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# The Impacts of Mobile Fishing Gear on Low Topography Benthic Habitats in the Gulf of Maine (Northwest Atlantic): A Preliminary Assessment

by

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## INTRODUCTION

While the scientific community is sure that fishing gear alters the bottom, controversy has continued from the 14th century to this day regarding the implications of various impacts (Graham 1955, deGroot 1984, Messieh et al. 1991, ICES 1992, Jones 1992, National Research Council 1994, Dayton et al. 1995). The overall impacts of mobile fishing gear are unknown despite research efforts in the U.S. spanning nearly 80 years (beginning with Alexander et al. 1914). Understanding the extent and role of mobile gear impacts is particularly important because of large increases in fishing effort over the last decade (NOAA 1993, Appendix 1). Studies of the impacts of mobile gear can be divided into two major categories: (1) those which focus on target species or on the target species of another fishery; and (2) those which focus on habitat, a portion of the benthic community, or the ecosystem.

Studies concerning the effects of fishing on one or two target species are the most common and usually deal with valuable fisheries such as lobster (*Homarus americanus*) or sea scallops (*Placopecten magellanicus*). Trawl impact studies on lobster populations found that damage and mortality to lobsters during trawling varied seasonally with molt state and air temperature (an important factor during handling on deck, especially during summer and winter) (Ganz 1980, Smith and Howell 1987). Caddy (1973) and Shepard and Auster (1991) found dredge-associated mortality of non-landed sea scallops increased with increased bottom hardness. Mortality was lowest on sand bottoms and greatest on pebble-cobble bottoms. Other studies pertaining to the effects of scallop dragging on lobsters (Jamieson and Campbell 1985), and the effects of raking for Irish moss on lobsters and scallops (Scarratt 1973, Pringle and Jones 1980) demonstrated the gear conflict issues that persist in geographically overlapping fisheries. While all of these studies provide estimates of target species mortality during harvest for particular fishing gear types and on particular bottom types, no connection was made between the effects of fishing activities and the continued ability of the habitat to support the target or related species.

Studies which examined the effects of fishing gear at the habitat and community level are less common. Early studies often drew conclusions based on little factual evidence. The effects of trawling and dredging on the seafloor have been of concern in the United States since the introduction and expansion of the use of this gear in the late 19th and early 20th century. Alexander et al. (1914) reported that the effect of trawling on the bottom was negligible, but they presented little evidence to support this conclusion. In fact, they boldly stated that "otter trawls do not seriously disturb the bottom over which they are fished nor materially denude it of organisms which directly or indirectly serve as food for commercial fishes". This conclusion was based on data from trawl catches monitored by fishery scientists who lacked any data on the impact of fishing gear on the seafloor habitat and community. Observations of shifts in species composition and abundance were attributed by them to harvesting by the fishery with no connection made to changes of the community or ecosystem. This conclusion is not surprising given the state of knowledge at the time regarding community and ecosystem ecology (Auster 1988). More recent studies found fishing changed associations and species composition of non-harvested taxa, but the effects of these changes on the dynamics of harvested populations are not yet known (Holme 1983, Langton and Robinson 1990).

An obvious problem with many of these studies is that most have been conducted over previously-fished grounds (Margetts and Bridger 1971, Caddy 1973, Gibbs et al. 1980). It is difficult to demonstrate trawling induced habitat changes if specific habitat types have already been altered. Recognizing this problem, recent studies have begun to utilize areas that contain both trawled and reference sites (Van Dolah et al. 1987, Riemann and Hoffmann 1991) or they have sequentially surveyed an untrawled area before and after initial fishing activities (Sainsbury 1987, Peterson et al. 1987).

Herrington (1947) was the first to make a connection between habitat composition and production of exploited stocks. He suggested the removal of benthic fauna such as sponges and the overturning and burying of rocks would reduce spatial complexity of bottom habitats and affect the production of prey species utilized by target species. Peterson et al. (1987), using a manipulative field experiment, linked seagrass destruction by mechanical clam harvesting to reduced bay scallop production. The complex habitat formed by dense seagrass was directly linked to settlement density of scallops.

Tropical fish species distributions are also well linked to specific habitats. On the northwest Australian shelf, Sainsbury (1987, 1988) found that golden thread (*Saurida* spp.) and lizardfish (*Nemipterus* spp.) occurred predominately on open sand/"sparse" emergent benthos bottoms, while porgies (*Lethrinus* spp.) and snappers (*Lutjanus* spp.) occurred in areas of "dense" emergent benthos (e.g. sponges, gorgonians, alcyonarians). Their data showed the bycatch of sponges and associated corals fell during the course of the developing trawl fishery, eliminating "dense" habitat types. Concurrently, fauna associated with sand/"sparse" emergent habitats increased in the catch while the fauna associated with "dense" emergent habitats decreased. This is the first study which demonstrated a direct link between habitat change and subsequent changes in catch.

Recent levels of fishing effort on the continental shelf of the northeast U.S., by trawl and dredge gear, may have had profound impacts on the early life history in general, and survivorship in particular, of a variety of species due to alterations of small-scale habitat (=microhabitat) features. We posit that mobile fishing gear has measurable effects on microhabitat availability through a range of sedimentary habitat types from mud and sand to gravel (including cobble and boulder) bottoms. Herein we summarize studies conducted at three different locations in the Gulf of Maine (Fig. 1) which show measurable impacts of mobile fishing gear on habitat complexity and discuss the implications of fishing gear impacts on the sustainability of harvested species.

## CASE STUDIES

### Swans Island

The area off Swans Island (44° 08.0' N 68° 23.0' W; 30-40 m) consists of coarse grained material where cobble-shell and sand-shell bottoms predominate. The Swans Island Conservation Area was closed to mobile fishing gear in 1983. Comparisons of habitat complexity, measured from video transects on cobble-shell and sand-shell bottoms, were made between reference (inside) and impacted (outside) sites using a remotely operated vehicle (ROV) during July 1993. The ship was anchored for all dives and the length of anchor line was adjusted to position the ROV to conduct multiple transects without traversing areas previously surveyed. Transects were referenced to a downweight and were approximately 50 m in length. The ROV skids were kept on the bottom during all transects in order to keep the video camera referenced to the bottom and reduce changes in field-of-view caused by changes in altitude and bottom morphology. Transects were conducted with the video camera set at a fixed angle. Each video frame imaged an area of 0.35 $m^2$.

Video transects were treated as a series of non-overlapping adjacent video quadrats (sensu Auster et al. 1991). Video was recorded from a composite signal on Hi-8 format tape (NTSC standard, 60 fields $s^{-1}$). Video transects were time coded (i.e., hour, minute, second, video frame number) to identify and facilitate multiple viewing of individual video frames. Habitat types for the cobble-shell bottom were: (a) cobble-shell pavement, (b) cobble-shell with emergent epifauna, and (c) cobble-shell with sea cucumbers (*Cucumaria frondosa*). Habitat types on the sand-shell bottom included: (a) flat sand-shell, (b) sand-shell with biogenic depression, and (c) sand-shell with sea cucumbers. (Sea cucumbers are considered as a habitat feature independent of attached epifauna because they are mobile.) A cover index (CI) for each habitat type was determined using random dot techniques. The CI was used rather than percent cover as the video images were trapezoidal (due to the oblique angle of the camera) and had foreground-background bias. In order to reduce foreground-background bias, each video frame was divided into two sections to assess cover. The nearfield half of each quadrat, on the video monitor, was overlaid by 20 computer generated random dots on acetate. After the forward portion of the frame was enumerated, the farfield portion of the quadrat was "rolled" forward using the shuttle search feature of the video player. Different random dot patterns were used for each frame within a transect. The CI was expressed as a percentage of the dots (n=40) covering each habitat type within each frame. The CI was arcsine transformed and comparisons of habitat cover within and outside the conservation area were made using two sample t-tests.

Emergent epifauna (i.e., hydroids, bryzoans, sponges, serpulid worms) and sea cucumbers were the dominant habitat features on cobble-shell bottoms (Fig. 2a and b). The cover provided by emergent epifauna was significantly lower outside the conservation area (Table 1). We attribute this pattern to direct removal of epifauna by mobile fishing gear. Observations of tracks in the epifaunal cover at the border of the conservation area showed cleared swaths indicative of disturbance by both scallop dredges and trawl doors.

Habitat complexity on the sand-shell bottom consisted primarily of biogenic depressions created by mobile fauna (Fig. 2c) and sea cucumbers attached to shell and other biogenic debris. The cover provided by both types of structures was significantly lower outside the conservation area (Table 1). Reductions in the cover provided by biogenic depressions is attributed to harvest of those species which produce such structures (e.g., sea scallop, lobster, crab, white hake). It is not known if sea cucumbers were removed as bycatch or targeted for a directed fishery.

**Jeffreys Bank**

Jeffreys Bank is a large mud-draped gravel bank (43° 22.5' N, 68° 44.5' W) with large boulders resting on the gravel bed. Because of the size of some of the boulders (occasionally exceeding 2 m diameter) some parts of the bank until recently have been inaccessible to mobile fishing gear. As part of a wide-ranging study of the gravel bank fauna in the Gulf of Maine, a submersible dive was conducted near the top of Jeffreys Bank during July 1987 at 88 m depth. This location was chosen specifically to sample an area that had not experienced reductions in the fauna due to gear impacts. During the dive, large sponge communities were noted on a gravel bottom with a thin veneer of mud, and a 10-minute video transect was conducted to document the extent of this community. The rock surfaces were covered with an assortment of invertebrates, including long-legged pycnogonids, bryozoans, hydroids, anemones, sponges, crinoids, and tunicates. Also abundant were the smaller fauna including several species of crustaceans, snails, and bivalves.

This site was resurveyed five years later in August 1992. The camera was set closer to the bottom and at a different angle than in 1987 so video transects were not directly comparable. Even so, it was possible to determine that much of the thin mud veneer was missing, exposing more of the gravel base, most of the epifaunal species were not present, and the extensive sponge community was reduced to the occasional small colony attached to the large boulders. Evidence of boulders having been moved could be seen in the video images. Further analysis of the approximately two hours of videotape taken during this dive led us to surmise that the area had been disturbed by fishing gear and it is likely that trawling activity, that was occurring during our study, was responsible for the observed changes.

Percent cover of sponges was calculated for all fields of view in the video tape from 1987 where the camera was at a constant distance from the bottom, and from the same number of fields of view (starting at a randomly selected point) from the 1992 transect. Methods for this type of analysis are outlined in Auster et al. (1989). While there were several fields of view with no sponge cover in 1987, 15 fields of view had at least 10% cover, and a few had more than 25% cover (Fig. 3a and b). In 1992, no field of view had more than 7% sponge cover. Analysis of the 1987 transect ended in a region where the sponge cover was the greatest (Fig. 3a), and the camera angle was changed to cover more area, dubbed the "sponge garden". In two hours of videotape taken in 1992, sponge cover was never greater than 7%.

**Stellwagen Bank**

Recent side-scan sonar mapping of the crest and upper flanks of Stellwagen Bank (42° 11.5' N, 70° 20.0' W, 20-55 m) has shown it is not a homogeneous sand sheet, as suggested by previous generalized maps of the region (Schlee et al. 1973). It is covered by large expanses of sand, gravelly sand, shell deposits, and gravel. These sedimentary environments are created and altered by large storm waves from the Gulf of Maine to the northeast (Valentine and Schmuck 1995). Although strong storms from the northeast are the primary cause of bottom disturbance, they do not occur every year. By contrast, mobile fishing gear is deployed on the bank on a nearly daily basis. Storm sand ripples of coarse sand that measure 30-60 cm between crests and 10-20 cm in height are disturbed by scallop dredging (Fig. 4a). In addition to sand ripples, storms deposit large sheets of fine sand whose surface is sculpted into low sand waves that measure 15-35 m between crests. The troughs of these sand waves are filled with shell debris (primarily the ocean quahog *Arctica islandica*) that make up 10-20% of the bottom in these areas. The shell deposits form a complex habitat that is easily dispersed by mobile gear (Fig. 4b).

Observations on the crest of the bank in July 1993 (32-43 m) showed that epibenthic organisms which anchor in the coarse sand are easily removed by mobile fishing gear, changing the densities and associations of mobile species. *Corymorpha pendula* is a hydrozoan which attaches to the bottom during its annual benthic phase. Densities of *Corymorpha* and shrimp (primarily *Dichelopandalus leptoceros* and *Crangon septemspinosa*) were measured in 10 video quadrats (0.42 $m^2$ each) from each of three 50 m ROV transects (n=30). There was a positive association between the density of shrimp and increasing cover provided by *Corymorpha* ($r^2=0.852$, ANOVA $p<0.001$). Wide linear paths in benthic microalgal cover indicated recent passage of trawls and scallop gear through the area. In areas where microalgae were removed, aggregations of *Corymorpha* were absent. The density of shrimp was reduced from a mean of 13.3 $m^{-2}$ at the sites outside the drag path to zero (from a single 50 m transect in a scallop dredge path covering 199.1 $m^2$). Additional observations in July 1994 showed that the ascidian, *Mogula arenata*, was widely distributed over the bottom rather than the hydrozoan (Fig. 2d). Tracks from trawls were evident as the ascidians were removed in linear patterns consistent with this type of gear.

## DISCUSSION

We have shown that mobile fishing gear impacts the physical structure of benthic habitats and reduces habitat complexity. Both sedimentary structures and emergent epifauna are impacted. Mobile species, including commercially important species, have been shown to have associations with specific sedimentary and biogenic habitat features (Able et al. 1982, Grimes et al. 1986, Shepard et al. 1987, Cooper et al. 1988, Langton and Robinson 1990, Auster et al. 1991, 1994, 1995, Malatesta et al. 1992, 1994, Auster and Malatesta 1995, Felley and Vecchione 1995, Langton et al. 1995). Various taxa (primarily groundfish and crustacean species) associate with structures such as biogenic depressions, shell, burrows, sand wave crests, sponges, amphipod tubes, cerianthid anenomes, and holothurians. For example, the density of postlarval silver hake (*Merluccius bilinearis*) increased as cover provided by amphipod tubes increased (Auster et al. 1994). Similarly, redfish (*Sebastes fasciatus*) density increased in patches of cerianthid tubes (Shepard et al. 1987). Also, there are groups of species which produce habitat features such as depressions (e.g., *Raja* spp.) and those that utilize the depressions produced by others (e.g., squid, *Loligo pealii*; scup, *Stenotomus chrysops*) (Auster et al. 1991, 1995). While use of these habitat features is not obligate, the association of many taxa with various components of a complex habitat implies that there is some increase in individual fitness realized as a result.

Reductions in habitat complexity may lead to increased predation on juvenile sizes of living marine resources with subsequent negative effects on recruitment (e.g., Walters and Juanes 1993). Field studies on Georges Bank have indicated that juvenile Atlantic cod (*Gadus morhua*) are abundant on gravel habitat but are almost absent on adjacent sand bottom, presumably due to increased predation on sand (Lough et al. 1989). Laboratory studies have demonstrated that the use of various microhabitat features can play a functional role in enhancing juvenile survivorship. For example, in the presence of a predator, juvenile cod survivorship was enhanced by a shift in their substrate preference from sand or gravel-pebble to cobble (Gotceitas and Brown 1993). Individuals used the interstices of the cobble substrate to seek refuge from predation. This work illustrated that use of habitats with even subtle changes in complexity can have an effect on survivorship. Young-of-the-year Atlantic cod established territories around shelter sites in a bay off eastern Newfoundland (Tupper and Boutillier 1995). Territory size increased with size of fish, and fish in larger territories grew faster. It follows that if settlement density is sufficient to saturate available habitats, cohort strength may be determined by competition for high quality shelter sites. Individuals occupying low quality sites would be subject to more intense predation. Population responses to changes in habitat complexity have yet to be quantified in the field.

The abiotic and biotic features of habitat are dynamic at a variety of spatial and temporal scales (Langton et al. 1995). The abiotic, or physical features, of the Gulf of Maine seafloor are the product of glacial processes, tidal currents, storm currents and surge, and depositional processes (Belknap et al. 1988). Tidal currents effect the seafloor at scales of minutes to months while storm events occur at scales of days to centuries. Both processes produce erosional and depositional features depending on water depth and sediment type. Biotic, or biogenic features, are in contrast, the result of the interaction between an animal's life-history and abiotic habitat features. Recruitment of benthic species varies, for example, over wide spatial and temporal scales (Scheltema 1986) as a result of larval transport, predation, competition, and available substrate for settlement.

The effects of the disturbance by fishing gear can also vary on a variety of spatial and temporal scales depending on physical oceanographic processes, life history characteristics of epibenthic species, and the level and timing of fishing effort in an area. Physical structures such as sand waves can, if altered by fishing gear, reform rapidly due to tidal currents or reform more episodically due to aperiodic storm events. Similarly, animal life histories are unique and the time for re-establishment of the benthic community following a perturbation by fishing gear can vary significantly. For example, the impact on taxa such as hydroids, that typically have life spans of approximately one year, would be short-term, whereas sponges are long lived and growth of newly-settled colonies is slow, often taking many years. The timing and intensity of mobile fishing gear impacts, interacting with substrate and fauna, may therefore profoundly alter benthic community structure. For example, 41-53% of rocks (> 5 cm maximum dimension) were dislodged and rotated by a single pass of a scallop dredge during an experimental gear impact study (unpublished data). Fishing gear disturbance could continuously reduce survivorship of epifauna which settle on the exposed surfaces of rocks.

Long-term effects, due to changes in community structure, can unfortunately not yet be predicted (Witman and Sebens 1992).

Any habitat-based management strategy must consider mobile fishing gear impacts. Fish assemblages on the northeast U.S. are part of a system where predation mortality on postlarval and juvenile fishes has a major effect on year-class strength (e.g., Sissenwine 1984, Sissenwine et al. 1984). Much work has been directed at understanding the role of egg and larval mortality as a factor establishing year-class strength although post-settlement mortality is of comparable magnitude (Sissenwine 1984). If use of specific benthic habitats significantly reduces predator induced mortality (e.g., Lough et al. 1989, Wahle and Steneck 1992), then maintaining complexity should be part of the management regime (Langton et al. in press).

Impacts of fishing gear have to be understood not simply in terms of removal of the targeted species but, more importantly, in terms of their impact on ecosystem productivity. Productivity has a strict biological definition but, in a broader ecosystem-based management sense (Slocombe 1993), it is defined to include human values and a vision of what the fishery should produce and what degree of biodiversity should be maintained in the system. In this paper we have presented data on the impacts of fishing gear at three locations on a variety of bottom types, together with a calculation on the extent of trawling region wide (Appendix 1). This data, however, only begins the debate on the merits and demerits of mobile gear fisheries. Clearly, these are efficient ways to harvest living marine resources in the short - term, but economic efficiency may have an ecological price that requires restriction of the activity in select areas. Unfortunately, our current understanding of the impacts of mobile fishing gear is often more correlative than causal, particularly in the Gulf of Maine. We have observed impacts that suggest a potential for long-term deleterious effects on harvested populations. There is an immediate need to provide information on the extent and magnitude of these effects with a directed program of study.

The time and space components of gear impacts need to be critically evaluated and ultimately balanced against the need for resource harvesting. Unfortunately developing an understanding of these impacts in the Gulf of Maine is difficult as no areas exist which can act as a true reference sites or non-impacted controls. One approach to this problem is the designation of marine reserves (Dugan and Davis 1993, Auster and Malatesta 1995, Shackell and Willison 1995, Auster and Shackell in press) which would provide reference sites in selected biogeographic regions. Experiments on the intensity and magnitude of fishing effort with specific gear types could be conducted at sites adjacent to such protected areas. These experiments should be long-term in their execution in order to understand natural versus gear induced changes in habitat. As information becomes available it could be incorporated into a scheme of ecosystem-based management that attempts to balance resource harvesting with maintaining habitat integrity to produce sustainable harvestable populations.

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Table 1. Analysis of cover index (CI) for each bottom type and habitat feature. Note that CI is an index of cover and not a direct measure of percent cover. (I = inside conservation area, F = fished site outside conservation area)

| Bottom Type | Number Transects | Mean CI | SD | T-test |
|---|---|---|---|---|
| Cobble-shell | I 13 | 60.25 | 2.47 | t=5.51 |
| (emergent epifauna) | F 12 | 48.89 | 7.13 | *p*<0.001 |
| Cobble-shell | I 13 | 9.64 | 2.36 | t=3.76 |
| (holothurians) | F 12 | 6.19 | 2.21 | *p*=0.001 |
| Sand-shell | I 18 | 16.47 | 1.90 | t=6.10 |
| (biogenic depressions) | F 17 | 11.82 | 2.54 | *p*<0.001 |
| Sand-shell | I 18 | 3.53 | 3.21 | t=3.09 |
| (holothurians) | F 17 | 0.95 | 1.47 | *p*=0.005 |

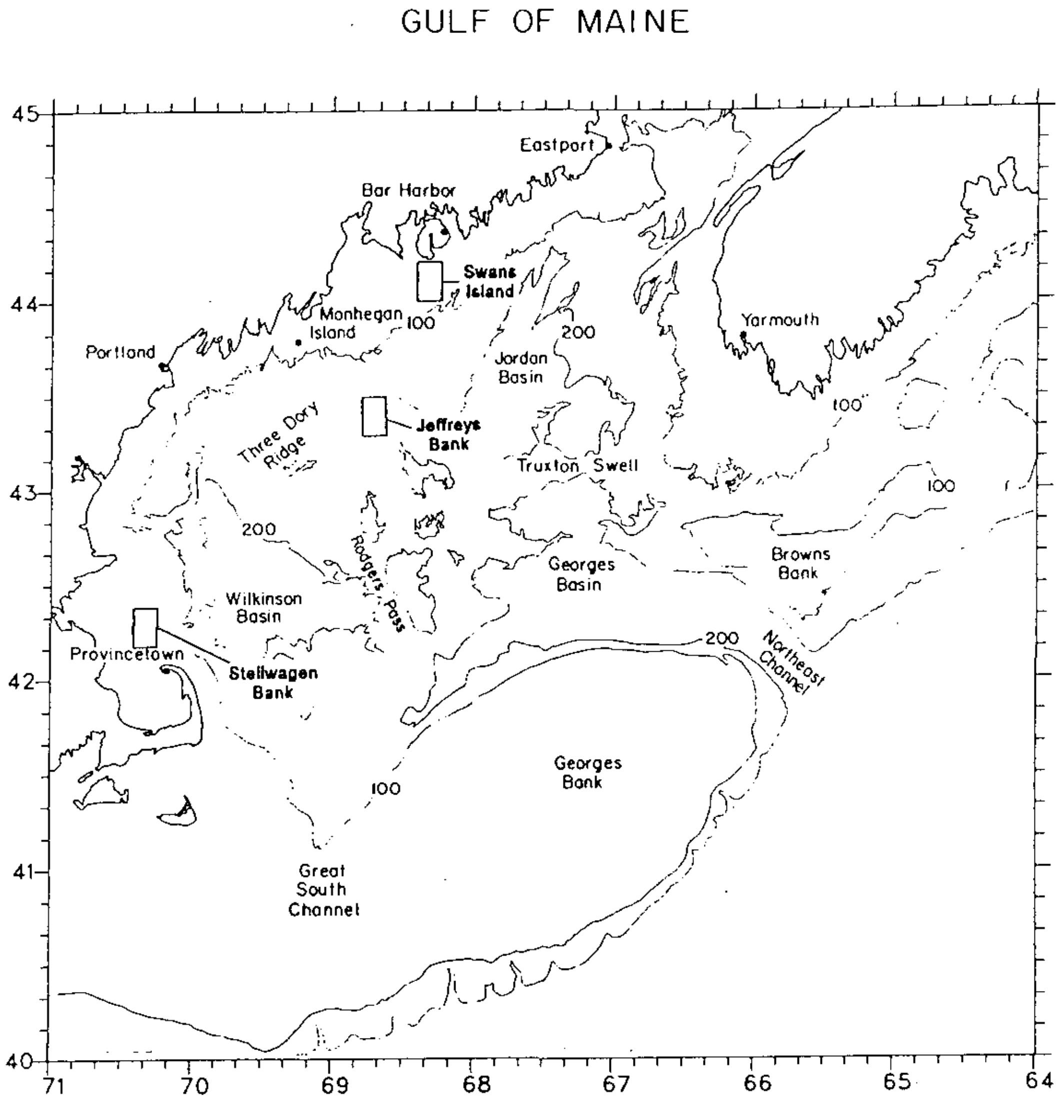
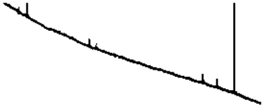


Figure 1. Chart of Gulf of Maine showing the three study areas (depths in meters).



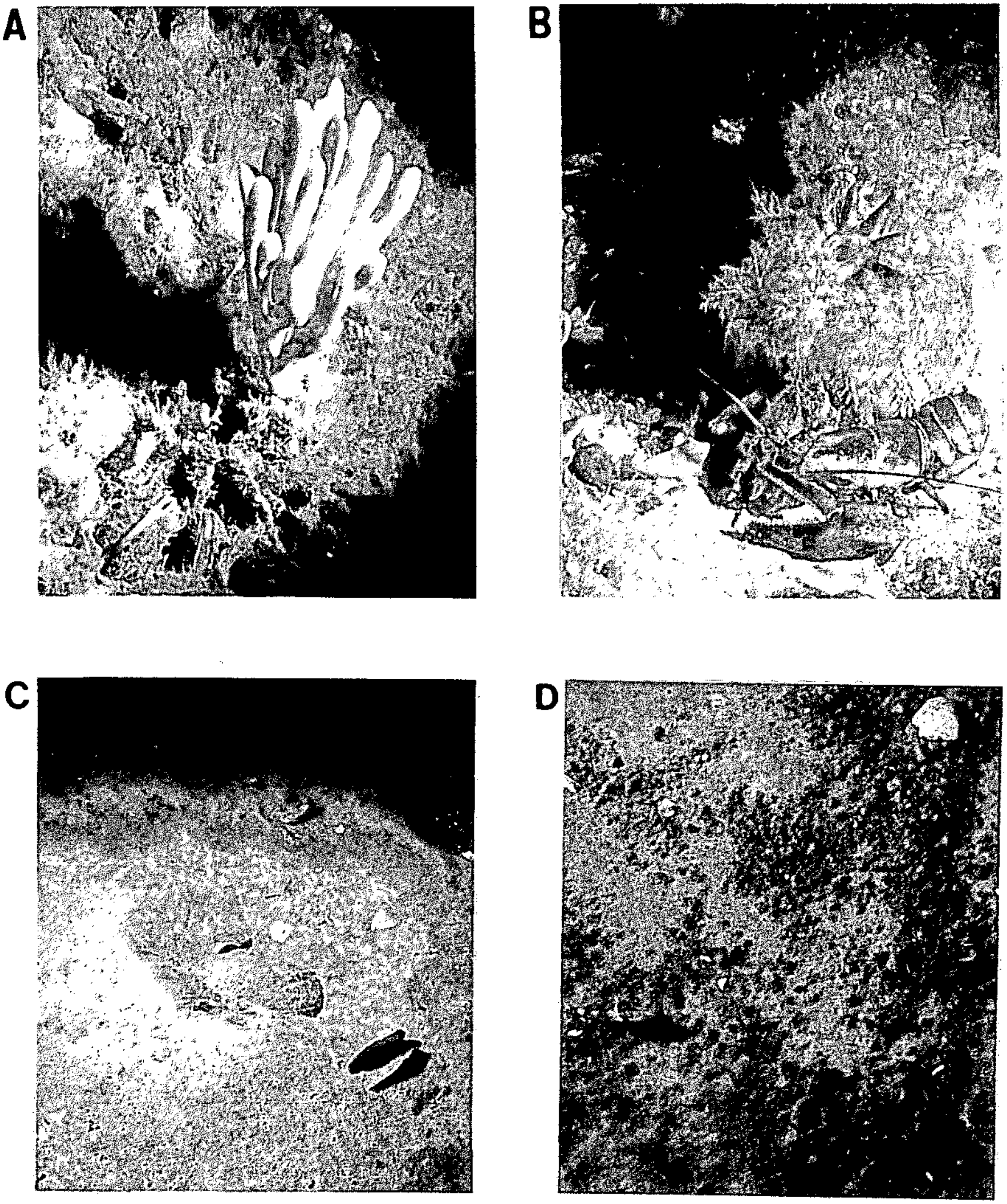
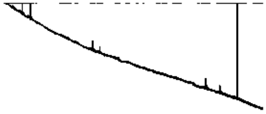


Figure 2. A. Emergent epifauna (i.e., sponge, bryozoans) attached to cobble and shell substrates. B. A sea cucumber used as shelter by an American lobster. C. Depressions were formed by harvested species such as the sea scallop. D. The ascidian, *Mogula arenata*, was distributed on coarse unconsolidated sand.



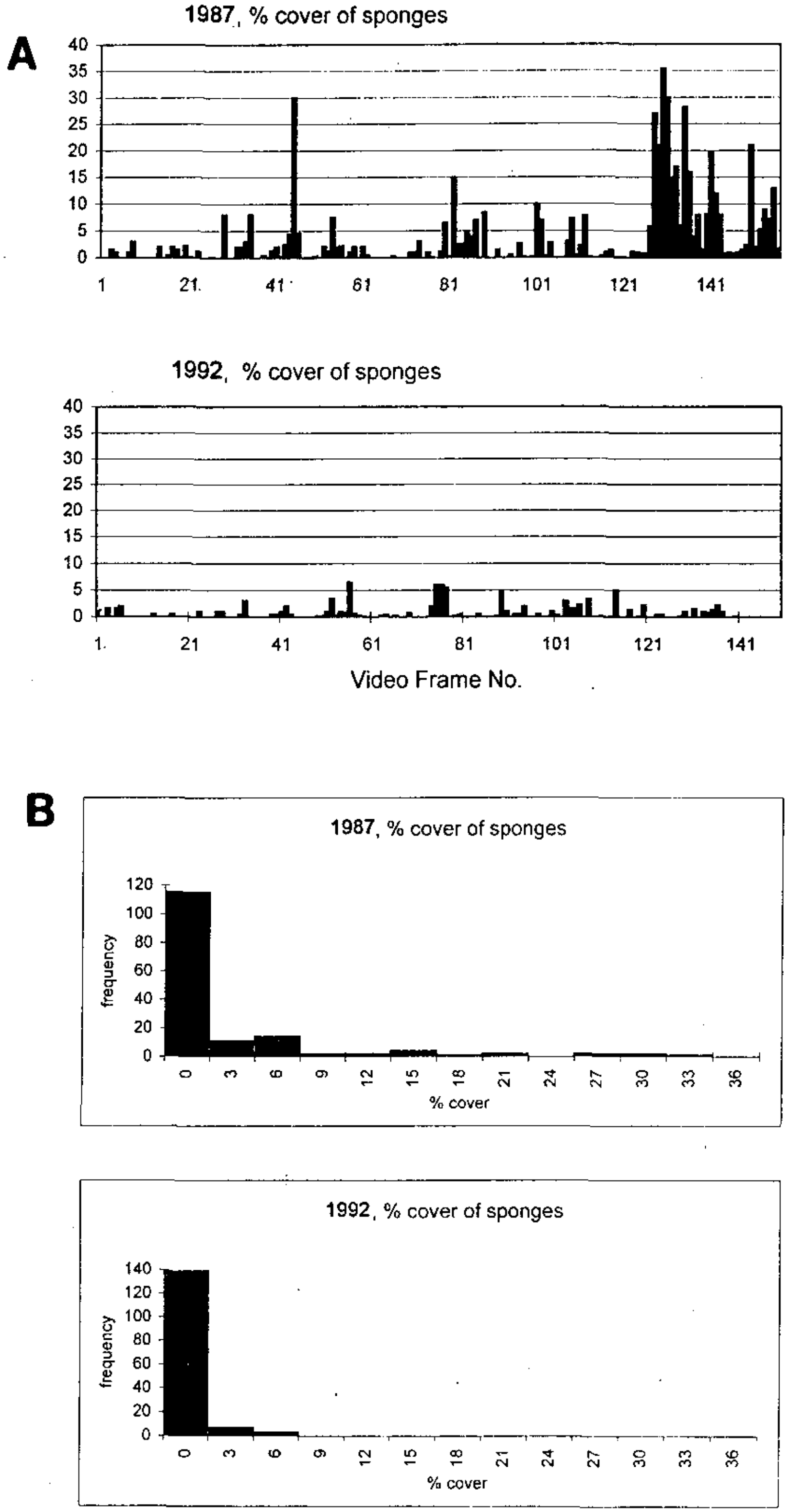


Figure 3. A. Percent cover of sponges per sequential field of view from 1987 and 1992 transects. B. Frequency of percent cover categories from 1987 and 1992 transects.

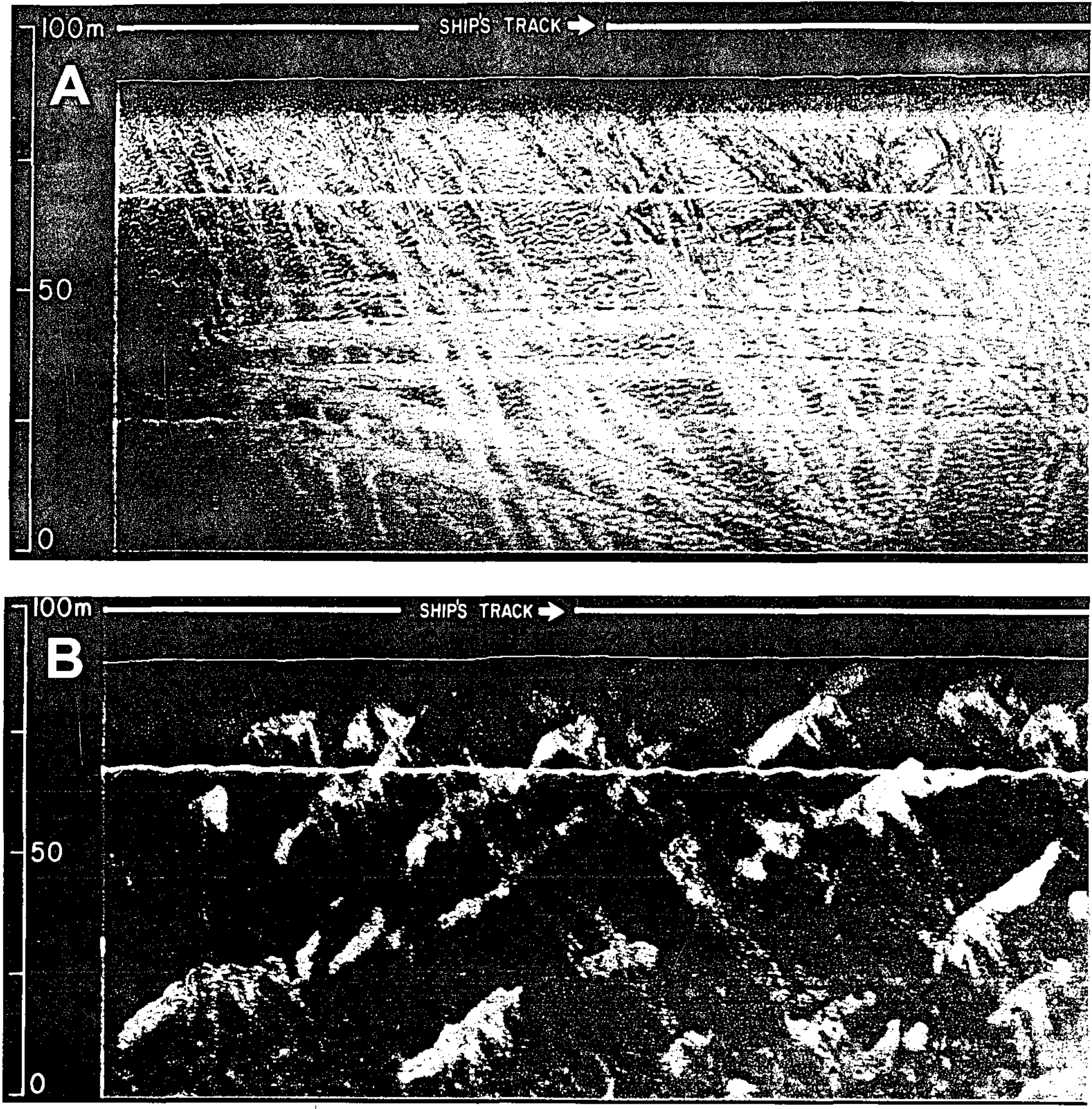


Figure 4. A. Side-scan sonar image of Stellwagen Bank seafloor showing storm sand ripples disturbed by scallop dredge gear. B. Side-scan sonar image of Stellwagen Bank seafloor showing storm dunes of fine sand with shell debris packed in the troughs (light linear areas). Scallop dredging has smoothed the bedforms and dispersed the shell.

## APPENDIX 1

Trawling activities occur over large parts of the northeastern continental shelf of North America. Using fishing effort data compiled by NMFS, it was possible to estimate the area impacted by mobile fishing gear on the U.S. side of the Gulf of Maine and on Georges Bank (Fig. A1). Fishermen report catch and effort data when they unload fish at the dock after each trip and are required to report data on days fished. Days fished is an index of fishing effort based on the time that fishing gear is in the water. These data were summarized for trawl and scallop fisheries within each region. In this analysis, the area altered by trawlers was estimated by using an average distance of 40 m between the doors for all size classes of trawler. For scallop dredge gear, 2, 4 and 6 m were used as gear widths for class 2, 3, and 4 vessels respectively. Vessel speed was assumed to be 5.5 km $hr^{-1}$ in both fisheries. Total area fished was then calculated by multiplying days fished (in hours) by gear width and vessel speed (Fig. A2). We believe these to be conservative estimates. The U.S. side of the Gulf of Maine is approximately 65,000 $km^2$ and Georges Bank is approximately 41, 000 $km^2$. Therefore, approximately all of the U.S. side of the Gulf of Maine, on a percentage basis, was impacted annually by mobile fishing gear since 1982. Between 200 and 300% of the U.S. side of Georges Bank, on a percentage basis, was impacted since 1976 (the time frame of our available data). Of course, some areas are not impacted at all and others are impacted even more frequently.

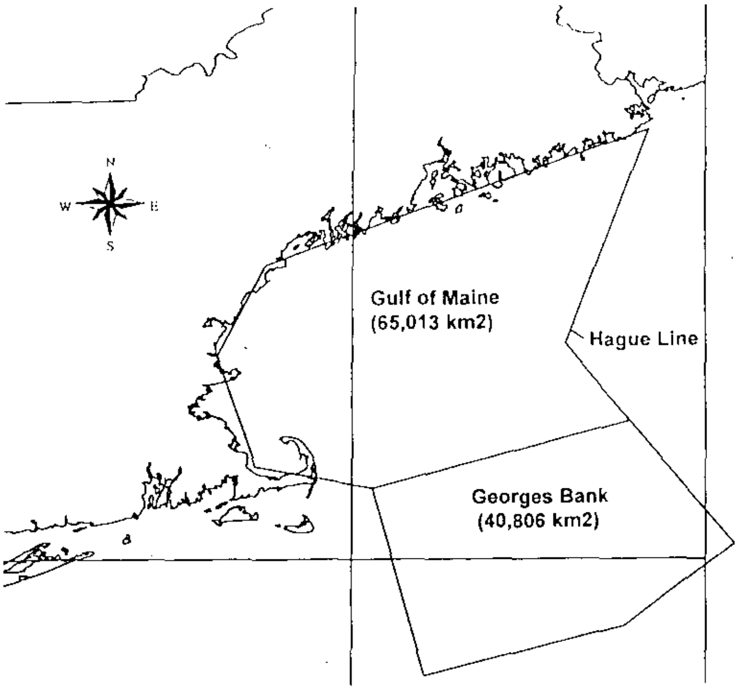


Figure A1. Approximate area (km$^2$) on the U.S. side of the Gulf of Maine and Georges Bank.

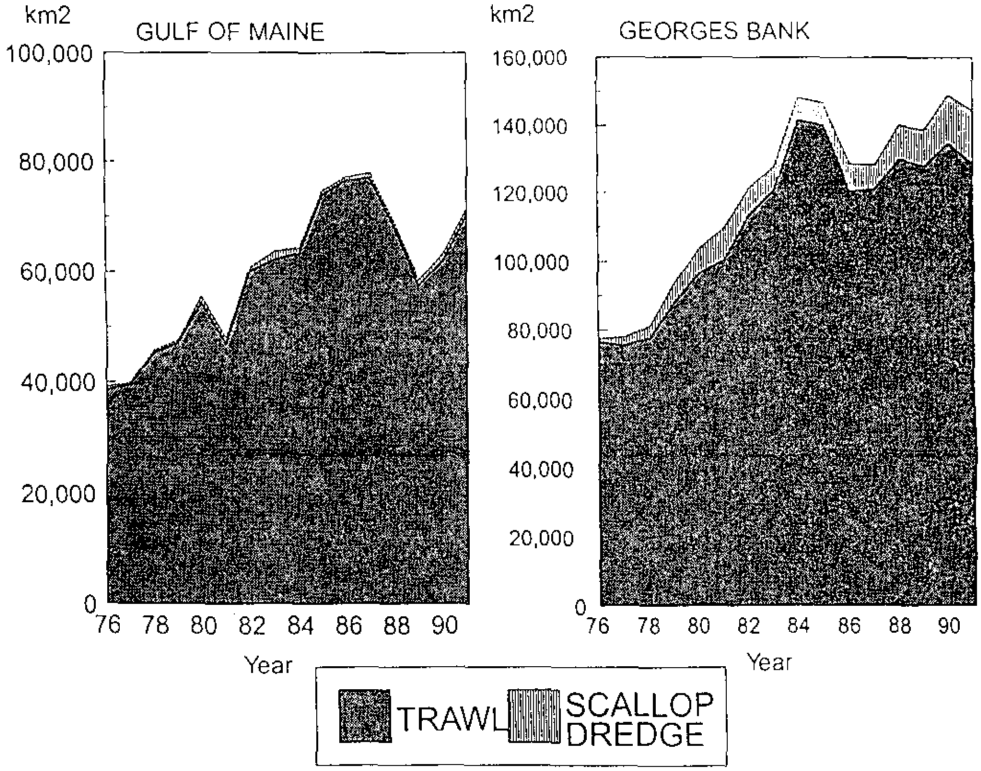


Figure A2. Area impacted by mobile fishing gear on the U.S. side of the Gulf of Maine (left) and on Georges Bank (right).