INTRODUCTION

One of the priority problems identified by the Galveston Bay National Estuary Program is the abundance and impact of floating, submerged and shoreline debris on the Galveston Bay Estuary. The purpose of this study was to compile debris data to determine the magnitude and distribution of debris and to evaluate the possible sources and effects of these materials in the Galveston Estuary.

No previous surveys of debris have been done for the whole Galveston Bay Estuary. Therefore, the extent and severity of debris as a problem for the Galveston Bay Estuary has not been characterized. Two surveys of floating debris were undertaken by the Environmental Protection Agency (EPA) in the Houston Ship Channel as part of the Harbor Studies Program. Plastic, especially plastic pellets, was the most frequently encountered material. A total of 475,209 and 225,135 plastic pellets were collected by the EPA in the two Houston surveys (United States Environmental Protection Agency, 1992). At one location, an explosion at a Phillips 66 plastics plant one month prior to sampling may have contributed to the large number of plastic pellets sighted. It is interesting to note that Houston has one of the greatest concentrations of plastics industries in the United States and several plants are located along or near the channel (United States Environmental Protection Agency, 1992). The combination of population density, manufacturing capability, shipping and recreation occurring within this area provides the potential for debris to be a serious problem.

SAMPLING METHODS

Data for this study was collected between June 1, 1992 and September 30, 1992. Sample sites were selected randomly throughout the estuary so as not to bias the estimates of debris in the estuary. Shoreline sites sampled by volunteers were based on random bag seine sample locations done by the Texas Parks and Wildlife Coastal Fisheries monitoring program in 1991.

In shoreline samples, citizens were asked to sample 100 feet of shoreline at a given location. All debris material located between the waters edge and the high tide mark for the site was counted and recorded. The high tide mark was determined by a drift line of material more or less paralleling the shore. Approximate widths of the sampling area were recorded along with weather conditions, wind speed and direction. In addition, citizens were asked to record any toxic materials seen in the sample area, as well as any other information they felt was helpful regarding sources, etc. Areas were then often cleaned of debris. A total of 37 samples were collected by volunteer citizens groups during this time.

In addition, the Texas Parks and Wildlife Department (TPWD) staff recorded debris items found in samples during their regular bag seine and trawl fisheries monitoring program. Details of the fisheries monitoring procedures are described in the TPWD Marine Resource

Monitoring Operations Manual (Texas Parks and Wildlife Department, 1991), which is updated annually.

Debris caught in bag seine samples were used to characterize the shallow nearshore environment. Bag seines were 18.3 m long and 1.8 m deep, with a 19 mm stretched nylon #5 multifilament mesh wing (8.3 m long) and a 13 mm stretched nylon #5 multifilament mesh bag. The bag seine was pulled parallel to the shoreline for a distance of 30 m. The area covered by each bag seine sample was 0.03 hectare. A total of 80 bag seine samples (20 per month) was collected.

Trawl nets were used to characterize the deeper submerged environment in the estuary. Trawls were flat otter trawls, 6.1 m wide with 38 mm stretched #9 nylon multifilament thread. Samples were done by pulling the net along the bay bottom at a speed of approximated 5-6 km/hr in a circular pattern for 10 minutes. Area covered by trawl samples was approximately 0.47 hectares. A total of 104 trawl samples (six per month in the intracoastal waterway (ICWW) and 20 per month in the remaining parts of Galveston Bay Estuary) was collected.

In addition, six transects to characterize floating debris were done in August of 1992 by TPWD staff. Transect locations were random with two transects each in West Bay, East Bay and the central part of Galveston Bay. Observations of floating items located within 25 feet of either side of the boat were recorded.

All data were recorded on beach cleanup data sheets designed by the Center for Marine Conservation (CMC).

STATISTICAL ANALYSIS PROCEDURES

Debris items were classified as to major category and analyzed to determine the percentage composition of the debris in each environment in the bay. These environments were shoreline, nearshore, submerged and floating. Data were not pooled, but were analyzed for each environment separately. Major categories included: plastics, styrofoam, glass, rubber, metal, paper, wood, cloth and construction/industrial. The construction/industrial category, which was not originally present on the beach cleanup sheets, was added during compilation because items such as shingles, tar, bricks, etc. were commonly found. In addition, totals and percentages for the most prevalent items were calculated.

The latitude and longitude coordinates for each sample were entered into a map database using ATLAS/GIS software. Spatial distribution maps of the total number of debris items were plotted for each environment to determine if aggregations of debris occurred in any part of the estuary. This showed areas of concentration and allowed for the visual delineation of areas having unusually high or low concentrations of debris within the estuary.

Areas with obvious aggregations were tested for statistical significance using either a t-test or test of independence (χ^2). In areas where most samples did not contain any debris items, a test of independence (Dixon and Massey, 1969) was done to test for a significant difference in the percentage of samples with no debris items between the two areas. When most samples contained debris items, t-tests were run to determine if the means from the two areas were significantly different.

If aggregations were significantly different, the total debris in all strata was estimated using:

$$\hat{y} = \sum_{i=1}^{k} n_i \bar{x}_i$$

where $\hat{y}$ = estimate of total debris along shoreline or in an area
n_i = length of shoreline or area in the i^{th} strata

$\bar{x}_i$ = mean number of items coming from the i^{th} strata
k = total strata in the estuary.

Since there was no basis to form apriori reasons for stratification, stratification was done by visually inspecting the data on an aposteriori basis. To guard against creating areas which were not significantly different, stratification was not done unless the probability (P) of observing a test value was less than or equal to 0.01.

RESULTS AND DISCUSSION

Shoreline

The number of samples collected by the citizens group was much smaller than those done in bag seine and trawl. However, the majority of debris was collected from these shoreline samples (Table 1). A total of 3,855 debris items were collected in 37 samples along the shoreline by the citizens groups, compared with 28 and 27 items in the 80 nearshore and 104 submerged samples, respectively. This suggests that debris does not remain in the water long but is washed up and accumulates along the shore or is rapidly buried.

Of the 3,855 items, 1,909 (approximately 50 percent) were plastic (Figure 1; Table 2). The most prevalent plastic items collected were plastic pieces, plastic food bags, plastic caps, plastic cigarette filters and miscellaneous plastic items including items such as boat pieces, beads, and other unidentifiable plastic. Other prevalent items included glass pieces, metal beverage cans, lumber pieces, styrofoam pieces and glass beverage bottles (Table 3).

Geographic distribution maps of debris for the shoreline environment indicated that debris might be less prevalent in the East Bay area than in the rest of the Galveston Bay Estuary

(Figure 2). A t-test using the square root of debris items was run to determine if the two areas were statistically different. The transformation using the square root of items was necessary due to the skewed distribution and large kurtosis value of the untransformed data. This test showed there was a significant difference between the two areas ($t_{0.99}$=2.86, df=35).

Several factors probably account for this difference. East Bay is less developed than other areas of the bay. In contrast, the western area of Galveston Bay is more heavily industrialized and more heavily populated. As might be expected, the total number of debris items is much higher in western Galveston Bay than in East Bay (Figure 2). In addition, the prevailing wind direction in the Galveston Bay area is from the southeast. This would tend to carry items away from East Bay and towards the northwest shoreline of the estuary.

Due to the statistically significant difference between East Bay samples and shoreline samples from other areas of the estuary stratification was performed. However, since there were no shoreline samples taken in the Trinity Bay section, the bay was stratified into three areas rather than two as indicated in the above test. These areas were: East Bay, the Trinity Bay area between Cedar Bayou and Oak Island and the remaining section of the estuary, including West Bay and the western section of Galveston Bay. Since the magnitude of debris was not known in the Trinity Bay area the mean number of debris items was assumed to be equal to the pooled mean value for the entire unstratified data set. The total number of debris items along the shoreline was estimated to be 2,105,931 ± 832218 (95% confidence interval)(Table 4). This is approximately one item per foot for the entire estuary.

While East Bay appeared to contain less debris, it should be noted that no shoreline samples were taken by volunteers along the ICWW. Observations by TPWD staff made during floating debris surveys gave the impression that debris in the ICWW is more numerous than indicated by other East Bay samples. Large debris piles were seen along the shore in the ICWW, suggesting the data in East Bay may be unrepresentative of the total debris problem in the area. Discussions with shrimpers also support the notion of a larger problem in the ICWW. Therefore, it is possible that the magnitude of debris estimates in East Bay, and, therefore, the total magnitude for the estuary would be higher if the ICWW had been sampled.

Nearshore

Plastic and construction materials were the most prevalent debris items collected in the nearshore environment, accounting for 25 percent each of the materials collected (Figure 1). The main plastic items collected were plastic bags of various types, while the main construction material collected were bricks (Table 2). Riprap may be the source of the bricks found in these samples.

As in the shoreline environment, geographic distribution maps in the nearshore environment seemed to indicate that debris was less prevalent in the East Bay area (Figure 3). Since approximately 87 percent of the samples did not contain debris, a test of independence was done comparing the percentage of samples with no debris items in the East Bay area with those in the rest of the estuary. Results indicated that there was no significant difference between the areas (χ^2=1.735, df=1). Estimates of debris in this nearshore environment were 480,923 ± 288,554 items (Table 5).

Submerged

Plastic materials accounted for 59 percent of the debris items collected in the submerged environment (Figure 1). Trash bags were the most numerous plastic items collected. Metal materials were the second most common debris category found, accounting for 37 percent of the items. Metal beverage containers were the most common item found in this category (Table 2).

Debris samples taken in the submerged areas of the ICWW showed a higher magnitude of debris than those taken in other areas of the bay (Figures 4 & 5). While only 23 percent of the submerged samples were taken in the ICWW, they accounted for approximately 78 percent of the debris items collected in trawls. Approximately 42 percent of the ICWW samples contained debris items compared with about 4 percent of the remaining submerged samples (Table 6). A test of independence was significant (χ^2=20.9, df=1), showing that there was a higher percent of ICWW samples containing debris.

It has been suggested (Horsman, 1982) that debris tends to concentrate in ship corridors. This appears to hold true for our data. An even larger concentration of items occurred near passes -Bolivar Roads and Rollover Pass.

While samples were taken in the ICWW, no samples were done in the Houston Ship Channel. Since no data were present for this area, it is not known if the magnitude of debris items is similar to that in the ICWW. Previous studies of floating items done in the Houston Ship Channel by the EPA have shown a large number of plastic items, especially plastic resin pellets, plastic pieces and bags, etc. In fact, plastic pellets were found to be more abundant in the Houston Ship Channel than any other harbor surveyed in the United States (United States Environmental Protection Agency, 1992). It is not known if the floating debris items in the EPA survey are indicative of deeper submerged areas in the ship channel which were not surveyed in this study. Therefore, the ship channel was not stratified with the ICWW and estimates of the magnitude of debris for the submerged areas are conservative at best. Estimates based on ICWW areas and other submerged areas show total debris in this environment to be 16,153 items. (Table 7).

Floating

Floating debris items were not frequently found in the transects. However, debris has been shown to accumulate in slicks and a random sampling effort, such as the one employed in this study, may not encounter areas with high debris concentrations (United States Environmental Agency, 1992).

A total of nine items was collected in the six surveys done. Debris was seen scattered throughout the bay (Figure 6). The majority of items counted in the transects (45%) were plastic. Another prevalent floating item found was metal beverage containers, which comprised 22 percent of the items (Figure 1).

Once again, the ICWW was not surveyed for this environment but may contain a larger number of floating debris items than areas surveyed. TPWD Coastal Fisheries staff have suggested that floating objects are not often encountered in most areas of the bay but when they are seen they are more often observed in the ICWW.

Estimates of the total debris items were not calculated in this environment due to the small number of samples.

Potential Sources of Debris

The primary source of debris in the estuary is people discarding used manufactured goods. This debris may be generated along the shore, in upland areas where it is washed into drainages or on the bay itself by boaters throwing or allowing materials to blow overboard. Many of the most numerous items, such as plastic bags, plastic pieces and metal beverage containers probably come from upland litter, shoreline recreationalists or boaters.

Often the composition or distribution of debris items in the estuary indicate the major source of the debris. The prevalence of debris in the ICWW would suggest that shipping is a major contributor to the debris problem. Other areas of the estuary have different sources. At least one observer collecting shoreline data in West Galveston Bay has suggested that most of the debris at that sample site was generated by park users.

Particular items indicate their source. Plastic items such as fishing line, nets, floats and light sticks are generated through fishing activities. These particular items represented 2% of the items collected. Construction materials probably come from dumping. Bricks collected may be from riprap.

The role of industry in the debris problem is not clear. While numerous plastic pellets were found in the EPA floating debris survey of the Houston Ship Channel, they were not sighted in this study. In fact, they are not even listed the CMC's beach cleanup sheets which were used in the data collection. Not one observer indicated seeing plastic pellets though other materials not contained on the data sheets were noted. This may not be due to the absence of pellets but rather may be due to the fact that they are unnoticeable to most observers. Their small size and resemblance to fish eggs makes them appear innocuous.

Debris is often carried many miles down rivers or through the Gulf before it reaches a destination. Therefore, solutions to the problem must span the same wide range. Ultimately, people are responsible for the problem, whether they interact with the bay indirectly from rivers upstream or whether they work on the bay itself.

Legislation

Several pieces of legislation are in place to help deal with the debris problem. The first is Title I of the Marine Protection, Research and Sanctuaries Act, commonly called the Ocean Dumping Act. This act places restrictions on disposal of wastes in the ocean and requires permits from the EPA for disposal. This law only applies to U.S. vessels, however (Bean, 1987).

Internationally, Annex V of the International Convention for the Prevention of Pollution from Ships, or MARPOL, prevents the dumping of all plastic wastes from ships at sea. This law only pertains to the countries, such as the United States, who are signatory to it. In addition, restrictions are placed on dumping of other materials within certain distances from shore. Special areas are further designated to limit disposal regardless of distance from shore. The Gulf of Mexico is designated as a special area under MARPOL (Marine Debris Action Plan, 1991).

In addition, the Marine Plastic Pollution Research and Control Act of 1987 prohibits the dumping of all plastics by any vessel within U.S. waters. This includes bays, sounds and inland waterways out to 200 miles (O'Hara, 1988).

While legislation has been enacted to help alleviate the debris problem, many problems still exist. Illegal dumping is not easy to detect and non-enforcement has been the norm (Bean, 1987). In addition, laws in effect by the U. S. Department of Agriculture (USDA), while expressing concern with public safety, may contribute to the problem by making illegal open water dumping a more economical alternative to proper disposal of wastes. Under USDA laws all foreign food-contaminated plastics must be incinerated and disposed of so that disease-bearing insects are not brought in to the country (Martin, 1987).

Degradable plastics have received increasing attention recently. However, this is not a solution to the marine debris problem. Degraded plastics do not disappear but merely break down into smaller pieces. While degradable plastic may help to reduce the time an individual is entangled, they may compound the problem of ingestion by organisms (O'Hara et al, 1989).

Estimates of small plastic pieces are somewhat low due to at least one case of volunteers commenting that plastic pieces were "too numerous to count." While this gives a good description of the problem it does not provide the type of data necessary for magnitude estimates.

Potential Effects

The debris problem is more than just an aesthetic problem. It has environmental and economic consequences as well. Debris poses potentially serious problems in four major areas: economic and navigation problems and health and wildlife hazards.

In 1987, tourism was the state's second largest income producer with $13 billion dollars being spent annually. A third of this or approximately $4.5 billion was being spent in coastal counties (Martin, 1987). Since people don't like to visit dirty beaches, revenue suffers when debris items are numerous on the beaches. Also, collecting and disposing of this garbage cost Texas coastal cities and counties in excess of $14 million annually in 1987 (Martin, 1987) and this cost will continue to increase unless a solution is found.

Productivity of fisheries is also potentially affected. Lost traps and nets may continue to fish but the catch is never retrieved- a process known as "ghost fishing." In addition, animals die due to entanglement or ingestion of debris items. This will affect revenue for fishing operations.

Debris is also a navigation hazard. It can wrap around boat propellers or clog intake ports, causing damage to vessels and putting boaters at risk. Large items may also do serious structural damage to vessels.

There are some potential health hazards in Galveston Bay as well. No metal drums or plastic containers containing toxic chemicals were detected in the samples collected during the study period. However, one plastic 5 gallon container still containing tertiary methyl butadiene was found when sample procedures were being developed. This was not included in the study due to its location in an instruction area and not a pre-selected sample site However, it is important to note its occurrence since it indicates such pollutants do occur.

Hospital waste, while not prevalent in the samples, was found at one site, indicating that the potential risk to health does exist. In this case, a syringe was found along the shoreline in West Bay. Using estimates of shoreline distance (Matlock & Ferguson, 1982) it can be extrapolated that approximately 546 syringes could be found in the Galveston Bay Estuary if all of the shoreline were sampled (Appendix 1).

While it is difficult to make general statements on the prevalence of these hazardous materials due to the small number of samples collected, the data suggest they are not a major problem at this time.

Ecologically, we are not certain of the effects of debris on fish and wildlife populations as a whole. However, consequences to individual animals are obvious (Pruter, 1987). Studies have shown plastic items, like those prevalent in this study, cause death in organisms due to entanglement and ingestion. Ingested plastic items cause blocked digestive tracts and damaged stomach linings. Small pieces accumulate in digestive tracts of animals, lessening feeding drives and resulting in possible starvation. Animals then become weakened and have their ability to feed, reproduce or avoid predators impaired. In addition, debris items may provide a source of toxic chemicals (Day et al, 1985).

While there were no reports of animals dying due to marine debris nor any animals witnessed entangled in debris, we can not rule out this problem in the Galveston Estuary. Sightings can be somewhat rare due to a number of factors. Animals interact with debris items over vast areas which are difficult to sample. It is likely that dead or disabled organisms are eaten by predators or decompose before an observation is made (Laist, 1987).

Chance encounters with plastic by estuarine organisms are enhanced by the fact that items tend to accumulate in drift lines due to tides and wind factors. These drift lines provide substrate for larvae of sedentary animals, as well as a good shelter for other organisms. Many creatures will attach themselves to the debris, increasing the chance that debris items will be mistaken for prey. This concentration of food items is attractive to both estuarine organisms and birds (Carr, 1987). In addition, debris items may be viewed as a curiosity or object of play by marine mammals, causing these animals to become entangled (Laist, 1987).

Plastic items have been shown to be confused with prey species in a number of organisms. Sea turtles have been shown to ingest plastic bags which they confuse with jellyfish, a favorite food item (Carr, 1987; Gramentz, 1988). This is of concern for the species survival since all sea turtle species found in the Galveston Bay Estuary are listed as threatened or endangered under the Federal Endangered Species Act. Scientists at the National Marine Fisheries Service and the University of Texas have indicated that one-third to one-half of the stranded sea turtles they examined had ingested plastic products (USEPA, 1990).

Birds also ingest plastic items. To date, 80 of the world's 280 seabird species have been shown to ingest a range of items from small plastic pellets and polystyrene pieces to cigarette lighters and toys (American Management Systems, Inc., 1991). Studies have indicated that plastic pellets are confused with fish eggs (Day et al, 1985).

Plastic items were, by far, the most common debris item. Potentially harmful plastic items made up 31% of the debris collected and projections indicate that approximately 793,891 items are currently in the Galveston Bay Estuary (Appendix 1).

Plastic was not the only harmful item found. Tar balls, while not numerous, were found in a number of samples. Tar balls have been another potential ingestion problem for sea turtles.

RECOMMENDATIONS

Stopping debris from entering the Galveston Bay Estuary is the key to solving the debris problem. Removing debris once it has entered the system is costly and, while certainly necessary, does not solve the fundamental problem. Any number of solutions, some very simple and some much more complex, may help to alleviate the problem. For example, the simple practice that trash collectors have of turning over trash cans after emptying them contributes to the debris problem as trash remaining in the can spills out and blows away. This procedure is not costly to correct and simply requires education.

Education and public involvement are crucial for any solution to work. Television programs could be used to educate the public about the harm debris causes to wildlife and to tourism. Such programs could stress that simple solutions are to recycle and dispose of trash in a proper manner. In addition, encouraging the use of reusable materials as opposed to disposable items is not only effective for keeping wastes out of the Bay but has the additional benefits of decreasing the need for additional landfills and reducing costs of cleanup and disposal.

Providing sufficient trash cans and recycling bins along sidewalks in upland areas, beaches, marinas and ports is also a fairly simple solution. Containers should have lids so that trash would not blow away. Obviously, effective trash pick-up and disposal are critical. Incineration facilities may need to be added to ports to deal with shipping wastes.

Stormwater could be screened to remove debris in areas where debris tends to collect, such as parking lots. This would help alleviate runoff problems into storm drains.

Various programs, such as the Shoreline Adoption and Beach Cleanup Programs in existence for the Gulf of Mexico, may be useful to help alleviate problems in the bay. In the shoreline adoption program, a group "adopts" an area of shoreline and cleans up debris in the area periodically. Problems relating to privately-owned areas and access to sites would need to be taken into consideration in the implementation of such a program.

To learn more about the debris problem, additional studies could be done to more accurately pinpoint sources of debris, as well as amounts of debris in some of the areas which were not sampled in this study, notably the Trinity Bay area and the shoreline of the ICWW. An additional sampling effort could be used to obtain more data across the estuary.

Debris data sheets should be updated to include the numerous construction/industrial items found in this study, as well as plastic pellets. Plastic pellets are important in the role of industry in the debris problem.

Given the method used in this sampling effort, it was not possible to tell if debris had accumulated over a long period of time or if large amounts of debris items were being added to the system over time. A procedure which would provide an answer to this question is to adopt a similar sampling scheme to that of the Center for Marine Conservation. In this sampling system, several locations are visited periodically over time. On each visit the same section of beach is sampled. In one half of the sampled distance, all debris items are counted and the beach is thoroughly cleaned. In the other half, items are counted, marked and their exact location is noted. However, they are left on the beach where they were found. On the next visit to the area, it is noted if these old debris items are still present and where they are located. In addition, new items are counted. Once again half of the beach is cleaned while the other half is not. Data collected in this manner will allow analyses to see what percentage of material moves along the beach and in what direction, how much new material is coming in and if old material has left the system. A deposition rate may then be estimated. This would help in pinpointing answers for many of the questions which were not fully addressed in this study.

In addition, studies at the mouth of tributaries would be useful to identify which streams are major sources of debris entering the bay. Such studies should be conducted during dry, as well as wet, weather. It might be possible to use surface nets to strain out debris for such a study. These nets could then be installed permanently at areas where debris occurs in large volumes. Cleaning these nets may be easier than cleaning up miles of shoreline and less costly in the long run.