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Short-Term Effects of the Cessation of Shrimp Trawling on Texas Benthic Habitats

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Abstract. We compared sediments and benthos of two adjacent zones of the middle Texas coast, one of which was closed to shrimp trawling for 7 months. We hypothesized that the no-trawling zone would experience accumulation of fine surficial sediments, leading to increased proportions of silt, clay, and organic matter and decreased proportions of rubble and sand. We also hypothesized that cessation of trawling would affect benthic community structure, directly or indirectly leading to altered types and densities of dominant taxa between zones. During June 2001, divers collected benthos and sediment cores from 32 sites in each zone, using random stratified sampling based on previously mapped sediments. Benthic organisms were identified to family or higher taxonomic levels, counted, and weighed. Our study indicated that the predicted accumulation of fine materials over the 7-month closure did not occur, as we found no sedimentary differences that could not be referenced to sampling design. This lack of change was likely due to the short closure period and to the shallow, sand-dominated nature of the study zones, wherein winter storms, summer tropical cyclones, and seasonally reversing coastal currents more likely influence long-term sediment structure than does presence or absence of shrimp trawling. Densities and biomasses of most abundant taxa and major taxonomic groups were similar between zones, although there were significant differences between zones for nemerteans, amphipods, mactrid clams, and spionid polychaetes. Our data indicate that ambient shrimp trawling effort during winter and spring off the middle Texas coast had little impact on small benthic organisms. A better way to determine whether community and ecosystem structure (and function) might be different from what we now see is to make comparisons between areas closed to all extractive uses for an extended period of time (years to decades) and areas open to all maritime users.

Introduction

Fishing can affect the structural components of habitat and the biotic communities dependent on those habitats. Auster and Langton (1999) summarized literature that indicated mobile fishing gear, such as shrimp trawls, can reduce habitat complexity by removing, damaging, or killing epifauna and infauna, by mixing or smoothing surface sediments, and by removing biogenic structures such as tubes, reefs, burrows, and pits. Postimpact recovery of habitat and community structure and function was difficult to measure and predict since timing, severity, and frequency of impacts all interact with habitat type and recovery processes.

There are very few areas of the northern Gulf of Mexico continental shelf that are closed to the penaeid shrimp fishery, which operates bottom trawls from shoreline to 90-m depths or more (Nance 1993). Opportunities to examine trawl impacts to benthic habitats and communities without fishing gear disturbance are, thus, limited in space or time. In 2000, the Texas Parks and Wildlife Department enacted a seasonal closure of nearshore waters to all shrimp trawling from Corpus Christi Fish Pass south to the U.S.–Mexican border. This closure provided a window of opportunity to study short-term effects of the cessation of shrimp trawling on sediments and benthos. The Southern Shrimp Zone (SSZ) encompasses waters from the shoreline out 9.3 km for the period 1 December to the opening of the season for brown shrimp *Farfantepenaeus aztecus* (formerly known as *Penaeus aztecus*), usually during 1–15 July, each year. A complementary Northern Shrimp Zone (NSZ) extends from Corpus Christi Fish Pass north to the Texas–Louisiana border and permits daytime shrimp trawling during that time period.

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Our project describes a comparison of benthic community and habitat characteristics between these two adjacent areas after cessation of shrimp trawling in the SSZ for 7 months.

Trawling results in resuspension of fine sediments and may result in current-driven, cross-shelf transport of fines to offshore locations (Churchill 1989). We hypothesized that the no-trawling SSZ would experience accumulation of fine surficial sediments, leading to increased proportions of silt, clay, and organic matter and decreased proportions of rubble and sand. Trawling can also impact benthic community composition, either directly, by disturbing, injuring, or killing organisms, or indirectly, by altering their habitat characteristics (Thrush et al. 1998; Auster and Langton 1999). We hypothesized that cessation of trawling would lead to altered types and densities of dominant benthic taxa between zones.

Methods

The dividing line between SSZ and NSZ runs perpendicular to the coast at Corpus Christi Fish Pass (27.675°N, 97.000°W). We designated two blocks on either side of the dividing line as our research areas: a block 18.5 km long and 9.3 km wide at the northern end of the SSZ, and an adjoining block of the same dimensions at the southern end of the NSZ (Figure 1). Because of their immediate proximity, most environmental or human-induced disturbances such as storms, currents, and fishing were believed to have similar impacts equally in each block. The NSZ block was immediately adjacent to a tidal inlet and may have experienced tide-induced differences in water quality (e.g., temperature, salinity, and turbidity). There are no indications that sediments in the area have higher than expected concentrations of trace elements or contaminants other than in the immediate vicinity of oil and gas production platforms (White et al. 1983; Montagna and Harper 1996).

The SSZ was closed to all shrimp trawling from 1 December 2000–1 July 2001. We collected sediment and benthos samples from each block during 18–22 June 2001. We used a geographic information system (GIS) database to develop a stratified sampling procedure that was based on a 1976 survey of Texas coastal sediments conducted at sites 1.6 km apart (White et al. 1983; Sheridan and Caldwell 2002). Five sediment texture classes (Folk 1980) were noted within two broad categories: sand, silty sand, or sand–silt–clay (hereafter referred to as sand-dominated), and sandy silt or clayey silt (hereafter referred to as fines-dominated). Sampling effort was allocated among the five textural classes in proportion to the area covered within each block, with at least two sites per class. Each block was divided into 1-km × 1-km grids, and grids were chosen randomly for each sediment class. The center of each grid became a sampling site, except for the clayey silt class, which only appeared in one grid per block and, thus, contained two sites separated by about 1 km in each (Figure 1). Latitude and longitude of each site were preselected using the GIS database. Some sites were moved approximately 500 m from their preselected locations due to the presence of oil or gas production platforms and their potential to cause benthic community changes within that range (Montagna and Harper 1996). We expected to sample 28 sand-dominated sites and 4 fines-dominated sites per block.

Sites were located via vessel-mounted global positioning systems. Divers collected sediment and benthos cores from 32 sites at 5–20-m depths in each block. Single sediment samples were collected at each site with a 5-cm diameter corer to a depth of 10 cm. The top and bottom of the sediment corer were capped prior to diver ascent. The top 5 cm of sediments were stored on ice or refrigerated for 5 d, then frozen until analysis. Sediment processing included rubble–sand–silt–clay ratios (Folk 1980) and organic content (Dean 1974). Benthos at each site was sampled with four 10-cm-diameter cores taken to depths of 10 cm, which were later pooled to form a single sample. To prevent animal loss during diver ascent, the top of each corer was covered with 0.3-mm mesh, and the bottom of each corer was capped on removal from the substrate. Samples were rinsed through a 0.5-mm-mesh sieve, stored on ice to relax animals, then preserved in 10% formalin containing rose bengal (Birkett and McIntyre 1971). Intact organisms or anterior ends were counted. Funding constraints limited identifications to family level for polychaetes and mollusks and to order level for other groups. We felt this would not compromise the value of our study, since marked community changes are still detectable with aggregated taxonomic data (Somerfield and Clarke 1995). The 10-cm-diameter corer is not effective in sampling large, deep-dwelling, structure-building, or other long-lived taxa; however, this gear is effective for quantifying sediment characteristics and densities of small, shallow-dwelling, short-lived organisms (Holme 1971; Blomqvist 1991). These organisms are also likely to be disturbed by trawl passage, and disruption of benthic communities might disrupt ecosystem energy flow (Jennings et al. 2002). Fishes, decapods, squillids, and chaetognaths were excluded entirely, and polychaete fragments not attributable to any family were excluded from biomass analyses. Animal groups were then blotted dry

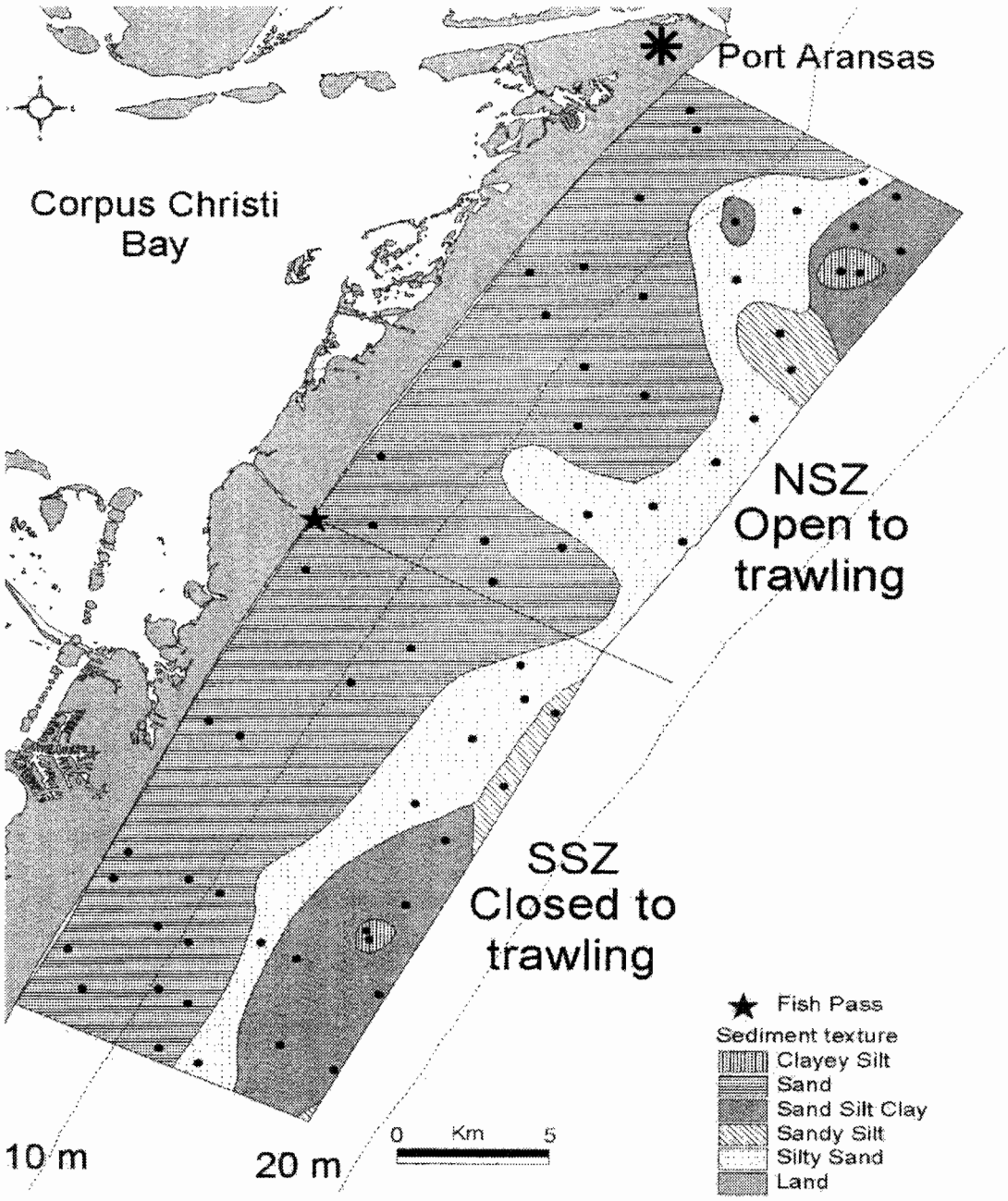

Figure 1. Benthic sampling sites relative to sediment characteristics and depth contours at the junction of the Northern Shrimp Zone (NSZ) and Southern Shrimp Zone (SSZ) off Texas.

(mollusks were not removed from their shells) and weighed to the nearest 0.1 mg.

Zone-related sediment and benthos differences were examined by one-way analysis of variance (ANOVA) with balanced cell sizes ($N = 32$ samples per block). We compared sediment components, densities of numerical and biomass dominants (those with ≥2% of either total), major taxonomic groups (e.g., polychaetes or mollusks), and number of taxa. All data were found to be heteroscedastic using Levene's test (see review by Day and Quinn 1989) and were transformed prior to ANOVA using arcsine for sediment proportions or $\log_{10}(x + 1)$ for benthic density and biomass. Tables and figures present nontransformed data for density or biomass dominants only (a complete taxonomic list is available from the senior author). All analyses were conducted using Statistica (StatSoft, Inc. 1997).

We examined shrimp trawling effort statistics collected by National Oceanic and Atmospheric Administration (NOAA) Fisheries for the area to determine the level of effort prior to the first closure and determine whether shrimp trawling was occurring in NSZ during SSZ clo-

sure. Effort is tabulated as 24-h d fished within statistical subareas and 9-m depth strata (Patella 1975). The dividing line between SSZ and NSZ falls in NOAA Fisheries Statistical Subarea 20, with about 40% of the shoreline falling into the open NSZ (Patella 1975; National Ocean Survey Chart 11300). The seaward extent of each zone (9.3 km) encompasses all of the 1–9-m stratum and most of the 10–18-m depth stratum used by NOAA Fisheries to tabulate trawling effort.

Results

Among sediment characteristics, mean percent sand was significantly ($P = 0.037$) higher in the Southern Shrimp Zone (Figure 2), in part because more Northern Shrimp Zone sites were actually located in fines-dominated habitats than were expected from the GIS sediment map. We were expecting to sample four fines-dominated sites per block, but we actually sampled seven fines-dominated sites in the NSZ. Discrepancies from the sediment map were likely due to a variety of factors including: (1) less-accurate position data from 1976 when original sediment sampling sites were located using LORAN C (White et al. 1983); (2) use of different sampling gear and processing methods; and (3) actual changes in surficial sediment composition. No significant differences in mean proportions of rubble, silt, clay, or sediment organic matter were detected between SSZ and NSZ (Figure 2).

We recorded a total of 12,572 individuals and 83 taxa of benthic organisms, coincidentally subtotaling 6,286 individuals and 73 taxa each in NSZ and SSZ. Total benthic biomass was 136.1 g, with NSZ yielding 104.9 g and SSZ yielding 31.2 g. Among major groups, numbers and biomass were dominated by polychaetes (58.0% of total number, 17.9% of total biomass) and bivalves (11.7% and 55.4%, respectively). Among polychaetes, families Spionidae, Magelonidae, and Paraonidae each composed more than 10% of the total number of individuals, but each was less than 1% of the total biomass. The bivalve family Mactridae was the dominant biomass (47.6% of the total) and ranked sixth in numerical abundance (5.1% of the total individuals). Clypeasteroida was a distant second in total biomass (7.8% of the total).

With few exceptions, densities and biomasses of major groups and dominant taxa were similar between zones (Tables 1, 2). Polychaetes were significantly more numerous in the SSZ, while bivalve biomass was significantly higher in the NSZ (ANOVA, $P < 0.05$). Among dominant taxa, spionid polychaetes and nemerteans were significantly more numerous in the SSZ, mactrid clams and amphipods were significantly more numerous in the NSZ, and mactrid clam biomass was significantly higher in the NSZ (ANOVA, $P < 0.05$). Spionid polychaetes and nemerteans were found at all 32 stations within each block. Amphipods and mactrid clams were patchily distributed. Twelve of 32 sites in the NSZ had no amphipods, and 2 of the remaining 20 sites yielded 196 of 303 individuals (64.7%). In contrast, all but one site in the SSZ had at least 1 amphipod and no site had more than 25 amphipods. As for mactrid clams, 53% of 646 individuals were

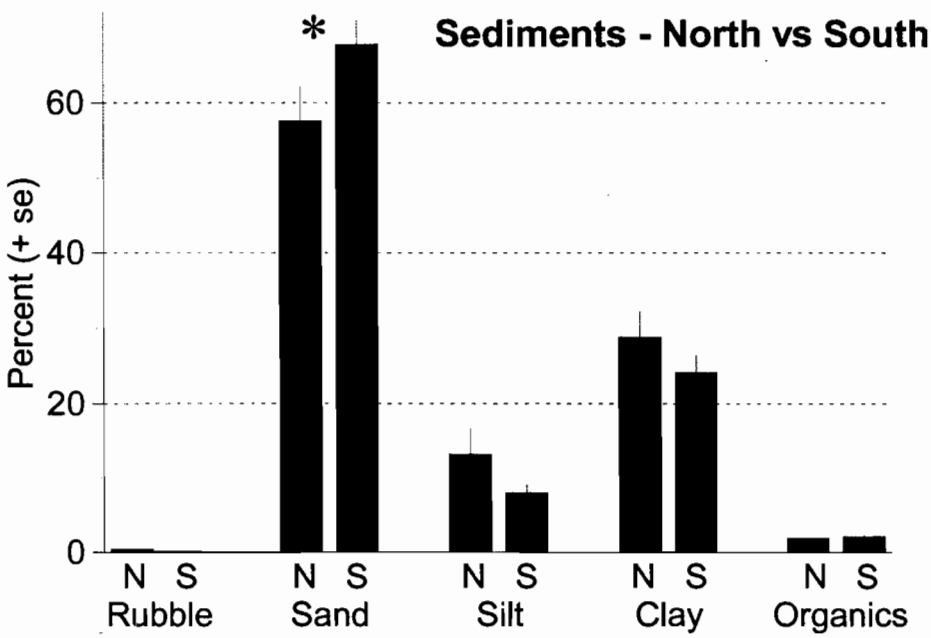

Figure 2. Mean sediment characteristics of Northen (N) and Southern (S) Shrimp Zones. Asterisk indicates significant difference (ANOVA, $P < 0.05$).

Table 1. Mean density (number/314.4 cm²) and standard error (SE) of major taxonomic groups and dominant taxa in the Northern Shrimp Zone (NSZ) and Southern Shrimp Zone (SSZ) off Texas during June 2001. N = 32 sites per zone. Asterisk indicates ANOVA; P < 0.05.

	NSZ		SSZ	
Organisms	Density	SE	Density	SE
Major taxonomic groups				
Polychaeta (P)	98.7	9.7	129.2*	9.0
Crustacea (C)	16.9	4.9	15.4	2.0
Gastropoda (G)	7.1	1.3	5.6	1.2
Bivalvia (B)	30.5	11.4	15.5	1.8
Miscellaneous (M)	40.7	7.1	30.0	3.7
Total taxa	22.9	1.2	23.8	0.9
Dominant taxa				
Spionidae (P)	14.9	2.3	30.0*	3.5
Paraonidae (P)	16.8	3.1	24.0	3.2
Capitellidae (P)	20.7	2.7	15.2	1.5
Lumbrineridae (P)	7.7	1.1	10.5	1.3
Nephtyidae (P)	5.4	2.0	4.4	2.1
Cossuridae (P)	2.9	0.6	4.8	1.0
Mactridae (B)	20.2*	11.3	0.0	0.0
Tellinidae (B)	6.1	1.5	9.7	1.8
Nassariidae (G)	4.8	1.0	3.4	1.0
Amphipoda (C)	9.5*	4.3	8.3	1.2
Nemertinea (M)	6.4*	0.8	9.1	0.8
Phoronida (M)	4.8	1.2	3.6	0.9

Table 2. Mean biomass (blotted wet, mg/314.4 cm²) and standard error (SE) of major taxonomic groups and dominant taxa in the Northern Shrimp Zone (NSZ) and Southern Shrimp Zone (SSZ) off Texas during June 2001. $N = 32$ sites per zone. Asterisk indicates ANOVA; $P < 0.05$.

	NSZ		SSZ	
Organisms	Density	SE	Density	SE
Major taxonomic groups				
Polychaeta (P)	105.4	11.2	124.4	26.8
Crustacea (C)	2.3	1.0	2.1	0.4
Gastropoda (G)	37.2	8.4	25.1	6.5
Bivalvia (B)	255.9*	70.1	29.5	13.4
Miscellaneous (M)	152.6	35.1	68.7	29.9
Dominant taxa				
Spionidae (P)	5.4	1.3	10.1	2.4
Terebellidae (P)	12.3	5.6	2.7	2.0
Glyceridae (P)	12.9	4.3	7.5	2.8
Lumbrineridae (P)	20.0	3.8	31.1	8.6
Onuphidae (P)	20.1	5.8	24.0	6.2
Paraonidae (P)	2.9	0.9	30.3	26.3
Mactridae (B)	205.6*	69.8	0.0	0.0
Tellinidae (B)	32.6	13.5	15.7	13.1
Lucinidae (B)	5.5	3.5	8.2	4.0
Veneridae (B)	24.2	20.4	4.3	2.1
Nassariidae (G)	26.0	5.7	18.6	6.3
Ophiurida (M)	54.0	23.5	6.8	3.3
Actiniaria (M)	15.3	11.2	28.9	28.8
Clypeasteroida (M)	61.1	29.9	10.4	10.4
Nemertinea (M)	11.3	2.5	14.8	3.9

found at a single NSZ station, 83% were found at three stations, and 98% were found at seven stations. Only one mactrid clam was collected in the SSZ. We do not know whether these patchy distributions were due to experimental design or biological interactions.

Shrimp trawling was recorded in the vicinity of our sampling sites. Trawling effort in Statistical Subarea 20 at 1–18-m depths during December 2000–June 2001 was 358 24-h d (NOAA Fisheries, unpublished data) and should have been restricted to the NSZ (there were no reported violations of the SSZ in Statistical Subarea 20; R. Riekers, Texas Parks and Wildlife Department, personal communication). By way of comparison, preclosure effort in Statistical Subarea 20 during the December–June periods of 1990–1999 and at 1–18-m depths averaged 1,224 24-h d for NSZ and SSZ combined, with a range of 261–5623 24-h d. Even though trawling was recorded within the NSZ, it is unknown whether trawl tows directly impacted any given benthic sampling site since NOAA Fisheries only records statistical subarea and depth strata fished.

Discussion

Bottom trawling resuspends sediments, particularly silts and clays, that may or may not be transported away from a trawling region, depending upon such factors as compaction, current speed and direction, or storm frequency (Churchill 1989; Lindeboom and de Groot 1998; Pilskaln et al. 1998). Thus, it is difficult to predict whether or not trawling will change surface sediment texture at any given locale. Previous research has reported both outcomes. Lindeboom and de Groot (1998) reported that sand-dominated substrates were less likely to be physically affected by passage of bottom-tending beam and otter trawls than were fines-dominated substrates, particularly if sand habitats were located in areas of current-induced or storm-induced turbulence. These authors did note, however, that fine surficial sediments were removed from hard-packed sands by trawling at times. In contrast, Van Dolah et al. (1991) found no consistent differences in sediment texture between sand-dominated substrates that were either open or closed to commercial shrimp trawling. Engel and Kvitek (1998) found no significant differences in sediment characteristics between a lightly trawled and a heavily trawled fishing ground. Schwinghamer et al. (1998) could not induce significant changes in sediment grain size by experimental trawling over sand bottoms. Our study indicates that the predicted accumulation of fine materials in the SSZ over the 7-month closure did not occur, as we found no sedimentary differences that could

not be referenced to sampling design. This lack of change was likely due to the short closure period and the shallow, sandy nature of the study blocks, wherein winter storms, summer tropical cyclones, and seasonally reversing coastal currents more likely influence long-term sediment structure than does presence or absence of shrimp trawling.

Most research conducted elsewhere using cores or grabs in sand-dominated habitats indicates little or no impact to small benthic organisms. Van Dolah et al. (1991) reported no consistent differences in shallow, sand-bottom benthic communities between trawled and nontrawled areas before and after a shrimp trawling season. Engel and Kvitek (1998) recorded few significant differences in infaunal taxa in annual surveys of a lightly trawled area versus a heavily trawled area over a 3-year period. Brylinski et al. (1994) found some short-term effects of trawling on nematode densities but no other short-term or long-term benthic community impacts. Jennings et al. (2002) could not link changes in infaunal production or size structure to changes in beam trawl effort. Thrush et al. (1998) found that trawling pressure resulted in significant decreases in densities of certain infaunal indicators captured by coring (densities of echinoderms, diversity, number of species, and polychaete to mollusk ratio) but not in others (densities of deposit feeders, long-lived surface dwellers, scavengers, small opportunists, and total individuals). Even fewer significant changes were recorded using grab or suction dredge sampling (Thrush et al. 1998). Our data are in agreement with these studies and indicate that ambient shrimp trawling effort off the middle Texas coast has little impact on small benthic organisms. This is a shallow, sand-dominated ecosystem that is frequently disturbed by strong cold fronts in winter and by tropical cyclones in summer. Thus, benthic communities have likely adapted in response to physical disruption (Posey et al. 1996).

Shrimp trawling effort can be intense, especially in spring and summer when juvenile penaeid shrimps move from estuaries to the shallow continental shelf (Nance 1993). Shrimp trawling effort according to NOAA Fisheries is recorded as 24-h d fished in each of four Statistical Subareas (numbered 18–21) along the Texas coast. Statistical Subarea 20 encompasses our study zones and traditionally receives the highest trawling effort in depths less than 20 m (annual mean effort during 1990–1999 = 40 h/km^2; Sheridan and Caldwell 2002). The expected frequency of shrimp trawl passage over any particular area of bottom can be estimated as follows. Texas offshore vessels typically tow four 18.3-m headrope nets at an average speed of 4.6 km/h (NOAA Fisheries, unpublished data). Nets actually spread to about 70% of headrope length at this speed (Watson et al. 1984), so the area swept by a vessel approximates 0.25 km^2/h or 6 km^2/24-h d. A total of 358 24-h d were expended in NSZ during the closure (NOAA Fisheries, unpublished data); thus, a total of 2,148 km^2 were impacted by trawling if effort was expended uniformly throughout the NSZ. Our NSZ study block covered 172 km^2, encompassing about half of the available NSZ in Statistical Subarea 20, and thus, experienced half of the total area trawled (1,074 km^2). The expected frequency of trawl passage over any given sample site is, thus, the total area trawled (1,074 km^2 per 7 months) divided by the total area in the study block (172 km^2), which equals 6.2 per 7-month study period or approximately once per month given uniform effort. At this level of activity, ambient trawling effort during winter and spring months has little or no apparent effect on sediments or benthos in the shallow waters off central Texas.

It is possible that we might have had a better chance of detecting trawl-induced community change if we had employed finer-scale identification of benthic organisms. For example, Vanderklift et al. (1996) noted that identification to species level permitted greater ability to separate a stress-related "signal" from the background, habitat-related "noise." However, it is not always necessary to identify organisms to species in order to detect community change (Ferraro and Cole 1990, 1992; Somerfield and Clarke 1995), and it certainly is not always cost-effective if significant changes are evident at family or order levels. Although we found few significant zone-related differences in density or biomass, particularly among the most abundant polychaete and mollusk families, it remains possible that changes could have occurred at the species level.

Our sampling gear addressed the smaller, short-lived, shallow-dwelling benthos. Large, deep-dwelling, structure-building, or other long-lived taxa may have been otherwise affected by the 7-month closure. It has been noted by others, however, that shallow sand communities have evolved in naturally stressful environments (Posey et al. 1996), and it is communities in deeper waters and muddier substrates that are more likely to change when stress such as trawling is removed (Churchill 1989; Auster and Langton 1999). Sampling of the larger infauna and epifauna would best be conducted with other methods such as large-area grabs, video transects, or sonar, as employed elsewhere (e.g., Engel and Kvitek 1998; Thrush et al. 1998).

It is also possible that removing trawlers from the SSZ led to increased densities of fishes and decapods that affected benthic communities through increased bioturbation or predation. We know of no contemporary, directed assessments of the density of mobile macrofauna in the research blocks off Texas. However, we detected few differences between research blocks, so even if macrofaunal densities changed there was little basis for

arguing such impacts. Engel and Kvitek (1998) found no detectable differences in catch per unit effort of fishes in a study of lightly trawled versus heavily trawled fishing grounds and, coincidentally, found few differences in benthic organisms.

We conclude that we were unable to detect significant sediment or benthic community changes resulting from the cessation of shrimp trawling for 7 months off the middle Texas coast. We concentrated our efforts on the smaller organisms whose disruption might have altered community energy flow to higher trophic levels, and it is possible that other (larger) groups of organisms may have been affected differently. The question of whether this temporal refuge has any lon-term impact on ecosystem structure (or function) is moot, however, since the closed area is reopened annually for the 5 months of heaviest shrimp trawling effort (Nance 1993). Any faunal "recovery" to the unstressed state is, thus, eliminated. A better way to determine whether community and ecosystem structure (and function) might be different from what we now see is to make comparisons between areas closed to all extractive uses for an extended period of time (years to decades) and areas open to all maritime users.

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