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SOME REEFS AND CORALS OF ROATAN (HONDURAS), CAYMAN BRAC, AND LITTLE CAYMAN

BY

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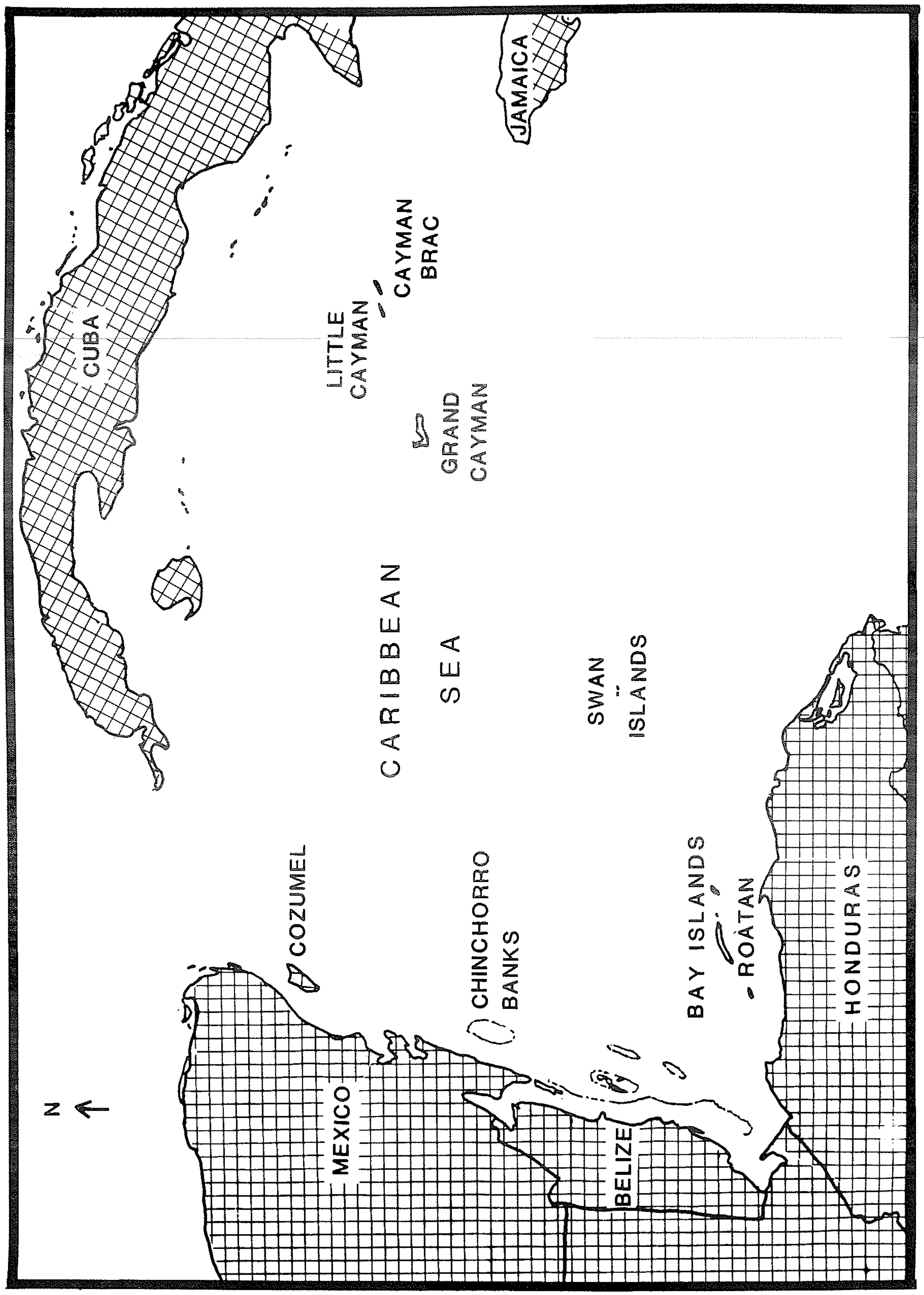

Figure 1. Map of the western Caribbean, showing island locations.

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Abstract

The topography, zonation, and coral communities of small sections of the reefs which surround three western Caribbean islands were studied for comparison with well-studied Caribbean reefs. The reefs of northwestern Roatan (Honduras), southwestern Cayman Brac, and northwestern Little Cayman all have terraces at 5-10 m depth and 15-20 m depth, and a nearly vertical deep forereef, with the exception of one section on Little Cayman which lacks the deep terrace, and sections on Roatan that have only one terrace. Northwestern Roatan has a well-developed set of buttresses and sand channels, although it receives little wave energy. Forty-four taxa of corals were found on Roatan, 47 on Cayman Brac, and 45 on Little Cayman. Nine were new records on Roatan, 24 were new on Cayman Brac, and 20 on Little Cayman. The Shannon-Weaver diversity index averaged 1.38 over a 0.1-15 m depth range at Roatan, and 1.58 over 0.1-25 m depth at Cayman Brac, indicating slightly low and average coral diversities compared to other Caribbean reefs. Coral cover averaged 21% at Roatan and 20% at Cayman Brac, indicating a slightly low coral cover for Caribbean reefs, well within the range reported.

INTRODUCTION

At one time, Caribbean coral reefs were considered to have much less abundant and diverse life than Indo-Pacific reefs (Wells, 1988). Intensive study by many investigators at a few Caribbean sites (such as Discovery Bay, Jamaica, and Carrie Bow Cay, Belize) has revealed a surprising abundance and diversity of organisms (e.g., Wells and Lang, 1973; Liddel and Ohlhorst, 1989; Rutzler and Macintyre, 1982a). One group, the sponges, has been found to be as diverse and have greater biomass in the Caribbean than in the western Pacific (Wilkinson, 1988). Only by the study of additional reefs will it become clear whether the faunas of well-studied reefs are unusually abundant and diverse, or representative of other reefs. In addition, our understanding of the topography and zonation of Caribbean reefs is derived from a limited number of well-studied reefs, and may benefit from the study of additional reefs.

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Roatan (Honduras), Cayman Brac, and Little Cayman are three small islands of the western Caribbean surrounded by coral reefs that have received limited quantitative study (Wells, 1988). The Bay Islands of Honduras (Utila, Roatan, and Guanaja) have well-developed reefs that support a small diving industry (Halas and Jaap, 1982; Wells, 1988). The reefs of Roatan have been surveyed in an unpublished study by Halas and Jaap (1982), who found 47 taxa of stony corals. Numbers of coral taxa are adjusted here to be consistent with Wells and Lang (1973) as modified by Cairns (1982). The first part of the present study concentrates on the protected reefs of northwestern Roatan. Burke (1982) reported that the Belize Barrier Reef is best developed where it is protected from waves by 3 atolls, and Fenner (1988) and Jordan (1988) reported better developed reefs on Cozumel's leeward side than the small reefs briefly studied on its windward side (Boyd et al., 1963; Jordan, 1989). Yet in the same area, the windward reefs of three Belize atolls (Stoddart, 1962) and Banco Chinchorro (Jordan and Martin, 1987) show at least as much development as their leeward reefs. The best developed reefs of Belize, Mexico, and Grand Cayman are not subjected to siltation stress (Burke, 1982; Fenner, 1988; Roberts, 1974). The Bay Islands are high islands which, although small, may release significant amounts of sediments onto surrounding reefs (Halas and Jaap, 1982). The first part of this study describes the protected reefs of northwest Roatan (Honduras) with quantitative reef profiles and coral population studies.

The Cayman Islands are three limestone islands surrounded by coral reefs (Wells, 1988). The coral reefs of Grand Cayman have been described in detail (Roberts, 1971; Roberts, 1974; Raymont et al., 1976; Rigby and Roberts, 1976; Roberts, 1977; Roberts, in press). Cave-dwelling invertebrates of Grand Cayman have also been described (Logan, 1977; 1981), as well as some boring sponge populations (Rose and Risk, 1985) and coral bleaching (Ghiold and Smith, 1990). Fifty-six species of corals have been reported from Grand Cayman (Roberts, in press; Logan, 1981; Fenner, unpublished report of *Thalamophyllia riisei*). Reefs of Cayman Brac and Little Cayman have been described and mapped by Logan (1988; in press). The topography and zonation of the reefs of Cayman Brac and Little Cayman are similar to those at Grand Cayman in most places (Rigby and Roberts, 1976; Roberts, 1977; Logan, in press; Roberts, in press). Most of Cayman Brac is surrounded by a fringing reef with no lagoon, but a shallow lagoon is present along a small section of southwestern Cayman Brac. Most of Little Cayman is surrounded by a fringing reef, enclosing a shallow lagoon (Logan, in press). The reefs around both islands have two terraces separated by a small, coral-covered escarpment. In the Bloody Bay area of northwestern Little Cayman, the lower terrace is absent; a near-vertical wall begins in as little as 7 m depth. In the second segment of this study, quantitative reef profiles and coral population studies of small sections of southwestern Cayman Brac and northwestern Little Cayman (Bloody Bay) are reported.

ISLAND DESCRIPTION

Roatan (Honduras), Cayman Brac, and Little Cayman are all relatively long, thin islands oriented in a nearly east-west direction, located in the western Caribbean (Fig. 1). The island of Roatan and surrounding submarine areas are described elsewhere (Banks and Richards, 1969; McBirney and Bass, 1969; Davidson, 1974; Wilensky, 1979; Halas and Jaap, 1982; Wells, 1988). Cayman Brac and Little Cayman have also been described (Stoddart and Giglioli, 1980; Wells, 1988; Logan, in press). Roatan is a hilly island, with little limestone, while all three Cayman islands are low-lying limestone islands. Rainwater runoff is extensive on Roatan, but very limited on the Caymans. Thus, the reefs surrounding Roatan are periodically subjected to siltation during heavy rains (Halas and Jaap, 1982). Rainwater percolates through the porous limestone of the Cayman Islands, removing any silt. Hurricane Allen which greatly damaged Jamaica's north coast in 1980 (Woodley et al., 1981) may have had less effect on Cayman Brac, since it passed by more rapidly. A major hurricane struck Cayman Brac in 1932, taking over 100 lives. Hurricane Gilbert passed over the Caymans on September 13, 1988, after the present study of Cayman Brac, but before the present study of Little Cayman. No damage from Gilbert was found on Little Cayman's northwestern reefs. The reefs of Roatan had no legal protection at the time of this study, and were subject to limited amounts of fishing, coral collecting, sewage, and refuse dumping. All of the reefs in Cayman waters have been legally protected since 1986. The reefs at all sites showed little diver-related damage.

METHODS

Data for this study were gathered from Roatan in April 1987, from Cayman Brac in January 1988, and from Little Cayman in June 1989.

Measurements were made of depth profiles and coral species diversity. Depth profiles were made using a taut 5 m polypropylene line and a depth gauge. The maximum depth of this study was 30 m. Species diversity data were obtained in Roatan by photo belt-quadrats and a visual line transect, and in Cayman Brac by making belt-quadrats with a movable grid. Weinberg (1981) found that photo and grid belt-quadrats were more accurate than line transects. Photo belt-quadrats were made in Roatan by photographing approximately 1 x 0.65 m rectangles of reef from points directly above the surface of the reef. Coral cover and diversity data were obtained by projecting the photographic slides and approximating the corals as measured rectangles and triangles. The photo belt-quadrats were taken parallel to depth contours (e.g., Bradbury et al., 1987; Wilkinson and Evans, 1989; Cortes, 1990; Gates, 1990), as was the visual line transect (e.g., Loya, 1972; Porter, 1972; Liddell and Ohlhorst, 1987). Belt-quadrats and line transects were placed in different zones or habitats (e.g., Bradbury et al, 1987; Liddell and Ohlhorst, 1987; Cortes, 1990). This design does not allow capturing the zonation between the depths selected. Belt-quadrats were made at 3, 8, and 15 m depth at "Overheat Reef" (86°35'W, 16°19'W; Fig. 4B) and "Deep Eel Garden" (86°35'W, 16°20'W; Fig. 4B). These similar-appearing sections of the same reef were marked with mooring buoys attached to the coral rock, and separated by about 1 km. Dive site names are those used by local dive operators and which appear in the popular dive press. The number of photos taken at each location is indicated in Table 2. Species-area curves began to level out after 10-15 quadrats (Fig. 2), requiring the combination of the two belt-quadrats at each depth. The number of colonies was not counted, since connections between colonies might be hidden in the photos, making such a count unreliable. A line transect of the reef crest in Roatan was made by laying a taut 5 m length of polypropylene line across the bottom parallel to the shoreline. The line was moved to produce 10 contiguous extensions of the first placement. A ruler was placed on corals to measure the section of line traversing each coral colony; Porter (1972) found parallax problems to be very small. Vertical extensions of colonies and hidden sections of corals were

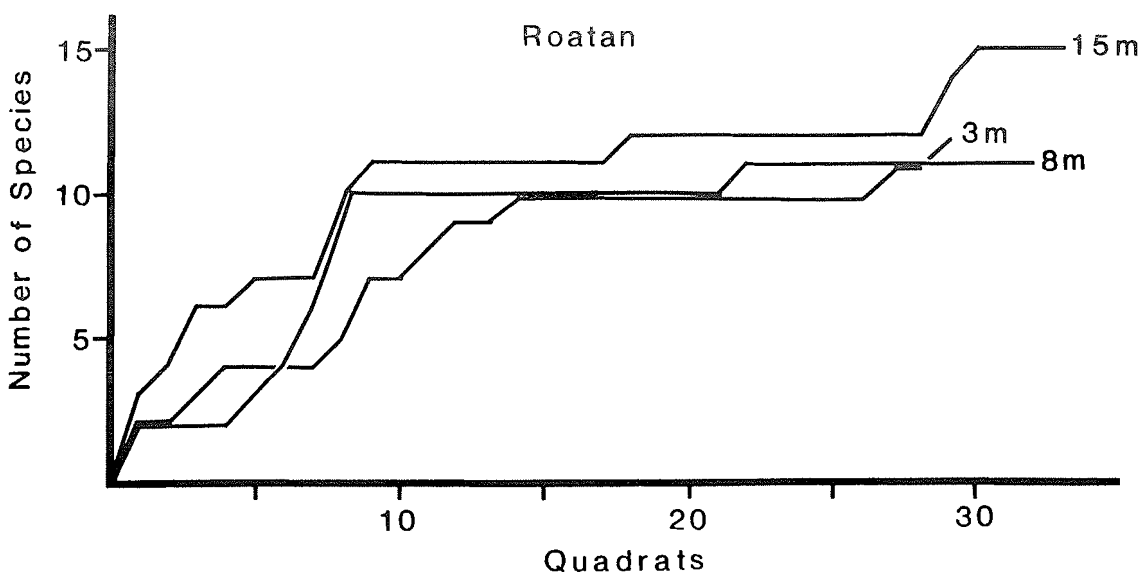

Figure 2. Species-area curves for Roatan.

not included in the measurements, nor were other organisms. A line transect was made on the crest because the water was too shallow to allow a photo transect. The line transect was made in front of Anthony's Key (86°35'W, 16°20'N; Fig.'s 4B, 5).

The moveable grid used for belt-quadrats on Cayman Brac consisted of a 1 x 1 m frame of PVC tubing divided into 16 equal squares by 6 lines. The grid was placed on the reef, and the coverage of each coral species estimated. Estimates of large corals were made in squares, and small corals in cm^2. After coral cover estimation, the frame was moved to the adjacent area, in a straight line along the depth contour. Belt-quadrats were made in each of 6 visually identifiable zones which are listed along with the depth and location in Table 3. Reef locations were named and marked with buoys as in Roatan. Two belt-quadrats were made in the terrace reef zone, one on top of the buttresses, and one on the sides of buttresses. These belt-quadrats were made perpendicular to shore because of an observed gradient in coral composition along the length of the top of each buttress, and because the buttress tops were quite narrow. Species-area curves began to level out in 15-20 frames (Fig. 3), requiring the combination of the two belt-quadrats at each depth. Vertical extensions of colonies and hidden sections of corals were not included in the measurements.

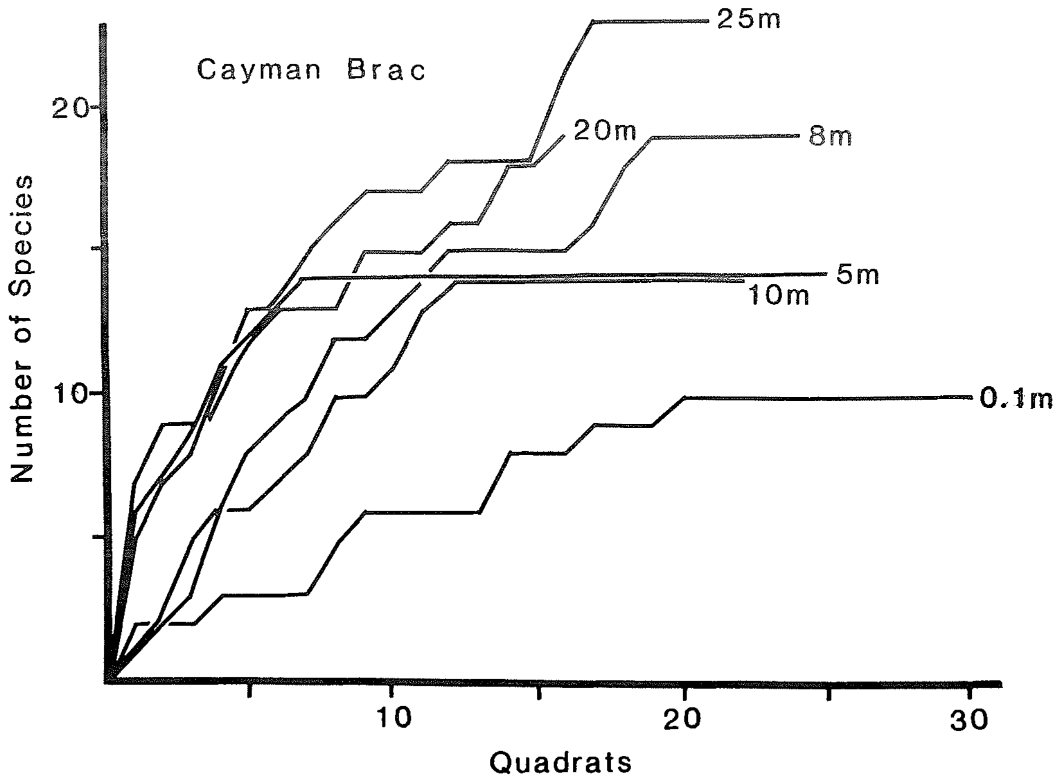

Figure 3. Species-area curves for Cayman Brac.

Zooxanthellate, constructional (Schuhmacher and Zibrowius, 1985) coral species were identified in the field by the author, using Almy and Carrion-Torres (1963), Roos (1971), Smith (1971), Wells (1973), and Humann (1983), in addition to the references given in Fenner (1988).

The taxonomic system of Wells and Lang (1973) as modified by Cairns (1982) was used, since several of the species synonymized by Zlatarsky and Estallela (1982) are separable on biological criteria (e.g., Lang, 1971; van Moorsel, 1983; de Weerdt, 1984; Szmant, 1986; Fenner, in press). *Agaricia humilis* was not distinguished from *Agaricia agaricites* in transects due to time limitations, nor was *Agaricia lamarcki* distinguished from *Agaricia grahamae*. Azooxanthellate, non-constructional species were

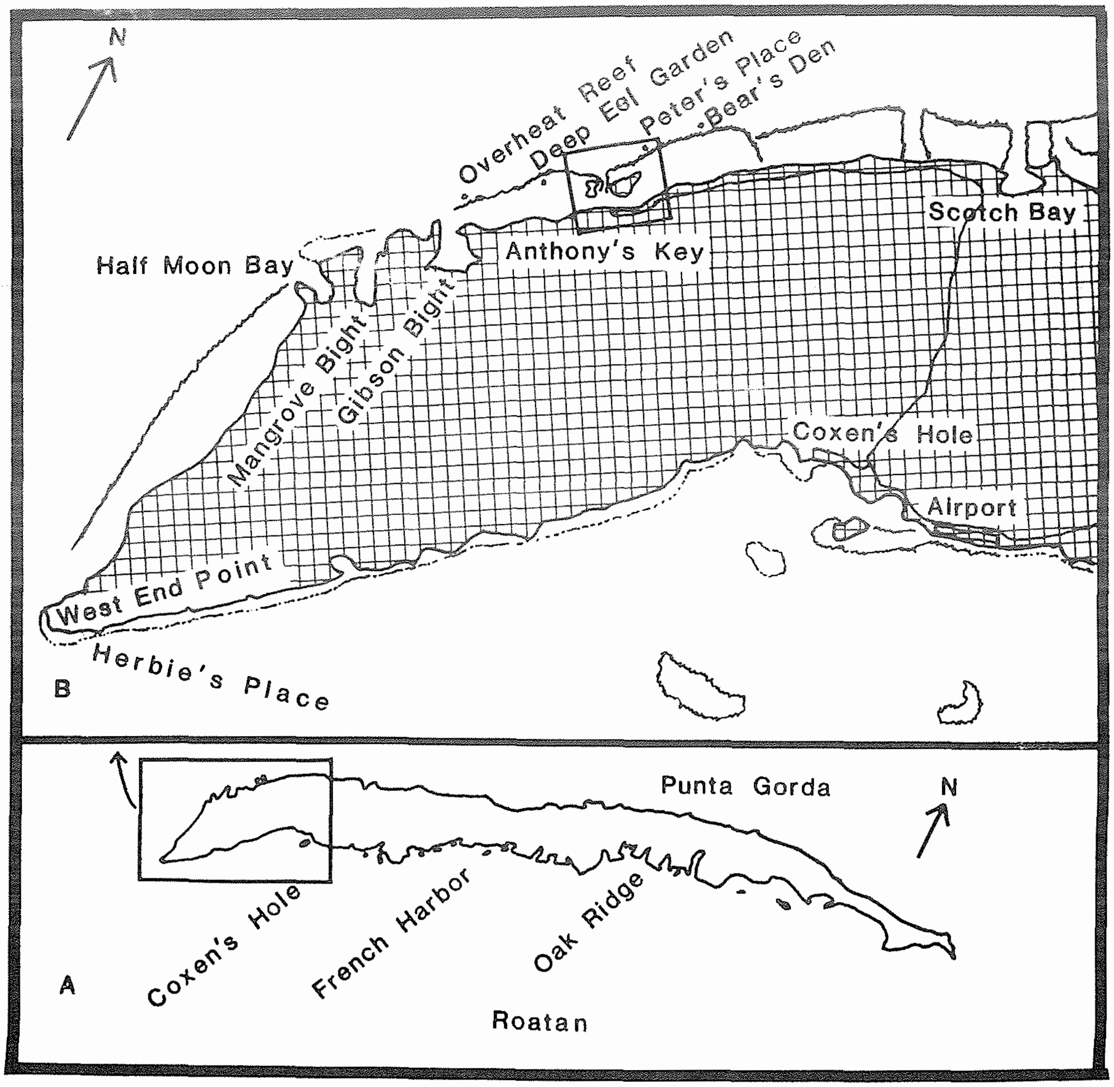

Figure 4. Maps of Roatan study area. A. Roatan. B. Western Roatan. A redrawn from Wilensky, 1974. B redrawn from Davidson, 1974.

identified by S. Cairns from specimens deposited at the U.S. National Museum, except for *Thalamophyllia riisei*, a distinctive species which was identified in the field by the author. Shannon and Weaver's diversity index H'_c was calculated using coverage measures ($H'_c = p(\ln p)$), as was the evenness index ($J = H'_c/H'_c max$)(Pielou, 1969).

RESULTS

Roatan

The coast of northwestern Roatan is bordered by a fringing reef (Fig. 4). Six zones were distinguished: lagoon, crest, shallow forereef, spur-and-groove, deep forereef, and deep forereef slope.

Lagoon

The lagoon was visually surveyed east of Anthony's Key, and west of Bailey's Key (Fig. 4B & 5) at about 86°35'W, 16°20'N. On the east side of Anthony's Key, the lagoon is about 365 m wide. It is about 1 m deep behind the reef

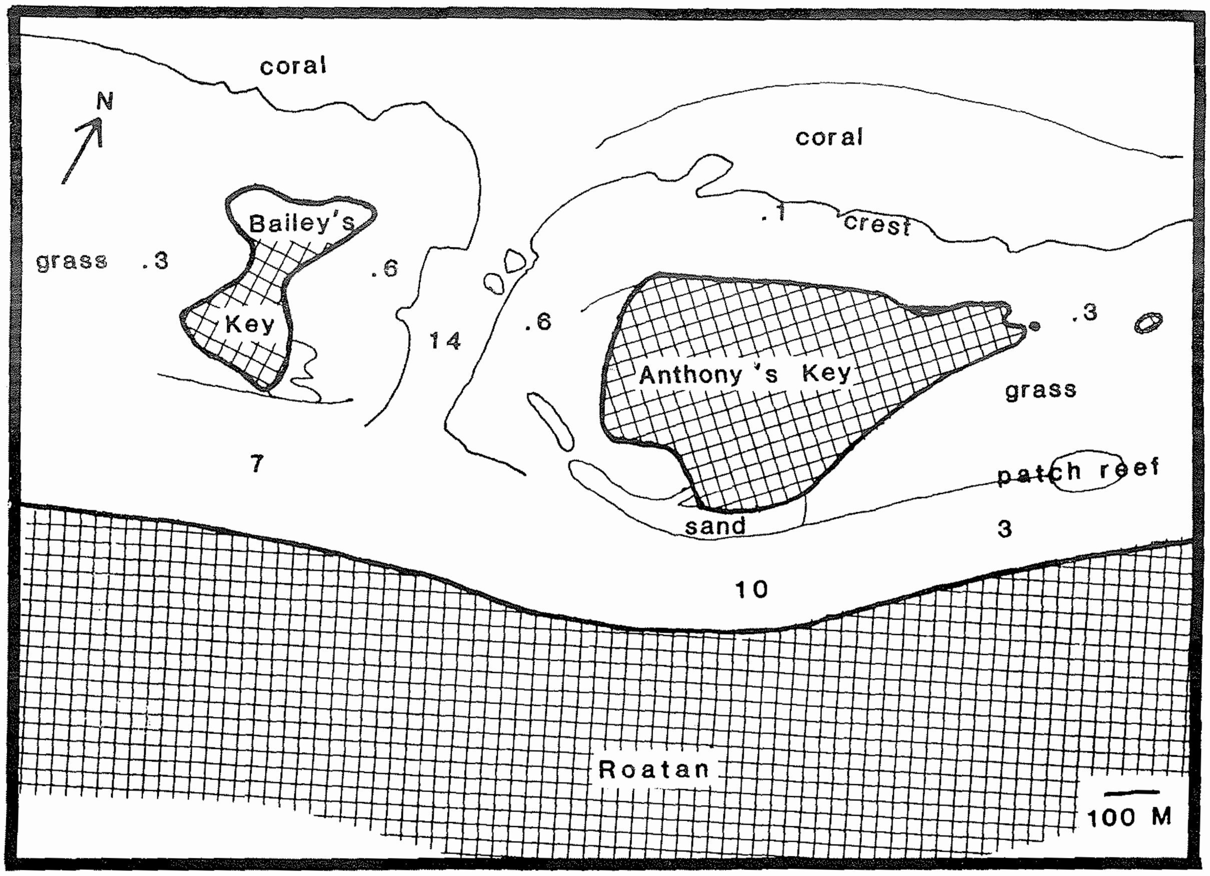

Figure 5. Anthony's Key area, northwest Roatan. Redrawn from areal photograph in Wilensky (1979). Depths in meters.

crest, deepening to about 3 m within about 100 m of the shore of Roatan. Coral heads and clumps of *Porites porites* forma *furcata* were found in the outer part of the lagoon. The middle and inner parts of the lagoon have an almost continuous bed of the seagrass *Thalassia testudinum*, with a dense community of the anemone *Bartholomea annulata*. Bare sand spots are burrowed by the heart urchin *Meoma ventricosa*.

Crest

The reef crest rises vertically from the lagoon to a depth of about 10 cm. During low tide, the reef top is emergent, and waves break over the crest. The crest is about 3 or 4 meters wide, and its upper surface consists of coral rock covered with brown algae (e.g., *Sargassum* and *Turbinaria* sp.) and crustose (e.g., *Porolithon pachydermum*) and articulated (e.g., *Amphiroa* sp.) coralline algae (Fig. 6). The vertical surface on the lagoon side supports living corals, primarily *Agaricia tenuifolia*. The line transect revealed that only 7.5% of the surface is covered with living corals, with *A. tenuifolia* covering 4.8%, *Porites astreoides* covering 1.3%, and five other species covering smaller areas.

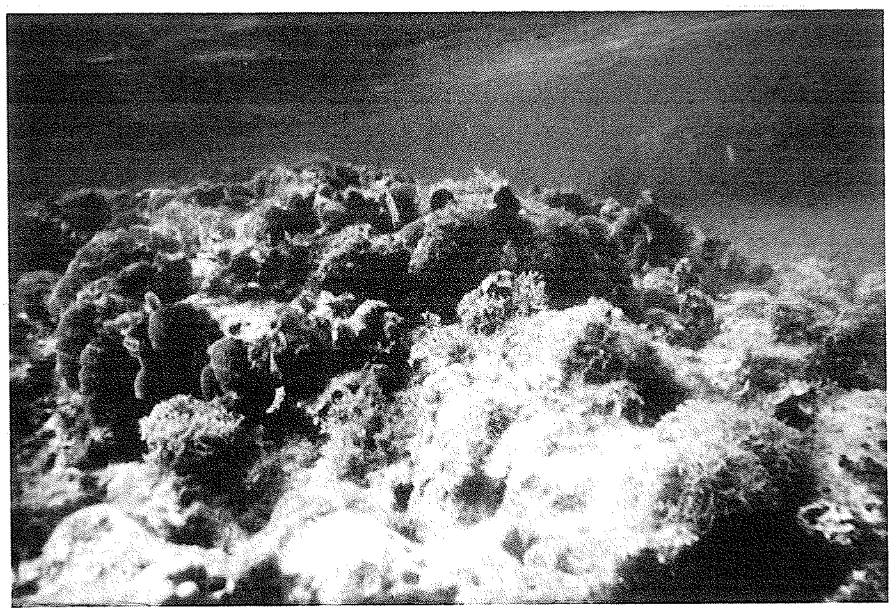

Figure 6. Reef crest, 0.1 m depth, Anthony's Key, Roatan. Left center, *A. tenuifolia*.

Shallow forereef

The reef front can be divided into four zones. The shallowest zone is the shallow forereef which has corals

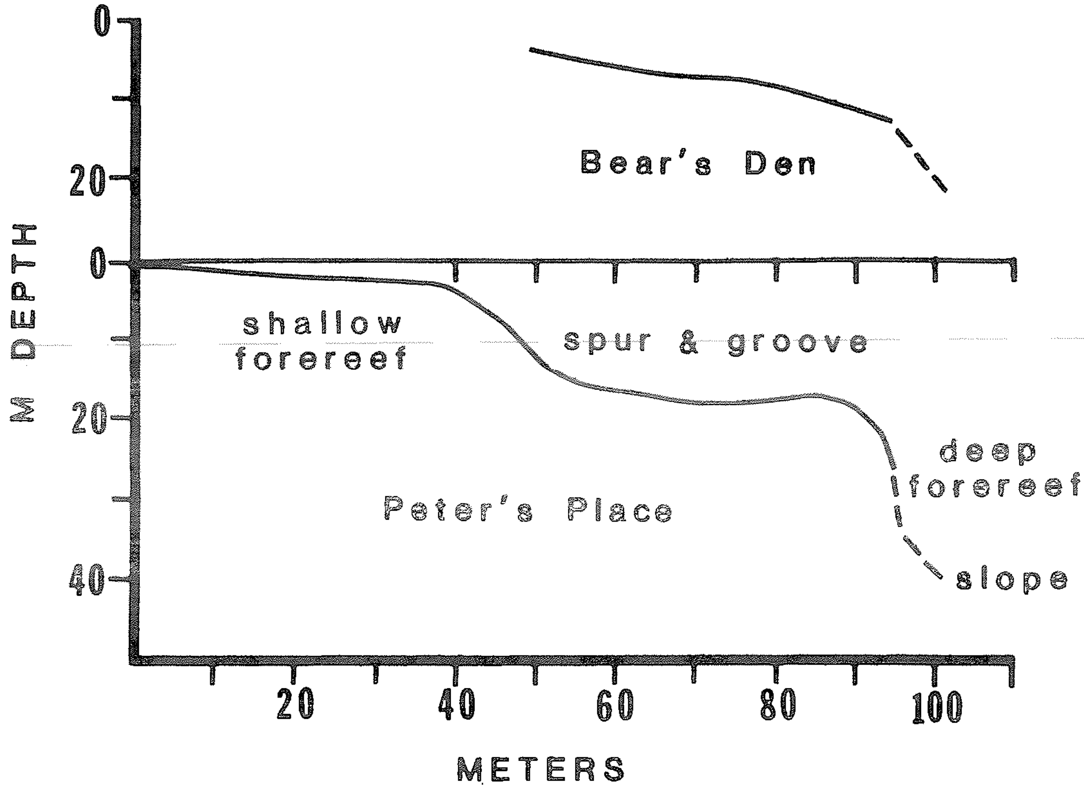

Figure 7. Depth profiles of two Roatan reefs, each taken from one transect. Dotted line extensions observed but not measured.

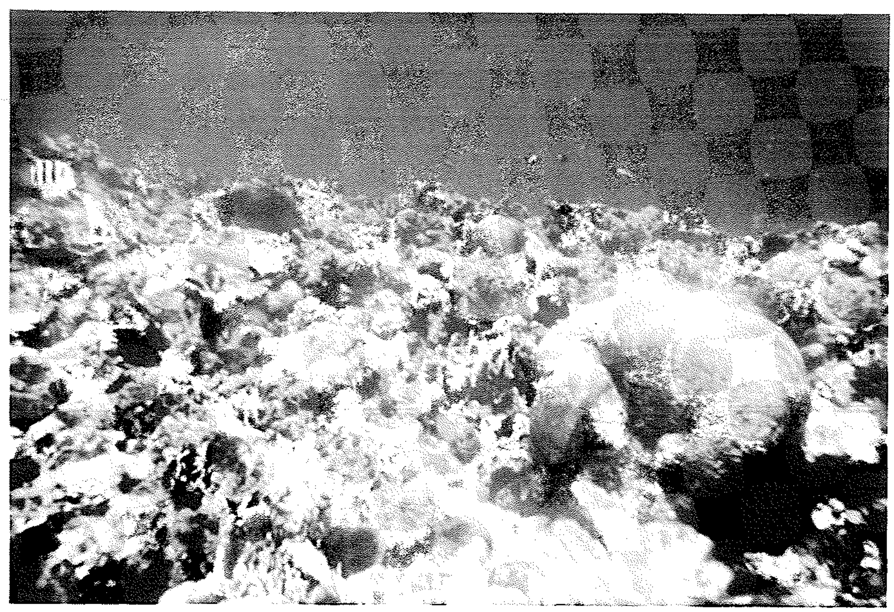

Figure 8. Shallow Forereef, 3 m deep, "Overheat Reef", Roatan. Right, *M. annularis*.

scattered on a relatively flat coral rock base, extending to about 5 m depth (Fig. 7 & 8). The coral rock is nearly completely covered with crustose coralline algae and bears many chiton holes about 1 cm in diameter (Littler et al., 1989, p.220-221). The sea urchin *Diadema antillarum* is uncommon, yet green and brown algae are also uncommon, probably due to common herbivorous fish. Photo belt-quadrats revealed that 18% of the surface is covered with corals. The hydrocoral *Millepora complanata* covers 5.7%, *Diploria strigosa* 4.2%, *A. tenuifolia* 2.9%, *Siderastrea siderea* 2.2%, *Montastrea annularis* 1.4%, *Diploria clivosa* 1.1%, and six other corals cover smaller areas.

Spur-and-groove

The shallow forereef grades into a spur-and-groove zone dominated by massive *M. annularis* colonies on the tops of the buttresses, and dissected by grooves or sand channels. At some locations a dropoff separates these two zones, as it does at "Peter's Place" buoy, while at other locations such as "Bear's Den" buoy (both at about 86°34'W, 16°20'N), no such sharp demarcation exists (Fig. 7). The grooves or sand channels are often only 1-2 m wide, and run parallel to each other down the forereef slope (perpendicular to the shore). In places, some of the sand channels widen considerably, to a width of 12 m or more, known locally as 'white holes'. The grooves vary in depth, but in places extend to about 5 m below the adjacent reef tops. Their sides support less living coral than the spur tops, and their bottom is

Figure 9. Spur top, 8 m depth, "Gibson Bight", Roatan. All visible coral is *M. annularis*.

typically flat and covered with rounded loose coral rubble up to 30 cm in diameter, resting on sand. In some locations, living *M. annularis* grows in flattened colonies out over the groove, closing a ceiling over a small tunnel, most often at the deeper end of this zone. The coral buttresses growing between the grooves are often 3-5 m wide (Fig. 9). The quadrat photos were taken only on the tops of buttresses. The two photo belt-quadrats revealed that 28.8% of the surface is covered with corals. *M. annularis* covers 22.7%, *A. tenuifolia* covers 4.1%, and nine other species cover smaller areas.

Deep forereef

At a depth of about 12 to 18 m, a sharp increase in slope marks the beginning of the deep forereef. In most locations, e.g. "Peter's Place" (Fig. 7), the deep forereef descends at an angle just less than vertical. Many corals grow on the surface in flattened colonies projecting from the slope as shelves (Fig. 10). Spaces between corals are dominated by brown algae (e.g., *Lobophora variegata, Dictyota* sp.). Although *M. annularis* is clearly present, it

Figure 10. Deep Forereef, 15 m depth, "Gibson Bight". Center right: *C. natans* and *M. annularis.*

does not appear as prevalent as in the spur-and-groove zone. The undersides of projecting corals are dominated by pink crustose coralline algae, with few sponges or ahermatypic corals. Such coral overhangs rarely extend more than 1 m. Thus, they correspond closely to the overhangs and mouths of caves at Grand Cayman (Logan, 1981). The deeper grooves found in the forereef zone extend over the edge onto the deep forereef in a modified form. On the deep forereef they typically are less than 1 meter deep, and their floor and sides are covered with living coral. The two photo belt-quadrats showed that 28% of the surface is covered with coral. *M. annularis* covers 16.5%, *Colpophyllia natans* 3.4%, *P. astreoides* 1.8%, *D. strigosa* 1.6%, *Montastrea cavernosa* 1.5%, *A. agaricites* 1.4%, *A. tenuifolia* 1%, and nine other species cover smaller areas. Averaged over the 4 zones, *M. annularis* is the most common coral at Roatan, covering 10.3%, followed by *A. tenuifolia* with 3.2%, *M. complanata* 1.6%, and *D. strigosa* 1.4%.

Deep forereef slope

Although the deep forereef slope was not reached in this study, the bottom could be seen to assume a slope of about 45^{o} at a depth of about 35 m. This deep slope appeared to have fewer corals, separated by a sandy bottom.

South shore

Observations were also made at three locations on the southwestern shore of Roatan. "Mary's Place", near French Harbor (Fig. 4A), has a 2 m-wide cleft in the reef that parallels the reef front and extends from the reef surface at a depth of about 12 m to below 35 m. In the cleft the undersides of projecting corals have azooxanthellate, non-constructional coral communities (e.g., *Colangia immersa* and *Paracyathus pulchellus*) in addition to crustose pink coralline algae. The reef at Dixon Cove, between French Harbor and Coxen's Hole (Fig. 4A), has an almost pure stand of *Acropora cervicornis* offshore at a depth of about 5 m. The steep forereef from about 12-15 m on down appears very similar to the same zone on the northwest shore of Roatan, and below it a deep forereef slope appears similar to the same zone on the northwest shore. At "Herbie's Place", near West End Point (Fig. 4B), the reef slopes continuously from the shoreline outward, at an angle of about 45^{o}. Coral cover is less than on the forereef of northwest Roatan, but there are more sponges and gorgonians. No signs of coral bleaching or disease were seen at any location in Roatan.

Diversity

A total of 40 species and 2 forms of Scleractinia were found in Roatan, plus 3 species of hydrocorals, as listed in

Table 1. Seven of the Scleractinia are azooxanthellate and non-constructional. Corals found both in and out of the transects were included in this count. *Colpophyllia breviserialis* was observed, but not considered a valid species or form because intermediate forms between it and *C. natans* were also observed, as in Zlatarski and Estallela (1982). It is listed in parentheses in Table 1. The *Balanophyllia grandis* listed in Table 1 was identified by similarity in living coral and skeleton to a larger individual from Cozumel identified as *B. grandis* (USNM 82093). It is the same as the Balanophyllia sp. 1 listed in Fenner (1988), and can be distinguished in the field from the *Leptopsammia* or *Balanophyllia* sp. in Fenner (1988) by the dull red color of the former and the bright yellow color of the latter when alive, which is probably *Leptopsammia trinitatis* (Hubbard and Wells, 1986). Nine new records for Roatan are indicated in Table 1.

Table 1

Stony Corals of Roatan (Honduras), Cayman Brac, and Little Cayman

		Roatan	Cayman Brac	Little Cayman
Stephanocoenia michelinii		5	3	4
Madracis decactis		5	3*	4*
Madracis mirabilis		4	3*	3*
Madracis pharensis forma *pharensis*	+	5	5*	5*
Madracis formosa			4*	3*
Acropora palmata		4	2	3
Acropora cervicornis		4	3	3
Acropora prolifera			5	
Agaricia agaricites forma *agaricites*		4	3	2
forma *danai*			4**	3**
Agaricia humilis			3**	4**
Agaricia lamarcki		3	4*	4*
Agaricia grahamae			3*	3*
Agaricia fragilis				4*
Agaricia tenuifolia		2		
Leptoseris cucullata		4	4	4
Siderastrea radians		5	3*	4*
Siderastrea siderea		3	3	3
Porites porites forma *porites*		5	5	3
forma *furcata*		3*	2	4
forma *divaricata*		5	5	5
Porites astreoides		2	2	2
Porites branneri			5*	5*
Favia fragum		4	4*	4*
Diploria strigosa		2	3	3
Diploria clivosa		3	4	3
Diploria labyrinthiformis		3	3*	3*

		Roatan	Cayman Brac	Little Cayman
Manicina areolata forma *areolata*		4		
forma *mayori*				5
Colpophyllia natans (=*breviserialis*)		2	2	3
Montastrea annularis		1	1	1
Montastrea cavernosa		3	2	2
Colangia immersa	+	5*		5*
Caryophyllia sp.	+			5*
Meandrina meandrites forma *meandrites*		4	4	4
Dichocoenia stokesi (=*stellaris*)		4*	4	4
Dendrogyra cylindrus		3	5	
Mussa angulosa		5	4	5
Scolymia cubensis		5	4	4
Isophyllia sinuosa		4*	5*	5*
Isophyllastrea rigida		4	4*	5*
Mycetophyllia lamarckiana		4	3	4
Mycetophyllia danaana		4	3*	4*
Mycetophyllia aliciae		4	5*	3*
Mycetophyllia ferox		4	4	4
Mycetophyllia reesi				4*
Thalamophyllia riisei (?)	+	5*		
Eusmilia fastigiata forma *fastigiata*		4	4	4
Balanophyllia grandis (?)	+	5*	4**	5**
Paracyathus pulchellus (=*defilippi*)	+	5*		
Paracyathus sp.		5*	5**	
Millepora alcicornis	#	3	4*	3*
Millepora complanata	#	2	3	3
Stylaster roseus	#+	4*	4	4

1 = common 2-4 = intermediate 5 = rare
+ azooxanthellate non-constructional (ahermatypic)
* new report for this island # hydrocoral
** new report for the Cayman Islands

Coral cover was greatest on the spur-and-groove zone (spur tops) and steep forereef slope, but coral diversity was greatest on the shallow forereef and deep forereef. Measures of coral cover and diversity are presented in Table 2. The number of species was least at the crest, and greatest at the deep forereef. Coral cover was lowest at the crest, and highest on the spur-and-groove zone (spur tops) and deep forereef. The diversity index H'_c was greatest in the shallow forereef, intermediate at the deep forereef, and lowest at the spur-and-groove zone and crest. The evenness index J showed a pattern similar to H'_c, except that the crest had an intermediate value. Together these indices reveal a pattern of increasingly dense coral populations with depth to at least 8 m depth. Species diversity was lowest in the shallowest zone and in an intermediate depth zone (spur-and-groove zone, spur tops) where one species (*M. annularis*) was dominant. Below about

35 m the coral populations appear less dense.

Table 2

Coral diversity at Roatan. Number of quadrats at "Overheat Reef", OR; Number of quadrats at "Deep Eel Garden", DEG; Number of species, S; percent living coral coverage, % Cov.; Shannon and Weaver's diversity index, H'_c; species evenness, $J' = H'_c/H'_c max$.

Zone	Depth	OR	DEG	S	% Cov.	H'_c	J'
crest	.1m			8	7.5%	1.18	.57
shallow forereef	3m	10	19	12	18.2%	1.96	.76
spur and groove	8m	10	23	11	28.8%	.82	.34
deep forereef	15m	9	23	15	28.3%	1.54	.57

Cayman Brac

Depth profile

Coral reefs surround most of Cayman Brac (Logan, 1988; in press), including the southwestern area studied (Fig. 11). Unlike most of the reef surrounding Cayman Brac, the study reef breaks the surface offshore, and is separated from the shore by a shallow lagoon. Six zones associated with the reef are distinguished here, based on the nomenclature of Logan (in press), Roberts (e.g., 1977; in press), and Rigby and Roberts (1976): lagoon, crest, shallow terrace, terrace reefs, deep terrace, and deep forereef. The lagoon's depth profile was measured at Channel Bay, (Fig. 11B) at about 79°53'W, 19°41'N.

The lagoon at Channel Bay is about 125 m wide (Fig. 12), and no more than 1 m deep. The lagoon in the study area, like the other zones, appears as described in Logan (in press), except as noted below. Several small patch reefs near the seaward margin of the lagoon are about 2-3 m in diameter, with steep sides and a flat top. They rise from the bottom in about 1 m of water to within about 20 cm of the surface. The reef crest rises gradually from the lagoon to a depth of about 10 cm. The crest is about 50 m wide. Most of the width of the crest dips slightly away from land, reaching about 30 cm depth at the seaward margin. A depth profile of the shallow terrace and the terrace reef was taken at "Heddie's Reef" buoy at about 79°51'W, 19°41'N) from a depth of 3 m to a depth of 15 m (Fig. 12). Although the depth profile taken did not extend through the surf to the crest, extrapolation indicates the width of the omitted area to be about 120 m. The shallow terrace ends abruptly in spurs (Fig. 12). The spurs or buttresses are quite narrow, only 1-2 m wide at their top. They extend in nearly straight lines perpendicular to the shore, and their crests describe an irregular profile (Fig. 12). The grooves or

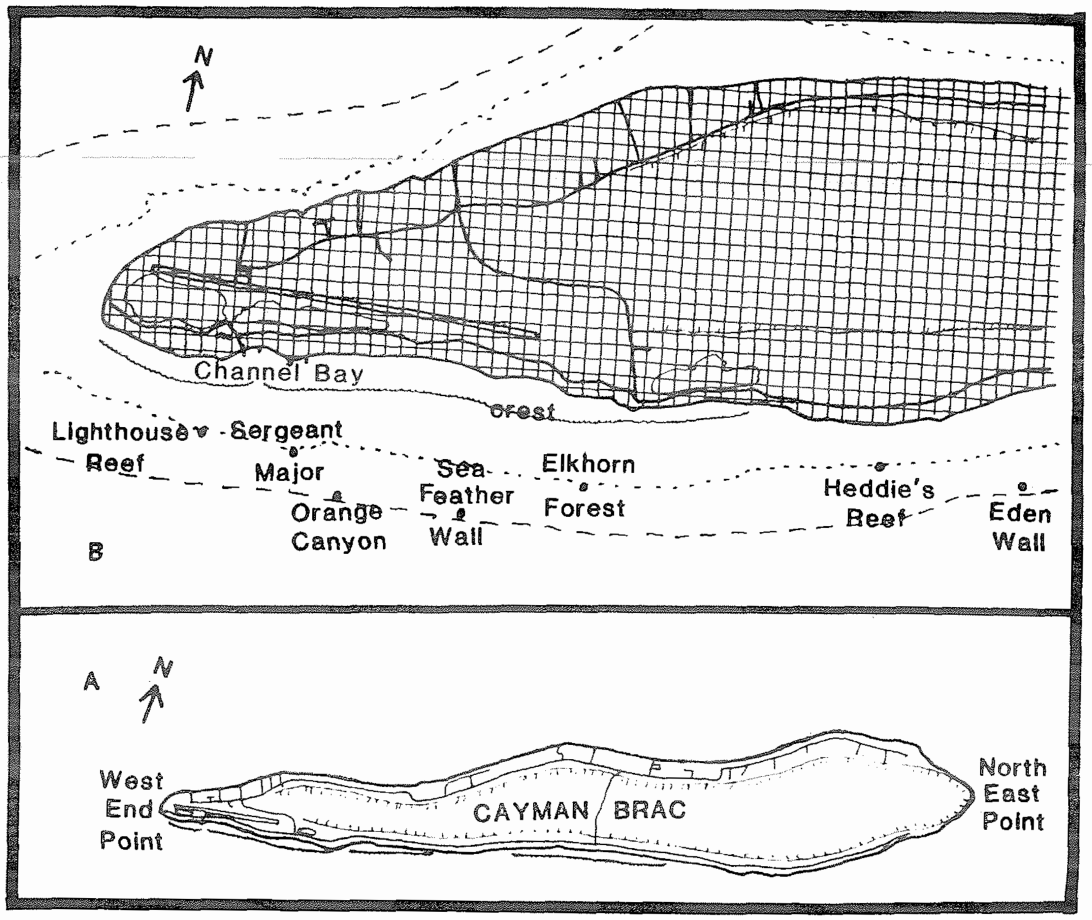

Figure 11. Maps of Cayman Brac study area. A. Cayman Brac. B. Western Cayman Brac. A redrawn from British Admiralty chart #462 of the Lesser Caymans. B redrawn from Logan (1988).

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sand channels between the spurs are about 2-5 m wide. The spurs in the terrace reef end abruptly by falling sharply to meet the sand channel bottom and the deep terrace at a depth of about 15 m (Fig. 12). A depth profile of the deep terrace and deep forereef was taken at "Eden Wall" buoy (79°51'W, 19°41'N). The entire width of the deep terrace was not measured due to time limitations; however, it is estimated to be 100-200 m wide. At a depth of about 18 m, the bottom dips at a steep angle, marking the boundary between the deep terrace and deep forereef, and reaching nearly vertical by a depth of 25 m (Fig. 12). At some locations, such as "Eden Wall", where the depth profile was taken, the deep forereef continues to descend vertically to what appears to be about 50 m, and then descends at about 45°. In other locations, a 45° slope cannot be seen from 30 m depth, while elsewhere the deep forereef descends at less than vertical, though always at a steeper angle than 45°.

Coral populations

In the lagoon, areas of coral rubble bottom have a sparse community of small corals, mainly *Siderastrea radians*. A belt-quadrat of rubble bottom revealed only 2% of the bottom is covered with live coral, and the diversity is quite low (H'_c =.87, Table 3). *S. radians* covers 1% of the bottom, and only 4 other corals were found in the transects. Coral cover appears greater on the sides of patch reefs than their tops. A belt-quadrat composed of grid placements on top of the patches revealed 6 species of corals, covering 22% of the surface with an intermediate diversity (H'_c = 1.45, Table 3). Four species of coral are most common on the patch reefs: *P. porites* f. *furcata* (7.8%), *A. agaricites* (5.8%), *M. annularis* (4.3%) and *P. astreoides* (3.6%).

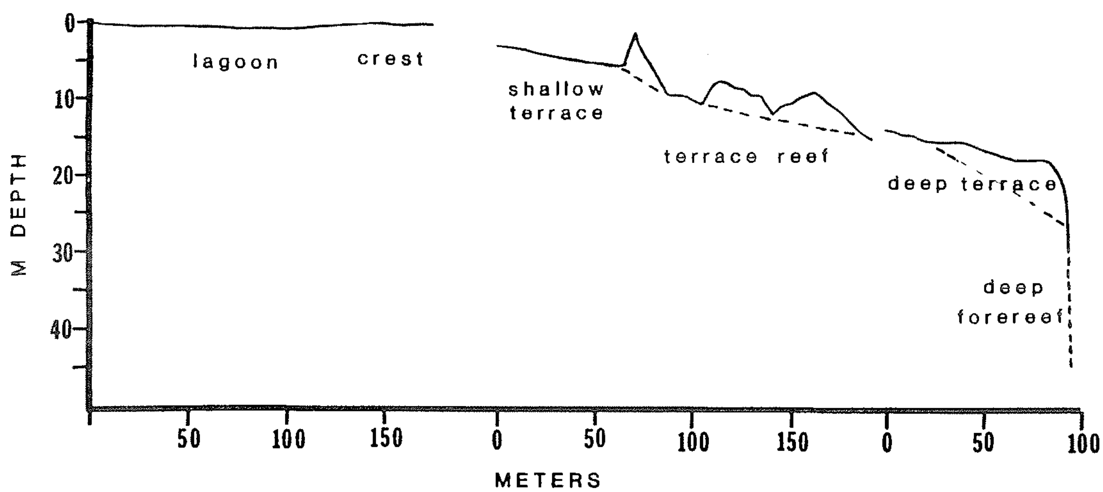

Figure 12. Depth profiles of southwest Cayman Brac reefs. The lagoon and crest were measured in Channel Bay, in front of the Brac Reef Hotel, the shallow terrace and terrace reef were measured at "Heddie's Reef", and the deep terrace and deep forereef were measured at "Eden Wall".

A belt-quadrat on the reef crest revealed 10 species of coral covering just 2% of the bottom, with an intermediate diversity (H'_c = 1.58, Table 3). *P. porites* f. *furcata* is the most common coral in this zone, with 1.1% cover. A belt-quadrat on the shallow terrace revealed 14 species of coral covering 12% of the bottom with the highest diversity found on the reef (H'_c = 1.96, Table 3). The most common corals on the shallow terrace are *D. strigosa* (3.2%), *P. astreoides* (2.3%), *S. siderea* (2.1%), and *M. annularis* (1.6%).

The crests of spurs of the terrace reef are dominated by massive *M. annularis* (Logan, in press) at their seaward end, and have scattered large *Acropora palmata* colonies on their middle and shoreward crests. The sides of the spurs have *M. annularis* extending down over their seaward end. A belt-quadrat on the top contained 19 species of corals, covering 30% of the surface with a moderate diversity (H'_c = 1.65, Table 3). *A. palmata* (11.1%) is the most common coral, followed by *M. annularis* (7.5%), *M. complanata* (3.3%), *P. porites* f. *furcata* (2.3%), *C. natans* (1.7%), and platy *Agaricia* sp. (1.2%). Belt-quadrats taken on the sides of the spurs reveal 14 species of coral, covering 14% of the sides, with an intermediate diversity (H'_c = 1.61, Table 3). The most common corals are *M. annularis* (5.8%), platy

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Table 3

Coral diversity at Cayman Brac. Number of species, S; percent of living coverage, % Cov.; Shannon and Weaver's diversity index, H'_c; species evenness, $J' = H'_c/H'_c\max$.

Zone	Depth	Sites*	S	% Cov.	H'_c	J
lagoon rubble	.5m	CB:11	5	1.6%	.87	.54
patch	.2m	CB:10	6	22.3%	1.45	.81
crest	.1m	CB:30	10	2.4%	1.58	.69
shallow terrace	5m	SM:25	14	11.6%	1.96	.74
buttress top	8m	EF:14,L:10	19	29.7%	1.65	.56
sides	10m	EF:14,L:10	14	13.6%	1.61	.61
deep terrace	20m	OC:11,SF:5	19	44.6%	1.94	.66
deep forereef	25m	OC:10,SF:11	23	33.8%	1.87	.60

*CB = Channel Bay, in front of Brac Reef Hotel ($79^{\circ}53'$W, $19^{\circ}41'$N. SM = "Sergeant Major Reef" ($79^{\circ}53'$W, $19^{\circ}41'$N). EF = "Elkhorn Forest" ($79^{\circ}52'$W, $19^{\circ}41'$N). L = "Lighthouse Reef" ($79^{\circ}53'$W, $19^{\circ}41'$N). OC = "Orange Canyon" ($79^{\circ}53'$W, $19^{\circ}41'$N). SF = "Sea Feather Wall" ($79^{\circ}53'$W, $19^{\circ}41'$N). Number is number of quadrats at that location.

Agaricia sp. (4.0%), and *P. astreoides* (2.3%). Belt-quadrats were also taken on the reef near the seaward end of the deep terrace. Nineteen species of coral were found in these belt-quadrats, covering 44% of the bottom, with a high level of diversity (H'_c = 1.94, Table 3). *M. annularis* is the most common species of coral (16.6%), followed by *M. cavernosa* (7.5%), *C. natans* (6.4%), *P. porites* f. *furcata* (4.1%), *A. agaricites* (3.0%), *Stephanocoenia michelinii* (2.3%), *D. strigosa* (1.9%), and *P. astreoides* (1.0%).

Belt-quadrats were taken on the deep forereef at a depth of about 25 m. Twenty-three species of coral were found in the belt-quadrats, covering 33% of the surface with a high diversity (H'_c =1.87, Table 3). *M. annularis* is most common (Logan, in press) in this zone (16.2%), followed by *M. cavernosa* (5.2%), *C. natans* (3.1%), platy *Agaricia* sp. (1.8%), *P. astreoides* (1.5%), *A. agaricites* (1.3%), and *S. michelinii* (1.0%). When averaged across all zones, *M. annularis* was the most common coral, with 6.5% cover, followed by *P. porites* f. *furcata* with 2%, *M. cavernosa* (1.8%), *A. agaricites* (1.4%), *P. astreoides* (1.4%), *C. natans* (1.4%), and *A. palmata* (1.4%). Total coral cover averaged 20%.

Diversity

A total of 40 species and 3 forms of Scleractinia were found on Cayman Brac, plus 3 species of hydrocorals, as listed in Table 1. Five of the Scleractinia are azooxanthellate and non-constructional. Corals found both in and out of the belt-quadrats were included in this count. Twenty-four species of stony corals are new records for Cayman Brac, as indicated in Table 1.

The richest coral communities are on the deep terrace and deep forereef. The poorest coral communities are on lagoon rubble and on the reef crest. Measures of coral cover and diversity are presented in Table 3. The number of species in transects increases with depth throughout the range studied, except that spur tops have more species than their sides. The percentage of surface covered by coral increases up to the end of the deep terrace, at about 18 m depth, except for spur tops which have higher coverage than their sides, and a high coverage on lagoon patch reefs. The diversity index H' also increases with depth to the deep terrace, except for higher values on the spur tops than on their sides, and a high value on the shallow terrace. The evenness index J showed no overall trend. Together these indices reveal a pattern of increasingly dense and diverse coral populations with depth to at least 18 m depth. Spur tops consistently have greater coral coverage and diversity than the spur sides (which are deeper) perhaps as an edge effect due to reduced sedimentation (Porter, 1972). Below about 35 m, the coral populations appear less dense.

Little Cayman

Little Cayman is surrounded by fringing reef, enclosing a shallow lagoon (Logan 1988; in press). Zonation of this reef is similar to that on Cayman Brac and Grand Cayman, except for a short section of the study site at Bloody Bay, on the northwestern shore at about $80^{O}5$'W $19^{O}41$'N. In this area, the reef does not reach the surface offshore, and there is no lagoon. Thus, four zones can be distinguished: shallow terrace, terrace reef, deep terrace, and deep forereef. In the center section of Bloody Bay, the shallow terrace extends to the edge of the deep forereef, omitting the terrace reef and deep terrace (Logan, in press; Fig. 13).

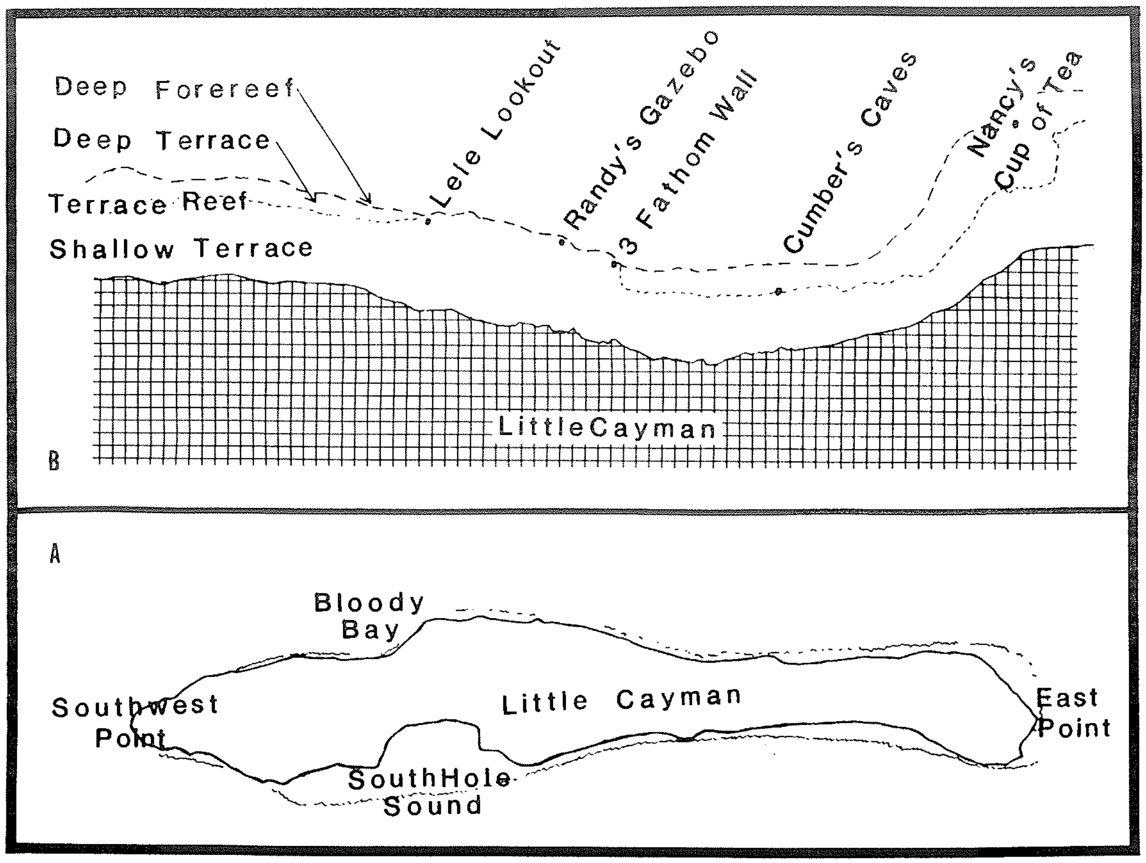

Figure 13. Maps of Little Cayman study area. A. Little Cayman. B. Bloody Bay. A redrawn from British Admiralty chart #462 of the Lesser Caymans. B redrawn from Logan (1988) and Cayman Aggressor captain's sketch.

A depth profile of the reef where there are four zones was taken at "Cumber's Caves" buoy at $80^{O}5$'W $19^{O}41$'N, and shown by the lower trace in Fig. 14. A gently dipping terrace extends from the shoreline about 100 m out to a depth of about 6 m. The terrace reef extends up to 20 m horizontally from a depth of about 6-13 m. Only one groove was found in the terrace reef, at "Cumber's Caves" (Fig. 13), and it extends only a short way into the base of the escarpment.

The deep terrace consists of a gently sloping plane of sand, about 65 m wide, and from 13 to 17 m deep. In areas such as "Nancy's Cup of Tea" buoy (Fig. 13) buttresses of coral extend to connect the terrace reef with the deep forereef (Logan, in press). Buttresses appear to be about 10-30 m wide, and the intervening sand 100-200 m wide. At the outer edge of the deep terrace, coral grows upward abruptly, with overhangs present at some locations. A crest is reached at about 13 m depth. Then the reef dips downward at an angle that increases to near vertical by 25 m depth, and continues at that angle to at least 35 m depth.

In the central section of Bloody Bay, only two zones remain: shallow terrace and deep forereef (Logan, in press).

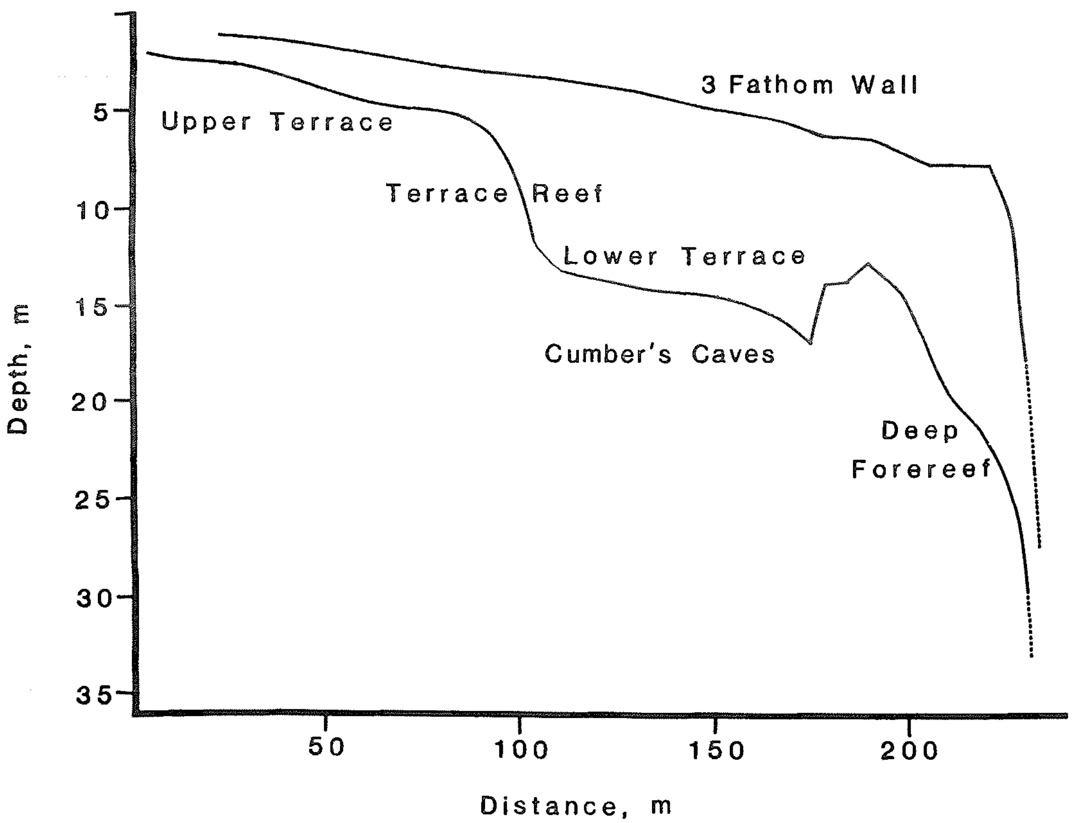

Figure 14. Depth profiles of Bloody Bay, northwest Little Cayman. The upper curve was measured at "3 Fathom Wall", and the lower curve at "Cumber's Caves". The curves are not offset.

This is formed by the terrace reef escarpment curving out to join the deep forereef at each end of this section (Fig. 13). In this central section, the shallow terrace extends from the shoreline out about 250 m to a depth of about 6-8 m, where the bottom dips steeply as the deep forereef. This can be seen in a depth profile (Fig. 14, top trace) taken at "3 Fathom Wall" buoy (80°5'W, 19°41'N). The deep forereef in this area is a very steep, smooth wall that has a covering of scattered corals and sponges.

Diversity

Thirty-nine species and 3 forms of scleractinia and 3 species of hydrocorals were found at Little Cayman (Table 1). Twenty species of stony corals were reported for the first time for Little Cayman, as indicated in Table 1.

DISCUSSION

The reefs of northwestern Roatan, Little Cayman, and southwestern Cayman Brac all feature a 15-20 m deep terrace above a steep forereef wall. Deep terraces are common in coral reefs around the world, and have been called the "Ten-Fathom Terrace" (Stoddart. 1969). All three of the Cayman Islands are surrounded by such a terrace (Rigby and Roberts, 1976; Roberts, 1977; in press; Logan, in press). However, one short section of Bloody Bay, on northwest Little Cayman, lacks a deep terrace for unknown reasons (Logan, in press; Fig. 13). The southern shore of Roatan has a terrace at 10-12 m depth that may correspond to the "Ten-Fathom Terrace", or to a shallow terrace common on many Caribbean reefs. The shallow terrace in the Cayman Islands is typically 6-10 m deep at its deep end (Rigby and Roberts, 1976; Logan, in press; Fig. 12, 14). Such a terrace, here called the "shallow forereef" was found at one location on northwest Roatan, but not at a second location, for unknown reasons. Some other Western Caribbean reefs show similar terrace features (Belize: Rutzler and Macintyre, 1982b; Chinchorro: Jordan and Martin, 1987; Cozumel: Fenner, 1988), though others may not (Yucatan: Jordan, 1979).

The reef off the northwest coast of Roatan has a very regular and well-developed spur and groove, or buttress and sand channel system. The grooves are common, oriented at right angles to the crest, and fairly uniform in dimensions. It is unusual for a spur and groove system to be found along a leeward shore (Stoddart, 1969), though they do exist along some leeward shores (e.g., Puerto Rico: Morelock et al., 1977; Barbados: Stearn et al., 1977; Grand Cayman: Logan, 1981; Cozumel: Fenner, 1988). In some cases where a spur and groove system exists on the leeward side of an island, the spurs and grooves are smaller and less well organized than on the windward side (Roberts, 1974; Jordan and Martin, 1987). And yet northwest Roatan, western Barbados, and southwest Puerto Rico have well organized spur and groove systems. The slope of a reef is an important factor in addition to the amount of wave action in producing an ordered spur and groove system. As Woodley and Robinson (1977) point out, good sediment drainage allows the growth of spurs. Sloping reef fronts, like wave action, promote sediment drainage, allowing spur and groove formation.

The coral populations at Roatan and Cayman Brac are not unusual for the Western Caribbean. A total of 44 taxa of stony corals were found at Roatan, compared to 47 found there by Halas and Jaap (1982) (according to the taxonomic system of Wells and Lang (1973) as modified by Cairns (1982)). Nine taxa reported here were new reports for Roatan, bringing the total reported at Roatan to 56. A total of 47 taxa were found on Cayman Brac and 45 on Little Cayman, compared to 25 for both these islands by Logan (in press), and 56 for Grand Cayman by Roberts (in press), Logan (1981), and Fenner (unpublished report of *Thalamophyllia riisei*). Twenty-four taxa were new reports for Cayman Brac, and 20 for Little Cayman, but only four were new for the Cayman Islands as a whole. The number of coral taxa reported here are similar to those reported from other western Caribbean reefs at Belize: 53 (Cairns, 1982) and Chinchorro Banks, Mexico: 47 (Jordan and Martin, 1987), but less than that at (more intensely studied) Cozumel: 71 (Fenner, 1988; Jordan, 1988; Muckelbauer, 1990; Fenner, in press; Fenner, unpublished report of *Madracis formosa*, *Manicina areolata* f. *mayori*, *Porites colonensis* (Zlatarski, 1990), *Eusmilia fastigiata* f. *flabelliformis*, *Oculina* sp., *Montastraea annularis* sp. 2 & 3 (Knowlton, et al., 1992), and *Madrepora carolina*). There are a wide range of numbers of coral taxa reported from regional reefs, from 16 at Swan Islands (Tortora and Keith, 1980) and 36 at Yucatan reefs (Jordan et al., 1981) to 78 in Jamaica (Wells and Lang, 1973; Cairns, 1986; Fenner, 1988; Knowlton, et al., 1992, Fenner, in press). The differences appear to be primarily a function of the extent of study of a location (Liddel and Ohlhorst, 1988); the total number of corals on many Caribbean reefs may be close to that found in Jamaica after intensive study.

Liddel and Ohlhorst (1988) suggested that the number of species found in transects would be a better indicator of diversity than total species lists. They compared the number of scleractinian species found in transects at about 15 m depth at 12 locations in the Caribbean. From 11 to 20 species were found in these transects, with a mean of 15 species. In the present study, 14 coral species were found at 15 m depth at Roatan (Table 2, *Millepora* removed), and 18 species were found at 20 m at Cayman Brac (Table 3, *Millepora* removed). In a previous study of Cozumel (Fenner, 1988), 18 species were found in transects at about 15 m depth (Table 2, *Millepora* and *Stylasterina* removed). Liddel and Ohlhorst (1988) reported that 14-28 scleractinia were found among all transects at the 12 locations, with an average of 20 species. In the present study, 21 scleractinia were found in Roatan transects, 31 at Cayman Brac, and in the previous study of Cozumel (Fenner, 1988) 28 were found. Thus, by these measures, coral diversity at Roatan was typical for a Caribbean reef, and Cayman Brac and Cozumel had relatively rich coral diversities.

Diversity indices derived from transect samples may not be as heavily biased in one direction by the total amount of effort expended as the total number of coral taxa reported. Shannon and Weaver's diversity index H'_c ranged from .82 to 1.96 in northwest Roatan, with an average of 1.38 over the four zones. The same index ranged from .87 to 1.96 in southwest Cayman Brac, with an average of 1.58 over the six zones. On Little Cayman, Logan (in press) reported an H'_c on the terrace reef of 1.63, which is very close to the values found in this study at Cayman Brac for terrace reef buttress tops (1.65) and buttress sides (1.61). The diversity of corals on other western Caribbean reefs have been reported at Panama, where H'_c was 1.95 (Porter, 1972), Yucatan where H'_c was 1.59 (Jordan et al., 1981), Cahuita (Costa Rica) 1.44 (Cortes and Risk, 1985), Jamaica 1.43 (Huston, 1985) and 1.35 (Liddel and Ohlhorst, 1987), and Cozumel 1.70 to 1.72 (Fenner, 1988; Muckelbauer, 1990). Liddel and Ohlhorst (1988) found that H'_c at about 15 m depth for 12 Caribbean locations averaged 2.0, with a range of 1.45-2.47. Roatan had an H'_c at 15 m of 1.54 (Table 2), Cayman Brac 1.94 (Table 3) and Cozumel 1.74 (Fenner, 1988, Table 2). Thus, this index indicates that Cayman Brac has a coral diversity similar to other western Caribbean reefs, and Roatan has slightly less coral diversity than other regional reefs.

Live coral cover on the Roatan and Cayman Brac reefs surveyed in this study was slightly low for the western Caribbean. Live coral cover ranged from 8 to 29% at Roatan, with the average being 21% cover. Coral cover ranged from 2 to 45% at Cayman Brac, averaging 20%. Logan (in press) reported 39% coral cover on the terrace reef of Little Cayman, which is more than that found in this study of Cayman Brac on the terrace reef buttress tops (29.7%) and buttress sides (13.6%). The average Cayman Brac cover of 20% and Roatan cover of 21% are more than the average 9% coral cover reported for the Yucatan (Jordan et al., 1981), but less than the 23% cover on the Belize Barrier Reef (Rutzler and Macintyre, 1982b), 28% to 32% cover at Cozumel (Fenner, 1988; Jordan, 1988; Muckelbauer, 1990; 15% after Hurricane Gilbert: Fenner, 1991), 37% to 41% cover at Jamaica (Huston, 1985; Liddel and Ohlhorst, 1987), 40% cover at Cahuita, Costa Rica (Cortes and Risk, 1985), and 63% off southwest Grand Cayman (Cortes and Risk, 1985).

Thus, the number of coral taxa reported, the diversity index, and percent coral cover indicate that Roatan's northwestern reefs and Cayman Brac's southwestern reefs are well within the range reported for other western Caribbean reefs.

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