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ANALYSIS OF POTENTIAL OIL SPILL IMPACTS IN THE NASSAU-SUFFOLK COASTAL ZONE

Task 7.6

Contract Number D93781

Prepared by

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1.0 Summary and Conclusions

This report provides information and maps on the natural resources found in the marine portion of the Nassau-Suffolk coastal zone that are utilized in the assessment of the biological impacts of hypothetical oil spill events, which could occur as a result of oil and gas production in the Georges Bank and Baltimore Canyon Troughs. The principal sections of the report deal with:

1. scope of the analysis (section 2.0);
2. description of Nassau-Suffolk coastal zone habitats and special features (section 3.0);
3. analysis of population responses to oil spills (section 4.0);
4. analysis of habitat recovery to oil spills, in terms of physical/chemical recovery and biological recovery (section 5.0);
5. review of oil production and transport spill statistics and oil spill trajectory studies to assess the likelihood of spills impacting the Nassau-Suffolk coastal zone (section 6.0); and
6. analysis of the biological impacts of oil spill events defined by spill time to shore and impact zone (section 7.0).

Maps showing the distribution of habitats (high energy beach, protected sand bottom, protected mud bottom, salt marsh, eelgrass system, mussel reef, rocky shore, pelagic estuarine, and pelagic coastal) and special features (soft-shell clam, hard clam, oyster, bay scallop, surf clam, mussel, razor clam, lobster, and blue claw crab; waterfowl nesting and feeding areas; and public outdoor recreation facilities) in the Nassau-Suffolk coastal zone are included in the report. The analysis of oil spills includes maps showing the spatial relationship of offshore production sites, tanker traffic lanes, and oil spill stranding probability contours to the Nassau-Suffolk coastal zone. A framework for analyzing the biological impacts of oil spills is presented. Although available data do not permit definitive quantitative predictions of population/community response to oil spills, rough order-of-magnitude estimates of habitat recovery are presented which can be used in connection with habitat and special features maps to determine the vulnerability of the various areas in the coastal zone to oil-related damage.

The conclusions of this study are as follows:

1. Available statistics on oil production and transport related spills indicate that there will probably be several large oil spills (greater than 1,000 barrels) in the mid-Atlantic region during the production life of the Georges Bank and Baltimore Canyon Troughs, should in fact commercial quantities of crude oil in these areas be found to exist. The exact location of these potential spills is unknown, however, they could be expected to occur at the site of production, along transport routes, or at product destination points.

2. Spills occurring within tracts leased as a result of OCS Sale No. 40 pose little threat to the Nassau-Suffolk coastal zone. Spills occurring within the tracts proposed for lease in OCS Sale No. 42 also pose little threat to Nassau-Suffolk shores, with the exception of those tracts to the west of Great South Channel. Drift card return data indicate that spills originating at these tracts during the summer could strand on Long Island within 60 days. Such a spill would be very weathered at the time of stranding.

3. No comprehensive statistics concerning crude oil or petroleum related vessel trips have been developed for the mid-Atlantic region. Also, it is not definitively known to what extent Atlantic OCS produced oil refined in Port of New York/New Jersey will replace foreign sources of crude oil. Therefore, the net increase in New York Bight tanker

traffic as a result of Georges Bank and Baltimore Canyon development is not known. This factor is significant in determining estimates of potential tanker related discharges in the future.

4. The Nassau-Suffolk coastal zone is susceptible to tanker related oil discharges that could occur in the established navigation lanes servicing the Port of New York/New Jersey. The chances that such discharges will strand on Nassau-Suffolk shores are higher in summer than in winter. For tanker related discharges occurring in the Ambrose/Nantucket lanes south of western Suffolk County and Nassau County during summer, the percent probability of stranding on Long Island varies between 40 and 80%. Time to shore data indicate that spills occurring in summer could strand in two days (the oil would be unweathered), but it is more likely that the time to shore would be 3-10 days (the oil would be weathered).

5. The persistence of oil resulting from impact of the main body of a spill in marine substrates varies from 2-3 years on rocky, high energy shores to a minimum of 3-10 years in fine sediments.

6. Rough estimates of biological recovery for the various habitats considered from a worst-case spill event are presented, but differentiation on the basis of these estimates is not possible because of a lack of data and the similarity of habitat responses. Estimates of total habitat recovery time (physical/chemical recovery time plus biological recovery time) are a first step towards quantitative estimates of the biological effects of oil spills. Extensive research efforts are required to refine and validate the estimates.

7. In general, total habitat recovery from oil spills causing 100% mortality is likely to take 10 years. This is an order-of-magnitude estimate. Habitat recovery from an event causing less than 100% mortality may be much more rapid.

8. Habitat and special features maps provide a perspective on the physical and biological structure of the Nassau-Suffolk coastal zone and its relationship to resources considered by man to be important. It is not possible to estimate the effects of oil spills on special features, other than to say that they are vulnerable to damage if exposed to a spill.

9. This report provides a basis for establishing oil spill cleanup priorities should an oil spill endanger the Nassau-Suffolk coastal zone. In general, habitats associated with protected bays have longer oil residence and recovery times than those habitats associated with the open coast or hard substrates. Thus, in the event of a spill, bay habitats should receive the highest priority when employing resources for oil spill protection and cleanup.

2.0 Introduction

This report fulfills the requirements of Activity #7 - Analysis of Natural Resources, Task 7.6 as described in Contract Number D93781 between the New York State Dept. of State and the Nassau-Suffolk Regional Planning Board, and provides information and maps relating to natural resources in the marine portion of the Nassau-Suffolk coastal zone that are vulnerable to spilled oil. The report provides estimates of the potential biological effects of hypothetical oil spills which could occur in the study area as a result of the production and transport of crude oil from the Georges Bank Trough and the Baltimore Canyon Trough. Potential oil spills resulting from marine transport of refined petroleum products to local terminals are not specifically discussed; however the methodology and results contained herein can be used to estimate the impacts of such spills. The geographic scope of the analysis of potential biological impacts is limited to those important marine related resources located in or adjacent to Nassau and Suffolk Counties and subject to New York State jurisdiction.

A framework for analyzing the biological effects of oil spills is presented in the report. Specific spill events impacting habitats at a particular location are not evaluated because it is not known with certainty where and when spills will originate, nor where and when the spilled oil will hit the coast. However, the vulnerability of Nassau-Suffolk coastal zone habitats to damage from oil spills, should they occur, is assessed. Vulnerability depends upon three sets of variables:

1. probability of spill occurrence
2. physical characteristics of coastal zone habitats
    a. spill trajectories: where oil goes and how fast

    b. persistence and ultimate fate of oil in the environment

3. biological factors - individual responses and sensitivities to oil, and population/community recovery following exposure to oil.

Variable #1 depends on the activity(s) which might cause the spill. Information relating to spill occurrences is found in Devanney and Stewart (1975). Variable #2a depends on the time and place of the spill, the type of substance spilled, weather conditions, and currents; Devanney and Stewart (1974), Stewart and Devanney (1974), and Hardy *et al.* (1975a, 1975b) provide information on this point. Variables #2b and 3 are dealt with in Schrader *et al.* (1975), and Moore *et al.* (1974), both of which have been utilized to a great extent in the preparation of this report.

No claim is made that the analysis herein definitively answers the question: "What are the biological impacts of oil spills occurring in Nassau-Suffolk coastal zone waters?" The available data simply do not allow a comprehensive answer to that question. From the available data and numerous assumptions a synthesis of information regarding oil spill impacts is made leading to a set of conclusions which can be used in policy formulation. Where possible, assumptions are made using a large range of parameter values and emphasis is placed on "worst case" analysis, i.e., conditions which may be surmised to yield the greatest environmental effects. The results therefore represent order-of-magnitude estimates.

2.1 Modeling the Nassau-Suffolk Coastal Marine Environment

One of the most difficult problems in this study is the size and complexity of the Nassau-Suffolk coastal zone. Spatially diverse, the study area includes an expanse of widely varying marine environments.

Temporally diverse, these environments change physically, biologically, and chemically wtih periods ranging from hours and days to decades or more. In order to reduce the problem to a manageable level, the Nassau-Suffolk coastal marine environment has been analyzed at several organizational levels, including individual species, and groups of selected species which are representative of habitats.

A habitat, as conceived herein, is defined as a subsystem of the marine environment which can be characterized by certain similar physical/chemical variables, such as sediment type and salinity, and which contains a characteristic assemblage of populations, i.e., a community. Examples are the rocky shore, salt marsh, and eelgrass habitats. It is assumed that each habitat type is physically and biologically uniform wherever it occurs within the coastal zone. For each habitat type, a subset of species from all species associated with the habitat is identified for further analysis. It is not assumed that the selected species are sufficient to account for community level dynamics in each habitat or are necessarily ecologically dominant or "key". Species may be selected for analysis for any number of reasons, including scientific importance, commercial/recreational interest, ecological dominance, endangered or unique species status, and well-known status.

The habitat response to oil spills is a useful approach for analyzing the effects of oil spills in the Nassau-Suffolk coastal zone. First, the relationships between oil and various physical factors are essential aspects of the effects of oil. Habitats provide a focal point for differentiating physical factors. Second, although the communities of organisms associated with various types of habitats are not strictly uniform and, in fact, may be widely variable, many important assemblages can be delimited according to habitats, with special cases noted where appropriate. Third, the definition of a habitat's community may assist in identification of species which should be selected for population level analysis.

Several reasons exist for using populations as the basic element of analysis. From an analytical point of view, a population is a manageable unit for which some dynamic models exist of both density and age-structure. In addition, man's attention is most often directed towards the health of a population(s) that serves as the basis for commercial and recreation fisheries, bird watching, etc. As a result, most biological data is centered on species level information. Most importantly, responses of individual organisms and population/community recovery processes are an essential feature of oil spill effects and therefore population level models are necessary for assessment of effects.

2.2 Assessing Effects of Oil

Four basic processes determine the impacts of oil discharges on the marine environment: inputs, transport and dispersion, biological effects, and ultimate fate. Inputs must be characterized according to amount, location, temporal distribution, and chemical form. Impacts of infrequent massive inputs (spills) are likely to differ from low-concentration, continuous discharges.

Transport and dispersion processes by physical, chemical, and biological agents determine the ultimate extent and intensity of exposure to contaminants. In the case of oil, weathering processes, which alter the chemical composition of spilled oil during transport, are particularly important. Biological transfers and modifications may profoundly alter the nature of oil by either biotransformation (metabolism) or accumulation and storage within the lipid fraction of an organism.

The primary focus of impact assessment is biological effects, at several levels. Specific actions of a pollutant occur on individual organisms, but the effects are cascaded throughout a community by resulting changes in populations.

The utlimate fate of substances depends largely on biodegradability. Most constituents of oil in aerobic environments are ultimately degraded to CO_2, but rates of degradation vary widely due to variations in chemical structure and composition.

2.3 Effects of Accidental Spills

Effects of accidental oil spills are divided into two parts: 1) initial impacts; and 2) recovery. Initial impacts are the actual perturbations of physical/chemical and biological variables in an environment. Recovery is the dynamic process of returning to the prespill "equilibrium" following initial impacts. Both physical/chemical and biological recovery must be included in the analysis. Initial biological impacts depend primarily on sensitivity of the individual organisms and the composition and amount of oil to which they are exposed. Therefore an important step in the analysis is to identify critical concentrations of petroleum hydrocarbons. Population response and recovery depend on both the characteristics of specific species--life history parameters such as age specific mortality, natality, migration and growth, and on community characteristics--competition and predation. Community dynamics are not treated in detail. Interspecific relationships for selected species known or hypothesized to play an important role in recovery are noted, and their implications are considered qualitatively in an attempt to estimate overall habitat recovery times under worst case conditions.

2.4 Caveat Regarding Continuous (Chronic) Discharges

The state-of-the-art does not permit the development of reliable models for assessing the chronic population effects of relatively continuous, low concentration oil discharges. The problem in this case is to estimate relatively long-term (many generations) effects of subtle changes in birth and death rates because massive mortalities from direct lethal toxicity do not occur. Even with estimates of sensitivities to low-level concentrations (less than that causing direct lethal toxicity), it may be virtually impossible to distinguish population changes occurring due to oil discharges from those caused by natural fluctuations, such as temperature and salinity. Even though the cumulative chronic effects of oil discharges are not treated in detail in this report, the long-term population, and hence, habitat responses to low level oil pollution may be more insidious and potentially more dangerous than dramatic catastrophic spill short-term massive mortality (Evans and Rice, 1974).

2.5 Special Features

Oil spills impact entire ecosystems. However, concern over spill impacts is usually focused on certain special features of the environment, which have a particular use by man. Emphasis is given to the effect on fisheries because of their commercial and recreational value. Bird populations are carefully watched because of recreational and aesthetic interests. In this report, areas in the Nassau-Suffolk coastal zone that are important producers of shellfish and crustaceans, as well as areas that provide valuable waterfowl habitat are identified.

Human activities in shoreline recreation areas can be adversely impacted by spilled oil. Recreation areas are therefore given special feature status; a map of such areas in Nassau-Suffolk Counties is included in the report.

Knowing the location of these special features enables the policymaker to determine which areas of the coastal zone, if exposed to spilled oil, may sustain damages affecting recreational and commercial activities. The response to potential oil spills of the special features, with the exception of recreation areas, can be estimated from the habitat analyses. Determination of social and economic impacts of potential spills is, however, beyond the scope of this report.

3.0 Identification of Habitats and Special Features

This section describes and discusses the distribution of the habitats found within the marine portion of the Nassau-Suffolk coastal zone. Special features of interest are also identified.

Four primary characteristics were utilized to distinguish the habitats:

1) sediment type (in areas with no overwhelming dominant plant or animal species)
2) dominant plant or animal
3) degree of exposure to high energy waves and/or currents
4) salinity (in the water column)

Clearly, the use of so few characteristics to define habitats results in these units being broadly characterized. Many of the variations in the environment are averaged out, resulting in a fairly coarse description of the actual environment in the study area.

It is important to realize that the habitats described herein do not constitute an ecologically definitive breakdown of the environment. A finer description could be produced by examining some additional characteristics, such as location in the tidal regime, presence of biological communities, degree of organic loading, and dredging activity by man. Such additional details are not warranted for the purpose of this report; further sub-division would not produce sub-areas with a measurably different response than those defined. However, for other aspects of coastal zone management, different habitat breakdowns may be required.

Each habitat description includes the selected species for that habitat. The relative numbers of selected species in the habitats is not intended to reflect the relative productivity or diversity of the habitats. The habitat descriptions and selected species lists presented are based on Moore *et al.* (1974) and Schrader *et al.* (1974).

3.1 Habitat Descriptions

This report identifies the following habitats in the study area:

High Energy Beach
Protected Sand Bottom System
Protected Mud Bottom System
Salt Marsh
Eelgrass System
Mussel Reef
Rocky Shore
Pelagic Estuarine
Pelagic Coastal

3.1.1 High Energy Beach

High energy beaches are all beaches and adjacent subtidal areas exposed to waves and/or strong tidal currents. The habitat extends from the mean high water shoreline out to a depth of 20 meters, the approximate limit of effective wave action. The substrate consists of medium sand, coarse sand or gravel. As the environment is comprised of a mobile and incohesive substrate, epifaunal and tube-dwelling species do not appear in significant numbers. Most of the animals found in this habitat are strong bodied and capable of becoming re-established after burial or sudden exposure. The habitat, as compared with other habitats is not densely populated, even though the conditions provide high concentrations of oxygen and suspended food. The rocky shore habitat is often found within the high energy beach habitat, e.g., on groins and jetties, and glacial erratics. It is probable that the rocky shores interact somewhat with the neighboring sandy communities; however, this effect is neglected when studying large areas. Selected species for this habitat are listed in Table 1.

Table 1. Selected Species for High Energy Beach

Cerianthus americanus	sand anemone
Diopatra cuprea	polychaete (tube worm)
Nephthys picta	polychaeta (sand worm)
Spisula solidissima	surf clam
Tellina agilis	clam
Astarate castanea	clam
Haustoridae	amphipod
Emerita talpoida	sand mole crab
Cancer irroratus	rock crab
Echinarachnius parma	sand dollar
Asterias forbesi	starfish
Ammodytes americanus	sand launce (fish)
Morone saxatilis	striped bass
Paralichthys dentatus	summer flounder
Sterna hirundo	common tern
Passerculus princeps	Ipswich sparrow
Crocethia alba	sanderling
Halichoerus grypus	grey seal

3.1.2 Protected Sand Bottom

The protected sand bottom habitat is characterized physically by a substrate of sand or silty-sand, situated such that it is protected from the pounding of high energy waves. Areas with both moderate and high currents are included; thus, fine sediments do not accumulate in this habitat. This substrate is defined quantitatively, for the purposes of this study, as containing more than 90% sand and gravel by weight.

Both intertidal and subtidal areas with these characteristics are included in this habitat, since they typically occur adjacently to each other across the line of mean low water (mlw). The macrofauna in the protected sand bottom habitat, similar above and below mlw, is characterized by polychaete worms and bivalves; many of the species are filter feeders. Most of the food for these lower consumers is imported into the protected sand bottom habitat from the salt marshes and eelgrass systems nearby. Depending on the currents, this habitat can exist to depths of 20 meters before significant biological changes are noticed. Some of the species which occur in this habitat may also be found in the protected mud bottom habitat. Selected species for this habitat are listed in Table 2.

3.1.3 Protected Mud Bottom

The protected mud bottom habitat is characterized physically by a substrate of mud, silt, clay, or sandy-mud, -silt or -clay. Like the protected sand bottom habitat, this habitat is protected from pounding of high energy waves. However, the protected mud bottom habitat is subject only to low currents. Hence, silt and clay can accumulate to form a low profile zone of particles, sorted with fine fractions in the upper zone. This substrate is defined quantitatively, for the purposes of

Table 2. Selected Species for Protected Sand Bottom

Cerianthus americanus	sand. anemone
Nereis virens	polychaete (sand worm)
Diopatra cuprea	polychaete (tube-building worm)
Clymenella torquata	polychaete (tube worm)
Pectinaria gouldii	polychaete (trumpet worm)
Tellina agilis	clam
Ensis directus	razor clam
Mya arenaria	soft clam
Mercenaria mercenaria	quahog or hard clam
Gemma gemma	pea or gem clam
Aequipecten irradians	bay scallop
Polynices hero	predatory snail
Acanthohaustorius millsi	amphipod
Leptocheirus pinguis	amphipod
Pagurus longicarpus	hermit crab
Crangon septemspinosus	mud shrimp
Limulus polyphemus	horseshoe crab
Emerita talpoida	sand mole crab
Carcinus maenas	green crab
Callinectes sapidus	blue crab
Pseudopleuronectes americanus	winter flounder
Paralichthys dentatus	summer flounder
Ammodytes americanus	sand launce (fish)
Sterna hirundo	common term
Passerculus princeps	Ipswich sparrow
Crocethia alba	sanderling

this study, as containing more than 10% silt, clay, and mud (i.e., less than 90% sand and gravel).

Both intertidal and subtidal zones are included in this habitat. Intertidal and subtidal areas with the above physical characteristics are typically contiguous. Furthermore, under the protected conditions present in this habitat, there is no significant variation in the biota of an intertidal mud bottom area and an adjacent subtidal mud bottom area. Indeed, this habitat can exist down to a depth of 20 meters before significant biological changes are noticed. This habitat is characterized by deposit feeding polychaete worms and bivalves. The protected mud bottom habitat is dependent for food on the exported detritus from salt marshes and eelgrass beds. Some of the species which occur in this habitat may also be found in the protected sand bottom habitat. Selected species for this habitat are listed in Table 3.

3.1.4 Salt Marsh

Salt marshes are defined as wetlands where the emergent vegetation is composed of salt tolerant grasses (particularly *Spartina alterniflora* on Long Island). Features also include salt pans, tidal creeks, and subtidal areas of mud adjacent to the grass areas. Salt marshes occur in protected waters where mud deposition causes sufficient shoaling to allow colonization by grasses with subsequent accumulation of peat substrates. This habitat has the highest annual production of plant material of any in the world, with half of it being exported by the tides to serve as food for the organisms in surrounding estuarine and coastal waters. Many pelagic species spend some part of their life cycle inhabiting the marsh. The supply of fresh nutrients, the large extremes in temperature, the variation in salinity, and the regular cycle of sub-

Table 3. Selected Species for Protected Mud Bottom

Cerianthus americanus	sand anemone
Nereis virens	polychaete (sand worm)
Nereis succinea	polychaete
Pherusa affinis	polychaete
Streblospio benedicti	polychaete (tube worm)
Pectinaria gouldii	polychaete (trumpet worm)
Tellina agilis	clam
Mya arenaria	soft clam
Nassarius obsoletus	snail
Leptocheirus pinguis	amphipod
Corophium volutator	amphipod
Carcinus maenas	green crab
Callinectes sapidus	blue crab
Pseudopleuronectes americanus	winter flounder
Paralichthys dentatus	summer flounder
Trinectes maculatus	hogchoker (fish)
Urophysis chuss	squirrel or red hake

mergence, all caused by the tides, are major determinants of the structure of salt marshes. Selected species for this habitat are listed in Table 4.

3.1.5 Eelgrass System

The eelgrass systems are shallow, subtidal communities based upon and dominated by *Zostera marina,* eelgrass. These systems occur over broad ranges of temperature and salinity. Depth ranges from one foot above mlw, above which dessication prevents the occurrence of eelgrass, to about 7.5 meters, the limit to which light can penetrate the turbid waters of Long Island bays. Eelgrass occurs primarily in slow moving, sheltered waters, preferring a sand or sand-mud bottom. Often the dense growth inhibits the current enough to appreciably still the water, causing considerable mud deposition and creation of a quiet microcosm, inhabited by many other plants and animals. Eelgrass itself provides a substrate for plants--red and green epiphytic algae--and animals. Some also use it as a food source. Other plants and animals live in the calm areas around the *Zostera* plants. This system is extremely important to many species of wintering and migrating waterfowl (e.g., the brant), some of which are dependent upon *Zostera* for as much as 85% of their diet. The decayed portions of eelgrass provide detritus which feeds many of the members of this rich and varied biota. Selected species for this habitat are listed in Table 5.

3.1.6 Mussel Reef

Mussel reefs are intertidal and subtidal communities based on and dominated by beds of mussels. They may overlap with the rocky shore community or be found among sand bottom or mud bottom communities where a preliminary source of attachment (such as a small rock or boulder, or empty clam or snail shell) allows settlement. Mussels developing on soft

Table 4. Selected Species for Salt Marsh

Spartina alterniflora	cordgrass
Ulva lactuca	sea lettuce (algae)
Enteromorpha sp.	algae
Nereis virens	polychaete (sandworm)
Clymenella torquata	polychaete (tube worm)
Modiolus demissus	ribbed mussel
Melampus bidentatus	snail
Littorina littorea	periwinkle
Orchestiidae	amphipod
Uca spp.	fiddler crabs
Crangon septemspinosus	mud shrimp
Diptera larvae (Aedes ssp. and other dipterids)	flies and mosquitoes
Prokelisia marginata	plant hopper
Fundulus heteroclitus	mummichog (fish)
Ammodytes americanus	sand launce (fish)
Menidia menidia	silversides (fish)
Anguilla rostrata	american eel
Ammospiza caudacuta	sharptail sparrow
Agelaius phoeniceus phoeniceus	eastern redwing blackbird
Pandion haliaetus	osprey
Anas rubripes	black duck
Larus argentatus	herring gull
Rallus longirostris	clapper rail (bird)
Malaccemys terrapin	diamond back terrapin
Ondatra zibethica	muskrat

Table 5. Selected Species for Eelgrass System

Zostera marina	eelgrass
Agardhiella tenera	red algae
Ulva lactuca	sea lettuce (algae)
Cladophora gracilis	green algae
Elektra crustulenta	bryozoan
Scolopos fragilis	polychaete (tube worm)
Bittium spp.	snail
Crepidula convexa	slipper shell
Urosalpinx cinerea	oyster drill
Aequipecten irradians	bay scallop
Mercenaria mercenaria	quahog or hard clam
Paracereis caudata	isopod
Corophium volutator	amphipod
Menidia menidia	silversides (fish)
Branta bernicla	brant (bird)

bottoms gradually convert the area into a firm substrate of shells as numbers accumulate. These reefs thus provide substrate for a wide variety of benthic organisms, including algae, sponges, cnidarians, flatworms, nemerteans, bryozoans, polychaetes, other mollusks, crustaceans, and tunicates. The fauna and flora associated with a given mussel reef depend in large part upon salinity, with those of higher salinities having a greater number of species represented. Mussel reefs depend on imported food from the pelagic zone or from salt marshes and eelgrass systems. Selected species for the habitat are listed in Table 6.

Table 6. Selected Species for Mussel Reef

Cliona spp.	boring sponges
Metridium senile	anemone
Harmothoe imbricata	polychaete worm
Polydora spp.	polychaete (tube worm)
Urosalpinx cinerea	oyster drill
Mytilis edulis	edible mussel
Crepidula fornicata	slipper shell
Modiolus modiolus	horse mussel
Asterias vulgaris & forbesi	starfish

3.1.7 Rocky Shore

Rocky shores include intertidal and subtidal rock informations such as outcroppings, boulders, pilings, and jetties, and other hard substrates. Man-made structures (such as groins, walls, and pilings) account for most of the locations where this hard substrate habitat occurs on the south shore; on the north shore this habitat is found locally on glacial boulders.

Table 7. Selected Species for Rocky Shores

Codium sp.	algae
Fucus sp.	algae
Ascophylum nodosum	algae-rockweed
Laminaria sp.	kelp
Metridium senile	anemone
Mytilis edulis	edible mussel
Urosalpinx cinerea	oyster drill
Modiolus modiolus	horse mussel
Littorina littorea	periwinkle
Cancer borealis	jonah crab
Asterias vulgaris & forbesi	starfish
Tautogolabrus adspersus	cunner (fish)
Somateria spectabilis	king eider (duck)
Larus argentatus	herring gull

3.1.8 Pelagic Estuarine

The pelagic estuarine habitat is defined as the water column in open (unvegetated) waters with depth-averaged salinity between 16.5 and 30.0 parts per thousand. Pelagic estuarine habitats are subjected to sudden fluctuations in salinity due to varying freshwater and ocean water inputs; the result is low species diversity. On the southern coast of Long Island, the pelagic estuarine habitat occurs in the protected bays behind the barrier islands; all Long Island Sound waters are pelagic estuarine. Production from phytoplankton in the water column accounts for less than half of the productivity in these waters.

Table 8. Selected Species for Pelagic Estuarine

Skeletonema costatum	diatom
Chaetoceros sp.	diatom
Mnemiopsis leidyi	ctenophore
Acartia spp.	copepod
Pseudocalanus minutus	copepod
Oithona spp.	copepod
Pisces larvae	
Menidia menidia	silversides
Osmerus mordax	american smelt
Fundulus majalis	striped killifish
Pomatomus saltatrix	bluefish
Cynoscion regalis	weakfish
Branta bernicla	brant (bird)
Aythya marila	greater scaup
Larus argentatus	herring gull

3.1.9 Pelagic Coastal

The pelagic coastal habitat is defined as the water column in open waters with depth-averaged salinity greater than 30.0 parts per thousand (i.e., ocean salinities). This habitat is of low to moderate productivity, with a low standing stock of planktonic producers. Selected species for this habitat are listed in Table 9.

Table 9. Selected Species for Pelagic Coastal

Skeletonema costatum	diatom
Leoptcylindrus spp.	diatom
Ceratium spp.	dinoflagellate
Mnemiopsis leidyi	ctenophore
Oithona spp.	copepod
Acartia spp.	copepod
Centropages spp.	copepod
Brevoortia tyrannus	menhaden
Clupea harengus	herring
Squalus acanthias	spiny dogfish
Morus bassanus	gannet (bird)
Melanitta deglandi	white winged scoter

3.2 Distribution of Habitats

The habitats identified in section 3.1 are shown on two maps entitled, "Habitat Distribution." Map 1 shows the high energy beach, protected sand bottom and protected mud bottom habitats, as well as the general distribution of sand and mud bottoms; Map 2 shows the salt marsh, eelgrass system, pelagic estuarine and pelagic coastal habitats. The rocky shore and mussel reef habitats are not shown on the maps because both occur locally on a small scale, e.g., on boulders, piles, jetties, and groins, or on tidal deltas that have formed at bay/ocean inlets (Caldwell, undated). However, because mussels are an important commercial fishery, they are one of the special features considered in section 3.3.

The habitat map contained in Schrader *et al.* (1974) was reviewed and updated to include the entire marine portion of the Nassau-Suffolk coastal zone. Information on the procedures utilized for mapping the habitats is given below:

1. High energy beaches were located by utilizing soils maps contained in U.S. Dept. of Agriculture Soil Conservation Service (1975), and various reports dealing with coastal erosion, e.g., Davies *et al.* (1973). Beaches were considered high energy beaches if they were exposed to open water wave attack, wide, and backed by bluffs, scarps, or dune fields.
2. The protected sand bottom system habitat occurs in areas that are not exposed to high energy waves, and where the substrate consists of sand and gravel. Published reports that contained sediment information--O'Connor and Lin (1976), Feldhausen and Ali (1976), O'Brien and Ali (1974), Williams (1976), Nichols (1974), Schlee and Sanko (1974), Gross *et al.* (1972) and Penn (1968)--as well as unpublished sediment data provided by Mr. Gary Bigham, Tetra Tech, Inc., Smithtown, N.Y. were utilized to map this habitat.
3. The protected mud bottom system habitat was located primarily by determining substrate sediment type. The sources utilized to map this habitat are those referenced in 2. above.
4. Salt marshes were located by utilizing the summary map contained in O'Connor and Terry (1972), as amended.
5. Very little information is available concerning the distribution of eelgrass in Nassau-Suffolk coastal zone waters. It was decided to map areas with physical characteristics suitable for eelgrass growth as a proxy for actual eelgrass distribution. Eelgrass grows on mud or sandy mud substrates in waters with low

current velocities, and is limited to the photic zone (Elder, 1976). A review of secchi disc measurements taken in Great South Bay indicates that light extinction occurred at depths between 1.5 to 2.5 meters (Marine Sciences Research Center, 1973). Therefore, the eelgrass system was assumed to occur in protected bay areas that were 6 feet or less in depth. Bay areas where sea lettuce is dominant, such as Hempstead Bay, were included in the eelgrass system habitat (Burkholder and Doheny, 1968). In some instances available information did not permit determination of whether an area was either eelgrass system or protected mud bottom.

6. Pelagic estuarine and pelagic coastal environments were determined on the basis of water column salinity. Long Island Sound, the Peconics, as well as the south shore bays were found to be pelagic estuarine; pelagic coastal waters exist in the Atlantic Ocean and Block Island Sound. Primary references utilized include Hollman (1976), Koppelman *et al.* (1976), Hair and Buckner (1973), and Hardy (1976).

It should be noted that there were gaps in the available information used to delineate and map the various habitats. However, it is believed that in light of the many uncertainties regarding the biological impacts of oil spills, the generalized habitat descriptions and map provide a base for the evaluation of oil spill impacts.

3.3 Special Features

This report expands the discussion of special features given in Schrader *et al.* (1974). The special features selected for consideration in this report include: 1) major shellfish production areas; 2) major crustacean production areas; 3) major waterfowl nesting and feeding areas; and 4) recreation areas.

An attempt was made in Schrader *et al.* (1974) to specifically locate high and low production areas for various species of shellfish. Such an approach was reviewed in this study, and found to be deficient for the following reasons: 1. lack of detailed benthic studies for Nassau-Suffolk coastal zone waters; and 2. variability in shellfish standing crops from year to year due to both commercial and recreational harvesting activities and natural fluctuations in environmental conditions. Also, for the purposes of coastal zone management, it is better to consider entire bays or regions that are either currently high production areas or potentially high production areas in the future for selected species of shellfish when considering management options. For these reasons, both high and low production areas for selected shellfish and crustacean species of commercial and recreational importance were mapped. The selected species include the following:

Mya arenaria (soft-shell clam) - Map 3
Mercenaria mercenaria (hard clam) - Map 4
Crassostrea virginica (oyster) - 5
Aequipecten irradians (bay scallop) - Map 6
Spisula solidissima (surf clam) - Map 7
Mytilis edulis (blue mussel) - Map 8
Ensis directus (razor clam) - Map 8
Homarus americanus (lobster) - Map 9
Callinectes sapidus (blue claw crab) - Map 10

Mr. S.A. Hendrickson, Mr. R.B. MacMillan, and Mr. P.T. Briggs, Region I, New York State Dept. of Environmental Conservation provided information for the above maps which accompany this report.

The waterfowl nesting and feeding areas mapped were based on the map prepared in Schrader *et al.* (1974), with revisions supplied by Mr. J.L. Renkavinsky, Region I, New York State Dept. of Environmental Conservation. Areas utilized by both marsh ducks and diving ducks are included on Map 11 - "Major Waterfowl Feeding & Nesting Areas."

Map 12 entitled, "Outdoor Recreation Facilities," is a Nassau-

Suffolk Regional Planning Board inventory which shows recreational areas in public ownership that are susceptible to oil spill damage should oil spills occur. Although not necessarily related in a biological sense to the habitats described above, outdoor recreation facilities can be impacted in an adverse fashion from a spill through the restriction of fishing, boating, and swimming activities. Detailed treatment of such aesthetic or human impacts is beyond the scope of this report, therefore such impacts are not discussed further.

4.0 Population Responses to Oil Spills

4.1 Introduction

The effects of oil spills on populations is discussed in this section. Attention is focused on population responses, rather than individual responses, because: 1) population size and age-distribution are principal measures of a species as a resource; and 2) population sensitivity may differ significantly from that of individual organisms. This difference in sensitivities arises because population characteristics (size, age-distribution, and spatial distribution) depend on the aggregation of individual births, deaths, and migrations in the area of interest. For example, a population widely dispersed spatially, consisting of very sensitive individuals may also have a high reproductive rate and effective dispersal mechanism, and therefore may be relatively resistant to detectable effects of oil spills. That is, a population may have an effective mechanism (strategy) -- birth and immigration rates -- to counter an unexpected high death rate. In order to predict population level effects of oil, it is necessary to translate individual responses and sensitivities into changes in population birth, death, and migration rates which exist in the absence of exposure to oil. This section attempts to analyze this essential, but little studied problem, it is based on Scrader *et al.* (1974) and Moore *et al.* (1974), parts of which have been reproduced below.

4.2 Population Models and Data

Although mathematical models dynamically describing population density and age structure and embodying birth, death, and migration rates as a function of oil exposure are most desirable, several sources of uncertainty as well as information gaps prevent development of such models. With such limitations in mind, an alternative approach is adopted -- formulation of conceptual, largely qualitative models which have some theoretical basis, but are not thoroughly verified. The results provide some insight to the population level problem, indicate more precisely data needs, and establish a departure point for developing better models. Many implicit and explicit assumptions are made and the results must be viewed with caution.

Qualitative models developed in Moore *et al*. (1974) are used here. The models are based on the list of life history information shown in Table 10. Primary information on longevity, larval life style, and order-of-magnitude fecundity are available for approximately 90% of the selected species in this study, permitting wide application of the more qualitative models. Special information on movement of non-wide dispersal species is not available. Information on all other items is frequently available, but is too sketchy to permit any quantitative refinements on the qualitative models used. The information on selected species for this study is extracted from TRIGOM (1973) and VIMS (1973).

4.3 Background - Oil and the Physical Environment

As oil is spilled and begins to affect the biota of a region, the oil also interacts with the physical aspects of the environment. These interactions modify the composition and toxicity of the oil, and determine its persistence in a region following a spill. Hence, the initial composition of the oil, and the physical conditions present as an oil spill approaches and impacts the coast, may largely determine the spill's severity and the duration of biological impact.

Table 10. Important Life History Information for Selected Species

Intraspecific

* 1) Longevity: average, maximum, and minimum; at least annual/perennial

* 2) Larval life-style(s): in particular, is the organism in a wide-dispersal (typically planktonic) form at any point in its larval stage?

* 3) Fecundity: order-of-magnitude

* 4) Adult (including juvenile) life-style(s): Sessile vs. mobile?

* 5) Special information on non-wide-dispersal species: What is method of locomotion? How far, how fast, and how frequently can/does it move? What is the range (average, maximum and minimum) covered by an organism in a year? Rate of expansion into an unpopulated area?

6) Migratory patterns

7) Natural mortality rates -- age-specific

8) Age-specific fecundity

9) Are chemical cues used for spawning, feeding, or migration?

10) Density

Interspecific

11) Major food species

12) Major parasites and/or major commensals

13) Major predators

14) Major competitors

(*Starred information is of primary concern)

4.3.1 Oil Composition

The composition of petroleum products varies widely; even the composition of different crude oils differs among sources. Petroleum products typically contain hydrocarbons of the following structural groups, in varying proportions:

1) n-paraffins (normal and branched) (also called alkanes)
2) cyclo-paraffins
3) aromatics (mono-, di-, and polycyclic)
4) naptheno-aromatics

Table 11 shows one possible classification of petroleum substance composition according to eight fractions. These groups can also be divided into high-boiling (boiling point greater than 250°C) and low-boiling fractions. The product compositions shown in this table are only examples and are not definitive averages of all products within a product group.

4.3.2 Oil Degradation and Weathering Processes

The chemical composition of petroleum in the environment is altered by weathering processes, including evaporation, dissolution, microbial oxidation, chemical oxidation, and photochemical reactions. The rates of degradation are functions of the physical environment: temperature influences most degradation processes; nutrient and inorganic substances effect microbial degradation; the strong forces of the wind, tides, currents, and waves have pronounced effects on evaporation, dissolution, and sedimentation processes.

Evaporation depletes the lower-boiling components (fractions 1, 3 and 5, Table 11), but leads to little or no fractionation between hydrocarbons of the same boiling point that belong to different structural

Table 11. Estimated % Composition (by weight) and Comparison of Solubilities for Various Petroleum Substances

FRACTION	DESCRIPTION	HEAVY CRUDE	MEDIUM CRUDE	#2 FUEL OIL	BUNKER C
1	Low Boiling Paraffins $(C_6 - C_{12})$	5	30	15	0
2	High Boiling Paraffins $(C_{13} - C_{25})$	5	5	10	5
3	Low Boiling Cyclo-Paraffins $(C_6 - C_{12})$	5	15	15	0
4	High Boiling Cyclo-Paraffins $(C_{13} - C_{25})$	5	10	20	5
5	Mono-Cyclic Aromatics $(C_6 - C_{11})$	5	15	10	0
6	Polycyclic Aromatics $(C_{10} - C_{18})$	1	1	10	5
7	Naphtheno-aromatics $(C_9 - C_{25})$	10	10	20	5
8	Residual	64	14	--	80
Estimated Maximum & Soluble Aromatic Derivatives		.1-10	.1-10	1-10	1-5
ppm Soluble Aromatics Obtained in 10% Seawater Extracts[a]			10	5.7	1.3

series. Dissolution also removes preferentially the lower molecular weight components of an oil. However, aromatic hydrocarbons have a higher solubility than n-paraffins of the same boiling point. Biochemical (microbial) attack affects compounds within a much wider boiling range than evaporation and dissolution. Normal paraffins are most readily degraded. Extended biochemical degradation results next in the gradual removal of the branched alkanes. Cycloalkanes and aromatic hydrocarbons (fractions 3-8) are even more resistent and disappear at a much slower rate. Chemical and photo-oxidation also affect petroleum substances, but the processes are not well understood. Photo-oxidation can be significant.

The rates of degradation of each fraction are not well known. In general, the effects of weathering processes are the rapid (1-2 days) depletion of lower boiling fraction (boiling point 250° C) from a slick by evaporation and dissolution and slow degradation (in terms of years) of higher boiling fraction by microbial and chemical oxidation.

The heavy residuals of oil which are not degraded or deposited in sediments are found in floating tarry globules known as tar lamps or tar balls. In this form, petroleum can be transported long distances to be deposited later in bottom sediments or washed ashore.

It is useful in analyzing oil spills to classify the oil as weathered or unweathered. In weathered oil the concentration of hydrocarbon fractions with boiling points less than 250-300°C has been reduced to concentrations which do not cause toxic effects. One to two days has been estimated as a typical time oil must be in the pelagic environment to be considered weathered.

An important process affecting the ultimate fate of oil in marine environments is sedimentation and deposition in subtidal and intertidal substrates. The chemical composition of oil is not altered directly, and oil incorporated in unconsolidated sediments may persist for long periods of time, especially higher boiling fractions. In addition, loss of low-boiling fractions from unweathered oil incorporated in sediments may also proceed at much slower rates than from a slick (months rather than hours or days). This hypothesis is suggested by data from the West Falmouth spill.

A quantitative model of weathering and sedimentation of oil, based on the above processes, has not been developed, though in theory such a model is possible. The complex chemical composition of oil complicates the problem; in addition, many of the functional relationships between physical conditions and process rates are poorly known. Furthermore, little data is available on which to base such a model. However, a qualitative summary of the factors increasing and decreasing rates of weathering, degradation, and incorporation into the sediments has been prepared for estimating the relative importance of these processes in different habitats. See Figure 1.

Based on these factors and on a review of several actual spill events, one can summarize estimated oil retention times for each habitat. (See chapter five in Moore *et al.* (1974).) The minimum residence time of oil in unconsolidated sediments is between three and 10 years. The minimum residence time in hard substrate habitats is two to three years. Local conditions may change these estimates severalfold.

4.4 Oil Effects on Individuals

Chapter six in Moore *et al.* (1974) is a synthesis of the present

Figure 1. Factors Governing the Rates of Weathering, Incorporation into Sediments, and Degradation of Spilled Oil

Weathering

Faster ⟵	⟶ Slower
1) High proportion of low-boiling fractions in original spilled	1) Small proportion of low-boiling fractions in original spilled
2) High winds and waves	2) Calm conditions
3) Warm water and/or air conditions	3) Cold water and air conditions
4) Bright light	4) Overcast or dark conditions

Incorporation into Sediments

More ⟵	⟶ Less
1) Fine sediments	1) Coarse sediment or solid substrate
2) Heavy wave action	2) Calm surface condition
3) Naturally turbid water with high sediment load	3) Naturally clear water with low sediment load

Degradation

Faster ⟵	⟶ Slower
1) High proportion of low-boiling n-alkanes in retained oil	1) Small proportion of low-boiling fractions in oil retained in habitat
2) Large microbial population already present	2) Small microbial population
3) High nutrient concentration	3) Low nutrient concentration (nitrogen, phosphorous, oxygen)
4) High temperatures	4) Low temperatures
5) Heavy wave and current action	5) Calm water
6) Oil retained by coarse sediments and/or solid substrate	6) Oil retained by fine sediment

state of knowledge regarding the effects of oil on individual organisms. The conclusions reached in that study continue to be valid, and are adopted without change.

Effects of oil on individuals are categorized as: 1) lethal toxic effects due primarily to soluble aromatic hydrocarbons (boiling point < 250°C); 2) sub-lethal toxic effects from soluble aromatics; 3) coating of birds, mammals and inter- and sub-tidal sessile species with oil; 4) alteration of substrates by oil, which makes habitats uninhabitable for normally found species; and 5) incorporation of hydrocarbons into organism tissues causing tainting or accumulation of potential carcinogens. Insufficient data exist to identify sensitivity of each selected species (in the habitats described in section 3) to these effects. It is hypothesized that exposure of adult marine organisms to 1-100 ppm soluble aromatics for a few hours can be lethal. Concentrations as low as 0.1 ppm may be lethal to larval stages. Such concentrations are expected to result from oil slicks less than one to two days old, that is, unweathered. It is assumed that coating of inter-tidal areas with the main body of a slick (weathered or unweathered) will kill most sessile species. Although the amount of oil necessary to exclude benthic species from their substrates is largely unknown, this is one of the most important effects of oil spills because of the potentially long persistence times (of the order of years) of oil in sediments. Sublethal toxic effects of oil, in particular interference with chemical cues, causing disruption of feeding, reproduction or other essential life sustaining activities, may result from concentrations of soluble aromatics as low as 10 ppb. Tainting and hydrocarbon accumulation in organism lipid pools probably occurs in virtually all marine species due to either chemical equilibration with ambient water quality or food chain accumulation. Analysis of population level implications of sub-lethal effects and incorporation phenomena is virtually impossible given the present lack of understanding of governing phenomena. However, these effects of oil must be recognized as potentially important environmental impacts. Toxicity data for various classes of organisms are shown in Table 12.

4.5 Accidental and Continuous Discharges

Development of petroleum resources in nearshore coastal waters may result in two distinctly different types of oil discharges, each with significantly different biological effects: 1) accidental spills -- discrete events causing sudden, large perturbations of the environment; and 2) continuous releases of effluents containing relatively low hydrocarbon concentration.

Three environmental conditions associated with accidental spills can be identified: pre-spill "equilibrium," immediate post spill impact, and recovery from impact conditions back to an "equilibrium" condition. Pre-spill "equilibrium" is a dynamic condition of a habitat in which species' numbers, population densities, and age structure remain within identifiable bounds. Population birth, death, and migration rates are in balance over time periods measured on the order of years. The immediate potential impact of a spill is an immediate but short lived (by definition) increase in population death rates. Magnitudes of mortality depend on the nature of the exposure and sensitivity of individuals exposed. Recovery from an accidental spill involves dispersion and degradation of spilled oil and return of populations to "equilibrium" conditions. During recovery population birth,

Table 12. Summary of Toxicity Data

Class of Organisms	Estimated Concentration (ppm) of Soluble Aromatics Causing Toxicity
Flora	10-100
Finfish	5-50
Larvae (All Species)	0.1-1.0
Pelagic Crustaceans	1-10
Gastropods (Snails, etc.)	10-100
Bivalves (Oysters, Clams, etc.)	5-50
Benthic Crustaceans (Lobsters, Crabs, etc.)	1-10
Other Benthic Invertebrates (Worms, etc.)	1-10

death, and migration rates are, by definition, not in balance. The time period necessary for recovery is a critical parameter in determining the ultimate environmental effects of an accidental spill.

The other genre of discharge is continuous, or nearly continuous, releases of oil to the environment. In general, continuous spills are effluents from sources, such as oil-water separators, consisting of low concentration, oil contaminated water which does not elicit the impact-recovery response of accidental spills. Oil deposited in inter- and sub-tidal substrates following an accidental spill may also act as a continuous spill source due to slow and continuous releases of oil fractions from the sediments. Such continuous releases do not have dramatic sudden impacts, but instead may cause subtle changes in birth, death, and migration rates which are only differentiable from natural population fluctuations after long time periods with many years of data.

4.5.1 Accidental Spill Model: Initial Impact

An idealized concetpualization of total population density before and after an accidental oil spill is shown in Figure 2. Two distinct events are identified: initial impact and recovery. The initial impact of oil on a portion of the environment depends on the exposure of individual organisms to oil in the impacted zone.

Actual oil exposure resulting from a spill is characterized by several parameters:

1. Oil composition - the relative and absolute amounts of various hydrocarbon fractions; of particular interest is the concentration of lower boiling (<250°C) aromatic hydrocarbons.
2. Oil amount - actual volume of oil impacting an area; thick-

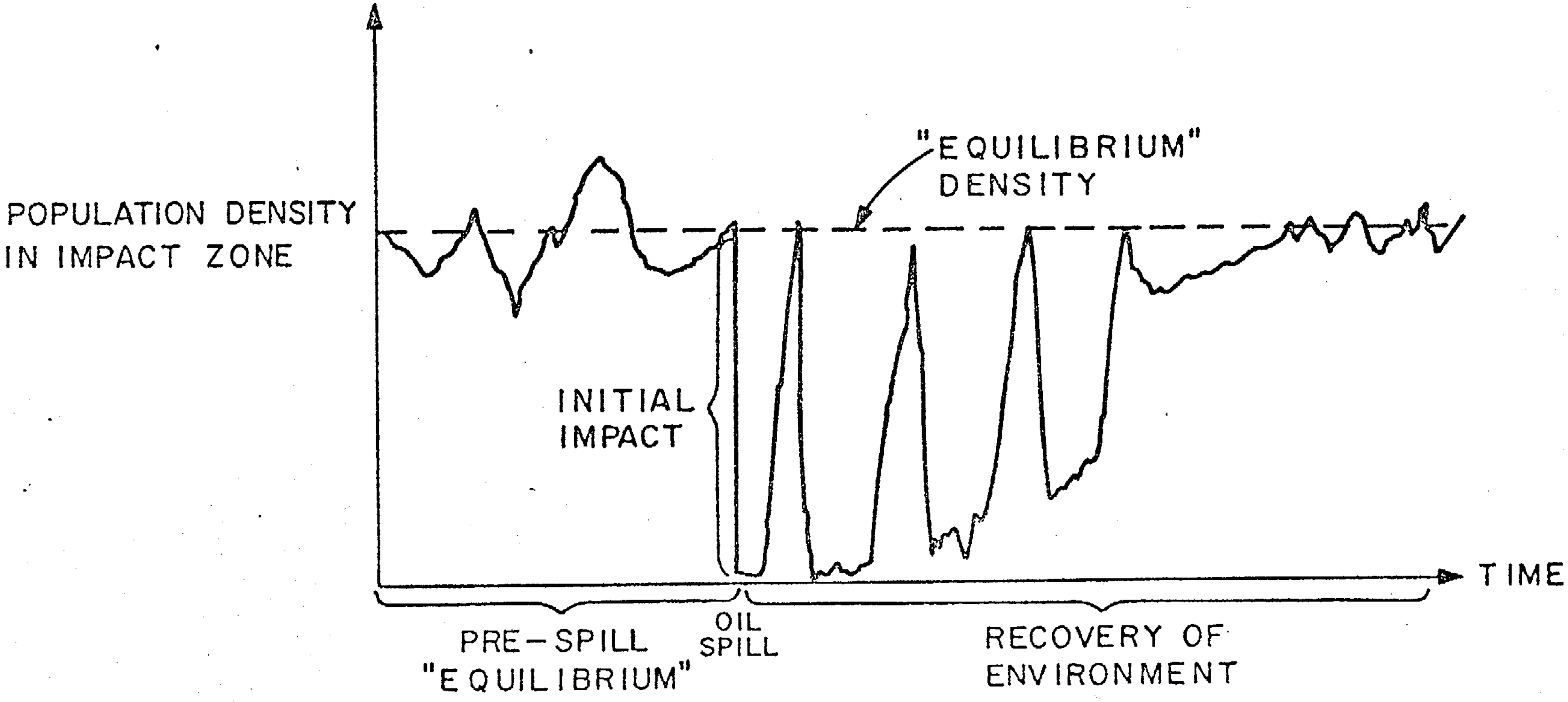


Figure 2. Idealized Conception of Recovery Process

ness and areal extent of slicks, patches, etc.

3. Degree of coverage - geographical; the percentage of area covered with oil and distribution of oil coating within the area of interest.
4. Meteorologic/oceanographic conditions - sea conditions (waves, surf, etc.) important in determining the extent to which oil is mixed in the water column and into sediments.

Given the large biological uncertainties, it is unrealistic to attempt to definitively describe a particular hypothetical spill precisely in terms of the above parameters. However, as described below, broad categories, such as weathered/unweathered, are useful in obtaining rough estimates of possible initial impacts. The following characterizations are made:

1. unweathered crude oil can be assumed to contain sufficient low boiling toxic fractions to cause mortality in most marine organisms exposed to the slick;
2. coating by the main body of a slick or by patches of weathered oil is likely to kill most sessile species and to alter any substrates covered;
3. sub-lethal effects due to accidental spills cannot be accounted for in most situations;
4. hydrocarbon incorporation is likely to occur in most species, especially filter feeders, from exposure to all but residual fractions. The degree of incorporation of tarry, residual substances is unknown.

The percentage of a population within a habitat or region killed or otherwise affected by a spill depends on the parameters described above. Although estimating such percentages is extremely difficult, if not impossible, at least the problem is bounded by two real cases: the no kill situation - zero recovery time; and 100% mortality situation - maximum recovery time required. For any case between these extremes, i.e., partial mortality, definition of initial impacts is complicated because both reduction in population size (density) and alteration of age-structure must be considered. Realistic estimates of such changes are virtually impossible to make, and analysis of subsequent recovery is equally difficult. Therefore, the recovery analysis in this report is confined to worst-case situations of 100% mortality.

4.5.2 Accidental Spill Model: Recovery

The total recovery process for a population can be partitioned into two overlapping time periods: 1) the time required before the physical substrate is suitable to permit recolonization; and 2) the time required for a species to recover in terms of density and age distribution. Oil persistence was discussed earlier. The latter problem is discussed below.

Four classes of recovery or recovery "strategies" are defined based on the dynamic processes contributing to population return to "equilibrium." In only one case can recovery time be estimated. The other three cases are qualitatively discussed and important features of recovery for such species identified.

4.5.3 Analytical Framework

As previously discussed, habitats in the Nassau-Suffolk coastal zone are characterized in part by selected representative species. Analysis of the response to and recovery from oil spills by these species is assumed to be sufficient to gain insight to recovery processes and to compare biological vulnerability of various habitats and regions to oil spill impacts.

A thorough approach to the recovery problem would require an understanding of the interrelations among various species as well as the internal dynamics of each population. Much of the necessary quantitative information, required to assess intra- or interspecies phenomena, is lacking, such as natural population density, average fecudnity, in situ age-specific mortality, longevity, identity and intensity of predators, etc. Much basic biological research is necessary, however, at least some data on many species are available. Therefore, it is appropriate to postulate general classes of recovery strategy, classes with sufficiently broad bounds that even a sketchy description of a species' characteristics will suggest its class of recovery strategy. These classes are distinguished by their different modes of colonization and expansion in unsettled, hospitable habitats. Each class requires a different form of analysis, a format which will be applicable to all member species in that class.

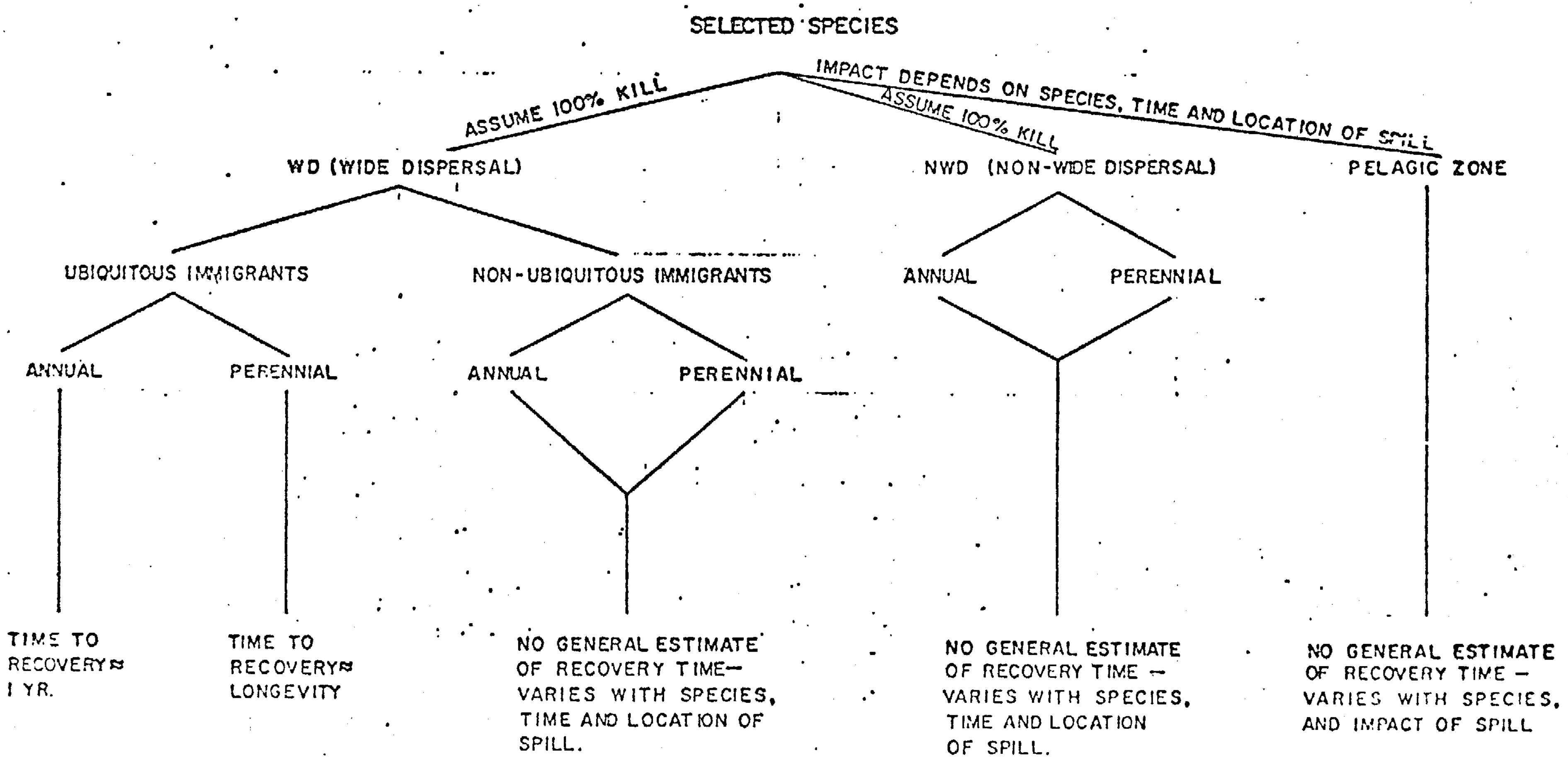
The various classes of recovery (i.e., colonization) strategy identified are shown in Figure 3.

There are four events which comprise the recovery process of a population whose ranks have been reduced by oil (or any other catastrophe).

1. Recovery begins with survivors. Some fraction $0 \le f < 1$ of the original population within boundaries of interest survives the spill. (Note that f may be zero--the 100% mortality case.)

2. Colonizers enter recovery area. Immigrants, usually larvae

Figure 3. Recovery Strategy Categories and Estimated Recovery Times in Uninhabited, Hospitable Environment



or other new-born, disperse in their own particular manner into and within the habitat. Two classes of dispersal--wide and non-wide--are identified. Wide-dispersal (WD) species are defined in the sense that if the entire spatial extent of a species' pre-spill habitat is (equally) accessible to reinvading members of the species, then the species is a wide-dispersal species. Species whose dispersal is limited, so that areas of a habitat under consideration cannot be reached by colonizers in a single reproductive season, are considered non-wide dispersal (NWD) or incremental growth species. One can imagine that the range of an NWD strategist will expand incrementally, "creeping" outward from a pocket of survivors or inward from the edges of the spill. It is evident then that both spatial and numerical recovery must be tracked in the NWD species recovery. This contrasts with the WD species case, where only temporal recovery need be predicted and spatial recovery is assumed uniform in the sense that all available sites are filled without regard to spatial location. Of course, organisms will not recover in areas which are always unattractive to them.

A second distinction arises from the question of availability of immigrants (usually larvae) in WD species. Are only a few arriving to resettle the area, or are they washing in on the tides in millions? The latter case, where enough immigrants arrive to fill every available site, is termed the "ubiquitous immigrant" case (WD-U). If there is a shortage of settlers, whether due to limited adult stock in the vicinity, or low fecundity, or unfavorable transport (currents, tides, winds), then this is the "non-ubiquitous" case. This final case--wide dispersal non-ubiquitous (WD-NU)--is difficult to analyze due to the uncertainty of immigrant availability. It is, however, an exceptional case for which only a few species qualify, and these are primarily birds.

3. Colonizing individuals settle. After oil has degraded sufficiently to allow successful settlement, colonizers are exposed to the usual physical rigors of the habitat (temperature, salinity, waves), which may be altered significantly in the wake of the spill (e.g., loss of marsh grasses permits wave induced erosion). They also suffer a milieu of biological pressures which changes continuously with recovery. Predation, parasitism, competition, and commensalism during recovery may differ dramatically in intensity and identity from these processes in the established pre-spill habitat.

4. Recovery is completed. For annual species, recovery is defined as reestablishment of pre-spill population density. For perennial species recovery is equated to regeneration of a pre-spill stable age distribution within the population. The rationale for this criterion is simply that a species with a stable age distribution seems well entrenched in its habitat. A stable age structure criterion is favored over a minimum density criterion because the latter is even more difficult to define and implement. Natural fluctuations in density are great, and especially in species of commercial importance where age implies size, a recovery criterion ought to reflect age structure as well as density.

The question of whether natural marine populations ever exhibit stable age distributions deserves attention. In fact, it would appear that such phenomena as dominant age classes and highly variable planktonic conditions preclude occurrence of stable age distribution, at least in WD marine species. Nevertheless, with assumptions on fecundity and mortality, a time to stable age distribution is theoretically calculable for any perennial species and is considered a working definition of time to recovery.

Figure 3 shows one additional class of recovery yet to be discussed: pelagic species. Admittedly, "pelagic species" is not a recovery strategy in the same sense that WD-U or NWD are strategies; however, the pelagic habitats are sufficiently unique in size and dispersal characteristics to require separate consideration. They are dealt with in section 4.5.7.

In summary then, the following classes of dispersal (recovery) strategy are defined:

1. wide dispersal-ubiquitous immigrants (WD-U)
2. wide dispersal-non-ubiquitous immiegrants (WD-NU)
3. non-wide dispersal immigrants (NWD)
4. pelagic species

Each dispersal type may be either annual or perennial. From available data a species can be placed in one of the above categories. If data permits, an additional distinction concerning age specific survivorship can be drawn, and then the time to stable age distribution can be computed for each class of recovery strategy.

Before proceeding to summaries of the recovery model for each recovery strategy, the reader is cautioned to view estimates of recovery time with respect for factors not fully considered. Interspecies dynamics, blooms (explosive population growth), inhibiting predation, competition and over grazing are not modeled--nor can they be in the wide range of cases considered here. It is assumed that there is always room for a species once decimated to return and recolonize;

that no other species will usurp its niche and its niche will still exist. Gaining a foothold in the environment is not considered a problem. An organism simply needs time to grow to the proper age and recovery is complete. None of these assumptions is necessarily true. However, the theoretical approximation to recovery processes developed herein is a working hypothesis from which some insight to the problem is gained and more adequate answers to the problem can ultimately emerge.

4.5.4 Recovery Model Summary: Wide-Dispersal-Ubiquitous Species

Recovery time from 100% mortality in a habitat for any WD-U species is estimated to be approximately the longevity (life span) of that species. This result is derived using simple demographic techniques, methods which keep track of the density and age structure of a population. Under conditions where a species' larvae can fill every vacant site in a recovering zone yearly, these techniques indicate that the age structure is stable after a period of one life-span. The most important assumptions of this recovery model are:

1) Adult mobility is ignored in the above result. Among those species with significant adult mobility, a modified model is proposed which shows an estimated recovery time of one-half the longevity.

2) Interspecies interactions are assumed not to vary significantly between the pre-spill and post-spill environments in an impacted area. However, these effects may cause significant errors in recovery time estimates approximated by the use of pre-spill "equilibrium" interaction rates throughout the post-spill recovery process. It is likely that the resulting estimates are too low, but the size of any error is unknown.

4.5.5 Recovery Model Summary: Wide Dispersal-Non-Ubiquitous Species

Specific estimates of recovery time from 100% mortality in a habitat for WD-NU species are not made. Great uncertainties in immigrant availability--by definition, non-ubiquitous immigrants--make development of quantitative models difficult. Birds apparently constitute the only selected group which falls into this class, and a qualitative discussion of bird recovery indicates that, should a spill kill a large percentage of a breeding population, a very long recovery time is quite possible. No general model is proposed because wide variations in initial kill and recovery are possible given different species and oil spills at different times and places.

4.5.6 Recovery Model Summary: Non-Wide Dispersal Species

Insufficient data exist on immigration rates of NWD species to allow prediction of specific recovery times. Variations in recovery conditions from site to site further complicate any predictions of recovery time. Recovery of NWD species is defined as requiring that the species reach its pre-spill density, in addition to a stable age distribution. NWD species by definition require longer than most species to reenter a decimated zone under favorable conditions. In addition, uncertainties about unfavorable conditions surrounding particular spills increase the expected recovery time of these species. Because of these conditions, NWD species populations are reckoned among the most sensitive to oil spills.

4.5.7 Recovery Model Summary: Pelagic Species

Fish, birds, and certain plankton species appear to be the only species in the pelagic zone in which a significant population response to a catastrophic oil spill is possible. All other species are considered effectively immune because:

1) they are nektonic (active swimmers) and can thus actively avoid a contaminated area; or

2) they are planktonic (passive drifters), but their population is too diffuse and widespread to be significantly impacted by one catastrophic spill. The sensitivity and recovery of birds is treated in section 4.5.5. Furthermore, plankton impact and recovery are also not considered, because none of the selected species of plankton in the study area exhibits potential population level sensitivity to oil.

Fish populations are vulnerable to oil spills through various mechanisms:

1) The population migrates or reproduces in confined areas, and thus is vulnerable to a spill occurring at the same place and time that the population is congregated.

2) The species depends on specific spawning or nursery areas, and thus is vulnerable to destruction or pollution of these areas.

3) The species produces eggs or larvae which float and are closely grouped, and thus is vulnerable to elimination of a year class if the eggs or larvae coincide with an oil spill. Because the impact of an oil spill depends so much on the time and location of the spill and on the particular species impacted, no general model of impact and recovery of fish populations is proposed. Each selected species is treated individually, to the degree that the necessary information is available.

4.6 Accidental Spill Model: Population Recovery Time Estimates

In this section, the models developed to assess oil spill impacts on population levels are applied to the species selected for each habitat in the Nassau-Suffolk coastal zone. The results presented below are for the worst-case condition of 100% mortality to a population in a habitat. They provide a basis when combined with oil retention times for estimating habitat vulnerability.

Tables 13 to 21 list by species approximate time to recovery for a population decimated by a worst-case (i.e., 100% kill) oil spill, excluding the lapse until the substrate becomes suitable for resettlement. For WD-U species, it is argued that recovery time is of the order of longevity. Certainly if replacement of elder individuals is held a partial criterion for recovery, then longevity provides a lower bound on recovery time (provided adult individuals are immobile). For WD-NU species, such as birds, recovery time is not predicted and the symbol, **, is entered in the recovery time column. Recovery will depend on fecundity and dispersal patterns in a manner not known. In addition, the population unit of interest (e.g., breeding population) will affect recovery time, as will intermixing among populations. NWD species such as amphipods, and certain molluscs and worms, are also not assigned recovery times. The symbol, *, is entered in the tables under recovery time. Recovery of NWD species will depend on expansion rate, fecundity, areal extent of kill, and the particular site of impact.

Table 13. Selected Species Population Recovery Analysis - High Energy Beach

Species (common name)	Recovery Class	Longevity	Implied Recovery Time	Relevant Interspecies Effects
Cerianthus americanus (sand anemone)	WD-U (?)	"many years"	"many years"	Suspension feeder.
Diopatra cuprea polychaete (tube worm)	?	? (perennial)	?	Tube harbors a microcommunity of algae and invertebrates
Nephthys picta polychaete worm	?	?	?	Member of *T. agilis* community and *M. mercenaria* community. Errant deposit feeder.
Spisula solidissima (surf clam)	WD-U	6 to 10 years (avg.) 17 years (maximum)	6 to 10 years	Filter feeder. May have slight adult mobility.
Tellina agilis (clam)	WD-U (?)	10^+ years	10 years	Bottom feeder and filter feeder. A major fish food.
Astarte castanea (clam)	?	?	?	Abundant sub-tidally in some areas.
Haustoridae (amphipod)	NWD	Annual	*	Detrital feeder. Eaten by fish and shore birds.
Emerita talpoida (sand mole crab)	WD-U	1 to 2 years	1 to 2 years	Filter feeder.
Cancer irroratus (rock crab)	?	?	?	Feeds on detritus and small invertebrates. Significant adult mobility.
Echinarachnius parma (sand dollar)	WD-U	? (perennial)	?	Detrital feeder.
Asterias forbesi (starfish)	WD-U	? (perennial)	?	Predator on bivalves. Significant adult mobility.
Sterna hirundo (common tern)	WD-NU	25 to 30 years (maximum)	**	Two to three eggs/year.
Passerculus princeps (ipswich sparrow)	WD-NU	5 to 9 years	**	Four to five eggs/year.
Crocethia alba (sanderling)	WD-NU	?	**	Eats *Donax*, *Emerita*, amphipods, and other beach invertebrates. Four eggs/year.
Ammodytes americanus (sand launce)	WD-U	3 years	1 to 3 years	No distinct, separate breeding populations. Demersal eggs and pelagic larvae.
Morone saxatilis (striped bass)	WD-U	> 5 years	?	Anadromous, running up the Hudson River.
Paralichthys dentatus (summer flounder)	WD-U	> 4 years	?	Possibly separate breeding populations. Pelagic eggs and larvae.
Halichoerus grypus (grey seal)	WD-NU	25 to 35 years	** (decades, if kill occurs).	Breeds on Sable Island, Nova Scotia.

Table 14. Selected Species Population Recovery Analysis - Protected Sand Bottom

Species (common name)	Recovery Class	Longevity	Implied Recovery Time	Relevant Interspecies Effects
Cerianthus americanus (sand anemone)	WD-U(?)	"many years"	"many years"	Suspension feeder.
Nereis virens polychaete (sand worm)	WD-U	4 years	4 years	Predatory and deposit feeder.
Diopatra cuprea polychaete (tube-building worm)	?	? (perennial)	?	Tube harbors a microcommunity of algae and invertebrates.
Clymenella torquata polychaete (tube worm)	NWD	? (perennial)	*	?
Pectinaria gouldii (trumpet worm)	WD-U (?)	3 years	3 years	?
Tellina agilis (clam)	WD-U (?)	10+ years	10 years	Filter feeder. A major fish food.
Ensis directus (razor clam)	WD-U	? (perennial)	?	?
Mya arenaria (soft clam)	WD-U	7 years	7 years	Filter feeder.
Mercenaria mercenaria (quahog or hard clam)	WD-U	6+ years	6 years	Filter feeder.
Gemma gemma (pea or gem clam)	NWD	2 years	*	
Aequipecten irradians (bay scallop)	WD-U	2 years	2 years	Disappeared with decline of *Zostera* 1930's. Still recovering, even after *Zostera* has been reestablished.
Polynices hero (predatory snail)	?	?	?	
Acanthohaustorius millsi (amphipod)	NWD	Annual	*	
Leptocheirus pinguis (amphipod)	?	?	?	Important fish food.
Pagurus longicarpus (hermit crab)	WD-U	perennial (?)	?	Scavenger.
Crangon septemspinosus (mud shrimp)	WD-U	1 to 3 years (disputed)	1 to 3 years	Scavenger.
Limulus polyphemus (horse shoe crab)	WD-U	14 to 19 years	≃15 years	?
Emerita talpoida (sand mole crab)	WD-U	1 to 2 years	1 to 2 years	Filter feeder.
Carcinus maenas (green crab)	WD-U	3 years (average) 6 years (maximum)	3 years	Major predator on bivalves.
Callinectes sapidus (blue crab)	WD-U	3 to 4 years	3 to 4 years	Predator and scavenger.

Table 14 (Cont'd)

Species (common name)	Recovery Class	Longevity	Implied Recovery Time	Relevant Interspecies Effects
Pseudopleuronectes americanus (winter flounder)	WD-U	? (perennial)	?	Evidence of separate breeding populations.
Limanda ferruginea (yellowtail flounder)	WD-U	7 years	?	Evidence of separate breeding populations.
Paralichthys dentatus (summer flounder)	WD-U	4+ years	?	Evidence of separate breeding populations.
Ammodytes americanus (sand launce (fish))	WD-U	3+ years	3 years	No separate breeding populations.
Sterna hirundo (common tern)	WD-NU	25 to 30 years (maximum)	**	Two to three eggs/year.
Passerculus princeps (ipswich sparrow)	WD-NU	5 to 9 years	**	Four to five eggs/year.
Crocethia alba (sanderling)	WD-NU	?	**	Eats *Donax*, *Emerita*, amphipods and other beach invertebrates. Four eggs/year.

Table 15. Selected Population Recovery Analysis - Protected Mud Bottom

Species (common name)	Recovery Class	Longevity	Implied Recovery Time	Relevant Interspecies Effects
Cerianthus americanus (sand anemone)	WD-U ?	"many years"	"many years"	Suspension feeder.
Nereis virens (polychaete (sand worm)	WD-U	4 years	4 years	Predatory and deposit feeder.
Nereis succinea (polychaete)	?	?	?	
Pherusa affinis (polychaete)	WD-?	?	?	A very significant food for winter flounder; a deposit feeder.
Streblospio benedicti polychaete (tube worm)	WD-U	annual	1 year	
Pectinaria gouldii (trumpet worm)	WD-U	3 years	3 years	
Tellina agilis (clam)	WD-U	10+ years (maximum)	10 years	Filter feeder, a major fish food.
Mya arenaria (soft clam)	WD-U	7 years	7 years	Filter feeder.
Macoma balthica (clam)	NWD	2+ years	*	Deposit feeder.
Nassarius obsoletus (snail)	WD-U	3+ years	3+ years	
Leptocheirus pinguis (amphipod)	?	?	?	Important fish food.
Corophium volutator (amphipod)	NWD	(sub) annual	*	Tube-dwelling amphipod.
Carcinus maenas (green crab)	WD-U	3 years (average) 6 years (maximum)	3 years	Major predator on bivalves.
Callinectes sapidus (blue crab)	WD-U	3 to 4 years	3 to 4 years	Predator and scavenger.
Pseudopleuronectes americanus (winter flounder)	WD-U	? (perennial)	?	Evidence of separate breeding populations.
Paralichthys dentatus (summer flounder)		> 4+ years	?	Evidence of separate breeding populations.
Trinectes maculatus (hog choker (fish))		* 7 years	?	No information on existence or non-existence of separate breeding population.
Urophycis chuss (squirrel or red hake)		3+ years	?	No information on existence or non-existence of separate breeding populations.

Table 16. Selected Population Recovery Analysis - Salt Marsh

Species (common name)	Recovery Class	Longevity	Implied Recovery Time	Relevant Interspecies Effects
Spartina alterniflora (marsh grass)	NWD (?)	Shoots = annual Rhizomes = perennial	*(Depends on whether or not rhizomes are killed).	Very important source of organic detritus; indispensable in energy flow pattern of inshore waters. Also provides habitat prerequisite to occurence of the following species.
Ulva lactuca (sea lettuce)	WD-U	Annual	1 year	Rapid colonizer.
Enteromorpha sp. (green algae)	WD-U	Annual	1 year	Rapid colonizer.
Nereis virens (sand worm)	WD-U	4 years	4 years	Errant deposit feeder.
Clymenella torquata (polychaete)	NWD	Annual	*	Detrital feeder: lives under moist seaweed between high and low water.
Modiolus demissus (ribbed mussel)	WD-U	6 to 7 years	7 years	A filter feeder. A major food for birds and mammals. Young are predation-limited; adults are competition-limited.
Melampus bidentatus (snail)	WD-U	5 years	5 years	Detrital feeder lives on grass stems of *Spartina*.
Littorina littorea (periwinkle)	WD-U	2 years	2 years	A browser living on stems near marsh's saltwater margins.
Orchestiidae sp. (amphipod)	NWD	Annual	*	A detrital feeder.
Uca spp. (fiddler crabs)	WD-U	> 2 years	2 to 3 years	Scavengers; significant adult mobility.
Crangon septemspinosus (mud shrimp)	WD-U	disputed; 1 to 3 years	1 to 3 years	Predator and scavenger.
Dipterous larvae (*Aedes* spp. and other *Dipterids*)	WD-U	Annual	1 year	Detrital feeders.
Prokelisia marginata (plant hopper)	WD-U	Annual	1 year	Feeds on living *Spartina*, consuming 6+ % of annual production. Comprises 30-95% of *Spartina*.
Fundulus heteroclitus (mummichog (fish))	WD-U	?	?	Found next to shore in a few inches of water. Omnivorous.
Ammodytes americanus (sand launce (fish))	WD-NU	3+ years	3 to 4 years	Indication of separate inshore and offshore populations, but homogeneous within bays.
Agelius phoeniceus phoeniceus (eastern red-winged blackbird)	WD-NU	4 to 7 years	**	Feeds on insects.
Pandion haliaetus (osprey)	WD-NU	21 years (maximum)	**	Migration timed to shad and herring runs. Rare.
Anas rubripes (black duck)	WD-NU	16 to 20 years (maximum)	**	Nests on marsh edges. Feed on plants, seeds, crustaceans and mollusks.
Larus argentatus (herring gull)	WD-NU	4 to 8 years (avg.) 30 years (maximum)	**	Feeds on fish, insects, mollusks, crustaceans, garbage and detritus.
Rallus longirostris (clapper rail)	WD-NU	?	**	Nests on Long Island from April to November, Feeds mostly on invertebrates.

Table 16 (Cont'd)

Species (common name)	Recovery Class	Longevity	Implied Recovery Time	Relevant Interspecies Effects
Malaclemys terrapin (diamond-back terrapin)	?	?	?	?
Ondatra zibethica (muskrat)	WD-NU	21 years (maximum)	**	Density varies widely from marsh to marsh.

Table 17. Selected Population Recovery Analysis - Eelgrass System

Species (common name)	Recovery Class	Longevity	Implied Recovery Time	Relevant Interspecies Effects
Zostera marina (eelgrass)	NWD	Shoots are annual; rhizomes are perennial.	*(Depends on whether or not rhizomes are killed)	Provides habitat for bay scallop and other species. Provides a substrate for epiphytic species. Reduces current action.
Ulva lactuca (sea lettuce)	WD-U	annual	1 year	Colonizes before *Zostera*.
Agardhiella tenera (red algae)	NWD (?)	?	*	Epiphytic on *Zostera*.
Cladophora gracilis (green algae)	WD-U	annual	1 year	Epiphytic on *Zostera* and other hard surfaces.
Electra crustulenta (bryozoan)	WD-U	sub-annual	1 year	Forms encrusting colonies on *Zostera* and other hard substrates.
Scolopos fragilis (polychaete)	NWD	2 to 3 years	?	Tube-building worm.
Bittium spp. (snail)	NWD	1.5 years	*	Lives on *Zostera* and other hard substrates.
Crepidula convexa (slipper shell)	NWD	3 to 4 years	*	Filter feeder. Lives in mud adjacent and among *Zostera*.
Urosalpinx cinerea (oyster drill)	NWD	5 years	*	Preys heavily on oysters.
Aequipecten irradians (bay scallop)	WD-U	2 years	2 years	Disappeared with decline of *Zostera* in 1930's. Still recovering, even after *Zostera* had been reestablished.
Mercenaria mercenaria (quahog or hard clam)	WD-U	6+ years	6 years	Filter feeder.
Paracercis caudata (isopod)	NWD	1.5 years (?)	*	Fastens on to *Zostera* blades; grazes epiphytic algae.
Corophium volutator (amphipod)	NWD	1 month	*	Tube-dwelling amphipod.
Menidia menidia (silversides (fish))	WD-U	?	Depends on initial impact and local conditions	Feed on *Elektra*, *Scolopos*, *Paracerceis* and *Corophium*, among others.
Branta bernicla (brant)	WD-NU	5 to 8 years (?)	**	85% to 100% of diet is *Zostera*.

Table 18. Selected Population Recovery Analysis - Mussel Reef

Species (common name)	Recovery Class	Longevity	Implied Recovery Time	Relevant Interspecies Effects
Cliona spp. (boring sponges)	WD-U	?	?	Completely (slowly) destroys oyster shells on which it grow.
Metridium senile (anemone)	?	?	?	?
Harmothoe imbricata (polychaete worms)	WD-U (?)	?	?	Often lives in tubes or burrows of other invertebrates.
Polydora spp. (polychaete (tube worms))	WD-U	(sub) annual	1 year	*P. websteri* grows on oysters and snails often at quite high densities, (3-232 worms/oyster) as well as on scallops and quahogs.
Urosalpinx cinerea (oyster drill)	NWD	12 years (maximum) 5 years (average)	*	Preys heavily on oysters.
Mytilis edulis (edible mussel)	WD-U	4 years, 7 years maximum	4 years	Filter feeders.
Crepidula fornicata (slipper shell)	NWD	? (perennial)	*	?
Modiolus modiolus (horse mussel)	?	?	?	?
Asterias vulgaris *A. forbesi* (starfish)	WD-U	? (perennial)	?	Predator on bivalves. Significant adult mobility.

Table 19. Selected Population Recovery Analysis - Rocky Shores

Species (common name)	Recovery Class	Longevity	Implied Recovery Time	Relevant Interspecies Effects
Codium spp. (algae)	?	?	?	Has been invading southern New England waters.
Fucus spp. (algae)	WD-U	?	?	Creates a microhabitat supporting numerous species.
Ascophylum nodosum (algae-rockweed)	WD-U	8 years (15 years maximum) -	8 years	Competitor fucoids are more prolific and can repopulate denuded areas faster.
Laminaria sp. (kelp)	WD-U	1 to 2 years	2 years (if kill occurs)	Recovery can be seriously imparied by sea urchin grazing off roots.
Metridium senile (anemone)	?	?	?	?
Mytilis edulis (edible mussel)	WD-U	4 years, 7 years max.	4 years	Filter feeder.
Urosalpinx cinerea (oyster drill)	NWD	12 years (maximum) 5 years (average)	*	Preys heavily on oysters and other bivalves.
Modiolus modiolus (horse mussel)	?	?	?	?
Littorina littorea (periwinkle)	WD-U	2 years	2 years (if kill occurs)	Browser.
Cancer borealis (Jonah crab)	WD-U	? (perennial)	?	Scavenger. Significant adult mobility.
Asterias vulgaris *A. forbesi* (starfish)	WD-U	? (perennial)	?	Predator on bivalves. Significant adult mobility.
Tautogolabrus adspersus (cunner (fish))	WD-U	> 2 years	2 years	No evidence of separate breeding populations.
Somateria spectabilis (king eider)	WD-NU	15 years	**	May transmit a parasite (via feces) to mussels, causing "pearls". Five to ten eggs/year.
Larus argentatus (herring gull)	WD-U	4 to 8 years (30 years maximum)	**	Three to five eggs/year. Feeds on small fish and invertebrates, detritus and debris.

Table 20. Selected Population Recovery Analysis - Pelagic Estuarine

Species (common name)	Recovery Class	Longevity	Implied Recovery Time	Relevant Interspecies Effects
Skeletonema costatum (diatom)	pelagic	(sub) annual	a few weeks at most	The dominant phytoplankton during the spring and summer blooms. Primary producers--basis of pelagic food chain.
Chaetoceros spp. (diatom)	pelagic	(sub) annual	a few weeks at most	
Mnemiopsis leidyi (ctenophore)	pelagic	?	?	This and other ctenophores the major predator on zooplankton.
Acartia spp. (copepod)	pelagic	(sub) annual	a few months at most	The dominant herbivores; main food source for higher consumers.
Pseudocalanus minutus (copepod)	pelagic	(sub) annual	a few months at most	
Oithona spp. (copepod)	pelagic	(sub) annual	a few months at most	
Pisces (larvae)				
Menidia menidia (silversides (fish))	WD-U	?	Depends on initial impact and local conditions.	
Osmerus mordax (american smelt)	WD-U	5+ years	?	Anadromous.
Fundulus majalis (striped killifish)	WD-U	?	?	No information on the existence or non-existence of separate breeding populations.
Pomatomus saltatrix (bluefish)	WD-U	5+ years	?	No information on existence or non-existence of separate breeding populations.
Cynoscion regalis (weakfish)	WD-U	5+ years	?	No information on existence or non-existence of separate breeding populations.
Branta bernicla (brant (bird))	WD-NU	?	**	85% to 100% of diet is *Zostera*.
Aythya marila (greater scaup)	WD-NU	11 years maximum	**	Dives for fish.
Larus argentatus (herring gull)	WD-NU	4 to 8 years (avg.) 30 years (max.)	**	Feeds on fish, insects, mollusks, crustacea, detritus and debris.

Table 21. Selected Population Recovery Analysis - Pelagic Coastal

Species (common name)	Recovery Class	Longevity	Implied Recovery Time	Relevant Interspecies Effects
Skeletonema costatum (diatom)	pelagic	(sub) annual	a few weeks at most	The dominant phytoplankton during the spring and summer blooms. Primary producers—basis of pelagic food chain.
Leptocylindrus spp. (diatom)	pelagic	(sub) annual	a few weeks at most	
Ceratium spp. (dinoflagellate)	pelagic	(sub) annual	few days—few weeks	
Mnemiopsis leidyi (ctenophore)	pelagic	?	?	This and other ctenophores comprise the major predators on zooplankton.
Oithona spp. (copepods)	pelagic	(sub) annual	a few months at most	The dominant herbivores; main source of food for higher consumers.
Acartia spp. (copepods)	pelagic	(sub) annual	a few months at most	
Centropages spp. (copepod)	pelagic	(sub) annual	a few months at most	
Brevoortia tyrannus (menhaden)	WD-U	6+ years	6 years	No evidence for separate breeding populations.
Clupea harengus (herring)	WD-U	14 years (maximum)	?	Evidence of separate breeding populations.
Squalus acanthias (spiny dogfish)	WD-U	25-30 years maximum	?	No evidence for separate breeding populations. However, low reproductive potential—ovoviviparous.
Morus bassanus (gannet (bird))	WD-NU	20 years (maximum)	**	Dives for fish.
Melanitta deglandi (white-winged scoter)	WD-NU	?	**	Dives for fish.

5.0 Habitat Response to Oil

5.1 Introduction

A habitat has been defined to include both a characteristic physical/chemical environment and a characteristic biotic community (i.e., an assemblage of characteristic populations). In this section, a framework for predicting the responses of habitats (i.e., the "habitat-level" response) to oil spills is developed. Habitat recovery times are estimated on the basis of the physical/chemical response and selected population responses.

There are several reasons for analyzing oil spill impacts at the habitat level. Operationally, it simplifies analysis. Since an impacted stretch of coastline can be treated as an assemblage of habitats, estimates of habitat responses provide a simple scheme for spill impact assessment. Habitat responses can also be used to assess the relative vulnerability of a region to potential oil spills. Furthermore, the environment's response to an oil spill is more realistically analyzed at the habitat level. A habitat level analysis takes into account interactions between populations, which are ignored when individual population responses are analyzed independently of each other. Consequently, a habitat's sensitivity may differ significantly from that of it's constituent populations. For example, a habitat may be dominated by one particular species, which provides food or suitable physical/chemical conditions for the rest of the habitat. Though the other populations may have potentially rapid recovery given hospitable conditions, their total population recovery may be significantly delayed while the central species' population is recovering.

The different types of recovery should be clarified. "Population recovery" is used in reference to recovery of a population, given hospitable conditions. "Total population recovery" refers to recovery of a population starting from the date of the spill (i.e., under inhospitable conditions). "Habitat recovery" refers to the recovery of a habitat starting from the date of a spill.

5.2 Framework

An idealized conceptualization of the recovery process for a selected species is depicted in Figure 2. This figure shows the failure or partial failure of a species' initial attempt to recover, due to environmental conditions that are not yet suitable for re-establishment. Environmental conditions which might hinder a species recovery are physical unsuitability (e.g., sediments too incohesive or too solid), chemical unsuitability (e.g., toxicity), or biotic unsuitability (e.g., unavailability of necessary food or substrate species, predominance of a superior predator or competitor). The framework used to analyze habitat recovery breaks down the total recovery process of a selected species, depicted as a continuum in Figure 2 into discrete stages:

1) recovery of the physical/chemical environment to suitable conditions;
2) recovery of requisite food and substrate species;
3) recolonization and regrowth of the selected species population; i.e., population recovery in a hospitable environment.

The analysis of habitat recovery is restricted to worst-case (i.e., 100% initial mortality) accidental oil spills. Spills causing only partial mortality present insurmountable difficulties in assessment of both initial mortality and subsequent recovery. The duration of the third stage of a selected species' recovery is estimated from the population recovery time in a hospitable environment from a worst-case spill (section 4.0). The first stage of a selected species' recovery is based on oil residence time. The duration of the second stage of a species' recovery depends on its position in the habitat food web. The complete recovery of one of a consumer's food species is considered sufficient to permit recovery of the consumer species to begin. This second stage may also be lengthened if the species in question depends on another species for a substrate.

According to this framework, a habitat recovery scenario following a 100% kill event might run as follows. No biological recovery occurs in the habitat during the period of residence of the oil. At the end of the estimated oil residence time, recovery of the species in the lowest trophic levels begins. As each of these species completes recovery, their respective predator species begin recovery, and so on. As a species providing a substrate completes recovery, those species attaching to it begin recovery. For the purposes of this study, habitat recovery is defined to occur when all of the selected species in a habitat have completed their recovery (i.e., have achieved both a stable age-structure and their pre-spill density).

Admittedly, selection of this definition is somewhat arbitrary. It assumes that by accounting for recovery of the selected species, one will have largely accounted for recovery of the habitat. There is in this definition the implicit assumption that the selected species in some sense are sufficient to characterize the habitat; this is a weak assumption. Ideally, habitat recovery can be defined as: a return of the habitat to the conditions that would have prevailed in the absence of the spill. However, the conditions that "would have prevailed....." can never be known with certainty. All habitats are constantly fluctuating in structure. In order to arrive at potentially useful conclusions regarding habitat recovery, this operational definition of habitat recovery is selected.

This analysis does not pretend to give an accurate model of the process of habitat recovery. However, it is hoped that by simplifying this process, a useful estimate of the time to ultimate recovery may be derived. There are varying levels of uncertainty in the estimates of oil residence times and population recovery times. There is also uncertainty introduced in the analysis by the way that these stages fit together. Hence, the uncertainty in an estimate of habitat recovery time is quite large. However, a quantitative estimate of this uncertainty cannot be obtained at present, leaving estimates of average habitat recovery time fairly vague. A further difficulty with the use of average habitat recovery time is that maximum recovery times are not estimated for many species. Thus, in an effort to present some quantitative treatment of habitat recovery, the minimum recovery times of the species are used to estimate a minimum recovery time for the habitat. All estimates are for worst-case spills, unless otherwise noted.

5.3 Habitat Impact and Recovery Analyses

The high energy beach, salt marsh, and eelgrass system habitats have been selected for in-depth analysis. These habitats were selected on the basis of high exposure to oil spills (high energy beach), or on the basis of ecological (not necessarily commercial) importance to the Nassau-Suffolk coastal zone (salt marsh and eelgrass system). Food web diagrams for each habitat were prepared and estimates of population recovery times were taken from Tables 13 - 22.

"Habitat recovery" is summarized, for each spill scenario, in a "recovery time-line". This time-line shows when a species is expected to begin and to complete total population recovery, based on the minimum estimates for population recovery of each species and on the physical/

chemical conditions. By the definition of habitat recovery presented in the preceding section, a minimum estimate of habitat recovery time is the time at which the last species completes total population recovery, on the recovery time-line.

5.4 High Energy Beach

5.4.1 Introduction

This habitat is by definition one of strong currents and vigorous water circulation. These characteristics give the high energy beach habitat the potential for faster recovery than the salt marsh or eelgrass system. Based on the interspecies information shown in the food web (Figure 4) and available life history data, it is possible to estimate recovery times for most of the selected species in this habitat.

5.4.2 Discussion of Habitat Recovery by Species

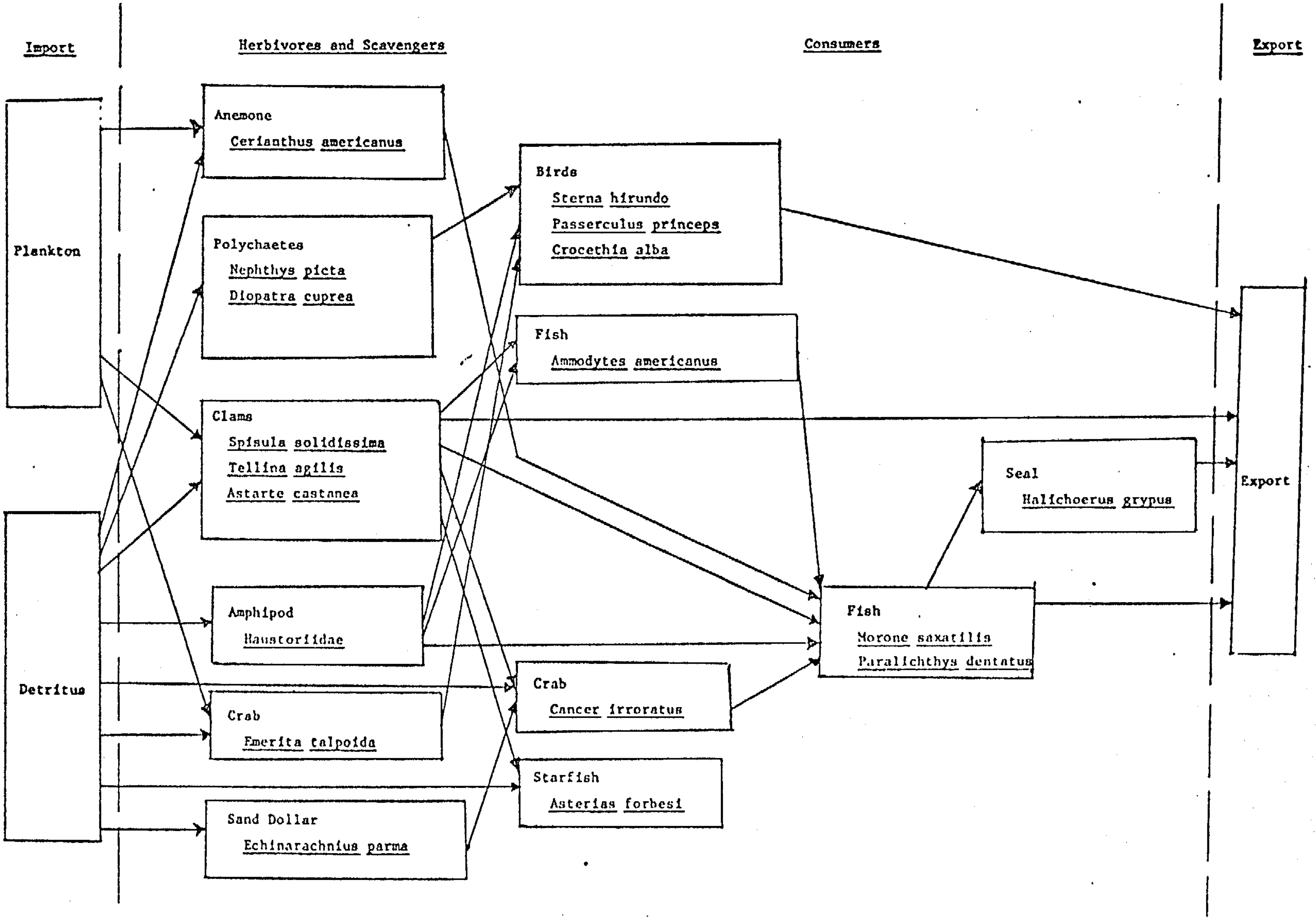
Population recovery times for each selected species in the high energy beach habitat are given below. In general, the estimated three year minimum time for recovery of the physical/chemical conditions is not included in the following estimated recovery times. That is, unless otherwise stated, the recovery times estimated below include the total population recovery process, except for the first stage of physical/chemical recovery (which is the same for all species).

All of the following analyses relate to a worst-case oil spill, i.e., a spill causing 100% mortality of all species in the impacted zone.

Cerianthus americanus (sand anemone)

There is only limited life history data on this species. It occurs commonly in sand and is widely distributed along the Atlantic coast. It is a burrowing, tube-dwelling, suspension feeder. Thus, food availability is not expected to delay recovery of this anemone. The larval

Figure 4. High Energy Beach - Food Web of Selected Species



stage is planktonic. Hence, *Cerianthus* is WD-U. The longevity of *Cerianthus americanus* is unknown; however a Mediterranean relative, *Cerianthus membranaceus*, is known to live for 10 to 40 years. Furthermore, long life spans are typical of this whole sub-class *(Zoantharia)*, of the phylum *Cnidaria*. Hence, recovery of *Cerianthus americanus* is estimated to take at least 10 years, once the physical/chemical environment is suitable.

Nepthys picta (sand worm)

No life history data has been found for this burrowing polychaete worm. However, from data available on a relative of the same genus, *Nepthys incisa*, one may infer some general information about *Nepthys picta*.

Nepthys incisa, which has a planktonic larval stage, is a non-selective deposit feeder, it can exist in an anaerobic environment for a limited period, up to 10 minutes. It spawns throughout the year with peak periods in spring and fall.

From the above, an estimated recovery time for *Nepthys picta* of two to three years from physical/chemical suitability may be inferred; however, without accurate data on this specific species a conclusive estimate cannot be given.

Diopatra cuprea (polychaete worm)

No life history data has been found on this tube-building polychaete worm. It is therefore impossible to estimate a recovery time.

Tellina agilis (clam)

This small thin-shelled bivalve is both a filter feeder and a bottom feeder, eating both detritus and microorganisms. It has been suggested that *Tellina* is a deposit feeder when the tide is out and a filter feeder when the tide is high.

Tellina agilis has a WD-U strategy and is not dependent upon the prior recovery of its food sources. The estimated longevity of *Tellina agilis* is 10 years. Adult mobility, which might hasten recovery, does not appear to be significant in *Tellina*. Hence, an estimated maximum recovery time for this species is 10 years, given suitable physical/chemical conditions.

Astarte castanea (clam)

This clam is abundant sub-tidally in portions of this habitat. However, no life history information has been found. No recovery time is estimated.

Spisula solidissima (surf clam)

The surf clam is an important commercial shellfish occurring in Long Island Sound and Atlantic Ocean waters to depths of about 20 meters. Larvae are planktonic; hence it has a WD-U strategy. The maximum age for the species is 17 years; however, average adult longevity is more likely between six and 10 years, owing to heavy commercial taking of five to 10 year olds. *Spisula* is not dependent upon the prior recovery of its food source, thus, the recovery process is successfully initiated as soon as the oil concentrations within the substrate allow it. This species of clam does exhibit some mobility in its adult stage, due to wave and current forces and self-locomotion. Thus some adults can be expected to wash into the recovering zone, hastening the onset of a stable age-distribution. Based on the above, a recovery time of six to 10 years following physical/chemical suitability, is estimated.

Emerita talpoida (sand mole crab)

This crab is common in the swash zone on sandy beaches. The animal projects food gathering antennae into receding waves to gather minute organisms, mostly dinoflagellates. *Emerita* adults tend to congregate and are found densely packed in the swash zone, moving up and down the beach with the tide. Because of their location in the swash zone, they are extremely vulnerable to an oil spill.

Emerita does not depend on any other selected species in the habitat for recovery. Since this crab has a WD-U strategy, and a longevity of one to two years, recovery time for *Emerita talpoida* is estimated as one to two years, following suitability of the physical/chemical environment.

Cancer irroratus (rock crab)

This crab has a pelagic larval stage and high fecundity--in the hundreds of thousands--hence, it is classified as WD-U. Its food sources include detritus and small invertebrates, such as juveniles of the clams and the sand dollar. Adults are very mobile; therefore, older specimens may be present in the habitat after a relatively short period of time. Because its diet includes detritus, this crab's recovery is not likely to be delayed by the recovery of another species. The longevity of *Cancer irroratus* is not known. However, as this species has a WD-U strategy and significant adult mobility, its recovery time will largely be determined by the size of the recovering area, rather than by its longevity. The estimated recovery time is one to six years after physical/chemical suitability, depending on the size of the impacted area.

Haustoriidae (amphipods)

The amphipods of primary concern are those which occur in the tidal zone. They are sand burrowers, scavengers and detritus feeders. At low tide they are preyed upon by shore birds and at high tide, by fish. Their position in the tidal zone indicates that they would be severely impacted by an oil spill.

Most species in this family have a NWD strategy--larvae are carried on the females' back until metamorphosis to juveniles. However, it is unlikely that a single spill will decimate the beach habitat along the Nassau-Suffolk coast. Hence, a stock population of *Haustoriidae* will always be available at the edges of the impacted zone. The adults are mobile and should therefore be able to colonize the effected area from these edge populations. The food supply of this species--detritus--does not limit recovery. Recovery of this annual species is therefore predicted to be within one to four years after physical/chemical recovery, depending on the area of the impacted zone.

Asterias forbesi (starfish)

This starfish feeds on mollusks, and is also a scavenger. Adults of this perennial species are very mobile, and the species has a WD-U strategy. No estimate of *Asterias'* longevity is available. However, because of its high adult mobility, plus its WD-U strategy, recovery time is likely to be determined largely by the size of the impacted area. Food availability will not hinder this species' recovery. Thus, depending on the size of the impacted area, a recovery time of two to five years is estimated for *Asterias*, in a suitable physical/chemical environment.

Echinarachnius parma (sand dollar)

This species occurs from low tide to a depth of 1600 meters. This perennial species has a WD-U strategy; its food is detritus. However, no life history data have been found. In particular, lacking both an estimate of longevity and an estimate of adult mobility, it is not yet possible to estimate a recovery time for this species.

Ammodytes americanus (sand launce)

This small fish is common throughout the high energy beach habitat. The open-coast population of this species is fairly evenly distributed along the coast; however, separate populations are suspected between the bays and the open coast. Spawning occurs in late November to late March in shallow waters. The species migrates from shallow to deeper water during midsummer, returning as the water cools. A heavier kill of *Ammodytes* is more likely in the winter than in the summer.

Ammodytes americanus is WD-U with a lifespan of up to three years. Furthermore, the adults of this species are mobile. Consequently, since separate breeding populations along the barrier beaches are not characteristic of this species, recovery of *Ammodytes* is estimated to occur in one to three years after food is available, depending on the size of the recovering area. *Ammodytes* food species (amphipods, clams, anemone) are estimated to take from two to 10 years to recover. Hence, a minimum estimate of *Ammodytes* recovery time is three years, following physical/chemical recovery.

Morone saxatilis (striped bass)

This species, which supports a very popular sport fishery, is anadromous; most populations in the study area migrate up the Hudson River, from the ocean, to spawn in May and early June. Thus, there is the potential for a very serious impact if a spill should hit a migrating group. A lower threat exists during the rest of the year when the population is less densely congregated.

The occurrence of distinct populations of this species precludes estimating a recovery time. Under this situation the impact of one spill on a particular population could be severe. If there is little interaction between populations, then recovery of the particular impacted population may take several decades. On the other hand, rapid recovery might also be possible. More information is required on the interpopulation interactions of this species. Such information may exist among currently available fisheries data; this is a fruitful avenue for further research. No recovery time is estimated.

Paralichthys dentatus (summer flounder)

This flatfish is taken by both sportsmen and commercial fishermen. They are WD, and have a maximum lifespan of four years. There are a number of separate spawning populations along the Atlantic seaboard, generally close to the coast. The population south of Long Island spawns in September. Juvenile fish live in shallow water and move offshore as they grow. There is also an offshore-onshore migration from winter to summer. Thus, the potential exists for a wide variation in initial impact. The occurrence of separate populations of *Paralichthys* precludes estimation of a recovery time.

Sterna hirundo (common tern)

The common tern breeds on sandy beaches and small islands from Newfoundland to North Carolina, including Long Island. The tern winters in eastern South America, and is absent from Long Island from November to April.

Sterna feeds by diving for small fish, and spends little time resting on the surface. When diving this species is susceptible to oiling.

Because the tern has a large population, both locally and worldwide, little damage to the species is expected at the population level. A spill during the breeding season, when the adults feed (dive) frequently, is likely to have a greater effect than one during the spring or fall. A spill during the winter would have no effect. In the worst case, a large oil spill covering the nearshore waters with oil is likely to result in high tern mortality, yet still small relative to the whole population of the study area.

An incomplete understanding of *Sterna's* population distribution permits estimation only of the minimum recovery time. Recovery in the worst-case would be limited by two conditions. The return of the fish population is the first condition, and is expected to take at least three years after the oil is removed from the environment. The second condition is the immigration of adult birds from surrounding areas. This could occur within the same year that the food species recover. Thus, a minimum recovery time from a worst-case spill is three years following physical/chemical recovery.

Crocethia alba (sanderling)

This relatively abundant bird breeds in northern Canada and Greenland during June and July, then migrates southward in the fall and winter along the Atlantic coast as far as South America, returning in the spring. Peaks of migration pass through Long Island in mid-May and September.

The sanderling preys on *Emerita*, amphipods, and other beach invertebrates. It feeds in the swash zone, by probing in the sand with its bill, running down to the water's edge as the waves recede to get organisms washed in, then running back up as the next wave breaks. The probability of the sanderling being coated is fairly high; however, the bird is also likely to suffer from ingestion of oil which has coated its prey. Further, the sanderlings are likely to be attracted by a kill of invertebrates and thus drawn to the most hazardous area, increasing the number of birds affected.

Because the species' population is large and is not restricted to a small area, the possibility of great species-wide damage is low. Since a worst-case spill scenario is not likely to decimate all high energy beach habitats simultaneously, food is expected to remain available elsewhere for migrating birds passing in the wake of a spill. If the migrating populations are present at the time of the spill, there is a likelihood of high mortality over a restricted area; yet, relative to the overall migrating population, this mortality is expected to be small. Because of the sanderling's large, diffuse population and very high adult mobility, adult birds are expected to be present during any subsequent migration, once the invertebrates on which they feed are present. Recovery from a worst-case event could occur as early as one year after the return of suitable invertebrate prey.

Passerculus princeps (Ipswich sparrow)

Little is known about this rare bird. It nests on Sable Island, Nova Scotia, and winters on the coastal dunes, from Massachusetts to Georgia, feeding on seeds and insects. On Long Island, only a winter spill could have any effect on the species, and then only a very small effect as the species' density is very low.

The feeding and nesting habits of the bird seem to indicate only a very slight likelihood of significant initial mortality from an oil spill. However, there presently exists only a small breeding population. Any widespread mortality, either on its wintering grounds or its nesting areas in Nova Scotia, could lead to the extinction or near extinction of the species, or to extremely long recovery time in any case.

One possible effect an oil spill might have would be the elimination of the insects on which the sparrow feeds by oiling the larva, or elimination of the seeds that it eats, by killing the plants. The food of this bird is not likely to be completely eliminated, as insects are WD-U, and the seeds that it eats probably come from terrestrial plants. Although very sensitive to other environmental perturbations, this species is potentially very sensitive to the effects of an oil spill, at the population level. However, the degree of initial impact cannot be predicted.

Halichoerus grypus (grey seal)

Halichoerus grypus breeds on rocky coasts from Labrador south to

New Jersey. The larger colonies are in the northern portion of the range; only a few seals occur in the study area. Maximum age for bulls is 25 years, and for cows, 35 years. The animals are not migratory but have a feeding range of several hundred miles from their breeding zone. *Halichoerus* is only rarely sighted off New Jersey and southern Long Island. It is not expected that more than a few would be in a spill zone near Long Island; furthermore, these animals are likely to avoid the zone of the spill. Thus, only a very small kill, is anticipated for this species. Experience from the Santa Barbara spill with oil and seals supports this assumption.

Consequently, a negligible initial impact on the populations of *Halichoerus* is expected from oil spills in the study area, and "recovery" will be immediate. This result applies only to this study area. In an area farther north, a large kill might be possible.

5.4.3 Habitat Recovery

Recovery of the overall habitat can be summarized graphically by combining the recovery processes of all the selected species into a habitat recovery time-line. The time-line shown in Figure 5 depicts an estimate of the high energy beach habitat's recovery process from a worst-case spill event: fresh, toxic oil; well mixed into the sediments; 100% kill of all benthic species within the impacted zone, both inter-tidal and sub-tidal; maximum possible kill of finfish, birds, and mammals in the impacted zone. Clearly, if any of these conditions does not apply to a spill, certain stages of recovery will take much less time. It is estimated that the physical/chemical conditions of the high energy beach will require a minimum of three years to become suitable for re-settlement. Once the environment is suitable, the species requiring the longest time to recover are the long-lived sessile species, notably *Spisula solidissima*

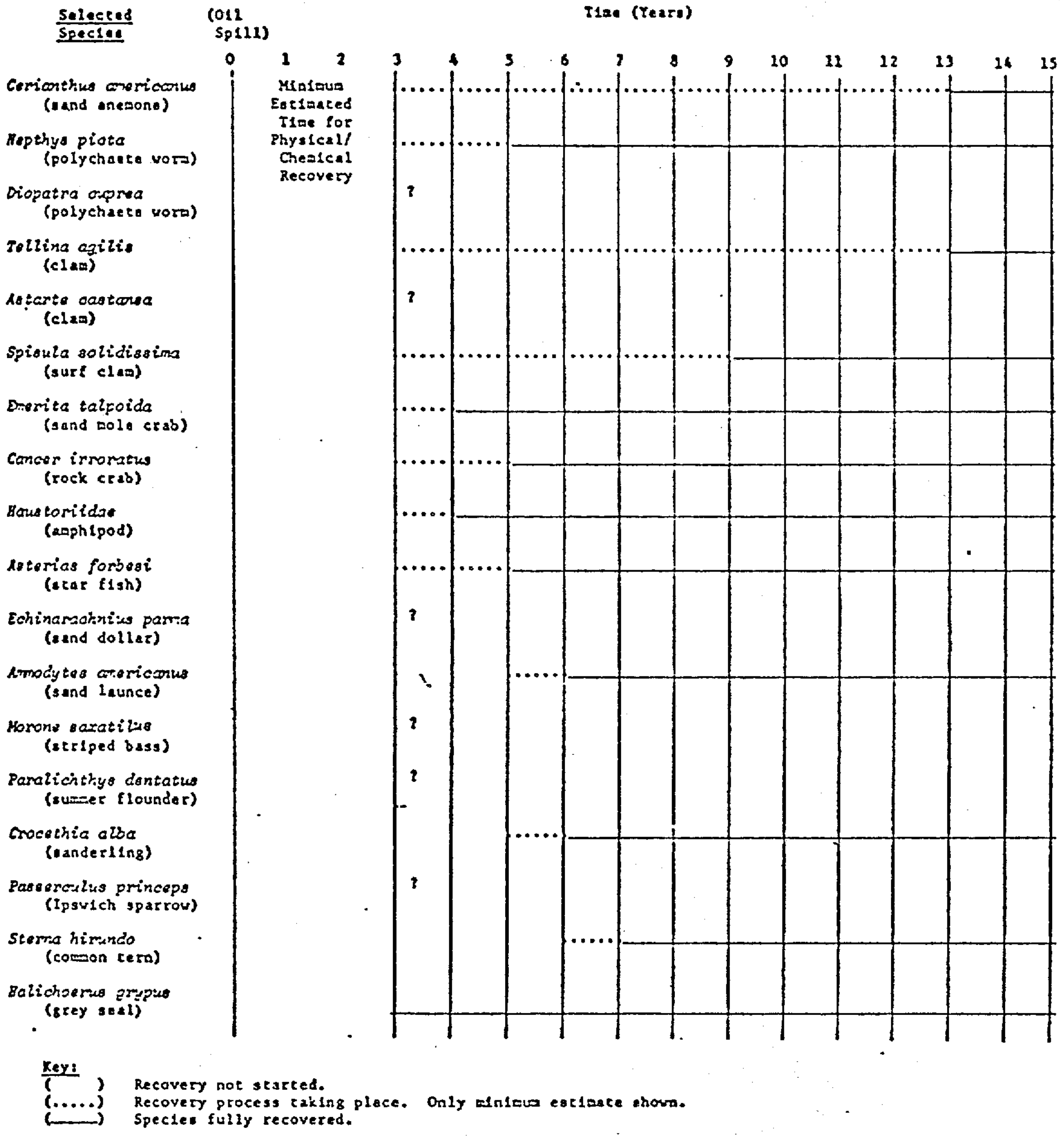


Figure 5. High Energy Beach Habitat Recovery Time Line (For Worst-Case Event-Minimum Estimates Only)

(surf clam), and *Cerianthus americanus* (sand anemone), with minimum recovery times of six and 10 years, respectively. The herbivores and scavengers are only dependent upon imported food and detritus for survival and are therefore able to start their recovery processes as soon as the oil is removed from the environment. The carnivores, although they depend upon the recovery of the lower trophic levels, all have fairly short recovery times once the necessary food species appear. In general, recovery of these higher trophic level species is delayed by an estimated two years.

There is insufficient life history data available, for several of the selected species, to permit estimates of recovery time. Nevertheless, based on estimates for the other selected species, a minimum time for recovery of this habitat can be estimated. Given a worst-case spill event, habitat recovery of the high energy beach habitat is estimated to take at least 13 years.

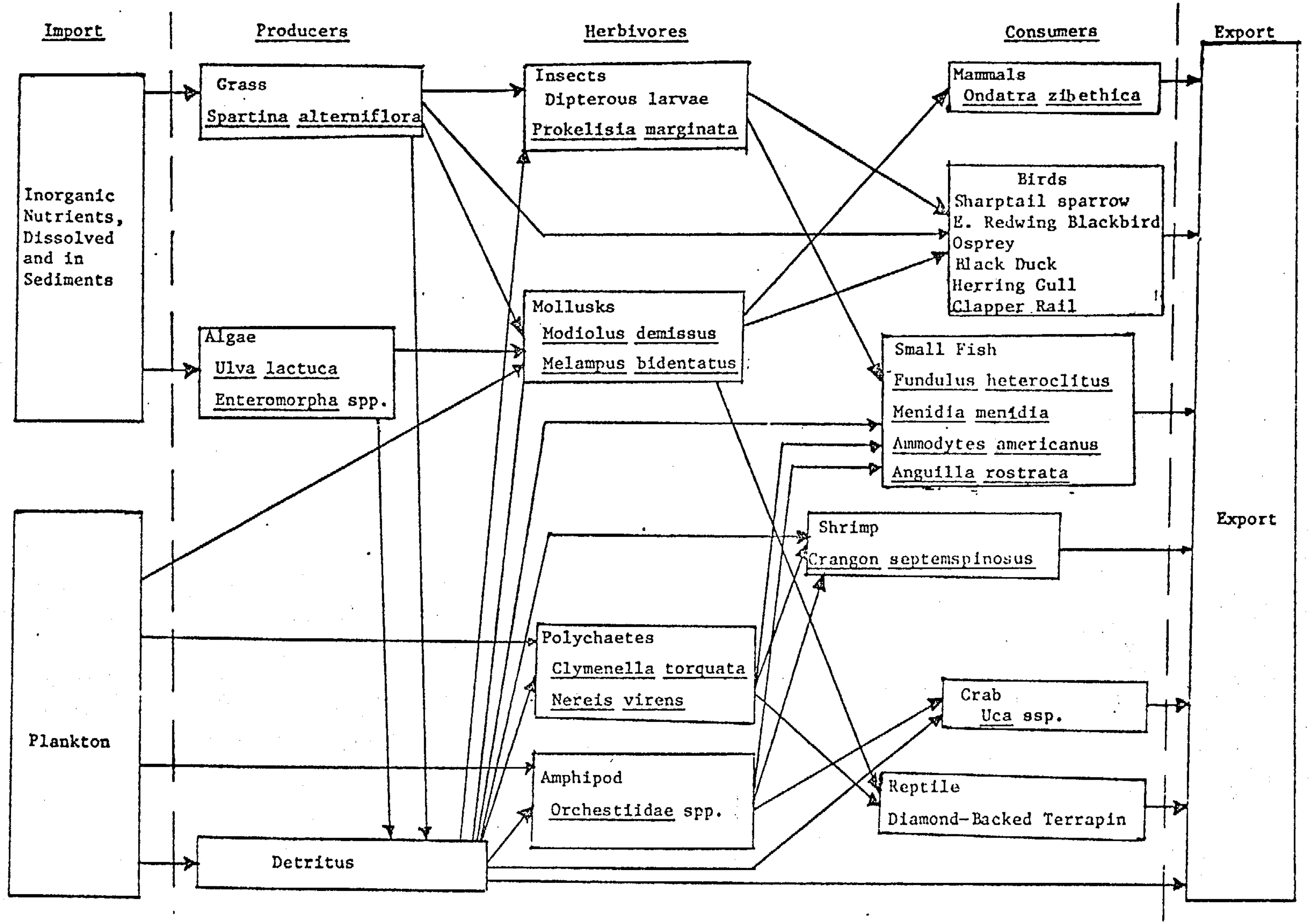
5.5 Salt Marsh

5.5.1 Introduction

This habitat is dominated by *Spartina alterniflora*, which supplies over 85% of the food for higher trophic levels. Its recovery is essential to the recovery of the whole marsh. *Spartina* serves as food, substrate, or former-of-the-environment for most of the other species inhabitating the marsh. Figure 6 shows some of the interactions between the selected species of this habitat.

Salt marshes are interdependent with the other estuarine habitats. Almost half of a marsh's primary production is exported, and consumed in other habitats. Most of this export is in the form of detritus, though some of it is carried out by species spending only part of their lifecycle in the marsh (e.g. various fish larvae), or by those that range

Figure 6. Salt Marsh - Food Web of Selected Species



over several habitats (e.g. raccoon, hawks, owls). Loss of a marsh as a food supply may harm surrounding habitats. For example, a large loss of marsh area (relative to the surrounding estuary) may cause a significant loss in the populations of filter feeders (e.g. clams, shrimp) and their predators in surrounding waters. These inter-habitat effects are not considered in this analysis. However, as this cautionary note indicates, there are potentially great regional ramifications from a spill in a salt marsh.

5.5.2 Discussion of Spill Scenarios

Two spill scenarios are hypothesized: 1) a truly worst-case spill, in which 100% of all species in the impacted zone are killed, and 2) a nearly worst-case event, in which 100% of all species are killed, except that the *Spartina* root system (rhizomes) survives.

A kill of the *Spartina* rhizomes is much more serious than a kill of just its leaves and stalk. *Spartina* rhizomes are fairly hardy, and are likely to be killed by only the severest stress. If the plants have been weakened by other forms of pollution the roots have a poorer chance of surviving a spill. If the rhizomes are not killed, *Spartina* will come back completely during the next growing season, since it is a perennial. Some of the rhizomes can stay dormant over a period of at least six years, and still produce shoots, if the environment is unsuitable in the interim.

If the rhizomes are completely killed, *Spartina* has to be re-seeded solely from other marshes (via seed and rhizome fragments). Population recovery time depends on how rapidly the plants get started from seed and rhizome fragments, and how quickly they fill in the space between new plants to cover the marsh. If the rhizomes are completely killed, it is quite possible that erosion of the marsh's mud will occur in the interim, as the roots decay and stop stabilizing the mud. Such erosion may significantly lengthen the marsh's recovery time. Separate habitat recovery time lines are prepared, for the worst-case and near-worst-case spill scenarios hypothesized.

5.5.3 Discussion of Habitat Recovery, by Species

In general, the estimated minimum time for recovery of the physical/chemical environment (four years) is not included in the following estimates of population recovery times. In addition, estimates of recovery time are developed only for that portion of each species' total recovery process following recovery of *Spartina*. Thus, the following estimates are relevant to either spill scenario. For all species but *Spartina*, both scenarios hypothesize a 100% kill of all individuals in the impacted zone.

Spartina alterniflora

This grass has a perennial rhizome network which produces annual stems and leaves. The longevity of the rhizomes is unknown, and the dispersal characteristics of the species are not well understood. Almost all spill events will cause the annual parts of the plant to yellow and die. Recovery to pre-skill density of these parts can be completed within one growing season, once all of the rhizomes are recovered.

Severe spill events, such as the worst-case and near-worst-case hypothesized herein, can affect the rhizomes, either killing them, in the first case, or leaving them dormant for several years, in the second case. There is a small amount of data on *Spartina* recovery from dormant rhizomes, but no data on recovery from a total kill. *Spartina* plants can return from several years dormancy at near-normal densities, though the density of returning plants decreases with prolonged dormancy. Under these conditions, it appears that oil in the surface sediments inhibits the annual growth of leaves. Thus, it is expected that when physical/chemical recovery is completed, the surviving plants will be fully recovered. However, complete population recovery of *Spartina* requires a return to pre-spill density; to achieve this, the rhizomes must "grow in" between the initially returning plants. The rate of spread of *Spartina* and the likely distance between initially recovering plants is not known. Hence, no quantitative estimate is made of *Spartina's* population recovery time from dormant roots (i.e., from a near-worst-case oil spill). All that is known is that recovery cannot begin until physical/chemical recovery is nearly complete.

All that can be said about *Spartina* recovery from a total rhizome kill is that it will take as long or longer than recovery from dormant roots. In addition to the "filling in" process between new plants, those new plants must themselves recolonize the decimated area, and grow into mature plants with mature rhizome systems. The process of recolonization may take place via floating seeds and root fragments. In addition, extending rhizomes from surviving plants at the edge of the impacted zone may account for much recolonization. No quantitative estimates of population recovery time are developed for the case of a total rhizome kill.

Ulva lactuca (sea lettuce) and *Enteromorpha* sp. (algae)

These species of algae are sub-annuals, with a WD-U strategy. Both species are aggressive colonists, releasing spores each month. *Ulva* and *Enteromorpha* are both expected to recover within one growing season, independent of *Spartina*, given suitable physical/chemical conditions.

Nereis virens (sand worm)

This burrowing polychaete is primarily a detrital feeder. *Nereis* is WD-U and has a longevity of approximately four years. It will start to recover as soon as the physical/chemical conditions are suitable, independent of *Spartina*, and is estimated to be fully recovered within four years.

Clymenella torquata (bamboo worm)

This tube-building polychaete lives in sandy substrates, eating suspended detritus. *Clymenella* is NWD and annual.

Recovery time depends on the rate of recolonization from unaffected areas. Complete recovery may occur within a year to two of the introduction of a small breeding population to a marsh with recovered *Spartina*. However, the time required to establish successfully a "small breeding population" cannot be estimated, since *Clymenella's* dispersal rate is unknown. An exact recovery time is not estimated with present data.

Modiolus demissus (ribbed mussel)

The ribbed mussel is a WD-U filter feeder which settles around the roots of *Spartina*. It can return as soon as *Spartina* has recovered, requiring *Spartina* as a substrate and source of detritus. Specimens of *Modiolus* that are 20 years old have been found, though the average adult longevity is five to seven years. Recovery of *Modiolus* is expected within seven years of *Spartina's* recovery.

Melampus bidentatus (snail)

This WD-U snail lives on the *Spartina* leaves and feeds on suspended detritus. Its longevity is approximately five years. Recovery is estimated to occur within five years of *Spartina's* recovery.

Littorina littorea (periwinkle)

The periwinkle is WD-U and lives on *Spartina* stems near the saltwater margins. It grazes decaying *Spartina* and the epiphytic algae attached to the *Spartina* leaves. The longevity of *Littorina* is two years; hence, recovery is estimated to occur within two years of *Spartina's* recovery.

Orchestiidae sp. (amphipods)

These amphipods are NWD annuals. As detrital suspension feeders, their recovery is not delayed by food availability. The time to recovery for these NWD species depends on the rate of recolonization from unaffected areas, the size of the recovering area, and the proximity of unaffected areas. Values for these factors cannot be estimated for these species; hence, no estimate of recovery time for *Orchestiidae* is derived.

Uca spp. (fiddler crab)

These crabs are WD-U scavengers with a longevity of at least two years. Their recovery is expected to be delayed one to two years beyond recovery of *Spartina*, while sufficient scavengeable prey accumulates. Recovery of *Uca* is estimated to take four to five years, after *Spartina* has recovered.

Crangon septemspinosus (mud shrimp)

Crangon is a WD-U predator and scavenger feeding on larvae, eggs, small polychaetes and isopods and similar organisms. Its longevity is disputed, with values varying from one to three years. *Crangon* can start recovery as soon as several of the smaller organisms return to the marsh (two years). Recovery is estimated to be complete within two to four years of *Spartina's* recovery.

Diptera larvae (fly larvae)

This selected group of species includes the larvae of *Aedes* sp. and other dipterids. Food is not a limiting factor, as these larvae feed on detritus. These larvae occur annually in the marsh, ubiquitously. There is sufficient adult mobility for the larvae to be recovered within one year of *Spartina's* return.

Prokelisia marginata (plant hopper)

Prokelisia is WD-U, possessing considerable adult mobility. It feeds directly on living *Spartina*, consuming over five per cent of *Spartina's* annual production. *Prokelisia* is estimated to be fully recovered within one year of *Spartina's* recovery.

Fundulus heteroclitus (mummichog)

This fish stays close to shore, preferring still, brackish water. Found in schools, *Fundulus* feed in the tidal creeks of salt marshes.

Fundulus are omnivorous. They spawn during the summer, in shallow water. Because *Fundulus* lives and spawns only in shallow water, it is vulnerable to oil spills. However, the population of this fish is large and diffuse; there is little evidence of distinct populations between separate marshes. The impact of a spill on the overall population is thus not expected to be large, and adults are expected to be available for immigration into the recovering area.

The schools are fairly mobile within protected estuarine areas like Great South Bay. Schools of *Fundulus* have been known to travel up to five miles per day. Thus, *Fundulus* is expected to move into an impacted marsh from unaffected areas within one to two years (provided that the affected area is not too large). Recovery of *Fundulus* can occur only after the return of an adequate food supply (small animals and detritus). A minimum recovery time of two to four years, after *Spartina's* return is estimated for this species.

Ammodytes americanus (sand launce)

This fish is common to both estuarine and exposed habitats. There is indication that there are separate estuarine and coastal populations; however, within the protected bays, separate populations are not expected. *Ammodytes* is predatory on smaller marine animals and utilizes the salt marsh as a feeding ground.

Ammodytes exhibits considerable adult mobility. Thus, *Ammodytes* is expected to recolonize an impacted marsh from unaffected areas within two to four years of *Spartina's* return, depending on the size of the recovering area.

Menidia menidia (silversides)

This fish is confined to the shallows and schools are found feeding in the salt marsh during high tide. It is omnivorous. *Menidia* spawns in the early summer.

Menidia exhibits adult mobility. Provided that the affected areas are small, *Menidia* can return to the marsh when an adequate food supply has recovered. Recolonization by adults from neighboring unaffected areas is expected to bring about recovery within one to four years of *Spartina's* return.

Anguilla rostrata (american eel)

Anguilla spawns at sea with the young immigrating landward to settle in salt marshes, estuarine waters, and freshwater streams. They consume any animal matter, dead or alive. Average longevity is 10 to 15 years. Significant adult mobility is present.

Young eels are expected to re-inhabit a marsh within two or three years after *Spartina's* return, when an adequate food supply is present. Recovery is estimated to take from two to three years after *Spartina's* return.

Malaccemys terrapin (diamond back terrapin)

Neither the longevity nor dispersal strategy has been found for this species. It is not possible to estimate a recovery time.

Ammospiza caudacuta (sharptailed sparrow)

This common sparrow nests in the salt marshes of Long Island during

June and July. It winters in the Mid-Atlantic states from October to May.

The sharptailed sparrow feeds on aquatic insects and grass seeds, both of which are found at the edges of the marsh. It nests in tussocks of grass, just above the highest tidal level, where three to five eggs are laid.

This sparrow is vulnerable to oil spills in three ways. Birds could be coated with oil or could ingest oil while feeding at or near the edges of the marsh; the birds' supply of insects and seeds could be depleted in the impacted zone; or the nests could be oiled, killing all hatchlings.

Nevertheless, the impact on the overall *Ammospiza* population of a kill in a certain area is not expected to be large. *Ammospiza* does not exhibit distinct breeding populations within the study area; hence 80% of the total Long Island population is expected to be available for repopulation of the impacted area. Because of the highly mobile, diffuse population, recovery of the sharptailed sparrow in the impacted zone is possible as soon as the necessary food and nesting sites are available. Insects will be prevalent as soon as the *Spartina* is recovered, being WD-U. Seed plants (including *Spartina*) may take many more years, and are likely to be the limiting factor in the recovery of this bird. Recovery of the sharptailed sparrow is thus estimated to occur within one year of the recovery of *Spartina*.

Agelaius phoeniceus phoeniceus (eastern redwinged blackbird)

This common bird of the marshes feeds on flying insects and occasionally seeds. Most of the blackbirds migrate to the Mid-Atlantic states in November, returning in March to nest; however, some remain on Long Island all winter.

Because this bird has very little direct contact with the water, adult mortality due to coating by oil is not expected to be high. Most insects, however, are likely to be killed, especially if the spill occurs while the insects are in larval stages. This loss of food would force the adults to move to adjacent marshes. It is not likely that this blackbird will eat many dead, oiled insects. They would return as soon as the marsh is capable of supporting insect life. Insects are likely to return as soon as the oil is gone, among the earliest colonizers. This species is judged to be only slightly susceptible to a large initial kill from an oil spill and is expected to return within one year after most spills. However, a worst-case kill of the marsh during this bird's breeding season could cause a significant population impact, for which recovery is not estimated.

Pandion halietus (osprey)

The osprey is no longer as numerous as it once was, partly as a result of pesticide use in the last 30 years. Active nesting areas are still found on Plum and Gardiner's Islands. Returning from its wintering grounds in Florida and the West Indies in March, osprey breed in huge nests in the tops of trees. They return to the south in November.

The osprey feeds almost exclusively on fish which it seizes at the surface of the water. It is likely that some ospreys will either become coated or ingest oil during a spill. Since the osprey has a considerable range there does not seem to be significant danger from a lack of fish in one particular area. The initial impact of an oil spill on population cannot be predicted; it may vary widely from one spill to the next.

The life history of the osprey, in conjunction with its rarity, indicates an extremely slow recovery of the population should a significant mortality occur. Osprey mate for life, and generally return to the same nest each year. If a pair from a given area are killed they might never be replaced. If a pair does not return to the impacted zone, the osprey's long life span (21 years maximum) and low fecundity (one to three eggs per year) indicate a very long time before a stable age-structure and pre-spill density are achieved. No estimate of total population recovery of *Pandion* is made, because the initial impact cannot be predicted.

Anas rubripes (black duck)

The black duck is the most common duck of Long Island's estuarine areas. Present throughout the year, they nest at the edges of marshes, where eight to 10 eggs are laid.

The black duck dabbles, feeding off the bottom in the shallow areas a meter or less in depth. It feeds largely on eelgrass and other plants and seeds, as well as on crustaceans and mollusks. Because it spends most of its time in the water, the black duck is very vulnerable to oil spills. The ducks are often found in small flocks; those flocks in an oil spill area would probably suffer a high mortality

Black ducks are quite common in the Nassau-Suffolk coastal zone; hence, high local mortality will not represent a large percentage of the population. Thus, with their high adult mobility and large, diffuse population, recovery (by immigrating adults) is expected as soon as food and nesting sites are available, i.e., as soon as *Spartina* has completed recovery.

Larus argentatus (herring gull)

This very common gull is often present all year long on Long Island. Many migrate to the coast of northern New England where they breed during the months from June to August. There they nest on small islands, laying three eggs.

When on Long Island, they feed on fish, squid, insects, mollusks, crustaceans, and echinoderms as well as scavenging among garbage. Gulls are an important agent in keeping the bays and harbors free of rotting and decaying debris.

The gulls spend some time actually sitting on the water, but seldom swim or dive. Their food is usually seized from the water while in flight. They are moderately exposed to the coating effects of oil. Because they often feed on dead animals, which are abundant after a spill, they are also likely to ingest oil.

Because of its very large and diffuse population, the herring gull is not expected to suffer a major loss at the population level. The adults are extremely mobile, having a daily feeding range often over 10 miles. The recovery of the herring gull is expected almost immediately upon the return of any food organisms to the area. Within one year of the removal of oil from a spill area, there should be enough food, predominantly fish, to sustain a normal herring gull population.

Rallus longirostris (clapper rail)

The clapper rail nests in the salt marshes of Long Island from April until November; it winters in the Mid-Atlantic states. Nests are built on the ground near the salt marsh. This abundant bird feeds largely on invertebrates which it obtains as it walks about in the marsh.

Because it usually walks but seldom if ever is found swimming in the water, this bird has a moderate likelihood of becoming coated with oil. However, this bird may ingest considerable amounts of oil while feeding on dying, coated invertebrates. All of the rails within an affected area may die, though the absolute number of casualties may not be high.

No information has been found on the territorial habits of this bird to indicate the likelihood of neighboring adults moving into a decimated area. Thus, no recovery time is estimated.

Ondatra zibethica (muskrat)

The muskrat is WD-NU and has a maximum longevity of 21 years. It is not found in all marshes, and its population density varies widely in the marshes in which it does occur. Recovery depends on the rate of recolonization, size of the impacted area, and distance from the nearest unaffected population, and cannot be estimated in general, even within the study area.

5.5.4 Habitat Recovery

The main factor in the recovery of a salt marsh is the return of *Spartina alterniflora*. Unfortunately, no estimates are made of total population recovery time for *Spartina*, the central species in this habitat.

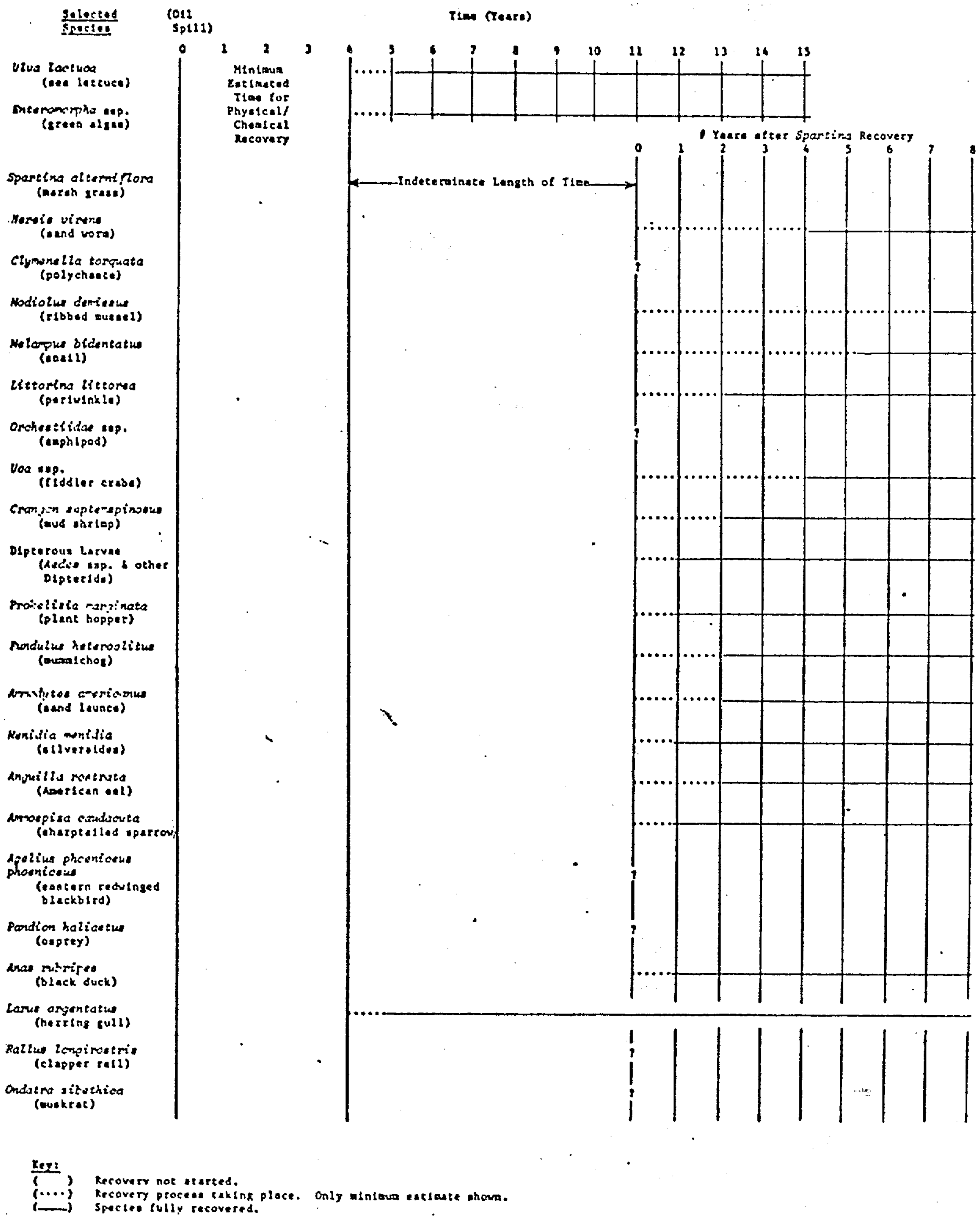
Within seven years of *Spartina's* recovery, most of the marsh's WD species are expected to be present and to have achieved a stable age-structure. For certain bird and fish species insufficient data has been obtained to estimate total population recovery time. Return of the NWD species will depend on each species' rate of immigration to a particular marsh; no recovery time is estimated for most NWD species.

The habitat recovery time-line shown in Figure 7 depicts an estimate of the salt marsh habitat's recovery process from a worst-case or near-worst-case spill event: fresh, toxic oil; well-mixed into the sediments; 100% kill of all benthic species within the impacted zone, both intertidal and subtidal; maximum possible kill of finfish, birds, and mammals. Clearly, if any of these conditions does not apply to a spill, certain stages of recovery will take much less time.

An interval of indeterminate length represents total population re-

Figure 7

Salt Marsh Habitat Recovery Time Line
(For Worst-Case and Near-Worst-Case--Minimum Estimates Only)



covery time for *Spartina*. The only difference between habitat recovery from the near-worst-case (dormant rhizomes) and worst-case (rhizomes killed) spills is that *Spartina* recovery is expected to take longer, from a worst-case; however this difference cannot be quantified.

In the absence of healthy *Spartina*, erosion of the marsh may occur, which may drastically increase the time required for habitat recovery. If erosion has occurred, the eroded area has to be rebuilt in a process similar to the formation of a new marsh. This process can take hundreds of years with the marsh slowly being built out from its existing edges. The time to recovery depends on the area eroded and the rate of marsh reformation; these factors are very dependent on the particular marsh effected. No quantitative estimate can be made of the time required for reestablishment of sufficient sediment.

Without an estimate of *Spartina's* total population recovery time, no definitive estimates of habitat recovery time can be obtained. Nevertheless, based on seven years for recovery of most WD species, plus a minimum of four years for physical/chemical recovery, a lower bound on salt marsh habitat recovery time is estimated to be 11 years. This estimated lower bound applies to both the spill scenarios studied, though recovery from the worst-case event is likely to take longer than from the near worst-case.

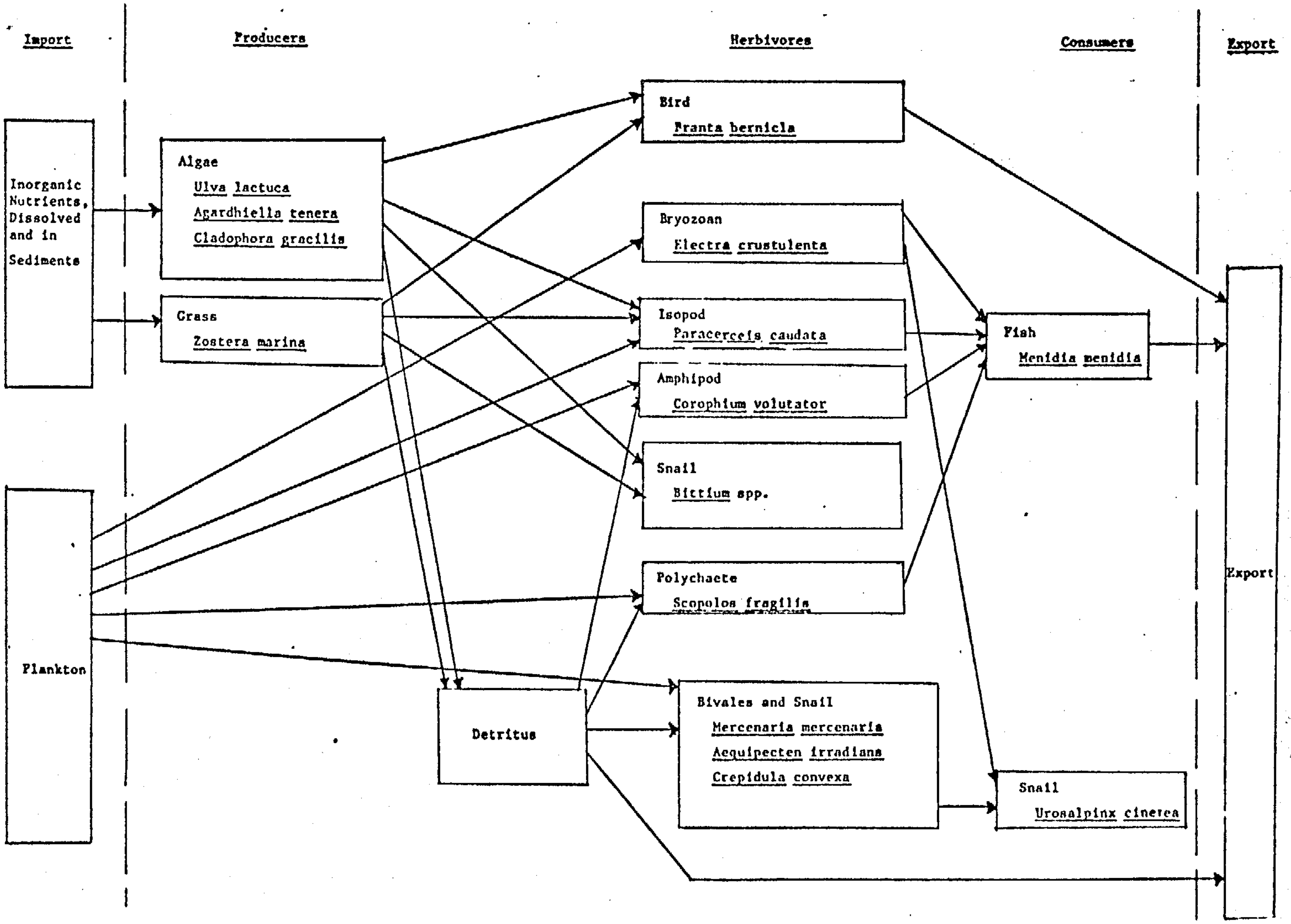
but impact on salt marsh are worse than on high-energy beach

5.6 Eelgrass System

5.6.1 Introduction

Eelgrass systems are shallow, subtidal communities based upon and dominated by *Zostera marina*, eelgrass. The food web diagram shown in Figure 8 shows the major role of *Zostera*. Virtually all species depend upon *Zostera*, either directly, as a food source, or indirectly, utilizing the microcosm that is created.

Figure 8. Eelgrass System - Food Web of Selected Species



5.6.2 Discussion of Spill Scenarios

Two spill scenarios are hypothesized: 1) a truly worst-case spill, in which 100% of all species in the impacted zone are killed, and 2) a nearly worst-case event, in which 100% of all species are killed, except that the *Zostera* root system (rhizomes) survives.

Not enough is known about *Zostera's* sensitivity to oil to estimate how much more severe a spill must be to kill the *Zostera* plants and rhizomes, than to kill just the plants. Data on another marine grass, *Spartina alterniflora* suggests the possibility of very different sensitivities for these two events. Since habitat recovery from these two events is quite different, it is useful to hypothesize both spill scenarios, for further study.

A kill of the *Zostera* rhizomes is much more serious than a kill of just its leaves and stalk. If the rhizomes are not killed, and the physical environment is suitable, *Zostera* will reestablish completely during the next growing season, since it is a perennial. If the physical environment remains unsuitable for several years, the rhizomes may survive in dormancy like *Spartina alterniflora*, or they may die.

If the rhizomes are completely killed, *Zostera* has to be reseeded solely from other eelgrass beds (via seed and rhizome fragments). Population recovery time depends on how rapidly the plants get started from seed and rhizome fragments, and how quickly they fill in the space between new plants. If the rhizomes are completely killed, it is possible that erosion of the mud in the eelgrass bed will occur in the interim, as the roots decay and stop stabilizing the mud. Such erosion may significantly lengthen the eelgrass system's recovery time.

5.6.3 Discussion of Habitat Recovery by Species

In general, the estimated minimum time for recovery of the physical/

chemical environment (four years) is not included in the following population recovery estimates. In addition, estimates of recovery time are developed for each species following the recovery of *Zostera*. Thus the following estimates are relevant to either spill scenario. For all species but *Zostera*, both scenarios hypothesize a 100% kill of all individuals in the impacted zone; the following analyses relate only to total population recovery from such a 100% kill event for the species.

Zostera marina (eelgrass)

Zostera marina is by far the most important species in this system, and as such, affects almost every other species. The *Zostera* plant has an annual leaf and stem structure which sprouts each year, and a system of rhizomes (roots) which is perennial, providing a base for the next year's standing crop. The rhizomes continue to grow for about four years, while the leaves and shoots die each winter. The dispersal characteristics of *Zostera* are not well understood.

There exists almost no data on the response of *Zostera* to oil, regarding either the sensitivity of individual plants to oil and recovery from oil spills. Data regarding oil effects on another marine grass, *Spartina alterniflora*, may apply to *Zostera*; however, *Zostera* and *Spartina* are botanically so different that this data cannot be assumed to apply to *Zostera* without further research.

There is also insufficient data on the growth of eelgrass beds to permit prediction of *Zostera's* recovery from hypothetical oil spill impacts. In the case of a worst-case spill (100% kill of all plants and rhizomes), an estimate of the rate of recolonization (from seeds and root fragments) and an estimate of the rhizome system's rate of expansion are both needed before population recovery of *Zostera* can be discussed. In the case of a near-worst-case spill (100% kill of all plants; rhizomes alive), an estimate of the number of rhizomes surviving dormancy is needed, in addition to the recolonization and expansion rates mentioned above.

A review of historical data on the recovery of *Zostera* from a disastrous epidemic suggests that estimates of recovery time from this epidemic are not necessarily applicable to recovery from an accidental oil spill. In 1931, a mycetozoan parasite, *Labyrinthola*, destroyed the *Zostera* population in many areas of the north and mid-Atlantic. Burkholder and Doheny (1968) estimate that full recovery was not complete until 40 years later. Other studies in Europe on similar species indicate "recovery times" of a similar length. It is likely that this relatively long recovery time is due to the continued presence of the parasite during much of the epidemic. The true population recovery time (the interval from the decline of the parasite to recovery) is not estimated in the literature. Toxic oil from an accidental oil spill is not expected to persist as long as the parasite seems to have persisted.

In the absence of *Zostera*, there may be many changes in the microcosm which will affect the other species in the system. Species which are attached to *Zostera* must either transfer to the bottom, or await *Zostera's* return. Species which feed on *Zostera* may be able to transfer to the other algae or else must await *Zostera's* return. Other changes which could have effects on the species present are a change in the bottom sediments, due to the scouring action of water currents and a decrease in the proportion of fine particles, an increase in turbidity, and a change in the pH and amount of dissolved oxygen. These environmental changes might make the area temporarily unsuitable for many species, and could even be drastic enough to prevent *Zostera's* return, thereby permanently altering the environment. Accurate prediction of such alterations is not yet possible.

In summary, no estimates of population recovery time are made for *Zostera marina* due to lack of data. As is the case for *Spartina alterniflora*, recovery from the worst-case spill (100% kill of all plants and rhizomes) is expected to take as long or longer than recovery from the near-worst-case event (100% kill of all plants; rhizomes survive); however, the difference between these recovery times cannot be quantified. In the habitat recovery time-line shown in Figure 9, an interval of indeterminate length is used to represent total population recovery time for *Zostera* for both spill scenarios.

Ulva lactuca (sea lettuce)

This algae is an aggressive colonist. *Ulva* is eaten by many waterfowl species. It usually grows between clumps of *Zostera*, although *Ulva* is sometimes an epiphyte of *Zostera*. *Ulva* frequently grows better in the absence of *Zostera*, indicating that *Zostera* outcompetes it. *Ulva* releases spores each month and is therefore expected to be fully recovered within one season, once physical/chemical recovery is complete.

Agardhiella tenera (algae)

This red algae is epiphytic on *Zostera* and other hard surfaces. It appears to be NWD, not having any pelagic forms of dispersal. *Agardhiella* may have to await the return of *Zostera* before it can colonize, although small colonies may precede the latter, attached to other hard surfaces. Dispersal is limited; hence, total population recovery is estimated to take at least two years longer than *Zostera*.

Cladophora gracilis (algae)

This green filamentous algae is epiphytic on *Zostera* and most other substrates. It is very common and is widely dispersed. *Cladophora* is eaten by many of the species in the system. Its total population recovery time, like *Ulva lactuca*, is estimated as one season, after physical/

chemical recovery.

Elektra crustulenta (bryozoan)

These sessile animals form encrusting colonies on *Zostera* and many of the other solid substrates in this system. Each individual is less than 0.5 mm in length.

Elektra filters small plankton, chiefly diatoms, from the water. *Elektra* is in turn eaten by *Urosalpinx cinerea* (oyster drill) and other predators.

Because there is a pelagic larval stage, these invetebrates are WD-U. *Elektra* is likely to be killed in the event of a worst-case oil spill, either by coating or by the toxic fractions in the water. Since they are not restricted to living on *Zostera, Electra* are expected to begin recovery as soon as the physical/chemical conditions are suitable. As they mature within a year, total population recovery of *Elektra* is expected within one year of physical/chemical recovery.

Scolopos fragilis (polychaete worm)

This sedentary polychaete lives in a tube in the sand-silt bottom and filter-feeds on detritus and plankton. It is eaten by *Menidia* and other predators. A conspicuous egg cocoon is laid on the surface of the substrate in the early spring of the second year. These eggs hatch into juveniles which are not pelagic; the adults do not exhibit significant mobility, so the species is NWD. *Scolopos* lives three to four years. Though there is some slight adult and juvenile mobility, these rates are unknown. Hence, insufficient data is available to justify estimating a recovery time for *Scolopos*.

Crepidula convexa (slipper shell)

This filter-feeding gastropod does not depend on *Zostera* as a substrate, but lives in the adjacent mud. The eggs are often laid on the stem of *Zostera*, however, *Crepidula* can be present in *Zostera's* absence.

Eggs are laid in May and July, and go through direct development--there is no larval stage, and the egg develops into the adult form immediately. It has no pelagic stages, so *Crepidula* is classified as NWD. Young adults are mobile, and phoresis--"hitching a ride"--on other creatures, such as the hermit crab *Pagurus*, is an important means of mobility. Nevertheless, mobility is limited.

Because *Crepidula* feeds on detritus and plankton, recovery can begin immediately upon the removal of oil from the community. Full recovery, however, is dependent upon the dispersal rate of *Crepidula*, for which no data has been found. Hence, no estimate of recovery time can be developed for *Crepidula*.

Bittium spp. (snail)

These gastropods live on the surface of *Zostera*. They have a lifetime of about 1.5 years. *Bittium* has no free-swimming larval stage; hence, it is NWD. *Bittium* feed by scraping bits of algae and the encrusing bryozoa, *Elektra*, off *Zostera*. As a NWD species, the recovery time estimate depends on the estimate of adult dispersal rates. Since the dispersal rate is unknown for *Bittium*, no recovery time is derived.

Urosalpinx cinerea (oyster drill)

This snail feeds on *Crepidula convexa* (slipper shell), *Elektra crustulenta* (bryozoa), and *Scolopos fragilis* (polychaete), among the selected species of the eelgrass habitat. It is noteworthy as a primary predator of *Crassostrea virginica* (oyster). There are no pelagic stages in the life history of *Urosalpinx*; hence it is classed as NWD. Longevity is approximately five years. Because no estimate of dispersal rate is available, no estimate of total population recovery time is developed for *Urosalpinx cinerea*.

Aequipecten irradians (bay scallop)

Aequipecten are detritus filter-feeders, and are an important commercial shellfish. Larvae of this bivalve are spawned in the early summer. They are pelagic for two weeks and then settle, usually onto the blades of *Zostera*; eventually, they transfer to the bottom. The longevity of *Aequipecten* is approximately two years. Although *Aequipecten* are WDU and independent of *Zostera* in the adult stages, their dependence on *Zostera* in the larval stage permits them to recover only after *Zostera* does. Total population recovery is estimated to take approximately two years beyond the recovery of *Zostera*.

Mercenaria mercenaria (hard clam)

This bivalve is a very important commercial species. *Mercenaria* has a pelagic larval stage and so is WDU. It is not dependent on *Zostera*, and is expected to recover independently of that plant. Because its longevity is approximately six years, total population recovery of *Mercenaria* is estimated to take approximately six years, once physical/chemical recovery has been achieved.

Paracereis caudata (isopod)

This isopod fastens upon *Zostera* and feeds off of the *Zostera* blades. *Paracereis* feeds on detritus and epiphytic algae. They are eaten by many fish, polychaetes, and other predators. Larvae are held in a brood pouch by the adult until they are juveniles, so this species is NWD. No data on the dispersal rate of *Paracerceis* has been found; hence, no recovery time is estimated.

Corophium volutator (amphipod)

This burrowing amphipod is a selective deposit feeder, ingesting particles of mud and organic detritus. *Corophium* falls prey to *Menidia* and other fish and birds. Although the amphipod digs a tube in which to live, it is often out of the tube, feeding and swimming.

Eggs are laid and held in the brood pouch until the first moult. The juveniles are then released, at which time they burrow immediately; hence *Corophium* is classed as NWD. The dispersal rate is unknown. It has been hypothesized that the adult amphipod is carried elsewhere by currents, or that it has limited mobility.

Because *Corophium* lives only about one month, and because detritus is always present, population recovery is governed by the dispersal rate. Since this dispersal rate is unknown, no estimate of recovery time is derived for *Corophium*. (Estimation of a recovery time by the procedure used for the *Haustoriidae* of the high energy beach is not justified. The assumption of a continuous strip of high energy beach, invoked in that analysis, is not valid for the eelgrass system.)

Menidia menidia (silversides)

These omniverous fish feed on isopods, amphipods, polychaetes, bryozoa and molluscan larvae. The longevity of *Menidia* is not known. However, *Menidia* have pelagic, widely dispersed larvae, and are very mobile as adults. *Menidia* are abundant in the eelgrass habitat and in all the surrounding habitats; the population is large and diffuse. Hence, the impact of any single spill on the overall population is not likely to be major, and immigration of surrounding adults is likely to be large. Within one year of physical/chemical recovery, some of *Menidia's* prey species are expected to have recovered. Depending on the size of the impacted area, total population recovery of *Menidia* is estimated within one to three years of the recovery of its food species.

Branta bernicla (brant)

This bird has been included because it is more dependent upon *Zostera* than any of the other game birds. *Zostera* provides 85% of the diet of this bird. When *Zostera* died in the 1930's, *Branta's* populations were reduced 90% in accustomed feeding and nesting areas. The remainder shifted to feeding on *Ulva*. *Branta* winter in the southeastern states, but almost the whole American population stops, en masse, on Long Island in March and October, on its way to and from its breeding grounds in northern Canada. It is very important that food be available to the birds while on their migration northward. While they are on Long Island, they are vulnerable to the after-effects of an oil spill, if the *Zostera* is extensively killed. In most cases, however, *Branta* will be able to feed on *Zostera* in areas not subject to the spill.

The severity of initial impact cannot be predicted. Because the entire brant population may be tightly congregated within the study area, the potential exists for mortality of a significant proportion of the breeding population. No estimate is made for recovery of these birds from a massive oil spill except that such recovery would clearly extend beyond recovery of *Zostera*.

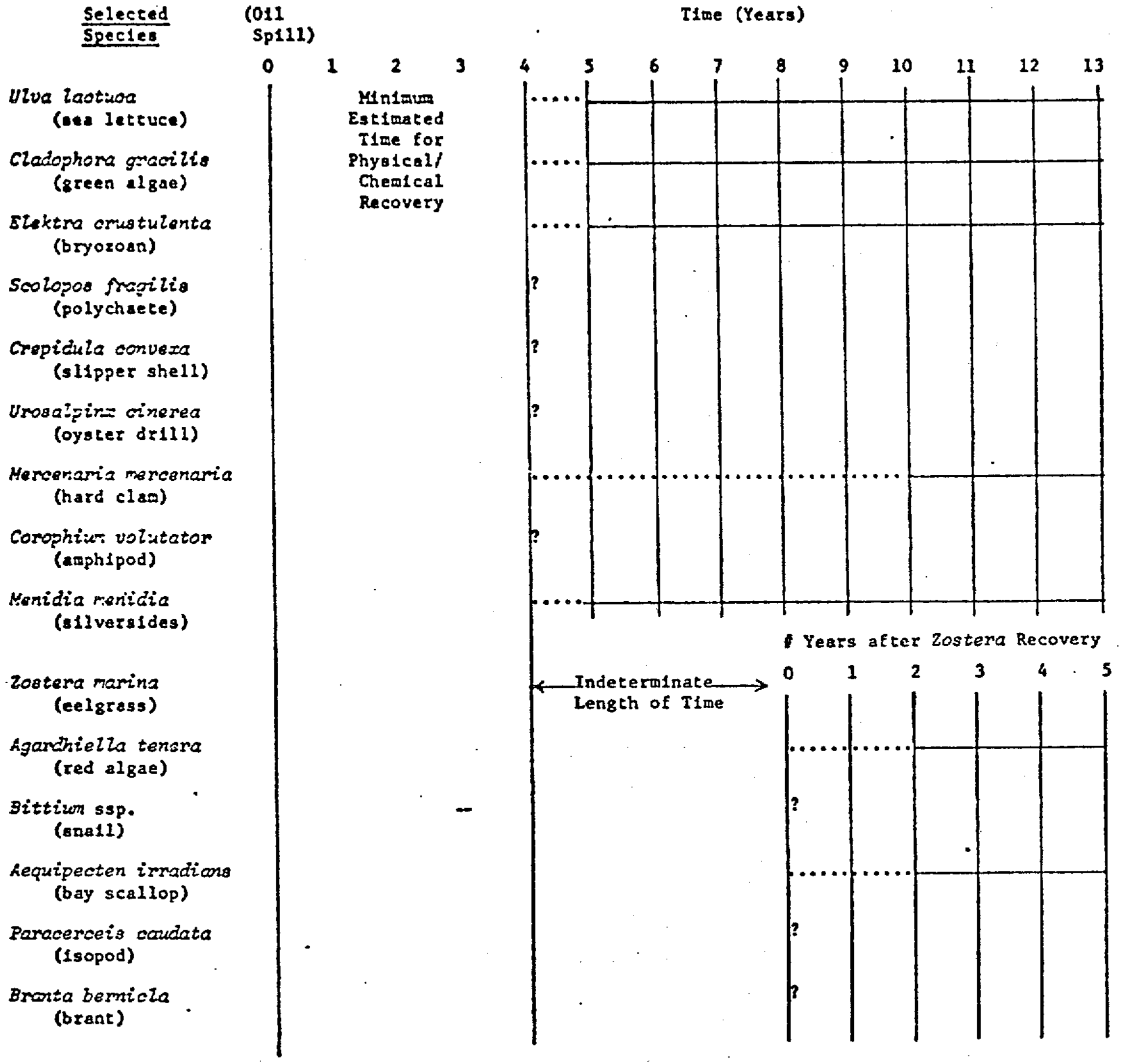
5.6.4 Habitat Recovery

The main factor in the recovery of the eelgrass system is the return of *Zostera marina*. Unfortunately, no estimates are made of total population recovery time for *Zostera*, the central species in this habitat. Within a minimum of two years of *Zostera's* recovery, those species dependent on *Zostera* may have recovered. Of those species not directly dependent on *Zostera*, the hard clam has the longest expected recovery time of 6 years. Return of the NWD species will depend on each species' rate of immigration to a particular area; no recovery time is estimated for most NWD species.

The habitat recovery time-line in Figure 9 depicts an estimate of the eelgrass habitat's recovery process from a worst-case or near-worst-

Figure 9

Eelgrass System Habitat Recovery Time Line
(For Worst-Case and Near-Worst-Case--Minimum Estimates Only)



Key:
( ) Recovery not started.
(····) Recovery process taking place. Only minimum estimate shown.
(——) Species fully recovered.

case spill event: fresh, toxic oil, well-mixed into the sediments; 100% kill of all benthic species within the impacted zone, both intertidal and subtidal; maximum possible kill of finfish, birds, and mammals in the impacted zone. Clearly, if any of these conditions does not apply to a spill, certain stages of recovery will take much less time. An interval of indeterminate length represents total population recovery time for *Zostera*. The only difference between habitat recovery from the near-worst-case (dormant rhizomes) and worst-case (rhizomes killed) spills is that *Zostera* recovery is expected to take longer, from a worst-case; however, this difference cannot be quantified.

In the absence of healthy *Zostera*, changes in the physical/chemical conditions of the locale may occur, which may drastically increase the time required for recovery of the original eelgrass habitat. No estimates of the likelihood or severity of this effect are made.

Nevertheless, based on six years for recovery of the species independent of *Zostera*, plus a minimum of four years for physical/chemical recovery, a lower bound on eelgrass habitat recovery time is estimated to be 10 years. This estimated lower bound applies to both spill scenarios studied, though recovery from the worst-case event is likely to take longer than from the near-worst-case.

5.7 Recovery Times for Remaining Habitats

Utilizing the implied recovery time estimates for the various habitat species contained in section 4, minimum habitat recovery times for the protected sand bottom, protected mud bottom, mussel reef, and rocky shore habitats were derived as shown in Table 22. The recovery times for the high energy beach, salt marsh, and eelgrass system habitats derived in section 5 are also shown. Major data gaps preclude estimates for the pelagic coastal and pelagic estuarine habits. The pelagic habitats are

Table 22. Summary of Estimated Habitat Recovery Times

Habitat Type	Min. Estimated Time Physical/Chemical Recovery	Min. Estimated Time for Biological Recovery	Min. Estimated Time for Total Recovery
High Energy Beach	3 - 5 years	10 years	13 years
Protected Sand Bottom	3 - 10 years	10 years	13 years
Protected Mud Bottom	3 - 10 years	10 years	13 years
Salt Marsh	4 years	7 years after the recovery of *Spartina Alterniflora*[a]	11 years after the recovery of *Spartina Alterniflora*[a]
Eelgrass System	4 years	6 years after the recovery of *Zostera*	10 years after the recovery of *Zostera*[a]
Mussel Reef	2 - 3 years	4 years	6 years
Rocky Shore	2 - 3 years	8 years	10 years
Pelagic Estuarine	?	?	?
Pelagic Coastal	?	?	?

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[a] numbers given are lower bound estimates

extremely important because of their role in the larval development and dispersal of most marine species, including those exploited by recreational and commercial interests. Therefore, adverse pelagic impacts could result in population reductions of those species selected as characteristic of the other habitats.

Organisms of the pelagic habitats (with the exception of birds) may be conveniently subdivided into planktonic species ("drifters") and nektonic species ("swimmers"). Plankton include phytoplankton, "resident" zooplankton or holoplankton (copepods, arrowworms, cladocerans, other minute crustacea), and "transient" zooplankton or meroplanktron (the larval stages of most fish, polychaete worms, crustacea, molluscs, echinoderms, cnidarians, ctenophores, and other "lesser" phyla). Nekton includes adult fishes, squid, some shrimp, aquatic mammals, and a number of smaller species, including adult sea butterflies and jellyfish from selected species lists.

The plankton-nekton distinction proves useful in assessment of potential impact of oil occurring in the pelagic habitats. This is so simply because pelagic oil takes its toll at or near the surface on organisms unable to avoid contact with a spill. Nektonic species are thus assumed essentially invulnerable to a slick, because they can avoid contaminated areas.

The impact of oil spills on planktonic species (including species which have a planktonic stage in their life history, e.g., many mollusc and fish species) depends on the nature of the species' breeding population. In general, the bigger and more diffuse the breeding population, the smaller the potential effect of an oil spill. If small or localized breeding populations exist, impacts may be more severe. This is especially true when a species utilizes particular spawning grounds and nursery areas.

The degree of impact of a spill on the survival of, for example, hard clam larvae, depends on the timing of the spill in relation to the season and duration of spawning (Hard clams spawn when the water temperature is about 21°C.), the fraction of the total population exposed to the spill, and whether or not the larvae are in the planktonic stage or have settled and found an appropriate substrate for growth. Significant larvae mortality could have a drastic effect on commercial harvesting that would be delayed, if in fact most individuals in a year class are destroyed. It is known that dominant age classes can support a fishery for many years. If such a larval class succumbs to oil under worst-case conditions, the loss would be potentially great, although it would never be known how great.

The estimates of recovery time found in Table 22 do not reflect the recovery of WD-NU species. Birds constitute the major species which fall into this class. No WD-NU recovery times were estimated because they are contingent upon a number of factors about which we have little or no information. These include total population, degree of aggregation of species into discrete breeding stocks ("discrete breeding stocks" are those which would not assist each other in recovery), and extent-of-kill. Extent-of-kill in turn depends on spatial aggregation of species (the percent of the population that visits the oiled area during the period of danger), feeding techniques (diving birds are most likely to become oil-coated), and migratory patterns, which determine whether and when a population occurs in an area.

The birds of the sea and coastal areas are the only organisms which are so seriously affected by oil spills that local or even the world populations of any species may be jeopardized. Among the factors which determine the probable effects on the birds of Long Island are the following: degree to which spilled oil is weathered; location of spill; seasons during which the species is present; food type, as well as location and method of feeding; local numbers and degree of gregariousness; range of an individual bird; and the species' reproductive potential. Information on all of these factors is not available for all of the selected bird species in the study area.

Oil has many effects on birds, most them fatal to a high percentage of the affected birds. If a bird comes in contact with floating oil, the bird becomes coated. This coating of oil damages the plumage. Far more important, however, the derivatives of the spilled oil break down the waxes and oils which form the waterproof coating of the bird's feathers. When this happens, the bird becomes waterlogged. This generally causes the bird to freeze to death, even in relatively warm water. Finally, birds will preen themselves in an attempt to remove oil. They invariably injest some and thus poison themselves. Any birds that are not killed are undoubtedly weakened to such a great extent that they can no longer feed and perhaps no longer fly. This is the fate of those birds which come into direct contact with the floating oil; the seabirds, the ducks and geese, and the fishing birds. Others contact the oil indirectly, by feeding on other oiled birds or on dead or dying fish and invertebrates, which have either accumulated oil derivatives or are coated with oil. Ospreys, eagles and herring gulls are examples of these affected birds. It is probable that there is a build-up of the toxic derivatives in the food chain, the toxin becoming concentrated many times over at the bird's level in the food web. This is probably not an important effect, however, because death due to direct uptake is likely to occur before there is time for the toxic build-up to occur in an individual bird. Birds appear to be vulnerable to both crude oil and any of the other derivatives; fuel oil, light oil, etc. Tarballs, the extreme case of weathered oil, are not known to have any toxic effect on birdlife. With that exception, any contact with oil can be expected to be fatal to most of the birds contacted.

The location of the spill is one of the important factors in determining the effects of an oil spill. Most of the birds have a fairly restrictive habitat preference. A spill which remains off the coast, never coming ashore, may effect the osprey, king eider, gannet and white-winged scoter. A spill which comes ashore on the high energy beach will effect the sanderling. Spills coming ashore within the estuaries could effect the clapper rail, black duck, brant, herring gull, among others.

The season during which a given species is present in the Nassau-Suffolk coastal zone is another important parameter in determining the effects of an oil spill. Some birds are present only during the winter, when they are often present in large colonies, in areas of open water with abundant food. During the summer, these species breed far to the north. Others winter far to the south and are only present during the summer, when they breed and raise their young. At this time, abundant food is necessary, as there is little foraging done during the nesting season. Others are only present for a few weeks in the spring and the fall, as they migrate between their nesting grounds and their wintering grounds. Some are present during three seasons, others all year long. Thus, the time of the spill is very important in determining the probability of oil-caused mortality.

The size and distribution of a population are important in determining the effect of an oil spill on a species. Most habitat species were selected because of their ecological dominance; a few were selected because of their relative scarcity, and are thus more prone to lasting population damage. Some are widespread enough across the country so as to make any prolonged damage to the species unlikely. Others sometimes congregate to such an extent that a large percentage of a total breeding population is present at one place. At such times, such a species is especially vulnerable to oil damage. Examples of such cases are the wintering aggregations of brant and the greater scaup.

Another important factor in the determination of oil spill damage to a species is the manner in which it feeds, together with the type of food that it eats. Birds can, for convenience, be divided into two groups: those that rest on or dive into the water while feeding, and those which do not. Obviously the former are much more susceptible to oil damage than the latter. The dabblers include the brant and the black duck, as well as many of the other waterfowl that inhabit the estuaries. These birds feed by tipping up, eating what they can reach in this manner, usually a diet composed of eelgrass, algae, and crustaceans. The diving birds, such as the greater scaup, king eider, white-winged scoter, and the gannet, actually dive to considerable depths to feed on fish, molluscs, and polychaetes. It is clear that these two types are very susceptible to the effects of oil, though not as much so as the other. The birds which do not sit on the water can be divided into two groups: one which feeds on marine creatures and plants, and one which is largely terrestrial. Among the former are ospreys and terns, which seize fish from the water. Since fish are often killed or weakened by oil, these birds would be more susceptible to the secondary poisoning by oiled food rather than by the direct coating of their feathers. The terrestrial birds include the redwinged blackbird and the Ipswich and sharp-tailed sparrows, which feed on insects and seeds, and so are not particularly sensitive to direct effects of oil spills,

The reproductive potential of the species may also be a factor. Relative to most marine species (most fish, clams, crabs, copepods, for example) the reproductive potential of all birds is very low. However, within the class of birds, differences in reproductive potential between species can be identified. A species' reproductive potential is a function of the maximum and minimum breeding ages, the longevity, the number of eggs and of surviving offsprings. For most ducks, this potential is very high, relative to most birds. They breed early, and have large clutches of eggs. Others, such as the osprey and gannet, breed late in life, and not every year thereafter, and have only a single egg, or at best a few. These birds have relatively higher probabilities of suffering prolonged population damage from an oil spill.

Two additional factors operate to greatly enhance the mortality caused by an oil spill to birds. The first is that birds apparently cannot detect an oil slick. They dive into it, or swim in it, as if it were not there. Fish apparently can detect oil, but because the birds cannot detect it, many are coated. The other factor is that a large invertebrate kill often accompanies a spill. Polychaetes will lie on the surface of the substrate, clams and mussels will remain halfway open, etc. This will draw birds from a considerable distance, greatly increasing mortality.

6.0 Oil Spill Scenarios

6.1 Introduction

This section describes the hypothetical oil spill scenarios associated with development of the Georges Bank and Baltimore Canyon Troughs that will be evaluated to determine potential biological impacts in the Nassau-Suffolk coastal zone. Available oil spill statistics for the region are analyzed to determine the hypothetical spill climate associated with OCS development during field life. Oil spill trajectory studies are reviewed to show the susceptibility of Long Island to oil spilled at various locations in the New York Bight.

6.2 Oil Spill Statistics

The U.S. Dept. of the Interior has estimated hypothetical tanker related oil spill discharges during the 25 year life of the development of the Baltimore Canyon Trough region for low and high production figures as follows (U.S. Dept. of the Interior, 1976a):

Volume of crude oil produced	Hypothetical tanker spillage
0.4 billion barrels	1,668,480 barrels
2.6 billion barrels	10,845,120 barrels

Volumes of oil expected to be released to the environment as a result of pipeline accidents, well blowouts, formation waters, explosions, and fires are very small compared to tanker related discharges. Maximum daily oil production from the Baltimore Canyon region has been estimated at 320,000 barrels. Half of this production (160,000 barrels/day) is expected to be refined in Port of New York/New Jersey area refineries; the other half will be refined in Port of Philadelphia/Delaware area refineries (U.S. Dept. of the Interior, 1976b).

The final environmental impact statement for OCS Sale No. 40 also contains an analysis of oil spill risks posed by the sale of tracts in the Baltimore Canyon region. This analysis indicated the following frequency estimates by source for oil spills greater than 1000 barrels during field life:

Source	Expected Number of Spills	Probability of at Least One Spill Occurrence
Platforms	2.3	.90
Pipelines	2.5	.92
Tankers	3.3	.96
Platforms & Pipelines	4.8	.99
Platforms & Tankers	5.6	.99

Estimates are given for the two options that combine production (platform) and transport mode (pipeline or tanker) spills. It is evident that use of tankers is more dangerous from an oil spill point of view than the use of pipelines.

The above figures also reveal that it appears almost certain that a large oil spill (i.e., a spill greater than 1,000 barrels) will occur as a result of development of the Baltimore Canyon region. Use of the U.S.G.S. oil spill trajectory model indicated that there is a probability of .39 that at least one spill greater than 1,000 barrels will strand on the shore of the mid-Atlantic coast during development of the Baltimore Canyon area. The Nassau-Suffolk coastline is at the northern end of the mid-Atlantic region; no separate breakdown of the risk posed to Nassau-Suffolk coastal zone resources was given in the impact statement. Also, the trajectory study was limited to spill sites chosen within the borders of the lease sale area.

Hypothetical tanker related oil discharges expected to occur during the 20 year life of the Georges Bank Trough region are as follows (U.S. Dept. of the Interior, 1976b):

Volume of crude oil produced	Hypothetical tanker spillage
0.18 billion barrels	734,616 barrels
0.65 billion barrels	2,652,780 barrels

Spills from other sources are again small in comparison to tanker related spills.

Maximum daily oil production from the Georges Bank region has been estimated at 181,000 barrels. Because no refinery capacity exists in New England, it is expected that Georges Bank oil will be refined at existing facilities located in the Port of New York/New Jersey. The capacity of these refining facilities is about 450,000 barrels/day.

An analysis of oil spill risk is contained in the draft environmental impact statement for OCS Sale No. 42, which covers lease areas in the Georges Bank region (U.S. Dept. of the Interior, 1976b). Spill frequencies (for spills greater than 1000 barrels) by source for this area during a 20 year production life are shown below:

Source	Expected Number of Spills	Probability of at Least One Spill Occurrence
Platforms	1.14	0.65
Pipelines	1.26	0.69
Tankers	1.69	0.81
Platforms & Pipelines	2.40	0.89
Platforms & Tankers	2.83	0.93

The above information indicates that the development of the Georges Bank Trough will most likely result in fewer spills than the development of the Baltimore Canyon Trough. The analysis of oil spill trajectories in the Georges Bank region contained in the draft environmental impact statement indicated that potential spill sites along hypothetical oil transport routes posed greater risk to shoreline areas than the proposed lease tracts. Oil spill trajectory data were combined with spill frequency estimates to obtain a total probability distribution for spills greater than 1,000 barrels that impact shoreline areas during the production life of the field. Assuming that oil produced on Georges Bank is transported by tanker to Port of New York/New Jersey refineries, and that a tanker spill occurred at a location approximately 35 nautical miles southeast of Montauk Pt., there is a probability of .56 that at least one large oil spill will impact shoreline resources. As was the case with the Baltimore Canyong oil risk analysis, no specific probabilistic assessment was prepared for the Nassau-Suffolk coastal zone. Therefore, for purposes of this report, reliance must be placed on studies which focus specifically on the Nassau-Suffolk coastal zone.

The Nassau-Suffolk coastal zone is located in a position such that it could be impacted by oil spills generated by OCS activities occurring as a result of the development of both the Georges Bank and Baltimore Canyon Trough regions. Eight large spills could result in the overall area if tankers are used to transport crude oil to refineries. The total maximum production from both the Georges Bank and Baltimore Canyon Troughs that is expected to be refined in Port of New York/New Jersey refineries is roughly 340,000 barrels/day, or 75% of refinery capacity. The extent to which this Atlantic OCS produced crude oil will replace imports of crude from foreign sources, as well as increase tanker traffic, is not clear, because no comprehensive statistics concerning crude oil or petroleum related vessel trips have been developed for the region. It appears that at peak production, one small tanker (26,000 dead weight tons) could accommodate the entire daily production from each field that is expected to be refined in the Port of New York/New Jersey. Therefore, roughly 730 tanker round trips per year would be expected between the fields and refineries. The net increase in tanker traffic (taking into consideration reductions in foreign oil imports arriving in tankers larger than 26,000 dead weight tons) in the New York Bight apex is not known. This factor is significant in determining estimates of potential tanker related oil discharges in the future. Should refinery capacity be expanded to meet refining demands of Atlantic OCS oil, and foreign crude oil imports are kept at present levels, a dramatic increase in tanker movements would occur. This, of course, assumes that pipelines are not utilized for crude oil transport.

6.3 Oil Spill Trajectory Studies

The previous section discussed the number and volume of hypothetical oil spills associated with the development of the Georges Bank and Baltimore Canyon Troughs. The significance of such spills in this report is whether or not they will impact Nassau-Suffolk coastal zone marine habitats. The relationship of oil spill location to the likelihood of spill stranding on Nassau-Suffolk shores is covered in this section.

Two oil spill trajectory studies sponsored by the Nassau-Suffolk Regional Planning Board provide the necessary information for determining the susceptibility of the Nassau-Suffolk coastal zone to spilled oil. Stewart and Devanney (1974) utilized the MIT oil spill trajectory model to describe oil spill movement based in part on the probabilistic nature of changes in wind speed and direction. Surface circulation in the New York Bight was determined by Hardy *et al.* (1975) in an empirical fashion through analysis of interface drift card release/return data. The interface drift cards were designed to simulate oil spill movement. The results of these studies will be described by utilizing base maps that show the tracts leased in the Baltimore Canyon Trough as a result of OCS Sale No. 40 held on 17 August 1976, the tracts proposed in OCS Sale No. 42 for the Georges Bank Trough, and the three shipping lanes which converge at the apex of the New York Bight that would be used by tankers for crude oil transport to refineries in the Port of New York/New Jersey.

Results from Stewart and Devanney (1974) shown in Figure 10 indicate that duirng the winter it is extremely unlikely (probability less than .01) that spills originating at tracts in either the Baltimore Canyon or Georges Bank Troughs will strand on Nassau-Suffolk beaches. However, the situation is potentially more serious for spills originating at drilling sites when such spills occur in the summer. Figure 11 shows that the Baltimore Canyon tracts pose little threat to Long Island in the summer. There is roughly a probability of .1 that spills originating at the westernmost tracts in the Georges Bank during summer, will strand on Long Island. Spills originating at the westernmost tracts in the Georges Bank could reach Long Island in as little as approximately 20 days; however, the average time to shore for such spills would be on the order of about 35 days. See Figures 12 and 13. Thus, oil stranding on Long Island beaches that originates at the site of production would most likely be classified as weathered.

An analysis of the Nantucket/Ambrose shipping corridor in relation to the probability contours in Figures 10-13 indicates that the potential oil spill problem is much more serious if tanker spills occur south of Long Island. The probability of such spills stranding in the Nassau-Suffolk coastal zone in summer could be higher than .6, depend-

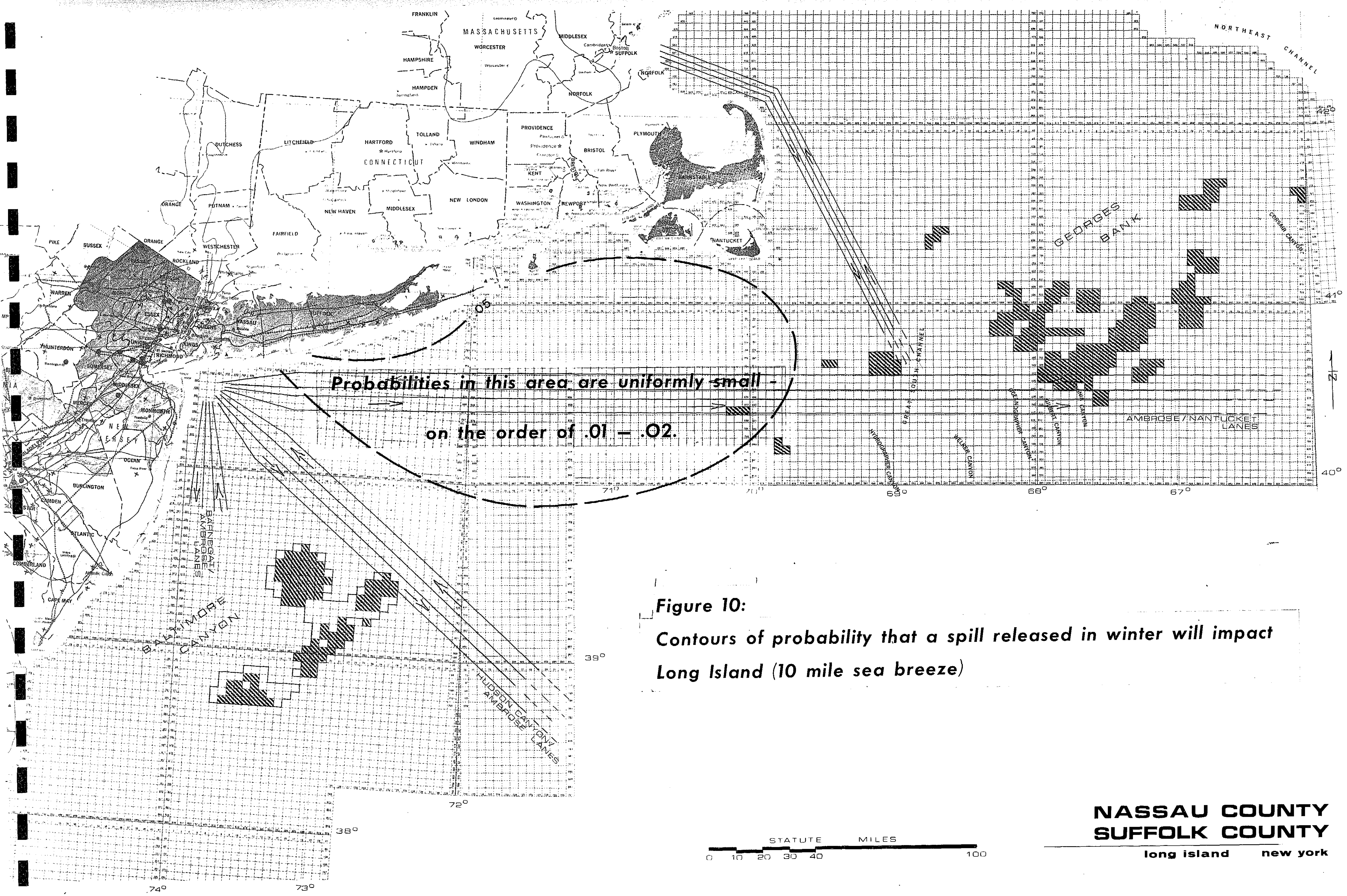

Figure 10:

Contours of probability that a spill released in winter will impact Long Island (10 mile sea breeze)

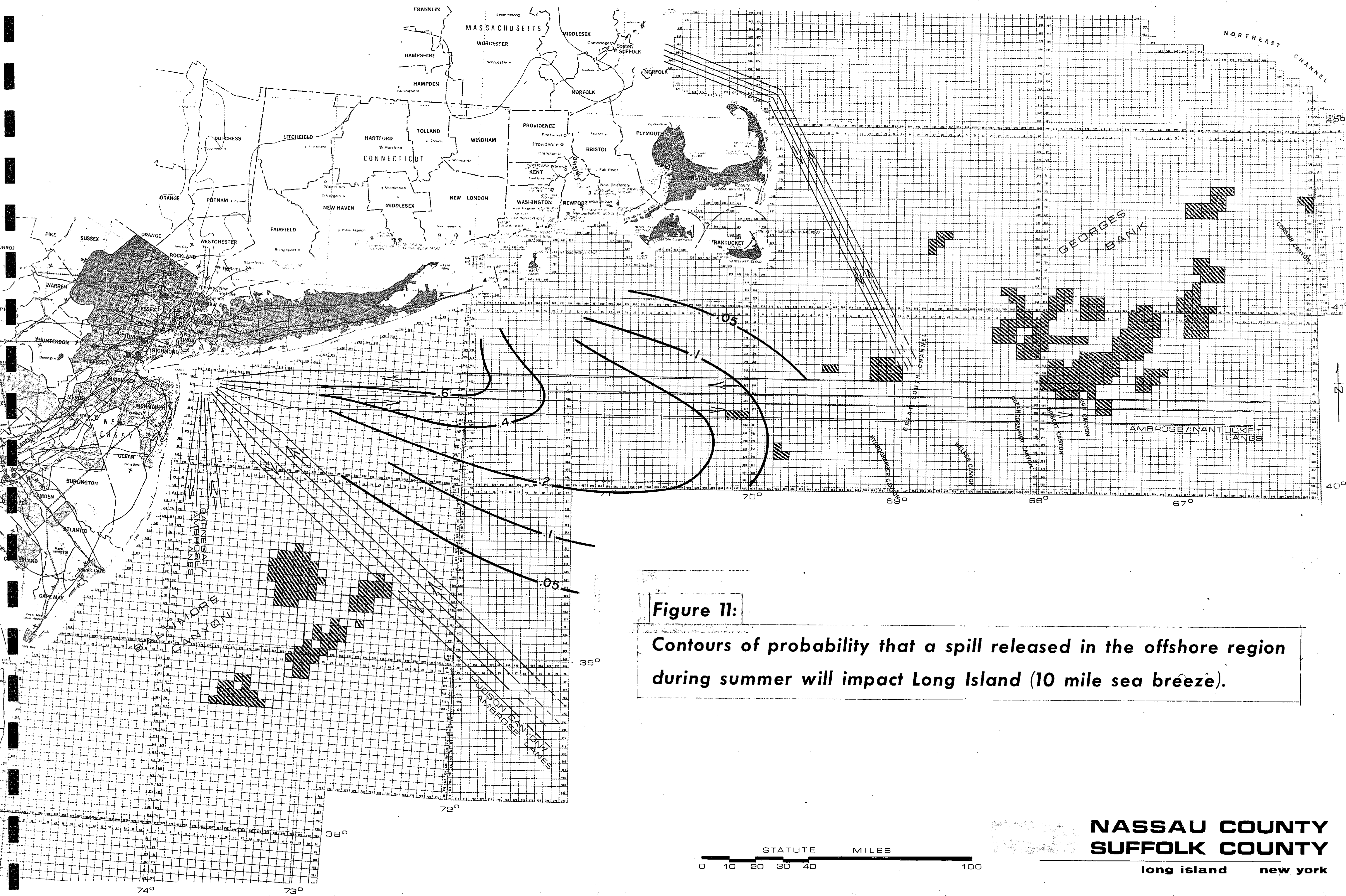

Figure 11:

Contours of probability that a spill released in the offshore region during summer will impact Long Island (10 mile sea breeze).

NASSAU COUNTY
SUFFOLK COUNTY
long island new york

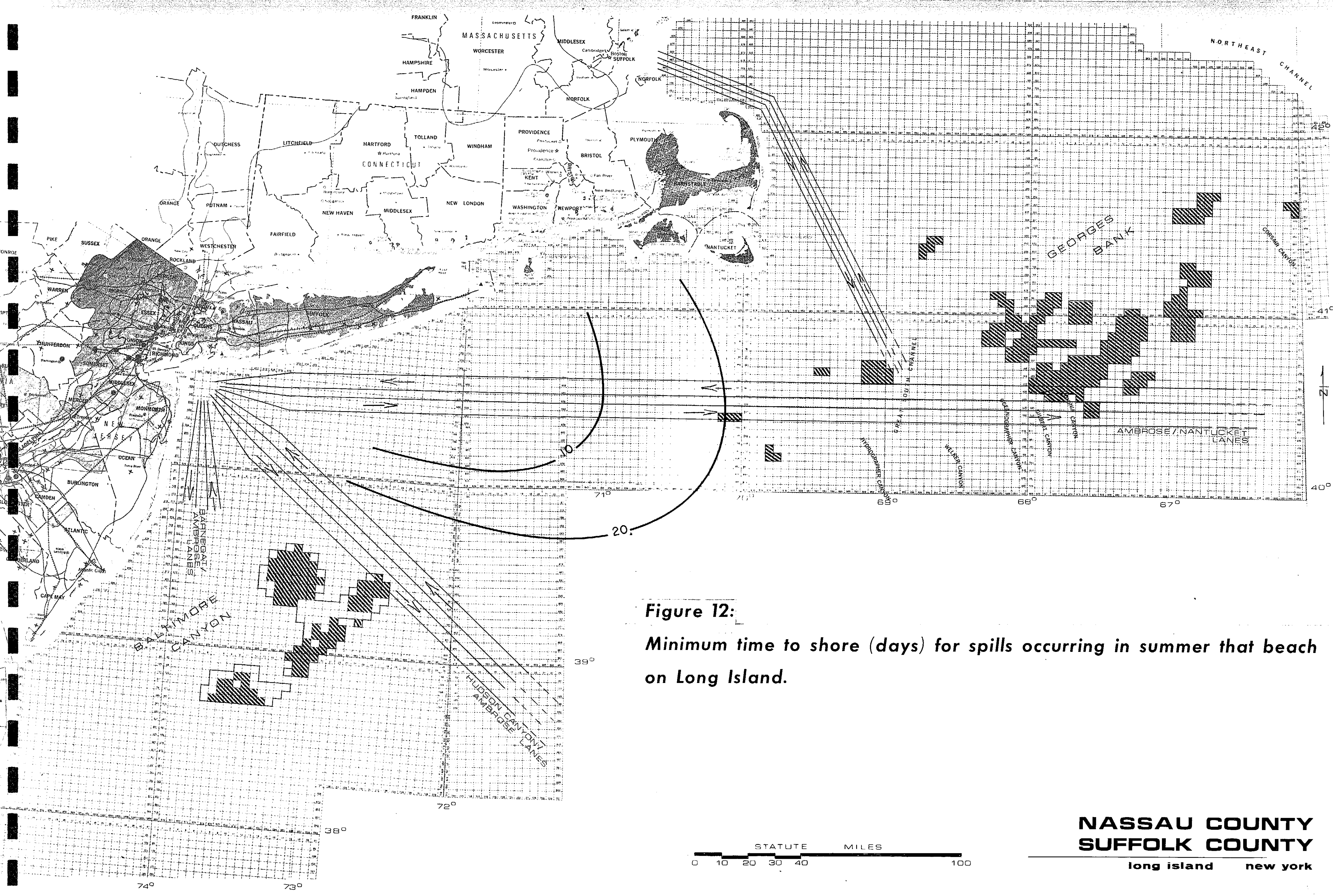

Figure 12:

Minimum time to shore (days) for spills occurring in summer that beach on Long Island.

NASSAU COUNTY
SUFFOLK COUNTY
long island new york

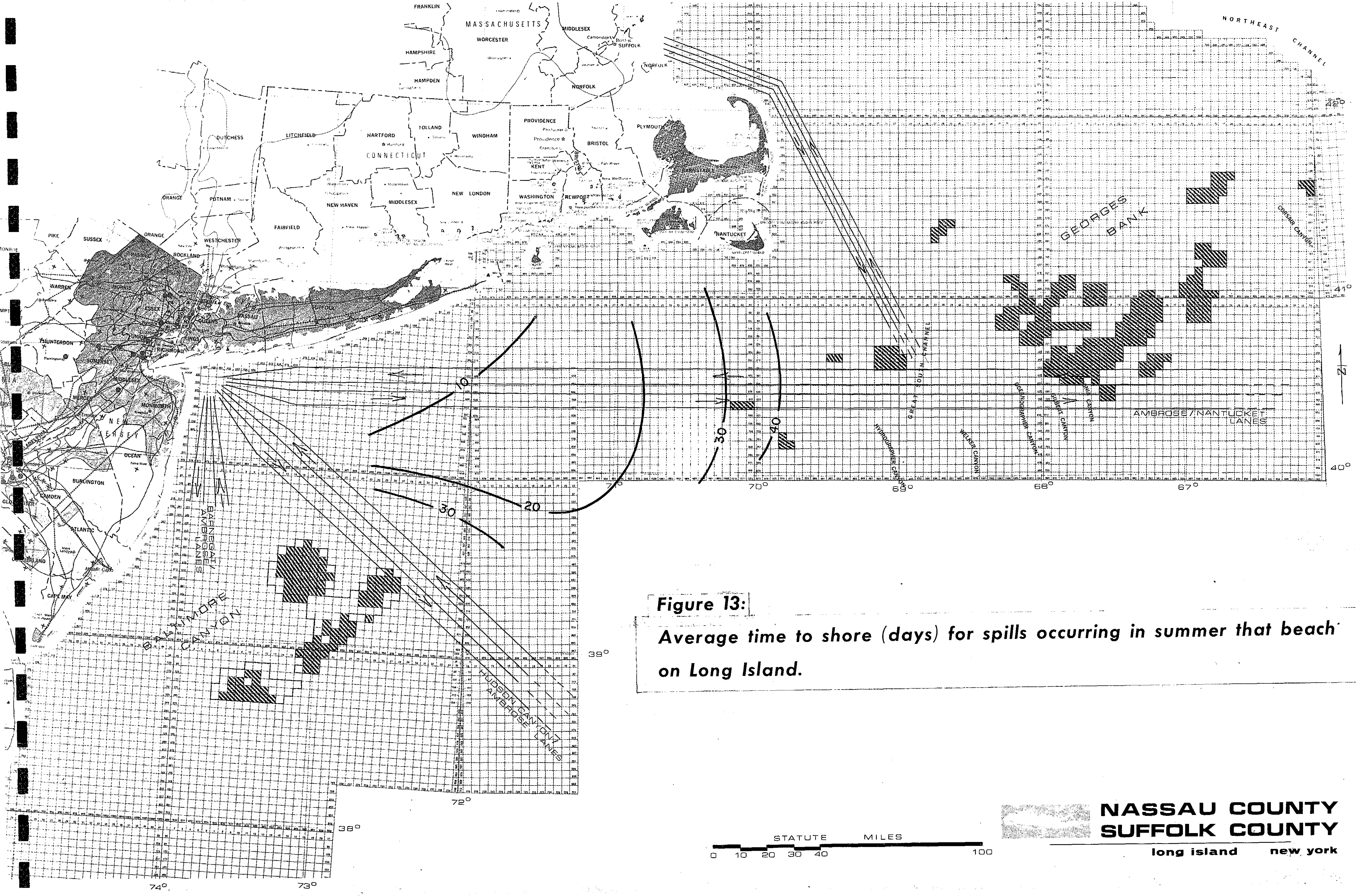

Figure 13:

Average time to shore (days) for spills occurring in summer that beach on Long Island.

NASSAU COUNTY
SUFFOLK COUNTY
long island new york

ing on spill location in the shipping corridor. Such spills could hit Long Island beaches in less than 10 days.

Figures 14 through 17 show the results obtained by Hardy *et al.* (1975). The various contour lines shown on these figures are based on drift card returns that occurred in 1974. One could expect that an oil spill would behave in a fashion similar to the cards should weather conditions and current regimes approximate those that existed in 1974 during the year the spill occurs. Figure 14 indicates that platform spills occurring on production sites at either the Baltimroe Canyon or Georges Bank Troughs would not pose a threat to Nassau-Suffolk beaches in winter. A comparison of Figures 14 and 15 reveals that should a spill occur in the region near Long Island's south shore in winter, it will most likely strand within 10 days of release or not at all. This is indicated by the similar position of contours with the same value.

The situation changes for the worse in summer. Figure 16 indicates that a platform spill originating at those tracts immediately to the west of Great South Channel has a greater than 20% probability of stranding on Long Island within 60 days during the summer. This figure also shows that a platform spill originating in the Baltimore Canyon will most likely not strand on Long Island. Figure 17 shows that it is virtually unlikely for any platform spill to strand on Long Island within 10 days in summer. For tanker spills occurring in the Ambrose/Nantucket lanes south of western Suffolk County and Nassau County in the summer, however, the percent probability of stranding on Long Island varies between 40 and 80%. Some drift cards released within the Ambrose/Nantucket lanes that stranded on Long Island were at sea for a maximum time of two days. This indicates that oil spilled by tankers could

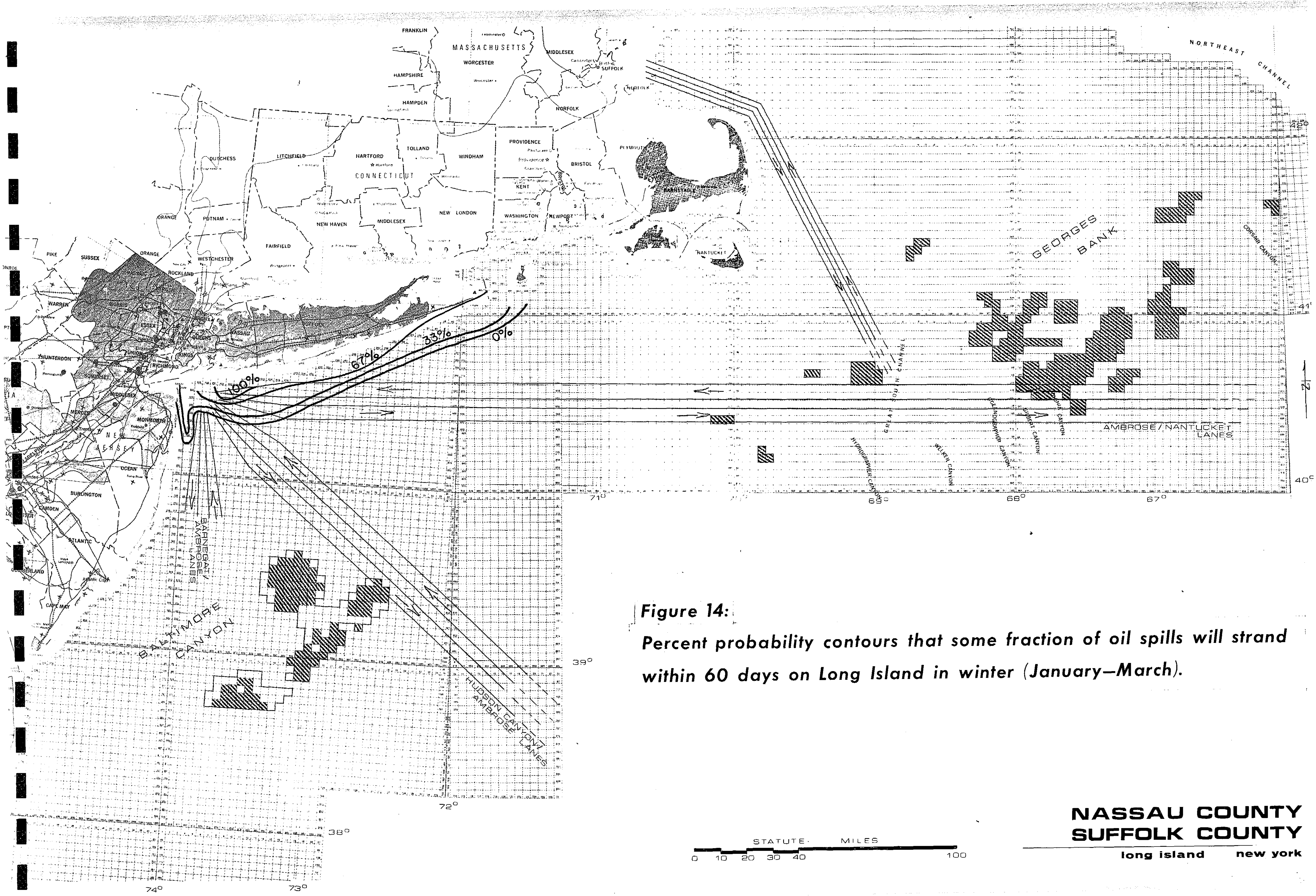

Figure 14:

Percent probability contours that some fraction of oil spills will strand within 60 days on Long Island in winter (January–March).

NASSAU COUNTY
SUFFOLK COUNTY
long island new york

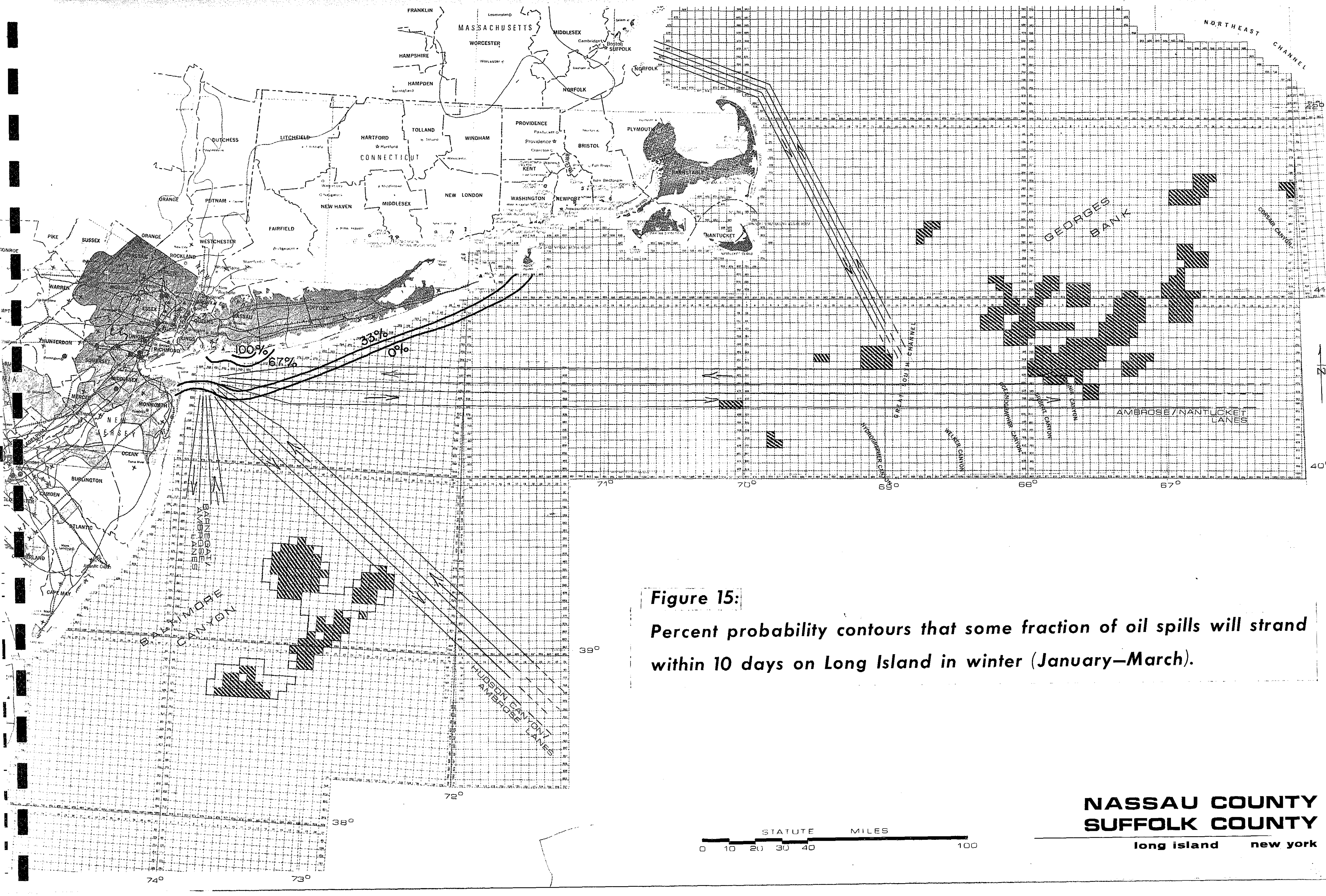

Figure 15:

Percent probability contours that some fraction of oil spills will strand within 10 days on Long Island in winter (January–March).

NASSAU COUNTY
SUFFOLK COUNTY
long island new york

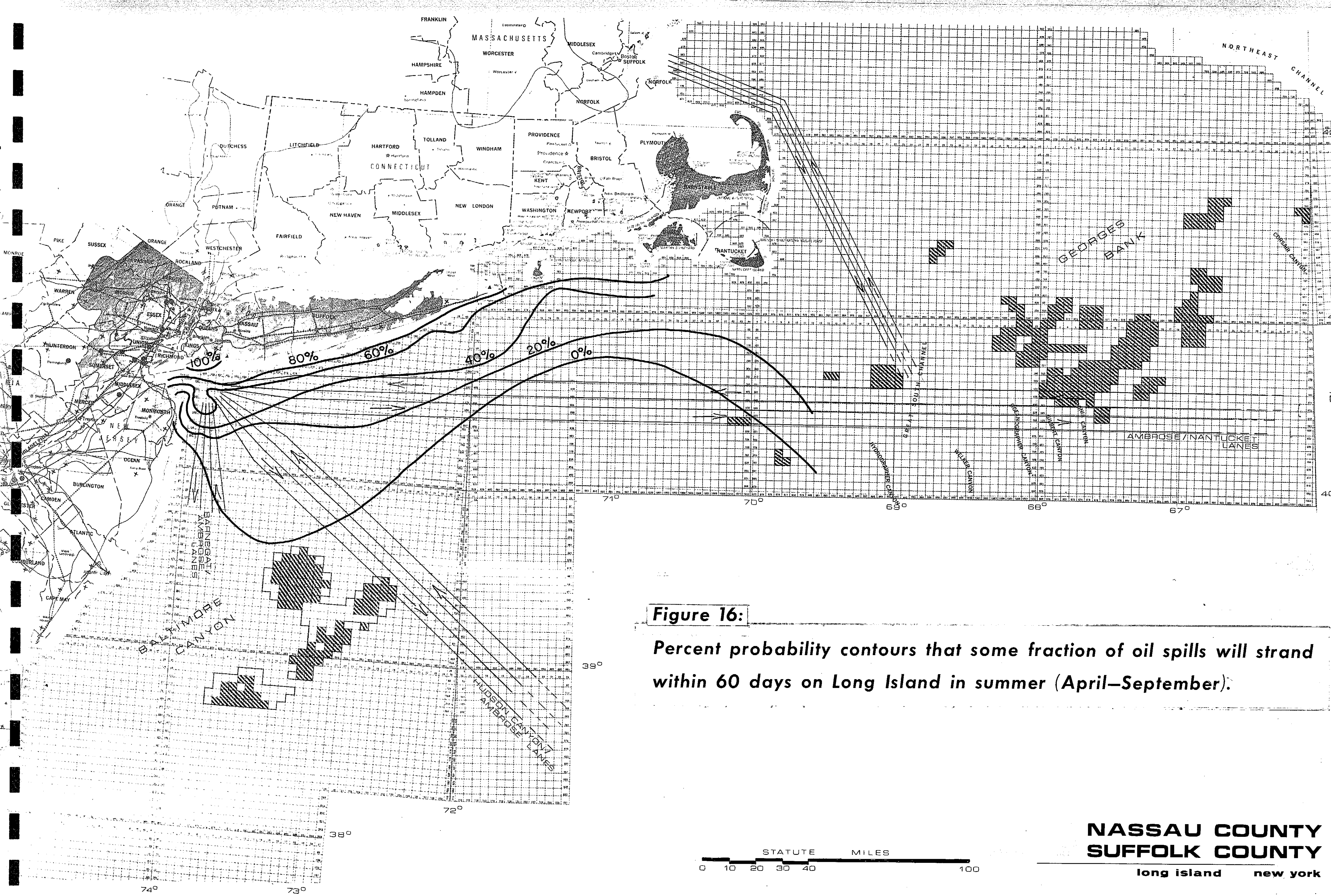

Figure 16:

Percent probability contours that some fraction of oil spills will strand within 60 days on Long Island in summer (April–September).

NASSAU COUNTY
SUFFOLK COUNTY
long island new york

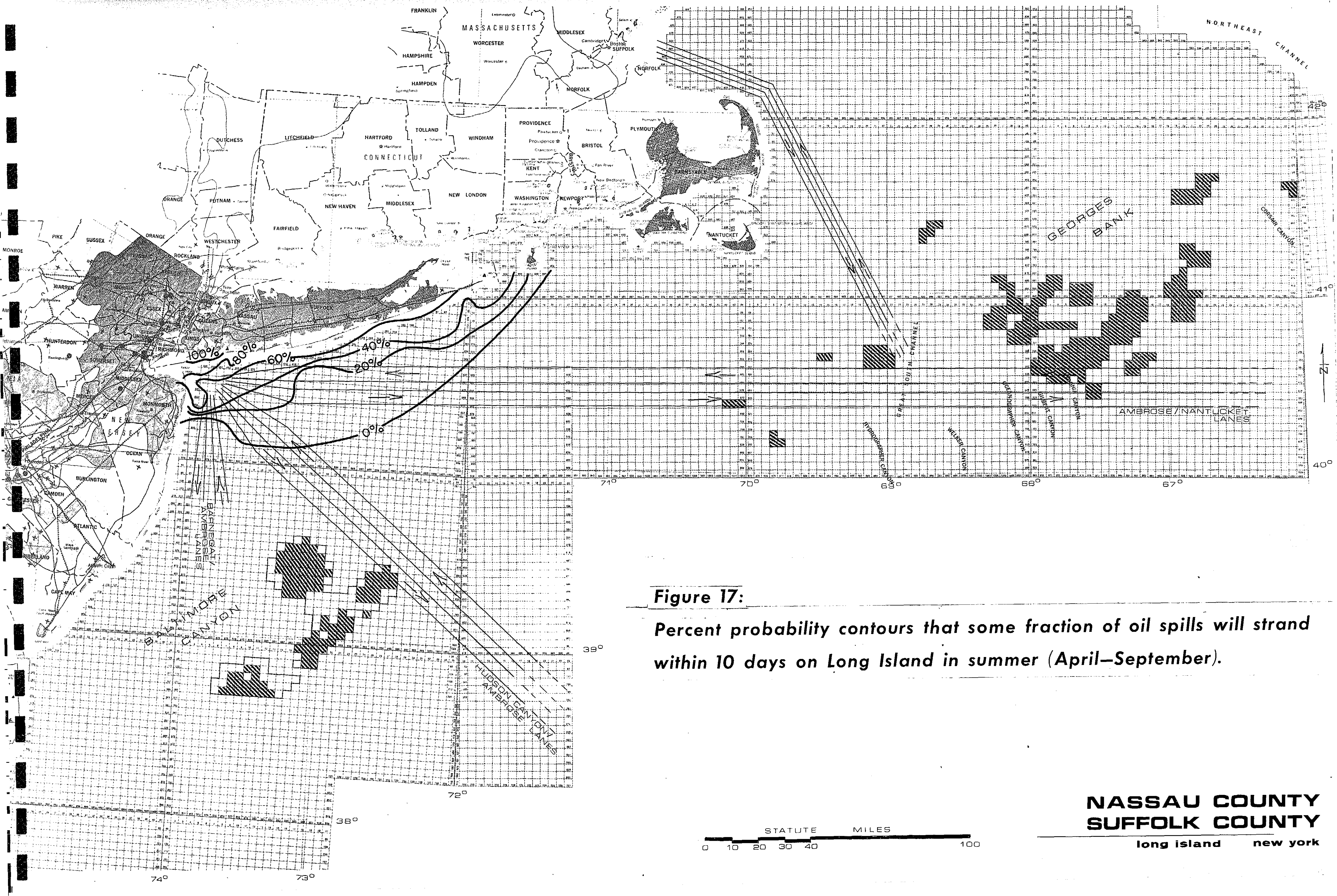

Figure 17:

Percent probability contours that some fraction of oil spills will strand within 10 days on Long Island in summer (April–September).

NASSAU COUNTY
SUFFOLK COUNTY
long island new york

strand on Long Island in an extremely toxic state, i.e., unweathered.

In general, the results found in Hardy *et al.* (1975) confirm the probabilistic model outputs generated by Stewart and Devanney (1974). Tanker spills occurring in the apex of the New York Bight during summer have high probabilities of hitting Long Island. It should be pointed out that Figures 14 through 17 are based on seasonal averages that in effect mask worst-case results obtained during individual months in winter and summer. All of the figures indicate that Long Island is more susceptible to oil spills occurring within the established shipping lanes that service New York Harbor. For this reason, oil spill scenarios will be develooped which reflect this situation.

6.4 Analysis of Oil Spill Scenarios

In order to evaluate potential biological impacts of hypothetical oil spills, it is first necessary to define general OCS development scenarios that appear likely should oil be found in sufficient quantity for production from the Georges Bank and Baltimore Canyon Troughs. The following scenario is proposed for the Georges Bank Trough:

- crude oil is transported to existing refineries in the Port of New York/New Jersey by tankers;
- no new refinery capacity is established in New England;
- gas is transported to New England by pipeline.

For the Baltimore Canyon Trough the following scenario is proposed:

- gas is shipped to New Jersey via pipeline;
- approximately one half of maximum daily production is transported to Port of New York/New Jersey refineries via tanker; the other half is transported to Port of Philadelphia/Delaware area refineries by tanker.

For the Georges Bank scenario, tanker traffic to and from refineries will follow the established Nantucket/Ambrose lanes. For the Baltimore Canyon scenario, tankers to Port of New York/New Jersey refineries will utilize the established Hudson Canyon/Ambrose Lanes.

It is speculated that tanker transport of crude oil from the Baltimore Canyon Trough to Port of New York/New Jersey refineries may be replaced by transport via pipeline, should a pipeline prove to be economically feasible. Fewer large spills are expected to occur over the life of the field if a pipeline is utilized. However, if the pipeline traverses the apex of the New York Bight, and pipeline spills occur in this region, the trajectory studies indicate that there is a high probability for such spills stranding on Nassau-Suffolk shores.

A predictive capability that enables one to determine the precise location of oil spill stranding within the Nassau-Suffolk coastal zone, given the point of origin of the spill on the continental shelf, as well as timing of the spill, does not exist. Use of drift card release/return data from specified drop stations, as well as use of computer simulations of spill events to determine the location of spill stranding was investigated, but the high variability of spill trajectories prevented spill stranding predictability on a local basis. That is, the wide range of stranding locations for hypothetical spills originating at a given location does not allow the capability of determining precise locations of spill stranding with any degree of confidence. This problem is complicated by the fact that the boundaries of the habitats found in the Nassau-Suffolk coastal zone were based on fairly well defined features and characteristics. Also, the location of future hypothetical spills is a major unknown upon which spill trajectories, and hence, potential coastal zone impacts depend. Because of these constraints, and the fact that habitats can vary within short distances, it was decided that, for the purpose of evaluating biological impacts, oil spill events would be described in general terms.

The main descriptor used is spill time to shore. The following were selected to reflect spill times to shore that could arise as a result of spills occurring in the shipping lanes utilized by tankers transporting crude oil from the Georges Bank and Baltimore Canyon Troughs to Port of New York/New Jersey refineries: less than two days; three days; and 20 days. Use of spill time to shore can be used to predict the impact of spills on the habitats exposed (high energy beach, protected sand bottom, protected mud bottom, eelgrass system, rocky shore, mussel reef, pelagic coastal, and pelagic estuarine). The impacts of a particular spill could be deemed worse if special features (waterfowl areas, coastal recreation areas, and production areas for shellfish and crustaceans) are exposed.

7.0 Analysis of the Biological Impacts of Hypothetical Oil Spills

7.1 Introduction

The objective of this study is to provide data and maps which can be used to describe the impacts of hypothetical oil spill events on the habitats and special features located in the Nassau-Suffolk coastal zone. Given the high levels of uncertainty associated with all aspects of the available data base, no definitive predictions can be made; however, rough estimates of the effects of classes of spills defined by time to shore can be made and the framework for making such estimates is presented.

7.2 Framework for Analysis

Although the characteristics of a particular spill that might actually occur at a given site are unknown, possible spill events may be hypothesized and their effects analyzed. Though no estimate is made here of how likely or unlikely these spill events are, analysis of their effects can give one a feel for the possible effects of oil spills, should such spills strand within the Nassau-Suffolk coastal zone. The range of spill events selected for analysis is representative of the types of events that could occur as a result of development of the Georges Bank and Baltimore Canyon Troughs. Spill events with similar characteristics from other sources would likely cause similar impacts.

Different spill events will cause a range of biological impacts. Within the accuracy of this analysis, the potential biological impacts of oil spills are determined largely by the spill's time to shore and the impact zone. Hence the range of possible spill impacts can be covered by plausible combinations of time to shore and impact zone. A spill's time to shore determines its degree of weathering at impact--that is, its toxicity. Though definite cut-offs do not exist, a spill at sea for two days or less can be considered an unweathered spill; three days, weathered; and 20 or more days, very weathered. These time to shore values are used to illustrate possible oil spill events. The impact zone is defined by the particular mix of habitats effected by a spill. Therefore, combinations of the above times to shore and the nine habitats found in the Nassau-Suffolk coastal zone represent plausible oil spill events.

Table 23 summarizes the biological effects associated with oil spill events. The oil spills are assumed to be moderate in size. The following information is utilized:

Time to Shore - 2, 3, or 20 days, depending on the spill event.

Oil Composition - Unweathered (contains sufficient lower boiling hydrocarbons to cause toxic responses), weathered (lower boiling hydrocarbon concentration too low to cause any significant toxic response), very weathered (only tarry, residual petroleum substance remains).

Oil Amount - An estimate of the fraction of the total volume of oil released which eventually comes ashore. Depends on time to shore.

Coverage - An estimate of the uniformity (or "patchiness) of impact within the stranding zone. Depends on time to shore.

Lethal & Sub-lethal Toxicity - Estimated extent of these effects on individuals in each habitat exposed.

Incorporation - The extent to which hydrocarbons may become incorporated in various organisms.

Habitat Impacted - The habitat type exposed to the spill.

Coating & Habitat Alteration - Estimate of extent of these effects.

Estimated Population Mortality - Estimate of percent of any population killed by spill.

Table 23 Biological Effects of Hypothetical Spill Events

Oil Spill Event	Habitat Impacted	Coating & Habitat Alteration	Estimated Population Mortality Within a Habitat	Residence Time (Physical/Chemical Recovery)	Total Habitat Recovery Time (Biological + Physical/Chemical)
Time to Shore - 2 days Oil Composition - unweathered Oil Amount - 100% of released oil impacts shore Coverage - nearly total: 95% of impact zone	High energy beach	Large coating effect on all intertidal flora and fauna, and on certain bird species. Possible effect on subtidal benthic species. Significant effect of habitat alteration on all species.	50 - 100%	3 - 5 years	3 - 5 years
Lethal & Sublethal Toxicity - moderate to high	Rocky Shore	"	"	3 - 5	3 - 5
Incorporation - ?	Protected Sand Bottom	"	"	3 - 10	3 - 10
	Protected Mud Bottom	"	"	"	"
	Salt Marsh	"	"	"	"
	Eelgrass	"	"	"	"
	Mussel Reef	"	"	2 - 3	"
	Pelagic Estuarine	"	?	?	?
	Pelagic Coastal	"	?	?	?

Table 23 Biological Effects of Hypothetical Spill Events (cont'd.)

Oil Spill Event	Habitat Impacted	Coating & Habitat Alteration	Estimated Population Mortality Within a Habitat	Residence Time (Physical/Chemical Recovery)	Total Habitat Recovery Time (Biological + Physical/Chemical)
Time to Shore - 3 days Oil Composition - weathered Oil Amount - 75-100% of released oil reaches shore Coverage - 50-100% of impact zone. Large patches 1-100 acres in size Lethal & Sublethal Toxicity - low Incorporation - ?	High energy beach	Moderate coating effect on intertidal fauna and flora. Large effect on certain bird species. Possible effect on subtidal benthic species. Significant effects of habitat alteration on most species.	10 - 50%	3 - 5 years	3 - 5 years
	Rocky Shore	"	"	3 - 5	3 - 5
	Protected Sand Bottom	"	"	3 - 10	3 - 10
	Protected Mud Bottom	"	"	"	"
	Salt Marsh	"	"	"	"
	Eelgrass	"	"	"	"
	Mussel Reef	"	"	2 - 3	"
	Pelagic Estuarine	"	?	?	?
	Pelagic Coastal	"	?	?	?

Table 23 Biological Effects of Hypothetical Spill Events (cont'd.)

Oil Spill Event	Habitat Impacted	Coating & Habitat Alteration	Estimated Population Mortality Within a Habitat	Residence Time (Physical/Chemical Recovery)	Total Habitat Recovery Time (Biological + Physical/Chemical)
Time to Shore - 20 days Oil Composition - very weathered Oil Amount - 0-50% of released oil reaches shore Coverage - 0-50% of impact zone. Very patchy and uneven. Tarballs and small patches. Lethal & Sublethal Toxicity - none Incorporation - ?	High energy beach	Small coating effect on intertidal and subtidal fauna, due to habitat alteration only. Significant effect of habitat alteration on most species.	Negligible	2 - 3 years	2 - 3 years
	Rocky Shore	"	"	2 - 3	2 - 3
	Protected Sand Bottom	"	"	3 - 10	3 - 10
	Protected Mud Bottom	"	"	"	"
	Salt Marsh	"	"	"	"
	Eelgrass	"	"	"	"
	Mussel Reef	"	"	2 - 3	"
	Pelagic Estuarine	"	?	?	?
	Pelagic Coastal	"	?	?	?

Residence Time - The estimated time for the physical/chemical conditions of a habitat to become suitable for resettlement.

Total Habitat Recovery Time - The estimated time for recovery of both the physical/chemical and the biological components of a habitat. For a partial-kill event, biological recovery is estimated to proceed roughly simultaneously with physical/chemical recovery.

High population mortality is associated with spills that are unweathered, not only because of toxic effects, but also because it can be assumed that nearly all of the oil spilled will strand on the shore when the time to shore is small. If high energy beaches or rocky shores are exposed to an unweathered spill, total habitat recovery time is estimated at 3-5 years. The total recovery time of protected sand bottom, protected mud bottom, salt marsh, eelgrass, and mussel reef habitats is estimated at 3-10 years.

Population mortality associated with the stranding of a weathered spill is estimated at 10-50%. Patches of oil, rather than large continuous slicks would reach shore habitats. Estimated total habitat recovery times are the same as those mentioned for an unweathered spill.

Spills at sea for more than 20 days are considered very weathered. Such spills would cause negligible population mortality. The extent of impacts within a habitat would vary because of uneven tarball distribution. High energy beaches and rocky shores would be completely recovered in 2-3 years; other habitats would take longer for recovery--3-10 years.

No attempt has been made to estimate the extent to which oil is incorporated into organisms causing flesh-tainting and other effects. Also, oil spill impacts on the pelagic coastal and pelagic estuarine habitats are not estimated as explained in section 5.7.

7.3 Conclusions

Within the accuracy of present predictive capability, it is not possible to predict sharp differences in the effects of oil spill events due to differences in the impacted habitats. A slightly faster recovery can be predicted for high energy beaches and rocky shores along the open coast than for the protected sand bottom, protected mud bottom, salt marsh, eelgrass, and mussel reefs habitats found in the bay areas. This is due primarily to differences in oil residence time. Also, differences in recovery from weathered vs. unweathered oil cannot be predicted at present; very weathered oil shows slightly shorter residence, and hence recovery time. Estimates of effects on the pelagic habitats can only be made in a qualitative fashion; no quantitative estimates of recovery time are possible.

A major hindrance to prediction of spill effects is the absolute ignorance of the amount of oil which will enter a bay and its trajectory within the bay. A concurrent problem is the present inability to analyze accurately impact and recovery from weathered oil. Nevertheless, the habitats with the longest residence and recovery times occur mainly in the bays. Thus, should a spill occur, actions to prevent oil from entering the bays should be the highest priority.

Without better data on population and ecosystem dynamics, the biological effects of oil spills on special features cannot be estimated, beyond the results given in sections 4 and 5. The significance of oil spill impacts on these features depends on the biological effects of the oil and on the features' value to man. All that can be said at present is that most of the special features are found in protected waters. This reinforces the point made above. Should a spill occur, so as to endanger the Nassau-Suffolk coastal zone, efforts should be made to protect bay habitats first; protection of high energy beach areas should be given second priority.

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