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Padre Island National Seashore

Shoreline Trash

Studies at Padre Island National Seashore, 1989-1998



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INTRODUCTION

Shoreline Trash

Shoreline trash is unpleasant and often hazardous to both humans and wildlife. In an attempt to clean the beaches of trash, many coastal communities spend millions of dollars each year and conduct volunteer clean-ups. Such measures, however, resolve the problem only temporarily and trash usually reappears on the shoreline within a short period of time. The most cost-effective and long-term solution to the beach trash problem is to identify the sources and eliminate illegal dumping. Shoreline trash monitoring projects provide useful information in understanding shoreline trash and enhance efforts to reduce it.

Several studies have been undertaken worldwide in an attempt to characterize and quantify beach trash. Most of these were conducted at infrequent intervals (monthly, quarterly or yearly), and for only a few years. The shoreline trash monitoring program undertaken at Padre Island National Seashore and described in this report is the most extensive of its type ever initiated in the United States. Statistical results from this project are more comprehensive than those gathered during any other similar study of shoreline trash.

The project was undertaken to determine the types and amounts of trash that litter the shoreline of Padre Island National Seashore, the temporal and spatial variations of trash, research methods required to obtain statistically valid data on shoreline trash, and specific sources. Protocols used to conduct other shoreline trash studies were generally unsuitable for Padre Island National Seashore mainly because of the large amount of trash typically found there. Additionally, very little in



Photo 1. Shoreline trash

the way of statistical models for evaluating shoreline trash was available, so Padre Island researchers had to develop both data collection and statistical analysis methodologies to complete this project. Therefore, results include both findings related to shoreline trash at Padre Island National Seashore and recommendations about methods for monitoring shoreline trash.

Research on Padre Island trash was conducted from 1989-98, employing a variety of data collection frequencies and methodologies. In 1989 and from 1991-93, several beach transects were surveyed quarterly. Additionally, from July-August 1993, surveys were conducted daily along an eight-mile length of shoreline. The most comprehensive study, conducted from 1994-96 and 1997-98, involved the daily enumeration of forty-three specific trash items found along a 16-mile length of shoreline. During this latter study, Padre Island National Seashore researchers collected 957 days' worth of data, cumulatively surveyed over 12,500 miles of shoreline, and collected nearly 400,000 trash items.

In the course of the research, investigators developed new methodological and statistical protocols for conducting shoreline trash studies. These methods and statistical analyses established that 1) eighty percent of Padre Island trash originates in the Gulf shrimping industry and 2) Marine Plastic Pollution Research and Control Act of 1988 (MARPOL V) regulations governing the discharge of plastics have not reduced the amount of plastics that wash ashore at Padre Island National Seashore.

Padre Island National Seashore as a Study Site

Padre Island National Seashore is a unit of the National Park System located on the Gulf of Mexico along the southeastern coast of Texas. Created by Congress in 1962, the park is 68 miles in length and protects the largest portion of the longest stretch of undeveloped barrier island beach in the United States. Approximately 800,000 people visit the seashore annually.

For much of the year, however, the beach at Padre Island National Seashore is heavily littered with trash. The five-year National Park Marine Debris Monitoring Program demonstrated that Padre Island National Seashore receives far more beach trash than any other park (Cole *et al.*, 1995; Cole and Kliwinski, 1998). Shoreline trash at Padre Island National Seashore has frustrated both managers and visi-



Photo 2. Shoreline trash

tors, and continues to be the most difficult natural resource and visitor management problem facing the park. This study attempted to understand and document the shoreline trash problem at Padre Island National Seashore and now provides guidance for research personnel undertaking shoreline trash surveys here and elsewhere.

Shoreline trash is not just an aesthetic problem, but also has ecological, safety, and economic implications. The trash includes non-hazardous wastes, such as commercial and household trash and debris, and numerous types of hazardous wastes, such as toxic chemicals and medical waste (Photos 3-4). Visitors not only must deal with the unsightliness of the trash but may also be exposed to dangerous waste. Additionally, each year an unknown number of marine and terrestrial animals appear on the shores of Padre Island that have been maimed or killed by entanglement in or ingestion of ocean-borne trash (Photos 5-7) (Cottingham, 1988; Environmental Protection Agency, 1989; Marine Mammal Commission, 1994; Faris and Hart, 1995; Shaver and Plotkin, 1998).

Unsanitary and unsafe beaches are adversely affecting the tourism and recreation industries of the Gulf coast. It is becoming increasingly expensive to clean and maintain beaches in order to provide the recreational experience anticipated by visitors.

The primary reason for trash accumulation on Padre Island is the convergent currents occurring along the Gulf coastline that deposit the trash floating in the Gulf of Mexico onto the South Texas coastline (Figure 1).

The amount of trash on the beach is directly related to the amount that is flushed or dumped into the Gulf, the strength, direction, and duration of the wind, and the height of the incoming tides.



Photos 3-7. Clockwise from left: Hazardous waste; medical waste; entangled shark; entangled sea turtle; entangled Ruddy Turnstone



Figure 1. Gulf currents

SCOPE OF THE PROBLEM

The aesthetic and environmental impacts associated with shoreline trash occur worldwide (Cottingham, 1988; Faris and Hart, 1995). To reduce the amount of trash dumped into U.S. waters, in 1988 Congress passed the Marine Plastic Pollution Research and Control Act. The United States joined 39 other nations ratifying Annex V of the International Convention for the Prevention of Pollution from Ships, known as MARPOL. Annex V of MARPOL makes it illegal for U.S. and foreign ships to discharge plastics into the world's oceans. This treaty was an important step in addressing the significant environ-

mental and economic problems caused by the dumping of trash in the ocean. The Padre Island study was in a good position to evaluate some provisions of MARPOL.

Demonstrating that shoreline trash is a worldwide issue, the Center for Marine Conservation (CMC) estimated that over 3,000 tons of trash were cleaned from beaches of participating countries and territories during their 1997 International Coastal Cleanup (Center for Marine Conservation, 1998). Of the 3,000 tons removed, CMC estimated that approximately 1,500 tons were collected on the United States coastline (Sheavly *et al.*, 1998).

While much information has been published on the subject of marine and shoreline trash (Hanson and Ribic, 1994), a scientific consensus is lacking. For example, estimates on the amount of trash dumped into the oceans each year range from 2 billion to 14 billion pounds (Cottingham, 1988; American Management Systems, Inc., 1991; U.S. General Accounting Office, 1995), indicating the lack of sound scientific measurement and reporting. Scientific opinions regarding shoreline trash methodologies and data collection techniques also vary.

Surveying the Problem: 1989-1998

From 1989 to 1993, Padre Island National Seashore was one of ten national park units participating in a national shoreline trash monitoring project. The project was initiated by the National Park Service and the National Marine Fisheries Service in an attempt to assess beach trash abundance, composition, and accumulation rates at each of the park units (Cole and Kliwinski, 1998) and to evaluate the long-term trend in ocean pollution. This project was the first shoreline trash research project of its type. Each participating park conducted quarterly surveys of several one-kilometer plots and recorded and removed 76 different trash items.

Although the initial project was completed in 1993, park staff at Padre Island continued to conduct shoreline trash research until December 1998. During the eight-year project, data collection methods were refined and a successful quality assurance program was established.

As sampling methods were analyzed and refined, sampling protocols changed. The sizes of the survey plots were changed from 50 x 100-meters (1991-1993), to a single survey plot encompassing a 16-mile-long section of shoreline (1994-1998). Survey frequency also changed from collecting trash on a quarterly basis to collecting data on a daily basis. In addition, the number of trash items surveyed and collected was reduced from 76 individual trash categories (1989-91), to 49 categories (daily survey/1992-93), to 43 categories (1994-98) as potential point sources of trash.

COLLECTING THE DATA

THE FIRST TRASH SURVEY: 1989-1993

In 1989, Padre Island National Seashore began shoreline trash monitoring as part of the National Park Service's five-year study, The National Park Marine Debris Monitoring Program. In the first year, park staff surveyed the five, one-kilometer plots as required by the national survey protocol. These plots were located in various areas along the length of the seashore and were separated by as much as 40 miles. Because of the quantity of trash and logistical difficulties in reaching the survey plots, the size of the plots and distance between them were reduced in the second year of the study. Instead of surveying the five, one-kilometer plots, six computer generated 50 x 100-meter survey plots were selected for monitoring within a 16-mile-long section of shoreline. These plots were placed between one and three miles apart and surveyed quarterly beginning in February 1991. Depending upon the amount of trash that was found within the plots, each quarterly survey usually required one to three days to complete. From 1991 to 1993, park staff collected 30 months of data from the quarterly surveys.

In an effort to obtain the most accurate data possible, small flags divided the individual survey plots into rows approximately two meters wide. Every trash item larger than five millimeters and visible from eye level was recorded and removed from the survey plots. The flags made it possible for surveyors to focus on recording and removing the trash items located only between the flags instead of the entire survey area (Photo 8).

To determine the extent of lateral movement of trash due to rain, wind and tidal fluctuations, all trash items located within 50 meters of each survey plot were painted (Photo 9).

The new paint kept surveyors from mistakenly counting the painted items as newly deposited items. That is, if a previously painted item was located within the survey plot on the day of the quarterly survey, surveyors knew it had moved in from the adjacent 50-meter zone and was not newly deposited trash from the ocean. In this way previously painted items were removed from the survey plots and not recorded in the database.

In September 1991, a storm washed hundreds of tons of natural debris and

thousands of man-made trash items onto the Padre Island shoreline (Photo 10). Within two weeks tides and winds had totally cleaned the debris and trash from the shoreline (Photo 11). These events occurred just prior to the quarterly survey. On the day of the quarterly survey trash was noticeably absent from the survey plots.

Winds and tides profoundly affect the movement of trash along the beach from shoreline to primary dunes and back. Depending on the wind speed, direction and duration, trash items can be blown back into the Gulf and subsequently float with the currents until they are re-deposited onto the shoreline with the incoming high tides. Park staff, therefore, decided to examine the overall effects of wind and tides on shoreline trash accumulation. In 1992 four new 50 x 100-meter survey plots were added to complement the six quarterly survey plots. Data were collected from the 10 survey plots for the succeeding 18 months. The new plots were established adjacent to two of the quarterly plots but were surveyed on a daily basis. All ten survey plots were identical in size and spaced at varying intervals along the 16-mile survey area. The close proximity of the new plots to the quarterly survey plots allowed park staff to compare the variation between daily and quarterly trash accumulation and composition. Trash items found within plots 1, 2B, 3B, and 4-6 were counted and removed quarterly, while items found within plots 2A and 3A were counted and removed daily. Items found within survey plots 2C and 3C were counted, painted and left in place (Figure 2).

On the day of the quarterly survey, all painted items found within survey plots 2C and 3C were counted and removed. That number was then sub-



Photos 8-11. *From top to bottom:* Park staff surveying study plot; Park staff painting trash items; Shoreline littered with natural debris and man-made trash after storm; Shoreline cleaned by winds and tides

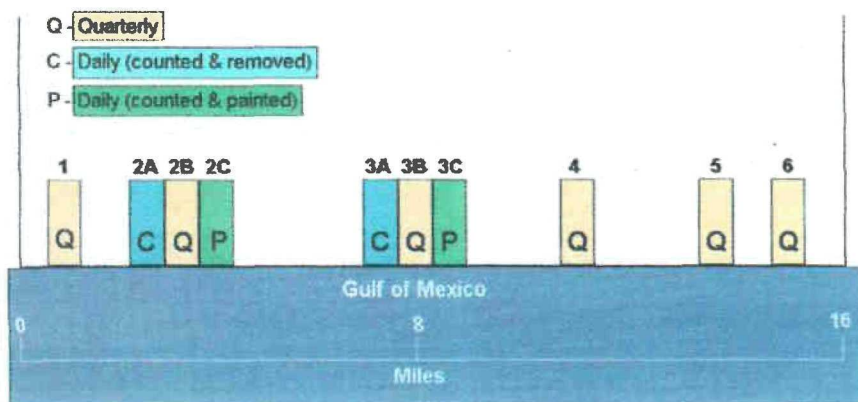


Figure 2. Location of daily and quarterly survey plots

tracted from the total number of items that had been painted over the quarter. The difference between these two numbers equaled the number of items that had been moved or buried by winds or tides. For example, if 3,000 items had been painted during the quarter but only 200 items were found remaining within the plots on the day of the quarterly survey, surveyors concluded that 2,800 items had either been moved or buried by winds or tides.

For the first two years of the study, the plots were surveyed from the water's edge through the coppice dunes. In 1992, a storm produced extremely high tides, washing or severely damaging many miles of coppice dunes and several miles of primary dunes. Thousands of trash items washed out of the coppice dune area, newly uncovered items that had been previously buried for an unknown period of time (Photo 12).

One of the study objectives was to obtain trash accumulation data on daily post-MARPOL accumulation rates. However, it was impossible to determine which items had been recently deposited (post-MARPOL), as compared to those items that had been uncovered by the tidal surge (possibly pre-MARPOL trash). For this reason, during this and all future storms, daily surveys were discontinued for several days to prevent data collection errors.

Additionally, to obtain a more refined understanding of actual trash accumulation, each daily survey plot was divided into two zones. These zones included the foreshore zone (the area of shoreline from the water's edge to the high tide line), and backshore zone



Photo 12. Trash in backshore zone exposed by high tides

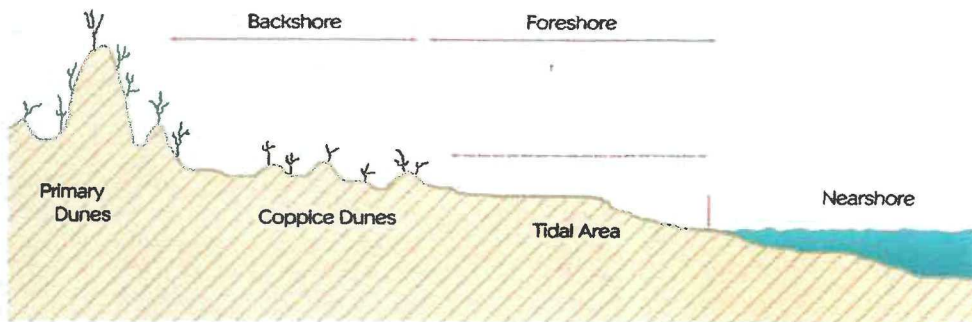


Figure 3. Shoreline zones

(the area of shoreline located from the high tide line to the primary dunes) (Figure 3). For the following 18 months, the locations of trash in the zones were recorded and the items removed from the survey plots. If the trash items could be recorded and collected daily, surveyors would then know exactly how much new trash was washing ashore.

ANALYSIS OF DATA FROM THE FIRST SURVEY

Accumulation

During the 10 quarterly surveys (1991-93), 54,755 trash items were counted from the six quarterly plots (Table 1). In comparison, during the 18 months of the daily survey (1992-93), 135,199 trash items were counted from the four daily survey plots.

Table 1. Quarterly surveys 1991-93

Year	Quarter	Total Items Collected
1991	Spring	3778
1991	Summer	7500
1991	Fall	7249
1992	Winter	3053
1992	Spring	5796
1992	Summer	6906
1992	Fall	3758
1993	Winter	3180
1993	Spring	7308
1993	Summer	6227
Total		54,755

Analysis by Zones

In the beginning of the survey the number of items recorded within the backshore zone of the survey plots was almost as great as the numbers recorded within the foreshore zone (Table 2). As winds and tides uncovered the trash located in the backshore zone and those items were removed from the survey plots, the number of items decreased dramatically.

Table 2. Comparison of the number of items collected in the foreshore zone with the number collected in the backshore zone from 1992-93

Sampling Zone	Number of Items	Percent of Total
Foreshore Zone	85,154	63%
Backshore Zone	50,045	37%
Total	135,199	100%

Analysis by Category

Of the 135,199 trash items collected from the daily surveys, 76 percent of the items came from only 10 percent of the categories. These items included foam fragments, tobacco items, small plastic bags, and small pieces of plastic sheeting (Table 3).

Table 3. Distribution of trash categories in the 1992-93 daily samples

Category Grouping	Number of Categories	Percent of Categories	Number of Items
Fragments	5	10%	102,127
Non-Fragment Categories	44	90%	33,072
Total	49	100%	135,199

Although the number of small pieces of plastic and foam was greater than the total number of items collected, these fragments could not be linked to a specific item. Thus, beginning in 1994, less emphasis was placed on the collection of fragments.

Analysis of Winds, Currents, and Tides

Trash from the Gulf of Mexico accumulates on Padre Island National Seashore because of currents, winds, and tides. The direction of the wind can greatly influence the amount of trash found on the beach on any given day. Contrary to what might be expected, there is actually less trash on the beach when the wind is blowing onshore (Table 4).

Table 4. Average number of items collected per day, per survey plots vs. wind direction

Wind Direction	Avg. Number of Items
Onshore	41.9
Offshore	55.6

How offshore winds could deposit more trash on the shoreline than on-shore winds was at first quite perplexing. Surveyors found the answer when higher than normal tides re-deposited trash from the dunes and backshore zone to the foreshore zone. Trash surveys conducted immediately after a high tide record a greater amount of trash in the foreshore



Photo 13. Trash exposed in the backshore zone of the beach

zone because high tides and wind expose trash that was deposited in the backshore zone weeks or even years before the tidal event (Photo 13). Once exposed, winds and tides move items into the survey area.

Using tidal data from the National Oceanic and Atmospheric Administration (NOAA) tidal station located on Padre Island, researchers analyzed the correlation between the number of trash items collected and the NOAA tidal data. They found that the amount of trash is most highly correlated with the height of mean higher high water (MHHW), though this correlation differs for the backshore zone and the foreshore zone (Table 5).

Table 5. Comparison of Spearman's correlation coefficients between MHHW and items collected from the backshore zone and foreshore zone

Wind Direction	Correlation between MHHW and Items Collected
Onshore	0.102
Offshore	0.403

In other words, the effect of high tides on increased trash is highest when winds are blowing offshore, again suggesting that high tides tend to move the trash that has been buried in the dunes onto the shoreline. In fact, the effect of wind is more pronounced when tides are higher, regardless of whether winds are blowing on-shore or offshore. Wind effects appear to be stronger when they blow offshore.

Figure 4 depicts the average effect of winds on the number of items collected. "Low" refers to days when the MHHW was below the 25th percentile. "Mid" refers to those days on which the MHHW was between the 25th and 75th percentiles (i.e., average high tide days). "High" denotes those days in which the MHHW was in the upper 75th and 100th percentile.

When the MHHW is at a lower level (i.e., the high tide is lower than usual), wind direction appears to have no effect. When tides are in mid-range, onshore winds appear to deposit more trash onto the shoreline. So it is only at the highest

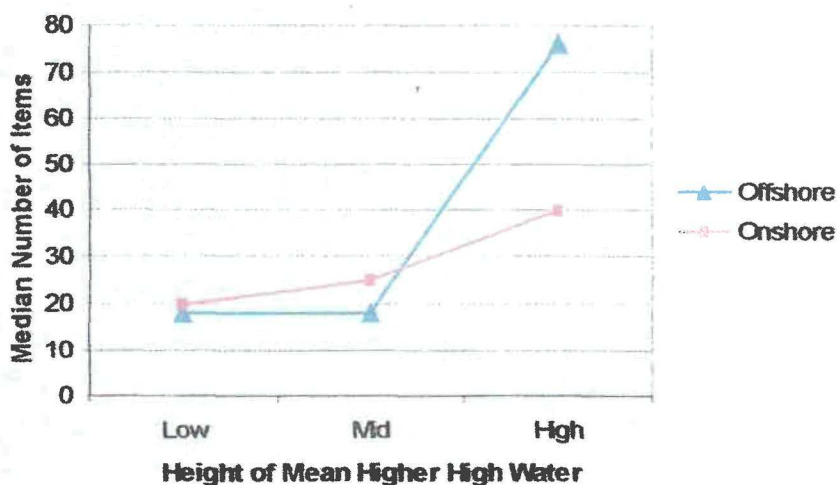


Figure 4. Effects of winds and tides on the number of items collected

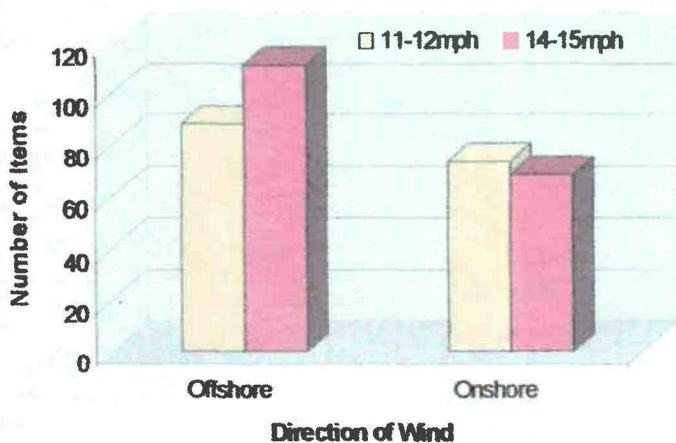


Figure 5. Wind effects on trash accumulation

tides, those in the upper 75th to 100th percentile, that offshore winds seem to deposit more items onto the shoreline.

As Figure 5 depicts, item counts are actually higher with an offshore wind and high tides. This effect of winds and tides, however, is noticeably different between the backshore and foreshore zones.

Table 6 and Figure 6 illustrate the combined effect of winds and tides. The highest number of trash items was found in the foreshore zone when the wind was blowing offshore and tides were high. Medians of 138 items per survey plot were collected under this condition. A much smaller median number was found in the

Table 6. Median numbers of items collected per day per survey plots vs. wind by sampling zone, wind direction, and height of MHHW

Sampling Zone	Wind Direction	Tides	Median Number of Items
Backshore	Offshore	Low	16
Backshore	Offshore	Mid	23
Backshore	Offshore	High	13
Backshore	Onshore	Low	22
Backshore	Onshore	Mid	28
Backshore	Onshore	High	29
Foreshore	Offshore	Low	20
Foreshore	Offshore	Mid	15
Foreshore	Offshore	High	138
Foreshore	Onshore	Low	18
Foreshore	Onshore	Mid	27
Foreshore	Onshore	High	53

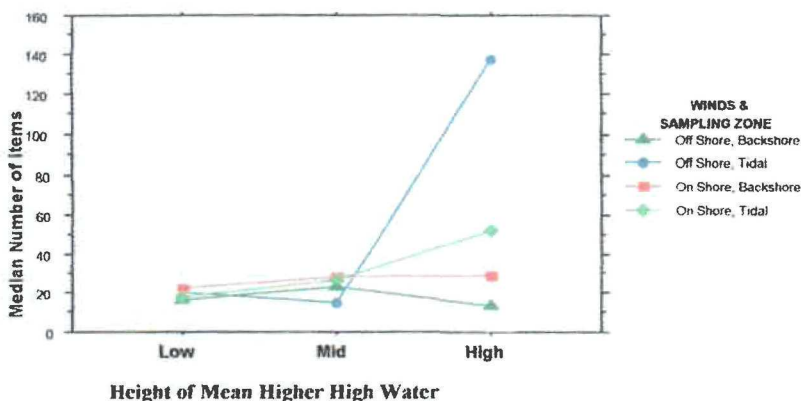


Figure 6. Effect of winds and tides for each sampling zone

foreshore zone when the tides were mid to low. Thus, the median number of items in the foreshore zone was five to nine times higher than the item counts under other conditions.

The effect of winds and tides on trash movement underscores the importance of daily removal of all recorded trash from survey plots.

Variability of Trash Accumulation

In surveys conducted only quarterly, the number of trash items fluctuated greatly, so much so that trash accumulation at different times and locations along the shoreline completely masked any seasonal trends. Furthermore, infrequent data collection could easily result in insufficient data and consequent misinterpretation of

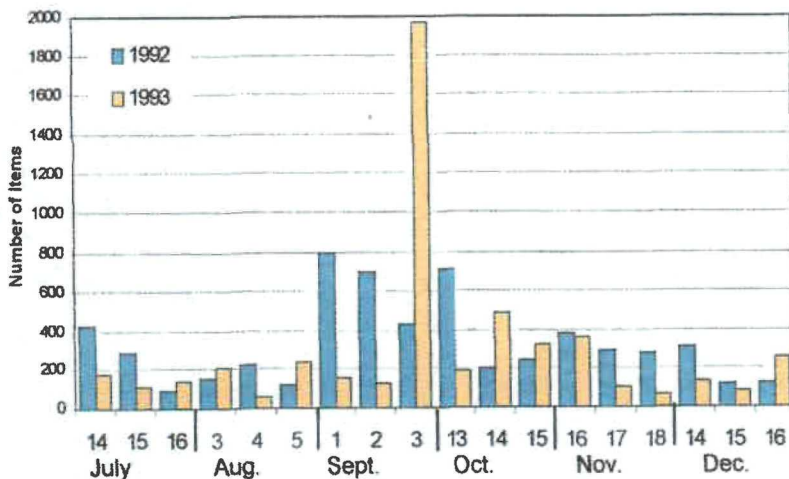


Figure 7. Variability in trash accumulation for randomly selected three-day periods from July-August 1992-93

trash accumulation rates and composition. Figure 7 represents trash accumulation for randomly chosen three-day periods for a two-year duration. Comparisons of the number of items counted from month to month, within months, and between years demonstrated extreme variability. No matter which days, months, or years were selected for comparison, daily trash accumulation varied substantially.

The number of trash items collected during the first week of August 1992 ranged from 100 to 200 per day (Figure 8). In contrast, the number collected each day during the last week of August ranged from 1300 to 2900. With only quarterly surveys, different conclusions would have been drawn depending on which week the survey data were collected.

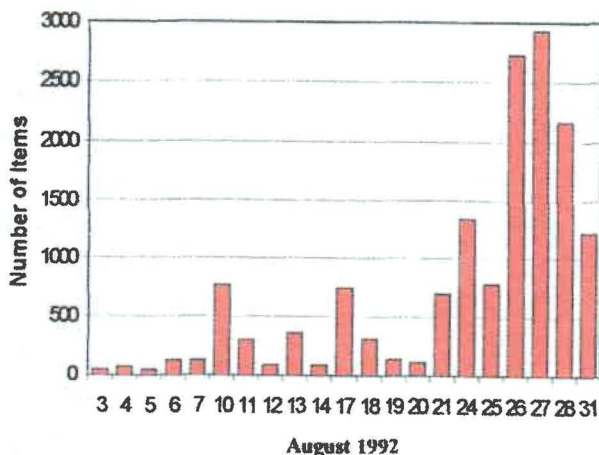


Figure 8. Total number of trash items surveyed for August 1992

Figure 9 depicts another example of the variability of trash accumulation. This example relates the differences between total trash accumulation for two quarterly survey plots (2B and 3B) and two daily-painted survey plots (2C and 3C), for one quarterly survey period. Survey plots 2B-2C' and 3B-3C were identical in size and located adjacent to each other.

Survey plots 2C and 3C were further delineated by counting the number of painted and unpainted items that remained in the plots on the day of the quarterly survey, making it possible to obtain several different types of temporal and spatial data analyses on trash accumulation rates. It did not matter which quarterly survey periods or survey plots were chosen for comparison because every period and every plot exhibited high variability.

On the day of the quarterly survey, all unpainted trash items (2C-2 and 3C-2) within survey plots 2C and 3C were counted and removed. These items had washed into the survey plots from the previous day's high tide(s). The number of unpainted items was then compared to the number of painted items remaining within the survey plots (2C-1 and 3C-1), allowing surveyors to determine the different rates of trash accumulation.

To compare quarterly trash accumulation rates and daily trash accumulation rates, the total number of items collected from survey plots 2C and 3C was compared to the total number of items collected from survey plots 2B and 3B. Additionally, the total number of painted items (2C-1 and 3C-1) remaining within the survey plots 2C and 3C was compared to the total number of items that were previously painted during the quarterly survey period. The difference between these numbers was an indication of the total number of trash items that had been either moved from the survey plot or buried during the quarterly survey period. For example, if 2000 items had been painted during the quarterly survey period, finding only 200

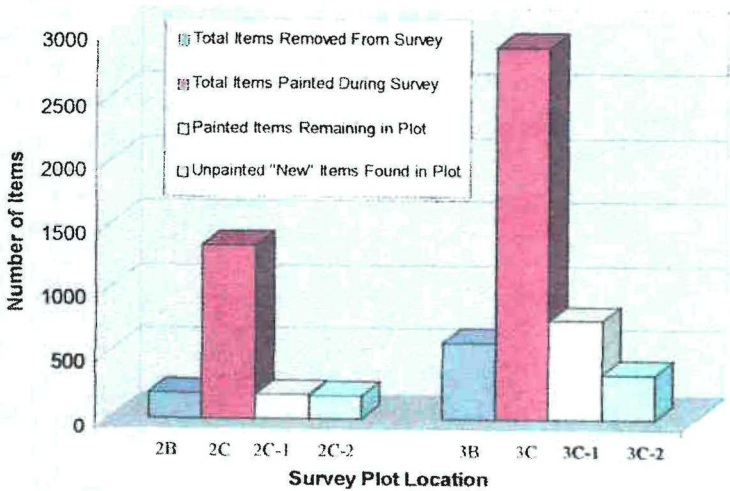


Figure 9. Variability in the number of trash items

remaining within the survey plot on the day of the scheduled survey would indicate that 1800 items had been moved or buried during that quarterly time period. This is an important aspect for understanding actual accumulation rates. Specifically, if these data had been collected only on the quarterly survey day, a count of the area would have indicated that only 200 trash items had accumulated in the survey plot during the previous three months. Such a conclusion would have produced misleading monitoring protocols for Padre Island National Seashore.

Data on the number of “new,” unpainted items (2C-2 and 3C-2) were compared to the number of items found in the quarterly survey plots (2B and 3B). They indicated that the amount of trash found in a quarterly survey plot is more likely to equal the amount of trash that washed ashore daily, and that both monthly and yearly trash accumulation totals were highly variable (Figure 10). Figure 10 demonstrates that trash accumulation between the same months in different years could vary by as many as 11,000 items (Note: The large amount of trash accumulation for Aug-Oct, 1992, was due to storms and abnormally high tides).

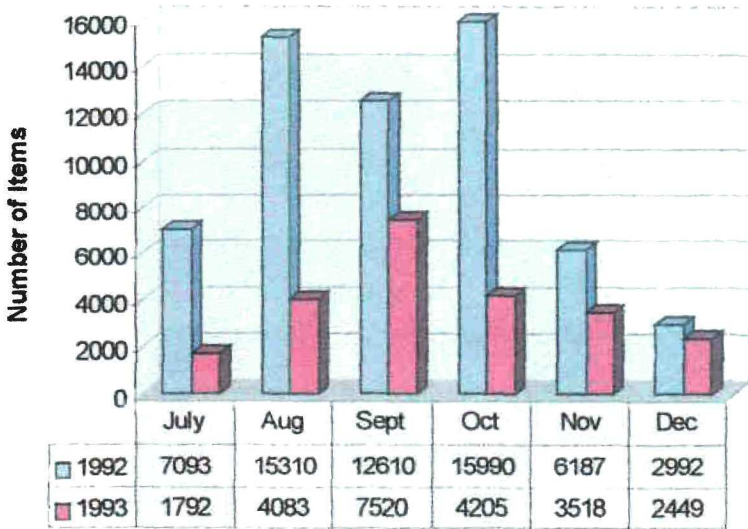


Figure 10. Monthly comparisons of the total number of trash items collected for July-December 1992-93 *Note: Aug.-Oct. 1992 accumulation due to storm conditions and high tides.*

Why Quarterly Surveys are Inadequate

Four considerations make quarterly surveys unsuitable for temporal monitoring at Padre Island National Seashore: (1) sample size, (2) environmental factors, (3) seasonal trends, and (4) the “accumulation assumption.”

Sample Size

Quarterly surveys at Padre Island do not appear to accurately depict temporal trash accumulation rates. If educational programs, regulations, and other measures are to be effective, more frequent monitoring is necessary. This study indicates that, at a minimum, *weekly* monitoring is needed.

Environmental Factors

Environmental variables at Padre Island have a major influence on trash accumulation, and may not be accounted for in quarterly surveys. For example, if a quarterly survey is conducted immediately after a storm or unusually high tides it will likely register a significant increase in trash accumulation. However, if the survey is conducted immediately before such an event the survey might register a large reduction in trash accumulation. Winds and tides that occur in the backshore zone erode the dunes and transport the trash to the foreshore zone. Therefore, it is important to continuously monitor the winds and tides in the survey area.

Seasonal Trends

Seasonal human activities in the vicinity of Padre Island affect trash accumulation. Some point sources of trash such as commercial fishing are seasonal, so quarterly surveys may miss them in the accumulation of specific trash items. For example, from 1994-98, daily surveys were conducted on a 16-mile-long survey area. The peak in trash accumulation for 1997 was in July. This peak occurred just after the opening of the Gulf shrimp harvest season. Had the survey been conducted on a quarterly basis, and initiated at any time other than mid-July, the seasonal increase in the specific trash items being surveyed would have been missed.

The Accumulation Assumption

The assumption behind quarterly surveys is that the data collected on any particular survey day can be extrapolated to represent 90 days of trash accumulation. However, the Padre Island National Seashore data indicate that, over the quarter, almost all of the trash that had washed into the quarterly survey plots was either buried, blown inland, or washed out of the plots by high tides. *For this reason, quarterly surveys at Padre Island National Seashore do not record the total amount of trash that washed ashore during any given 90-day time period and trends based upon quarterly data are therefore not statistically meaningful.* Identifying significant declines or increases in trash accumulation in the presence of high daily environmental variations and seasonal activities requires a statistically designed sampling plan with surveys conducted more frequently. Data on trash composition and accumulation rates obtained from the daily surveys proved to be more precise than quarterly surveys, which were also poor predictors of seasonal or annual trends.

Additional Considerations

Large differences can occur between the number of trash items counted even if the surveys are conducted on the same day and in the same area. These variations are a result of two problems: fragment counts and collection of backshore zone

trash. If fragments are collected and counted the same as larger items, they will skew the number of trash items upward, distorting the data and making temporal trends more difficult to identify.

The Padre Island National Seashore study demonstrated that the inclusion of fragments may be unnecessary and inappropriate to monitor trends. Fragment items include cigarette butts, balloons and ribbons, small plastic pieces, small pieces of rope, net or fishing line, and fragments of plastic bags, most of which were fragmented as a result of wave action and beach traffic. For example, whether a plastic bag is counted as one item or a dozen depends upon how long it remained on the beach and the decision of the surveyor. If fragments are counted, the number of trash items collected quarterly will be much higher than the number of items collected during weekly surveys that exclude fragments. For this reason, fragment data should not be collected. However, if fragment data are collected, such counts should be separated from the total number of items recorded. The total counts, minus fragment data, should be used to demonstrate temporal and spatial trends.

Old trash may accumulate into the backshore zone. If a surveyor includes within the count trash from the backshore zone, a large increase in accumulation may be expected following an unusually high tide or a windy storm. Therefore, backshore zone data should not be combined with data collected in the foreshore zone and winds and tides on a survey beach need to be monitored continuously.

THE SECOND TRASH SURVEY: 1994-1998

Statistical analysis of the first trash survey made clear the need for increased survey frequency and plot size for obtaining accurate information on trash composition, accumulation rates, and seasonal trends. In 1994 park staff initiated a new, more ambitious shoreline trash-monitoring program. It entailed recording and collecting 43 identifiable kinds of trash items from a 16-mile long section of foreshore zone on a seven-day per week basis. It became one of the most extensive shoreline trash monitoring research projects of its type.

The new survey area was divided into 16 mile-long survey plots, allowing surveyors to compare daily trash accumulation and composition among the individual survey plots. Daily removal of the trash items from the survey area allowed surveyors to obtain highly accurate accumulation data and prevented duplicate counting. Forty-three specific trash items were chosen for collection because the 1991-93 data had indicated that they were the most prevalent items deposited onto the shoreline.

The new 16-mile long survey area included the ten 50 X 100-meter plots that had been surveyed for the previous three years. This allowed surveyors the opportunity to obtain and compare data from different sized survey plots. Surveys on the other daily and quarterly plots were discontinued.

This new shoreline-monitoring program was conducted from March 1994 to February 1996, and from March 1997 to February 1998. During that time, surveyors collected 957 days worth of data, surveyed 12,574 miles of shoreline, and counted a total of 376,396 trash items and removed them from the survey area. Excluding fragments, they collected a total of 104,643 trash items.

Study Objectives

The extensive temporal and spatial data of this survey provide a unique opportunity to investigate fundamental issues and statistical questions about the collection and general analysis of shoreline trash data. The collection and analysis of shoreline trash is complicated by several statistical questions, which can be broadly grouped into two categories: survey design and data analysis.

Survey Design

Issues related to the design of shoreline trash surveys include:

- How frequently should the survey be conducted?
- How many sites should be surveyed?
- What types of data should be collected?

The evaluation and analysis of data collected at Padre Island National Seashore presented in this section address these three questions. Unique in their temporal and spatial depth, data analyses were complicated by a previous lack of comprehensive research into statistical models for evaluating shoreline trash data. Previously published statistical reports analyzing shoreline trash data use standard techniques including analysis of variance and repeated measures analysis. The validity of these analyses depends strongly upon the statistical model assumed for these data.

Data Analysis

Until now, it has been impossible to statistically evaluate the assumptions of these previous analyses because of the absence of adequate data. Other trash studies have collected data at various sites and times, often on a relatively infrequent basis. As previously noted, surveys conducted on an annual or even monthly basis may be inadequate for evaluating temporal changes, and are likely inadequate for identifying point sources of trash. Events associated with point sources of trash are likely to be seasonal, and a monthly or annual survey will not provide adequate statistical identification of this source. The Padre Island National Seashore database, however, allows for an evaluation of these assumptions and for improvement of these analyses or development of new methods for modeling shoreline trash data.

Key Questions

This section attempts to answer the following key questions:

1. *What is the magnitude of spatial and temporal variation in the Padre Island National Seashore data?* The magnitude of these sources of variation suggests how frequently sampling must be done in order to accurately estimate trash levels and detect increases or decreases in the amount of trash deposited on the shoreline.

2. *Is temporal variation greater than spatial variation?* Answering this question helps to determine how often samples should be collected and whether it is better to sample frequently or to sample more locations.
3. *Is the spatial distribution of trash along the Padre Island National Seashore shoreline homogeneous? If it is not, what is its distribution?* If the trash items are distributed uniformly along the shoreline, then sampling can be conducted at only a few sites and they can be contiguous. However, if the distribution is not uniform, then it is necessary to sample several different locations and the model of trash distribution should define optimum spacing between sampling locations.
4. *How frequently should trash data be collected?* In some areas it is common practice to collect trash items on a monthly, quarterly, or even annual basis. Such data are sometimes used to estimate the total amount of trash that has washed onto a shoreline. The Padre Island survey calls into question the accuracy of these estimates.
5. *Can principal component analysis be used to identify sources of shoreline trash?* The Padre Island National Seashore data classifies trash items into 43 different categories. Principal component analysis can be used to identify natural groupings of these categories and each grouping or principal component defines categories that tend to increase or decrease at the same time.
6. *What is the best variable to use to statistically evaluate temporal changes in the amount of trash washing onto a shoreline?* A key objective of the Padre Island National Seashore program is to identify point sources of trash. If the point source was infrequent or seasonal, one way to detect that source would be to detect changes in the amounts of certain categories of trash washing ashore.

Quality Assurance Program

Several scientists have discussed the importance of implementing a quality assurance program for shoreline trash surveys. According to Ribic et al. (1992), "[i]nformation concerning quality assurance program plans for beach surveys is scarce. For studies in which data are collected by volunteers, a training session to guarantee the quality of the data is imperative."

Since the inception of the trash monitoring program in 1989, the park staff used several quality assurance techniques, which included using survey flags to guide the field staff (1990-91), painting trash items to assure accuracy (1990-93), and conducting periodic recounts. During the 1994-98 project, five employees were

hired and trained to collect and record the field data. Once the sampling protocol was perfected, volunteers were brought in to supplement park staff.

Early in the study field staff occasionally disagreed in the identification and classification of certain trash items. While one surveyor might have considered a certain trash item as intact, another might record the same item as a fragment. Photograph 14 illustrates the type of confusion that might occur. One surveyor might classify the item as one plastic fragment, while another might have recorded it as one balloon. Or, a surveyor might wonder whether to record the item as one ribbon or eight.

As the study developed it became apparent that precise definitions were critically important to minimize variations in data classification, so park staff developed and implemented a comprehensive training program on item identification, collection, and recording techniques. Supervisors conducted periodic field reviews to ensure quality control in data collection practices. Other aspects of the quality assurance program included random recounting of collected trash items to ensure the accuracy of the original (Photo 15), and periodic review of database input to ensure accuracy.



The quality assurance program proved to be exceptionally effective at preventing data errors. From 1994-98, a total of 20 seasonal park employees worked between one and four years each as surveyors. To ensure continued data accuracy as field staff changed over time, veteran field staff

extensively trained new staff members. Once new surveyors became competent in their identification and recording skills they were administered a field test by the project supervisor. After passing this test the new employees were allowed to work independently on the survey.



Photo 14,15. Ribbon and balloon; Quality assurance program - item recount to ensure accuracy

ANALYSIS OF DATA FROM THE SECOND SURVEY

For the 1994-95 survey season, 37,644 identifiable trash items, excluding fragments, were recorded and collected from 4,893 miles of shoreline. For the 1995-96 survey season, 28,447 items, excluding fragments, were recorded from 3,918 miles of shoreline. During the 1997-98 survey season, 38,552 items, excluding fragments, were counted from 3,763 miles of shoreline (Figure 11).

The average number of trash items collected per month per mile was 7.5 for the 1994-95 survey season; 6.8 for the 1995-96 survey season; and, 10.8 for the 1997-98 survey season (Figure 12). As Figure 12 indicates, trash accumulation varied widely both monthly and yearly.

STATISTICAL ANALYSIS

This section describes an analysis of shoreline trash data collected from March 1994 to March 1998 and focuses on the statistical properties and modeling of these data. The data are unique and valuable in several regards:

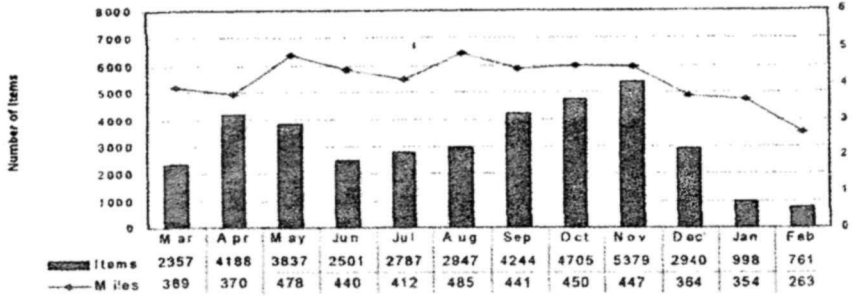
1. The Padre Island National Seashore data encompass an extended period of time during which trash items were collected nearly every day. Researchers logged a total of 957 collection days. The majority of other shoreline trash studies collect data on a monthly, quarterly, or yearly basis for fewer years.
2. Individual items were cataloged into 43 categories, including small items such as a rubber glove or egg carton as well as larger items, such as a 55-gallon barrel.
3. The data were collected over a contiguous sixteen miles of shoreline at Padre Island National Seashore. The five continuous miles of shoreline were closed to vehicular traffic, while the remainder was kept open.
4. Trash counts were recorded by collection category and by location along the 16-mile transect. A total of 12,566 samples was collected during the study period.
5. Surveyors were trained to recognize and catalog the 43 items, and quality assurance procedures were implemented to periodically assess the accuracy of data collection

Distribution of Items

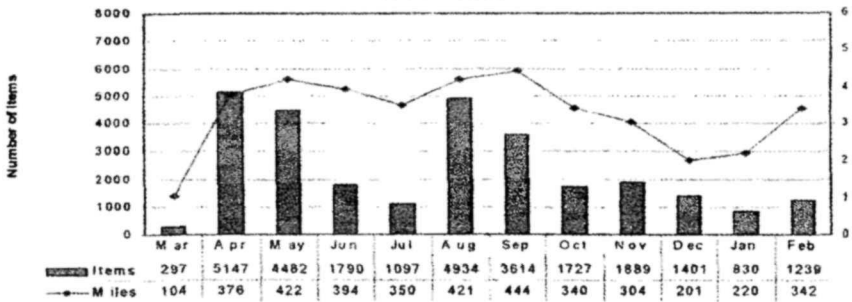
A commonly used measure for conducting trash surveys is analysis of the number of items collected. This method treats small and large items as equivalent. Counts are not usually normally distributed, and the square root of a count variable is used to convert them to data that are more normally distributed.

Determining the degree of spatial variation requires understanding whether or

1994 - 1995



1995 - 1996



1997 - 1998

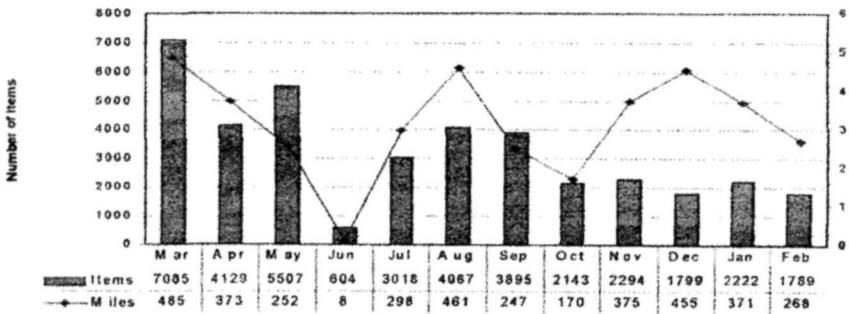


Figure 11. Total number of trash items collected per month and number of miles surveyed for each study year

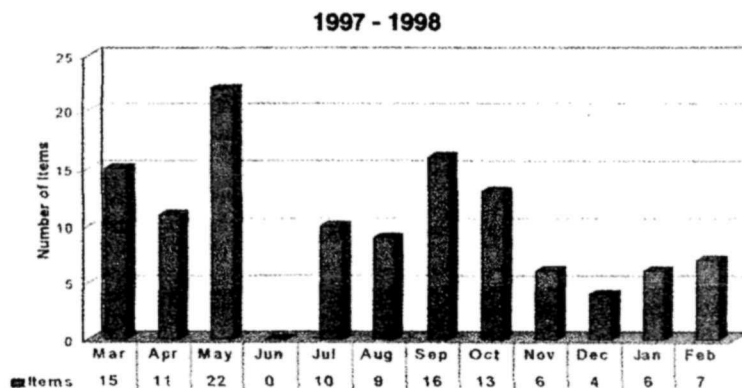
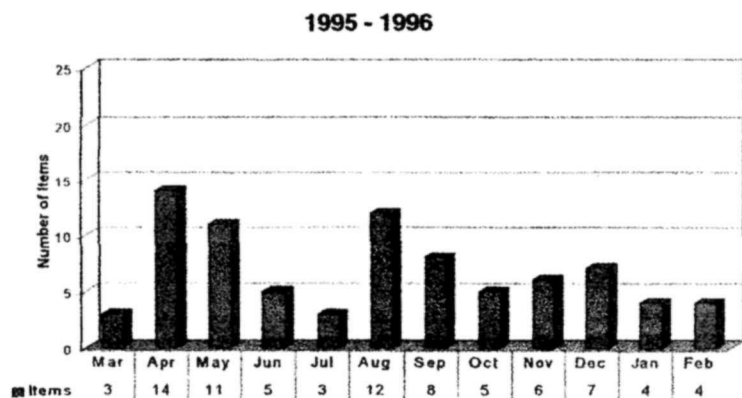
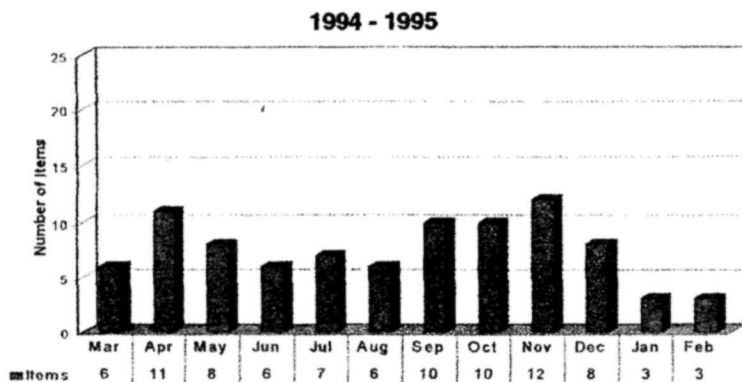


Figure 12. Average number of trash items collected per month per mile for each study year

not the distribution of trash along the Padre Island National Seashore shoreline is homogeneous. That is, are the individual trash items washing ashore at the same rate? This question is answered by determining whether the distribution of the amount of trash is Poisson and examining the spatial, temporal, and seasonal variation of trash.

Determination of Whether Distribution is Poisson

Poisson, used in the context of shoreline surveys, is indicative of homogeneous trash distribution along the shoreline. Counts are rarely normally distributed and such is the case with these data. The histogram of the total number of items collected per mile is clearly right-skewed and non-Normal. Because counts are not normally distributed they should not be used in statistical analyses that require an assumption of Normality (Figure 13).

Unfortunately, most of the published analyses of shoreline trash data use statistical methods that require an assumption of Normality, including tests such as analysis of variance and repeated measures analyses (Morrison, 1967; Lindsey, 1994).

The estimates and sample size calculations for shoreline trash data also assume that the trash counts are normally distributed. Several published reports are based on these assumptions (Ribic and Johnson, 1990; Ribic and Bledsoe, 1990).

A similar important question is whether the total counts are Poisson instead of Normal. If the distribution of trash along a shoreline is homogeneous the distribution of the number of items collected should follow a Poisson distribution. (For a more comprehensive discussion of Poisson data analysis see reports by Cochran, 1940 and Kingmann, 1995.)

In the current study, data analyses clearly show that the total number of items is not Poisson. A well-known characteristic of the Poisson distribution is that the mean and variance of a Poisson are equal. For these data, the mean number of items collected per mile, per day is 8.3, and the variance is over ten times larger, $S^2 = 111.4$. This is referred to as *over dispersion* and indicates trash clumping patterns. The survey thus

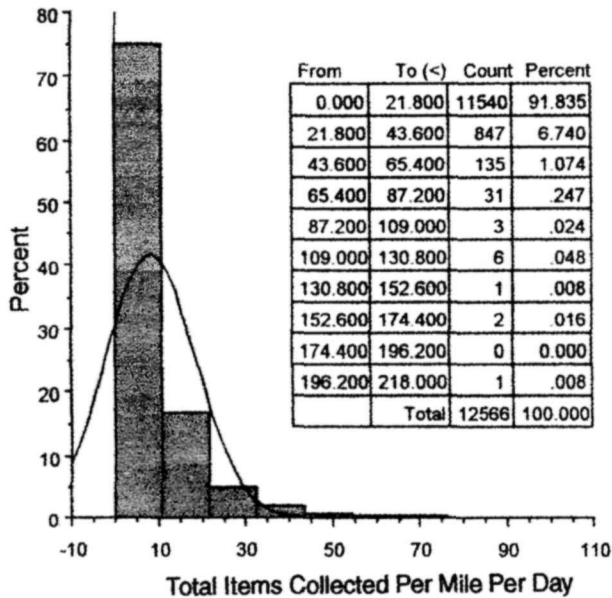


Figure 13. Distribution of total number of trash items per mile per day

indicates the importance of defining a sampling area large enough to provide sufficient accuracy in estimating the total amount of shoreline trash.

In an attempt to find a variable that was more normally distributed for use in the principal component analysis the square root of the number of items per mile was evaluated. The histogram of this variable is more normally distributed but it is still right-skewed (Figure 14 and Table 7).

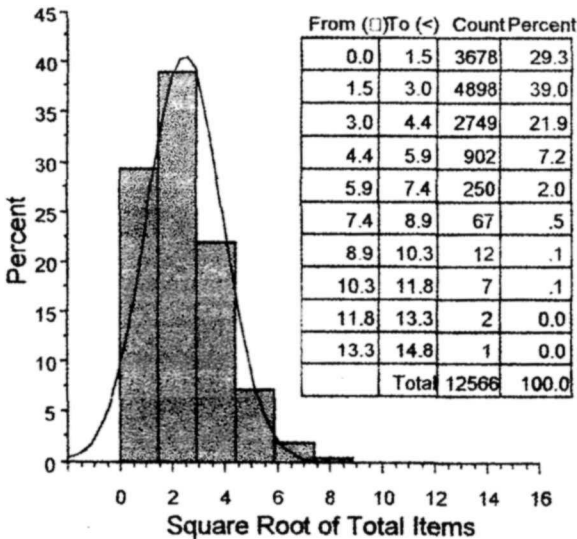


Figure 14. Distribution of square root of total items per mile per day

Table 7. Descriptive statistics for the total number of items collected per mile per day and for the square root of the total number of items

	Total Items	Sqr. Root
Mean	8.26	2.48
Std. Dev.	10.39	1.45
Std. Error	0.09	0.01
Count	12566	12566
Maximum	218	14.76
Variance	107.96	2.11
Coef. Var.	1.25	0.58
Range	218	14.76
Sum	104039	31215.8
Skewness	4.21	1.16
Kurtosis	38.12	2.67
Median	5	2.24
IQR	9	1.9
Mode	1	1
10% Tr. Mean	6.27	2.34
MAD	3	0.82

A comparison conducted between the moments of number of items and the square root of the total confirmed that the square root is more normally distributed with a skewness coefficient of 1.18. Therefore, the remainder of the analysis uses the square root of the total.

Analysis of Item Sampling

Additional important questions include:

1. Can principal component analysis be used to identify natural groupings of collection categories?
2. Are there some item categories that do not provide useful information for estimating the total amount of trash or identifying temporal changes in shoreline trash at Padre Island National Seashore?

The total number of items collected per mile can be represented mathematically using the following equation:

$$Y = X_1 + X_2 + \dots + X_m$$

where m is the number of item categories and X_i is the number of items collected in the i th category. This is a particular linear combination of the number collected in each category. This variable treats every category as equally important. A small piece of styrofoam is counted as equal to a 55-gallon barrel.

A more general form of the equation is:

$$Y = A_1X_1 + A_2X_2 + \dots + A_mX_m$$

A_i is a weighting assigned to X_i . Of course, the weighting can be zero if that variable is unimportant and larger for more important variables. For example, with only three item categories the total number of items would be:

$$Y = \text{Total} = X_1 + X_2 + X_3.$$

Calculating the total number of items in this fashion treats large and small items as equally important. Instead, if calculations were made using an adjusted total, $Y = \text{Total} = 0.3X_1 + 0.1X_2 + 0.6X_3$, the third category is weighted six times higher than the second category and only twice the weighting for the first category.

A statistical method for uncovering these weights is principal component analysis. This method was applied to the standardized square root of individual item totals for each collection date. The principal component method produces several choices for the A_i coefficients. Each choice is referred to as a principal component or as an individual principal component (Morrison, 1967; Harman, 1970; Muliak, 1972).

The principal component analysis produces components that are orthogonal, intersecting or lying at right angles to one another. Essentially, the A_i coefficients, defined by each principal component, are independent of other principal components (Table 8).

Table 8. First five principal components for square root of item totals

Item Category	1 st Principal Component	2 nd Principal Component	3 rd Principal Component	4 th Principal Component	5 th Principal Component
50 gal sodium meta-bisulfate container	0.020	0.009	0.094	-0.028	0.140
1-quart blue bleach container	0.430	-0.152	0.466	0.315	-0.238
Black plastic sheeting	0.220	0.404	-0.143	0.597	0.109
Brush or broom	0.468	0.418	-0.082	0.046	-0.224
Clear plastic sheeting	0.351	0.433	-0.207	0.595	0.048
Egg carton	0.635	0.162	-0.373	-0.176	-0.117
Fish basket	0.242	0.062	0.199	0.051	0.136
Fluorescent light	0.676	-0.297	-0.267	-0.232	-0.090
6-gallon sodium metabisulfate cont.	0.054	0.040	0.180	0.067	0.052
5-gallon container	0.583	-0.223	0.240	-0.102	0.286
55-gallon container	0.149	0.037	-0.159	0.075	0.444
1-quart green bleach container	0.530	-0.213	0.502	0.213	-0.223
Glass condiment bottle	0.798	-0.155	-0.113	-0.244	-0.236
Hard hat	0.580	-0.293	0.162	-0.084	0.055
Incandescent light	0.698	-0.112	-0.316	-0.306	-0.102
Life jacket	0.386	-0.229	-0.266	-0.001	-0.049
1-liter oil container	0.430	0.090	0.533	-0.059	0.139
Muriatic acid container	0.149	0.273	0.291	-0.089	-0.045
1-gallon oil container	0.765	-0.234	0.219	0.111	0.004
1-quart oil container	0.556	-0.339	-0.103	0.145	0.203
Oil or fuel filter	0.343	0.278	-0.165	0.051	-0.132
Onion sack	0.455	0.513	0.245	-0.213	0.049
Wooden pallet	0.407	-0.055	-0.351	0.069	0.263
Paper milk container	0.497	0.128	-0.109	-0.127	-0.290
Pipe thread protector	0.505	-0.055	0.003	0.154	-0.310
Plastic condiment bottle	0.785	0.096	-0.116	0.117	-0.286
Plastic 1-gallon milk container	0.683	-0.317	0.030	-0.034	0.177
Plastic 1/2-gallon milk container	0.560	-0.184	0.172	-0.035	-0.010
Propane or freon container	0.221	0.012	-0.262	0.147	-0.014
Rubber glove	0.444	0.614	0.111	-0.374	0.009
Salt bag	0.414	0.329	0.072	-0.101	0.388
Scoop	0.485	0.304	0.334	-0.195	0.300
Strip lumber piece	0.555	0.120	-0.270	0.090	0.282
Styrofoam buoy	0.328	-0.207	-0.233	-0.032	0.232
Tire	0.200	0.021	-0.068	-0.025	0.295
1-gallon white bleach container	0.648	-0.179	-0.005	0.178	0.137
1-quart white bleach container	0.609	0.055	0.079	0.294	-0.163
Wooden disk	0.217	0.331	-0.099	-0.217	-0.193
Wooden spool	0.204	0.205	-0.057	-0.014	0.046
Write enable ring	0.168	0.031	0.088	-0.009	-0.031

Each component is defined by the weights assigned to each item category. If a weight is close to zero the particular item is not important to that component. If the weight is large (bolded), then the item is important to the component. This defines a grouping of item categories for each component.

The orthogonality of the components ensures that groupings appear together onshore at the same time. This could mean that the items originated from the same source or were transported onshore by the same environmental forces, namely winds or tides.

The following scree plot describes the relative importance of each principal component (Figure 15). The vertical axis on the plot describes the eigenvalue associated with each component. As the eigenvalue of a particular principal component increases more information is captured. An examination of the scree plot indicates that the first principal component captures significantly more information in these data than the remaining components.

Table 9 describes the relationship between the principal components, their eigenvalues, and the percent of total variability of each component. The first component shows 23.1% of the total variability in these data.

The first five principal components as a group describe 43 percent of the total variability in the data. This implies that these first five components capture, or express, 43% of the total information contained in the list of item categories.

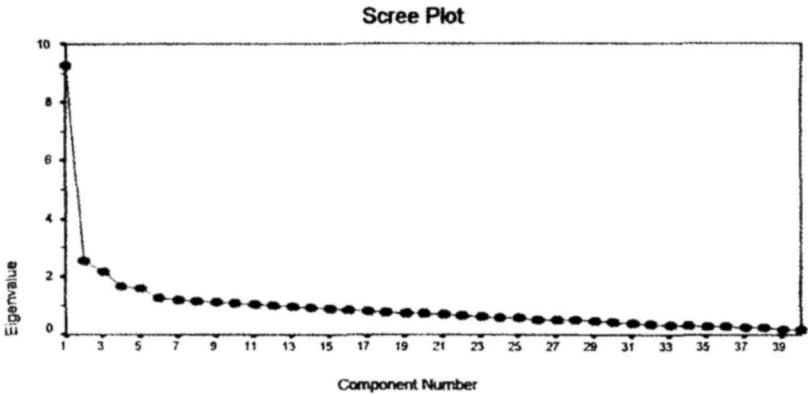


Figure 15. Scree plot of principal components

Table 9. Percent of total variation explained by the first through fifth principal components

Principal Component	Eigenvalue	Percent of Variance	Cumulative Percent Of Variance
1	9.258	23.1%	23.1%
2	2.522	6.3%	29.4%
3	2.174	5.4%	34.9%
4	1.663	4.2%	39.0%
5	1.574	3.9%	43.0%

In table 8 the first principal component identifies 25 of the 40 items as important to describe the information in these data. (Three of the original 43 item categories have been omitted from table 8: plastic strapping; balloons and ribbons; and netting.) These items are identified by the bold-faced values for their components. The larger the coefficient the more impact an item in a particular category will have on the component. The item categories with the largest coefficients are glass condiment bottles with a coefficient of 0.798, plastic condiment bottles with a coefficient of 0.785, 1-gallon oil containers (0.765), incandescent lights (0.698), and plastic 1-gallon milk containers (0.683).

Analysis of Spatial Variation

Analyses of spatial variation indicate that trash clumping occurs along the Padre Island shoreline. The total amount of trash collected per mile is over-dispersed, hence it is not homogeneous. Further, analyses indicate that the shoreline trash data, taken at one-mile intervals, are spatially one-dimensional. Data collected in this manner are called "lattice data" (Whittle, 1954; Besag, 1974; Bennett, 1975).

Researchers evaluated shoreline trash distribution by examining the correlation of trash collected at one of the sites as compared with the others. These correlations address the following questions:

- 1. Can trash collected at one location be used to estimate the total amount of trash along a shoreline?
- 2. How much sample area is necessary to accurately measure the total accumulation of trash?
- 3. What is an appropriate spacing to conduct trash collection?

To address these questions, trash was collected along 16 miles of shoreline and recorded separately during a three-year period. Figure 16 depicts the correlation between each of the 16 sites for the total amount of shoreline trash, excluding fragments and the square root of the total, excluding fragments.

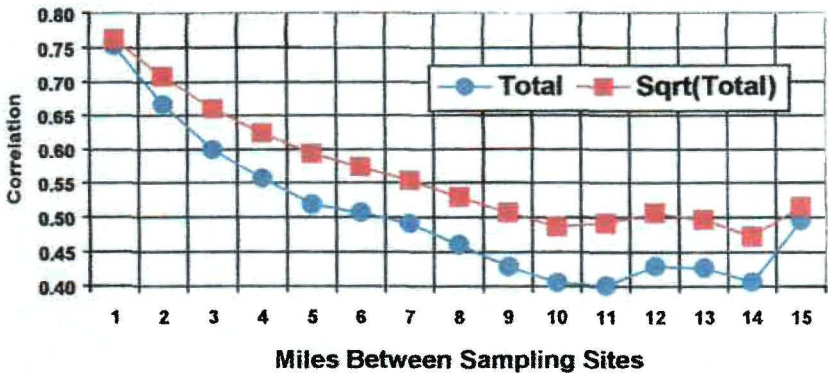


Figure 16. Spatial correlations between sampling locations

Table 10. Correlations of trash items collected at adjacent sites

1st Site	2nd Site	Square Root	Total
2	1	0.8052	0.8234
3	2	0.8064	0.8258
4	3	0.8187	0.8459
5	4	0.7234	0.6727
6	5	0.7769	0.8068
7	6	0.7761	0.7645
8	7	0.7640	0.7403
9	8	0.7400	0.7561
10	9	0.7705	0.7428
11	10	0.7350	0.7074
12	11	0.7382	0.6575
13	12	0.7257	0.6398
14	13	0.7721	0.7806
15	14	0.7131	0.7401
16	15	0.7377	0.7535

Table 11. Correlations of trash items collected at sites with a one-mile separation

1st Site	2nd Site	Square Root	Total
3	1	0.7639	0.7759
4	2	0.7583	0.7382
5	3	0.6902	0.6245
6	4	0.6627	0.5274
7	5	0.7175	0.6772
8	6	0.7163	0.6999
9	7	0.7139	0.6924
10	8	0.7163	0.6695
11	9	0.6798	0.6080
12	10	0.6663	0.5806
13	11	0.6921	0.6085
14	12	0.7077	0.6947
15	13	0.7296	0.7483
16	14	0.6954	0.6871

Table 12. Correlations of trash items collected at sites with a two-mile separation

1st Site	2nd Site	Square Root	Total
4	1	0.7123	0.7039
5	2	0.6763	0.6036
6	3	0.6578	0.5519
7	4	0.6391	0.4887
8	5	0.6560	0.6244
9	6	0.6472	0.6091
10	7	0.7010	0.6403
11	8	0.6670	0.6016
12	9	0.6215	0.5441
13	10	0.6342	0.5586
14	11	0.6417	0.5731
15	12	0.6362	0.6127
16	13	0.6870	0.6808

Table 13. Correlations of trash items at sites with an eight to ten mile separation

1st Site	2nd Site	Site Separation	Square Root	Total
10	1	8 miles	0.5454	0.4750
11	2	8 miles	0.5186	0.4544
12	3	8 miles	0.5242	0.3774
13	4	8 miles	0.5077	0.4247
14	5	8 miles	0.4672	0.4060
15	6	8 miles	0.4449	0.3769
16	7	8 miles	0.5283	0.4803
11	1	9 miles	0.5101	0.4435
12	2	9 miles	0.4906	0.3279
13	3	9 miles	0.4921	0.4115
14	4	9 miles	0.4720	0.4117
15	5	9 miles	0.4374	0.3731
16	6	9 miles	0.5108	0.4691

To prepare Figure 16, correlations were examined individually for the 16 sites. Table 10 lists the correlations between adjacent sites for each of the four key variables used to evaluate temporal changes in trash.

Analyses indicated that the correlations between adjacent sites were approximately the same without regard for which sites were examined or their distances apart. Because of this similarity the modeling of these data was greatly simplified. This allowed for one area of the shoreline to be averaged with those calculated from another area. This similarity suggests that the mechanisms, sources, and environmental principal components that cause the trash to deposit on the shore are equal from one site to another (Tables 11-13).

Somewhere between the seven and ten mile sites the correlations appear to plateau (Table 14). Table 14 provides the average correlation of site separation.

Table 14. Average correlation (R) between shoreline trash item samples vs. separation in miles (M), demonstrating the plateau effect

M	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
R	.76	.71	.66	.62	.59	.57	.55	.53	.51	.49	.49	.51	.50	.47	.51

Figure 17, a graph of the correlations for each of the four variables, indicates that the correlation between sampling locations falls rapidly and plateaus at approximately the ninth mile. This suggests that optimum sample spacing would be every seven to ten miles.

These findings underscore the importance of considering both the frequency and the spacing of samples when designing shoreline trash surveys. The plateaus encountered at approximately nine miles, with a correlation of 0.49, illustrate the importance of considering both the frequency and spacing of samples (Table 14).

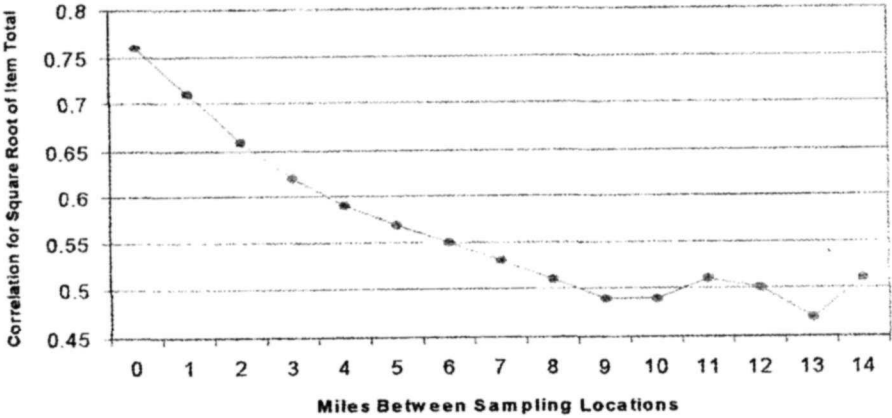


Figure 17. Average correlation vs. sampling distance (miles)

When conducting a trash shoreline survey, a decision must be made in the planning stages as to whether to sample at greater frequency or survey a larger area. Data collected and analyzed in the current research established that the spatial correlation is high, even for widely spaced survey areas, a minimum of 0.45 for all the variables. Therefore, surveys should be designed to collect data more frequently rather than to sample a larger area.

This study indicates that data can also be modeled using standard time series methods. Distance between sites can be viewed as a time series and the correlations can be considered an autocorrelation among samples collected on the same day.

Analysis of Temporal Variation

Time series analysis can be used to develop a model of how trash items vary over time. Because spatial variation is initially high (approximately 0.7, reaching a plateau around seven to nine miles), it is useful to evaluate the temporal variation and compare autocorrelations of items collected on different days, using the square root of the total to develop a model of the time series for each of the 16 sample locations. While most shoreline trash surveys are conducted infrequently and within a small sample area, the 1994-98 Padre Island National Seashore survey was conducted daily over a 16-mile area, making analyses and modeling of temporal variation possible.

These data allow for analyses of the following questions:

1. What is the temporal model for each of the 16 sites?
2. Does this model vary for different sites?
3. What are the implications of this model for the design of an optimum shoreline trash survey?

The development of a model for the temporal distribution of trash items will determine whether the deposition of items upon the shoreline is uniform over time or seasonal. The answer is dependent upon the variable selected to model. Therefore, it is important to determine whether temporal or spatial variation is larger before conducting a trash survey. If temporal variation is larger than spatial variation in the number of trash items collected, it would be more important to sample frequently and to sample fewer locations. Conversely, if the spatial variation is higher, then the survey should be designed to sample many locations less frequently.

A model based on ARIMA time series was developed to analyze temporal correlations in the Padre Island National Seashore data (Box and Jenkins, 1970; and Christensen, 1991). However, missing data and unequal sampling intervals complicated the application of this method to Padre Island data. While trash items were usually collected on a daily basis, at times environmental factors prevented sampling. Because most statistical software for the analysis of times series does not allow for gaps, it was necessary to develop new approaches for evaluating temporal correlation of the Padre Island data. These new approaches were developed by individually calculating the lags for each of the 16 sampling locations, taking care to account for data gaps, then calculating the autocorrelations for each lag separately.

An examination of the autocorrelations revealed that the temporal model does not seem to vary among the 16 locations (Figure 18). The average autocorrelation for every lag was calculated by weighting the autocorrelations at each location by the number of observations at that location.

Analysis of Figure 18 indicates three significant findings.

1. The first order autocorrelation is only 0.46, which is much less than the first order spatial autocorrelation of 0.76. This suggests that temporal variation is much smaller than spatial variation along the Padre Island National Sea-shore shoreline.
2. The temporal autocorrelation function disappears rapidly. At eight days the autocorrelation drops to nearly zero; it then rises slightly and falls again to zero. This pattern is the noted signature for an autocorrelation function of an autoregressive time series. Examination of the partial autocorrelations is necessary to determine the order of the autoregressive time series. This order is then used to determine the number of previous days needed to predict the amount of trash expected for future days.
3. At 30 days lag and greater the autocorrelation is essentially zero. This implies that data collected on one particular day are poor predictors of the amount of trash that will wash ashore the following month. Furthermore, the same holds true for any prediction of trash accumulation beyond a week.

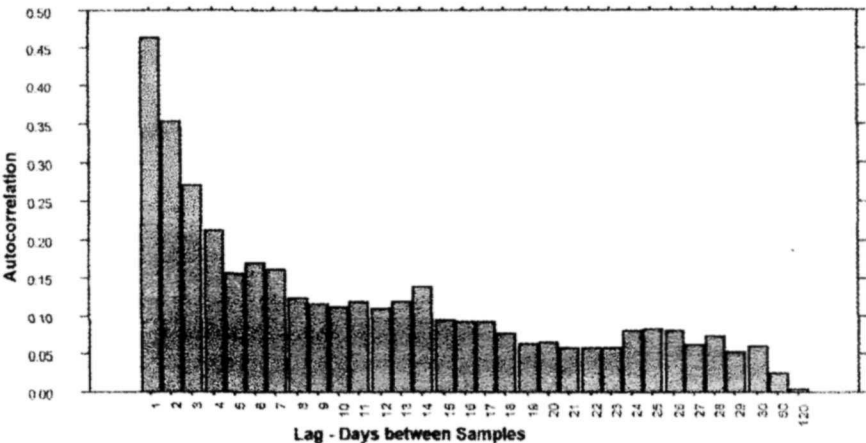


Figure 18. Autocorrelation vs. days between sampling

The partial autocorrelation function was calculated to identify the order of the autoregressive times series (Figure 19). The partial autocorrelation appears to decrease rapidly after the first lag. However, the presence of higher correlations at lags 14 and 20 might suggest that the temporal model is more complicated than a simple autoregressive time series. A consideration of Figure 19 in its entirety, however, suggests that the temporal distribution of trash items can be represented using a first order autoregressive process:

$$Y_t = \mu + \phi Y_{t-1} + \varepsilon_t$$

This formula is explained as follows: Y_t is the square root of the total number of items collected on day t ; μ is the long-term average of the square root or the total; ε_t is the noise added to the observation at time t ; and ϕ is the parameter for the first order autoregressive process. For a first order autoregressive process, a good estimate for the parameter is the first order autocorrelation. Hence these data yield the following temporal model:

$$Y_t = \mu + 0.46Y_{t-1} + \varepsilon_t$$

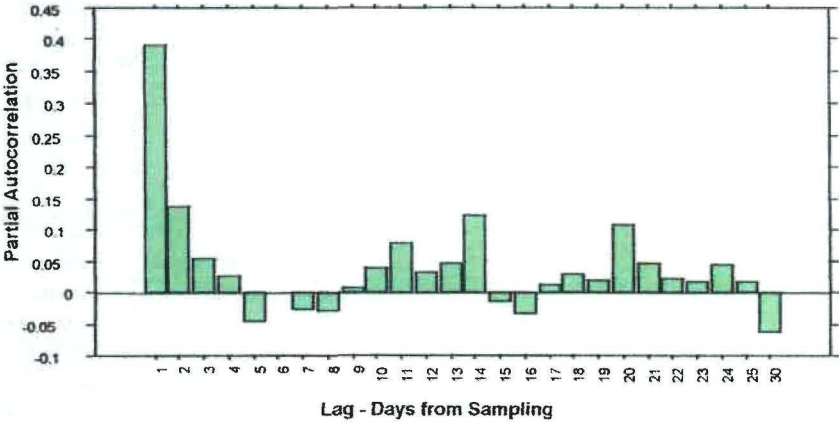


Figure 19. Partial autocorrelation vs. days between sampling

Analysis of Seasonal Variation

Figures 20 and 21 show that the amount of shoreline trash at Padre Island National Seashore varies greatly from month to month. Note that no data were collected in June 1997. From these figures the amount of trash appears to have two peaks between the years 1994-1998. The first peak is in the months of April and May, probably corresponding to the spring tides. The second peak occurs in the fall. In 1995 and 1997, the fall peak occurred in August-September and in 1994 it occurred in September-November. The period with the least amount of trash on the shoreline appears to be December-February and June-July.

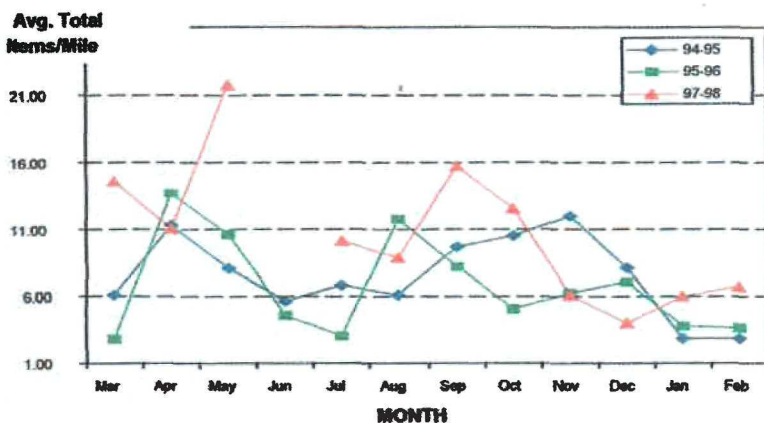


Figure 20. Plot of the average total of trash items collected per day/per mile

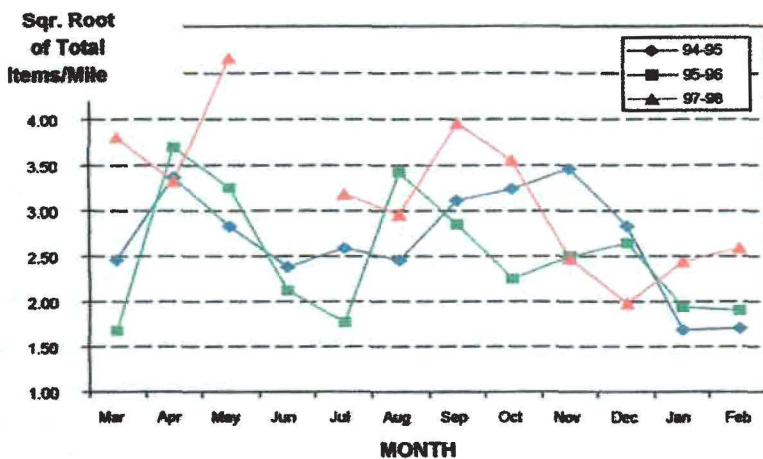


Figure 21. Plot of square root of total trash items collected per month/per mile

POINT SOURCE INVESTIGATIONS

Determining origin of shoreline trash has been difficult. One research report concluded that "75-90 percent of shoreline trash originates from commercial vessels and the offshore marine industry, while the remaining 10-25 percent is deposited by visitors" (Center for Marine Conservation, 1987). Another study found that "most of the trash found on Gulf States' shorelines is traceable to offshore sources" (American Management Systems, Inc., 1991). Still another report concluded, "commercial fishermen generate shoreline trash that is probably the most easily identified and the most obvious, particularly in Alabama, Louisiana, and Texas" and "galley wastes consistently have been a major source of shoreline trash in the Gulf" (Center for Marine Conservation, 1990).

Other researchers disagree, maintaining that tracking trash items to a specific source is speculative at best (Reggio, 1985). One report states “[t]he exact source of most marine debris is difficult to determine. Few items can be accurately traced to a specific source except for commercial fishing gear, offshore oil platforms, or cruise ship industry” (Ribic *et al.*, 1997). Another maintains that, “approximately 80 percent of ocean trash is deposited from onshore, not offshore sources” (Faris and Hart, 1995; National Oceanic and Atmospheric Administration, 1996).

In many instances trash items are industry or user-specific. For example, mooring buoys and hard hats can usually be traced to the offshore petroleum industry, while shrimp netting can be traced to gulf shrimping (Photo 16). On the other hand, identifying point sources for some trash items can be difficult to impossible because they may have washed into the water from land-based sources, such as city storm drains or may derive from beach visitors, pleasure boats, commercial fishing boats, or petroleum platforms.

In late July 1992, many miles of Padre Island beach became littered with large amounts of trash. This quantity of trash was unusual because typically only a storm could have generated the amount that had washed ashore. However, it had been several months since the last storm at the national seashore. The newly deposited trash not only included hundreds of individual trash items but also numerous trash-filled onion sacks and salt bags (Photos 17-18). Several shrimping trawlers were nearby, working adjacent to Padre Island (Photo 19).



Photos 16-19. Top to bottom: Hard hat; Trash-filled onion sack; Trash-filled salt bag washing ashore; Shrimp trawler adjacent to Padre Island shoreline

All the items were unweathered and thus appeared to have been recently discarded. (When exposed to sun and saltwater, color quickly fades, fabric rots, plastics become brittle, and metal rusts rapidly.) As an example, photograph 20 shows an onion sack washed onto the shoreline with the incoming high tide. Within just a few days the onion sack's color faded and was beginning to disintegrate (Photo 21). Several days later the onion sack was completely bleached of color.

A survey of the types of trash items littering the shoreline revealed that a significant percentage was characteristic of galley wastes, such as bacon wrappers, milk and juice containers, coffee jars, egg cartons, bread wrappers, meat packages, soft drink cans, glass and plastic condiment bottles for ketchup, mustard, peanut butter, and other similar items. The trash also included numerous rubber gloves, onion sacks, salt bags, light bulbs, oil filters, white bleach bottles, and round wooden disks. Moreover, the onion sacks and salt bags contained trash identical to the individual types of items that had washed ashore at the same time (Photo 22).

The round wooden disks are devices that Gulf shrimpers attach to their nets to prevent them from snagging on the sea floor (Photo 22). Because these disks are used exclusively by Gulf shrimpers, other types of trash found within the onion sacks and salt bags were probably also discarded by the shrimpers (Photos 24-25).

Salt bags, rubber gloves, and onion sacks are other items used in the Gulf Coast region by the shrimping industry. Photograph 26 depicts a salt bag that is used in the industry to separate shrimp from undesirable by-catch. Rubber gloves are used



Photos 20-23. Clockwise from left: Onion sack washed ashore; Sack deteriorating and color fading; Onion sack containing galley wastes; Wooden disks, rubber glove, and onion sack found within another onion sack



Photos 24,25. Trash found in discarded onion sacks and salt bags; Besides gally wastes, trash items included rubber gloves, light bulbs, oil filters, and bleach bottles.

by shrimp trawler crewmen to protect their hands while processing the catch. Because of the connection between these items and their uses by the shrimping industry, wooden disks, salt bags, rubber gloves and onion sacks, were considered to be point source items.

These observations led to an additional trash monitoring study the following year, one designed to supplement the other ongoing daily and quarterly trash surveys.

1993 Point Source Investigation

Even though hundreds of trash items had washed ashore from the atypical 1992 event, very few of the items washed into the daily or quarterly survey plots, demonstrating that the 50 x 100-meter survey plots were too small to evaluate trash accumulation rates or composition. The new trash monitoring study would need a survey of the high-tide line over a continuous eight-mile-long section of shoreline.

In addition to the four point source items – wooden disks, salt bags, rubber gloves and onion sacks, six common trash items exhibited a strong relationship to the shrimping industry: egg cartons, light bulbs, one-gallon plastic milk jugs, oil filters, condiment containers, and white bleach bottles. Each of the ten items washed ashore in the same condition and location as the trash-filled onion sacks and salt bags. These ten items were placed into two categories: probable and suspected. The “probable” category included seven items: onion sacks and salt bags, and the most numerous items found within them – rubber gloves, wooden disks, egg cartons, light bulbs, and one-gallon plastic milk jugs. The three suspected items, oil filters, condiment containers, and white bleach bottles, were also found within the onion sacks and salt bags but to a lesser degree than the other probable items.



Photo 26. Salt bag with shrimp trawler logo

The new survey was initiated on a daily, five days per week interval, beginning July 1, 1993, one week before the opening of the Gulf shrimp harvest season, and continu-

ing until August 8, 1993, when the Gulf shrimp trawlers moved away from the Padre Island shoreline. Each day for a week prior to the opening of the 1993 shrimp season surveyors removed all identifiable trash items from the survey area. Beginning with a clean, trash-free shoreline, surveyors collected the data daily on the numbers of probable and suspected items that washed ashore over the eight-mile survey plot. Almost immediately upon the opening of the shrimp harvest season the trash, both filled sacks and individual items, washed ashore. During this survey a total of 5,411 trash items from the two categories were recorded. Of the 5,411 items, 2,489 items were from the "probable" category and 2,922 were from the "suspected" category.

Figure 22 describes fluctuations in the temporal patterns of trash accumulation for both probable and suspected categories. This indicated a high probability that both categories were discarded by the same source, Gulf shrimpers.

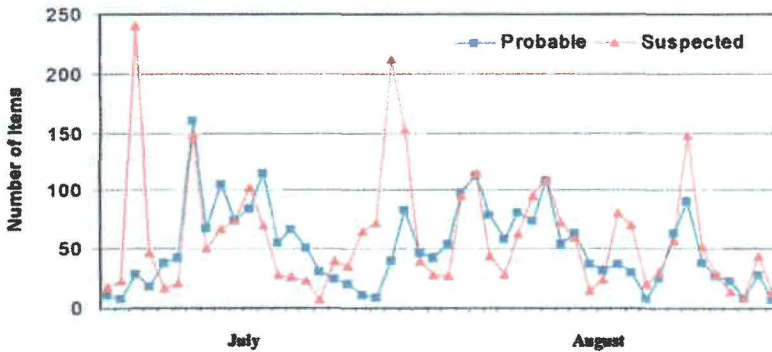


Figure 22. Daily variability of ten trash items for July-August 1993

Although the 1993 Point Source Investigation data were convincing, they could only be viewed as conjectural because a statistical correlation between trash accumulation and Gulf shrimping had not been scientifically tested. Nonetheless, the investigation did prove to be invaluable to park staff, who now had an understanding of the temporal and spatial survey requirements needed to obtain a statistical correlation. Armed with this information, they began a second point source investigation on March 1, 1994.

1994-1998 Point Source Investigation

The 1994-98 Point Source Investigation was initiated to collect data on probable point source polluters. The investigation specifically focused on two potential sources, Gulf shrimping and the offshore petroleum industry. Items were selected based on prior field investigations.

Gulf Shrimping Industry

By analyzing the 1992 data and the 1993 Point Source Investigation, park staff had concluded by 1994 that the ten identified items were consistently discarded by one source, Gulf shrimpers. This conclusion was corroborated when trash discovered aboard an abandoned shrimp trawler was found to be identical with that contained in the trash-



Photos 27, 28. Trash items on shrimp trawler; Close-up of point source items found on shrimp trawler

filled onion sacks and salt bags (Photos 27 and 28). For the remainder of this report the ten identified items will be referred to as point source items.

From 1994 -1998, a total of 104,643 individual trash items, excluding fragments, were counted. A total of 69,965 items were from the ten point source items, representing 66.9 percent of the trash items counted (Table 15). Four out of the ten point source items represented over 52,000 individual trash items—13,000 one-gallon milk jugs, 19,000 rubber gloves, 13,000 condiment containers, and 7,600 incandescent light bulbs.

Data analysis also indicated that 11 other kinds of trash items could be associated with Gulf shrimping (Table 16). The statistical components analysis test verified that for the entire three-year survey period, these items washed ashore at the same times

Table 15. Number of point source items collected from 1994-98

POINT SOURCE ITEM	1994-95	1995-96	1997-98	TOTAL
Rubber gloves	6517	5132	7575	19224
Onion sacks	1922	1479	1901	5302
Salt bags	769	860	826	2455
Wooden disks	45	24	97	166
Egg cartons	1407	786	2154	4347
Incandescent lights	2506	2578	2571	7655
Condiment containers	4617	2647	6402	13666
1-gallon milk containers	4938	5296	3636	13870
White bleach bottles	744	830	1426	3000
Oil filters	66	58	156	280
TOTAL	23,531	19,690	26,834	69,965

Table 16. Number of trash items recorded as new or suspected point source items between 1994-98

NEW ITEMS	1994-95	1995-96	1997-98	TOTAL
Fish basket	26	27	34	87
Shrimp scoop	1971	582	1015	3568
Sodium metabisulfate	7	8	4	19
½-gallon milk jug	256	235	206	697
Paper milk container	214	222	405	841
Florescent light bulb	978	942	708	2628
Quart oil container	1610	1096	1135	3841
1-liter oil container	850	906	391	2147
1-gallon oil container	284	242	208	734
TOTAL	6196	4260	4106	14562
SUSPECTED ITEMS				
Green bleach bottle	3299	1927	1452	6678
Blue bleach bottle	295	177	191	663
TOTAL	3594	2104	1643	7341

and locations and in the same condition as the ten point source items. Gulf shrimpers are the primary users of three of the 11 items: shrimp scoops, fish baskets, and sodium metabisulfate. These 11 items were not initially counted as trash linked to the shrimping industry because the items had not been found inside onion sacks or salt bags, as had the ten original identified trash items.

Shrimp scoops are typically fashioned from one-gallon plastic milk containers and are used to scoop shrimp from a trawler's deck into fish baskets or other containers (Photo 29 and 30), which are subsequently used to transport shrimp into a trawler's



Photo 29, 30.
Shrimp scoop;
Fish basket

holding compartment. Sodium metabisulfate is dissolved in water and then used to clean the shrimp.

Five other items—half-gallon plastic and paper milk containers, green and blue bleach bottles, and florescent light bulbs—, were found to be subsets of three point source items. After principal component analysis, half-gallon plastic and paper milk containers were added to the Milk Container category. Similarly, florescent light bulbs were added to the Light Bulb category.

As for the green and the blue bleach bottles, because of the Spanish labeling, many Gulf shrimpers have maintained that Mexican, not U.S. shrimpers, are responsible for discarding the bottles. Although these two items have been included in the category *Bleach container*, they have been separated and placed in the “suspected” point source category for later discussion. The *Oil container* category includes oil containers ranging in size from one quart to one gallon, and is not a subset of the ten point source items.

Table 16 depicts the number of the eleven additional categories of trash items counted during the survey. A total of 14,562 trash items were recorded for the nine new point source items, while 7,341 bleach bottles were recorded from the suspected category. Excluding the controversial blue and green bleach bottles, a total of 81% of the trash collected during the survey period was significantly correlated to Gulf shrimping activities.

Analysis of Trash Accumulation Versus Shrimping

Data from the National Marine Fisheries Service (NMFS) helped quantify the relationship between Gulf shrimping and trash accumulation. NMFS has divided the Gulf of Mexico into individual zones and collects statistical data on a monthly basis on the number of shrimp trawlers operating within each zone. Zones 18-21 occur off the Texas coast (Figure 23).

During the 1994-98 study period, researchers worked with shrimp harvest data for Zone 20, the zone adjacent to Padre Island National Seashore's 16-mile long

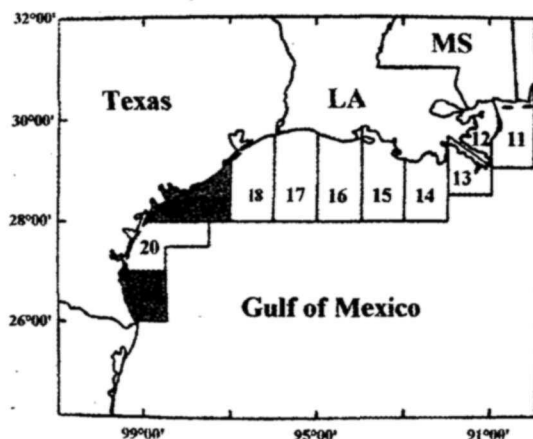


Figure 23. Shrimp harvest zones

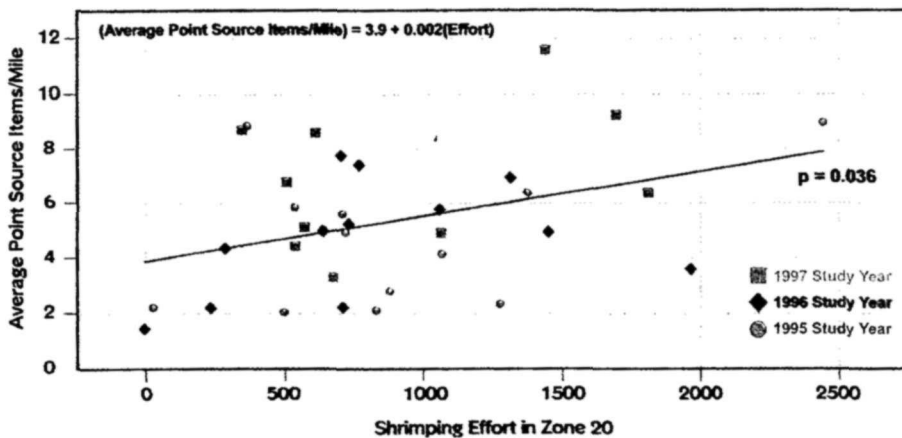


Figure 24. Plot of Gulf shrimp harvest effort vs. point source items per day per mile

survey plot. These were statistically analyzed with trash accumulation data for the ten point source items to determine the Pearson's correlation coefficient for shrimping effort versus number of point source items (Figure 24). The Pearson's correlation coefficient was found to be statistically significant ($p = 0.036$), demonstrating that with increased shrimping there is a significant increase of trash accumulation along the adjacent shoreline.

Analysis of Trash Accumulation Vs Duration of Shrimping Season

Researchers then attempted to quantify the relationship between trash accumulation and shrimping, using the dates in which the shrimp season annually opens and closes as provided by the Texas Parks and Wildlife Department and NMFS. These dates for the 1994-97 shrimp seasons are shown in Table 17.

Table 17. Dates of Spring/Winter shrimp harvest season 1994, 1995, and 1997

Season	1994	1995	1997
Opened	Feb. 1	Feb. 1	Feb. 1
Closed	May 13	May 15	May 15
Opened	July 7	July 15	July 15
Closed	Dec. 16	Dec. 16	Dec. 16

Figure 25 depicts the relationship between the accumulation of the original ten point source trash items and the annual Gulf shrimping season. Note no sampling was conducted during June 1997. Analyses of the graph and related statistics clearly indicate that the total number of recorded trash items peaks during the spring and winter shrimp harvest seasons and drops rapidly to nearly zero when the seasons are closed.

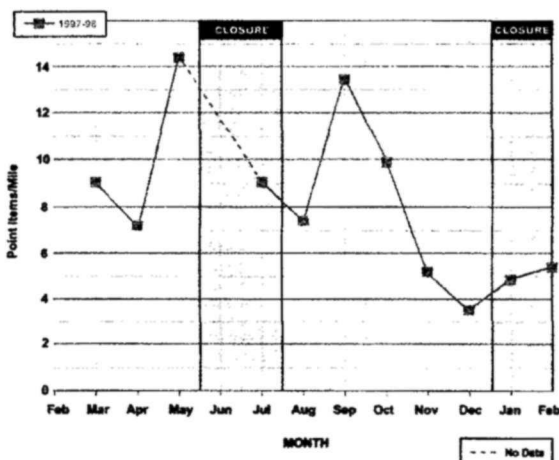
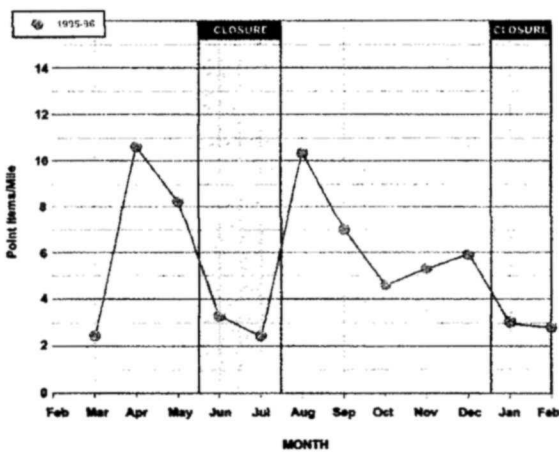
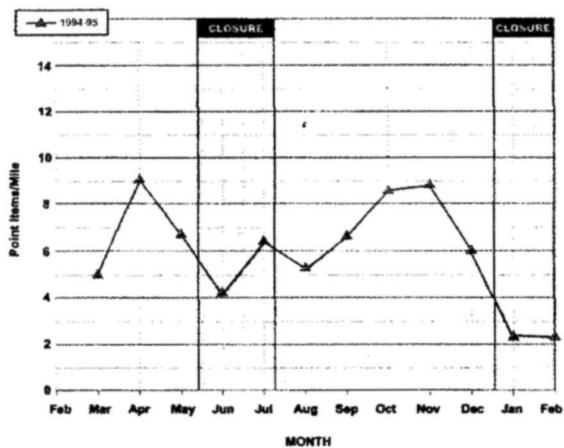


Figure 25. Seasonal variation of ten suspected Gulf shrimp industry point source items

Offshore Petroleum Industry

In 1990, ARCO Oil and Gas Company conducted a marine trash survey to assess its compliance with MARPOL Annex V. The survey identified nine items that were reported to be associated with the offshore petroleum industry (Table 18). As a result of this item selection, park staff chose these same nine items for the 1994-98 Point Source Investigation. To ensure that these items were indeed representative of the petroleum industry, park staff obtained endorsement from both Minerals Management Service and the Offshore Operators Committee (inclusive of the major oil and gas companies operating in the Gulf of Mexico).

A total of 10,565 point source items were collected between 1994-98, representing 10.01 percent of all trash collected (Table 19).

Table 18. Offshore petroleum industry items

Offshore Petroleum Industry	
Item	Use
Strip lumber	Stripping over pipe or equipment
Plastic sheeting	Weatherproofing material used during transportation and storage
Wooden pallet	Transporting chemicals and equipment
Wooden spool	Transporting wire, rope and electrical wire
Hard hat	Personal protective equipment for platform personnel
Write enable ring	Storing platform information
Pipe thread protector	Protection of drilling pipes
Styrofoam buoy	Marking underground pipelines and equipment

Table 19. Offshore petroleum industry shoreline trash

ITEM	1994-95	1995-96	1997-98	TOTAL
Hard hat	240	243	169	652
Pipe thread protector	152	63	329	544
Write enable ring	3	13	21	37
Wooden spool	13	7	29	49
Styrofoam buoy	124	142	109	375
Strip lumber	2875	1026	3771	7672
Wooden pallet	112	106	114	332
Plastic sheeting	148	37	719	904
TOTAL	3667	1637	5261	10565

Distribution of Point Source Trash

Figure 26 depicts the relationship between the point source categories and the total trash items counted. It includes an Unknown Source category whose total percentage is representative of items that could not be statistically related to any point source.

Many people who live in the Gulf of Mexico region believe that the majority of trash occurring on local beaches originates in Mexico. This study, however, found that only 11 percent of the non-fragment items had non-English labels and, of these, only a small percentage of the labels were in Spanish.

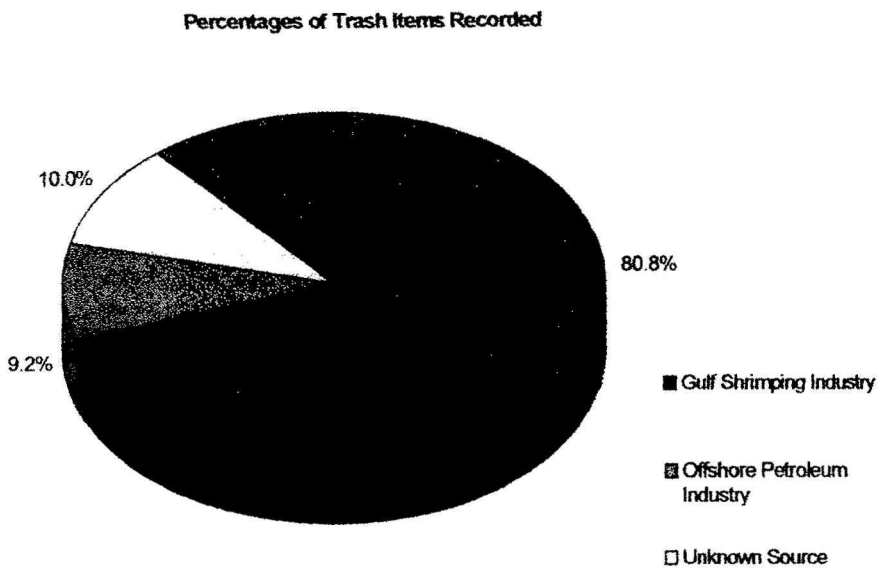


Figure 26. Percentages of recorded trash items

CONCLUSIONS, FINDINGS, AND FURTHER RECOMMENDATIONS

Conclusions

- The shrimping industry is the source of the majority of 43 item categories of shoreline trash at Padre Island National Seashore. The amount of shoreline trash is significantly correlated with both the shrimp harvest and the opening and closing of the shrimp harvest season. Further work should be done to estimate the total impact of the Gulf shrimp harvest industry on shoreline trash here and elsewhere.
- MARPOL V regulations, governing the discharge of plastics, have not reduced the amount of plastics that wash ashore at Padre Island National Seashore. Despite the MARPOL treaty and enforcement by the U.S. Coast Guard, trash statistically identified as galley and shipborne wastes continues to wash onto the Padre Island National Seashore shoreline in large quantities. Table 20 shows that the number of identifiable items collected *increased* overall from 1994-98.

Table 20. Average number of identifiable items collected per mile 1994-98

Study Year	Number of Miles Surveyed	Number of Survey Days	Average Number of Non-Fragment Items per Mile
3/94-3/95	4893	355	7.69
3/95-3/96	3918	302	7.26
3/97-3/98	3763	300	10.25

Methodological Findings

- Quarterly surveys do not accurately depict trash accumulation or composition. To obtain the data essential for comprehensive statistical analysis more frequent sampling is required.
- Small-sized survey plots do not accurately depict the trash accumulation or composition that is representative of a larger beach area. To obtain quantifiable data, survey areas should be large enough to provide a statistical understanding of trash accumulation and composition rates.
- Fragments should not be included in item counts in shoreline surveys. Fragments can misleadingly dominate survey data, and including them with other categories completely masks the information contained in these other categories and contributes substantially to the high day-to-day variability of item totals.

- Backshore zone data should not be combined with data collected in the foreshore zone because winds and tides affect these areas differently. The backshore zone is a repository for trash that may be transported into the foreshore zone. Shoreline surveyors should be careful to distinguish data collected in the backshore zone from that collected in the foreshore zone. Data from the foreshore zone are likely to be cumulative and only reflect trash recently transported into that area from winds or tides, while the backshore zone contains items that may have been deposited prior to the sampling date.
- Wind direction, wind velocity, and tidal heights should be recorded and considered in estimating the average amount of trash washing ashore. Counting and removing items visible on the surface of the backshore zone does not account for items buried beneath the sand. Subsequent storms and high tides, combined with offshore winds, may still transport trash from the backshore zone into the foreshore zone.

Statistical Findings

- The Padre Island National Seashore data are very different from data used by others to develop recommendations for sampling shoreline trash. Padre Island data are not normally distributed and appear to be hyper-Poisson because the variance in these trash counts is ten times larger than the average. Sampling calculations and other statistical tests that rely on the assumption of normality should not be applied to the number of trash items collected. If these data are modeled, a distribution that properly models over dispersion should be used. The square root of the number of trash items collected yields an approximation.
- Temporal variation in these data is very high and is much higher than the spatial variation. A time series analysis suggests that data collected on a single shoreline is a first-order autoregressive process:

$$Y_t = \mu + 0.46Y_{t-1} + \epsilon_t$$

where Y_t is the square root of the amount of trash measured at t , which equals time; μ is the long-term average of the square root of the number of trash items; and, ϵ_t is noise. During this period, μ was approximately 2.9.

- Analysis of temporal variation also suggests that the sampling frequency should be weekly because the correlation between days is high, at about 0.46, and quickly drops to nearly zero at five to seven days.
- More modeling of these data, using techniques similar to those described by Whittle (1954), Bennett (1975) and Ali (1979), is needed to account for hyper-dispersion and spatial-temporal variation.

- Spatial correlation appears to be larger than temporal correlation. That is, consecutive days have a smaller correlation than adjacent sampling sites. However, the correlation between consecutive days is high. From analysis of the spatial correlation it appears it is also a 1st order autoregressive process. Moreover, the optimum spacing of sampling sites at Padre Island National Seashore should be seven to ten miles apart because the spatial correlation appears to plateau at that distance.

Further Recommendations for Shoreline Trash Studies

- Additional studies should be undertaken to quantify the impact of shrimping on shoreline trash accumulation along the Gulf coast. The principal component analysis can be used to identify point source items and obtain a better estimate of the impact the industry has on shoreline trash accumulation.
- Efforts should be expanded to identify additional point sources using a combined methodology of principal component analysis and monitoring beach trash, environmental factors, and human activities
- Long-term programs should provide for continuous monitoring of beach trash in specific areas. Survey areas need to be accessible to survey crews. They should be located in areas of low wave impact and with higher than normal trash accumulation.
- Quality assurance programs should be implemented for all surveys.
- Survey personnel should be informed of specific criteria for items versus fragments.
- Crews should be supervised and trained in the collection and identification of beach trash.
- Survey plots should be periodically reviewed to assure that trash is being removed and that the items are correctly categorized.
- Trash should be recounted frequently to guarantee the accuracy of database entry.
- Trash items being counted should be removed from the survey area to prevent recounting.
- Researchers should be flexible in the types of trash items they collect, since certain items reflect a seasonal trend that might otherwise be overlooked.
- The strategy used by the offshore petroleum industry to reduce the amount of trash being discarded from the Gulf platforms—that of inventorying all

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