Ecological Processes and Coral Reef Recovery in the Florida Keys

Struan R. Smith (Bermuda Biological Station for Research, Inc., St. George's GE01, Bermuda)
Richard B. Aronson and Thaddeus Murdoch (Dauphin Island Sea Lab, Dauphin Island, AL)
John C. Ogden (Project Director) (Florida Institute of Oceanography, St. Petersburg, FL)

Goals

The primary purpose of this continuing study of ecological processes and ecosystem function is to evaluate the relationships among coral cover, coral recruitment, and juvenile mortality in fully protected ("no-take") zones and adjacent reference sites in the Florida Keys National Marine Sanctuary (FKNMS). The initial set of fully protected marine zones (FPMZs) consisted of South Carysfort (Carysfort Sanctuary Preservation Area [SPA]) in the Upper Keys, and Eastern Sambo Research Only Area (ROA) and Western Sambo Ecological Reserve (ER) in the lower Keys. The initial reference sites were Maitland, located near the *M/V Maitland* ship-grounding site in the Upper Keys, and Middle Sambo Reef and Pelican Shoal in the lower Keys. These sites have been monitored since 1998, and those efforts continued in 2002. New monitoring sites were established in the Upper Keys in 2002, at the Molasses Reef SPA. Nearby Pickles Reef was selected as a reference area. The expansion of the study was considered necessary for a more representative assessment of the efficacy of FPMZs.

Findings to Date

Coral Reef Community Structure (Aronson and Murdoch)

The study sites were videographically monitored for the sixth year, in late September-early October 2003, to assess the cover of components of the sessile biota (corals, gorgonians, and sponges). Ten randomized video transects were sampled at each shallow and deep site. Analysis of the 2002 data was completed, and analysis of the 2003 data is nearing completion.

Coral cover remained consistently different between sites from 1998 to 2002 (Fig. 1). As in previous years, the Western Sambo ER shallow site exhibited considerably higher cover than the other shallow sites. Substantial declines in coral cover were detected at Western (ER), Middle (reference), and Eastern Sambo (ROA) Reefs from 2001 to 2002; further monitoring will reveal whether those one-year declines represent real signals. Coral species richness was consistent within sites over the monitoring period, as was the cover of sponges. The cover of encrusting octocorals (*Erythropodium caribbaeorum* and *Briareum asbestinum*) increased at all shallow and deep sites from 2000 to 2001, and this trend continued at most sites from 2001 to 2002. The cover of sponges also increased from 2001 to 2002 at all shallow sites.

The effects of year, protection status, and depth were assessed statistically using three-way analysis of variance (ANOVA) designs. Prior to ANOVA, the assumptions of parametric statistics were tested and the data were transformed as necessary. For coral cover, gorgonian cover, and sponge cover, significant interaction terms made interpretation of the ANOVAs problematic.

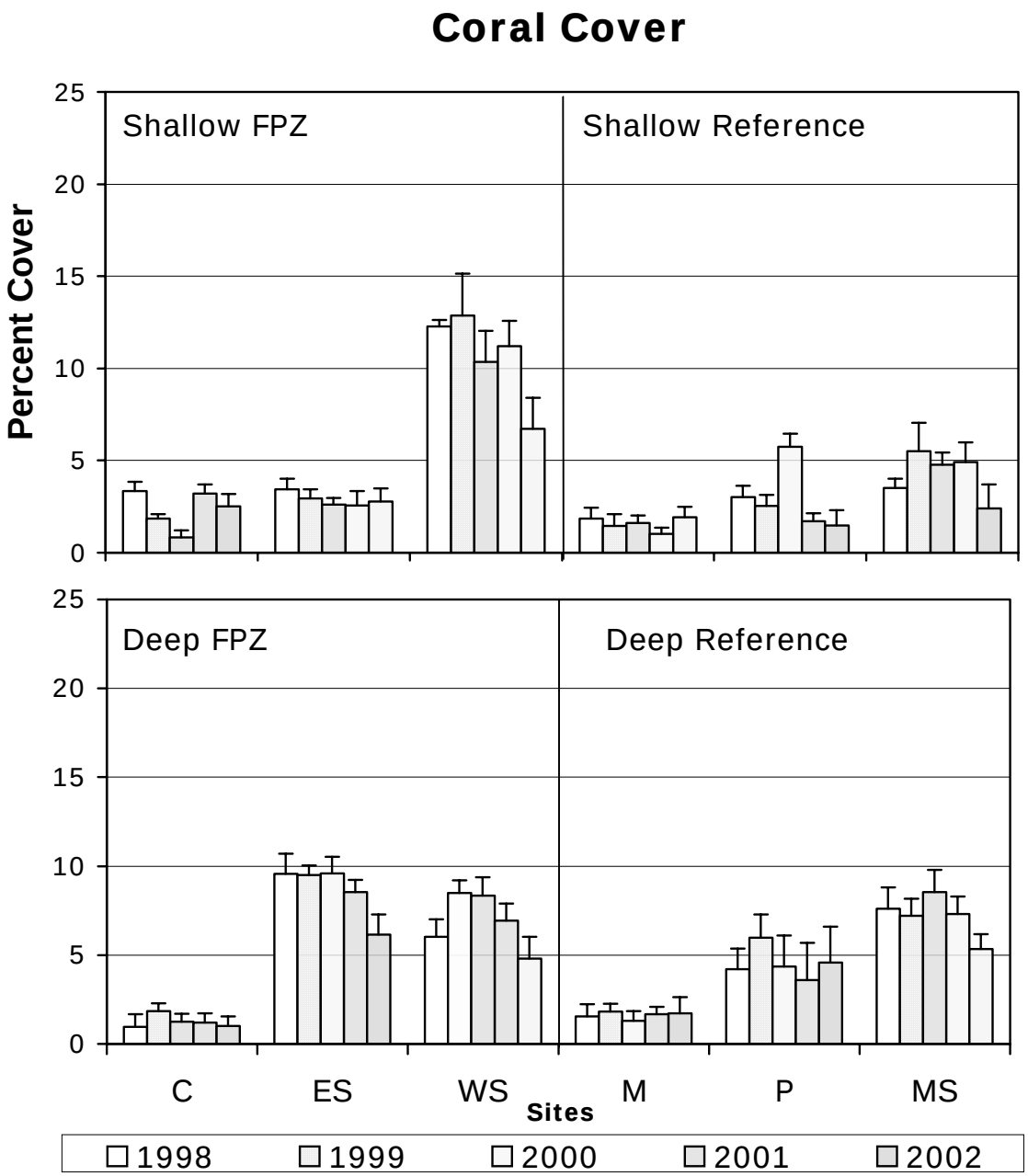

Figure 1. Coral coverage from 1998 to 2002. Mean values are shown with standard error bars. Site codes for Fully Protected Marine Zones (FPZ) are: W = Western Sambo ER, E = Eastern Sambo ROA, C = Carysfort SPA. Site codes for the reference areas are: MS = Middle Sambo, P = Pelican Shoal, M = Maitland.

The transect data were ordinated by multidimensional scaling (MDS) to search for patterns in species composition of the coral assemblages at the sites. Community composition was quite similar at all sites/depths from 2001 to 2002. In the shallow depth range, *Siderastrea siderea* and *Millepora alcicornis* increased at all sites while *Montastraea* spp. (the *M. annularis* species complex and *M. cavernosa*) and *Meandrina meandrites* decreased or remained static at all sites. *Porites porites* increased at two of the three FPMZs and declined at two of three reference sites.

In terms of functional groups, broadcast-spawning, massive coral species have declined dramatically over the years at most sites. Branching species that brood planulae have declined slightly at all sites. Brooding, massive corals have increased in the Upper Keys and declined in Lower Keys sites but only on the reference reefs. In a separate MDS ordination, the deep sites showed a different pattern. They clustered by sector of the reef tract, with sites in the Lower Keys set apart from sites in the Upper Keys, reflecting the lower cover and diversity of corals at the latter sites.

Coral Population Dynamics (Smith)
The recruitment and mortality of juvenile corals were monitored in sets of 32 permanent quadrats established within the initial FPMZs and reference sites from 2001 to 2002 within two depth ranges: shallow, 6-9 m, and deep, 16-18 m. Prepared annotated photographic images of each quadrat from 2001 were used to resurvey the quadrats in situ in 2002, facilitating rapid assessment of changes in the extant corals and occurrence of new corals. This was the fourth period of annual changes observed in the juvenile coral populations since the project began in 1998. QA/QC of 2002 data is mostly complete. Further data are required to verify species-specific patterns of recruitment. The 2003 data are needed to verify provisional identification of some recruits observed in 2002. All corals are entered into a custom Access database.

Permanent quadrats at the shallow depths at the new study sites at the Molasses Reef SPA and Pickles Reef (reference) were established in 2002. However, no data on recruitment and mortality rates will be available until the re-survey in 2003. There appeared to be significantly more juvenile corals present at Pickles reference sites than at the Molasses SPA. There was not sufficient time to establish deep site quadrats in 2002 and that work will be done in 2003.

Coral Recruitment Patterns
After five years of assessment, coral recruitment patterns are showing some clear patterns between depths and between regions in the Florida Reef Tract (Fig. 2). There appear to be very few indications that FPMZs have higher coral recruitment than adjacent reference sites. Only the Western Sambo ER shallow site has shown consistently higher coral recruitment compared to the shallow reference site at Middle Sambo, even though the former site has showed a steady decline in recruitment since 2000. In contrast, recruitment rates at the Pelican deep reference site have been consistently and significantly higher than the adjacent Eastern Sambo ROA.

Shallow sites in both the Lower and Upper Keys have had nearly uniform recruitment rates of three to five new colonies/m^2/yr, with the exception of the Western Sambo ER shallow site, which has had recruitment of about 10 colonies/m^2/yr since 2000. Recruitment has increased steadily at deep sites in the Lower Keys since 2000. Three of the four lower Keys deep sites had significantly higher recruitment rates in 2003 compared to the previous year, with only the Middle Sambo reference site showing no increase from 2002. The overall impression is that recruitment is highly site-specific, with an indication of higher recruitment at Lower Keys deep sites.

The greatest distinctions in recruitment rates appear to be between the Upper and Lower Keys. Recruitment rates have been consistently and significantly lower at both depths in the Upper

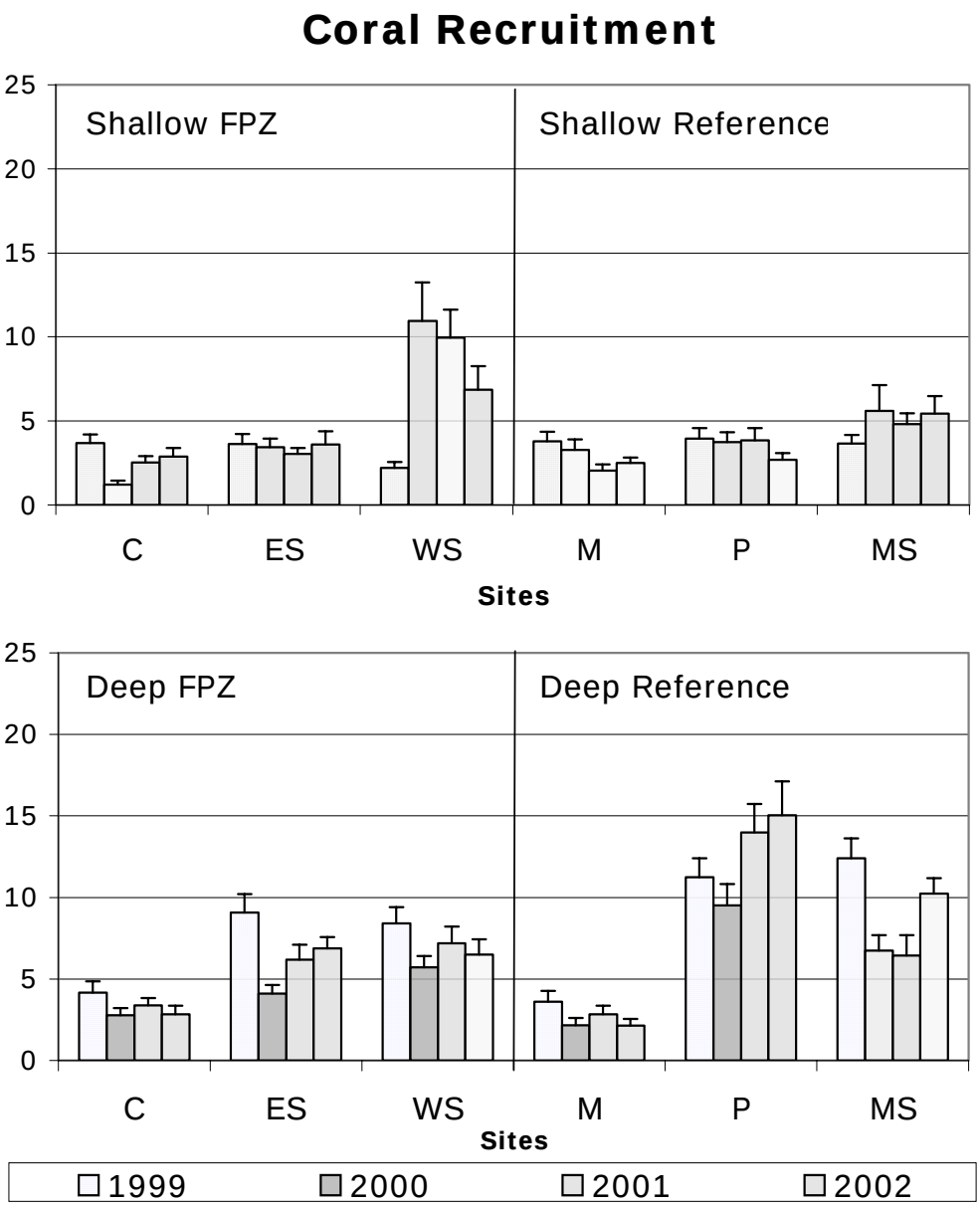

Figure 2. Patterns of juvenile coral recruitment in Fully Protected Marine Zones (FPZ) and adjacent reference areas from 1998 to 2003. Thirty-four permanent quadrats were censused visually on an annual basis at each depth at each site. C = Carysfort SPA, ES = Eastern Sambo ROA, WS = Western Sambo ER, M = Maitland, P = Pelican Shoal, MS = Middle Sambo. FPZ and reference pairs are C+M; ES+P; WS+MS. Error bars = 1 SE.

Keys. An ad hoc study was initiated in 2002 to begin to understand one aspect of the many that may influence coral recruitment. Settlement tile arrays were deployed at the deeper depths at the Carysfort SPA and Maitland reference sites and at the Eastern Sambo ROA and Middle Sambo reference sites in July 2002. The arrays will be retrieved in 2003 and all newly settled corals on the tiles identified. Differences in patterns of larval settlement may indicate differences in larval

supply to the Upper and Lower Keys. A parallel project is being conducted simultaneously by NOAA scientists (Piniak, Fonseca, and Kenworthy) in the Tortugas. The combined data sets will give us an indication of possible gradients in coral larval settlement along the Florida Reef Tract.

Juvenile coral mortality patterns

Juvenile coral mortality rates are generally more consistent (20 to 40% per year) across sites and depths with little distinction between FPMZs and reference sites since 1999 (Fig. 3). Also, no distinctions appear between the Lower and Upper Keys sites. This might indicate that factors that contribute to juvenile coral mortality (sedimentation, algal overgrowth, and predation) are more uniformly distributed along the Florida Reef Tract than the factors that promote recruitment. However we lack any data with regard to these potential agents of coral mortality.

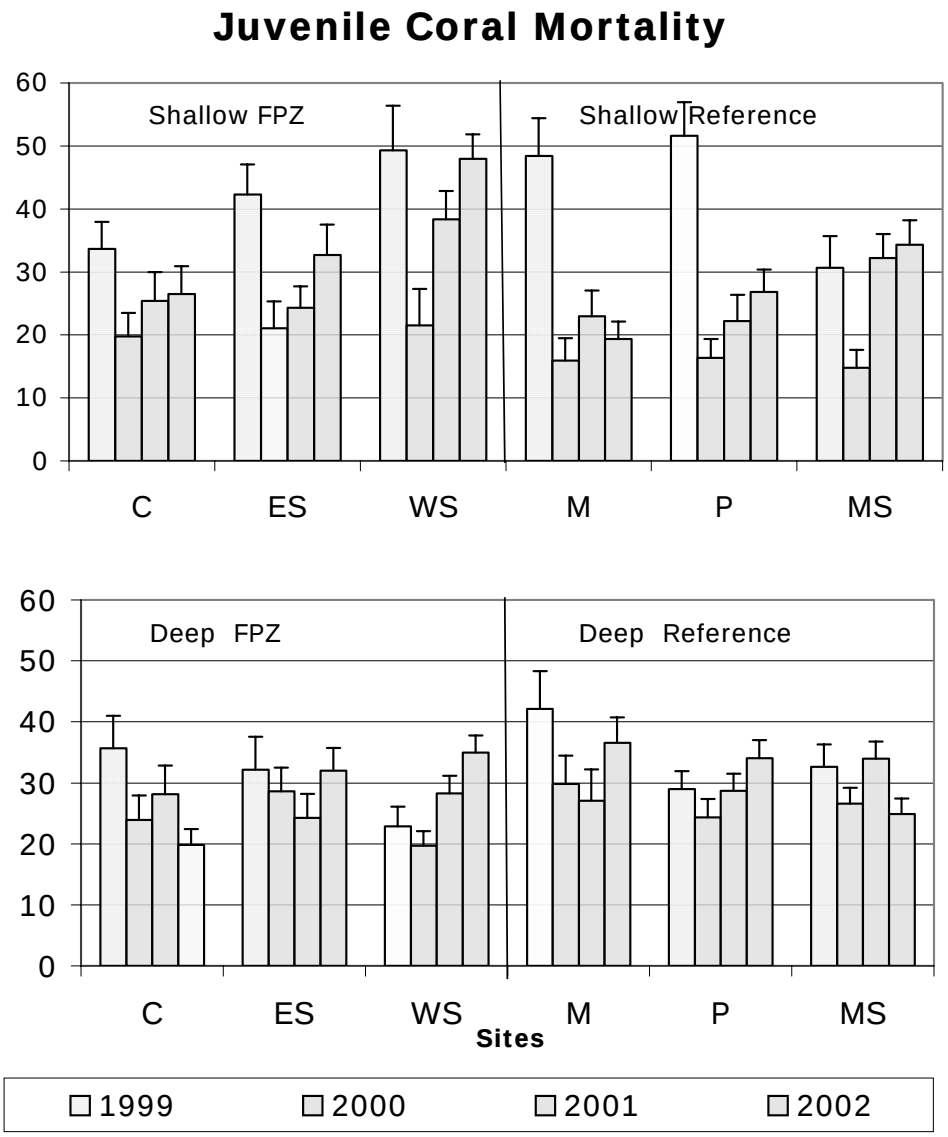

Figure 3. Patterns of juvenile coral mortality in Fully Protected Marine Zones (FPZ) and adjacent reference areas in the permanent quadrats from 1998 to 2003. Site labels as listed in Fig. 2. Error bars = 1 SE.

All the shallow sites, except for the Maitland reference site, have experienced increasing rates of mortality since 2000. Mortality rates at the Western Sambo ER shallow site were nearly 50% and there was a concomitant reduction in recruitment at this site. Correlation analyses of recruitment and mortality were performed by region and by depth, but no significant patterns existed between these data sets. The Western Sambo ER deep site has had consistent increases in mortality rates since 2000. All the other deep sites have had both increases and decreases in mortality since 1999.

Species-specific Patterns of Recruitment and Mortality

In general terms, both brooding corals (agariciids and poritids) and broadcast-spawning corals (*Siderastrea siderea* and *Montastraea cavernosa*) have recruited successfully since 1999 (Fig. 4). The 2002 data require follow-up surveys (i.e., in 2003) to confirm the initial species identifications. The older, larger colonies show species characteristics more clearly.

Very few of the massive framework-building species (*Diploria* spp., *Montastraea, "annularis,"* and *Colpophyllia natans*) have recruited successfully, if at all. Since 1998 we have only confirmed two new *Montastraea "annularis"* recruits in the original six sites (12 depth locations). The indications are that recruitment of these key species does occur, albeit widely dispersed in time and space, an inherent trait of these K-selected species. The fact that other broadcasting species (*Siderastrea siderea* and *Montastraea cavernosa*) are more successful indicates that water column processes (fertilization, predation, and hydrography) are not limiting factors. The sporadic success of some broadcasting species may be due to one or more factors such low population density (an Allee effect, in the case of *Colpophyllia* and *Diploria*), lack of recruitment cues, or species-specific post-settlement processes.

Patterns of mortality in the marked juvenile corals within the quadrats did not show strong differences between species, within years, or across depths (Fig. 5). Also, there do not appear to be differences in mortality rates between FPMZs and reference sites. The presented data for *Agaricia* spp. and *Montastraea cavernosa* show the high mortality in 1999 as a result of the effects of storm waves from Hurricanes Georges and Mitch in the fall of 1998. Mortality rates were reduced in subsequent years, but were not consistently low at all sites or depths. Once the 2002 data are fully processed the species-specific mortality data will be subjected to a nested ANOVA to test for treatment effects.

Adequacy of Sampling Effort

The aggregate quadrat area from the original 12 locations is 252 m^2, which may appear to be a trivial area with which to assess key processes along the Florida Reef Tract. However, the 2002 data brought the total number of unique corals observed in the study to just under 10,000 or approximately 25 colonies recruiting, growing, or dying in each of the 384 quadrats over the five annual periods. This level of data density does provide a robust picture of changes in juvenile coral populations. Data from the new study sites in the Upper Keys will provide a clearer picture of similarity or difference between the Upper and Lower Keys and between FPMZs and reference sites.

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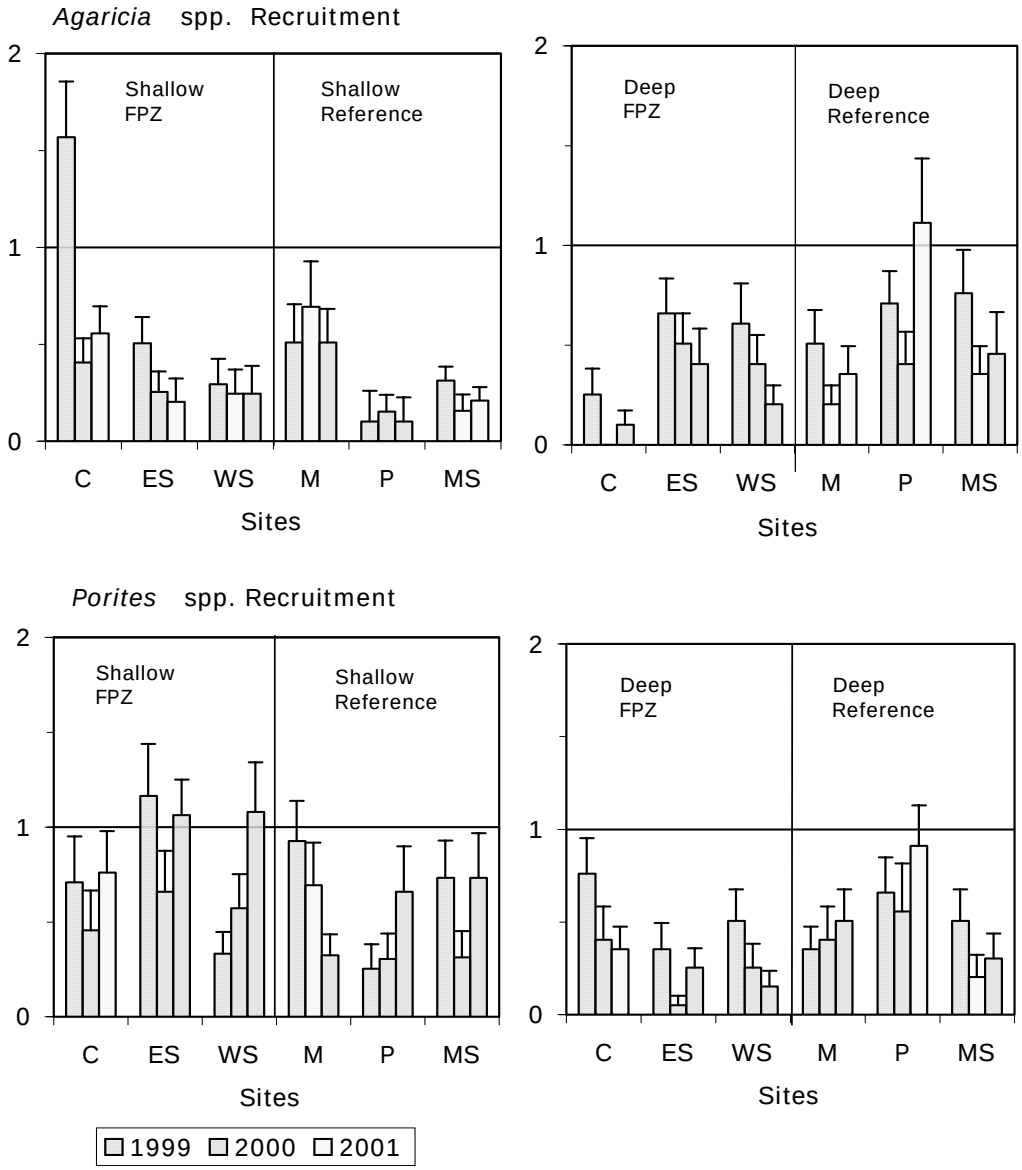

Figure 4. Patterns of recruitment by the dominant brooding corals in Fully Protected Marine Zones (FPZ) and adjacent reference areas. Site labels as listed in Fig. 2. Error bars = 1 SE.

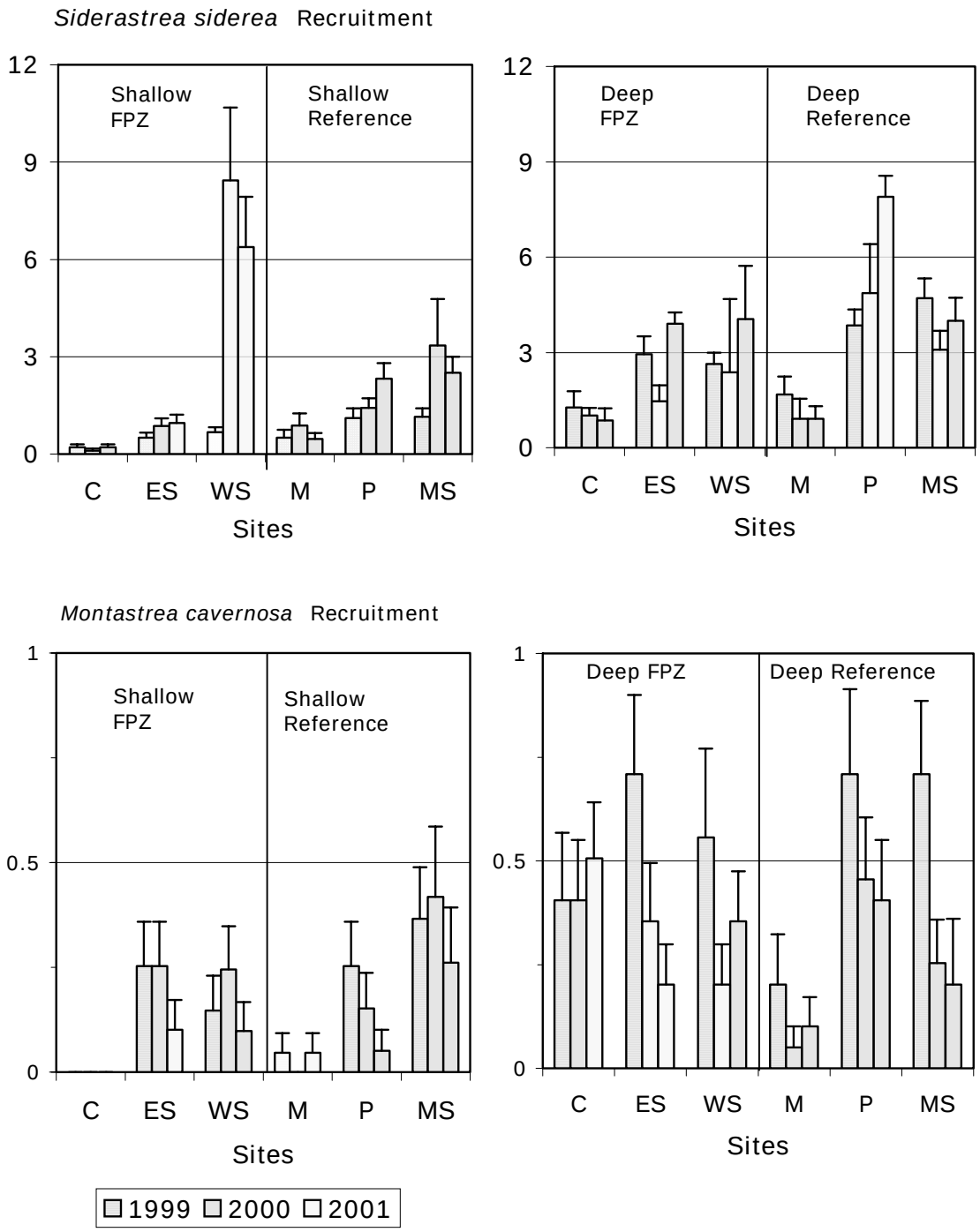

Figure 5. Patterns of recruitment by the dominant broadcasting corals in Fully Protected Marine Zones (FPZ) and adjacent reference areas. Site labels as listed in Fig. 2. Error bars = 1 SE. No *M. cavernosa* recruits have been observed in the quadrats at the Carysfort SPA shallow site.

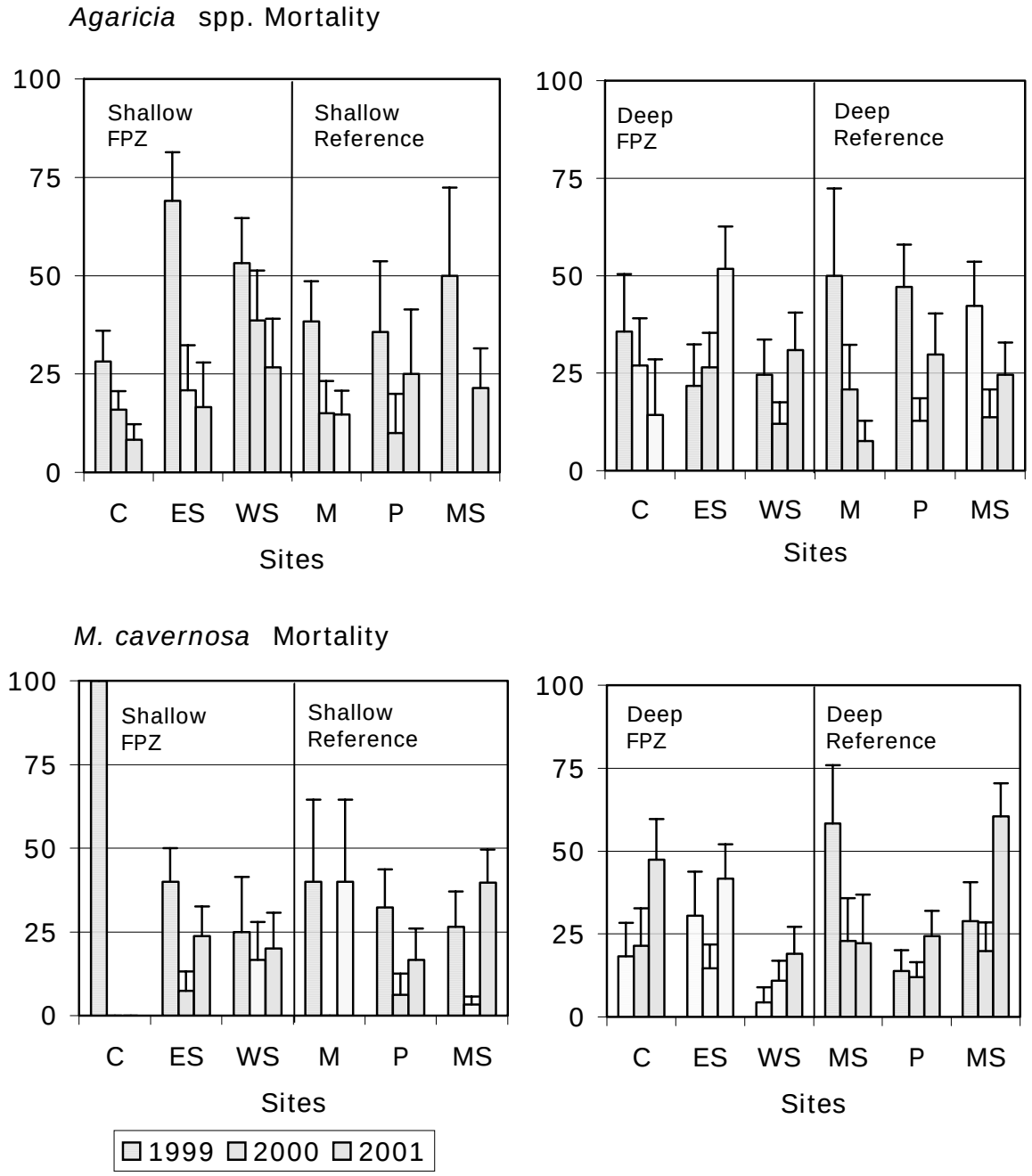

Figure 6. Patterns of mortality for juvenile colonies of two common corals in Fully Protected Marine Zones (FPZ) and adjacent reference areas. Site labels as listed in Fig. 2. Error bars = 1 SE. All *M. cavernosa* juvenile corals in the Carysfort SPA shallow site were killed off in 1998-99.