EXECUTIVE SUMMARY

Natural and man-made debris are common components of the upper intertidal zone on Gulf of Mexico beaches. Stranded pelagic algae, primarily *Sargassum* spp. (Phaeophyta, Fucales) and driftwood constitutes the bulk of natural material deposited as beach wrack on Padre Island National Seashore (PINS) (Amos, 1993; Smith et al., 1995). In 1950, a band approximately 14 m wide and 0.3 m deep was reported lining the Texas coast for over 300 mi (Gunter, 1979).

PINS employs mechanical raking as a public-use management practice for removal of beach wrack to improve the aesthetic and recreational quality of the beach for visitors. The potential for disturbance of biotic components due to mechanical raking has been recognized by resource managers within the National Seashore system. Some national parks regulate the type of equipment, depth of penetration into the sand and tire pressure of machinery to minimize impact to the natural resources while others actively prohibit mechanical removal to allow materials to provide nutrients to the sand through decomposition. Mechanical raking is also prohibited to protect sea turtle nesting areas. Wicksten et al. (1987) discussed managerial implications of debris removal on PINS and state that raking by tractors and other motor vehicles almost certainly would be damaging to upper beach invertebrates, which congregate in the very areas where trash is likely to accumulate. This study was undertaken to determine if raking affected the upper intertidal zone on padre Island National Seashore and to make recommendations to PINS management concerning the use of mechanical raking for wrack removal.

Four sites along Malaquite Beach were systematically sampled from May 1997 through September 1997. Two treatments were applied, one site was raked once a week (Visitor Center) and another site was raked biweekly (Campground). Each treatment was associated with a control site. Samples were collected on Day 3, 7, 10, and 14 following raking (Day 0). Species abundance and biomass were determined for macrofauna in raked and unraked areas and differences were determined by performing a two factor ANOVA. Sediment parameters (chlorophyll *a*, %TOC, and % water content) were also measured to determine whether differences existed between raked and unraked areas and were also analyzed using a two factor ANOVA. Results indicate that dominant macrofauna can be grouped into benthic organisms (*Haustorius* spp. and polychaetes) and organisms associated with wrack material (*Orchestia grillus* and insects). Both groups were affected by mechanical raking to some extent. The greatest differences between raked and unraked sites occurred within three days following raking where mean density and biomass were significantly higher in unraked areas for all macrofauna. On Day 7 and 10, mean density and biomass of *O. grillus* and polychaetes were significantly lower in raked sites. No significant differences existed between raked and unraked areas on Day 14. Sediment parameters exhibited no significant differences between sites for any days. Since environmental conditions could be excluded as a primary source of variation, it was concluded that macrofaunal density and biomass decreased as a result of direct removal during raking or due to vertical migration into the sand column in response to the disturbance caused by raking.
Gulf beaches along PINS are important stopovers for migrant birds to rest, refuel, spend the winter and to use as a landmark guide for their north and south movements (Chaney et al., 1993). The wrackline has been observed as an important feeding area for shorebirds, especially Sanderling, Ruddy Turnstone, Black-bellied and Wilson’s plovers, and a resting area for Willet, Black Tern and Least Tern (Chaney et al. 1993). Ruddy Turnstones and plovers were also observed foraging along wracklines of other south Texas beaches (Withers, pers. obs.). During the present study, use of the intertidal zone by gulls, terns and shorebirds was only slightly higher than use of the wrackline. The number of birds on Gulf beaches fluctuates seasonally, with peak abundances coinciding with fall and spring migrations (Chaney et al. 1993). Peak abundance of fall migrants on PINS coincides with the period when wrack biomass decreases. The management concern is to provide visitors with an aesthetically pleasing recreational area while maintaining ecosystem health.

Management recommendations are as follows:

- To manage food resources for birds, the Visitor Center and Campground beaches could be raked until August, then allowed to recover before the majority of the fall migrants arrive. At least 10 days were needed for macrofaunal populations to recover from raking. This schedule considers public use patterns since visitation decreases in August and drops off after Labor Day.

- Management of overall ecosystem health requires that the Visitor Center and Campground beaches be raked no more than biweekly, and less often when possible.
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INTRODUCTION

One of the most distinctive and frequently cited features of exposed sandy beaches as ecosystems is their almost complete lack of in situ primary production (McLachlan et al., 1981). Wave action excludes all but the most hardy biota from colonizing the intertidal zone. Macrophytes are unable to find suitable attachment sites and diatoms are unable to establish abundant communities due to mobility of sediments. As a result, production in the intertidal zone is based on offshore inputs of detritus and phytoplankton held in motion by breaking waves (Britton and Morton, 1989) and on carrion and stranded macrophytic algae deposited as beach wrack (Griffiths et al., 1983). Seasonally, beaches on Padre Island National Seashore (PINS) receive large quantities of stranded macrophytic algae, primarily Sargassum spp. In 1950, a band approximately 14 m (46 ft) wide and 0.3 m (1 ft) deep was reported lining the Texas coast for over 483 km (300 mi). (Gunter, 1979).

The contribution of nutrients from wrack algae to nearshore coastal food chains adjacent to the sandy beach has been disputed by several authors. Robertson and Hansen (1982) found a quarter of total coastal primary production on western Australian beaches passed through the surf zone and sandy beaches as detached algae. Koop et al. (1982) and Koop and Lucas (1983) found 95% of nitrogen released from bacterial decomposition of wrack kelp may ultimately be returned to the adjacent nearshore ecosystem, but did not constitute a significant contribution to that system. Griffiths et al. (1983) also found the amount of nutrients returned to the adjacent nearshore ecosystem was insignificant in relation to nutrient demands.

Although nutrient contributions to adjacent systems may be insignificant, decomposition of stranded macrophytic algae has been cited as a major organic input on many beaches (McGwynne et al., 1988). Intertidal macrofauna and meiofauna utilize wrack algae, directly or indirectly, as food. Interstitial bacteria constitute the primary decomposers of buried wrack (Griffiths et al., 1983) and subsequently provide the principle food source for meiofauna. McGwynne et al. (1988) compared a wrack-loaded beach (WLB) and a sparse-wrack beach (SWB) in South Africa and reported that optimal loadings of wrack kelp released particulate and dissolved organics into sediment which attracted meiofauna to regions where abundance of food coincided with favorable oxygen, spatial and granulometric characteristics.

Several authors have focused on the importance of fresh and decomposing wrack algae to associated wrack fauna. Wrack algae accounted for 95% (Griffiths et al., 1983) and 60-80% (Griffiths and Stenton-Dozey, 1981) of the food supply of wrack fauna on two South African beaches. Amphipods (Family Talitridae), fly larvae and adults (Order Diptera) and carnivorous and herbivorous beetles (Order Coleoptera) constituted wrack fauna on beaches in South Africa (Griffiths and Stenton-Dozey, 1981; Griffiths et al., 1983; Stenton-Dozey and Griffiths, 1983), western Australia (McLachlan, 1985), northern New England (Behbehani and Croker, 1982) and central California (Lavoie, 1985). Behbehani and Croker (1982) also found oligochaetes, especially Enchytraeus sp. and springtails (Insecta, Order Collembola), primarily Anurida maritima, were important wrack fauna. While investigating
beach fauna on PINS, Wicksten et al. (1987) noted an association of staphylinid beetles, amphipods, nematodes and oligochaetes living among Sargassum deposits in the upper intertidal zone. They speculated these fauna may be beach wrack residents and stated the need for further study to determine ecological interactions among upper intertidal beach animals. Wicksten et al. (1987) is the only report of wrack faunal associations on the Texas coast found to date.

The wrack line is an important habitat for shorebirds (Charadriiformes) which utilize the intertidal zone and wrack line for feeding, resting and loafing. Chaney et al. (1993) found the intertidal zone was preferred habitat for shorebirds on PINS. Their bird surveys excluded gulls and terns. They also observed that the berm, when it consisted of an abundance of Sargassum spp., was an important feeding area for Sanderling, Ruddy Turnstone, Black-bellied and Wilson’s plovers, and a resting area for Willet, Black Tern and Least Tern. Withers (pers. obs.) also observed Ruddy Turnstones and plovers foraging along wrack lines on South Texas beaches.

Natural and man-made debris are common components of the high intertidal zone on Gulf of Mexico beaches. Stranded pelagic algae, primarily Sargassum spp. (Phaeophyta, Fucales) and driftwood constitutes the bulk of natural material deposited as beach wrack on PINS (Amos, 1993; Smith et al., 1995). Most Sargassum species live attached as a lower intertidal and shallow subtidal hard bottom macrophyte in shallow warm-temperate and tropical seas (Britton and Morton, 1989). Two species form extensive rafts in the central North Atlantic (Sargasso Sea) and are transported by currents (Sze, 1993). Sargassum natans is the most common species in the Gulf of Mexico (Parr, 1939). Both S. natans and S. fruitans, which also occurs in the Gulf of Mexico, are able to survive, grow and propagate vegetatively as pelagic species (Britton and Morton, 1989; Sze, 1993).

PINS employs mechanical raking as a public-use management practice for removal of beach wrack to improve the aesthetic and recreational quality of the beach for visitors. The potential for disturbance of biotic components due to mechanical raking has been recognized by resource managers within the National Seashore system. Some national parks regulate the type of equipment, depth of penetration into the sand and tire pressure of machinery to minimize impact to the natural resources while others actively prohibit mechanical removal to allow materials to provide nutrients to the sand through decomposition (Smith et al., 1995). Mechanical raking is also prohibited to protect sea turtle nesting areas. Wicksten et al. (1987) discussed managerial implications of debris removal on PINS and stated raking by tractors and other motor vehicles almost certainly would be damaging to upper beach invertebrates, which congregate in the very areas where trash is likely to accumulate.

A literature search produced no research on the effects of mechanical raking, especially on South Texas beaches. To date, infaunal studies conducted on PINS have focused on assessing species abundance, composition and distribution in the subtidal bar and trough zone, surf zone and intertidal zone (Kindinger, 1981; Tunnell et al., 1981; Vega 1985; Vega and Tunnell, 1987; Vega, 1988; Rocha, 1995). Wicksten et al. (1987) looked at infaunal assemblages from the subtidal zone to the foredunes. No research has been conducted on
PINS specifically on upper intertidal benthos along the wrack line. The purpose of this project, therefore, was to quantitatively assess effects of mechanical raking on the upper intertidal beach ecosystem on Padre Island National Seashore, Texas.

**OBJECTIVES**

The objectives of this study were to:

1. Determine if macrofaunal abundance and biomass were significantly different between raked and unraked areas.
2. Determine if shorebird abundance was significantly different between raked and unraked areas.
3. Determine if macrophytic algal biomass, total organic carbon, chlorophyll $\alpha$ levels and percent water were significantly different between raked and unraked areas.
4. Make recommendations to PINS management concerning effects of mechanical raking on upper intertidal ecosystem functioning.

**STUDY AREA**

PINS is located on the southeastern coast of Padre Island, Texas (Fig. 1). PINS extends 130 km south to the Port Mansfield Ship Channel and is 0.4-4.8 km (0.2-2.9 mi) in width (Ditton et al., 1979). The region is characterized as subtropical and semiarid with annual precipitation ranging from approximately 74 cm (29 in) on the northern end of the island to approximately 66 cm (26 in) at the southern end (Weise and White, 1980). Southeasterly winds predominate from March through October while wind direction fluctuates between northerly and southeasterly as “northers” pass through the area during winter months. Hurricanes and tropical storms are infrequent but normal and important to the island’s ecology (Weise and White, 1980). Northern Padre Island is stable to regressive (building seaward), with sediments supplied by south moving longshore currents (Carls et al., 1990).

The tidal regime on Padre Island is governed primarily by meteorological tidal conditions or wind tides. Astronomical tides average about 0.4 m (1.4 ft) along the Gulf shoreline in the vicinity of Padre Island and are diurnal, semidiurnal, or mixed during certain times of the month (Weise and White, 1980). Beaches on northern Padre Island are classified as high energy systems receiving strong wave action (Odum and Copeland, 1974). Heights of breaking waves are 0.3-1 m (1.0-3.3 ft) except during storms, when breakers may exceed 2 m (6.5 ft) (Hill and Hunter, 1976).

Northern Padre Island beaches consist of lithogenous sands, derived from central Texas rivers (Britton and Morton, 1989). Grain size is characterized as fine to very-fine (0.05-0.1 mm) and well sorted, although small patches of shelly sand occur in cusps (Shelton and Robertson, 1981; Wicksten et al., 1987; Britton and Morton, 1989).
Fig. 1. Location of Malaquite Beach study area on Padre Island National Seashore, Texas.
Beach zonation on Padre Island is typical of that found in the southeastern United States. The seaward side of Padre Island features a dune-beach-bar-trough system. The foredunes are well developed and are usually stabilized by vegetation. The backshore is the landward termination of the beach and is characterized by little plant or animal life. The intertidal or foreshore zone lies between the upper limit of wave wash at high tide and the low-water swash mark (Britton and Morton, 1989) and is narrow, approximately 24-45 m (79-148 ft), compared to a much wider backshore, approximately 65-115 m (213-377 ft), (Hill and Hunter, 1976). The intertidal can be divided into two areas based on extent of tidal inundation. The upper intertidal is characterized by periodic inundation while the lower intertidal is continually covered with water. A slight rise or berm separates backshore from foreshore. A subtidal bar and trough zone which consists of a series of three continuous bars running parallel to the shore lies seaward of the foreshore.

The upper intertidal zone is faunally depauperate because of harsh environmental conditions. The zone is numerically dominated by haustoriid amphipods, *Haustorius* spp., the polychaete *Scolelepis squamata*, and the bivalves *Donax texasiana* and *D. variabilis roemeri* (Shelton and Robertson, 1981; Wicksten et al., 1987; Vega, 1988; Rocha, 1995). Rocha (1995) characterized the upper intertidal as a *Haustorius-Scolelepis* community. Wicksten et al. (1987) noted an abundance of staphylinid beetles on Padre Island along the intertidal wrack line. They speculated that *Sargassum* constituted their major food source.

**METHODS AND MATERIALS**

Two open coast, surf-exposed beach areas on Malaquite Beach were chosen for this study: Visitor Center (VC) and Campground (CG). In addition, two control sites were established, one south of the Visitor Center (C1) and a second north of the Campground (C2). All sites were approximately 400 m (0.25 mi) long and closed to public vehicular traffic.

Data was collected twice weekly. VC and C1 were sampled from 12 May 1997 to 8 August 1997 with one set of post-disturbance samples collected on 15 September 1997, 38 days following the final raking event. CG and C2 were sampled from 12 May through 1 August. Mechanical difficulties with the tractor prevented sampling until the project end date on 8 August 1997. An attempt was made to sample 38 days following the final raking event as was done at VC and C1, but a red tide prevented samples from being collected. The sampling period corresponded to the period of greatest macroalgae accumulation and highest visitation (PINS, pers. comm.). At the start of the project, five permanent benchmarks, 75 m apart were established along the upland edge of the vegetation at each of the four sites. Two benchmarks were randomly chosen prior to each sampling event and the corresponding upper intertidal area was sampled (Fig. 2). Boundaries of the upper intertidal zone were determined at the time of sampling. The distance from the benchmark to the sample area and the wrack were measured. Distance from the benchmark to the water line were measured in order to provide information about the tide stage at the time of sampling. Core samples were collected within a 1 x 5 m quadrat, parallel to the water’s edge.
Fig. 2. Schematic of sampling design used at each of the four study sites at Padre Island National Seashore, Texas.
Two treatments were applied. PINS personnel mechanically raked VC once a week and CG every other week during the study period. Control areas were not raked. A tractor equipped with a metal rake, approximately 3 m (10 ft) wide was pulled parallel to the water’s edge from the upper backshore to the intertidal zone, as close to the water’s edge as possible. The entire upper intertidal zone was raked. Organic debris was piled along the duneline as the rake became full. Raking occurred on Fridays (Day 0). Post-disturbance samples were collected at VC and C1 on two occasions after raking (Day 3 and Day 7) and on four occasions after raking at CG and C2 (Day 3, 7, 10, and 14). Measurements were recorded immediately following raking from the benchmark to the edge of the raked area, perpendicular to the water line, to ensure Day 3, 7, 10, and 14 samples were collected within raked areas.

Macrofaunal Sampling

Macrofauna (organisms which are retained on a 0.5 mm sieve) were sampled using a 10 cm (4 in) diameter PVC core inserted to a depth of 10 cm. Five cores from each of the two quadrats at each of the four sites were placed in 0.5 mm mesh biobags and returned to lab where they were preserved in 10% formalin for at least 24 hours. Samples were then sieved in a U.S. Standard 0.5 mm mesh sieve, separated, identified to the lowest possible taxon, and counted. Abundance was reported as number of individuals of a species per square meter. Identification was done using taxonomic keys and published literature: Polychaeta (Harper, ND), Mollusca (Chaney, 1983; Andrews, 1992), Amphipoda (Bousfield, 1973) and Insecta (Merritt and Cummins, 1984).

Dry weight biomass was calculated in order to provide a reliable estimate of the amount of organic matter available for higher trophic levels (Widbom, 1984). Dry weight was determined using a Denver Instrument Company AA - 160 analytical balance accurate to the nearest 0.0001 g. Taxa were grouped as follows for biomass determinations: haustoriids, Orchestia grillus, polychaetes, insects. Molluscs were only rarely encountered so were not included in this analysis. Specimens were placed into pre-weighed aluminum pans and dried in a laboratory oven at 90° C for approximately 72 hours. After drying, pans were placed in an air-tight desiccator and cooled for at least 1 hr. Final dry weight biomass was calculated by subtracting the initial pan weight. Dry weight biomass was reported as grams per square meter.

Bird Census

Birds were censused at the start of each sampling day at each site from the lower intertidal zone to the duneline. Bird location was recorded within one of three habitats: intertidal, wrack, or backshore. Intertidal was defined as the lowest low tide mark to the highest high tide mark at the time of the survey. The Wrack habitat was defined as the upper intertidal area and included the wrackline where wrack material and debris accumulated at the time of the survey. The Backshore was defined as the area above the wrackline extending to the duneline. Data was reported as number of individuals of a species per habitat per site. Birds were grouped as follows for statistical analysis: 1) Gulls and Terns and 2) Shorebirds
(including plovers). Several other species (e.g. Great Blue Heron, Brown Pelican) were recorded five or fewer times throughout the study and were not included in statistical analyses.

**Wrack Biomass**

Wrack biomass was estimated by randomly tossing a 0.25 m² quadrat five times along the wrack line before each raking event at VC and CG. In control sites, samples were collected only along a newly established wrackline, if present. Individual samples were collected in plastic bags and frozen until processed. Man-made and natural debris present within the sample was removed before the sample was processed. In the laboratory, samples were transferred to paper lunch bags and placed in a laboratory oven at 90° C for approximately 72 hours. Dry weight biomass was calculated as final dry weight minus paper bag weight. Biomass was reported as grams of macrophytic algae per square meter.

**Sediment Total Organic Carbon (TOC) and Water Content**

Three cores for TOC determination were collected from each of two quadrats at all four sites using a 2.5 cm diameter coring device constructed from a plastic, disposable syringe with the needle cut off and inserted to a depth of 10 cm. Cores were refrigerated until processing. A portion of each sediment sample was placed in a crucible and initial weight recorded. Samples were dried for 3-5 days in a laboratory oven at 90° C. After drying, samples were placed in a dessicator for at least one hour, re-weighed and transferred to a muffle furnace for ignition at 500°C for 4 hours. This method recovered 99.4% of the TOC from a standard sediment of known organic content (Byers et al., 1978). After ignition, samples were placed in a dessicator to cool for at least one hour and weighed. TOC was calculated as weight loss after ignition. Results were reported as percent TOC per sample using the following equation:

\[
\%\text{TOC} = \left[\frac{(W_B - W_A)}{(W_B - W_C)}\right] 100
\]

where \(W_B\) is the sample weight before drying, \(W_A\) is sample weight after drying and \(W_C\) is crucible weight. Percent water was calculated by subtracting sample weight before ignition from initial sample weight and recorded as percent water per sample.

**Sediment Chlorophyll \(\alpha\)**

Three cores for chlorophyll \(\alpha\) determination were collected in the same manner as described for TOC determination and were stored frozen, in the dark until processing. Chlorophyll \(\alpha\) was determined using standard acetone extraction techniques and spectrophotometry using a Milton Roy 20D series, calibrated according to manufacturer’s specifications. Each sample was ground using a mortal and pestle for 1-2 minutes. One hundred milliliters of reagent grade 90% acetone, buffered with 1-2 drops of sodium hydroxide (NaOH), was added to the sample and both the sediment and the acetone transferred to a 500 ml Erlenmeyer flask. Flasks were covered with parafilm wax to decrease evaporation and samples were extracted
in the dark for no more than 24 hours. Flasks were shaken once during extraction. After extraction, the supernatant was transferred to a 13 mm test tube and centrifuged at 75 rpm for approximately 5 minutes. The supernatant was then transferred to a cuvette. Absorbance was recorded at 665 nm before and after acidification with 1 drop hydrochloric acid (HCL). Results were calculated using the following equation from Wetzel and Westlake (1969):

\[
\text{mg chl } \alpha \text{ per sample} = \frac{[11.9 \times 2.43 [(D_b - D_a)] (V/L)]}{1000}
\]

where,
11.9 = constant
2.43 = constant
\(D_b\) = optical density before acidification
\(D_a\) = optical density after acidification
\(V\) = volume of solvent (100 ml)
\(L\) = path length of cuvette (1.17 cm)
1000 = conversion from μg to mg

Statistical Procedures

Statistical analysis was performed using SAS Version 6.03 (SAS Institute, 1988). Significant differences (\(P \leq 0.05\)) between control and treatment sites were determined using the general linear models analysis of variance (Proc GLM). Site and Day were treated as independent variables or factors and dependent or response variables included: macrofaunal density and biomass, bird abundance, chlorophyll \(\alpha\), TOC and water content. Data were pooled from both treatments for Day 3 and Day 7 analyses; Day 10 and Day 14 were analyzed only for CG and C2.

Benthic density and biomass was transformed prior to analysis using \(\log_{10} (X + 1)\), where \(X\) = density or biomass. This transformation is considered the most useful since variance in benthic samples is often greater than the arithmetic mean (Elliott, 1977) and zeros were present within the dataset. Bird numbers and chlorophyll \(\alpha\) data were also log transformed. Significantly different means (\(P \leq 0.05\)) were evaluated using Tukey’s HSD.

RESULTS

A total of 1,040 benthic core samples were analyzed, yielding 33,138 organisms. A total of 9 taxa representing two phyla were identified (Appendix A). Amphipods comprised 78.9% of total organisms collected (Fig. 3) and were represented by two species, *Haustorius* spp. (F: Haustoriidae) and *Orchestia grillus* (F: Talitridae). Haustorids comprised 97.8% of total amphipods collected. Insects comprised 12.4% of total organisms and were represented by individuals in the orders Coleoptera, Diptera, Collembola, and Hemiptera. Coleopterans, represented only by the rove beetle *Bledius* spp.(F: Staphylinidae), were most abundant and
Relative abundance of major macrofaunal taxa collected from both raked and unraked areas between May and September 1997.

Comprised 62.7%, followed by collembolans (Fig. 4). Polychaetes were represented by two species which together comprised 8.7% of total organisms collected. *Scolelepis squamata* (F: Spionidae) was dominant, comprising 99.9% of the total polychaetes collected.

A total of 2,675 birds representing 22 species were recorded (Appendix B). Gulls and Terns were the most abundant group, comprising 73.1% followed by Shorebirds (Fig. 5). Bird use of the three habitat types (Intertidal, Wrack, Backshore) showed similar abundance patterns among groups. Gulls and Terns were the most abundant group in all three habitats, ranging from 68.3-77.3% with the highest number occurring in the Wrack habitat (Figure 5). Shorebird abundance was similar in all three habitat types as well, ranging from 21.9 - 28.0% with the highest abundance occurring in the Intertidal habitat. Brown pelicans and Great Blue Herons (“Other”), were recorded in greater numbers within the Intertidal habitat while Plovers seemed to prefer the Backshore area.

**Macrofaunal Density and Biomass**

Mean density and biomass of haustoriid amphipods showed two peaks in May and July at VC and C1, with the higher peak occurring in May (Fig. 6). At CG and C2, mean density and biomass was highest in May and generally decreased throughout June with a relatively steep decline in late June through July (Fig. 7). A slight increase in mean density and biomass occurred at C2 in late July to early August. There were no significant differences between
Fig. 4. Relative abundance of insects collected from both raked and unraked areas between May and September 1997.

Mean density and biomass of the talitrid amphipod, *Orchestia grillus*, was low throughout May and June then peaked in late June and again in early August at VC and C1 (Fig. 8). At CG and C2, mean density and biomass of *Orchestia grillus* were relatively low throughout the study period (Figure 9). Mean density peaked in early July at C2. Values at CG were uniformly low with the exception 18 July when density was extremely high. There were significant differences between treatments and controls for this species (Table 1). Both density and biomass were significantly higher in control areas for Day 3, Day 7, and Day 10. Density and biomass were not significantly different on Day 10 (CG and C2) or Day 38 (VC and C1).

Mean polychaete density and biomass were variable throughout the study period at VC and C1 but peaked in July, with a smaller peak occurring in May (Fig. 10). At CG and C2, mean polychaete density and biomass peaked at the end of July (Figure 11). Peaks at CG were similar to peaks at C2. Both density and biomass were significantly higher in controls on Day 3, Day 7, Day 10 (CG and C2) but there were no differences on Day 14 (CG and C2) or Day 38 (VC, C1) (Table 1).
Fig. 5. Relative abundance of birds overall and in beach habitats on Padre Island National Seashore, Texas, from May to August 1997.
Fig. 6. Mean haustoriid amphipod density (A) and biomass (B) between 12 May and 15 September 1997 for sites in the weekly raking treatment.
Fig. 7. Mean haustoriid amphipod density (A) and biomass (B) between 12 May and 1 August 1997 for sites in the biweekly raking treatment.
Table 1. P-values of a two factor ANOVA for major macrofaunal groups. Data from treatment sites (VC and CG) and control sites (C1 and C2) was combined for Day 3 and Day 7 analyses; Day 10 and Day 14 analyses included data from CG and C2 only (biweekly raking treatment); Day 38 analyses included data from VC and C1 only (weekly raking treatment).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Day 3</th>
<th>Day 7</th>
<th>Day 10</th>
<th>Day 14</th>
<th>Day 38</th>
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<td></td>
<td>df</td>
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<td>0.0002*C</td>
</tr>
<tr>
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<td>0.0019*A</td>
<td>0.0011*B</td>
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<td>0.1000</td>
</tr>
<tr>
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<td>0.0183*A</td>
<td>0.0033*B</td>
<td>0.7848</td>
<td>0.0808</td>
</tr>
<tr>
<td>biomass</td>
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<td>0.0019*A</td>
<td>0.0011*B</td>
<td>0.3041</td>
<td>0.1000</td>
</tr>
<tr>
<td><em>Polychaete</em></td>
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<td>0.0019*A</td>
<td>0.0011*B</td>
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<td>0.1000</td>
</tr>
<tr>
<td>density</td>
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<td>0.1247</td>
<td>0.0902</td>
<td>0.0014*C</td>
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<td>0.3238</td>
<td>0.0913</td>
<td>0.0759</td>
<td>0.0045*C</td>
</tr>
</tbody>
</table>

*A Means higher in control sites
*B Means higher in C2 (Control 2, biweekly raking treatment)
*C Means higher in VC (Visitor Center, weekly raking treatment)

Mean insect density and biomass peaked in mid-June, with a smaller peak occurring in late July at VC (Fig. 12). A peak in mean abundance at C1 coincided with the June peak at VC, but was higher. Insect density at C1 peaked again in early August. Mean density was low at both sites in May and late June to early July. At C2, mean insect density peaked in mid-June followed by a rapid decline until July during which density gradually increased (Fig. 13A). A similar pattern was observed at CG, but with a much lower peak in June. The rapid increase in mean density in June at C2 did not result in a similar increase in biomass (Fig. 13B). Both density and biomass were significantly greater in control sites on Day 3 (Table 1), but there were no differences on Day 7, Day 10, or Day 14. Both mean density and biomass were significantly greater at VC on Day 38.
Fig. 8. Mean *Orchestia grillus* density (A) and biomass (B) between 12 May and 15 September 1997 for sites in the weekly raking treatment.
Fig. 9. Mean *Orchestia grillus* density (A) and biomass (B) between 12 May and 1 August 1997 for sites in the biweekly raking treatment.
Fig. 10. Mean polychaete density (A) and biomass (B) between 12 May and 15 September 1997 for sites in the weekly raking treatment.
Fig. 11. Mean polychaete density (A) and biomass (B) between 12 May and 1 August 1997 for sites in the biweekly raking treatment.
Fig. 12. Mean insect density (A) and biomass (B) between 12 May and 15 September 1997 for sites in the weekly raking treatment.
Fig. 13. Mean insect density (A) and biomass (B) between 12 May and 1 August 1997 for sites in the biweekly raking treatment.
**Bird Abundance**

A total of 2,642 birds were recorded from 12 May to 8 August. Bird abundance was analyzed as total numbers of Gulls and Terns and Shorebirds (including Plovers and Other). Gulls and Terns were the most abundant group found in either treatment or control sites (Fig. 14); Shorebird numbers were typically low throughout the study period. Mean abundances of shorebirds declined through early June at VC and C1 (Fig. 14A); fall migrants began to show up in late June and were most abundant through late July and early August. A similar pattern of Shorebird abundance was observed at CG and C2 (Fig. 14B). Overall, there were no significant differences between treatments and controls for either Gulls and Terns (VC, C1: df, 1,12; P=0.3364; CG, C2: df 1,11; P=0.8806) or Shorebirds (VC, C1: df 1,12; P=0.8399; CG, C2: df 1,11; P=0.9542).

**Wrack Biomass**

A total of 510 wrack samples were collected. Samples of stranded wrack material on PINS contained mostly *Sargassum* spp. with lesser amounts of other macrophytic algae and debris including fragments of plastic, glass and wood. Fresh wrack material was deposited irregularly throughout May and June (Fig. 15). Mean biomass ranged from 0 to approximately 650 g/m² collected on May 23 from CG. Wrack deposition decreased sharply after 27 June at all four sites after which no fresh material was collected throughout the remainder of the study with the exception of 11 July.

**Sediment Total Organic Carbon (TOC) and Water Content**

A total of 610 sediment core samples were analyzed. Mean values of % TOC per sample were similar for all sites throughout the study period (Fig. 17). Values were approximately equal for both VC and C1 on 17 of 26 days, and on 10 of 26 days for CG and C2 with slight variations in associated standard errors. There was little variation in sediment water content for all sites throughout the study period (Fig. 18). There were no significant differences between controls or treatments for either % TOC or % water content for Day 3, 7, 10, or 14 (Table 2), however, % water content was significantly greater at VC on Day 38.

**Sediment Chlorophyll α**

A total of 610 sediment core samples analyzed. Mean chlorophyll α values (mg/m²) at VC and C1 remained relatively constant throughout the study period with a few exceptions (Fig. 16A). Extremely high values were recorded in C1 samples collected 23 May. Values at both sites were low in samples collected on May 12-16. In general, mean chlorophyll α values were similar at both CG and C2 (Figure 16B). Values gradually increased through May and June and again in mid July, with a slight decrease in late June to early July. With the exception of a few days, chlorophyll α values were slightly higher at CG over the study period. Mean chlorophyll α values were not statistically different between treatments and controls on any day (Table 2).
Fig. 14. Mean numbers of birds per week in weekly raking treatment sites (A, VC and C1) and biweekly raking treatment sites (B, CG and C2).
Fig. 15. Mean Sargassum spp. biomass throughout the study period at weekly raking treatment sites (A) and biweekly raking treatment sites (B).
Fig. 16. Mean sediment chlorophyll α throughout the study period at weekly raking treatment sites (A) and biweekly raking treatment sites (B).
Table 2. P-values of a two factor ANOVA for sediment parameters. Data from treatment sites (VC and CG) and control sites (C1 and C2) was combined for Day 3 and Day 7 analyses; Day 10 and Day 14 analyses included data from CG and C2 only (biweekly raking treatment); Day 38 analyses included data from VC and C1 only (weekly raking treatment). Degrees of freedom associated with each analysis are in parenthesis.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Day 3</th>
<th>Day 7</th>
<th>Day 10</th>
<th>Day 14</th>
<th>Day 38</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chlorophyll α</td>
<td>0.3228(1, 225)</td>
<td>0.8300(1, 225)</td>
<td>0.7701(1, 70)</td>
<td>0.2006(1, 69)</td>
<td>0.2259(1, 10)</td>
</tr>
<tr>
<td>TOC</td>
<td>0.2623(1, 226)</td>
<td>0.0653(1, 226)</td>
<td>0.3652(1, 69)</td>
<td>0.1793(1, 70)</td>
<td>0.2938(1, 10)</td>
</tr>
<tr>
<td>Water Content</td>
<td>0.1414(1,226)</td>
<td>0.5660(1,226)</td>
<td>0.9325(1, 69)</td>
<td>0.0811(1, 70)</td>
<td>0.0001*^A(1,10)</td>
</tr>
</tbody>
</table>

*Significant at P≤0.05
^A Means higher in VC (Visitor Center, weekly raking treatment)

**DISCUSSION**

Conditions within and underneath the wrackline are harsh. Typically, the front of the wrackline is subjected to wave action, with further aeration occurring only if material is moved by heavy wave action. Temperature increases rapidly within the wrack bank, reaching 30-40°C after several days (Robertson and Hansen, 1982). Generally, upper portions of the material are decomposed aerobi cally, while anaerobic processes dominate in water-saturated sediments beneath wrack.

Treatment sites were raked from the duneline to the water line. Although the majority of the wrack material was removed, on occasion it was not possible to remove all wrack during a single raking event due either to tide level or accumulations too large to be removed within reasonable time limits. Small clumps of wrack typically remained on the sand surface after raking. Buried deposits were not effectively removed by raking. Wrack deposition was highest in May and June. During June sampling, wrack material was approximately 0.3 m (1 ft) deep and was not completely removed during raking. These portions of wrack were removed as they dried and were spread out over the beach by wind, but buried deposits remained within the sand until removed by wave action or raking at a later date.

While raking appears to alter the density of some benthic macrofauna and wrack-associated macrofauna, the disturbance does not appear to alter the chemistry of the benthic environment. Chlorophyll α, % TOC and % water content within the sediment were not significantly different between treatment and control sites during the study period. Chlorophyll α was used as a measure of microfloral biomass available for consumption by macrofaunal detrital and deposit feeders. Raking did not appear to affect microflora in the
Fig. 17. Mean sediment total organic carbon (per sample) throughout the study period at weekly raking treatment sites (A) and biweekly raking treatment sites (B).
Fig. 18. Mean sediment water content (per sample) throughout the study period at weekly raking treatment sites (A) and biweekly raking treatment sites (B).
upper intertidal zone. Organic carbon enters the sediments as a result of leaching of wrack material, deposition of surf-zone phytoplankton and diatoms, animal exudates and fecal material. Percent TOC was used as a measure of the organic carbon available to benthic organisms. Decreased TOC could result in an indirect decrease in macrofaunal food resources due to decreased microfloral, bacterial and meiofaunal productivity. Sediment water content is an important parameter to benthic, intertidal organisms. Sediments within the intertidal zone, especially the upper intertidal, become drier throughout the summer with lowering tide levels. Intertidal organisms respond by gradually moving toward the water with the tides. Mechanical raking disturbs the top portion of the sand column, leaving the underlying layer and its associated organisms exposed to evaporative processes. The disturbance to the top centimeters of the sand column was obviously not significant enough to allow for increased evaporation and dessication of benthos since percent water content within samples was not significantly different between treatment and control sites.

Two distinct groups of macrofauna were collected during the study period: benthic organisms (polychaetes and haustoriid amphipods) and organisms directly associated with wrack material (insects and talitrid amphipods). General factorial results indicated that mechanical raking affected both groups to some extent. Significant differences in mean density and biomass existed between treatment and control sites during the 10 day period following mechanical raking. Mean density and biomass of the amphipod Orchestia grillo, polychaetes and insects were higher in control sites on Day 3 following raking. Density and biomass of O. grillo and polychaetes remained greater in control sites through Day 7 and Day 10. By Day 14, there were no statistical differences in density or biomass of any macrofaunal groups. Higher densities at control sites can be attributed to the importance of wrack material as food for insects and talitrid amphipods, while for polychaetes and haustoriid amphipods, conditions became detrimental either due directly to raking or due to conditions created through the accumulation of wrack material such as decreased sediment oxygen.

The two polychaete species collected were both in the family Spionidae. Spionids are tube-dwelling suspension and deposit feeders, feeding on organic aggregates and detritus at the sediment surface (Levin, 1981). Their feeding behavior requires that they inhabit the upper, aerobic portions of the sand column. Need for aerobic habitat may explain lower densities during May and June when wrack biomass was highest and higher densities later in the study period when wrack biomass decreased. Oxygen potential within the sediment was not measured, but anaerobic condition based on sediment color of each sample was observed and recorded. Anaerobic conditions, observed as dark gray sediment color, prevailed at all sites during the period of highest wrack accumulation and continued at control sites, particularly in areas of heavy wrack deposition. Despite presumably decreased aerobic conditions at control sites, density and biomass were higher than at treatment sites. The population appeared to recover between Day 10 and Day 14. Because chlorophyll α, %TOC and % water not significantly different between treatment and control sites, environmental conditions did not contribute to variability. The population at VC (weekly raking treatment) recovered within 38 days of the final raking event. Differences in density, therefore, appear
to directly result from mortality due to raking rather than to microscale changes in environmental conditions.

Haustoriid amphipods were unaffected by raking, with no significant difference in density or biomass between treatment and control sites throughout the study period. Haustoriids are adapted to a wide range of environmental conditions and are also capable of rapid movement (Croker, 1967). These characteristics may explain their persistence throughout this study. Haustoriids, particularly *Haustorius* spp., have been found in greater abundance at higher tide levels and deeper sand layers (Croker, 1967). Haustoriids have been found at maximum depths of 12 cm, with optimal depth being 5 cm (Keith and Hulings, 1965). The raking machinery penetrated approximately 0-3 cm, leaving deeper-dwelling haustoriids unaffected. Haustoriids collected for the present study were taken from within 10 cm. Keith and Hulings (1965) investigated burrowing behavior in five species of haustoriid amphipods. They found that although no species were capable of burrowing in dry sand, all were capable of rapid vertical burrowing in slightly moist sand, with *Haustorius* spp. being able to burrow somewhat faster than others. Moisture content ranged from 8.5% to 29.4% during this study. Although no significant differences existed during the study period, mean density and biomass were significantly higher at VC 38 days after the final raking event. These results may be attributed to patchy recruitment along the beach.

A major portion of accumulated wrack is biodegraded within the beach ecosystem. Koop et al. (1982) reported that approximately 80% of wrack deposited passed through the grazer and heterotrophic pathways. Semi-terrestrial amphipods, kelp fly larvae and isopods constitute the dominant macrofaunal decomposers on the aerobic wrack surface, while heterotrophic bacteria dominate in anaerobic leachate pools and interstitial water beneath deposits (Griffiths et al., 1983). During this study, insects and the semi-terrestrial amphipod, *Orchestia grillus* (F: Talitridae) were the dominant grazers collected.

Insects collected were from the orders Coleoptera, Collembola, Hemiptera (nymphs) and Diptera (larvae). The rove beetle, *Bledius* spp. (F: Staphylinidae) was the dominant insect collected. *Bledius* spp. are found throughout the world inhabiting burrows in sandy substrate (Moore, 1964) and are commonly associated with wrack material (Craig, 1970). Higher density and biomass occurred only on Day 3 following raking. This may be attributed to the succession of insects that occurs as wrack material ages and is weathered. Lavoie (1985) found that flies (Diptera) colonize wrack material first, followed by staphylinids, other insects and amphipods. Insect numbers decrease within a patch of wrack material as it dries and is either blown away or returned to sea. On treatment sites, abundance was lower due to direct removal by raking and remained low due to removal of the wrackline. Concurrently on control sites, abundance fluctuated over time as older material was weathered and removed and new material was deposited. Higher mean density at VC (weekly raking treatment) on Day 38 may have been due to greater wrack deposition at that site.

*Orchestia grillus* density and biomass were affected by raking. Density and biomass of *O. grillus* were lower at treatment sites until Day 14. Decreased abundance was probably due to either direct removal by raking or possible migration to areas with more abundant food...
sages. Talitrid amphipods feed on macrophytic algae and other organic waste, so as food sources were removed they probably migrated to small clumps left behind, back to the dunes or to deposits on control beaches. Robertson and Lucas (1983) found that semi-terrestrial amphipods prefer decomposing macrophyte tissue. They suggest that the presence of microbes or the effect of microbes on tissue structure and chemistry makes decomposing tissue more palatable to amphipods. As discussed previously, semi-terrestrial amphipods are the last organisms to colonize wrack material. Even though new material was deposited within treatment sites following raking, *O. grillus* may not re-establish until some time after the material is deposited.

Management Recommendations

Mechanical raking is an effective means of removing beach wrack to improve the aesthetic and recreational quality of the beach for visitors. While raking decreases wrack biomass it also appears to decrease density and biomass of some intertidal macrofauna. The greatest effects occurred following weekly raking, but biweekly raking resulted in decreases as well. Benthic- and wrack-associated macrofauna are an important food source for many species of birds inhabiting the beach, increasing the effects of their removal from the system.

Gulf beaches along PINS are important stopovers for migrants to rest, refuel, spend the winter and to use as a landmark guide for their north and south movements. Resident species use the area during courtship, nesting, rearing young, obtaining food and as a staging area to move south during the fall (Chaney et al., 1993). The wrackline has been observed as an important feeding area for shorebirds, especially Sanderling, Ruddy Turnstones, Black-bellied and Wilson’s plovers, and a resting area for Willet, Black Tern and Least Tern (Chaney et al., 1993). Ruddy Turnstones and plovers were also observed foraging along wracklines of South Texas Beaches by Withers (pers. obs.) During the present study, use of the wrackline by gulls and terns and shorebirds was only slightly lower than use of the intertidal zone. The number of birds on Gulf beaches fluctuates seasonally, with the peak abundance coinciding with fall and spring migrations (Chaney et al., 1993). Peak abundance coincides with the period when wrack biomass decreases. The management concern is to provide visitors with an aesthetically pleasing recreational area while maintaining ecosystem health.

Management recommendations are as follows:

- To manage food sources for birds, the beach could be raked (weekly or biweekly) until August, then allowed to recover before the majority of the fall migrants arrive. At least ten days were needed for macrofaunal populations to recover from raking. This schedule considers public use patterns since visitation decreases in August and drops off after Labor Day.
- Management of overall ecosystem health requires that the beach be raked no more than biweekly and less often when possible.

LITERATURE CITED


Texas A&M University-College Station. Sea Grant No. TAMU-SG-79-203. College Station, TX. 129 pp.


Systematic list of macroinvertebrate species collected from the intertidal zone at Padre Island National Seashore, Texas, May 1997 through September 1997.

**PHYLUM ANNELIDA**
Order Spionida

**SPIONIDAE**
*Scolelepis squamata* (O.F. Müller, 1806)
*Streblospio benedicti* Webster, 1879

**PHYLUM ARTHROPODA**
Subphylum Crustacea
Class Malacostraca
Order Amphipoda

**HAUSTORIIDAE**
*Haustorius* sp. Müller, 1775

**TALITRIDAE**
*Orchestia grillus* Bosc, 1802

Subphylum Insecta
Class Insecta
Order Hemiptera

**CORIXIDAE**
*Hesperocorixa* sp.

**SALDIDAE**
nymphs

Order Coleoptera

**STAPHYLINIDAE**
*Bledius* sp.

Order Diptera

larvae

Order Collembola
APPENDIX B

**Phylum Chordata**  
Class Aves  
Order Pelecaniformes  
**PELECANIDAE**  
Pelecanus occidentalis Linnaeus  
Brown Pelican

Order Ciconiiformes  
**ARDEIDAE**  
Ardea herodias Linnaeus  
Great Blue Heron

Order Charadriiformes  
**CHARADRIIDAE**  
Pluvialis squatarola (Linnaeus)  
Black-bellied Plover  

Charadrius alexandrinus Linnaeus  
Snowy Plover  

Charadrius wilsonia Ord  
Wilson’s Plover  

Charadrius melodus Ord  
Piping Plover  

**SCOLOPACIDAE**  
Catoptrophorus semipalmatus (Gmelin)  
Willet  

Numenius americanus Bechstein  
Long-billed Curlew  

Arenaria interpres (Linnaeus)  
Ruddy Turnstone  

Calidris alba (Pallas)  
Sanderling  

Calidris mauri (Cabanis)  
Western Sandpiper  

Calidris minutilla (Vieillot)
Least Sandpiper

Peep spp.

*Limnodromous* spp.
Dowitchers

**LARIDAE**

*Larus atricilla* Linnaeus
Laughing Gull

*Larus argentatus* Pontoppidan
Herring Gull

*Sterna nilotica* Gmelin
Gull-billed Tern

*Sterna caspia* Pallas
Caspian Tern

*Sterna maxima* Boddaert
Royal Tern

*Sterna sandvicensis* Latham
Sandwich Tern

*Sterna forsteri* Nuttall
Forester’s Tern

*Sterna atillarum* (Lesson)
Least Tern