1993

Dynamics of Fish Assemblages Associated with an offshore Artificial Reef in the Southern Mid-Atlantic Bight

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Recommended Citation

Adams, Aaron J., "Dynamics of Fish Assemblages Associated with an offshore Artificial Reef in the Southern Mid-Atlantic Bight" (1993). *Dissertations, Theses, and Masters Projects.* Paper 1539617663.
https://dx.doi.org/doi:10.25773/v5-81y6-m990

DYNAMICS OF FISH ASSEMBLAGES ASSOCIATED WITH AN OFFSHORE ARTIFICIAL REEF IN THE SOUTHERN MID-ATLANTIC BIGHT

A Thesis
Presented to
The Faculty of the School of Marine Science
The College of William and Mary in Virginia

In Partial Fulfillment
Of the Requirements for the Degree of
Master of Arts

by
Aaron J. Adams
1993

This thesis is submitted in partial fulfillment of
the requirements for the degree of

Master of Arts

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Dedication

To my parents, Joe and Sandy, and my sister, Joellen, who gave me the support to get this far.

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Acknowledgments

This project was possible due to the support of many people. Most notable, Mark Brotman, Bruce Layman, Judy Haner, and Buck Stockhausen braved countless hours of less than optimal diving and sea conditions to assist with the visual surveys. Dave Eggleston and Kirt Moody were able substitute divers on two occasions. Patrick Baker, Maria Cochran, Ed Heist, Jon Lucy, Niels Moore, Mike Seebo, and Paul Rudershausen provided support as topside crew. Danny Gouge and Shirley Crossley provided pain-free access to SCUBA and vessel equipment, respectively.

John Piano and Aquasafaris of Virginia Beach, VA provided much needed, and affordable, boat charters during the difficult winter months. Officer Shawn Hendricks, captain of the VMRC vessel 'Lynnhaven', provided transportation to the 4A Reef on numerous occasions.

I am grateful to Jon Lucy, my major professor, for the help and guidance, beyond what was expected, throughout my stay at VIMS. I am also indebted to the members of my thesis committee for their constructive comments.

Funding for this project was provided by two grants from the Sport Fishing Research Program of the Sport Fishing Institute (SFRP-91-15 and SFRP-92-16).

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Abstract

There is limited natural hard bottom in the Mid-Atlantic Bight, thus artificial reefs have been placed in offshore waters to provide additional shelter. High concentrations of fishes have been observed at these reefs but there is little information on the dynamics of these fish assemblages. The dynamics of the fish assemblages associated with a 10-year-old artificial reef, located on sand bottom 14 km offshore of southern Virginia were assessed at two week intervals from June - October, 1991, monthly intervals from November, 1991 - May, 1992, and weekly intervals from June - October, 1992. The abundance and size of fish were estimated with a stationary point visual census method using SCUBA over three reef strata (reef crest, reef edge and open sand). Species (24 total) were divided into four groups based on their use of the structure and duration of stay at the site: 1) core resident species (all demersal species) used the reef for shelter and were present for extended periods, 2) seasonal resident species (all demersal species) used the reef for shelter but were only present for brief periods, 3) transient species (all pelagic species) were seasonally associated with the reef but did not use the reef for shelter, and 4) visitor species (all demersal species) were observed near the reef on a sporadic basis but did not use the reef for shelter. Total reef abundance and species richness were positively correlated with bottom water temperature, and species composition and relative abundance varied seasonally. Seasonal resident species and transient species were only present from mid-August - October, months of highest temperatures. All species were closely associated with the reef.

Core resident species (black sea bass, *Centropristis striata*, scup, *Stenotomus chrysops*, tautog, *Tautoga onitis*, and cunner, *Tautogolabrus adspersus*) were the primary users of the reef structure and relied on the reef for shelter. Their abundance varied seasonally. Mean abundance of these species was highest on the reef crest and edge strata. Only black sea bass and scup also utilized the open sand stratum. Most colonization by black sea bass, tautog and cunner was by fish age I or older, but most scup were young-of-the-year. Reproductive activity was not observed. The 4A Reef appeared to provide habitat for adults of all the demersal species, and recruitment habitat for scup, black sea bass, and cunner, but only concentrated pelagic species.

DYNAMICS OF FISH ASSEMBLAGES ASSOCIATED WITH AN OFFSHORE ARTIFICIAL REEF IN THE SOUTHERN MID-ATLANTIC BIGHT

Introduction

Temperate marine communities vary seasonally in a number of parameters, including species composition, richness and abundance (Johnson, 1970; Hastings et al., 1976; Menge and Sutherland, 1978; Stephens and Zerba, 1981; Stephens et al., 1984; Chandler et al., 1985). Water temperature is a major factor influencing these changes in a variety of geographic locations and substrates (Hastings et al., 1976; Stephens et al., 1984; Chandler et al., 1985; Musick et al., 1985). The seasonal presence and abundance of fish species in an area may be determined by species-specific temperature tolerances (Ihnat and Bulkley, 1984; Ingersoll and Claussen, 1984), and influenced by the area's range of temperatures, rate of temperature change, and duration of high and low temperature extremes.

In the nearshore waters of the Middle Atlantic Bight (MAB) the annual temperature range can be as great as 25°C (Musick et al., 1985). Some species migrate along isotherms in order to maintain residence in a specific temperature range, resulting in large geographical ranges for even some demersal fish species (Musick and Mercer, 1977; Colvocoresses and Musick, 1984; Musick et al., 1985). The seasonal distribution, migration and geographic range of most fish species found in the MAB are so consistent that Colvocoresses and Musick (1984) and Musick et al. (1985)

assigned faunal zones and species groupings to describe the seasonal changes in species composition and abundance.

Although there are isolated outcroppings of natural hard substrate in the MAB (Emery, 1966), a majority of the research on hard bottom communities along the United States east coast has been in the South Atlantic Bight (SAB). The information from the studies of hard bottom areas in the SAB is not entirely applicable to the MAB hard bottom areas. The fish assemblages in the SAB were less migratory and different in species composition and richness than findings for the MAB (Sedberry and Van Dolah, 1984). For instance, tagging studies in the SAB of *Centropristis striata* (black sea bass), a major species in the MAB, "revealed that adult sea bass were year-round residents in given areas and, in contrast to Mid-Atlantic sea bass, did not undertake seasonal migrations" (Musick and Mercer, 1977).

Most of the bottom substrate in the MAB is sand (Emery, 1966), and the majority of information on fish species found in the MAB is from open bottom collections (e.g., otter trawl collections - Musick et al., 1985). Only recently has there been quantitative documentation of the fish assemblages associated with a natural hard bottom area in the MAB (Eklund and Targett, 1991). Eklund and Targett (1991) recorded species presence and relative abundances using commercial black sea bass traps on hard bottom areas off of northern Virginia and southern Maryland. Since their data were dependent on incidental catch of a trap fishery, they could only determine 'seasonal catch rates and relative abundances' of hard bottom associated species, which limits the study's ecological inferences. Due to the catchability bias of a trap toward certain species, the relative abundance estimates of species, such as those that actively seek shelter, might be biased.

In addition to the lack of information on MAB hard bottom fish assemblages, there is also insufficient information on the biota associated with man-made structures, 'artificial reefs', placed in the marine environment. Research on the biota associated with artificial reefs has not kept pace with the construction of new reefs (Steimle and Figley, 1989). Moreover, there are few studies of seasonal and long-term changes in fish assemblages associated with artificial reefs (Bohnsack, 1989; Seaman et al., 1989; Steimle and Figley, 1989; Bohnsack and Sutherland, 1985). In theory, the ecology of artificial reefs should be the same as natural reefs, but many studies comparing the two systems have revealed differences in species composition, richness, abundance and biomass (reviewed in Bohnsack and Sutherland, 1985). In most cases, fish density and biomass are higher on artificial reefs than on natural reefs; the causes are unknown.

In Virginia, the first documented artificial reef, made of discarded car bodies, was deployed in 1959. Liberty ships and 'materials of opportunity' (e.g., automobile tires) were placed in offshore waters as artificial reefs beginning in the early 1970's (Meier et al., 1985). It was not until 1982 that the first biological study on artificial reefs in Virginia was conducted. That study focused on structure durability and fouling growth and estimated the relative abundance of fish with hook-and-line (catch per unit effort) data (Feigenbaum et al., 1985, 1989). The only additional research on Virginia artificial reefs involved a fishery-dependent analysis of angler catch rates on reefs and other artificial structure fishing sites (Lucy and Barr, in press). Catch per unit effort studies, such as Feigenbaum et al. (1985), have inherent biases, such as species catchability differences based on hook size, bait, and time of feeding, which limit their ability to determine relative and absolute abundance (Dewees and Gotshall, 1974; Bannerot and Austin, 1983). Angler catch data (Lucy and Barr, in press) provided information on the presence of some species at a reef site, but were more a measure of 'catchability' than abundance. Similarly, a shortage of quantitative information on reef fish assemblages exists for the entire MAB region.

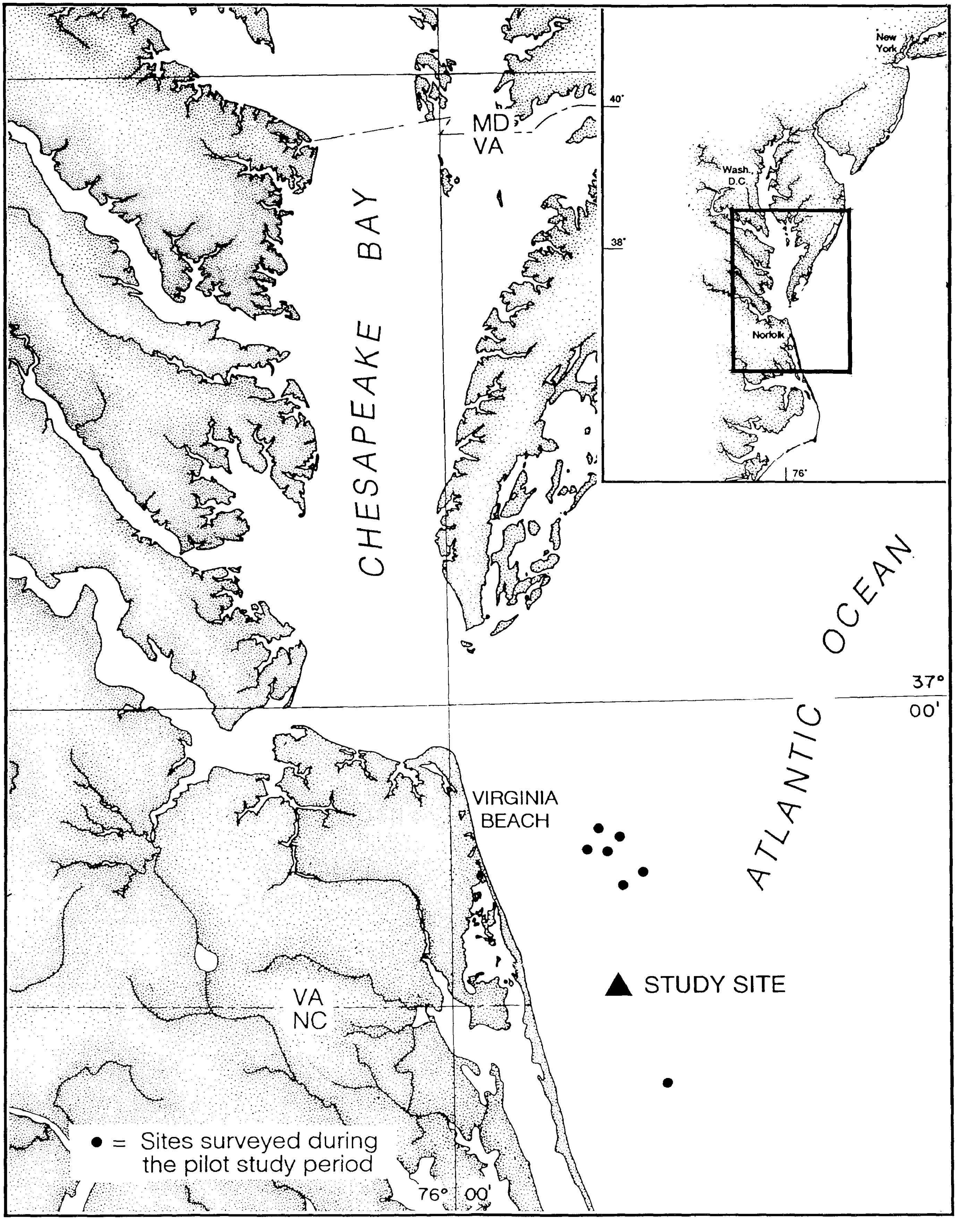
Given the limited extent of the information available on the reef fish assemblages near the Virginia coast, and in the MAB region in general, this study was designed to document the species of fishes associated with an offshore artificial reef and estimate the community characteristics of the observed finfish assemblages. Specific objectives of the research were to: 1) determine the presence and abundance of species over time; 2) determine reef spatial utilization patterns using abundance and length data; 3) document reproductive behavior and juvenile recruitment events; and 4) compare the data with other regional studies on open bottom and natural hard bottom substrates.

Methods and Materials

Description of the Study Area The 4A buoy artificial reef (4A Reef) is a metal (1/3 reef area) and wood (2/3 reef area) drydock that accidentally sank in October, 1981. The 4A Reef lies on open sand bottom approximately 34.6 km southeast of Rudee Inlet, Virginia Beach, Virginia and 14.8 km east of the nearest shore (Fig. 1). Water depth ranges from 19.2 m at the reef crest to 21.3 m on the surrounding sand bottom. The area and shape of bottom covered by the structure is 61 m x 30.5 m, with the longer axis laying NE to SW. There are two known structures within 4 km of the site. The 4A buoy channel marker, which attracts pelagic species, is 3.5 km east of the reef site, and a pile of steel beams (Length = 7.6 m x Width = 2.1 x Height = 0.3 m) lies on the bottom approximately 3.7 km to the north. The next closest structure is the Tiger Wreck artificial reef, which is located 16.7 km to the north.

During a two month pilot study, divers surveyed eight different artificial reef sites along the Virginia - North Carolina coast (Fig.1). The 4A Reef was chosen for four reasons. First, the 4A Reef is relatively isolated from any other structure, which reduced the amount of movement by fishes onto and off of the reef (Anderson et al., 1987; author, unpubl. data). Estimates of the perimeter of influence for a reef may be more than 100 m for benthic

Figure 1. Map showing the location of the 4A Reef and other area reefs that were surveyed in the pilot study


New York
40°
Wash., D.C.
38°
Norfolk
76°
MD
VA
CHESAPEAKE BAY
ATLANTIC OCEAN
37° 00'
VIRGINIA BEACH
▲ STUDY SITE
VA
NC
● = Sites surveyed during the pilot study period
76° 00'

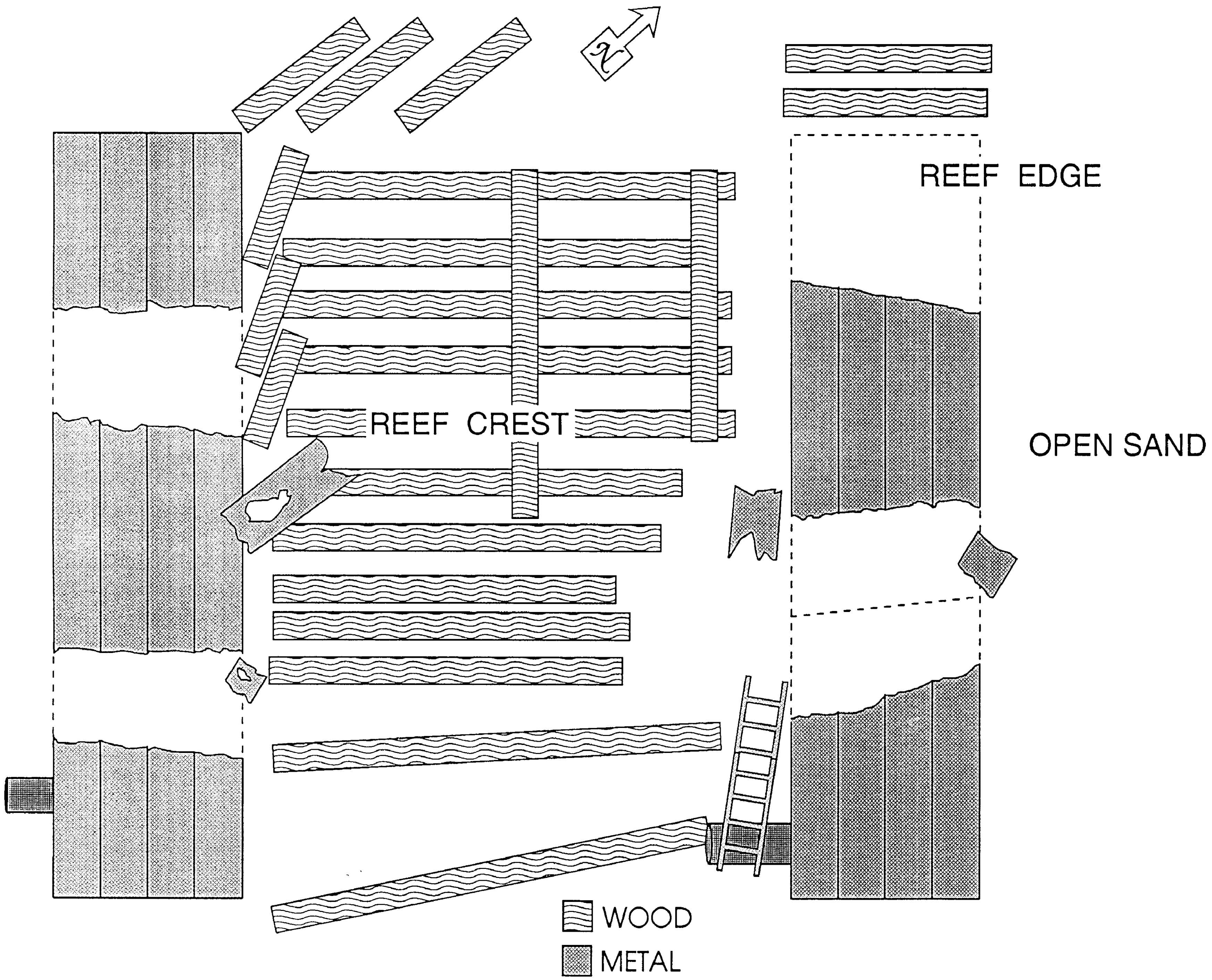
species (Olla et al., 1974) and 300 m for pelagic species (Bohnsack and Sutherland, 1985). Second, due to the distance from Virginia Beach, the nearest port, fishing pressure was considered lower on the 4A Reef than on the other reefs surveyed, except for the North Carolina site, which was too far to be financially feasible. Although fishing pressure on the 4A Reef varied annually, within each year it was lower than on the other reefs which were considered. Third, the location of the 4A Reef is normally not in the sediment plume associated with the mouth of the Chesapeake Bay. Inside the plume, visibility is too variable to allow visual sampling on a regular basis. Fourth, the 4A Reef is old enough (10 years at the beginning of the study) to eliminate problems associated with initial colonization. Newly placed reefs often exhibit an initial overshoot in total abundance and species richness; estimates of time for a reef to reach a more stable state are five years or more (Stone et al., 1979; Bohnsack, 1985; Wilson et al., 1991).

Sampling Design The 4A Reef site was sampled at two-week intervals from June through October, 1991, at monthly intervals from November, 1991 through May, 1992, and at one- to two-week intervals from June through October, 1992 (Table 1). All sampling was conducted by SCUBA divers using a stationary point visual census method (Bohnsack and

Bannerot, 1986), which was modified by reducing the sample radius from 7.5 m to 3 m to accommodate the moderate and inconsistent visibility (2 - 20 m) encountered off the Virginia coast. The reef site was partitioned into three strata (modified from Anderson et al., 1987): reef crest, reef edge and open sand (Fig.2), and sampled with a stratified random sample design. The reef crest was defined as the area that was completely covered by reef material, the reef edge was the area of bottom consisting of the reef/sand interface, and the open sand stratum was the sandy area six to twelve meters from the reef edge in which there was no reef material. Each stratum was sampled independently using random sample points, each point corresponding to coordinates on a map of the reef site.

Due to no-decompression limitations at the depths of the study site (19.2 m - 21.3 m), bottom time was limited to thirty minutes for each dive. During this time, each of two divers was able to complete two census. Two dives were completed each day, resulting in a minimum of eight samples for each sample date (2 census per diver x 2 dives x 2 divers). For each sample divers recorded: abundance and estimated lengths (minimum, maximum and mean) for each species, estimated visibility, bottom water temperature, depth, and stratum type. Water temperature was recorded with a temperature gauge attached to a SCUBA dive-console. Whenever possible, more than one diver was equipped with a

Figure 2. Diagram of the 4A Reef showing the three reef strata and the structural materials


N
REEF EDGE
REEF CREST
OPEN SAND
WOOD
METAL

temperature gauge for comparison readings. Temperature gauges were periodically calibrated by submersion in a large sea-water aquarium with a known temperature. Any deviation by the gauge from that temperature was incorporated into the readings taken on the 4A Reef.

During the pilot study, data were collected from surveys of the 4A Reef which determined the number of samples required to provide equivalent sampling coverage within each of the three strata. Sampling effort was not allocated by observed abundances and variances on each stratum because of the expected extreme variations in abundance with changes in temperature. Rather, sampling allocation was roughly equal to the proportional area covered by each stratum; crest = 1900 m^2, edge = 1100 m^2, and sand = 1100 m^2. Given a no-decompression limit of eight samples per day, the sampling ratio was crest - four samples: edge - two samples: sand - two samples.

Data Analyses Species were categorized as residents, transients or visitors (modified from Talbot et al., 1978), based on observed behavior patterns, duration of stay at the site, and utilization of the reef. Resident species occupied the confines of the reef structure, sought shelter within the reef when disturbed, and were observed on consecutive sample dates. Transient species were associated with the reef but generally did not enter the reef structure or use the reef as a shelter site, and were observed on consecutive sample dates. Visitor species were observed sporadically (i.e., not on consecutive sample dates), and did not use the reef as a source of shelter.

Total reef-fish abundance and species richness (for each sample date) were log-transformed to achieve approximate normality and homogeneity of variances (Zar, 1984). The relationships between bottom water temperature and total reef abundance and species richness were examined with linear least-squares regression analyses. The 17 month study was divided into 5 seasons based on qualitative relationships between bottom water temperature, total reef-fish abundance, species richness, and seasonal changes in species composition. Only the four resident species that were present for extended periods and were in high abundance (black sea bass, *Centropristis striata*, scup, *Stenotomus chrysops*, tautog, *Tautoga onitis*, and cunner, *Tautogolabrus adspersus*), designated as core resident species, were analyzed for seasonal and spatial utilization differences. Other species were not quantitatively analyzed since they were either present for only brief periods or in low abundance.

Mean abundance (no. fish/sample) and mean length of the core residents were examined by season and stratum. Mean abundance is expressed as no. fish/sample rather than no. fish/m^3 due to the nature of the sampling method. The sample area covered a circular portion of the bottom with a radius of 3 m as well as a volume above the bottom. However, a precise calculation of the volume (m^3) of the sample space was not possible, since the sample space extended upward the distance allowed by visibility. Accurate estimates of distance in open water were difficult, and visibility varied between sample dates. Estimates of demersal species abundance were not affected by changes in height of the overhead area since none were observed more than 2 m above the sampling substrate. Variation in estimates of pelagic species abundance was considered minimal since most species were observed within 3 - 4 m of divers, and identification of fish greater than 6 m from the diver was rarely possible. Mean abundance and mean length from each core resident species were examined for spatial utilization patterns and seasonal differences with a two-way, fixed-factor ANOVA, with season (early summer of 1991, late summer of 1991, early summer of 1992, and late summer of 1992) and stratum (reef crest, reef edge, and open sand) as factors and sample abundance and length as dependent variables. When effects were significant, a Tukey-Kramer multiple comparisons test was used to determine the source of the difference. Winter was not used in quantitative comparisons due to low sample size over a long period (four sample dates over seven months). When necessary, mean abundance data were transformed by log(X + 1) to achieve approximate normality and homogeneity of variances.

Baitfish were treated as a single species in each year for the purpose of species richness calculations, although divers observed at least two different species in each year. Attempts at collection in 1991 were successful at capturing only the dominant species (*Etrumeus teres*), but the low abundance in 1992 made collection impossible. Video and still photographs aided in the identification of the dominant species in 1992 (*Sardinella aurita*). The extremely high densities of clupeids in 1991 made accurate estimations of abundance difficult, but the estimated abundances were considered adequate for within-study comparisons.

Results

Field Sampling

Visibility was too low (< 3 m) to sample on 2 (October 2 and 21, 1992) of 33 visits to the 4A Reef (Table 1). On both dates low visibility was due to suspended sediment. October 2 followed a two week period during which three storms caused extremely high seas (reported waves to 15 feet) along the mid-Atlantic coast. On October 21, there was an unusually strong current on the bottom and surface, which may have disturbed sediment. Poor weather prohibited sampling in the months of December, 1991 and March and May, 1992, and hindered efforts to sample at weekly intervals throughout 1992.

During the pilot study, I used both transect and stationary point census methods to determine their effect on reef-associated species, primarily the core resident species. An actively swimming diver, as in the transect method, caused an avoidance response in black sea bass, tautog, and cunner, and an attraction of scup to the sediment disturbed by the diver's fins. A stationary diver appeared to have the minimum possible effect on the core resident species. After divers had remained in place for five minutes, individuals in the area appeared to return to 'normal' behavior. There was no discernable effect of the diver on fish behavior.

Table 1. Sample dates by season and year, with total abundance, species richness, and bottom temperature for each date.

Date	Abundance*	Richness	Temperature (°C)
Early Summer, 1991 (June - mid-August)			
June 3	204	5	16.1
June 20	244	4	17.0
June 21	382	6	17.0
July 10	431	6	20.0
July 23	411	7	20.0
August 13	352	5	16.1
Late Summer, 1991 (mid-August - October)			
August 27	279	10	21.7
September 13	689	12	22.8
September 23	440	8	21.7
October 4	801	8	21.1
October 21	635	5	18.3
Winter (November, 1991 - May, 1992)			
November 20, 1991	257	3	12.8
January 30, 1992	16	3	7.2
February 22	8	2	6.1
April 19	32	3	11.1
Early Summer, 1992 (June - mid-August)			
June 1	58	3	12.8
June 23	131	3	14.4
June 29	215	4	14.4
July 9	329	4	13.9
July 14	219	5	13.9
July 22	310	6	13.9
July 29	282	6	15.0
August 5	141	3	13.9
Late Summer, 1992 (mid-August - October)			
August 19	328	5	18.9
August 25	224	7	20.6
September 2	444	5	17.8
September 9	652	7	16.7
September 17	1349	11	20.6
October 2	274	7	19.4
October 14	524	12	18.3
October 28	691	10	16.1

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* Total abundances during late summer of 1991 and 1992 do not include baitfish.

Presence and Abundance

Over the entire study period, a total of 24 species, including the baitfish, was recorded on the 4A Reef (Table 2). There were 12 resident species, 6 transient species and 7 visitor species (gray triggerfish, *Balistes capriscus* was present as a visitor in 1991 and a resident in 1992). Eighteen species were recorded in 1991 and 17 in 1992. All resident and visitor species were demersal and all transient species were pelagic (Table 2).

In addition to the species recorded in diver samples, other species were observed on and above the reef site. Additional transient species included king mackerel, *Scomberomorus cavalla*, dolphin, *Coryphaena hippurus*, and cobia, *Rachycentron canadum*. Moreover, higher abundances of the recorded transient species were observed in the surface waters above the reef than on the reef itself. Although the sample area extended above the bottom as far as the diver was able to see, the distance from the reef to the surface was too great for positive fish identification of fish near the surface. Divers occasionally observed other species outside the sample space or between samples, all in low abundance and only sporadically: spiny dogfish, *Squalus acanthias*, in January and February, 1992; sand tiger shark, *Odontaspis taurus*, ocean sunfish, *Mola spp.*, and red drum, *Sciaenops ocellatus*, in September, 1992; juvenile spot-fin butterfly, *Chaetodon sedentarius*, stingray, *Dasyatis spp.*,

Table 2. List of all species recorded in diver samples.

Species Name Common Name	Year of Occurrence	Reef Use Classification	Total Abundance	Percent Frequency by sample date (1991 n=12, 1992 n=19)
Archosargus probatocephalus				
Sheepshead	1992	Resident	180	16
Astroscopus guttatus				
Northern Stargazer	1991	Visitor	1	8
Balistes capriscus				
Gray Triggerfish	1991	Visitor	1	8
	1992	Resident	14	21
Centropristis striata				
Black Sea Bass	1991	Resident	2665	100
	1992		1606	100
Chaetodipterus faber				
Atlantic Spadefish	1991	Transient	20	17
	1992		7	5
Conger oceanicus				
Conger Eel	1991	Resident	1	8
	1992		1	5
Diplodus holbrooki				
Spot-tail Pinfish	1991	Visitor	9	33
	1992		5	11
Euthynnus alletteratus				
Little Tunny	1991	Transient	6	17
Mycteroperca microlepis				
Gag	1991	Resident	64	33
Parablennius marmoreus				
Blennie	1991	Resident	1	8
	1992		2	10
Paralichthys dentatus				
Summer Flounder	1992	Visitor	1	5
Pollachius virens				
Pollack	1992	Visitor	2	10

Table 2, continued.

Species Name Common Name	Year of Occurrence	Reef Use Classification	Total Abundance	Percent Frequency by sample date (1991 n=12, 1992 n=19)
Pomacentrus leucostictus				
Beaugregory	1991	Visitor	2	17
Prionotus carolinus				
Northern Sea Robin	1991	Visitor	1	8
Sarda sarda				
Atlantic Bonito	1991	Transient	35	8
Scomberomorus maculatus				
Spanish Mackerel	1991	Transient	286	33
	1992		1	5
Seriola dumerili				
Greater Amberjack	1991	Transient	36	17
	1992		87	32
Sphyraena barracuda				
Barracuda	1992	Transient	1	5
Stenotomus chrysops				
Scup	1991	Resident	1891	92
	1992		4105	74
Tautoga onitis				
Tautog	1991	Resident	50	75
	1992		93	95
Tautogolabrus adspersus				
Cunner	1991	Resident	61	83
	1992		126	95
Urophycis spp.				
Hake	1992	Visitor	1	5
Baitfish (Clupeidae)				
Etrumeus teres	1991	Resident	61930	42
Sardinella aurita	1992	Resident	1020	21

and cownose ray, *Rhinoptera bonasus*, in October, 1992.

Core Resident Species

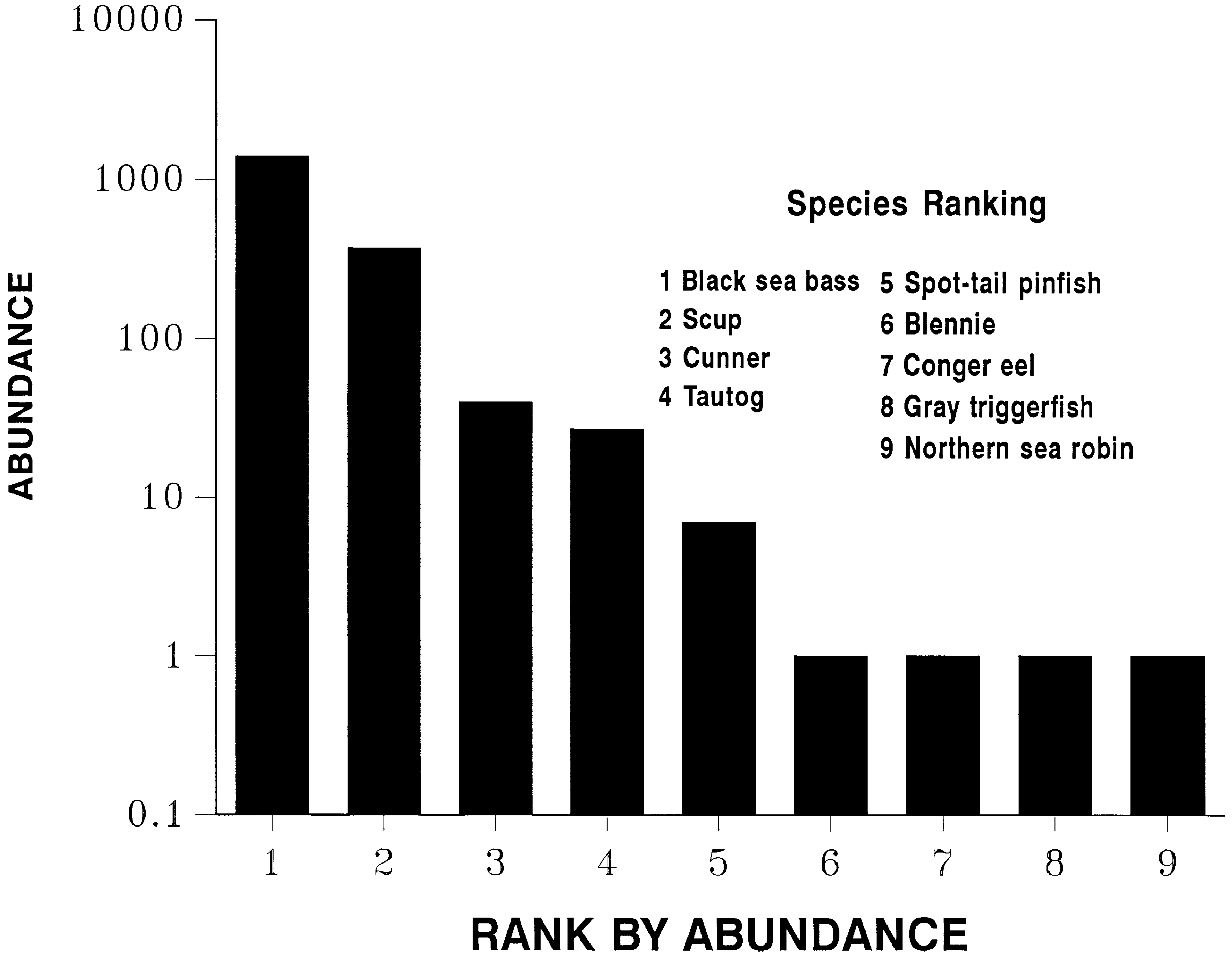
Seasonal and Spatial Variation

Black sea bass

Black sea bass was the only species present on all sample dates. It was the most abundant species in early summer of both years (1991, Fig. 3; 1992, Fig. 6) and in winter (Fig. 5), and was the third most abundant species in late summer of both years (1991, Fig. 4; 1992, Fig. 7). Mean abundance differed significantly by stratum and season (Table 3). As the interaction effect between stratum and season was also significant, treatment effects within each stratum and season were analyzed (Underwood, 1981). Mean abundance was lowest on the open sand stratum in all seasons (Table 3, Fig. 8). Mean abundance was highest in 1991 relative to 1992 within all strata (Table 3, Fig. 8), which resulted in lower overall mean abundance in 1992 (Fig. 9). In 1991, mean abundance on the crest and edge was higher in early summer than late summer, but the trend was not significant (Table 3, Fig. 8). Although only significant on the reef crest, mean abundance was higher on all strata in early summer than late summer of 1992 (Table 3, Fig, 8).

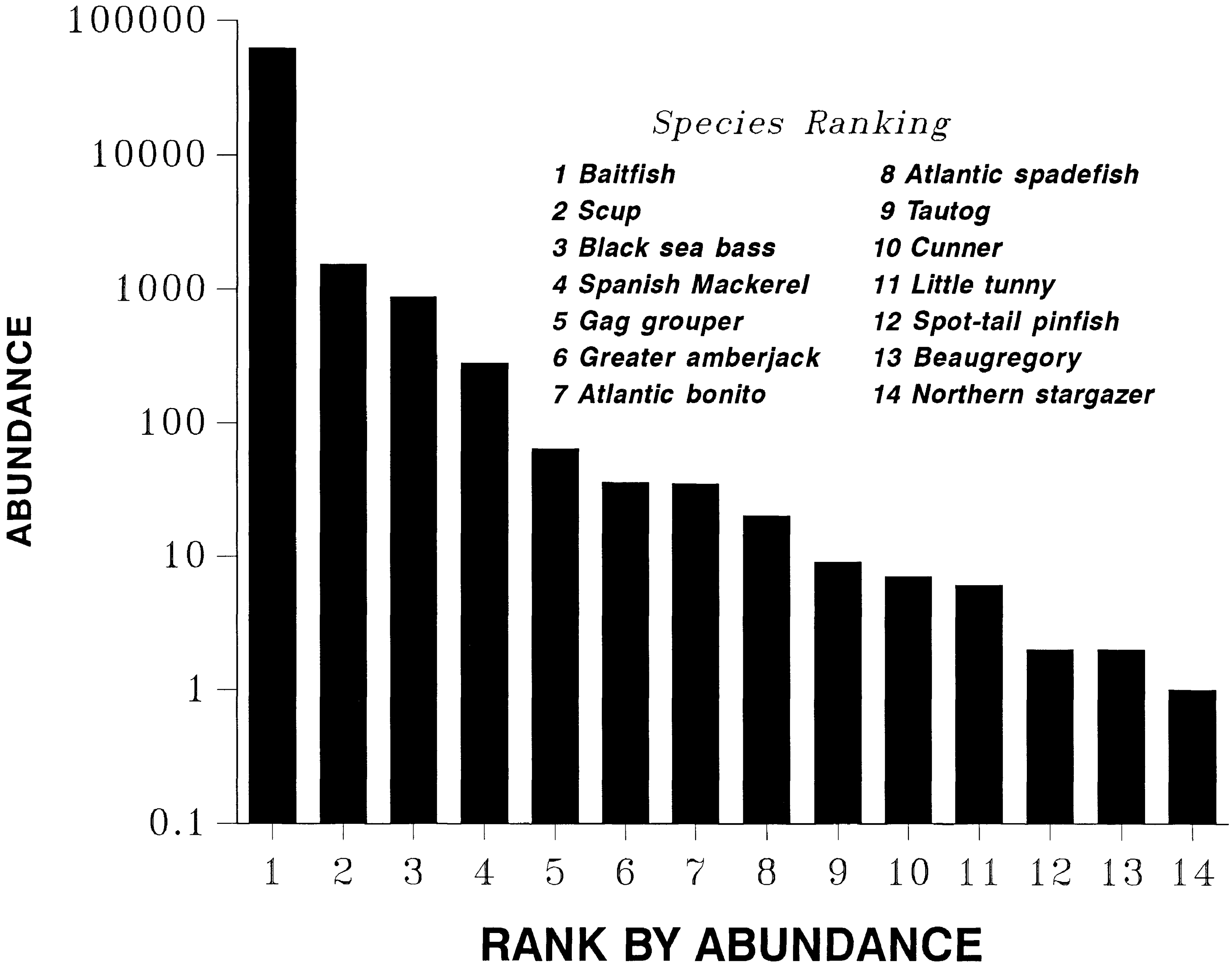
Mean length was significantly different by stratum and season, and the interaction effect was also significant (Table 4). In early summer of both years mean length was

Figure 3. Species ranking by abundance for early summer of 1991. Abundance is on a log scale



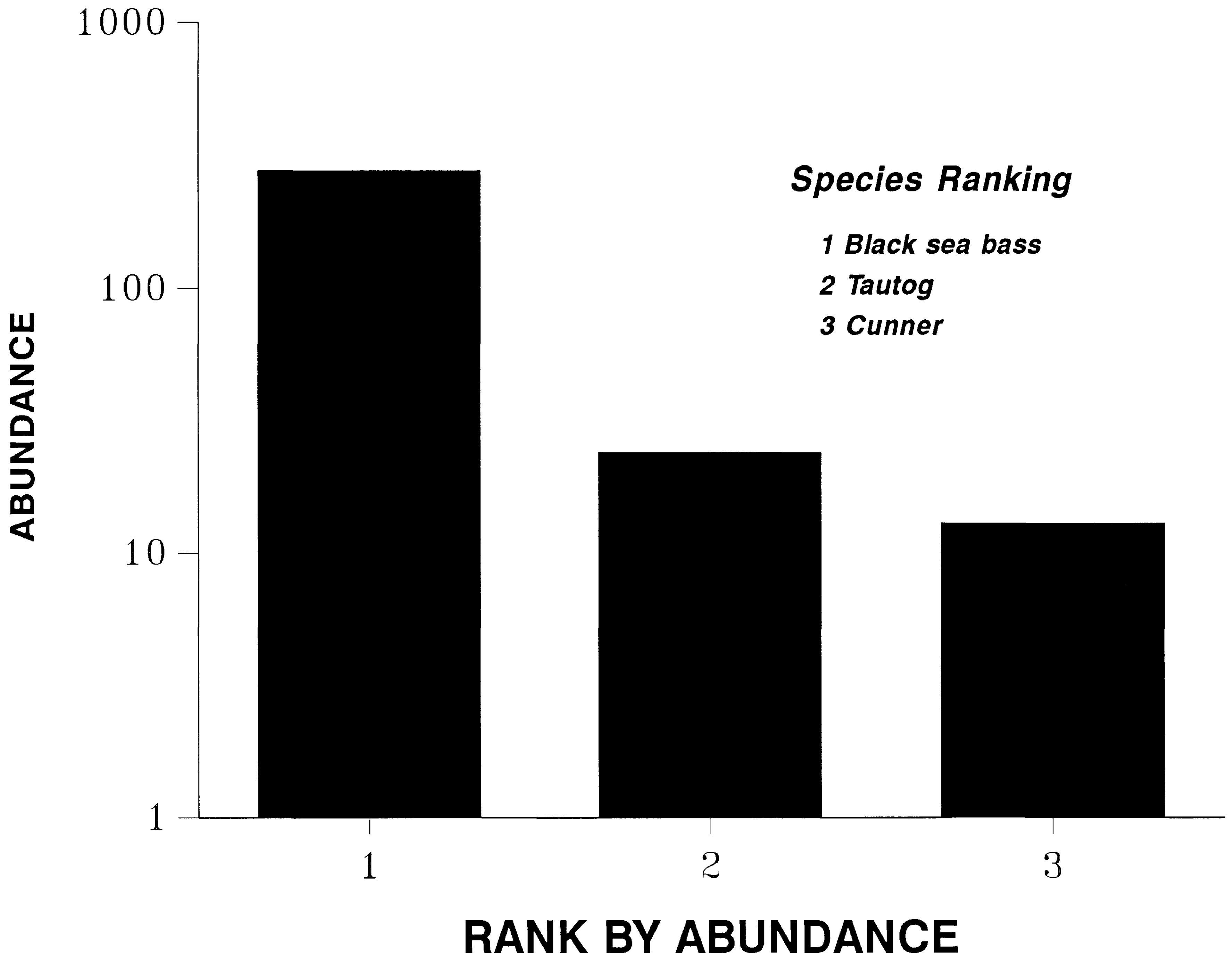
early summer, 1991

Figure 4. Species ranking by abundance for late summer of 1991. Abundance is on a log scale



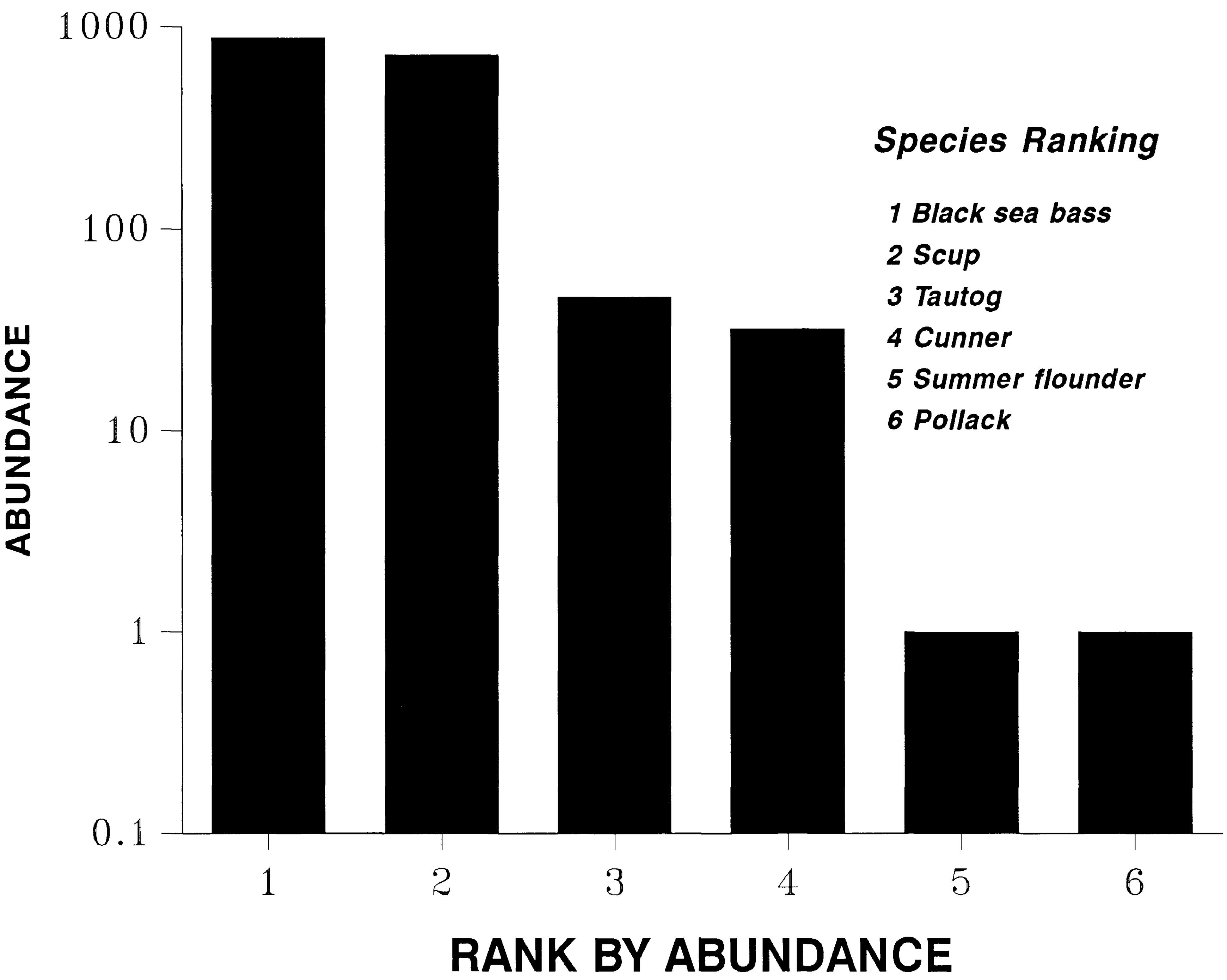
late summer, 1991

Figure 5. Species ranking by abundance for winter. Abundance is on a log scale


1000
100
10
1
ABUNDANCE
1
2
3
RANK BY ABUNDANCE
Species Ranking
1 Black sea bass
2 Tautog
3 Cunner

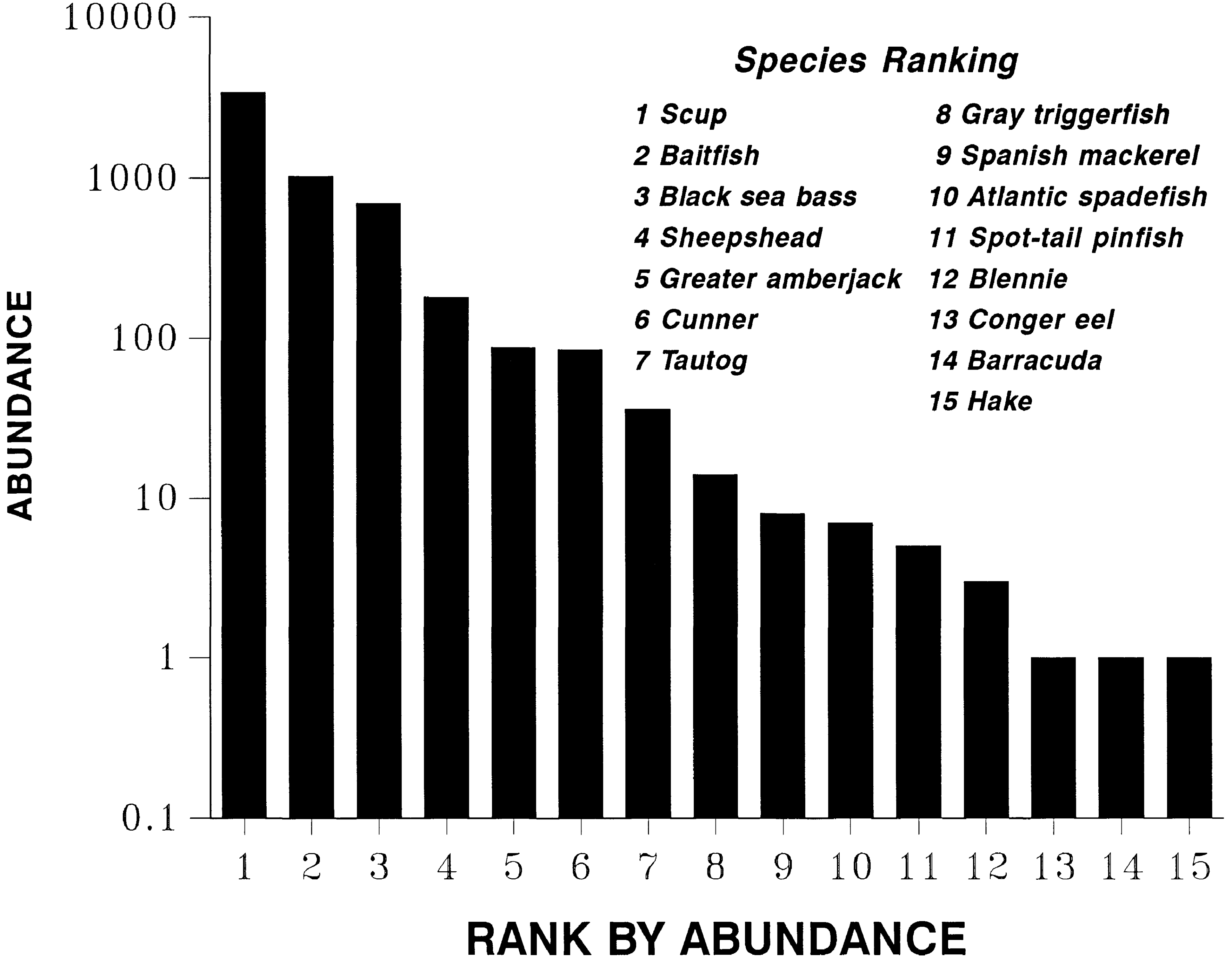
winter

Figure 6. Species ranking by abundance for early summer of 1992. Abundance is on a log scale



early summer, 1992

Figure 7. Species ranking by abundance for late summer of 1992. Abundance is on a log scale



late summer, 1992

similar across all strata, but in late summer of both years mean length was lowest on the open sand and highest on the reef crest and edge, which were similar (Table 4, Fig. 10). This resulted in a decrease in overall mean length from early summer to late summer of each year (Fig. 11). Although not significant on all strata (Table 4, Fig. 10) mean length was higher in 1992 than 1991, and highest overall in early summer of 1992 (Fig. 11).

Scup

Scup were ranked second highest in abundance in early summer of 1991 (Fig. 3) and 1992 (Fig. 6) and late summer of 1991 (Fig. 4), and ranked highest in abundance in late summer of 1992 (Fig. 7). Scup were not present in winter. They were present on all sample dates from June 20 through October 21, 1991, and all sample dates from June 29 through October 28, 1992. Mean abundance differed significantly by stratum and season, and the interaction effect was also significant (Table 5). In all seasons mean abundance was lowest on the open sand (Table 5, Fig. 12). In early summer of both years mean abundance was similar on the reef crest and edge (Table 5, Fig. 12). In late summer of 1991 mean abundance was highest on the reef edge, but in late summer of 1992 it was highest on the reef crest (Table 5, Fig. 12). Mean abundance was higher in late summer in both years within all strata, which resulted in higher overall mean

Table 3. Black sea bass: Effect of stratum (crest, edge and open sand) and season (early summer 1991, late summer 1991, early summer 1992, late summer 1992) on log-transformed mean no./sample.

a) Two-Way ANOVA.

Source	SS	df	MS	F	p
Stratum	2194.56	2	1074.78	248.16	< 0.001
Season	43.36	3	14.45	3.34	< 0.001
Stratum*Season	65.13	6	10.86	2.51	0.023
Error	905.19	209	4.33		

b) Tukey-Kramer multiple comparison test. Treatment levels that are not significantly different at the 0.05 level share an underline. Listed in order of increasing abundance from left to right.

Interaction

Season	Stratum		
Early summer, 1991	sand	edge	crest
Late summer, 1991	sand	edge	crest
Early summer, 1992	sand	edge	crest
Late summer, 1992	sand	edge	crest

Stratum	Season			
Crest	late summer 1992	early summer 1992	late summer 1991	early summer 1991
Edge	late summer 1992	early summer 1992	late summer 1991	early summer 1991
Sand	late summer 1992	early summer 1992	early summer 1991	late summer 1991

Figure 8. Mean abundance (no. fish/sample) of black sea bass by stratum and season

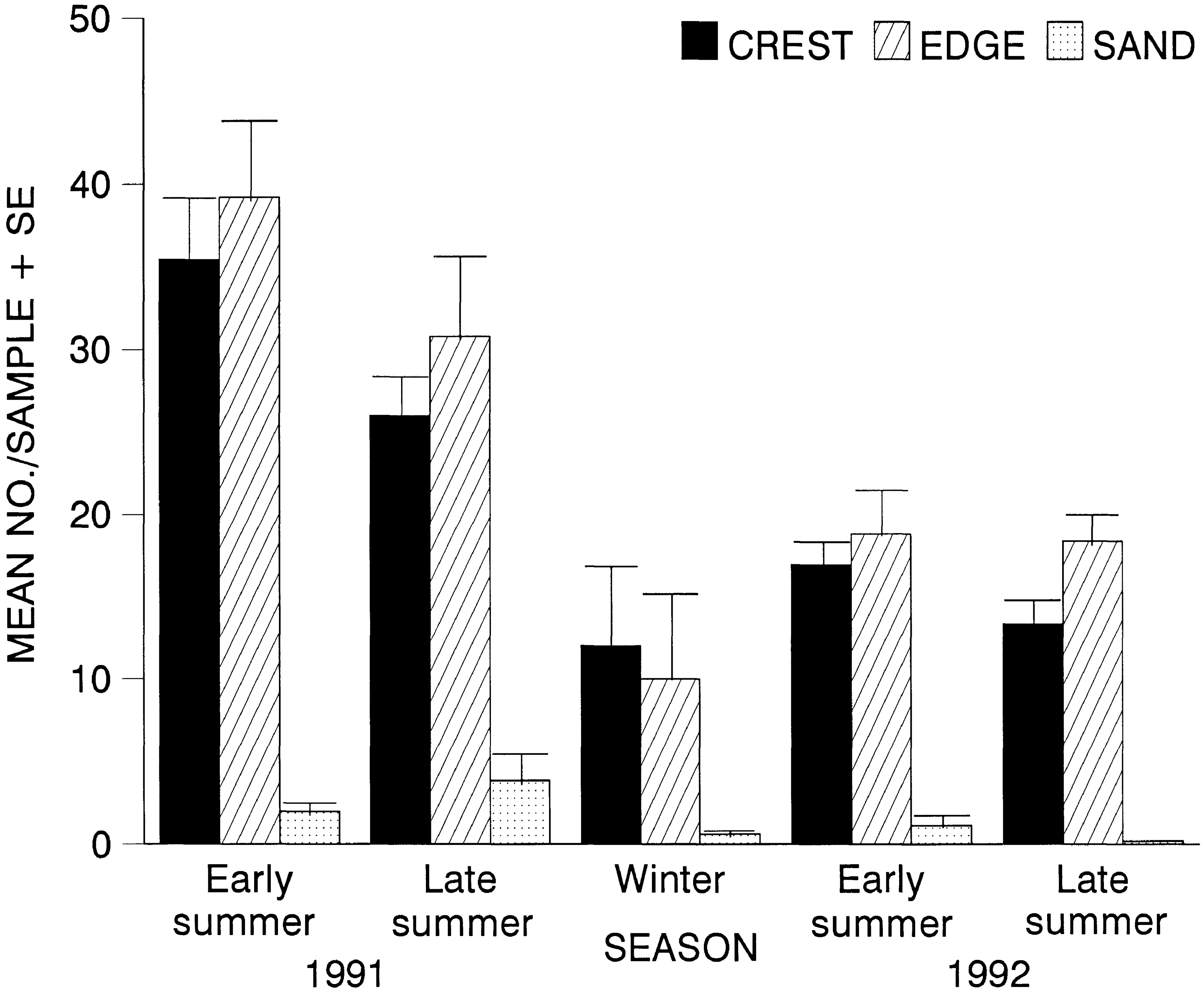
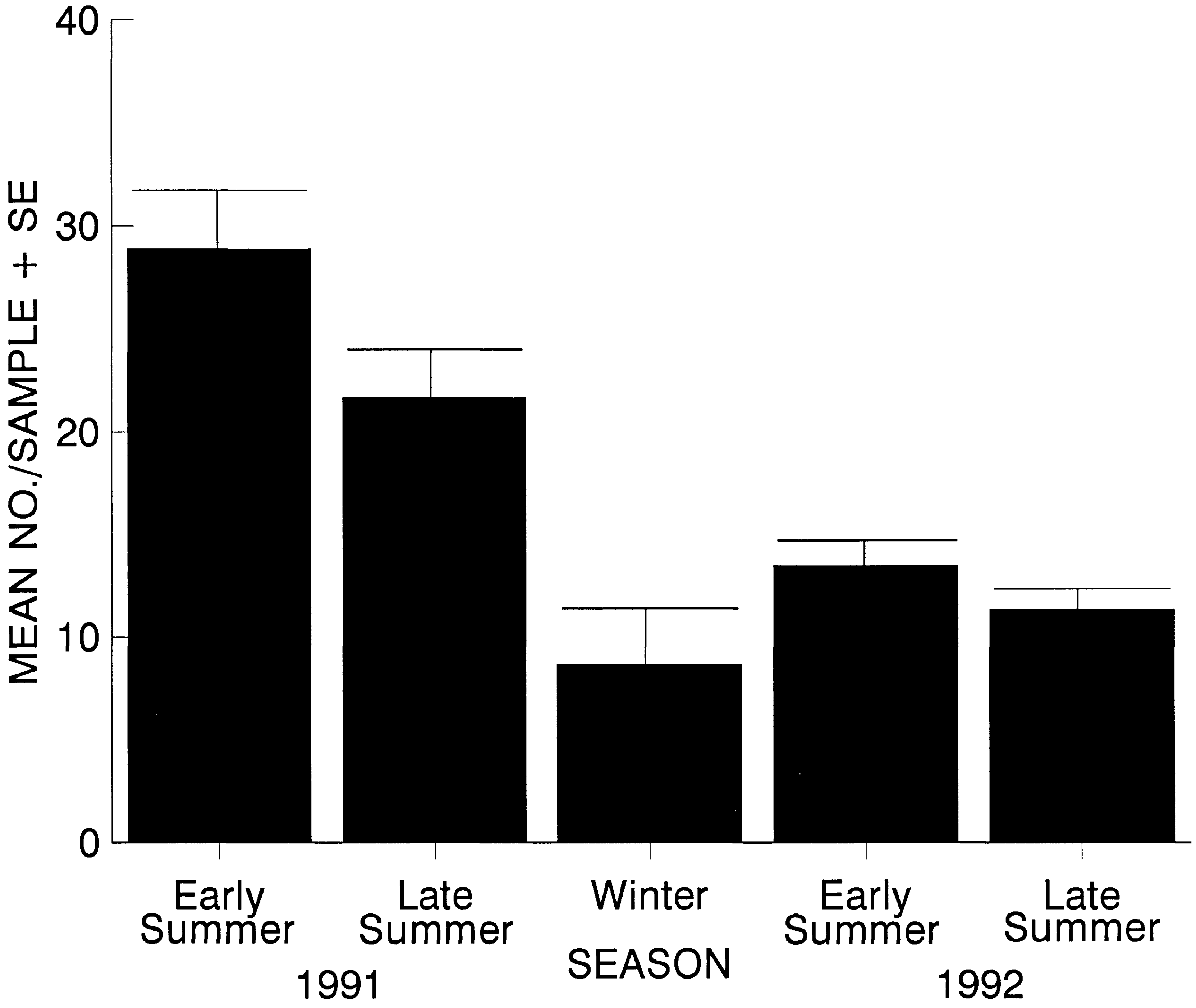

CREST
EDGE
SAND
MEAN NO./SAMPLE + SE
50
40
30
20
10
0
Early summer
Late summer
Winter
Early summer
Late summer
1991
SEASON
1992

Figure 9. Overall mean abundance of black sea bass by season



40
30
20
10
0
MEAN NO./SAMPLE + SE
Early Summer
Late Summer
Winter
Early Summer
Late Summer
1991
SEASON
1992

bass

Table 4. Black sea bass: Effect of stratum (crest, edge and open sand) and season (early summer 1991, late summer 1991, early summer 1992, late summer 1992) on mean length.

a) Two-Way ANOVA.

Source	SS	df	MS	F	p
Stratum	415.76	2	207.88	13.91	< 0.001
Season	613.80	3	204.60	13.69	< 0.001
Stratum*Season	293.93	6	48.96	3.28	0.004
Error	2705.93	181	14.95		

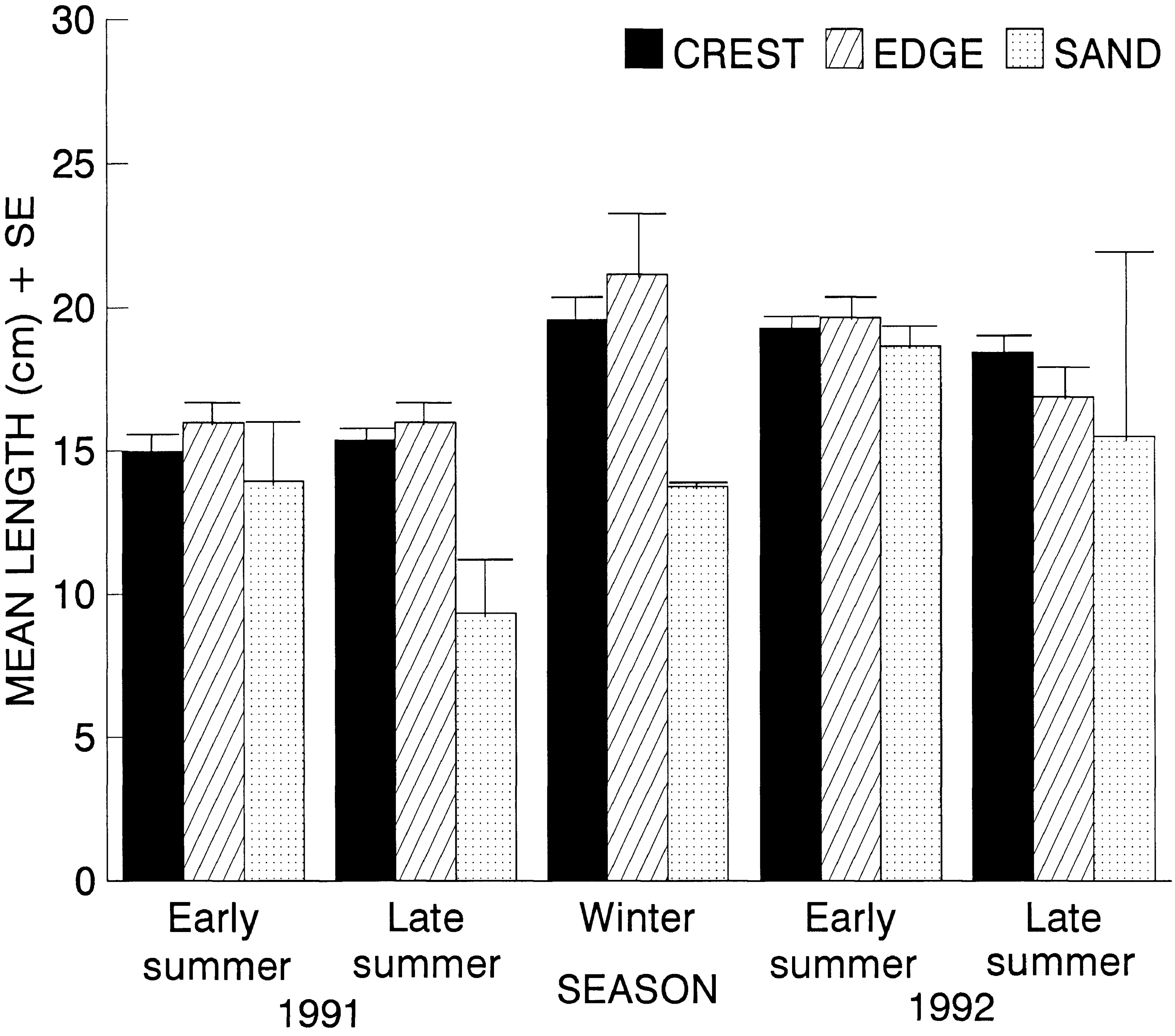
b) Tukey-Kramer multiple comparison test. Treatment levels that are not significantly different at the 0.05 level share an underline. Listed in order of increasing mean length from left to right.

Interaction

Season	Stratum		
Early summer, 1991	sand	edge	crest
Late summer, 1991	sand	edge	crest
Early summer, 1992	sand	edge	crest
Late summer, 1992	sand	edge	crest

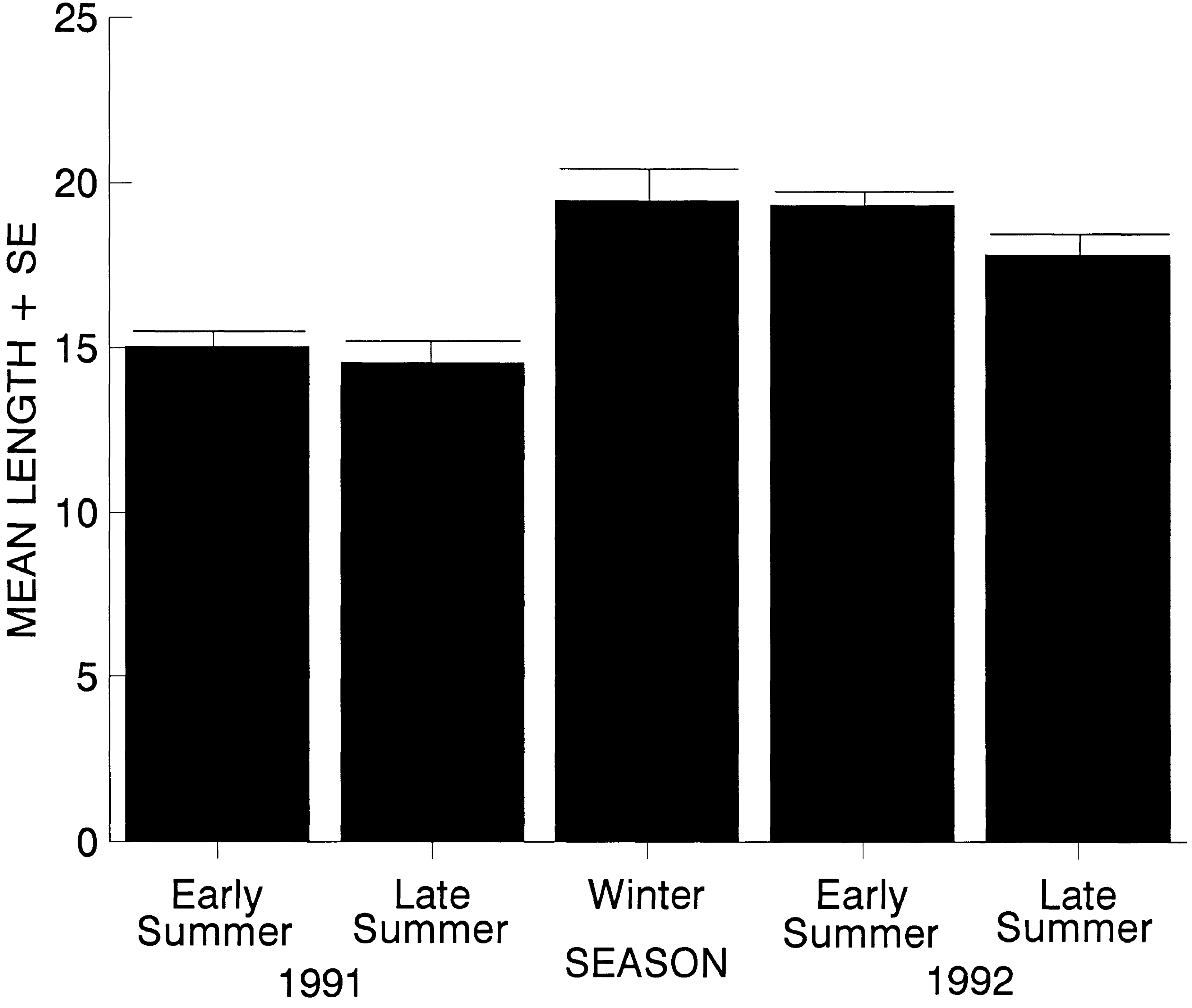
Stratum	Season			
Crest	early summer 1991	late summer 1991	late summer 1992	early summer 1992
Edge	early summer 1991	late summer 1991	late summer 1992	early summer 1992
Sand	late summer 1991	early summer 1991	late summer 1992	early summer 1992

Figure 10. Mean length of black sea bass by stratum and season



CREST
EDGE
SAND
30
25
20
15
10
5
0
MEAN LENGTH (cm) + SE
Early summer
Late summer
1991
Winter
SEASON
Early summer
Late summer
1992

Figure 11. Overall mean length of black sea bass by season


MEAN LENGTH + SE
0
5
10
15
20
25
Early Summer
Late Summer
Winter
Early Summer
Late Summer
1991
SEASON
1992

bass

abundance in late summer of both years (Fig. 13). On the reef edge and open sand mean abundance was significantly higher in late summer of each year (Table 5, Fig. 12). Mean abundance was highest in late summer of 1992 on all strata (Table 5, Fig., 12).

Mean length differed significantly by stratum and season, and the interaction effect was significant (Table 6). In all seasons, mean length was similar on the reef crest and edge (Table 6, Fig. 14). In late summer of both years mean length was lowest on the open sand, but this was significant only in 1991 (Table 6, Fig., 14). Mean length was higher in early summer within all strata in both years (Table 6, Fig. 14).

Tautog

Tautog were present on 91% of the sample dates for the entire study but were ranked low in abundance in all seasons (Figs. 3 - 7). Tautog were absent from the 4A Reef on September 23 (temperature = 21.7°C), October 4 (21.1°C) and October 21 (18.3°C) of 1991. Mean abundance differed significantly by season but not by stratum and there was no interaction effect (Table 7). Tautog were not present on the open sand at any time. In both years, mean abundance decreased from early summer to late summer (Table 7, Fig. 16). Mean abundance was higher throughout 1992 relative to 1991 (Table 7, Fig. 16).

Table 5. Scup: Effect of stratum (crest, edge and open sand) and season (early summer 1991, late summer 1991, early summer 1992, late summer 1992) on log-transformed mean no./sample.

a) Two-way ANOVA

Source	SS	df	MS	F	p
Stratum	122.24	2	61.12	44.16	< 0.001
Season	75.26	3	25.09	18.13	< 0.001
Stratum*Season	23.76	6	3.96	2.86	0.011
Error	254.65	184	1.38		

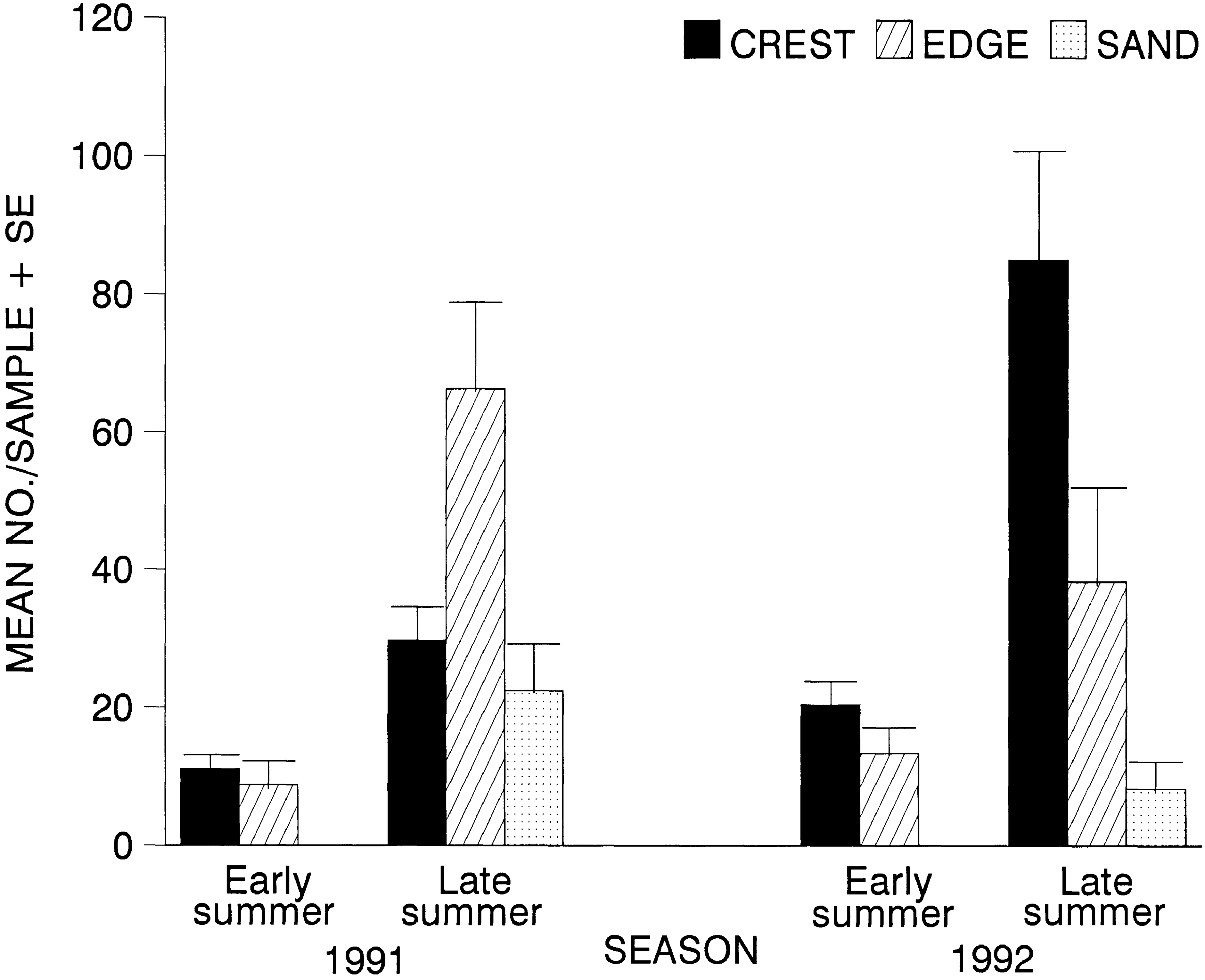
b) Tukey-Kramer multiple comparison test. Treatment levels that are not significantly different at the 0.05 level share an underline. Listed in order of increasing abundance from left to right.

Interaction

Season	Stratum		
Early summer, 1991	sand	edge	crest
Late summer, 1991	sand	crest	edge
Early summer, 1992	sand	edge	crest
Late summer, 1992	sand	edge	crest

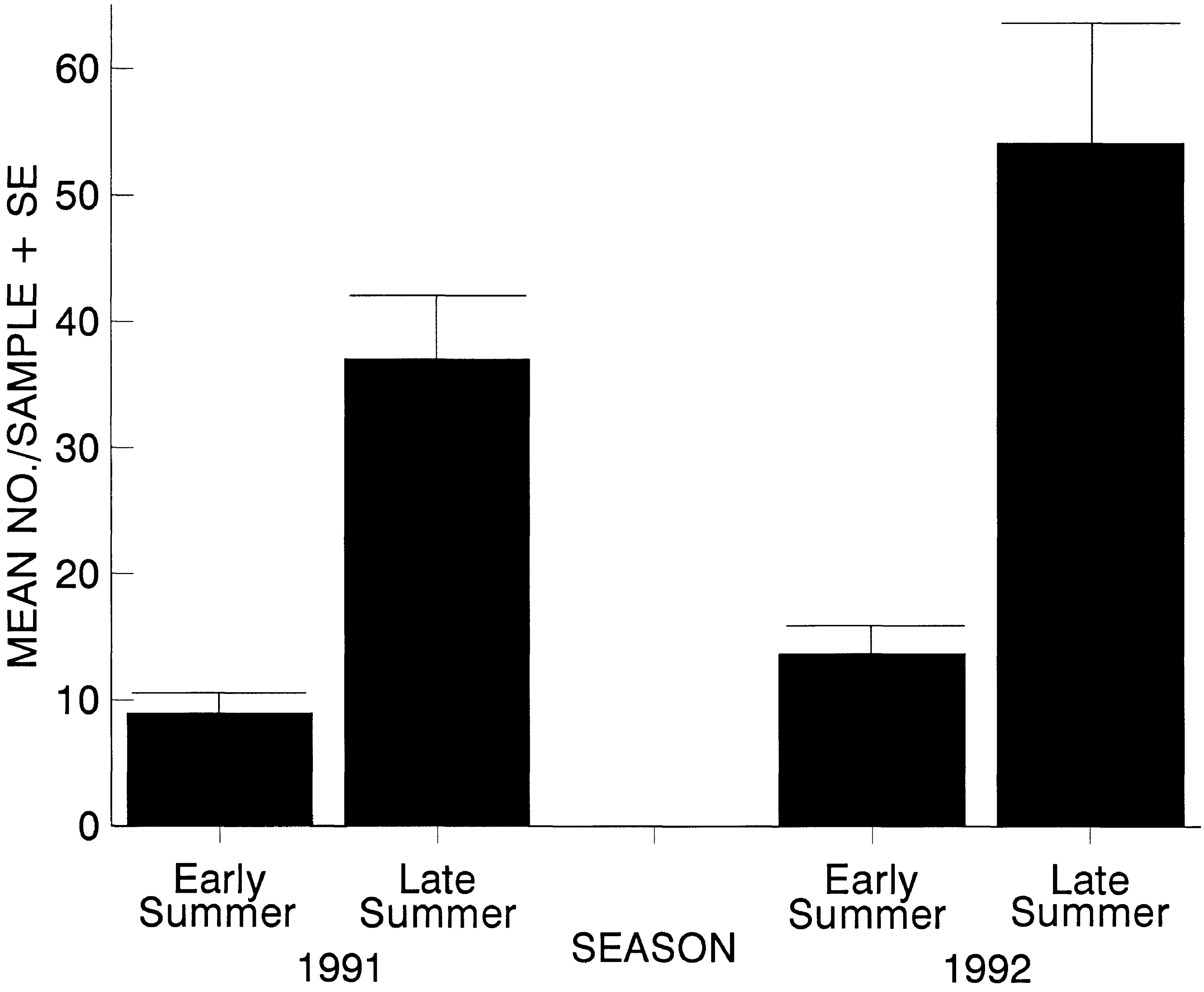
Stratum	Season			
Crest	early summer 1991	early summer 1992	late summer 1991	late summer 1992
Edge	early summer 1991	early summer 1992	late summer 1992	late summer 1991
Sand	early summer 1991	early summer 1992	late summer 1992	late summer 1991

Figure 12. Mean abundance (no. fish/sample) of scup by stratum and season



CREST
EDGE
SAND
MEAN NO./SAMPLE + SE
120
100
80
60
40
20
0
Early summer
Late summer
1991
SEASON
Early summer
Late summer
1992

Figure 13. Overall mean abundance of scup by season


MEAN NO./SAMPLE + SE
0
10
20
30
40
50
60
Early Summer
Late Summer
1991
SEASON
Early Summer
Late Summer
1992

scup

Table 6. Scup: Effect of stratum (crest, edge and open sand) and season (early summer 1991, late summer 1991, early summer 1992, late summer 1992) on mean length.

a) Two-way ANOVA

Source	SS	df	MS	F	p
Stratum	1583.25	2	791.62	130.06	< 0.001
Season	103.10	3	34.37	5.37	< 0.001
Stratum*Season	1018.13	6	169.69	27.88	< 0.001
Error	1119.93	184	6.09		

b) Tukey-Kramer multiple comparison test. Treatment levels that are not significantly different at the 0.05 level share an underline. Listed in order of increasing mean length from left to right.

Interaction

Season	Stratum		
Early summer, 1991	edge	crest	no scup on sand
Late summer, 1991	sand	edge	crest
Early summer, 1992	edge	crest	no scup on sand
Late summer, 1992	sand	edge	crest

Stratum	Season			
Crest	late summer 1992	late summer 1991	early summer 1992	early summer 1991
Edge	late summer 1992	late summer 1991	early summer 1991	early summer 1992
Sand	late summer 1992	late summer 1991	no scup on sand in early summer of 1991 or 1992	

Figure 14. Mean length of scup by stratum and season

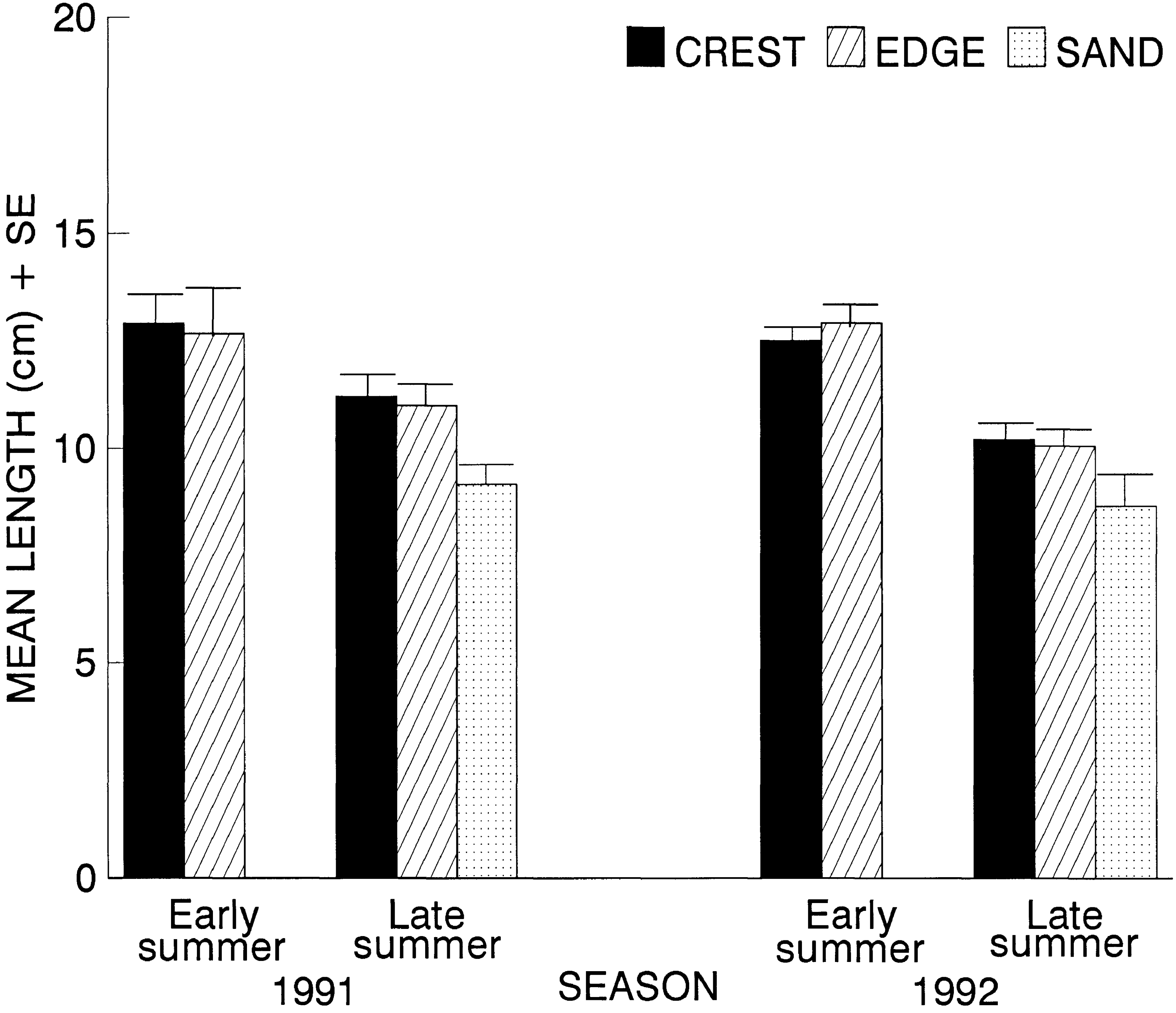
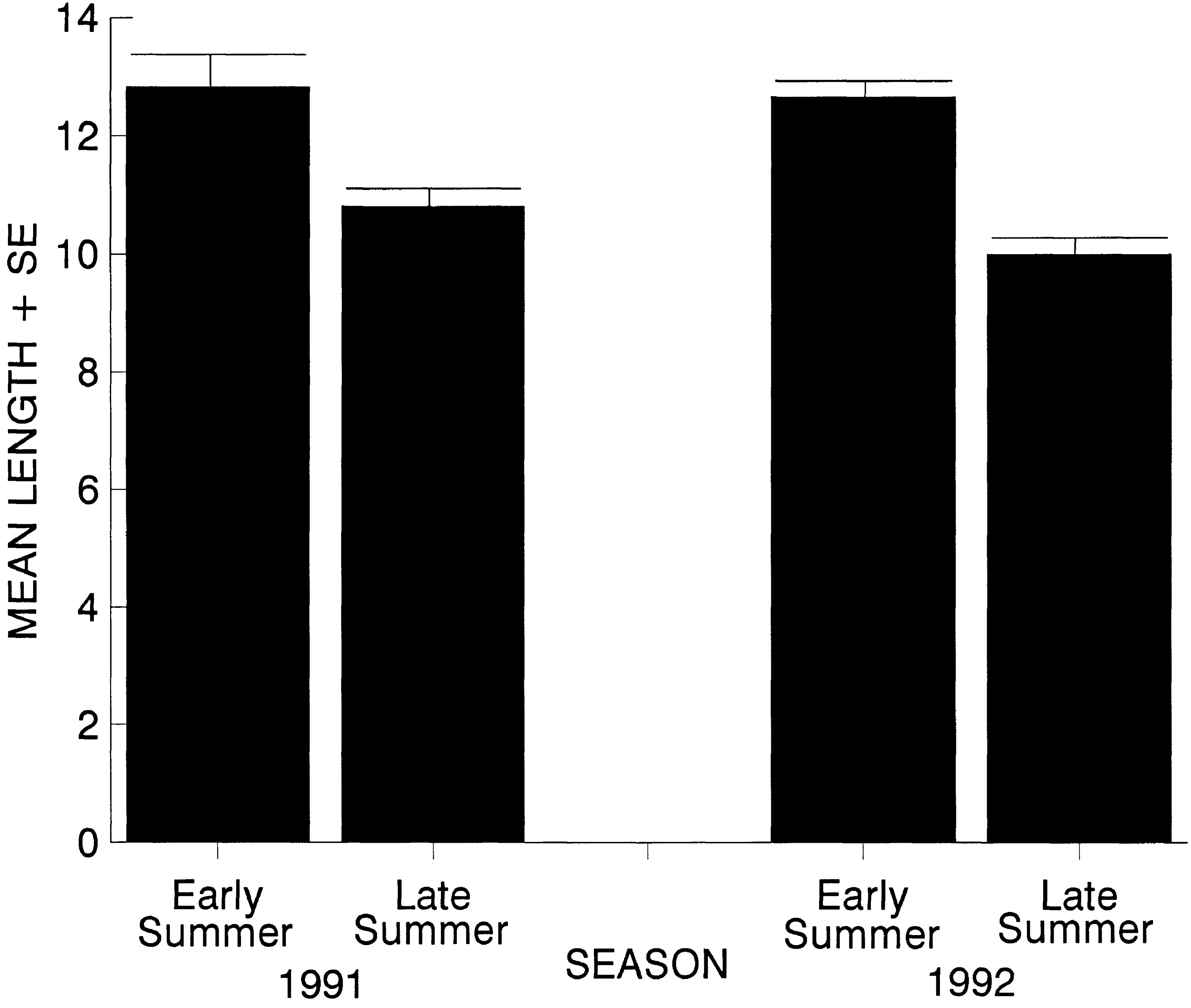

CREST
EDGE
SAND
MEAN LENGTH (cm) + SE
0
5
10
15
20
Early summer
Late summer
1991
SEASON
Early summer
Late summer
1992

Figure 15. Overall mean length of scup by season


MEAN LENGTH + SE
14
12
10
8
6
4
2
0
Early Summer
Late Summer
1991
SEASON
Early Summer
Late Summer
1992

scup

Mean length was significantly different by season but not by stratum (Table 8). The power of the test was calculated for the interaction effect due to the insignificance level ($p = .056$) (Zar, 1984), but the interaction effect was insignificant (power ca. 0.93). Mean length was different in all seasons, and was higher in 1992 than in 1991 (Table 8, Fig. 17). In 1991 mean length was higher in early summer, while in 1992 mean length was higher in late summer (Table 8, Fig. 17).

Cunner

Cunner were present on 91% of all sample dates but were ranked low in abundance in all seasons (Figs. 3 - 7). Cunner were absent on September 23 (temperature = 21.7°C) and October 21 (18.3°C), 1991 and February 22 (6.1°C), 1992. Mean abundance differed significantly only by season (Table 9). Cunner were never present on the open sand stratum. There was no distinct trend in seasonal or annual changes in mean abundance. In 1991, mean abundance decreased from early summer to late summer, but in 1992 mean abundance increased from early summer to late summer (Table 9, Fig. 18). When seasons were compared by year, in early summer mean abundance was higher in 1991 and in late summer it was higher in 1992 (Table 9, Fig. 18).

Mean length also only differed significantly by season (Table 10). In 1991 mean length was similar between

Table 7. Tautog: Effect of stratum (crest and edge) and season (early summer 1991, late summer 1991, early summer 1992, late summer 1992) on log-transformed mean no./sample.

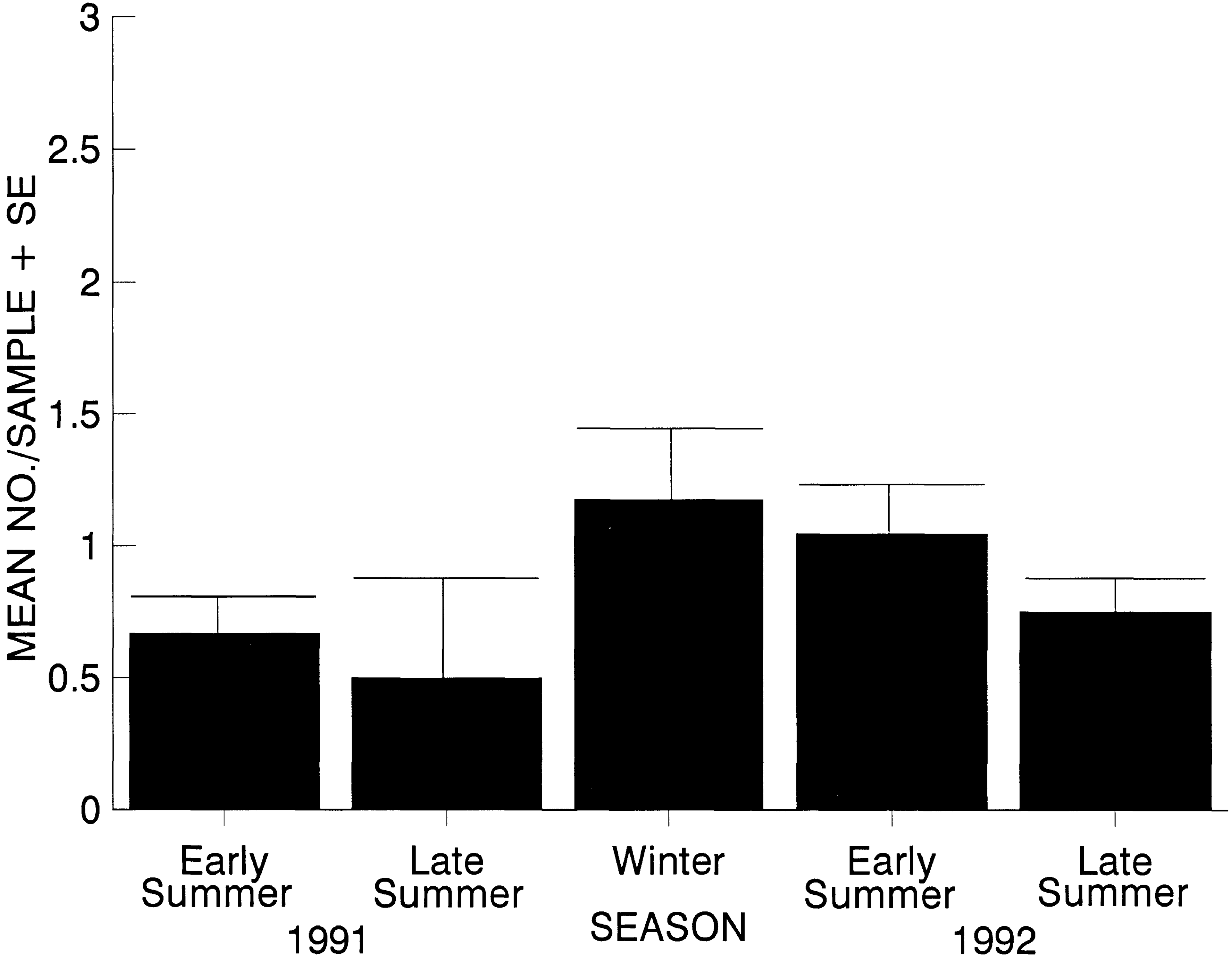
a) Two-way ANOVA.

Source	SS	df	MS	F	p
Stratum	0.80	1	0.80	3.07	0.082
Season	2.11	3	0.70	2.69	0.048
Stratum*Season	1.05	3	0.35	1.34	0.263
Error	37.63	144	0.26		

b) Tukey-Kramer multiple comparison test. Treatments that are not significantly different at the 0.05 level share an underline. Listed in order of increasing abundance from left to right.

late summer of 1991	late summer of 1992	early summer of 1991	early summer of 1992

Figure 16. Overall mean abundance (no. fish/sample) of tautog by season


MEAN NO./SAMPLE + SE
3
2.5
2
1.5
1
0.5
0
Early Summer
Late Summer
Winter
Early Summer
Late Summer
1991
SEASON
1992

tautog

Table 8. Tautog: Effect of stratum (crest and edge) and season (early summer 1991, late summer 1991, early summer 1992, late summer 1992) on mean length.

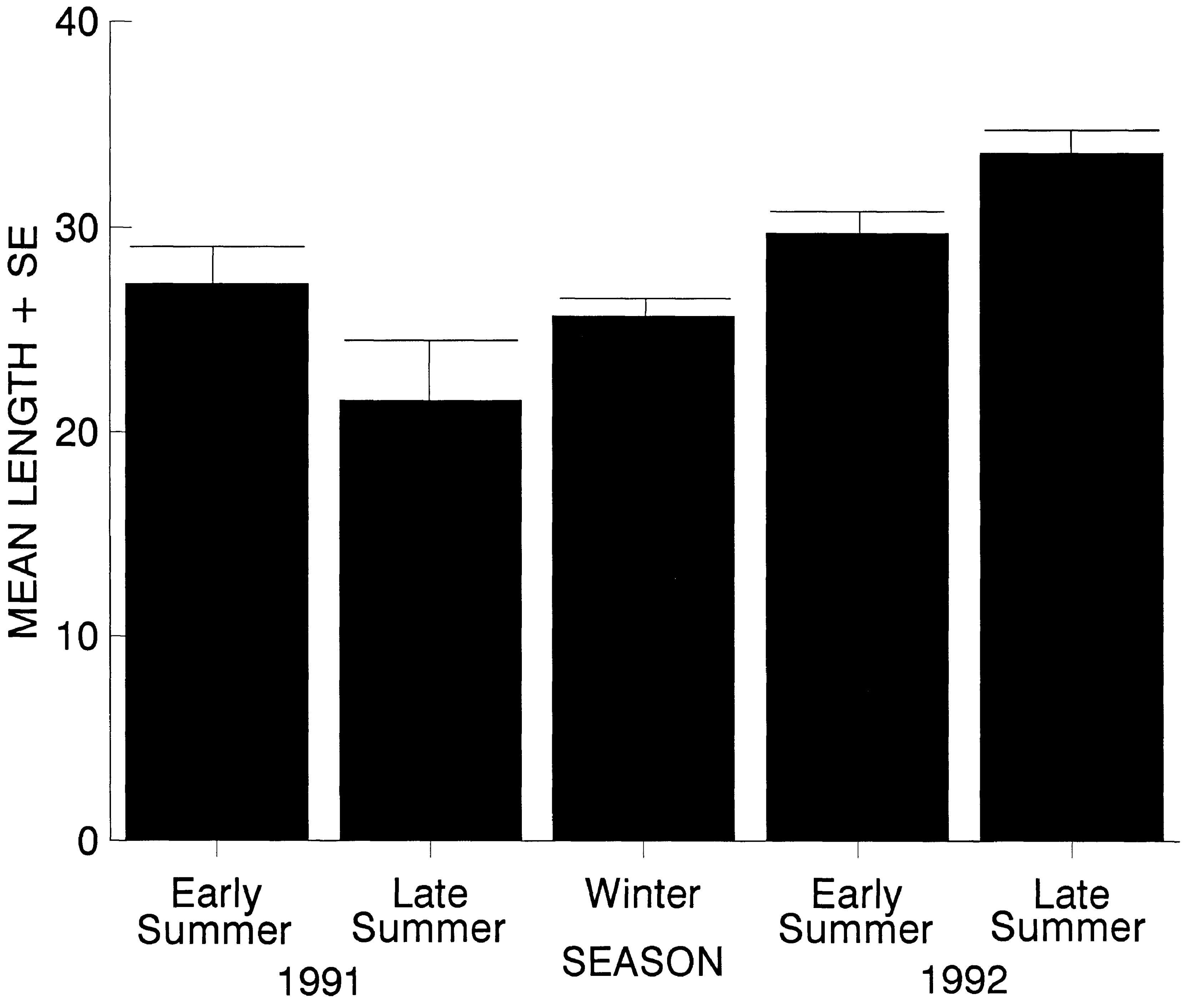
a) Two-way ANOVA.

Source	SS	df	MS	F	p
Stratum	5.08	1	5.08	0.12	0.731
Season	400.69	3	133.56	3.15	0.031
Stratum*Season	338.32	3	112.77	2.66	0.056
Error	2588.341	61	42.43		

b) Tukey-Kramer multiple comparison test. Treatments that are not significantly different at the 0.05 level share an underline. Listed in order of increasing mean length from left to right.

late summer of 1991	early summer of 1991	late summer of 1992	early summer of 1992

Figure 17. Overall mean length of tautog by season


MEAN LENGTH + SE
40
30
20
10
0
Early Summer
Late Summer
Winter
Early Summer
Late Summer
1991
SEASON
1992

tautog

seasons, but in 1992 mean length decreased from early summer to late summer (Table 10, Fig. 19). When compared between years, the early summer mean length was higher in 1992, but the late summer mean length was higher in 1991 (Table 10, Fig. 19).

Reproduction

There was no reproductive activity observed on the 4A Reef.

Recruitment

Black sea bass

In both years, the reef was populated primarily by adult black sea bass. Mean length was 15 cm in 1991 and 18 cm in 1992. In 1991, there were a few individuals less than 10 cm throughout the year. In mid-August of 1992, there was a major settlement pulse of juvenile black sea bass (< 3 cm total length). The juvenile black sea bass were observed on all three strata, either solitary or in groups of four or more. On the reef crest and edge, they were closely associated with crevices and holes in the reef, which provided shelter. The juveniles on the open sand were associated with depressions in the sand and with shell fragments.

Table 9. Cunner: Effect of stratum (crest and edge) and season (early summer 1991, late summer 1991, early summer 1992, late summer 1992) on log-transformed mean no./sample.

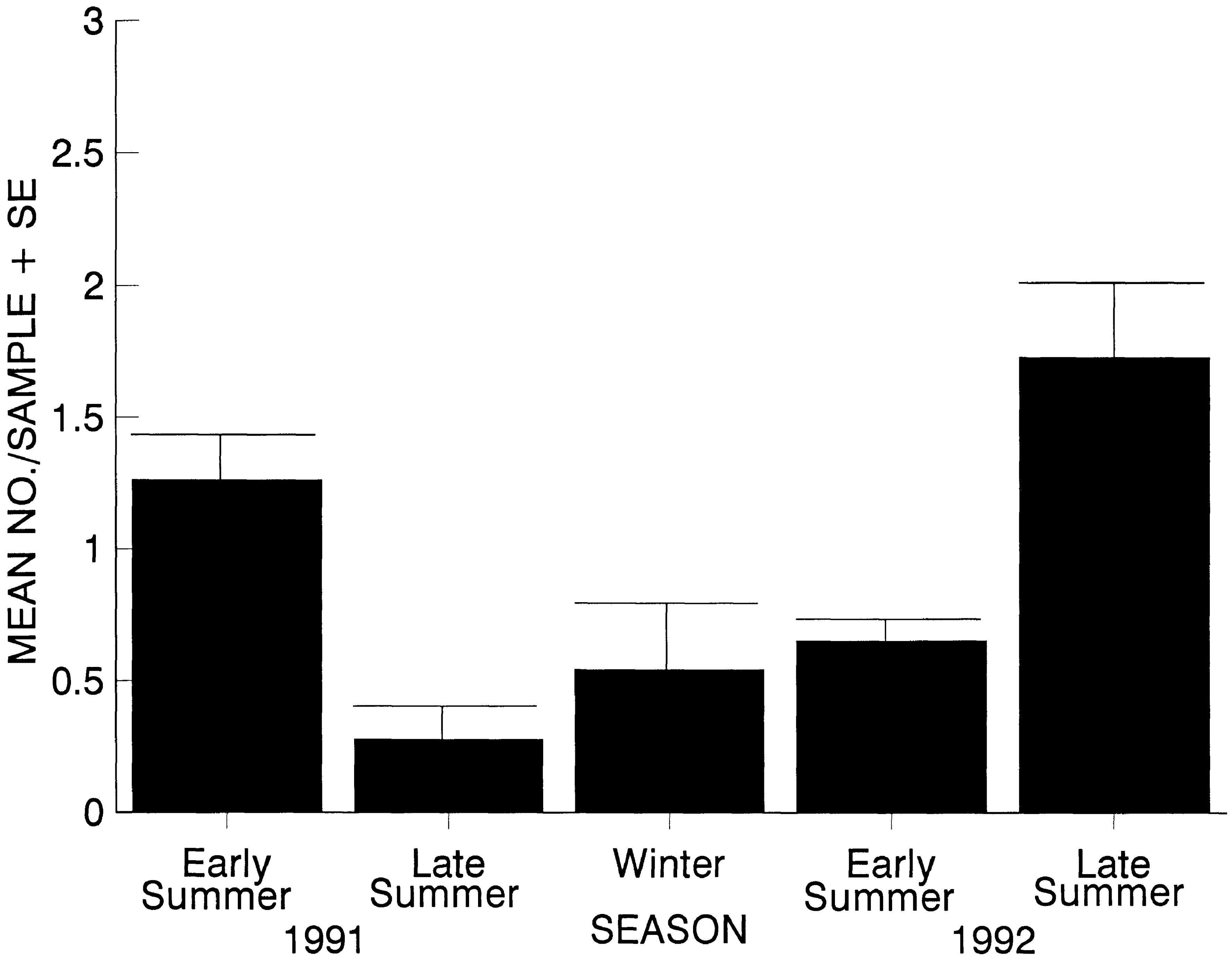
a) Two-way ANOVA.

Source	SS	df	MS	F	p
Stratum	0.09	1	0.09	0.30	0.588
Season	4.80	3	1.60	5.28	0.002
Stratum*Season	0.22	3	0.07	0.24	0.870
Error	45.14	149	0.30		

b) Tukey-Kramer multiple comparison test. Treatments that are not significantly different at the 0.05 level share an underline. Listed in order of increasing abundance from left to right.

late summer of 1991	early summer of 1992	early summer of 1991	late summer of 1992

Figure 18. Overall mean abundance (mean no./sample) of cunner by season


MEAN NO./SAMPLE + SE
3
2.5
2
1.5
1
0.5
0
Early Summer
Late Summer
1991
Winter
SEASON
Early Summer
Late Summer
1992

cunner

Table 10. Cunner: Effect of stratum (crest and edge) and season (early summer 1991, late summer 1991, early summer 1992, late summer 1992) on mean length.

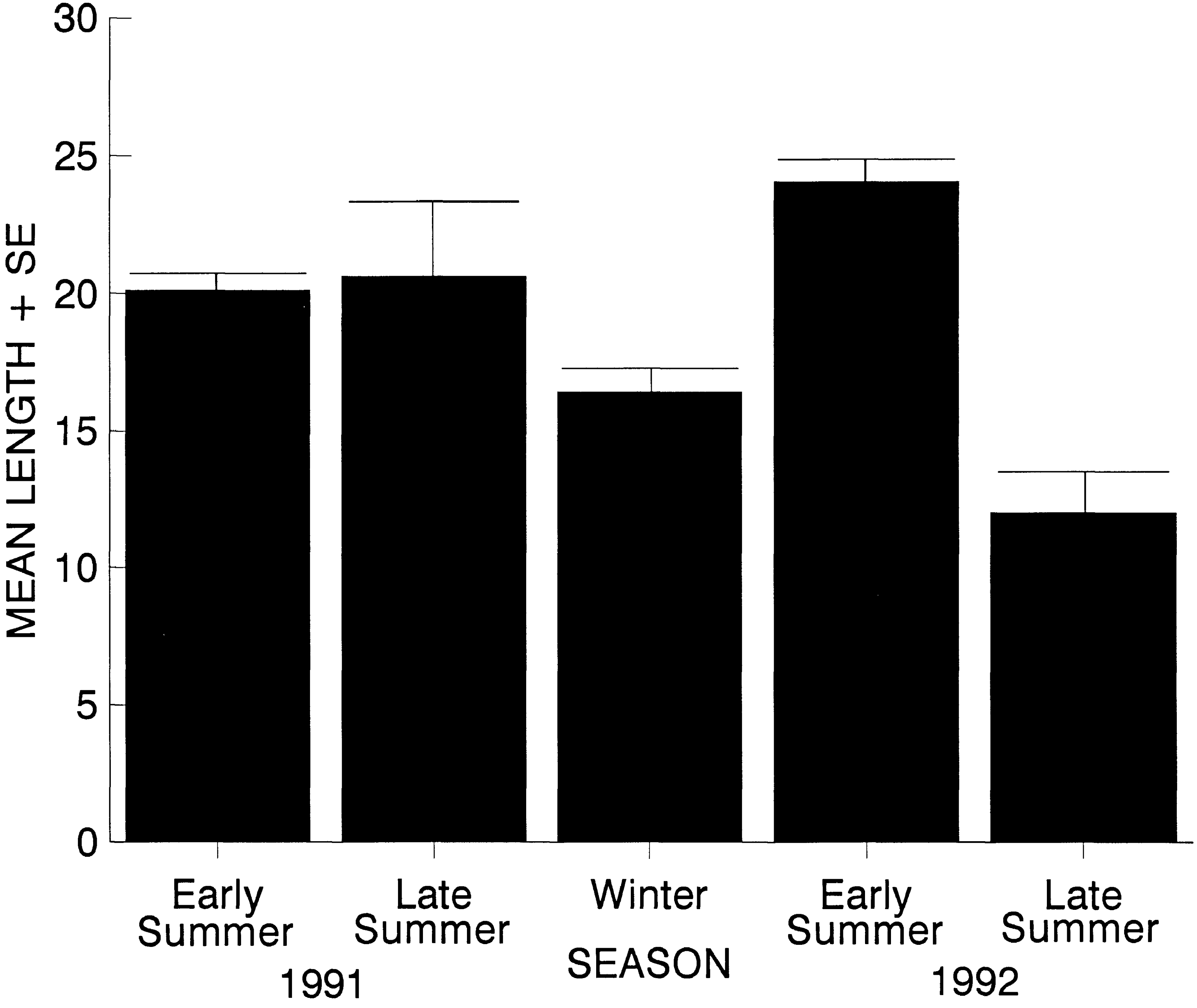
a) Two-way ANOVA.

Source	SS	df	MS	F	p
Stratum	79.75	1	79.75	1.94	0.167
Season	1997.23	3	665.74	16.23	< 0.001
Stratum*Season	125.67	3	41.89	1.02	0.388
Error	3323.28	81	41.03		

b) Tukey-Kramer multiple comparison test. Treatments that are not significantly different at the 0.05 level share an underline. Listed in order of increasing mean length from left to right.

late summer of 1992	early summer of 1991	late summer of 1991	early summer of 1992

Figure 19. Overall mean length of cunner by season


MEAN LENGTH + SE
0
5
10
15
20
25
30
Early Summer
Late Summer
Winter
Early Summer
Late Summer
1991
SEASON
1992

cunner

Scup

In both years, scup were primarily young-of-year (YOY) fish (< 15 cm total length). No newly settled juveniles and only a few isolated adults (> 15 cm) were observed.

Cunner

In both years, the reef was populated primarily by adult cunner. Mean length was 20 - 24 cm in all but late summer of 1992, when there was a major settlement pulse of juvenile (< 3 cm) cunner in mid-August. The juveniles were only observed on the reef crest and edge in groups of two or more. They were most often associated with structurally complex habitat consisting of mussel beds, piles of timbers, metal pipes and beams, or infra-structure within the reef crest.

Seasonal Resident Species

In late summer of each year, additional demersal species colonized the 4A Reef in high abundance for a brief period (26 - 42 days). Each seasonal resident species was only present in one year.

Gag, *Mycteroperca microlepis* were present from September 13 - October 21, 1991 (4 sample dates). Bottom water temperature ranged from 18.3°C to 22.8°C. Total abundance was 64 fish (Table 2), and mean sample abundance was 2.7 fish/sample. Gag were only observed on the reef crest and edge strata within approximately 1 m of shelter. Estimated mean total length was 20 cm (range = 15 - 30 cm).

Sheepshead, *Archosargus probatocephalus* were present from October 2 - October 28, 1992 (3 sample dates). Bottom water temperature ranged from 16.1°C to 19.4°C. Total abundance was 180 fish (Table 2), and mean sample abundance was 10 fish/sample. Sheepshead were observed within the reef structure and up to 4 m above the structure on the reef crest and edge strata. Estimated mean total length was 34 cm (range = 15 - 60 cm).

Gray triggerfish, *Balistes capriscus* were present as seasonal residents from September 17 - October 28, 1992 (4 sample dates). A single gray triggerfish was also present in June, 1991 and was considered a visitor. Bottom temperature ranged from 16.1°C to 20.6°C. Total abundance was 14 fish (Table 2), and mean sample abundance was 3.5 fish/sample. Gray triggerfish were observed within the reef structure and up to 2 m above the structure on the reef crest and edge strata. Mean estimated total length was 29 cm (range = 15 - 45 cm).

Baitfish (Clupeidae) were present in late summer of both years, but were dominated by a different species and in different abundance each year. Although divers observed more than one species in both years, it was possible to identify only the dominant species within a year. In 1991 the dominant species, red-eye round herring, *Etrumeus teres*, was identified from video footage and collected individuals (identified by John Olney, Virginia Institute of Marine Science). In 1992, identification of the dominant species, spanish sardine, *Sardinella aurita*, was made from still photographs (identified by George Sedberry, South Carolina Marine Research Institute). Due to the low abundance of the baitfish in 1992, collection attempts were not successful.

In 1991, baitfish were observed from August 27 to October 21 (5 sample dates), and were the most abundant group overall in late summer (Fig. 4). Total estimated abundance was over 61,000 fish (Table 2), and mean sample abundance was over 2,000 fish/sample. Estimated abundance was highest on August 27 and September 13, and gradually dropped off on each subsequent sample date. After a four week interval between sample dates, baitfish were absent from the reef on November 20.

In 1992, baitfish were present on September 2, 9 and 17, and October 28 (4 sample dates), and were the second most abundant group of late summer (Fig. 7). Total estimated abundance was 1,020 fish (Table 2), and mean sample abundance was 32 fish/sample.

Transient species

Transient species were only present during late summer of each year, and species composition differed between years. In 1991, greater amberjack, *Seriola dumerili* was the only transient species recorded (in samples or by diver observation) prior to the occurrence of baitfish. Greater amberjack were present on 33% of the sample dates in late summer and were sixth highest in abundance overall (Fig. 4). Mean length was 120 cm (range = 75 - 180 cm). Atlantic spadefish, *Chaetodipterus faber*, the only transients that were not observed feeding on baitfish, were present on 33% of the sample dates in late summer and were ranked eighth in abundance overall (Fig. 4). Mean length was 35 cm (range = 25 - 45 cm). Spanish mackerel, *Scomberomorus maculatus* were the most abundant transients, were observed on 4 of 6 (67%) sample dates in late summer, and were fourth highest in overall abundance in late summer (Fig. 4). Mean length was 50 cm (range = 30 - 80 cm). Atlantic bonito, *Sarda sarda* were present on only one sample date, but were ranked seventh in abundance overall (Fig. 4). Mean length was 65 cm. Little tunny, *Euthynnus alletteratus* were present on one sample date in low abundance (Fig. 4). Estimated length was 60 cm. All transient species were absent prior to the departure of baitfish.

Transient species abundance in late summer 1992 was lower than in 1991. Greater amberjack was the most abundant transient species in 1992, and was the only transient which increased in abundance relative to 1991. Amberjack were present on 6 of 8 sample dates in late summer and were ranked fifth in overall abundance (Fig. 7). Mean length was

130 cm (range = 100 - 150 cm). All other species present in 1991 were either absent or in lower abundance in 1992. Spanish mackerel were present on only one sample date in 1992 and were ranked ninth in abundance overall in late summer (Fig. 7). Mean length was 21 cm (range = 15 - 23 cm). Atlantic spadefish were present on only one sample date and were ranked tenth in abundance overall in late summer (Fig. 7). Estimated length was 50 cm for all individuals. A barracuda, *Sphyraena barracuda* was present in one sample and ranked fourteenth in abundance overall for late summer (Fig. 7), but up to 6 barracuda were observed in surface waters above the reef over a 4 week period. Estimated length was 100 cm. Atlantic bonito and little tunny were not present in 1992.

Seasonal Variability

Changes in total abundance and species richness were correlated with seasonal changes in water temperature. Bottom water temperature varied seasonally, from a low of 6.1°C in February, 1992, to a high in September of 22.8°C in 1991 and 20.6°C in 1992 (Table 1). The temperature in 1992 was lower than in 1991 on all sample dates. Total fish abundance was positively correlated with temperature ($R^2 = 0.668$, $F = 59.106$, $df = 1,29$, $p < 0.001$) (Fig. 20), with a low in February, 1992 and a high in late summer of both years (Table 1). Species richness also varied throughout the study and was positively correlated with bottom water temperature ($R^2 = 0.671$, $F = 58.394$, df = 1,29, $p < 0.001$) (Fig. 21). The lowest species richness level was in February, 1992, and the highest occurred in the late summer of both years (Table 1).

Figure 20. Relationship between bottom water temperature and total reef fish abundance. Abundance is on a log scale

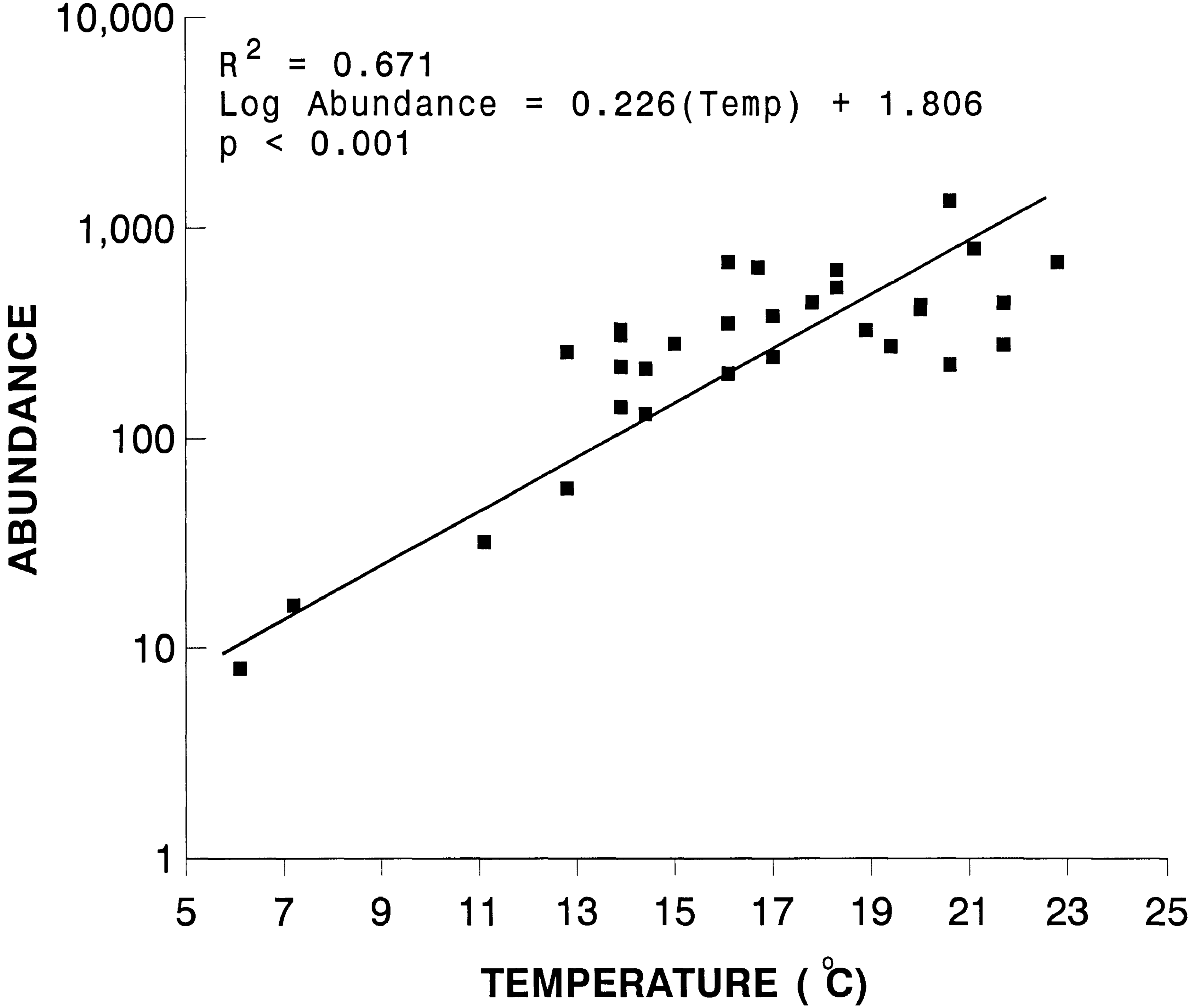
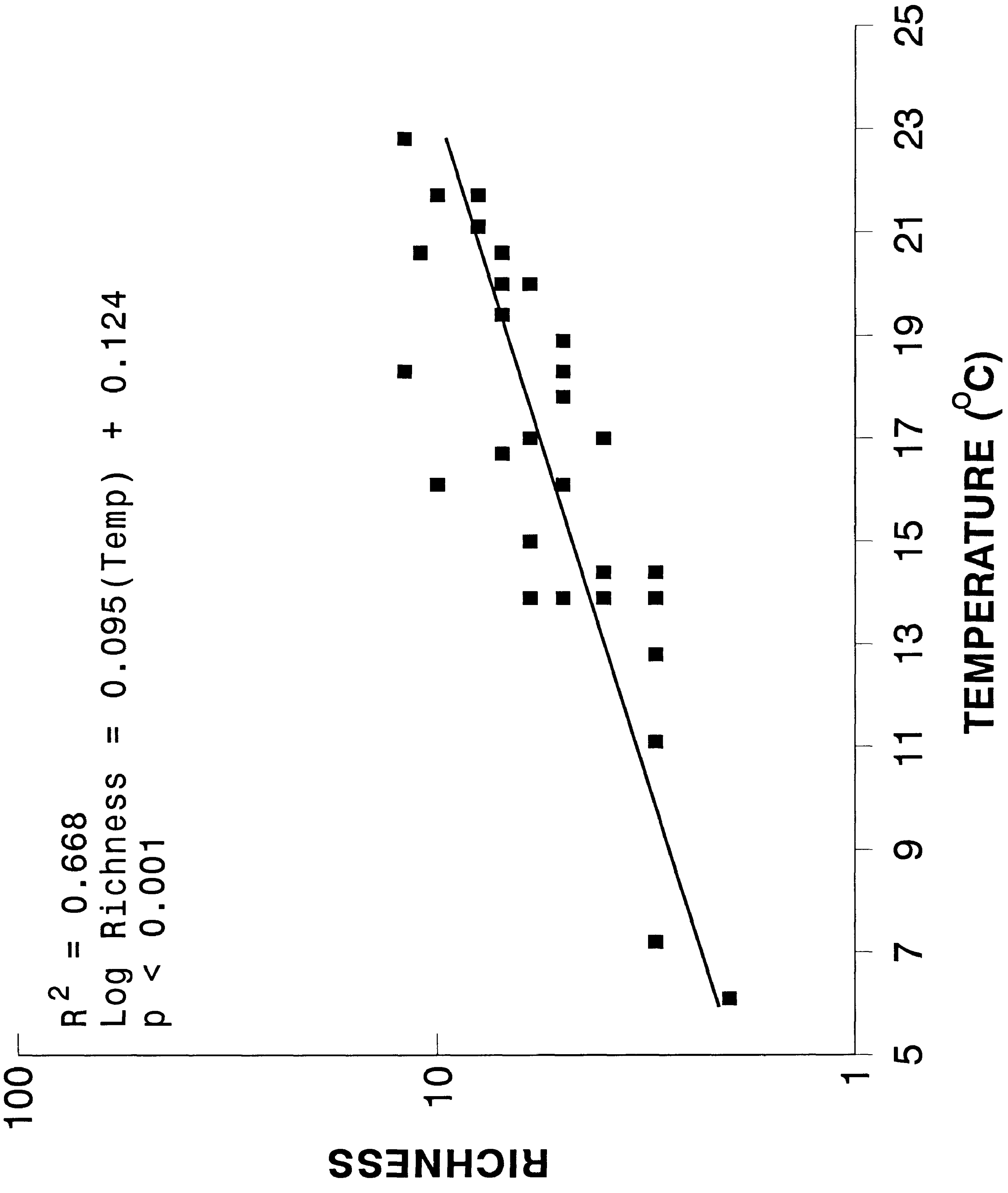

$R^2 = 0.671$
Log Abundance = 0.226(Temp) + 1.806
$p < 0.001$
ABUNDANCE
10,000
1,000
100
10
1
5
7
9
11
13
15
17
19
21
23
25
TEMPERATURE (°C)

Figure 21. Relationship between bottom water temperature and total species richness. Richness is on a log scale


R 2 = 0.668
Log Richness = 0.095(Temp) + 0.124
p < 0.001
RICHNESS
100
10
1
TEMPERATURE (°C)
5
7
9
11
13
15
17
19
21
23
25

Discussion

Core Resident Species

Seasonal and Spatial Variation

Black sea bass

Black sea bass are associated with structure throughout their range (Kendall, 1977; Musick and Mercer, 1977; Mercer, 1989) and their close association with the 4A Reef was probably due to attraction to structure. The diet of black sea bass is varied (including invertebrates and fish) (Kendall, 1977) and does not suggest a preference for a stratum due to a potential food source. Although black sea bass were present on the open sand in all seasons, their high abundance on the crest and edge suggests a reliance on the 4A Reef for shelter.

The seasonal variation in overall abundance of black sea bass was probably largely the result of migratory behavior. In the spring, black sea bass migrate into the nearshore region of the MAB from areas offshore and south, where the majority of the MAB population over-winters (Musick and Mercer, 1977). Musick and Mercer (1977) report that the first juvenile black sea bass of the year were caught in the York River estuary in March and April, at temperatures of 9 - 10°C, similar to the pattern of black sea bass spring arrival observed in this study. In 1991, black sea bass were already abundant on the 4A Reef during the pilot study (April - May), when temperature ranged from 10 - 13.3°C. In 1992, abundance increased when the temperature reached 12.8°C on June 1.

Contrary to the conclusions of other studies, observations of black sea bass behavior on the 4A Reef indicate that they are active throughout the summer. Musick and Mercer (1977) and Eklund and Targett (1991) attributed higher catch rates in May and June to a higher catchability of black sea bass migrating inshore, and lower summer catch rates to a seasonally static population. They hypothesized that black sea bass in the summer months remained in shelters (natural hard bottom and artificial reefs) inaccessible to trawls (Musick and Mercer, 1977) and did not move enough to encounter traps placed within these shelter areas (Eklund and Targett, 1991). In this study black sea bass moved about the reef in a level of activity that did not vary noticeably from June through October of either year.

The decrease in overall mean abundance and mean length from early summer to late summer of both years suggests loss of fish due to fishing mortality and seasonal movement, contrary to the hypothesis of Musick and Mercer (1977) mentioned above. Mortality due to fishing may explain the decrease in overall mean abundance and mean length in each year since fishing pressure would selectively remove the larger fish. However, the decrease in mean abundance occurred primarily on the reef crest in each year (Table 3, Fig. 8), but the decrease in mean length occurred predominately on the open sand in 1991 and both the open sand and edge in 1992 (Table 4, Fig. 9). There was no significant decrease in mean abundance on either the open sand or edge to account for movement of large fish from the sand and edge to the crest. In 1992, the decrease in mean length was partly due to the large settlement of juveniles, but in 1991 there was no settlement event. Furthermore, fishing pressure appeared to be higher in 1992 relative to 1991, but the greatest decrease in overall mean abundance from early summer to late summer was in 1991. Juvenile abundance in 1992 did not appear to be high enough to offset the difference. Since a large-scale tagging project was beyond the scope of this study, it is speculation that black sea bass move between reef areas throughout the summer. If within summer movement does occur, then black sea bass could move onto the 4A Reef in place of those removed by fishing. The decrease in mean abundance from early summer to late summer may have been caused by a rate of removal (fishing mortality and emigration) that was greater than the rate of movement onto the reef.

If fishing pressure did affect the changes in abundance and size of black sea bass on the 4A Reef, then data are needed to determine the long-term and region-wide impact of reef-associated fishing mortality on the MAB black sea bass population. If a large portion of the MAB black sea bass population is concentrated on artificial reefs in summer months, high reef-associated fishing mortality may offset the positive effect of additional shelter provided by these reefs. For example, in the SAB, where fishing mortality may account for over 80% of the maximal yield-per-recruit, a minimum size was established due to the potential over-fishing of small fish (Mercer, 1989). There is no such size minimum in the MAB. Since black sea bass are protogynous hermaphrodites, with most females less than 26 cm standard length and most males greater than 28 cm, removal of larger fish may skew the sex ratio in the favor of females to such a degree that there are not enough males for adequate reproduction (Musick and Mercer, 1977). This can only be offset by the ability of females to reverse sex at a younger age (smaller length) to restore the sex ratio to adequate levels. However, even the ability of the population to adapt to the disproportionate removal of larger males may be offset by the over-harvesting of small fish that may occur in the absence of appropriate catch and size limit regulations. Research that simultaneously examines artificial reef fish assemblages from different perspectives (i.e., visual census, catch per unit effort, tag-recapture) may provide information on the significance of fishing pressure to these fish assemblages. In addition, estimates of the distribution of black sea bass in the MAB (i.e., proportion of black sea bass on artificial reefs versus on open sand bottom) are needed to establish the importance of the reef-associated fish assemblages to the overall MAB black sea bass population.

The higher mean abundance and smaller mean length of black sea bass in 1991, compared to 1992, was not limited to the 4A Reef site and was probably not related to differences in temperature. In both years I observed black sea bass on other artificial reefs in abundances similar to the levels recorded on the 4A Reef. Although temperatures were lower in 1992 than 1991 they were above minimum temperature for spring migration (Musick and Mercer, 1977). Furthermore, when bottom water temperature in 1992 increased to a level similar to the high in 1991 there was no increase in the overall mean abundance. Perceived low catch by anglers in 1992 is also suggestive of lower abundance of black sea bass at other locations during this time.

In the fall, black sea bass appeared to use the 4A Reef as a resting point in their southward and offshore migration. Black sea bass in the MAB begin migration from inshore habitats to offshore over-wintering grounds when the temperature falls below 14°C (Morse, 1978). The 4A Reef is the only known structure south of the Chesapeake Bay and the Chesapeake Light-Tower Artificial Reef Complex. On November 20, 1991, when bottom water temperature fell to 12.8°C, there was an increase in abundance of black sea bass, especially large fish (estimated mean length = 21.5 cm). Mean abundance had substantially decreased by the next sample date (January 23, 1992), when the bottom water temperature was 7°C.

While the majority of the MAB black sea bass population winters in deeper waters offshore, some individuals over-wintered at the 4A Reef site. Musick and Mercer (1977) suggested that black sea bass actively avoid temperatures below 6°C, and their trawl catches at temperatures close to 6°C consisted of small fish (< 11 cm) in depths > 29 m. Winter temperatures at the 4A Reef were also near 6°C, but maximum depth was only 21.3 m and there were larger black sea bass (up to 32 cm) than in the trawls. The black sea bass observed at the 4A Reef in winter were resting on the bottom under structure or in crevices, in a state of low activity. Divers were able to easily approach many of the fish. This behavior is similar to that exhibited by cunner and tautog, which over-winter in a torpid state at low temperatures (Olla et al., 1974, 1975, 1979). I did not visit other area artificial reefs during this period, so I do not know the extent of black sea bass over-wintering in inshore areas of the MAB. However, if black sea bass over-winter on other inshore artificial reefs, a large number of artificial reefs placed in the nearshore environment may have an impact on the migratory behavior of the species.

Scup

The high abundance of small scup in both years suggests that they use the 4A Reef as a seasonal nursery. The spring arrival of scup coincided with the inshore migration from wintering grounds offshore and south of the 4A Reef, in areas similar to those used by black sea bass (Morse, 1978; Musick and Mercer, 1977). However, scup were expected to arrive inshore in April (Hildebrand and Schroeder, 1972), but did not appear on the 4A Reef until June. The later arrival of scup at the 4A Reef relative to published reports may be explained by the nature of the inshore migration of the species, which is reported to occur in three distinct waves (Morse, 1978). The larger fish of 30 - 36 cm arrive first, followed by 25 cm fish and finally by YOY fish of 10 - 15 cm.

The increase in mean abundance and decrease in mean length from early summer to late summer in both years, and similar changes in seasonal spatial distributions in both years, also supports the hypothesis that smaller fish arrive later and use the 4A Reef as a nursery area. Scup are associated with structure throughout their range (Morse, 1978; Eklund and Targett, 1991), and their diet consists of various benthic-associated invertebrates, which were likely available at the 4A Reef. Scup appeared to be attracted to the reef structure and used only the reef crest and edge when they were in low mean abundance in early summer of both years. When mean abundance increased in late summer they were forced to utilize the open sand surrounding the reef as well as the crest and edge. For example, the presence of the smallest fish on the open sand in late summer of both years suggests that there was segregation across stratum by size. It is possible that, when in high abundance, size segregation was due to competition for the limited shelter provided by the reef structure.

The numerical dominance of scup at the 4A Reef in late summer was similar to the findings of area trawl surveys (Musick et al., 1985). However, scup were never numerically dominant on the natural hard bottom areas studied by Eklund and Targett (1991). Even in months of highest abundance, scup did not contribute more than 40% of the incidental catch, which excluded black sea bass (Eklund and Targett, 1991). No length data were provided in either study, so it is not known if the catch of scup was dominated by a particular size-class. The low abundance of scup on the natural hard bottom was likely due to the method of sampling. Eklund and Targett (1991) used incidental catch data from traps employed in the local black sea bass fishery to measure relative abundances of fish species. This method of sampling is biased toward fish that may seek shelter. Scup are often associated with structure, but are not known to actively seek shelter areas (Morse, 1978). Moreover, if YOY scup were abundant during sampling in the Eklund and

Targett (1991) study, the smaller fish may have been able to exit small holes in the traps, resulting in an underestimation of their abundance. The visual census method used in this study enabled me to document the importance of scup to MAB reef fish assemblages.

In the fall, scup migrate offshore to over-wintering grounds (Morse, 1978). Although scup are thought to begin migration at 10°C, scup were absent from the 4A Reef on November 20, 1991 when bottom water temperature was 12.8°C. There is no data available from this study that would explain the early exit of scup from the 4A Reef in 1991. In 1992, this study was terminated prior to the fall migration period.

The absence of older scup on the 4A Reef and other area reefs suggests that they do not utilize the reef after their first year, but are likely inhabiting the open sand habitat of the nearshore region. The utilization of the sand habitat by older scup is reflected in the high abundance of scup in the inshore trawl surveys in the spring and summer months (Musick et al., 1985). Other area reefs that I observed during these periods were also dominated by YOY scup. The importance of artificial reefs to recruitment success of juvenile scup needs to be examined to determine consequences of reef placement on the MAB scup population.

Tautog

The presence of tautog only on the crest and edge strata is likely due to their dependence upon structure for food, primarily blue mussel, and shelter (Olla et al., 1974, 1975; Auster, 1989). The area of the 4A Reef available for shelter and feeding was limited to the reef crest and edge.

The stable nature of the tautog assemblage on the 4A Reef from winter to early summer of 1992 and between years suggests that tautog use the 4A Reef as an over-wintering site rather than over-wintering offshore. In the northern MAB, small tautog over-winter in nearshore areas but larger fish spend the winter offshore and migrate inshore in the spring (Olla et al., 1974, 1979). The high catch rates of tautog on MAB natural hard bottom habitat in the spring were attributed to an increase in abundance as a result of the inshore spring migration (Eklund and Targett, 1991). However, similar abundances of tautog from winter to early summer of 1992 and between early summer of both years (Fig. 12) suggests that although seasonal migrations may occur, some individuals may be residents on artificial reefs throughout the year.

Eklund and Targett (1991) attributed lower catch rates of tautog in the summer months to lower activity levels and residence in confined shelter areas; the observations from my study do not support this hypothesis. Differences in mean abundance (Fig. 12) and mean length (Fig. 13) between seasons suggest possible migration during the summer. In 1991, the extended period of bottom water temperature greater than 20°C may have initiated movement away from the 4A Reef by larger fish. Since seasonal migrations are influenced by temperature, it is possible that within-season movements may also be influenced by temperature. Although the upper lethal temperature for tautog is around 26°C, previous laboratory studies have demonstrated a change in behavior (primarily residence in shelters) of small tautog at temperatures approaching the upper limit (Olla et al., 1974, 1980). Tautog on the 4A Reef were not confined to a small tank, as in lab studies, and larger fish may have left the area due to the higher temperatures. Although there were only two dates with bottom temperature above 20°C in 1992, the higher mean length in late summer suggests movement in this year as well. The seasonal decrease in abundance was not likely due to fishing mortality since most fishing for tautog occurs from November through April. Within season movements in the southern portion of the MAB appear to occur on an annual basis, but more data is needed before making regional inferences.

Some of the tautog present on the 4A Reef in late summer remained rather than migrating offshore in the fall. In the northern MAB, small tautog generally do not migrate in the fall and become torpid and reside in shelters when water temperature falls to 8°C (Auster, 1989). Larger tautog generally migrate offshore at about 10°C (Olla et al., 1974), but some may remain nearshore and become dormant at lower temperatures (Auster, 1989). Contrary to reports of torpor at low temperatures, tautog at the 4A Reef were active throughout the winter months, even when bottom water temperatures were 7.2°C in January and 6.1°C in February. Eklund and Targett (1991) also reported catches of tautog at artificial reef habitats during winter, which is additional evidence of active behavior by nearshore resident tautog throughout the year. The presence of active tautog on artificial reefs in Virginia throughout the year was also observed by Hostetter and Munroe (in press), who suggest that tautog in the southern MAB remain in the vicinity of artificial reefs throughout the year.

In addition to the resident tautog that remained on the 4A Reef during the winter, I also observed large tautog (> 75 cm TL) outside the sample space during an observational dive in February. These large tautog were well within the reef structure and were only visible when divers illuminated small holes with a flashlight. This was the only time at which tautog this large were observed on the 4A Reef. The presence of these large fish at the 4A Reef, which is only 14 km from shore and is the only known reef in the area, suggests that large tautog in the MAB may be seeking an isolated area for over-wintering rather than moving great distances offshore. The 4A Reef may supply a structural shelter for large tautog in the winter months, providing a shorter migration than to offshore sites.

Cunner

Cunner were present only on the reef crest and edge strata due to their dependence on structure for food, benthic and near-bottom invertebrates, and shelter (Olla et al., 1975, 1979; Auster, 1989). Cunner feed during the day and remain within a few meters of shelter when foraging (Olla et al., 1975, 1979), which limited their range to the crest and stratum.

In spring cunner move from over-wintering areas to nearshore seasonal habitats, such as seagrass (Olla et al., 1979), but no definitive spring migrations were observed in cunner on the 4A Reef. In studies of cunner in nearshore areas, Olla et al. (1979) hypothesized that the spring migration to seasonal habitats may be due to aggression related to spawning, which occurs from May - June (Auster, 1989). In this study comparison of winter and early summer of 1992 data shows no change in mean density and there was no reproductive behavior observed in either year.

It was difficult to define the summer population of cunner on the 4A Reef due to the great deal of seasonal and annual variation in mean abundance (Figs. 14) and length (Fig. 15). In 1991, the decrease in density from early summer to late summer may have been due to active avoidance of high temperatures, a response similar to that of tautog in 1991. In 1992, the increase in mean abundance and mean length from early summer to late summer was probably due to a settlement event of juvenile cunner. Since only maximum, minimum and mean length were estimated, any change in adult mean abundance in 1992 was concealed by the settlement event.

In contrast, the variations in mean abundance and length between early summer of 1991 and 1992 were probably not related to differences in temperature. The temperatures at the 4A Reef in early summer of 1991 and 1992 were well within the range suitable for normal cunner activity (Auster, 1989). Moreover, the mean abundance of tautog, which inhabits similar temperature ranges, was similar between years. The higher abundance and lower mean lengths in late summer of 1992 was likely due to the settlement of juveniles in mid-August.

Cunner remained at the 4A Reef throughout the winter months, which is similar to their behavior in the northern MAB (Olla et al., 1979). When the temperature falls to 6°C cunner reside in shelters in a torpid state, and remain there until temperatures rise in the spring (Olla et al., 1975). Cunner were absent only in February, when the bottom water temperature was 6.1°C, and may have been hidden in a torpid state.

The differences in cunner behavior at the 4A Reef, such as the apparent lack of spring migration to nearshore seasonal habitats and apparent emigration in late summer of 1991, compared to other studies may be due to differences arising from the offshore and isolated location of the 4A Reef. Olla et al. (1975, 1979) studied cunner in nearshore areas of the northern MAB, which are subject to different environmental stresses (e.g., greater temperature extremes in shallower water). They acknowledge the presence of cunner on offshore shipwrecks, but did not believe they were a significant part of the regional cunner population. As such, there is no information on behavior or colonization of cunner associated with offshore sites (Olla et al., 1979). If cunner associated with offshore reefs behave similarly to tautog (i.e., capable of migrating long distances), they would be able to migrate to and from MAB artificial reefs, and potentially colonize reefs where cunner were in low abundance. If they are not able to migrate long distances, then the only source of new individuals is juvenile settlement, the success of which may vary. Thus, the relative importance of biotic and physical factors to recruitment success of cunner on artificial reefs is critical to defining how these structures may fulfill certain life history requirements in this species.

Reproduction

Black sea bass

Since ripe black sea bass have been caught on natural hard bottom in the MAB I expected reproductive activity on the 4A Reef, but none was observed. Black sea bass probably spawn off the Virginia coast beginning in late May, with a peak in July in depths of 18-45 m (Musick and Mercer, 1977; Kendall, 1977). Since black sea bass larvae have been found in MAB trawls in November and the larval stage is short, spawning may occur until this late in the year (Kendall, 1977). Eklund and Targett (1990) reported ripe black sea bass from mid-July through mid-August on natural hard bottom off the coasts of Maryland and northern Virginia, and female black sea bass with eggs were caught throughout this same season on artificial reefs in nearshore Virginia waters (Feigenbaum et al., 1985). Black sea bass mature at between age I and IV (9 - 20 cm) (Mercer, 1978), and mature fish were present on the 4A Reef in both years. There has been published observations of black sea bass spawning behavior. I monitored the black sea bass for territorial displays, mate selection and group spawning behavior. Black sea bass behavior was not obviously different at any point in the study.

Scup

Scup did not spawn on the 4A Reef due to the dominance of immature fish. Scup spawn from May to August in nearshore waters of the northern MAB, which coincides with spawning times of other inshore spring spawners such as tautog (Morse, 1978). No information is available on spawning substrate. Scup mature at 11 - 21 cm fork length (Finklestein, 1969), but the mean estimated lengths of the scup on the 4A Reef were 9 - 11 cm total length throughout the study. Eklund and Targett (1990) were also unable to find evidence of spawning on natural hard bottom in 25-35 m depth. Since there is no information describing the mating behavior of scup I was only able to monitor for behavior distinctly different from the norm. Scup behavior did not differ throughout the study.

Tautog

Although ripe tautog occurred on other area reefs, no spawning was observed among the mature fish on the 4A Reef. Tautog in the southern MAB spawn from May - July (Eklund and Targett, 1991; Hostetter and Munroe, in press) in pairs or groups on hard substrate (Olla et al., 1974, 1981). Tautog in the MAB mature at age III, 21 - 25 cm total length (Hostetter and Munroe, in press), and mature fish were present on the 4A Reef in both years. Males attempt to set up territories, and whether spawning occurs in pairs or in groups there is usually male-male aggression prior to spawning, often along territorial boundaries (Olla et al., 1981). I monitored tautog behavior on the 4A Reef for territorial defense, aggression and courtship in May of 1992 and early summer of both years, but at no time did I observe such behavior.

Cunner

Mature cunner were present on the 4A Reef in both years, but no reproductive activity was observed. The smallest cunner on the 4A Reef, other than the juveniles in late summer of 1992, were age IV or more years (Serchuk and Cole, 1974). Cunner spawn from May - August and exhibit mating behavior and site selection similar to tautog (Auster, 1989). Males may become territorial and spawning occurs in pairs or in groups. Most male territorial behavior occurs in the afternoon (Auster, 1989), and most sampling at the 4A Reef encompassed the early afternoon hours. I monitored cunner for behavior patterns similar to those expected for tautog, but at no time did I observe such behavior.

In light of the lack of fish collection and gonad analysis, and possible differences in time-of-day of spawning and sampling, the lack of observed spawning behavior does not conclusively determine that the resident species do not use the 4A Reef as a spawning area. Data are needed on seasonal gonadal development of these four species on the 4A Reef before final conclusions can be made.

Recruitment

The routes of larval transport for black sea bass and cunner are not known, but larvae of both species have been found in plankton tows in the MAB. Black sea bass larvae up to 1.3 cm in length have been collected in plankton tows from June through November between Sandy Hook, New Jersey and Cape Lookout, North Carolina at distances of 4 - 82 km from shore (Kendall, 1977). The 4A Reef is 14.8 km from the nearest shore. The pelagic stage of black sea bass is short, and the larvae likely become demersal in the regions they were collected (Kendall, 1977). Cunner larvae were also found in summer plankton tows in the MAB (Colton et al., 1979). After a pelagic stage of 18 to 21 days, settlement probably occurs. The majority of cunner settlement in the Gulf of Maine occurs in July and August (Levin 1991), similar to the time of observed recruitment of juveniles to the 4A Reef. The difference in water temperature and the lack of settlement in 1991 may indicate annual variation in the hydrographic patterns of the area. Additional monitoring is necessary to determine; 1) if juvenile settlement is a consistent mechanism of colonization for these species, 2) survivability of juveniles on the reef, and 3) if the 4A Reef provides adequate habitat for the juvenile stages of these species.

Species-specific requirements are the cause for the difference in recruitment success between cunner and tautog.

The shelter provided by the 4A Reef was likely adequate for cunner, but may have been lacking for tautog. The association of juvenile cunner on the 4A Reef with complex habitat is similar to behavior of juvenile cunner in the Gulf of Maine (Levin, 1991). Juvenile cunner are cryptically colored, like the adults, and inhabit micro-habitats in areas of adult residence. Newly settled juvenile tautog also prefer structural habitat, but in nearshore areas with patches of sea lettuce (Sogard et al., 1992). Small juveniles are bright green in color, similar to the color of sea lettuce, which may make them more vulnerable to predation in areas without sea lettuce. Sogard et al. (1992) collected small, bright green juveniles (< 35 mm SL) only in patches of sea lettuce or artificial sea grass, but found larger juveniles with a darker, mottled, adult-like coloration in eelgrass and other structural habitats. This suggests a change in habitat requirements with life stage. The 4A Reef did not have patches of bright green algae or sea grass and was probably not a suitable habitat for juvenile tautog settlement. The smallest tautog observed on the 4A Reef was 12 cm (age I), and most likely migrated to the 4A Reef from inshore habitats.

Seasonal Residents

Gag on the 4A Reef were young fish that used the reef as a temporary source of shelter, and possibly food, on their southward migration. Gag are structure oriented with an adult population centered in the SAB (Naughton and Saloman, 1985). Young gag inhabit estuarine areas along the east coast of the United States, but it is not known if the estuaries are used as nursery areas (Manooch, 1984). Gag on the 4A Reef were age 1 - 2 (15 - 30 cm) (Manooch and Haimovici, 1978), and may have inhabited estuarine areas of the MAB during the summer and then used the 4A Reef as a stopover during the return to the MAB. Alternatively, they may have used the 4A Reef instead of estuarine areas as seasonal habitats. Baitfish are a seasonal component of their diet in the SAB (Naughton and Saloman, 1985), and may have been a source of food on the 4A Reef. Gag were also present seasonally in low relative abundance on the natural hard bottom in 1987 (Eklund and Targett, 1991), but no information was provided on the presence of baitfish or other potential food sources.

The sheepshead observed on the 4A Reef were adults age 1 to > 8 (15 - 60 cm) (Schwartz, 1990) that likely migrated from the SAB. Sheepshead range along the east coast of North America from Nova Scotia to Cedar Key, Florida. The minimum preferred temperature is above 15°C (Manooch, 1984), and individuals that spend summer months in the MAB probably migrate south in the fall. Sheepshead were once seasonally abundant in the Chesapeake Bay region (Hildebrand and

Schroeder, 1972), but more recently were not present on natural hard bottom (Eklund and Targett, 1991) or open bottom (Musick et al., 1985). In the SAB, sheepshead feed primarily on sessile invertebrates (Sedberry, 1987). Blue mussel, colonial tunicate (*Amaroucium stellatum*), and other fouling growth were abundant on the 4A Reef crest and edge, strata occupied by sheepshead.

The gray triggerfish associated with the 4A Reef were age 1 - 8 (15 - 45 cm) (Johnson and Saloman, 1984) and used the reef as a source of shelter and possibly as a source of food. Gray triggerfish range from Massachusetts to Brazil and are usually associated with hard structure (e.g., artificial reefs and rock outcroppings) (Manooch, 1984), and were present on the MAB natural hard bottom (Eklund and Targett, 1991). Their diet includes epibenthic invertebrates (e.g., mussels and urchins) and fishes (Manooch, 1984). Gray triggerfish in the Gulf of Mexico forage over open sand around artificial reefs, primarily for sand dollars (Frazer et al., 1991). Due to the varied diet of gray triggerfish, and the presence of urchins and mussels on the 4A Reef, the 4A Reef may have provided food as well as shelter.

The dominant species of baitfish from both years are seasonally migratory. Red-eye round herring inhabit nearshore and offshore waters (Hildebrand, 1963) and range from the Bay of Fundy to Venezuela (Whitehead, 1985).

Spanish sardine inhabit water 13 - 31°C from Cape Cod to Argentina in the western Atlantic, migrate along the continental shelf (Johnson and Vaught, 1986), and are attracted to artificial reefs (Klima and Wickham, 1971).

The difference between years in mean abundance of baitfish may have been due to temperature, but there is no explanation for the change in dominant species. Clupeids, and other families of baitfish, were also present on artificial reefs south of Cape Hatteras, North Carolina. They were present throughout the year, but increased in abundance in the warmer summer months (Stephan and Lindquist, 1989), which suggests seasonal migrations. In 1991, when red-eye round herring were dominant, the water column was well mixed by August 27, the date baitfish were first observed, and remained well mixed through the end of October. In 1992, when spanish sardine were dominant and total abundance was low relative to 1991, bottom water temperature was lower than in 1991 in the months prior to August, and there was a distinct thermocline until October 2. The lower temperatures and late mixing of the water column may have hindered seasonal migration of clupeids in 1992.

Transient Species

The high abundance of pelagic fishes noted at the 4A Reef in 1991 is generally not indicative of a low profile reef (Grove and Sonu, 1983), and the majority of transient species at the 4A Reef were probably there in response to the presence of baitfish. In the SAB, baitfish are a major component of the diets of the piscivorous transient species (Saloman and Naughton, 1983; Manooch et al., 1985; Johnson and Vaught, 1986) observed on the 4A Reef. Stephan and Lindquist (1989) also observed a high abundance of pelagic species on artificial reefs south of Cape Hatteras, North Carolina, which they attributed to the presence of baitfish.

In 1992, the low abundance of some species, and absence of others, was probably due to the low abundance and sporadic occurrence of baitfish and low water temperatures. Little tunny and atlantic bonito were likely absent due to the low abundance of baitfish, whose large numbers attracted them in 1991. The bottom water temperature reached 20°C on only two sample dates in 1992. Spanish and king mackerel begin to migrate southward when water temperature drops below 20°C (Huntsman and Manooch, 1978), and may have been in low abundance (spanish mackerel) or absent (king mackerel) due to the low water temperatures in addition to low baitfish abundance.

The presence of greater amberjack in the absence of baitfish may be explained by their varied diet and their association with structure. The diet of greater amberjack includes various fish and invertebrate species (Manooch and Haimovici, 1983), and many fish species were present on the

4A Reef in both years. Greater amberjack are also present at artificial reefs in North Carolina (Stephan and Lindquist, 1989), and are common at other artificial reefs in the region on a seasonal basis (pers. obs.).

Spadefish were associated with the 4A Reef as a point of orientation and possibly as a source of food. Spadefish are associated with artificial reefs in the SAB (Hayse, 1989) and with artificial reefs and channel markers in the MAB (author, pers. obs.). The diets of spadefish associated with artificial reefs in the SAB were dominated by epibenthic algae and invertebrates associated with the reefs (Hayse, 1989). The fouling community of the 4A Reef was composed of a number of different invertebrate taxa and may have served as a food source.

Barracuda prefer water temperatures above 20°C and are occasionally found as far north as Massachusetts along eastern North America (Manooch, 1984), but their presence in the Chesapeake Bay region is rare (Hildebrand and Schroeder, 1972). They have also been associated with artificial reefs in other areas (Ranasinghe, 1981). The surface waters above the 4A Reef were > 20°C during the brief period barracuda were present. Barracuda feed on a variety of fishes (Manooch, 1984), and may have used the 4A Reef as a food source. The barracuda that I observed in a sample was chasing small scup through the sample space. I also observed barracuda associated with the 4A Buoy channel marker, 3.5 km from the 4A Reef, but not on other area reefs.

Seasonal Variation

Seasonal variation in species composition, richness, abundance and total reef-fish abundance of the 4A Reef was positively correlated with water temperature, a similar finding to those reported in studies of fish assemblages in other temperate regions (Stephens et al., 1984; Lukens, 1981). Studies in the MAB also reported seasonal changes in species composition, richness, abundance, and total abundance for open bottom (Colvocoresses and Musick, 1984; Musick et al., 1985) and natural hard bottom (Eklund and Targett, 1991). However, each of the studies from the MAB reported higher abundance and species richness levels than were observed on the 4A Reef. The lower levels of abundance and species richness on the 4A Reef were likely due to its isolation, whereby it resembles an island, and its small size. Research on the effect of island size on populations reported that the number of species decreased in relation to a decrease in island area (Diamond and May, 1976). In addition, the open bottom survey (Colvocoresses and Musick, 1984) included species (e.g., *Dasyatis* spp., *Raja* spp.) which are associated with open bottom and therefore did not inhabit the 4A Reef.

Community Structure

The fish assemblages associated with the 4A Reef exhibited similarities with community patterns found in other reef systems and in other environments in that there was a decrease in abundance from a few abundant species to a few rare species (Hubbell, 1979). However, the community characteristics of the 4A Reef fish assemblages were different from those found on the natural hard bottom, where black sea bass dominated the reef community (relative abundance > 96%). The dominance of black sea bass was likely due to a bias created by the use of commercial sea bass traps since it is very unusual for a community to be dominated to this extent by a single species. The structure of the 4A Reef fish assemblages were also different from the fish communities on natural reefs in the SAB. The SAB fish communities were not dominated by one or two species, but the 4A Reef was dominated by black sea bass and scup. The difference between the SAB and the 4A Reef was probably due to higher species richness and more reef surface area in the SAB. Systems with higher diversity and species richness, such as the SAB, often exhibit a more linear drop-off in ranked species abundance (Bohnsack et al., 1987). The size and isolation of the 4A Reef likely limited the total number of species present on the reef.

Conclusions and Recommendations for Future Research

This study demonstrated that fish assemblages associated with artificial reefs in the MAB were highly seasonal in species richness, species composition, species abundance, and overall abundance. These results provide ecological information relevant to the management of recreationally and commercially targeted species, including black sea bass, tautog, gray triggerfish, sheepshead, and all transient species. Since significant fishing pressure in the MAB occurs on artificial reefs, data on seasonality, abundance, and size provide information on the status of the targeted species' populations.

Although species composition and abundance on the 4A Reef varied annually, there were distinct spatial patterns of reef use by the reef-associated fishes. These patterns suggest that the 4A Reef provided additional habitat to some species but may have only concentrated others, primarily due to species differences in reef use. For structure-oriented demersal species, the additional shelter provided by the reef potentially increased survivability of the individuals associated with the 4A Reef. However, the advantages of the additional habitat provided by the 4A Reef for the targeted demersal species may have been offset by fishing pressure due to the accessibility of the concentrated fish assemblages to fishermen. Thus, the reef-associated species must be managed so that the potential increased production of artificial reefs is greater than fishing mortality. Although the transient (pelagic) species did not use the reef for shelter, they likely benefited from the concentrated food source, which possibly decreased their search time while increasing their available foraging time.

The 4A Reef provided habitat for the early life stages of scup, black sea bass, and cunner. The additional habitat potentially increased recruitment of the juveniles, which in turn supplied additional individuals to the adult populations. Consistent recruitment success on MAB artificial reefs would increase overall production of some species.

In addition to providing impetus for better monitoring of reef-fish assemblages, the results of this research suggest several future research topics:

1) The size and isolation of a reef are important in defining species composition and abundance (Diamond and May, 1976). A small and/or isolated reef will not be able to support as many individuals and may not provide enough inhabitable area for as many species as a larger reef or a reef that is closely associated with other reefs. This may influence the movement of fishes onto and off of the reef. If fish movement off an isolated reef is limited, targeted species may be more heavily influenced by fishing pressure.

Tag-recapture studies, in conjunction with monitoring efforts via SCUBA, would provide information on the relative importance of migrations and fishing mortality to the dynamics of the reef fishes. Tagging of fish in other areas (e.g., Chesapeake Light-Tower Reef Site) may provide information on the source of the adults that are the primary colonizers of the reef, and on the amount of movement between reefs.

2) Food sources for the reef-associated species. Analysis of stomach contents, in conjunction with identification and quantification of fouling organisms and other reef-associated food sources (e.g., baitfish), would help determine to what degree these species are using the reef as a food source. If species are using the reef for food as well as shelter, then the reef is providing critical habitat.

3) The structural complexity of a reef may influence the presence and abundance of species on a reef (Chandler et al., 1985; Hixon and Beets, 1989). Manipulation of reef substrates may provide information on the importance of structural complexity to MAB fish assemblages.

4) Substrate type and structural complexity are also important to the early life stages of reef fishes. For example, suitable habitat on the 4A Reef was apparently available for juvenile cunner and black sea bass but not for juvenile tautog. Specifically, future research should

monitor artificial reefs to determine if juvenile settlement is a consistent mechanism of reef colonization, which species successfully recruit to the reef, and their levels of post-recruitment survivability. In addition, substrate type could be manipulated to determine differences in recruitment success and post-recruitment survivability on different reef substrates (e.g., tire units vs concrete modules vs 'liberty ships').

Artificial reefs are a popular method of enhancing recreational fishing opportunities throughout the United States, and likely will continue to be used in this fashion in the future. Due to the heavy fishing pressure often associated with these reefs, future funds should be allocated to research that would determine the impact of artificial reefs on fish populations. In addition, placement of artificial reefs provides opportunities for studying the dynamics of reef ecology in a more controlled situation than is possible on natural reefs, and appropriate studies would provide needed information on MAB reef fishes.

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