Effects of Marina Proximity on Certain Aspects of the Biology of Oysters and Other Benthic Macrofauna in a South Carolina Estuary

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EFFECTS OF MARINA PROXIMITY ON CERTAIN ASPECTS OF THE BIOLOGY OF OYSTERS AND OTHER BENTHIC MACROFAUNA IN A SOUTH CAROLINA ESTUARY

by

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Introduction

The tremendous influx of people to coastal areas of the United States has been accompanied by proliferation of commercial marinas designed to serve the growing number of recreational boaters. In South Carolina, boat ownership is among the highest of any state on the east coast. In 1984, South Carolina was second only to Maine in the number of boats per person and ranked fourth, behind Florida, Georgia and New York, in the total number of registered boats (Vismor, McGill and Bell, Inc., 1984).

In response to both the increasing demand for boating facilities and a growing concern for the protection of our estuarine environment, numerous documents have been prepared by various governmental agencies, marine advisory services and independent consulting firms, describing the potential environmental impacts of marinas and providing guidelines for their construction, maintenance and use (U.S. Department of Commerce, 1976; Chmura and Ross, 1978; South Carolina Coastal Council, 1984; Vismor, Mcgill and Bell Inc., 1984; U.S. Environmental Protection Agency, 1985).

Generally speaking, the construction of a marina may affect the ecology of an estuary by changing local shoreline configuration, bottom type and hydrographic regime. The operation of a marina may result in the introduction of various pollutants into the estuary, including fecal wastes, heavy metals and petroleum hydrocarbons (Chmura and Ross, 1978; Marcus and Stokes, 1985; Voudrias and Smith, 1986; Marcus et al., 1988). Although the potential effects of marinas are generally well known, few studies have documented their actual effects in the field (Reish 1961, 1963; Nixon et al., 1973; Soule and Oguri, 1977; Holmes et al., 1985). Because of this paucity of information, regulatory and advisory bodies charged with reviewing marina permit applications frequently have insufficient data regarding the ecological effects of marinas on which to base their decisions.

In order to address this problem, a study was undertaken by the South Carolina Marine Resources Research Institute to evaluate various methods for analyzing marina effects. Specific objectives of this study were to compare a marina and three control sites with respect to four criteria: 1) levels of selected aromatic hydrocarbons and heavy metals in samples of water, sediments, and the American oyster (Crassostrea virginica); 2) recruitment and survival of oyster spat; 3) physiological condition and gametogenesis of oysters; and 4) community structure, faunal abundance and species diversity of benthic macrofauna.

Study Sites

The Skull Creek Marina, on the island of Hilton Head, South Carolina, was chosen as an example of a moderate-size marina having no other obvious sources of pollution nearby (Figure 1). At the time of this study (1986 and 1987), the marina had been in operation for 8 years and had 100 boat slips. Because the marina is located in a well-flushed tidal creek, dredging is not required to maintain the appropriate bottom depths. Like most marinas, the Skull Creek marina provides its customers (who typically live aboard their boats for periods of two to four days at a time) with fuel and sewage pump-out facilities for marine sanitation devices.

Three closely spaced control sites, located in an undeveloped area about three kilometers northwest of the marina on Mackay Creek, were chosen to represent an area similar to the Skull Creek site prior to construction of the marina. The marina and control sites are approximately equidistant from Port Royal Sound, and are located within or adjacent to extensive salt marshes that are characterized by numerous intertidal oyster banks and large stands of smooth cord grass (Spartina alterniflora). The northwest shore of Pinckney Island in Mackay Creek (Figure 1A) served as the control site for oyster spat recruitment studies. Sediments and adult oysters were collected from another site on the opposite shore of Mackay Creek (Figure 1B) for contaminant, gametogenesis and condition index analyses. Finally, grab samples were collected from a shallow subtidal area near the mouth of a small tributary of Mackay Creek (Figure 1C) for benthic macrofaunal and sediment composition analyses.

Contaminants Analyses

Methods

Samples of surface sediments, water and oysters were collected intertidally during two or more seasons at both the marina and control sites. Each oyster sample consisted of the soft tissue from a composite of 30 oysters, all having a minimum shell

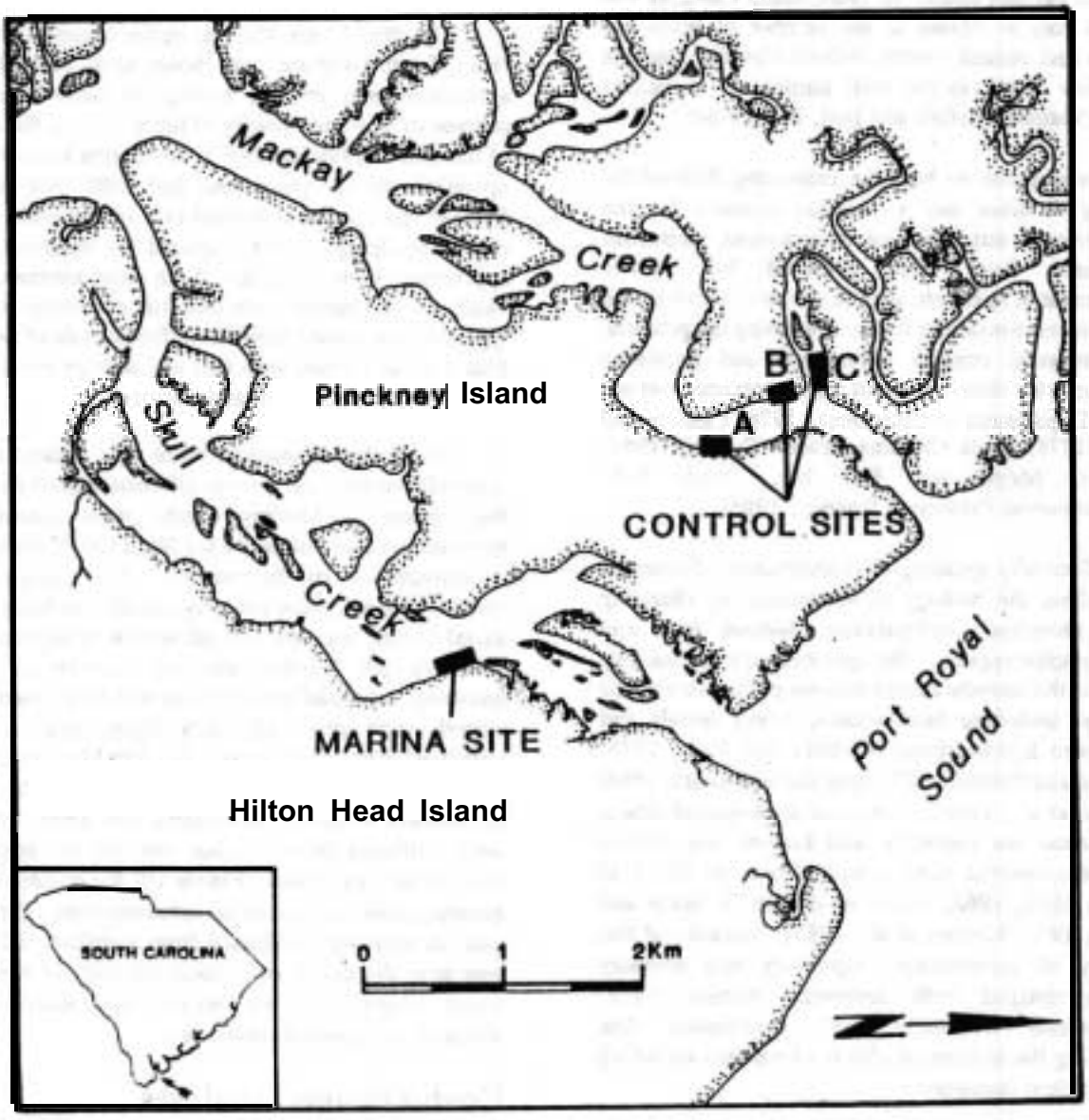

Figure 1. Location of marina and control situ. Control site (A) was used fot the recruitment studies; control site (B) was used for the oyster condition index and gametogenesis studies; and control Rite (C) was used for the benthic community study.

length of 7.6 cm. All samples were analyzed for nine polynuclear aromatic hydrocarbons (PAHs) and five heavy metals, using methods derived from EPA guidelines (EPA Method 525). Samples were prepared for PAH determinations by solid phase extraction and were analyzed using a gas chromatograph with a flame ionization detector. Samples were prepared for metals determinations by acid digestion and were analyzed for chromium, copper, cadmium, and lead using flame atomic absorption spectrophotometry (AAS). Mercury was analyzed using cold vapor AAS.

Results and Discussion

Polynuclear Aromatic Hydrocarbon Analyses

None of the nine polynuclear aromatic hydrocarbons (PAHs) for which analyses were performed were detected in water samples taken at either the marina or control site in spring (Appendix 1). In summer, low levels of acenaphthene and pyrene (<0.01 ppm) were present in water samples from both sites, while a similarly low concentration of benzo(a)anthracene (0.03 ppm) was detected in water from the marina but not from the control site.

During one or more seasons, three PAHs (benzo(b)fluoranthene, benzo(k)fluoranthene and benzo(a)pyrene) were detected in sediments from the marina but not in those from the control site (Appendix 1). Concentrations of these substances, two of which are known carcinogens (Marcus and Swearingen, 1983), were an order of magnitude greater than those measured by Marcus and Swearingen (1983) at three other marinas in South Carolina (Table 1). Three other PAHs (fluoranthene, phenanthrene and pyrene) were detected in sediment samples from the control site, but not in those from the marina; however, their concentrations were all less than 1.00 ppm.

No PAHs were detected in oysters collected from either the marina or the control site in winter or spring (Appendix 1); however, eight of the nine analyzed PAHs were detected in oysters collected from the marina in summer. The concentration of one of these substances (benzo(b)fluoranthene) was nearly two orders of magnitude greater than that reported by Marcus and Swearingen (1983) for oysters collected at other marinas in summer (Table 2). Only three PAHs were detected in oysters from the control site in summer, all in concentrations <1.00 ppm. Low concentrations of pyrene were detected in oysters from the marina and control sites in fall. During that season, benzo(a)pyrene was also detected in oysters from the marina, but not in those from the control site.

Heavy Metal Analyses

Heavy metal concentrations in sediments and oysters were generally higher in summer and fall than in spring at both the marina and control sites (Appendix 1). Cadmium, lead and mercury levels were similar at the two sites for any given season. Chromium concentration was higher in sediments at the marina than at the control site in summer, but this order was reversed in the fall. Since chromium is widely distributed in estuaries throughout the southeast (Mathews and Darr, 1990), and can be either naturally occurring or anthropogenic in origin, it is uncertain whether its presence in elevated levels at either site is indicative of pollution. Nevertheless, tissue levels of chromium were very low at both sites regardless of season. Copper concentrations were similar in sediments at the two sites, but were considerably higher in oysters from the marina than in those from the control site, particularly in summer and fall.

Heavy metal concentrations in both sediments and oysters from the Skull Creek Marina were generally comparable to or lower than those reported for other marinas in South Carolina, regardless of season (Tables 1 and 2). Tissue concentrations from both the Skull Creek Marina and Mackay Creek control sites were also similar to or lower than those previously reported from other areas of South Carolina (Table 3).

Oyster Spat Recruitment and Survival Studies

Methods

Two arrays of artificial substrata were placed at the marina and control sites to compare oyster spat recruitment over the course of one reproductive season, and to evaluate the suitability of different test surfaces. Both arrays were placed at identical elevations within the lower intertidal zone of each site, with all arrays oriented parallel to the shoreline to minimize differences due to shading or desiccation. Artificial substrata placed at the marina were located

Table 1. Concentrations (ug/g) of polynuclear aromatic hydrocarbons (PAHs) and heavy metals in sediments from several marina sites (SP = spring; SU = summer).

Chemical Component (ug/g)	Skull Creek[1] Marina		Palmetto Bay[2] Marina		Outdoor Resorts[2] Marina		Fripp Island[2] Marina		Buzzard's Roost[3] Marina	
	SP	SU	SP	SU	SP	SU	SP	SU	SP	SU
Acenaphthene	ND	ND	ND	ND	ND	ND	ND	ND	--	--
+Benzo (a) anthracene	ND	ND	<0.1	0.1	0.1	<0.1	<0.1	<0.1	--	--
+Benzo (b) fluoranthene	1.3	0.5	ND	0.1	<0.1	<0.1	ND	<0.1	--	--
Benzo (k) fluoranthene	*	1.0	<0.1	<0.1	<0.1	<0.1	ND	<0.1	--	--
+Benzo (a) pyrene	1.9	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	--	--
Fluoranthene	ND	ND	0.1	0.2	0.2	0.1	<0.1	<0.1	--	--
Naphthalene	ND	ND	ND	ND	ND	ND	ND	ND	--	--
Phenanthrene	ND	ND	0.1	0.1	ND	<0.1	ND	0.1	--	--
Pyrene	ND	ND	0.1	0.2	0.1	0.1	ND	0.1	--	--
Cadmium	<0.1	1.7	ND	ND	ND	ND	ND	ND	--	<1.0
Chromium	<0.1	20.8	27.2	22.8	19.6	15.2	25.0	28.2	--	9.9
Copper	<0.1	5.3	8.6	10.6	7.4	6.6	7.6	8.6	--	5.0
Lead	<0.1	15.2	24.8	27.8	26.6	29.6	22.4	28.0	--	<5.0
Mercury	ND	ND	ND	ND	ND	ND	ND	ND	--	0.2

SEDIMENT

1 Current study: wet weight PAH concentrations measured as ug/g (ppm); dry weight metal concentrations estimated by doubling wet weight concentrations.

2 Marcus and Swearingen (1983): wet weight PAH concentrations converted from ug/kg (ppb) to ug/g (ppm); dry weight metal concentrations measured as mg/kg (ppm) and reported herein as ug/g (ppm); PAH concentrations derived from single samples taken at the station located closest to each marina (Palmetto Bay: MD-702R; Outdoor Resorts: MD-707R; Fripp Island: MD-712R); metal concentrations represent mean values from stations located along the same side of each creek as the marina.

3 Gaymon and Marcus (1987): dry weight metal concentrations measured as mg/kg (ppm) and reported herein as ug/g (ppm); metal concentrations based on one sample taken from the station located closest to Buzzard's Roose Marina (MD-026).

\+ Known carcinogens (Marcus and Swearingen, 1983)

* unreliable data

\- not measured

Table 2. Concentrations (ug/g) of polynuclear aromatic hydrocarbons (PAHs) and heavy metals in oysters from several marina sites. (SP = spring; SU = summer).

OYSTERS

Chemical Component (ug/g)	Skull Creek[1] Marina		Palmetto Bay[2] Marina		Outdoor Resorts[2] Marina		Fripp Island[2] Marina		Buzzard's Roost[3] Marina	
	SP	SU	SP	SU	SP	SU	SP	SU	SP	SU
Acenaphthene	ND	<0.1	ND	ND	ND	ND	ND	ND	--	--
+Benzo (a) anthracene	ND	<0.1	<0.1	<0.1	ND	<0.1	ND	<0.1	--	--
+Benzo (b) fluoranthene	ND	6.1	ND	<0.1	ND	<0.1	ND	ND	--	--
Benzo (k) fluoranthene	ND	0.2	ND	<0.1	ND	ND	ND	ND	--	--
+Benzo (a) pyrene	ND	0.2	ND	<0.1	ND	ND	ND	ND	--	--
Fluoranthene	ND	ND	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	--	--
Naphthalene	ND	<0.1	ND	ND	ND	ND	ND	ND	--	--
Phenanthrene	ND	<0.1	<0.1	<0.1	ND	ND	ND	ND	--	--
Pyrene	*	<0.1	<0.1	<0.1	ND	<0.1	<0.1	ND	--	--
Cadmium	<0.1	0.2	0.5	0.6	0.5	0.7	0.5	0.6	--	--
Chromium	ND	1.9	ND	ND	ND	0.3	ND	0.5	--	--
Copper	0.1	11.6	17.0	29.0	18.0	46.0	13.0	19.0	--	--
Lead	<0.1	1.2	0.4	1.2	0.7	0.6	0.3	0.4	--	--
Mercury	--	ND	ND	ND	ND	ND	ND	ND	--	--

1 Current study: wet weight PAH and metal concentrations; measured as ug/g (ppm).

2 Marcus and Swearingen (1983): wet weight PAH concentrations converted from ug/kg (ppb) to ug/g (ppm); dry weight metal concentrations measured as mg/kg (ppm) and reported herein as ug/g (ppm); PAH and metal concentrations represent mean values for all samples taken at the station located closest to each marina (Palmetto Bay: MD-702R; Outdoor Resorts: MD-707R; Fripp Island: MD-712R).

3 Gaymon and Marcus (1987): oysters not analyzed from the Buzzard's Roost Marina site.

\+ Known carcinogens (Marcus and Swearingen, 1983)

* unreliable data

\- not measured

Table 3. Mean concentrations of heavy metals in oysters collected from the Skull Creek Marina and Mackay Creek control sites during spring, summer and fall, and in oysters collected in previous surveys.

Metal (ug/g)	Skull Creek Marina (1 station, N = 3)	Mackay Creek Control (1 station, N = 3)	Coastal Trend Network[1] (16 stations, N = 44) 1984 - 1986	USFDA[2] (5 stations, N = 37) 1974 - 1975	NMFS[3] (1 station, N = 10) 1978	USMW[4] (1 station, N = 3) 1976 - 1978
Cadmium	0.09	<0.01	0.54	0.29	0.50	0.35
Chromium	0.63	0.56	1.55	0.50	0.44	--
Copper	6.41	3.79	16.80	7.90	8.40	28.0
Lead	0.39	0.17	1.15	0.19	0.69	<0.1
Mercury	ND	ND	<0.25	0.02	0.13	--

[1]From Marcus (In prep.) as reported by Gaymon and Marcus (1987).

[2]From DeWees Inlet, SC (USFDA 1983) as reported by Gaymon and Marcus (1987).

[3]From Trace Element Survey, South Atlantic (Hall et al. 1978) as reported by Gaymon and Marcus (1987).

[4]From Charleston, SC mussel watch station (Goldberg et al. 1983) as reported by Gaymon and Marcus (1987).

adjacent to the dock facilities, approximately midway along the section of shoreline spanned by the marina.

One array of test substrata consisted of 225-cm^2 formica panels having the texture and color of dark gray slate. Four replicate panels were suspended vertically from a PVC frame so that the bottoms of the panels were approximately 3 cm above the sediment surface.

The second array of artificial substrata, commonly called "french collectors", consisted of 0.75-m lengths of grey, longitudinally corrugated PVC tubing (21 mm OD). Four replicate tubes were inserted in the sediment adjacent to the panel frames so that the top 25 cm of each tube was exposed above the sediment surface. This provided four 225-cm^2 test surfaces for spat settlement, the same surface area provided by the formica panels.

The panels and tubes were initially placed in the intertidal zone on April 8, 1986, and were subsequently collected and replaced with new surfaces at two-week intervals through October 14, 1986. This sampling regime generated 13 replicate sets of both panels and tubes for comparison of spat recruitment between the two types of surface during each two-week exposure period. Water temperatures and salinities were recorded on each sampling date in both areas. After collection, the substrata were returned to the laboratory and preserved in a 10% formalin solution.

A third array of artificial substrata was also deployed at each site to provide additional seasonal data on the survival of oyster spat in marina and control areas. Each array consisted of four replicate formica panels suspended in the intertidal zone in a manner identical to that described for the first array. These panels were also initially deployed on April 8, but were exposed for approximately three months before collection and replacement with new panels. This procedure was repeated three more times throughout the year, generating four sets of replicate panels, with each set representing exposure during a different season. All panels were collected and preserved as described for the first series.

In the laboratory, three of the four panels and french collectors from each treatment group were randomly selected and examined under a dissecting microscope to identify and count all oyster spat. Scars of oyster spat were also observed and counted. Panels or french collectors which showed signs of damage in the surface area to be analyzed were discarded and replaced with the fourth replicate from that treatment group.

Results and Discussion

Oyster spat were first observed on the panels and tubes exposed between May 6 and May 20, and settlement continued to occur on both types of test substrata until October 1 at the marina site and October 14 at the control site (Figure 2). Periods of peak spat recruitment differed between the two types of substrata, however. There were also differences between marina and control sites in the density of spat recruited to both types of test surfaces during several of the sampling periods.

The mean density of spat settling on the formica panels was generally greater at the control site than at the marina site, with significant differences noted between sites on five of the sampling dates ($P<0.05$, Mann Whitney U test; Figure 2A). Temporal differences in the settlement patterns also occurred between sites during spring and summer. In the control area, spat recruitment to the panels was highest during the May 6-20 exposure period, with a second smaller peak of recruitment occurring in August. In contrast, spat recruitment at the marina site remained low during the spring and early summer, with a single peak in recruitment occurring in late July and August. Even during August, the density of oyster spat on the panels was significantly lower at the marina than at the control site.

Recruitment of oyster spat to the french collectors was also generally greater in the control area than at the marina, with significant differences between sites observed on three of the sampling dates ($P<0.05$, Mann Whitney U test; Figure 2B). As noted for the formica panels, spat settlement in the control area showed two peaks of abundance, separated by a period of lower recruitment during July. A similar pattern was observed on collectors at the marina, although spat densities were generally lower. In contrast to the formica panels, the initial peak recruitment period on the french collectors was noted in late July rather than mid-May. The second peak of settlement occurred in August, which corresponded to the same period of peak settlement observed on the formica panels.

The bimodal peak in spat densities observed on all but one of the arrays of artificial substrata (marina

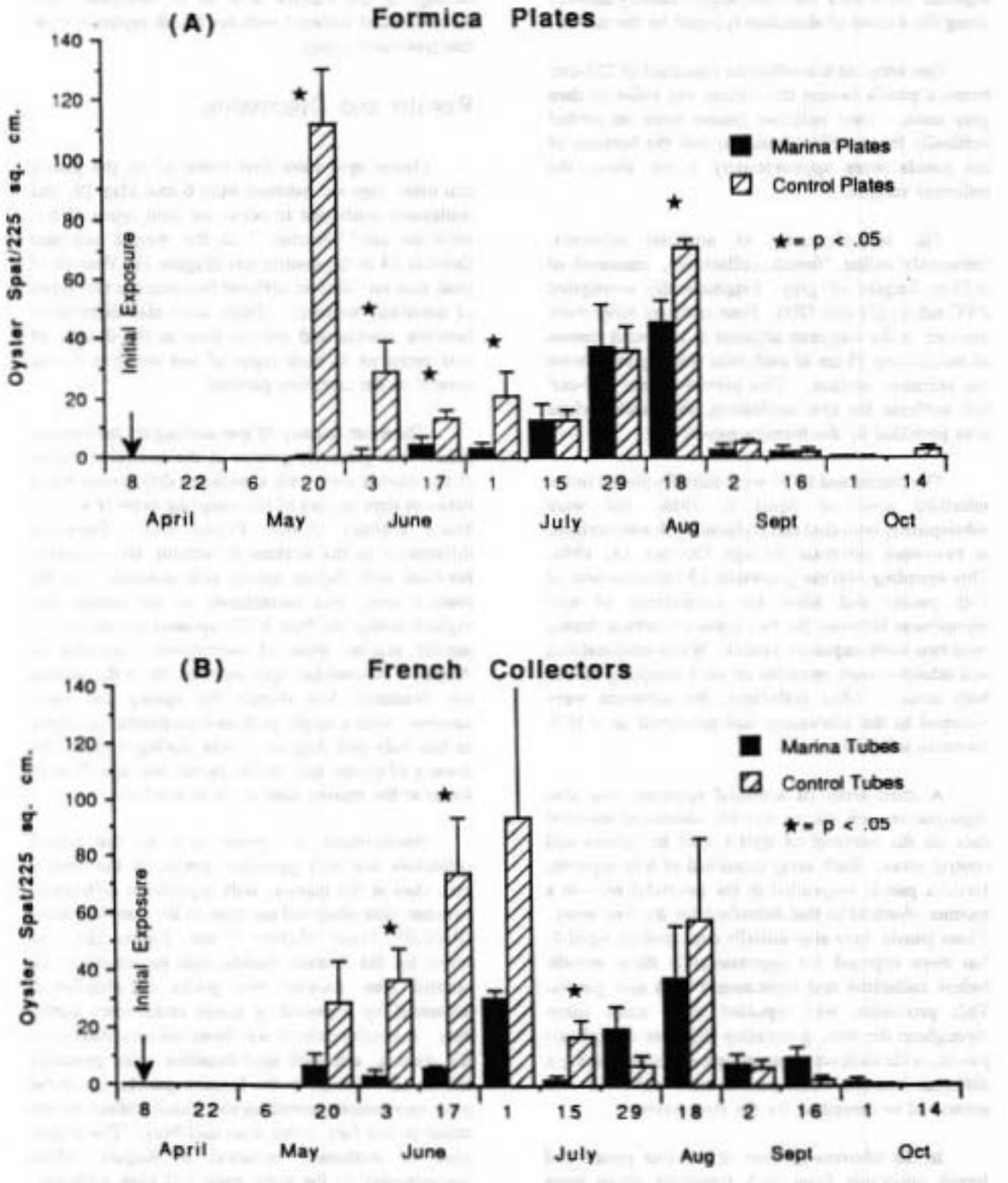

Figure 2. **Mean number of oyster spat on a) formica plates and b) PVC "french collectors" deployed for two-week periods at the marina and control sites. Stars indicate significant differences between sites ($p<0.05$, Mann-Whitney U test) in the mean number of spat collected on a particular sampling data. Dates are the pickup date and error bars represent ± 1 standard error of the mean.**

formica panels) represents a settlement pattern which has been commonly noted for C. virginica (McNulty, 1953; Shaw, 1967; Hayes and Menzel, 1981; Kenny et al., unpublished data). It is less clear, however, why we observed a disparity between the panels and french collectors in the timing of the first peak in spat densities. Results obtained from other studies suggest that peak settlement should have occurred in late May or early June. In a five-year study at North Inlet, South Carolina, Kenny et al. (unpublished data) noted that the first peak in intertidal oyster spat settlement generally occurred in late May or early June when water temperatures reached 23-25°C. In 1986, they observed the greatest spat set on their panels in late May. This corresponds well to the settlement patterns we observed on our panels exposed during the last two weeks in May when water temperatures were 24-28°C (Figure 2, Appendix 2). McNulty (1953), Hayes and Menzel (1981) and Burrell (1986) have also noted that peak settlement periods occur when water temperatures reach 22-29°C. Although the later peak in spat densities observed on the french collectors during June is not inconsistent with the trends observed in the other studies, it does appear to have occurred at slightly higher water temperatures than those reported by Kenny et al. (unpublished data).

The lower spat settlement on the panels and tubes deployed at the marina site, versus the control site, suggests that marinas may have an adverse effect on oyster spat recruitment, at least within a localized area. This could be due to a number of factors, such as proximity to boats which release toxic antifouling compounds from their hull paint, or small but frequent oil and fuel spills which could reduce larval viability, spat settlement, or spat survival. Smith and Hackney (1989) observed a significant reduction in oyster spat recruitment on panels treated with oil; however, they observed no effects on panels treated with a 40:1 gas:oil mixture. Conflicting results, such as these, suggest that more studies are needed to evaluate the effects of petroleum hydrocarbons on oyster spat recruitment and survival.

An alternative explanation for the reduced spat recruitment in the marina area may be related to natural differences between Skull Creek and Mackay Creek with regard to the density of oyster larvae. The banks of Mackay Creek were much more densely populated with oysters than were the banks of Skull Creek. In fact, a large portion of the oyster bed adjacent to the marina was composed of dead oysters, and field teams had difficulty finding sufficient live specimens for other study components. While the cause of this mortality is unknown and may be independent of the marina, it is clear that this area did not support a very productive oyster bed in comparison to the control area. Although such a discrepancy could have affected the pool of available spat, oyster veligers have a relatively extended free-swimming period before settlement occurs (Loosanoff and Davis, 1963), which should lead to wide dispersal and more uniform mixing of the pool of oyster larvae generally available for settlement in the two areas. Differences observed between areas were probably not related to salinity or water temperature since values of those parameters were essentially equivalent at both sites on all sampling dates (Appendix 2).

Plates exposed for the 3-mo time intervals over a one-year period provided further evidence that oyster settlement was lower in proximity to the marina (Figure 3). Significantly more oyster spat were present on the control panels, in comparison to the marina panels, deployed during the spring, summer and fall quarters ($P < 0.05$, Mann Whitney U test). No oysters settled on the panels deployed during the winter. Although the total number of spat settling on the panels was greater in the control area, the percentage of recruits which successfully settled and then died at the marina site during each exposure period (as evidenced by the number of scars) was similar to or lower than the percentage of recruits which died at the control area during the same exposure period (Figure 3). This suggests that oyster spat which successfully settled on the panels did not suffer a proportionally higher rate of mortality at the marina during the course of our study.

In summary, the density of oyster spat recruited to artificial substrata was significantly lower at the Skull Creek Marina than at the control site during much of the spring, summer and fall of 1986. Further studies are needed to conclusively determine whether this pattern is related to marina proximity or to some other environmental variables. Future studies should involve sampling at several other marinas of different sizes and locations, and should include the placement of recruitment surfaces at various distances from the marinas but in the same hydrographic regime.

Finally, despite unexplained discrepancies in recruitment patterns between the two types of test surfaces, our data suggest that both the french collectors and the formica panels provide suitable

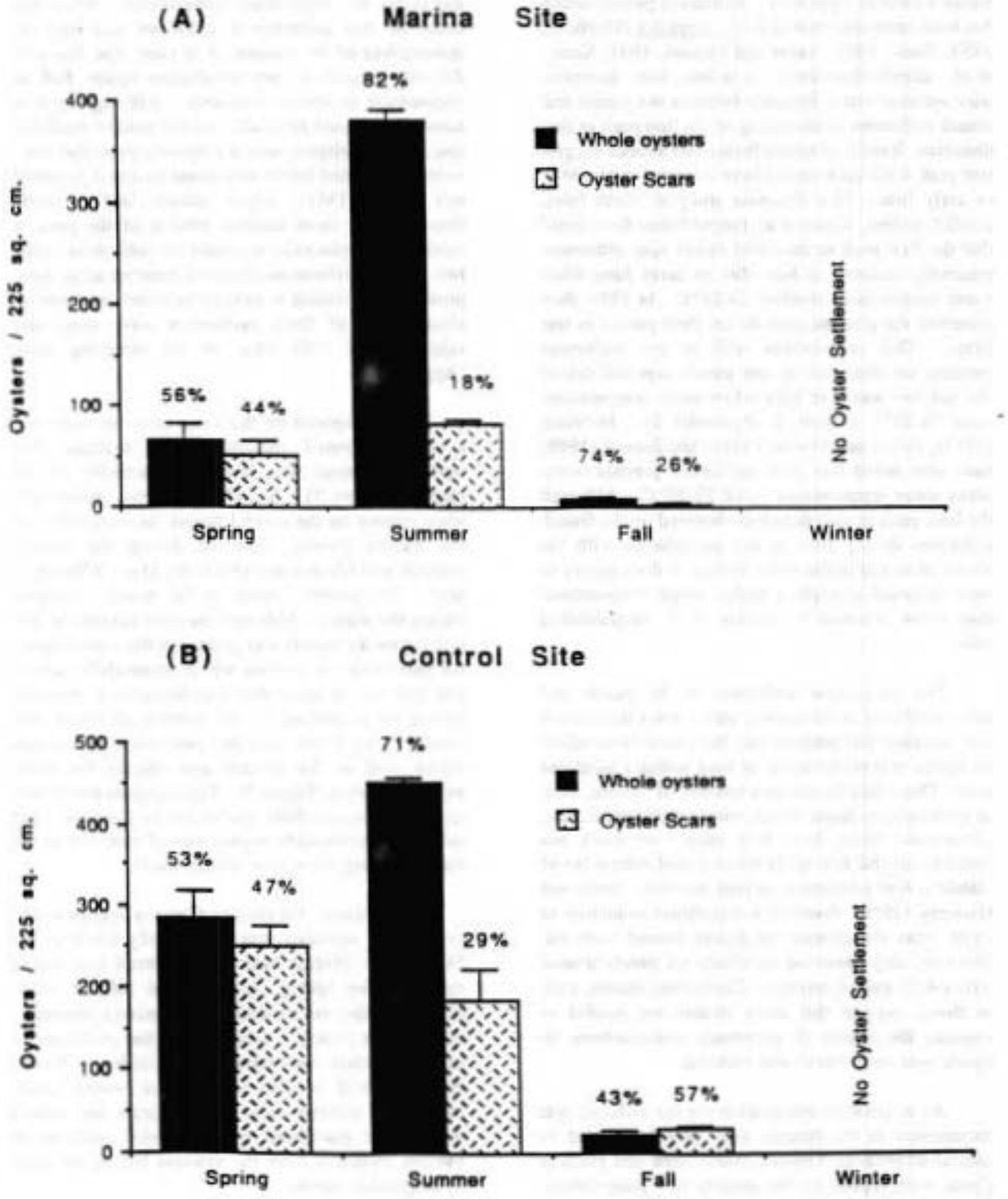

Figure 3. **Mean number of whole oysters and oyster scars observed on formica plates deployed for three-month periods at the marina and control sites. Scars denote either empty shells or remnants of the shells. Error bars represent 1 standard error of the mean and percent values represent proportion of total oysters on treatment surfaces which were alive (whole) or dead (scars) at the time of collection.**

substrate for spat recruitment. Recruitment patterns observed by Kenny et al. (unpublished data) on asbestos panels deployed during the same time period in North Inlet, were more similar to patterns observed on the formica panels in this study than on the french collectors. On the other hand, settlement patterns on the french collectors corresponded more closely to the maximum spawning period, as indicated by our gametogenesis studies, and settlement densities were often similar to or greater than those observed on the formica panels. The tubes have the added advantage of being simple to construct and deploy, and their cylindrical shape minimizes differences among treatments related to surface orientation effects. Therefore, we would recommend the use of french collectors over the panels in future studies of oyster spat recruitment.

Oyster Gametogenesis

Methods

Field Sampling and Laboratory Analyses

Oysters were sampled biweekly between February and July, 1986, from the Mackay Creek control site and from Skull Creek Marina (Figure 1B). Hydrographic data, collected coincidently with sampling, included measurements of water temperature and salinity. All oyster samples were transported in cool, dry containers to avoid premature aborting of gametes. Heights (longest dimension perpendicular to the plane of symmetry) of 25 oysters from each of the two study sites were measured to the nearest millimeter using a vernier caliper. Physiological condition (Quick and Mackin, 1971) and macroscopic gonadal condition (Burrell et al., 1984) were determined upon shell removal. The visceral mass (gonad, digestive diverticulum) was removed and fixed in formalin-acetic acid-alcohol (FAA) for three to four weeks. Three cross-sections were excised, washed in running tap water for approximately one hour, and stored in 50% ethyl alcohol. The tissues were then prepared histologically for microscopic examination, by dehydration in alcohol, clearing in xylene, and infiltration in 57° C paraplast (Preece, 1972). After embedding in paraplast, three 7 μm sections were taken from each sample at approximately 20 μm intervals.

Gonadal Index

After examination of gonad preparations, a gametogenic index was devised, incorporating staging concepts from other studies of Crassostrea virginica (Kennedy and Battle, 1964; Berg, 1969; Loosanoff, 1969; Kennedy and Krantz, 1982) and other bivalves (Durve, 1965, for Crassostrea gryphoides; Keck et al., 1975; Eversole et al., 1980; Manzi et al., 1985, for Mercenaria mercenaria). The following stages of the male and female gonadal condition represent an attempt to divide the reproductive process into distinct phases:

Inactive

The gonads are in a state of quiescence and the follicles are either absent or few in number and small in size. When present, follicles are found in the area between the body wall and the digestive gland or, more rarely, scattered in the form of small islands throughout the mass of vesicular connective tissue. Sex was not distinguishable.

Male Reproductive Phases

Early Development - The follicles begin to enlarge; however, the vesicular connective tissue still occupies considerable space between the follicles. Primary spermatocytes appear at the basal membrane of these follicles.

Late Development - As development proceeds, primary spermatocytes increase in number and there is the appearance of some spermatids beginning to migrate toward the center of the follicle where they arrange themselves in radial columns.

Early Ripe - Proliferation of spermatids and differentiation into spermatozoa begin to occur rapidly, with a general reduction in the earlier stages of gametogenesis.

Ripe - The follicle is filled with dense radiating bands of spermatozoa, the tails of which project into the central lumen.

Spawning - The lumen of the shrunken follicle is often empty because of the recent discharge of mature spermatozoa. A few spermatozoa remain in the radiating bands, but the rows of follicle cells gradually increase to replace the spawned spermatozoa.

Spent - The follicles are almost completely filled with follicle cells and the reduced lumen contains a few sex cells. The vesicular connective tissue proliferates.

Female Reproductive Phases

Early Development - Small primary oocytes are present around the periphery of small follicles. Some are elongated on stalks and accompanied by a decrease in the number of follicle cells and inclusions.

Late Development - The follicles begin to enlarge, anastomose, and proliferate; however, the connective tissue still occupies a considerable amount of space. A central lumen is present in each follicle, into which protrude the stalked oocytes.

Early Ripe - Oocytes increase in size and number and begin to fill the lumen of the follicles. There is a gradual appearance of a nucleolus.

Ripe - Many well-defined, mature ova, averaging 70 - 75 μm in diameter, appear to be free within the follicular lumen. There are few traces of earlier stages of gametogenesis. The voluminous vesicular connective tissue has disappeared and the enlarged follicles seem to come in contact with each other.

Spawning - There is a slight shrinkage of the follicles from which mature oocytes are gradually discharged. Very small oocytes are embedded in the follicle cells at the periphery of the empty alveoli. Usually, a large number of follicles still retain spawn, with the lumina almost entirely filled with mature ova.

Spent - Unspent oocytes, some in early phases of cytolysis, are present. Shrinking follicles are invaded with phagocytic cells, both inside the lumina and around the outside walls. Simultaneously, the vesicular connective tissue proliferates.

Each phase of gonadal development was scored on a 0-4 scale: 0 = inactive/spent follicle; 1 = early development; 2 = late development; 3 = early ripe; 4 = ripe/spawning. The monthly mean derived from this scale is expressed as the Gonad Maturation Index (GMI).

Results and Discussion

Between February and July 1986, 247 oyster gonads from Skull Creek Marina (marina site) and 262 gonads from Mackay Creek (control site) were examined and indexed. Careful histologic examination failed to reveal significant patterns of gametogenic differences between the two study sites. Gonads were examined carefully, but no cellular abnormality in gametic maturation was detected (Table 4 and Figures 4 and 5).

Marina Site Gametogenesis

Reproductively active individuals were encountered at the marina site throughout the six-month study period. Gonads in early and late phases of development were observed in over 80% of the population from February through March. In late March, when the water temperature was 17° C, approximately 50% of the individuals were in an early ripe phase that continued into early April. As the water temperature increased to 24° C in late April, over 80% of the oysters became completely ripe and began spawning. This peak of maturity continued through May and was followed by a peak of spawning activity in early June when about 80% of the population sampled indicated release of gametes. This ripe and spawning condition was evident in most individuals throughout the remainder of the study period. During this time, water temperatures increased to 30°C. At no time during this period did completely spent individuals comprise more than 20% of the population (Figure 4).

Control Site Gametogenesis

The reproductive cycle at the control site was similar to the marina site. Gonads in early and late stages of development were observed in the population through early March. By late March over 50% of the individuals were in an early ripe condition. As the water temperature increased to 21°C in early April, mature ova and sperm filling the lumen of the follicles typified over 80% of the population. This condition continued through early June and decreased when spawning was observed. Ripe and spawning individuals made up over 60% of the population to the end of the sampling period (Figure 4).

Inorganic and organic pollution can affect oyster populations in several ways: acute toxicity for adults;

Table 4. Gonad maturation index (GMI) for oysters collected at the Skull Creek Marina and Mackay Creek control sites. (n = number of oysters in each category: T = total including hermaphrodites; F = females; M = males).

	MARINA			CONTROL		
DATE		n	GMI		n	GMI
2-27-86	T	25	0.92	T	21	0.90
	F	19	1.05	F	10	1.00
	M	3	1.00	M	8	1.13
3-4-86	T	22	1.05	T	24	1.13
	F	16	1.19	F	20	1.15
	M	5	1.00	M	4	1.00
3-11-86	T	17	1.12	T	23	1.35
	F	15	1.06	F	18	1.61
	M	1	3.00	M	2	1.00
3-25-86	T	21	2.33	T	24	2.75
	F	17	2.47	F	20	2.65
	M	2	3.50	M	4	3.25
4-8-86	T	25	3.04	T	23	3.65
	F	21	2.86	F	19	2.10
	M	4	3.25	M	4	4.00
4-22-86	T	25	3.68	T	25	3.92
	F	21	3.81	F	20	3.89
	M	3	2.67	M	5	4.00
5-6-86	T	24	3.71	T	23	3.96
	F	19	3.84	F	16	3.94
	M	4	4.00	M	7	4.00
5-22-86	T	25	3.48	T	25	3.80
	F	20	3.35	F	17	3.76
	M	2	4.00	M	6	4.00
6-3-86	T	24	2.83	T	25	3.20
	F	21	2.86	F	24	3.17
	M	2	4.00	M	1	4.00
6-17-86	T	15	3.73	T	25	3.04
	F	14	3.71	F	21	3.05
	M	1	4.00	M	4	3.00
7-1-86	T	24	3.33	T	24	2.50
	F	21	3.62	F	20	2.80
	M	1	0.00	M	1	4.00

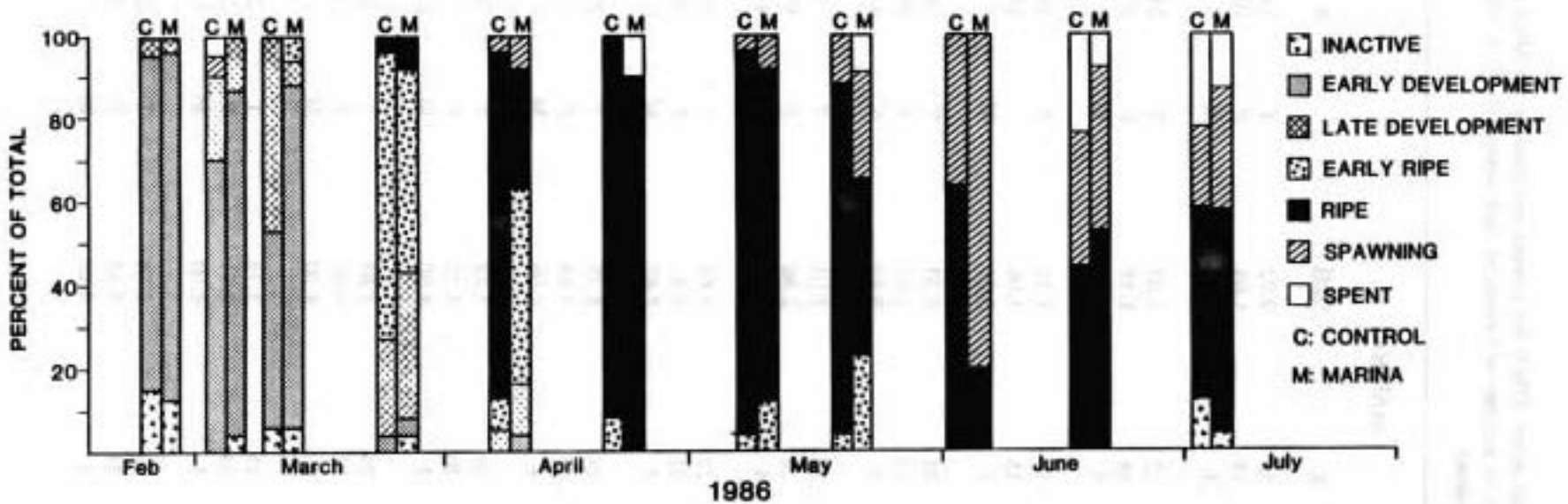

Figure 4. Percentage of total number of oysters in each reproductive phase collected at the control (C) and marina (M) sites during each sampling period.

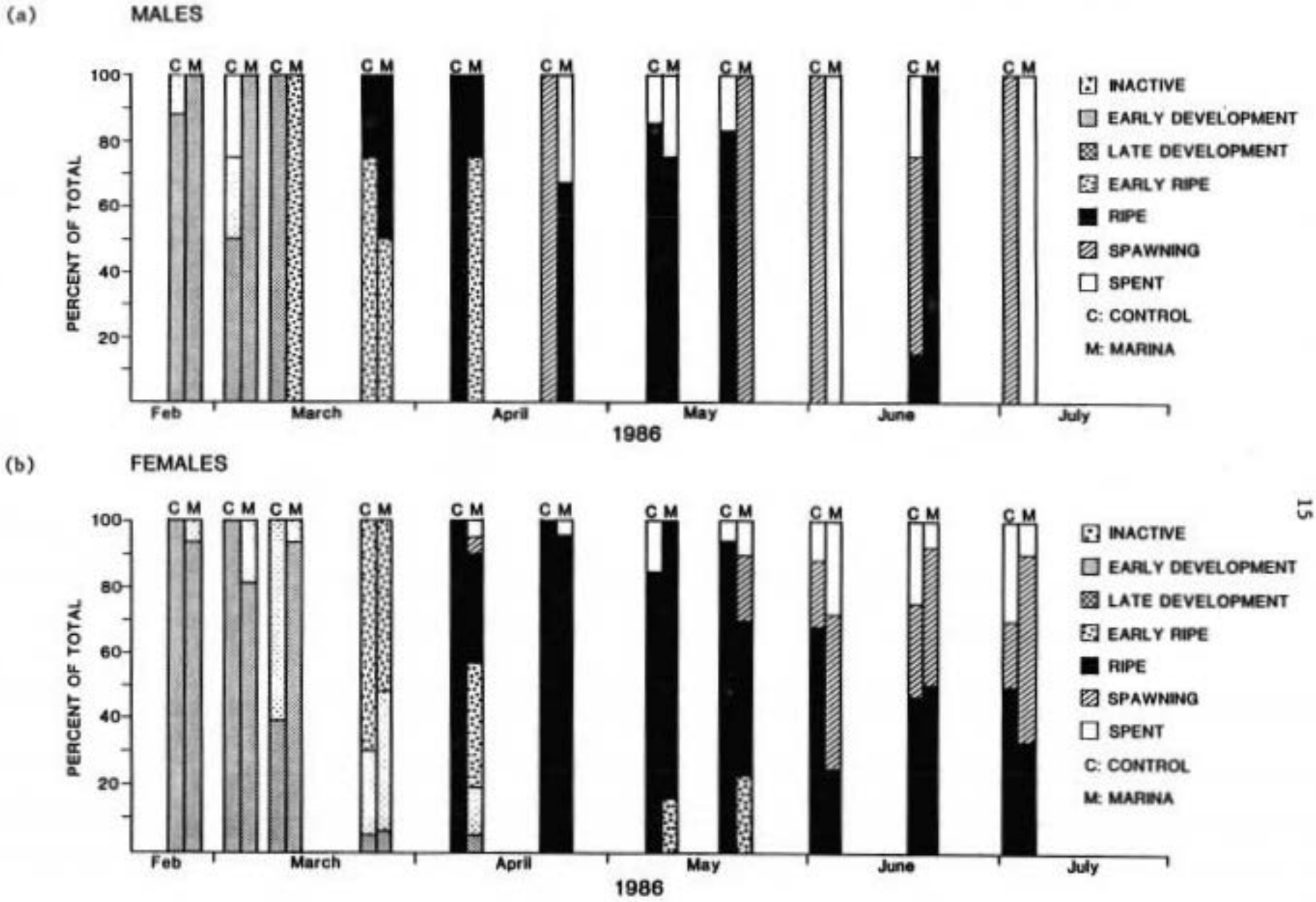

Figure 5. Percentage of total male (a) and female (b) oysters in each reproductive phase collected at the marina (M) and control (C) sites during each sampling period.

toxic effects on food organisms; inhibition of gametogenesis (either direct sublethal toxicity or indirectly through dietary imbalance) and release of gametes; inhibition of fertilization; inhibition of larval development; deleterious effects on veliger larvae; inhibition of growth of juvenile oysters, etc. Any of these effects could have important long-range consequences for reproducing populations (Tripp, 1974). Although our data indicate no apparent differences between marina and control site populations in the progression of gametogenesis, there is concern about possible sublethal effects. Once triggered by temperature and food stimuli, vitellogenesis in bivalve mollusks proceeds to completion in spite of sub-optimal environmental conditions. Following maturation, however, disintegration of gametes occurs unless further stimuli are received to initiate their release from the animal (spawning). The question is, as posed by Bayne (1972), "Are the larvae that develop from gametes produced in sub-optimal conditions affected by the stress experienced by the adult?" The 8 hermaphodites (3 percent) observed among the 247 sexually ripe oysters examined at the marina site is higher than the normal proportion indicated by Galtsoff (1964). Less than 1 percent of the control site population were hermaphrodites. Joseph and Madhyastha (1984) suggest that hermaphroditism can be a result of environmental stress.

Overall, there was no difference in the gametogenic development of sexes between the control and marina sites (Table 4). In some instances, it appeared that the marina males were in an early ripe condition longer than the control males or were spent when the control males were not (Figure 5a and Table 5). Furthermore, there were fewer males, representing a smaller percentage of the total sample, at the marina (11 percent) than there were at the control site (18 percent). Differences between sites were not apparent in the female populations (Figure 5b and Table 6).

The sampling and analyses reported here were designed to assess gross effects of marina pollution on oyster reproduction. Occurrences of sublethal or chronic effects, or adverse effects on progeny, have not yet been investigated. Further studies are needed to assess the quality of gametes from stressed adults and to determine whether stress during a particular year affects the storage of glycogen needed for gametogenesis the following spring.

Condition Index of Oysters

Methods

Biweekly samples of oysters from the Skull Creek Marina and the Mackay Creek Control site were collected to determine their physiological condition. Approximately 25 oysters (>50 mm shell lengths) were gathered from intertidal beds at each site and returned to the laboratory for analysis.

After a thorough cleaning, shell height (in millimeters) and whole weight (in grams) were recorded for each oyster. The shells were first pried apart slightly and the shell liquor was drained and discarded before cutting into the adductor muscle. The oyster meat was then completely separated from the shell into a pre-weighed aluminum dish. Wet weight measurements of the shells and meat were taken. Both shell and meat were dried for 24h at 100°C. The condition index (CI) was obtained from the formula by Walne (1976) as reported by Lucas and Beninger (1985):

$$CI = \frac{\text{mean dry meat weight (g)}}{\text{mean dry shell weight (g)}} \times 100$$

Results and Discussion

The condition index at both marina and control sites increased gradually throughout the early spring, reaching a maximum in late April and early May (Figure 6). This peak corresponded directly with the highest percentage of ripe individuals within the populations (Figure 4). A reduction in body weight occurred in late May and the lowest condition index (1.98-control and 1.81-marina) was observed in early June. This coincided with the first spat settlement recorded (Figure 6), indicating a prior release of gametes. From mid-June to the end of the study period in late July, the condition index at the marina site was slightly higher than that at the control site, possibly reflecting delayed spawning at the marina. Such a delay in spawning may result from high bacteria levels, as suggested by Scott and Lawrence (1982), although bacterial counts were not obtained during our sampling of these sites.

Condition index is known to undergo seasonal variations which reflect reproductive and physiological state (Walne, 1970; Trevallion, 1971; de Wilde, 1975). These variations are considered

Table 5. Percentage of males in each stage of development at the Skull Creek Marina (M) and Mackay Creek control (C) sites. (ED = early development; LD = late development; ER = early ripe; R = ripe; SP = spawning; ST = spent).

DATE		Sample Size	ED	LD	ER	R	SP	ST
2-27-86	M	3	100					
	C	8	88	12				
3-4-86	M	5	100					
	C	4	50	25				25
3-11-86	M	1			100			
	C	2	100					
3-25-86	M	2			50	50		
	C	4			75	25		
4-8-86	M	4			75	25		
	C	4				100		
4-22-86	M	3				67		33
	C	5				100		
5-6-86	M	4				75		25
	C	7				85		15
5-22-86	M	1					100	
	C	6				83		17
6-3-86	M	2					100	
	C	1					100	
6-17-86	M	1				100		
	C	4				25	50	25
7-1-86	M	1						100
	C	1					100	

Table 6. Percentage of females in each stage of development at the Skull Creek Marina (M) and Mackay Creek control (C) sites. (ED = early development; LD = late development; ER = early ripe; R = ripe; SP = spawning; ST = spent).

Date		Sample Size	ED	LD	ER	R	SP	ST
2-27-86	M	19	94	6				
	C	10	100					
3-4-86	M	16	81	19				
	C	19	79	16				5
3-11-86	M	15	93	7				
	C	18	39	61				
3-25-86	M	17	6	42	52			
	C	20	5	25	70			
4-8-86	M	21	5	14	38	33	5	5
	C	19		5	11	79		5
4-22-86	M	21				96		4
	C	20			10	90		
5-6-86	M	19			16	84		
	C	16			6	94		
5-22-86	M	20			23	47	20	10
	C	17				94		6
6-3-86	M	21				25	47	28
	C	24				67	12	21
6-17-86	M	14				50	43	7
	C	21				47	28	25
7-1-86	M	21				33	57	10
	C	20				50	20	30

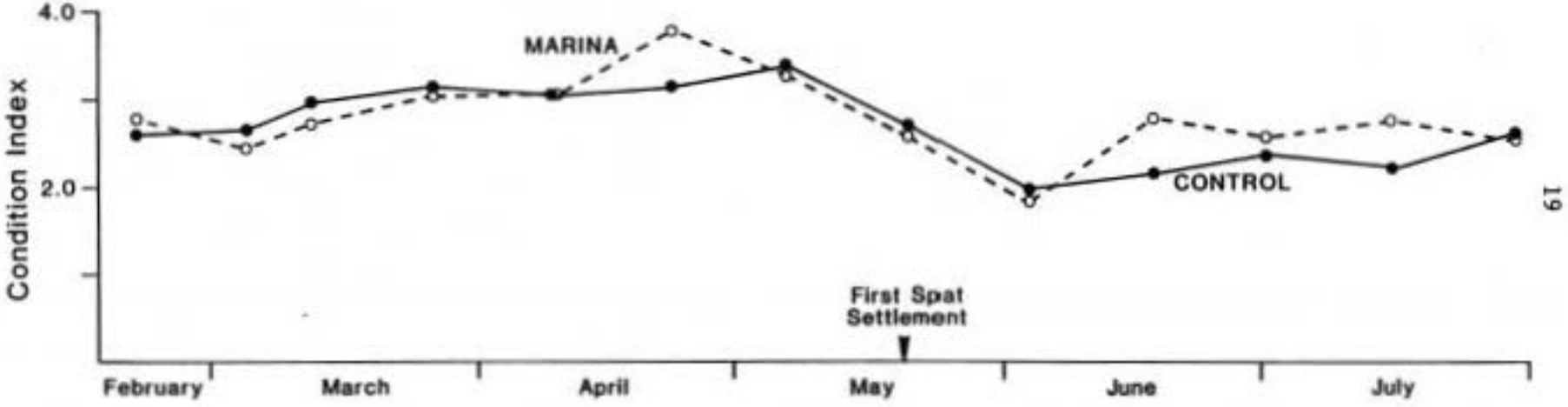

Figure 6. Condition index of oysters collected at the marina and control sites during each sampling period.

normal and have been correlated with seasonal changes in nutrient storage and utilization (Walne, 1970; Trevallion, 1971). Galtsoff (1964) indicated that seasonal fluctuations are related to reproductive activity in spring and summer and glycogen storage in fall. In our study, seasonal fluctuations in condition indices were clearly related to the storage and release of gonadal material, as indicated by corresponding fluctuations in the gonadal index measurements (Table 7).

In our study, there appeared to be no substantial difference in condition index between the marina and control sites. Low condition index values were recorded at both sites throughout the study period (Figure 6). Although high values (>10) generally indicate that oysters are in a good physiological condition, low values do not necessarily indicate poor health, because condition decreases whenever tissue is lost. Spawning, therefore, results in a short-term decrease in condition. A long-term decrease, however, may indicate stress from other sources such as pollutants, hypoxia, or disease (Trevallion, 1971; Abbe and Sanders, 1988). While no substantial differences in the condition of oysters from the marina and control sites were observed, it is possible that a longer-term study would have revealed chronic marina effects. Continued study might also clarify the existence of any relationship between the high mortality and the generally low condition index values evidenced at both sites. Newell (1985) indicated that MSX has a deleterious effect on feeding rates of oysters and can result in reduced condition index. Although we made no attempt to determine the cause of the low condition index values documented here, it is apparent that both sampling sites had comparably low values.

Benthic Macrofaunal and Sediment Composition Studies

Methods

Benthic Macrofauna

Macrofaunal samples were collected quarterly (February, May, August and November) during 1986, at six randomly selected sites in both the marina and control areas using a 0.05-m^2 Ponar grab. After removal of a small subsample of sediment for grain size and contaminants analyses, each grab sample was washed through a 0.5-mm mesh sieve. Organisms retained on the sieve were preserved in a buffered solution of 10% formalin for subsequent sorting and taxonomic identification in the laboratory. Surface and bottom water temperatures and salinities were recorded at both sites during each sampling period using a Hydrolab Surveyor II water quality monitoring instrument.

Analyses of variance, applied to $\log_{10}$-transformed data, were used to compare mean numbers of individuals and species between marina and control sites during each season. Species diversity (H'), species richness (SR) and evenness or equitability (J') were analyzed using equations from information theory (Pielou, 1975). Species diversity was measured using the Shannon-Weaver formula applied to pooled data from replicate samples:

$$H' = -\Sigma p_i \log_2 p_i$$

where H' is the diversity in bits of information per individual, and $p_i = n_i/N$ or the proportion of the pooled sample belonging to the i^{th} species. Species richness was calculated using the formula:

$$SR = S\text{-}1/\ln N$$

where S is the number of species and lnN is the natural logarithm of the total number of individuals of all species in the pooled sample. Evenness or equitability, a measure of how evenly the total number of individuals is distributed among the various species, was measured by:

$$J' = H'/\log_2 S$$

where H' and S are defined as above.

Cluster analyses (Boesch, 1977a) were used to describe similarities among sampling sites with respect to their species composition (normal analysis) and similarities among species with respect to their distributions among the various sampling sites (inverse analysis). The Bray Curtis (1957) similarity coefficient and flexible sorting classification algorithm (β = -0.25) (Lance and Williams, 1967) were used to perform the cluster analyses. Nodal analyses were used to interpret the results of the normal (site group) and inverse (species group) cluster analyses in terms of the classic community concepts of constancy and fidelity (Boesch, 1977a). Nodal constancy is a measure of how consistently the members of a particular species group occur among the collections in a particular site group. Nodal fidelity is a measure

Table 7. Average shell height (HT), condition index (CI) and gonadal maturity index (GMI) for oysters collected at the Skull Creek Marina and Mackay Creek control sites. (n = total number of oysters in each sample).

	HT (mm)	n	CI	GMI
CONTROL SITE				
2-27-86	95.20	25	2.60	0.90
3-04-86	97.52	25	2.65	1.13
3-11-86	94.76	25	2.99	1.35
3-25-86	84.00	25	3.12	2.75
4-08-86	89.44	25	3.06	3.65
4-22-86	92.96	25	3.15	3.92
5-06-86	93.12	25	3.36	3.96
5-22-86	89.96	25	2.52	3.80
6-03-86	88.24	25	1.98	3.20
6-17-86	93.48	25	2.15	3.04
7-01-86	93.84	25	2.37	2.50
7-15-86	81.52	21	2.21	-
7-29-86	75.20	24	2.60	-
MARINA SITE				
2-27-86	96.28	25	2.78	0.92
3-04-86	80.20	25	2.45	1.05
3-11-86	86.44	25	2.72	1.12
3-25-86	70.28	25	3.04	2.33
4-08-86	76.24	25	3.05	3.04
4-22-86	84.38	21	3.77	3.68
5-06-86	79.90	20	3.29	3.71
5-22-86	80.50	22	2.59	3.48
6-03-86	73.68	25	1.81	2.83
6-17-86	73.20	10	2.78	3.73
7-01-86	70.05	20	2.56	3.33
7-15-86	57.13	15	2.76	-
7-29-86	76.22	23	2.56	-

of the degree to which a particular species group is restricted to a particular site group. Mathematical expressions for these terms are given by Boesch (1977a).

Sediments

Percentages (by weight) of sand, silt, clay and calcium carbonate were determined for each sediment sample using procedures described by Folk (1974). Sand fractions were dry-sieved using a Ro-tap mechanical shaker, fitted with 12 screens graded in 0.5-phi intervals, for determinations of mean grain size and sorting coefficients. Total organic carbon content was measured by incinerating a portion of each sediment sample at 550°C for two hours as described by Plumb (1981).

Results and Discussion

Sediments and Hydrography

Average sampling depths, salinities and bottom water temperatures were remarkably similar at the marina and control sites throughout the study period (Table 8). Depths ranged from 4 to 5 m at both sites and salinities were consistently in the polyhaline to euhaline range. Bottom temperatures at both sites were lowest in February and highest in August.

The sediment grain size composition was not as similar between sites as our initial field observations had suggested. The marina sites encompassed a wider range of sediment types, but were generally muddier than control sites (Figure 7). Mean percentages of silt, clay, calcium carbonate and total organic carbon were all higher at the marina; however, well-sorted fine sands comprised the major sediment component at both marina and control sites.

Benthic Macrofauna

Over the course of four seasons, 4219 macrofaunal organisms representing 192 species were collected at the Skull Creek Marina. During the same time period, 5921 individuals representing 168 species were collected at the McKay Creek control site. The mean number of individuals per grab sample was significantly greater ($P<0.005$) at the control site than at the marina in winter and spring but not during the other two seasons (Figure 8). The mean number of species per grab did not differ significantly between sites during any season except fall (Figure 9); however, the total number of species was consistently higher at the marina during all four seasons (Table 9). Pooled diversity (H') values were also higher at the marina due to both higher species richness (SR) and higher evenness (J') values during all seasons except fall, when the evenness component was slightly higher at the control site (Table 9).

Taxonomic composition of the fauna also differed between marina and control sites. At the marina, polychaetes accounted for the greatest proportion of total abundance in winter, spring and summer, but were outranked by mollusks in fall (Figure 10). This large autumn increase in numbers of mollusks was due, primarily, to a rapid increase in the abundance of a small bivalve, Galeommatacea A, which appears to live commensally with the ophiuroid Microphiopholis gracillima. Amphipods ranked second in abundance at the marina in winter and spring, but were outranked by mollusks, ophiuroids and oligochaetes in summer and fall.

At the control site, polychaetes comprised the largest number of animals in winter, summer and fall, but were temporarily replaced by amphipods as the dominant taxon in spring when the gammaridean amphipod Ampelisca abdita increased dramatically in abundance (Figure 11). The other major taxa that accounted for at least 5% of the total abundance of organisms at the control site during one or more seasons were all crustaceans; these included isopods, ostracods and cumaceans. None of these groups was ever dominant at the marina. Some researchers have suggested that higher proportions of polychaetes and mollusks, relative to amphipods and other crustaceans, may be indicative of pollution (Long and Chapman, 1985). This theory is consistent with the elevated levels of some PAHs in sediments and oysters collected from the marina (see Contaminants section); however, our data are insufficient to conclude that there is necessarily a causal relationship between these contaminants and the taxonomic composition of the fauna.

Differences in species composition between marina and control sites are further elucidated by the results of our normal and inverse cluster analyses. A dendrogram depicting the nine site groups generated by a normal cluster analysis shows that most control site samples (groups 1 through 4) clustered separately from most marina samples (groups 6 through 9), regardless of season (Figure 12). There were, however, strong seasonal trends as well. This was particularly evident at the control site where, with

Table 8. Sediment and hydrographic data collected in conjunction with the benthic macrofaunal study.

	MARINA	CONTROL
% Sand (n = 24)	71.0 ± 2.8	87.1 ± 1.5
% Silt (n = 24)	11.1 ± 1.7	4.4 ± 0.7
% Clay (n = 24)	12.1 ± 1.7	7.3 ± 1.0
% $CaCO^3$ (n = 24)	5.7 ± 1.0	1.2 ± 0.4
% TOC (n = 24)	6.7 ± 0.8	2.7 ± 0.6
Mean Grain Size (sand fraction) (O, n = 24)	2.4 - 2.9 (range) 2.5 ± 0.05 (mean)	2.3 - 2.9 (range) 2.7 ± 0.02 (mean)
Sorting Coefficient (sand fraction) O, n = 24)	0.2 - 0.7 (range) 0.5 ± 0.02 (mean)	0.3 - 0.5 (range) 0.4 ± 0.04 (mean)
Mean Depth (m, n = 24)	4.5 ± 0.7	4.2 ± 0.6
Mean Bottom Salinity °/oo, n = 4)	31.9 ± 1.2	31.6 ± 1.0
Range of Bottom Temperatures (°C, n = 4)	11.5[a] - 30.2[b]	14.8[a] - 29.8[b]

[a]February, 1986
[b]August, 1986

Table 9. Total number of individuals, total number of species, and pooled community structure values (H', SR and J') for the marina and control sites.

	Total # Individuals		Total # Species		Pooled Shannon-Weaver Diversity (H')		Pooled Species Richness (SR)		Pooled Evenness (J')	
	Marina	Control	Marina	Control	Marina	Control	Marina	Control	Marina	Control
Winter	725	1901	109	108	5.59	5.00	16.40	14.17	0.83	0.74
Spring	1422	2502	105	94	5.23	3.62	14.33	11.89	0.78	0.55
Summer	950	902	101	86	5.25	4.82	14.58	12.49	0.79	0.75
Fall	1123	616	84	66	4.94	4.88	11.82	10.12	0.77	0.81

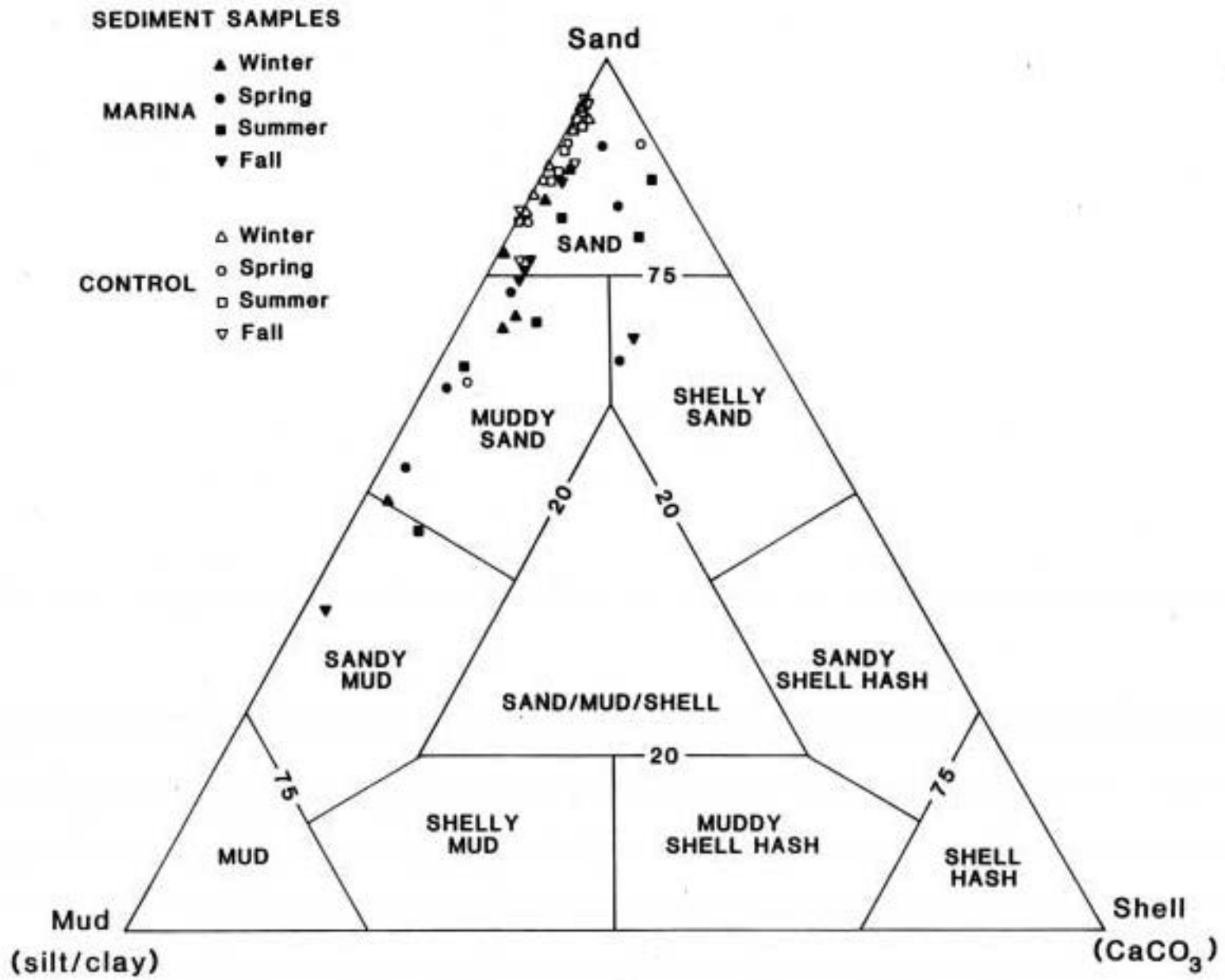

Figure 7. Classification of sediments from the marina and control sites based on percentages of sand, mud and shell.

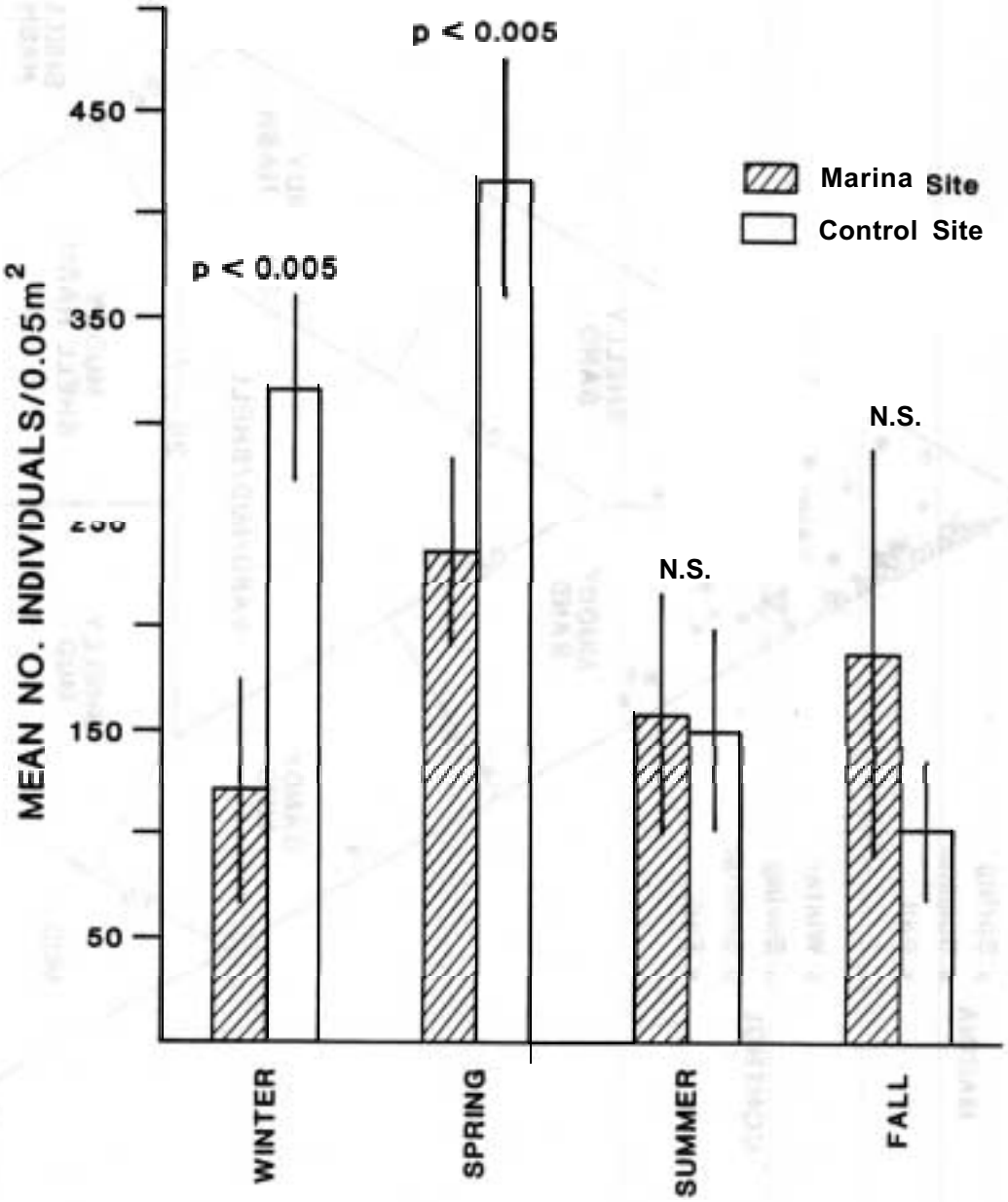

Figure 8. Mean number of macrofaunal organisms per grab sample (O.OSmt) at the marina and control sites during each season. (p = probability values associated with significant differences between sites modell ANOVA]; N.S. = no significant difference).

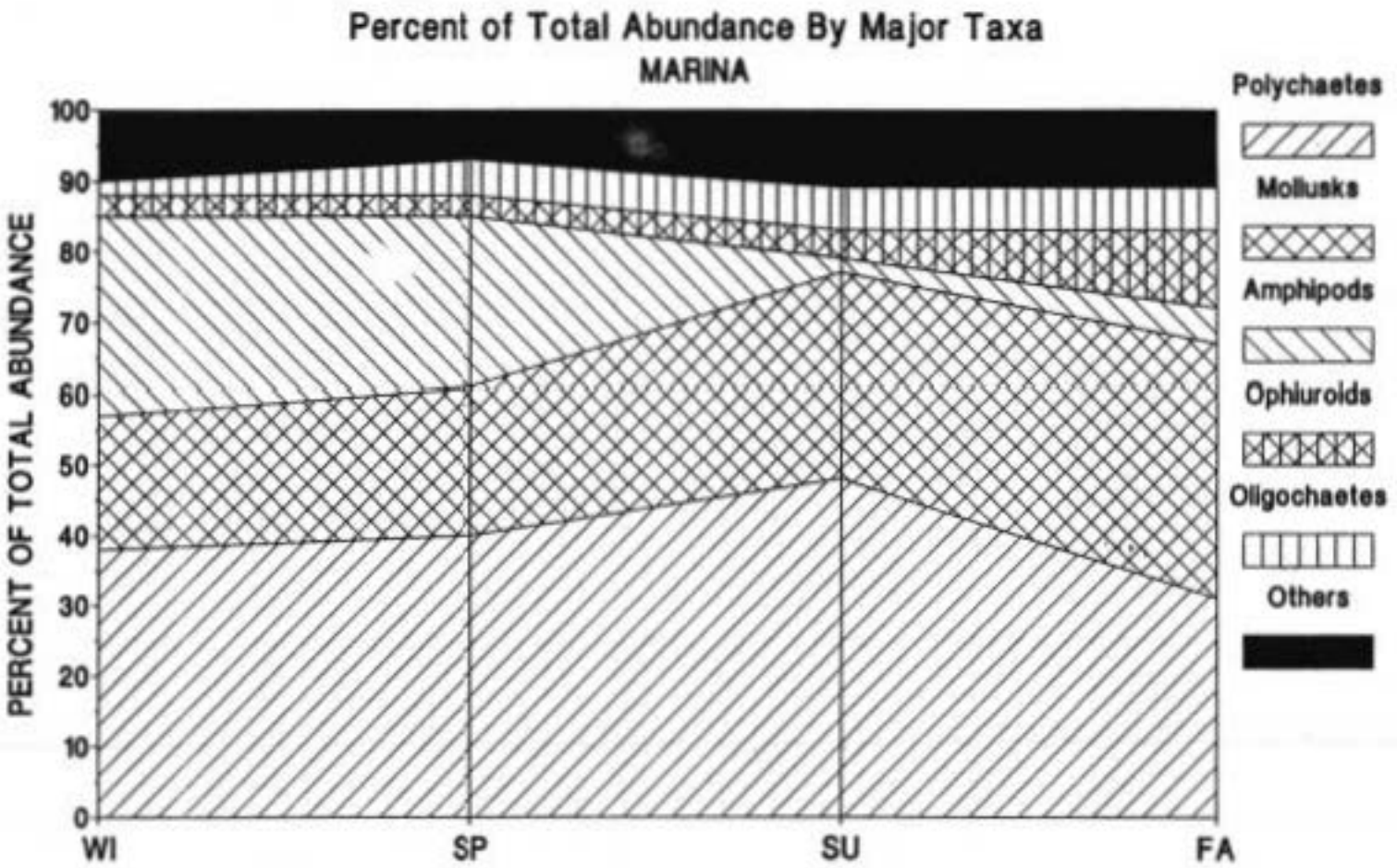

Figure 10. Percentage of total macrofaunal abundance contributed by each of the major taxa at the marina. Only those taxa accounting for ≥5.00% of the total abundance of organisms during one or more seasons are shown separately. Less abundant taxa are collectively shown as "Others".

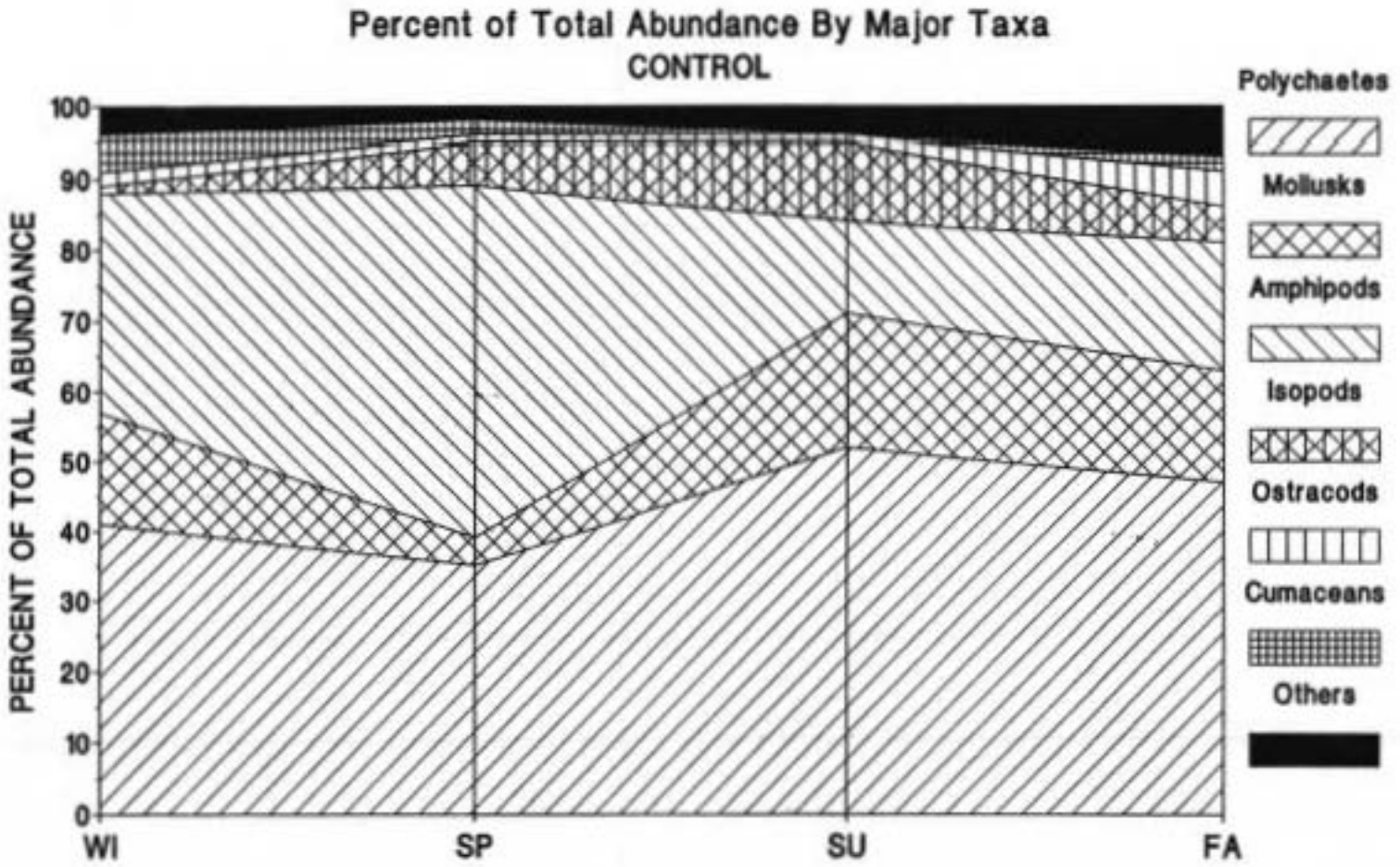

Figure 11. Percentage of total macrofaunal abundance contributed by each of the major taxa at the control site. Only those taxa accounting for $\geq$5.00% of the total abundance of organisms during one or more seasons are shown separately. Less abundant taxa are collectively shown as "Others".

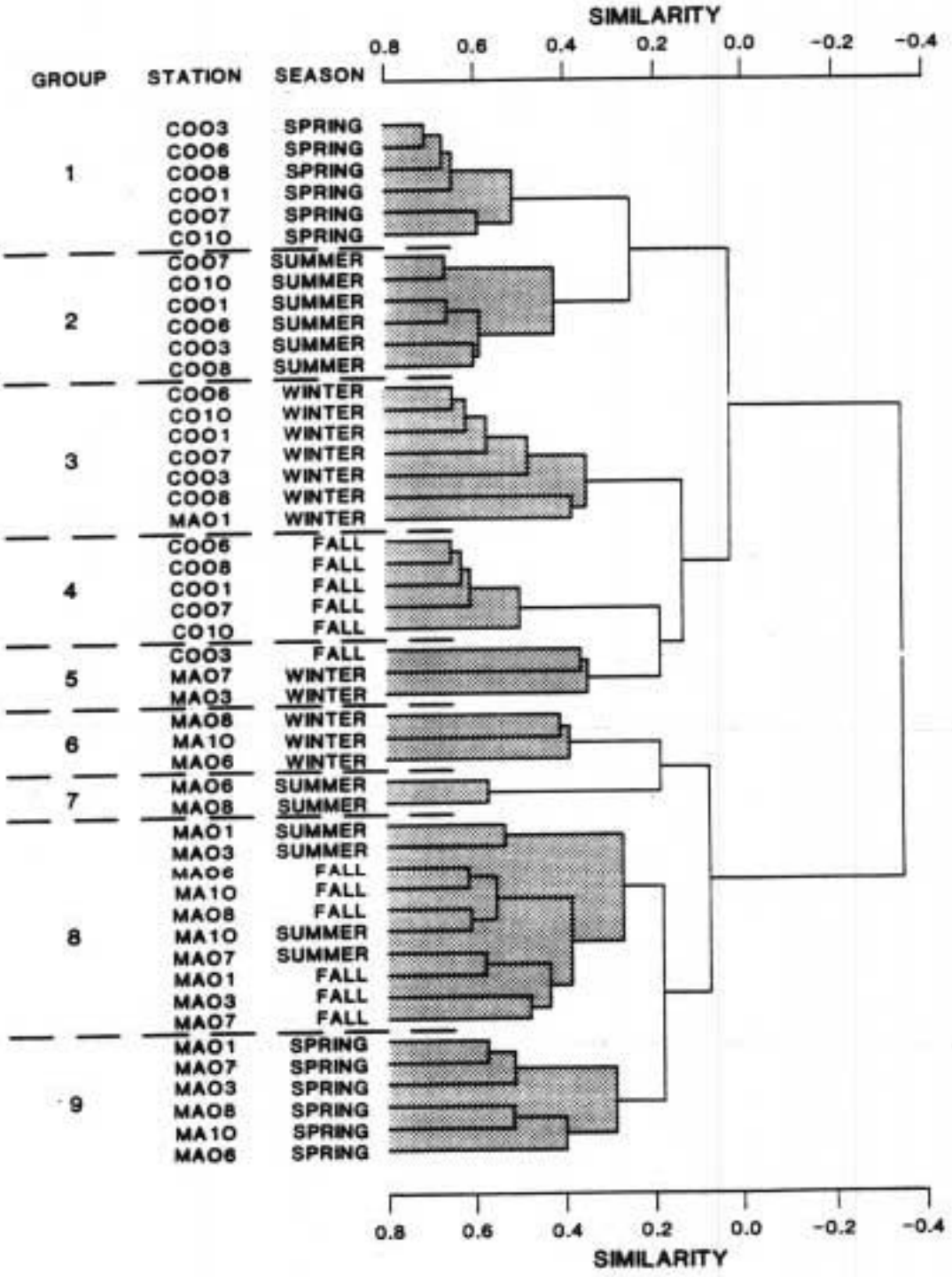

Figure 12. Dendrogram depicting the results of a normal cluster analysis of all marina (MA01 through MA10) and all control site (CO01 through CO10) collections.

one exception, all of the grab samples taken during a particular season clustered together. This seasonal pattern was not as pronounced at the marina, where summer and fall grab samples tended to be more similar to one another than at the control site. Nevertheless, some of the winter and all of the spring samples from the marina (groups 6 and 9, respectively) did form discrete assemblages in this hierarchy.

An inverse cluster analysis of all those species which occurred in at least two collections generated 21 species groups (Appendix 3). Their distributions among marina and control sites are illustrated by nodal constancy and fidelity diagrams (Figure 13). Species group A included several species that were neither abundant nor rare at either site, but were collected fairly consistently at both sites, particularly during winter and spring. These species were collected with somewhat greater frequency at the control site than at the marina, as evidenced by the generally higher level of constancy exhibited by this species group among site groups 1 through 5. Many of these species (e.g., Streblospio benedicti, Paraprionospio pinnata, Heteromastus filiformis, Glycinde solitaria and Acteocina canaliculata) are considered to be eurytopic because they inhabit a wide variety of sediment types and are ubiquitous constituents of the macrobenthos in the poly-and mesohaline zones of other estuaries in the Middle and South Atlantic Bights (Boesch, 1977b; Fox and Ruppert, 1985; Holland et al., 1989).

Species group B was composed of four species that were consistently collected at the control site, particularly during spring and summer. These species also occurred in most marina collections taken during the spring, but not during any other season. Three of these species (the isopod Cyathura burbancki, the amphipod Ampelisca verrilli, and the polychaete Clymenella torquata) were among the most abundant species taken at the control site during the entire course of this study (Table 10; Figure 14). None of these species was ever abundant at the marina, however. In general, species in group B were somewhat more restricted in their distribution with respect to sediment type than species in group A, as indicated by their moderate fidelity to the sandier control sites (Figure 13). Both A. verrilli and C. torquata are infaunal tube builders. Ampelisca verrilli, a suspension/surface deposit feeder, typically inhabits medium sand substrates (Bousfield, 1973), whereas, C. torquata, a sub-surface "conveyor belt" deposit feeder, is frequently found in fine to muddy sand (Rhoads, 1974). Rhoads (1974) has observed that C. torquata's habit of ingesting fine-grained deposits at depth and defecating the ingested particles at the surface produces positive relief structures which may support other tubicolous infauna. This suggests that the co-occurrence of C. torquata and A. verrilli may not be strictly fortuitous. This is certainly true for another associate of C. torquata and member of species group B, Aligena elevata, a small commensal bivalve that attaches by byssal threads to the bottom of C. torquata tubes (Fox and Ruppert, 1985).

The five species in group C were among the most abundant and ubiquitous species at both the marina and control sites (the amphipod Ampelisca abdita, the bivalve Tellina texana and the polychaetes Mediomastus californiensis, Spiochaetopterus oculatus and Lumbrineris tenuis). These species exhibited very high constancy and low fidelity among all site groups. Ampelisca abdita is more eurytopic with respect to sediment type than its congener A. verrilli, inhabiting a variety of substrates ranging from fine sand to silt-clay (Bousfield, 1973). It has also been characterized as an "opportunist", due to its ability to rapidly colonize defaunated substrates (McCall, 1977; Nichols and Thompson, 1985). This amphipod exhibited a peak in relative abundance at both the marina and control sites in spring, although its abundance was much greater at the control site during this season (Figure 14). The capitellid polychaete Mediomastus californiensis is similarly eurytopic, inhabiting sediments ranging from medium sand to mud (Ewing, 1984). This species has been described as a "generalist" because of its broad distribution in other coastal and estuarine habitats (Flint and Rabalais, 1980). The chaetopterid polychaete Spiochaetopterus oculatus, an infaunal tube-dweller and suspension/surface deposit feeder, also occurs in a wide variety of substrates ranging from medium sand to mud (Gilbert, 1984). Despite its eurytopism, S. oculatus was consistently more abundant at the control site than at the marina. The deposit feeding bivalve Tellina texana typically occurs in sand (Abbott, 1974); however, like many of its congeners, T. texana is probably able to successfully colonize muddy substrates (such as those at the Skull Creek Marina) by virtue of its thin shell and modified eulamellibranch gill structure, which controls the quantity of particulate material entering the mantle cavity (Rhoads, 1974). Finally, Lumbrineris tenuis, an infaunal burrower and non-selective deposit feeder (Sanders et al., 1962), typically inhabits coarse, fine and muddy sand. Its adaptability to a broad range of

Table 10. Species accounting for ≥1.00 percent of the total abundance of macrofaunal organisms collected in grab samples from the marina and control sites, and their rank by abundance for each season. (A = amphipod; B = bivalve; C = cumacean; G = gastropod; I = isopod; O = ophiuroid; P = polychaete).

MARINA SITE

Dominant Species	Winter		Spring		Summer		Fall		All Seasons	
	Rank	% Abund.	Rank	% Abund.	Rank	% Abund.	Rank	% Abund.	Rank	% Abund.
Paleomastacea A (B)	2	8.69	2	7.52	1	14.00	1	19.68	1	12.42
Mediomastus californiensis (P)	4	4.28	3	6.54	3	6.32	2	5.88	2	5.93
Ampelisca abdita (A)	6	3.45	1	13.29	40	0.42	18	1.51	3	5.57
Lumbrineris tenuis (P)	7	3.31	5	5.27	2	8.42	12	2.58	4	4.93
Tellina texana (B)	8	2.90	4	5.84	7	3.89	6	4.90	5	4.65
Oligochaeta	18	1.52	7	4.57	4	5.79	3	5.70	6	4.62
Spiochaetopterus oculatus (P)	3	4.97	6	4.71	9	3.16	8	4.27	7	4.29
Tharyx sp. (P)	--	---	9	2.95	5	5.37	7	4.54	8	3.41
Microphiopholis gracillima (O)	50	0.41	13	2.46	11	2.95	4	5.52	9	3.03
Caprella equilibra (A)	1	13.24	33	0.56	57	0.21	31	0.62	10	2.68
Acteocina canaliculata (G)	9	2.76	21	1.34	8	3.26	10	2.67	11	2.37
Aricidea fragilis (P)	12	2.07	14	2.25	12	2.32	11	2.67	12	2.35
Actiniaria A	82	0.14	46	0.28	6	4.53	13	1.96	13	1.66
Axiognathus squamata (O)	--	---	55	0.21	29	0.63	5	5.34	14	1.64
Ostracod B	44	0.41	12	2.46	25	0.84	17	1.51	15	1.49
Diopatra cuprea (P)	10	2.48	25	0.91	19	1.26	15	1.69	16	1.47
Lyonsia hyalina (B)	15	1.66	8	2.95	--	---	56	0.18	17	1.33
Nucula proxima (B)	51	0.41	15	1.97	16	1.58	28	0.80	18	1.30
Tagelus divisus (B)	67	0.28	87	0.07	10	3.05	19	1.42	19	1.14
Leitoscoloplus fragilis (P)	54	0.41	10	2.88	97	0.11	63	0.18	20	1.11
Streblospio benedicti (P)	14	1.53	17	1.62	27	0.84	--	---	21	1.07
Eulichiella appendiculata (A)	22	1.10	11	2.53	--	---	--	---	22	1.04
Heteromastus filiformis (P)	5	3.39	24	0.91	43	0.42	82	0.09	23	1.04

CONTROL SITE

Dominant Species	Winter		Spring		Summer		Fall		All Seasons	
	Rank	% Abund.	Rank	% Abund.	Rank	% Abund.	Rank	% Abund.	Rank	% Abund.
Ampelisca abdita (A)	2	13.78	1	37.49	21	1.00	8	5.03	1	20.94
Spiochaetopterus oculatus (P)	1	14.99	2	14.11	1	14.86	1	14.94	2	14.59
Ampelisca verrilli (A)	5	4.63	3	8.55	4	8.54	2	6.82	3	7.11
Cyathura burbancki (I)	40	0.17	5	6.24	2	11.42	6	5.36	4	5.05
Lumbrineris tenuis (P)	12	2.10	6	4.36	3	8.87	3	6.49	5	4.54
Clymenella torquata (P)	29	0.84	4	6.99	5	7.65	--	---	6	4.39
Tellina texana (B)	3	8.15	31	0.24	7	3.66	7	5.19	7	3.82
Mediomastus californiensis (P)	4	4.94	7	2.20	15	1.44	4	6.49	8	3.41
Acteocina canaliculata (G)	8	3.30	9	1.60	14	1.44	9	4.06	9	2.28
Oxyurostylis smithi (C)	6	4.37	8	1.60	--	---	28	0.65	10	2.14
Scoloplos rubra (P)	9	2.32	11	1.08	13	1.55	10	3.08	11	1.82
Aricidea fragilis (P)	32	0.74	13	0.88	9	2.99	5	6.17	12	1.71
Streblospio benedicti (P)	7	3.10	26	0.32	10	1.33	46	0.32	13	1.37
Glycinde solitaria (P)	14	1.53	21	0.44	10	2.33	24	0.81	14	1.15

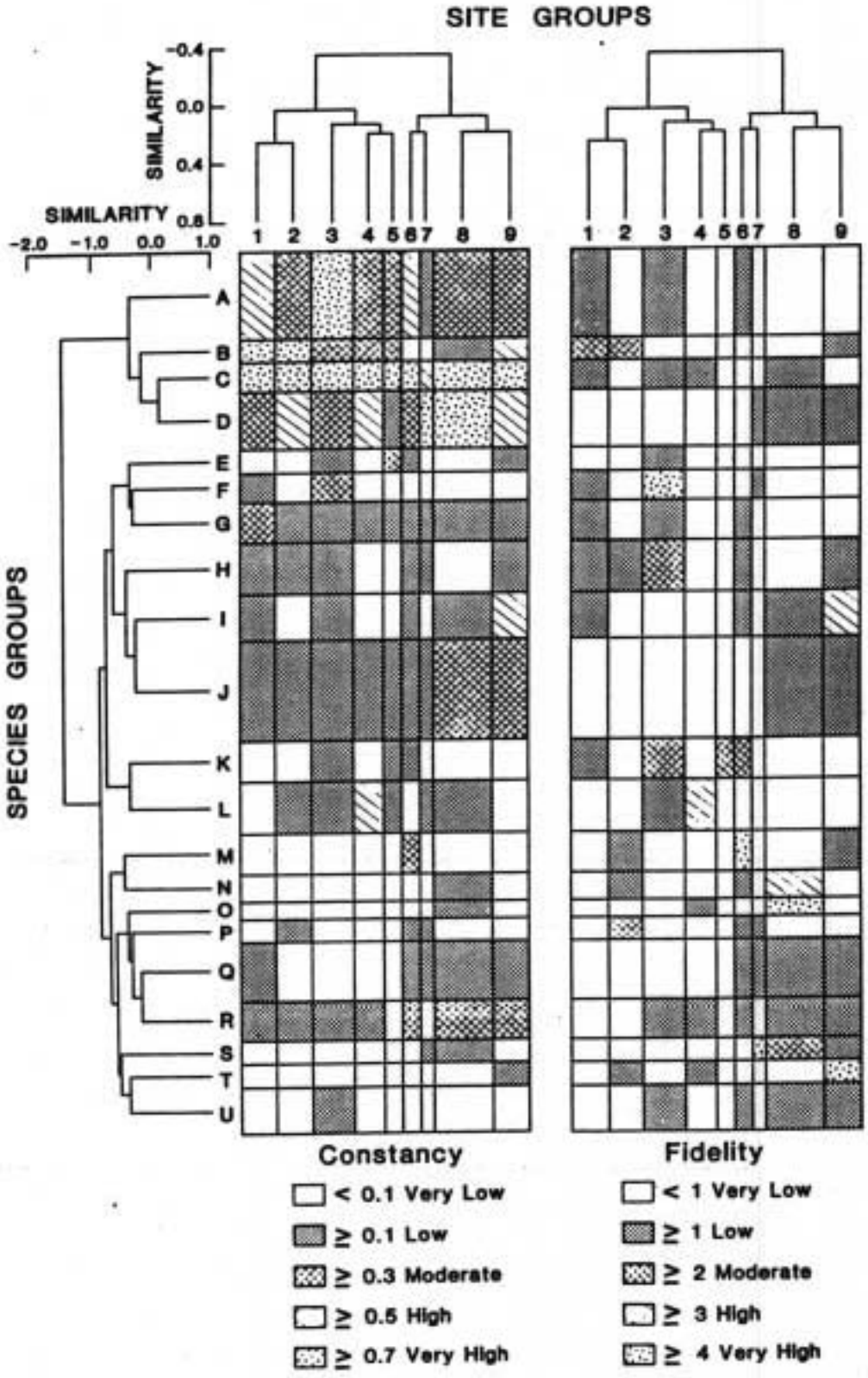

Figure 13. Nodal constancy and fidelity diagrams illustrating species group/site group coincidences. Species groups and site groups were generated, respectively, by inverse and normal cluster analyses.

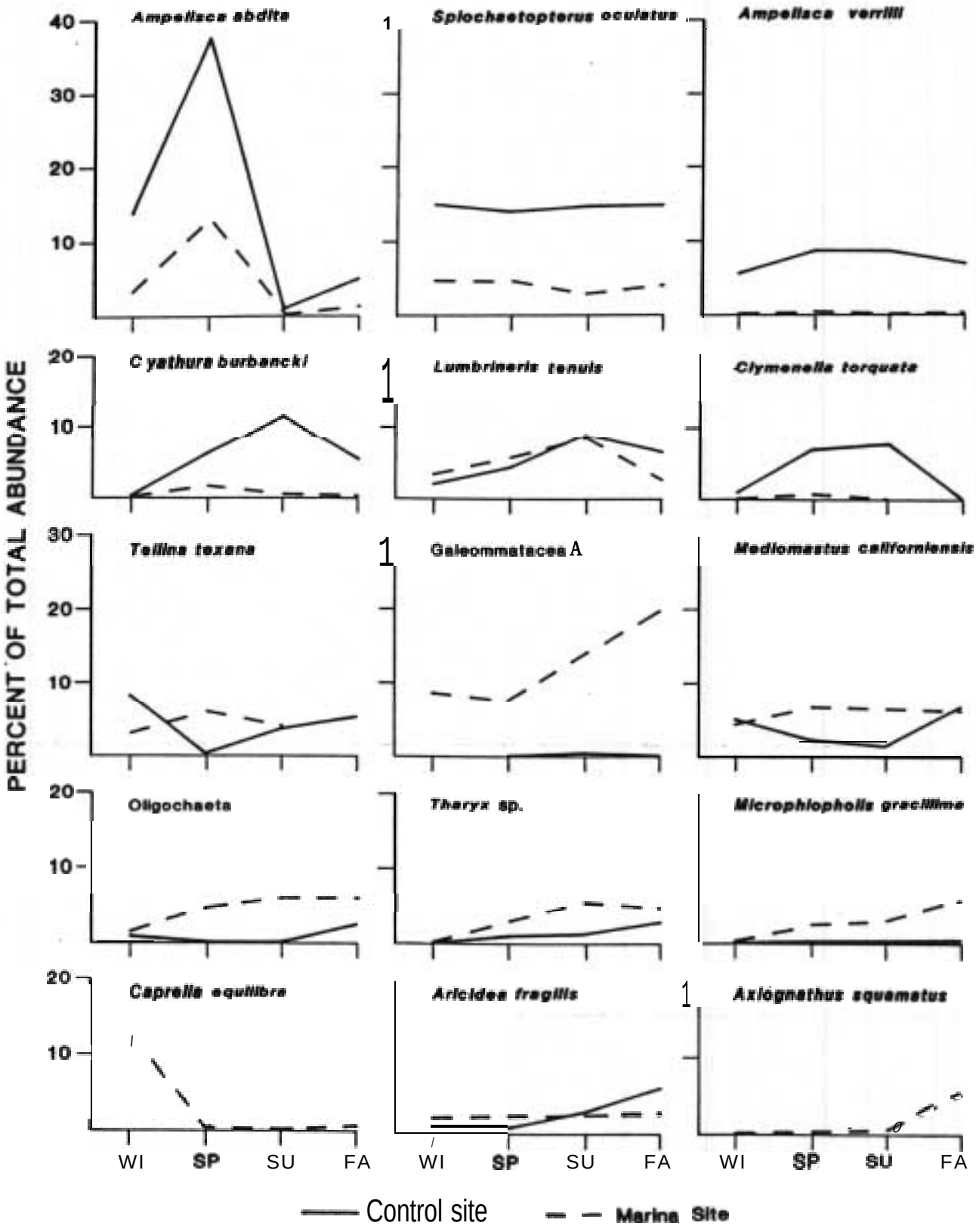

Figure 14. Percentage of total macrofaunal abundance contributed by each of the dominant species at either the marina (dotted line) or the control site (solid line). Only those species accounting for ≥5.00% of the total abundance of organisms at one or both sites during one or more seasons are shown.

sediment types may explain its similar abundance patterns at the marina and control sites.

Species group D was characterized by its high to very high constancy at both marina and control sites in summer and fall, its moderate to high constancy in spring, and its moderate to low constancy in winter. Despite their ubiquity, however, most species in group D were generally more abundant at the marina than at the control site. Seven of the 10 taxa in group D were among the 15 most abundant species at the marina, whereas, only two of the 10 taxa were among the 15 most abundant species at the control site (Table 10). Four constituents of group D (the ophiuroid Microphiopholis gracillima, the bivalve Galeommatacea A, the polychaete Tharyx sp. and all members of the class Oligochaeta) each accounted for $\geq$5.00% of the total abundance of organisms collected at the marina during one or more seasons (Figure 14). Microphiopholis gracillima is a selective deposit feeder that prefers sandy mud sediments containing large amounts of organic matter (Zimmerman et al., 1988). This pattern is consistent with its higher abundance at the marina, where sediments tended to be muddier and higher in total organic carbon content, than at the control site (Table 8). Galeommatacea A may be synonymous with Fox and Ruppert's (1985) Mysella sp. C, a small bivalve that lives commensally with M. gracillima, attached to the ophiuroid's arms. In this study, Galeommatacea A always co-occurred with M. gracillima and its abundance increased greatly in summer and fall as the abundance of M. gracillima increased, albeit more gradually.

Species group E included four species that were highly faithful to a small group of anomalous collections from both the marina and control sites (site group 5). These species were never abundant at either site and showed no clear pattern of distribution with respect to either site or season.

Species group F consisted of five species that exhibited a high degree of fidelity to control sites in winter (site group 3). These included the tubicolous polychaete Owenia fusiformis, which has been shown to prefer sandier substrates (Flint and Rabalais, 1980), such as those characteristic of the control site in this study. Group F also included the amphipod Listriella clymenellae, which lives commensally in tubes of the maldanid polychaete Clymenella torquata, a constituent of species group B. Unlike its host, which was taken in collections throughout the year, L. clymenellae occurred only in winter, thus explaining its assignment to a different species group characterized by seasonal fidelity.

Species groups G and H included several infrequently occurring species that, like group E species, showed no clear pattern of distribution with respect to either site or season.

Species group I was characterized by its high level of constancy and fidelity among marina samples collected in spring (site group 9). Several of these species (e.g., the amphipods Stenothoe georgiana, Corophium acherusicum, Dulichiella appendiculata, Eobrolgus spinous and Lembos hypacantha) are commonly associated with oyster reefs or floating docks, pilings and walls (Bousfield, 1973; Fox and Ruppert, 1985), most of which are conspicuous features of the Skull Creek Marina.

Species group J included several species that were either more frequently collected or more abundant at the marina than at the control site during one or more seasons. The epifaunal amphipod Caprella equilibra was the top-ranking numerical dominant at the Skull Creek Marina in winter, comprising 13.24% of the total number of organisms collected at the marina during that sampling period (Table 10; Figure 14). The abundance of C. equilibra declined in spring and remained low throughout the summer and fall. Caine (1987) observed a similar phenomenon at the Downtown Marina in Beaufort, South Carolina, and attributed the population decline of C. equilibra and three other (gammaridean) amphipods to increased predation coincident with the arrival of reproductive schools of Atlantic silversides. Caprella equilibra has been collected from sea grass, algae, sponges, hydroids, bryzoans, alcyonarian corals and ascidians (McCain, 1968; Caine, 1978). In South Carolina, C. equilibra occurs abundantly in numerous habitats, including oyster reefs, floating docks, pilings and walls (Fox and Ruppert, 1985). Several other species in group J are commonly associated with shells, rocks, other hard substrates or with the invertebrates and algae growing on those surfaces. These species include the ophiuroids Axiognathus squamatus and Hemipholis elongata; the bivalve Sphenia antillensis; the gastropods Pyrgocythara plicosa and Costoanachis avara; and the polychaete Exogone dispar (Pettibone, 1963; Fox and Ruppert, 1985).

Species group K exhibited moderate fidelity to collections taken in winter from both the marina and control sites (site groups 3, 5, and 6). Nevertheless, two of these species (the sea pansy Renilla reniformis

and the haustoriid amphipod Rhepoxynius epistomus) were collected only at the control site. Renilla reniformis has been described as a common inhabitant of protected beaches, creeks and sounds (Fox and Rupert, 1985), while R. epistomus is frequently collected in medium fine sands from shallow subtidal to >50 m depths (Bousfield, 1973).

Species group L was highly constant among, and faithful to, control site samples collected in fall (site group 4). Several of these species, including the amphipod Synchelidium americanum, the cumacean Cyclaspis varians and the gastropod Terebra dislocata, were never collected at the marina. All of these species are relatively stenotopic with respect to sediment type, occurring only in fine to muddy sand along protected beaches or in creeks and sounds (Bousfield, 1973; Watling, 1979; Fox and Ruppert, 1985). At least one of these species, Cyclaspis varians, also tends to be more abundant in highly saline, well-oxygenated waters (Modlin and Dardeau, 1987).

Species group M was highly faithful to marina sites in winter (site group 4), and several of these species (the amphipods Lembos smithi and Corophium acutum; the ophiuroid Ophiothrix angulata; and the holothurian Cucumaria pulcherrima) occurred only at the marina. Both L. smithi and C. acutum are commonly found in current-swept areas on pilings, walls, floating docks and oyster reefs (Bousfield, 1973; Fox and Ruppert, 1985). Ophiothrix angulata is also associated with shell and other hard substrates, while C. pulcherrima typically occurs in mud (Deichmann, 1930).

Species groups N and O were characterized by their high fidelity to summer and fall collections from the marina (site group 8). Some of these species are closely associated with hard substrates (e.g., the scorched mussel Brachidontes exustus and the carnivorous polychaete Paranaitis speciosa), while others occur in a variety of substrates ranging from sand to silt/clay (e.g., the carnivorous scale worm Sthenelais sp. and the mud snail Nassarius vibex). Rhoads (1974) observed that Nassarius spp., which are non-selective deposit feeders, are able to control the quantity of detritus entering the mantle cavity by means of an extensible proboscis or inhalant siphon. This would seem to be a highly adaptive trait for a species inhabiting muddy environments such as a marina basin.

None of the remaining species groups was more than moderately constant among any of the site groups, and only species groups S and T were highly faithful to any site groups (groups 7 and 9, respectively). These two groups included several species that were found only at the marina. Among these were two terebellid polychaetes (Amphitrite ornata and Thelepus setosus) which typically inhabit tubes attached to hard substrates (Kritzler, 1984) and a suspension feeding bivalve (Macoma sp.) that is successfully able to survive in muddy habitats as a consequence of its modified lamellibranch structure that controls the volume of particulate matter entering its mantle cavity (Rhoads, 1974).

The patterns that emerge from these faunal analyses suggests that sediment type and the proximity of hard substrate appear to determine most of the qualitative and quantitative differences in species composition between the marina and control sites. The higher percentage of silt/clay at the marina seems to have favored the occurrence of infaunal burrowers (e.g., ophiuroids and oligochaetes) over infaunal tube-dwellers (e.g., tubicolous polychaetes and ampeliscid amphipods), whereas, the latter were more abundant at the sandier control site (Table 11). Trophic mode was similarly affected by sediment type. Although deposit feeding was the predominant trophic mode at both sites, several suspension feeders were restricted in their distribution to the control site. These species apparently lack the morphological and behavioral traits that allow certain suspension feeding bivalves (e.g., Macoma and Tellina spp.) to occupy muddier habitats by controlling their position in the sediment and their intake of particulate matter. The disparity in sediment type between the marina and control sites may simply be a function of natural variability; however, it is conceivable that the current regime at the marina has been sufficiently altered by the presence of pilings, docks and other physical structures to have resulted in increased siltation and, consequently, muddier sediments in comparison to the control site. Unfortunately, the absence of any baseline data for the Skull Creek site prior to construction of the marina precludes a definitive answer to this question.

Although certain species may be effectively excluded from the marina by the finer sediments there, the higher concentration of organic matter may have contributed to the greater abundance of certain deposit feeders, such as oligochaetes and ophiuroids. Furthermore, the higher proportion of shell hash, as well as the presence of floating docks and pilings, has

Table 11. **Predominant feeding type, position in the sediment and typical substrate occupied by each of the numerically dominant species at the marina and control sites.**

DOMINANT SPECIES*

SPECIES	Rank by Abundance M	C	Predominant Feeding Type SF	DF	C	Position in the Sediment InB	InT	Ep	Typical Substrate
1. Ampelisca abdita (A)	3*	1*		X			X		fine sand-mud
2. Spiochaetopterus oculatus (P)	7*	2*	X	X			X		med. sand-mud
3. Ampelisca verrilli (A)	61	3*		X			X		coarse-med. sand
4. Cyathura burbancki (I)	27	4*		X		X			coarse-med. sand
5. Lumbrineris tenuis (P)	4*	5*		X		X			coarse, fine, muddy sand
6. Clymenella torquata (P)	69	6*		X			X		fine-muddy sand
7. Tellina texana (B)	5*	7*		X		X			sand
8. Galeommatacea A (B)	1*	75		**				***	host species
9. Mediomastus californiensis (P)	2*	8*		X		X			med. sand-mud
Oligochaeta	6*	30		X		X			--------
10. Tharyx spp. (P)	8*	15		X		X			sand, muddy sand
11. Microphiopholis gracillima (O)	9*	64		X		X			sandy mud
12. Caprella equilibra (A)	10*	---		X				X	sessile organisms, oyster reefs, docks, pilings
13. Aricidea fragilis (P)	12	12*		X		X			med. sand-mud
14. Axiognathus squamatus (O)	14*	140		X		X			commonly concealed (under stones, shells, seaweed)

M = Marina C = Control SF = Suspension Feeder DF = Deposit Feeder C = Carnivore
InB = Infaunal Burrower InT = Infaunal Tube-dweller Ep = Epifaunal

* Species accounting for ≥5.00% of the total abundance at either site during one or more seasons. A = amphipod; B = bivalve; I = isopod; O = ophiuroid; P = polychaete.

** May feed on food particles on ophiuroid arms

*** Commensal with M. gracillima

1-Mills (1967)
2-Gilbert (1984)
3-Bousfield (1973)
4-Frankenberg (1965); Fox and Ruppert (1985)
5-Sanders et al. (1962); Uebelacker (1984)
6-Rhoads (1974); Wolf (1984a)
7-Abbott (1974)
8-Fox and Ruppert (1985)
9-Ewing (1984)
10-Wolf (1984b)
11-Zimmerman et al. (1988)
12-Fox and Ruppert (1985); McCain (1968)
13-Gaston (1984)
14-Fox and Ruppert (1985)

resulted in greater microhabitat complexity and, consequently, a greater diversity of both sessile and motile epifaunal species than at the control site. This phenomenon is not surprising and, in fact, has been documented by other researchers as well (Nixon et al., 1973; Caine, 1987). Evidence suggests that sessile fouling communities may serve as "feeding stations" for fish, from which motile epifauna are grazed (Caine, 1987). Additionally, the fouling communities, themselves, may serve as an important food source, particularly for juvenile fish (Nixon et al., 1973). These juvenile "bait" fish may, in turn, attract greater numbers of sport fish to the marina. Despite these potentially beneficial effects, there can be some adverse environmental impacts associated with high densities of fouling organisms in marinas. Among these are reduced dissolved oxygen levels as a consequence of collectively high respiration rates and the bioaccumulation of toxic substances which may become concentrated in successively higher levels of the food chain (Nixon et al. 1973; Marcus and Stokes, 1985).

While the benthic community at the Skull Creek Marina is generally typical of estuarine communities elsewhere in South Carolina, the lower abundance of certain pollution-sensitive species may be indicative of some degree of environmental degradation. In particular, the tubicolous polychaete Spiochaetopterus oculatus was consistently less abundant at the marina than at the control site, despite its well-documented eurytopism with respect to sediment type. This species, whose susceptibility to the acutely toxic effects of number 6 fuel oil has been demonstrated in the laboratory (Hyland, 1973), also exhibited a drastic decline in abundance in response to an oil spill in the lower York River, Virginia (Bender et al. 1974). These findings suggest that the lower abundance of S. oculatus at the marina may be related to the somewhat higher concentrations of certain petroleum-derived aromatic hydrocarbons found in the sediments there (see Contaminants section).

The lower abundance of crustaceans, and the higher abundance of capitellid polychaetes and oligochaetes at the marina, may be further indication of some "insidious alteration of the estuarine environment" as described by Odum (1970). Several researchers have observed that organic enrichment of the sediments (e.g., from sewage or pulp mill effluents) may result in higher abundances of certain pollution-tolerant or "opportunistic" species, particularly capitellid polychaetes, while other species that are unable to utilize the additional food supply become progressively rare or disappear entirely (Pearson and Rosenberg 1978; Gray and Pearson, 1982; Pearson et al., 1983; Rygg, 1985a; Ansari et al., 1986; Madsen and Jensen 1987). These findings are consistent with the results of our study.

On the other hand, pollution resulting from the addition of heavy metals has been shown to be negatively correlated with species diversity, not because a few pollution-tolerant species increase in abundance as they do in areas of organic enrichment, but rather because the toxicity of these compounds results in an overall decline in the number of species present (Rygg 1985b, 1986). In our study, diversity values were consistently higher at the marina than at the control site. As noted above, this was largely a consequence of the additional habitat provided by physical structures at the marina. Nevertheless, the high species richness at the marina suggests that heavy metals such as copper, lead, or tributyltin are not present in sufficient concentrations to have seriously affected the community structure of benthic organisms there.

In summary, our study provides evidence for a variety of community responses to several environmental factors which seem to be related to the presence of the marina. These factors include 1) muddier sediments, which may be a function of altered hydrography; 2) hard substrata provided by docks and pilings; 3) possible organic enrichment of the sediments; and 4) possible contamination of the sediments by petroleum-derived hydrocarbons.

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Appendix 1. Concentrations of polynuclear aromatic hydrocarbons and heavy metals in water, sediment and oysters collected from the Skull Creek Marina and Mackay Creek control sites during spring (SP), summer (SU), fall (FA), and winter (WI).

Chemical Component	WATER								SEDIMENT[1]								OYSTERS[1]							
	MARINA				CONTROL				MARINA				CONTROL				MARINA				CONTROL			
(ug/g)	WI	SP	SU	FA	WI	SP	SU	FA	WI	SP	SU	FA	WI	SP	SU	FA	WI	SP	SU	FA	WI	SP	SU	FA
Acenaphthene	--	ND	<0.01	--	--	ND	<0.01	--	--	ND	ND	ND	--	ND	ND	ND	ND	ND	0.03	ND	ND	ND	<0.01	ND
+Benzo (a) anthracene	--	ND	*	--	--	ND	ND	--	--	ND	ND	ND	--	ND	ND	ND	ND	ND	0.02	ND	ND	ND	0.01	ND
+Benzo (b) fluoranthene	--	ND	ND	--	--	ND	ND	--	--	1.31	0.46	ND	--	ND	ND	ND	ND	ND	6.11	ND	ND	ND	ND	ND
Benzo (k) fluoranthene	--	ND	ND	--	--	ND	ND	--	--	*	1.00	ND	--	ND	ND	ND	ND	ND	0.25	ND	ND	ND	ND	ND
+Benzo (a) pyrene	--	ND	ND	--	--	ND	ND	--	--	1.89	0.12	ND	--	ND	ND	ND	ND	ND	0.18	0.14	ND	ND	ND	ND
Fluoranthene	--	ND	ND	--	--	ND	ND	--	--	ND	ND	ND	--	ND	ND	0.51	ND	ND	ND	*	ND	ND	ND	*
Naphthalene	--	ND	ND	--	--	ND	ND	--	--	ND	ND	ND	--	ND	ND	ND	ND	ND	<0.01	ND	ND	ND	ND	ND
Phenanthrene	--	ND	<0.01	--	--	ND	ND	--	--	ND	ND	ND	--	ND	0.64	ND	ND	ND	0.01	ND	ND	ND	ND	ND
Pyrene	--	ND	<0.01	--	--	ND	<0.01	--	--	ND	ND	ND	--	0.23	ND	0.16	ND	*	0.03	0.22	ND	ND	0.26	0.18
Cadmium	--	--	--	--	--	--	--	--	--	<0.01	0.83	ND	--	ND	0.67	ND	--	0.01	0.25	ND	--	0.02	ND	ND
Chromium	--	--	--	--	--	--	--	--	--	<0.01	10.40	12.40	--	0.02	5.90	21.00	--	ND	1.67	ND	--	<0.01	1.29	0.40
Copper	--	--	--	--	--	--	--	--	--	0.01	2.66	3.80	--	<0.01	2.95	3.68	--	0.10	11.59	7.55	--	0.07	7.78	3.51
Lead	--	--	--	--	--	--	--	--	--	<1.00	7.59	ND	--	<1.00	9.90	ND	--	<1.00	1.15	ND	--	<1.00	<1.00	ND
Mercury	--	--	--	--	--	--	--	--	--	ND	ND	--	--	0.03	--	--	0.08	--	ND	--	--	--	ND	--

\+ Known carcinogen (Marcus and Swearingen, 1983)

-- Not measured

* Component detected but concentrations not reliable

[1] All concentrations are wet weight (ug/g).

Appendix 2. Hydrographic data collected in conjunction with the oyster spat recruitment studies. All measurements were taken from near surface waters.

Date	Location	Temperature (°C)	Salinity (°/oo)
02-13-86	marina	11	29
02-20-86	control	15	30
03-05-86	marina	13	31
03-05-86	control	13	30
03-25-86	marina	17	30
03-25-86	control	17	28
04-08-86	marina	24	26
04-08-86	control	21	29
04-22-86	marina	23	32
04-22-86	control	20	31
05-06-86	marina	26	31
05-06-86	control	24	32
05-20-86	marina	28	30
05-20-86	control	25	31
05-22-86	marina	25	32
05-22-86	control	25	30
06-03-86	marina	28	28
06-03-86	control	28	26
06-17-86	marina	30	30
06-17-86	control	29	30
07-01-86	marina	30	30
07-01-86	control	--	31
07-15-86	marina	31	31
07-15-86	control	29	32
07-29-86	marina	31	33
07-29-86	control	31	33
08-05-86	marina	30	32
08-05-86	control	30	33
09-02-86	marina	25	31
09-02-86	control	26	31

Appendix 2. Continued.

Date	Location	Temperature (°C)	Salinity (°/oo)
09-16-86	marina	29	32
09-16-86	control	30	31
10-01-86	marina	30	31
10-01-86	control	29	29
11-06-86	marina	21	35
11-06-86	control	21	34
12-05-86	marina	16	33
12-05-86	control	14	33
02-18-87	marina	11	26
02-18-87	control	11	28

Appendix 3. Species groups generated by an inverse cluster analysis of macrofauna collected in grab samples from marina and control sites (Am = amphipod; An = anemone; As = ascidian; B = bivalve; C = cumacean; D = decapod; G = gastropod; H = holothurian; I = isopod; M = mysid; N = nemertean; Oc = octocoral; Op = ophiuroid; P = polychaete).

Group A

Molgula manhattensis (As)
Lembos unicornis (Am)
Erichthonius brasiliensis (Am)
Streblospio benedicti (P)
Paraprionospio pinnata (P)
Heteromastus filiformis (P)
Eteone heteropoda (P)
Oxyurostylis smithi (C)
Lyonsia hyalina (B)
Cerapus tubularis (Am)
Phoronida
Scoloplos rubra (P)
Glycinde solitaria (P)
Acteocina canaliculata (G)
Ostracod A

Group B

Cyathura burbancki (I)
Ampelisca verrilli (Am)
Clymenella torquata (P)
Aligena elevata (B)

Group C

Tellina texana (B)
Mediomastus californiensis (P)
Spiochaetopterus oculatus (P)
Lumbrineris tenuis (P)
Ampelisca abdita (Am)

Group D

Astyris lunata (G)
Tagelus divisus (B)
Aricidea fragilis (P)
Diopatra cuprea (P)
Ostracod B
Glycera americana (P)
Microphiopholis gracillima (Op)
Galeommatacea A (B)
Oligochaeta
Tharyx sp. (P)

Group E

Mulinia lateralis (B)
Drilonereis longa (P)
Abraaequalis (B)
Glycera sp. (P)

Group F

Amphiporus bioculatus (N)
Owenia fusiformis (P)
Ampelisca sp. (Am)
Lumbrineris sp. (P)
Listriella clymenellae (Am)

Appendix 3. Continued.

Group G

Ophiuroidea (undet.)
Turridae B (G)
Nematoda
Polyodontes lupina (P)
Leptochela serratorbita (D)
Solen viridis (B)
Cirratulidae (P)

Group H

Glycera sp. A (P)
Phyllodoce groenlandica (P)
Leitoscoloplos sp. (P)
Capitella capitata (P)
Spionidae
Lumbrineris impatiens (P)
Ampelisca vadorum (Am)
Polydora cornuta (P)
Lysianopsis alba (Am)

Group I

Nereis succinea (P)
Stenothoe georgiana (Am)
Corophium acherusicum (Am)
Nereis sp. (P)
Eobrolgus spinosus (Am)
Dulichiella appendiculata (Am)
Lembos hypacantha (Am)
Leitoscoloplos fragilis (P)

Group J

Ogyrides alphaerostris (D)
Podarkeopsis levifuscina (P)
Caprella equilibra (Am)
Harmothoe sp. (P)
Axiognathus squamatus (Op)
Sphenia antillensis (B)
Pyrgocythara plicosa (G)
Nucula proxima (G)
Drilonereis magna (P)
Notomastus latericeus (P)
Pinnixa sp. (D)
Hemipholis elongata (Op)
Nemertinae
Exogone dispar (P)
Batea catharinensis (Am)
Xanthidae (D)
Costoanachis avara (G)

Group K

Renilla reniformis (Oc)
Pelecypoda
Corophium sp. A (Am)
Polydora websteri (P)
Ostracoda
Heteromysis formosa (M)
Rhepoxynius epistomus (Am)

Appendix 3. Continued.

Group L

Aricidea suecica (P)
Aricidea sp. (P)
Listriella barnardi (Am)
Leucon americanus (C)
Ostracoda
Synchelidium americanum (Am)
Cyclaspis varians (C)
Turbonilla interrupta (G)
Terebra dislocata (G)

Group M

Corophium acutum (Am)
Sipuncula
Leucothoe spinicarpa (Am)
Loimia medusa (P)
Ophiothrix angulata (Op)
Cucumaria pulcherrima (H)
Lembos smithi (Am)

Group N

Solenidae (B)
Portunus gibbesii (D)
Amphiuridae (Op)
Terebellidae (P)
Nassarius vibex (G)

Group O

Brachidontes exustus (B)
Paranaitis speciosa (P)
Sthenelais sp. (P)

Group P

Elasmopus levis (Am)
Polydora socialis (P)
Polychaeta (undet.)
Eurypanopeus depressus (D)

Group Q

Panopeus herbstii (D)
Pista quadrilobata (P)
Odontosyllis fulgurans (P)
Syllis gracilis (P)
Schistomeringos rudolphi (P)
Arabella iricolor (P)
Sabella microphthalma (P)
Lepidonotus sublevis (P)
Paracaprella tenuis (Am)
Sabellaria vulgaris (P)

Group R

Amphiodia trychna (Op)
Marphysa sanguinea (P)
Ostracod C
Corbula sp. (B)
Carinomella lactea (N)
Actiniaria A (An)
Piromis roberti (P)

Group S

Cistenides gouldii (P)
Macoma sp. (B)
Thelepus setosus (P)
Trachypenaeus constrictus (D)

Group T

Edotea montosa (I)
Amphitrite ornata (P)
Neopanope sayi (D)
Epitonium angulatum (G)

Group U

Nudibranchia
Epitonium multistriatum (G)
Corophium sp. (Am)
Zygonemertes virescens (N)
Latreutes parvulus (D)
Parvilucina multilineata (B)
Nereis grayi (P)
Tharyx annulosus (P)