levels and noted highest concentrations in summer and early fall and lowest concentrations in winter.

Jones, Edmunds and Associates, Inc. (1979c) measured concentrations of nutrients, trace metals, and organic pollutants in waters from the Georgetown DMDS, as well as from four stations in the entrance channel. They did not detect any pesticides or PCBs in their samples, nor did they observe high concentrations of nutrients or trace metals among the samples tested. However, they did measure cadmium concentration in DMDS waters which was 22 times the limiting permissible concentration.

Bed sediments in Winyah Bay were analyzed for trace metals and pesticides by Johnson (1970). He concluded that Winyah Bay is relatively unpolluted by pesticides, although he found some trace metals. Sediments in the Georgetown DMDS have not been analyzed for pesticides or trace metals prior to the present study, but Van Dolah et al. (1983) noted only low concentrations of metals and nutrients in sediments collected from the Charleston DMDS.

Biology

Phytoplankton and zooplankton communities have not been well studied in the nearshore coastal waters of South Carolina. The limited data available for these planktonic groups is best summarized by Sandifer et al. (1980). In Winyah Bay, Allen et al. (1982) examined chlorophyll concentrations and noted highest values in summer months (July - Sept.). Just north of Winyah Bay, Lonsdale and Coull (1977) examined the seasonal composition of zooplankton communities in North Inlet. They noted that copepods dominated the community (64-69% of total density) with the most abundant species being Parvocalanus crassirostris, Acartia tonsa, Oithona colcarva, and Euterpina acutifrons. The US EPA (1982) also notes that inshore waters are dominated by copepods.

The potential effects of offshore disposal on plankton communities around the Georgetown DMDS cannot be easily defined, but it is likely that increased turbidities from disposal operations would have some localized impacts. Of most concern are the nauplii of certain species of shrimp (Penaeus setiferus, P. aztecus) and larval ichthyofauna. Short-term disposal of sand sediments should not have an enduring impact on these taxa, but longer-term disposal or disposal of silts and clays might be more severe in their effects.

Benthic communities are probably the best biological indicators of disposal impacts because most infaunal species comprising those communities are relatively sedentary. Benthic communities inhabiting sand bottom areas of shallow coastal waters have been examined in the Charleston DMDS (US EPA, 1982; Van Dolah et al., 1983) and at Murrells Inlet (Knott et al., 1983a, 1983b). Limited samples were also collected in the entrance channel to Winyah Bay just outside the jetties (Hinde et al., 1981). Relatively diverse infaunal assemblages were noted in all areas, with polychaetes generally dominating the communities. Abundant infaunal species in the Charleston DMDS area included the cephalochordate Branchiostoma caribaeum; the sipunculid Aspidosiphon spinalis; the polychaetes Spiophanes bombyx, Goniadides carolinae, Spio pettiboneae, Nephtys picta and Prionospio cristata; the lunulitiform bryozoan Cupuladria doma; the amphipod Rhepoxynius epistomus; and nematodes (Van Dolah et al., 1983). At Murrells Inlet, the abundant subtidal infauna were the polychaetes S. bombyx, Scolelepis squamata and Podarke obscura; the amphipods Protohaustorius deichmannae, Acanthohaustorius millsi, and Platyischnopidae; the bivalves Tellina sp., Crassinella martinicensis and Donax variabilis; and nematodes (Knott et al., 1983b). In the entrance channel to Georgetown Harbor, the bivalves Mulinia lateralis and Crassinella lunulata and the polychaetes P. cristata and Paraprionospio pinnata were most abundant (Hinde et al., 1981).

Sessile benthic invertebrates commonly found in the Charleston DMDS included the hydroid Clytia cylindrica; the bryozoans Membranipora tenuis, Microporella ciliata and Parasmittina nitida; and the barnacle Balanus venustus. Most of the these sessile species were attached to large shells, and other firm substrata. The bivalve Chama macerophylla and the sand dollar Mellita quinquiesperforata were also prevalent in this DMDS, with M. quinquiesperforata being most common in finer sediments (Van Dolah et al., 1983).

In the entrance channel to Georgetown Harbor, sand dollars (M. quinquiesperforata) were the most abundant large invertebrates collected by dredge, whereas shrimp (Penaeus setiferus, P. aztecus) and blue crabs (Callinectes sapidus) were the most abundant invertebrates caught by trawl (Hinde et al., 1981). Wenner et al. (1981) also found these decapod crustaceans to be numerically dominant in their study of Winyah Bay.

No long-term effects of disposal on benthic communities have been detected in the Charleston DMDS, primarily due to the similarity of dredged material to the existing sediments in the disposal area (Van Dolah et al., 1983). Data on benthic communities present in the Georgetown DMDS were lacking prior to the present study.

Demersal fish communities associated with sand bottom habitat in South Carolina coastal waters have been examined by Wenner and Barans (1980). Dominant species in the 9-18 m depth zone included southern porgy (Stenotomus aculeatus), sea cat (Arius felis), sand perch (Diplectrum formosum), lizard fish (Synodus foetens) and spot (Leiostomus xanthurus). Abundant fishes caught in the Winyah Bay estuarine system by Wenner et al. (1981) and Allen et al. (1982) included Atlantic menhaden (Brevoortia tyrannus), silver perch (Bairdiella chrysura), bay anchovy (Anchoa mitchilli), star drum (Stellifer lanceolatus), weakfish (Cynoscion regalis), spot (L. xanthurus), white catfish

(Ictalurus catus), Atlantic croaker (Micropogonias undulatus), hog choker (Trinectes maculatus) and tonguefish (Symphurus plagiusa). Hinde et al. (1981) also collected these species and numerous others.

Biological data collected from the above studies generally support the information presented by the US EPA (1982) for the South Atlantic Bight. However, exceptions are noted with respect to infaunal assemblages (see Results and Discussion).

LOCATION IN RELATION TO LIVING AND NON-LIVING RESOURCES

Fisheries and Shellfish Grounds

Commercially and recreationally important species found in the estuarine and coastal marine areas around Winyah Bay include shrimp (Penaeus setiferus, P. aztecus), blue crabs (Callinectes sapidus), oysters (Crassostrea virginica), clams (Mercenaria mercenaria), Atlantic sturgeon (Acipenser oxyrhynchus) and other finfish species such as black sea bass (Centropristis striata), porgy (Pagrus pagrus, Calamus leucosteus), grouper (Mycteroperca microlepis, M. phenax), red snapper (Lutjanus campechanus), mackerel (Scomberomorus cavalla) and many others. The general location of these fisheries is summarized in Figure 5.

Commercial shrimping occurs primarily within 3 miles of shore; however, around the entrance to Winyah Bay shrimpers often work further offshore (3-5 mi.). In South Carolina, shrimping occurs from May through December with peak catches in September and October. Incidental catches from the shrimp fishery are also economically important and include many finfish species (Keiser, 1977). Shrimp populations in the area around the disposal site might decline during periods of disposal due to the associated increased turbidity; however, the effects of offshore disposal of dredged materials on shrimp populations have not been adequately studied.

The mollusk fisheries are also seasonal, beginning in September and ending in May. In Georgetown County, clam landings were of much greater economic value than oyster landings during 1982 (SCWMRD, unpubl. data). Clam harvesting in the Santee estuary increased considerably after the introduction of hydraulic harvesting in 1974 (McKenzie et al., 1980). The scheduled rediversion of waters from the Cooper River estuary, however, is expected to largely destroy shellfish grounds in the Santee estuary. Disposal of offshore channel sediments in the Georgetown DMDS will probably not have much effect on the inshore shellfish grounds, since they are not close to the DMDS (Figure 5).

The amount of blue crabs caught in Georgetown County was greater during spring, summer and fall months than during winter, with greatest catches during March of 1982 (SCWMRD, unpubl. data). As noted for clam and oyster beds, it is unlikely that the blue crab fishery in the Winyah Bay and Santee River estuaries will be influenced by offshore disposal of sand sediments.

Commercial finfish landings in Georgetown County totaled more than two million pounds (SCWMRD, unpubl. data). As noted earlier, many of the fishes landed include black sea bass, grouper, snapper, porgy and other reef fishes. These fishes are associated primarily with offshore hard bottom reef habitats, which have not been found near the Georgetown DMDS.

Winyah Bay is the location of the biggest Atlantic sturgeon fishery in the Sea Islands coastal region (McKenzie et al., 1980) and almost 50,000 lbs. of sturgeon were landed in Georgetown County during 1982 (SCWMRD, unpubl. data). These fish are generally caught with nets set in the ocean near the jetties. Due to the proximity of this fishery to the Georgetown DMDS, there is the possibility of negative effects if disposal activities take place when sturgeon are abundant near the DMDS. Although specific effects of disposal operations on sturgeon populations have not been documented, Morton (1977) noted mortality and displacement of other fishes resulting from increased turbidity. Leland (1968) indicates that sturgeon gather at the inlets during February and March and then move up the inlets as temperatures rise. The fishing season around the jetties begins 15 February and ends 15 April, although sturgeon are still in the area after that date (Smith et al., 1982; SCWMRD, unpubl. data). Most sturgeon landings in Georgetown County occurred from February to June during 1982, with peak landings occurring during March and April. Negative impacts on the sturgeon fishery could be minimized if disposal operations are avoided during the period from mid-February through May.

Recreational finfish catches are primarily from head-boat charters to offshore reefs, fishing on private boats for reef fish and large pelagic species, and pier fishing. Most recreational finfish catches would not be influenced by disposal activities in the Georgetown DMDS

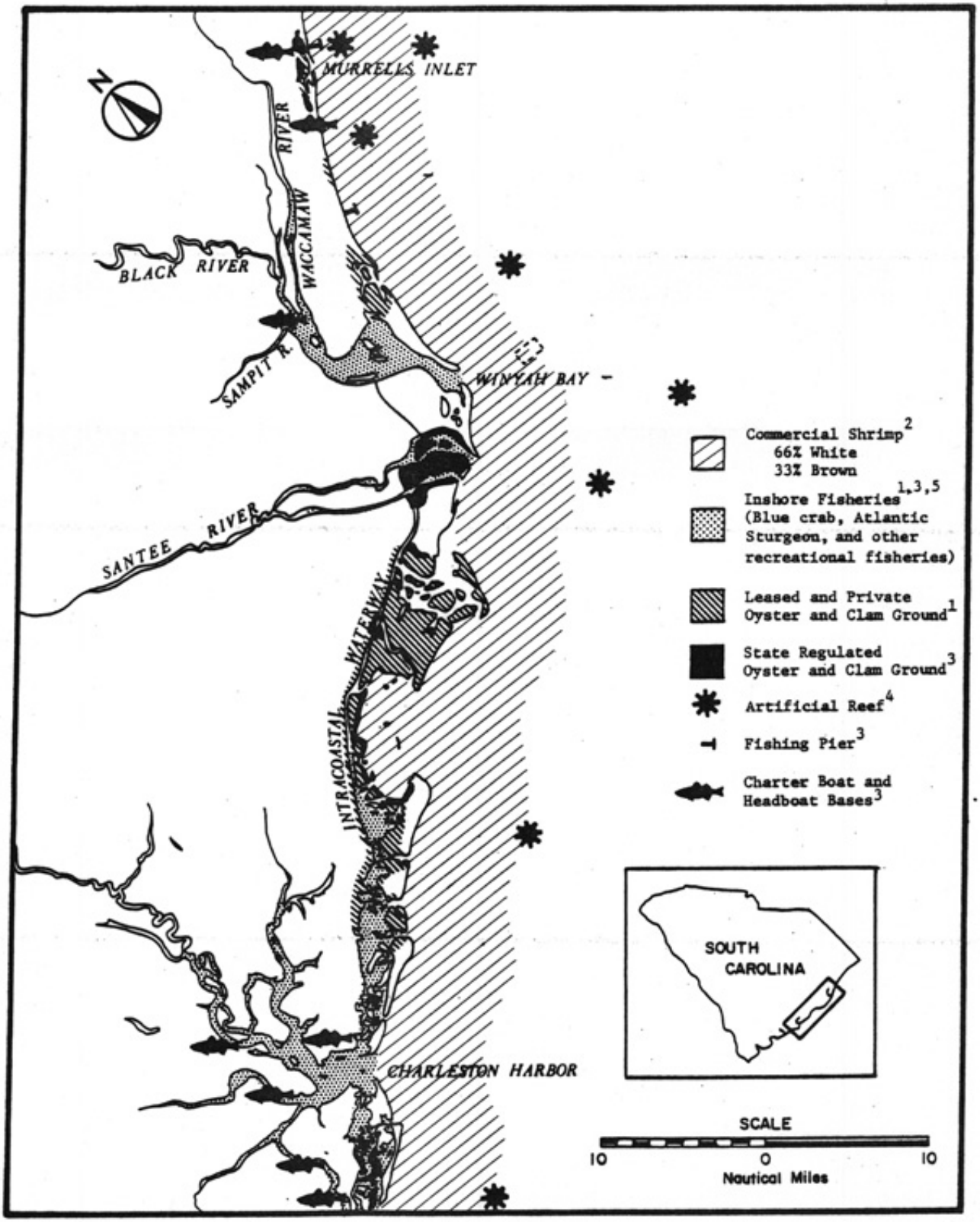

Figure 5. Location of commercial and recreational fisheries resources: [1]Davis, et al., 1980; [2]BLM, 1981; [3]Moore, 1980; [4]Myatt, 1978; [5]Smith, 1983.

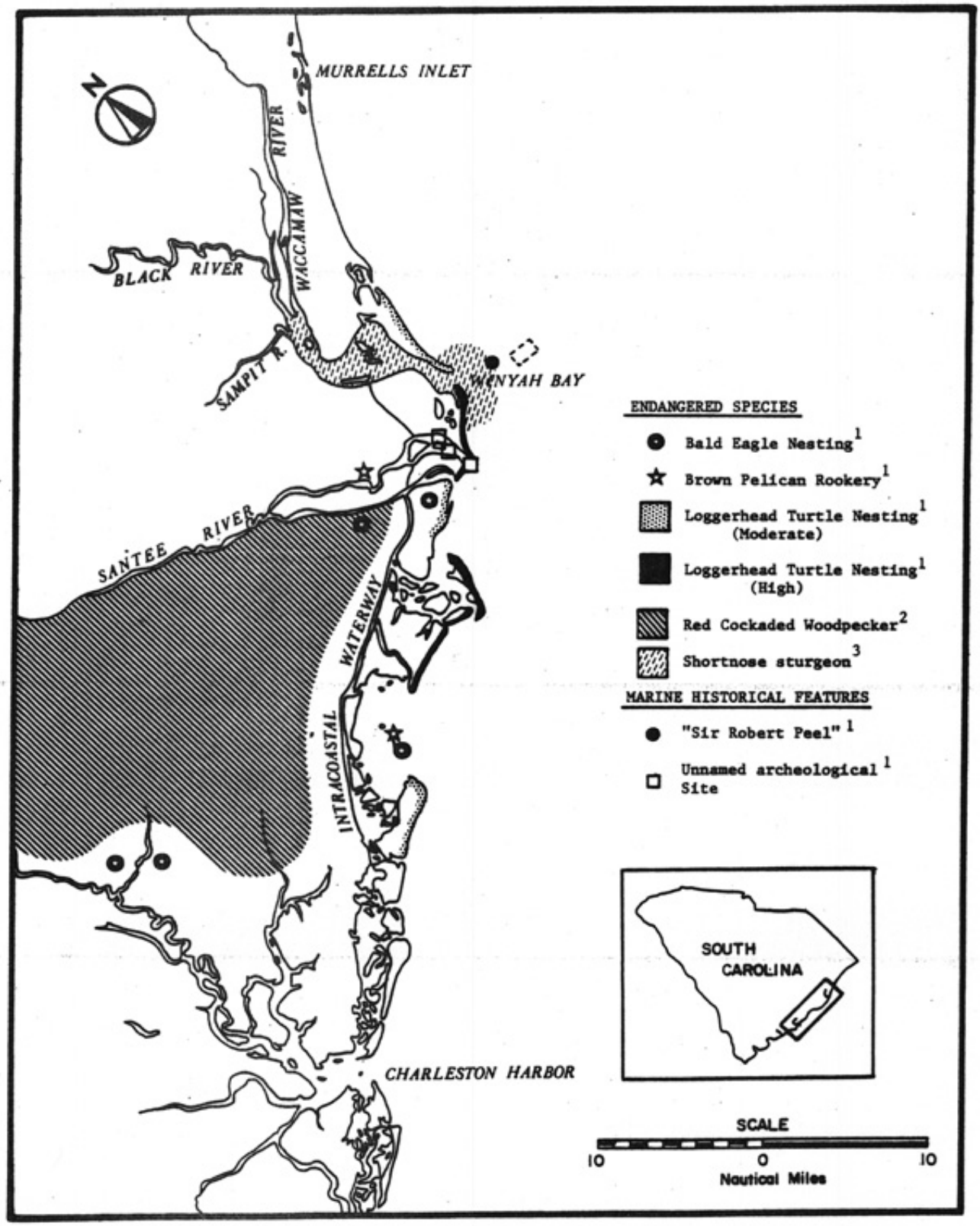

Figure 6. Location of endangered species and marine historical features: [1]Davis, et al., 1980; [2]BLM, 1981; [3]SCWMRD, unpublished.

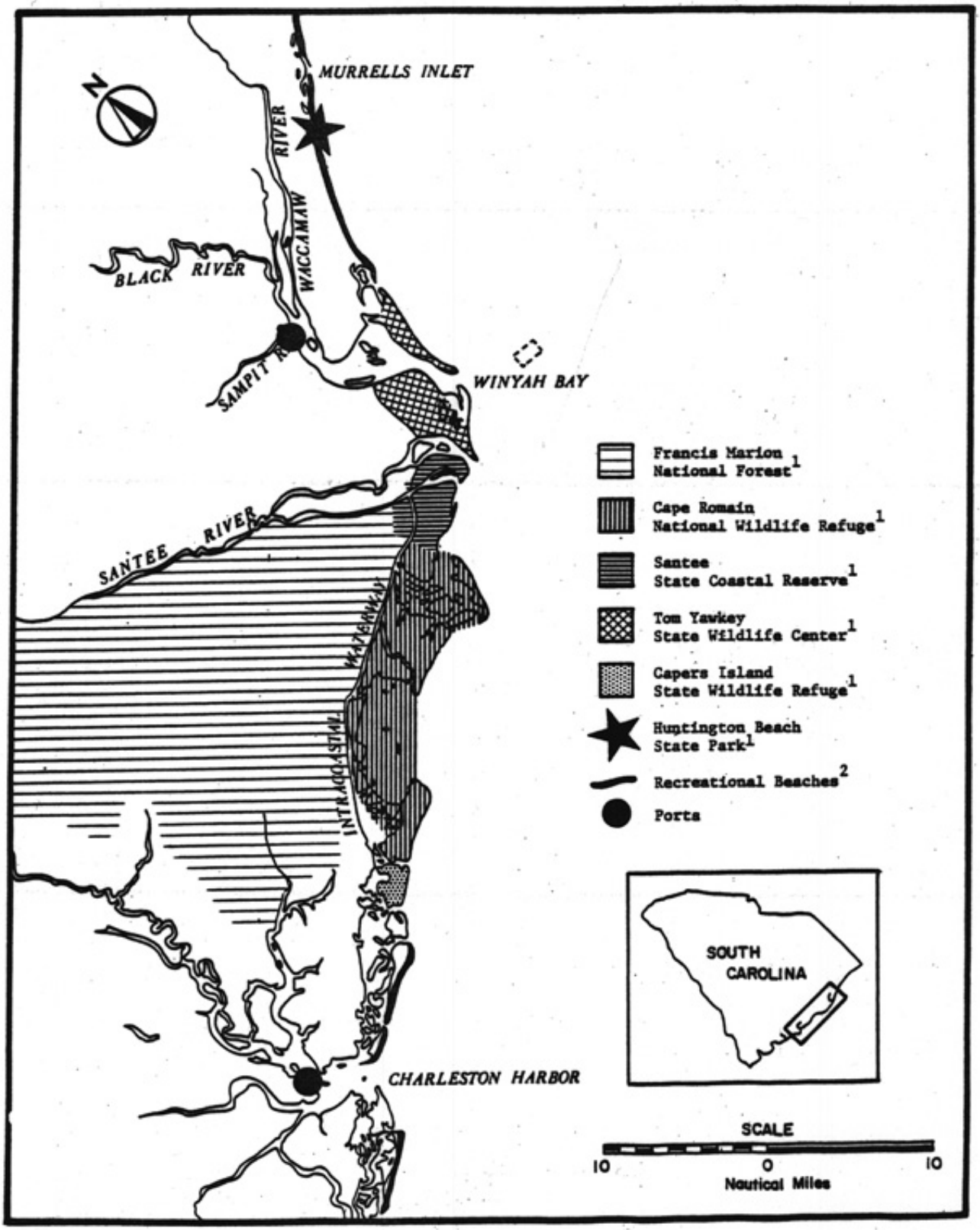

Figure 7. Location of preserves, wildlife centers, beaches and ports: [1]Davis, et al., 1980; [2]BLM, 1981.

since there are no piers or reefs nearby (Figure 5). Recreational fishing around the entrance channel jetties to Winyah Bay may be affected temporarily by increased water turbidity.

Natural and Artificial Reefs

The approximate locations of artificial reefs in the study region are identified in Figure 5. The "Georgetown Wreck" is the reef nearest the DMDS and is located approximately 5 miles to the northeast (Myatt, 1978). The only other reefs near the DMDS are the "Hector" and "City of Richmond" wrecks located approximately 9 miles to the south-southeast. It is unlikely that these reefs would be negatively influenced by disposal operations in the Georgetown DMDS, due to their distance from this site. Natural hard bottom reefs are not known to occur in the area around Winyah Bay; rather, most natural reefs are located further offshore (Henry and Giles, 1979; Miller and Richards, 1980; SCWMRD, 1982), or farther to the north (Parker et al., 1979). "East Bank", a shoal located approximately one mile to the southwest of the DMDS, may be a shell bank supporting sessile reef biota; however, no studies have been done on this bank.

Endangered Species

Habitat locations for endangered species in the study area are summarized in Figure 6. The two most important species that might be affected by offshore disposal operations are the shortnose sturgeon (*Acipenser brevirostrum*) and the loggerhead turtle (*Caretta caretta*). Shortnose sturgeon have been collected around the jetties in winter (Smith, T.I.J., pers. comm.), but this species spends most of its life in freshwater (Leland, 1968). The incidence of loggerhead turtle nesting is moderate on North Island and high on South Island (Davis et al., 1980). In South Carolina, adult females come ashore to nest from mid-May to mid-August, and many appear to use the waters around the DMDS during their movements (Hopkins and Murphy, 1981). The influence of disposal activities on turtle movements are not known, but effects would probably be limited to localized interruption of onshore migration rather than any direct impact on beach nesting areas.

Other Resources

The location of marine historical features, preserves, wildlife centers, recreational beaches and ports are shown in Figures 6 and 7. The only nearby historical feature, other than the shipwrecks mentioned previously, is the "Sir Robert Peel" wreck located just inshore of the DMDS. No historical features are known to be located within the DMDS. Although there are numerous preserves and wildlife centers along the coast, offshore disposal of sand sediments in the Georgetown DMDS is not expected to have any significant impact on the wildlife in those areas. Furthermore, disposal is not anticipated to adversely affect the nearest recreational beaches, which are located approximately 15 miles to the north of Winyah Bay. Finally, shipping to the port of Georgetown would not be impeded since the disposal area is located outside of the shipping channels.

Methods

LOCATION OF STUDY AREAS

The general location of stations sampled in this study is shown in Figure 8. Stations located in the Georgetown DMDS were within the boundaries defined by a rectangle having the following corner coordinates:

(1)	33°11'18"N 79°07'20"W	(2)	33°11'18"N 79°05'23"W
(3)	33°10'38"N 79°07'21"W	(4)	33°10'38"N 79°05'24"W

The control sites selected for study were also located within a rectangular area situated just north of the entrance channel to Georgetown Harbor. Water depths in this area were similar to the DMDS and the control area was approximately the same distance from shore. Coordinates of the corners of the control area were:

(1)	33°12'30"N 79°07'09"W	(2)	33°12'30"N 79°05'12"W
(3)	33°11'50"N 79°07'09"W	(4)	33°11'50"N 79°05'12"W

Within both the DMDS and the control sites, 15 points were located so that there were three rows of 5 equally spaced points (Figure 8). The four corner points in each area were located approximately 150 m inside the site boundaries. The east-west separation of points was approximately 680 m and the north-south separation of points was approximately 460 m. Five points from each of the above areas (DMDS, control) were randomly selected during winter (February 1983) and summer (July 1983) sampling periods using a stratified random selection technique; i.e., one point was randomly selected from each of the 5 columns of 3 points. This sampling design insured adequate sampling of each area for a complete representation of the bottom. The random sampling design also permitted appropriate statistical analyses. Stations selected for sampling during each season are listed in Table 1. All stations were located using Loran-C poisitiong with a Loran plotter system.

Based on the guidelines of Pequegnat et al. (1981) and on limited current data, two stations were located in the general direction of predominant nearshore currents, and a third

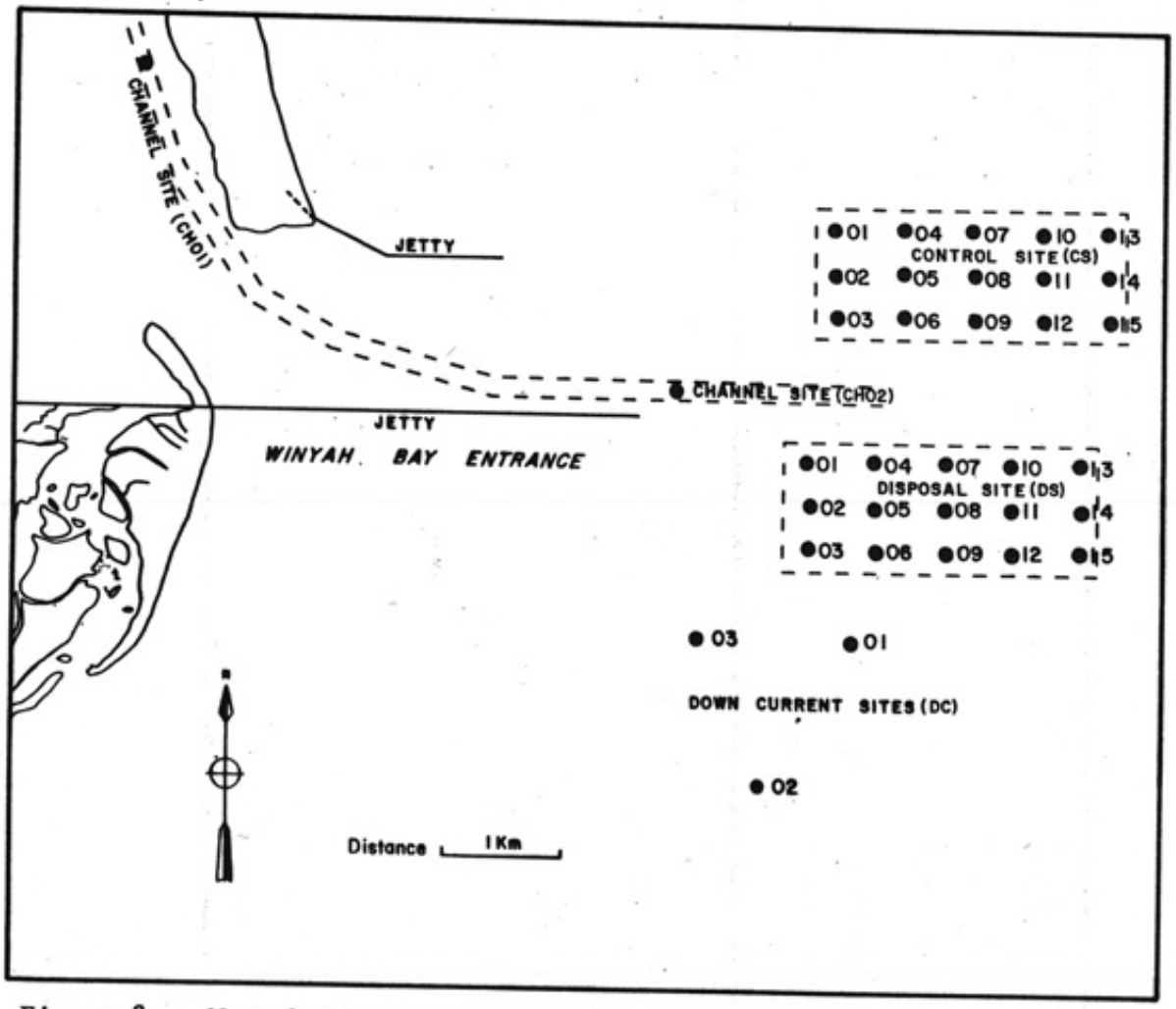

Figure 8. Map showing location of the 15 possible sampling locations in the control and DMDS sites, as well as the location of "down current" and channel sampling locations.

station was located between the DMDS and onshore resources. Coordinates for these stations, collectively referred to as "down current" stations (Figure 8), are listed in Table 1. Two additional stations were located in the entrance channel, one near the outer limit of the south jetty and one farther up the channel near the Georgetown lighthouse (Figure 8). These channel stations were only sampled during the summer season.

HYDROGRAPHIC ASSESSMENT

Temperature, salinity, dissolved oxygen and turbidity measurements were obtained at surface, midwater and bottom depth intervals using Van Dorn bottles. A standard thermometer was used for temperature measurements and Yellow Springs Instrument SCT-DO meters and probes (Model 33 SCT, Model 51 DO) were used to measure salinity and dissolved oxygen. The accuracy of these instruments was verified prior to sampling by separate measurements of a surface water sample taken at each site using a backup set of instruments. Turbidity samples were brought to the laboratory for measurement on a Hach Model 2100A turbidimeter. All water parameters were measured during winter and summer periods at nine stations: two in the DMDS area (most landward and most seaward stations), two in the control area (most landward and most seaward stations), the three "down current" stations, and the two channel stations (summer only).

During the summer sampling period, additional water samples were collected at four stations (CS09, DS08, DC02 and CH02) for analyses of oil and grease, lead, zinc, mercury, cadmium, arsenic, chromium, nickel, copper, PCBs (as Arochlor 1254), Heptachlor, DDT and metabolites, Endrin, Dieldrin, BHC, Mirex, Methoxychlor, Chlordane, Toxaphene and high-molecular-weight hydrocarbons. These samples were collected from bottom waters using a nonmetallic, acrylic, Van-Dorn type water bottle with silicon-coated end caps. The samples were collected, processed and analyzed in the laboratory using methods described by Pequegnat et al. (1981). In the case of trace metals, the alternative procedures described in Federal Registers (Vol. 44, No. 223, p. 69568; Vol. 44, No. 244, p. 75028; 1979) were used. Nutrients were measured using a Bausch and Lomb Model 70 spectrophotometer. Pesticides and hydrocarbons were measured using a Hewlett-Packard gas chromatograph, and oil and grease was measured by freon extraction. All metals were analyzed either on a Perkin-Elmer Model 306 or Model 460 atomic absorption spectrophotometer, with the Model 306 being used for all flame analyses plus the mercury flameless analysis, and the Model 460 being used for graphite furnace (flameless) analyses.

Current measurements were obtained at the 13 stations outside the channel during both seasons. An Endeco Model 110 current meter was used to obtain surface and bottom estimates of current speed and direction. All measurements were obtained while the research vessel was anchored on station. Surface measurements were obtained at approximately 3-m depth to insure that the instrument was at least 1 m below the vessel's keel. Bottom measurements were obtained approximately 1 m above the bottom. Intermediate current measurements were not taken due to the shallow water depths at the stations.

General meteorological and related observations were noted during every station visit. Observations included estimates of wind direction and speed, barometric pressure, cloud cover, precipitation, wave height and wave direction.

SEDIMENTOLOGICAL ASSESSMENT

Bottom sediments were collected at all 15 stations during the summer season using a Smith-McIntyre grab. This grab is designed to take an intact sample of offshore sandy sediments with minimal washout. Sediments were removed from the center of the first undisturbed grab sample collected at each site using methods described by Pequegnat et al. (1981).

Sediment subsamples for granulometric analyses were allowed to air dry and then disaggregated using a rubber-tipped pestle and split into two representative portions. One half of each sample was used for mineralogical analysis and the other for textural analysis. Those samples which contained significant quantities (more than a few percent) of material finer than 4 ϕ (0.0625 mm) were analyzed by both coarse sieving and pipette techniques.

A mineralogical analysis was performed on each of the samples to determine the percent weight of quartz and calcium carbonate (shells). Acid leaching using dilute (10%) HCl was utilized to determine the calcium carbonate content of the samples. Those samples which contained a high percentage of clay (making them very compact) were placed in distilled water and disaggregated using an ultrasonic dismembrator. After sample disaggregation was achieved, 200 ml of dilute HCl was added to dissolve the carbonate constituents. Upon complete leaching, the weight of the dried filtrate was determined and the percentage of acid-soluble calcium carbonate was calculated for each of the samples.

A grain size analysis of the bottom sediments was performed to determine the mean grain size, sorting, skewness and kurtosis for the samples. Grain size determinations were made using a Ro-tap mechanical shaker and 1/2 ϕ interval screens. The weight of the sediment retained on each screen (sieve fraction) was recorded. The weight percent and cumulative weight percent for each of the size classes were determined. These data were then plotted

Table 1. Geographic positions of sites sampled during the winter and summer, 1983.

SITE	STATION	SEASON	LATITUDE	LONGITUDE
DISPOSAL	DS03	winter, summer	33° 10.72'N	79° 7.23'W
	DS06	winter, summer	33° 10.72'N	79° 6.80'W
	DS08	summer	33° 10.97'N	79° 6.37'W
	DS09	winter	33° 10.72'N	79° 6.37'W
	DS10	summer	33° 11.22'N	79° 5.92'W
	DS11	winter	33° 10.97'N	79° 5.92'W
	DS13	winter, summer	33° 11.22'N	79° 5.48'W
CONTROL	CS02	winter, summer	33° 12.17'N	79° 7.05'W
	CS04	winter	33° 12.42'N	79° 6.62'W
	CS05	summer	33° 12.17'N	79° 6.62'W
	CS09	winter, summer	33° 11.92'N	79° 6.17'W
	CS10	winter	33° 12.42'N	79° 5.73'W
	CS11	summer	33° 12.17'N	79° 5.73'W
	CS13	winter, summer	33° 12.42'N	79° 5.30'W
DOWN CURRENT	DC01	winter, summer	33° 10.28'N	79° 6.92'W
	DC02	winter, summer	33° 9.53'N	79° 7.47'W
	DC03	winter, summer	39° 10.28'N	79° 7.88'W
CHANNEL	CH01	summer	33° 13.20'N	79° 11.35'W
	CH02	summer	33° 11.57'N	79° 8.0'W

to provide a cumulative frequency curve from which the statistical parameters were calculated according to Folk (1965).

A pipette analysis was performed on those samples which contained an appreciable amount of fine-grained material. These samples were dispersed by adding 100 ml of 1N sodium metaphosphate [$(NaPO_3)x \cdot Na_2O$)] as a dispersing agent and agitated using an ultrasonic dismembrator for 15 minutes. After complete deflocculation was achieved, the samples were wet-sieved through a #230-mesh stainless steel screen to separate the sand from the silt and clay. The silt and clay fraction was then transferred to a 1000-ml graduated cylinder and the sample was pipetted using the withdrawal times and depths as as outlined by Folk (1965). The percentages of sand, silt and clay were also recorded for these samples and plotted on a standard sediment-type triangular diagram.

Subsamples of sediment cores were also collected for analysis of the following parameters: Total organic carbon (TOC), chemical oxygen demand (COD), Kjeldahl nitrogen, nitrite nitrogen as NO_2, nitrate nitrogen as NO_3, oil and grease, lead, zinc, mercury, soluble phosphorus as PO_4, total phosphorus as PO_4, iron, cadmium, arsenic, chromium, nickel, copper, PCBs (as Arochlor 1254), Heptachlor, DDT and metabolites, Endrin, Dieldrin, BHC, Mirex, Methoxychlor, Chlordane, Toxaphene and high-molecular-weight hydrocarbons. All samples were preserved, processed and chemically analyzed using the procedures described by Pequegnat et al. (1981) and outlined for hydrographic analyses, except that metals were measured in two ways: after total extraction (bulk chemical analysis) and after partial extraction with 0.1N HCl. A second set of samples was collected from three stations (CS09, DS08, DC02) and preserved in the same manner for delivery to the Charleston District Corps of Engineers.

Sediment samples were not collected during the winter season. However, qualitative observations were made for each grab sample collected for benthos.

During summer, additional sedimentological studies included diver observations of the bottom. Unfortunately, very strong currents and extremely poor visibility drastically reduced the effectiveness of this effort and detailed results are not presented.

BENTHIC COMMUNITY ASSESSMENT

Macrofauna were sampled during both seasons at all randomly selected sites in the DMDS and control areas, as well as at the three "down current" stations. Prior to water chemistry or grab sampling during the winter, qualitative epifaunal samples were obtained at each of the 13 stations using a beam trawl similar to that described by Pequegnat et al. (1981). One tow was made in a north-south direction through each station, with all tow lengths standardized to 0.5 km based on Loran-C positioning. Similar beam trawls were made at the same 13 sites in summer, but only after sediment, grab and water chemistry sampling was completed in order to avoid disturbance of the bottom. Organisms obtained in each tow were preserved in 10% seawater-formaldehyde for later identification. Biomass estimates were also obtained for each sample.

Quantitative benthic samples of macrofauna were collected using a Smith-McIntyre grab while the research vessel was anchored on station. Five replicate samples were collected at each of the 13 stations (in addition to the separate sediment samples) both seasons. After measuring the volume of each grab sample, the collected material was washed through a 1-mm sieve. Organisms and sediment remaining on the sieve after washing were removed and preserved in 10% seawater-formaldehyde with rose bengal stain. Samples were then brought to the laboratory and organisms were sorted, identified to the lowest taxonomic level, and counted.

For qualitative collections by beam trawl, diversity was evaluated by comparing the number of species ($\underline{s}$) among stations. The Kruskal-Wallis one-way analysis by ranks (Siegel, 1956) was used to determine whether median $\underline{s}$ differed significantly among the three areas sampled: disposal, control and down current. A significant difference in $\underline{s}$ between winter and summer was evaluated by the Mann-Whitney U-test (Sokal and Rohlf, 1982).

Qualitative data on the presence or absence of species collected with the beam trawl were analyzed by cluster analysis to determine patterns of similarity among stations and species. Only species which occurred in two or more trawl collections were included in this analysis.

Species and collections were classified using a flexible sorting strategy (Lance and Williams, 1967) with a cluster intensity coefficient (β) of -0.25. The Jaccard similarity coefficient (Clifford and Stephenson, 1975) was used with presence/absence data obtained from beam trawl collections.

Normal and inverse classifications were produced for combined seasonal data. The result of normal classification was a dendrogram in which collections were clustered based on their degree of similarity in terms of species presence. Inverse classification produced a dendrogram in which species were clustered based on their degree of similarity in terms of presence in collections (Williams and Lambert, 1961).

Subsequent to cluster analysis, species and station groups were chosen using a variable stopping rule (Boesch, 1977). Nodal analysis was then used to express the degree of species/site group coincidence in terms of ecological constancy and fidelity. Constancy expresses

the frequency with which species of a particular group are found in a given collection group and fidelity measures the degree to which species are restricted to a particular collection group.

For trawl biomass estimates, a Model I two-way analysis of variance without replication was used to determine whether the mean log-transformed biomass of beam trawl collections differed significantly between seasons (winter, summer) and among areas (disposal, control, and "down current"). Due to non-normality and heterogeneous variances, a logarithmic [$\log_{10}$ (x+1)] transformation was used on each variate prior to calculation of means and analysis of variance.

Infaunal community structure based on grab collections was evaluated using several indices of species diversity and cluster analysis. Species diversity was calculated on the pooled samples collected during each station visit using Shannon's diversity index (H'), species richness (SR), and evenness (J') (Margalef, 1958; Pielou, 1975). Total number of species and faunal abundance were also evaluated. Normal and inverse cluster analyses were conducted on log-transformed abundance estimates from pooled (by station) grab samples using the Bray-Curtis similarity coefficient (Boesch, 1977). As with the trawl cluster analyses, a flexible sorting strategy with a standard cluster intensity coefficient (β) of -0.25 was used in both the normal and inverse analysis. Species which occurred in fewer than 7% of the 130 grab samples were deleted from the data set since rare species usually do not have easily defined distribution patterns and can confuse interpretation of cluster analysis. In all cases, species deleted because of rare occurrence were also rare in abundance. In order to accurately compare winter and summer data, bryozoans were also deleted prior to cluster analysis, since they were not enumerated during winter. Following normal and inverse analyses, a nodal analysis was performed using fixed station groups (DMDS, control, "down current", by season) and the inverse species groups to obtain estimates of fidelity and constancy as defined above.

BIOACCUMULATION ASSESSMENT

Specimens of the knobbed whelk, Busycon carica, were collected in the DMDS, control and "down current" areas for bioassay analysis. This mollusk was the only relatively sedentary organism which was present in all three sampling areas and was large enough to obtain sufficient biomass for analysis. The species is also commercially harvested in South Carolina. All B. carica specimens were collected from beam trawl samples taken in the three areas. After collection, specimens were preserved and analyzed according to the procedures outlined by Pequegnat, et al. (1981). All chemical contaminants, except oil and grease, which were analyzed in water samples were analyzed in the tissue samples.

Results and Discussion

HYDROGRAPHY

Water column chemistry in the study area can be influenced by runoff, nearshore and Gulf Stream current patterns, suspended sediments, eolian transport and other factors. As a result, the water chemistry may vary considerably on a temporal basis. Runoff from Winyah Bay and the Santee Rivers decreases salinities, increases turbidities and deposits fine sediments offshore. Normal runoff from these systems can be very high, with flows from the combined river systems being > 15,000 cfs (U.S. Geological Survey, 1979). In addition, a longshore drift to the southwest is usually present during summer months, while a northeasterly flow exists during winter months (Mathews and Pashuk, 1984). Therefore, depending on season and environmental conditions, waters from Winyah Bay may move either to the north or south along the coast as well as spread out towards deeper waters.

Oceanographic Parameters

Values recorded for the oceanographic parameters measured in this study generally agree with historic readings, although some of the salinities recorded during the winter cruise were particularly low. In that season, surface salinities were as low as 21.9 °/oo at station DC03 and < 30 °/oo at DC02, DS03 and DS13 (Table 2). These low salinities were the result of runoff from a massive rainstorm which preceded the winter sampling cruise. Summer salinities were generally higher than values observed during winter. Except for the station in Winyah Bay (CH01) which had salinities < 15 °/oo from surface to bottom, only one station (CS13) had surface water < 30 °/oo. During a two-year study in Winyah Bay, salinities at a station 2 miles upstream from the mouth averaged < 15 °/oo and ranged from < 2 °/oo to > 30 °/oo (Mathews and Shealy, 1982). Nearshore surface salinities off Winyah Bay are typically > 30 °/oo (Mathews and Pashuk, 1977, 1982, 1984).

Dissolved oxygen (DO) and water temperatures were also within normal ranges and DO was inversely related to temperature (Table 2). Both summer and winter DO concentrations were representative of the seasons sampled, with higher values (> 10 mg/l) being found in cold waters (< 9.0°C) and lower values (< 6 mg/l) found in warmer waters (> 26.5°C). Water temperatures were slightly cooler than usual for summer and winter, but not abnormally so (Mathews and Pashuk, 1984).

For all stations, turbidities were $\leq$ 8.0 FTU in surface samples and $\leq$ 13.0 FTU in mid-water samples (Table 2). Highest values were normally encountered in bottom waters, where

Table 2. Oceanographic parameters of water collected from the 7 winter and 9 summer stations sampled in and near the Georgetown Harbor DMDS.

WINTER

Station	Station Depth	Depth	Temp. (C)	Salinity (o/oo)	D.O. (mg/l)	Turbidity (FTU)
DS03	8.0	Surface	8.7	27.2	10.4	5.5
		Middle	8.7	33.6	10.1	3.8
		Bottom	8.8	33.8	9.5	42.0
DS13	11.0	Surface	8.5	29.7	9.3	4.8
		Middle	8.6	34.1	9.1	3.8
		Bottom	8.7	34.1	9.2	5.2
CS02	9.5	Surface	9.2	30.0	9.2	4.6
		Middle	8.9	33.9	9.4	5.3
		Bottom	8.9	33.9	9.5	11.0
CS13	11.0	Surface	8.9	32.2	9.4	2.2
		Middle	9.0	34.0	9.2	2.8
		Bottom	8.9	34.0	9.3	6.1
DC01	8.75	Surface	9.4	33.1	9.0	2.0
		Middle	9.4	33.2	9.0	2.3
		Bottom	9.3	33.6	9.1	2.8
DC02	8.25	Surface	9.0	29.6	9.2	4.3
		Middle	9.0	30.7	9.0	6.5
		Bottom	9.0	33.6	9.9	13.0
DC03	6.5	Surface	8.5	21.9	9.8	8.0
		Middle	8.7	33.3	8.8	12.0
		Bottom	8.9	33.6	9.2	27.0

SUMMER

Station	Station Depth	Depth	Temp. (C)	Salinity (o/oo)	D.O. (mg/l)	Turbidity (FTU)
DS03	8.5	Surface	26.8	33.7	5.9	2.6
		Middle	26.5	34.4	5.5	3.8
		Bottom	26.7	34.3	5.8	24.0
DS13	12.0	Surface	27.0	34.5	5.8	6.7
		Middle	27.2	34.5	5.8	1.8
		Bottom	27.1	34.5	5.7	1.6
CS02	9.5	Surface	27.4	32.3	5.8	4.7
		Middle	26.7	34.2	5.5	5.8
		Bottom	26.8	34.3	5.6	8.8
CS13	10.5	Surface	27.8	27.9	5.9	5.6
		Middle	27.3	33.7	6.1	3.6
		Bottom	27.0	34.3	6.2	4.8
DC01	9.5	Surface	27.8	34.3	6.1	3.3
		Middle	27.0	34.3	6.0	3.7
		Bottom	27.1	34.4	5.8	5.4
DC02	7.3	Surface	27.3	32.6	6.2	2.9
		Middle	26.8	34.3	5.8	11.0
		Bottom	26.7	33.8	5.5	11.0
DC03	7.5	Surface	27.5	34.2	5.9	2.8
		Middle	27.0	34.2	6.0	3.5
		Bottom	27.4	34.3	6.0	8.8
CH01	7.5	Surface	29.0	12.1	7.2	7.7
		Middle	29.0	13.5	6.4	10.0
		Bottom	28.9	14.5	5.6	20.0
CH02	9.5	Surface	27.3	33.6	5.8	5.8
		Middle	27.1	33.7	5.5	13.0
		Bottom	26.9	34.1	5.4	28.0

greatest trubidity would be expected due to suspended sediments. In these bottom samples, turbidities in winter would have been influenced by the high runoff from Winyah Bay, which produced a maximum of 42.0 FTU at station DS03. The highest bottom turbidities in summer (up to 28.0 FTU) may have resulted from the activity of shrimp trawlers in the area during the summer sampling cruise.

Turbidities at the mouths of other South Carolina estuaries have greatly exceeded the maximum value recorded during this study. Mathews and Shealy (1982) and Mathews et al. (1981) reported maxima of 135 FTU at the mouth of Charleston Harbor, 91 FTU at the mouth of the South Santee River, and 84 FTU at the mouth of the North Santee River. Our winter and summer maxima were much lower (42.0 and 28.0 FTU, respectively) and, hence, well within the extremes noted at other nearby sites.

Currents

Measurements obtained at the 13 offshore stations indicate that water movement in the DMDS, control and "down current" areas is strongly influenced by tidal currents (Figures 9-10). Current velocities ranged from 0.1-0.9 knots during winter and 0.1-1.1 knots during summer sampling periods (Appendix 1). Surface and bottom currents generally flowed in a southerly or south-easterly direction during ebb tides. This suggests that water leaving Winyah Bay is diverted by nearshore currents which generally run in a southerly direction along the coast (Mathews and Pashuk, 1977). Current directions measured near slack-tide periods were more variable and often differed between surface and bottom waters. Generally, flood-tide currents were first detected near the bottom and ebb-tide currents were first observed in surface waters (Appendix 1). During flood tides, the general current direction was towards the north, or towards the Winyah Bay entrance channel. Thus, tidal currents appear to have a stronger influence on waters in the vicinity of the DMDS than nearshore currents. However, the limited current measurements collected during this study were only intended to supplement other hydrographic data and these measurements probably do not adequately define current regimes in the study area.

Chemistry and Pollutants

Trace metals were generally low in concentration, with many being below the detection limits, e.g. nickel, copper, lead and mercury (Appendix 2 and Table 3). The values reported in this study are generally much lower than values noted by Jones, Edmunds and Associates (JEA) (1979c.) in their study of the Georgetown Harbor channel, but were more similar to the Interstate Electronics Corp. (IEC) results (US EPA, 1982) obtained for the Charleston DMDS (Table 4). Specifically, our cadmium concentrations were higher than the IEC Charleston values (maxima of 7.1 µg/l and 0.493 µg/l, respectively), but much lower than the JEA Georgetown results (up to 150 µg/l). Nickel and lead concentrations measured in the present study were below the detection limit for each metal, whereas concentrations noted by JEA were as high as 760 µg/l for nickel and 1600 µg/l for lead. Zinc concentrations (minus estimates measured in the control blank sample) were lower than the concentrations noted by JEA, but arsenic concentrations were all higher than those measured by JEA, i.e., 32.4-92.8 µg/l versus < 10.0-30.0 µg/l (Table 4).

A study in Corpus Christi Bay by Holmes et al. (1974) found a seasonal variation in cadmium and zinc concentrations, but their overall results for estimates obtained in winter correlate well with this study. Summer values obtained by Holmes et al. (1974) were much higher due to stagnation within the bay, a condition clearly not present in our study area. Windom (1972) reported copper, lead, cadmium, zinc and mercury concentrations in the Savannah River before, during, and after dredging operations. He noted values of < 1 to 56 µg/l for copper, < 2.0 to 9.8 µg/l for lead, 0.05-0.49 µg/l for cadmium, 11-32 µg/l for zinc, and 0.15-0.21 µg/l for mercury. Our values were comparable, although we noted higher cadmium concentrations and lower lead concentrations (Table 4).

The various PCBs and pesticides listed in Table 4 were below the 50 ppb detection limits listed by Pequegnat et al. (1981) and, hence, they are assumed to be trace amounts. The oil and grease determination however, was positive but not particularly high. Our values ranged from 3.0-4.0 mg/l as compared to the JEA (1979c) range of 20-29 mg/l.

BOTTOM SEDIMENTS

Granulometric Analyses

Bottom sediments at stations sampled in the DMDS consisted of moderately to poorly sorted quartz sand having an average mean grain size of 0.71ϕ (Table 5, Figure 11). The silt and clay content of the five samples collected from this area was less than 1% (Table 6, Figure 12), suggesting that finer-grained sediments are winnowed out as a result of wave and current activity. Bottom sediments in this region are apparently not below the wave base, thus inhibiting deposition and allowing for removal of fine-grained sediments. The coarse sandy bottom present in the disposal area suggests that any fine-grained sediments previously disposed in the DMDS have been largely dispersed from the study area.

The concentration of calcium carbonate (shell material) varied from 4.66 - 14.97% in the disposal area (Table 7, Figure 13). Station DS03 had the highest concentration of calcium carbonate (14.97%) as a result of the abundance of both whole and fragmented shell material. Some of the shell material present may be from "East Bank" (a large

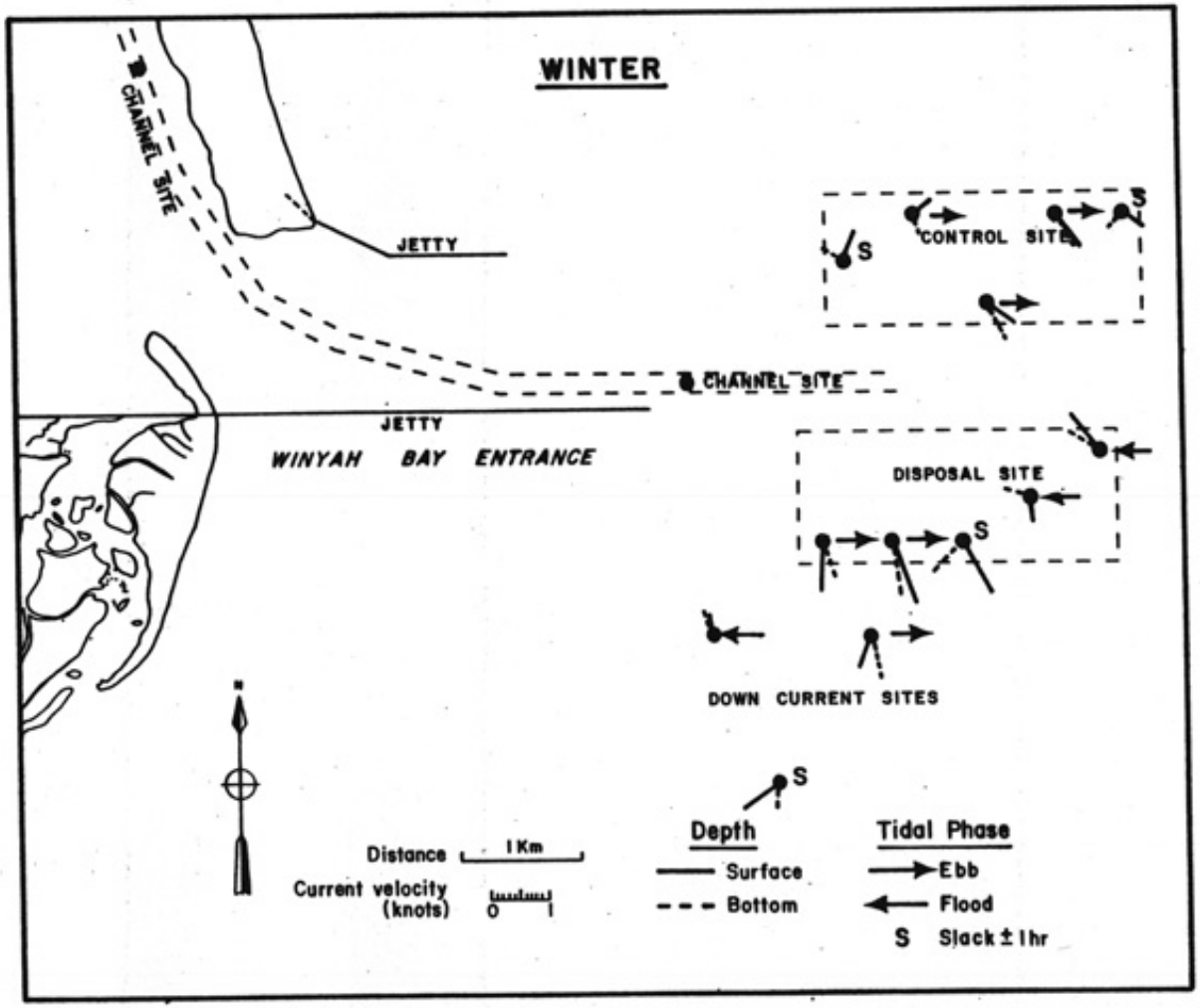

Figure 9. Current velocities and directions for the 13 stations sampled during the winter in and near the Georgetown Harbor DMDS.

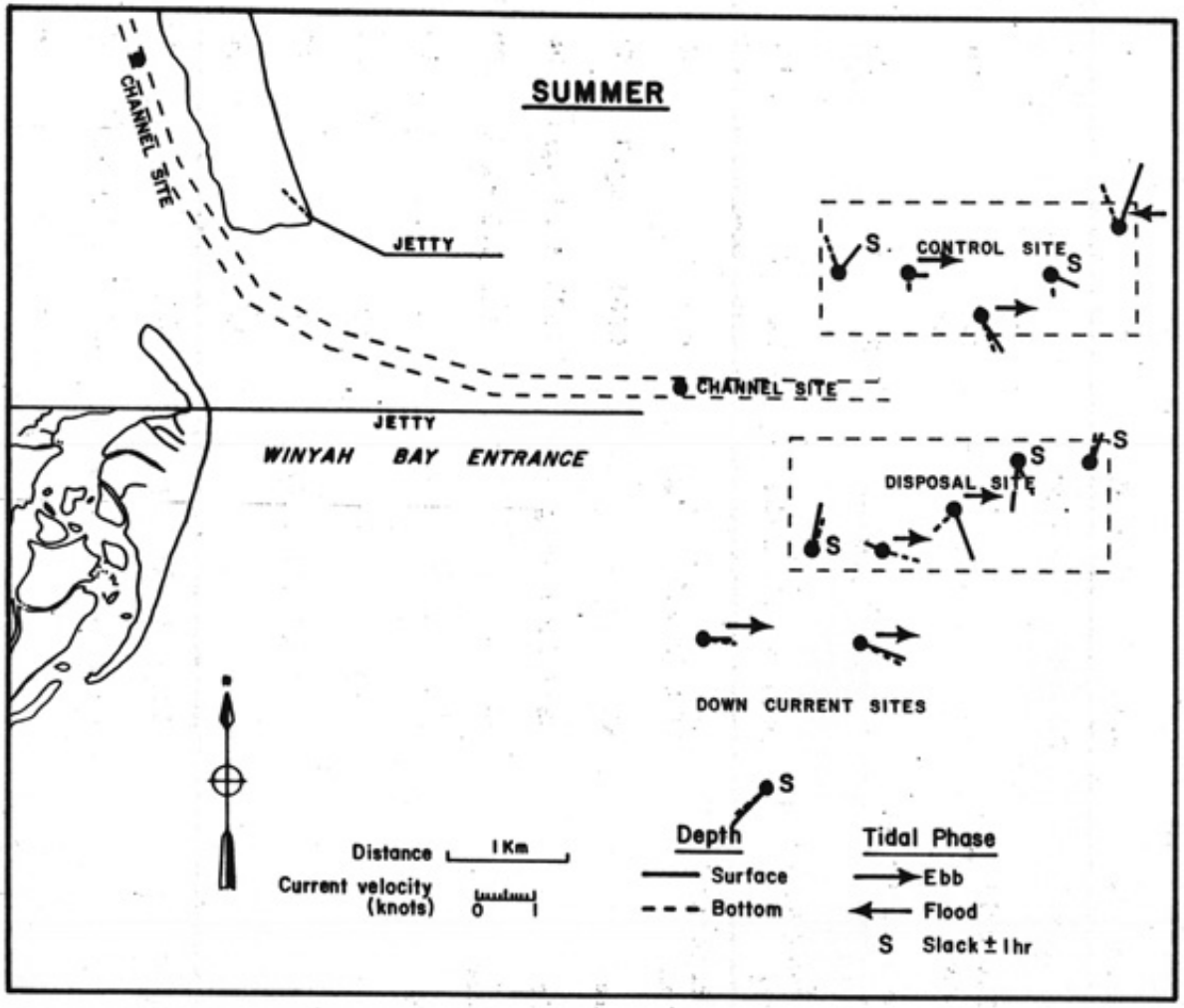

Figure 10. Current velocities and directions for the 13 stations sampled during the summer in and near the Georgetown Harbor DMDS.

Table 3. Maximum concentrations of various substances measured in sediment, water, and tissue samples collected from the vicinity of the Georgetown DMDS.

PARAMETER	SEDIMENT	WATER	TISSUE
Oil and grease	CH02 687 mg/kg	DS,DC 4.0 mg/l	ND
Nitrate as NO_3	CS13 533.33 mg/kg	NA	ND
Nitrite as NO_2	CH01 106.28 mg/kg	NA	ND
Total Kjeldahl Nitrogen	DC01 994 mg/kg	NA	ND
Soluble Phosphorus as PO_4	DS03 1.72 mg/kg	NA	ND
Total Phosphorus as PO_4	DC01 53.13 mg/kg	NA	ND
Total Organic Carbon	DC01 0.810% mg/g	NA	ND
Cadmium	ND	CS05 7.1 mg/l	ND
Arsenic	CS13 1.47 µg/g	CS05 92.8 mg/l	DS 2.34 mg/g
Chromium	ND	CS05 5.3 mg/l	ND
Nickel	ND	ND	ND
Copper	DC03 4.02 µg/g	ND	DS 9.65 mg/g
Iron	DC03 15,473 µg/g	ND	ND
Lead	ND	ND	ND
Mercury	DS08 0.61 µg/g	ND	ND
Zinc	CH02 41.04 µg/g	CH01 265 mg/l	DS 53.61 mg/g
Pesticides	ND	ND	ND
Total resolved Hydrocarbons	CS02 8.95 µg/g	CH01 416.63 mg/l	ND

ND - Not Detectable
NA - Not Analyzable

Table 4. Comparisons of hydrographic chemical analyses for Georgetown and Charleston Harbor areas.

	GEORGETOWN DMDS				IEC * CHARLESTON ODMDS	JEA ** GEORGETOWN HARBOR CHANNEL
	CHANNEL CH01	CONTROL CS05	DISPOSAL DS08	DOWN CURRENT DC02		
PCBs Aroclor 1254 µg/l	ND	ND	ND	ND	ND	< 1.0
BHC µg/l	ND	ND	ND	ND	ND	< 0.5
lindane µg/l	ND	ND	ND	ND	ND	NA
heptachlor µg/l	ND	ND	ND	ND	ND	< 0.5
DDE µg/l	ND	ND	ND	ND	ND	< 0.5
DDD µg/l	ND	ND	ND	ND	ND	< 0.2
DDT µg/l	ND	ND	ND	ND	ND	< 0.2
chlordane µg/l	ND	ND	ND	ND	ND	< 0.5
dieldrin µg/l	ND	ND	ND	ND	ND	< 0.1
endrin µg/l	ND	ND	ND	ND	ND	< 0.2
mirex µg/l	ND	ND	ND	ND	ND	< 0.3
methoxychlor µg/l	ND	ND	ND	ND	ND	< 1.0
toxaphene µg/l	ND	ND	ND	ND	ND	< 5.0
Oil and Grease µg/l	3.0	3.0	4.0	4.0	NA	20 - 29
Cadmium µg/l	0.8	7.1	1.6	3.4	0.040 - 0.493	110 - 150
Arsenic µg/l	78.6	92.8	41.4	32.4	NA	< 10.0 - 30.0
Chromium µg/l	1.4	5.3	4.7	2.1	NA	< 300
Nickel µg/l	< 5.0	< 5.0	< 5.0	< 5.0	NA	600 - 760
Copper µg/l	< 50	< 50	< 50	< 50	NA	< 100
Lead µg/l	< 1.0	< 1.0	< 1.0	< 1.0	0.032 - 3.20	1100 - 1600
Mercury µg/l	< 0.2	< 0.2	< 0.2	< 0.2	< 0.03 - 0.076	< 0.2
Zinc µg/l	265	150	172	172	NA	140 - 240

* IEC Interstate Electronics Corp. (IEC), US EPA (1982)
** JEA Jones Edmunds and Associates. (1979c)
NA - Not Analyzed
ND - Not Detected; Detection Limit is 50 ppb.

Table 5. Statistical analysis of the grain size distribution for sediments from the Georgetown DMDS and vicinity. Data presented in Ø units.

STATIONS	MEAN	MEDIAN	STANDARD DEVIATION	SKEWNESS	KURTOSIS
DS03	0.16	0.90	1.41	-0.56	0.83
DS06	0.91	1.10	0.83	-0.32	1.24
DS08	0.86	1.15	1.05	-0.45	0.94
DS10	0.80	1.10	0.78	-0.50	0.75
DS13	0.84	1.08	0.79	-0.39	1.04
CS02	0.83	1.15	0.83	-0.52	1.20
CS05	0.78	1.15	0.85	-0.58	1.34
CS09	0.60	0.70	1.00	-0.15	1.06
CS11	1.13	0.45	2.52	+0.48	2.12
CS13	0.83	1.08	0.95	-0.36	0.85
DC01	1.89	2.00	0.65	-0.39	1.27
DC02	1.03	1.20	0.85	-0.42	1.81
DC03	4.59	4.60	2.56	+0.05	0.83
CH01	1.58	1.50	0.83	-0.05	1.09
CH02	3.73	3.10	1.88	+0.53	1.02

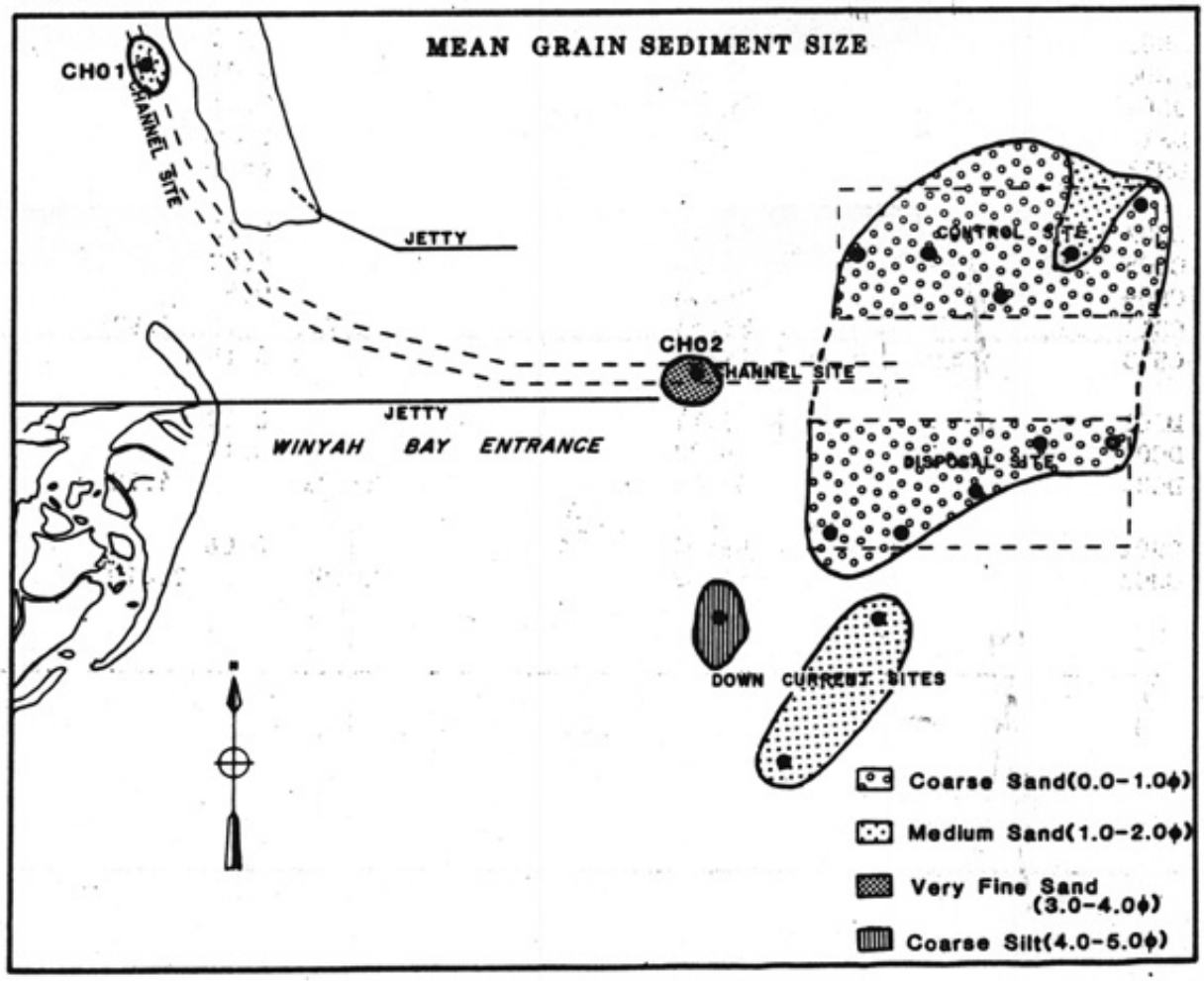

Figure 11. Distribution of mean grain size of sediments collected from the Georgetown DMDS and vicinity.

Table 6. Percentages of sand, silt and clay in sediments from the Georgetown DMDS and vicinity. Estimates represent percent by weight.

STATIONS	SAND	SILT - CLAY
DS03	99.74	0.26
DS06	99.96	0.04
DS08	99.33	0.67
DS10	100	trace
DS13	100	trace
CS02	99.40	0.60
CS05	99.98	0.02
CS09	99.46	0.54
CS11	83.66	6.42 9.92
CS13	99.85	0.15
DC01	99.11	0.89
DC02	99.88	0.12
DC03	37.89	27.39 34.72
CH01	99.94	0.06
CH02	54.72	20.09 25.19

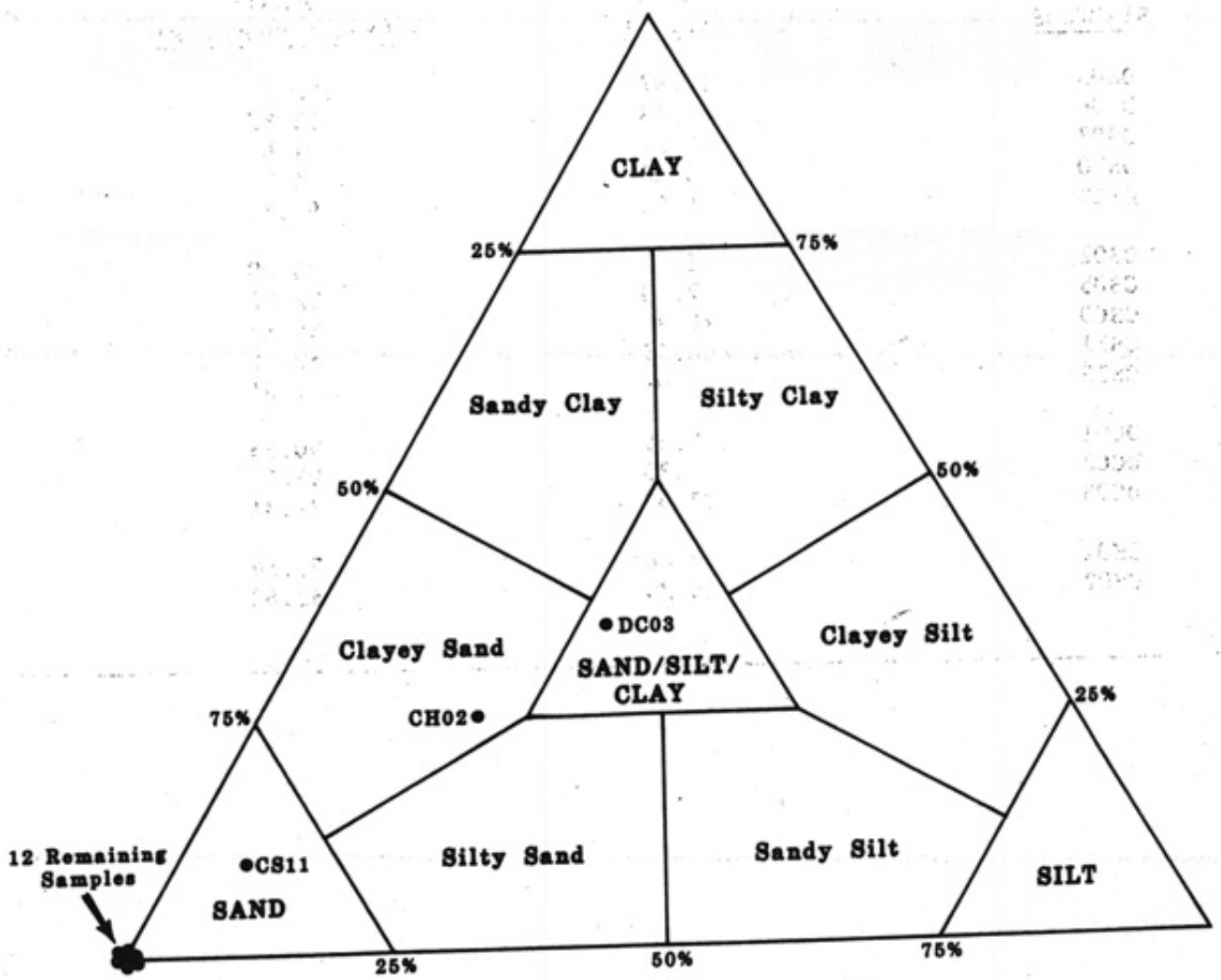

Figure 12. Shepard's classification of sediment types at stations in the Georgetown DMDS and vicinity.

Table 7. Calcium carbonate content of sediments from the Georgetown DMDS and vicinity. Estimates represent percent by weight.

STATIONS	$CaCO_3$ (Shell)	QUARTZ (Non-carbonates)
DS03	14.97	85.03
DS06	6.18	93.82
DS08	8.39	91.61
DS10	5.26	94.74
DS13	4.66	95.34
CS02	6.00	94.00
CS05	7.33	92.67
CS09	10.88	89.12
CS11	10.65	89.35
CS13	10.09	89.91
DC01	9.65	90.35
DC02	6.33	93.67
DC03	27.69	72.31
CH01	3.46	96.54
CH02	16.38	83.62

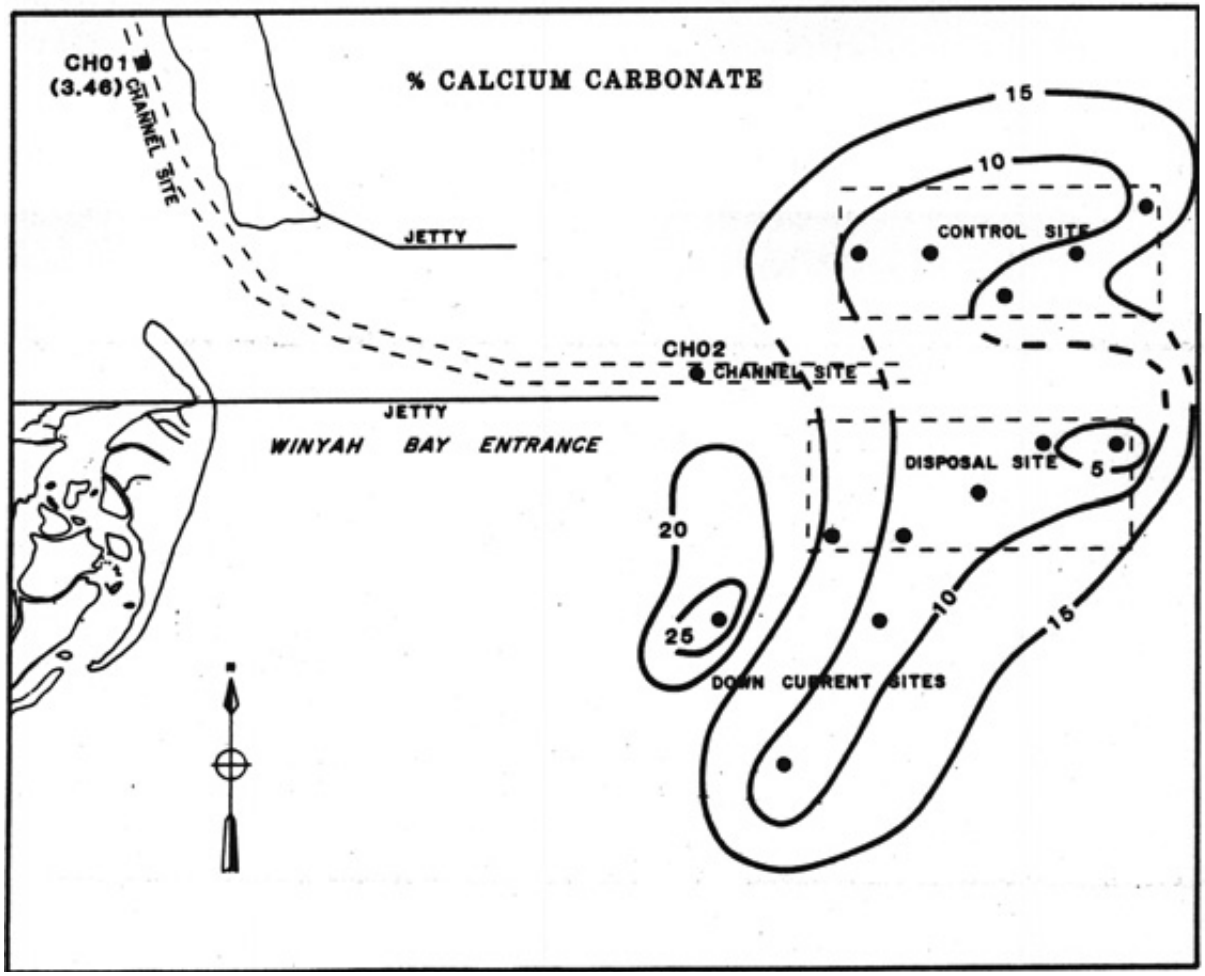

Figure 13. Distribution of percent calcium carbonate content of sediments collected from the Georgetown DMDS and vicinity. Click here to continue