardsi	1.654 (3)	0.075	3.301 * (12)	1.356	49.9
Merulina ampliata	0.756 (3)	0.049	2.917 * (18)	0.582	74.1
Mycedium elephantotus	1.330 (3)	0.057	2.323 (24)	0.519	42.7
Pectinia alcicornis	0.499 (3)	0.051	1.442 (18)	0.278	65.4
Psammocora digitata	1.428 (3)	0.248	2.974 * (18)	0.499	52.0

* denotes statistically equal mean value (ANOVA; Multiple range test: LSD method).

tissue components among coral species were descending ranked as follows: *M. elephantotus*, *P. digitata*, similarly *M. ampliata and P. alcicornis, and L. edwardsi*.

Table 15. Timing for recovery of tissue biomass for each bleached coral species.

Coral species	Weeks after onset of bleaching event			
	Zoox./cm^2	Chl.a/cm^2	Chl.a/zoox.	Prot./cm^2
L. edwarsi	19	27	27	27
M. ampliata	21	23	21	21
M. elephantotus	17	17	N.D.	21
P. alcicornis	21	23	21	21
P. digitata	19	19	17	21