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ASSESSMENT OF HURRICANE ANDREW EFFECTS ON THE BNP REEF CORALS

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INTRODUCTION

This report describes work accomplished during the past six months of the contract period. During this time we completed all the field work, including the transect survey of the last site (Bache Shoals) and the census of the recruitment quadrats in three sites (East Bache, Triumph, and Ball Buoy). We have devoted most of this period to the organization, editing, processing, graphing, analysis and interpretation of the data collected during the past two years. A brief, preliminary summary of the data and results is presented below. A more detailed, comprehensive presentation will be provided for the final report and in manuscripts prepared for peer-reviewed publication.

SUMMARY OF THE DATA COLLECTED FOR THE PROJECT.

TASK 1- QUANTITATIVE DESCRIPTION OF THE BENTHIC COMMUNITY STRUCTURE OF NINE REEF LOCALITIES.

Nine reef localities (five offshore and 4 inshore) within the Biscayne National Park were sampled using transect lines and 1 m² quadrats. The transects run parallel to the longer axis of patch reefs, and to the relief of offshore reefal areas usually in a northeast-southwest direction. In the offshore sites, the first transect was haphazardly placed in the deep side (front reef area) towards the east, 4 more, evenly spaced (20 or 25 m) parallel transects were placed towards the west to cover most of the different habitats within each site (front reef, slope, crest, back reef, etc). In the inshore patch reefs, four transects were placed; one on the eastern, wave exposed zone, one in the back reef zone and two on the top of the reef. A 1 m² quadrat divided in 100 areas of 100 cm² each was moved along the transect lines at 2-4 m intervals depending on the length of the reef. Two different methods were used to collect the data in each quadrat; the first method involved a very detailed collection of quantitative data on the cover (live tissue over the substrate), the abundances (number of colonies), and the health status of each species of scleractinian coral, octocoral and sponge, and the cover of fleshy, crustose and turf algae, miscellaneous, and other substrates such as sand, bare substrate, and rubble (see appendix 1). In the second method, the presence-absence of the same groups was registered under 49 random intersection points marked with flagging tape at crossing lines inside the quadrat.

All the data collected for the nine reef sites using these two methods has been entered in the computer, revised, edited and organized into spreadsheets for the analyses. In early November, 1995, an additional patch reef in the Bache Shoals area was sampled using only the point-intersect method. This reef and Alina's reef were sampled in 1988 by Glynn and Szmant (Glynn et al. 1989) providing us with historical data with which we can compare our results on coral and octocoral cover, abundances and health status.

The analysis of the data is now in process with some parts already completed. Each reefal community will be described in terms of: (1) the diversity, abundance (colonies/m²), and percent cover of scleractinians, octocorals, sponges, zoanthids and hard hydrozoans; (2) the percent cover of crustose, fleshy and turf algae (3) the

percent cover of other substrates such as sand, rubble and bare substrate; (4) the relative abundance of healthy (no injuries, no obvious disease, no overgrowth, etc) vs. unhealthy (sick, bleached, overgrown, overturned, etc.) colonies of scleractinian corals and octocorals; (5) the size frequency distribution of major coral species in each reef site, and (6) the relative abundance of recruits and juveniles of the main coral and octocoral species. **Tables 1a** and **1b** present a summary of the reef characteristics and variables measured and/or estimated from the transect-quadrat sampling. Table 2 includes a comparative summary of the community composition in each site estimated with the two methods used (transect-quadrat and point-intersection).

Table 1a. Reef site location and characteristics. Number of transects and 1 m² quadrats sampled in each reef. (O)= offshore; (I)= inshore.

REEF	latitude	longitude	depth	type	transects	quadrats
Fowey	25° 35.383	80° 05.697	8-30	Flat-relict (O)	5	100
Soldier	25° 35.256	80° 09.184	11-13	Flat-relict (I)	5	100
Triumph	25° 28.312	80° 06.725	8-21	"Barrier" (O)	5	100
East Bache	25° 28.984	80° 08.441	3-17	Patch (I)	4	80
Pacific	25° 22.186	80° 08.360	7-32	Flat-relic (O)	5	100
Elkhorn	25° 21.789	80° 09.948	3-17	Patch (O)	5	100
Alina's	25° 23.201	80° 09.779	5-19	Patch (I)	4	91
Ball Buoy	25° 18.524	80° 11.996	5-26	Barrier (O)	5	100
Isa's	25° 19.918	80° 11.879	6-19	Patch (I)	4	75

Table 1b. Variables measured and included in analyses.

In each 1 m² quadrat the following information was recorded:

- 1- Mean and total cover (cm², percent cover and area/m²) of scleractinian corals, octocorals, sponges, zoanthids, hard hydrozoan (*Milleporas*), crustose algae, fleshy algae, turf algae and other organisms (miscellaneous), sand, rubble and bare substrate.
- 2- Relative abundance of healthy vs. unhealthy colonies of scleractinians and octocorals.
- 3- Abundance of corals, gorgonians, sponges, zoanthids, and hard hydrozoans (colonies/m²).
- 4- Diversity of scleractinians, octocorals and sponges in each reef site (# of species).
- 5- Abundance and density of recruits (young colonies) of scleractinians and octocorals.
- 6- Size frequency and distribution of the major coral species

The large differences in the cover of octocorals between the two methods in table 2 is due to the different ways the data was collected. In the transect-quadrat survey the cover measured was the live tissue over the substrate, the base of the colony for most octocorals. In the point intersection method, the cover represents the number of points under which the canopy of a particular octocoral colony was observed, therefore, when these numbers are transformed into percentages, the octocorals appear as having high percent cover.

In general, scleractinian corals, octocorals and sponges show higher live cover and densities than zoanthids and milleporids in both offshore and inshore reefs. Live cover and density of scleractinians is higher on the inshore patch reefs (12-19 %; 8-12 colonies/m²) with the lowest cover and density at Soldier Key (0.46%, 0.81 colonies/m²) in the north (Table 2, Figure1). Coral cover increases from north to south in the offshore reefs (from 2 to 13%) but decreases somewhat in the inshore patches. Coral densities increase towards the south in both reef systems. Octocoral and sponge cover and densities are higher on inshore reefs and increase towards the south (Table 2, Figure1). The inshore patch reefs have significantly higher cover and density of octocorals and sponges. Octocoral and sponge cover and density are lower at Soldier and higher at Isa's in the south. In the northern area, Fowey has higher cover and density of cnidarians and sponges than the inshore locality. Isa's and East Bache show similar cover of octocorals but densities are significantly higher at Isa's reef (21.4 vs. 41 colonies/m²). Zoanthids and hard hydrozoans show low cover and densities in all reefs with a trend to increase towards the south (Figure 1D and 1E). Algae and crustose algae make up the main biological component of reefs with covers ranging from 8 to 72 % (Figure 1F-G). Cover of fleshy, turf algae and miscellaneous decrease towards the south with Soldier Key showing the highest cover of fleshy algae. Cover of crustose algae is higher on offshore reefs and increases towards the south with the highest cover on Alina's reef. Pacific, Elkhorn and Ball Buoy have more bare (dead) substrate (Figure1H-K). On all reefs, turf algae and miscellaneous together make up most of the cover, followed by fleshy and crustose algae (Figure 2). With the exception of Fowey, Soldier Key and Triumph in the northern part of the Park, all other sites show a higher percent cover of scleractinian corals compared to the other cnidarians and to the sponges. The octocorals show the highest abundances (colonies/m²) in all reefs except in Elkhorn, where scleractinians are more abundant due to a high number of juvenile colonies of *Porites astreoides* (Figures 2A-2I and 3).

Densities (colonies/m²) of cnidarians and sponges are higher on the inshore reefs and increase towards the south. Isa's has the highest densities of corals, octocoral, sponges, zoanthids and hydrozoans among the inshore reefs. Ball Buoy has similar densities of coral than Elkhorn, but higher densities of octocorals, sponges, zoanthids and hydrozoans (Figure 3)

The number of species and genera (biological richness) of corals, octocorals and sponges increases from north to south and is higher on the inshore reefs (Figure

4a). The sponges are significantly more diverse at the generic level (16-36 genera) than the cnidarians (7-20 and 9-12 in corals and octocorals respectively) in all reefs. Sponges are more diverse than corals and octocorals at the species level on Fowey, Pacific, and Isa's (Figure 4b). The lowest diversity of all three groups was found on Soldier Key. The number of species of scleractinian corals range from 12 on Soldier to 43 on Isa's (Appendix 2). The number of octocoral species range from 23 on Soldier to 41 at Isa's (Appendix 3), and the number of different sponges range from 21 on Soldier to 48 at Isa's (Appendix 4). A new record for this area is the scleractinian coral *Madracis senaria* which was observed in the deep areas of Pacific. This coral is also abundant on deep reefs of Key Largo (i.e. Conch). *Porites "branneri"*, a small, crustose species described for Brazil was reported by Burns (1983) as common on some of the reefs in the Park. This is a misidentification. This species is likely endemic to Brazil and what has been reported for the southern Caribbean as *P. "branneri"* is a different taxon (Weil, 1992a, b). In general, the biodiversity of zooxanthellate corals found in this study is comparable to those reported by Japp (1984), Dustan (1984), and Burns (1984) for the Florida reef tract.

Table 2. Summary table of community parameters for each reef site sampled in Biscayne National Park. OCTOC= octocorals; SPON= sponges; ALGAE= fleshy and calcareous algae; CRUST= crustose algae. TRANS= transects; QUAD= quadrats; NSPP= number of species; Densities in colonies/m².

QUADRAT METHOD

SITE	N TRANS	N QUAD	NSPP CORAL	NSPP OCTOC	NSPP SPONG	%COVER CORAL	DENSITY CORAL	%COVER OCTOC	DENSITY OCTOC	%COVER SPONG	DENSITY SPONG	%COVER ALGAE	%COVER CRUST
FOWEY	5	100	28	28	37	2.54	3.2	1.18	7.9	5.04	4.93	11.96	10.96
SOLDIER	5	100	12	23	21	0.46	0.8	0.80	6.4	1.83	2.39	72.25	0.48
TRIUMPH	5	100	23	32	31	1.96	2.8	1.69	14.5	2.22	3.34	13.07	8.76
EBACHE	4	80	40	40	31	19.38	7.7	9.23	21.4	5.43	8.46	9.245	10.3
PACIFIC	5	100	28	29	30	1.93	4.4	1.34	7.9	1.02	2.79	13.85	14.3
ALINA'S	4	91	39	39	34	15.11	10	4.70	19.3	4.33	8.48	24.57	5.88
ELKHORN	5	100	29	34	34	9.51	10.6	1.94	7.3	2.22	3.76	20.13	5.33
BBUOY	5	100	40	39	36	12.68	10.3	3.36	16.1	4.85	7.61	14.77	15.93
ISA'S	4	75	43	41	48	12.09	11.8	10.39	41.1	11.82	21.43	8.36	11.09

POINT INTERSECTION METHOD

SITE	N TRANS	N QUAD	NSPP CORAL	NSPP OCTOC	NSPP SPONG	%COVER CORAL	%COVER OCTOC	%COVER SPONGES	%COVER ALGAE	%COVER CRUST
FOWEY	5	100				2.2	10.6	4	10.9	
SOLDIER	5	100				0.5	16.2	3.1	77.8	
TRIUMPH	5	100				2.2	22.7	2.3	12.4	
EBACHE	4	80				15.8	31.5	5.3	12.4	
PACIFIC	5	100				2.4	9.4	1.5	15.4	
ALINA'S	4	91				11.7	24.6	6	23.1	
ELKHORN	5	100				8.6	12.6	2.1	22.3	
BBUOY	5	100				9.6	23.6	3.1	12.9	
ISA'S	4	75				7.2	43.7	8.3	8.4	

TASK 2: MONITORING CORAL RECRUITMENT ON REEFS.

We completed the monitoring of new recruits with our second and last census in early November of 1995. All thirty five 0.25 m² permanent quadrats placed in 1994 on old substrate and "fresh" bare substrate of overturned colonies in three reef sites (East Bache, Triumph, and Ball Buoy) were re-censused with a magnifying glass. Recruits from 11 scleractinian species and one milleporid were identified and counted in the quadrats (Figure 5). East Bache showed significantly more recruits (57 new recruits) than Ball Buoy (11 new recruits) and Triumph (4 new recruits). *S. siderea* was the most common recruit followed by *P. astreoides* and *A. agaricites*. Between 25 and 31 % of the initial recruits disappeared from the quadrats in one year (Table 3).

The relative abundance of coral recruits and juvenile colonies of scleractinian species were estimated using data from the transect-quadrat surveys. There were 21 scleractinian species with recruits and/or small juveniles in the quadrats (Table 4a). The relative abundance of the important recruiting species on each reef is shown in Table 4b and Figure 6. Recruits of *S. siderea* were the most abundant on 6 out of the 9 reefs. *P. astreoides* (both color morphs combined) was the species with higher abundance of recruits on Elkhorn, Alina's and Ball Buoy reefs. With the exception of Isa's patch reef in the southern end of the Park, the offshore reefs had a higher number of recruit and juvenile colonies. These data show that there is significant recruitment of scleractinians on these reefs and that many recruits are able to survive long enough to form small colonies in most reefs. Recruitment and survival increase from north to south (Figure 7).

The inshore patch reefs have higher spatial heterogeneity and this may provide shelter and protection with a consequent higher survival of the fewer coral spats. The offshore reefs to the center and north sections of the park are mostly flat, relic platform, with low spatial heterogeneity, thus coral spat and juveniles are less protected from intentional or accidental predation (fish, snails), sediment smothering, and other factors. As was shown by the caging experiment (see below), parrot fish and wrasses graze heavily on the reef substrate, killing or injuring many exposed recruits.

TASK 3: MONITORING HURRICANE-DAMAGED COLONIES.

3A- BACHE SHOALS

In July 1994 between 5 and 20 overturned colonies of 5 species (*Montastraea faveolata*, *M. annularis*, *Diploria strigosa*, *Siderastrea siderea*, and *Colpophyllia natans*), that were presumably damaged by hurricane Andrew, were selected and tagged in two patch reefs in the Bache Shoals area. In each colony, the edge between the live and dead tissue was marked with nails and the live tissue area was measured and sketched. Five healthy colonies of each species were tagged as controls and sketched. A year later (July 1995) all damaged and control colonies were re-censused and any recovery (new growth)

Table 4c. Densities (colonies/m2) of juveniles of 21 scleractinian species at each reef site.

REEF	Fowey	Soldier	Triumph	Bache	Pacific	Alina's	Elkhorn	Bbuoy	Isa's
Transects	5	5	5	4	5	4	5	5	4
Quadrats	100	100	100	71	100	91	100	100	75
<i>S.siderea</i>	0.240	0.330	0.230	0.282	0.330	0.286	0.170	0.240	1.240
<i>P.astreoides</i> B	0.040	0.000	0.080	0.155	0.120	0.516	1.640	0.430	0.200
<i>P.astreoides</i> Y	0.180	0.000	0.010	0.113	0.030	0.110	0.040	0.120	0.533
<i>M.faveolata</i>	0.020	0.000	0.000	0.014	0.000	0.033	0.020	0.070	0.053
<i>M.cavernosa</i>	0.020	0.000	0.120	0.056	0.050	0.055	0.030	0.120	0.133
<i>P.porites</i>	0.050	0.000	0.080	0.000	0.220	0.220	0.240	0.140	0.053
<i>A.agaricites</i>	0.020	0.000	0.050	0.085	0.280	0.099	0.110	0.050	0.133
<i>D.strigosa</i>	0.010	0.000	0.000	0.014	0.030	0.022	0.160	0.050	0.067
<i>M.lamarckiana</i>	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.050	0.160
<i>D.stockesii</i>	0.090	0.010	0.090	0.042	0.050	0.033	0.020	0.020	0.240
<i>M.franksi</i>	0.010	0.000	0.000	0.000	0.020	0.022	0.000	0.010	0.040
<i>D.labyrinthiformis</i>	0.040	0.000	0.000	0.000	0.030	0.022	0.020	0.070	0.027
<i>M.meandrites</i>	0.020	0.000	0.080	0.000	0.040	0.000	0.000	0.000	0.000
<i>S.intersepta</i>	0.030	0.000	0.020	0.014	0.040	0.000	0.000	0.000	0.093
<i>D.stellaris</i>	0.000	0.000	0.000	0.014	0.000	0.000	0.020	0.000	0.000
<i>A.cervicornis</i>	0.000	0.000	0.000	0.000	0.000	0.033	0.010	0.000	0.013
<i>M.annularis</i>	0.000	0.000	0.000	0.000	0.010	0.033	0.000	0.000	0.013
<i>C.natans</i>	0.000	0.000	0.000	0.014	0.000	0.011	0.000	0.000	0.040
<i>E.fastigiata</i>	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.080
<i>D.clivosa</i>	0.000	0.020	0.000	0.000	0.000	0.000	0.030	0.000	0.000
<i>P.divaricata</i>	0.000	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.000

and/or regression (new dead area) was measured for each colony. The net gain or loss of live tissue was calculated for each colony and averaged for each species (Figure 8), and compared with the controls.

Since our original census was almost two years after the original (Andrew) damage occurred, we were not able to determine the extent of coral death right after the storm. Nevertheless, our results imply that overall, and for these five species, the partially damaged colonies are stabilized and suffered no major tissue loss in the one year period between our censuses. All species but *M. annularis* had new areas of growth and regression (Figure 8A) with *D. strigosa* and *C. natans* showing the larger areas of tissue loss. In many localities (i.e. Bache, Alina's) *M. annularis* is usually heavily colonized by *Halimeda* spp in the areas between the columns. If these mats are not removed by occasional storms, they overgrow the live tissue, suffocating the coral and producing extensive mortality. *S. siderea* and *M. faveolata* showed a net gain (growth) in live tissue and *D. strigosa*, *C. natans*, and *M. annularis* a net loss in live tissue (Figure 8B). It should be noted however, that the maximum area of tissue loss in a single colony was 340 cm² ($\approx$ 0.034 m²/year) in two large colonies (over 1 m² in surface area) of *C. natans*. This mortality rate represents a net percent change of less than 4 % of the total live tissue (Figure 8B) and is probably within the natural rates of tissue loss for this species.

3B- BALL BUOY- ACROPORA PALMATA FRAGMENTS DAMAGED BY TROPICAL STORM GORDON.

Tropical Storm Gordon (Nov. 94) produced a large number of fragments of *Acropora palmata* at Ball Buoy reef. Fragments of three size categories (small, <20cm length; medium 20-50 cm length; and large >50cm length) were individually marked, sketched, and measured (max. length of live tissue in cm) in January, 1995. As many of the fragments as possible were relocated and re-censused in early July 1995, approximately 8 months after the storm disturbance. Fragments were scored as 1) completely dead, 2) < 50% dead 3) showing regression in size from initial census in January, 4) no change, or 5) growth and re-attachment evident.

The fragments of *A. palmata* showed a monotonic decline within 8 months of the disturbance. A total of 33 fragments were re-located at the July census, with the following results:

# fragments	small	med.	large
dead	6	8	0
>half dead	0	5	2
regression	0	4	3
no change	1	0	3
growth, reattachment	1	0	0

Only one fragment out of 33 (3%) showed signs of growth and re-attachment while 85% of the fragments we followed appeared to suffer decline and/or death within 8 months of the severe storm. These results contrasts strongly with results obtained by Diego Lirman when following *A. palmata* fragments at nearby Elkhorn reef damaged by Hurricane Andrew in 1992. These fragments showed high rates of recovery, re-attachment, and growth (D.Lirman, pers. comm.). Most could not be distinguished from standing colonies within 2 years of the disturbance. This contrast may be related to the timing of Gordon which occurred extremely late in the year, such that fragments may not have had time to recover and reattach before stressful winter temperatures and standard winter storms further depressed their viability.

TASK 4 : CORAL POPULATION SIZE-FREQUENCIES

Size frequency distributions of four common species of hermatypic corals were measured at five reef sites, Ball Buoy, Pacific, Triumph, EBache, and Isa's reefs. The species sampled were *Siderastrea siderea*, *Porites astreoides*, *Montastraea cavernosa*, and *Montastraea faveolata*. Colonies of each species within a 6m wide band along each transect used in the quantitative community descriptive sampling were haphazardly measured, striving to obtain a reasonable sample size for each species. Care was taken not to overlook small colonies. At certain sites where a species was rare, sample sizes obtained were significantly smaller than the desired 100 (noted on graphs). Data presented are based on an 'over-the-top' measurement made with a measuring tape.

In most cases, the outer shelf reefs, Pacific and Triumph, had a qualitatively distinct pattern of size frequency with populations being severely skewed toward small size classes (45-90% of populations in the smallest <10cm size class). At these two sites, larger size classes are virtually absent (Figures 9-12). Also, corals are overall rarer at these sites, reflected in the depressed samples sizes for *M.cavernosa* (Figure 9), *P. astreoides* (Figure 10), and *M. faveolata* (Figure 11) (for which insufficient numbers were encountered to even display the data). In contrast, the inshore patch reefs, EBache and Isa's, along with Ball Buoy Reef had much more even size distributions with both small and large size classes well represented. These sites are also the only ones where sufficient numbers of *M.*

faveolata were encountered.

These data, together with our other results suggests that recruitment of zooxanthellate corals is frequently occurring on the depauperate offshore reefs, since small colonies are relatively common, but that some combination of factors (slow growth, higher mortality, sediment abbrassion, etc.) prevents these colonies from attaining larger sizes.

A second set of data from the quadrat surveys is now being generated and processed to produce size-frequency histograms with larger sample sizes. Results will be compared with results of the method mentioned above.

TASK 5 : ASSESSMENT OF SPATIAL AND TEMPORAL VARIABILITY IN ENVIRONMENTAL PARAMETERS.

5a- Water Temperature:

Temperature was monitored more or less continually at several reef sites using Hobo-Temp temperature loggers (Onset Instruments, Pocasset, MA) anchored to the reef substrate in Ikelite clear plastic housings. The loggers were set to record approximately every 20 minutes, and were downloaded on a monthly schedule. It was determined that the housings provided some "greenhouse effect" during daylight hours, so data reported here are based on daily means of readings taken before 6 a.m. and after 8 p.m. Gaps in the data are due to dislodgement and loss of instruments, or instrument malfunction. Figure 13 (a-c) shows the time course of temperature readings (nightly means) over the course of the project.

In general, water temperatures at the inshore patch reef sites were more variable and had greater extremes of both cold in winter and warm in summer. This was most pronounced for the Soldier Key site (Table 6.).

Table 6: Number of days that nightly average temperatures were below 20 °C or above 30 °C (arbitrary lines for stressful cold and warm temperatures for corals).

SITE	<20 °C days	>30 °C days	SUM days	total # days	%stressful days
FOWEY	0	3	3	217	1.4
SOLDIER	19	29	48	306	15.7
TRIUMPH	0	4	4	332	1.2
EBACHE	9	0	9	290	3.1
ALINA's	2	6	8	287	2.8
BBUOY	1	0	1	271	0.4
ISA'S	5	6	11	322	3.4

From this table, it can be seen that Soldier Key is qualitatively distinct from all the other sites with an order of magnitude greater exposure to extreme temperatures. The other three inshore patch reef sites (EBache, Alina's and Isa's) also show approximately triple the exposure to extreme temperatures (mean = 3.1% of recorded days) as the outer shelf reef sites (mean = 1.0%).

While these data may help explain the lack of significant reef development at Soldier Key, it shows the opposite pattern from that which would help explain greater coral cover and reef development on the inshore patch reefs. i.e. temperature regimes are MORE, not less stressful at these inshore sites. It follows that, in the off-shore sites, temperature regimes are more favorable for reef development so the lack of such development in the offshore sites must have another explanation.

After several tests with the HOBO light meters, we deemed this device unreliable for accurate measurements of light intensity and therefore, the data have been discarded.

5b- Water column inorganic nutrients

Water samples were taken haphazardly approximating bi-weekly at the 9 sites where sediment traps were deployed. Dedicated water sample bottles were rinsed 3 times with surface water before samples were taken. Samples before May, 1995 were taken from surface water. After this time, the rinsed bottle was taken down on the dive and filled at the reef level. One sample was collected per site per date, transported back to the laboratory in a dark cooler, and frozen until analysis. Samples were then thawed and duplicates of each sample were analyzed for ammonia, nitrate+nitrite, and phosphate on the automated segmented flow analyzer. Data shown are means of the two duplicate analyses (Figures 14-16, time course graphs), or overall means of measures for all sampling dates (Figure 17; n= 16-21).

Overall, inorganic nutrient levels are quite variable, but long term means are around 0.1 μM for phosphate, 0.1-0.2 μM for ammonia, and 0.2-0.3 μM for nitrate + nitrite. No clear spatial patterns are present, though nitrate + nitrite is consistently marginally higher in overall mean in the offshore component of each inshore/offshore pair (i.e. mean for Fowey marginally higher than Soldier, for Triumph marginally higher than EBache, Pacific than Alinas, and BBuoy very marginally higher than Isa's). There are noticeable temporal spikes, though the only one of identifiable origin is the nitrogen signal (surface water sample, especially nitrate+nitrite) following Tropical Storm Gordon in Nov. 1994.

The lack of discernable spatial pattern in these data allows no insight into potential nutrient effects on reef community structure. Long-term means are in the ranges expected for subtropical reef areas.

5c- Sediment Accumulation Plates (Baynes 1993)

Sediment accumulation plates (Baynes, 1993) were used in short-term deployments (3 days). These devices (Astroturf surfaces) are intended to mimic benthic surfaces and provide an assessment of the sediment accumulation experienced by reef substrates. We performed five quarterly three-day deployments at each of six reefs (three inshore/offshore pairs). The plates ($n=9-12$) were attached even with the substrate to washers glued at fixed sites on the reef. At collection, lids with o-ring seals were carefully placed over the plates and brought back to the lab in an upside-down position. Accumulated sediments were rinsed out of the lids and Astroturf with a wash bottle and then washed through a series of sieves (1mm - .063 mm) to determine the size composition of the sediment particles. Water and sediment passing through the smallest sieve was poured into 60ml centrifuge tubes and centrifuged to concentrate the very fine sediments. Supernatant water was siphoned from these tubes and the concentrated sediments rinsed into pre-weighed drying dishes. All size fractions were dried to constant weight and weighed. Data presented are total accumulation (Figure 18) and percent of total accumulation in each size fraction (Figures 19-20).

One-way ANOVA was used to detect significant variation in total accumulation across sites. Size fraction data for each deployment was subjected to a Chi-squared test to determine if the distribution of sediments into size fractions varied by site. Also, individual fractions were tested by one-way ANOVA to determine if there was variation over sites ($n=5$ deployments). Lastly, for each fraction data for inshore and for offshore sites were pooled, respectively and t-tests (or Mann-Whitney rank sum tests, $n=15$) were used to detect significant differences in the percent of that fraction present at inshore versus offshore reef samples.

Results show Soldier Key to be qualitatively different from all the other sites in terms of total sediment accumulation. One-way ANOVA on total accumulation shows significant variation between sites ($p<0.0001$, $n=5$), and post-hoc tests indicate that Soldier Key is significantly higher than each of the other sites in pairwise SNK tests ($p<.05$). The consistently high accumulation in the July 1994 deployment corresponded with the strongest gust winds of the five deployments and a high average wind speed. The January 1995 deployment had highest average wind speed, but lower gusts, and showed typical levels of sediment accumulation (Table 7).

For each of the five deployments, Chi-square tests showed that the percentage distribution of sediment size fractions varied significantly from site to site ($p<.0001$ for each deployment). Also, tests on individual size fractions showed significant variation amongst sites, especially between inshore and offshore sites. That is, sediment accumulation at the offshore sites (especially Triumph) had greater incidence of the larger size fractions (>1mm and .25-1mm) while the inshore sites had greater incidence of the smallest fractions (.063-.25 mm and <.063mm) (Figure 19).

Thus, while the total accumulation data shows substantial temporal variation, and similar levels of accumulation at all sites except Soldier Key, this accumulation is

qualitatively different at inshore patch reefs versus offshore bank reefs. At the inshore sites, the sediment accumulated is consistently 60-85% composed of size fractions <.25mm while the offshore sites have a significantly greater component of coarser sediments.

These results further confirm the uniqueness of Soldier Key among the sites examined in this study. While the distinctive size distributions of accumulating sediments at inshore versus offshore sites agree with apriori notions of sediment dynamics, such as the greater energy regimes offshore filtering off the fine sediments allowing them to accumulate inshore, it is not clear how this result correlates with the depauperateness of coral populations at the offshore sites. That is, it is not clear that fine sediments should be more favorable to corals than coarser sediments. It may be that the abrasive effects of larger particles in the higher energy regimes of the offshore sites are detrimental.

It should be noted that the chronic levels of sediment accumulation we measured at the reef sites in this study of around 0.5 to 1 g/plate/deployment represents a level of deposition around 1.75 to 3.5 mg/cm²/day. This range is substantially below the threshold of 10 mg/cm²/day suggested by Rogers (1990) as representing stressful levels of sedimentation for reef corals.

Table 7. Wind data extracted from CMAN record for Fowey Rocks Light for the duration of each sediment accumulation (SA) plate and each sediment trap deployment. Mean speed and gust are given in knots, direction is given in degrees (i.e., 0 to 360).

SA PLATE DEPLOYMENTS:

<u>date placed</u>	<u>date retrieved</u>	<u>mean speed</u>	<u>mean max. gust</u>	<u>mean direction</u>
07/26/94	07/29/94	5.7	11.1	148
10/25/94	10/28/94	4.1	6.8	167
01/27/95	01/30/95	5.8	9.6	210
04/25/95	04/28/95	4.4	8.9	140
08/11/95	08/14/95	3.9	7	194

SEDIMENT TRAP DEPLOYMENTS:

<u>date placed</u>	<u>date retrieved</u>	<u>mean speed</u>	<u>mean max gust</u>	<u>mean direction</u>	<u>direction range</u>
07/13/94	08/09/94	4.9	14.6	137	92-235
08/09/94	09/07/94	4.9	17.6	120	83-169
9/28-9/94	10/13-14/94	4.8	13.9	141	79-258
11/09/94	11/22/94	8.4	26.0	159	43-294
12/14/94	01/03/95	6.8	23.8	202	76-316
01/20/95	2/2-8/95	6.8	20.2	250	144-311
02/16/95	03/01/95	6.8	16.5	143	86-251
03/23/95	04/05/95	6.6	13.4	166	55-245
04/28/95	05/15/95	5.1	17.7	139	84-185
05/25/95	06/09/95	6.2	15.5	136	93-200
06/27/95	07/11/95	4.1	11.5	159	59-219
08/11/95	08/28/95	5.1	19.3	183	94-236
09/20/95	10/06/95	4.9	17.4	120	81-199

5d- Sediment traps (total deposition)

Sediment deposition was measured with sediment traps at nine sites approximately monthly. Sediment traps were constructed from 3 inch (~7.5 cm) diameter pvc pipe with a Nitex mesh bottom (so that water would drain out upon collection) and were of two heights. Tall traps (~20cm) of the recommended 3:1 height:diameter ratio were deployed at about 0.75 m above the reef. We constructed additional shorter traps (~12cm tall) because we also wanted to deploy traps at close to reef level. Though these traps of different heights are not directly comparable, and even though the shorter traps might have been subject to greater loss of deposited sediments due to resuspension, they should provide a conservative measure of sediment movement along the substrate.

We deployed one tall and one short trap at each of three stations at each site (total n=6 traps). There were 13 deployments of approximately two weeks duration each. Weather and other problems caused slight variation in the length of each deployment. Data are expressed as deposition per day for the mean of 6 traps (3 short and 3 tall).

Upon collection, traps were capped underwater and then drained through the Nitex bottom on the boat, brought back to the lab, and frozen until processing within one week. Thawed sediments were rinsed from the traps into a pre-weighed dish with de-ionized water, dried to constant weight, and weighed. These dried sediments were then stored for later nutrient analysis (see next section). The average wind direction and strength for the period of each deployment was calculated from data collected by the Fowey Rocks C-MAN weather station.

The most striking aspect of these results is the extreme temporal variability (Figure 21). The traps were deployed during Tropical Storm Gordon (November 1994) and these samples were up to an order of magnitude greater than those of any other deployment, especially at the offshore reefs. Aside from the high deposition during Gordon (and perhaps during the December 1994 deployment) which was associated with the greatest magnitude of winds, the other occasions when anomalously high depositions were recorded at least at some sites (Sept 95, June 95, and Sept 94) were associated with more easterly wind directions (mean direction around 120-130), whereas winds during the rest of the deployments were from a more southerly direction on average.

A one way ANOVA on ranks (normality test failed) indicated that there was significant variation in overall sediment deposition among sites ($p=0.0153$, $n=13$), but the less powerful post-hoc tests did not yield any pairwise comparisons which were significant at the $p<0.05$ level. When the samples from inshore and offshore sites were pooled, a t-test indicated the offshore sites as a group had significantly higher rates of deposition than the inshore sites ($p=0.0145$, $n=51$), but this is probably attributable to the differentially high deposition at most offshore sites during the anomalous tropical storm sample (November 1994).

The most striking result from these data is the importance of episodic events in determining the sedimentation regime of these sites. While offshore sites seem to

experience greater sediment deposition (movement) during extreme storm events and perhaps during periods of more easterly winds, there is no clear spatial pattern in chronic sedimentation levels. These chronic levels ranged up to about 400 mg/trap/day or 8.6 mg/cm²/day which is still below the 10 mg/cm²/day threshold proposed by Rogers (1990).

5e- Sediment nutrients:

Samples collected from the sediment traps were analyzed in duplicate for total carbon and total nitrogen content on a Carlo-Erba 1108 elemental analyzer. For the initial deployment, all tall and short trap samples were analyzed and nitrogen content was generally higher in the tall trap samples. For subsequent sampling, only the samples from tall traps were analyzed, thus data presented represent means of ≤ 3 samples per date, each analyzed in duplicate.

Total phosphorus content of the sediments was determined by ashing the dried sediments in duplicate for at least 5 hours at 485°C, dissolving the calcium carbonate residue in 0.5N HCl, filtering out any non-soluble residue, and determining the concentration of dissolved phosphate in the resulting solution using the phospho-molybdate reaction with an autoanalyzer.

A clear spatial pattern was evident in the nitrogen data with resuspended sediments from inshore patch reefs containing higher levels of nitrogen (Figure 22A). Also, within the inshore sites there was a trend of decreasing nitrogen content from north to south. Phosphate levels were extremely variable and no spatial pattern was evident (Figure 22B). Thus, N:P shows a similar spatial pattern to N.

TASK 6: CORAL REPRODUCTIVE STATUS

In August 1995, one week before the annual mass spawning event, we collected tissue samples from overturned head corals we had been following, and from normal undisturbed colonies, at the Bache Shoals and E. Bache sites. Samples were collected from eight to 10 colonies of the following species: *Diploria strigosa*, *Siderastrea siderea*, *Montastraea annularis*, and *Montastraea faveolata*. The samples were fixed with Zenker's fixative, decalcified with buffered 10% HCl, embedded in wax blocks, and sectioned and stained for histological examination of gonad development. In some cases, samples were taken from the center and the lower edge of the live portion of the colony, the latter of which would have been the center of the colony before it was overturned.

For *Siderastrea siderea*, a dioecious species, all overturned and all control colonies displayed substantial gonad development. For the *Diploria strigosa*, three of four overturned colonies and three of three control colonies had substantial gonad development. Edge samples which had originally been the center of the colony showed no gonad development. In general, three years after the hurricane, reproduction was occurring normally in all of these species. Unfortunately, this study cannot determine

whether temporary suspension of coral reproduction had occurred during the year or two following Hurricane Andrew.

TASK 7 : CAGE/TRANSPLANT EXPERIMENT

To determine whether differential grazing intensity may help explain variation in benthic community structure between inshore and offshore reefs, we performed a caging experiment at one inshore (EBache) and one offshore (Triumph) site. Five cages paired with five half-cage controls (2 walls and roof) were attached to eyebolts epoxied into the reef substrate at each site. A mixed species assemblage of small juvenile corals were collected from the wall at Boca Chita, stained, moved and epoxied onto the natural reef substrate within each cage and to adjacent uncaged plots (no-cage controls). Around 10-15 colonies of 4 or 5 species including *Porites astreoides*, *P. divaricata*, *Favia fragum*, *Siderastrea radians*, and *Manicina aerolata* were placed in each cage or plot. The recruits were observed for 10-15 minutes after they were glued to the substrate, and notes and photographs were taken of fish activities and predation on the coral spat. Coral survival was censused after one week and algal cover and coral survival were assessed using a grided quadrat at the end of the 10-week experiment.

Juvenile corals experienced dramatic attrition from grazing in a very short time span. At the one week census, almost 100% of the transplants in full cages at both sites were intact, while 30-75% of the transplants that were not protected from grazing (half-cage and no cage controls) were missing or dead (Figure 23). Two-way ANOVA (site x cage treatment) on percent of transplants missing or dead from each cage (arcsin transformed, $n=5$) showed that full cages had significantly higher survival of transplants ($p<0.0001$) than either half-cage or no-cage controls (which did not differ from each other, SNK $p>0.05$). Also, survival was significantly greater at EBache than at Triumph reef ($p=0.003$). There was no statistical interaction of the two factors ($p=0.117$).

Macroalgae proliferated in the full cages where large grazers were excluded (Figure 24). Two way ANOVA on percent cover of macroalgae in each cage or plot indicated a significant interaction of site and cage treatment with more proliferation of macroalgal cover in full cages at Triumph than at Ebache.

We must caution that the novelty of gluing corals out on the reef may have resulted in artifactually high levels of coral attrition in this experiment. However, the relative difference in attrition between the inshore and offshore site is valid. Juveniles at the offshore site suffer higher mortality from grazers and this pattern is consistent with other findings such as low density, low cover, and small size of corals at the offshore reefs. Therefore, grazer pressure may be at least in part responsible for differences in coral abundance between patch and offshore bank reefs.

CONCLUSIONS

- 1- Overall, the nearshore patch reefs and offshore bank reefs in Biscayne National Park differ significantly in benthic community structure with the inshore reefs displaying quantitatively greater coral, octocoral and sponge cover and densities. These patch reefs also had larger coral colonies, particularly *Montastraea* spp. Of the offshore reefs, Ball Buoy is the only one with significant coral cover and with large stands of live *Acropora palmata*. The other offshore localities show very low cover of cnidarians and sponges and high cover of turf algae and crustose algae.
- 2- Live cover, density, and diversity of scleractinian corals, octocorals and sponges increase from north to south. Isa's reef had the highest diversity and density for these three groups. The Soldier Key site has a distinct biological community from the other sites. This site is mostly dominated by transient populations of fleshy algae over a fine sediment substrate with sparse colonies of octocorals and sponges.
- 2- Patterns of community composition do not correlate with measured variation in environmental factors such as temperature, sedimentation levels, or nutrient concentrations (sediment or water column). In fact, temperature regimes appear to be potentially more (not less) stressful on the inshore reefs.
- 3- Sedimentation rates are much more influenced by episodic events such as storms than by spatial gradients. Resuspended sediment nitrogen levels do show a spatial pattern with increased nitrogen levels in the inshore vs. offshore sediments.
- 4- Scleractinian and octocoral recruitment is high in most reefs. With the exception of Isa's reef in the south, the proportion of colonies that are juvenile (versus adult) is higher on the offshore reefs compared with the inshore reefs. Since the inshore reefs show higher densities of larger corals and octocorals, there appear to be greater rates of juvenile mortality on the offshore reefs.
- 5- The only measured environmental factor which did show a pattern congruent to the spatial patterns in community structure was grazing intensity. The caging experiment demonstrated significantly greater loss of coral juveniles due to grazing on an offshore versus an inshore reef.

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LIST OF FIGURES

Figure 1. Percent cover (% , bars) and density (colonies/m², symbols and lines) of dominant organism groups and substrate types presented group by group for the nine study reefs in Biscayne National Park. A. Scleractinian corals. B. Octocorals. C. Sponges. D. Zoanthids. E. Milleporan hydrocorals. F. Crustose algae. G. Fleishy algae, including calcareous species. H. Turf and other organisms includes turf algae and other small unidentifiable organisms. I. Calcareous sand. J. Bare substrate refers to substrate apparently devoid of any identifiable organism. Reef names are listed along the x-axis; bars for offshore reefs are solid, and those of patch reefs are stippled (see Figure 2 for more detail).

Figure 2. Summary of the percent cover (% , bars) and density (colonies/m², squares and lines) of dominant organism groups and substrate types (as in figure 1) presented for each study reef in Biscayne National Park. A. Fowey Rocks, northern offshore reef. B. Soldier, northern inshore hard bottom. C. Triumph Reef, mid-park offshore reef. D. East Bache, mid-park patch reef. E. Pacific Reef, mid-park offshore reef. F. Elkhorn Reef, southern park offshore reef. G. Alina's Reef, southern park patch reef. H. Ball Buoy Reef, southern-most park offshore reef. I. Isa's Reef, southern-most inshore patch reef.

Figure 3. Densities (colonies/m²) of main cnidarian groups and sponges on offshore and inshore reefs in Biscayne National Park. Scler= scleractinian corals, Octoc= octocorals, Zoant= zoanthids, Hydr = milleporan hydrocorals, Spon = sponges. BBuoy= Ball Buoy Reef. See figure 2 for reef locations.

Figure 4. Number of species (A) and genera (B) of scleractinian corals, octocorals, and sponges on the nine study reefs in Biscayne National Park.

Figure 5. Number of coral and milleporan recruits surviving or recruiting to three reefs in Biscayne National Park during a one year interval. Ten 0.25 m² quadrats per reef (15 on Bache Shoals) were mapped for small corals (< 2 cm max. diameter) and resurveyed one year later. Old = colonies found during the 1st survey that were relocated during the second survey; Dead = colonies found during the 1st survey that were not present during the second survey; New = small colonies found during the second survey that had not been observed during the first survey.

Figure 6. Distribution of coral recruits (percent of total recruits) by species and spawning characteristics for the offshore localities (A and B) and the inshore localities (C and D) studied in Biscayne National Park. Species shown are those with more than 5 % of recruits in any reef. Criteria for designating a colony as a recruit were: < 5 cm diameter for larger massive species (i.e. *M. faveolata*), and < 2 cm diameter for the smaller sized species (i.e. *P. astreoides*). Data were derived

from the transect-quadrat surveys ($n = 75\text{-}100\text{ m}^2$ per reef; see text).

Figure 7. Abundance of juvenile corals on the nine study reefs in Biscayne National Park. A. Density of juvenile corals (number of colonies/ m^2). B. Their proportion of the total population (percent of total colonies). Solid bars are the offshore localities.

Figure 8. Average loss or gain of tissue coverage ($\text{cm}^2/\text{colony}$) by large coral heads over-turned by Hurricane Andrew during a one year interval 2 to 3 years after the event. The interface between live and dead portions of each colony ($n = 20$ for *Montastraea faveolata*, and $n = 5\text{-}6$ for the rest) on two patch reefs in the Bache Shoals area, were marked and diagramed in September 1994 and resurveyed in September 1995. (A) Average growth and/or loss of tissue area in each species. (B) Percent change in live tissue in each species (negative numbers indicate a loss = solid dark bars). Change in tissue coverage for the control corals were negligible and not included in the plot.

Figure 9. Size-frequency distribution (in 10 cm size classes) of small colonies of *Montastraea cavernosa* at five reef sites in Biscayne National Park. Colony measurements were made by measuring their length from side to side over the top along the axis of their maximum diameter, and thus include an adjustment for their height as well as diameter. The smallest size class is sub-divided to show relative abundance of smaller sizes classes. n = number of colonies measured at each site.

Figure 10. Size-frequency distributions for *Porites astreoides* at four sites in Biscayne National Park. See Figure 9 for details.

Figure 11. Size-frequency distributions for *Montastraea faveolata* at three reef sites in Biscayne National Park.. Insufficient numbers of this species were encountered at Pacific and Triumph reefs to construct a distribution for these sites. See Figure 9 for details.

Figure 12. Size-frequency distributions for *Siderastrea siderea* at five reef sites in Biscayne National Park. See Figure 9 for details.

Figure 13. Temperature records obtained using Hobo-Temp logging meters at six reef sites in Biscayne National Park. Values are the means of all measurements recorded (every 24 minutes) from 8 pm to 6 am of each of each day. Panels depict records for inshore (red symbols)/offshore (black symbols) reef pairs (A) at the northern edge of the Park, (B) in the central region, and (C) at the southern part of the park. Periods of missing data were due to loss or malfunction of instruments.

Figure 14. Water column ortho-phosphate concentrations at nine reef sites in Biscayne National Park. Each point represents the mean of duplicate analyses of a single haphazard water sample. The upper panel shows the time-course for offshore reefs, the lower panel shows nearshore reefs. Reefs with the same symbol in both panels are of similar latitude in the park.

Figure 15. Water column nitrate + nitrite concentrations at nine reef sites in Biscayne National Park. See figure 14 for explanation.

Figure 16. Water column ammonium concentrations at nine reef sites in Biscayne National Park. See figure 14 for explanation.

Figure 17. Box plots summarizing water column nutrient data for each site. Upper panel, ortho-phosphate; middle panel, nitrate+ nitrite; lower panel, ammonium. The darker horizontal bar within each box is the mean and the lighter bar the median. Upper and lower limits of each box indicate the 25th to 75th percentiles, and the error bars indicate the 5th and 95th percentiles. Circles represent maximum and minimum values for each site.

Figure 18. Mean (± 1 s.d.) sediment accumulation observed during each 3 day sediment plate deployment at six reef sites in Biscayne National Park. A. Offshore reefs. B. Nearshore patch reefs. Sites with the same hatching pattern in the two panels have similar latitudinal position. n = number of plates per deployment per site.

Figure 19. Grain size distribution of sediments collected with the sediment accumulation plates in the July 1994 deployment. Sediments were wet-sieved into the various size classes, dried and weighed, and are reported as percent of total weight. The particle size classes (sieve meshes) used for this deployment were different than those used in later deployments (see text and Figure 20). n = 9-12 samples per site.

Figure 20. Grain size distribution of sediments collected with the sediment accumulation plates during additional deployments in 1994 and 1995.

Figure 21. Sediment deposition collected in sediment traps at nine sites. Each value is the mean of three short and three tall traps per station (see text). Results of eleven of the deployments are depicted in the upper panel, and those of two deployments during the winter 1994 (following Tropical Storm Gordon) are plotted in the lower panel with a different scale.

Figure 22. Resuspended sediment nutrient content for sediments collected in 11 deployments of the tall sediment traps. A. Percent (by weight) of nitrogen content (mean ± 1 s.d.) for three samples per deployment. Bars with similar

letters do not differ statistically (SNK post-hoc test, $p > 0.05$). B. Total phosphorus in $\mu\text{g-at P/gm}$ sediment (mean ± 1 s.d.) for three samples from each deployments.

Figure 23. Percent mortality (mean ± 1 s.d.) of coral transplants one week after transplantation. Small corals were transplanted into full cages, half cages (cage control) or open areas ($n = 5$ for each treatment) at two reef sites: East Bache (patch reef) and Triumph Reef (offshore bank reef), and resurveyed one week later. Results of a 2-way ANOVA are included in the box. P-values (site*cage treatment).

Figure 24. Percent cover by macroalgae (mean ± 1 s.d.) within the cage treatment areas (see Figure 23) measured at the end of the 10 week experiment. Results of a 2-way ANOVA are included in the box.

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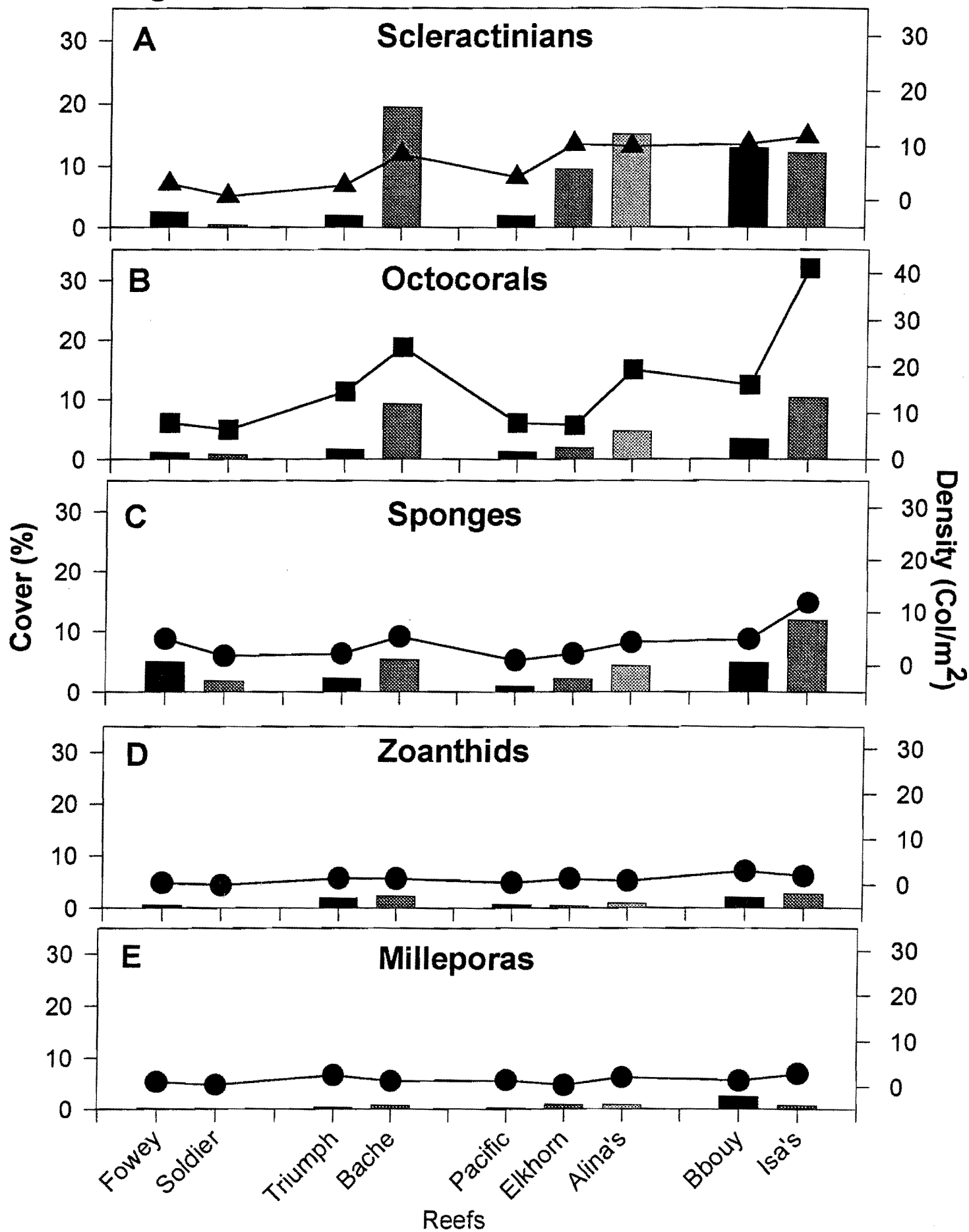


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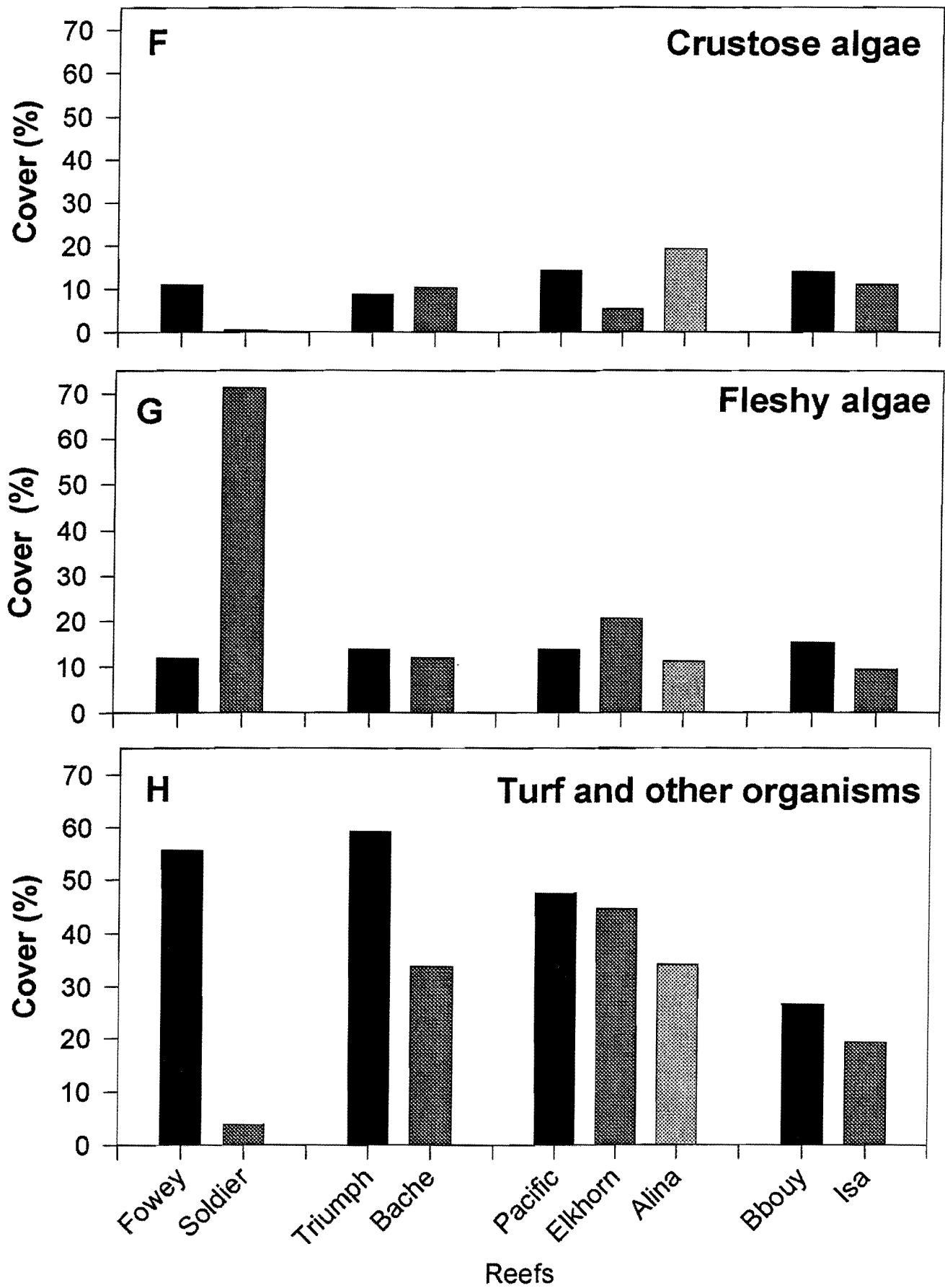


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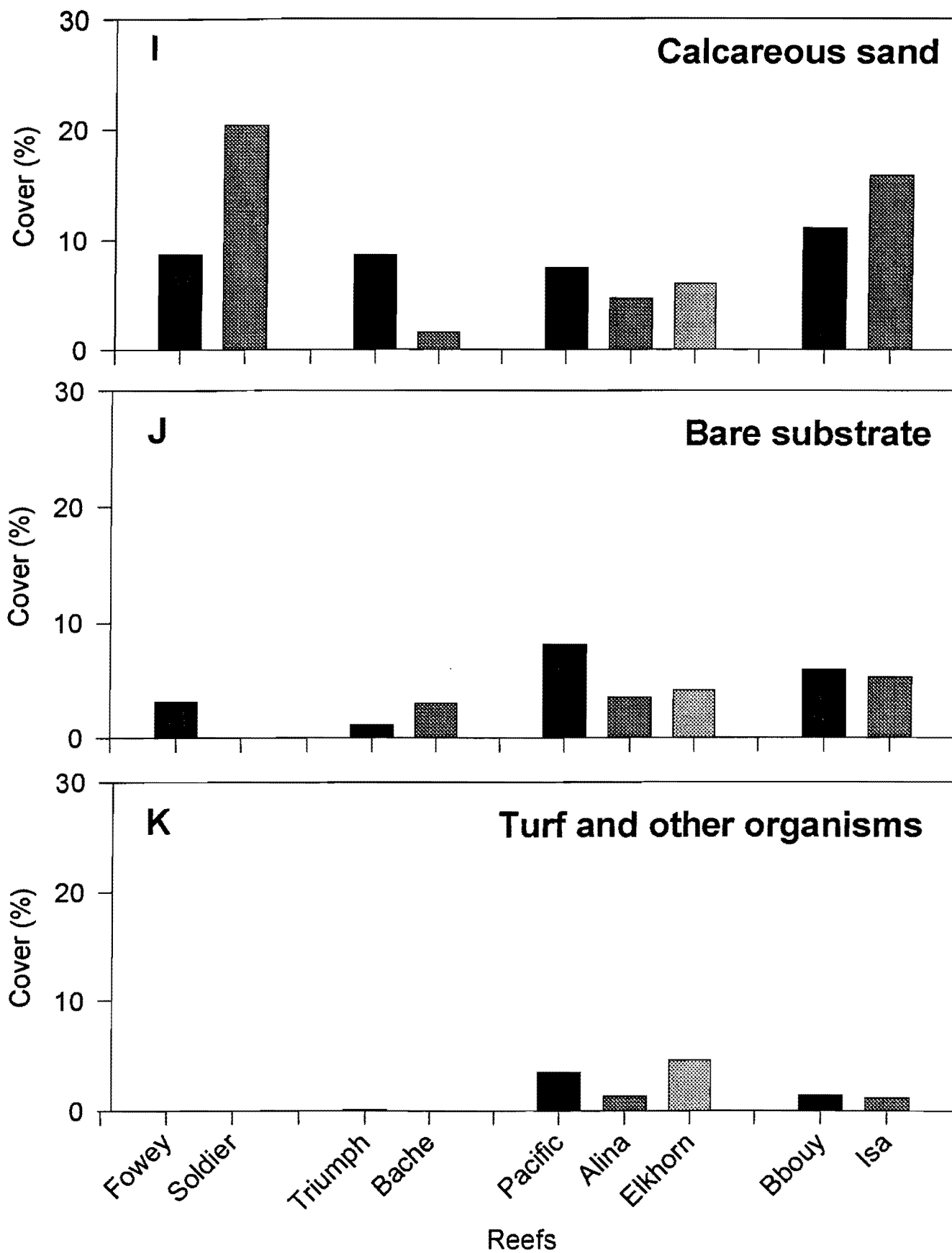


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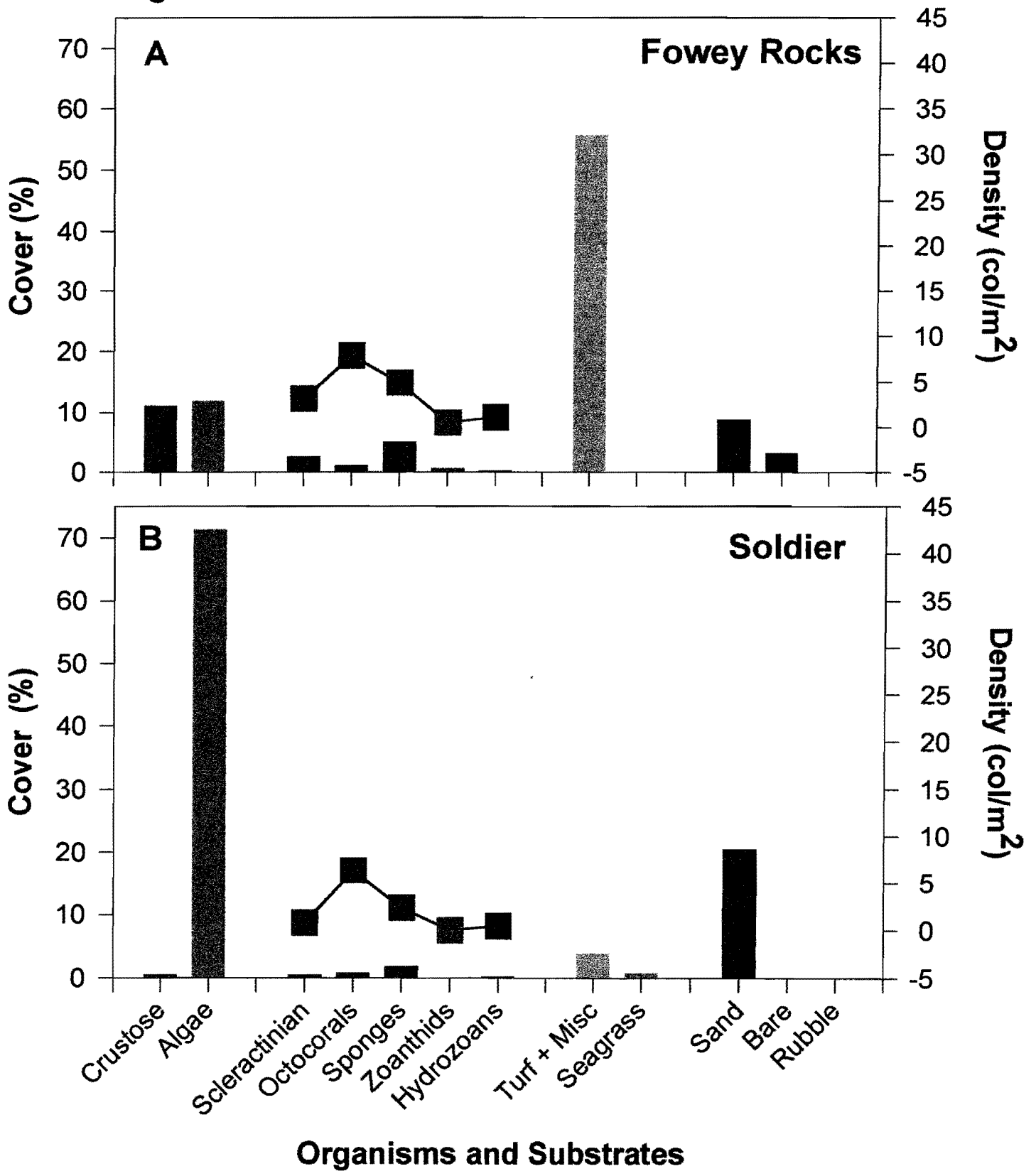


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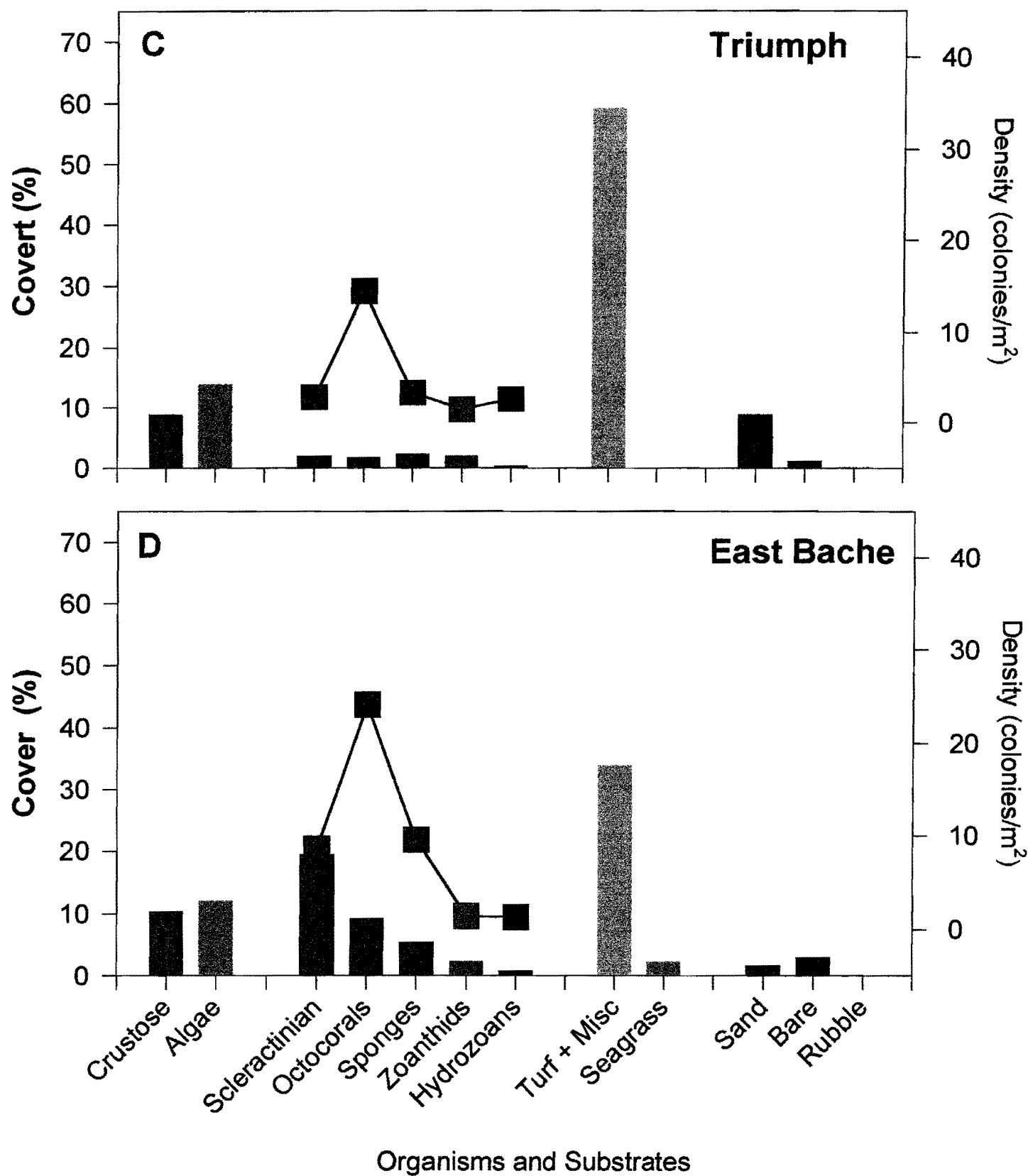


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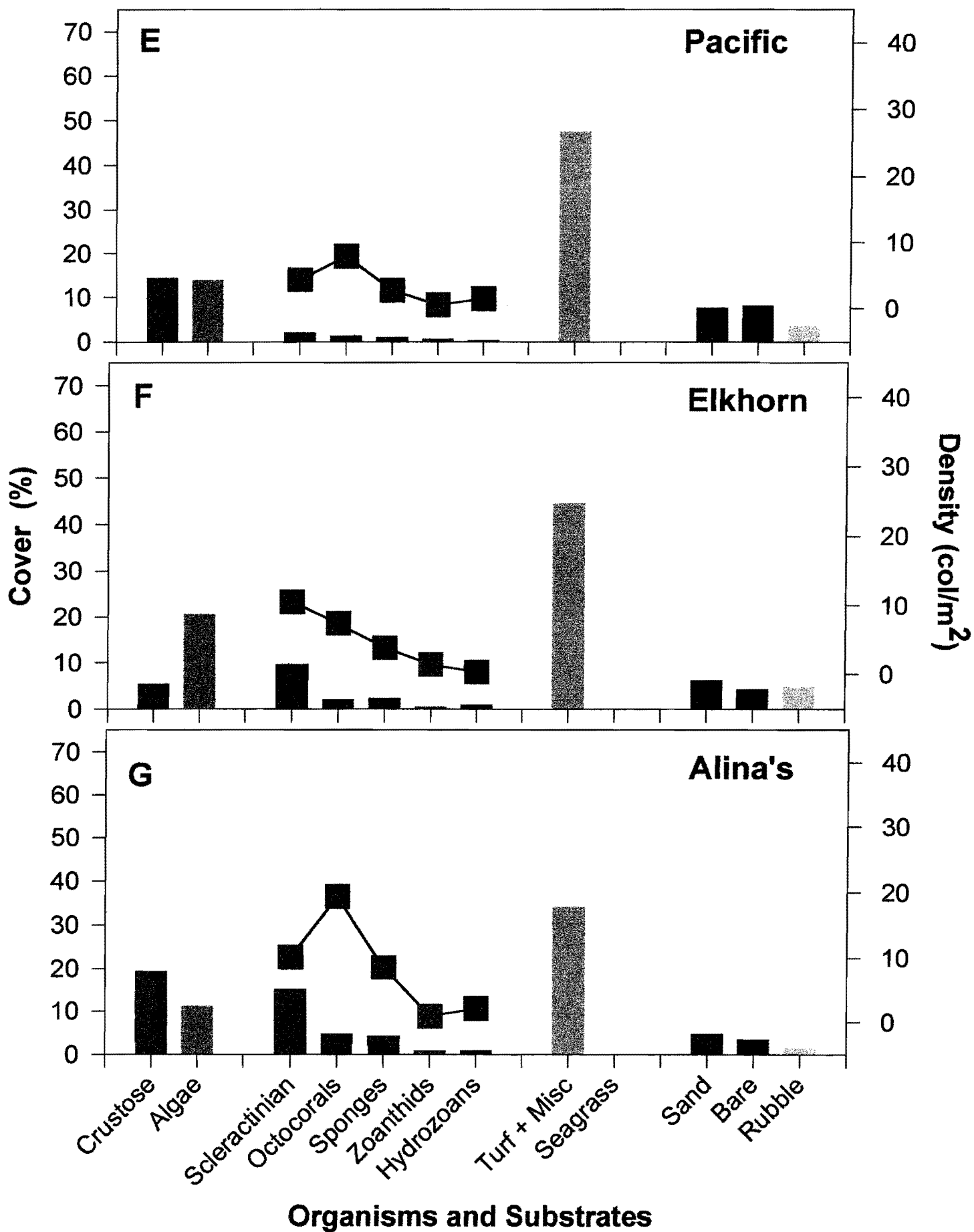


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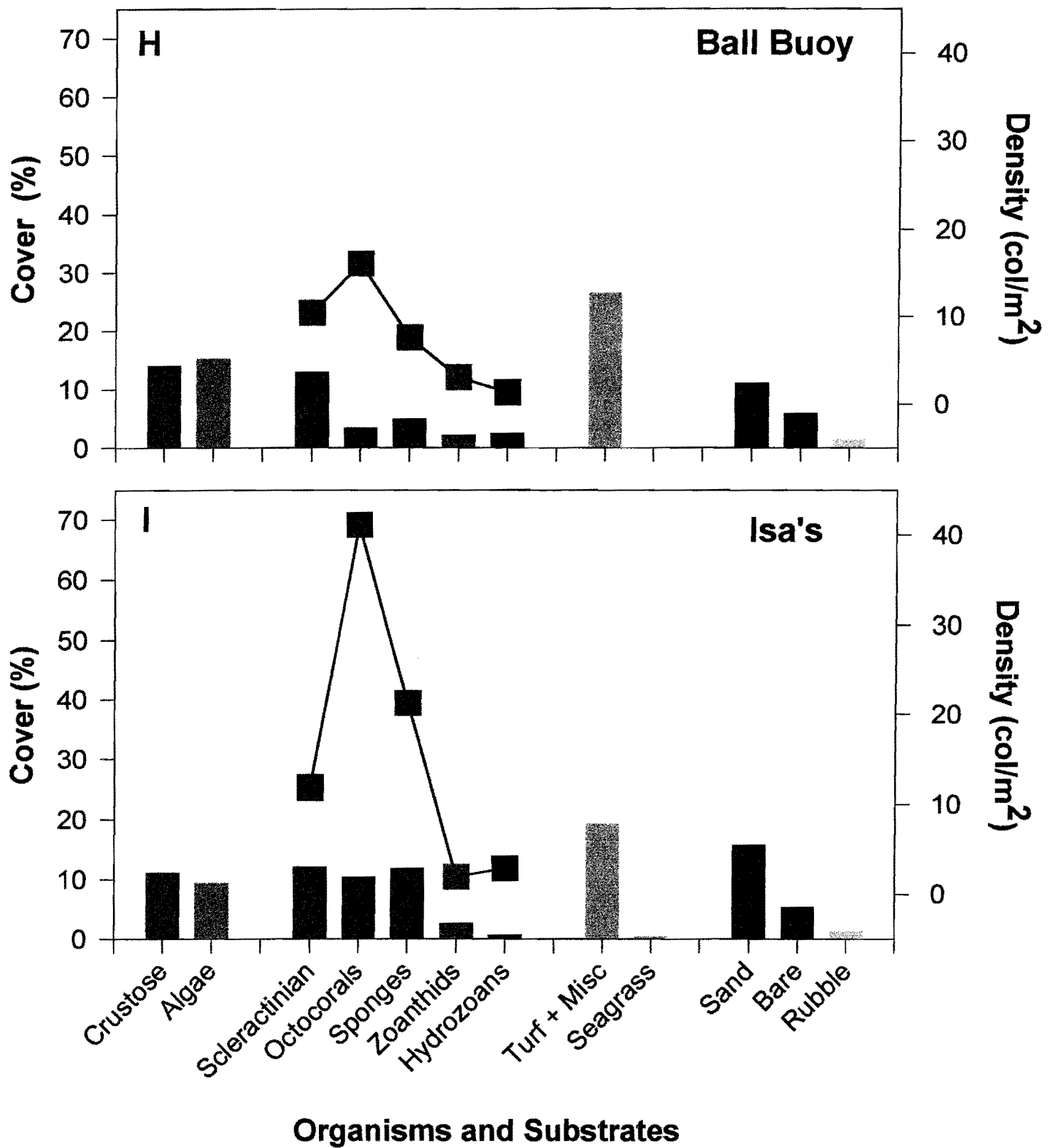


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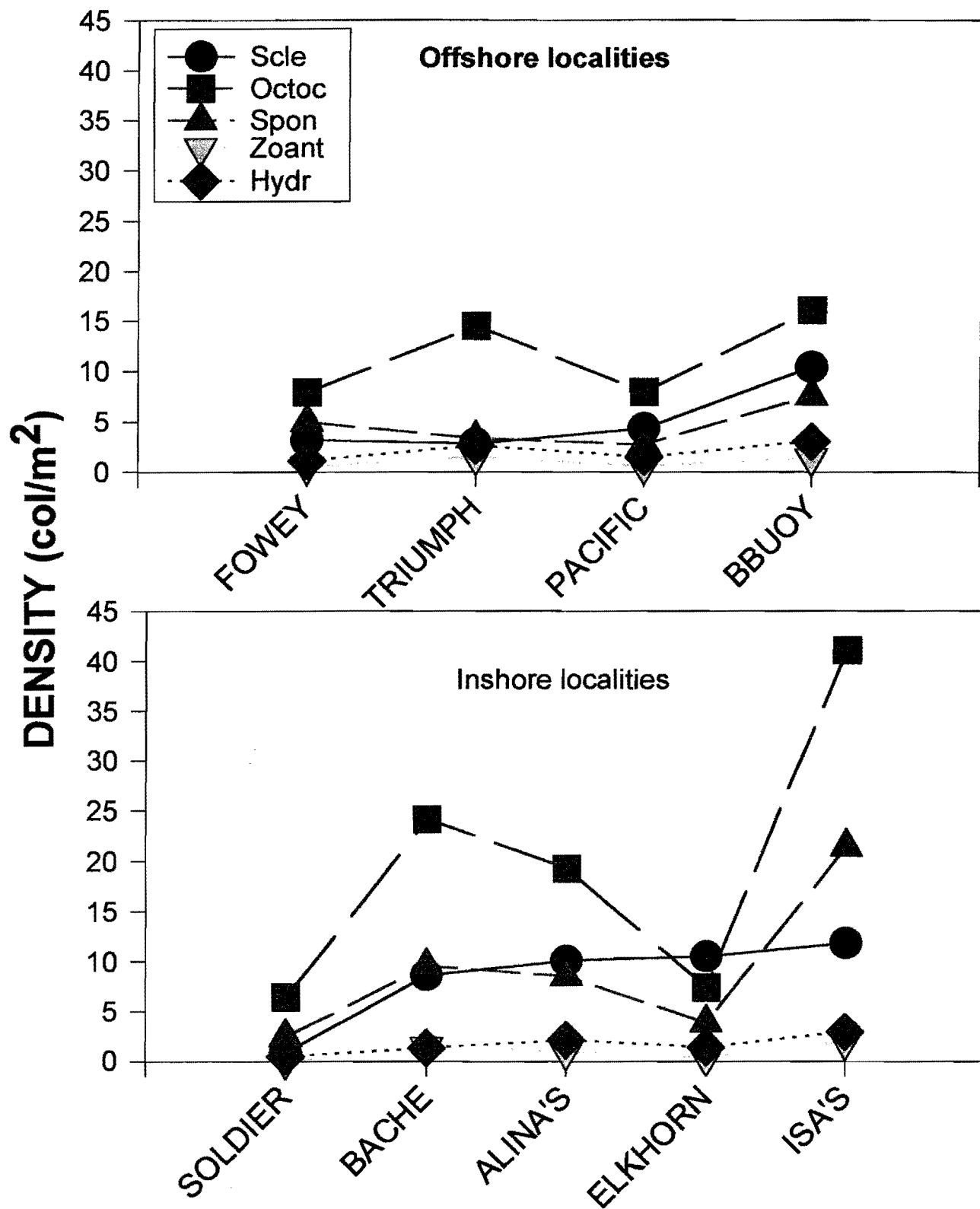


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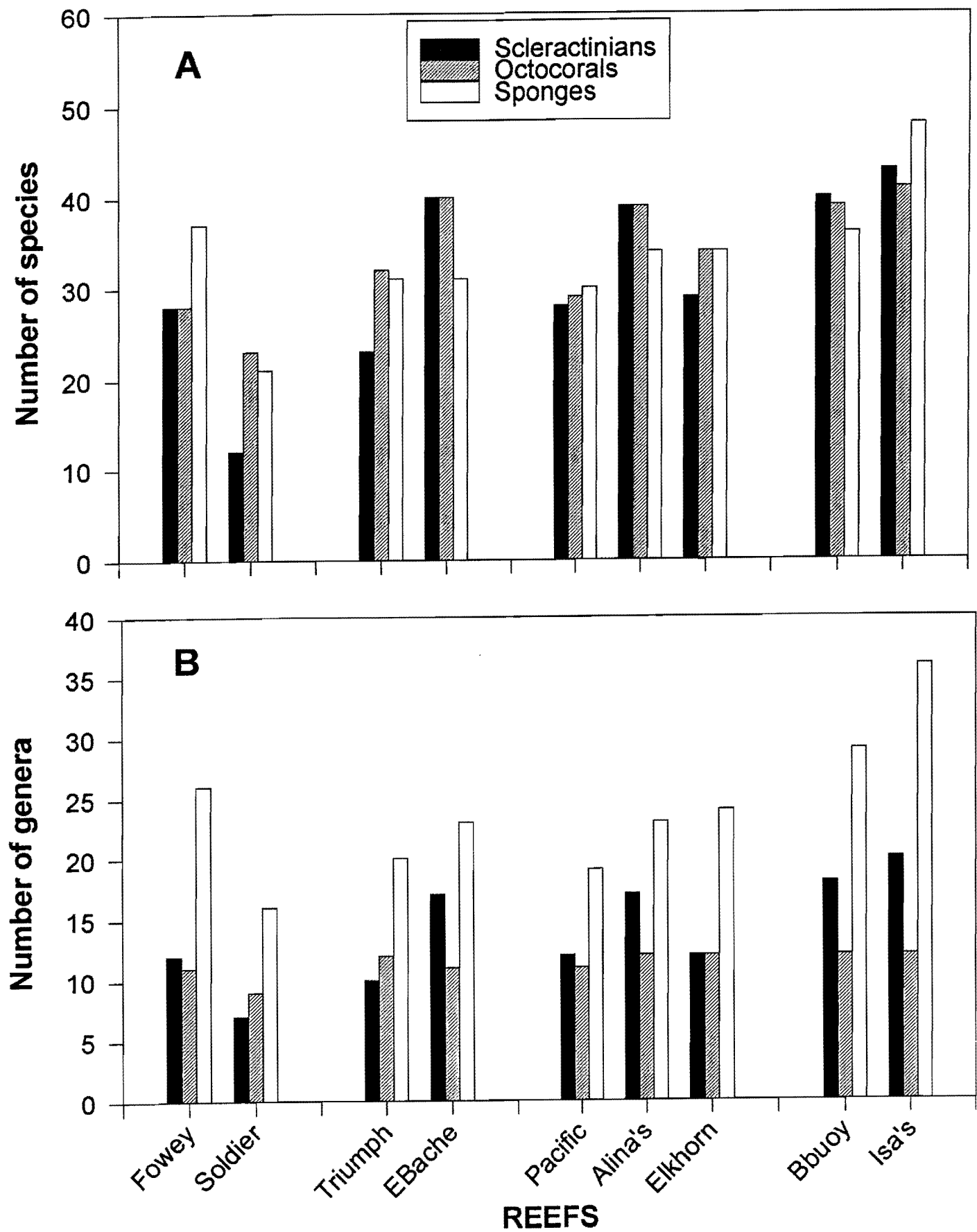


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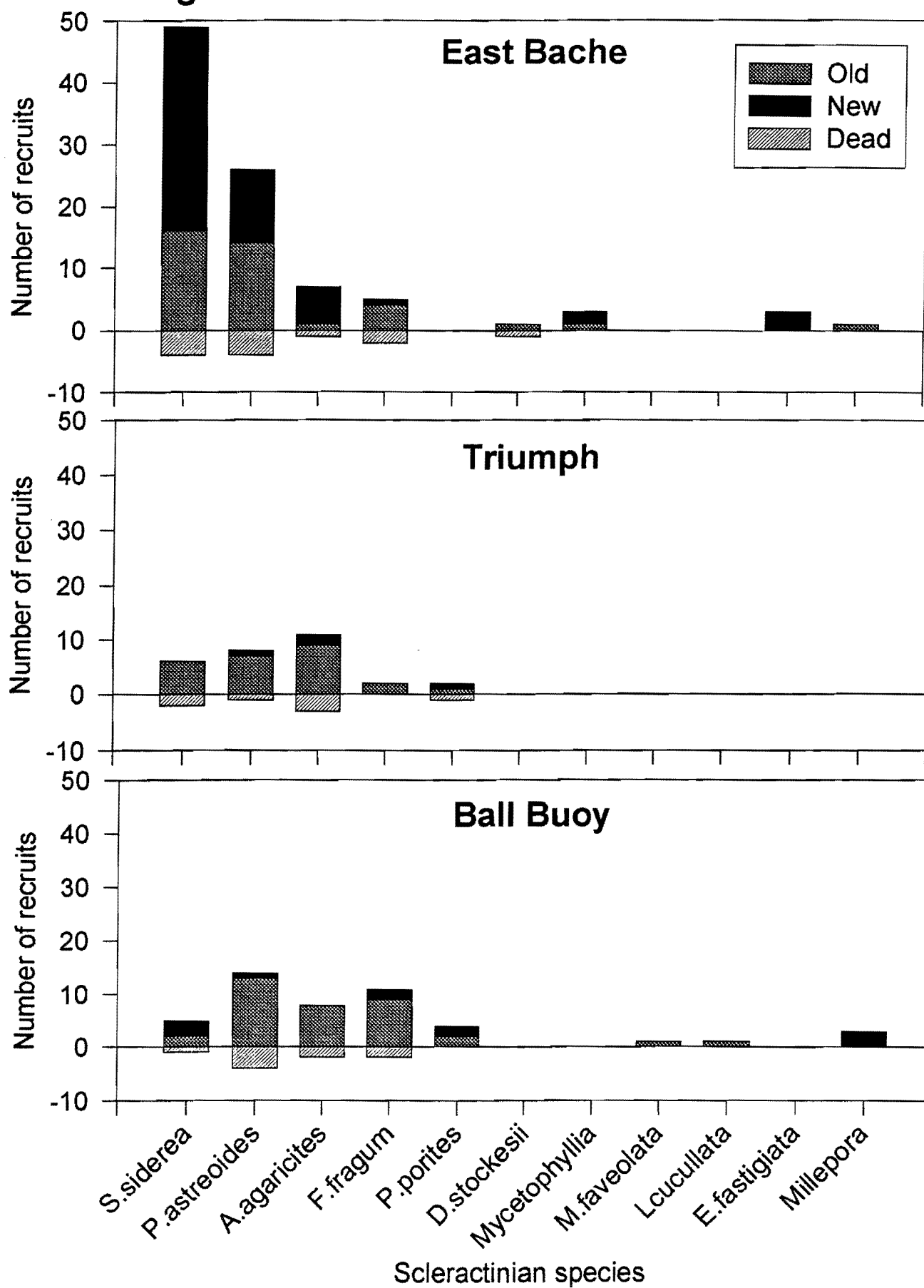


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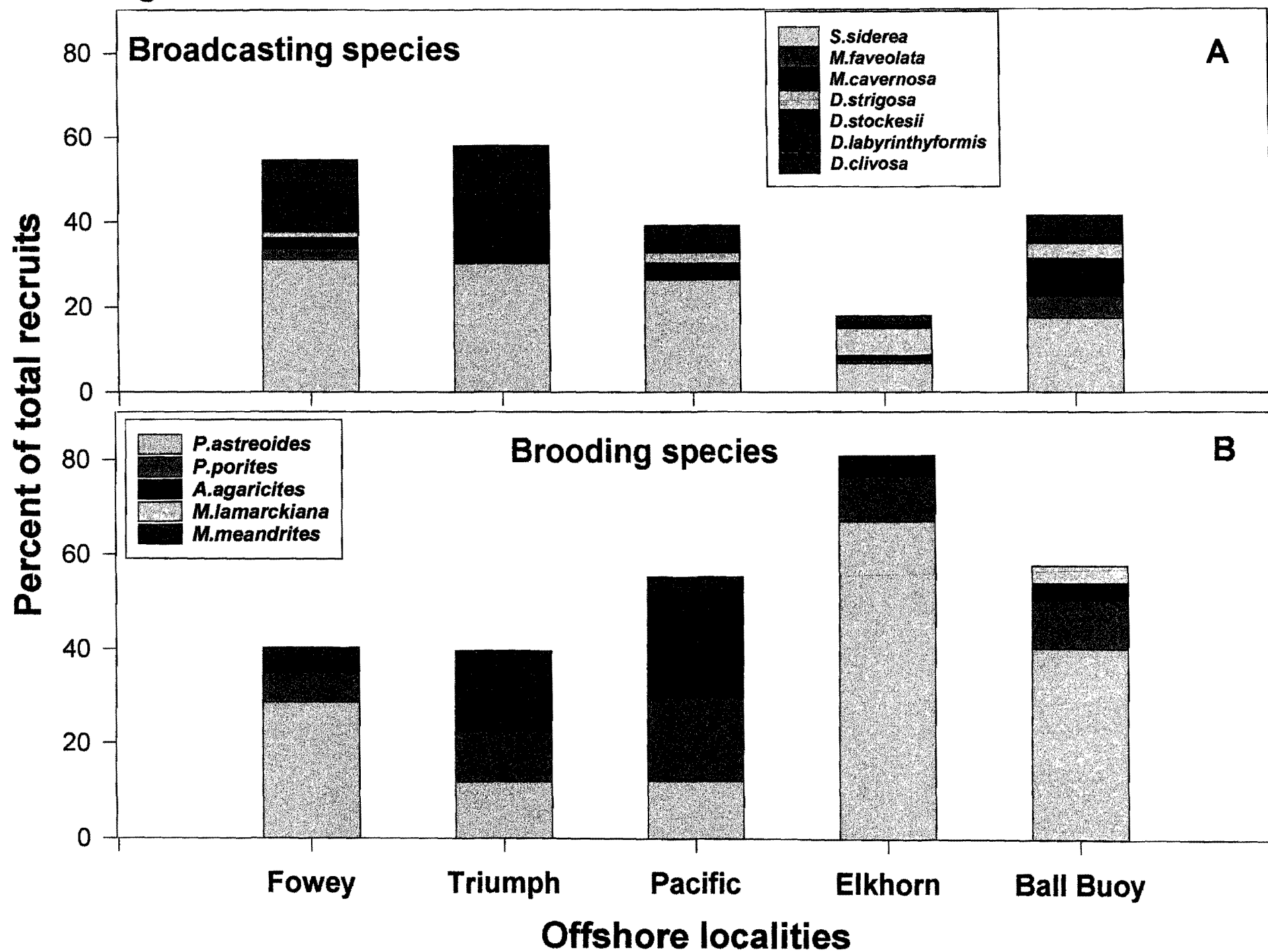


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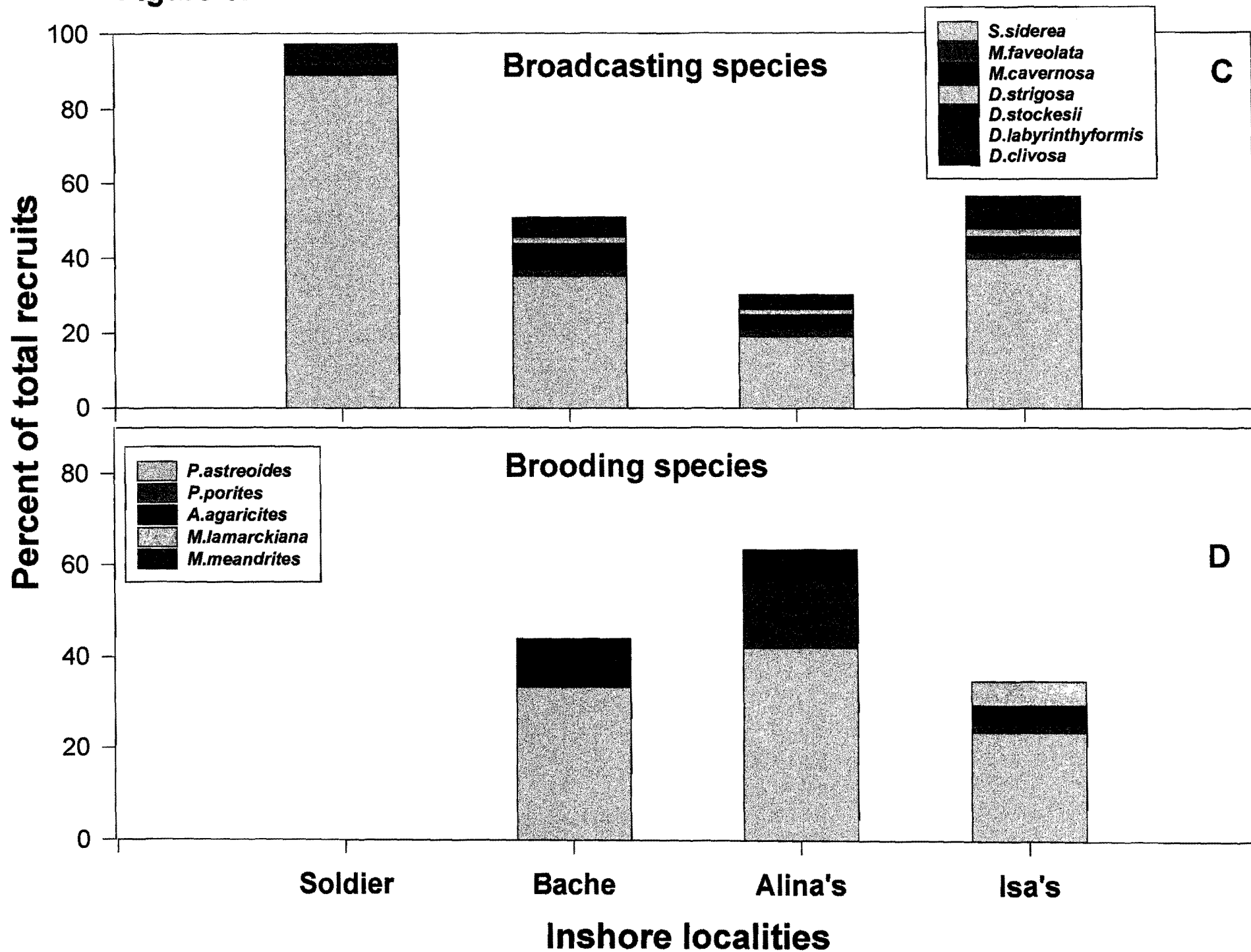


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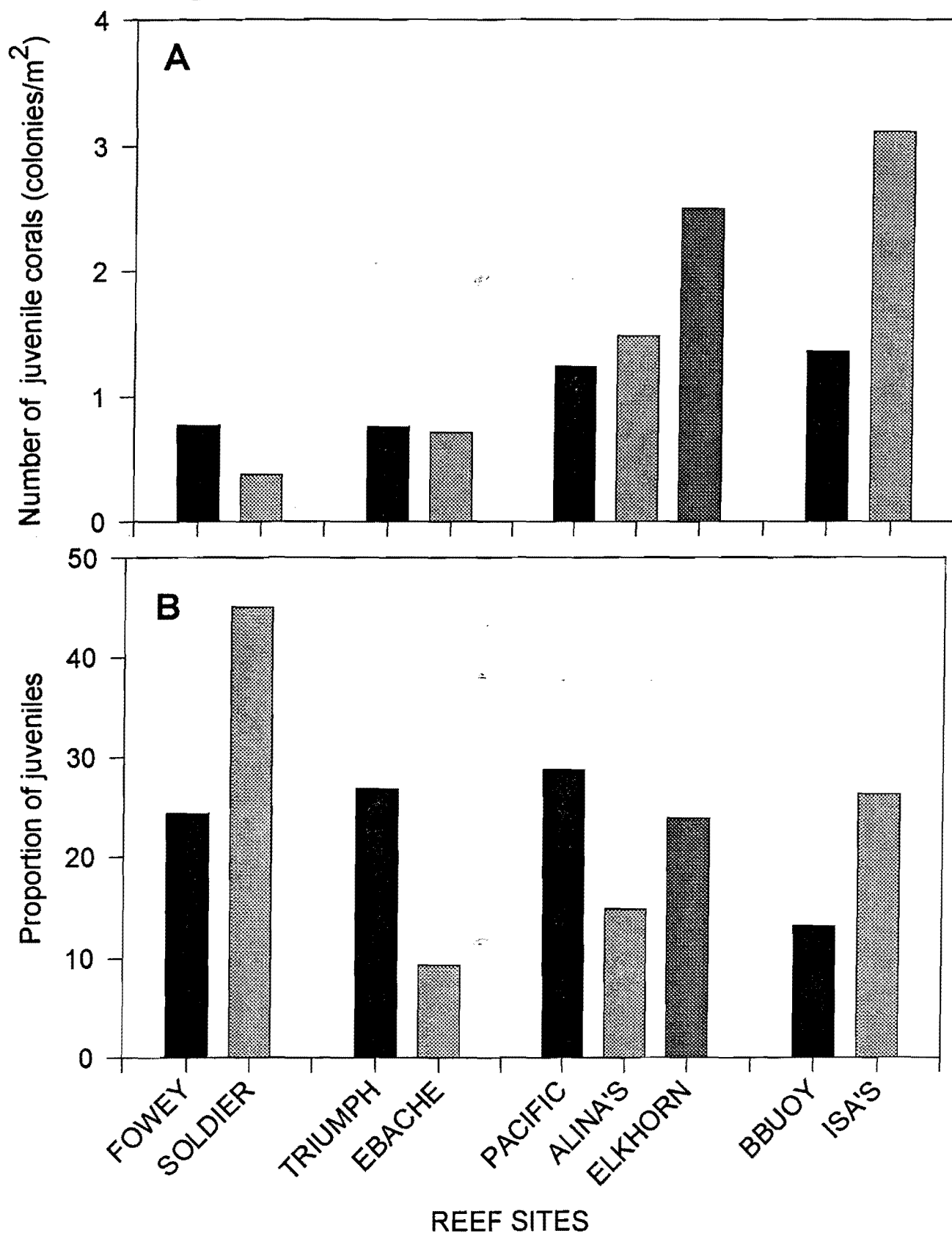


Figure 8.

Change in damaged colonies

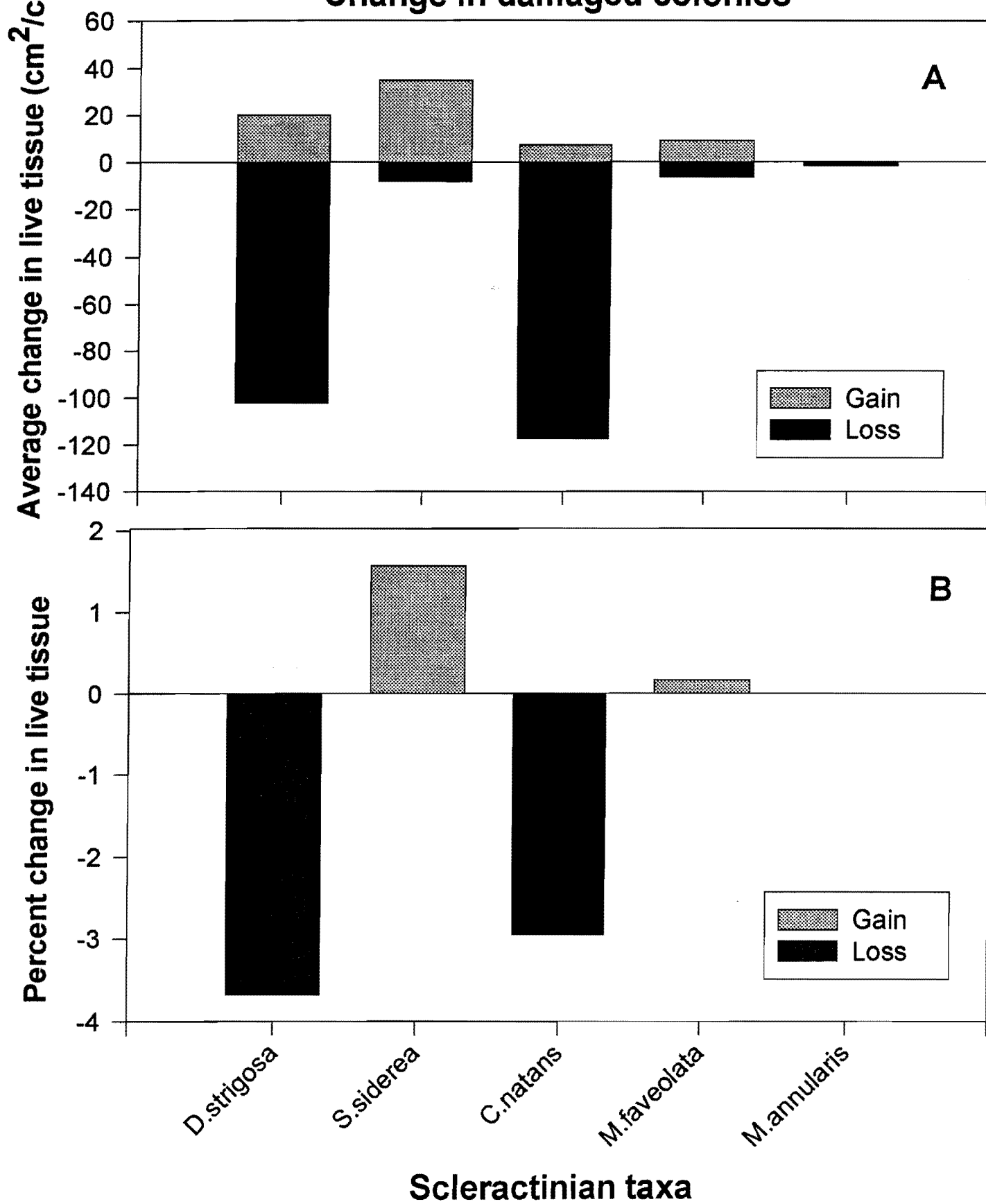


Figure 9.

MONTASTRAEA CAVERNOSA

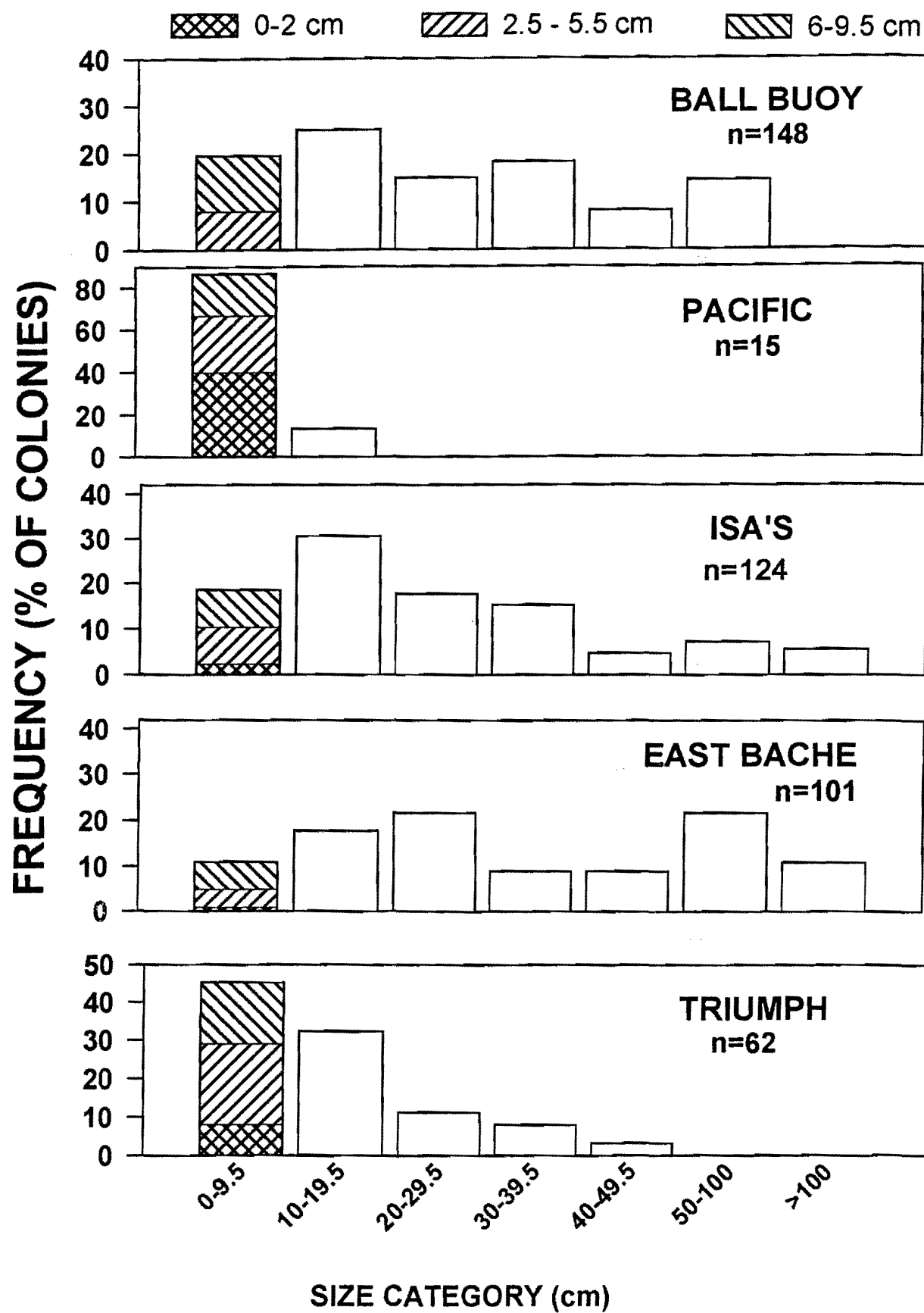


Figure 10.

PORITES ASTREOIDES

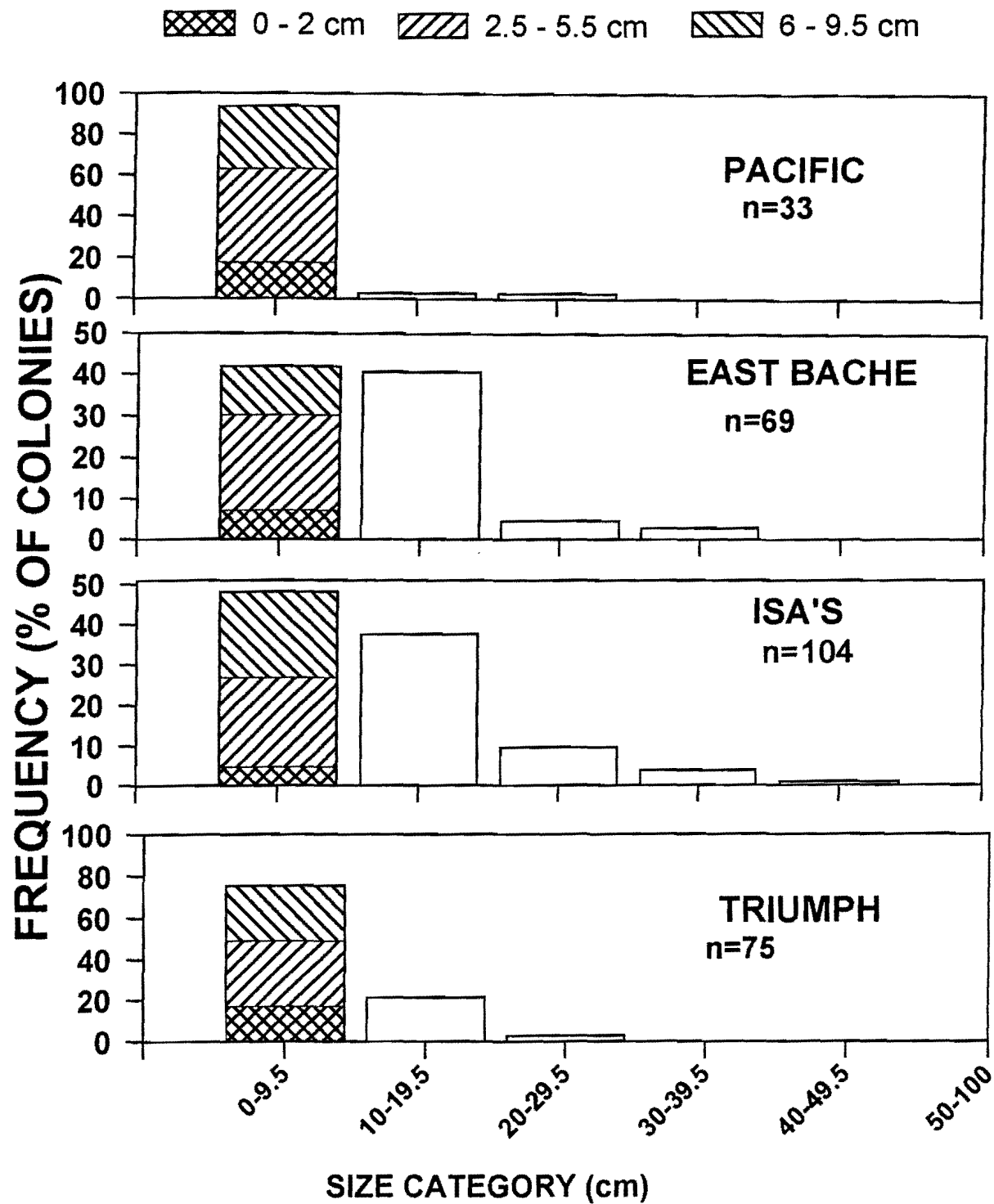


Figure 11.

MONTASTRAEA FAVEOLATA

0 - 2 cm 2.5 - 5.5 cm 6 - 9.5 cm

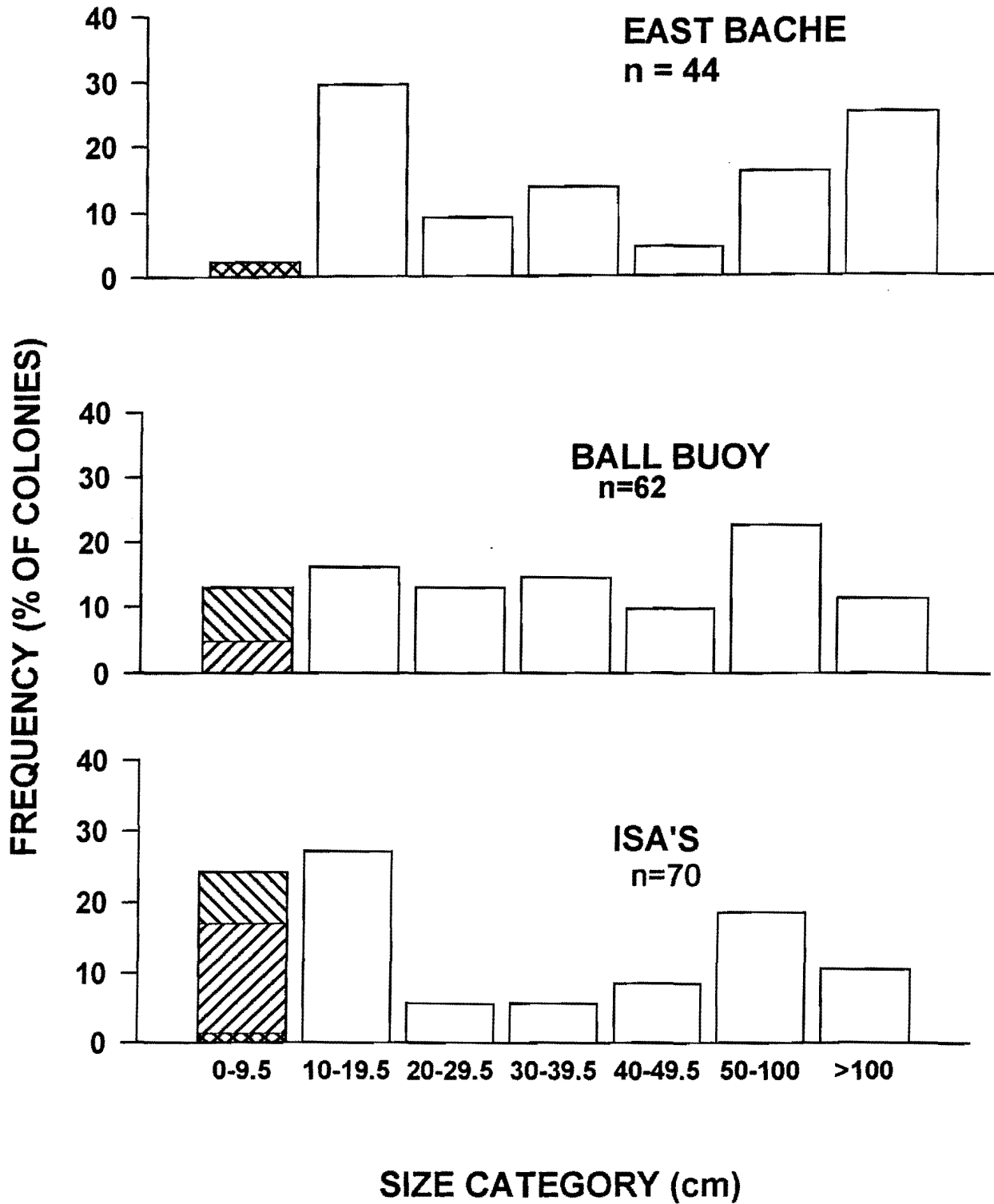


Figure 12.

SIDERASTREA SIDEREA

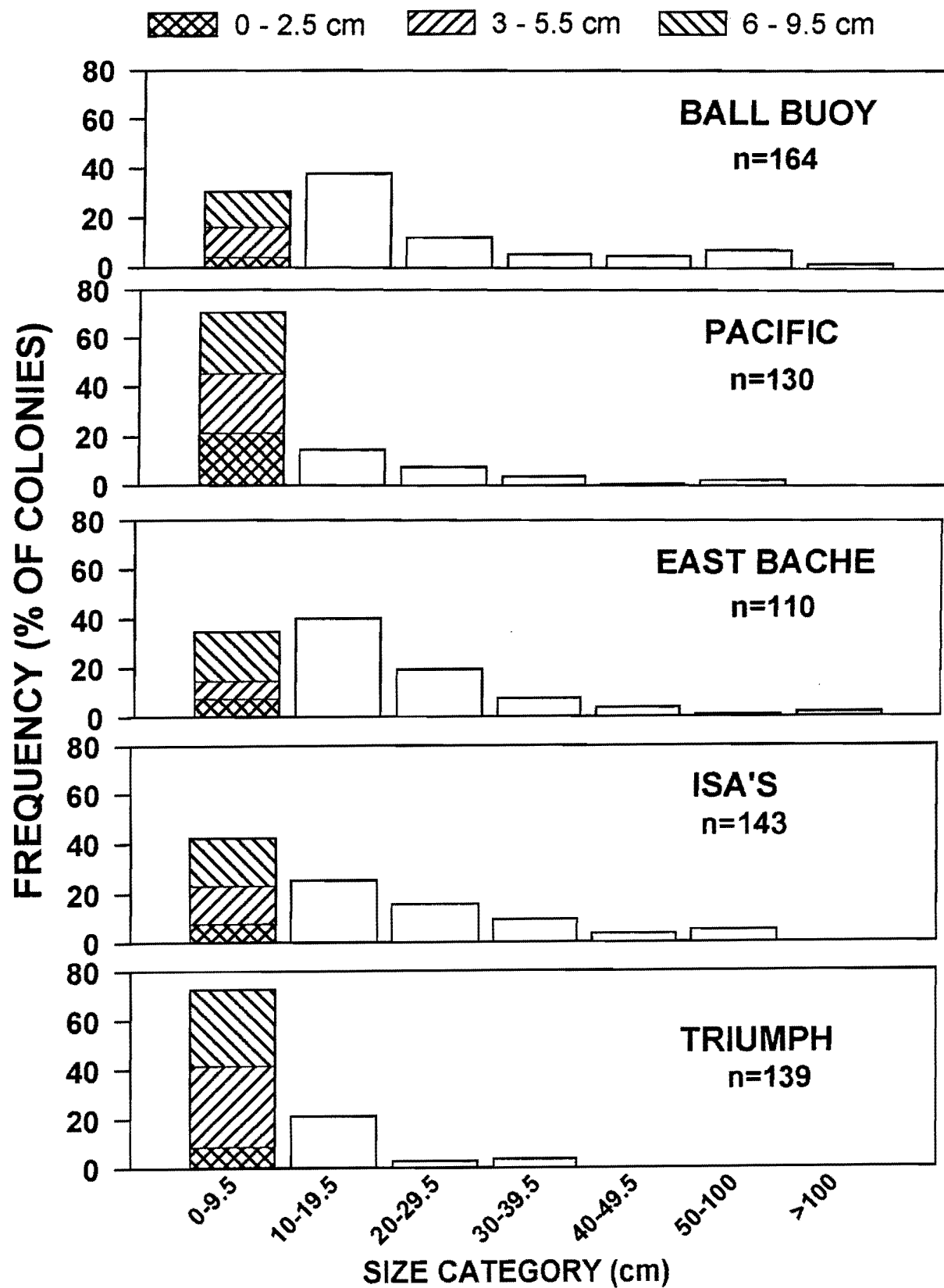


Figure 13.

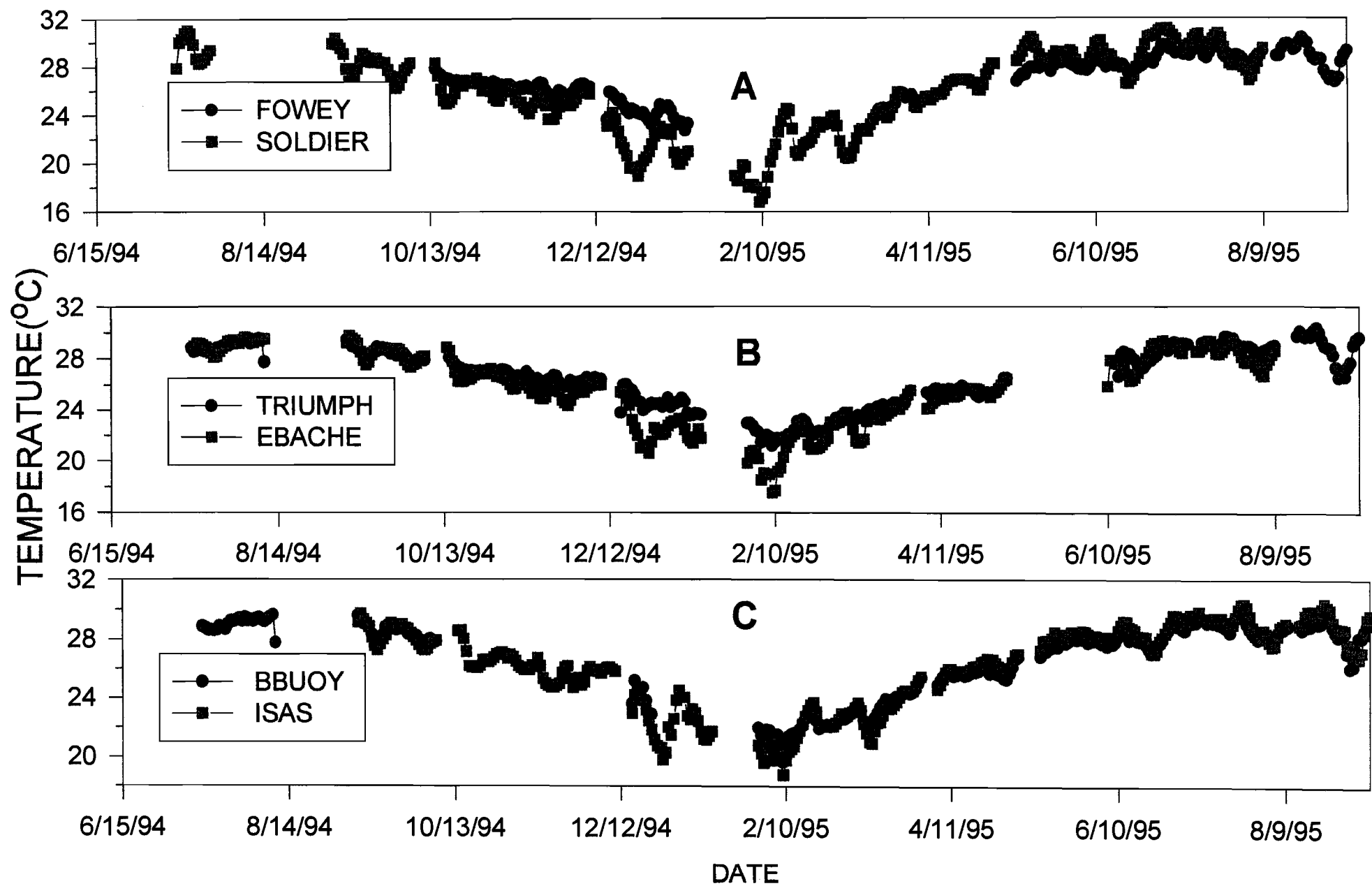


Figure 14.

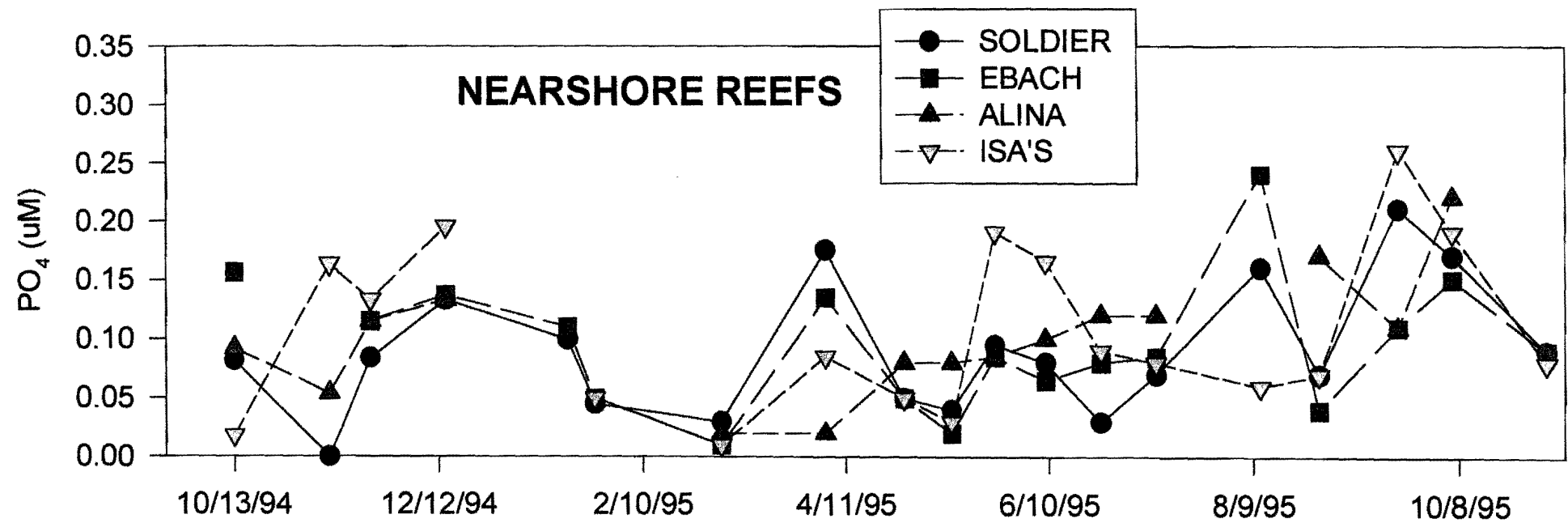
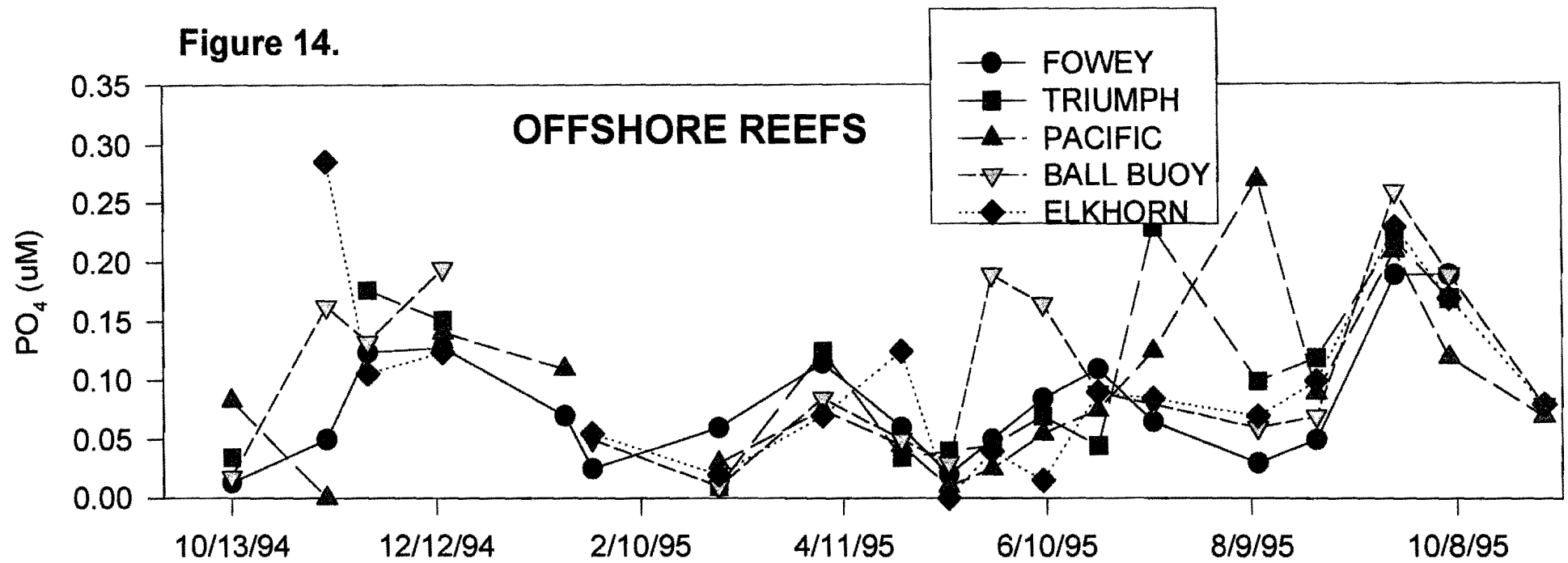


Figure 15.

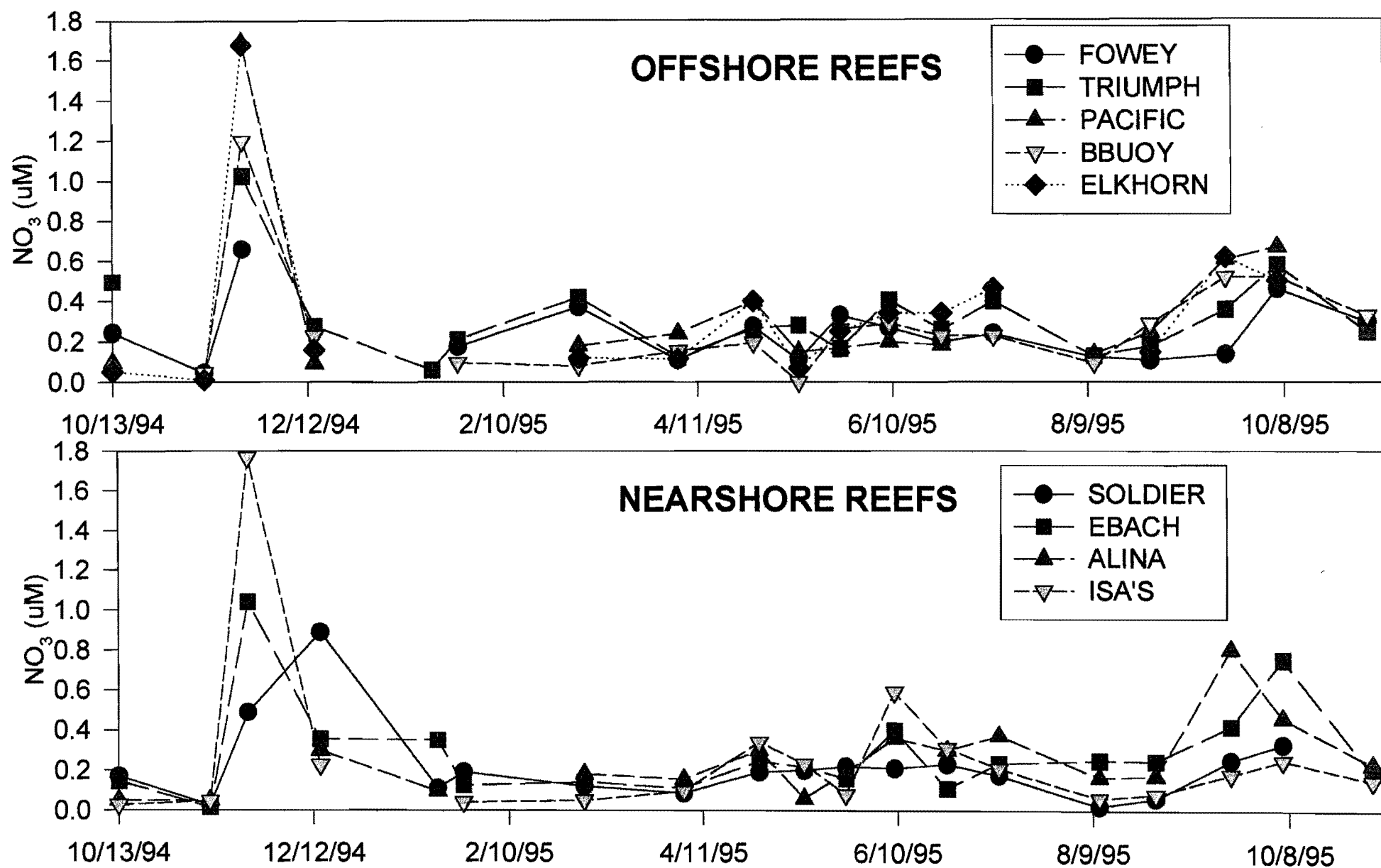


Figure 16.

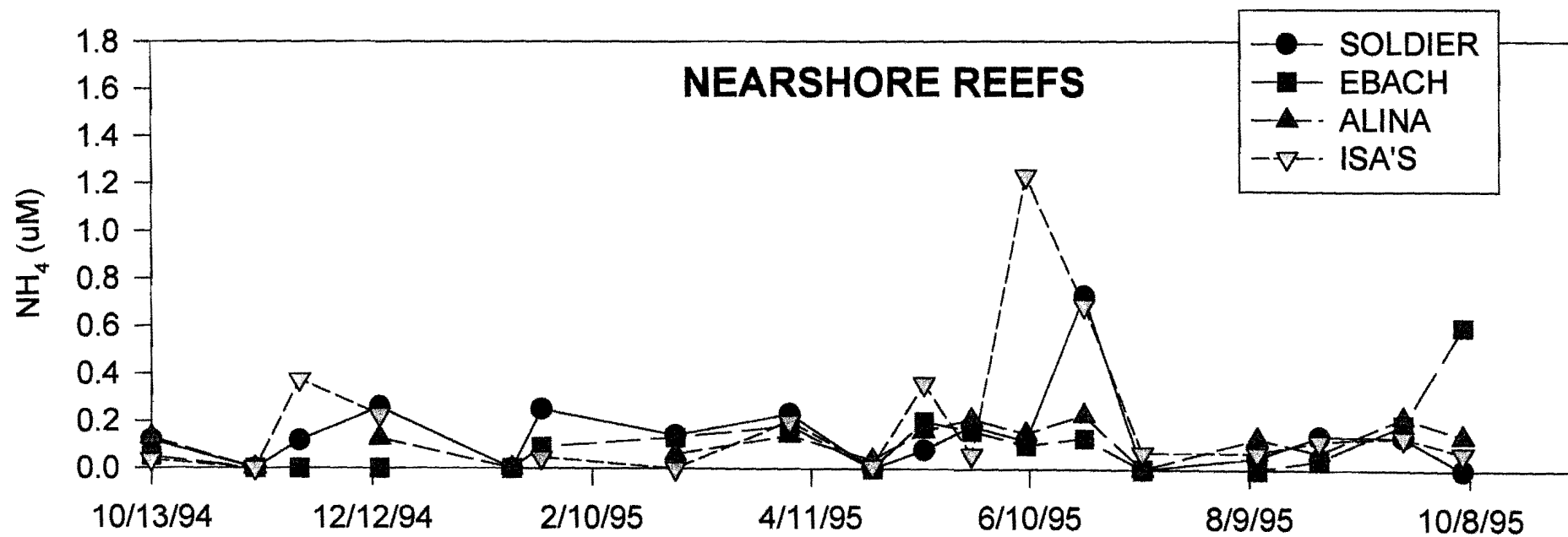
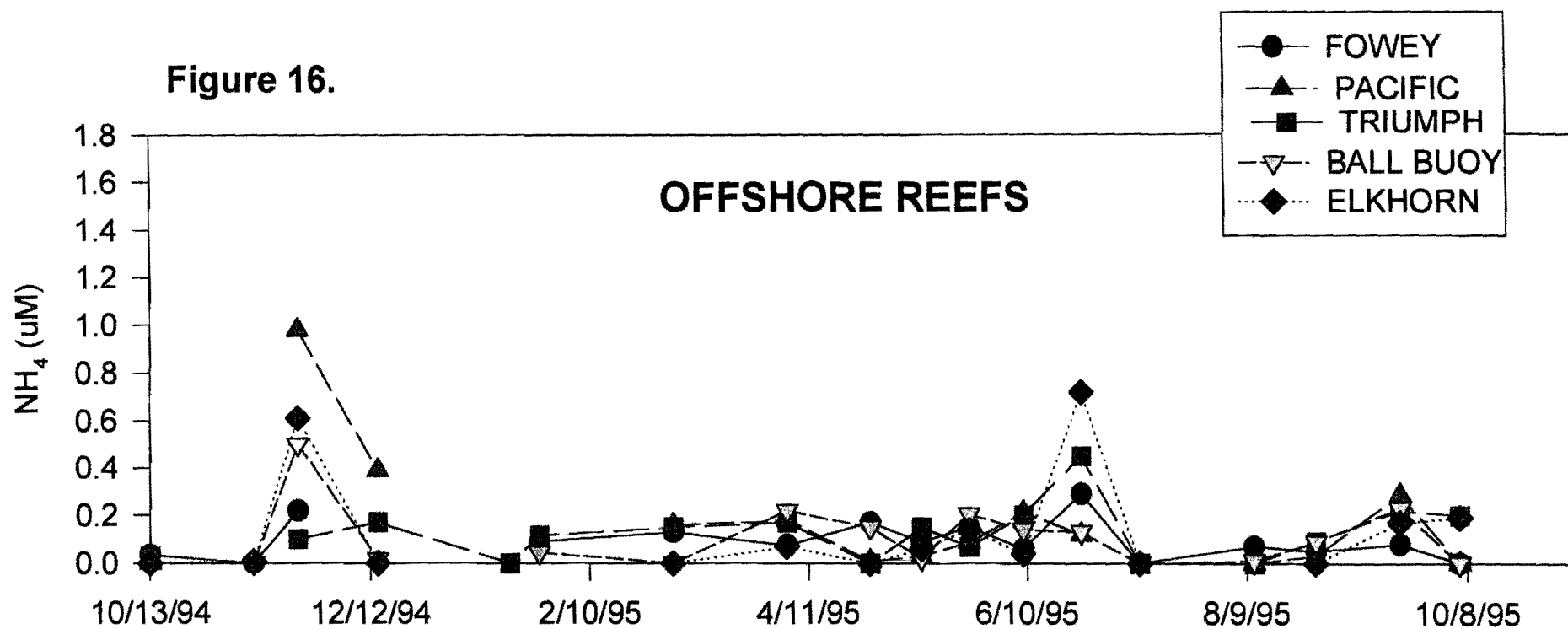


Figure 17.

BNP WATER COLUMN NUTRIENTS

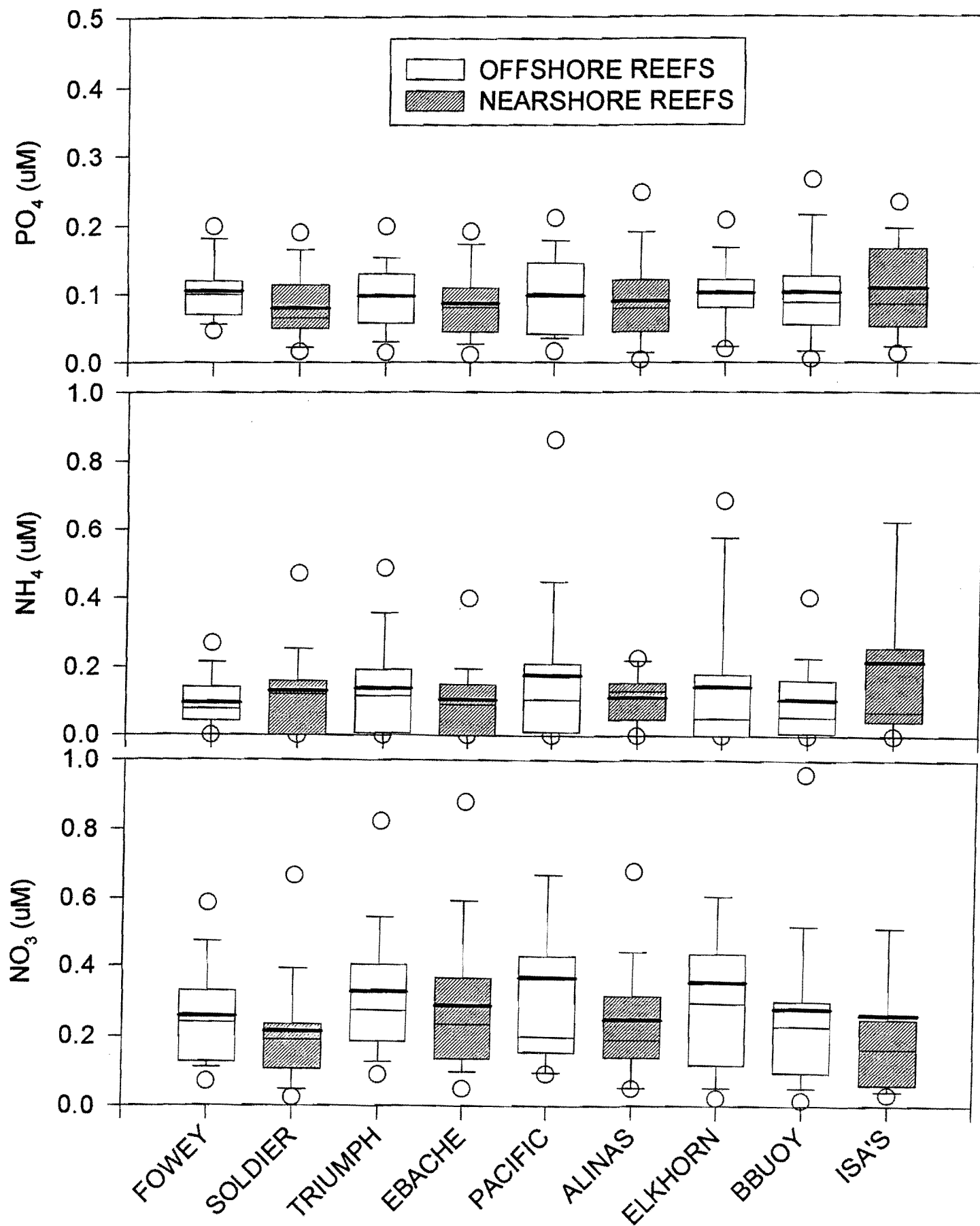


Figure 18.

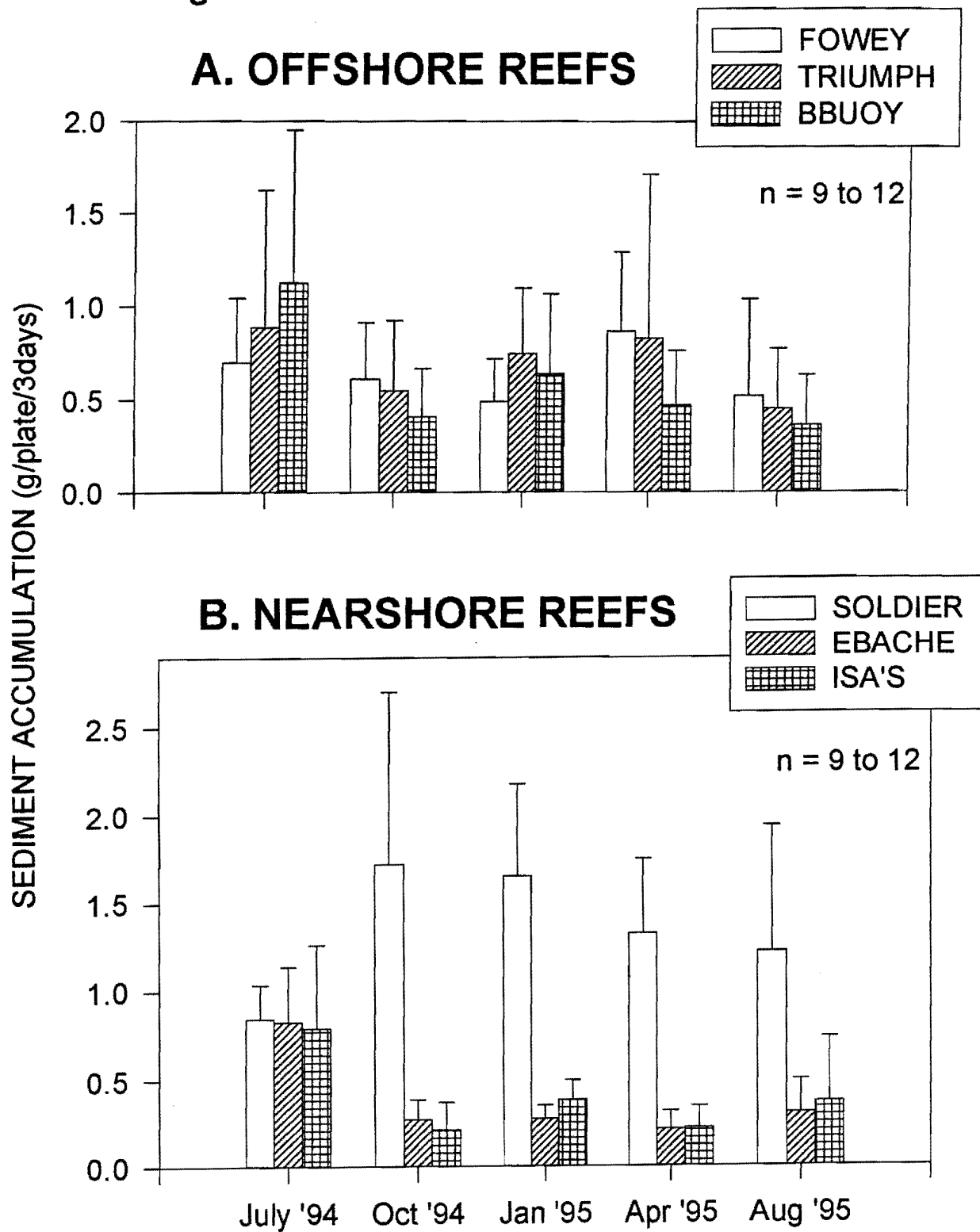


Figure 19.

JULY 1994

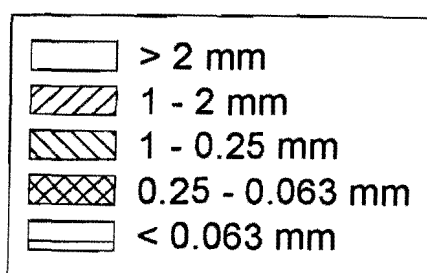
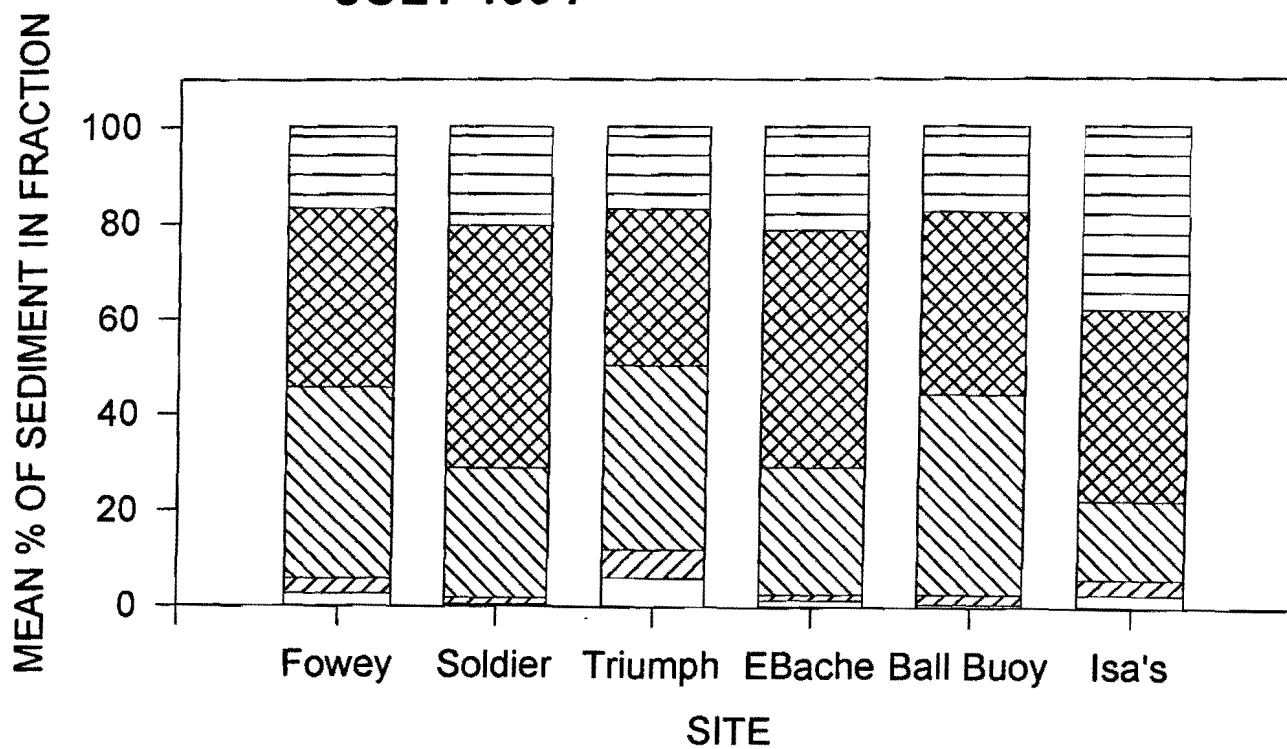
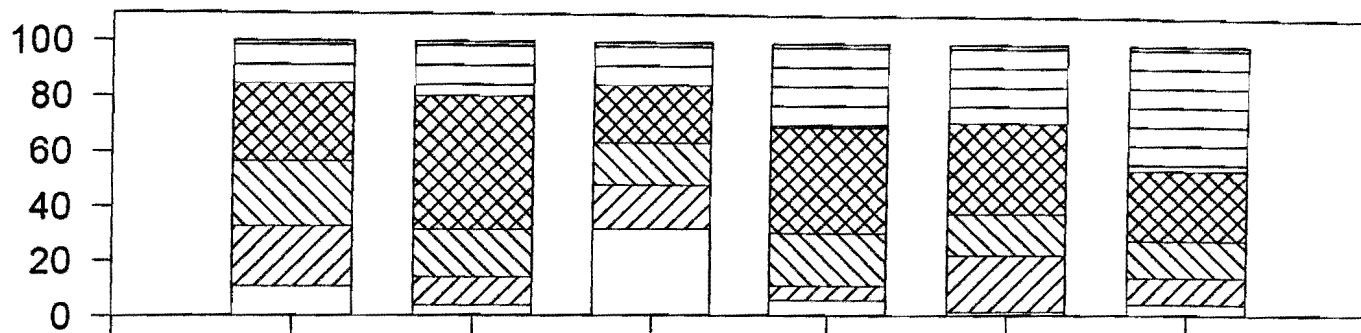
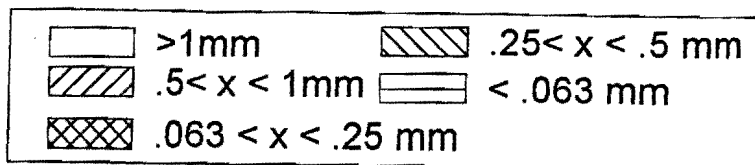
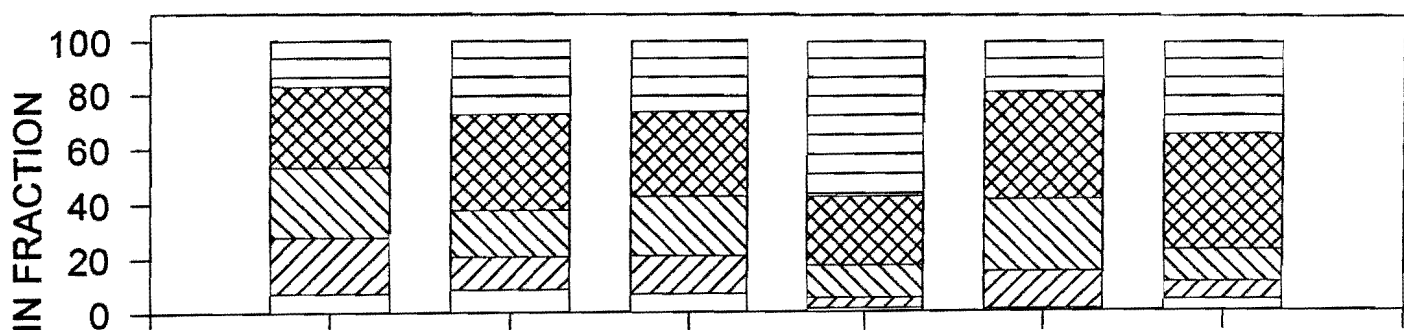


Figure 20.

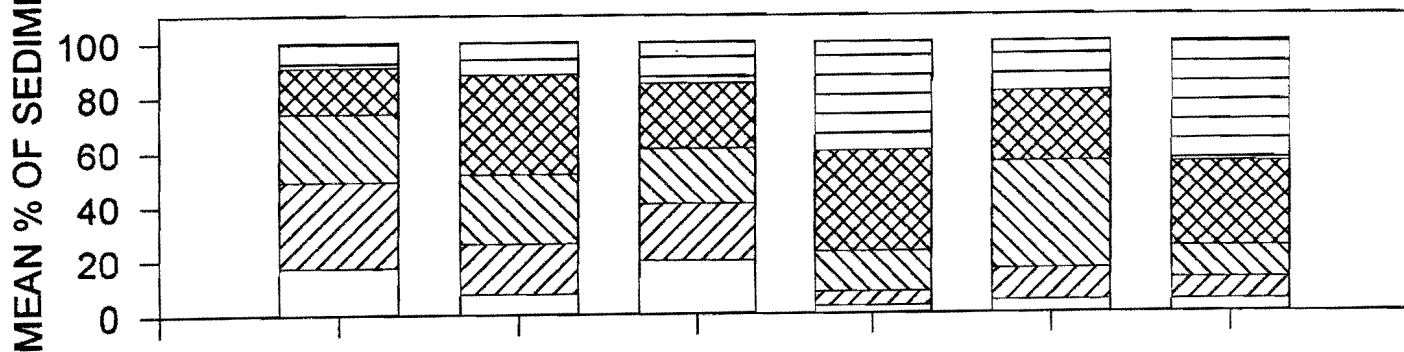
OCTOBER 1994



JANUARY 1995



APRIL 1995



AUGUST 1995

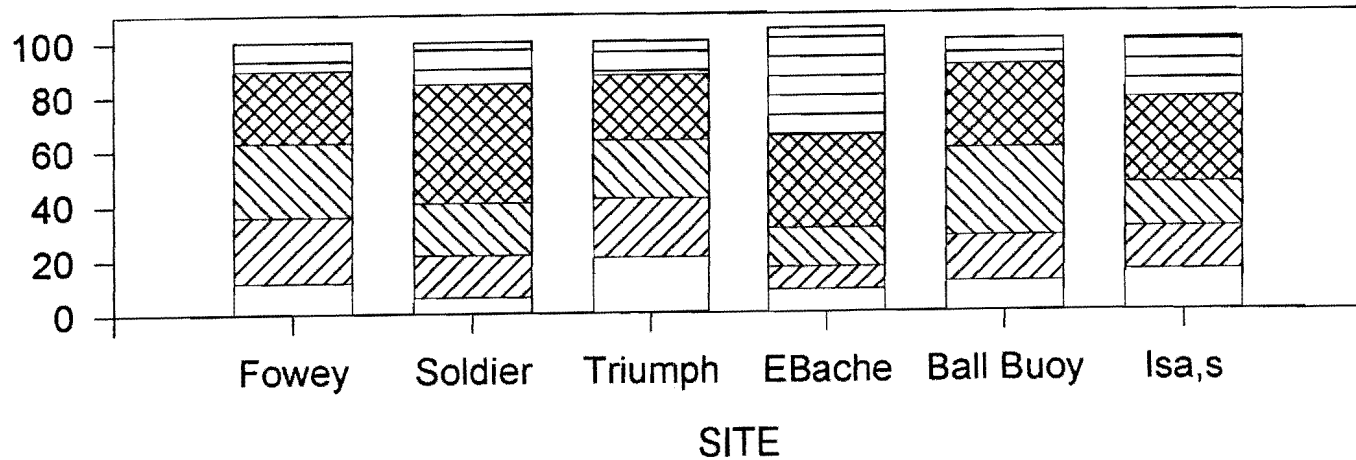


Figure 21.

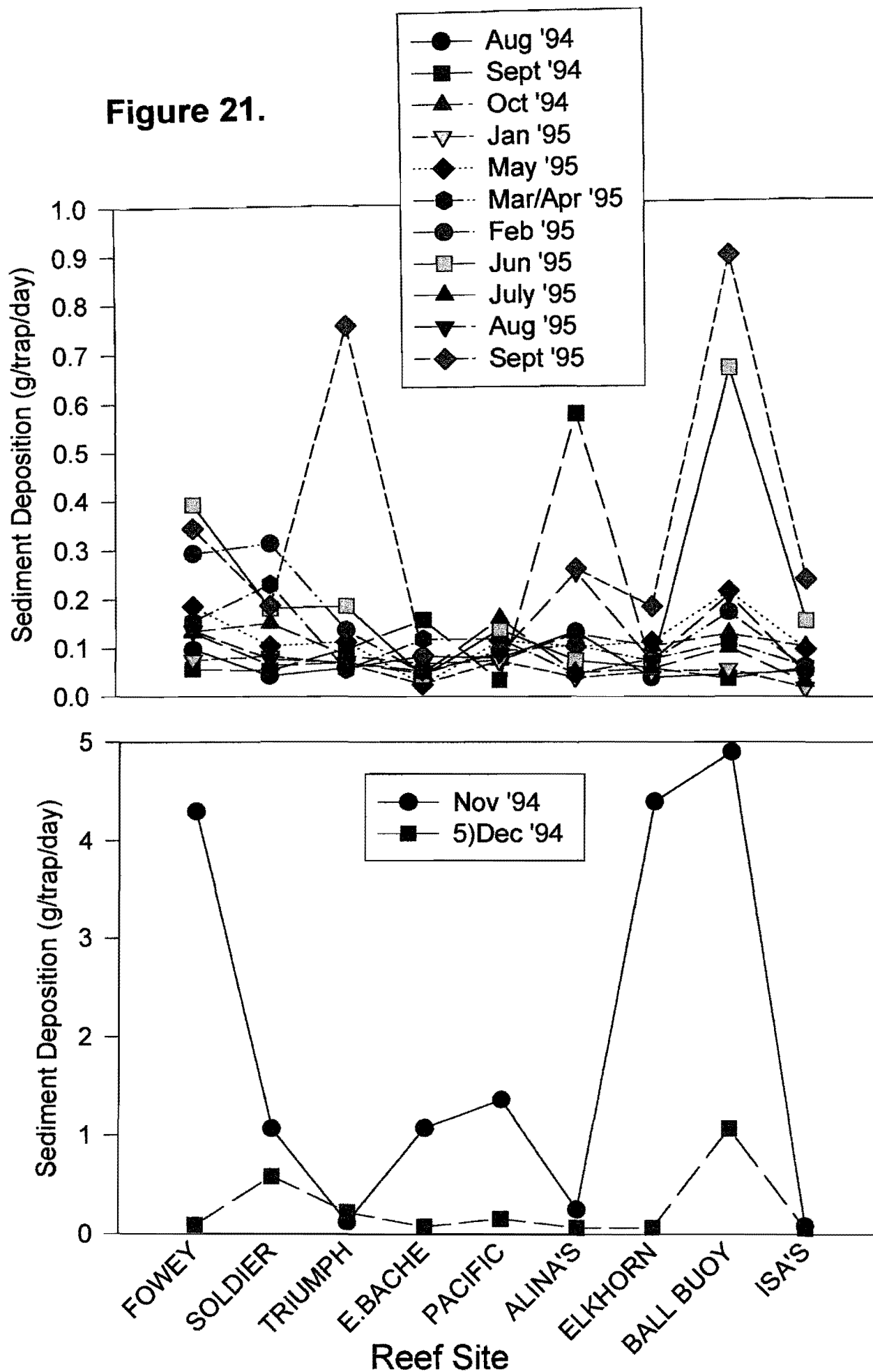


Figure 22.

OFFSHORE REEF
NEARSHORE REEF
N = 11 SAMPLING DATES

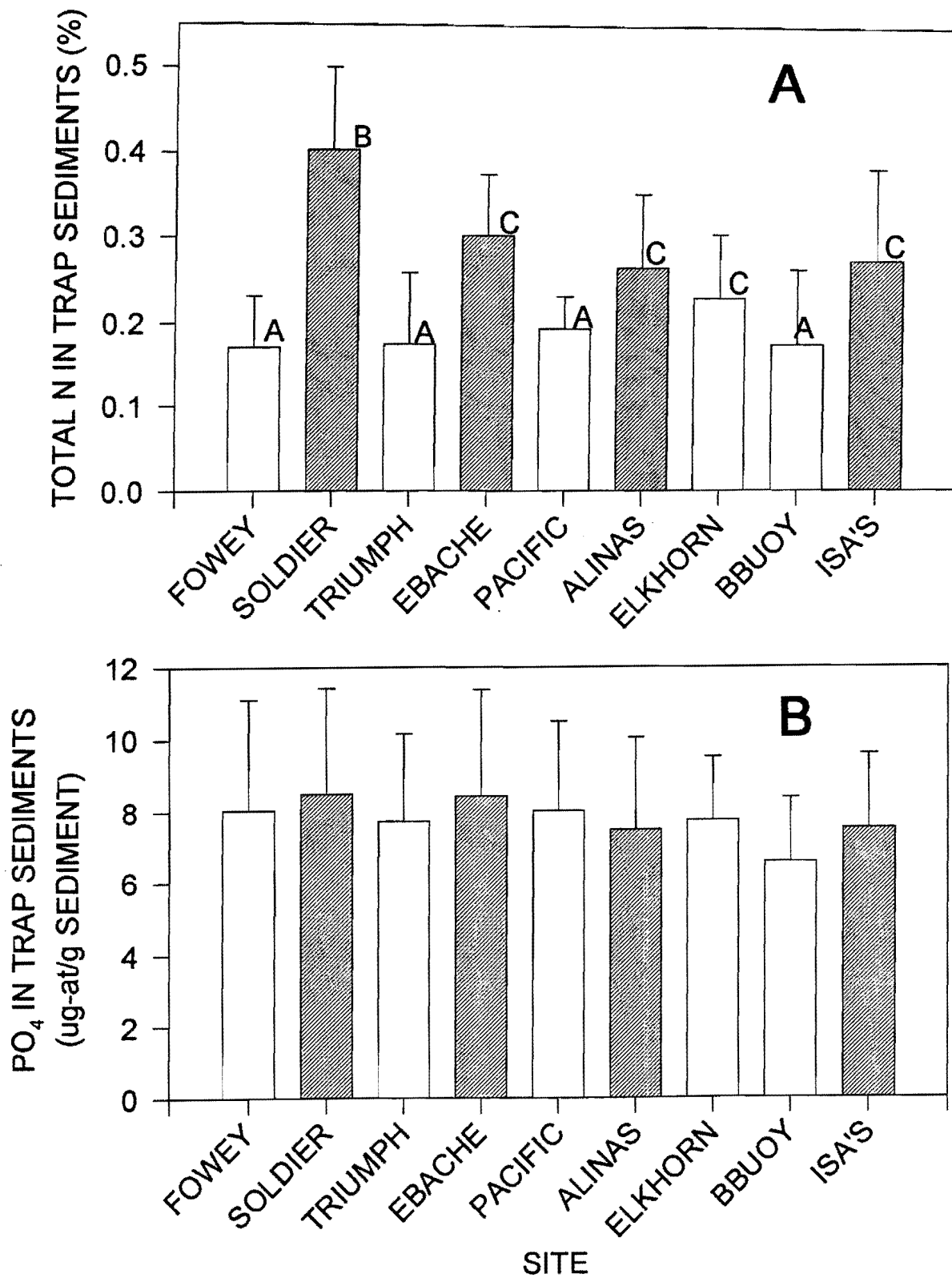


Figure 23.

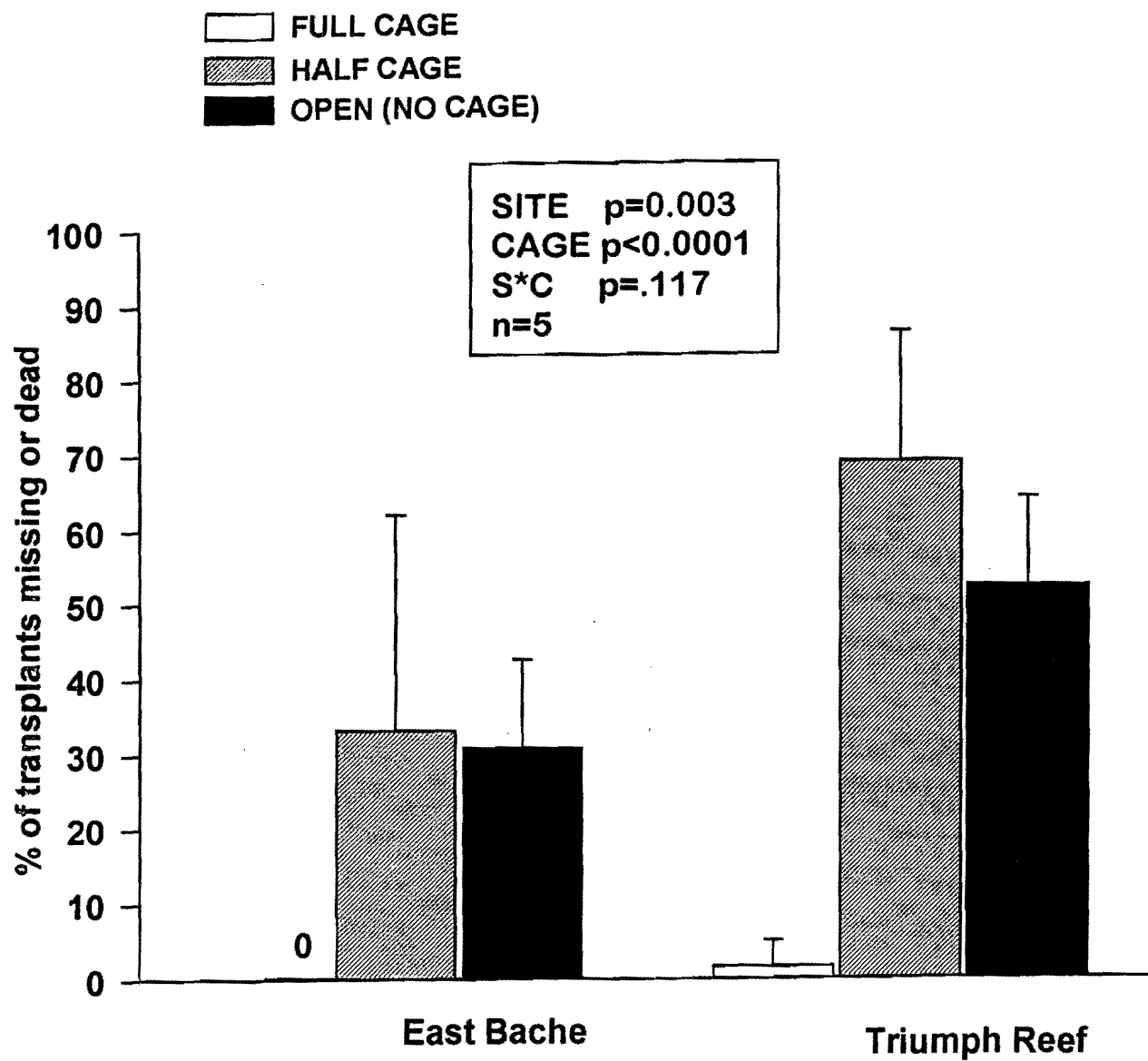
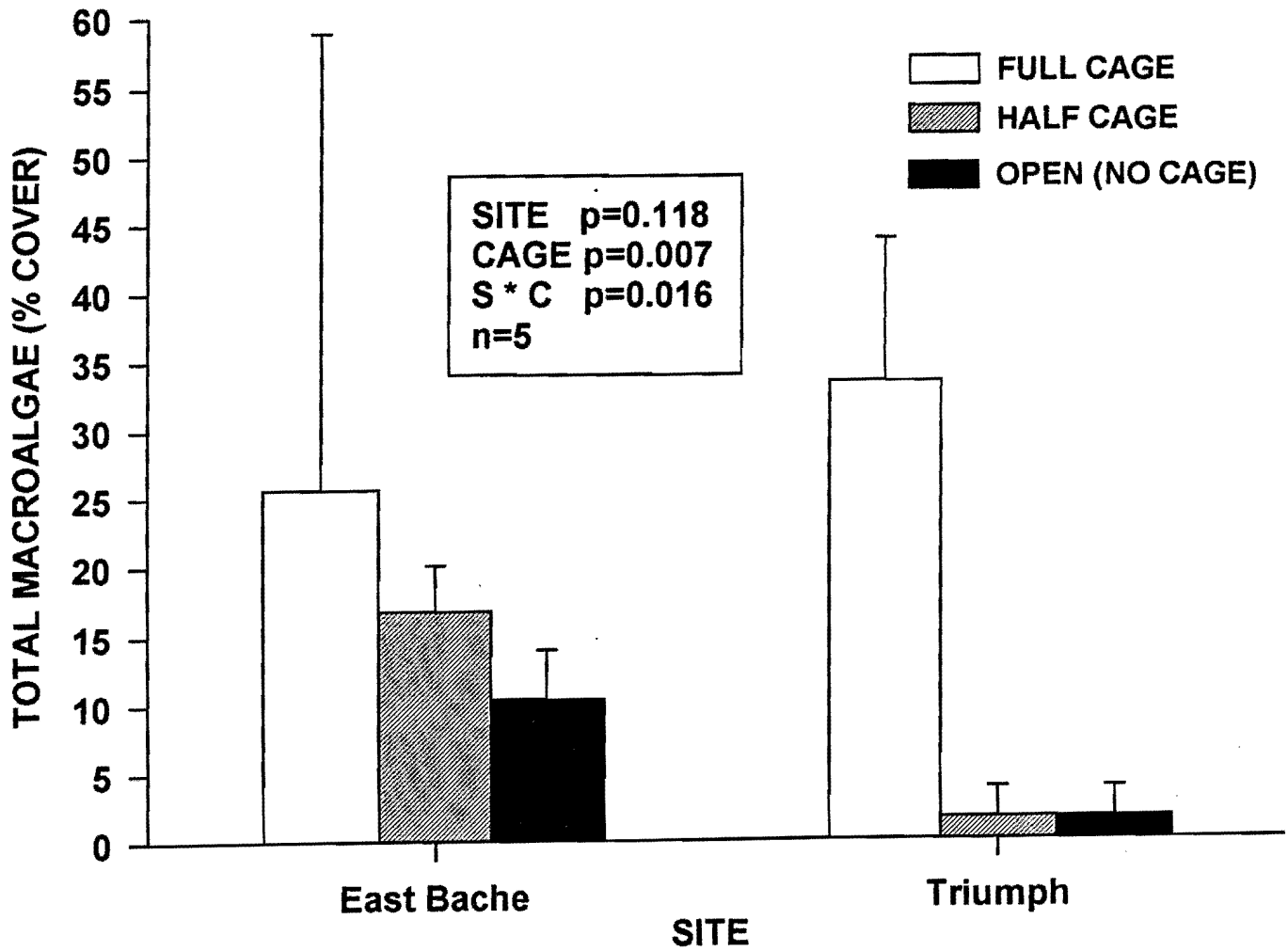


Figure 24.



Appendix 1

REEF DATA CODES

Reefs:

- 1 = Fowey
- 2 = Soldier
- 3 = Triumph
- 4 = East Bache
- 5 = Pacific
- 6 = Alina's
- 7 = Elkhorn
- 8 = Ball Buoy
- 9 = Isa's
- 10 = West Bache

Health of organisms

- 0= Healthy, no signs of illness
- 1= Predation (snail, worms, fish, etc)
- 2= Partial overgrowth by algae
- 3= Partial overgrowth by Millepora
- 4= Partial overgrowth by sponges
- 5= Partial overgrowth by zoanthids
- 6= Partial overgrowth by octocorals
- 7= Overturned (uprooted) colony
- 8= Partially bleached (occurring)
- 9= Bleached, recently dead
- 10= Tumors
- 11= Juveniles
- 12= Disease (black and white band disease)

Major organisms and substrates

SCL = Scleractinian corals

OCT = Octocorals

HYD = Hydrozoan milleporids

SPO = Sponges (Porifera)

ZOA = Zoanthids

ALG = Fleshy and calcareous (*Halimeda spp.* etc) algae

CRU = Crustose algae

X = sand

X₁ = bare substrate

X₂ = rubble

X₃ = Miscelaneous (turf algae + miscelaneous organisms and substrates)

Appendix 2. List of octocoral species observed on 9 study reefs in Biscayne National Park, Florida

SPP	Fowey	Soldier	Triumph	EBache	Pacific	Alina's	Elkhorn	Ballbuoy	Isa's
<i>B.asbestinum1*</i>	1	1	1	1	1	1	1	1	1
<i>B.asbestinum2*</i>	1		1	1	1	1		1	1
<i>E.caribaeorum</i>	1		1	1	1	1	1	1	1
<i>E.laxispica</i>	1				1	1		1	1
<i>EsuccineaS</i>	1	1	1	1	1	1	1	1	1
<i>E.succineaP**</i>	1	1	1	1	1	1	1	1	1
<i>E.lascinata</i>			1	1	1	1	1	1	1
<i>E.asperula</i>				1		1	1	1	1
<i>E.fusca</i>	1	1	1	1	1	1	1	1	1
<i>E.mammosa</i>	1		1	1		1	1	1	1
<i>E.laxa</i>									1
<i>E. clavigera</i>		1		1		1	1	1	1
<i>E.tourneforti1</i>	1	1	1	1	1	1	1	1	1
<i>E.tourneforti2***</i>	1		1						1
<i>E.calyculata</i>	1		1	1	1	1	1		1
<i>E.palmieri</i>	1	1	1	1	1	1	1	1	1
<i>E.knighty</i>				1	1	1		1	1
<i>Eunicea sp.</i>		1		1	1	1	1	1	1
<i>G.ventalina</i>	1		1	1	1	1	1	1	1
<i>G.flabellum</i>	1		1	1		1	1	1	
<i>G.mariae</i>	1		1	1	1	1	1	1	1
<i>I.schrammi</i>	1		1	1		1	1	1	1
<i>M.muricata</i>	1	1	1	1	1	1	1	1	1
<i>M.laxa</i>			1	1	1	1		1	1
<i>M.elongata</i>				1		1	1	1	1
<i>M.flavida</i>	1	1	1	1	1	1	1	1	1
<i>P.homomalla</i>	1	1	1	1		1	1	1	1
<i>P.flexuosa</i>	1	1	1	1	1	1	1	1	1
<i>P.kuna</i>		1	1	1	1	1	1	1	1
<i>P.dichotoma</i>	1	1	1	1	1	1	1	1	1
<i>P.grisea</i>				1		1		1	1
<i>P.nutans</i>		1	1	1		1	1	1	1
<i>P.flagellosa</i>	1	1		1	1	1	1	1	1
<i>P.porosa</i>	1	1	1	1	1	1	1	1	1
<i>P.crucis</i>				1		1	1	1	1
<i>P.wagenari</i>		1	1	1		1	1	1	1
<i>P.americana</i>	1	1	1	1	1	1	1	1	1
<i>P.kallos</i>	1		1	1	1	1	1	1	1
<i>P.acerosa</i>	1	1	1	1	1	1	1	1	1
<i>P.bipinata</i>			1	1	1				
<i>Pseudoterogorgia sp.</i>				1			1	1	1
<i>P.citrina</i>	1	1	1		1	1	1	1	1
<i>P.anceps</i>	1	1		1					1
<i>P.guadalupensis</i>		1	1	1	1	1		1	
Total species	28	23	32	40	29	39	34	39	41
Genera	11	9	12	11	11	12	12	12	12

* *B.asbestinum1* = is the crustose form. *B.asbestinum2* = is the erect form.**= *E.succineaP* = forma plantaginea.

*** = *E.tourneforti2* = forma atra.

Appendix 3. List of scleractinian species observed on 9 study reefs in Biscayne National Park, Florida.

SPP	Fowey	Soldier	Triumph	EBache	Pacific	Alina's	Elkhorn	Ball Buoy	Isa's
<i>S.intersepta</i>	1	1	1	1	1	1	1	1	1
<i>M.decactis</i>	1		1	1	1	1	1	1	1
<i>M.pharensis</i> L*	1			1	1	1		1	
<i>M.senaria</i> **					1				
<i>A.palmata</i>	1					1	1	1	
<i>A.cervicornis</i>				1		1	1	1	1
<i>A.agaricites</i>	1		1	1	1	1	1	1	1
<i>A.humilis</i>	1		1	1		1	1	1	1
<i>A.purpurea</i>	1		1	1	1	1	1	1	1
<i>A.danae</i>						1	1	1	1
<i>A.carinata</i>				1				1	
<i>A.tenuifolia</i>				1		1	1	1	1
<i>A.fragilis</i>			1	1	1				
<i>L.cucullata</i>	1			1		1		1	1
<i>S.siderea</i>	1	1	1	1	1	1	1	1	1
<i>S.radians</i>	1	1	1	1		1	1	1	1
<i>P.porites</i>	1	1	1	1	1	1	1	1	1
<i>P.furcata</i>					1		1		1
<i>P.divaricata</i>		1							
<i>P.astreoides</i>	1	1	1	1	1	1	1	1	1
<i>F.fragum</i>	1	1	1	1	1	1	1	1	1
<i>D.strigosa</i>	1		1	1	1	1	1	1	1
<i>D.clivosa</i>	1	1	1	1	1	1	1	1	1
<i>D.labyrinthiformi</i>	1		1	1	1	1	1	1	1
<i>D.clivosa</i> sp.	1				1	1			
<i>C.natans</i>				1	1	1	1	1	1
<i>M.aerolata</i>				1					1
<i>M.mayori</i>						1		1	1
<i>M.annularis</i>			1	1	1	1	1	1	1
<i>M.faveolata</i>	1		1	1	1	1	1	1	1
<i>M.franksi</i>	1		1	1	1	1		1	1
<i>M.cavernosa</i> 1	1		1	1	1	1	1	1	1
<i>M.cavernosa</i> 2***	1			1	1	1	1	1	1
<i>S.bourmoni</i>	1	1	1	1		1		1	1
<i>S.hyades</i>	1	1							1
<i>M.meandrites</i>	1		1	1	1	1	1	1	1
<i>M.memoralis</i> ****	1		1	1	1			1	1
<i>D.stockesii</i>	1	1	1	1	1	1	1	1	1
<i>D.stellaris</i>				1	1	1	1	1	1
<i>E.fastigiata</i>	1		1	1		1		1	1
<i>M.aliciae</i>				1	1	1	1	1	1
<i>M.lamarckiana</i>				1		1		1	1
<i>M.danaana</i>				1		1	1	1	1
<i>M.ferox</i>				1		1		1	1
<i>M.reesi</i>				1					
<i>M.angulosa</i>						1			1
<i>S.cubensis</i>				1		1		1	1
<i>I.rigida</i>							1	1	
<i>I.sinuosa</i>	1			1	1				1
<i>O.diffusa</i>				1		1		1	1
<i>O.varicosa</i>									1
<i>C.arbuscula</i>		1				1			1
<i>M.alcicornis</i>	1	1	1	1	1	1	1	1	1
<i>M.complanata</i>	1		1	1	1	1	1	1	1
Scleractinians	28	12	23	40	28	39	29	40	43
Genera	12	7	10	17	12	17	12	18	20
Hydrozoans	2	1	2	2	2	2	2	2	2

*= forma luciphogus. **= New report for the Florida area. ***= form with large calices. ****= form with wide colines and thick septa.

Appendix 4. List of the species of Porifera observed on 9 stusy reefs in Biscayne
National Park

SPP	Fowey	Soldier	Triumph	EBache	Pacific	Alina's	Elkhorn	BBuoy	Isa's
<i>A.compressa</i>	1		1	1	1	1	1	1	1
<i>A.erina</i>			1						
<i>A.varians</i>	1		1		1			1	1
<i>A.fulva</i>	1	1		1		1	1		1
<i>A.fistularis</i>	1	1		1		1	1	1	1
<i>A.cauliformis</i>	1	1	1	1	1	1	1	1	1
<i>A.archeri</i>	1								
<i>A.conifera</i>		1	1		1		1		
<i>A.wiedenmyeri</i>			1	1	1	1	1		
<i>A.clathrodes</i>			1		1				
<i>A.dispar</i>			1				1		
<i>C.podatypa</i>		1	1			1		1	1
<i>C.vaginalis</i>	1	1	1		1	1	1	1	1
<i>C.vaginalis2**</i>	1	1			1	1		1	1
<i>C.plicifera</i>	1				1		1	1	1
<i>C.armigera</i>	1								1
<i>Clathria sp.</i>			1	1				1	
<i>Cliona spp.</i>	1		1	1	1	1	1	1	1
<i>C.aprica</i>			1		1	1	1		1
<i>C.delitrix</i>	1			1					
<i>C.lampa</i>	1		1	1	1	1			
<i>C.langae</i>	1								
<i>C.vasculum</i>								1	1
<i>Cynachira sp.</i>				1					1
<i>D.anchorata</i>	1						1	1	1
<i>D.megastellata</i>				1	1	1		1	
<i>Diplastrella sp.</i>	1		1	1			1	1	1
<i>D.janiae</i>									1
<i>D.etheria</i>	1	1	1					1	
<i>E.ferox</i>	1	1	1	1	1	1	1	1	1
<i>G.neptuni</i>									1
<i>Halisarca sp.</i>									1
<i>H.intestinalis</i>							1		1
<i>H.helwigi</i>	1	1		1	1	1	1	1	1
<i>H.proteous</i>					1		1	1	1
<i>I.birotulata</i>	1	1	1	1	1	1	1	1	1
<i>I.felix</i>	1	1	1	1	1	1	1	1	1
<i>I.strobilina</i>	1	1	1	1	1	1	1	1	1
<i>I.campana</i>			1		1				
<i>M.unguifera</i>	1		1	1	1	1	1	1	1
<i>M.barbadensis</i>			1	1	1	1	1	1	1
<i>M.laevis</i>				1	1	1		1	1
<i>N.nolitangere</i>	1					1	1	1	1
<i>N.alba</i>						1			1
<i>N.erecta</i>	1	1	1	1	1	1	1	1	1
<i>N.digitalis</i>	1	1	1	1	1	1		1	1
<i>O.bartsi</i>						1			

Continuation appendix 4.

SPP	Fowey	Soldier	Triumph	EBache	Pacific	Alina's	Elkhorn	BBuoy	Isa's
<i>P.carbonaria</i>		1						1	1
<i>P.weinbergi</i>	1		1	1	1	1	1	1	1
<i>P.amaranthus</i>	1	1	1	1	1	1	1	1	1
<i>Plesiastrea sp.</i>									1
<i>P.luneacarta</i>	1			1		1	1	1	1
<i>P.crassa</i>	1					1	1	1	1
<i>S.coralliphagum</i>							1		
<i>S.vesparium</i>	1	1		1					1
<i>S.coccinea</i>									1
<i>S.obtusa</i>	1	1	1	1	1	1	1	1	1
<i>S.pertusa</i>						1	1		1
<i>Strongylacidon sp.</i>				1			1	1	1
<i>T.ignis</i>		1		1		1			1
<i>T.crypta</i>	1								
<i>U.ruetzleri</i>	1	1	1	1	1	1	1	1	1
<i>V.gigantea</i>									1
<i>V.rigida</i>	1		1	1	1	1	1	1	1
<i>X.muta</i>	1		1						
<i>X.proxima</i>	1								
Total species	37	21	31	31	30	34	34	36	48
Genera	26	16	20	23	19	23	24	29	36

*= dark gray, rope sponge with spine like protrusions

DUPLICATE
Original in
Museum Archives
BIOC-118