International Council
for the Exploration of the Sea
1989 Statutory Meeting
The Hague Netherlands

Shellfish Cttee.
C.M. 1989/K:27
Ref: Fish Capture Cttee.
Biol. Ocean. Cttee.

ENVIRONMENTAL EFFECTS OF OFFSHORE DREDGE FISHERIES FOR BIVALVES

by

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ABSTRACT

During 1986 and 1987 we conducted submersible observations and associated experiments studying offshore dredge fisheries for scallops and clams in the Mid-Atlantic region off the northeast USA. Objectives of the project were to: (1) evaluate the effects of commercial fishing operations on incidental mortality (gear-induced damage) of sea scallops (*Placopecten magellanicus*), ocean quahogs (*Arctica islandica*) and surf clams (*Spisula solidissima*); (2) assess the acute mortality rates of these species when dredged by commercial vessels and subsequently discarded as undersized; and (3) observe the general environmental effects of the offshore dredge fisheries for these shellfish. We conclude that, in the Mid-Atlantic region, harvest efficiency of commercial dredges is generally high, there is variable damage among species encountered by the dredges but not retained, and there are variable survival rates of small clams and scallops returned to the sea bed as undersized. Environmental effects of the dredges are likely sediment-type dependent.

RESUMÉ

Pendant 1986 at 1987 nous avons dérigé des observations submersible et expériences unis pour étudié les pêches au large de peignes et de palourdes dans la region Mis-Atlantique au large des Etats Unis nord-est. Les objectifs du projet étaient: (1) l'évaluation des effets d'operations de pêche commerciale sur la mortalite fortuite par la pêche (occasionné par dommage d'appareil) de peigne de mer (*Placopecten magellanicus*), quahog de mer (*Arctica islandica*), et de palourde de ressac (*Spisula solidissima*); (2) évalué les taux aigu de mortalité des trois espèces dragué par narvires commerciaux et par la suite écarté pour raison de taille insuffisante; et (3) observé les effets environnementals généraux des pêches au large par drague pour ces espèces. Nous avons déterminé que dans la région Mis-Atlantique, l'efficacité de recolte de drague commerciale est en général haut; il y a dommage variables parmi espèces rencontré par les dragues mais pas retenus; quil y a des taux variables de survivance de petites palourdes et peignes retournes au fond pout raison de taille insuffisante. Effets environnementaux des dragues sont probablement dépendent sur le type de sediment.

INTRODUCTION

Continental shelf waters off the northeast United States (Figure 1) support lucrative fisheries for three species of bivalve mollusks: the surf clam, *Spisula solidissima*, ocean quahog, *Arctica islandica*, and the sea scallop, *Placopecten magellanicus*. Fisheries for the two offshore clam species (surf clam and ocean quahog) were initiated primarily in response to declining production and increased contamination of nearshore (estuarine) clam resources, particularly since about 1930. Today, surf clams and ocean quahogs are the mainstay of the processed clam industry in the United States, supplying the raw material for such products as clam chowder, fried clams, dips, and juices (Murawski and Serchuk 1989). Commercial fishing for sea scallops originated in the mid-1880's (Serchuk et al. 1979) and is now the most valuable molluscan fishery in North America. In 1987, ex-vessel revenues from USA sea scallop landings totaled 125 million dollars (Serchuk and Wigley 1988).

All three species are fished with relatively large vessels (20-40 meters in length), towing heavy dredging equipment. The clam fisheries employ "hydraulic" dredges that utilize water pumped from the surface through a 20 cm diameter hose to a manifold on the front of the dredge (Meyer et al. 1981; Smolowitz and Nulk 1982). Water directed downward through narrow diameter cutting nozzles breaks up the coarse sand bottom and and transports clams to the after-portion of the dredge where they are retained (Figure 2). Unlike the two clam species, sea scallops are epibenthic animals generally found on firm sand, gravel, rock or mud bottoms, often in shallow depressions [formed by the jetting action created by rapid opening and closing of the animal's valves] (Bourne 1964). Sea scallop dredges tend to skim the bottom rather than cut into it (Smolowitz and Serchuk 1988). Because sea scallops are active swimmers and can move rapidly over short distances (1-2 meters), scallop dredges are towed at substantially greater speeds (about 4 knots) than clam dredges (1 knot).

Important questions exist regarding the potential for environmental damage caused by dredging equipment and procedures used to harvest bivalve resources (Glude and Landers 1953; Medcof 1961; Medcof and MacPhail 1967; Caddy 1968; 1973; Medcof and Caddy 1971; Peterson et al. 1983, 1987; Adkins et al. 1983; Meyer et al. 1981, 1987; Aschan 1988; Smolowitz and Serchuk 1988). The fate of small animals [sub-legals] culled from the catch at sea to comply with minimum size requirements is critical to determining the conservation and economic value of fishery regulations based on minimum or average landing sizes. As well, animals impaired by physical contact with the dredge gear during fishing but not captured, may constitute an important source of fishery-induced mortality not quantifiable from either on-deck catches or dockside landings. There is also concern, particularly in areas of intense dredging activity, that dredging operations may significantly alter physical habitat (sediment integrity), water chemistry (by creating local-scale hypoxia), and the structure and dynamics of the benthic community itself. Finally, the efficiency and selectivity of dredges used in the fishery (Smolowitz and Serchuk 1987, 1988) and in scientific resource monitoring programs (Serchuk and Smolowitz 1980; Smolowitz et al. 1985; Serchuk and Wigley 1987), are important in properly analyzing and evaluating population conditions and fishery management options.

These concerns led us to initiate in summer 1986 an *in situ* study assessing the environmental effects of offshore shellfish dredging in the Mid-Atlantic Bight region of the United States. The two-year project utilized research submersibles (the JOHNSON SEA LINK II, owned by the Harbor Branch Oceanographic Institute of Ft. Pearce, Florida, and the DELTA, operated by MARFAB Corporation of Torrance, California) to document and evaluate the operation and subsequent effects of offshore dredging activities. A total of nine research and fishing vessels participated in the project, with ocean dive sites located from off Delaware Bay to the Long Island coast (Figure 1). Dive time and logistical support was provided by the National Undersea Research Program (NURP) of the USA National Oceanic and Atmospheric Administration (NOAA), and coordinated through the NURP facility at the University of Connecticut at Avery Point.

RATIONALE OF STUDY

Shellfish resources on the northeast continental shelf of the United States are managed under provisions of the federal Magnuson Fishery Conservation and Management Act of 1976 (i.e., the legislation implementing USA 200-mile extended fisheries jurisdiction). Nearly all USA surf clam, ocean quahog, and sea scallop yields are derived from waters under federal management authority [though in a few areas, these resources occur within the 3-mile wide territorial sea governed by individual coastal states]. Management measures established by Fishery Management Plans (FMPs) differ among the three shellfish species but minimum landing size restrictions have been enacted in both the surf clam and sea scallop fisheries. In the surf clam and ocean quahog fisheries, catch quotas are also used to directly control exploitation rates.

Minimum landing size controls for surf clams and sea scallops were instituted to enhance/optimize biological and economic yield per recruit, reduce discarding, increase spawning potential, and promote a more balanced age structure within these resources (Smolowitz and Serchuk 1987; Murawski and Serchuk 1989). Since surf clams are landed in the shell, size limits were established based solely on shell length. For sea scallops, however, both shell height and meat size standards were enacted since most [but not all] commercially-caught scallops are shucked (eviscerated) at sea and only the cylindrically shaped adductor muscle (the 'meat') retained and landed. During shucking, the shell (and viscera) is cast overboard and thereby unavailable for enforcement monitoring. Landing size restrictions for shucked scallops are thus based on a maximum 'meat count' (i.e., the number of meats per pound of landed product). High meat counts reflect harvesting of small scallops while low meat counts reflect catches of larger-sized animals. Current regulations require that shucked meats not average more than 30 per pound. The present meat count measure *does not* preclude the landing of individual meats too small by themselves to meet the management standard so long as the average count of all meats from a fishing trip conforms to the standard. To comply with "average" count requirements, fishermen have developed elaborate strategies for 'mixing' or 'blending' small and large meats. This has enabled harvesters to continue landing large quantities of small scallops and still attain the average meat count standard (Serchuk 1983; Smolowitz et al. 1989). When the abundance of large scallops is so low that attaining the legal standard via mixing becomes problematical, fishermen begin to: (1) discard catches of small scallops; (2) seek out fishing areas containing relatively large-sized animals; and/or (3) urge managers to raise the meat count standard to allow smaller-sized meats to be landed.

Submersible-based research was considered indispensable in addressing several significant issues associated with shellfish management strategies. Firstly, fishing grounds commonly contain a mixture of different sized individuals, with some animals above and some below the minimum size limit or target meat count. The fate of small shellfish brought to the surface and subsequently culled and returned to the sea bed may be a critical element influencing the net productivity from a fixed number of animals. If handling and culling practices induce high mortality, then the conservation and economic rationale for regulations that encourage discarding of small animals is open to question. A second major issue is the extent of damage inflicted upon small animals not brought to the surface, but encountered in the dredge path. Shellfish dredges are heavy and often towed rapidly when fished. It has long been speculated that many animals not captured by the gear are damaged and/or killed on the bottom during dredging (Smolowitz 1983; Smolowitz and Serchuk 1988). If, in fact, dredge-induced, non-catch mortality is high, significant changes in harvesting technology and gear design may be required to attain maximum resource utilization. A third issue involves gear efficiency itself. If the harvesting process is inefficient (either in terms of capture/retention performance or species/size selectivity), then shellfish beds may be subjected to both dredge-induced and culling mortalities many times over. Thus, even if the efficiency of a single dredge tow is low, the cumulative effects of multiple dredge passes may be substantial and induce a significant loss in potential yield. Harvest efficiency is also a critical parameter in determining the requisite size and profitability of a fishing fleet to harvest the resource at optimum levels.

Similarly, dredge efficiency is an important factor in interpreting the results of research vessel surveys. Synoptic resource surveys for the three shellfish species have been conducted annually (sea scallops) or biannually (surf clams and ocean quahogs) for more than two decades with NOAA research vessels using modified commercial-type dredges as sampling equipment (Serchuk and Wigley 1987, 1988; Murawski and Serchuk 1989).

SEA SCALLOP STUDIES

Submersible diving and related field experiments proved particularly useful in assessing sea scallop dredge efficiency, gear-induced mortality, and culling mortality. To evaluate efficiency and gear damage, we had commercial vessels fish a shortened dredge track (0.3-0.6 n. mi), and carefully counted and measured the catch brought on deck. Just prior to the dredges landing on bottom at the beginning of a tow, an acoustic beacon was cast from the stern of the fishing vessel to mark the approximate starting point of the experimental dredge path. The beacon was needed to locate the dredge path afterwards with the submersible since water quality became murky for a short time after the tow. Equally, since the field work was performed in commercial scalloping areas, the transponder facilitated identification of the experimental track from all other dredge paths appearing on the bottom. A similar beacon was dropped at the end of the dredge tow to mark the approximate end point. We did not actually view the dredge as it fished on the bottom because of the danger of snagging the submersible with the fishing vessel's steel towing cables. Pre- and post-dredging transect surveys were conducted with the submersible to evaluate scallop densities in and around the location of the dredge path. These surveys employed high resolution video, and 35mm interval-timed cameras as well as visual counts and observations.

One of the most important results of the submersible dives was the dearth of broken or mutilated scallops observed in the vicinity of the path after the dredge had passed (Figures 4 and 5). Our observations suggest that dredge-induced damage and mortality of uncaught scallops is low (< 5%). Submersible observations of dredge tracks on scallop beds in the Gulf of St. Lawrence, Canada (Caddy 1973) indicated a much higher incidental dredge mortality rate (i.e., at least 13-17%), with dredge-induced damage greater on rocky ground than on sand. The Mid-Atlantic Bight scallop grounds have relatively smooth bottom [sand or mud] generally devoid of rocks and cobbles, whereas the substrate in the Gulf of St. Lawrence study area was sand overlaid with glacial gravel embedded with occasional boulders of up to 60 cm in diameter. It is probable that when dredges are fished in rocky areas, scallops are broken by the crushing action of the dredge passing over the animals (scallops in these habitats are literally "between a rock and a hard place") and by rocks dislodged from the dredge path or by rocks caught coincidentally in the dredge. Since heavier and sturdier dredges are used in hard bottom areas, dredge weight alone might account for some of the differences in gear-induced mortality of scallops between hard and soft bottom areas.

There are two potential explanations for the lack of significant numbers of broken scallops remaining in or near dredge paths in the Mid-Atlantic area: (1) dredge capture efficiency [ratio of scallops entering the gear to scallops in the dredge path: Caddy 1971] is high, resulting in all scallops encountered in the path being brought to the surface, or (2) scallops passing through the dredge are not damaged in the process. The net result of either or both explanations is a low incidental mortality. This is consistent with further submersible observations in or about the experimental tracks indicating relatively few potential fish or invertebrate predators capable of preying upon the soft parts of any scallops broken by the dredge. Unlike the ocean quahog and surf clam dredge tracks observed (Figures 6 and 7), significant feeding aggregations of predators did not occur in scallop dredge tracks. We did note, however, invertebrate predators (i.e., starfish) consuming scallop viscera cast from the fishing vessels after shucking. Finfish surveys have previously revealed significant quantities of scallop viscera in fish stomachs (e.g., Atlantic cod, *Gadus morhua*; spiny dogfish, *Squalus acanthias*) when fish sampling was conducted on scallop fishing grounds. Under natural conditions, scallops would not normally be eaten by these species. Thus, predation on scallop viscera seems to be an important path for energy transfer between trophic levels as a direct result of at-sea shucking of scallops.

In some areas, discarded scallop viscera may account for an significant fraction of energy recycling in the environment. An average scallop fishing trip from the Mid-Atlantic area currently yields about 10 thousand pounds of meats. If the landed meats average 30/pound, then the average trip catch of harvestable scallops (not counting those discarded as under-sized) would be 300 thousand individuals. The weight of the viscera of an individual scallop is approximately twice that of the edible muscle (Bourne 1964). As such, the 1988 USA scallop catch of 13 thousand metric tons of meats (Serchuk and Wigley 1988) represents 26 thousand tons of biomass recycled as potential fish and invertebrate food. At 30 meats per landed pound, the 1988 USA scallop catch was over 850 million individual scallops.

Survivorship of undersized scallops culled overboard was evaluated in several controlled experiments using tagged scallops released both at liberty and in submerged cages. Scallops caught in the experimental fishing tows were used and handled on deck as in actual fishing operations. Several batches of scallops were tagged with thin plastic tubing inserted through a small diameter hole drilled near the shell hinge. Based on a control group of scallops (handled but not tagged), the extra mortality induced by tagging operation appeared minimal when the procedure was done correctly. After tagging, scallops were cast to the bottom near submerged acoustic beacons. Subsequent submersible observation of the tagged scallops was undertaken to qualitatively assess short-term survival (1-3 days) and to evaluate the amount of dispersal immediately after release. Dispersal of tagged scallops proved problematic for quantitatively assessing survival rates since the released animals dispersed in a radius too wide to accurately determine their fate with the submersible. Thus, batches of live scallops taken in the experimental hauls were placed in wire cages which were subsequently offloaded to the bottom. After several days on the ocean floor, the cages were retrieved by the submersible and hauled aboard the mother ship where the survivorship of the caged animals was enumerated. A total of 501 scallops, ranging between 33 and 122 mm in shell height, were used in these studies. Cage survival rates averaged 91% with no differences in survival with size of scallop. These results suggest that culling mortality of scallops is probably no higher than 10%.

Submersible observation of tagged scallops revealed local scale dispersal of tens of meters within two days of release. Virtually all tagged individuals encountered within two days of release appeared to be alive, as evidenced by valve contractions (indicating respiration) and flight responses when animals were touched by the mechanical arm of the submersible. Although site and time specific (i.e., Mid-Atlantic region in summer), the tagging and cage results indicate that if undersized scallops are not damaged during dredging and/or on-deck handling, a large fraction will survive. Culling of undersized scallops from dredge catches thus appears to be a prudent conservation measure.

Scallop dredge efficiency was evaluated in two ways. By carefully counting and measuring the catch taken in the experimental tows, capture efficiency was estimated by comparing the catch retained by the dredge with the number of scallops observed in the dredge paths after dredging. There were several problems, however, with this method. Firstly, since scallops can swim out of the path of an oncoming dredge (Caddy 1968), some animals undoubtedly avoided the dredge and were not counted in the submersible transects. Secondly, because of the limited visibility near the dredge tracks, not all scallops remaining in the paths were seen or photographed. Inflated estimates of dredge efficiency would be expected under either of these conditions. Hence, capture efficiency was also evaluated by estimating scallop density before the dredge tows by submersible video and photographic surveys over fixed distance transects. By knowing the width and length of each transect, scallop density estimates (numbers per unit of area) could be derived. These estimates were then compared to those from the dredge tows themselves to estimate capture efficiency. Results of both methods indicated relatively high dredge efficiency (> 90%) for both commercial and research gear. If scallops avoided the oncoming dredges, elevated densities should have occurred outside of the dredge paths and in the strip of undredged bottom between dredge tracks (on commercial vessels, two dredges are concurrently towed from each side of the vessel). Neither condition was noted, however, further corroborating the conclusion of high dredge efficiency. These results are primarily applicable to smooth-bottom areas since dredge efficiency generally varies by bottom type (Smolowitz and Serchuk 1988). In rocky areas, much lower scallop dredge efficiencies (i.e., 1% to 20%) have been reported (Bourne 1966; Caddy 1971).

OCEAN QUAHOG - SURF CLAM STUDIES

Shellfish survival, gear efficiency, and environmental damage from hydraulic dredging were evaluated for ocean quahogs and surf clams using methods similar to those for scallops. Field efforts were primarily focused on the relatively deep-dwelling ocean quahog, since surf clam survival and dredge-induced mortality estimates were already available from studies using SCUBA techniques (Haskin and Starypan 1976; Meyer et al. 1981; Haskin and Wagner 1986; Meyer et al. 1987).

As previously noted, USA fisheries for both ocean quahogs and surf clams are regulated under quota systems requiring periodic population estimates of these species. For the ocean quahog resource, population size has been computed from 'area swept' estimates of several years of combined research vessel survey data (Murawski and Serchuk 1989), assuming complete retention of animals in the path of the survey dredge. The submersible work, however, revealed appreciable numbers of ocean quahogs and surf clams remaining in or near experimental dredge tracks after dredge passage. These observations indicate that the survey 'area swept' population estimates are too conservative.

Also taken into account in ocean quahog yield projection models is a factor accounting for dredge-induced, non-capture mortality (40% to 60%: Mid-Atlantic Fishery Management Council 1977). Submersible observations indicated that non-harvest mortality of ocean quahogs was significant and far greater, on a percentage basis, than for sea scallops. Heavily damaged quahogs were observed lying in dredge tracks, and up to five meters outside the tracks. Because of the high pressure water jets of the hydraulic dredges, these shellfish must have been "blasted" outside the dredge path. However, not all ocean quahogs encountered by the dredge and remaining on the bottom were damaged. In time-lapse dives on selected tracks, ocean quahogs were frequently observed re-burrowing after being dislodged by the dredge.

Unlike the sea scallop observations, numerous fish and invertebrate predators were seen in and near hydraulic dredge tracks consuming broken quahogs. Predominant predators were rock crabs (*Cancer irroratus*), starfish, and several species of finfish including red hake (*Urophycis chuss*), spotted hake (*Urophycis regia*), and skates (*Raja spp.*). In dives undertaken within one hour of an experimental tow, dredge track densities of crabs and starfish were clearly much higher than those in the surrounding environs (2-5 times more dense). Eight hours after dredging, predator density was more than 10 times that of the nearby vicinity indicating that predators are attracted to the tracks from an extensive area. Such predation, however, is probably beneficial in reducing the likelihood of small scale hypoxia in dredged areas. Clam grounds subjected to repeated intensive dredging often accumulate large amounts of clam tissue on the ocean floor. This biomass eventually decays resulting in the "sour bottom" noted by clam fishermen. The excess decaying clam biomass creates significant biological oxygen demand, and in extreme cases, localized hypoxia and mortality of otherwise healthy clams due to oxygen depletion. Predator consumption of clam biomass remaining in the dredge path thereby reduces the potential for these effects to occur.

Survival of discarded ocean quahogs and surf clams was evaluated differently than for scallops. Since these two species are essentially infaunal moving only in a vertical dimension (reburrowing), culling mortality was assessed by marking batches of dredged quahogs and clams and returning the animals to the sea bottom. The number of total clams marked that remained unburrowed was used as a measure of mortality. Animals were batch marked by spray-painting their shells; batches were then returned to the bottom using the submersible. It would have perhaps been more realistic to simulate discarding by broadcasting marked animals overboard but locating the scattered clams underwater would have been very time-consuming and much more difficult for the submersible.

Survival of the two species after discarding was very different. Over 90% of the marked ocean quahogs had reburrowed within five days at liberty. All of the quahogs unearthed with the submersible's hydraulic suction device were alive with shells tightly closed. By contrast, over 50% of the marked surf clams had died at the planting sites surveyed by the submersible. These results are consistent with data obtained by Haskin and Starypan (1976) and Haskin and Wagner (1986). The differences in survivorship between the two species is probably related to differences in their anatomy. The valves of the surf clam do not completely seal when the siphons are retracted and the shell closed. As a result, during hydraulic dredging, the high pressure water jets of the dredge force sand [and other material] though the shell gap inflicting damage to the clam. The ocean quahog, by comparison, can completely seal its valves and avoid being "sand blasted". The submersible results indicate that discarding of surf clams generates a significant loss of potential yield since culling mortality is so high. This is not true for ocean quahogs which do not exhibit significant mortality when discarded.

Hydraulic dredging appears to generate greater short-term disruption of the benthic community and underlying sediments than scallop dredging. Sediment penetration depth by the hydraulic dredge is controlled by the pitch of the skimming "blade" and the water pressure at the dredge manifold. Bottom trenches produced by hydraulic dredging will persist to varying degrees based on sediment type. In coarse gravel, the sides of the trench collapse almost immediately; the bottom shows little sign of dredge passage apart from a short-term increase in water turbidity and, of course, damaged clams. In hard-packed, finer-grained sediments, dredge tracks were observed with the submersible several days after dredging, with the sharply sloped sides of the dredge track only beginning to slump. Communities of non-harvested animals such as sand dollars, crustaceans and worms were significantly disrupted by the action of the hydraulic dredge. Colonies of sand dollars, however, appeared to re-form almost immediately, and seemed to suffer little appreciable mortality. Equally, not all predators observed foraging in the hydraulic dredge paths were eating remains of damaged shellfish. The considerable numbers of minute starfish and benthic feeding fishes seen in the dredge tracks suggest that benthic microfauna 'tilled up' by the action of the dredge were a major prey source. The long-term effects of such exposure of infaunal organisms to predation has not been evaluated, but it is likely that short-term reductions in infaunal biomass occur after dredging.

SUMMARY

Field experiments during summer 1986 and 1987 using manned submersibles were successful in investigating critical biological and technological issues influencing management strategies for sea scallop, ocean quahog, and surf clam resources. Although many questions were resolved through this research, others remain unresolved including: (1) the differential effects of bottom type and season on dredge efficiency and culling mortality; and (2) the impacts of alternative harvesting technologies. Nonetheless, the information obtained from the present study is already being used in developing more realistic population dynamics and fishery models for exploited shellfish resources. As a consequence, more accurate and precise projections of the effects of exploitation on shellfish populations should be possible.

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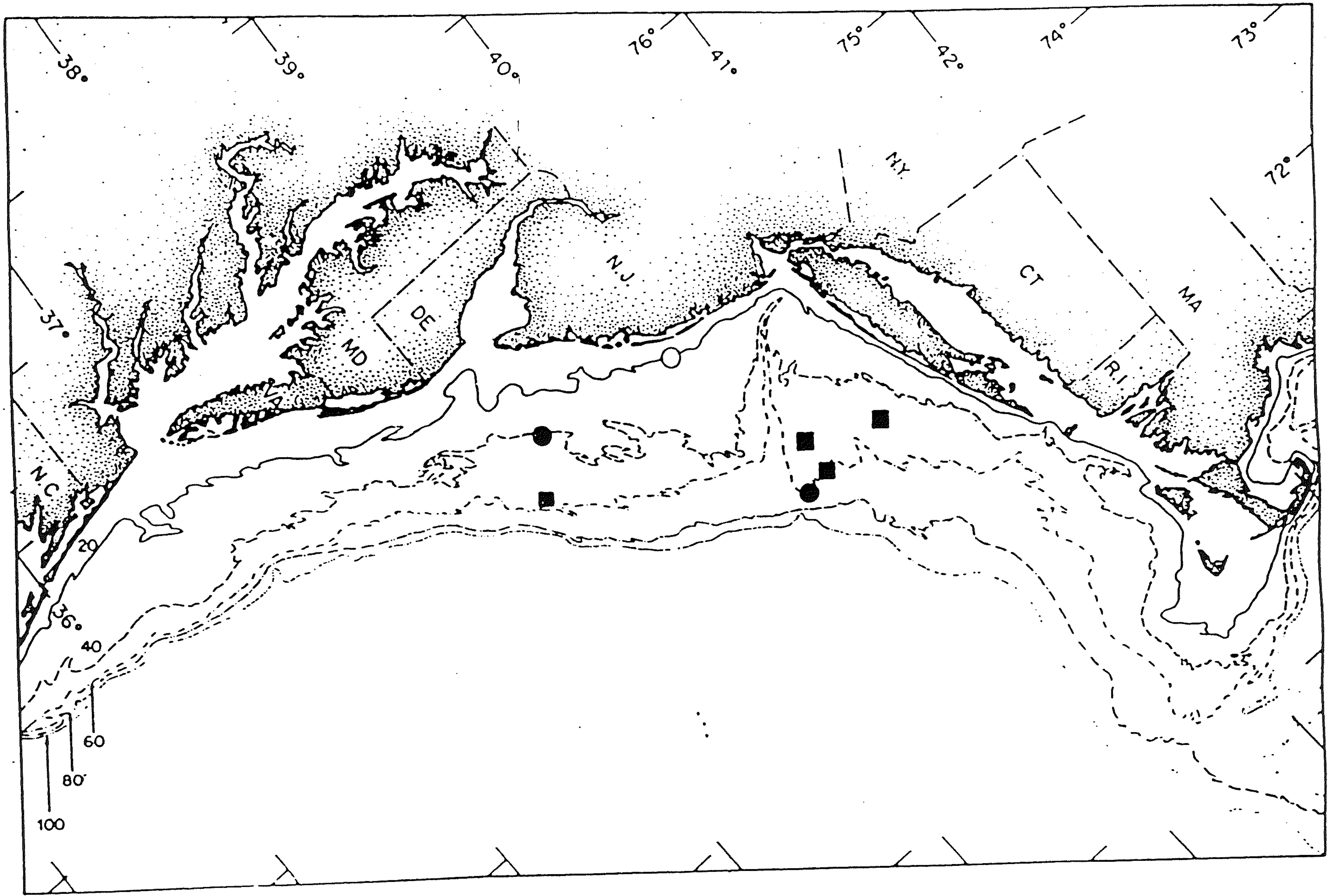


Figure 1. Locations of submersible observation sites of offshore shellfish dredging operations off the Northeast USA, 1986 and 1987. Locations where sea scallop diving operations were conducted are indicated by squares; ocean quahog sites indicated by closed circles; surf clam area indicated by an open circle.

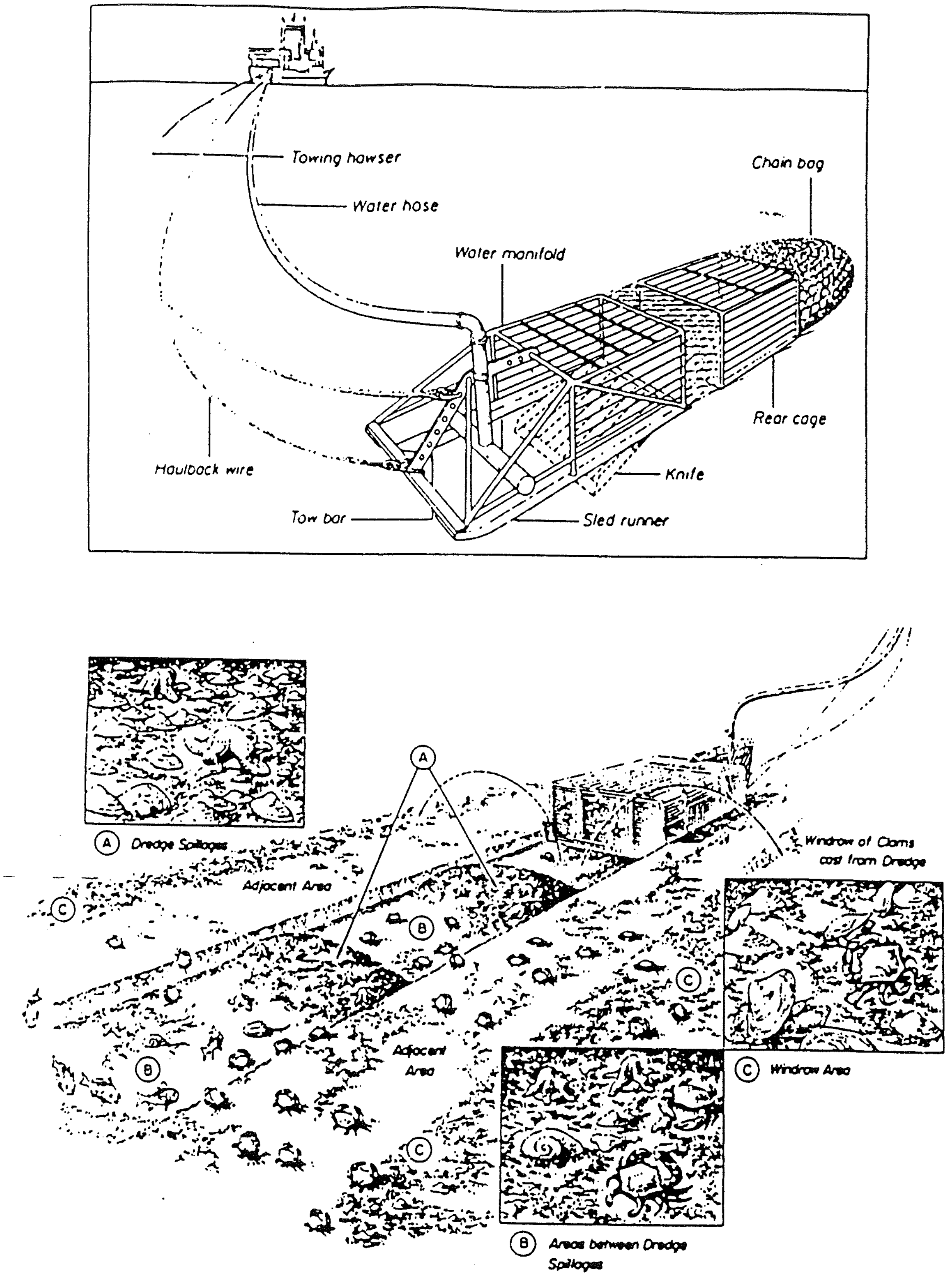


Figure 2. Schematic of a typical surface-supplied hydraulic dredge used for surf clam and ocean quahog fisheries. Typical dredge width is 3 meters, weight is >1,000 kilograms. Bottom figure is an example of a dredge track observed in nearshore waters by Meyer et al. (1981).

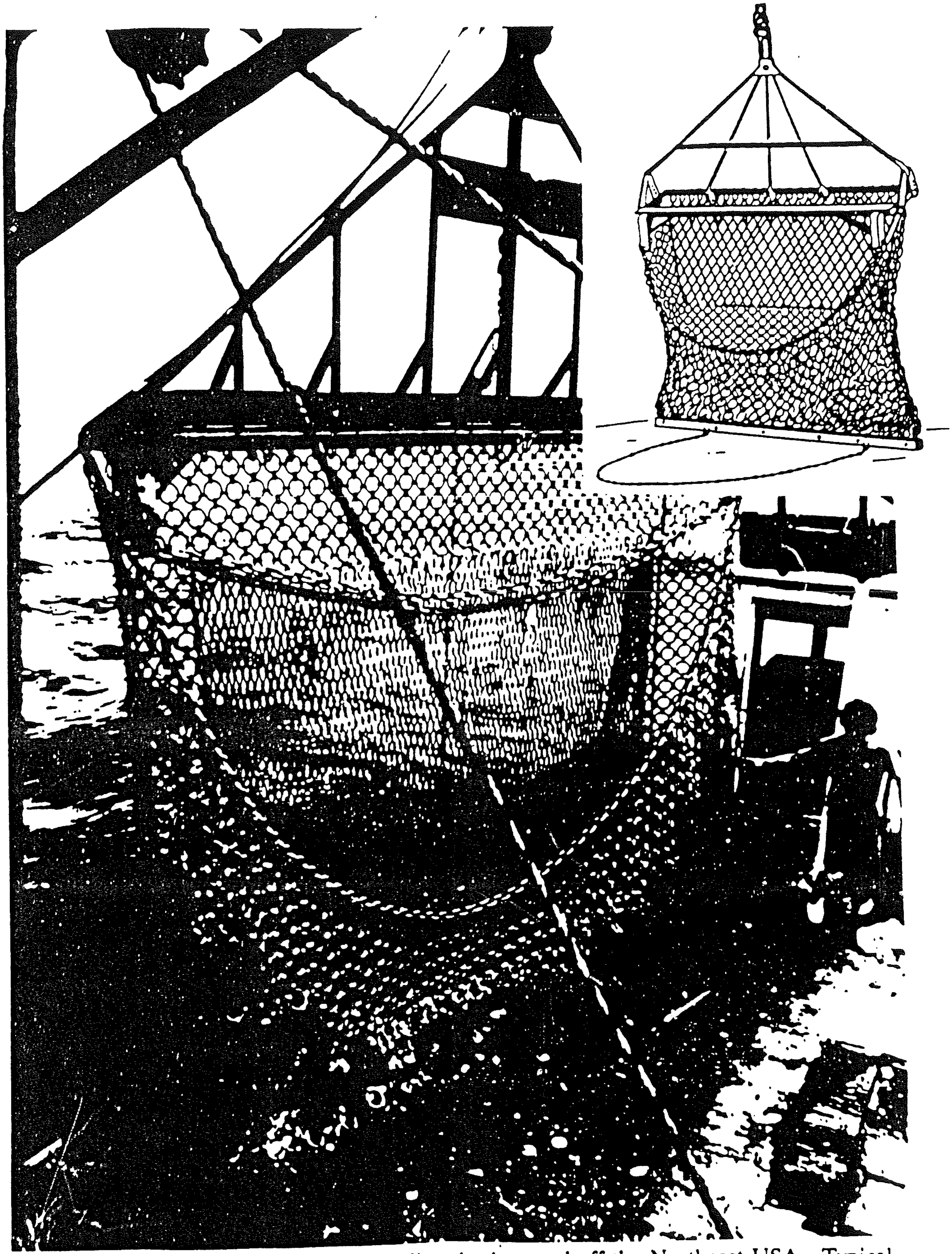
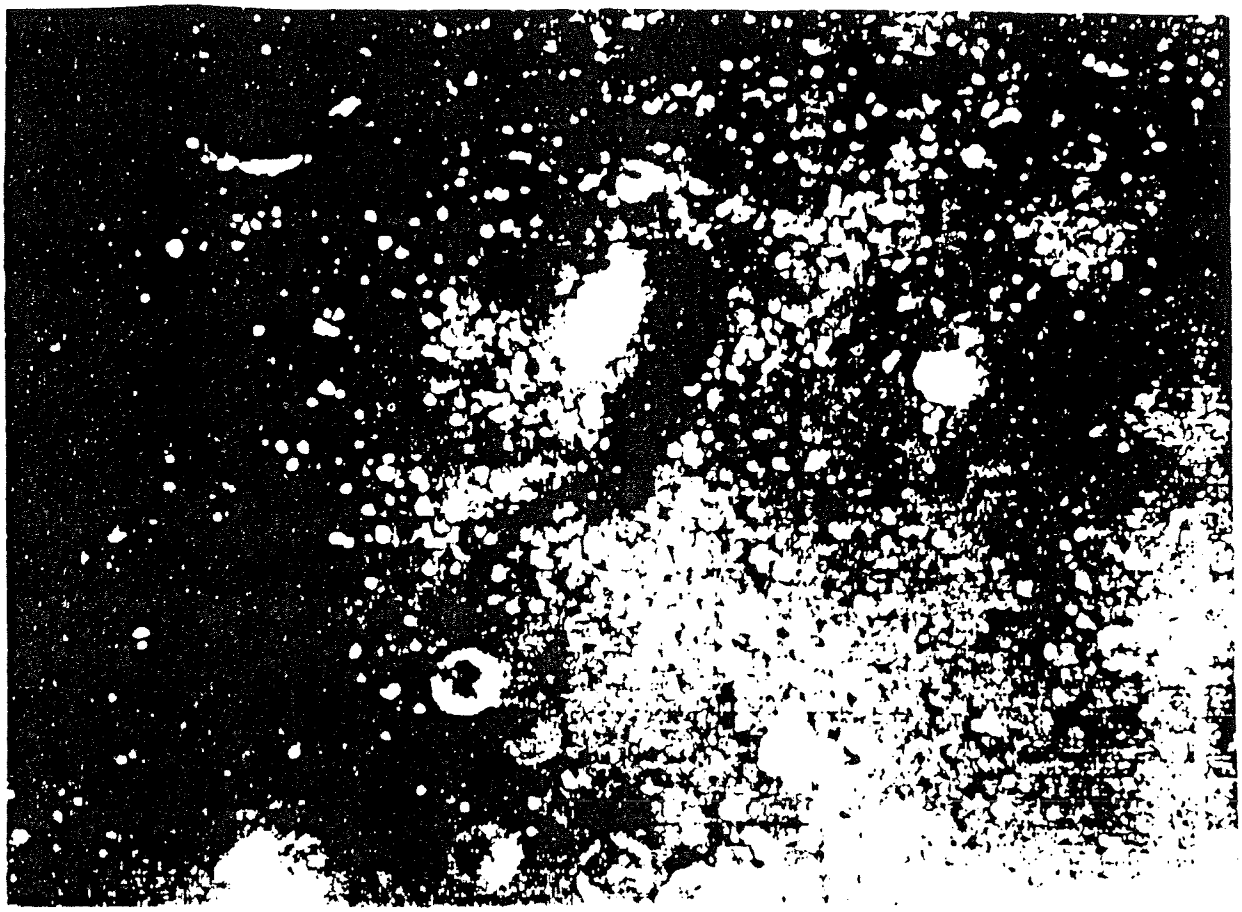


Figure 3. Configuration of a sea scallop dredge used off the Northeast USA. Typical dredge width is 6 meters, weight is >1000 kilograms.

Figure 4. Sea scallop fishing grounds off Long Island, NY, before (above) and after (below) dredging. Prior to the dredge passing the scene shows two scallops (about 9 cm in shell diameter) lying in shallow (2 cm) depressions formed by jetting action produced by rapid opening and closing of the shells. The pre-dredging scene also shows a colony of seven sand dollars (*Echinarachinus parma*) at the lower margin of the photograph. When not disturbed, the species is usually encountered in these highly contagious aggregations. The sediments consist of fine-grained sand and silt, with some shell "hash" (1-2 cm pieces of broken shell). In the post-dredging scene much more shell "hash" is apparent, as it has been turned up by the dredge and is among the first constituents to precipitate to the bottom. Recent dredge paths can be distinguished by a white strip contrasting with darker surrounding areas (as in the above photograph). After dredging, the scallops have been selected by the dredge, the depressions filled with sediment, and the aggregations of sand dollars disrupted. Subsequent observation of sand dollar movements indicate that a large fraction of sand dollars survive the dredging process.



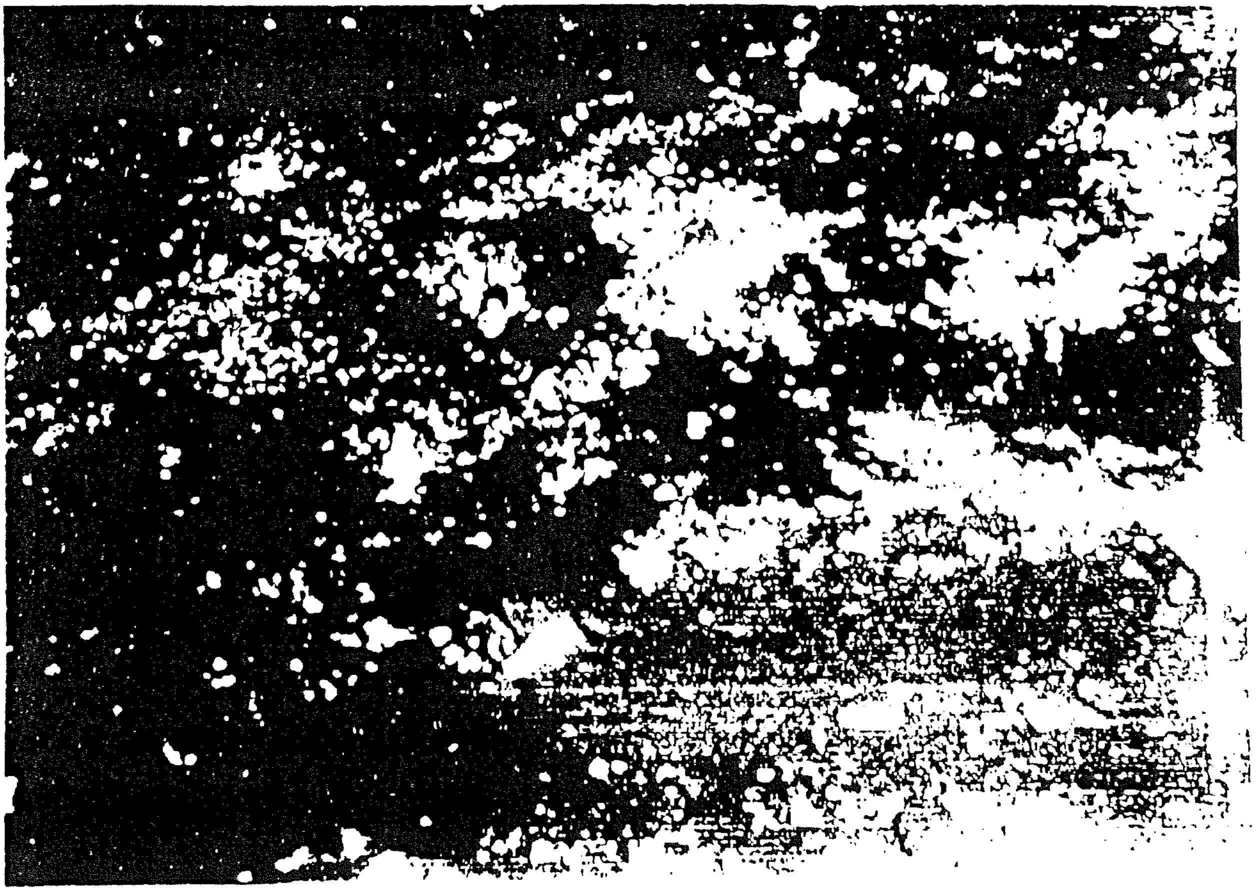
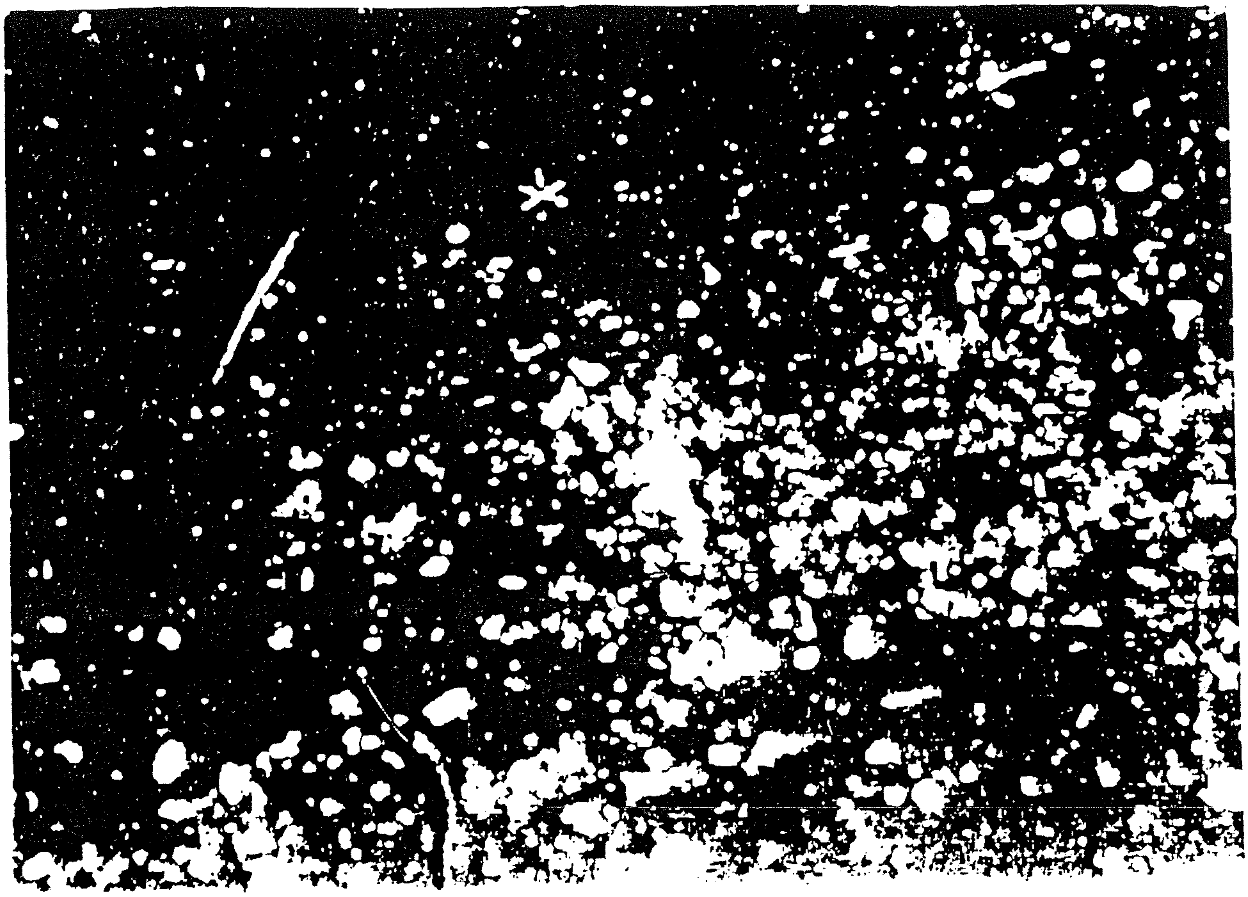


Figure 5. Sediment disruption caused by sea scallop dredging off Long Island, NY (above). The bottom consists of fine sand and silt with medium sized gravel (1-2 cm), and shell hash. The diagonal mound (5-8 cm high) was created by a sea scallop dredge. This was one of the most apparent scallop dredge marks encountered in the submersible operations. Generally, these marks are not as pronounced, perhaps due to the construction of the bottom and sides of the dredge from 3 inch steel rings, that tends to grade the dredge path after the front bar of the dredge has passed. A little skate, ***Raja erinacea***, forages (presumably) in the dredge track, while a fawn cusk-eel, ***Lepophidium cervinum***, is visible in the foreground. Few potential predators of broken sea scallops were observed during submersible dives on scallop dredge tracks, reflecting the lack of damaged scallops remaining in or near the paths. The opposite was true for observations associated with hydraulic surf clam and ocean quahog dredges. The bottom photograph is of a 5-6 cm (shell diameter) sea scallop "jetting" away from the submersible by rapidly opening and closing the valves. This response was relatively common for smaller scallops, but was observed rarely for larger ones. It is possible that smaller scallops may avoid capture by the dredge, but such avoidance has not been observed directly, nor have large quantities of small scallops been observed along-side recent dredge tracks.



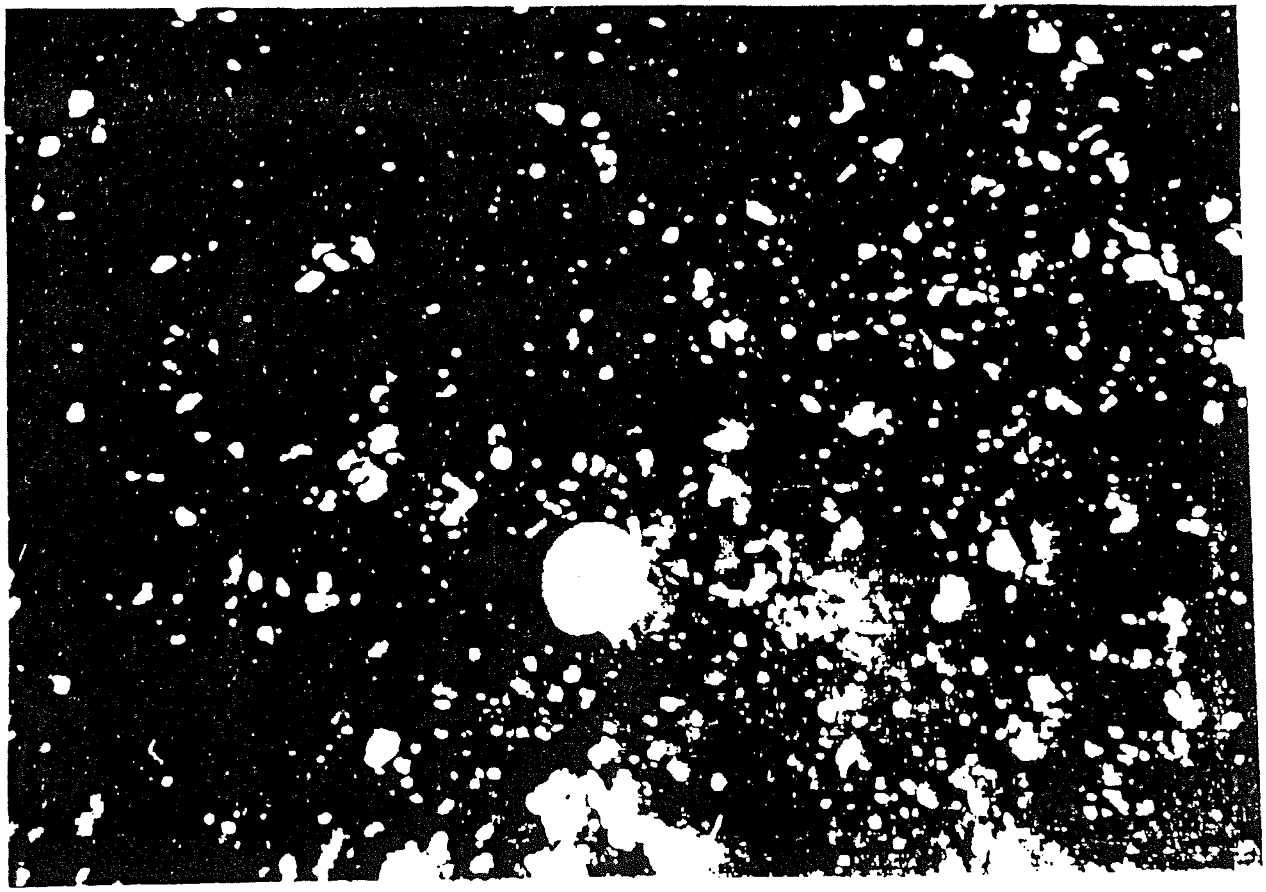
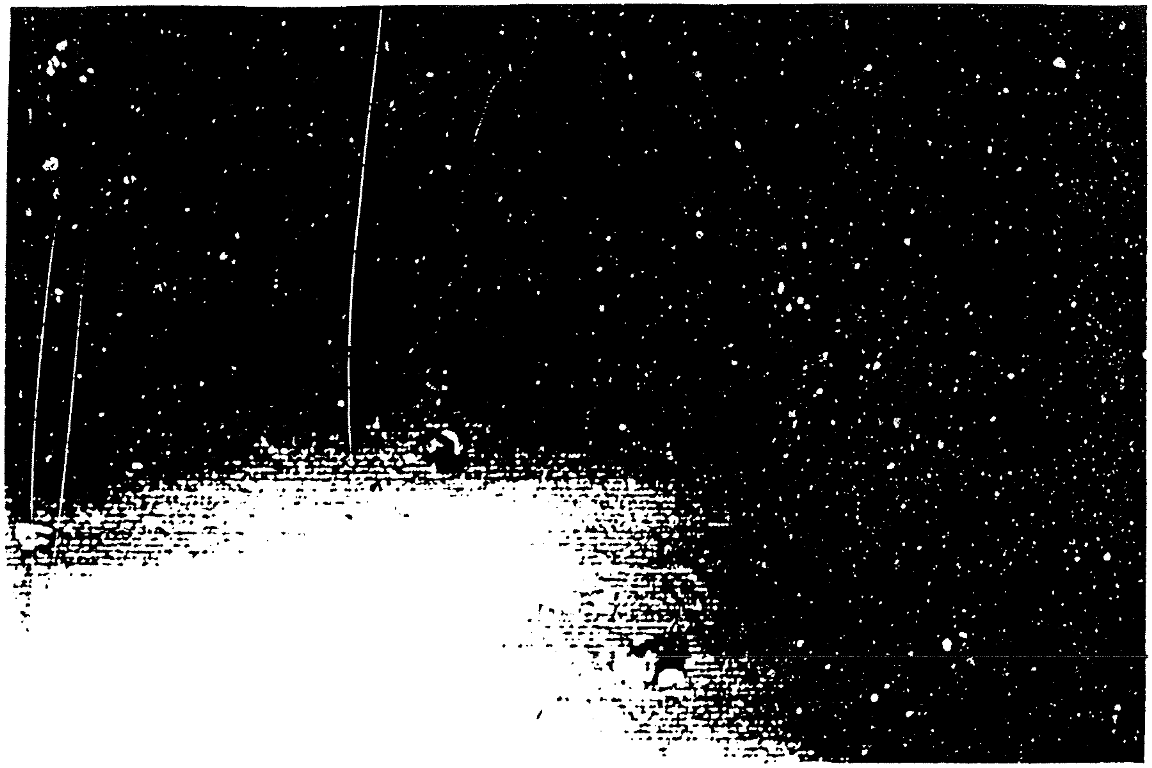


Figure 6. Tracks created by an hydraulic dredge fishing for ocean quahogs in 40 meters water depth off Delaware Bay. The foreground of both photographs is inside the dredge path. The path is about 15 cm deep, 2.5 m wide, and has maintained relatively steep sides 8 hours after the dredge tow, due to the fine-grained, hard-packed bottom sediments. In the above photograph one ocean quahog encountered in the dredge path partially dug itself back into the sediment, while an obviously heavily damaged one lies just outside the track. In the bottom photograph one quahog has almost completely reburrowed (right foreground), while one that has been sliced in half, at the edge of the path appears to be attracting a rock crab, ***Cancer irroratus***, to eat the soft body parts exposed in the broken clams. Under normal circumstances the crab would not be capable of preying upon quahogs greater than about 2 cm shell length. Several small starfish are also visible in the lower photograph, perhaps attracted by small prey items exposed by the dredging process.



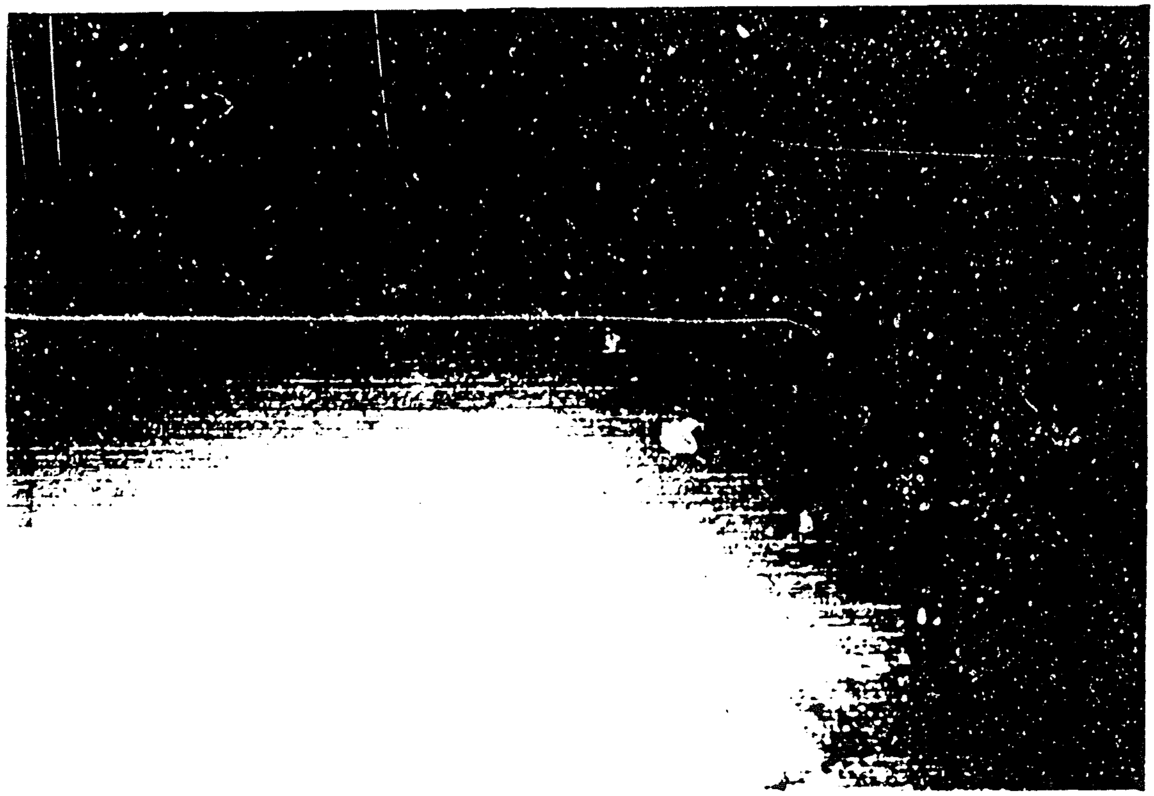


Figure 7. Path created by an hydraulic ocean quahog dredge 8 hours after the tow (above). The edge of the path extends from the lower left, diagonally to the upper middle of the photograph. Within the path two rock crabs and numerous small and large starfish forage on animals uncovered by the hydraulic action of the dredges. Based on surveys within and outside these paths, predator densities were significantly higher within the tracks than in the surrounding areas. The effect was more pronounced 8 hours after the tow than one hour after. Other predators encountered included skates, squid, and spotted and red hakes among other fishes. In the lower photograph, sand dollars, ocean quahogs, and sediments have been "blasted" beyond the dredge track by the high pressure water jets of the hydraulic dredge. Many of the sand dollars have been stuck on edge in the sediments, The quahog at the right center is heavily damaged and will be subject to predation by crabs, fish and/or starfish. A small starfish attacks a quahog at the right of the photograph. Subsequent observation of this site revealed that many of the sand dollars survived the dredging process and reformed discrete aggregations.