Connecticut · Coastal Zone Management Program

Coastal Ecosystem Database Study
Western Long Island Sound, Greenwich to Housatonic River

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THE OCEANIC SOCIETY

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Education, Research, Conservation

-FINAL REPORT-

Coastal Ecosystem Database Study Western Long Island Sound, Greenwich to Housatonic River

Conducted with financial assistance provided by the Coastal Zone Act of 1972, as amended, and administered by the Office of Ocean and Coastal Resource Management, National Oceanic and Atmospheric Administration, Department of Commerce and the State of Connecticut Office of Policy and Management.

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Note: Appendices are available for review at The Oceanic Society, Stamford, Conn. or the State of Connecticut's Coastal Area Management Office in Hartford.

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Additionally, the Society notes with appreciation the assistance of Mr. Robert W. Jackson and Mr. Ben Grundstein in the development of the computer systems and programs utilized in the analysis of data for this project.

I. Introduction

The "Coastal Ecosystem Database Study Western Long Island Sound, Greenwich to Housatonic" study was conducted by the Oceanic Society for the South Western Regional Planning Agency (SWRPA) under financial assistance provided by the Coastal Zone Management Act of 1972, as amended, and administered by the Office of Ocean and Coastal Resource Management, National Oceanic and Atmospheric Administration, Department of Commerce and the State of Connecticut Office of Policy and Management under the Coastal Energy Impact Program (CEIP). The principal objective of this two-year research project is to establish a database covering principal species of marine life, exclusive of vegetation, currently found from the Byram River in Greenwich to Charles Island off Milford. Data developed during this CEIP study may assist government and corporate officials responsible for oil spill control along Connecticut's southwestern coast.

Five principal sampling and research techniques were utilized during this study to assess current marine conditions at sites selected in consultation with the program's scientific advisor. Sampling stations were chosen to include known distributions of economically important marine species and sampling was sufficiently frequent to reflect seasonal variation in populations of these species. This data set provides a baseline for assessing the impact of future oil spills. Samples of benthic dwelling organisms were collected at 83 locations to provide a basis for gauging habitat quality of the benthic environment. Benthic sampling sites were selected to reflect both geographical and coastal resource considerations. A series of otter trawls was taken at 12 sites to identify areas where concentrations of important commercial or recreational species (finfish and lobsters) are to be found and to document their seasonality. Gill nets were set at 13 locations to identify shallow water sites where significant transitory and migratory schooling fishes can be found on a seasonal basis. In the gut of economically significant finfish taken in the otter trawls, contents were noted or identified as algae, egg masses, or when possible, animal (prey). Finally, an analysis of hydrocarbons in sediment samples and selected organisms was conducted by Dr. Dennis Waslenchuk at the University of Connecticut's Marine Science Institute, (see Appendix 6 for his full report).

Methodology utilized during this CEIP research is summarized in section II of this report. Results are presented and summarized in Section III. A summary of study results keyed to coastal municipalities in the study area comprises Section IV. Recommendations for further study are found in Section V. Ten Appendices containing detailed field data sheets, species lists, the hydrocarbon report, site location charts, and the bibliographic sources are available for review in the Oceanic Society's library in the Stamford Marine Center and the State of Connecticut's Coastal Area Management office in Hartford.

The CEIP study presents a comprehensive coastal ecosystem database detailing environmental conditions within the study area from June 1981 to March/April 1983. The study area, extending 35 linear miles, encompasses nine municipalities and accounts for an actual coastline measuring more than 125 miles. This report represents the first comprehensive attempt at collecting baseline data on benthic and demersal species along with endemic and migratory finfish. The data can be used to assess seasonal and year-by-year trends at specific sampling sites and trends manifested on a broader geographical scale.

Taken without further documentation or research, this CEIP project confirms known distributions of, and presents new information on, economically important finfish and crustaceans. Our report also presents a significant amount of new baseline data and provides a relative habitat ranking of sites studied within southwestern Connecticut's coastal zone and inshore areas. However, the true value of this CEIP report lies in its use as a baseline data reference. It should serve as a starting point for further evaluation of important environmental and economic questions. For example, this data can be used as a reference in future studies of:

1) control of non-point hydrocarbon pollution sources;

2) investigation of the parasite Glugea stephani's impact on winter flounder recreational fisheries; and

3) examination of the role opportunistic (pioneering) benthic invertebrates play as a major food source for the winter flounder.

Increased population density and a continued dependence on petroleum products for transportation, generation of electricity, and heating purposes has intensified transport of petroleum products along the coastline and into the harbors of southwestern Connecticut. Significant tidal wetlands; shellfish beds; commercial and recreational fishing areas; and breeding areas for marine species are found in the study area. Before distribution of this research report, only a few marine studies, limited in scope, had been conducted in this region.

This CEIP project provides a comprehensive coastal ecosystem database which provides a basis for future oil spill damage assessment and management. It is complemented by a second CEIP research project conducted for the Connecticut State Department of Agriculture's Aquaculture Division by Dr. Peter Pellegrino of Southern Connecticut State University. The Aquaculture Division's study sampled offshore sites along Connecticut's coast once during the two year study period. In contrast, our study sampled inshore sites repeatedly along western Connecticut's coast. These studies are designed to be used together in developing a Sound-wide view of coastal energy impact problems and conditions.

II. Study Area & Methods

The methodology used in this study is described first in general and then in more specific terms. After describing the boundaries of the study area, details of procedures used for collection and identification of benthic, otter trawl, gill net and hydrocarbon samples is presented. This section concludes with a discussion of the computer program used in statistical analysis of data.

Study Area

The area studied in this CEIP research project encompassed coastal waters off Fairfield and a small portion of New Haven counties in southwestern Connecticut. The study area was bounded to the east by Charles Island off Milford, CT; to the north by the mean low water line along the shore; to the west by the Byram River which separates Greenwich, CT from New York state; and to the south by the 30-foot bottom depth contour line. All sites for collection of samples during this two year study were within this area.

Boundaries of the study area were based on three principal factors:

1. a review of primary navigation routes for transportation of petroleum products to marine terminals within Connecticut's coastal waters;

2. an assessment of recognized nearshore navigational hazards along these navigation routes in western Long Island Sound; and

3. an absence of scientific studies reporting and evaluating density and diversity of benthic community life; hydrocarbon levels in sediments and invertebrates; and seasonal spawning patterns of finfish and lobsters.

This study was conducted by the Oceanic Society's scientific staff utilizing facilities in the Stamford Marine Center and the Society's research vessel, the R/V OCEANIC. An examination of hydrocarbon levels in sediment and marine life in this study area was conducted by Dr. Dennis Waslenchuk at the University of Connecticut's Marine Sciences Institute as part of this research contract.

Collection of specimens in the field during the study was timed to reflect seasonal variations in resident or migratory species. Sampling was repeated during the spring, winter, summer and fall seasons of 1981-82 and 1982-83. Both commercially important species, such as the lobster, Homarus americanus, and significant sport fish, such as the winter flounder, Pseudopleuronectes americanus, were collected during the study's eight sampling periods. Benthic infaunal invertebrates, sediments, and representative bivalve molluscs were also collected during this study.

Within the study area, sampling stations were located to include those areas which are potentially vulnerable to a spill of petroleum products which are commonly carried on the Sound. The vast majority of oil presently carried along Connecticut's coast is either No. 2 (home heating) or No. 6 (industrial). (U.S. Coast Guard, personal communication.) Shipment of petroleum products comprise between 65 and 96 percent of the commercial tonnage received at ports in the study area. Marine environmental effects of a spill of these substances are expected to be especially significant on species living in areas $\leq$ 30 feet of water. (Rhoads, personal communication.) Benthic, otter trawl and gill net sampling sites were located throughout the entire study area while hydrocarbon sampling stations were concentrated on those urban ports which have marine petroleum terminals.

Initially, the study included 83 benthic, 12 otter trawl, 13 gill net and 46 hydrocarbon sampling stations. Benthic, otter trawl and gill net sites were sampled in June, 1981; August, 1981; November, 1981; March/April, 1982; June, 1982; August, 1982; November, 1982; and March/April, 1983. This sampling schedule was designed to study successional development of benthic community life. (Rhoads, personal communication.) The principal hydrocarbon sampling occurred during August, 1982 and eight additional samples were gathered in March, 1983.

Benthic, otter trawl and gill net locations were designed to:

1. reflect an equitable geographical distribution among coastal communities;

2. allow analysis of the successional theory for estuarine benthic communities which may have experienced ecological stress;

3. reflect known migratory patterns of finfish deemed important as a commercial or recreational resource;

4. reflect known navigational hazards which could cause accidental release of petroleum products to the marine environment; and

5. identify habitats and their communities which would be endangered if an oil spill occurred.

The objectives of our hydrocarbon research were:

1. to provide a synoptic baseline for petroleum hydrocarbon concentrations in the nearshore and inshore sediments of a segment of western Long Island Sound's northern coast;

2. to attempt to relate the distribution of petroleum hydrocarbons in sediments to local shipping activities and land use practices; and

3. to attempt to relate petroleum hydrocarbon burdens in sediments to those found in associated shellfish.

The hydrocarbon study area encompassed the inner harbors and nearshore waters along the Connecticut coastline from Greenwich to Bridgeport. Cos Cob Harbor, Stamford Harbor, Holly Pond, Norwalk Harbor, Black Rock Harbor, Bridgeport Harbor, and the estuary of the Housatonic River were chosen for inshore study sites because of the likely occurrences there of oiled sediments and organisms due to extensive shipping and handling of petroleum products, (see charts in Appendix 9).

Sediments sampled for hydrocarbon analysis ranged in appearance from relatively clean sand to black quasi-fluid mud and contained a variety of benthic life forms. One hundred fifteen sediment samples and 31 shellfish samples (bivalves) from the August 1982 sampling period were analyzed by synchronous fluorescence (see Appendix 6). Eight additional sediment samples collected in March 1983 were also analyzed to provide data on the seasonal persistence of polyaromatic hydrocarbons (PAHs) relative to the earlier synoptic survey. Shellfish examined in this project included the clams *Mya arenaria* and *Mercenaria mercenaria*, as well as the mussels *Mytilus edulis* and *Geukensia demissus*.

SAMPLING AND ANALYTICAL TECHNIQUES

This section examines in detail methods used in field collection and laboratory analysis of benthic, otter trawl, gill net and hydrocarbon samples. We also include a description of the computer program used to analyze our data.

Benthic Sampling

Samples of bottom dwelling organisms were collected and evaluated to assess benthic conditions along Connecticut's southwestern coast. Animals gathered in the Van Veen grab were counted and identified by genus and species. This information was used in calculating species diversity for each site using the Shannon-Weiner formula (Log base 10) as supplied by Dr. Robert Cerrato at the State University of New York in Stony Brook, Long Island. Data on density of benthic animal life was used to estimate productivity at sampling locations. Of 83 initial benthic sampling stations, 57 were to be sampled eight times during the two year study. Another 26 sites were to be sampled twice during the study. After the second sampling period (August, 1981), in consultation with the Scientific Coordinator, six of these 83 sites were discontinued and samples from another 12 stations were archived. Discontinued sites were judged to be either duplicative of remaining sampling locations or seen as areas of minimal benthic life due to gravel or rocky bottoms. Sites 18, 26, 39, 44, 53 and 64 were discontinued. Sites selected for archiving were duplicates of nearby stations. Samples were collected and archived for sites 2, 14, 16, 22, 29, 31, 33, 46, 50, 70, 74 and 76 throughout the remaining six sampling periods.

Most of the benthic sampling was completed aboard the 40-foot R/V OCEANIC. An 18-foot boat was used to reach shallow water samples. For offshore stations, Loran C and latitude/longitude coordinates were taken at each site during the first sampling period using a Raytheon Northstar 6000 aboard the R/V OCEANIC. For shallow water sites, coordinates of landmarks were taken by triangulation using a hand compass and nautical chart. During each sampling period, these coordinates were taken and then used to return to each station for repeated sampling, (see Appendix 7).

At each sampling station, four replicate benthic grabs were taken four feet off the port side (amidships) using a Van Veen type bottom grab which sampled an area of 1/25th of a square meter. Once a sample came onboard, the thickness of the redox layer was measured, type of bottom material noted, and a general description of the sample recorded on a field data sheet. This description included notation of tubes of polychaetes and/or amphipods; shells; algae; rocks; and fluff (a floccular layer of surficial material). Information on polychaetes and amphipods is recorded as "Comments" on benthic data sheets in Appendix 1 while descriptive field data is recorded in Appendix 7.

Each replicate sample was placed in a bucket and then passed through a 1 millimeter mesh sieve. Materials retained by the sieve were fixed in a 10 percent pH buffered formaldehyde solution containing Rose Bengal and returned to the Society's Stamford Marine Center lab. After each period of field work, samples were transferred to a 70 percent ethyl alcohol solution in the lab.

Observations or readings were recorded at each sampling station for: meteorological conditions; sea conditions; secchi disk readings; surface and bottom dissolved oxygen levels; salinity; water temperature; water conductivity; and water pH. The data recorded for these readings can be found in Appendix 7 of this report. Instruments used in completing these measurements included a YSI dissolved oxygen meter (Model #57), a Beckman Electrodeless Salinometer, and a Corning pH meter (Model #3) which was replaced by a Beckman meter (Model #pHI30) after the second sampling period.

In the Stamford Marine Center laboratory, each of the four replicate samples from a single site were examined and sorted by phyla. Individual organisms were then identified by genus and species and counted within these categories. Fauchald, 1977, was used to identify polychaete genera and a series of taxonomic keys was utilized to identify the species of these worms. These taxonomic keys included

Hartman, 1968; Hartman, 1969; Barnes, 1974; Smith, 1964; and Day, 1973. Samples of Capittellidae Orbinida and Eunicida were sent to Taxon, Inc. in Salem, Massachusetts for confirmation of our identification. In identifying the molluscs to genus and species the following taxonomic keys were used: Gosner, 1979, 1978; and Morris, 1951. A representative sample of molluscs was sent to Taxon for confirmation of identification. Arthropods were keyed to genus and species using Bousfield, 1973; Gosner, 1971, 1979; and Miner, 1950. Results of this work are found in Appendix 1, 8-A and 8-B.

Otter Trawls

Finfish and other benthic and demersal species were sampled at 12 previously described locations using an otter trawl 30 feet long and 15 feet across. It was determined after the initial sampling period that sites 5 and 6 were in close proximity and yielded repetitive data. Therefore site 6 was deleted from the remainder of the study. The body of the net consisted of a 2-inch stretch netting woven with #21 nylon tarred twine. The cod end was 1-1/2 inch stretch of a heavier #30 untarred twine. Two (32 by 16-1/2 inch) oak and iron doors were attached directly to the wings without legs. A cod end buoy was attached to the cod end by 30 feet of line and was used to facilitate net retrieval.

The net was towed from the stern of the boat using a 1/4 inch steel cable attached to the door chains. The length of cable deployed was determined by water depth. For depths less than 25 feet, 100 feet of cable was used, and for depths greater than 25 feet, 150 feet of cable was used. The length of trawling time was 15 minutes from the moment the required length of cable was extended to the time of retrieval. Trawling was done at idle speed (500 to 600 rpm) along a set course. Latitude and longitude coordinates were taken with a Raytheon Northstar 6000 at the start and end of each trawl.

Two trawls were made at each otter trawl site. Where possible, these were made in a straight line, first in one direction, then back along the same trawl path in the opposite direction. Exact trawling paths were dictated by bottom topography and substratum type. This sampling method was restricted to flat sandy or muddy bottoms.

After each 15 minute trawl period, the net was recovered using the winch, and the catch deposited in a seawater-filled sorting table on board. Commercial and recreationally important fish (Pseudopleuronectes americanus, Tautoga onitis, etc.) were counted and measured to the nearest 1/2 cm and sex of the winter flounder was determined using the rough/smooth peduncle method, (Pertmuller, 1947). Lobsters were sexed, carapace length measured to the nearest 1/2 cm with a ruler, and any deformities or missing appendages recorded. The sex of other arthropods was determined visually, if possible, and the numbers of each sex counted. The remaining organisms were simply counted, or in the case of ctenophores, algae and various colonial organisms, only presence was noted.

All organisms from the first trawl at a location were retained alive on board until the second trawl had been retrieved. This ensured that none of these organisms would be recaptured by the second trawl. When the second trawl was on board, organisms from the first trawl were released except for the Pseudopleuronectes americanus, Tautoga onitis, Stenotomus chrysops, and other commercial or recreational species. These were retained and frozen for gut and gonadal analysis. Any animal captured in the second trawl were also retained for gut and gonadal analysis unless the number captured in the first trawl was large enough for statistically meaningful results.

Otter trawl data are reported in Appendix 2. A count of otter trawl species is found in Appendix 3 while the otter trawl species list is included as Appendix 8-C.

Gill Nets

To document the seasonal presence and spawning condition of schooling fish (menhaden, Brevoortia tyrannus; Atlantic mackerel, Scomber scombrus; Atlantic herring, Clupea harengus; etc.) gill nets were set at 13 sites equally distributed through the sampling area. A net of three 6-foot by 25-foot segments of three, four, and five inch mesh respectively was set at a depth not exceeding 15-feet mean low water. Mesh sizes were selected to obtain results which would be used for comparing catches in different mesh sizes. Each net was left for approximately 12 hours, from late afternoon until early morning. The gill nets were set at night after we found that schooling fish avoid the light colored twine net during daylight hours. Ensnared fish were collected from the net, and their location in the net relative to mesh size, overall length, and spawning condition was noted. Fish were identified, counted, and measured to five-tenths of a centimeter, forklength.

Gut Analyses

Gut analysis was performed on the commercially and recreationally important finfish captured in otter trawls. When possible, this analysis was done while onboard within a few hours of capture of the organisms. Otherwise, all specimens were iced onboard and frozen upon return to the laboratory.

The number of organisms retained for gut analysis varied for each species. For *Pseudopleuronectes americanus*, when possible, a minimum of 60 fish were retained. If this number was captured in the first trawl, all of the *P. americanus* from that trawl were retained. If the first trawl yielded an insufficient number, the *P. americanus* from both trawls were kept. For the other major commercial and/or recreational species, all fish from both trawls were kept.

Gut analysis was performed by evisceration and examination of the contents of both the stomach and intestine of each fish. Organisms from the gut were identified to the familial or generic level when possible. Otherwise, organisms were placed into the phyla or orders. This method minimized the time consuming use of dissecting scopes for identification.

For each gut analyzed, presence or absence of each prey organism was recorded. No attempt was made to quantify numbers or weights of each prey category in each gut. Gonadal development was noted, as was any sign of disease, parasitism or morphologic abnormality.

Gut analysis data for the *P. americanus* was grouped according to fish size-class categories <15 cm, 15-20 cm, 20-25 cm, and >25 cm, although the specific size of each fish dissected within these size-class categories was not correlated with its gut content. These data are reported in Appendix 5 and a gut analysis species list is found in Appendix 8-D.

Hydrocarbon Measurements

Synchronous fluorescence spectroscopy has been used for qualitative hydrocarbon analysis, including multicomponent mixtures of polyaromatic hydrocarbons (PAHs). (Lloyd, 1971). Synchronous fluorescence involves the simultaneous variation of excitation and emission wavelengths at a constant wavelength offset ($\Delta \lambda$). The resulting synchronous spectrum is properly known as a "synchronously excited emission spectrum." (Vo-Dinh, 1978).

Synchronous fluorescence spectrophotometry can also be used for semi-quantitative to quantitative determinations. Advantages over more elaborate techniques such as gas chromatography and mass spectrometry include ease of sample preparation and speed of analysis. However, errors would arise if a basic assumption; i.e., that the fluorescence intensity of an unknown (a sample) would be quantitatively related to a set of standard reference oils was invalid. The quantitative relationship between unknowns and standards becomes invalid if naturally occuring heterocyclic and aromatic compounds are present and have high fluorescent intensities at positions on the spectrum that corresponded to peaks caused by PAHs. Such coincidences are not known to exist at present, but their likelihood has not been studied comprehensively. However, as the spectra of control samples (those collected for this study at locations more or less remote from obvious sources of PAHs as reported upon in Appendix 6) showed no natural background fluorescence that might confound the PAH spectra, we assume that interference from natural compounds was not significant.

Shellfish examined in this project are all filter-feeders. Some are infaunal (the clams Mya arenaria and Mercenaria mercenaria) and some epifaunal (the mussels Mytilus edulis and Geukensia demissus, and the oyster Crassostrea virginica). Although the organisms ingest suspended matter from the water column, the hydrocarbon body burdens of their tissue might be expected to reflect concentrations in surrounding bottom sediments if tissue comes into direct contact with contaminated bottom sediment, or if a major portion of the ingested suspended matter is actually locally resuspended bottom sediment. It has been found, for instance, that petroleum hydrocarbon concentrations in the mantle edge and siphon epidermis, tissues which are in contact with bottom sediments of Mya arenaria, are substantially greater than those in other internal tissues (Vendermeulen et al, 1977). Mercenaria mercenaria has mantle margins sealed to a lesser degree (Barnes, 1974), hence contact of body tissue with ambient sediment might be greater, along with a greater potential for hydrocarbon contamination.

Sediment samples for hydrocarbon analysis were taken with a Van Veen grab, and were dumped into a pre-cleaned, solvent rinsed porcelain pan. Subsamples were taken randomly from the interior portion of each grab sample, or from the interiors of distinct sedimentary layers where present. These aliquots were transfered to cleaned glass vials. The mouths of the vials were covered with a double layer of aluminum foil and capped. Samples were then stored at -20°C until analysis.

PAHs were extracted from a two gram (wet weight) sediment aliquot. Two (2) ml of methanol were added to a test tube containing the aliquot, and the contents were vortex-mixed for about 30 seconds. This initial methanol treatment was intended to ensure that the sample became solvent-wetted. Next, 8 ml of cyclohexane were added and the preparation was vortex-mixed for 30 seconds to create a slurry which was then shaken by a wrist-action shaker for 20 minutes. Before the sample was centrifuged for 20 minutes, the test-tube was filled with distilled-deionized water (DDW) and was vortex-mixed for about 5 seconds. Addition of the DDW ensured that the extraction medium was polar, such that the non-polar PAHs would be effectively driven into the non-polar cyclohexane. The cyclohexane phase was subsequently removed and stored at -20°C until analysis.

Bivalves that were collected along with sediments were identified to the generic level and frozen until preparation for analysis. Shellfish were shucked and the tissue of all collected specimens of a genus were pooled, weighed and homogenized before PAH extraction. Analytic methods were the same as described for sediments. For G. gemma, and some samples of M. arenaria, small shell sizes prevented efficient shucking. In this case, entire organisms (including shells) were pooled, weighed and homogenized. A number of M. arenaria from a single location were homogenized both in the shell and after shucking, and the two treatments compared to provide a conversion factor. All analyses are reported on the same basis; i.e., soft tissue weight only. Analysis of shell material alone revealed no detectable PAHs.

The extraction method described yields the greatest quantity of fluorescing material of any method tested, including extraction from a dried sample, extraction without the initial methanol treatment, extraction with other solvents, and various vortex-mixing/shaking routines. Re-extraction of samples previously extracted as described above yielded no detectable residual fluorescence. Hence, the concentrations reported may be considered operationally as representing the "maximum extractable fluorescing hydrocarbons concentration."

Synchronous fluorescence spectra were obtained using a Ferrand MK-2A Spectrofluorometer. Spectra were obtained in the uncorrected mode of operation. The instrumental parameters were: time constant 0.7s; scanning speed 40 nm/min; and fixed gain setting. The spectral bandwidths for the excitation (Ex) and emission (Em) monochromators were 2.5 nm. The monochromators were scanned synchronously employing a 5 nm offset ($\Delta\lambda$) between excitation and emission monochromators. A $\Delta\lambda$ equal to 5 nm was found to be optimum in terms of spectral resolution and discrimination, a $\Delta\lambda$ less than or equal to 4 nm resulted in Rayleigh scatter interferences, and a $\Delta\lambda$ greater than 45 nm resulted in a loss of selectivity. A detailed description of the criteria used to select optimal spectral bandwidths and $\Delta\lambda$ can be found in Passwater, 1973; Andre et al, 1979; and Inman et al, 1982. Standard, fluorescence-free fused silica cells with a 10 mm pathlength were used to contain samples during analysis.

A Burrell wrist-action shaker, a Scientific Products deluxe Vortex Mixer, a Clay-Adams centrifuge and a Tekmar tissue homogenizer were used in sample preparation. Distilled-deionized water and HPLC grade reagents were used throughout. Preparation of API Reference Bunker-C Oil and #2 Fuel Oil, and cleaning procedures, followed ASTM D3650-78 criteria.

Sample extracts were intially screened at fixed EX290, EM360 to ensure that the analytic concentration was not so high as to cause quenching of the fluorescence emission due to inner filter effects and solute quenching. The fluorescence intensities of different dilution factors of the sample were measured and plotted against the dilution factors. An aliquot, with a fluorescence intensity falling on the quenching-free, linear, positive-slope portion of the characteristic bell-shaped fluorescence responses curve, was selected for synchronous scanning. A synchronous scan of each sample was thus obtained at a non-quenching dilution. The presence of Bunker-C oil, or #2 Fuel Oil, or both, was determined by direct visual comparison to the synchronous spectral pattern of the standards. The spectral patterns obtained for sediment and tissue extracts with few exceptions resembled those of only two reference standards (Bunker-C and #2 Fuel Oil). The sample spectra reflects the complex mixture of compounds originally present in the oils spilled and those produced by subsequent environmental alteration of these petroleum products. Therefore, hydrocarbons extracted from environmental samples may no longer be related to a "fresh" petroleum product.

Concentrations reported here are therefore labeled "Bunker-C equivalents" and "#2 Fuel Oil equivalents." This distinction is similar to that reported in fluorescence determinations of "oil" in seawater conducted for the global Pilot Project on Marine Pollution (Petroleum) Monitoring (MAPMOPP) under the sponsorship of the Intergovernmental Oceanographic Commission (IOC) and the World Meteorological Organization (WMO) (23). However, instrumental determinations in the MAPMOPP program were based only on single excitation (Ex310 nm) and emission (Em360 nm) wavelengths, rather than on synchronous determinations, and hence yielded less specific quantification than that achieved here. Results of this analysis are described in Appendix 6.

Computer Data Treatment

Compilation and analysis of data developed during this CEIP project was done on a TRS Model 12 microcomputer connected to a TRS-80 dot matrix line printer. Data from this study is filed on computer floppy disc and a reference hard copy is available at the Oceanic Society's headquarters in the Stamford Marine Center. A second copy of this information is filed with the Connecticut Coastal Management Program in Hartford, Connecticut.

Information statistics (Shannon-Weiner) were computed for each benthic sample in order to estimate a measure of sample diversity. The Shannon and Weiner (1964) formula

$$H_x = -\sum_{i=1}^{n} p_i \log 10\ p_i$$

was used where p_i = proportion of individuals belonging to species i.

The Computer program for this calculation was developed in consultation with Dr. Robert Cerrato at the State University of New York, Stony Brook. Diversity statistics for the study's eight sampling periods, as well as raw data for genera and species for each of four replicate samples, are found in Appendix 1. This appendix also includes a fifth, cumulative calculation which shows the sum total of species collected and species diversity for all animals collected during one sampling period at each site. Cumulative diversity results for the summary set of statistics are shown on nautical charts in Appendix 9.

Benthic data files in Appendix 1 are labeled to show when the samples were collected and the location of each sampling site. Specimens collected in the first sampling period during June of 1981 at the first station, for example, are labeled JUN81101 (ie., JUN-81-101) while the sample from that location during the second sampling period in August, 1981 is labeled AUG81201, (ie., AUG-81-201). This nomenclature is used throughout the report.

Otter trawl data were processed with a standard TRS Statistical Analysis program yielding descriptive statistics, such as size, frequency distribution, and bar-graph histograms. These calculations were made for those sampling sites which provided sufficient data for a statistically meaningful analysis. Statistical analysis of lobster data from otter trawls, for example, could be completed for 48 of 88 trawls. Size-frequency histograms require a minimum of eight data points and could not be completed for lobster trawls due to insufficient data. Otter trawl data are reported in Appendix 2.

III. Results

Benthic Results

Benthic diversity was computed for each of four replicate samples collected at a site during each period of field work. A cumulative diversity value was calculated using the sum total of data from the four replicate grabs. Cumulative diversity for each of the eight sampling periods is shown at each station in Table 1, (See Appendix 1 for all benthic data and diversity values). In order to compare diversity results to other parameters measured in this study, a value of (+1), (0), or (-1) was assigned to each site based on data in Table 1. Diversities in the upper third of the range for each sampling period were valued at (+1), diversities in the middle third of that range were valued at (0), and diversities in the bottom third were valued at (-1). These values are reflected in Table 2.

Benthic secondary productivity (turnover rate of biomass per unit time) can be estimated from standing stock biomass. In this study, this is simply the density of organisms per square meter. Stations with $\geq$ 10,000 individuals M^{-2} are inferred to have higher relative turnover rates than stations with densities of 1,000 to 9,999 individuals M^{-2}. Stations with < 1,000 individuals M^{-2} are inferred to have relatively low productivities. The correlation of standing stock density (biomass) to population turnover rate is based on the observation that opportunistic species attain much higher densities than "equilibrium" species. (Rhoads, McCall, Yingst, 1978). Productivity, estimated in this way, is conservative in this study as most opportunistic species are small and readily

Table # 1 Title Benthic Diversity

Values shown are for the combined four replicates.

Site #	Sampling Period 1	2	3	4	5	6	7	8
1	0.66082	0.55938	0.86142	0.70147	0.72458	0.72592	0.53265	0.62092
2	A	A	A	A	A	A	A	A
3	1.09087	0.99610	0.98665	1.00386	1.12833	0.94133	0.85297	0.72889
4	0.50945	0.42669	0.45225	0.73107	0.78425	0.82220	0.59543	0.88440
5	0.98687	/	/	/	1.15294	/	/	/
6	0.45154	0.63526	0.37918	0.90977	0.46878	0.00000	0.00000	0.43873
7	0.00000	0.31948	0.45062	0.55340	0.53936	0.22112	0.50878	0.39170
8	0.81838	/	/	/	0.87016	/	/	/
9	0.60206	0.84466	0.17397	0.62031	0.27643	0.48968	0.17820	0.11066
10	0.68023	0.44566	0.74922	0.84938	0.77274	0.76384	0.77676	1.03000
11	0.83539	/	/	/	0.62413	/	/	/
12	0.70720	0.45077	0.59087	0.19758	0.68007	0.66030	0.90283	0.65468
13	0.99982	/	/	/	0.86410	/	/	/
14	A̸	A̸	A̸	A̸	A̸	A̸	A̸	A̸
15	0.00000	/	/	/	0.55826	/	/	/
16	A̸	A̸	A̸	A̸	A̸	A̸	A̸	A̸
17	0.22565	0.81434	0.44085	0.12512	0.57800	0.76915	0.66744	0.94781
18	D	D	D	D	D	D	D	D
19	1.05567	0.69727	0.94508	0.95427	0.94467	0.43959	1.10310	0.87829
20	0.30018	/	/	/	0.46151	/	/	/
21	0.85992	/	/	/	0.84396	/	/	/
22	A	A	A	A	A	A	A	A
23	0.85775	0.41525	0.81714	0.58079	0.71006	0.37514	0.19744	0.13086
24	0.61227	1.01231	0.79109	0.63625	0.99344	0.62614	0.82806	0.55486
25	0.69215	/	/	/	0.86354	/	/	/
26	D	D	D	D	D	D	D	D
27	0.63847	0.63399	0.55803	0.26090	0.30103	0.40689	0.46623	0.37086
28	0.84688	1.04478	0.87514	0.86099	0.97343	0.83626	1.12976	0.93192
29	A	A	A	A	A	A	A	A
30	0.43925	0.45585	0.43203	0.33689	0.55838	0.82476	0.15147	0.18757
31	A	A	A	A	A	A	A	A
32	0.89588	0.27752	0.96482	0.82991	0.86542	1.04037	0.82963	1.00354
33	A	A	A	A	A	A	A	A
34	0.96484	/	/	/	0.77813	/	/	/
35	0.88159	0.96440	0.93585	1.06291	1.10327	1.04048	0.26866	0.84016

Table # 1

Site #	1	2	3	4	5	6	7	8
36	0.49903	/	/	/	0.71608	/	/	/
37	0.99322	1.12547	1.04561	0.95242	0.75839	0.82102	0.94375	0.87435
38	0.82417	/	/	/	1.15736	/	/	/
39	D	D	D	D	D	D	D	D
40	0.95388	1.02603	0.67653	0.44893	0.82612	1.18468	0.67805	0.91050
41	0.82369	/	/	/	0.97254	/	/	/
42	1.09367	0.64630	0.79930	0.80031	0.79057	0.42570	0.55047	0.38818
43	0.54829	/	/	/	0.78820	/	/	/
44	D	D	D	D	D	D	D	D
45	0.98260	1.00619	0.88487	0.69758	0.78846	1.14477	0.60980	0.83974
46	X	X	X	X	X	X	X	X
47	0.44131	0.87072	0.73656	0.62360	0.61176	0.95771	0.63911	0.10349
48	0.93776	1.24379	0.77923	0.69894	0.62534	0.62043	0.81087	1.20875
49	0.36858	/	/	/	0.46726	/	/	/
50	A	A	A	A	A	A	A	A
51	0.44060	/	/	/	0.82957	/	/	/
52	0.72306	0.76151	0.71125	0.83394	1.01861	0.71241	0.80900	0.66199
53	D	D	D	D	D	D	D	D
54	0.93585	0.76808	0.74937	0.95581	0.61988	0.60006	0.64743	0.38811
55	0.62109	0.96787	0.76823	0.83553	0.85212	0.84347	0.69988	0.50710
56	0.31846	0.26882	0.43753	0.09234	0.49694	0.30717	0.55796	0.36636
57	0.81323	/	/	/	0.35749	/	/	/
58	0.15567	0.91105	0.48527	0.72977	0.11160	0.57025	0.46459	0.54751
59	0.24120	0.74660	1.08700	0.88044	0.89315	1.18657	0.94394	0.82767
60	0.63925	/	/	/	0.95072	/	/	/
61	0.66649	0.82527	0.76552	0.78444	0.47208	0.41683	0.47950	0.41738
62	0.67131	0.51892	0.37951	0.46565	0.81781	0.73150	0.41463	0.84690
63	0.58288	0.52574	0.72701	0.37998	0.83168	0.41270	0.67328	0.61033
64	D	D	D	D	D	D	D	D
65	0.53097	0.68418	0.55963	0.67613	0.40442	0.46623	0.74422	0.76291
66	0.00000	0.50104	0.32987	0.91286	0.14118	MISSING	0.67781	0.00000
67	0.00000	/	/	/	0.00000	/	/	/
68	0.48145	0.60959	0.41079	0.30746	0.31650	0.34939	0.34430	0.22583
69	1.12942	1.24938	0.90867	1.07586	0.79203	0.82735	0.74554	0.95464
70	A	A	A	A	A	A	A	A

Table # 1

Site #	1	2	3	4	5	6	7	8
71	1.05579	0.97016	0.97040	0.86818	0.36713	1.00630	0.43754	0.86107
72	0.00000	/	/	/	0.27643	/	/	/
73	0.71633	MISSING	0.49854	0.81151	1.07854	0.97780	0.64721	0.88150
74	X	X	X	X	X	X	X	X
75	1.16892	1.26759	0.70959	0.92830	0.05380	0.74427	0.59283	0.65099
76	A	A	A	A	A	A	A	A
77	0.53631	0.51648	0.82882	0.58360	0.28257	0.92455	0.18497	0.21122
78	0.13816	0.37765	0.00000	0.51057	0.09304	0.13712	0.83585	0.60629
79	0.59897	/	/	/	0.39290	/	/	/
80	0.69665	0.34572	0.30103	0.72883	0.48161	0.69660	0.97317	0.36587
81	0.66567	0.73209	0.59114	0.69648	0.31778	0.40652	0.58185	0.43724
82	0.04839	0.92027	0.97074	0.24262	0.10156	0.20368	0.45815	0.66463
83	0.32323	/	/	/	0.95640	/	/	/

/ = Sampled annually

A = Archived

X = Archived -- sampled annually

D = Dropped

Value	Range of Data by Sampling Period							
	1	2	3	4	5	6	7	8
+1	1.16892 0.779281	1.267589 0.934667	1.08700 0.724667	1.075860 0.748020	1.15736 0.771573	1,18657 0.791047	1.12976 .753173	1.20875 .805833
0	0.779280 0.389641	0.934666 0.601744	0.724666 0.362334	0.748020 0.420181	0.771572 0.385787	0.791046 .395524	.753172 .376587	.805832 .402917
-1	0.389640 0	0.601743 0.26882	0.362333 0	0.420180 0.09234	0.385786 0	.395523 0	.376586 0	.402916 0

Note: In this table, (+1) should be read as high or above average; (0) should be read as medium or average; and (-1) should be read as low or below average. Please remember these terms apply only to the factors measured through the study's sampling program and are not an absolute indication of overall marine environmental quality.

Table # 2 Title Benthic Diversity (H_5) Grouping of Data from Table 1

Site #	Sampling Period 1	2	3	4	5	6	7	8	Total Value
1	0	-1	+1	0	0	0	0	0	0
2	A	A	A	A	A	A	A	A	A
3	+1	+1	+1	+1	+1	+1	+1	0	+7
4	0	-1	0	0	+1	+1	0	+1	+2
5	+1	/	/	/	+1	/	/	/	+2
6	0	0	0	+1	0	-1	-1	0	-1
7	-1	-1	0	0	0	-1	0	-1	-4
8	+1	/	/	/	+1	/	/	/	+2
9	0	0	-1	0	-1	0	-1	-1	-4
10	0	-1	+1	+1	+1	0	+1	+1	+4
11	+1	/	/	/	0	/	/	/	+1
12	0	-1	0	-1	0	0	+1	0	-1
13	+1	/	/	/	+1	/	/	/	+2
14	X	X	X	X	X	X	X	X	X
15	-1	/	/	/	0	/	/	/	-1
16	X	X	X	X	X	X	X	X	X
17	-1	0	0	-1	0	0	0	+1	-1
18	D	D	D	D	D	D	D	D	D
19	+1	0	+1	+1	+1	0	+1	+1	+6
20	-1	/	/	/	0	/	/	/	-1
21	+1	/	/	/	+1	/	/	/	+2
22	A	A	A	A	A	A	A	A	A
23	+1	-1	+1	0	0	-1	-1	-1	-2
24	0	+1	+1	0	+1	0	+1	0	+4
25	0	/	/	/	+1	/	/	/	+1
26	D	D	D	D	D	D	D	D	D
27	0	0	0	-1	-1	0	0	-1	-3
28	+1	+1	+1	+1	+1	+1	+1	+1	+8
29	A	A	A	A	A	A	A	A	A
30	0	-1	0	-1	0	+1	-1	-1	-3
31	A	A	A	A	A	A	A	A	A
32	+1	-1	+1	+1	+1	+1	+1	+1	+6
33	A	A	A	A	A	A	A	A	A
34	+1	/	/	/	+1	/	/	/	+2
35	+1	+1	+1	+1	+1	+1	-1	+1	+6

Table # 2

Site #	1	2	3	4	5	6	7	8	Tota Valu
36	0	/	/	/	0	/	/	/	0
37	+1	+1	+1	+1	0	+1	+1	+1	+7
38	+1	/	/	/	+1	/	/	/	+2
39	D	D	D	D	D	D	D	D	D
40	+1	+1	0	0	+1	+1	0	+1	+5
41	+1	/	/	/	+1	/	/	/	+2
42	+1	0	+1	+1	+1	0	0	-1	+3
43	0	/	/	/	+1	/	/	/	+1
44	D	D	D	D	D	D	D	D	D
45	+1	+1	+1	0	+1	+1	0	+1	+6
46	A̸	A̸	A̸	A̸	A̸	A̸	A̸	A̸	A̸
47	0	0	+1	0	0	+1	0	-1	+1
48	+1	+1	+1	0	0	0	+1	+1	+5
49	-1	/	/	/	0	/	/	/	-1
50	A	A	A	A	A	A	A	A	A
51	0	/	/	/	+1	/	/	/	+1
52	0	0	0	+1	+1	0	+1	0	+3
53	D	D	D	D	D	D	D	D	D
54	+1	0	+1	+1	0	0	0	-1	+2
55	0	+1	+1	+1	+1	+1	0	0	+5
56	-1	-1	0	-1	0	-1	0	-1	-5
57	+1	/	/	/	-1	/	/	/	0
58	-1	0	0	0	-1	0	0	0	-2
59	-1	0	+1	+1	+1	+1	+1	+1	+5
60	0	/	/	/	+1	/	/	/	+1
61	0	0	+1	+1	0	0	0	0	+2
62	0	-1	0	0	+1	0	0	+1	+1
63	0	-1	+1	-1	+1	0	0	0	0
64	D	D	D	D	D	D	D	D	D
65	0	0	0	0	0	0	0	0	0
66	-1	-1	-1	+1	-1	MISSING	0	-1	-4
67	-1	/	/	/	-1	/	/	/	-2
68	0	0	0	-1	-1	-1	-1	-1	-5
69	+1	+1	+1	+1	+1	+1	0	+1	+7
70	A	A	A	A	A	A	A	A	A

Table # 2

Site #	1	2	3	4	5	6	7	8	Total Value
71	+1	+1	+1	+1	-1	+1	0	+1	+5
72	-1	/	/	/	-1	/	/	/	-2
73	0	MISSING	0	+1	+1	+1	0	+1	+4
74	A̸	A̸	A̸	A̸	A̸	A̸	A̸	A̸	A̸
75	+1	+1	0	+1	-1	0	0	0	+2
76	A	A	A	A	A	A	A	A	A
77	0	-1	+1	0	-1	+1	-1	-1	-2
78	-1	-1	-1	0	-1	-1	+1	0	-4
79	0	/	/	/	0	/	/	/	0
80	0	-1	-1	0	0	0	+1	-1	-2
81	0	0	0	0	-1	0	0	0	-1
82	-1	0	+1	-1	-1	-1	0	0	-3
83	-1	/	/	/	+1	/	/	/	0

/ = Sampled annually

A = Archived

A̸ = Archived -- sampled annually

D = Dropped

Note: In this table, (+1) should be read as high or above average; (0) should be read as medium or average; and (-1) should be read as low or below average. Please remember these terms apply only to the factors measured through the study's sampling program and are not an absolute indication of overall marine environmental quality.

pass through a 1 mm mesh sieve. Because a 1 mm mesh sieve was used in this study, our retention efficiency is low for these opportunists. Data on abundance of benthic organisms is summarized in Table 3 which reports the sum total of animals collected in four replicate grabs at each site during eight sampling periods. To compare these findings with other elements of our report, highly productive areas were assigned a value of (+1), moderately productive areas received a value of (0), and remaining locations received a value of (-1). This information is summarized in Table 4.

It is important to note that while the values computed for diversities and shown in Table 2 are relative to other samples collected during a single sampling period, values for productivity based on abundance ($\geq$1 mm size) and shown in Table 4 relate to a set of standards which do not vary from sampling period to sampling period. Results of this research confirmed the expectation that benthic secondary productivity values for sites in the study area are low. Values for both diversity and secondary productivity are evaluated in the report conclusions. Initial analysis of benthic diversity and secondary productivity does not appear to have either seasonal or cumulative patterns, (see Table 5). Further analysis of this data and additional field work (with finer mesh sieves) might determine if the study area is characterized by a high proportion of opportunistic species. If so, consideration of these productive opportunistic species as a source of food for economically important predators (demersal fish and crustaceans) may be an important factor in oil spill evaluation and management along Connecticut's southwestern coast.

Table # 3 Title Relative Benthic Secondary Productivity (Abundance) Data Showing Cumulative Numbers of Individuals/Number of Species for Four Replicate Samples During Each Period

Site #	Sampling Period 1	2	3	4	5	6	7	8
1	115/13	101/12	138/18	216/19	36/10	87/11	155/11	22/6
2	A	A	A	A	A	A	A	A
3	32/17	208/26	238/22	173/19	248/26	66/15	1207/27	242/17
4	47/12	941/19	205/14	77/12	755/24	540/22	856/20	79/16
5	81/21				88/24			
6	8/3	518/15	1441/11	40/10	92/7	2/1	12/1	19/4
7	0/0	8/3	17/4	150/10	249/9	14/3	1119/13	31/6
8	30/9				512/22			
9	4/4	385/24	127/4	212/16	3/2	14/5	2045/18	584/5
10	76/11	179/10	161/18	88/17	254/16	63/11	171/17	106/17
11	29/10				86/10			
12	48/9	313/11	56/9	41/5	93/13	96/9	1228/34	127/11
13	24/13				525/33			
14	X	X	X	X	X	X	X	X
15	0/0				588/13			
16	X	X	X	X	X	X	X	X
17	14/2	98/12	202/8	401/9	666/14	937/18	1114/32	48/12
18	D	D	D	D	D	D	D	D
19	80/20	278/18	598/29	359/22	517/23	580/18	1479/36	1230/33
20	22/3				152/9			
21	61/13				243/20			
22	A	A	A	A	A	A	A	A
23	78/12	844/14	231/16	395/15	52/11	1254/23	708/12	250/3
24	90/9	310/20	163/19	121/11	123/17	2398/21	178/14	53/5
25	68/14				197/16			
26	D	D	D	D	D	D	D	D
27	14/5	53/7	158/9	488/12	2/2	9/3	8/4	19/4
28	96/18	210/22	69/17	92/18	350/25	987/26	159/35	206/19
29	A	A	A	A	A	A	A	A
30	6/3	65/6	92/8	22/4	151/12	171/16	40/4	76/5
31	A	A	A	A	A	A	A	A
32	122/19	259/10	346/26	197/18	344/24	224/22	170/14	195/21
33	A	A	A	A	A	A	A	A
34	54/15				63/11			
35	39/10	218/17	733/29	302/24	579/37	236/27	235/6	498/29

Table # 3

Site #	1	2	3	4	5	6	7	8
36	9/4				112/12			
37	34/13	215/30	95/18	236/23	898/30	601/29	299/21	48/13
38	29/9				465/34			
39	D	D	D	D	D	D	D	D
40	46/15	125/17	100/8	16/4	138/16	228/26	202/19	111/13
41	132/14				560/28			
42	252/29	1977/22	277/17	59/10	72/13	3858/18	52/5	1178/20
43	366/11				626/18			
44	D	D	D	D	D	D	D	D
45	234/22	74/19	253/24	162/16	150/15	126/25	488/24	220/22
46	A	A	A	A	A	A	A	A
47	150/12	76/16	218/20	478/27	541/26	93/17	693/27	1087/17
48	49/11	234/31	133/20	130/19	250/25	98/16	920/28	355/32
49	9/3				83/6			
50	A	A	A	A	A	A	A	A
51	639/15				1005/21			
52	61/8	28/7	44/9	22/9	58/17	170/13	138/12	485/16
53	D	D	D	D	D	D	D	D
54	107/14	80/11	141/13	17/10	346/16	32/6	4010/23	2825/25
55	19/6	48/14	175/16	67/12	152/19	99/13	1449/32	798/21
56	36/4	195/8	71/7	45/3	295/12	39/4	978/15	1631/15
57	46/11				559/14			
58	383/9	134/15	571/13	207/26	543/7	64/9	269/7	277/10
59	479/10	340/18	94/21	199/19	205/15	139/27	237/28	241/18
60	808/24				119/23			
61	23/6	65/12	224/17	256/19	823/19	114/10	6943/42*	2618/26
62	55/8	58/6	176/9	107/10	209/14	144/13	2990/21	740/19
63	16/5	15/4	91/11	71/5	51/11	5/3	317/9	157/9
64	D	D	D	D	D	D	D	D
65	25/6	134/11	84/9	199/10	1561/15	8/4	352/12	126/12
66	0/0	82/9	11/3	378/18	10/2	MISSING	6/5	2/1
67	0/0				0/0			
68	25/5	62/9	84/7	65/4	545/9	28/5	4701/16	3013/18
69	101/24	166/28	182/20	103/22	24/9	30/9	1579/28	120/17
70	A	A	A	A	A	A	A	A

Table # 3

Site #	1	2	3	4	5	6	7	8
71	242/24	174/24	204/18	128/15	1854/27	147/20	630/18	876/31
72	0/0				3/2			
73	409/16	MISSING	80/11	23/9	89/19	553/26	47/7	599/24
74	~~A~~	~~A~~	~~A~~	~~A~~	~~A~~	~~A~~	~~A~~	~~A~~
75	135/28	201/36	309/21	233/20	1638/7	129/16	798/25	1098/34
76	A	A	A	A	A	A	A	A
77	531/24	27/5	540/22	17/6	2579/21	108/13	12014/32*	5243/28
78	2067/6	66/5	1/1	26/5	587/3	353/4	65/14	93/10
79	152/13				587/9			
80	470/18	903/10	2/2	20/7	92/6	218/15	1457/30	92/11
81	717/15	533/13	315/12	88/7	988/8	361/9	428/11	159/6
82	1226/9	510/15	154/17	28/4	4649/8*	200/7	5/3	80/6
83	258/10				302/25			

A = Archived

~~A~~ = Archived -- sampled annually

D = Dropped

* = Number of individuals excluded from calculation of range below and value of +2 assigned in table 4

Value	Range of Data by Sampling Period							
	1	2	3	4	5	6	7	8
+1	2,067 1,379	1,977 1,322	1,441 962	488 327	2,579** 1,721	3,858 2,573	4,701** 3,137	5,243 3,497
0	1,378 690	1,321 665	961 482	326 164	1,720 862	2,572 1,288	3,136 1,571	3,496 1,750
-1	689 0	664 8	481 1	163 0	861 3	1,287 2	1,570 5	1,749 2

** Higher data point excluded to make range of numbers more representative.

Note: In this table, (+1) should be read as high or above average; (0) should be read as medium or average; and (-1) should be read as low or below average. Please remember these terms apply only to the factors measured through the study's sampling program and are not an absolute indication of overall marine environmental quality.

Table # 4 Title Relative Benthic Secondary Productivity Values from Tables/Data

Site #	Sampling Period 1	2	3	4	5	6	7	8	Total Value
1	-1	-1	-1	0	-1	-1	-1	-1	-7
2	A	A	A	A	A	A	A	A	A
3	-1	-1	-1	0	-1	-1	-1	-1	-7
4	-1	0	-1	-1	-1	-1	-1	-1	-7
5	-1	/	/	/	-1	/	/	/	-2
6	-1	-1	+1	-1	-1	-1	-1	-1	-6
7	-1	-1	-1	-1	-1	-1	-1	-1	-8
8	-1	/	/	/	-1	/	/	/	-2
9	-1	-1	-1	0	-1	-1	0*	-1	-6*
10	-1	-1	-1	-1	-1	-1	-1	-1	-8
11	-1	/	/	/	-1	/	/	/	-2
12	-1	-1	-1	-1	-1	-1	-1	-1	-8
13	-1	/	/	/	-1	/	/	/	-2
14	~~A~~	~~A~~	~~A~~	~~A~~	~~A~~	~~A~~	~~A~~	~~A~~	~~A~~
15	-1	/	/	/	-1	/	/	/	-2
16	~~A~~	~~A~~	~~A~~	~~A~~	~~A~~	~~A~~	~~A~~	~~A~~	~~A~~
17	-1	-1	-1	+1	-1	-1	-1	-1	-6
18	D	D	D	D	D	D	D	D	D
19	-1	-1	0	+1	-1	-1	-1	-1	-5
20	-1	/	/	/	-1	/	/	/	-2
21	-1	/	/	/	-1	/	/	/	-2
22	A	A	A	A	A	A	A	A	A
23	-1	0	-1	+1	-1	0	-1	-1	-4
24	-1	-1	-1	-1	-1	+1*	-1	-1	-6*
25	-1	/	/	/	-1	/	/	/	-2
26	D	D	D	D	D	D	D	D	D
27	-1	-1	-1	+1	-1	-1	-1	-1	-6
28	-1	-1	-1	-1	-1	-1	-1	-1	-8
29	A	A	A	A	A	A	A	A	A
30	-1	-1	-1	-1	-1	-1	-1	-1	-8
31	A	A	A	A	A	A	A	A	A
32	-1	-1	-1	0	-1	-1	-1	-1	-7
33	A	A	A	A	A	A	A	A	A
34	-1	/	/	/	-1	/	/	/	-2
35	-1	-1	0	0	-1	-1	-1	-1	-6

Table # 4

Site #	1	2	3	4	5	6	7	8	Total Value
[illegible]	-1	/	/	/	-1	/	/	/	-2
37	-1	-1	-1	0	0	-1	-1	-1	-6
38	-1	/	/	/	-1	/	/	/	-2
39	D	D	D	D	D	D	D	D	D
40	-1	-1	-1	-1	-1	-1	-1	-1	-8
41	-1	/	/	/	-1	/	/	/	-2
42	-1	+1*	-1	-1	-1	+1*	-1	-1	-4**
43	-1	/	/	/	-1	/	/	/	-2
44	D	D	D	D	D	D	D	D	D
45	-1	-1	-1	-1	-1	-1	-1	-1	-8
46	~~A~~	~~A~~	~~A~~	~~A~~	~~A~~	~~A~~	~~A~~	~~A~~	~~A~~
47	-1	-1	-1	+1	-1	-1	-1	-1	-6
48	-1	-1	-1	-1	-1	-1	-1	-1	-8
49	-1	/	/	/	-1	/	/	/	-2
50	A	A	A	A	A	A	A	A	A
51	-1	/	/	/	0	/	/	/	-1
[illegible]	-1	-1	-1	-1	-1	-1	-1	-1	-8
53	D	D	D	D	D	D	D	D	D
54	-1	-1	-1	-1	-1	-1	+1*	0*	-5**
55	-1	-1	-1	-1	-1	-1	-1	-1	-8
56	-1	-1	-1	-1	-1	-1	-1	-1*	-8*
57	-1	/	/	/	-1	/	/	/	-2
58	-1	-1	0	0	-1	-1	-1	-1	-6
59	-1	-1	-1	0	-1	-1	-1	-1	-7
60	0	/	/	/	-1	/	/	/	-1
61	-1	-1	-1	0	-1	-1	+2*	0*	-3**
62	-1	-1	-1	-1	-1	-1	0*	-1	-7*
63	-1	-1	-1	-1	-1	-1	-1	-1	-8
64	D	D	D	D	D	D	D	D	D
65	-1	-1	-1	0	0	-1	-1	-1	-6
66	-1	-1	-1	+1	-1	MISSING	-1	-1	-5
67	-1	/	/	/	-1	/	/	/	-2
68	-1	-1	-1	-1	-1	-1	+1*	0	-5*
[illegible]	-1	-1	-1	-1	-1	-1	0	-1	-7
70	A	A	A	A	A	A	A	A	A

Table # 4

Site #	1	2	3	4	5	6	7	8	Total Value
71	-1	-1	-1	-1	+1*	-1	-1	-1	-6*
72	-1	/	/	/	-1	/	/	/	-2
73	-1	MISSING	-1	-1	-1	-1	-1	-1	-7
74	Ⱥ	Ⱥ	Ⱥ	Ⱥ	Ⱥ	Ⱥ	Ⱥ	Ⱥ	Ⱥ
75	-1	-1	-1	0	0	-1	-1	-1	-6
76	A	A	A	A	A	A	A	A	A
77	-1	-1	0	-1	+1*	-1	+2*	+1*	0**
78	+1*	-1	-1	-1	-1	-1	-1	-1	-6*
79	-1	/	/	/	-1	/	/	/	-2
80	-1	0	-1	-1	-1	-1	-1	-1	-7
81	0	-1	-1	-1	0	-1	-1	-1	-6
82	0	-1	-1	-1	+1*	-1	-1	-1	-5*
83	-1	/	/	/	-1	/	/	/	-2

* = Each time high abundance (more than 10,000 individuals per $meter^2$)

/ = Sampled annually

A = Archived

Ⱥ = Archived -- sampled annually

D = Dropped

Note: In this table, (+1) should be read as high or above average; (0) should be read as medium or average; and (-1) should be read as low or below average. Please remember these terms apply only to the factors measured through the study's sampling program and are not an absolute indication of overall marine environmental quality.

Table 5: Comparison of Benthic Sites by Diversity and Productivity Values from Tables 2 and 4

Site Numbers	Diversity Value (Table 2)	Productivity Value (Table 4)
1	0	-7
2	A	A
3	+7	-7
4	+2	-7
5	+2	-2
6	-1	-6
7	-4	-8
8	+2	-2
9	-4	-6
10	+4	-8
11	+1	-2
12	-1	-8
13	+2	-2
14	A	A
15	-1	-2
16	A	A
17	-1	-6
18	D	D
19	+6	-5
20	-1	-2
21	+2	-2
22	A	A
23	-2	-4
24	+4	-6
25	+1	-2
26	-D	D
27	-3	-6
28	+8	-8
29	A	A
30	-3	-8
31	A	A
32	+6	-7
33	A	A
34	+2	-2
35	+6	-6

Site Numbers	Diversity Value (Table 2)	Productivity Value (Table 4)
36	0	-2
37	+7	-6
38	-2	-2
39	D	D
40	+5	-8
41	+2	-2
42	+3	-4
43	+1	-2
44	D	D
45	+6	-8
46	A	A
47	+1	-6
48	+5	-8
49	-1	-2
50	A	A
51	+1	-1
52	+3	-8
53	D	D
54	+2	-5
55	+5	-8
56	-5	-8
57	0	-2
58	-2	-6
59	+5	-7
60	+1	-1
61	+2	-3
62	+1	-7
63	0	-8
64	D	D
65	0	-6
66	-4	-5
67	-2	-2
68	-5	-5
69	+7	-7
70	A	A

Site Numbers	Diversity Value (Table 2)	Productivity Value (Table 4)
71	+5	-6
72	-2	-2
73	+4	-7
74	A̸	A̸
75	+2	-6
76	A	A
77	-2	0
78	-4	-6
79	0	-2
80	-2	-7
81	-1	-6
82	-3	-5
83	0	-2

1 = Sampled Annually

A = Archived

A̸ = Archived Annually

D = Dropped

Note: In this table, (+1) should be read as high or above average; (0) should be read as medium or average; and (-1) should be read as low or below average. Please remember these terms apply only to the factors measured through the study's sampling program and are not an absolute indication of overall marine environmental quality.

Azoic conditions were judged to be found when no live animals were retained on the 1 mm sieve and no live organisms were seen passing through the 1 mm sieve. Azoic conditions were consistently reported at site 67 in Bridgeport's Black Rock Harbor. Other Bridgeport sites which were found to be azoic include: site 72, (June, '81); site 66, (June, '81); and site 67, (June '81 and June, '82). Azoic conditions were also found off the mouth of the Housatonic River at site 78, (November, '81); in Stamford Harbor at site 15, (June, '81); and in Greenwich at site 7, (June, '81).

Benthic sites were classified as highly productive (+1 in Table 4) when the abundance of organisms collected in a single sampling period exceeded a concentration of 10,000 individuals per square meter. By season, these sites included: spring, sites 71, 77, and 78; summer, sites 24 and 42; fall, sites 19, 54, 61, 62, 68 and 77; and winter, sites 54, 56, 61 and 77. Only site 77 was found to have high secondary productivity in three seasons during the study's two year duration. Site 42 was found to be highly productive during both summer sampling periods. Both sites 54 and 61 were found to be highly productive in two consecutive sampling periods (fall and winter).

Otter Trawls

Otter trawls were conducted and the catch assessed to identify areas off the Connecticut coast which hold significant concentrations of commercially or recreationally important marine species during specific periods of the year.

To equate otter trawl results to other elements of this study, the total number of organisms collected at each trawl site during the eight sampling periods was computed, (see Table 6). The range of animals caught (total number of individuals ranked highest to lowest) was divided into three equal parts for each sampling period. Sites in the top third received a value of (+1), sites in the middle third received a value of (0), and sites in the lowest third received a value of (-1). These site specific values are summarized in Table 7. Otter trawl location, duration, distance and raw catch data are found in Appendices 2 and 3.

Six significant commercial or recreational species were collected during the otter trawls. Two of these economically important species, the winter flounder (Pseudopleuronectes americanus) and lobster (Homarus americanus), were consistently caught. Catch of bluefish (Pomatomus saltatrix), scup (Stenotomus chrysops), weakfish (Cynoscion regalis), and blackfish (Tautoga onitis), varied by season. A majority of winter flounder taken during the fall (November '81 and '82) sampling periods appeared to be ready to spawn. Blackfish taken during the second spring sampling period (June, '82) at sites 5, 7, 10, 11 and 12 were sexually mature and ready for spawning. Other species collected did not appear to be in spawning condition.

Definite seasonal trends can be seen in otter trawl data collected during this two-year study. Concentrations of finfish caught in the otter trawl were highest during spring and fall sampling periods and lowest in summer and winter. A review of cumulative results for total number of significant commercial or recreational finfish gathered in the trawls during the study shows the following descending order: site

Table # 6 Title Otter Trawl Data Summary Showing Total Numbers of Commercially and Recreational Finfish and Lobsters* Taken from "A and B" Trawls

Site #	Sampling Period 1	2	3	4	5	6	7	8
1	182	261	134	52	122	54	118	11
2	132	64	93	25	263	10	110	16
3	114	31	50	5	39	16	57	7
4	135	109	119	31	126	159	179	11
5	56	42	69	36	404	296	263	64
6	D	D	D	D	D	D	D	D
7	148	22	812	9	29	53	79	16
8	214	38	10	14	377	48	121	10
9	19	2	10	12	187	101	195	13
10	118	15	34	41	97	56	180	29
11	19	6	6	22	38	23	26	15
12	62	31	28	16	35	2	71	38

D = Dropped

Value	Range of Data by Sampling Period 1	2	3	4	5	6	7	8
+1	214 to 150	261 to 176	812 to 546	52 to 37	404 to 280	296 to 199	263 to 185	64 to 46
0	149 to 85	175 to 89	545 to 276	36 to 21	279 to 155	198 to 101	184 to 106	45 to 27
-1	84 to 19	88 to 2	275 to 6	20 to 5	154 to 29	100 to 2	105 to 26	26 to 7

* Homarus americanus, pseudopleuronectes americanus, Stenotomus chrysops, Tautoga onitis, Paralichthys dentatus, Pomatomus saltatrix, Cynoscion regalis, Brevoortia tyranus taken during two 15-minuted trawls during each period.

Note: In this table, (+1) should be read as high or above average; (0) should be read as medium or average; and (-1) should be read as low or below average. Please remember these terms apply only to the factors measured through the study's sampling program and are not an absolute indication of overall marine environmental quality.

Table # 7 Title Otter Trawl Values Based on Total Values of Commercial and Recreational Species of Finfish* and Lobster Homarus Americanus

	Sampling Period								Total
Site #	1	2	3	4	5	6	7	8	Value
1	+1	+1	-1	+1	-1	-1	0	-1	-1
2	0	-1	-1	0	0	-1	0	-1	-4
3	0	-1	-1	-1	-1	-1	-1	-1	-7
4	0	0	-1	0	-1	0	0	-1	-3
5	-1	-1	-1	+1	+1	+1	+1	+1	+2
6	D	D	D	D	D	D	D	D	D
7	0	-1	+1	-1	-1	-1	-1	-1	-5
8	+1	-1	-1	-1	+1	-1	0	-1	-3
9	-1	-1	-1	-1	0	0	+1	-1	-4
10	0	-1	-1	+1	-1	-1	0	0	-3
11	-1	-1	-1	0	-1	-1	-1	-1	-7
12	-1	-1	-1	-1	-1	-1	-1	0	-7

D = Dropped

* *Pseudopleuronectes americanus*, *Stenotomus chrysops*, *Tautoga onitis*, *Paralichthys dentatus*, *Pomatomus saltatrix*, *Cynoscion regalis*, *Brevoortia tyranus*.

Note: In this table, (+1) should be read as high or above average; (0) should be read as medium or average; and (-1) should be read as low or below average. Please remember these terms apply only to the factors measured through the study's sampling program and are not an absolute indication of overall marine environmental quality.

5, 1,230 individuals; site 7, 1,168 individuals; site 1, 934 individuals; site 4, 869 individuals; site 8, 829 individuals; site 2, 714 individuals; site 10, 570 individuals; site 9, 539 individuals; site 3, 319 individuals; site 12, 283 individuals; and site 11, 155 individuals.

In terms of the two-year cumulative catch of winter flounder, these sites can be ranked in the following descending order: site 7, 1,109 flounder; site 1, 884 flounder; site 5, 861 flounder; site 4, 770 flounder; site 8, 727 flounder; site 2, 662 flounder; site 10, 524 flounder; site 9, 485 flounder; site 12, 263 flounder; site 3, 247 flounder; and site 11, 148 flounder.

Seasonal trends can also be seen in the lobster trawl data, with the largest catch occurring in the summer sampling periods of both years. In terms of the two-year catch of lobster, these sites can be ranked in the following descending order: site 5, 334; site 4, 105; site 8, 74; site 3, 66; site 2, 64; sites 7 and 9, 61; site 10, 60; site 1, 48; site 12, 43; and site 11, 16.

Otter trawl data from this study suggests that the following sites may be significant for specific species during certain seasons: site 3, Stamford, blackfish (*T. onitis*), June; site 4, Stamford, blackfish, June; site 5, Norwalk, scup (*S. chrysops*), August; site 5, Norwalk, bluefish (*P. saltatrix*), August; site 7, Norwalk, scup, June; site 8, Westport, weakfish (*C. regalis*), August; site 11, Stratford, blackfish, August; site 12, Stratford, blackfish, June; and site 12, Stratford, scup, June. These species of finfish were found consistently at these trawl areas during these seasonal sampling periods.

Gill Nets

Gill nets were set during each of the study's eight sampling periods to identify areas where economically significant finfish can be found on a seasonal basis and to note which species are preparing to spawn.

In order to compare gill net data to other elements of this report, the total number of fish collected at each sampling site was entered on Table 8. A value of (+1), (0), or (-1) was assigned to each station based on this data. A total catch in the upper third of the range for a sampling period received a (+1) while a catch in the middle third received a (0) and a catch in the remaining third received a (-1). These values are found in Table 9 and appear to reflect definite seasonal trends.

Menhaden, *Brevoortia tyrannus*, occurred predominantly in the spring sampling periods. The largest catch for this species was recorded in the second spring sampling. Atlantic mackeral, *Scomber scombrus*, were found at sites 1, 2, 3, 4, 5, 7, 8, 10 and 12 during the first summer sampling period. This catch was not repeated during the second set of summer gill nets. Bluefish, *Pomatomus saltatrix*, were taken in a number of locations and sampling periods. The bluefish catch peaked during the spring sampling period of the second year. Atlantic herring (*Clupea harengus*) were persistently found in significant numbers during the winter sampling periods of both years.

Table # 8 Title Gill Net Data Total Numbers of Commercial and Recreational Fish Taken*

Site #	Sampling Period 1	2	3	4	5	6	7	8
1	0	/	/	/	57	/	/	/
2	0	54	0	2	41	80	1	2
3	0	/	/	/	35	/	/	/
4	60	13	0	0	27	27	0	3
5	11	/	/	/	/	/	/	/
6	0	1	0	0	13	0	3	1
7	0	/	/	/	16	/	/	/
8	0	2	1	2	18	0	0	1
9	4	/	/	/	17	/	/	/
10	0	18	0	1	5	0	8	9
11	73	/	/	/	4	/	/	/
12	1	/	/	/	/	/	/	/
13	1	0	0	0	184**	0	24	1

/ = Sampled annually

** = Total number for this site excluded from calculation of range and value of +2 assigned in Table 8.

* Brevoortia tyranus, Morone saxatilis, Clupea harengus, Alosa pseudoharengus, Morone saxatilis, Scombec scombrus, Ponomotus triacanthus, Pomolobus mediocris, Morone americana

Value	Range of Data by Sampling Period 1	2	3***	4	5	6	7	8
+1	73 50	54 37	1	2	57 40	80 54	24 16	9 7
0	49 25	36 19	0	1	39 22	53 27	16 9	6 4
-1	24 0	18 0		0	21 4	26 0	8 0	3 1

*** Insuffcent data available for computing full range of values.

Table # 9 Title Gill Net Ranking Values of Table 8 Data

Site #	Sampling Period 1	2	3	4	5	6	7	8	Total Value
1	-1	/	/	/	+1	/	/	/	0
2	-1	+1	0	+1	+1	+1	-1	-1	+1
3	-1	/	/	/	0	/	/	/	-1
4	+1	-1	0	-1	0	0	-1	-1	-3
5	-1	/	/	/	/	/	/	/	-1
6	-1	-1	0	-1	-1	-1	-1	-1	-7
7	-1	/	/	/	-1	/	/	/	-2
8	-1	-1	+1	+1	-1	-1	-1	-1	-4
9	-1	/	/	/	-1	/	/	/	-2
10	-1	-1	0	0	-1	-1	-1	+1	-4
11	+1	/	/	/	-1	/	/	/	0
12	-1	/	/	/	/	/	/	/	-1
13	-1	-1	0	-1	+2	-1	+1	-1	-2

/ = Sampled annually

Note: In this table, (+1) should be read as high or above average; (0) should be read as medium or average; and (-1) should be read as low or below average. Please remember these terms apply only to the factors measured through the study's sampling program and are not an absolute indication of overall marine environmental quality.

More than 75 percent of the menhaden taken from trawling sites off Greenwich, Stamford, Norwalk and Westport appeared to be ready to spawn. During the spring and summer periods, none of the other species collected in the gill nets showed signs of being ready to reproduce.

Gut Analyses

Gut analysis was performed on economically important finfish collected from otter trawls. A comprehensive list of prey animals found in the guts of winter flounder is in Appendix 5 and a listing of prey species found is included in Appendix 8.

Opportunistic or pioneering species of polychaetes were found in the digestive tract of the majority of fish analyzed. This data suggests that opportunistic species are an important source of food for winter flounder in western Long Island Sound. Polychaetes and amphipods of various species were found during gut analysis of fish taken throughout the year at all sampling stations.

The hypothesis that winter flounder fed only in morning hours is not substantiated by data reported in this study. Afternoon trawls consistently yielded fish that had just eaten substantial amounts of food. Additional research is needed to examine the feeding habits of this species in western Long Island Sound.

The microsporidian *Glugea stephani*, a parasite which is lethal to winter flounder, was found to be widespread during gut analysis of these fish. Up to seven percent of the flounder caught in a sampling period, for example, were found to have advanced levels of infestation by this parasite. Very little is currently known about this parasite which has been found in large concentrations in fish from New Jersey waters. Dr. Ann Cali, an Associate Professor of Zoology at Rutgers State University, is studying *G. stephani* and confirmed our identification of this parasite. Our research is the first to publish documented evidence of *G. stephani* in Long Island Sound winter flounder. Further study of this parasite is needed to gauge its affect on this economically important species.

Hydrocarbon Analyses

The synchronous spectrofluorometric spectra of cyclohexane extracts of sediments and bivalve tissues closely resembled those of the standard reference oils, Bunker-C and #2 Fuel Oil. In some samples, however, the various components of the multi-peaked spectra used for calibration of Bunker-C concentration equivalents were not in internal agreement, suggesting that those samples contained environmentally degraded, or "weathered" oil.

Bunker-C was present in all sediment samples, at a mean concentration of 46 ppm outside of harbors and estuaries, and at a mean concentration of 111 ppm inside. Bunker-C is a heavy, residual fuel oil (ie., it is largely composed of the higher boiling-point compounds that remain as a residuum after the distillation of crude oil). Residual oils were once the most common marine fuels (now being supplanted by diesel oils) and are still commonly used in industrial burners. Hence, one might expect to see the most elevated levels of Bunker-C in sediments beneath heavily used waterways; adjacent to loading/offloading terminals and tank farms; and adjacent to industrial facilities that utilize high temperature burners.

In many cases, the highest levels of Bunker-C occurred in sediments near or adjacent to likely industrial point sources, or beneath relatively heavily used sea lanes. Only about 23% of the sediment samples had detectable quantities of #2 Fuel Oil, and half of those contained 100 ppm; the other half contained 100 to 410 ppm. Number 2 Fuel Oil was found mostly in open-water or outer-harbor sediments. In a few cases the highest concentrations of #2 Fuel Oil were located near obvious source areas.

Concentrations of Bunker-C in sediments ranged from 2.7 μg/g (parts per million) to 520 μg/g. Approximately 86% of the samples had concentrations distributed between 0 and 100 ppm, and for this group the median concentration was 50 ppm. The lower values occurred mostly in the nearshore sediments, whereas highest values were encountered in the inshore and inner harbor areas. Fifty-one samples comprising a 'harbor sediment' group had a mean and standard deviation for Bunker-C concentration of 46 $\pm$ 24 ppm. In the broad view, then, there exists a gradient of Bunker-C contamination in sediments, with concentrations decreasing offshore. There is no discernable trend of Bunker-C contamination in sediments in an east-west (along-shore) transect. Concentrations of #2 Fuel Oil in sediments ranged from undetectable (<1 ppm in samples free of Bunker-C) to 410 μg/g. However, the sediments of the study area were not sampled densely enough to establish any cause-effect links between possible shoreside point sources and sediment concentrations.

Shellfish

Some generalities regarding petroleum hydrocarbons in shellfish tissue from the inshore waters of western Connecticut's Long Island Sound can be noted: (1) the small clam *Mya arenaria* contained Bunker-C oil at concentrations from below detection to 62 ppm, and #2 Fuel Oil at levels between undetectable and 108 ppm. Most often (nine instances) samples of *Mya* had both Bunker-C and #2 Fuel Oil contamination. At two sites (CC8, SH1) *Mya* contained only #2 Fuel Oil, and at three sites (CC2, N10, N3) only Bunker-C; (2) the clam Mercenaria mercenaria contained Bunker-C at concentrations from below detection to 333 ppm, and #2 Fuel Oil at levels between undetectable and 184 ppm. Most often (four instances) samples of M. Mercenaria had only #2 Fuel Oil contamination. M. Mercenaria contained only Bunker-C at one site (N-3), and both Bunker-C and No. 2 at one site (BH4); (3) the oyster Crassostrea virginica contained both types of oil at all four sites where it was encountered. Bunker-C concentrations were between 2.6 ppm and 42 ppm, and #2 Fuel Oil concentrations were between 5.4 ppm and 22 ppm; (4) the mussel Mytilus edulis, found in two locations (HR6, HR5), contained both types of oil. Bunker-C concentration was 39 ppm in both samples, and #2 Fuel Oil occurred at 59 ppm and 76 ppm; and (5) the mussel Geukensia demissus was found at one site (SH3) with a #2 Fuel Oil concentration of 173 ppm.

The tissues of clams, mussels, and oysters contained up to 33 ppm Bunker-C and up to 184 ppm #2 Fuel Oil. There was typically a concentration gradient, decreasing shoreward, of #2 Fuel Oil in both sediments and tissue of bivalves, although the levels of oil in tissue did not seem to reflect the levels in the immediate surrounding sediments. This gradient may indicate that open waters outside harbors and estuaries is the predominate source of #2 Fuel Oil. Each species of bivalve accumulated No. 2 even though the oil may not have been present in associated bottom sediments. Number 2 Fuel Oil is apparently carried on suspended sediments and effectively taken up by filter feeders. That #2 Fuel Oil should be so widely available to filter-feeders, yet not commonly present in bottom sediments, reflects the relatively high rate of degradation of light polyaromataic hydrocarbon compounds that make up No. 2. There was some indication that the most particle selective feeders amongst the bivalves studied had the highest exposure to oil, perhaps due to preferential ingestion of fine, oil-coated particles.

That suspended sediments are effective carriers of #2 Fuel Oil, even when bottom sediments are devoid of it, is consistent with the earlier observation that high No. 2 anomalies in bottom sediments were commonly found far from likely point sources. One may suppose, then, that those high bottom sediment anomalies were related to patterns of sediment transport and deposition. Although #2 Fuel Oil is widely available to filter-feeders, it was not found to be widespread in bottom sediments. This may reflect the relatively quick degradation (by weathering) of the lighter components of heating oil in the environment (as demonstrated in laboratory experiments done for the U.S. Coast Guard). Note too that in three out of four cases where August '82 "hotspots" of #2 Fuel Oil in sediments were resampled in March '83, (HR5, HR3, BH1), No. 2 was found in the second sample. In the fourth case (BRH2) the first sample contained 106 ppm, and the second only 73 ppm #2 Fuel Oil. Taken together, the results seem to point out that #2 Fuel Oil is relatively short-lived in the environment. On the other hand, under certain depositional conditions (such as rapid sedimentation, or sedimentation below the photic zone perhaps) #2 Fuel Oil may persist in sediments. Sediments from a subsurface layer at one location, SH6, had a large amount of #2 Fuel Oil (177 ppm) that may be protected from aerobic weathering due to burial.

If it is correct to attribute the commonly observed gradient of seawardly increasing #2 Fuel Oil concentrations to a primarily open water source, and if this heating fuel is indeed short-lived in the environment, then the now illegal practice of flushing contaminated seawater ballast from cargo tanks into the sea outside of ports may continue at a sufficient rate to cause a chronic pollution of Long Island Sound. As discussed above, though, the bivalve tissue concentration gradient may be deceptive in this regard.

The ubiquitousness of Bunker-C in bottom sediments prevents one from making similar arguments about the relative importance of suspended sediments and nearby bottom sediments as sources of Bunker-C to filtering bivalves. No correlation between Bunker-C burdens in bivalve tissues and those in associated bottom sediments can be seen from the data. This may be additional evidence that contaminated suspended sediments are again the primary source.

A final observation can be pointed out, which addresses the possible role of feeding behavior in the accumulation of petroleum hydrocarbons from suspended matter. Some bivalves feed more selectively than others. _Geukensia demissus_ and _Mercenaria mercenaria_ seem to reject a wide assortment of food in the laboratory, _Crassostrea virginica_ and _Mytilus edulis_ somewhat less so, and _Mya arenaria_ seems more or less indiscriminate in feeding, at least based on the ease of raising them in the laboratory (Dr. Bob Whitlatch, personal communication). As pointed out earlier, _G. demissus_ and _M. mercenaria_, the selective eaters, had in almost all cases only #2 Fuel Oil contamination, not the heavier Bunker-C. Hence, feeding habits may preclude uptake of certain oil types if oil types are in fact fractionated amongst various particle sizes. It is also interesting to notice that when different species were found together, they had relative accumulations of #2 Fuel Oil that corresponded to our notions of relative feeding size selectivity: at BH4, M. mercenaria had almost five times as much as C. virginica, at N4, M. mercenaria had about 28 times as much as C. virginica, and at SH3, G. demissus had 2.5 times the burden of M. arenaria. It would appear, then, that size (fine) selective feeders might have increased exposure to petroleum hydrocarbons. Since preferential intake of fine-grained particles is an important part of selectivity in feeding, then the increased exposure may simply arise because fine-grained particles are preferentially oil-rich.

Several aspects of this inquiry into the relationships between hydrocarbon burdens in filter-feeders and those in bottom sediments have implicated apparently important roles for suspended sediments. Suspended matter, as a carrier of oil, likely dictates the depositional fate and biological consequences of spilled oil. Future studies of petroleum hydrocarbons in the coastal environment should pay attention to suspended matter transport and its contaminant concentrations. The present study, having established the pervasive occurrence of petroleum hydrocarbons in sediments and shellfish of western Long Island Sound, justifies further work. The environmental persistence of the two commonly encountered oils, #2 Fuel Oil and Bunker-C, should now be examined directly through controlled field and laboratory studies. Intensive samplings of the suspended matter might reveal contemporary sources of petroleum products to the environment (ie., offshore flushing of contaminated ballast and bilge waters, or inner harbor spills). As benthic faunal succession takes place, species participating in colonization change with respect to the way in which they interact with marine sediments (Rhoads and Boyer, 1982). Future studies of hydrocarbons in sediments and organisms might benefit from such a successional perspective.

IV. Municipal Overview

Information from more than 1,000 pages of data sheets and field reports has been summarized in this report. Yet, if this research is to be used by government or corporate officials, it must be organized in a framework which permits clear and accurate comparison of results. Because much of Connecticut's government centers on municipal boundaries, this overview focuses on conditions along southwestern Connecticut's nine coastal communities. Within this context, 11 ecological sub-systems -- systems which function without regard to political boundaries -- are considered in detail.

Despite the breadth of data collected and assessed, this research does not provide a comprehensive understanding of marine environmental quality of each municipality. This study should be supplemented with additional field work and analysis to expand and interpret the extensive data base developed through this study. In the interim, this discussion of results is designed to provide a means for decision making relative to existing sampling sites and findings.

Relative ranking values for benthic diversity and secondary productivity along with catch data from otter trawls and gill nets are taken from Tables 2, 4, 7, and 9 and organized by municipality in Table 10. Values for each of these four factors were totaled by community and these sums were then placed in descending order. A value of (+1) was assigned to values in the top third of each range while a value of (0) was given to municipalities in the middle third and those in the lower third received (-1). Table 11 summarizes the resulting values for each community.

TABLE 10: Municipal Data Summary

Municipality	Site Numbers	Benthic Diversity	Benthic (Secondary) Productivity	Otter Trawl	Gill Net
Greenwich	B1	0	-7		
	B3	+7	-7		
	B4	+2	-7		
	B6	-1	-6		
	B7	-4	-8		
	B9	-4	-6		
	B10	+4	-8		
	T-1			-1	
	T-2			-4	
	G-2				+1
Greenwich	Totals	+4	-49	-5	+1
Stamford	B12	-1	-8		
	B17	-1	-6		
	B19	+6	-5		
	B23	-2	-4		
	T-3			-7	
	T-4			-3	
	G-4				-3
	G-6				-7
Stamford	Totals	+2	-23	-10	-10
Darien	B24	+4	-6		
	B27	-3	-6		
	B28	+8	-8		
Darien	Totals	+9	-20	/	/
Norwalk	B30	-3	-8		
	B32	+6	-7		
	B35	+6	-6		
	B37	+7	-6		
	B40	+5	-8		
	T-5			+2	
	T-7			-5	
Norwalk	Totals	+21	-35	-3	/

TABLE 10: Municipal Data Summary

Municipality	Site Numbers	Benthic Diversity	Benthic (Secondary) Productivity	Otter Trawl	Gill Net
Westport	B42	+3	-4		
	B45	+6	-8		
	B47	±1	-6		
	B48	+5	-8		
	B52	+3	-8		
	B54	+2	-5		
	T-8			-3	
	G-8				-4
Westport	Totals	+20	-39	-3	-4
Fairfield	B55	+5	-8		
	B56	-5	-8		
	B58	-2	-6		
	B59	+5	-7		
	B61	+2	-3		
	B62	+1	-7		
	T-9			-4	
	G-10				-4
Fairfield	Totals	+6	-39	-4	-4
Bridgeport	B63	0	-8		
	B65	0	-6		
	B66	-4	-5		
	B68	-5	-5		
	B69	+7	-7		
	B71	+5	-6		
	T-10			-3	
	G-13				-2
Bridgeport	Totals	+3	-37	-3	-2
Stratford	B73	+4	-7		
	B75	+2	-6		
	B78	-4	-6		
	T-11			-7	
Stratford	Totals	+2	-19	-7	/

TOTAL 10: Municipal Data Summary

Municipality	Site Numbers	Benthic Diversity	Benthic (Secondary) Productivity	Otter Trawl	Gill Net
Milford	B77	-2	0		
	B80	-2	-7		
	B81	-1	-6		
	B82	-3	-5		
	T-12			-7	
Milford	Totals	-8	-18	-7	/

/ = Sampled annually

Value	Range of Data by Sampling Period			
	Benthic Diversity	Benthic Productivity	Otter Trawl	Gill Net
+1	+21 +12	-18 -28	-3 -4	+1 -2
0	+11 +2	-29 -39	-5 -7	-3 -6
-1	+1 -8	-40 -49	-8 -10	-7 -10

Note: In this table, (+1) should be read as high or above average; (0) should be read as medium or average; and (-1) should be read as low or below average. Please remember these terms apply only to the factors measured through the study's sampling program and are not an absolute indication of overall marine environmental quality.

Table # 11 Title: Municipal Habitat Values Summary

Municipalities are listed from west to east in study area

	Benthic Diversity	Secondary Productivity	Otter Trawl	Gill Net	Total
Greenwich	0	-1	0	+1	0
Stamford	0	+1	-1	-1	-1
Darien	0	+1	/	/	+1
Norwalk	+1	0	+1	/	+2
Westport	+1	0	+1	0	+2
Fairfield	0	0	+1	0	+1
Bridgeport	0	0	+1	+1	+2
Stratford	0	+1	0	/	+1
Milford	-1	+1	0	/	0

/ = Sampled annually

Note: In this table, (+1) should be read as high or above average; (0) should be read as medium or average; and (-1) should be read as low or below average. Please remember these terms apply only to the factors measured through the study's sampling program and are not an absolute indication of overall marine environmental quality.

Table 10 reflects -- within the findings of this study -- a relative value for marine environmental quality of specific municipalities. A municipality's sum total of ranking values in Table 10, then, reflects one measure of habitat quality which must be considered in assessing existing or potential effects of hydrocarbon contamination in the study area. Benthic diversity can be related as a measure of habitat quality in that benthic diversity is inversely related to secondary productivity. This supports the idea that pioneering stages (low diversity) are represented by dense assemblages of small, high turn-over rate species. (Personal communication, Dr. Donald Rhoads).

Greenwich Findings

The Greenwich harbor and islands area sampled extends from the Byram River east to Greenwich Point. It includes Greenwich Harbor, Cos Cob Harbor, and Greenwich Cove as well as Great Captains and Little Captains Islands. A marine terminal for hydrocarbon products is located at the railroad's Cos Cob electrical generating station on Cos Cob harbor.

Benthic sampling revealed high numbers of opportunistic or pioneering species in this area. These animals are often seen as a sign an area is undergoing or recovering from environmental stress. Abundance of these organisms appeared to vary greatly during the eight sampling periods. One location which reflected a low concentration of benthic life in the first fall sampling period was found to have the highest benthic concentration in the second fall sampling. Additional research is needed to relate the frequency of population peaks of opportunistic species with factors such as frequency of sampling or disturbance of the benthic environment. Otter trawl catch did not appear to be related to benthic diversity within this area. Regarding the Greenwich area, benthic sampling site #3 located south of Calf Island near Trawl #1 had the highest values for both diversity and productivity for six of the eight sampling periods. During the remaining two sampling periods, site 3 ranked second. For a comprehensive review of diversity and secondary productivity, please see Tables 1 and 3.

The shallow water nearshore areas, including site #1, outside Port Chester Harbor; Site #4, Byram Harbor; site #6, Greenwich Harbor; site #8, Cos Cob Harbor; and site #9, Greenwich Cove, had lower diversity and secondary productivity values as compared with offshore sites 3, 5, and 10 south of Calf Island, off Cormorant Reef, and Greenwich Point respectively. The offshore location #7, near Hens and Chickens, did not conform with these findings and like nearshore waters had consistently low values for diversity and secondary productivity. Both trawl sites 1 and 2, for example, yielded a high flounder catch. Yet trawl site 1 was near benthic site 3 (which reported consistently high diversity) while trawl site 2 was near benthic site 7 (which was azoic during this same period).

Winter flounder collected at both of these trawl sites were found to be ready to spawn during the fall. These and similar locations off Greenwich should be seen as potentially important areas in the flounder's reproductive cycle during this time of year.

Gill net sites 1 and 2 off Greenwich collected Atlantic herring during both winter sampling periods. The recent decline of the alewife Alosa pseudoharengus may make this finding of interest. Our field observations confirm that the area around the Greenwich Islands is known to be an important area for lobstering and sport fishing. Seasonally, bluefish, weakfish and striped bass are taken along with blackfish, summer flounder and winter flounder. The harbors and cove are important for the taking of menhaden by sport fishermen.

Analysis of hydrocarbons throughout Cos Cob Harbor indicate that Mya arenaria and Mercenaria mercenaria contain relatively moderate to very high levels of #2 Fuel Oil and little or no Bunker-C, with the exception of M. arenaria at Cos Cob site 2 (CC2). Apart from this exception, there was a gradient of #2 Fuel Oil levels in tissue, increasing seaward. Only in the most seaward sediment sample (CC8) was any #2 Fuel Oil observed. Hence, it would appear that if there was a local source of #2 in Cos Cob Harbor, the oil became associated with suspended sediments but was not deposited until flushed from the Harbor. Alternatively, the source of #2 Fuel Oil might have been from outside the Harbor, as suggested by the gradient in tissue levels. However, it has been reported that M. Mercenaria (Stainken, 1978) and Crassostrea virginica, (Stegeman and Teal, 1973) exposed under controlled laboratory experimental conditions to higher water column concentrations of petroleum hydrocarbons, accumulated less oil than those exposed to lower concentrations. This was related to reduced filtration activity of the bivalves subjected to greater hydrocarbon exposures.

It was suggested that M. mercenaria suffered from dose-dependent narcosis, and in the latter case it was observed that after a certain water column hydrocarbon concentration was exceeded, oysters (C. virginica) remained closed, presumably ceasing to feed. Similarly, M. arenaria in lightly to moderately oiled environments (Gilfillan et al 1976, 1977) (contaminated by maritime accidents or spills) were reported capable of accumulating greater hydrocarbon burdens than those from nearby heavily oiled environments. Hence the gradient in #2 Fuel Oil concentrations in Cob Cob Harbor may actually reflect an opposite gradient in the availability of oil to the filter feeders, in which case an inner harbor source would be implicated.

Sample replicates indicate that there can be considerable lateral and vertical variation of Bunker-C concentrations over small distances (i.e., replicate grabs were taken no more than a few meters apart, and depth penetration limited to about 1/4 meter); specifically, lateral variation was large at CC1 (the replicates were 110 and 180 ppm), and at CC8 (17 and 30 ppm), but not at CC5 (63 and 67 ppm). It is important to note, too, that the spatial variation seems much larger than the analytic variations that occur due to calibrations being based on various peaks of the spectra. Also at Cos Cob Harbor, surface and subsurface layers of sediment were discerned and subsampled from replicate grabs at CC2 and CC4. There was large vertical spatial variation. At CC2, surface sediments containing 150 ppm of Bunker-C overlay sediments with only 38 ppm. At CC4, surface sediments also had relatively high Bunker-C concentrations (78 ppm) compared to an apparently inhomogenous subsurface layer which yielded 16 and 63 ppm of Bunker-C from each of two replicate grabs.

In Cos Cob Harbor, the sediments with the highest levels of Bunker-C were found at the innermost stations, adjacent to commercial vessel docks (CC2) and adjacent to an unkempt shorefront area that is apparently used for cast-off barrels of unknown contents (CC1). These locations may have received relatively localized inputs of Bunker-C, whereas surficial sediments in downstream portions of the harbor seem to have received a uniform loading of 63-78 ppm (CC3, CC4, CC5). Just seaward of the harbor, Bunker-C occurred at only 17-30 ppm (CC8).

A large concentration of #2 Fuel Oil was found in the sediments of a shoal area just outside Cos Cob Harbor (CC8). No. 2 is a light distillate home heating fuel. Its presence in the sediments at CC8 cannot be accounted for by any obvious nearby point source. It is possible that an isolated spill from a tanker vessel caused the contamination of these outer harbor sediments. Alternatively, contaminated suspended sediments from the inner harbor may have been deposited there due to flow characteristics.

Stamford Findings

Stamford sampling stations encompassed both Stamford Harbor and Cove Harbor areas. The Stamford Harbor segment of shoreline stretches east from the tip of Greenwich Point, encompasses the East and West Branch, and continues to the tip of Shippan Point. The Cove Harbor area continues east from the tip of Shippan to Long Neck Point, Darien, including Holly Pond and the Noroton River. Marine terminals handling hydrocarbons are found on both branches of Stamford Harbor while retail gasoline stations are located near Holly Pond. The Rippowam River empties into the West Branch of Stamford Harbor while the Noroton River flows into Holly Pond.

Benthic sampling in Stamford confirms that channels of both branches of the harbor are azoic. Tidal mudflats bordering the West Branch exhibited extreme variations in abundance of individual organisms. The East Branch mudflat off Czesick Park was not found to be important in our sampling. But our finding that coastal birds are feeding in this area may indicate this area merits further study. Tidal mudflats along Kosciuszko Park and near the upstream side of the Hurricane Barrier were found to have well established infaunal benthic communities which merit additional study. In contrast to these conditions, sampling stations from Greenwich Point east to the Harbor area contained low abundances of individual species but relatively high diversity of species (low stress area). The offshore sites had relatively higher diversity values than the nearshore site locations. In the Stamford area site location #19 in Westcott Cove ranked first in highest diversity values and in the third highest grouping overall. Site #17, at the confluence of Stamford Harbor's east and west branches, showed higher values than many of the study's sites in terms of secondary productivity. In terms of site #17, while the east and west branches of Stamford Harbor support little life, the fingers of the channels and other areas possibly do support benthic assemblages which are important to migratory birds and sport finfish as winter flounder.

Otter trawls in Stamford Harbor collected the highest catch of economically important species (principally flounder) in the spring sampling compared with other trawls in the study area. These finfish were also found in high numbers during fall sampling periods. Flounder caught in the fall were frequently found to be ready to spawn, suggesting that the trawl sites and adjacent areas may merit special attention.

An area off Shippan Point, known as the Cows near the Stamford lighthouse, is an important area of commercial lobstering and sport fishing. Striped bass, bluefish, weakfish, winter flounder and blackfish are regularly taken here on a seasonal basis.

All sediments collected from Stamford Harbor contained high concentrations of Bunker-C, (from 130 ppm to 450 ppm). The highest levels were found in West Branch sediments (SH1, SH2), which lie adjacent to tank farms and associated loading/offloading docks. Bunker-C occurs at only about 60 ppm in the sediments of the outer harbor (site 612, 613). The sample from the East Branch of the inner harbor (SH6) also contained a large quantity of #2 Fuel Oil (115 ppm in surficial sediments, 177 ppm in a subsurface layer). This No. 2 contamination may reflect inputs related to extensive industrial activity located along the East Branch.

In Stamford Harbor, where sediments were dominated by high Bunker-C concentrations, the soft shell clam, Mya arenaria and ribbed mussel, Geukensia demissus were found to be contaminated by #2 Fuel Oil. At one location, SH1, there was no detectable Bunker-C in M. arenaria, despite Bunker-C concentration in bottom sediments of 290 ppm. At two other sites, SH2 and SH3, *M. arenaria* contained 30 ppm to 54 ppm of Bunker-C, and surrounding sediments contained 170 ppm to more than 300 ppm.

Different environmental conditions were found east of Stamford Harbor in the Cove Harbor-Holly Pond area. This section of shoreline includes the eastern side of Shippan Point, Westcott Cove, Holly Pond and part of Long Neck Point. As such, this area stretches from Stamford into the Town of Darien. The Noroton River empties into Holly Pond and affects this area.

Benthic samples from this area suggest that an established benthic community exists. This assemblage has apparently not undergone recent change due to environmental stress. Although diversity of benthic species was not uniformly high, benthic secondary productivity estimates, based on abundance of organisms, ranked high. In part, this ranking was based on large numbers of *Ampelisca abdita*, *Gemma gemma*, and *Tellina agilis*. Active oyster grounds are also found in this area.

Otter trawls caught the greatest numbers of winter flounder during the fall and winter sampling periods. In the second sampling period, 60% of the winter flounder collected were ready for spawning. Although lobsters were not consistently caught here, high numbers of lobsters were taken during both of the fall sampling periods.

Gill net catch data shows that the following economically important finfish are found in this area: bluefish, (spring and summer); and Atlantic herring (winter). Some menhaden taken were ready for spawning.

Observations in the field suggest Westcott Cove is a prime seasonal fishing area for bluefish, winter flounder, menhaden, blackfish and striped bass. The area also appears to be a popular lobstering ground. Typically, with the other areas sampled for Bunker-C and #2 fuel oil, the lowest values occurred in nearshore sediments and the highest values were reported for inshore and inner harbor areas. A similar gradient of Bunker-C contamination was found in sediment from Stamford. Number 2 oil was found mostly in open-water or outer harbor sediments, with respectively few inner harbor occurrences.

Although Holly Pond's shore is not lined with petrochemical facilities, it does receive the Noroton River which drains a watershed containing industrial facilities. The petroleum hydrocarbon distribution observed for August '82 sediment samples seems to reflect the general absence of point sources and vessel sources in the Pond and suggests that sediments at the head of the Pond (HP1) are heavily contaminated by industrial activity along the Noroton River (i.e., Bunker-C concentration of 520 ppm in sediments). In March '83, a grab sample composed mainly of decaying terrestrial vegetation was obtained from the general area of HP1, and it too was relatively contaminated (i.e., Bunker-C concentration of 140 $\pm$ 5.2 ppm).

The soft shell clam Mya arenaria was found in one Holly Pond sample, HP3, near the entrance to the Pond. Bunker-C and #2 Fuel Oil were both found in tissues (80 ppm and 98 ppm, respectively). Sediments had a concentration of 83 ppm Bunker-C. Sediment hydrocarbon concentration of the Pond, HP1, suggest Bunker-C inputs to the Pond from the Noroton River. Sediments just outside the Pond (HP4) had #2

Fuel Oil contamination levels of 29 ppm. Contamination of *Mya arenaria* at HP3 may therefore reflect sources of Bunker-C from the Noroton River and #2 Fuel Oil from outside the Pond. An external (Long Island Sound) source of No. 2 was also suggested for Cos Cob Harbor. The levels of oil in tissues do not appear to be correlated with levels in the immediately surrounding sediments. Sediments collected from Stamford Harbor contained high concentrations of Bunker-C, (from 130 ppm to 450 ppm). The highest levels were found in the West Branch sediments, SH1 and SH2, which lie adjacent to tank farms and associated loading/offloading docks. In the sediments of the outer harbor, sites 12 and 13, Bunker-C was found at only 60 ppm. The sample from the East Branch (SH6) also contained a large quantity of #2 Fuel Oil (115 ppm in surficial sediments, 117 ppm in a subsurface layer).

The existence of well established benthic communities and productive fishing grounds suggests that this area should be given high priority for protection in the event of an oil spill. The head of Holly Pond merits further study and an effort is needed to identify the source of this petroleum pollution.

Darien Findings

This area extends eastward from the tip of Long Neck Point and at the tip of Noroton Point. It includes Ziegler's Cove, Scott Cove, and the Five Mile River.

Benthic sampling data show very low diversity and secondary productivity for sites in Ziegler's Cove and the Five Mile River estuary. Despite this, Scott Cove and a site off Noroton Point had the highest diversity and productivity values measured in this study. These sampling areas also rated high in otter trawl catches. Large quantities of lobster, winter flounder, blackfish, scup, bluefish and summer flounder were taken. A high percentage of winter flounder caught in November were ready to spawn.

Gill net data was also collected in this area. A description of habitat conditions from Holly Pond to the tip of Long Neck Point in Darien is found under the Stamford Harbor section of Cove Harbor.

Bunker-C and #2 Fuel Oil sampling was not as extensive here as in larger urban harbors. However, samples taken at benthic sites were consistent with others throughout the study area showing a decline in hydrocarbon concentrations as distance from shore increased.

Based on our data, the Scott Cove-Noroton Point-Norwalk Islands areas are highly productive and this region merits consideration for preservation of existing habitat conditions.

Norwalk Findings

This sampling area extends from the tip of Noroton Point eastward to the end of Seymour Point. Principal natural features in this area include the Norwalk Islands, Manresa Island and Norwalk Harbor. Hydrocarbon facilities are found in the Harbor area and an oil fired electrical generating station is located on Manresa Island. The Norwalk River flows into this harbor and the Norwalk Islands at the Harbor's mouth is an important wildlife habitat. Active shellfish beds are found in much of the area outside the inner Harbor. Benthic sampling data in this area show that the habitat quality can be divided between the upper Harbor and the area extending out from the mouth of the Harbor. Norwalk Harbor samples had very low diversity and productivity values. But sampling sites located near the Norwalk Islands had some of the highest values for both diversity and secondary benthic productivity.

Otter trawls taken off Sheffield Island captured large quantities of winter flounder in the fall sampling period. Summer flounder and weakfish were taken intermittently. Fewer flounder collected in November were ready for spawning compared to other locations. Field observations suggest the outer Harbor Islands and adjacent sections of the coastline are a popular fishing grounds for blackfish, bluefish, striped bass, winter flounder and lobsters.

Sediment from outer Norwalk Harbor, N9 and N11, was not heavily contaminated (Bunker-C concentrations were about 30 ppm). But samples taken adjacent to the offloading dock at the Manresa Island power plant (N10) were higher in concentration (Bunker-C of 73 or 75 ppm). Bunker-C levels generally increased towards the inner harbor (from 47 to 83 ppm between N8 and N2), and were elevated (350 ppm) at the innermost station, (N1). Activities associated with a petrochemical manufacturing facility upstream from N1 may have contributed Bunker-C oil to inner harbor sediments. In March'83, sediments from the general vicinity of N1 were collected again; they also contained high levels of Bunker-C, (138 to ± 25 ppm). Outside Norwalk Harbor, Sheffield Island Harbor sediments contained Bunker-C at levels between 24 ppm and 55 ppm. However, an anomalously high concentration of #2 Fuel Oil (410 ppm) was encountered in deeper water (>30 ft.) sediments south of Sheffield Island (station 635) and in sediments from a shoal area near Wilson Point (113 ppm at station 633).

In Norwalk Harbor, the soft shell clam _Mya arenaria_ and quahog _Mercenaria mercenaria_ tissues contained high concentrations of #2 Fuel Oil while the ambients bottom sediments did not. No. 2 oil is encountered in bottom sediments only well outside Norwalk Harbor, at sites 631, 633, and 635, reinforcing our earlier observation that open Long Island Sound waters are the source of #2 Fuel Oil to outer harbor sediments. Concentrations of Bunker-C, ranging from undetectable to 62 ppm, occurred in _M. arenaria_ and eastern oyster _Crassostrea virginica_ throughout Norwalk Harbor, although the Bunker-C concentration range in associated sediments was somewhat greater (28 ppm to 350 ppm). _M. mercenaria_ at two stations in close proximity accumulated different levels of Bunker-C (undetectable at N4, 333 ppm at N3), although sediments at each of these sites contained about 70 ppm Bunker-C.

The area around the Norwalk Islands is a habitat of high quality which merits special management attention in order to protect a productive and diverse ecosystem.

Westport Findings

This study area encompasses both the Saugatuck River estuary and the Sherwood Island area. The Saugatuck River area extends east from the tip of Seymour Point and terminates at Sherwood Mill Pond. This segment of shoreline is dominated by the Saugatuck River. The Sherwood Island area encompasses the state park and marsh area and continues on to Frost Point in Fairfield.

Benthic sampling data from the Saugatuck River estuary show that sites outside the River and to the southeast of Cockenoe Island did not have as high a diversity value as the upper area. In part, this was due to the fast currents and substratum of coarse sand and rock. The upper Saugatuck River sites were populated by opportunistic species while more established benthic communities were found near the River's mouth. Opportunistic species generally signal an environment has recently experienced either natural or anthropogenic stress. Diversity was higher for upper River locations while secondary productivity was higher for samples collected at the mouth of the Saugatuck. The highest diversity values during a sampling period were found at both nearshore and offshore locations in this area.

Otter trawls off the Saugatuck River yielded an average catch. Winter flounder were in a spawning condition during fall sampling periods.

Gill nets set in this area yielded a diversity of species but low numbers of fish were taken. Atlantic herring and menhaden were found in some gill nets.

Testing for Bunker-C and #2 Fuel Oil was not as extensive here as it was in the harbors of Greenwich, Stamford, Norwalk, Black Rock and Bridgeport as well as the Housatonic River estuary. Samples taken at benthic sites for hydrocarbon analysis were consistent with others throughout the study area showing a decline in hydrocarbon concentrations as distance from shore increased. (See Appendix 6).

The Sherwood Island marsh dominates the second section of shoreline. It contains a well established benthic community which would be profoundly affected by a major oil spill. Benthic diversity and productivity data from sites off Sherwood Island ranked in the middle to upper half of sites studied.

Neither otter trawls nor gill nets could be set in this area. Hydrocarbon data collected for benthic stations near the marsh reflected a pattern of results which was similar to those throughout the study, i.e.; a gradient of Bunker-C levels which decrease with movement toward the open Sound and finding of No. 2 oil principally at offshore sampling stations. The Sherwood Island Marsh is an important ecological and recreational resource.

Fairfield Findings

The sampling area between the tip of Frost Point and Penfield Reef is dominated by the Southport Marsh.

Benthic areas sampled were found to consist of established communities suggesting the environment has not undergone natural or anthropogenic stress recently. The area behind Pine Creek is of special interest as it ranked high in overall diversity and secondary productivity among the 83 benthic sites. This area may benefit from high tidal flushing. An extensive mussel bed was noted at this sampling location.

Otter trawls off Fairfield captured winter flounder, bluefish, blackfish, summer flounder and menhaden. Numbers taken in the trawl were not as great as those taken in western Long Island Sound sites. Penfield Reef is known to be an important area for sports fishing and lobstering.

Hydrocarbon samples taken at benthic sampling locations show a decline in hydrocarbon concentrations with increasing distance from shore.

Bridgeport Findings

Both Black Rock and Bridgeport Harbors are included in the study area. The Black Rock Harbor study area is restricted to the Harbor proper near Penfield Reef. The Bridgeport Harbor area extends eastward from the reef to the tip of Stratford Point and encompasses Lewis Gut.

Black Rock Harbor contains hydrocarbon terminals and is an active industrial waterfront. Some of the filled land rests atop an old dump which received both household and industrial waste. Bridgeport's municipal dump is also located in this area. The harbor sediments, according to the U.S. Army Corps of Engineers, New England Divisions's 1980 "Environmental Atlas of New England Channel and Harbor Bottom Sediments" and subsequent work on the Corps' "Field Verification Program" (in progress) have significant levels of heavy metals and toxic chemical concentrations.

Benthic samples support this evaluation. Diversity and productivity values for this harbor consistently rate near the bottom of the range for all 83 sampling stations.

Habitat quality deteriorates at sampling stations in the upper harbor.

Otter trawls and gill nets were not set in this area.

Hydrocarbon analyses show Bunker-C concentrations in most Black Rock Harbor sediments to be moderately high in August '82, ranging from 57 ppm in the shoal area adjacent to the Burr Creek backwater (BRH2), to 72 ppm at the innermost site (station 667), and 81-100 ppm adjacent to the entrance channel (BRH3). In comparison, sediments from outside the harbor contained between 14 ppm Bunker-C (station 665) and 83 ppm (station 663). An exception occurred in inner harbor sediments found adjacent to the large garbage dump (BRH1), where Bunker-C concentration was 170 ppm. Sediments near BRH2, resampled in March '83, again contained relatively little Bunker-C (10 $\pm$ 0 ppm), and resampled BRH1 sediments contained substantially less Bunker-C than those from August '82 (31 $\pm$ ppm). No. 2 Fuel Oil concentrations were very high in the three innermost samples from Black Rock Harbor (319 ppm at BRH1, 106 ppm at BRH2, and 245 ppm at station 667). The March '83 samples corresponding approximately to BRH1 and BRH2 contained similarly elevated #2 Fuel Oil concentrations, (354 ppm and 73 respectively). In addition to the garbage dump near BRH1, the large industrial plant with fuel offloading docks near station 667 may be a source point of oil to the harbor.

The Black Rock Harbor sediments collected for this study were devoid of bivalves, hence no petroleum hydrocarbon body burdens can be reported from tissue analysis.

Bridgeport Harbor also contains marine petrochemical terminals. Two oil-fired electrical generating stations are also found on this Harbor.

Within this area, highest benthic values were found at sites located near the breakwater. These values declined with movement away from the breakwater and toward either the open Sound or inner harbor. A marked difference was also found in benthic samples taken to the east and west of Bridgeport's marine channel. Eastern sampling stations consistently ranked lower for benthic diversity and productivity than sites to the west of the channel.

Otter trawls also reflected this east and west asymmetry in benthic biology. Catches at trawl site 11 (east) ranked low while trawl site 10 yielded moderate catches.

Gill nets set in this area showed winter flounder ready to spawn in the fall. Trawls during other seasons yielded insignificant catches. Field observations suggest the Harbor has a large seasonal population of menhaden and Atlantic herring can occasionally be found here.

Five out of eight sediment samples taken along approaches to Bridgeport Harbor had relatively high Bunker-C concentrations (72 to 97 ppm), while the other three had 45 ppm. Elevated levels in sediments along the entrance channel may reflect chronic inputs of marine engine fuel associated with commercial vessel traffic. Sediments from the innermost station in Bridgeport Harbor (BH1) adjacent to a power plant, contained 240 ppm of Bunker-C and 250 ppm of #2 Fuel Oil in the August '82 sample. Only 66 $\pm$ 3.4 ppm Bunker-C and no #2 Fuel Oil were found in the March '83 sample. Too few samples were taken to characterize spatial patterns in hydrocarbon distributions. Therefore we are not able to make firm conclusions regarding temporal or spatial trends in levels of contamination. Differences between August '82 and March '83 levels could be related to slight differences in sampling location. In March '83 a new location was sampled, adjacent to a large tank farm about midway along Johnsons Creek (east of the channel, not plotted on map in Appendix 6). This station yielded heavily contaminated sediments with a Bunker-C concentration of 234 ± ppm. In August '82 there was little Bunker-C (28 ppm) in sediments at the mouth of Johnsons Creek (BH2), but a relatively large amount of #2 Fuel Oil (52 ppm) was encountered. The absence of #2 Fuel Oil in the March '83 Johnsons Creek sample may indicate that the tank alongside the Creek was not the contamination source of #2 Fuel Oil to the sediments at the mouth of the Creek (at BH2).

Samples of the eastern oyster Crassostrea and quahog Mercenaria were found at one site inside Bridgeport Harbor, (BH4). Both oysters and clams were contaminated by Bunker-C and No. 2, but the clams had accumulated substantially more of the two types of oil than did the oysters. Bottom sediments were devoid of No. 2. Here too, though, bottom sediments outside of the Harbor (sites 670 and 674) were contaminated with #2 Fuel Oil. But unlike the harbors to the west, there were also strong anomalies in the distribution of No. 2 in the innermost harbor sediments, BH1 and BH2. The most seaward location at which bivalves, soft shell clam Mya arenaria were collected for hydrocarbon analysis was BH7, adjacent to the entrance channel to Bridgeport Harbor. These clams contained a moderate amount of Bunker-C (38 ppm), and a relatively high concentration of #2 Fuel Oil (82 ppm). The sediments at BH7 were relatively rich in Bunker-C (97 ppm), but were devoid of No. 2. However, bottom sediment at nearby open water areas (sites 670 and 674,) showed the presence of No. 2.

Stratford Findings

This study area includes the Housatonic River estuary and extends from the tip of Stratford Point eastward to Charles Island. The Nells Island Marsh is included in this segment of shoreline.

Benthic sampling data show low values for both diversity and secondary productivity relative to the other 83 sites. Sampling stations in Stratford consistently ranked toward the low end of this range.

Data for benthic diversity and secondary productivity varied greatly from one sampling period to another, making it difficult to document any seasonal or spatial patterns in these numbers.

Otter trawls yielded low catches. The fall sampling showed winter flounder to be ready for spawning. No gill nets were set in this area.

The Nells Island marsh is known as an important ecological system and is one of the most significant tidal marshes in Connecticut. It merits continuing study.

Hydrocarbon tests of the August '82 sediment samples from the Housatonic River estuary contained relatively little Bunker-C. The exceptions to this are a 172 ppm level in subsurface sediments at the most upstream location (HR1), and an 85 ppm concentration in tidal creek sediments of the salt marsh (HR7). Neither concentration can be related to an obvious point source, although there is a power plant upstream of station HR1. Similarly, no obvious point sources can be found to account for two anomalously high concentrations of #2 Fuel Oil at HR3 and HR5. Samples obtained from the latter two sites in March '83 had very different petroleum hydrocarbon burdens. At HR3, #2 Fuel Oil was absent and Bunker-C was relatively high 105 $\pm$ 19 ppm. Similarly at HR5, No. 2 was absent and Bunker-C was high, 92 $\pm$5 ppm.

At the mouth of the Housatonic River estuary, (stations HR5 and HR6), bottom sediments and tissues of Eastern oyster *Crassostrea* and blue mussel *Mytilus* contained both types of oil. There were anomalously high concentrations of #2 Fuel Oil in these outermost sediments, (as was the case for most of the harbors to the west). Number 2 Fuel Oil was absent from sediments at three upper estuary locations, however number 2 was found in a shoal area further up the estuary, HR3. At this upper estuarine location, *Mya* was found to have a No. 2 body burden of 34 ppm. The Housatonic River estuary was unique in our study, in that both the shellfish and their associated sediments contained Bunker-C and #2 Fuel Oil.

V. Summary Recommendations

1. Additional field sampling should be undertaken to maintain and enlarge the coastal ecosystem data base developed during this research program.

2. Areas with high concentrations of hydrocarbons should be examined further to: (a) determine if it represents a case of ongoing or historical hydrocarbon contamination, and (b) monitor recovery of the area if, and when, pollution ceases.

3. Occurrence of the parasite *Glugea stephani* in winter flounder of Long Island Sound merits additional study to protect this important sports fish.

4. The extent to which suspended sediments may serve as a reservoir of #2 oil in Long Island Sound should be examined through a focused study of #2 concentration in suspended sediments. Data developed during our hydrocarbon analysis support a conclusion that body burdens of #2 oil in filter feeders is not directly related to either the proximity of direct point sources or of #2 oil levels in surrounding bottom sediments. Study of concentrations of #2 oil on suspended sediments would show if these sediments are a principal source of contamination for filter feeders.

5. A more detailed comparison should be made of hydrocarbon body burdens in differing forms of benthic life. Our CEIP study focused on concentrations in filter feeders but did not include other functional types of bottom dwelling organisms. Additional study is needed to determine

if surface deposit feeders and subsurface (or conveyor belt) feeders accumulate hydrocarbon body burdens at the same rate as filter feeders.

6. Data presented in the Appendices should be analyzed further and compared with information reported in related CEIP studies.

7. Additional study is needed to determine if economically important species spawn in the study area and to better define our definition of critical spawning areas in this report.