Nearshore hardbottom fishes of southeast Florida and effects of habitat burial caused by dredging

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Abstract.–Fish assemblages of nearshore hardbottom habitats of southeast Florida were quantified at three sites from April 1994 to June 1996. Random 2 × 15 m transects were visually censused within two replicate areas at each site. The hardbottom at one site was buried by a dredge project to widen a beach one year into the study. A total of 394 transects were sampled. Eighty-six taxa (77 identified to species) from 36 families were censused. Grunts (Haemulidae) were the most diverse family (11 species), followed by the wrasses (Labridae) and parrotfishes (Scaridae) with seven and six species, respectively. The most abundant species were sailors choice (*Haemulon parra*), silver porgy (*Diplodus argenteus*), and cocoa damselfish (*Stegastes variabilis)* with mean abundances (individuals/transect) of 4.5, 3.8, and 3.7, respectively. Early life stages (newly settled, early juvenile, and juvenile) represented over 80% of the individuals at all sites. Newly settled stages of over 20 species were observed in association with hardbottom reef structure. Outside of lagoons, nearshore hardbottom areas are the primary natural structures in shallow waters of mainland Florida's east coast and were estimated to have nursery value for 34 species of fishes. After one year, burial of approximately five ha of hardbottom habitat at one site lowered the numbers of individuals and species by over 30× and 10×, respectively. Due to their early ontogenetic stage, many of these species may not be adapted for high mobility in response to habitat burial. Dredging effects may be amplified by burial prior to and during spring and summer periods of peak larval recruitment.

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The southeast coast of mainland Florida is within a biogeographic transition zone of high marine biodiversity (Briggs, 1974; Gilmore, 1995). This region is also undergoing some of the most rapid human population growth of any area of the United States (Culliton et al., 1990). Due to the economic and recreational value of beaches, substantial marine dredging projects (up to 1.5×10^5 m^3 of fill/project) are commony used to widen beaches that are subject to erosion in the area (ACOE, 1996). Nearshore hardbottom habitats are the primary natural reef structures of this region at depths of 0–4 m and are often buried or indirectly affected by these projects. To date, no quantitative studies of the fish fauna of these habitats or the effects of beach dredge-and-fill projects on nearshore fishes are available (NRC, 1995).

Nearshore hardbottom habitats of this area are derived from accretionary ridges of coquina mollusks, sand, and shell marl which lithified parallel to ancient shorelines during Pleistocene interglacial periods (Duane and Meisburger, 1969; Hoffmeister, 1974). The habitat complexity of these limestone structures has been expanded by colonies of tube-building polychaete worms (Kirtley and Tanner, 1968) and other invertebrate and macroalgal species (Goldberg, 1973; Nelson, 1989; Nelson and Demetriades, 1992). In southeast Florida, most nearshore hardbottom structures are within 200 m of the shore. These habitats are often centrally located between mid shelf reefs to the east and estuarine habitats within inlets to the west. Therefore, they may serve as settlement habitats for immigrating larvae or as intermediate nursery habitats for juveniles emigrating out of inlets (Vare, 1991; Lindeman, 1997a). Nonetheless, most administrative reviews have concluded that the fish habitat value of nearshore hardbottom and the effects of dredge-based beach restoration projects are minimal (e.g. ACOE, 1996).

This study quantifies nearshore hardbottom fish assemblages on the southeast coast of mainland Florida over a 27-month period. The effects of dredge-fill placement were also examined because the hardbottom habitat at one site was buried on account of a beach restoration project 12 months into the study. Three primary objectives were examined. First, spatial and temporal attributes of fish assemblages at

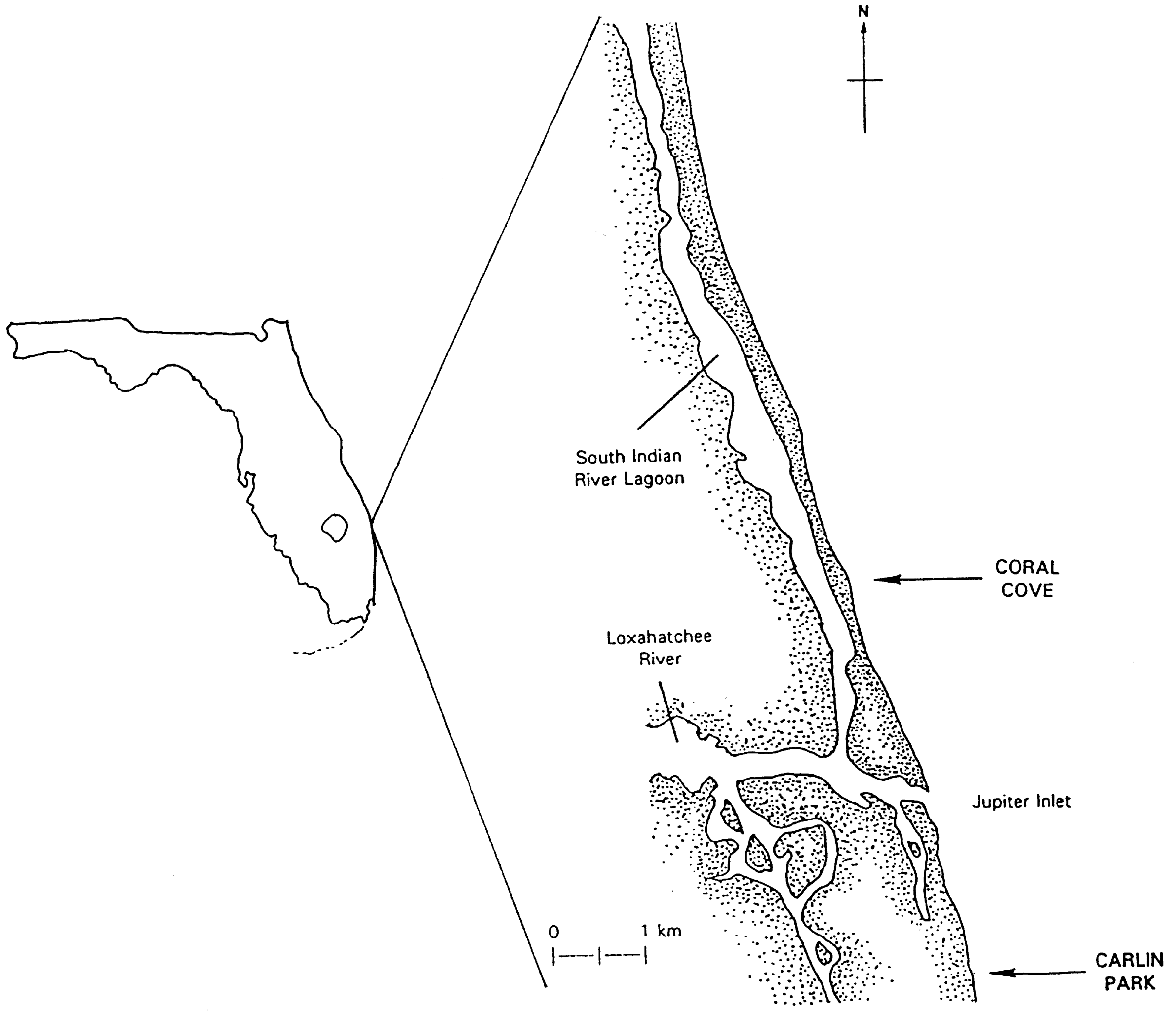

Figure 1

Primary study sites for fish surveys of nearshore hardbottom habitats at Jupiter, Florida (26°56'N, 80°04'W).

three undisturbed hardbottom sites were characterized. Second, abundances of different life stages were compared to assess the potential nursery value of nearshore hardbottom habitat. Third, effects of dredge burial on numbers of individuals and species were compared between a site subjected to burial and a control site.

Methods

Study areas

Fish abundances were quantitatively surveyed on two nearshore hardbottom sites approximately 2 km north (Coral Cove) and 2 km south (Carlin Park) of Jupiter Inlet, Florida (26°56'N, 80°04'W) from April 1994 through June 1996 (Fig. 1). Sampling at both sites extended approximately 100 m offshore to a depth of 4 m. Nearshore hardbottom of similar depth and structure at Ocean Ridge, immediately south of the South Lake Worth Inlet (26°31'N, 80°02'W) was also surveyed for comparative purposes during the summer of 1995.

Weathered limestone outcroppings were common between depths of 0 and 4 m at all sites. These structures have a variety of names (e.g. *Anastasia* formation outcroppings, coquina reefs, worm reefs) but are referred to by their most common name, “nearshore hardbottom,” in the present study. In some areas, the hardbottom extended 1.75 m above the bottom and was highly convoluted. Shoreward portions of the hardbottom were exposed at low tide. Epibiota consisted of a variety of invertebrates and algae. The most widespread encrusting organism was the reef-building sabellariid worm *Phragmatopoma lapidosa* (=*P. caudata*; Kirtley, 1994), often covering over 50% of the hardbottom at all sites.

A beach restoration project occurred at Carlin Park in March and April of 1995. More than 350,000 m^3 of beach-compatible sediments were excavated by a cutter-head dredge from a site 0.8 km offshore and hydraulically pumped along 1.8 km of shoreline. Bulldozers extended the fill seaward to an estimated width of 60 m. An estimated total of 4.9 to 5.7 ha (12–14 acres) of nearshore hardbottom was buried.[1] Visual surveys of fishes were conducted for 12 months before burial and 15 months after burial at both Carlin Park (the impact site) and Coral Cove (the control site). Little or no hardbottom was observed in fish surveys at Carlin Park after the project.

Survey protocol

During each site visit, three to five transects within two adjacent areas (=6–10 total transects/site) were censused. These 2 × 15 m transects were randomly located at depths ranging from one to four m. Transects were deployed along random compass headings at random distances between successive transects. Random number tables were used prior to site visits to determine the compass headings and distances between transects (based on numbers of fin kicks). All fishes observed within one m of each side of the transect line were identified and tallied by a snorkeler. The survey zone extended from the bottom to the surface and 2 m in front of the observer. Ledges and sand-rock interfaces were examined for fishes. Rocks were not overturned. The proportion of hardbottom to sand was estimated within each transect. An estimated 35% of the area within all transects was sand. Surveys were conducted between 0900 and 1700 and avoided twilight periods. To compare fish abundances at hardbottom and sand areas, identical transect methods were used at nearshore sand plains greater than 50 m from any hardbottom structures.

Monthly visual censusing occurred from April 1994 to June 1996 as permitted by nearshore visibility and sea state. Discharges of turbid water from Jupiter Inlet and wave resuspension of fine sediments sometimes resulted in turbidity levels that precluded sampling. Samples were obtained for all months except October through January when waves and turbidity were typically prohibitive.

In addition to total abundances, early life stages were also enumerated. Fork length was used for size estimation. Following Lindeman (1986; 1997a), life stages of grunts (*Haemulon* and *Anisotremus*) were recorded as follows: newly settled (<2 cm), early juvenile (2–5 cm), juvenile (5–15 cm), and adult (>15 cm). For other families, the same newly settled size range (<2 cm) was used. The early juvenile designation was used only for grunts because of the distinct morphological features of the 2–5 cm size range (Lindeman, 1986). Juvenile and adult stages were based on size and pigment patterns reported in the literature (e.g. Robins and Ray, 1986; Humann, 1994). Species identifications of the newly settled or juvenile stages for certain taxa were limited by very similar morphological features (e.g. scarids, kyphosids, gerreids, haemulids, clupeids). Some early stage identifications were therefore recorded only at the genus or family level. Collections of small schools of newly settled grunts were made with hand nets at both Jupiter sites in 1994 and 1995 to supplement field identifications. All collections were deposited at the Florida Museum of Natural History, University of Florida.

Data analyses

To address the first objective of our study, two complementary multivariate methods were used to spatially and temporally characterize the assemblages at the three sites. The second objective was addressed by univariate testing of the hypothesis that abundances of different life stages would not differ significantly within sites. The third objective was examined with the hypothesis that numbers of individuals and species would not differ significantly between an impact site where allmost all the hardbottom was buried and a control site that was unaffected by the burial. In univariate analyses, data were standardized as the mean number of individuals per transect and as the mean number of species per transect.

Samples were temporally unbalanced owing to the inability to visually sample during portions of the winter. Therefore, to examine the first objective, multivariate ordination and classification (cluster analysis) of a samples-by-taxa matrix for the entire, unpooled data set were used. These analyses were performed on a data set of 31 samples (16 from Coral Cove, 12 from Carlin Park, and 3 from Ocean Ridge) and 61 taxa. Each sample represented a site visit where 6 to 10 transects were censused. Samples from Carlin Park did not include postdredging site visits because these samples contained few or no fishes. The 61 taxa were those remaining from a total of 86 after eliminating taxa occurring only once across all

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[1] Davis, P. 1998. Palm Beach County Department of Environmental Resources Management, 3323 Belvedere Rd., Bldg. 502, W. Palm Beach, FL 33406. Personal commun.

samples. Within each sample, counts for individual taxa were averaged over all transects to provide values for the matrix. These values were log-transformed [$\log_{10}(n+1)$] to prevent abundant taxa from dominating the ordination or classification results.

The transformed matrix was analyzed by correspondence analysis (CA), a method that employs a two-way weighted averaging algorithm to produce simultaneous ordination of sites and taxa (Gauch, 1982; Jongman et al., 1995). These analyses were performed with the program CANOCO (ter Braak, 1988). From the same log-transformed data matrix, normal (samples) and inverse (taxa) resemblance matrices were generated by using the Bray-Curtis dissimilarity index (Bray and Curtis, 1957). Normal and inverse resemblance matrices were clustered separately by the unweighted paired-group method of averaging (UPGMA) (Sneath and Sokal, 1973). All dissimilarity and cluster analyses were computed with NTSYS-pc software (Rohlf, 1997).

To address the second project objective, numbers of life stages per transect were compared within each site. Data were analyzed by using a parametric one-way ANOVA when variances were homogeneous (Bartlett's test). *A posteriori* comparisons of differences among means employed Tukey's HSD test. Variances of numbers of life stages of grunts per transect at the two Jupiter sites remained heterogeneous after $\log_{10}(n+1)$ transformation and a Kruskall-Wallis non parametric, single classification ANOVA was used. Probability was calculated using the χ^2 approximation. Two-sample *t*-tests for unequal variances were used to compare numbers of individuals at hardbottom and natural sand sites. Only hardbottom samples from months when natural sand sites were sampled (March and April 1995) were used for these tests. In all statistical tests, differences were considered significant at $P<0.05$.

The third objective, examining dredging effects at the impact site (Carlin Park) and the control site (Coral Cove), employed a BACIPS (before after control impact paired series) design (Stewart-Oaten et al., 1986; Osenberg and Schmitt, 1996). This approach compares differences in variables between sites over time before and after the impact. The differences in the paired series were examined by two-sample *t*-tests by using the mean number of both individuals and species as the variables (Stewart-Oaten, 1996).

Results

A total of 352 transects was sampled at the two Jupiter sites: 204 at Carlin Park and 148 at Coral Cove. At Carlin Park, 112 transects were sampled before burial and 92 after. At Coral Cove, 58 transects were sampled before the burial of the Carlin Park reef and 90 after. Eight transects were sampled over natural sand habitats at Carlin Park and six at Coral Cove. An additional 36 hardbottom and 6 sand transects were sampled at Ocean Ridge.

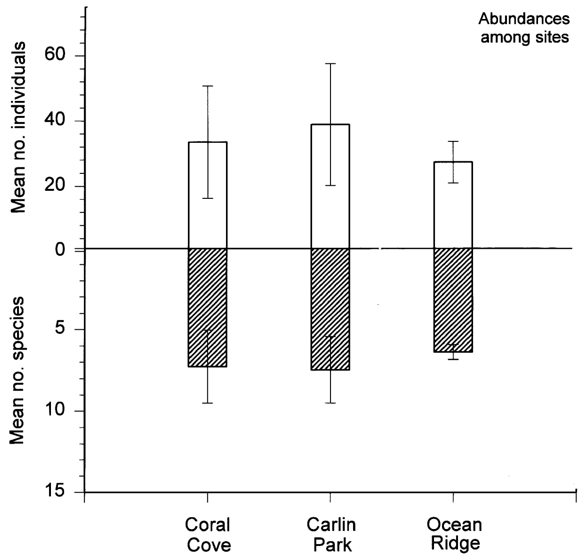

Figure 2

Mean number of individuals and species per transect (with 95% confidence intervals) for all nearshore hardbottom sites. Only predredging data were used for Carlin Park site. Sample sizes: Coral Cove: 148 transects; Carlin Park: 112; Ocean Ridge: 36.

Family and species abundances

Thirty-six families of fishes were censused among the three hardbottom sites. The most speciose family was the grunts and margates (Haemulidae) with 11 species of *Haemulon* and *Anisotremus*. The wrasses, parrotfishes, and damselfishes (Labridae, Scaridae, and Pomacentridae) had seven, six, and five species, respectively. Four species each of jacks (Carangidae), snappers (Lutjanidae), and clinids (Labrisomidae) were recorded. These seven families contained 50% of the total species censused. Eighty-six taxa (77 identified to species) and 10,491 individuals were censused at all sites (Appendix). At Coral Cove, 64 species and 5093 individuals were recorded. At Carlin Park, 53 species and 4438 individuals were recorded. At Ocean Ridge, 48 species and 960 individuals were recorded. Mean numbers of both species and individuals per transect were similar among all sites (Fig. 2).

Table 1

Mean number of individuals/transect and frequency of occurrence for the most abundant three families, genera, and species at all nearshore hardbottom sites. Only predredging data were used for Carlin Park site. CC: Coral Cove (148 transects); CP: Carlin Park (112 transects); OR: Ocean Ridge (36 transects); GM: grand mean.

	Mean number/transect				% frequency occurrence			
	CC	CP	OR	GM	CC	CP	OR	GM
Family								
Haemulidae	15.5	17.4	9.4	15.5	89	90	92	90
Pomacentridae	5.9	7.9	5.7	6.6	81	95	86	87
Sparidae		5.9	3.7	3.9		37	44	38
Labridae	3.2			3.0	65			64
Genus								
Haemulon	9.8	15.3	6.2	11.4	75	80	42	75
Stegastes	3.4	6.1		4.3	72	89		73
Anisotremus	5.7		3.2	4.1	74		39	69
Diplodus		5.8	3.7	3.8		35	36	65
Species								
Haemulon parra	4.4	5.0	3.4	4.5	62	64	33	59
Diplodus argenteus		5.8	3.7	3.8		35	36	36
Stegastes variabilis		5.4		3.7		86		71
Labrisomus nuchipinnis	3.1			2.7	73			69
Abudefduf saxatilis			3.1	2.3	17			31
Anisotremus surinamensis	3.5			2.2			36	43

The three most abundant species were the sailors choice (*Haemulon parra*), silver porgy (*Diplodus argenteus*), and cocoa damselfish (*Stegastes variablis*) with means of 4.5, 3.8, and 3.7 individuals/transect over all sites (Table 1). The most abundant species at Coral Cove, sailors choice, black margate (*Anisotremus surinamensis*), and hairy blenny (*Labrisomus nuchipinnis*), represented 32% of all individuals. Seven of the 15 most abundant species at Coral Cove were grunts. At Carlin Park, silver porgy, cocoa damselfish, and sailors choice represented 41% of all individuals. Eight of the 16 most abundant species were grunts. At Ocean Ridge, the most abundant species were silver porgy, sergeant major (*Abudefduf saxatilis*), and sailors choice. Grunt species ranked first in frequency of occurrence per transect at Coral Cove and Ocean Ridge, and second at Carlin Park (Table 1). Damselfish species ranked first in frequency at Carlin Park and second at the other sites. The most frequently occurring species overall were cocoa damselfish, hairy blenny (*Labrisomus nuchipinnus*), and sailors choice (Table 1).

Normal cluster analysis of samples from all sites resolved three groups that broadly reflected temporal patterns (Fig. 3). No distinct spatial groupings emerged in the normal analysis. Group 1 consisted of 21 samples (eight from Carlin Park, ten from Coral Cove, and three from Ocean Ridge) mostly taken in spring and summer months. Group 2 consisted of 8 samples (four each from Carlin Park and Coral Cove) taken in mid and late summer. Group 3 included the only winter samples (February 1995 and 1996) taken during the project.

Inverse cluster analysis revealed seven groups of taxa (Fig. 4). Group A contained 26 common taxa including the most frequently occurring and abundant species from visual surveys such as sailors choice, cocoa damselfish, hairy blenny, and silver porgy (Table 1). This group characterized the spring-summer group of samples defined by normal group 1. The remaining six groups consisted of taxa that were temporally variable in their abundance and occurrence in the samples. Group B was characterized by species that occurred at lower abundances. Groups F and G were represented by single taxa: *Apogon maculatus* and *Archosargus probatocephalus*, respectively. The latter species was important in defining normal group 3 (Fig. 3).

Ordination of samples projected on CA axes 1 and 2 produced a pattern that generally agreed with the normal cluster analysis (Fig. 5A). The eigenvalue for CA axis 1 was 0.218 and accounted for 16.9% of the variation in the data set, whereas the eigenvalue for CA axis 2 was 0.124 and accounted for 9.7% of the variation in the data set. Samples from August and September at Coral Cove and Carlin Park separated from all other samples along CA axis 1. In general, samples were not spread widely along CA axis 2; however, two samples, May 1995 at Ocean Ridge and February 1995 at Carlin Park, did separate from the other sites.

The ordination of taxa on CA axes 1 and 2 showed how the taxa were distributed in relation to the hardbottom samples along these same axes (Fig. 5B). The most common species (e.g. Table 1) clustered near the origin of the ordination. Taxa with high scores along CA axis 1 included infrequently occurring species such as *Halichoeres poeyi*, *Haemulon aurolineatum*, *Mulloidichthys martinicus*, and *Caranx ruber*. Low scores on CA axis 1 were *Echidna catenata*, *Acanthurus chirurgus*, *Chaetodon ocellatus*, and Sciaenidae sp. Species with high scores on axis 2 were *Sparisoma aurofrenatum*, *Chaetodon ocellatus*, and *Sparisoma viride*. These were most abundant at Ocean Ridge in May 1995 and were responsible for the separation of this sample from all others along CA axis 2.

In comparisons of hardbottom and natural sand, 20 transects over natural sand plains recorded only four taxa. The clupeid, *Harengula jaguana*, was most abundant (18 juveniles in two schools total). An unidentified *Eucinostomus* species, *Gerres cinereus*, and *Caranx bartholomaei* were also recorded (four, one, and one individuals, respectively). Hardbottom habitats typically had over thirty times the individuals per transect as natural sand habitats. Two-sample *t*-tests comparing hardbottom with sand habitats rejected the hypothesis of no differences in mean numbers of individuals per transect ($P<0.005$).

Life-stage abundances

At all sites, juveniles were the most abundant life stage among the top ten species (Table 2). At the two intensively sampled sites in Jupiter, the numbers of juveniles of all species pooled were significantly greater than any other life stage (ANOVA, $P<0.01$, Tukey's HSD). There were no significant differences in abundances among newly settled, early juvenile, and adult stages (Tukey's HSD). At both Jupiter sites, at least 80% of the individuals were early life stages (pooled newly settled, early juvenile, and juvenile stages)(Fig. 6). Abundances of newly settled and early juvenile stages at Ocean Ridge were similar to the Jupiter sites (Table 2), although numbers of juveniles and adults were lower. Newly settled stages of over 20 species were recorded on nearshore hardbottom structures among the three sites.

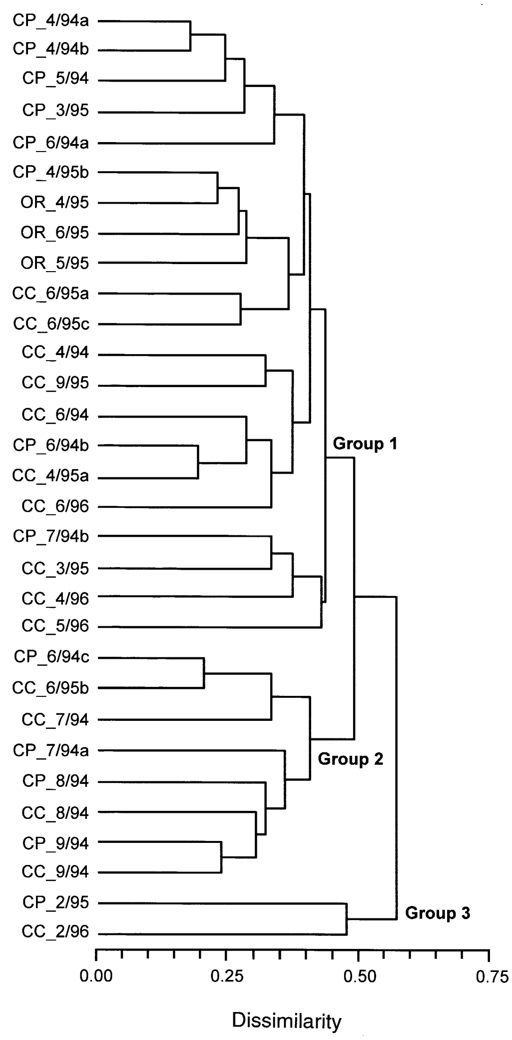

Figure 3

Clustering of visual census samples (sites and times) by UPGMA analysis of a normal Bray-Curtis dissimilarity matrix. CC: Coral Cove; CP: Carlin Park; OR: Ocean Ridge.

Eight of the ten most abundant taxa by site were represented primarily by early stages (Table 2). Cocoa damselfish and hairy blenny occurred most abundantly as adults. Adults of at least five of the top ten species occurred as residents, not transients. These included sergeant major, hairy blenny, cocoa damselfish, silver porgy, and black margate. Adults of a variety of less common species occurred but were often less abundant than early life history stages. Newly settled and juvenile stages often appeared to display more site-fidelity with hardbottom structure than did adults.

Six species of grunts (four *Haemulon* and two *Anisotremus*) and two species of damselfishes (*Stegastes*

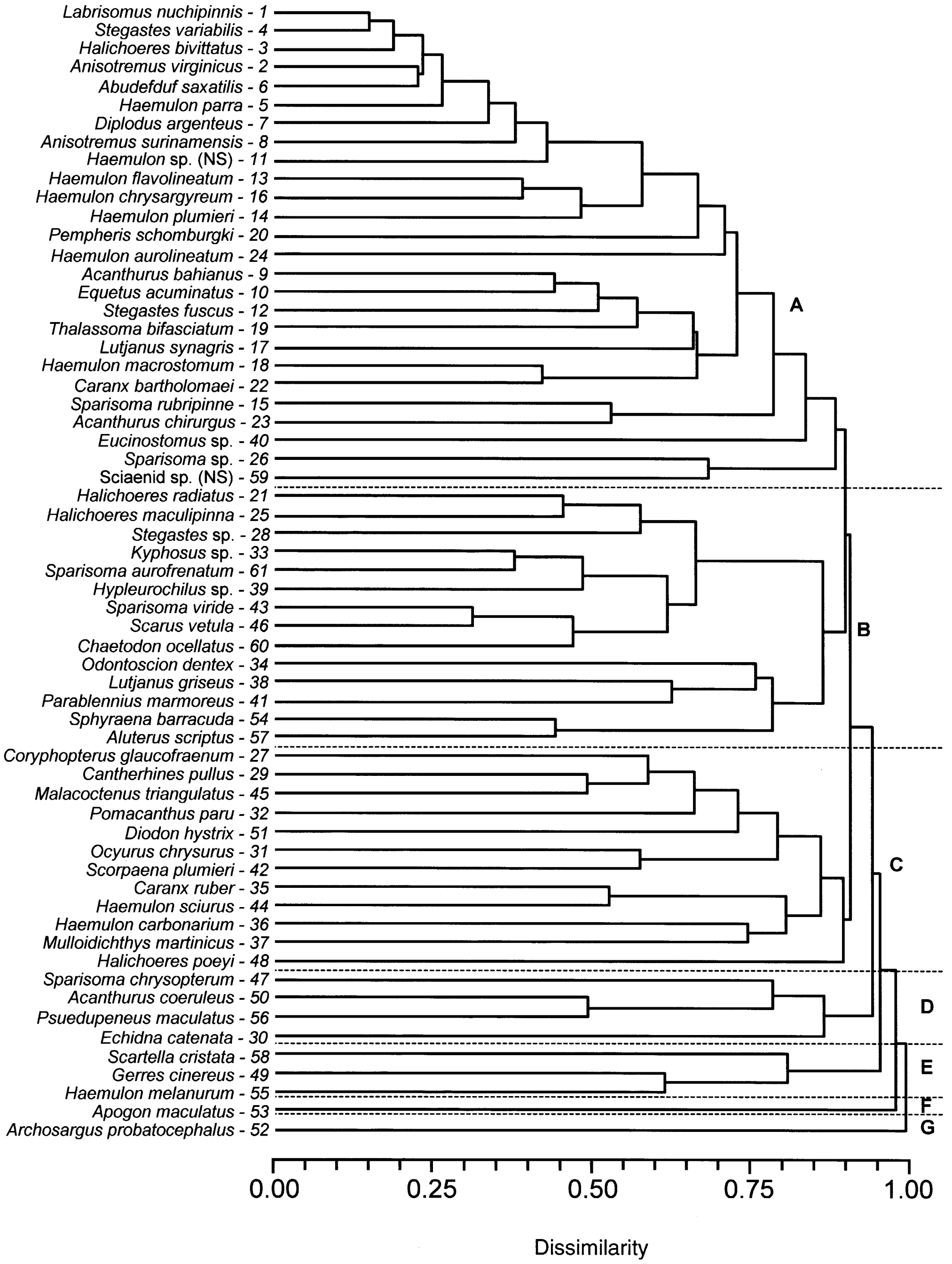

Figure 4

Clustering of fish taxa co-occurrence at three nearshore hardbottom sites by UPGMA analysis of an inverse Bray-Curtis dissimilarity matrix. Numeric codes used in correspondence analysis are next to each name. NS: Newly Settled. Dashed lines delineate groups A–G.

and *Abudefduf*) ranked within the ten most abundant species from all three sites (Table 2). Relative abundances of the life stages of all grunts censused at the Jupiter sites are shown in Figure 7. Early juvenile stages of the most abundant species, sailors choice, were significantly more abundant than any other life stage at each of the three sites (Kruskal-Wallis ANOVA, $P<.001$, and *a posteriori* pairwise comparisons). Adult sailors choice were significantly lower in abundance than juvenile stages (Kruskal-Wallis ANOVA, $P<0.001$). Black margate and porkfish, *Anisotremus virginicus*, ranked second and

Table 2

Mean number of individuals/transect by life stage for the ten most abundant taxa at each of three sites. NS: Newly Settled; EJ: Early Juvenile (for haemulids only); J: Juveniles; A: Adults. Only predredging data were used for Carlin Park site. na = not available.

	Mean number individuals/transect											
	Coral Cove				Carlin Park				Ocean Ridge			
	148 transects				112 transects				36 transects			
Species	NS	EJ	J	A	NS	EJ	J	A	NS	EJ	J	A
Haemulon parra	0.7	2.7	0.8	0.2	0.7	3.8	0.8	0.1	0.4	2.6	0.4	<0.1
Diplodus argenteus	0.3	na	1.7	0.3	1.6	na	4.1	0.1	0.7	na	2.8	0.2
Stegastes variabilis	0.2	na	1.4	1.3	0.4	na	1.4	3.5	0.4	na	0.9	0.6
Halichoeres bivittatus	0.2	na	2.3	0.5	0.3	na	2.1	0.5	0.3	na	1.1	<0.1
Labrisomus nuchipinnis	0	na	0.8	2.3	0	na	0.3	2.0	<0.1	na	0.5	1.8
Abudefduf saxatilis	0.4	na	2.0	0.1	0.3	na	1.1	0.4	1.3	na	1.7	0.1
Anisotremus surinamensis	0.4	1.9	1.1	0.1	0.1	0.3	0.3	0	0.5	0.6	0.4	0
Anisotremus virginicus	0.9	0.7	0.4	0.2	0.3	0.9	0.3	<0.1	0.9	0.2	0.4	0.3
Haemulon aurolineatum	0	0.7	1.0	0	0	0.1	2.5	0	0	0	0	0
Haemulon sp.	1.8	<0.1	0	0	2.1	<0.1	0	0	0.9	0	0	0
Haemulon flavolineatum	<0.1	0.6	0.3	<0.1	0	0.9	1.0	<0.1	0	1.1	0.1	0
Haemulon chrysargyreum	0	<0.1	0.3	0	<0.1	0.3	1.7	0	0	0	0	0
Total means of life stages per site	4.9	6.6	12	5.0	6.3	6.3	15.5	6.6	5.0	5.4	7.4	3.0

third in overall abundance among grunts and were represented by all life stages (Fig. 7). Tomtate, *Haemulon aurolineatum*, ranked fourth on the basis of large but infrequent influxes of early stages. Outside of these pulses, tomtate was not an abundant or frequently occurring species at any site during any life stage.

Some newly settled grunts could not be positively identified during visual surveys and were pooled as *Haemulon* sp. (newly settled larvae of *Anisotremus* are distinctive, Lindeman, 1997a). This group contained epibenthic larvae of several species and ranked tenth in abundance among all taxa (Table 2) and fifth among haemulids (Fig. 7). The largest component of these unidentified schools was probably sailors choice. This assumption is based on 1) the greater relative abundances of sailors choice early juveniles at all sites; 2) the close proximity of sailors choice early juveniles to these newly settled *Haemulon* sp.; and 3) collections of several newly settled *Haemulon* sp. schools most commonly contained sailors choice upon microscopic examination.

Early stages of commercially valuable species occurred infrequently during the surveys, although recreationally important species were common. The most abundant commercial family at the nearshore hardbottom sites was the Lutjanidae (snappers). Four snapper species, totaling 58 individuals, were recorded at all sites. Thirty-eight of these were lane snapper, *Lutjanus synagris*. Thirty-three of these were juveniles, the majority less than five cm. Five newly settled individuals (<2 cm) were also recorded. Ten yellowtail snapper, *Ocyurus chrysurus*, were recorded, nine small juveniles and one newly settled individual. Unlike grunts, newly settled and small juvenile snappers were not gregarious, occurring individually or in pairs near interfaces of hardbottom structure and sand. Gray snapper, *Lutjanus griseus*, and schoolmaster, *Lutjanus apodus*, occurred only as older juveniles or adults and in low numbers (eight and two individuals, respectively).

Comparisons of interannual and seasonal patterns of life stage abundances were limited by temporally unbalanced sampling. Wind and wave conditions from September through February made collection of nearshore visual data in fall and winter erratic or impossible. Several hurricanes during July and August of 1995 produced wave and turbidity conditions that interrupted summer sampling as well. Other phenomena, including high winds and discharges of turbid water from the Jupiter Inlet, also precluded sampling for extended intervals. Nonetheless, samples were obtained from Coral Cove (the control site) for three consecutive years for the months of April and June. Comparisons of both numbers of species and numbers of individuals per transect for April among 1994–96 revealed no significant interannual differences (ANOVA, $P=0.34$; ANOVA, $P=0.21$). Identical comparisons for June among the same three-year period revealed no differences among mean numbers of individuals (ANOVA, $P=0.06$), but significant differences among numbers of species (ANOVA, $P<0.05$). Pairwise comparisons using Tukey's HSD showed that Coral Cove in June 1995 had significantly more species than in June 1996 (mean species numbers: 8.7 versus 5.3).

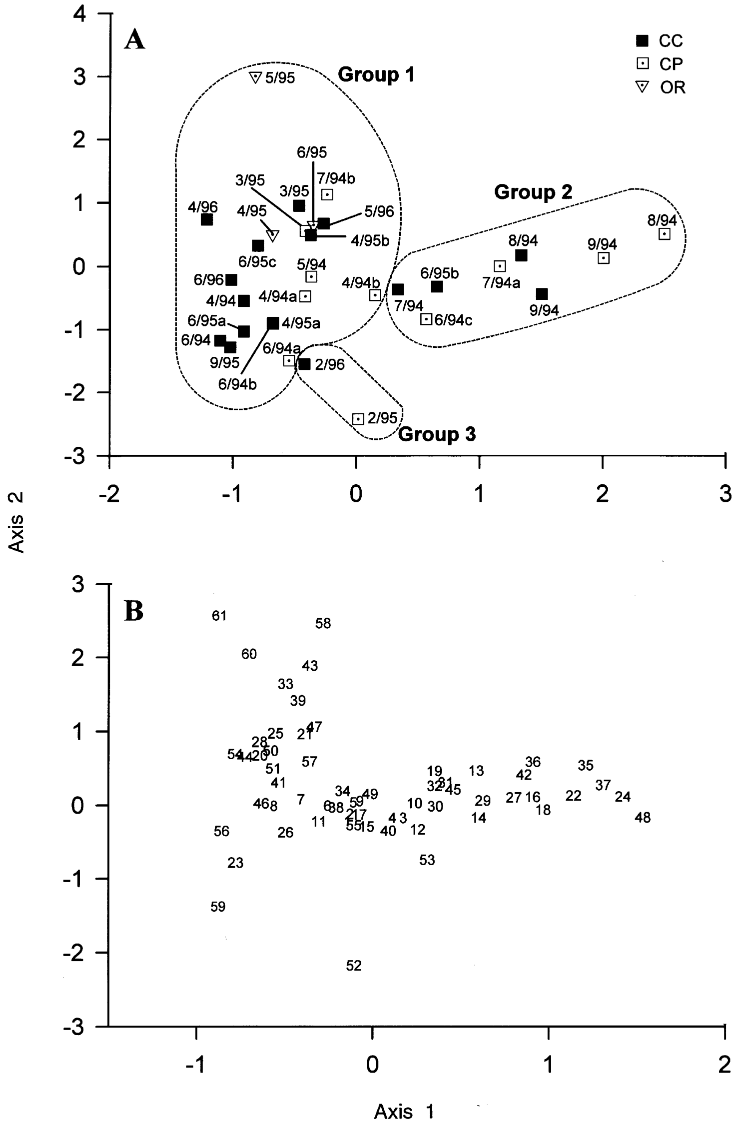

Figure 5

(A) Ordination of sample scores on axes 1 and 2 from correspondence analysis of a samples by taxa matrix of census data from Coral Cove (CC), Carlin Park (CP), and Ocean Ridge (OR). Groups 1–3 from Figure 3. (**B**) Ordination of taxa scores from the same correspondence analysis. Numeric codes for taxa are given in Figure 4.

Seasonal occurrence of only newly settled stages was examined at Coral Cove (Fig. 8). The timing and abundance of species occurrences suggested seasonal variations with peaks of newly settled stages in late spring and early summer. Sizes and numbers of individuals typically increased as summer progressed. Abundances of early stages for most species appeared to be low in February and March prior to peak spawning activity for many species (García-Cagide et al., 1994). However, difficulties in the collection of visual surveys constrained the examination of fall and winter patterns.

Ichthyofaunal characteristics after habitat burial

Prior to habitat burial, fish assemblages at the two Jupiter sites were similar in species composition and relative abundance (Figs. 2, 3, and 5A). Pre- and postburial numbers of individuals and species at the control and impact sites are plotted in Figure 9. The hypotheses of no differences in total numbers of individuals and species before and after dredge burial of hardbottom were both rejected ($P<0.001$) in two sample t-tests for equal variances following a BACIPS design (Stewart-Oaten et al., 1986; Osenberg and Schmitt, 1996).

No fishes or exposed hardbottom were recorded in the first postdredging surveys at Carlin Park (13 April 1995). Several hardbottom outcroppings (1 m high by 3 m wide), parallel to the shore, were exposed at a depth of 1.5 to 2.5 m at the site during the second postdredging surveys on 24 April. Two of ten transects crossed narrow outcrops with dense schools of newly settled stages of three grunt species and one drum species (Sciaenidae). Before burial of the reef by extension of the beach width by approximately 60 m, such outcrops were deeper and further offshore than the original hardbottom sampling area. Small outcrops were still present in May and were occupied in two of ten transects by three species of grunts and one damselfish (Fig. 9). Schools of newly settled stages predominated. Such outcrops were not encountered during the 20 surveys in June, and no fishes were present with the exception of several round scad, *Decapterus punctatus*. Ten

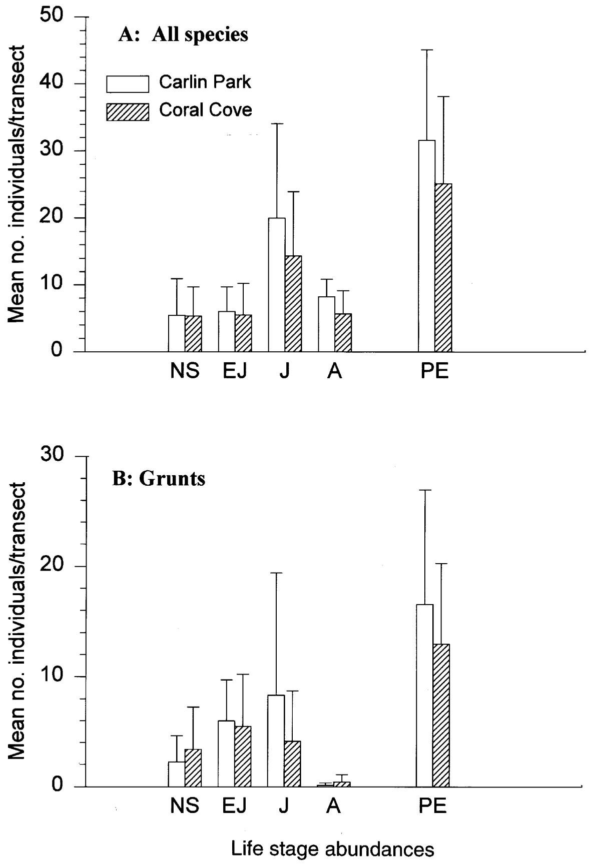

Figure 6

Abundances of different life history stages at the Jupiter hardbottom sites (with 95% confidence intervals). A: All species pooled. B: Pooled grunt species only. Only predredging data were used for Carlin Park site. NS: Newly Settled; EJ: Early Juvenile (for grunts only); J: Juveniles; A: Adults; PE: Pooled Early Stages (=NS+EJ+J).

surveys in September 1995 recorded no exposed outcrops or fishes. During the following winter, erosion occurred and the width of the new beach was reduced. Some outcrops were re-exposed by the loss of dredgefill. However, wind and waves prohibited visual sampling during this period. Surveys in February, April, and May of 1996 (22 transects total) recorded no species (Fig. 9).

Discussion

Fish assemblages of nearshore hardbottom

The diversity of fishes utilizing nearshore hardbottom habitats of mainland Florida has not been quantified. Qualitative studies by ichthyologists experienced with the substantial taxonomic problems

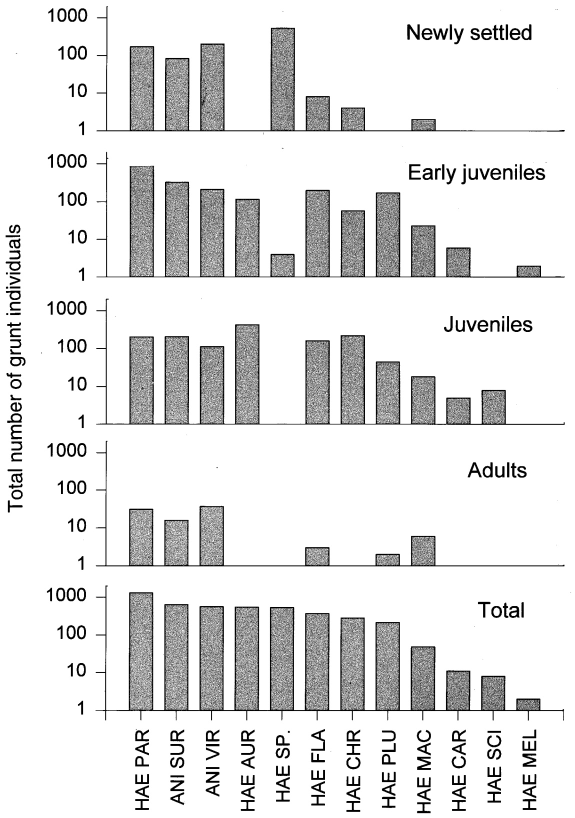

Figure 7

Comparative abundances of grunts among 12 taxa and 4 life history stages. Data pooled from all Coral Cove surveys and predredging Carlin Park surveys (260 transects total). Species represented by abbreviated genus and species names.

within these diverse, largely juvenile assemblages are also lacking. Three studies have included sections on nearshore hardbottom fishes as part of larger project goals. Gilmore (1977) listed 105 species in association with "surf zone reefs" at depths less than two m. Two additional species were added in later papers (Gilmore et al., 1983; Gilmore, 1992). Using visual surveys, Vare (1991) recorded 118 species from nearshore hardbottom sites in Palm Beach County. Futch and Dwinell (1977) included a list of 34 species obtained from several ichthyocide collections on "nearshore reefs." Including species from these prior studies, 192 species have now been recorded in association with nearshore hardbottom habitats of mainland southeast Florida (Table 3.3 in Lindeman, 1997a). Numbers of labrisomid, blenniid, gobiid, and apogonid species may be underestimated owing to their small size or cryptic behaviors. Other hardbottom habitats of the southeast United States occur in areas with substantially different physiographic regimes (Sedberry and Van Dolah, 1984; Chiappone and Sullivan, 1994) and may show differing patterns of fish diversity.

Spatial and temporal attributes of fish assemblages at the three sites in the present study were examined by using ordination and cluster analysis. Visual census samples collected from March through July were similar in species composition and relative abundance among sites (Fig. 3). This finding is in agreement with the similar plots of individual and species abundances among sites (Fig. 2). The relative homogeneity of these samples was further reflected in the co-occurrence of many taxa including haemulids (*Haemulon parra, H. flavolineatum, H. chrysargyreum, Anisotremus virginicus, A. surinamensis*), pomacentrids (*Stegastes variabilis, Abudefduf saxatilis*), labrisomids (*Labrisomus nuchipinnis*), sparids (*Diplodus holbrooki*), labrids (*Halichoeres bivittatus, Thalassoma bifasciatum*) and scarids (*Sparisoma rubripinne*) (Fig. 4). With the exception of *L. nuchipinnis* and *S. variabilis*, most taxa occurred as early life stages.

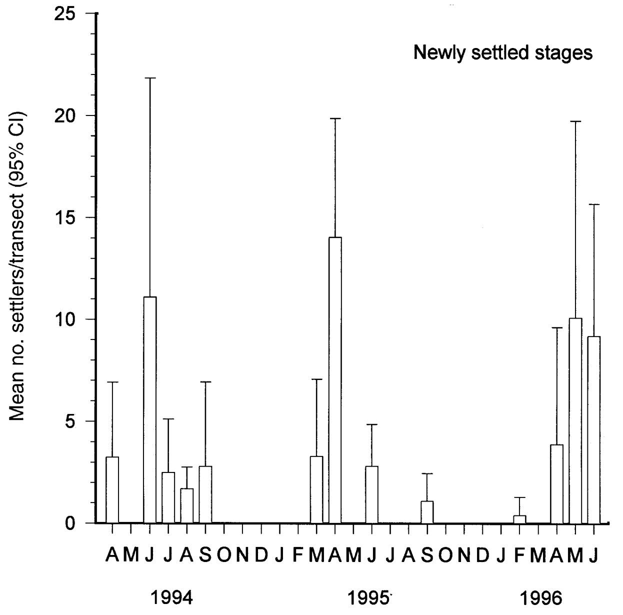

Figure 8

Mean number of newly settled individuals per transect for all species pooled at Coral Cove, 1994-1996 (*n* =148 transects).

Samples from late summer (August and September) were distinct from the spring and early summer in both cluster analysis and ordination (group 2, Figs. 3 and 5). The only two samples taken in winter (February) differed from all other samples in the analyses (group 3, Figs. 3 and 5). These patterns suggest that some seasonality in assemblage structure existed. This may reflect late spring and summer peaks in larval settlement in contrast to reduced winter settlement and, possibly, influxes of older juveniles from inshore lagoonal habitats. Substantial numbers of many species still settled in late summer but were possibly subject to higher predation from older individuals that settled earlier in the year. Various physical disturbances (e.g. winter cold fronts, summer hurricanes) and biological phenomena (variation in larval recruitment) affect the composition of fish assemblages of nearshore hardbottom. The turbidity generated by physical disturbances constrains the visual surveys needed to assess their immediate effects.

Nursery habitats and nearshore hardbottom

With increasing human modifications of coastal areas, detailed knowledge of habitat usage is a key component of informed fishery and coastal land management. Identification of essential habitats includes the evaluation of spatial distributions of structural habitats across the shelf and habitat requirements of key taxa. Several lines of evidence suggest that nearshore hardbottom habitats along the mainland coast of east Florida can serve as nursery areas for many coastal fish species. Over 80% of the individuals at all sites were early life stages. Eight of the top ten species were consistently represented by early stages. Use of hardbottom habitats was recorded for newly settled stages of more than 20 species. In addition, other natural habitats with substantial vertical relief were absent from the shallow physiographic regimes where nearshore hardbottom occurred.

Although suggestive of nursery value, these lines of evidence need to be viewed in the appropriate context. High abundances of early life stages compared with adults do not guarantee that a habitat is a valuable nursery. High mortality rates in many reef fish populations (Sale, 1980; Shulman and Ogden, 1987; Richards and Lindeman, 1987; Jones, 1991) suggest that early stages will typically be more abundant than adults. If spatial distributions of all life stages are homogeneous, all habitats will have more early stages than adults. However, the abundances of early stages on nearshore reefs probably reflect more than just larger numbers of homogeneously distributed recruits. Newly settled stages of eight of twelve species of grunts and eight of nine species of snappers of the southeast mainland Florida shelf have been recorded primarily in depths less than ten m (Lindeman et al., 1998). Adults of most species are typically uncommon or absent in shallow habitats. There is considerable evidence for cross-shelf habitat segregation among life stages of many grunt and snapper species from other regions as well; early demersal stages appear to most commonly use shallow habitats (Starck, 1970; Dennis, 1992). Similar ontogenetic differences in distribution and abundance exist for many other taxa that utilize nearshore hardbottom habitats.

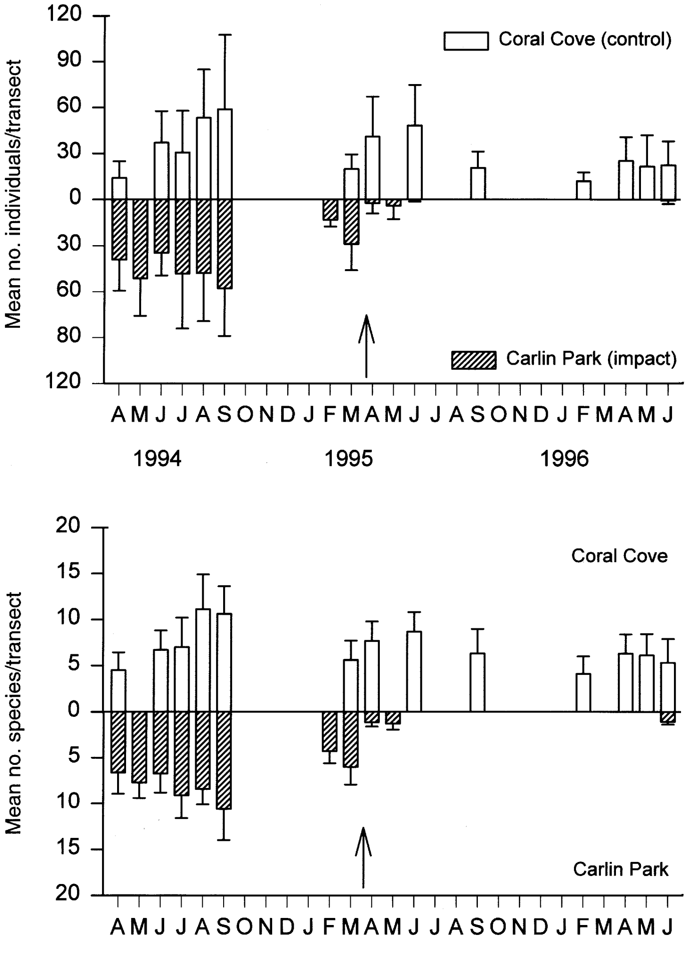

Figure 9

Mean numbers of individuals and species at control and impact sites in Jupiter, FL. Arrows indicate timing of dredge burial of hardbottom reef.

Determining if the availability of habitat structure limits survival of early stages is important in assessing nursery value. Absences of habitat structure can result in increased predation or lowered growth (Hixon, 1991). In southeast mainland Florida, many natural nearshore marine habitats outside of coastal lagoons and between 25°30'N and 26°20'N (Dade and Broward Counties) are sand plains lacking hardbottom and substantial three-dimensional structure (ACOE, 1996). Although large stretches of nearshore hardbottom exist between 26°20'N and 27°50'N (Palm Beach, Martin, St. Lucie, and Indian River Counties) these habitats are often separated by kilometers of sand plains. There are no other natural habitats in the same nearshore areas that can support equivalent abundances of early life stages. These conditions could promote a demographic bottleneck that limits local adult populations owing to limited habitat availability for early stages.

Despite their shallow depth, nearshore hardbottom reefs are positioned within current and tide regimes that can support considerable larval abundances. The occurrence of presettlement larvae in these areas is reflected by the abundances of newly settled stages in the present study and larvae in nearshore zones of Gulf of Mexico barrier islands (Ruple, 1984; Ross et al., 1987). Newly settled individuals were not recorded during any surveys of pure sand habitats in the present study. However, the presence of nearshore hardbottom promoted substantial colonization of shallow outcrops by larvae of many species, including haemulids, lutjanids, sparids, labrids, gerreids, sciaenids, and scarids. Ecotones with high vertical relief (e.g. hardbottom-sand interfaces near ledges) sometimes had large aggregations of newly settled stages of these taxa. However, microhabitat-scale distributions of fishes on nearshore hardbottom remain unquantified.

Use of nearshore hardbottom reefs as nurseries may be bidirectional across the shelf. Both inshore and offshore migrations during differing ontogenetic stages can be facilitated by habitats positioned centrally on the shelf. Nearshore hardbottom may serve a primary nursery role for incoming early life stages that would undergo increased predation mortality without shelter. Nearshore hardbottom may also serve as secondary nursery habitat for juveniles that emigrate out of inlets towards offshore reefs. This pattern is seen in gray snapper and bluestriped grunt which often settle inside inlets and primarily use nearshore hardbottom as older juveniles. In addition, some species use these structures as resident nurseries, settling, growing-out, and maturing sexually as permanent residents (e. g. pomacentrids, labrisomids). A secondary nursery role may also result from increased growth because of higher food availabilities in structure-rich environments. The intermediate cross-shelf positioning and other attributes reviewed above suggest nearshore hardbottom represents essential fish habitat for many species following NOAA (1996). Bidirectional use of nursery habitats positioned between inshore grassbeds and offshore reefs requires further study.

From abundance patterns of early life stages and the absence of any nearby natural habitats with high vertical relief, nearshore hardbottom of southeast mainland Florida was estimated to have nursery value for 34 species (Appendix). Empirical correlation of variation in early survival with adult population size is an important but rarely achieved component of nursery area evaluation. Combining experimental studies of habitat requirements with broad field surveys can aid in connecting organism-scale attributes with population-scale patterns (Serafy et al., 1997). Early demersal stages of several of the most representative taxa of nearshore hardbottom (e.g. grunt and damselfish species) can be collected and manipulated in the field and laboratory with relative ease (Lindeman, 1986; 1997a). These taxa may serve as useful models for nursery habitat studies that experimentally assess habitat requirements.

Effects of dredge-and-fill activities on ichthyofauna

Burial of the nearshore hardbottom habitat at Carlin Park with dredged sand significantly lowered the abundances of both species and individuals (Fig. 9). Before burial, 54 species were recorded, with mean abundances of 38 individuals and 7.2 species per transect (n=112 transects). After burial, eight species were recorded with mean abundances of less than one individual and species per transect (n=92 transects). No quantitative studies on the effects of nearshore hardbottom burial on fishes are available in the peer-reviewed literature for comparison.

The final supplemental environmental impact statement (EIS) for the Carlin project (Palm Beach Co. Dep. Environ. Resources Management, 1994) summarized several agency and contractor surveys between 1985 and 1990 at Carlin Park. Ten to forty-eight fish species were recorded from qualitative surveys of the hardbottom. Statements regarding the habitat value of nearshore reefs and dredging effects in the Carlin Park EIS emphasized the variable nature of reef exposure and forecast that fish impacts would be minimal and temporary. Primary impacts predicted for fishes were 1) short-term displacement during construction; and 2) temporary loss of food sources. The EIS also emphasized that impacts would be reduced by several features of the project design and nearshore environment. These features included the following: 1) the fishery value of impacted species was low; 2) some amount of hardbottom would remain or would be constructed for mitigation if needed; and 3) construction of the project would take place when fish populations were at their lowest. No mention of direct or indirect mortality upon fishes was made.

The biological assumptions within this EIS are similar to those found in related documents (e.g. ACOE, 1996). For the following reasons, it is suggested that some of these assumptions may be tenuous. The majority of individuals displaced by hardbottom burial in southeast Florida are early stages of economically and ecologically valuable species (Appendix; Figure 9). Early demersal life stages are particularly vulnerable to predators (e.g. Shulman and Ogden, 1987). Displacement was permanent for most individuals because almost all prior habitat was eliminated for at least 15 months (the postburial duration of the present study). Because of behavioral and morphological constraints on flight responses, high mortalities are probably unavoidable for many cryptic species, newly settled life stages, or other site-associated taxa subjected to direct habitat burial (Table 4.10 in Lindeman, 1997a). Whether a fish population is seasonally low at the time a project begins is insignificant if dredging will bury the habitat immediately before the peak period of larval settlement,[2] as in the Carlin Park project. In addition, loss of reef-associated food sources was probably substantial over this period.

No substantial habitat structure was present within at least 0.8 km of the Carlin Park reef during its burial. The closest natural structure was eastward at depths of at least 10 m. These deeper midshelf habitats may be utilized by relatively few grunt and snapper species during the newly settled and early juvenile stages. To the south, no substantial hardbottom was present for at least 4 km. To the north, the jetties of the Jupiter Inlet were approximately 2 km away. However, fishes in a northerly flight response had to negotiate a water column with zero visibility because dredge fill was dumped north-to-south. Any early stages of fish reaching the jetties would probably encounter high predation from older piscivores utilizing the large cavities among the armor-stone boulders of the artificially deepened jetty area (Lindeman, 1997a).

A postburial mitigation project using shallow artificial reefs of limestone boulders was proposed in the

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[2] Hackney, C. T., M. H. Posey, and S. W. Ross. 1996. Summary and recommendations. *In* C. T. Hackney, M. H. Posey, S. W. Ross and A. R. Norris (eds.), A review and synthesis of data on surf zone fishes and invertebrates in the south Atlantic Bight and the potential impacts from beach renourishment, p. 108–111. Rep. to U. S. Army Corps of Engineers, Wilmington District, Wilmington, NC.

Carlin Park EIS. In the summer of 1998, three years after the burial, construction of approximately 1.6 ha of mitigation reefs began. If constructed before burial and at similar depths, mitigation reefs may have provided a refuge for a sizeable fraction of the thousands of displaced fishes during the burial of the hardbottom reef, as well as thousands of subsequent new recruits. Even with prompt construction of artificial reefs, many factors can limit the net production of biomass (Grossman et al., 1997). Some buried outcroppings were uncovered because of erosion of the project fill. However, structural support for two years of larval recruitment, shelter from post-settlement predation, and food for growth, were probably eliminated at the hardbottom burial site.

Nearshore hardbottom areas, such as Carlin Park, can be exposed to extended periods of wave energy and turbidity, particularly during winter months. However, conditions in winter do not dilute the potential significance of artificial burial during the spring and summer months. These are the periods of peak usage of hardbottom habitats by newly settled and juvenile stages of fishes. In the absence of dredging, nearshore areas typically show high reef exposures and reductions in physiological stressors during the spring-summer recruitment window. Elimination of this recruitment window by habitat burial for one or more years, regardless of winter dynamics, may substantially degrade the value of the primary natural nursery habitats along the windward shorelines of Florida's east coast. The above reasons suggest a risk-averse approach to hardbottom burial, as previously suggested for invertebrate fauna (Nelson, 1989).

The cumulative effects on fishes of repeated burial of nearshore habitats and other byproducts of these projects remain unknown. Cascading disturbances with ecosystem-scale effects can be hypothesized for a number of cumulative anthropogenic modifications in south Florida (e.g. Butler et al., 1995; Ault et al., 1998). Habitats affected by dredging or filling can show effects over temporal and spatial scales that are rarely considered (Vestal and Rieser, 1995; Lindeman, 1997b). For example, chronically elevated turbidities could lead to declines in primary production for frequently dredged areas of the southeast Florida shelf. Conclusive statements on the cumulative effects of large-scale dredging upon fishes will ultimately depend on the correlation of variations in early survival with adult population sizes, a rarely achieved task, even when effects may be substantial (Osenberg and Schmitt, 1996). However, the current absence of basic information on both short- and long-term scales can also be treated as an opportunity. Large dredge projects affecting midshelf and nearshore habitats will continue along the southeast Florida shelf at one- or two-year intervals. Basic questions on dredge-and-fill effects upon habitat use, predation, and growth, await study within a diverse assemblage of nearshore fishes.

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Appendix

Total abundances of all species visually surveyed at three nearshore hardbottom sites, southeast Florida. Only predredging data were used for Carlin Park site. * = hypothesized to use nearshore hardbottom as a nursery habitat (see discussion).

Rank	Common name	Species	Coral Cove	Carlin Park	Ocean Ridge	Total
1	Sailors choice	*Haemulon parra**	649	555	122	1326
2	Silver porgy	*Diplodus argenteus**	344	647	132	1123
3	Cocoa damselfish	*Stegastes variabilis**	420	600	66	1086
4	Slippery dick	*Halichoeres bivittatus**	439	327	50	816
5	Hairy blenny	*Labrisomus nuchipinnis**	463	262	81	806
6	Sergeant major	*Abudefduf saxatilis**	367	199	112	678
7	Black margate	*Anisotremus surinamensis**	513	68	55	636
8	Porkfish	*Anisotremus virginicus**	331	174	61	566
9	Tomtate	*Haemulon aurolineatum**	245	295	8	548
10	Grunt sp.	*Haemulon* sp.*	266	233	34	533
11	French grunt	*Haemulon flavolineatum**	134	210	43	387
12	Smallmouth grunt	*Haemulon chrysargyreum**	60	222	10	292
13	White grunt	*Haemulon plumieri**	70	150	1	221
14	Glassy sweeper	*Pempheris schomburgki**	153	21	32	206
15	Dusky damselfish	*Stegastes fuscus**	75	83	9	167
16	High-hat	*Equetus acuminatus**	54	59	13	126
17	Ocean surgeon	*Acanthurus bahianus**	51	12	17	80
18	Doctorfish	*Acanthurus chirurgus**	63	2	7	72
19	Redfin parrotfish	*Sparisoma rubripinne**	52	14	2	68
20	Mojarra sp.	*Eucinostomus* sp.	37	20	2	59
21	Spanish grunt	*Haemulon macrostomum**	14	35	1	50
21	Yellow jack	*Caranx bartholomaei*	9	41	0	50
23	Yellow goatfish	*Mulloidichthys martinicus*	34	8	0	42
24	Lane snapper	*Lutjanus synagris**	23	12	3	38
25	Bluehead wrasse	*Thalassoma bifasciatum*	22	7	7	36
25	Croaker sp.	Sciaenid sp.	22	14	0	36
27	Redtail parrotfish	*Sparisoma chrysopterum**	16	14	3	33
28	Damselfish sp.	*Stegastes* sp.	9	5	18	32
29	Parrotfish sp.	*Sparisoma* sp.	14	14	0	28
30	Reef croaker	*Odontoscion dentex**	13	3	8	24
30	Bar jack	*Caranx ruber*	2	20	2	24
32	Chub sp.	*Kyphosus* sp.	10	4	9	23
33	Bridled goby	*Coryphopterus glaucofraenum*	2	19	1	22
34	Clown wrasse	*Halichoeres maculipinna**	8	5	4	17
35	Anchovy sp.	Engraulid sp.	15	0	0	15
36	Puddingwife	*Halichoeres radiatus**	4	6	4	14
36	Orangespotted filefish	*Cantherhines pullus*	2	11	1	14
38	French angelfish	*Pomacanthus paru**	5	5	3	13
39	Seaweed blenny	*Parablennius marmoreus*	2	5	5	12
40	Caesar grunt	*Haemulon carbonarium**	3	7	1	11
41	Yellowtail snapper	*Ocyurus chrysurus**	3	5	2	10
41	Striped croaker	*Bairdiella sancteluciae**	10	0	0	10
43	Stoplight parrotfish	*Sparisoma viride*	4	1	4	9

continued

Appendix (continued)

Rank	Common name	Species	Coral Cove	Carlin Park	Ocean Ridge	Total
43	Redband parrotfish	*Sparisoma aurofrenatum*	1	0	8	9
44	Gray snapper	*Lutjanus griseus*	6	0	2	8
44	Porgy sp.	Sparid sp.	0	8	0	8
44	Bluestriped grunt	*Haemulon sciurus*	2	4	2	8
44	Spanish sardine	*Sardinella aurita*	8	0	0	8
49	Molly miller	*Scartella cristata**	2	5	0	7
49	Blackear wrasse	*Halichoeres poeyi*	6	1	0	7
51	Sheepshead	*Archosargus probatocephalus*	1	5	0	6
51	Blue tang	*Acanthurus coeruleus**	3	3	0	6
51	Spotted goatfish	*Pseudupeneus maculatus*	3	0	3	6
54	Saddled blenny	*Malacoctenus triangulatus**	1	3	1	5
55	Barbfish	*Scorpaena plumieri*	2	2	0	4
55	Queen parrotfish	*Scarus vetula*	0	1	3	4
57	Flamefish	*Apogon maculatus*	0	3	0	3
57	Yellowfin mojarra	*Gerres cinereus*	3	0	0	3
57	Blue runner	*Caranx crysos*	3	0	0	3
57	Spotfin butterflyfish	*Chaetodon ocellatus*	0	1	2	3
61	Balloonfish	*Diodon hystrix*	1	0	1	2
61	Chain moray	*Echidna catenata*	2	0	0	2
61	Scrawled cowfish	*Lactophrys quadricornis*	1	0	1	2
61	Schoolmaster	*Lutjanus apodus*	2	0	0	2
61	Blenny sp.	Bleniid sp.	2	0	0	2
61	Cottonwick	*Haemulon melanurum*	2	0	0	2
61	Great barracuda	*Sphyraena barracuda*	1	0	1	2
61	Scrawled filefish	*Aluterus scriptus*	1	0	1	2
69	Bicolor damselfish	*Stegastes partitus*	0	0	1	1
69	Orangespotted goby	*Nes longus*	0	1	0	1
69	Spanish hogfish	*Bodianus rufus*	0	1	0	1
69	Spotted snake eel	*Myrichthys acuminatus*	0	1	0	1
69	Gray angelfish	*Pomacanthus arcuatus**	1	0	0	1
69	Sharpnose puffer	*Canthigaster rostrata*	1	0	0	1
69	Greater soapfish	*Rypticus saponaceus*	1	0	0	1
69	Smooth trunkfish	*Lactophrys triqueter*	1	0	0	1
69	Hogfish	*Lachnolaimus maximus*	0	1	0	1
69	Puffcheck blenny	*Labrisomus bucciferus*	1	0	0	1
69	Nurse shark	*Ginglymostoma cirratum*	0	1	0	1
69	Squirrelfish	*Holocentrus rufus*	0	1	0	1
69	Blue angelfish	*Holacanthus bermudensis**	0	0	1	1
69	Rosy blenny	*Malacoctenus macropus*	0	1	0	1
69	Spotted moray	*Gymnothorax moringa*	1	0	0	1
69	Goldentail moray	*Muraena miliaris*	0	1	0	1
69	Atlantic spadefish	*Chaetodipterus faber*	1	0	0	1
69	Sand drum	*Umbrina coroides*	1	0	0	1
		Total taxa	72	60	50	86
		Total individuals	5093	4438	960	10491