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THE NEW YORK BIGHT GEOGRAPHIC INFORMATION SYSTEM: DEVELOPMENT, RESULTS, AND FUTURE EFFORTS

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THE NEW YORK BIGHT GEOGRAPHIC INFORMATION SYSTEM: DEVELOPMENT, RESULTS, AND FUTURE EFFORTS

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SUMMARY

In the Port of New York and New Jersey it is necessary to dredge an annual volume of between 2 and 20 million cubic yards (1.5 to 15.3 million m^3), with an average volume of 5.9 million cubic yards (4.4 million m^3) being removed every year. Almost all this material is presently being disposed in the ocean at the Mud Dump Site, 5.75 miles (9.25 km) east of the coast of New Jersey. Under the Water Resources Development Act (WRDA) of 1986 (PL 99.662), the Environmental Protection Agency (EPA) was directed to find an alternative site at least 20 miles (32 km) from the shore for the disposal of *unacceptable* dredged sediment. *Acceptable* dredged sediment would continue to be disposed of at the present site which is expected to reach capacity in the near future. Thus, in addition, there is a need to replace this site with a new disposal site. The terms *acceptable* and *unacceptable* have never been technically defined. Theoretically *acceptable* could be defined as material greater than 90 percent sand. Section 412(a) of the Water Resource Development Act of 1990 rescinded the 1986 requirement for a dredged material disposal site greater than 20 miles (32 km) offshore. It allows the EPA to look for the most *appropriate* dredged material disposal site regardless of distance from shore.

A hierarchical geographic information system (GIS) has been constructed for the New York Bight and the Bight Apex, as a management tool. A GIS is *an automated system for the capture, storage, retrieval, manipulation, analysis, and display of geographic data.* Eighty-five GIS data layers, including fisheries, sediments, currents, contaminants, sediment biomass and chemistry, and other pre-existing data from the Bight, were digitized from a number of different sources and formats, rectified to Universal Transverse Mercator coordinates, and gridded at a 500 meter cell size for the New York Bight GIS and at a 100 meter cell size for the Bight Apex GIS. Ongoing efforts involve further hierarchical insert layers at larger scales, including a database for the Mud Dump Site.

The GIS was applied to the New York Bight initially in order to aid in the search for candidate areas within which both alternate and replacement disposal sites might be located. Candidate areas were to be within economically and operationally feasible areas and sufficiently removed from ecologically sensitive or incompatible use areas. All ocean dredged material disposal sites are to be located in areas where dumping will cause "no unacceptable adverse effects". Overlays were constructed from weighted distribution of selected parameters. Distribution of fisheries were weighted by the ratio of the dollar value of the catch of that species divided by the Bight area in which that species is caught. Overlays showing areas with over five percent gravel (indicative of dispersive areas) and shipping lanes were added to this fisheries overlay (dollar value per hectare) in a further analysis.

The Corps had previously identified four areas in the Bight (labeled C1-C4) to be evaluated as possible replacement sites and the EPA identified two areas further offshore (E1-E2). Based upon all the results from the GIS analyses, there appears to be no advantage to choosing sites more than 20 miles (32 km) from the port. The most promising areas are the southern corners of C1 and C2, and C3. The location of the most promising candidate areas are consistent with other independent analyses including the 1989 field work involving side scan sonar and REMOTS imagery, physical oceanographic measurements, benthic infauna and grainsize distributions, and the numerical model studies of currents, all aimed at identifying the least dynamic sites.

An insert database was then constructed for the New York Bight Apex at a larger scale. This additional database allows more detailed analysis of existing parameters. The results of these more detailed analyses are consistent with the results from the New York Bight GIS, and further serve to pinpoint specific areas for future investigations. As expansion of the existing Mud Dump Site eastward or southward seems reasonable, an insert of the Mud Dump Site and adjacent area is being developed to examine this area.

Introduction

This report describes the first application of a geographic information system (GIS) to aid in the selection of ocean disposal sites for dredged sediment, specifically alternate and replacement disposal sites for the Port of New York and New Jersey. Accordingly, four topics will be discussed. These are: (a) the design of the GIS, (b) the site-selection criterion used in the GIS, (c) the available data, and (d) the results.

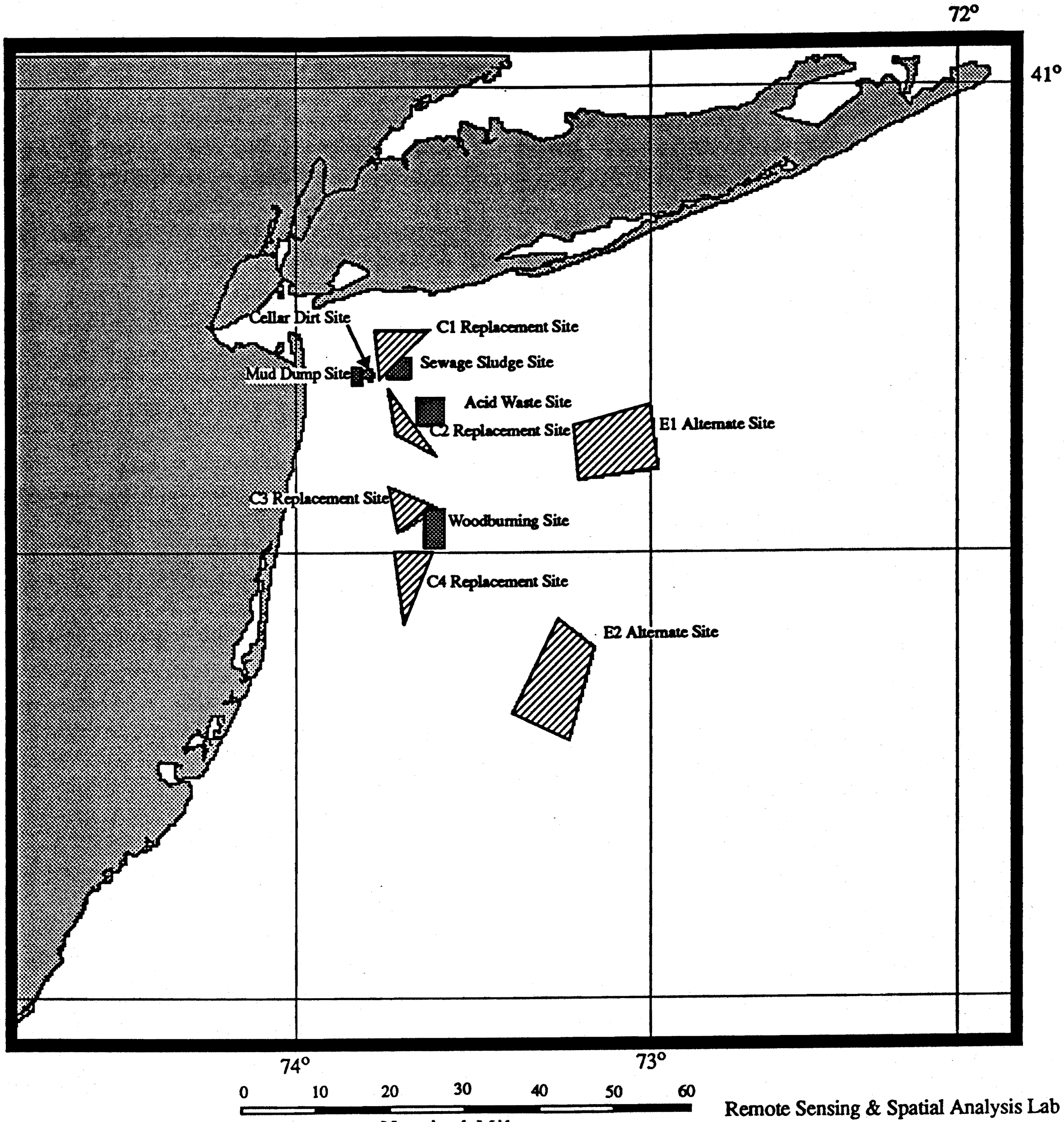
There are approximately 4,000 GISs in the United States (Burrough, 1989). Most of these have been developed in the last few years. Many attempts to apply this technology to site specific problems have failed because of a lack of understanding of a GIS's capability or flaws in the application of ready-made software. The use of GIS in the marine environment is a relatively recent development. As a result, one of the objectives of this study was to explore the capability of a GIS in a specific marine application.

The GIS was constructed to aid in the determination of the best candidate for new disposal sites in the New York Bight which would receive sediment dredged from the Port of New York and New Jersey. Maintenance of the port requires the disposal of between 2 and 20 million cubic yards (1.5 to 15.3 million m^3) of dredged sediment annually (O'Connor, 1989). Most of this sediment is suitable for unrestricted disposal in the oceans under current criteria. Between two and five percent of the dredged sediment does not meet the requirements for unrestricted ocean disposal but does not pose a definite threat to marine life; this material may be placed in the ocean if covered, or capped, with acceptable sediment. A smaller amount is unsuitable for ocean disposal and can only be placed in a confined disposal site.

The present ocean disposal site is the Mud Dump Site (Figure 1). This site covers an area of 2.3 square miles (5.93 square kilometers) centered at 40^{o} 22' 48" N, 73^{o} 50' 44" W. Use of this site began in 1914 and it has received a total of 96 million cubic yards (73.44 million m^3)between 1976 and 1990, 46 million cubic yards (35 million m^3) of dredged sediment between 1984 and 1990 (Pechko, U.S. Army Corps of Engineers-New York District, 1991, personal communication). Since it is expected to reach its capacity of approximately 100 million cubic yards (76.5 million m^3) in this decade, a site must be designated to replace it. In addition to a search for a replacement site, a search was enacted by the Environmental Protection Agency (EPA) and the U.S. Army Corps of Engineers to find an alternative disposal site at a distance greater than 20 miles (32 km) from shore which could be used to isolate and contain material that was "unacceptable" for unrestricted ocean disposal. (Other disposal options are discussed by O'Connor (1989) such as containment islands, subaqueous burial or upland disposal, but they are not the subject of this study.)

Both the U.S. Army Corps of Engineers and the EPA had previously completed a preliminary exercise, without the benefit of a GIS, to identify candidate areas. The EPA selected two areas from the regions recommended by Maciolek, et al. (1988). The alternative disposal site was most likely to be placed within one of these two areas which were referred to as ***E1*** and ***E2***. The Corps delineated four areas which were referred to as sites ***C1*** to ***C4***, within which a search for a replace-

Past and Present Disposal Sites and Candidate Areas in the New York Bight



Source: Corps Of Engineers N.Y. District

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Figure 1

Table 1 CORNER COORDINATES OF THE SIX CANDIDATE AREAS

Site	Latitude	Longitude
E1	40° 18.0' N	73° 00.0' W
	40° 15.5' N	73° 13.3' W
	40° 08.5' N	73° 12.4' W
	40° 10.5' N	72° 59.0' W
E2	39° 50.0' N	73° 17.0' W
	39° 40.0' N	73° 25.5' W
	39° 36.5' N	73° 17.0' W
	39° 46.0' N	73° 10.5' W
C1	40° 29.0' N	73° 47.0' W
	40° 29.0' N	73° 38.0' W
	40° 23.0' N	73° 46.5' W
C2	40° 21.0' N	73° 45.0' W
	40° 12.0' N	73° 37.0' W
	40° 15.0' N	73° 44.0' W
C3	40° 08.0' N	73° 44.0' W
	40° 02.0' N	73° 43.0' W
	40° 05.0' N	73° 38.0' W
C4	40° 00.0' N	73° 43.0' W
	40° 00.0' N	73° 37.0' W
	39° 51.0' N	73° 42.0' W

ment disposal site would be concentrated.The Corps then completed an analysis incorporating the results of the GIS to identify candidate areas from within the economically and operationally feasible region (Pechko and Freeman, 1990). Other options, such as expanding the existing Mud Dump Site were also to be considered. These candidate areas are shown in their relation to existing disposal sites in Figure 1 and the exact coordinates of their apices are given in Table 1.

The GIS was developed to provide a relative assessment of the suitability of different areas based on available data. It can be used to compare the characteristics of any particular area to all other areas of the Bight. A GIS is especially suited for such analysis because of its ability to combine data from different sources and to put it into a common coordinate system, thus enabling comparison between the data.

Development of the Geographic Information System

Data of use to decision makers in the selection of candidate areas is plentiful, but it is scattered in a large number of reports, papers, maps, and monographs (e.g., Freeland and Swift, 1978; Long and Figley, 1981; Pacheco, 1988; Reid, et al., 1982; and Swanson, 1989). Although some of these data already exist in digital form, the bulk of it lies as a large number of sheet maps and page maps in report appendices. Collectively, these data represent the sum factual knowledge about the New York Bight.This information is presented here in map form, as data layers within a geographic information system (GIS). A GIS is an *automated system for the capture, storage, retrieval, manipulation, analysis, and display of geographic data*. Geographic data are unique in that they have attached to them attributes which describe locations or regions on the Earth's surface. The geographic attributes describe spatial location, in a recognized coordinate system and on a particular map projection.

For the purpose of this project, digital cartographic data sets were provided in GIS format for two areas, the total New York Bight and a more detailed analysis of the Apex portion of the New York Bight. An additional part of this effort was to construct overlays and to perform data manipulations. The manipulation of such data layers allow decision makers to create and experiment with different ocean-disposal siting scenarios as they relate to the vast quantity of information available. The scenarios can be viewed as maps within the GIS and spatial properties, such as distance buffers, can be added by the system as required. Additionally, these data sets provide a foundation for decision making with respect to monitoring the New York Bight, as well as providing gridded and digestible data for the planned New York Bight Hydrodynamic and Water Quality Models.

The selection of an appropriate software system is an important consideration in setting up a geographic information system. Developing criteria for evaluating and testing the various systems available is a common theme in the literature. Burrough (1989) devotes an entire chapter to the subject, covering aspects such as defining user requirements, choosing among the available technologies, and factoring in economic, organizational, and personal considerations.

One of the most basic questions in choosing an appropriate system is deciding between raster and vector data. Vector data structures, in which geographic features are represented by points, lines, and polygons offer advantages in terms of output and display quality. Other advantages include the ability to perform network analysis, easy conversion to larger or smaller scales, and relatively simple conversion to raster format. Vectors provide a better description of topological structure through network linkages (Clarke, 1990). A disadvantage in vector data structures is the complexity involved in data storage and display. Another drawback is that combining two or more vector maps when creating an overlay is a very computationally intensive task.

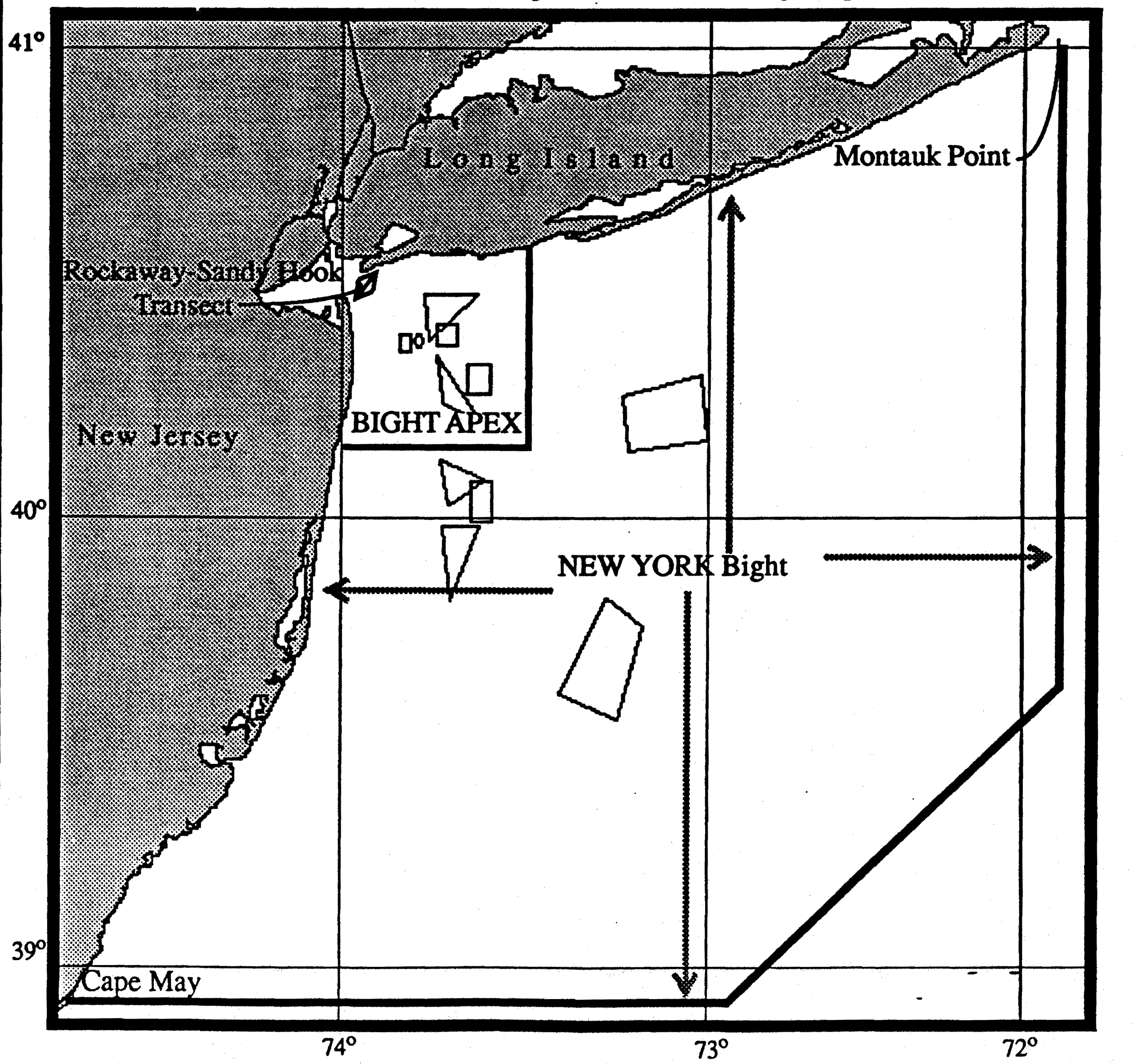
Raster, or grid cell format, allows for easier and faster map overlays and matrices. It is also easier to incorporate satellite data, an increasingly important source of information. Raster data allows easier statistical and analytical operations such as filtering, variograms, autocorrelation, and interpolation (Clarke, 1990). Continuous terrain (but not contour lines) is better represented by grid cells. The resolution of raster structures is limited by the grid cell size, storage requirements are high and increase geometrically with a decrease in cell size. Graphical output from raster is typically poor, the original choice of grid cell size locks the map into a certain resolution, zooming in simply produces a jagged effect from the square grid cells.

The major goal of the GIS was to aid in a site-selection process, evaluating candidate areas using the available data on fisheries, currents, bottom sediments among others. This necessitated producing a number of overlays which combined the data based on various scenarios. For this reason the decision was made to use ERDAS, a raster-based GIS software system. The Hunter College Remote Sensing and Spatial Analysis Laboratory (RESSAL) has three ERDAS 386-based PC workstations with color monitors and digitizing tablets. One of the workstations also consists of a video digitizer and a matrix camera.

New York Bight GIS

For this study the New York Bight (Figure 2) is defined as the area bounded by the limits of New York Harbor to the landward, by Montauk Point, N.Y. (41° 5' N, 71° 55' W) to the north-east, and Cape May, N.J. (38 ° 55' N, 74 ° 50' W) to the southwest , out to the edge of the

Figure 2. Area of New York Bight and New York Bight Apex



continental Shelf. This area will be expanded to incorporate the results of the Hydrodynamic and Water Quality models, in a smaller scale database extending out to the Nantucket Schoals.

Clearly an important first decision was which coordinate system to use in mapping. The system being used throughout the project is the Universal Transverse Mercator system. The UTM coordinate system divides the world into 60 zones, each 6 degrees of longitude wide. Unfortunately, the New York Bight falls over the boundary between two zones. The system allows overlap between zones, so for this reason, zone 18 was used, stretching from 78° West to 72° West, with a 5 minute overlap into zone 19. The locational error due to the Earth's curvature and the chosen map projection, therefore, will be greatest in the eastern portion of the map area (around Montauk) and, to a lesser extent, in the north. The maximum error on the surface because of these causes is about 1 in 2000.

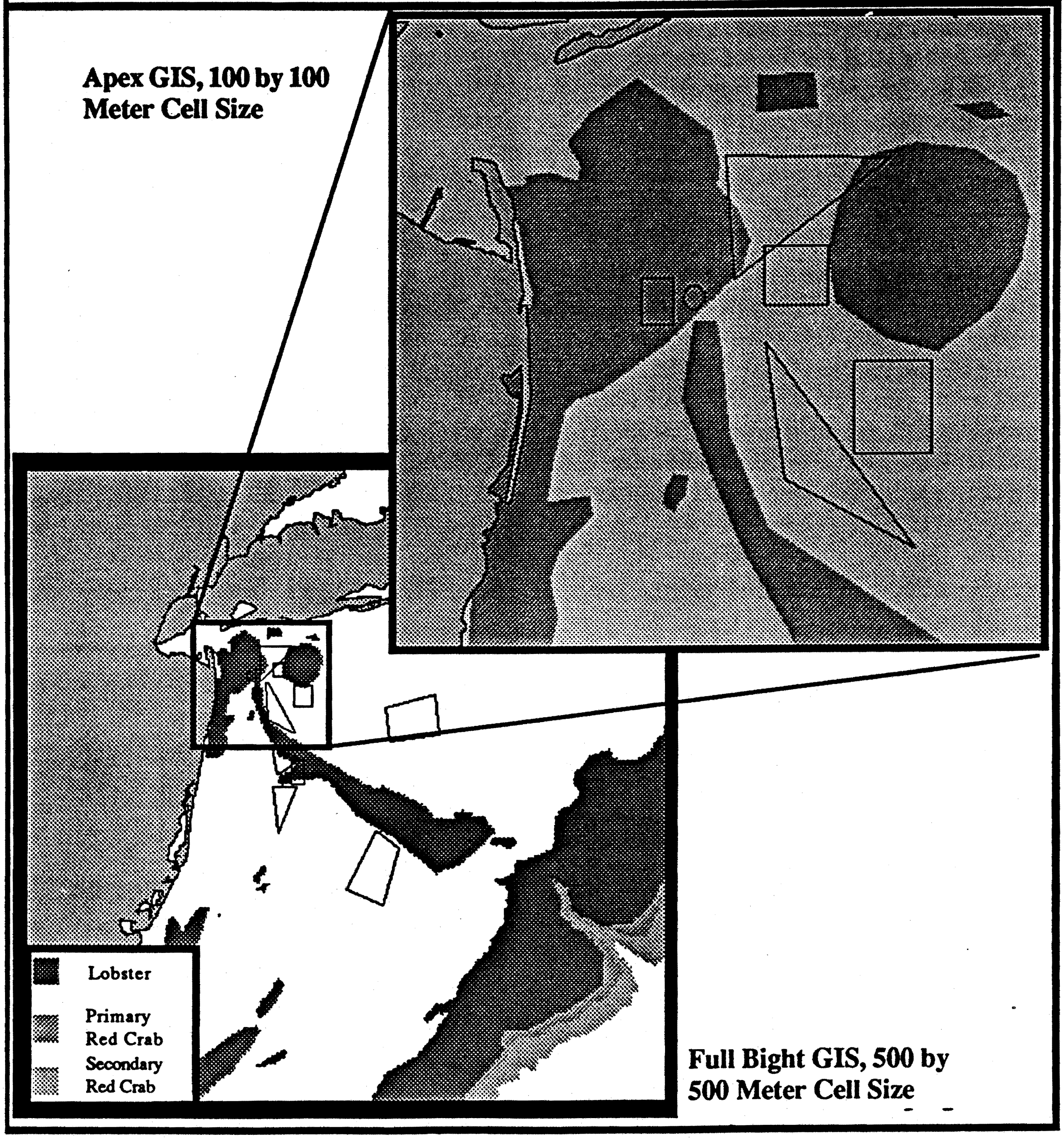
The base map to which all others have been registered is the NOAA National Ocean Service, Charting and Geodetic Service digital shoreline data (C3 Long Island and C4 Delaware Bay areas) containing precise coastline data from 1:40,000 scale harbor charts and other sources. Where data were already georegistered, direct conversion was accomplished using ERDAS and software developed by K. Clarke. Where no coordinates were available, registration was achieved by identifying between 12 and 20 ground control points on the base map, which were then indicated on each additional map as it was being digitized. Accurate shorelines of the Bight were obtained from the Coast and Geodetic Survey on two magnetic tapes. Some gaps existed in these shoreline data, but they were not large enough to affect the New York Bight GIS. Since the total number in the digital coastline file exceeded 200,000 points, and included information on scale, date digitized, and source map, specialized software was written to resample the digital coastline data. Each input map was then digitally warped to fit the base map using a technique called rubber-sheeting, available from ERDAS. Rubber-sheeting uses least-squares methods in two dimensions to compute the empirical parameters of the space transformation necessary to map one set of control points onto the other. These same transformations are then applied to the map and the map is rewritten in the new coordinate system. A root mean square error tolerance of 1.5 pixels was used to calculate the coefficient matrix and input pixels were resampled using a nearest neighbor algorithm. Each rectified output GIS file has a pixel size of 500 meters by 500 meters, an area of 25 hectares. Tests on topographic maps show that using this technique, SPOT satellite data with a 10 meter resolution can be transformed to a scale of 1:50,000 within the national map accuracy standards. Tests have shown that the spatial reliability and accuracy of each map is greater than the stability of the paper on which most maps were printed.

The actual digitizing of base maps took place at RESSAL using Calcomp semi-automated digitizing tablets and both ERDAS and in-house software. By using these formats and using software developed by K. Clarke, a high degree of data interchangeability with other GIS software is possible. The ERDAS GIS files are currently being converted to Idrisi Image file format. Idrisi, a grid based GIS package developed by Clark University, has been installed on the U.S. Army Corps of Engineers, New York District GIS PC workstation. Existing and future GIS data layers will be converted into Idrisi format and transferred to the Corps' New York District office.

Apex GIS

The second series of data files were created at a larger scale. These layers comprise an insert to the existing geographic information system, allowing more detailed evaluation and examination of the Bight Apex. Figure 3 shows the area of the Apex GIS in relation to the full Bight GIS.

Figure 3. Area of Apex GIS in Relation to Full Bight GIS



The insert area extends from the outer harbor into the Bight approximately 37 miles (59 km) from the Rockaway-Sandy Hook transect. The area of the Apex GIS was established in order to examine candidate areas C1 and C2 in more detail as well as to consider ways in which the Mud Dump Site could be expanded.

The upper left UTM coordinates of the Apex GIS are 577500 E and 4492900 N and the lower right UTM coordinates are 627500 E and 4442900 N. The smaller areal coverage compared to the full Bight GIS results in an increase in scale. This increased scale means that each pixel on the full Bight GIS will be covered by 5 x 5, or 25 pixels, on the Apex GIS. The base map for the Apex GIS was recreated from the original digital shoreline data. The digital shoreline data is a file containing the coordinates of points which form lines and comprise the mean high water of the shoreline. This vector file was rasterized to be used in the ERDAS system. The current ERDAS shoreline file has been generalized to a pixel size of 500 by 500 meters. Since the digital points file was created from large scale NOAA coastal charts at a scale of 1:40,000, the full precision of data is not used. The new file has a pixel size of 100 by 100 meters, this increased resolution will reduce the amount of generalization involved in rasterizing the shoreline data.

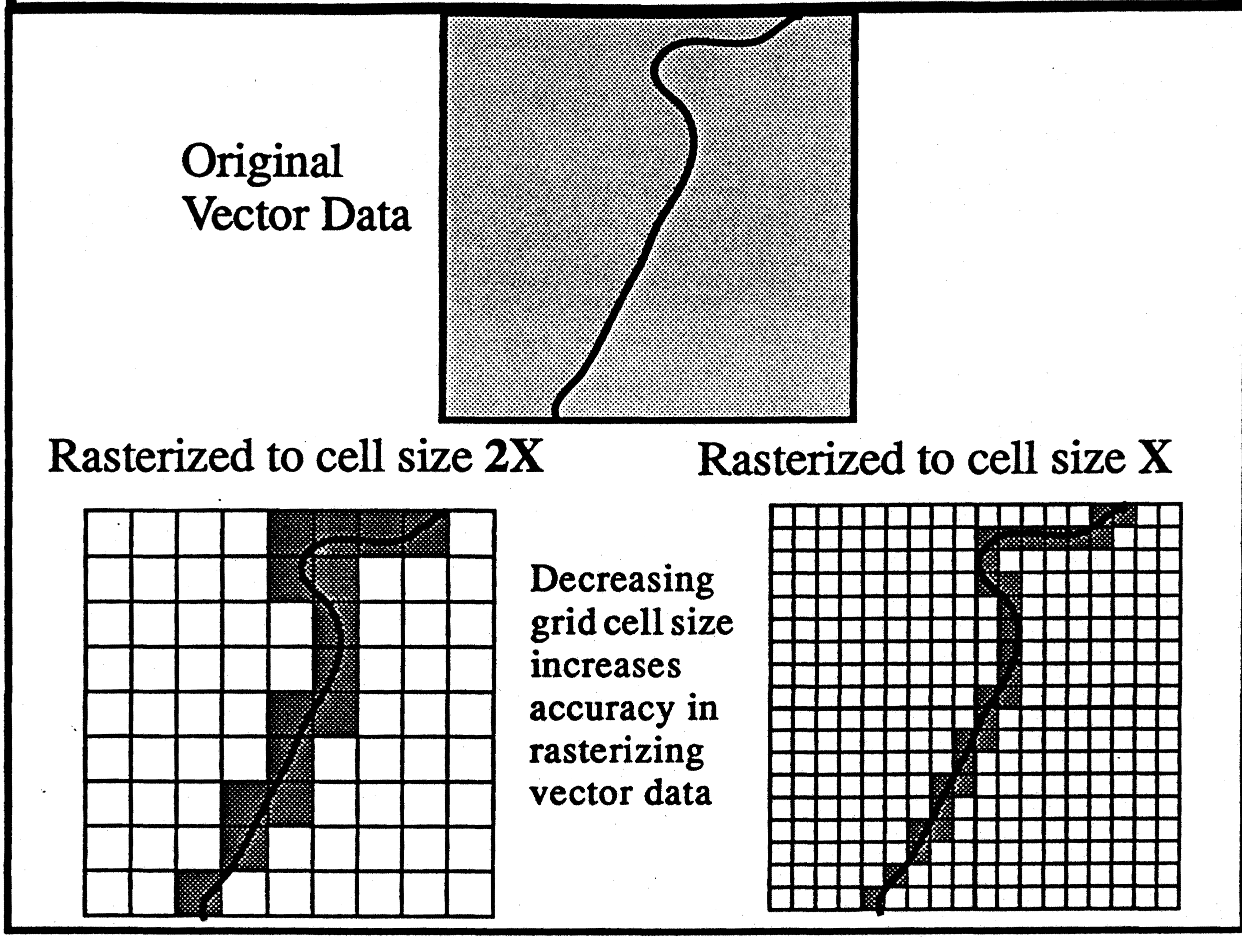
The increased resolution also means more accurate registration with the Apex GIS. On a pixel by pixel basis, this means a 25 times increase in registration accuracy.

A new series of control points had to be identified since only six of the original control points fell within this area. Creating the Apex GIS essentially meant starting a new project from the beginning but this was necessary in order to make the best use of available data. Simply using the existing GIS files at the increased scale would mean retaining the generalizations used in creating a GIS which covered the entire New York Bight. The issue of scale selection in creating a raster based GIS is an important consideration. Star and Estes (1990) discuss the concept of *resel* or resolution element in determining grid cell size. The smallest element to be mapped in the area of interest must be larger than the grid or it will be lost during data capture. The sampling theorem states that for a pixel size of R, objects of size R will be randomly detectable, but not identifiable. The minimum size feature which can be handled effectively has size 2R. When the GIS for the entire Bight was established, the pixel size of 500 meters by 500 meters was chosen for the following reasons:

1. The smallest polygons on any of the input files could still be adequately resolved at this scale.
2. The entire Bight area could fit onto a 512 x 512 display for viewing on the color monitor and for hardcopy output.
3. The scale is comparable to the resolution of the fisheries data.

The relationship between grid cell size and map accuracy was examined by Wehde (1982). It was found that percent error in assigning cells to the correct polygon increased linearly with an increase in cell size. The process of assigning continuous regions to cells results in errors along region boundaries. Converting vector data to raster data, as was done with the digital shoreline data and the digitized fisheries data, involves assigning the vectors or boundaries to grid cells. If a boundary passes through the upper corner of a grid cell, the entire cell would be classified as a boundary. This means a boundary can be mislocated by a distance equal to the diagonal grid cell size, in the case of the full Bight this is equal to 707 meters (2319.5 ft.). For the Apex GIS the maximum error is reduced to 141 meters(462.6 ft).(Figure 4)

Figure 4. Effect of Cell Size on Accuracy in Rasterizing Vector Data



The increased resolution of the Apex GIS allows more precise use of existing data on the Bight. Data such as contaminants, grain size, organic concentration and biomass have been sampled in greater detail in the Apex than the rest of the Bight. Under the current GIS this data was generalized during interpolation in order to cover the areas of the Bight not sampled with such detail. The existing data layers were recreated for the Apex GIS from the original digitized file, rather than resampling the existing GIS files which cover the entire Bight. Under the ERDAS system, digitized files are vector files containing the coordinates of points which comprise the polygons. The digitized file polygons are generalized to create the raster GIS files. This results in a loss of detail when using a large pixel size such as 500 by 500 meters. The increased resolution of the insert GIS allows more accurate rendering of these polygons when they are rasterized. Any data, originally in points files, were interpolated into smaller cell size using a smaller search area in carrying out the nearest neighbor interpolation.

Hierarchical Database

The creation of an Apex GIS has expanded the scope of the New York Bight GIS from a single resolution multi-layered system to a hierarchical system with multiple sets of data layers at increasing scales. This results in a pyramidal data structure (Star and Estes, 1990) in which an attribute layer is represented by increasingly fewer cells stacked on top of each other as if in a pyramid. For the New York Bight GIS, the increased scale hierarchies would be limited in areal coverage to specific sites of interest rather than the entire Bight in order to maintain a 512 by 512 file size. Creating a 100 meter cell size GIS for the entire Bight would mean a file size of 2560 by 2560 or 6.5 megabytes for an eight bit GIS file. This is clearly impractical in terms of storage and processing time when performing tasks such as overlays and indexing. For a smaller area, however, a pixel size of even 10 meters could cover a 25 km square area (9 mi^2) in a single 512 x 512 image. Such an array could be resampled at 500 meters for inclusion in the lower resolution dataset.

Producing Grayscale Maps

The digitized data, and consequent manipulations and resulting overlays, are produced on a color monitor with a capability of employing up to 256 different colors. These data can be produced on either Polaroid pictures or as 35mm color slides, on a matrix camera using the video feeds directly from the high resolution color monitor. A set of slides accompanied the interim report to the U.S. Army Corps of Engineers on the initial development of the New York Bight GIS (Bokuniewicz, et al., 1989). However useful for presentations, this color format does not lend itself to mass production of reports, such as required by the U.S. Army Corps of Engineers and EPA. In order to prepare the 92 black and white figures in this report from the color maps, it was necessary to create a Postscript file from each ERDAS file. Since the version of ERDAS used at the Remote Sensing and Spatial Analysis Lab does not produce Postscript output, creating grayscale maps which can be printed on a laserjet printer requires a number of steps.

In the initial step the ERDAS GIS files were recoded. Each class was assigned a value corresponding to the desired output grayscale value, between 0 (black) and 255 (white). Software written by M. Hodgson at the University of Colorado at Boulder was used to convert the ERDAS files into TARGA format files. The TARGA files were then converted to Graphical Interchange Format (GIF) files. Since both of these formats are PC based, the programs to convert them were run on the RESSAL's high-resolution color graphics 386-based workstation. Data exchange between the PCs, the ERDAS workstation and the Color Graphics workstation, and the RESSAL SUN system, were done over an Ethernet LAN using PC-NFS. The GIF files were transferred to the SUN system and converted to SUN rasterfiles.The rasterfiles were then imported into a Framemaker document. Framemaker is a Unix-based desktop publishing system. Annotation and grid coordinates were done using Framemaker. The final product was a Postscript file printed out on the RESSAL laserjet printer.

Availability of the New York Bight GIS Data Base to Other Users

The digitized data in the New York Bight GIS is in the ERDAS GIS file format which consists of an 8 bit data file (suffix .gis), a trailer file (.trl) and an annotation file (.ant). Data which were interpolated (e.g., the DIFID data) and concentration of metals, are also in ERDAS Image file format (.lan). The Remote Sensing and Spatial Analysis Lab is in the process of converting the existing ERDAS GIS files into Idrisi format files and providing them to the U.S. Army Corps of

Engineers. This involves recoding the ERDAS files into 4 bit values (values between 1 and 16). The files are then converted into ERDAS version 7.3 files and transferred from the ERDAS PC workstation to the Lab's 386 graphics PC workstation where Idrisi is installed. The files are then converted to Idrisi format using the Idrisi command ***erdidris.***

Once the files have been converted to Idrisi format, a documentation file is constructed for each file. An Idrisi map consists of an image file, .img and its associated document file, .doc. The Image file contains the GIS values, it can be in binary format, ASCII format or run-length encoded format. The documentation file is a header file consisting of such information as the corner coordinates of the file, title of the image and rows and columns. A file can also have its own color palette file which is used when the image is displayed using color or printed out on a hardcopy device.

CRITERIA FOR SITE SELECTION

The purpose of site selection is to locate potential sites that are within an economically and operationally feasible area and are sufficiently removed from ecologically sensitive or incompatible use areas. All ocean dredged material disposal sites are to be located in areas where dumping will cause "no unacceptable adverse effects".

The first task in locating a new site is to define a Zone of Siting Feasibility (ZSF) within an economically and operational feasible area. Information on critical uses of the Bight, marine resources and the physical environment is gathered and used to identify candidate sites within the ZSF. Existing data is used whenever possible in order to keep costs reasonable.

In accordance with the EPA's "Ocean Dumping Site Designation Delegation Handbook for Dredged Material" (Science Applications International, 1986), a proposed site must be located within an economically feasible distance from the point of dredging. In a hierarchical selection process, areas that do not meet this criteria are eliminated first. Then areas containing critical resources and areas needed for other purposes are eliminated.

The cost of transporting dredged material offshore will, in many cases, limit the determination of the ZSF. However, the cost of disposal cannot be the main consideration used for locating a site. Alternate sitings at greater distances must be considered when they offer environmental benefits at reasonable incremental costs. Impacts on specific dredging projects, as well as impacts on regional dredging needs and budgetary constraints must be considered. A draft report prepared for the EPA, Region II by Kearney, Inc. and Battelle (1988), "Dredged Material Transportation Cost Analysis for Alternative Ocean Disposal Sites for the Port of New York and New Jersey", excludes the use of sites greater than sixty-five miles(40.4 km) from Ambrose Light based on economics, this eliminates areas beyond the continental shelf. The EPA, under WRDA, is studying alternate disposal sites between 20 and 65 miles (12.4 - 40.4 km) offshore. In order not to duplicate their effort, the U.S. Army Corps of Engineers limited their ZSF to areas within 20 miles (12.4 km) of the shoreline.

Potential candidate areas within the ZSF are selected through a screening process which starts by considering site-specific, available data. The distribution of some important resources and uses were superimposed using a geographic information system (GIS).

The purpose of identifying and mapping sites for the ZSF is to ultimately exclude areas that contain critical resources and areas with proposed or current uses that are incompatible with a disposal site. By overlaying maps of these areas, "windows", or areas that are not excluded from further consideration, become apparent. Every area of the Bight contains some marine resource or alternate use. The selection of a site, therefore, depends upon the interpretation of what constitutes protection of critical resources and the degree of incompatibility of uses.

As a starting point the following assumptions were made:

1. If areas can be identified that equally avoid incompatible uses and avoid unacceptable impacts to critical resources, then the site closest to the harbor will be preferred for economic and safety reasons.

2. Every area of the sea floor has some value as a fishery resource but not every area has an equal value. It is reasonable to assume that any fishery could lose some area without significantly impacting the resource. In some cases, the area that could be sacrificed is much too small to provide an adequate disposal site. This may be the case for the lobster fishery, for instance, which is confined to a relatively small area. In other cases, relatively large areas of the fishing grounds might be committed to other uses without substantially reducing the total area available for fishing. This would be the case, for example, with the surf clam fishery, which utilizes most of the shelf area. In an initial assessment, only fisheries that are restricted to small areas of the shelf needed to be considered. Later in this report we will apply a more comprehensive method of comparing the fishing grounds through the use of a weighting factor.

3. Shoaling due to the deposition of dredged sediments must not be allowed to become a hazard to navigation. Other disposal sites have been located in or near shipping lanes without any adverse impact on either shipping or disposal activities. It may be preferable, however, to avoid establishing a new site in a shipping lane, if possible (Figure 5). Within a shipping lane the separation lane or the deeper regions may be the most feasible locations for a dump site.

4. Preferably, a replacement site should not contain historically valuable shipwrecks (Figure 6). If they do, a case-by-case evaluation will be done.

5. The replacement disposal site must be non-dispersive for dredged material. This requires that fine-grained sediment be capable of reaching the sea floor when discharged and that it is retained on the sea floor after it is deposited. A report prepared for the EPA by the U.S. Geological Survey, Woods Hole (Signell and Butman 1991) examined the resuspension and movement of varying size class material in the Bight. Additionally, results from the U.S. Army Corps of Engineers' DAMOS program demonstrate that the processes occurring during the open-water discharge of sediment have been shown to result in the emplacement of sediment on the sea floor in water depths of up to 100 m (322 ft.). Since the shelf break is at an average depth of 130 m (419 ft.), most of the Bight area would be at a suitable depth except for some small areas of the Hudson Canyon (Figure 7). As a further test of this condition, a DIFID (Disposal-From-Instantaneous Dump) model was run at the U.S. Army Corps of Engineers Waterways Experiment Station (Scheffner, 1989) and those results have been incorporated in the site selection process.

6. Potential mining sites for mineral resources, primarily sand and gravel, will be eliminated later by another criteria based sediment grain size. Generally, sites that are preferable for subaqueous mining probably would be unlikely candidates for a disposal site to contain dredged material.

Available Data

In principle, data sets must be mappable in order to be useful in discriminating among areas and sites within those areas. Their measurements must be fairly uniformly distributed throughout the Bight and the density of measurements must be sufficient to distinguish gradients in the distribution of properties. In addition, time varying properties should be represented by distributions covering the range in variation in proportion to their lifetimes, although averaged values may be appropriate in many, if not most, cases. In practice, such data sets are rare. Whenever possible, the professional judgment of the original investigators of each data set has been relied upon to interpolate among sparse data; that is, we have incorporated maps of properties whenever such maps were available. We made no attempt to reassess the quality of those data. When maps had not been generated by the original investigators, data was interpolated into grids using a number of nearest neighbor interpolation methods depending upon the format of the original data. To evaluate areas according to our criteria, 50 data sets were used.

Bathymetry

The bathymetry data input to the New York Bight GIS was obtained from the U.S. Geophysical Data Center. The data is from the National Ocean Service Hydrographic Data Base (NOSH-DB), and provides the most accurate and extensive digital bathymetric data available for the coastal waters of the continental United States. The data base includes all depth values obtained on all survey cruises, so more detailed information is found than would be available on nautical charts compiled from a single survey. The depth values, or soundings, are corrected to mean low water tidal datum. The horizontal control is North American Datum 27.

The data base for the entire U.S. consists of a total of 681 files, each file covers a one-degree square area. Fifteen files were needed to provide complete coverage of the Bight. The data were provided on one 2400 foot high-density magnetic tape. A density plot of the files was provided with the data showing the tracts of the survey cruises. Together the fifteen files comprising the New York Bight bathymetric data base contained 3,022,813 data point: 2,936,736 of the points are depths, 8778 navigation features and 77,299 bottom descriptors. The file required over 122 megabytes of storage space when it was downloaded onto the RESSAL's SUN fileserver. The file is in ASCII text format with 128 records (5120 bytes) per block. It was downloaded using the lab's high-density tape drive by the Unix *"dd"* function which facilitates reading data in any format.

Each data point is structured as a 40 character record consisting of twelve fields. The fields consisted of the survey register number, date of the survey, latitude and longitude (listed by degrees, minutes and seconds), depth and the cartographic code. The cartographic code indicates the format and units of the depth value. Units of depth for this area consisted of 1.9 million soundings in feet, 800,061 soundings in feet and tenths, 43,010 soundings in feet and fraction, 52,889 soundings in fathoms, and 54,850 soundings in fathoms and tenths. Software to read the tape and write out a file consisting of latitude and longitude in decimal degrees and depths converted to meters was written at RESSAL. The cartographic code which indicates the format of the depth was read first and according to the format the appropriate conversion was done to the depth value. The fields indicating survey date and number were not needed for the output points file. The points file created by this program consisted of 2,942,000 points.

The points file was interpolated and gridded using the RESSAL Terrapin terrain mapping package. The software was modified to handle the large number of points. The interpolating program uses an inverse distance squared weighting function. The search for points is speeded up by initially processing the points to partially fill the grid and then using an outward spiral search to fill unfilled grid cells. Even with this method which decreases processing time, the interpolation program runs for almost two hours on the lab's SPARC SUN fileserver. The program produces a binary grid file, with the specified size of 491 by 491, the size of the New York Bight GIS files.The grid file was then converted to an ERDAS format file using Terrapin. The ERDAS GIS bathymetry file was transferred to the Compaq ERDAS workstations. The file was rectified to the shoreline base map (Figure 7).The bathymetry file was used to create a slope map of the Bight (Figure 8). The ERDAS function SLOPE computes the slope of each pixel using the topographic base file. The output file showed areas with between a one and two percent slope and areas with over two percent slope.

New, detailed bathymetric surveys have been conducted recently at each of the candidate areas; such data can be incorporated into larger-scale GIS's for each area but was not considered in this report.

Shipwrecks

Historical shipwrecks are important cultural features and, if possible, these areas should be avoided as possible site locations. A catalogue of shipwreck sites are provided on the National Ocean Service Hydrographic Data Base magnetic tapes. As part of the GIS, these are displayed in Figure 6. None occur in the candidate sites. Prior to any site designation, coordination between the Corps and both the New York State Department of Parks, Recreation and Historical Preservation, Office of Historical Preservation and the U.S. Department of the Interior National Park Service Advisory Council on Historic Preservation would take place.

Fisheries

The main source of information on the geographical distributions of sport and commercial fishery grounds in the New York Bight is Long and Figley (1981). The maps compiled by these authors were digitized and incorporated in the GIS (Figures 9 to 38). All the present shelf disposal sites, as well as the six candidate disposal areas, are superimposed on these maps. Some of these maps appeared to be biased toward the New Jersey shoreline, but similar published data was not yet available from New York for comparison.

A simple way to account for the relative importance of different fisheries would be to select a few sensitive high-yield species. This was done in the preliminary trials to select candidate areas using shellfish. Another approach, using a weighting factor, involves the value of the catch divided by the area fished. This puts a direct dollar value on each unit area of the fishing ground to indicate the relative importance. High values (high income from fish caught in a small area) indicate more valuable ground. For example, lobster fishing areas cover a relatively small area of the shelf, whereas scallops cover essentially the entire shelf. Therefore, putting a replacement disposal site in a reported lobster area could have a greater effect on this fishery than a site in a scallop fishing area. Computing the areas fished, as well as the weighting factor as a whole, is easily done within the framework of the GIS.

The areas of both recreational fisheries and commercial fisheries grounds were calculated from the maps compiled by Long and Figley (1981). The dollar value of the commercial catch was taken from the National Marine Fisheries Service Reports for New York and New Jersey for 1987 (National Marine Fisheries Service, 1989). The numbers of fish caught by the recreational fishery were reported for 1986, although for a few species (red hake, bluefin tuna, tautog, striped bass) 1971 figures had to be used. The dollar value of the recreational fishery was estimated as follows. From 1983 to 1986 the total mass of the recreational catch of food fish (excluding invertebrates) was about equal to the total mass of the commercial catch (excluding invertebrates). Since the number of fish caught by the recreational fishery is known, the average value of recreational fish could be calculated ($0.54). This average value was applied to all species of the recreational catch. For assigning a weighting factor, only the relative contribution of each catch to the total value is needed. This approximation can be improved if more detailed catch statistics become available. For the purpose of this assessment, however, these relative values were adequate.

Two other assumptions needed to be made. A map was not available to show the recreational fishing ground for scup, so we assumed that it was the same as the commercial ground for scup. The value of the commercial catch of swordfish and shad were also unavailable. For the purposes of the calculation, they were assumed to be the same as the recreational value.

A series of maps were produced using the fisheries distribution data and the value of the total catch. The first map produced was based on this relative value of each species compared to the total catch. Each species was assigned a value based on its percent of the total dollar value of all fish caught in the Bight. The GIS files for each of the 27 data layers were recoded using this percent value. An overlay file was created using the ERDAS software, specifically the INDEX function which adds the values found in corresponding grid cells. The ERDAS software is limited in the number of files which can be indexed -no more than four- so there were a number of preliminary files created. The resulting output files were indexed together; the total process required three series of indexings. The final output map (Figure 39) shows the areas with the highest relative value based on the percentage of the total dollar value made up by the species in that area. The value of each area is not a quantifiable value, but a percentage.

To create a more quantitative map, a second overlay was created. The area covered by each species fishing grounds was factored into the value given to the data layers. Each file was recoded and given a number based on the total dollar value made up by that species, divided by the total area covered by that species. This new value represents the dollar value per unit area made up by that particular species. The total dollar value for each species was divided by the area covered by that species in hectares to yield a dollar value per hectare. The area covered by each species was calculated using the ERDAS program BSTATS on each of the files.

The weighting factors ranged in value from approximately $0.01 per hectare for sport striped bass to $47.94 for commercial yellowtail flounder (Table 2). The values range from $0.006 to $47.90, a numerical range of 10^4, which is too large for a one byte (0 - 255) ERDAS file. The ERDAS function INDEX cannot overlay two byte data, so the overlays had to be done in a series of steps. Files with a similar range in values such as tenths of dollars, hundreths of dollars, were indexed together in the preliminary overlay steps. Values were then rounded off to integers and, in order not to lose values under $0.5, values were rounded up for the final overlay. The resulting map ranged in value from one (including all values of one and under) to eighty-six. Figure 40 shows this overlay map..

Table 2. New York Bight: Value of Fish Catch per Unit Area

Description	Value in Dollars	Area in Hectares	Dollars per Hectares
Sport (sp)			
Striped Bass Sharks	30498.8	4587625	.006648
Mackerel	1524940	943925	1.6155
Cod-Pollack	15249.4	572825	0.0266
Whiting	914964	759240	0.1205
Red Hake	3507362	759240	0.4619
Black Sea Bass	1273324	9705100	18.058
F.Albacore, Bonito, Skipjack	2439904	1203950	0.20265
Bluefin Tuna	869215.8	1241300	0.700211
Weakfish	1707932.8	73575	23.213
Bluefish	7304462.6	812850	8.986
Yellowfin	1540189.4	579000	2.660
Albacore	3659856	209625	17.45
Bigeye	457482	144100	0.317
Tautog, Swordfish	91496.4	1016475	0.090
Fluke, Marlin	8707407.4	956075	9.107
Commercial (cm)			
Bluefish and Weakfish	2455153.4	606475	4.048
Fluke (by season)	10796575.2	3332975	3.239
Yellowtail Flounder	442232.6	9225	47.938
Mackerel	16557242	1891800	0.3466
Whiting and Red Hake	4102088.6	1569775	2.613
Cod	472731.4	23850	19.821
Black Sea Bass	1189453.2	2940500	0.4045
Scup	4239333.2	2270400	1.867
Butterfish	884465.2	973900	0.908
Menhaden, Tilefish	7319712	7297501	0.030
Swordfish, American Shad	91496.4	366425	0.249
Surf Clam	17506311.2	1038300	16.861
Quahog	30178562	1216025	24.810
Scallops	13983699.8	1983975	7.048
Lobster, Red Crab	8051683.2	861350	9.348
Squid	5047551.4	1331025	3.792

Source: National Marine Fisheries Service, 1988 Survey

Sediments

The sediment data that is included here is the surface gravel and clay distributions (Figures 41 and 42) from Freedland and Swift (1978), and the silt concentration in surface cores (Figure 43) from Reid, et al. (1982). These sediment data include some inconsistencies because they come from more than one source. An updated sediment data base for the New York Bight is being developed by Dr. Poppe of the U.S. Geological Survey at Woods Hole, and his data are being incorporated into our GIS where they supplement our sediment maps.

Benthic Biomass

Data sets on benthic populations covering the entire Bight are rare, but such information can provide a useful surrogate for benthic productivity. Information on population densities and diversity were not available, but sediment biomass concentration has been measured (Wigley and Theroux, 1981) and is presented in Figure 44. There were no maps available representing the temporal variability of the benthic biomass.

We know of no widely-accepted method to quantify the effects of the loss of an area of the sea floor on the ecosystem in general. In principle, the ecological value of a particular area might be considered to be proportional to its productivity, but productivity is virtually impossible to measure especially when migratory species are involved. Data on population densities or biomass, as described above, can be a useful surrogate for benthic productivity in a site-selection process.

Since this valuable data is sparse, the GIS may be used to search for correlations between the characteristics of benthic populations and more easily measured parameters in order to better interpolate or extrapolate any available biological data throughout the entire Bight. As an example of the type of analysis that can be preformed with the GIS, the biomass was overlaid with some of the clay sediment file to determine if there is any correspondence between these factors. Figure 45, which displays these categories, illustrates the relationship between these two parameters; i.e., most of the shelf surface has either low biomass and low clay, or high biomass and low clay. The map shows that only the shelf slope has high clay and low/high biomass.

Sediment Chemistry

The surficial sediment chemistry data from Reid, et al. (1982), including total organic carbon, total Kjeldahl nitrogen and concentrations of chromium, lead, cadmium, mercury, nickel, zinc, and copper are shown in Figures 46 -54. These maps were generated from the point data using the ERDAS SURFACE program. It uses an inverse distance weighting interpolator.

In general, all the contaminants have a similar distribution.They are associated with the finest sediments and suggest dispersal from the port across the shelf along the Hudson Channel. Since the Ocean Dumping Act requires "no further degradation" of the environment, it has been proposed that future disposal sites should be located in areas that are already contaminated to avoid the contamination of new areas. This criteria has not been applied to the present study, but the data in map form are available to do so.

Current Data From Numerical Models

The DIFID data results are based upon a combined flood tide and non-storm induced circulation (Scheffner, 1989). Unlike the other data sets which are primarily from digitizing existing maps, these data were incorporated in our GIS by directly inputting the separate latitude, longitude and current velocity table data, as well as the latitude, longitude, and current direction table, from Scheffner (1989). As with the contaminants a point was created for the current direction data and the current velocity data. The files were interpolated into a grid using the Terrapin program. The grid files were converted to ERDAS GIS files and the candidate sites were superimposed on this map. The current velocity data are displayed in Figure 55.

The separate current velocity and direction files were overlaid to create a map showing current velocity and direction (Figure 56). The current velocity map was recoded into two categories, high velocity (29 cm/sec.and over) and low velocity (under 29 cm/sec).The current direction file was recoded into onshore and offshore current direction. The two files were combined using the ERDAS INDEX function.

Data Analysis

A Zone of Siting Feasibility Study incorporating the information provided by the GIS was prepared by Pechko and Freeman (1990). The following section describes the type of analyses that were performed using the GIS to aid in the selection process.

A preliminary assessment of the six candidate areas was made by overlaying first five, and then seven, data sets (Figures 57 and 58). In the first assessment, the data included the New York shipping channels (which cover a significant portion of the shelf area), the Hudson Canyon (as defined by the 50 m contour), the areas containing over five percent gravel in the surface sediments representing potential dispersive areas, recreational fishing areas, and areas of important shellfish populations. The six candidate areas were superimposed on these data. The shelf area was assigned values from 0 to 5, depending on the number of times any given area falls within one of the five above categories. Thus, 0 indicates the most likely candidate areas and 5 indicates the least likely areas.

It can be seen that candidate area C1 (the northernmost) is at the confluence of the three shipping channel, and is, therefore, not a good candidate area based on these criteria. Candidate area C2 (the second to the south) was the best of the four areas, based on these five parameters only, as it does not occur coincident with any adverse criteria (Figure 57). Candidate areas C3 and C4 (the two southernmost sites) contain at least 2 of the designated categories.

A second test was made by adding two additional parameters: biomass and changing the shellfish category into two alternatives; the presence of one or two species of shellfish (from among lobster, clams and red crab). The conclusions are the same as the five parameter overlay. C1 is the least likely candidate area; C2 is the best; and C3 and C4 are intermediate (Figure 58). Area C3 is characterized by two species of shellfish, whereas area C4 contains two species of shellfish and a high percentage of gravel in the bottom sediments. In these analyses, at least two other areas, which were outside the four preliminary areas, appeared as likely candidates. One was between the northern and central shipping lanes, and the other area was southeast of area C4. Since these areas appear similar to area C2, they might merit further consideration.

Further clarification is achieved by a more detailed analysis of the seven data layers. Even with only seven data sets, 56 different categories can be discriminated, each a unique combination of the seven data layers or their absence. For the shelf, as a whole, the combination categories that make up more than 3% of the shelf area in descending order include: shellfish (one species); high biomass and one shellfish; high gravel and one shellfish; Hudson Canyon and high biomass; gravel high biomass and one shellfish; shipping lanes and one shellfish; and Hudson Canyon. Because of the complicated mosaic resulting from the input of only 7 of the 80 data layers which are available, it is obvious that mere superimposition of all data layers will not in itself delineate the best areas for a replacement dredged material disposal site.

A statistical listing of the file by category provides information on the number of pixels in each category, the area covered by each category (in hectares) and the percent of the entire area contained within that category is presented in Table 3

Table 3. Number of Hectares and Percent of Total Bight Area in 56 Matrix Categories

KEY TO ABBREVIATIONS USED: High Biomass(HB),Shellfish(1S,2S),Gravel(G), Recreational and Commercial fishing(R),Hudson Canyon(C),Shipping Lanes(S)

VALUE	POINTS	Hectares	%	DESCRIPTION
0	22865.	571625.000	0.00 %	Land
1	1304.	32600.000	0.60 %	HB
2	41773.	1044325.000	19.14 %	1S
3	23374.	584350.000	10.71 %	HB,1S
4	4053.	101325.000	1.86 %	2S
5	335.	8375.000	0.15 %	HB,2S
6	84.	2100.000	0.04 %	G
7	28.	700.000	0.01 %	G,HB
8	12342.	308550.000	5.66 %	G,1S
9	8468.	211700.000	3.88 %	G,HB,1S
10	569.	14225.000	0.26 %	G,2S
11	891.	22275.000	0.41 %	G,HB,2S
12	103.	2575.000	0.05 %	R
13	4366.	109150.000	2.00 %	R,1S
14	1687.	42175.000	0.77 %	R,HB,1S
15	555.	13875.000	0.25 %	R,2S
16	98.	2450.000	0.04 %	R,HB,2S
17	645.	16125.000	0.30 %	R,G,2S
18	1111.	27775.000	0.51 %	R,G,HB,1S
19	119.	2975.000	0.05 %	R,G,2S
20	28.	700.000	0.01 %	R,G,HB,2S
21	8173.	204325.000	3.75 %	C
22	11226.	280650.000	5.14 %	C,HB
23	1940.	48500.000	0.89 %	C,1S
24	2263.	56575.000	1.04 %	C,HB,1S
25	113.	2825.000	0.05 %	C,2S
26	273.	6825.000	0.13 %	C,HB,2S
27	333.	8325.000	0.15 %	C,G
28	1724.	43100.000	0.79 %	C,G,HB
29	67.	1675.000	0.03 %	C,G,HB,1S
30	99.	2475.000	0.05 %	C,G,HB,2S
31	247.	6175.000	0.11 %	C,G,R,HB,1S
32	50.	1250.000	0.02 %	C,G,R,2S
33	11.	275.000	0.01 %	S
34	17.	425.000	0.01 %	S,HB
35	7955.	198875.000	3.65 %	S,1S
36	5495.	137375.000	2.52 %	S,HB,1S
37	977.	24425.000	0.45 %	S,2S
38	113.	2825.000	0.05 %	S,HB,2S
39	2004.	50100.000	0.92 %	S,G,1S
40	22.	550.000	0.01 %	S,G,2S
41	32.	800.000	0.01 %	S,G,HB,2S
42	159.	3975.000	0.07 %	S,R,HB,1S
43	16.	400.000	0.01 %	S,R,2S
44	62.	1550.000	0.03 %	S,R,HB,2S

Continued on Next Page

Table 3. Continued

VALUE	POINTS	Hectares	%	DESCRIPTION
45	29.	725.000	0.01 %	S,R,G,2S
46	32.	800.000	0.01 %	S,R,G,HB,2S
47	982.	24550.000	0.45 %	S,C,HB
48	52.	1300.000	0.02 %	S,C,1S
49	175.	4375.000	0.08 %	S,C,HB,1S
50	44.	1100.000	0.02 %	S,C,2S
51	15.	375.000	0.01 %	S,C,HB,2S
52	2298.	57450.000	1.05 %	S,C,G,HB
53	16.	400.000	0.01 %	S,C,G,HB,1S
54	18.	450.000	0.01 %	S,C,G,HB,2S
55	154.	3850.000	0.07 %	S,C,R,2S
Totals:	218216.	5455400.000		

To better account for the diverse fisheries in the Bight, the individual fisheries were weighted, as described earlier, by the ratio of the total value of the catch to the area of the fishing grounds. The results of these calculations are shown in Figures 39 and 40. These data were then related to other layers in the GIS. Two other files, in particular, represented important factors which needed to be evaluated along with the economic value of the fisheries. One of the files to be overlaid was the distribution of areas with over five percent gravel in the bottom sediments as indicative of a non-depositional site. The second file shows the three commercial shipping lanes into the New York Harbor. The gravel and shipping lanes files needed to have a numerical value assigned to them in order to relate them to the fisheries map. The value is essentially an artificial one since assigning a comparable economic value to shipping areas or dredged sediment dispersion area is problematical. The values of the fisheries map are based on dollars per hectare, and while factors such as percent gravel and shipping lanes are important, a dollar value is not applicable. For our analysis the gravel and shipping lanes were assigned a value based on the average dollar value of the fisheries file. This choice essentially assigns an equal weight to the two physical criteria and to the combined fisheries criteria. Each file was assigned the value of the average dollars per hectare for the entire Bight. The total area covered by all the fisheries in the Bight is 3,754,325 hectares, while the total value of the commercial and sport fisheries catch in the Bight is $152,494,000. This comes out to an average value per hectare of $40.61. The recoding was done within the INDEX function of ERDAS, the resulting file had values ranging from 1 to 166. The existing and proposed dumpsites were then overlaid onto this map.The result of this overlay is shown in Figure 59.

Field work in March, 1989 involving current measurements, side scan sonar, REMOTS (Remote Ecological Monitoring of the Seafloor) imagery and sub-bottom profiling, was employed in order to determine the bottom energy for potential stability of the sites under consideration (Battelle 1990) and (Dragos and McDowell, 1990). Portions of C1, the northwest corner of C2, and portions of E1 were recommended for further consideration as potential disposal sites based on the results of these studies. Candidate areas C3 and C4, were not recommended by Battelle and Science Applications International (1990), as these were considered too dynamic for a potential disposal site. These results are consistent with our own independent GIS analysis based upon all available prior data. These conclusions are further supported by the results of the physical oceanographic analysis (Dragos and McDowell, 1990) in which the potential for sediment resuspension by currents and/or surface waves was examined. It was concluded that, "...tides and wind driven currents are rarely (i.e., less than a few percent) strong enough to resuspend natural sediments within the six study areas." However, when all wave heights, periods and directions are taken into account, wave-induced resuspension of medium to coarse grained natural sediments is most likely to occur at area C4, perhaps as often as 25% of the time. Estimated frequency of resuspension of dredged material is lower at C2, than at C4(Dragos and Mcdowell, 1990).

This information was supplemented by studies employing numerical computer models at the Waterways Experiment Station in Vicksburg, Mississippi (Scheffner, 1989). Here, two dispersive aspects were investigated: the effect of the descending sediment plume, and the longer term stability of the in-place disposal mound. Whereas DIFID was used to compute the short term fate of the sediment plume, a coupled hydrodynamic/sediment model was used to compute the long term fate of the disposal mound. It can be seen that candidate areas C1 and C2 fall in the highest velocity area (31 to 39 cm/sec.), C4 falls in the lowest category (<20 cm/sec), and the currents at C3 reach intermediate velocities (Figure 55). Figure 56 shows the result of the overlay done with the DIFID current velocity data and the DIFID directional data. Here, we see that areas C1 and C2 fall in areas predicted by DIFID to have high velocity, onshore currents. From these computations for the New York Bight, Scheffner (1989) ranked the candidate disposal sites in the following order, from less to more dispersive:

C4, C3	Least Dispersive
C2	
C1	Most dispersive

However, all candidate areas were shown to be less dispersive than the present Mud Dump Site, and it was concluded by Scheffner (1989) that all these areas, as well as most other areas of the New York Bight, could be considered as non-dispersive areas.

The Apex GIS

The location and bathymetry of the Bight Apex is shown in Figure 60. Superimposed on this figure are the present Mud Dump Site, three other formerly active disposal sites on the shelf, Cellar Dirt Site, Sewerage Sludge Site, and the Acid Waste Site, and the C1 and C2 candidate areas (see Figure 1). In the bathymetric gradient map of the Apex (Figure 61), the Hudson Canyon is clearly delineated.

As previously discussed, simply enlarging the data sets from the New York Bight GIS, does not provide more detail because of the raster structure of this GIS. Thus, it was necessary to redigitize the original data in order to construct the Apex GIS. An example of the difference in detail between enlarging the New York Bight GIS data layers and constructing the Apex GIS is shown by Figures 62 and 63 (Lobster Distribution) and between Figures 64 and 65 (Biomass Density).

Figures 66 to 94 present the Apex GIS data layers. In nearly every case, these are the same data, but at a much better resolution, than in the New York Bight GIS although the fisheries for some species do not occur in the Apex, and therefore, these figures are not included. The five category overlay of the New York Bight GIS has been recalculated and the ranking of various portions of the Apex area is shown in Figure 91. The value of the commercial and recreational fisheries, in dollars per hectare was completely recalculated using the Apex GIS fisheries data, and the results are shown in Figure 92. In comparing the differences of these two Apex GIS figures with the computed figures from the New York Bight GIS, it can be seen that portions of C1 and C2 have large areas of high dollar value of fishing grounds (>90 dollars per hectare), whereas other portions of C1 and C2 do not. The area due east and to the south of the existing Mud Dump Site also appears promising in that these areas contain the lowest dollar values of fishing grounds. The results of the Apex GIS are consistent with the results of the New York Bight GIS. However, its importance is that the greater detail needed to delineate potential candidate dump site areas is now available to the decision makers.

In addition, data covering only the Apex area which could not be used in the full Bight GIS can now be used, such as detailed sediment data from Freedland (1981) shown in Figure 89. Also included in the Bight Apex GIS database are the results of the Transportation Cost-Distance Analysis done by Kearney, Inc./Battelle (1988), shown in Figure 93. This map can be used as an additional weighting factor that can be incorporated into the fisheries and other data in responding to queries on disposal site location.

DISCUSSION

Although this GIS has been successfully applied to the New York Bight with regards to delineating the best possible areas for candidate disposal areas, some basic philosophical questions were raised. These concern the differences between a Terrestrial *GIS* and a Marine *GIS*. The term geographic information system has been considered synonymous with land information system, and the development and implementation of these systems is biased toward two-dimensional continuous surfaces. Such systems have been widely implemented to a great range of applications. The potential for use in the marine environment is very high but there are fundamental differences between land-based and sea-based systems that place special demands on the marine GIS. These demands pose new classes of problems to be addressed before the GIS potential can be realized. The particular characteristics of a marine GIS have been discussed by Davis and Davis (1988) and Ehlers, et al. (1990). One of the principal problems is the varying scale of available data. Oceanographic information is usually in sparse arrays covering very large areas. Patterns of current, salinity, temperature or migratory routes, for example, are defined only broadly by regional gradients without sharp or permanent boundaries. Human activity, however, is usually restricted to very small areas which might not be delineated on the regional scale. Areas important for the use of the marine resource, like disposal areas or sand mining sites, would be represented by only a few pixels while other cultural features such as wrecks, fishing reefs, navigational aids or oil rigs cannot be resolved on the regional system. Because of the activity in these areas however, data acquisition is often concentrated around them. The problem is to represent the details of these data within the regional GIS so that it can both contribute to, and be interpreted in the regional context. To do this a sea-based GIS must be able to simultaneously retain both small and large scales.

In contrast to a land-based GIS, a complete marine GIS also will need at least three dimensions in order to represent the distribution of attributes in the ocean, their change with time and interdependence with other non-spatial parameters.Terrestrial GIS systems function primarily in describing variations on a surface. The fluid nature of the marine environment makes it difficult to map as a static GIS data layer. Fundamental parameters such as currents and tides, are not adequately described by a single numerical value or attribute label. The ability of a GIS to combine data layers in order to answer questions is what makes it such a powerful tool. This task is difficult in the marine environment since there are such different, yet related, phenomena. Interactions which need to be measured occur spatially in three dimensions, as well as continually in time.

The question of scale is also a factor when looking at time, the different parameters occur over widely varying cycles. Surface temperature changes seasonally while tidal change occurs both monthly and daily. Obtaining data over the relevant time scale can become a limiting factor. Cruises are costly and are limited by factors such as weather, ocean depth and distance from land. High cost data such as satellite imagery, provide a "snapshot" which may or may not be representative of the typical conditions.

Specifically, the future efforts needed in GIS analyses include:

1. The bathymetric data in the GIS might be used to extrapolate DIFID results to the whole New York Bight area. In addition, other "derived" maps could be produced, such as the maximum bottom shear stress under combined waves and currents, and a stratification parameter (the water depth divided by the maximum tidal velocity cubed). The latter param-

eter is a dynamic stratification number used by Pingree and Griffiths (1978) for the North Sea to denote stratification zones and mixed water columns. It has also been used in Long Island Sound. The data to produce these derived maps should be readily available in the GIS. This information is useful in predicting stability of frontal systems, which is of great interest in determining dispersive conditions, as well as being important inputs to models.

2. As was shown at the recent workshops on monitoring and modeling (U.S. Army Corps of Engineers/N.Y. District, June and July, 1989), much useful information for the New York Bight can be gleaned from satellite images. For example, sea surface temperature and the Hudson River sediment plumes are easily discernible from Advanced Very High Resolution Radiometer (AVHRR) data, considered reliable, and can be extracted from the images with known and reliable techniques (e.g., Polcyn and Sattinger, 1979). The sediment plume data can give useful information on surface currents and dispersive characteristics over the shelf. The concentration of chlorophyll a in the New York Bight has been mapped using the Coastal Zone Color Scanner (CZCS) (Johnson and Ohlhorst, 1981). Such satellite derived data has already been used as input to a GIS for the Gulf of Maine (Ehlers, et al., 1990). The ERDAS software allows for relatively easy manipulations between the remote sensing imagery and the GIS. LANDSAT and other multispectral data can add sea surface color, while scan-digitized space shuttle hand-held and other high altitude infrared and visual photography, especially when showing sun glint, can add wave direction and other information. Radar altimetry data such as GEOSAT can be used to calculate wave height and surface wind speed.

3. Much physical oceanographic data exists, such as in the summary of Stoddard and Han (1989). One of the questions, at the frontiers of GIS research, is how to incorporate these three-dimensional and time series data into the GIS. One obvious way is to treat each depth and time step as a separate map and to develop interactive links between the associated data. Another possibility is to construct vertical cross-sections, such as at the Rockaway - Sandy Hook traverse boundary. A GIS's ability to grid data in various ways can be used to format data for input into modeling efforts.

4. Expansion of the GIS into additional hierarchical data layers. Ongoing efforts involve creating additional layers, both smaller scale and larger scale. The larger scale layers are the C1 Candidate Site area, C2 Candidate Site area, Mud Dump and Adjacent area, and the Mud Dump Site (Figure 94). Each layer is at a specific scale using data obtained for the specific site. A smaller scale GIS is planned to incorporate the results of the modelling effort being carried out by the U.S. Army Corps of Engineers Waterways Experimental Station.

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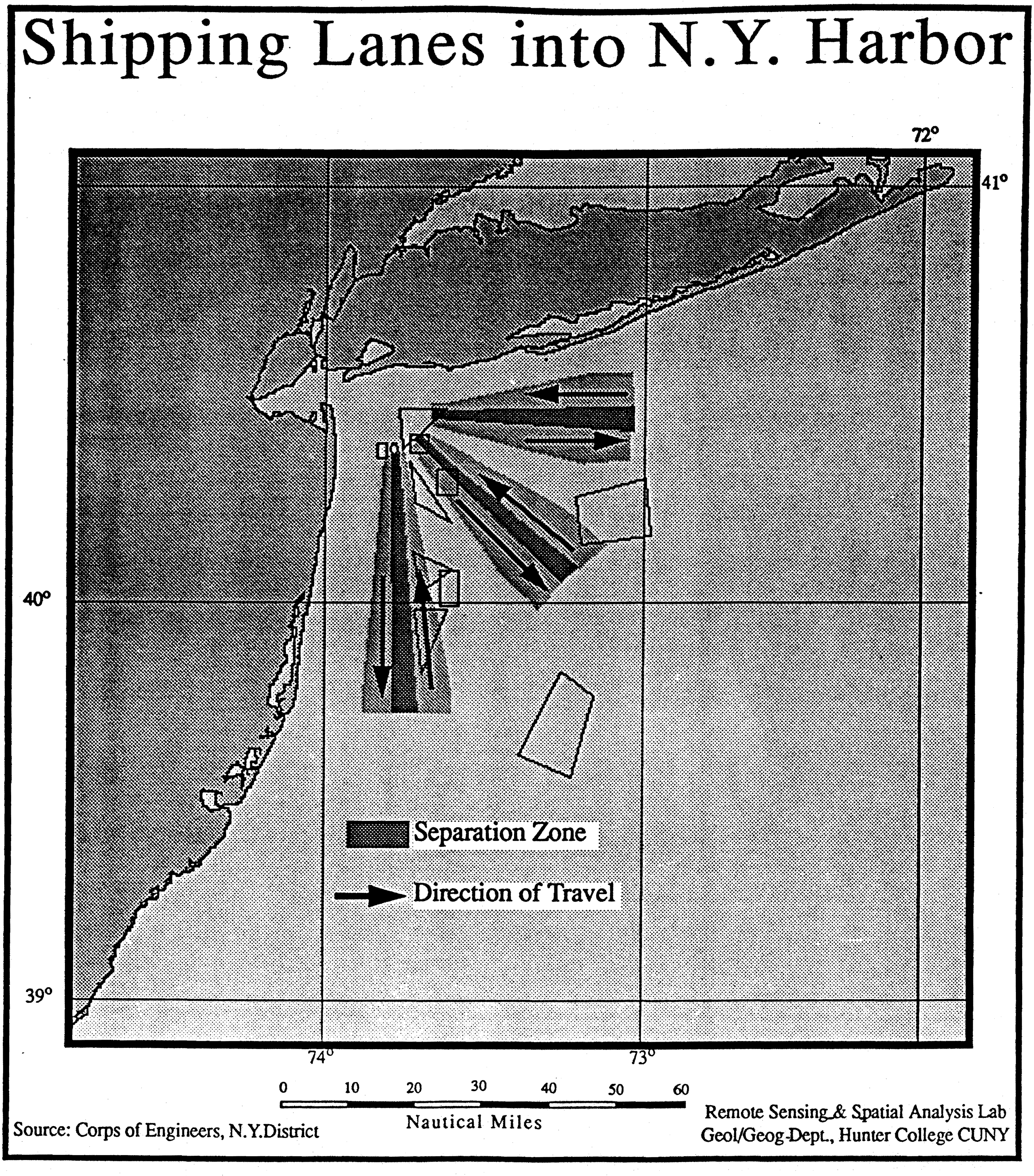

Shipping Lanes into N.Y. Harbor
72°
41°
40°
39°
74°
73°
Separation Zone
Direction of Travel
0
10
20
30
40
50
60
Nautical Miles
Source: Corps of Engineers, N.Y.District
Remote Sensing & Spatial Analysis Lab
Geol/Geog Dept., Hunter College CUNY

Figure 5

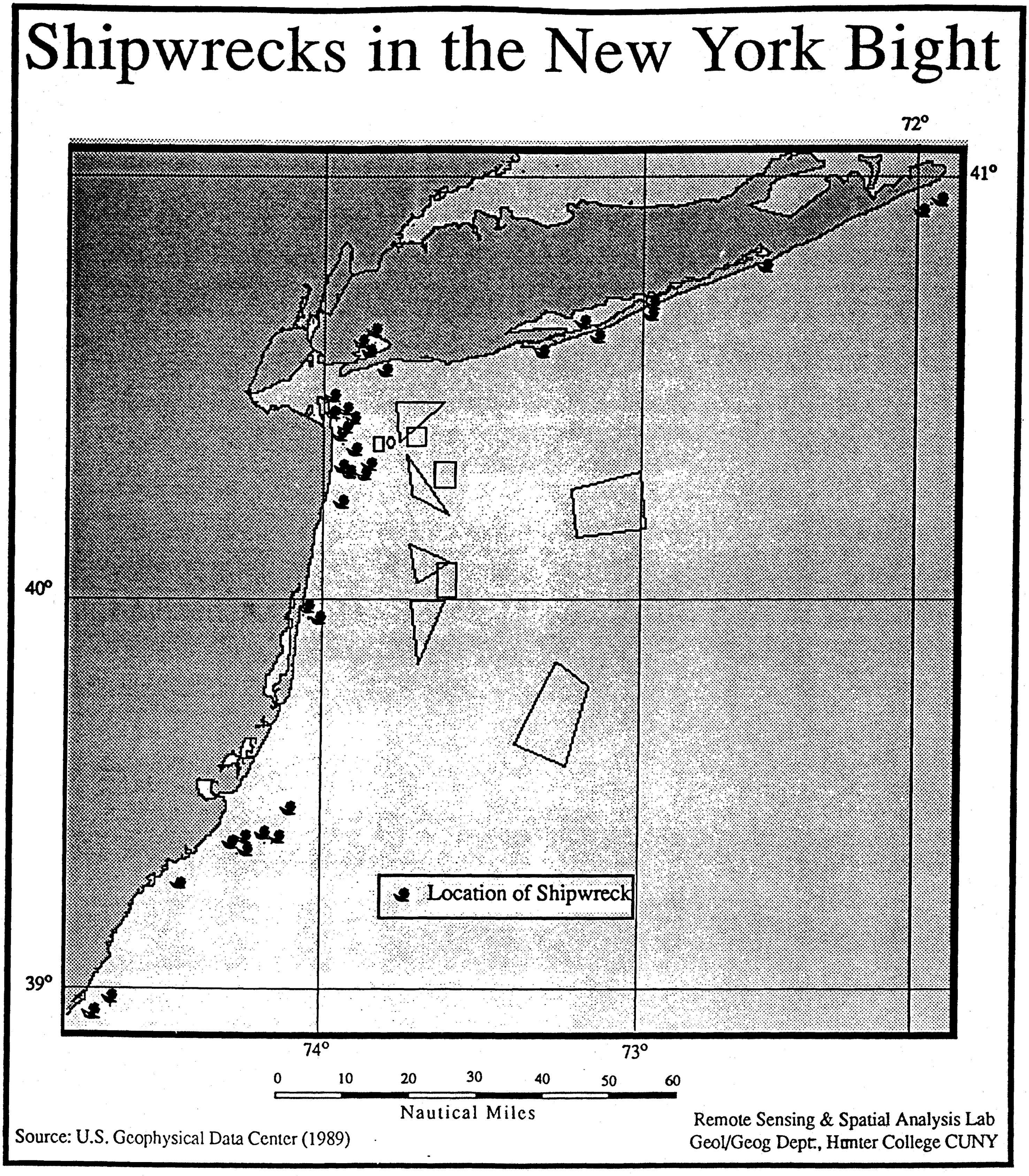

Shipwrecks in the New York Bight
72°
41°
40°
39°
74°
73°
Location of Shipwreck
0 10 20 30 40 50 60
Nautical Miles
Source: U.S. Geophysical Data Center (1989)
Remote Sensing & Spatial Analysis Lab
Geol/Geog Dept., Hunter College CUNY

Figure 6

New York Bight Bathymetry

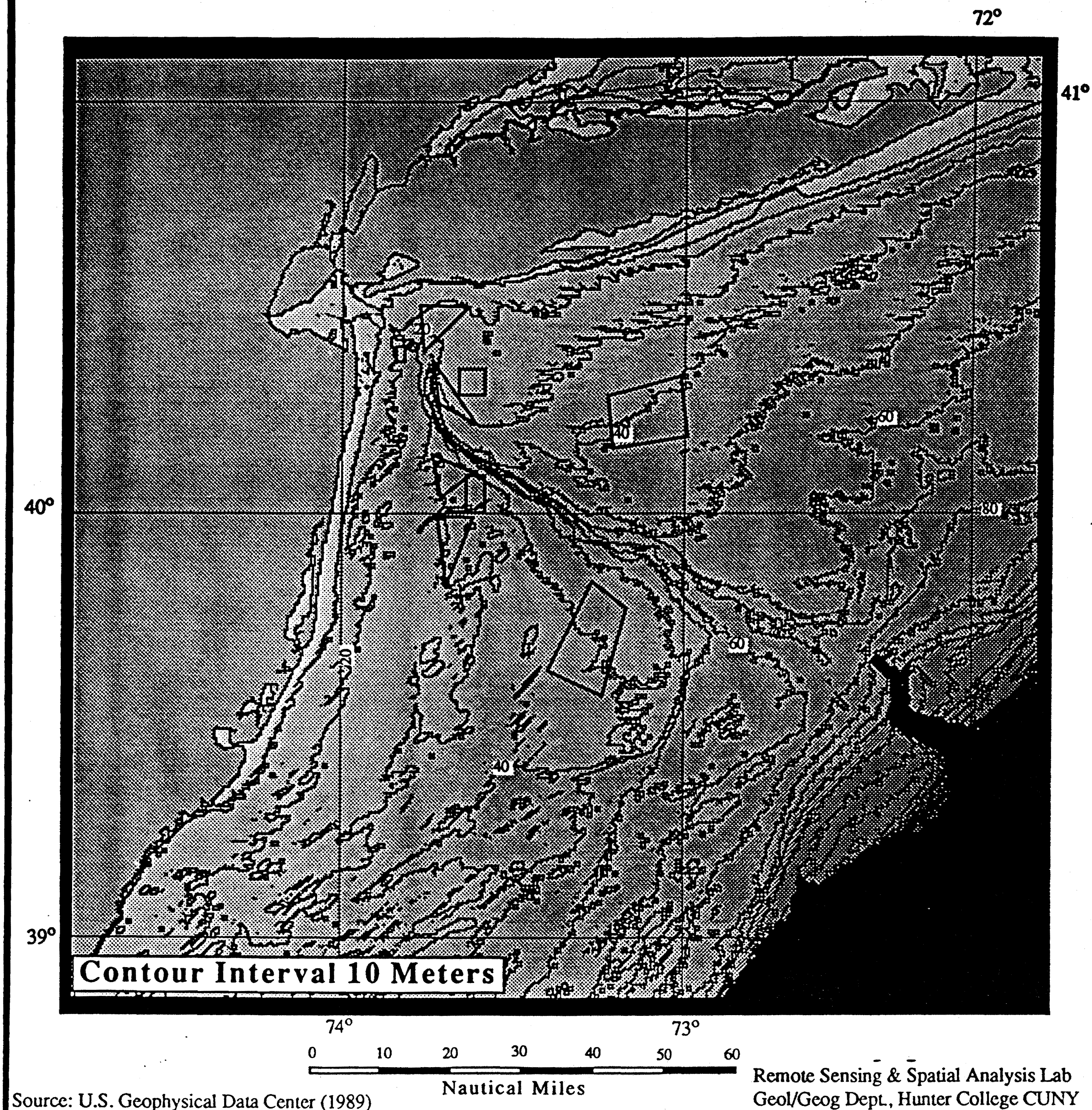
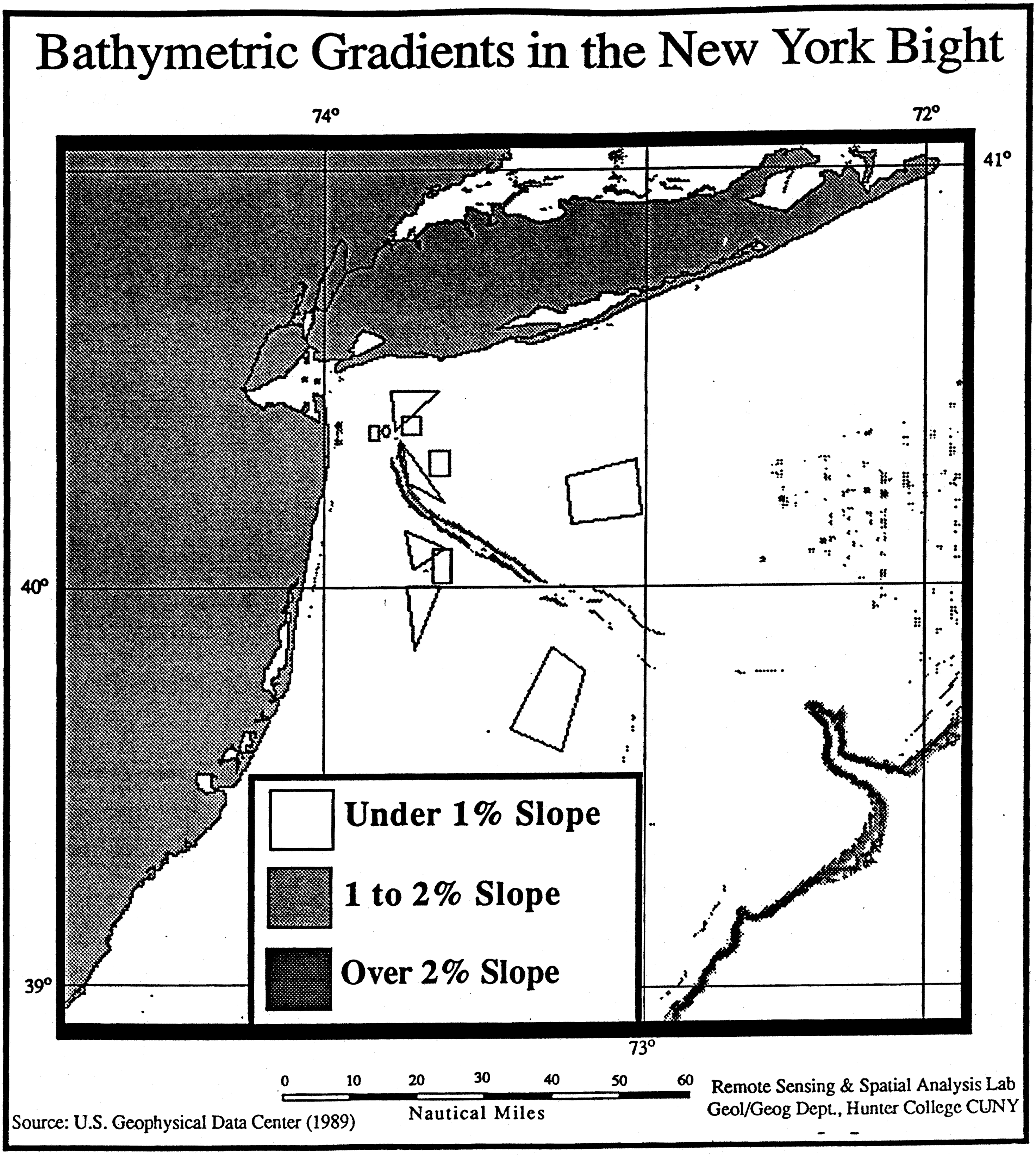
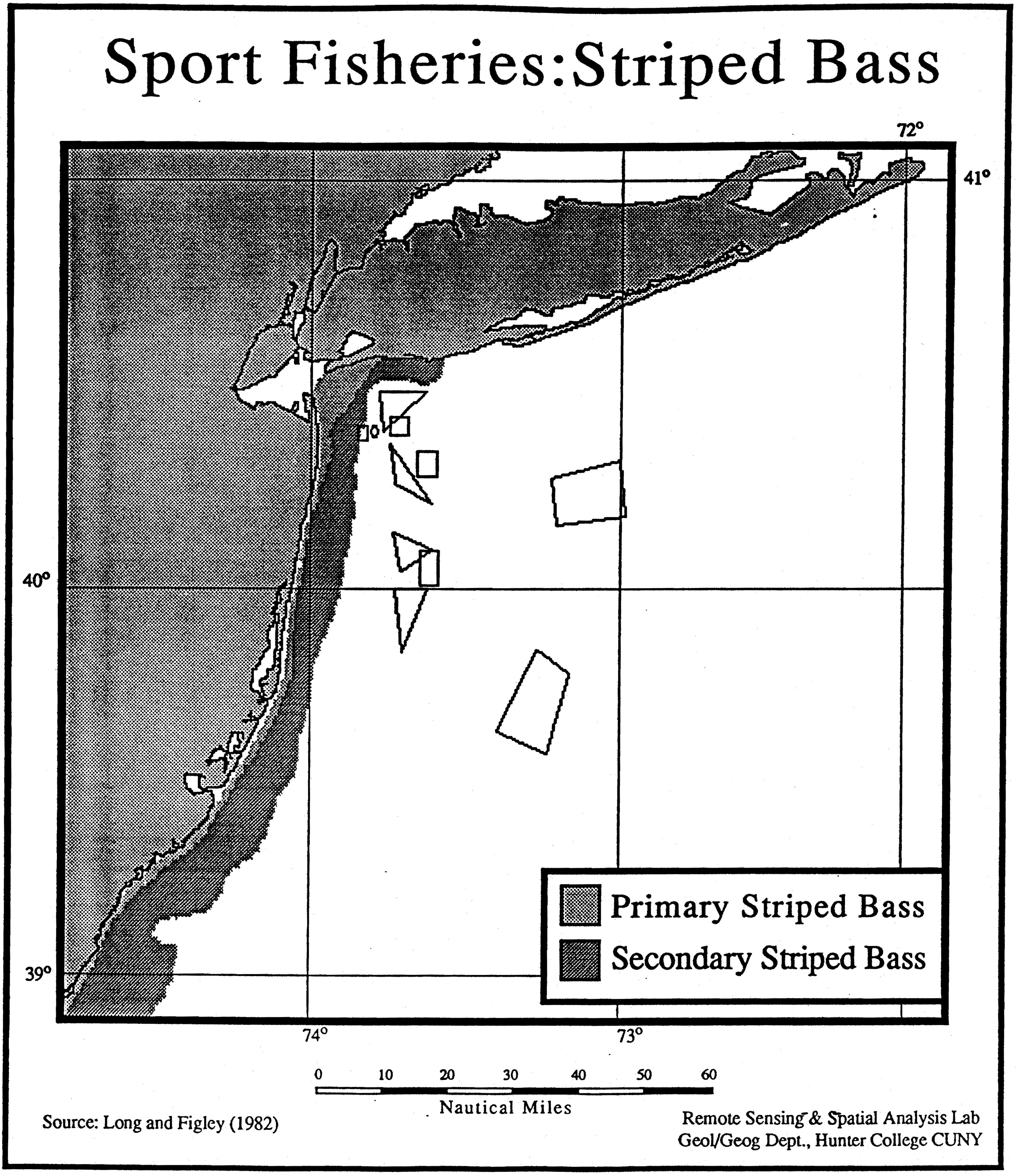


Figure 7



Bathymetric Gradients in the New York Bight
74°
72°
41°
40°
39°
73°
Under 1% Slope
1 to 2% Slope
Over 2% Slope
0
10
20
30
40
50
60
Nautical Miles
Source: U.S. Geophysical Data Center (1989)
Remote Sensing & Spatial Analysis Lab
Geol/Geog Dept., Hunter College CUNY

Figure 8



Sport Fisheries:Striped Bass
72°
41°
40°
39°
74°
73°
Primary Striped Bass
Secondary Striped Bass
0
10
20
30
40
50
60
Nautical Miles
Source: Long and Figley (1982)
Remote Sensing & Spatial Analysis Lab
Geol/Geog Dept., Hunter College CUNY

Figure 9

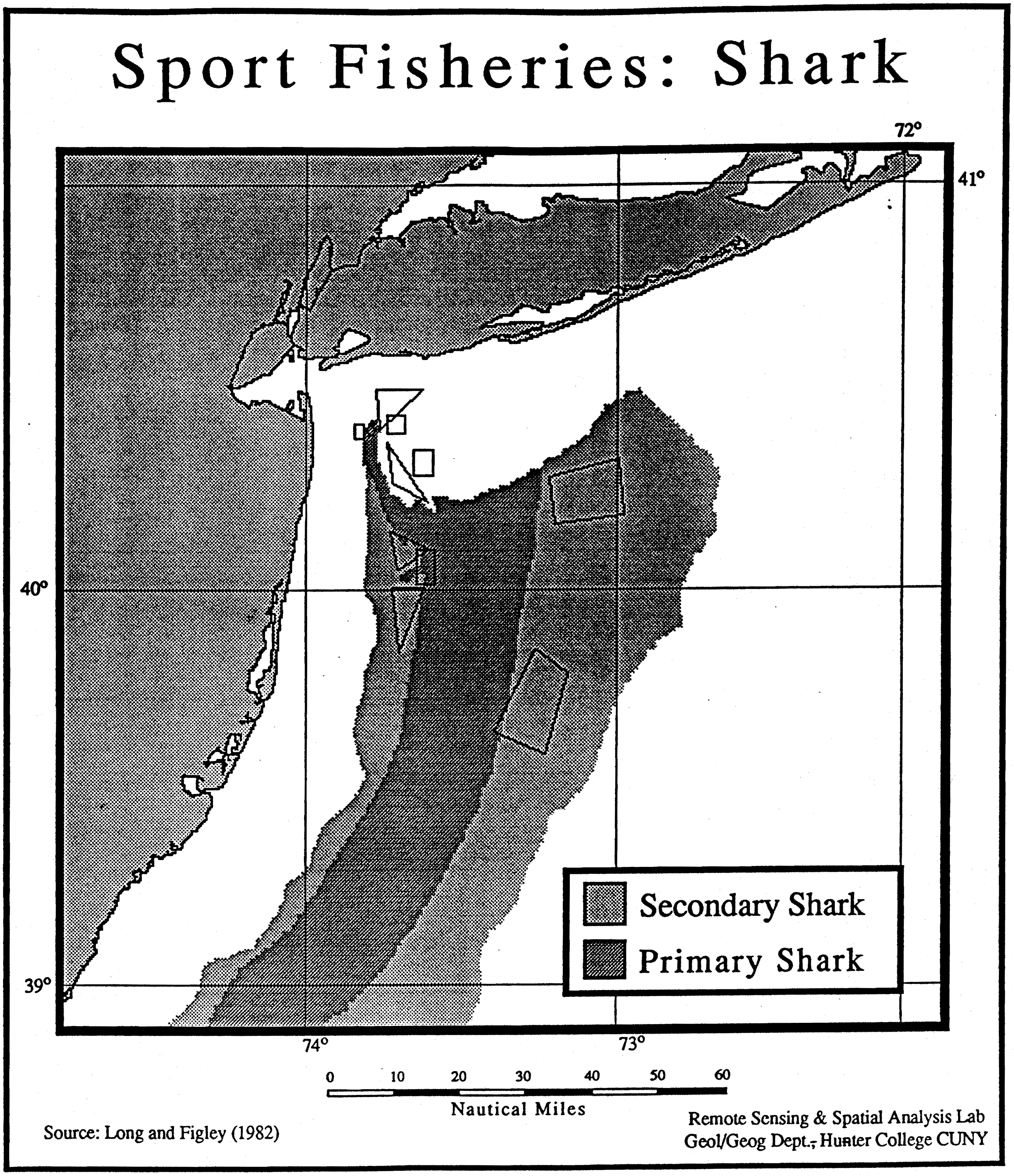

Sport Fisheries: Shark
72°
41°
40°
39°
74°
73°
Secondary Shark
Primary Shark
0
10
20
30
40
50
60
Nautical Miles
Source: Long and Figley (1982)
Remote Sensing & Spatial Analysis Lab
Geol/Geog Dept., Hunter College CUNY

Figure 10

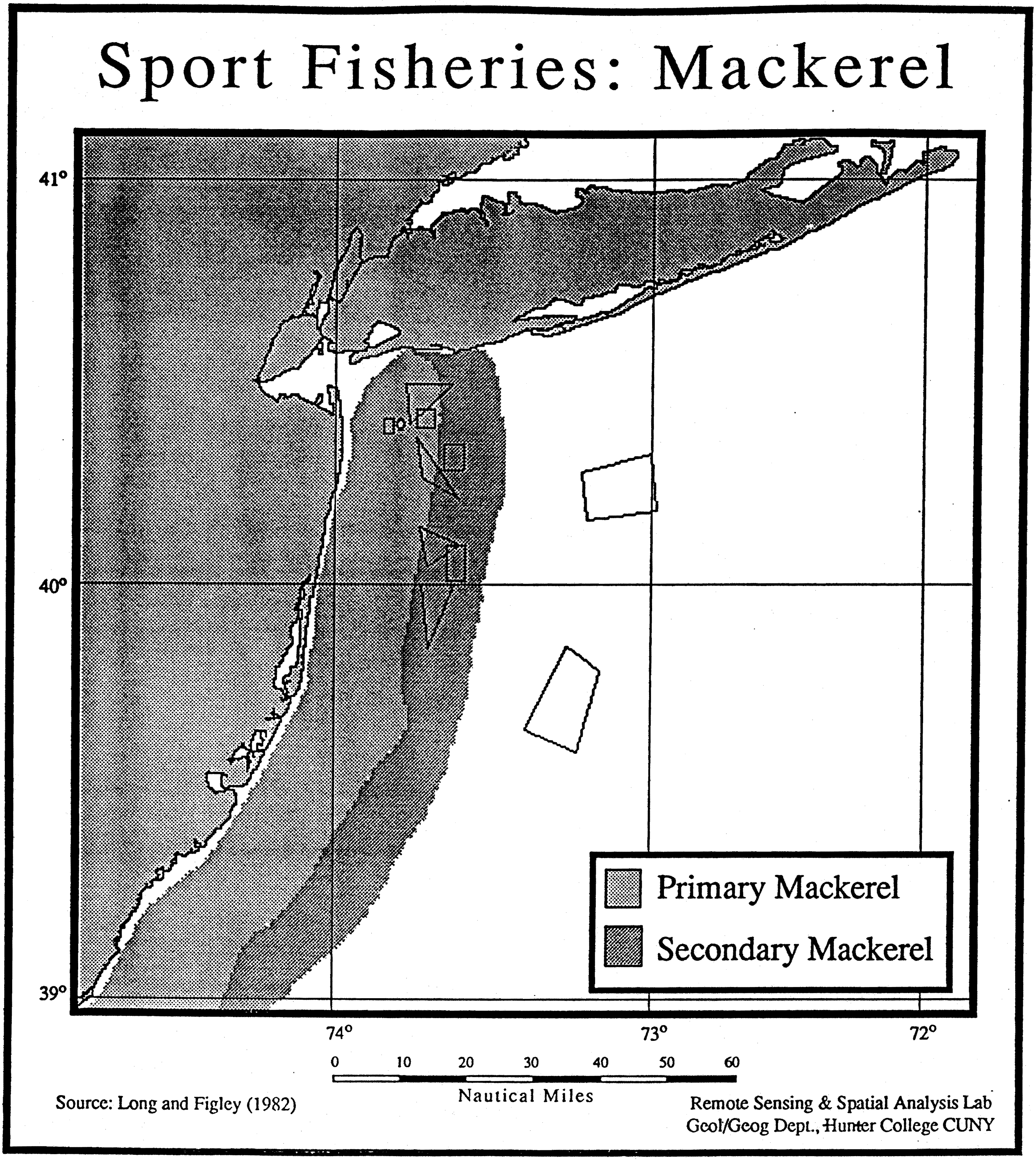
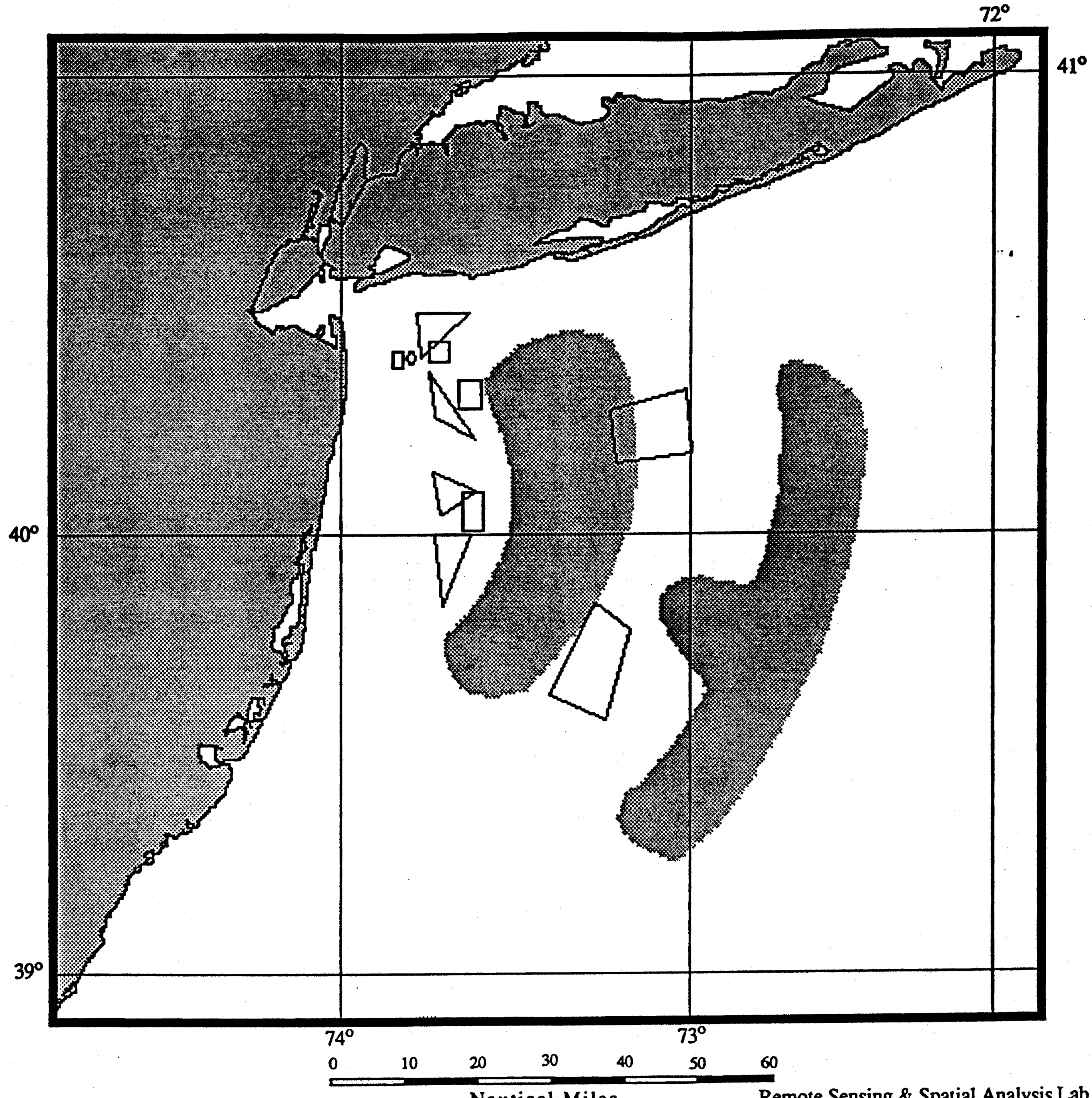

Sport Fisheries: Mackerel
41°
40°
39°
74°
73°
72°
Primary Mackerel
Secondary Mackerel
0 10 20 30 40 50 60
Nautical Miles
Source: Long and Figley (1982)
Remote Sensing & Spatial Analysis Lab
Geol/Geog Dept., Hunter College CUNY

Figure 11

Sport Fisheries: Cod - Pollack



Source: Long and Figley (1982)

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Figure 12

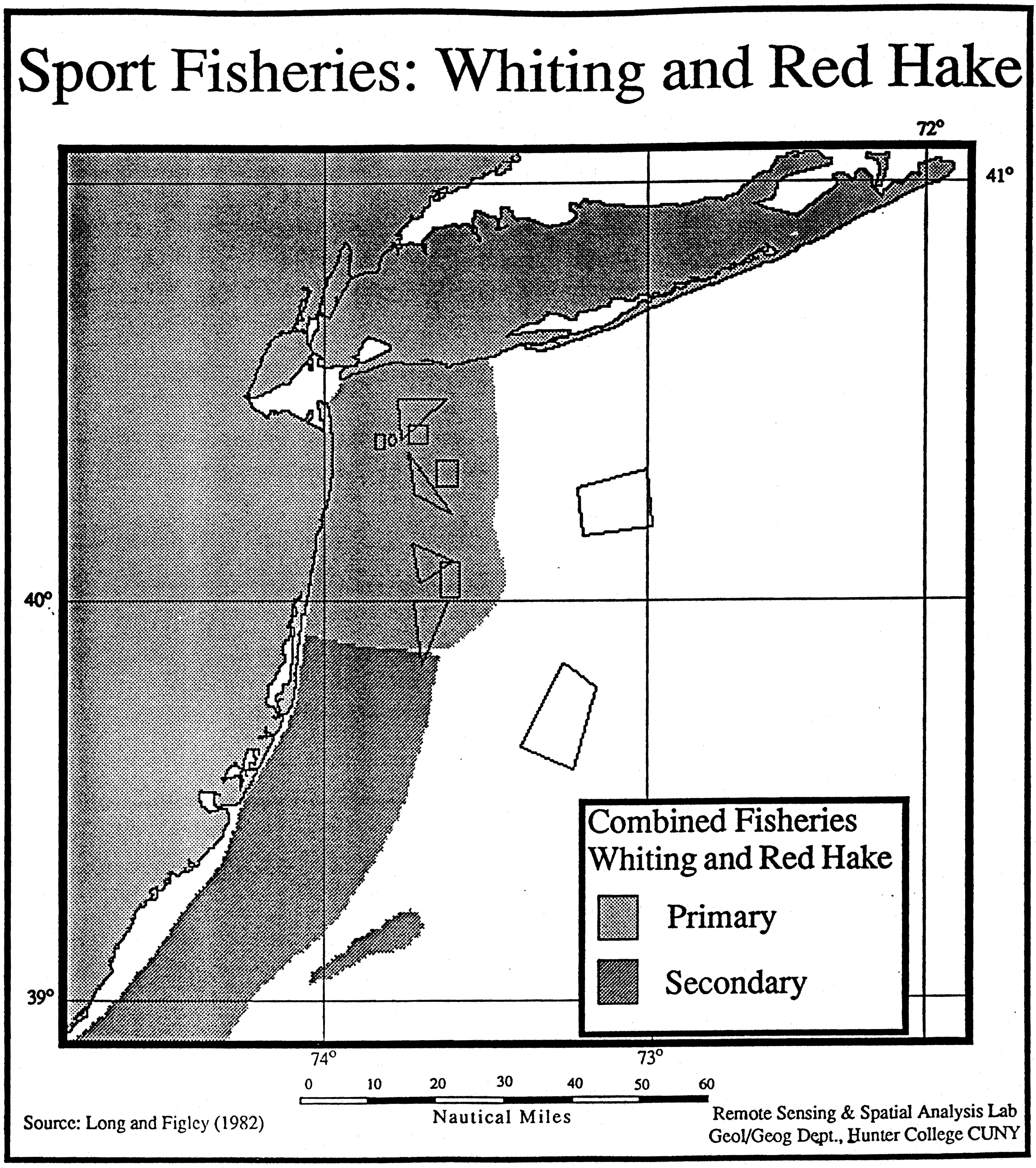

Sport Fisheries: Whiting and Red Hake
72°
41°
40°
39°
74°
73°
Combined Fisheries
Whiting and Red Hake
Primary
Secondary
0
10
20
30
40
50
60
Nautical Miles
Source: Long and Figley (1982)
Remote Sensing & Spatial Analysis Lab
Geol/Geog Dept., Hunter College CUNY

Figure 13

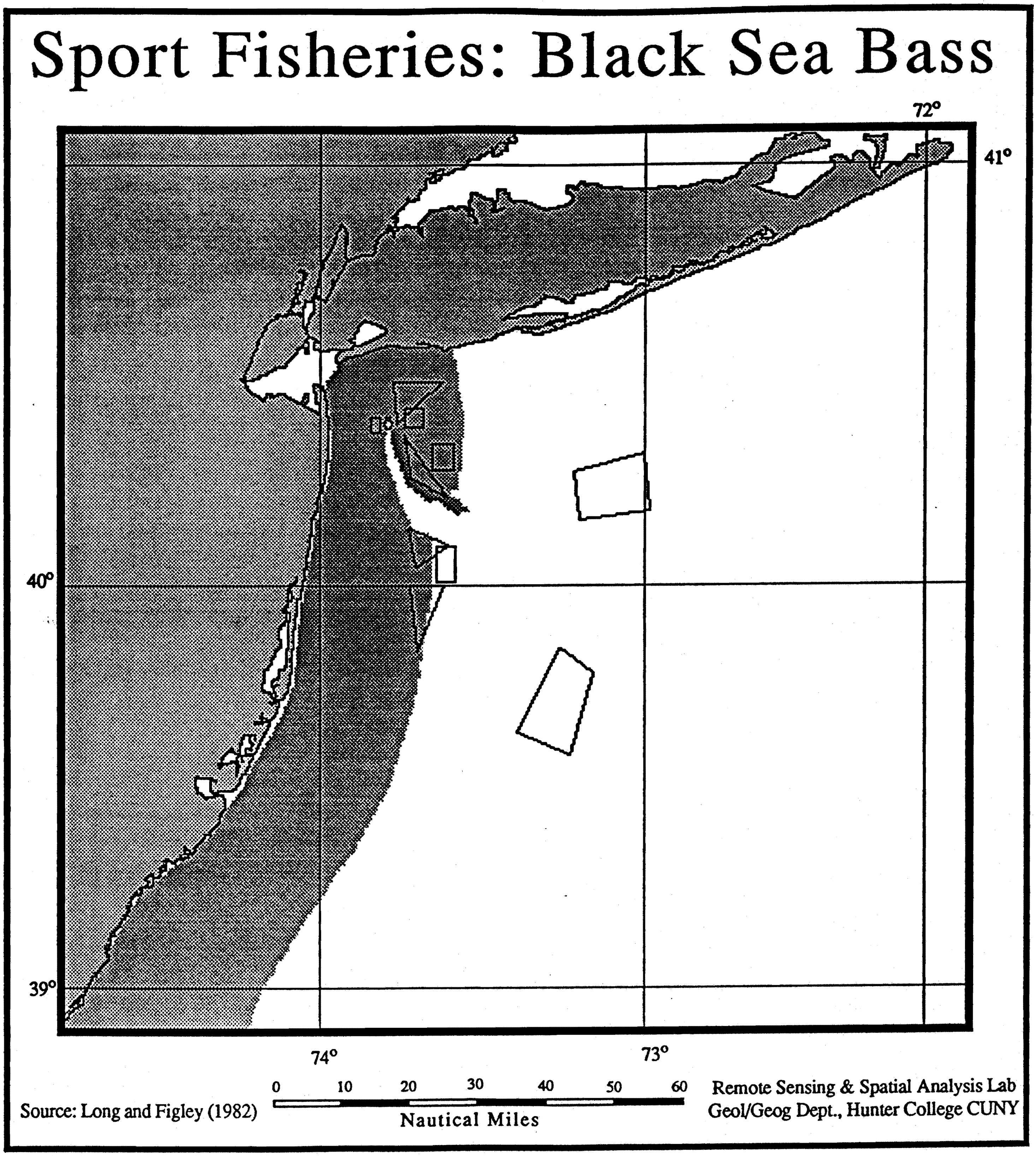

Sport Fisheries: Black Sea Bass
72°
41°
40°
39°
74°
73°
0 10 20 30 40 50 60
Nautical Miles
Source: Long and Figley (1982)
Remote Sensing & Spatial Analysis Lab
Geol/Geog Dept., Hunter College CUNY

Figure 14

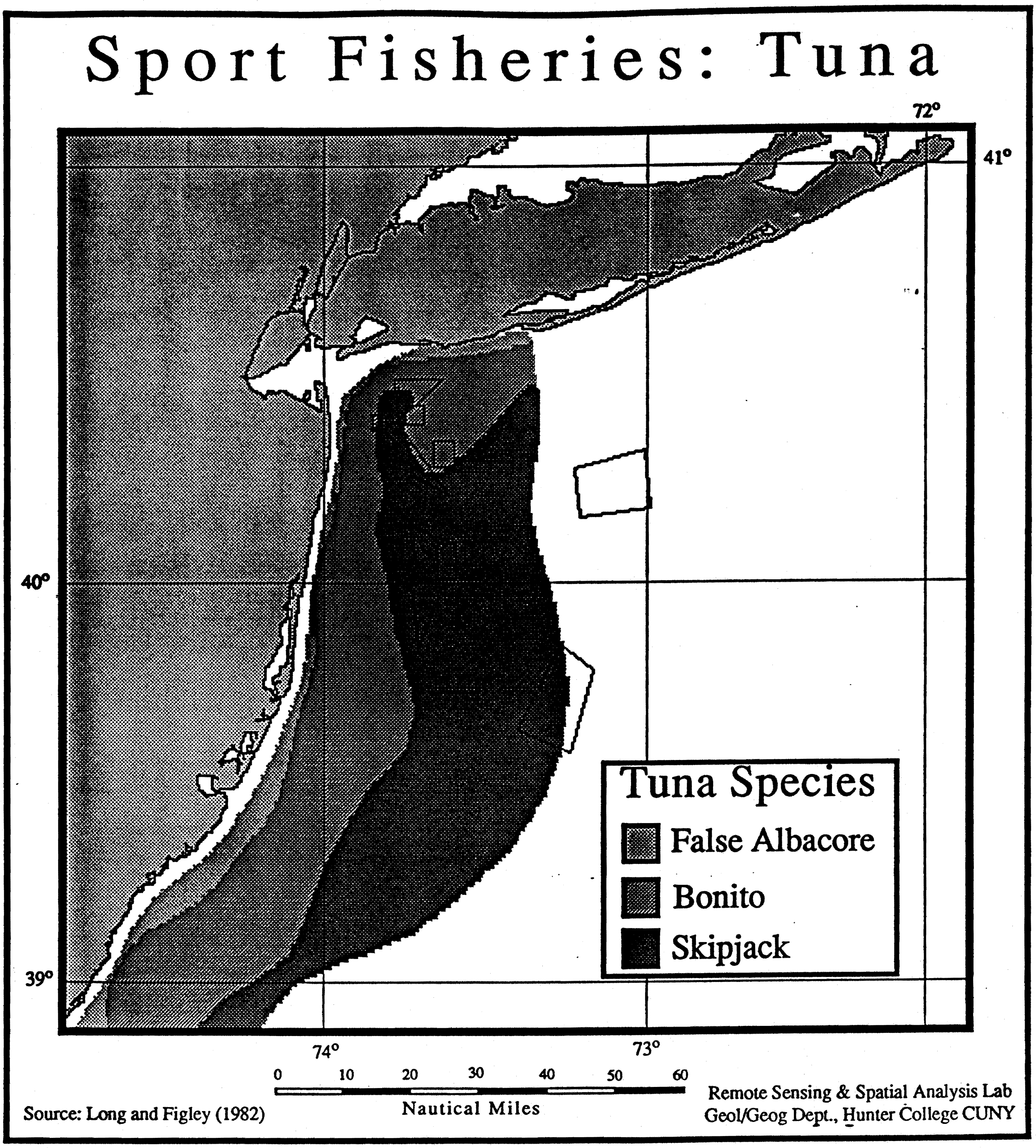

Sport Fisheries: Tuna
72°
41°
40°
39°
74°
73°
Tuna Species
False Albacore
Bonito
Skipjack
0 10 20 30 40 50 60
Nautical Miles
Source: Long and Figley (1982)
Remote Sensing & Spatial Analysis Lab
Geol/Geog Dept., Hunter College CUNY

Figure 15

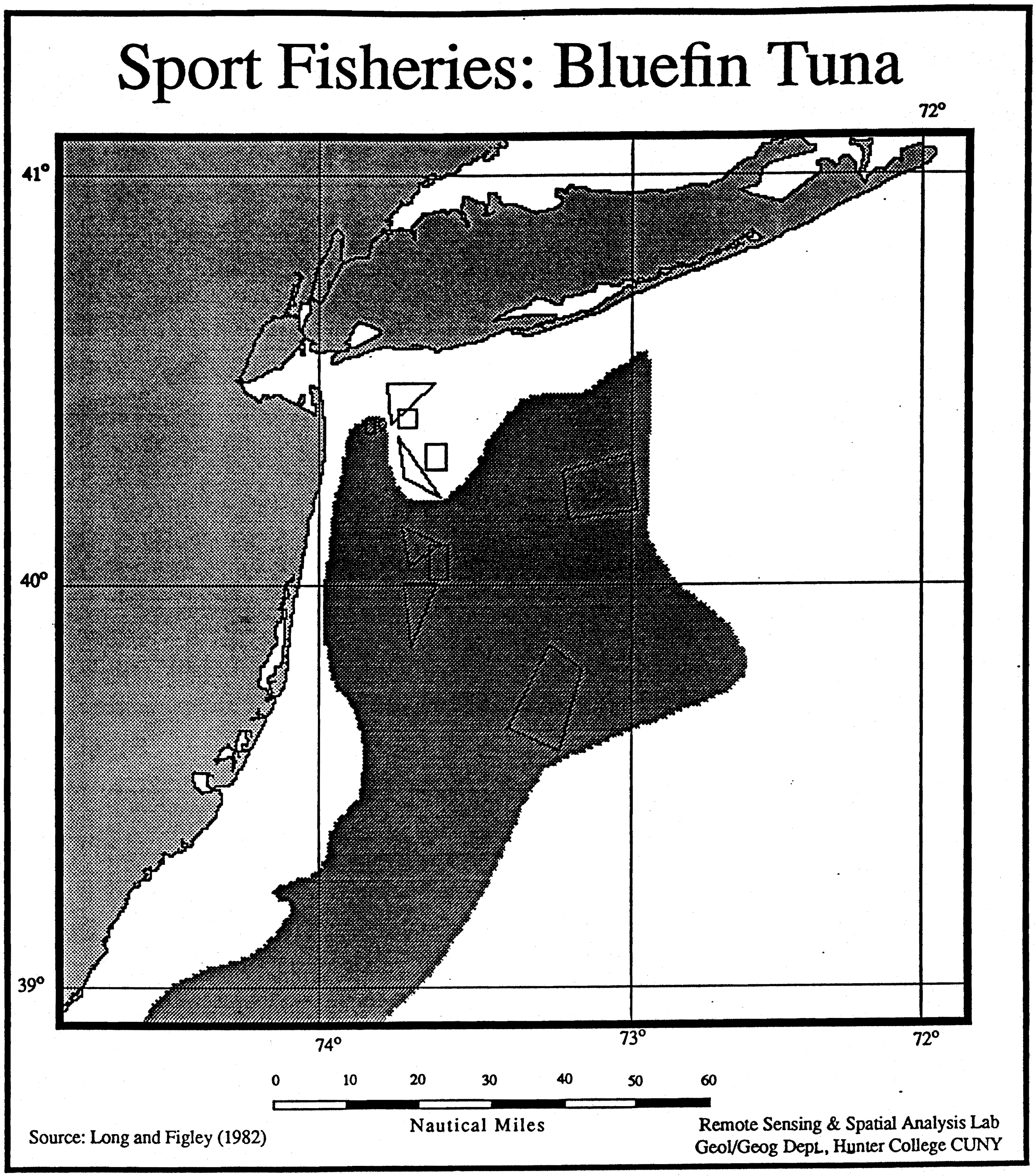

Sport Fisheries: Bluefin Tuna
72°
41°
40°
39°
74°
73°
72°
0
10
20
30
40
50
60
Nautical Miles
Source: Long and Figley (1982)
Remote Sensing & Spatial Analysis Lab
Geol/Geog Dept., Hunter College CUNY

Figure 16

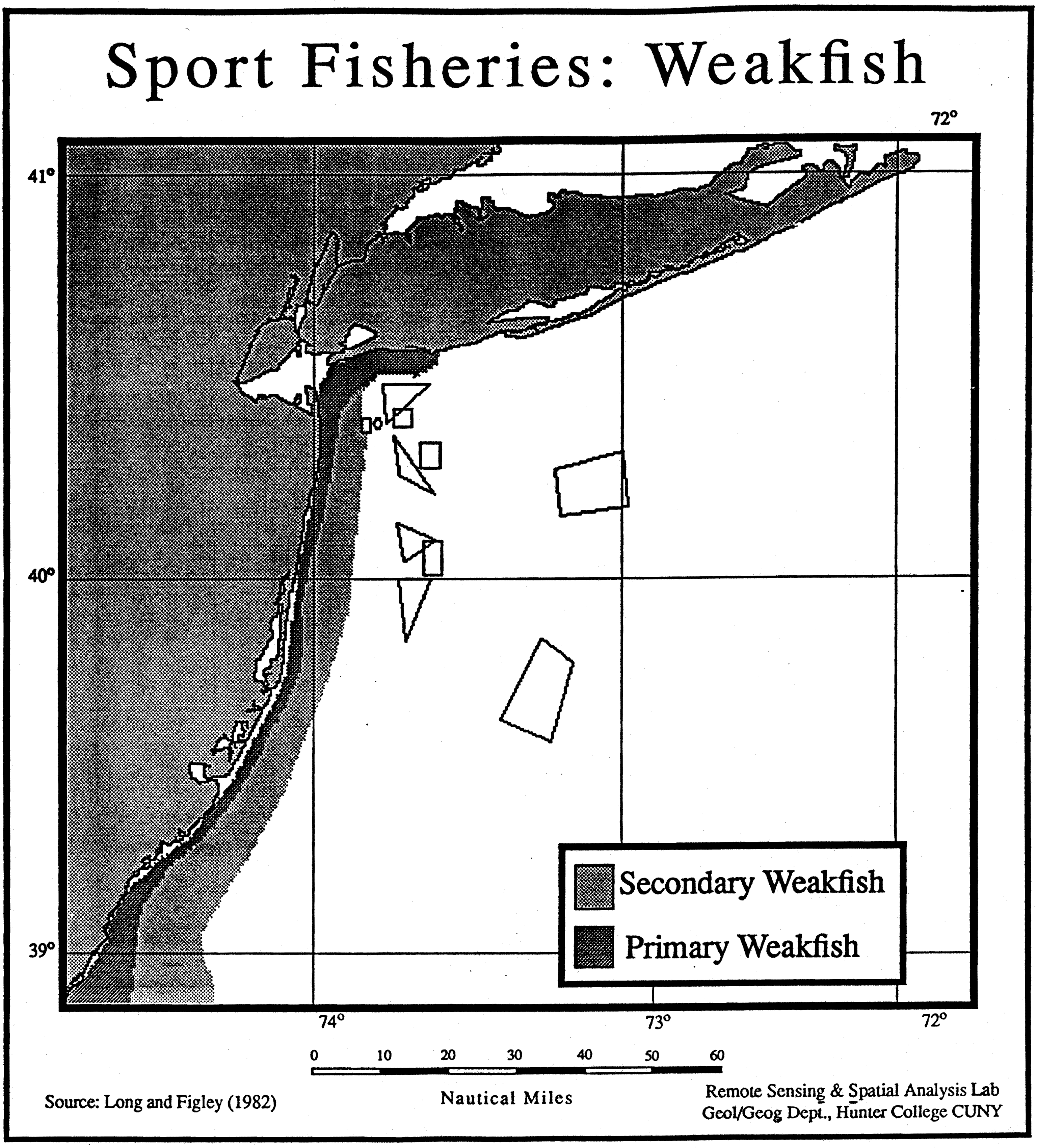
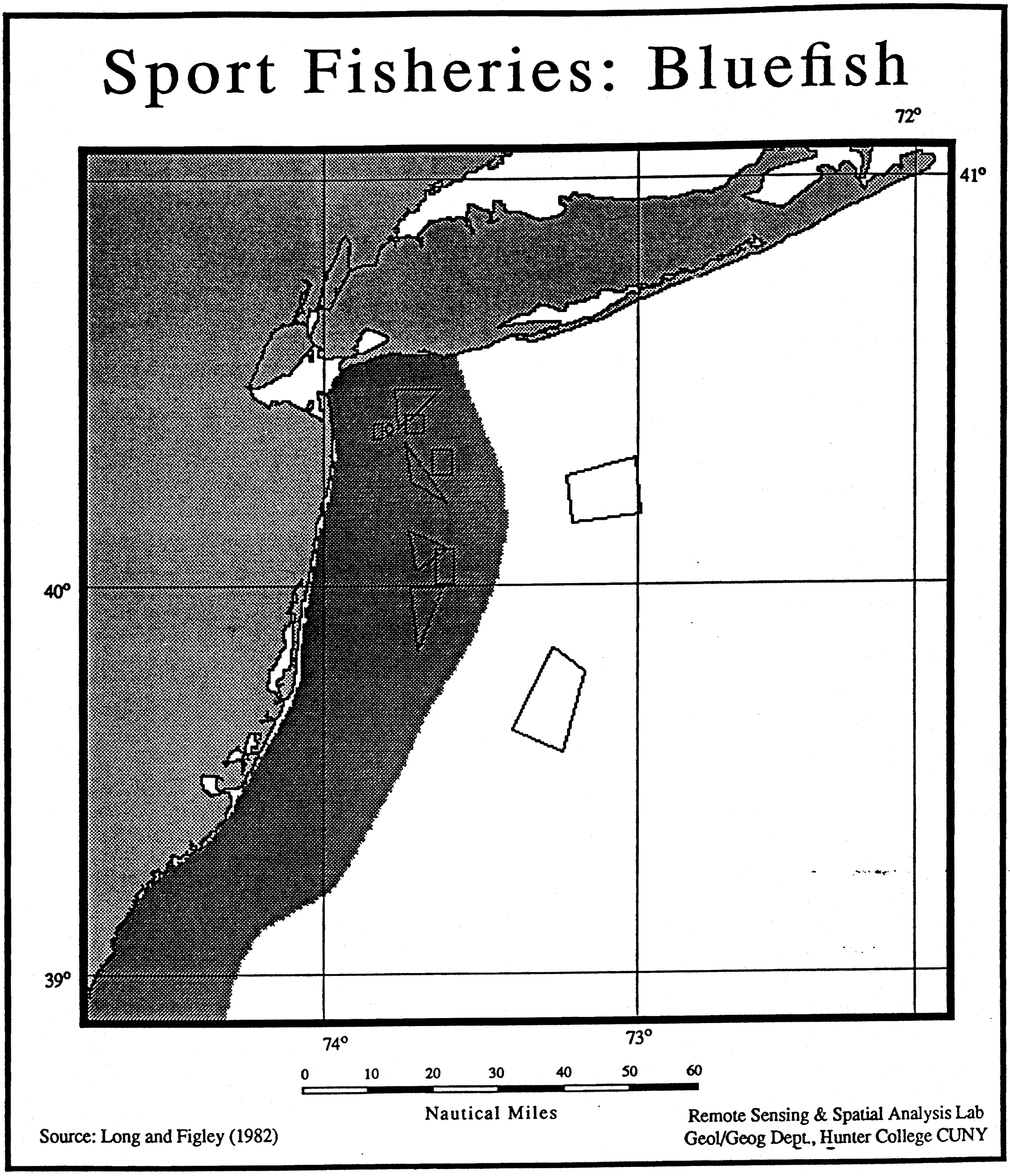

Sport Fisheries: Weakfish
72°
41°
40°
39°
74°
73°
72°
Secondary Weakfish
Primary Weakfish
0
10
20
30
40
50
60
Nautical Miles
Source: Long and Figley (1982)
Remote Sensing & Spatial Analysis Lab
Geol/Geog Dept., Hunter College CUNY

Figure 17



Sport Fisheries: Bluefish
72°
41°
40°
39°
74°
73°
0
10
20
30
40
50
60
Nautical Miles
Source: Long and Figley (1982)
Remote Sensing & Spatial Analysis Lab
Geol/Geog Dept., Hunter College CUNY

Figure 18

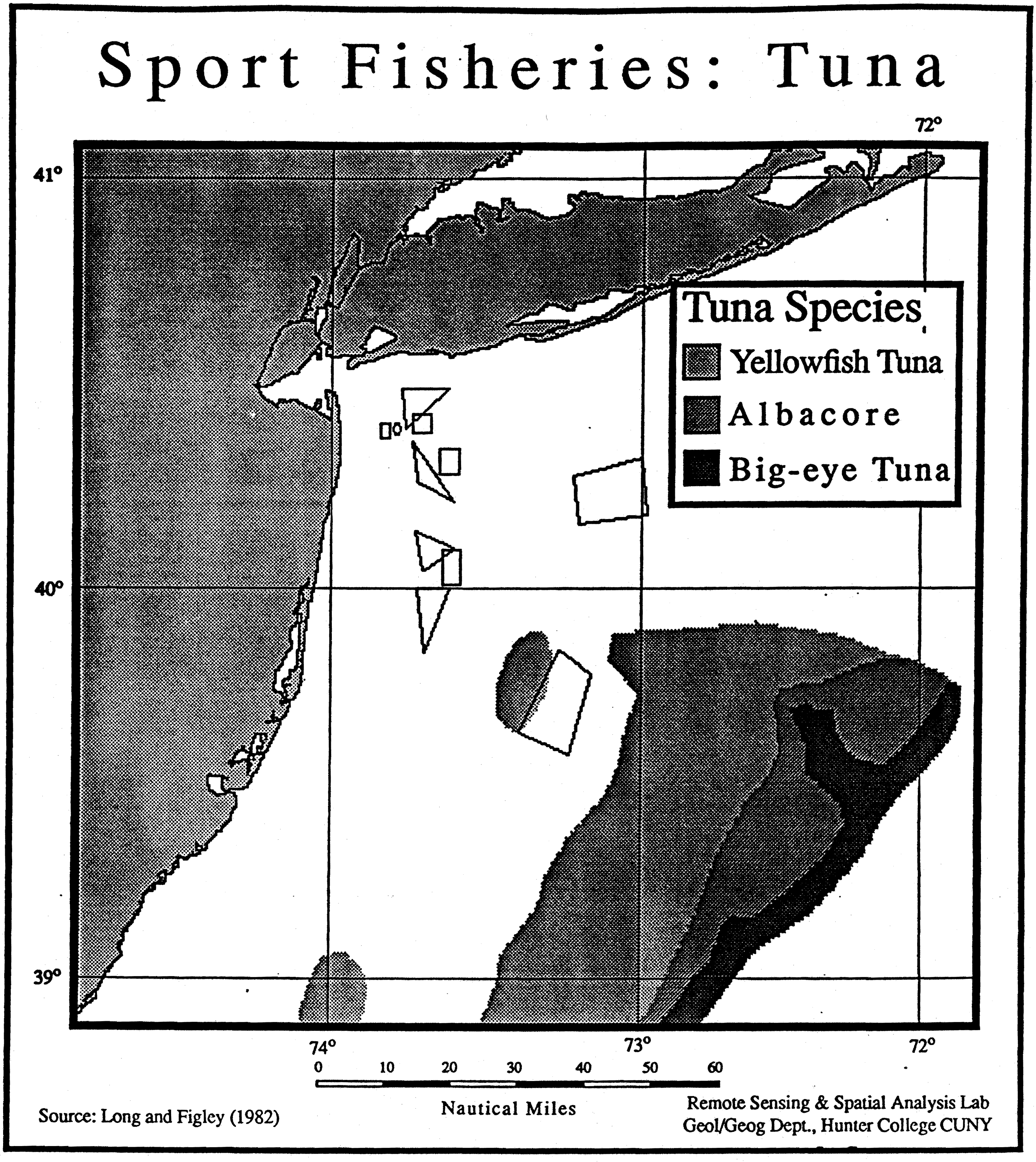
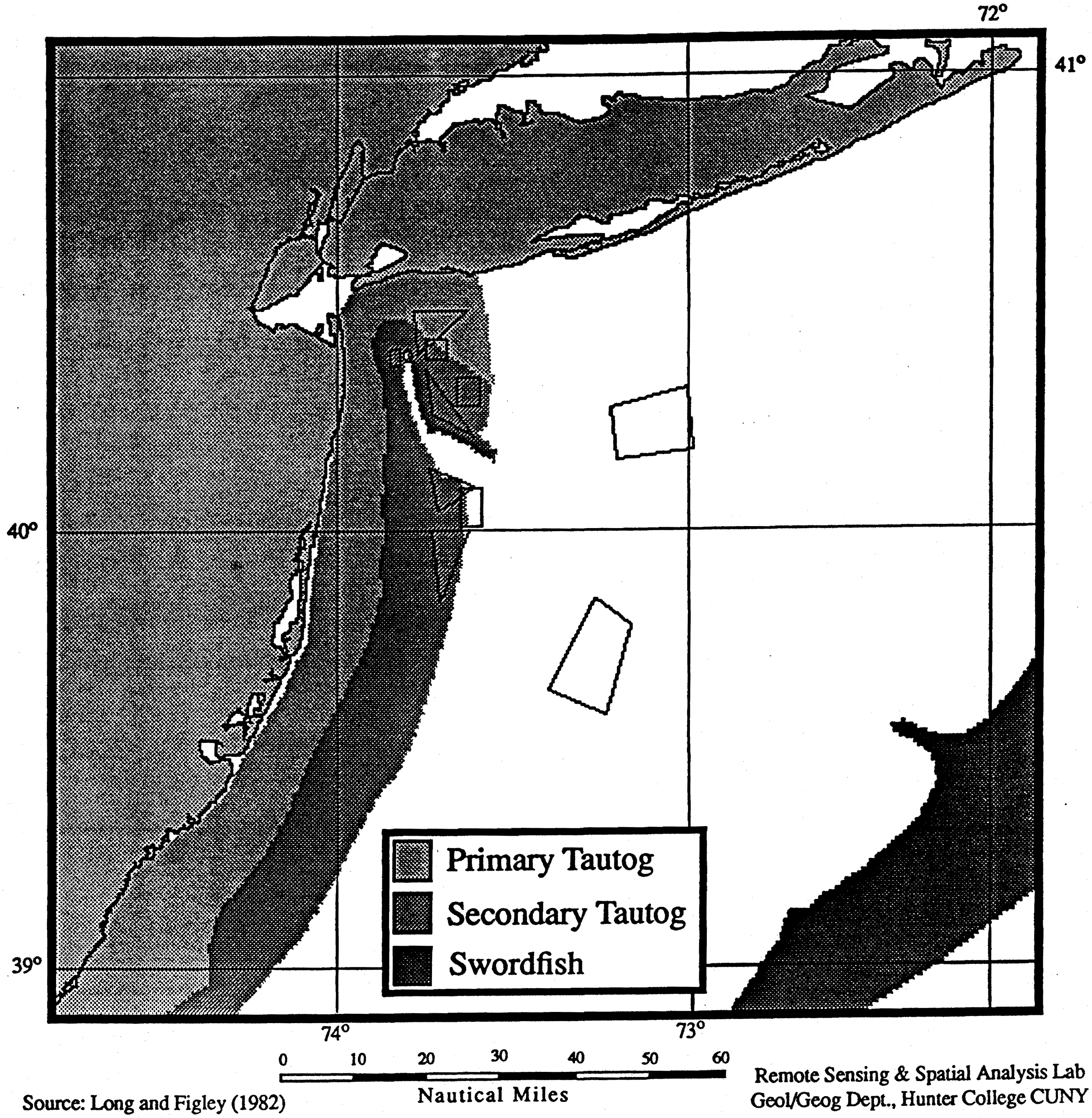

Sport Fisheries: Tuna
72°
41°
40°
39°
Tuna Species
Yellowfish Tuna
Albacore
Big-eye Tuna
74°
73°
72°
0
10
20
30
40
50
60
Nautical Miles
Source: Long and Figley (1982)
Remote Sensing & Spatial Analysis Lab
Geol/Geog Dept., Hunter College CUNY

Figure 19

Sport Fisheries: Tautog and Swordfish



Source: Long and Figley (1982)

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Figure 20

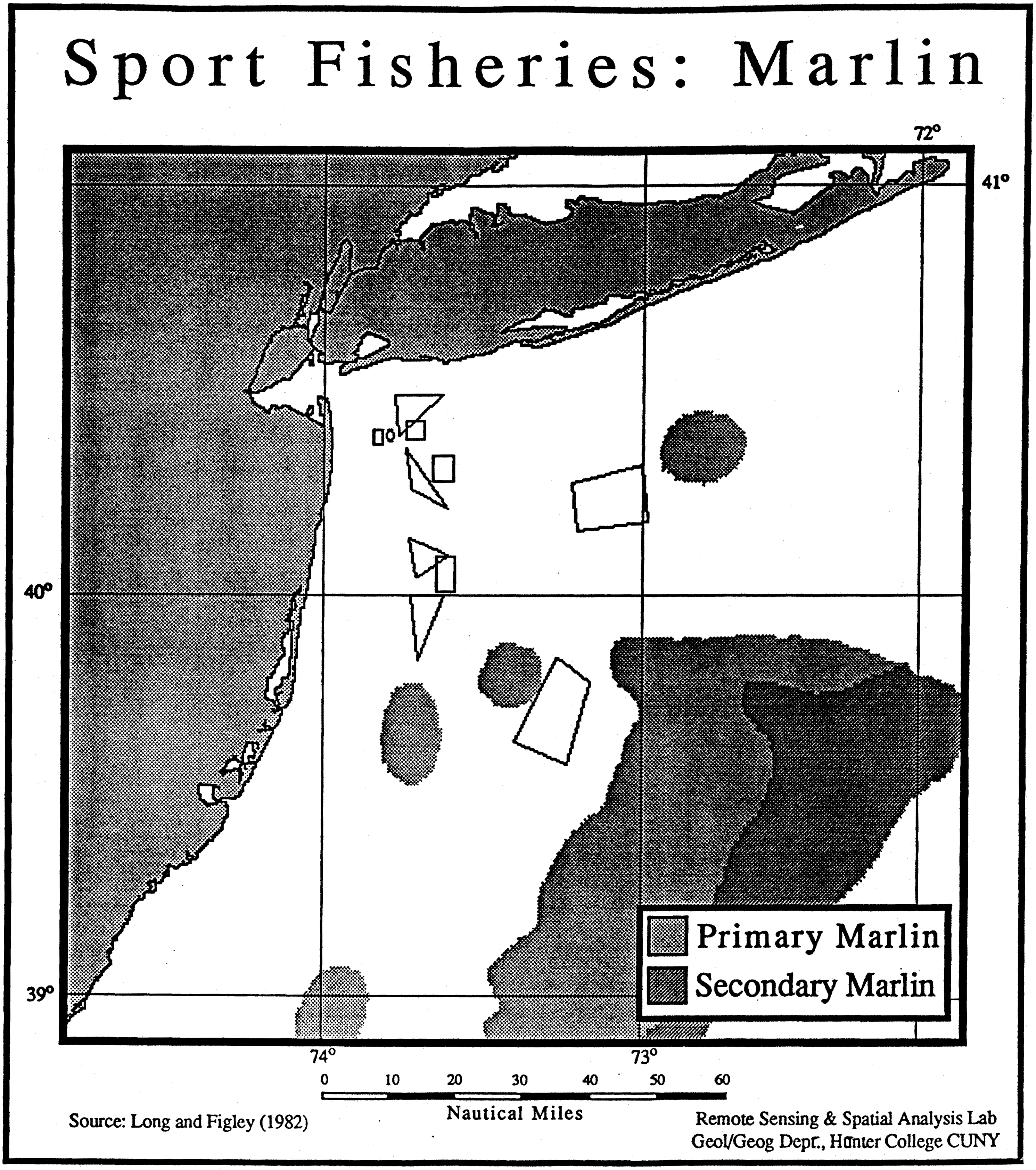

Sport Fisheries: Marlin
72°
41°
40°
39°
74°
73°
Primary Marlin
Secondary Marlin
0
10
20
30
40
50
60
Nautical Miles
Source: Long and Figley (1982)
Remote Sensing & Spatial Analysis Lab
Geol/Geog Dept., Hunter College CUNY

Figure 21

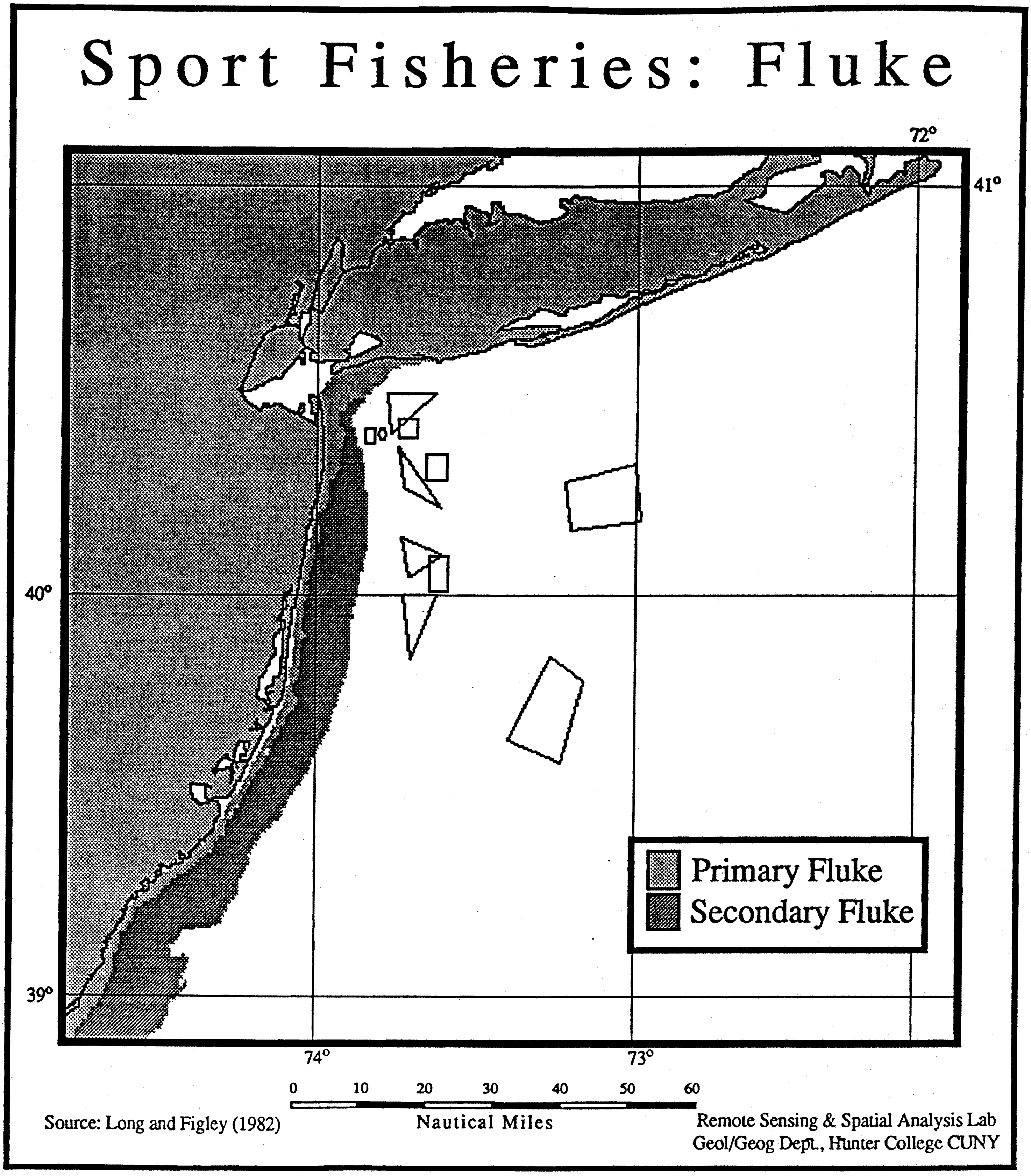
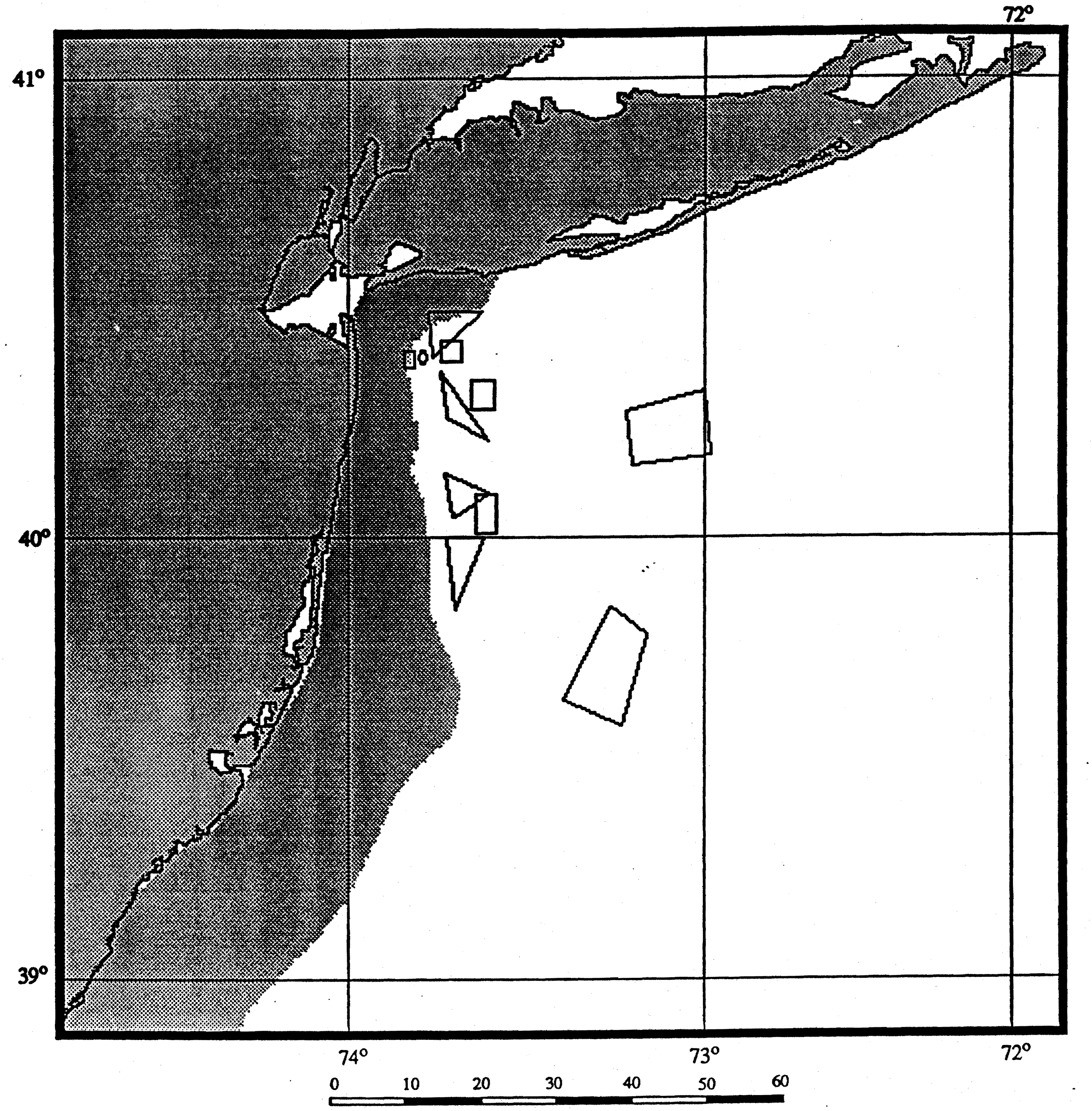

Sport Fisheries: Fluke
72°
41°
40°
39°
74°
73°
Primary Fluke
Secondary Fluke
0
10
20
30
40
50
60
Nautical Miles
Source: Long and Figley (1982)
Remote Sensing & Spatial Analysis Lab
Geol/Geog Dept., Hunter College CUNY

Figure 22

Commercial Fisheries: Bluefish and Weakfish



Source: Long and Figley (1982)

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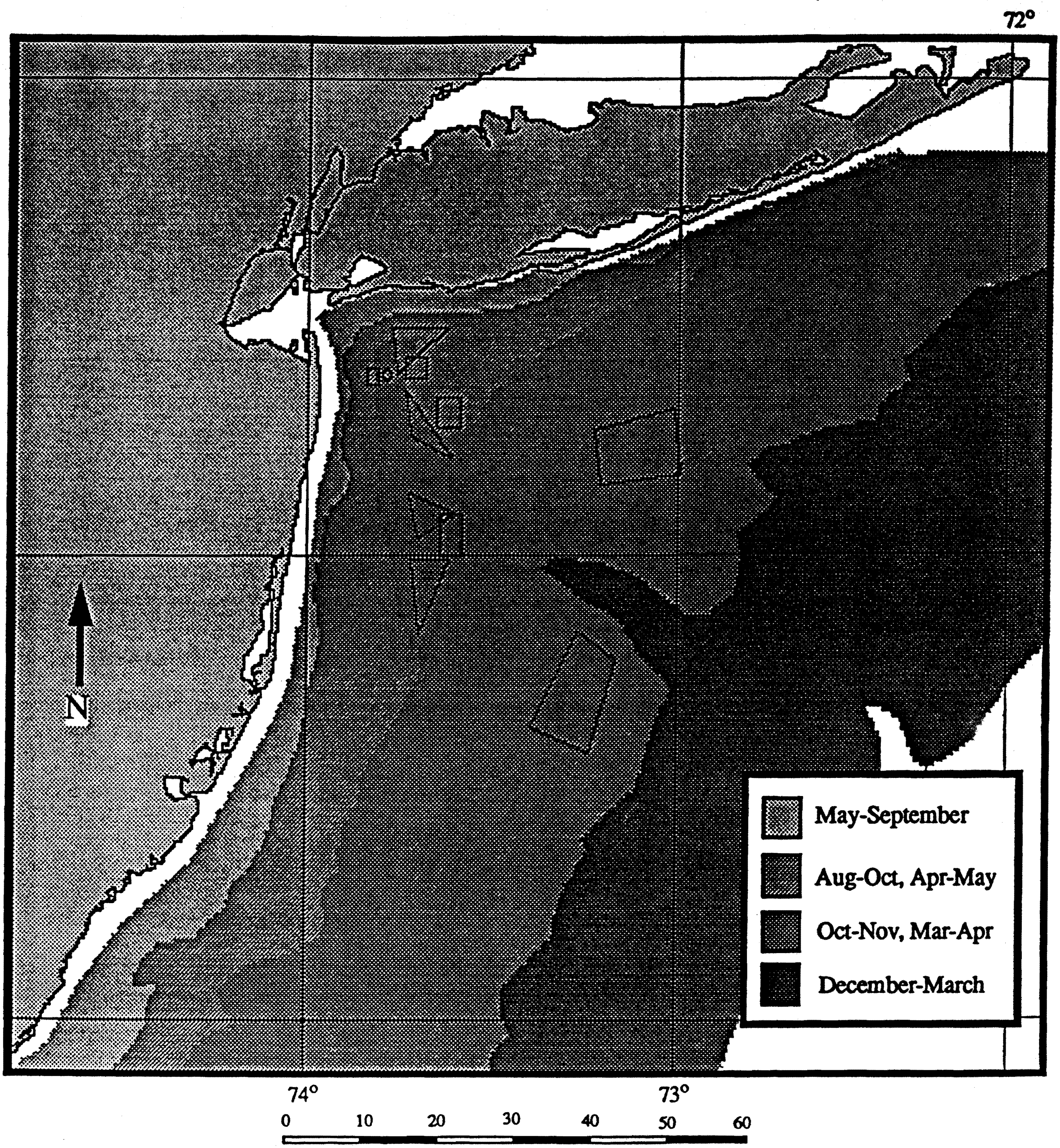
Figure 23

Commercial Fisheries: Fluke



Source: Long & Figley, (1982)

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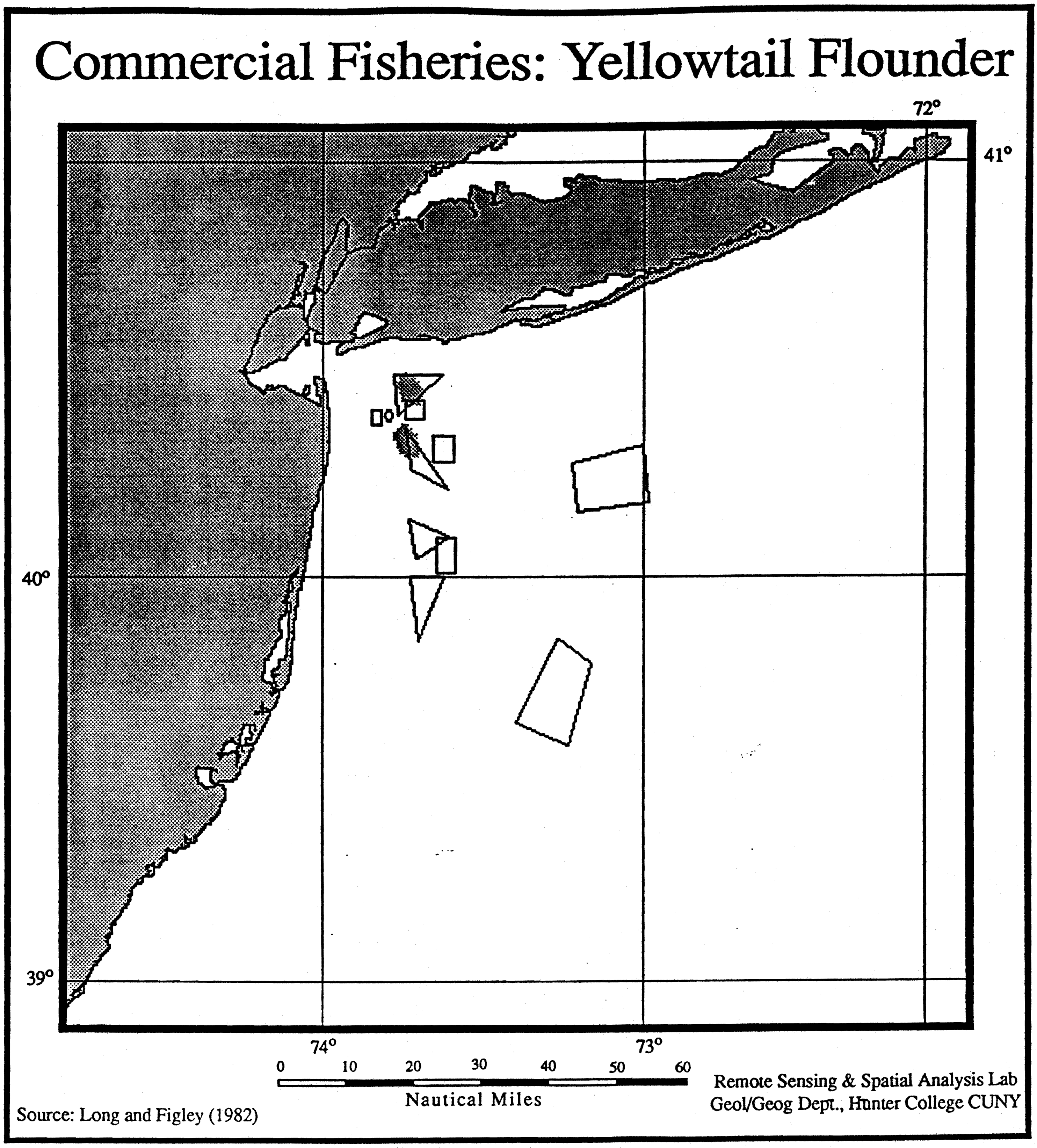
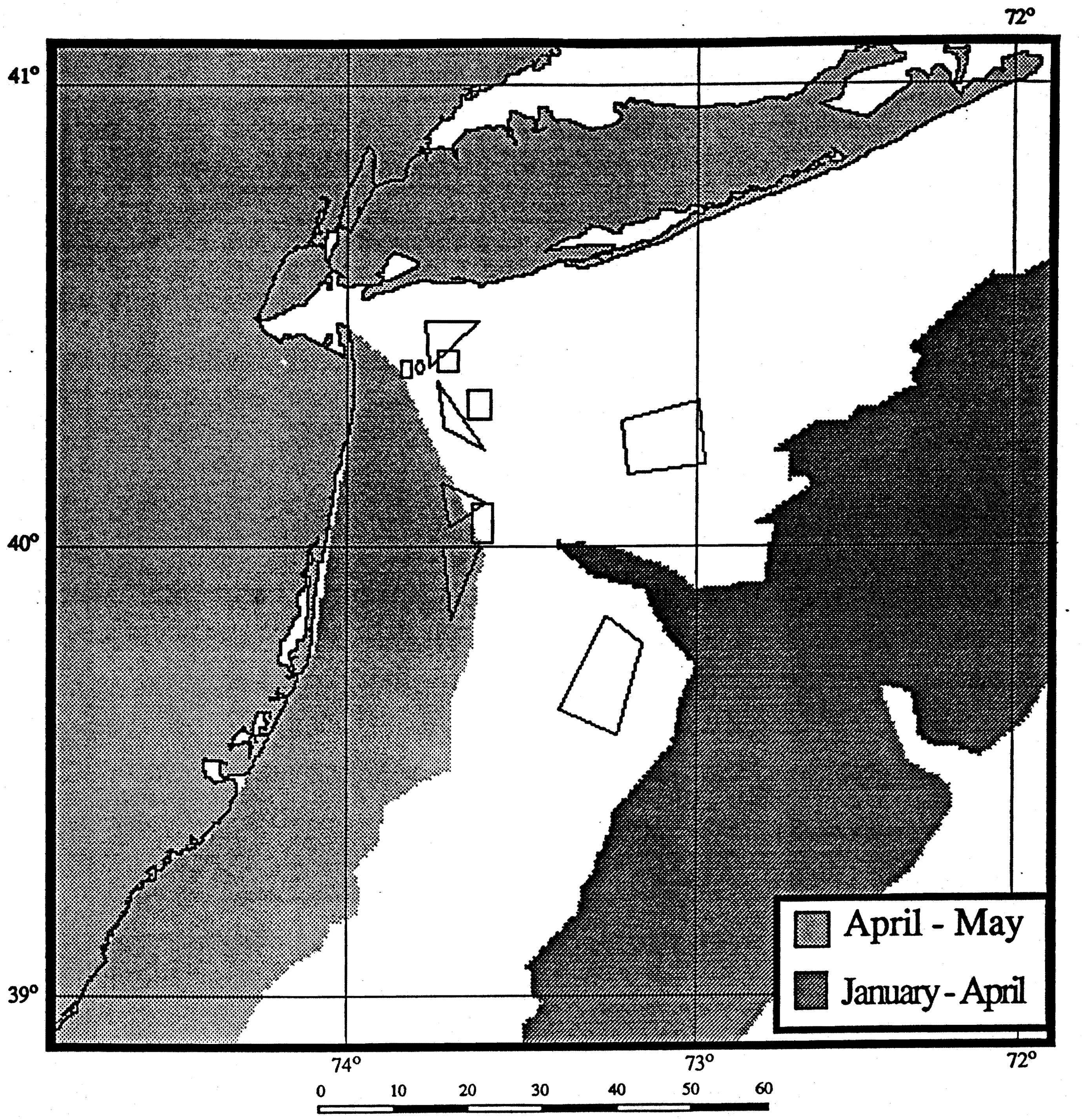
Figure 24



Commercial Fisheries: Yellowtail Flounder
72°
41°
40°
39°
74°
73°
0
10
20
30
40
50
60
Nautical Miles
Source: Long and Figley (1982)
Remote Sensing & Spatial Analysis Lab
Geol/Geog Dept., Hunter College CUNY

Figure 25

Commercial Fisheries: Mackerel



Source: Long and Figley (1982)

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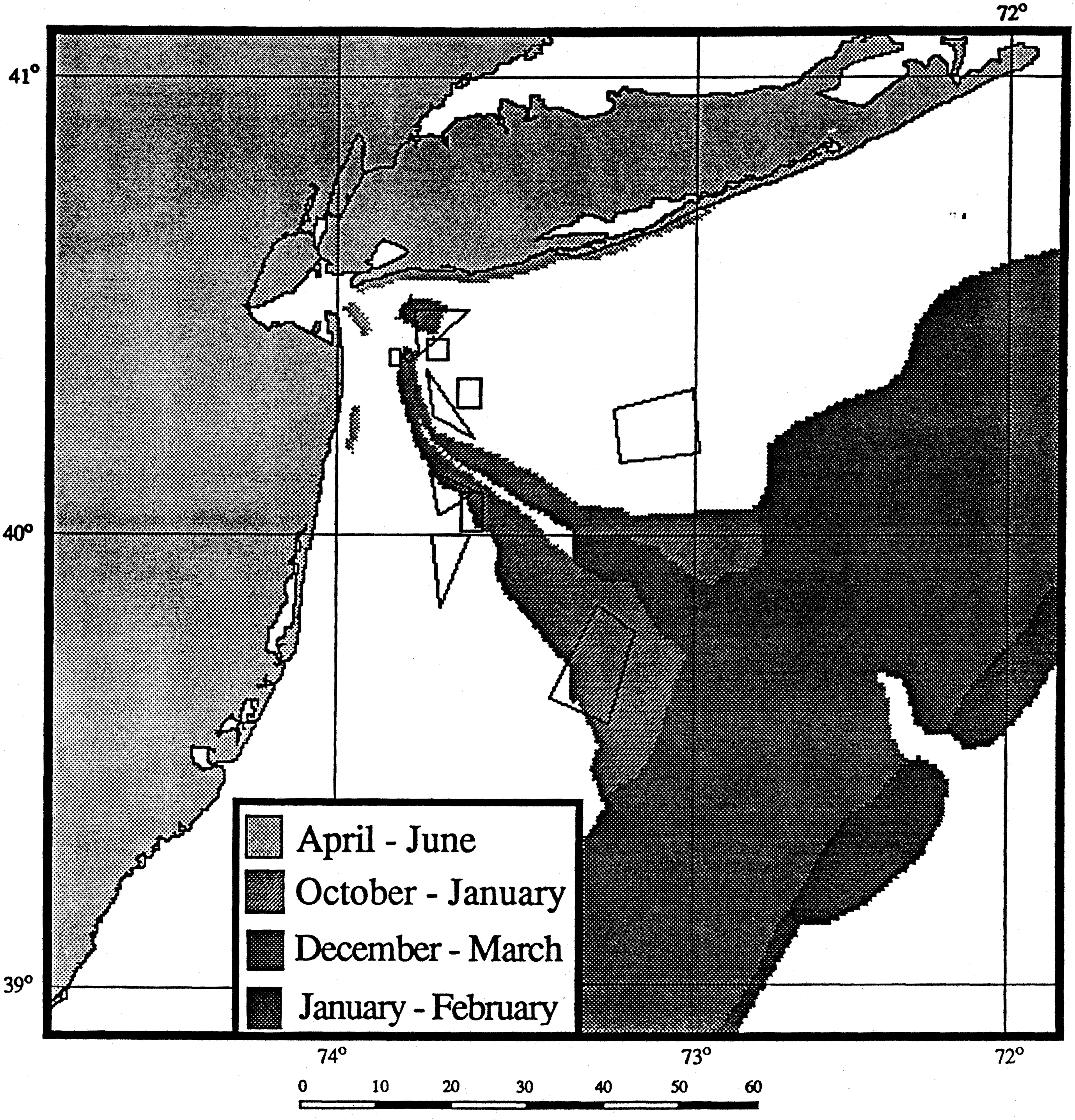
Figure 26

Commercial Fisheries: Whiting & Red Hake



Source: Long and Figley (1982)

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Figure 27

Commercial Fisheries: Cod

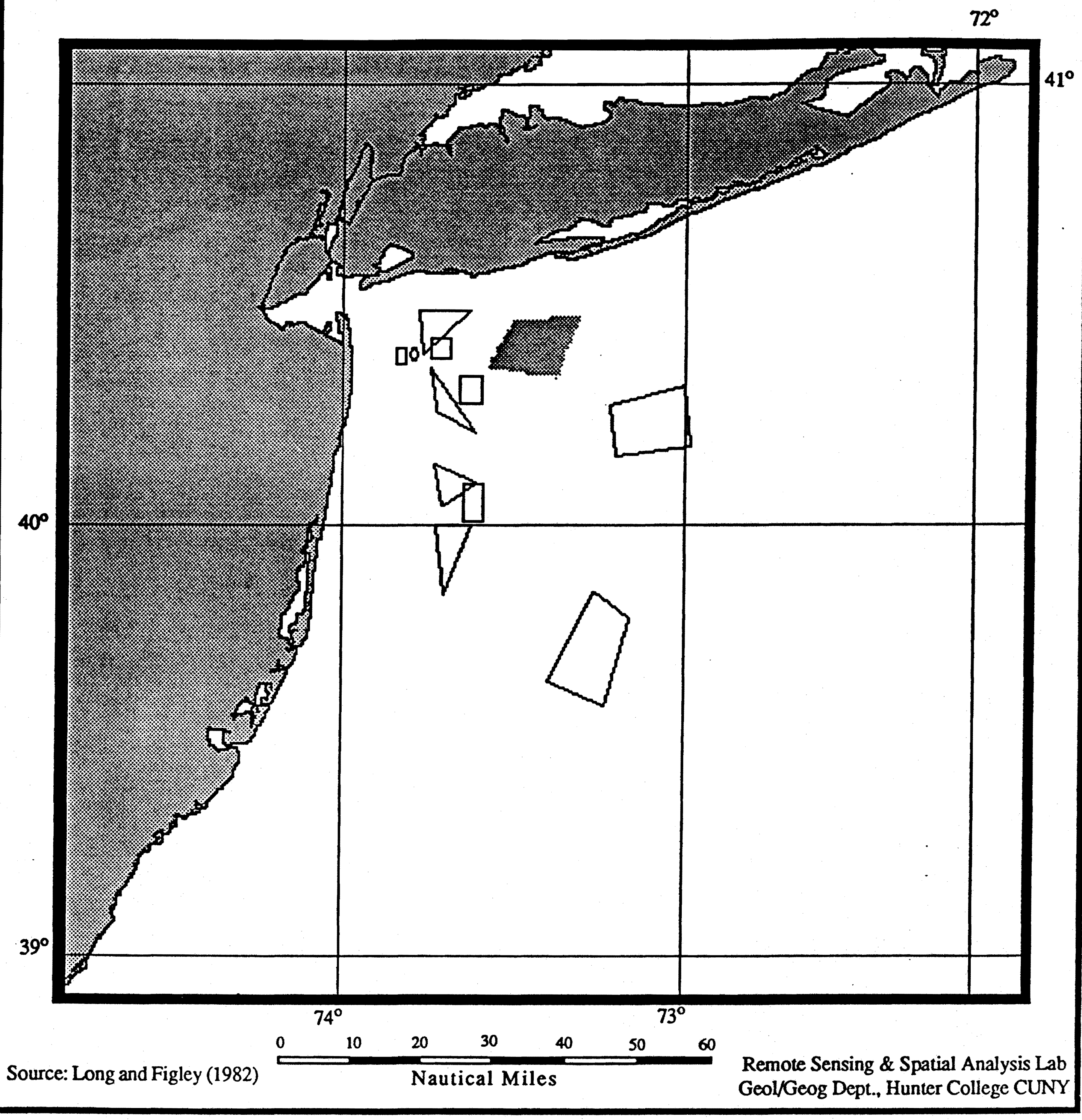
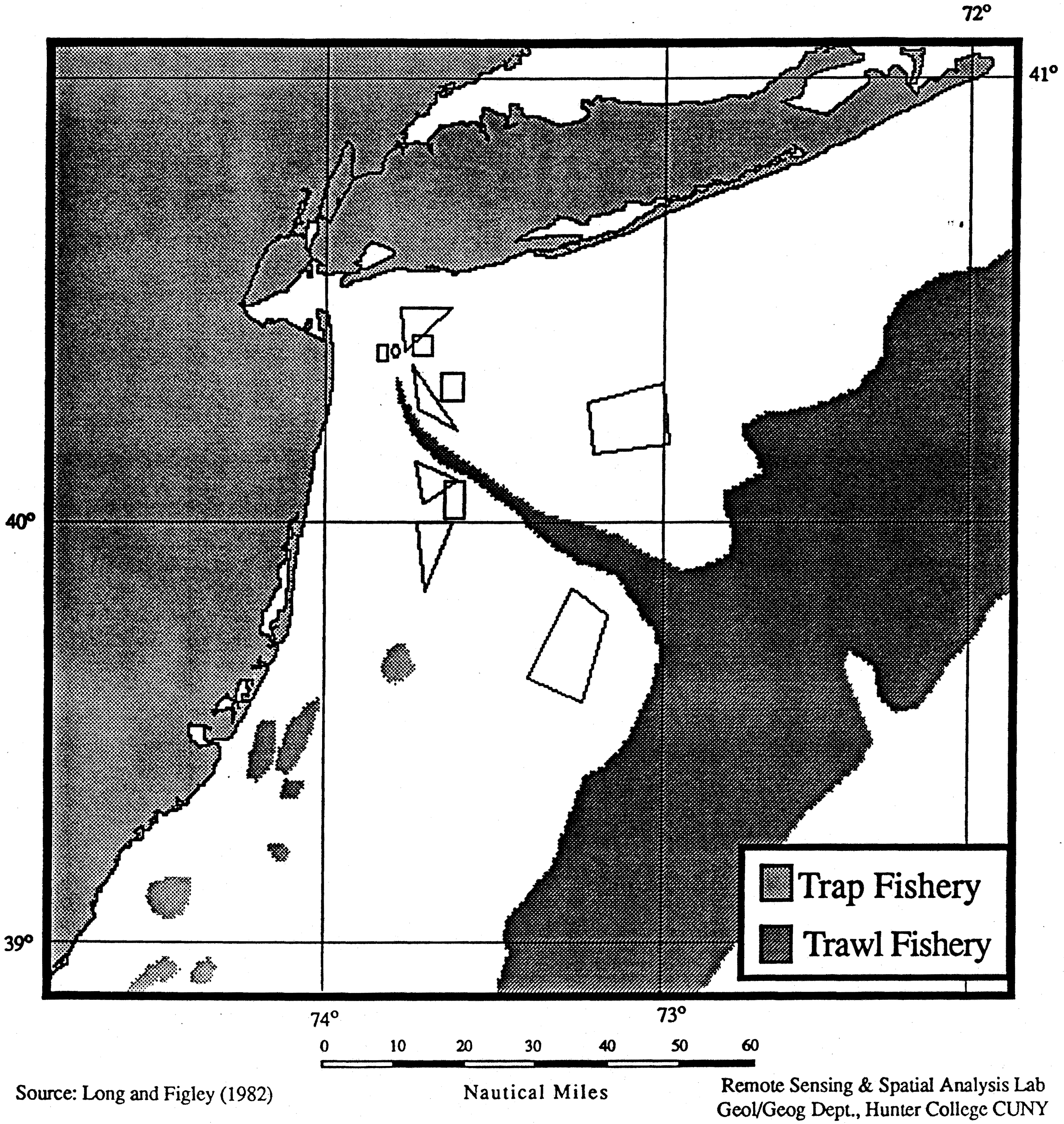


Figure 28

Commercial Fisheries: Black Sea Bass



Source: Long and Figley (1982)

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Figure 29

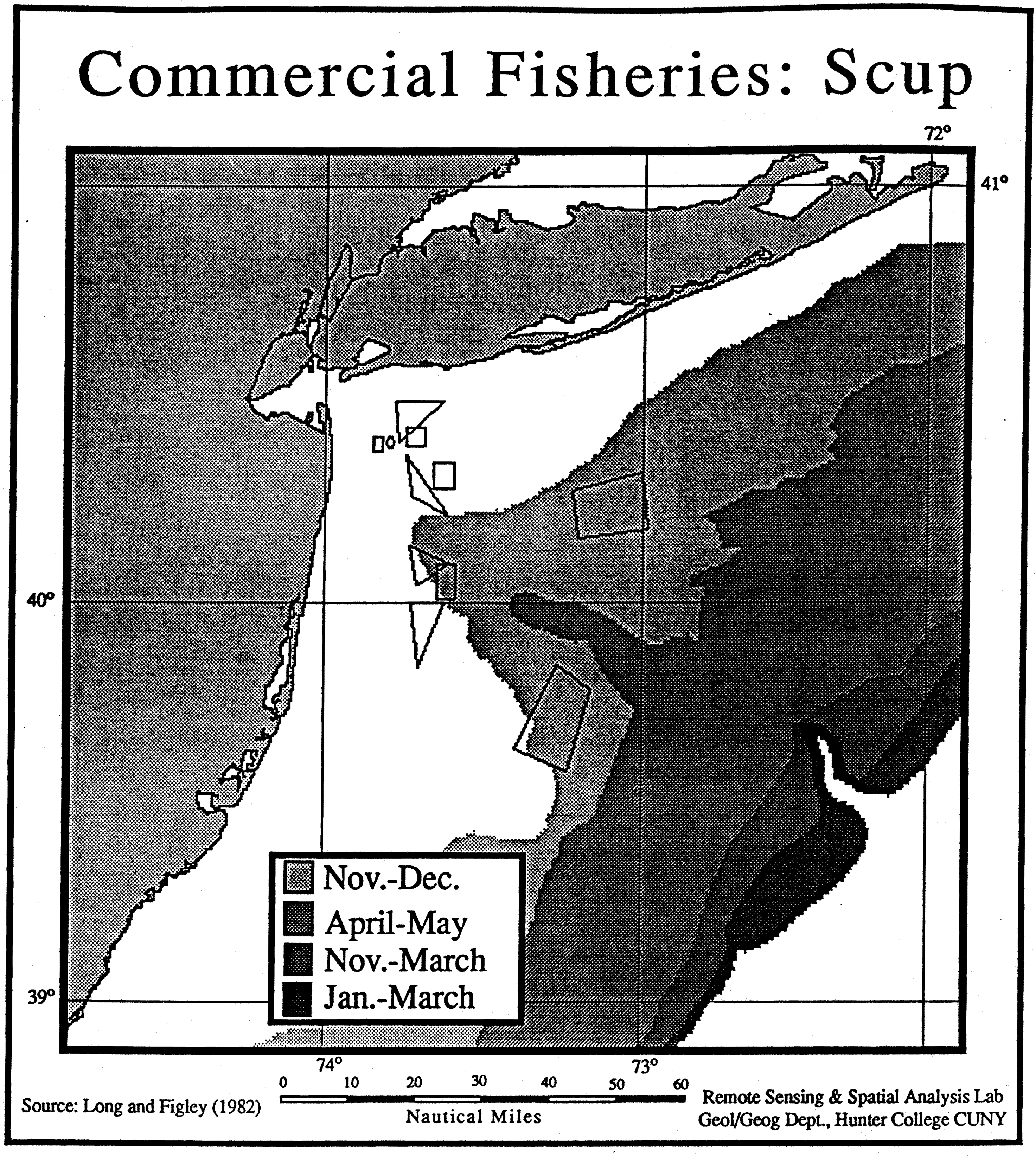
Commercial Fisheries: Scup
72°
41°
40°
39°
74°
73°
Nov.-Dec.
April-May
Nov.-March
Jan.-March
0
10
20
30
40
50
60
Nautical Miles
Source: Long and Figley (1982)
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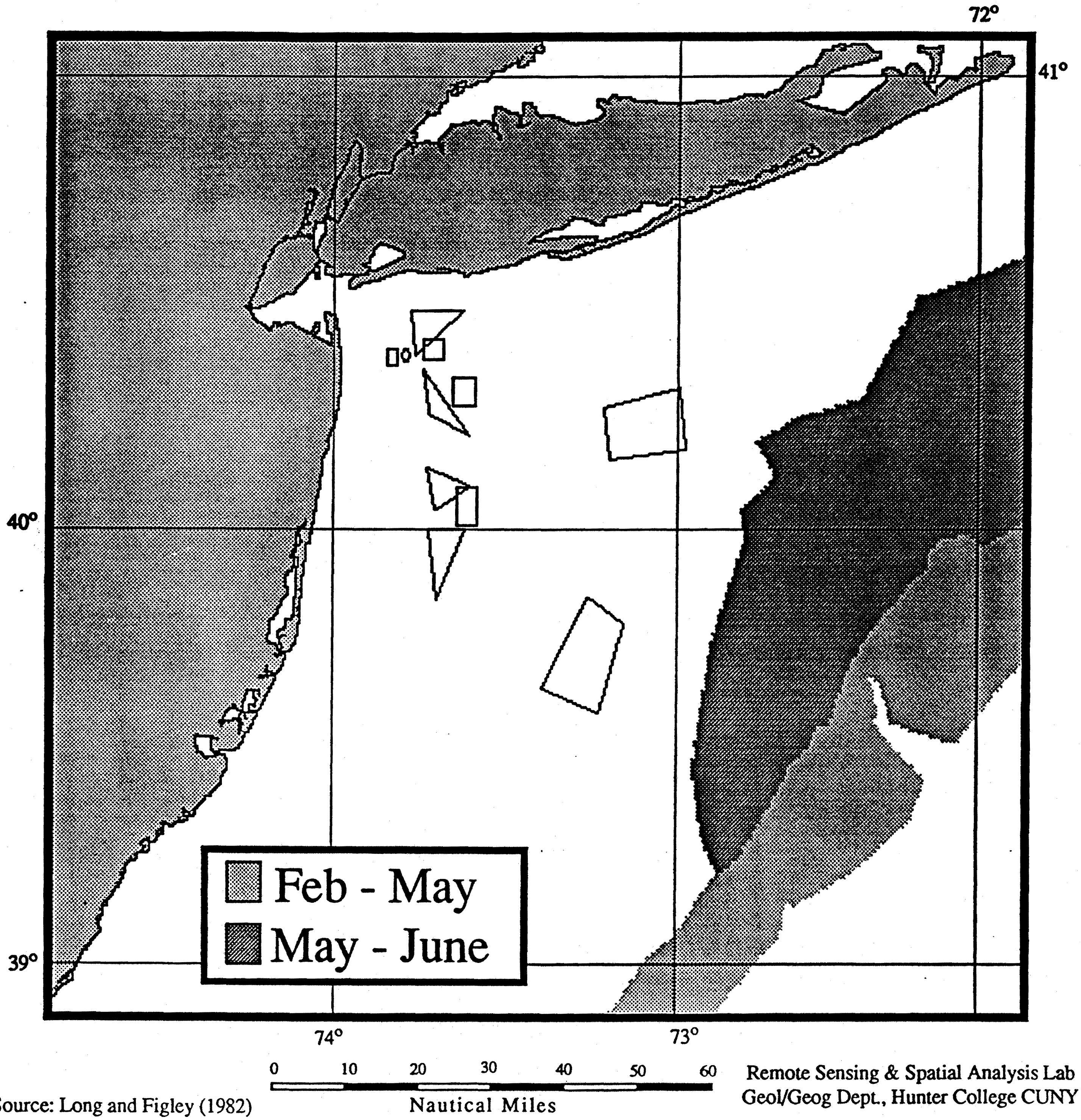
Figure 30

Commercial Fisheries: Butterfish



Source: Long and Figley (1982)

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Figure 31

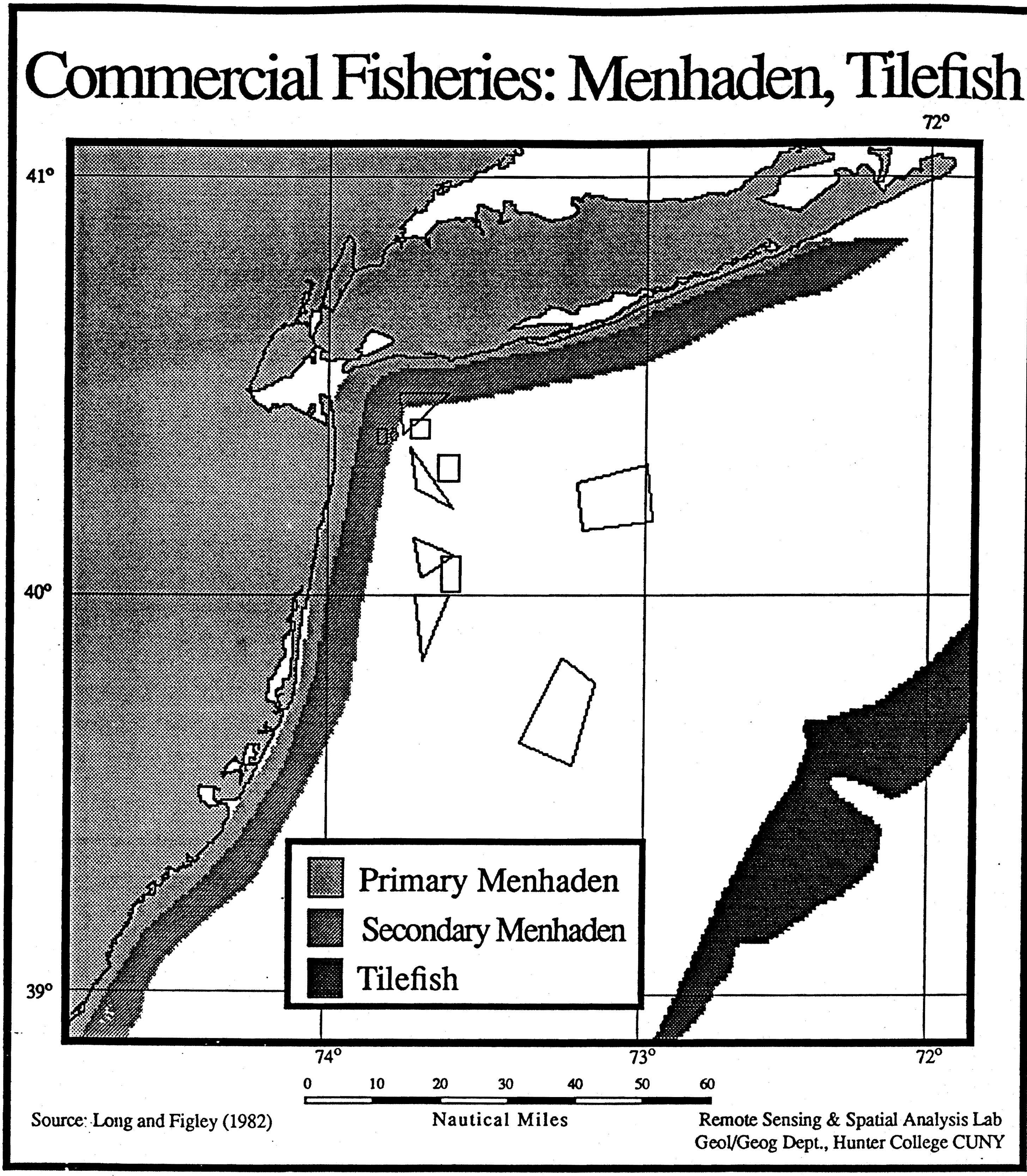
Commercial Fisheries: Menhaden, Tilefish
41°
40°
39°
74°
73°
72°
72°
Primary Menhaden
Secondary Menhaden
Tilefish
0 10 20 30 40 50 60
Nautical Miles
Source: Long and Figley (1982)
Remote Sensing & Spatial Analysis Lab
Geol/Geog Dept., Hunter College CUNY

Figure 32

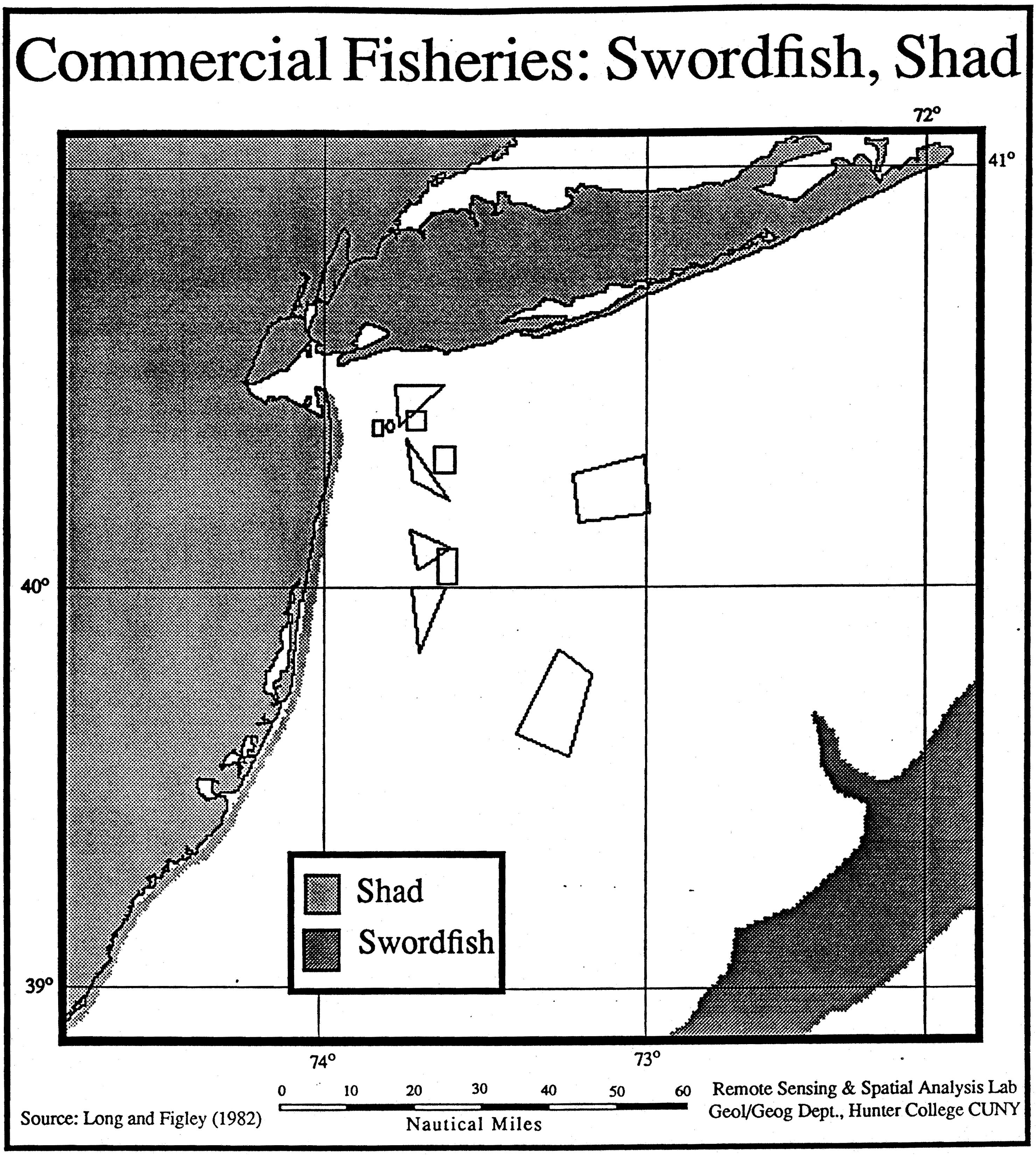
Commercial Fisheries: Swordfish, Shad
72°
41°
40°
39°
74°
73°
Shad
Swordfish
0 10 20 30 40 50 60
Nautical Miles
Source: Long and Figley (1982)
Remote Sensing & Spatial Analysis Lab
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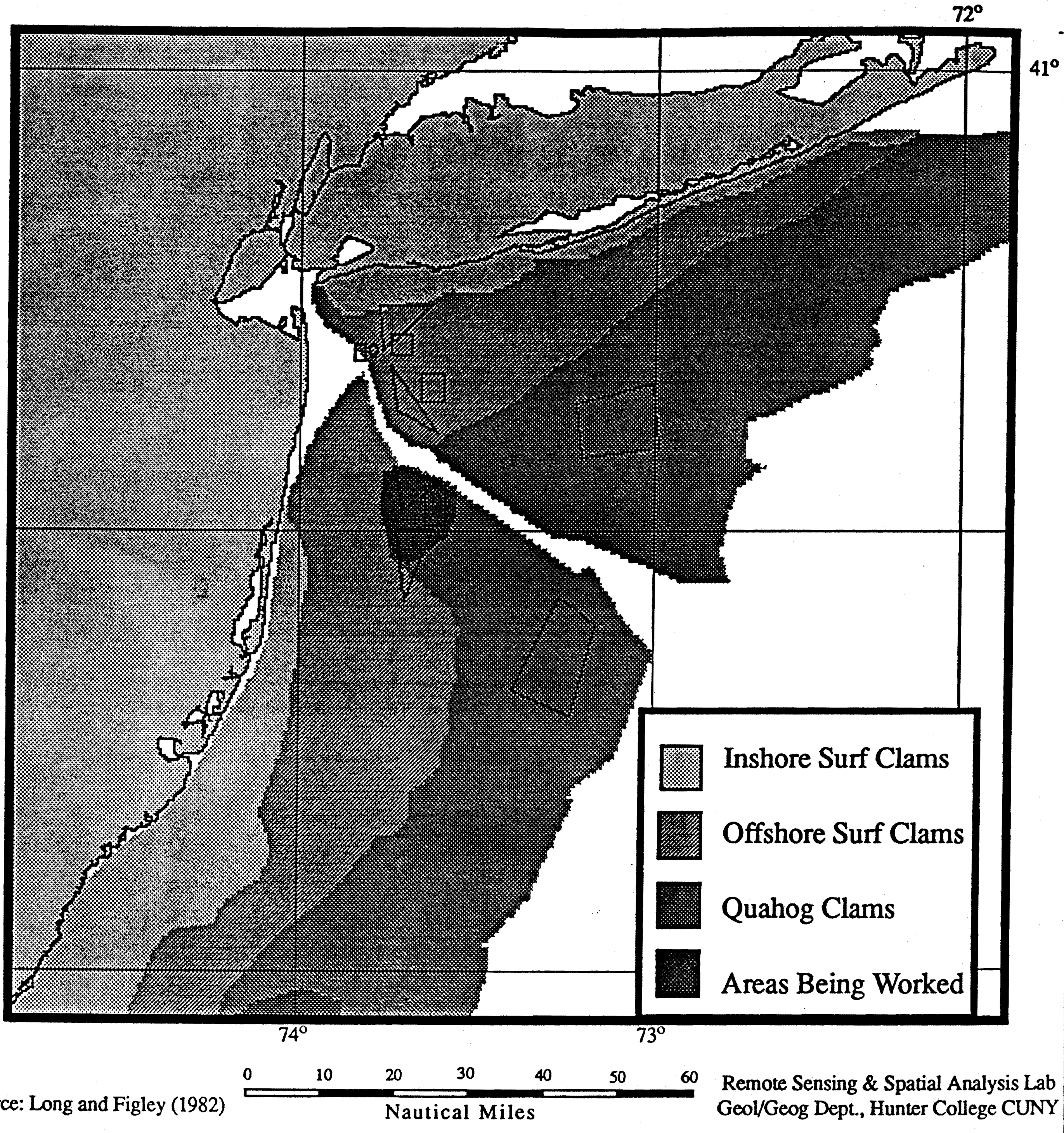
Figure 33

Commercial Fisheries: Clams



Source: Long and Figley (1982)

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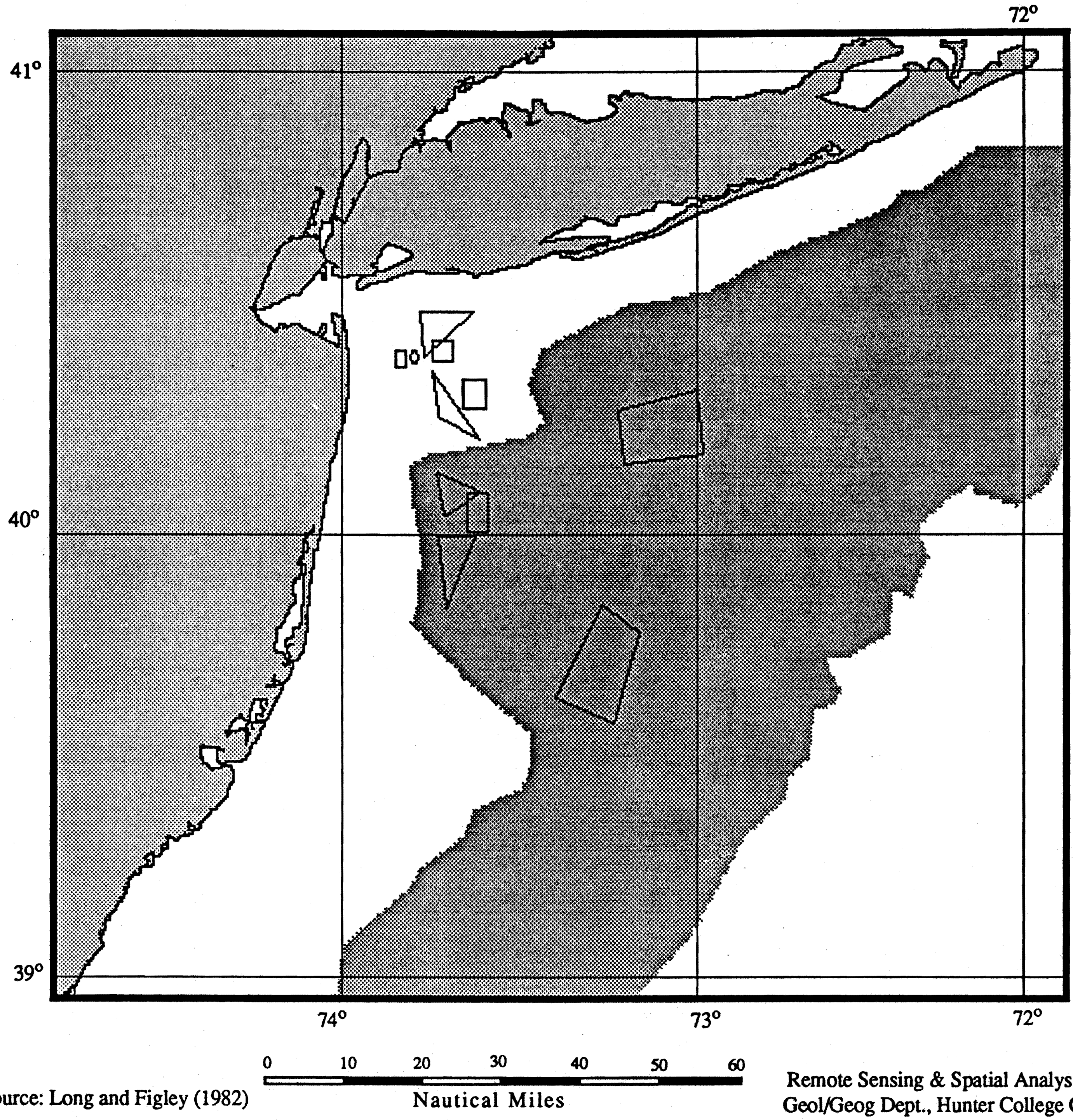
Figure 34

Commercial Fisheries: Scallops



Source: Long and Figley (1982)

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Figure 35

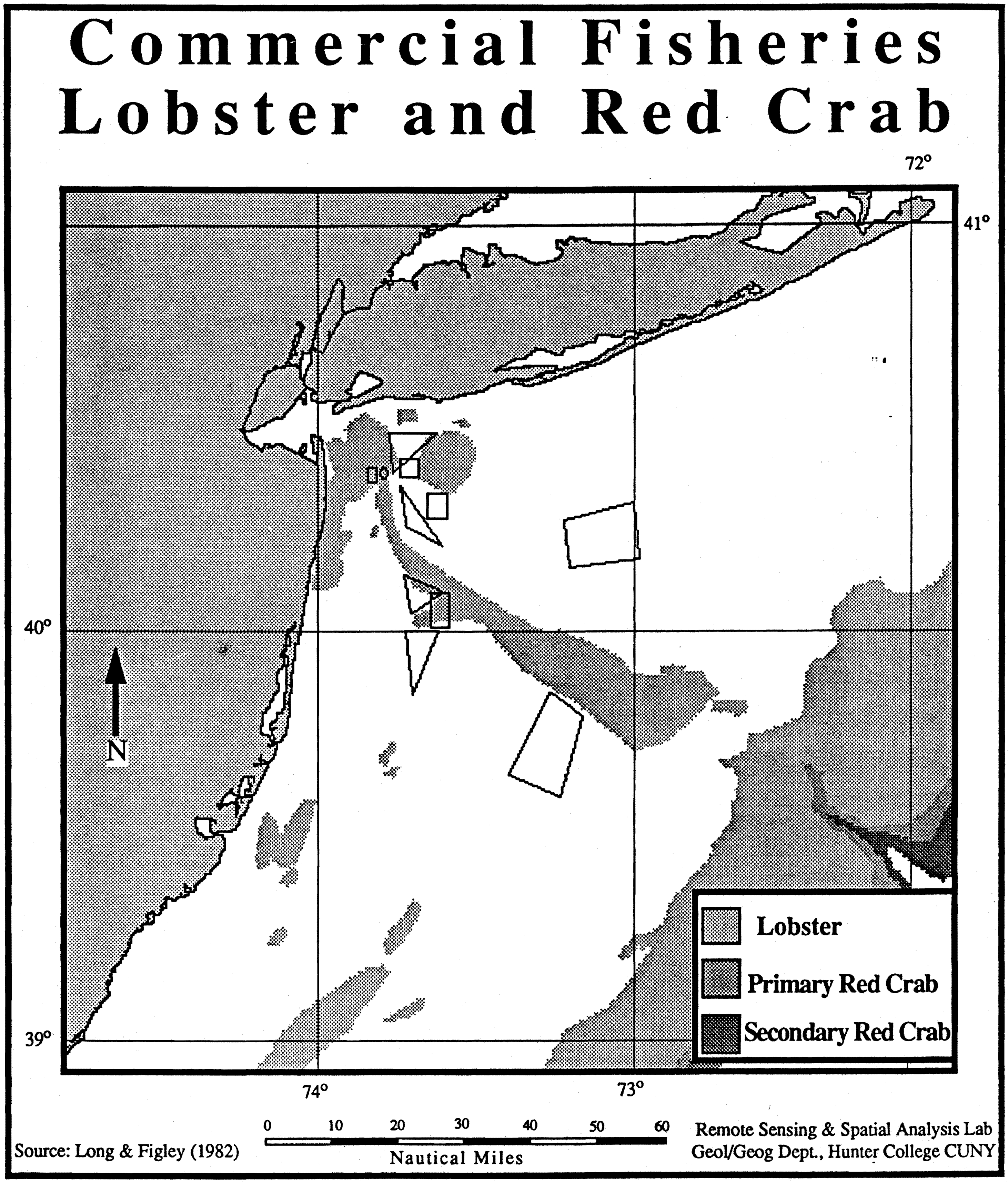
Commercial Fisheries
Lobster and Red Crab
72°
41°
40°
39°
N
74°
73°
Lobster
Primary Red Crab
Secondary Red Crab
0
10
20
30
40
50
60
Nautical Miles
Source: Long & Figley (1982)
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Figure 36

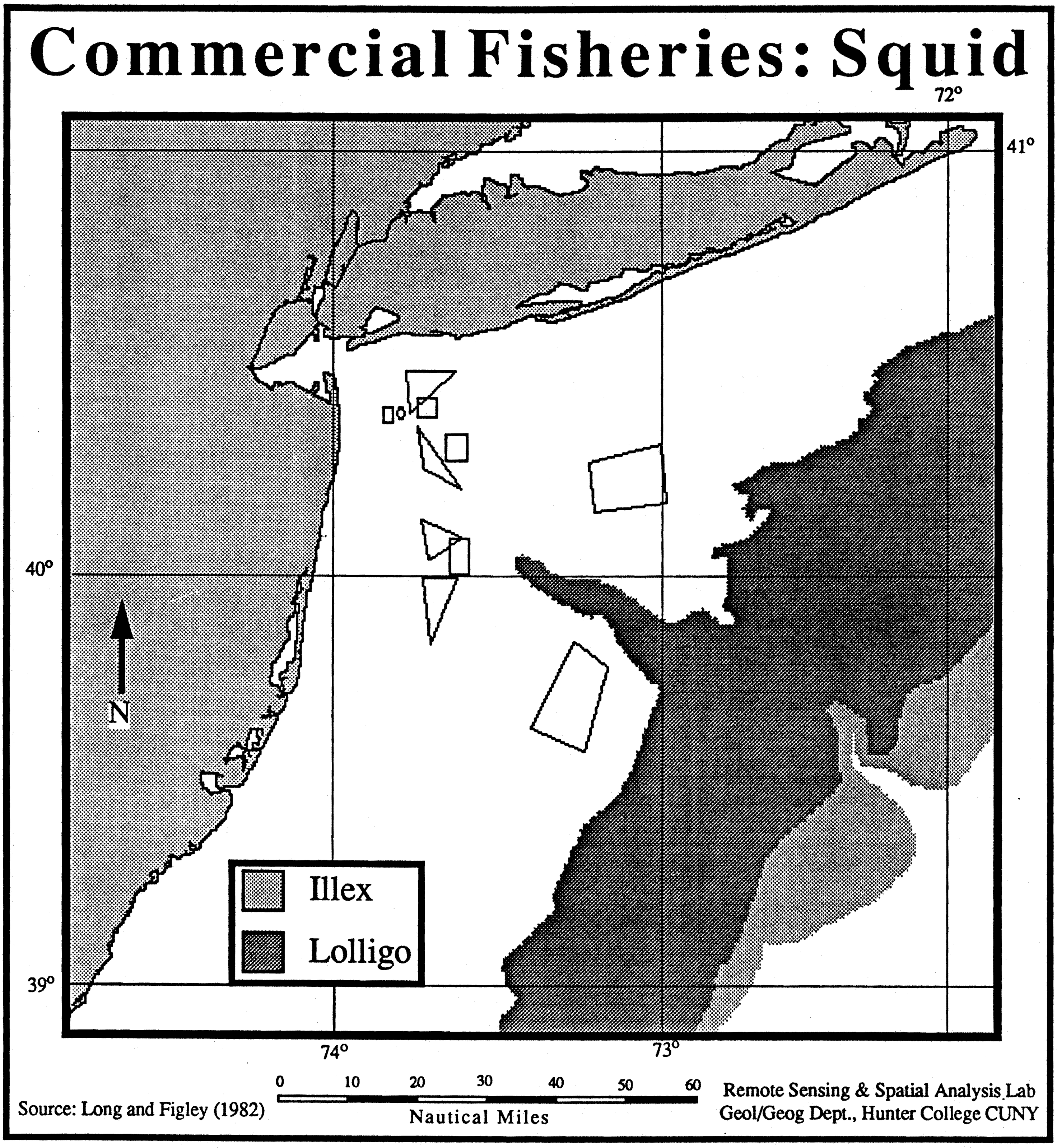
Commercial Fisheries: Squid
72°
41°
40°
39°
74°
73°
N
Illex
Lolligo
0
10
20
30
40
50
60
Nautical Miles
Source: Long and Figley (1982)
Remote Sensing & Spatial Analysis Lab
Geol/Geog Dept., Hunter College CUNY

Figure 37

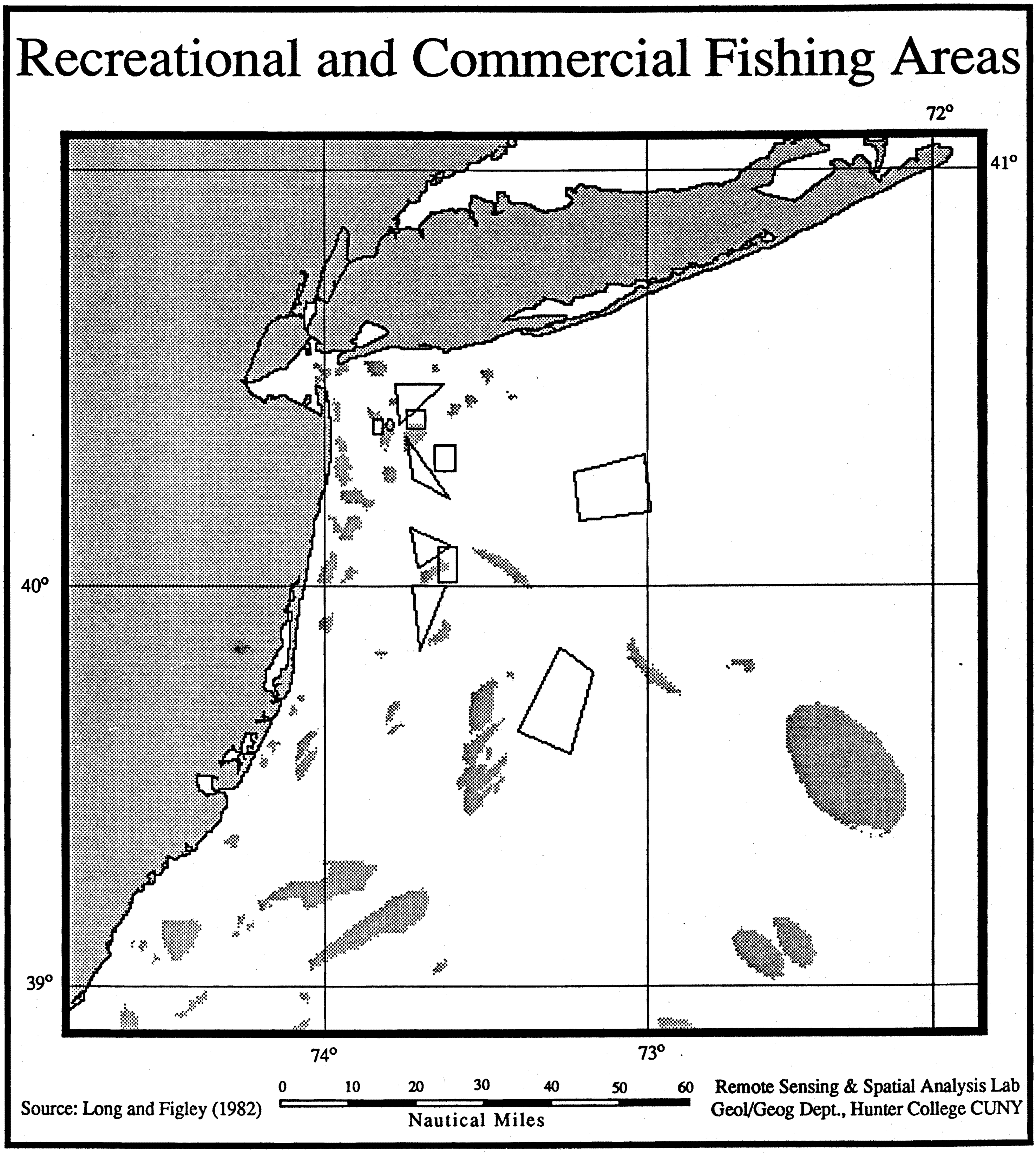
Recreational and Commercial Fishing Areas
72°
41°
40°
39°
74°
73°
0
10
20
30
40
50
60
Nautical Miles
Source: Long and Figley (1982)
Remote Sensing & Spatial Analysis Lab
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Figure 38

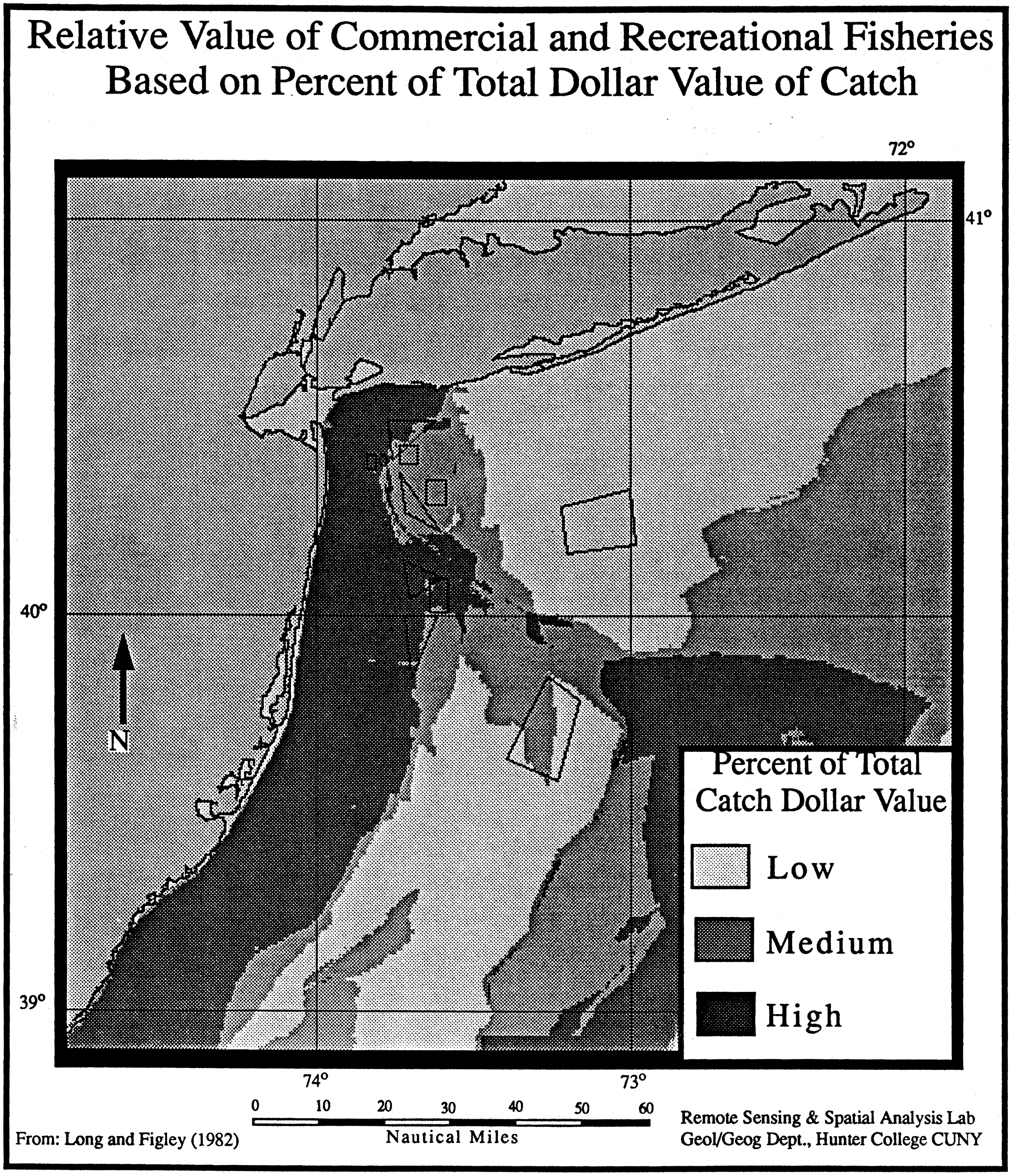

Relative Value of Commercial and Recreational Fisheries
Based on Percent of Total Dollar Value of Catch
72°
41°
40°
39°
74°
73°
N
Percent of Total
Catch Dollar Value
Low
Medium
High
0 10 20 30 40 50 60
Nautical Miles
From: Long and Figley (1982)
Remote Sensing & Spatial Analysis Lab
Geol/Geog Dept., Hunter College CUNY

Figure 39

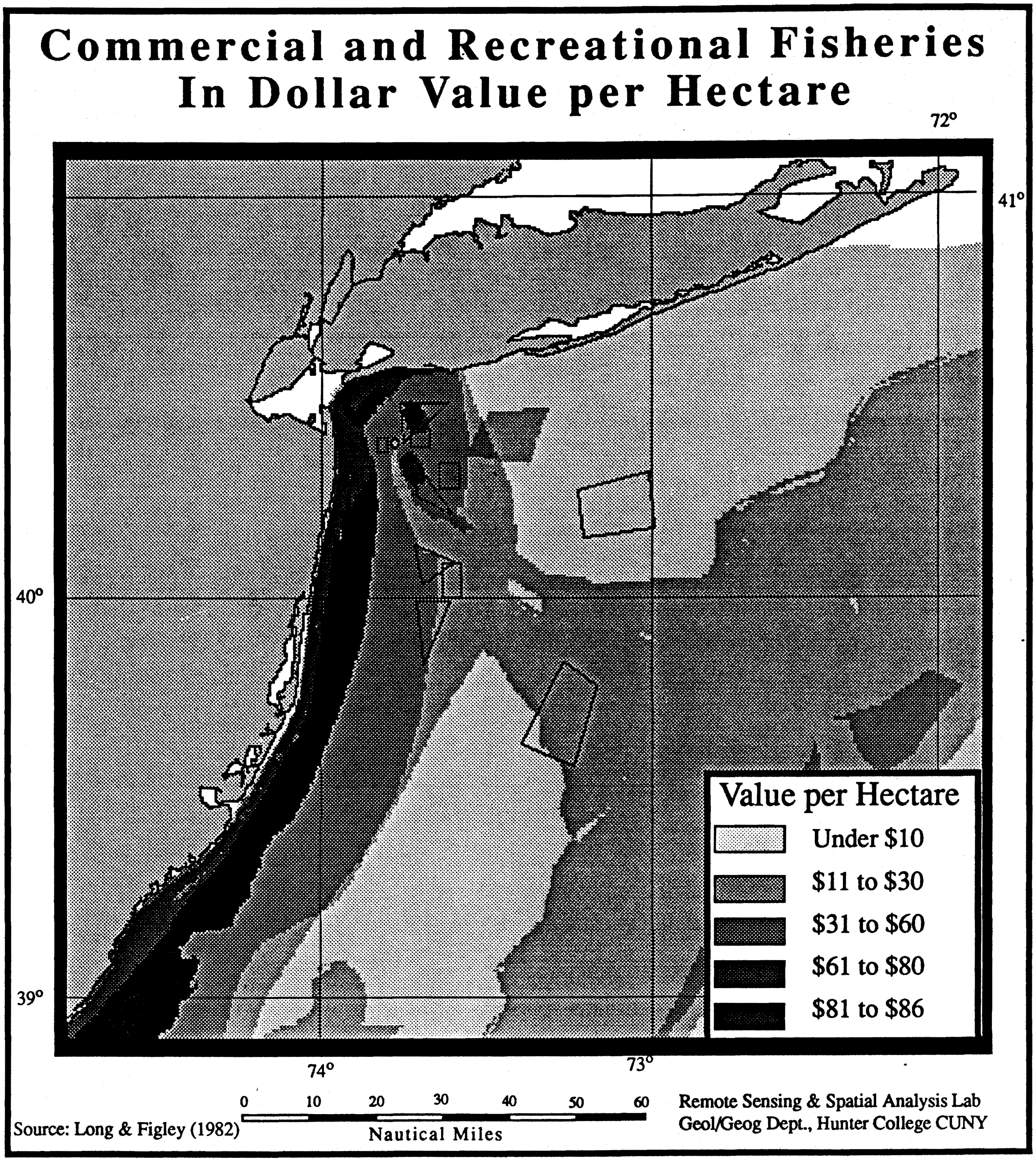
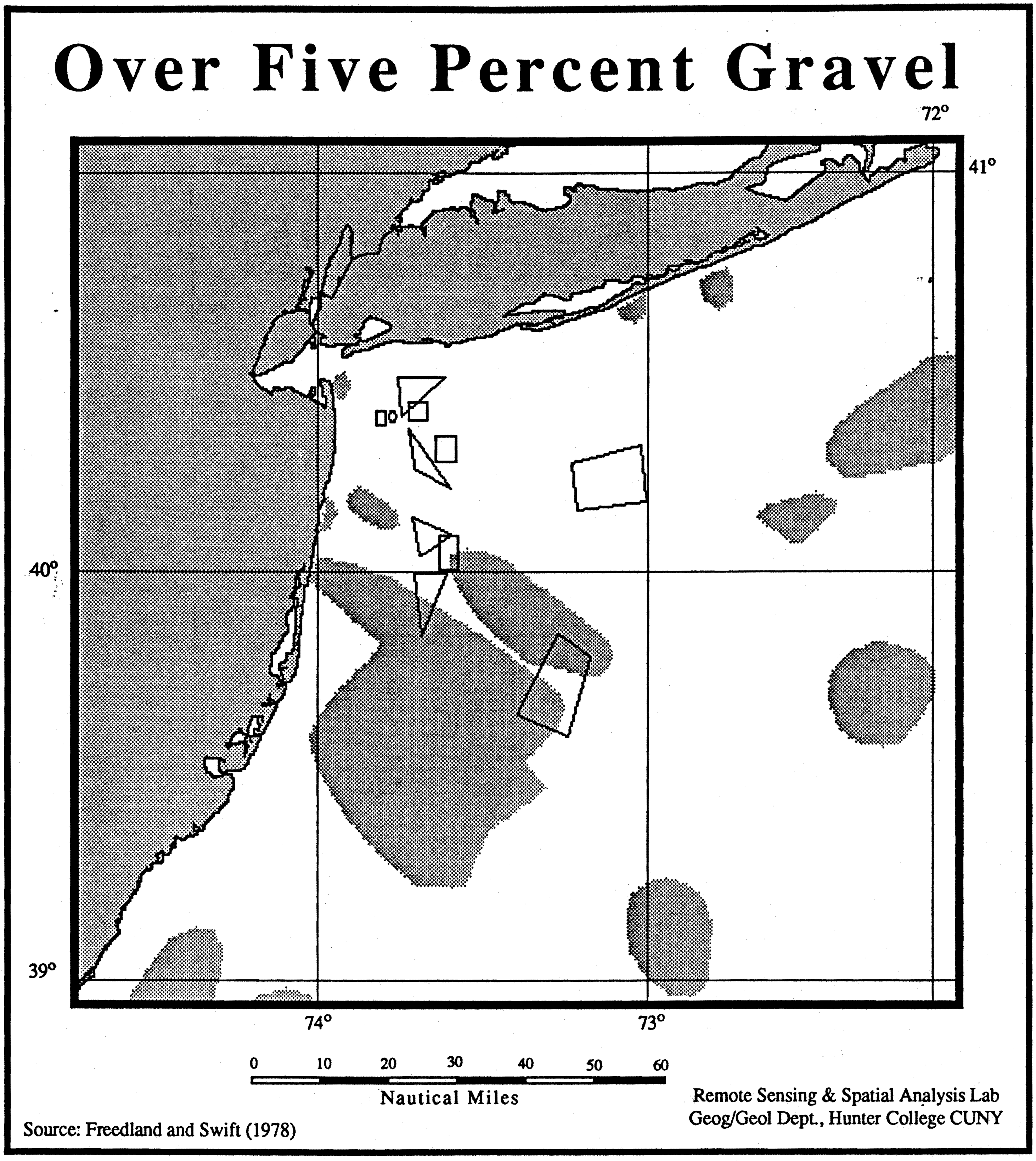
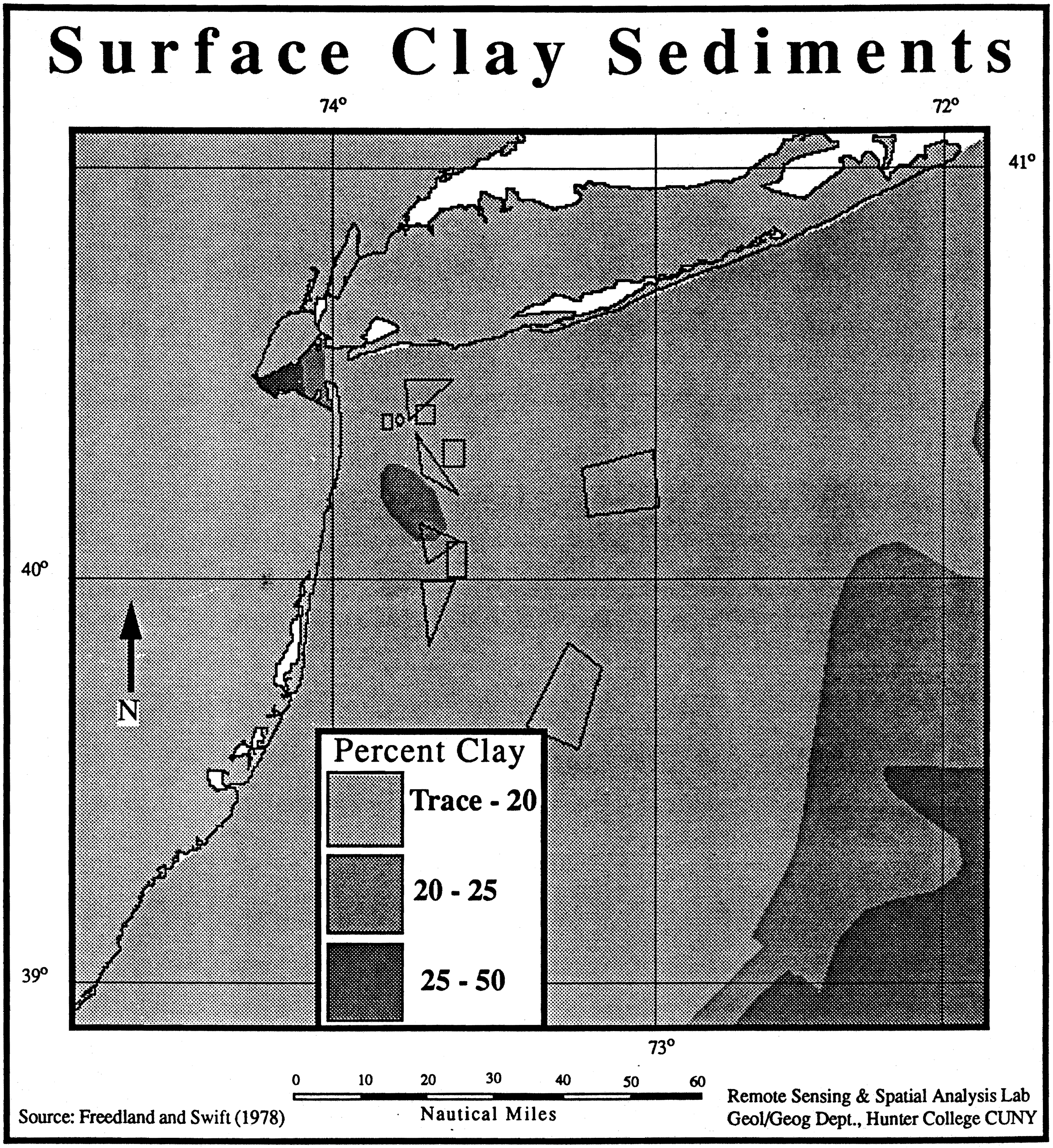

Commercial and Recreational Fisheries
In Dollar Value per Hectare
72°
41°
40°
39°
74°
73°
Value per Hectare
Under $10
$11 to $30
$31 to $60
$61 to $80
$81 to $86
0
10
20
30
40
50
60
Nautical Miles
Source: Long & Figley (1982)
Remote Sensing & Spatial Analysis Lab
Geol/Geog Dept., Hunter College CUNY

Figure 40



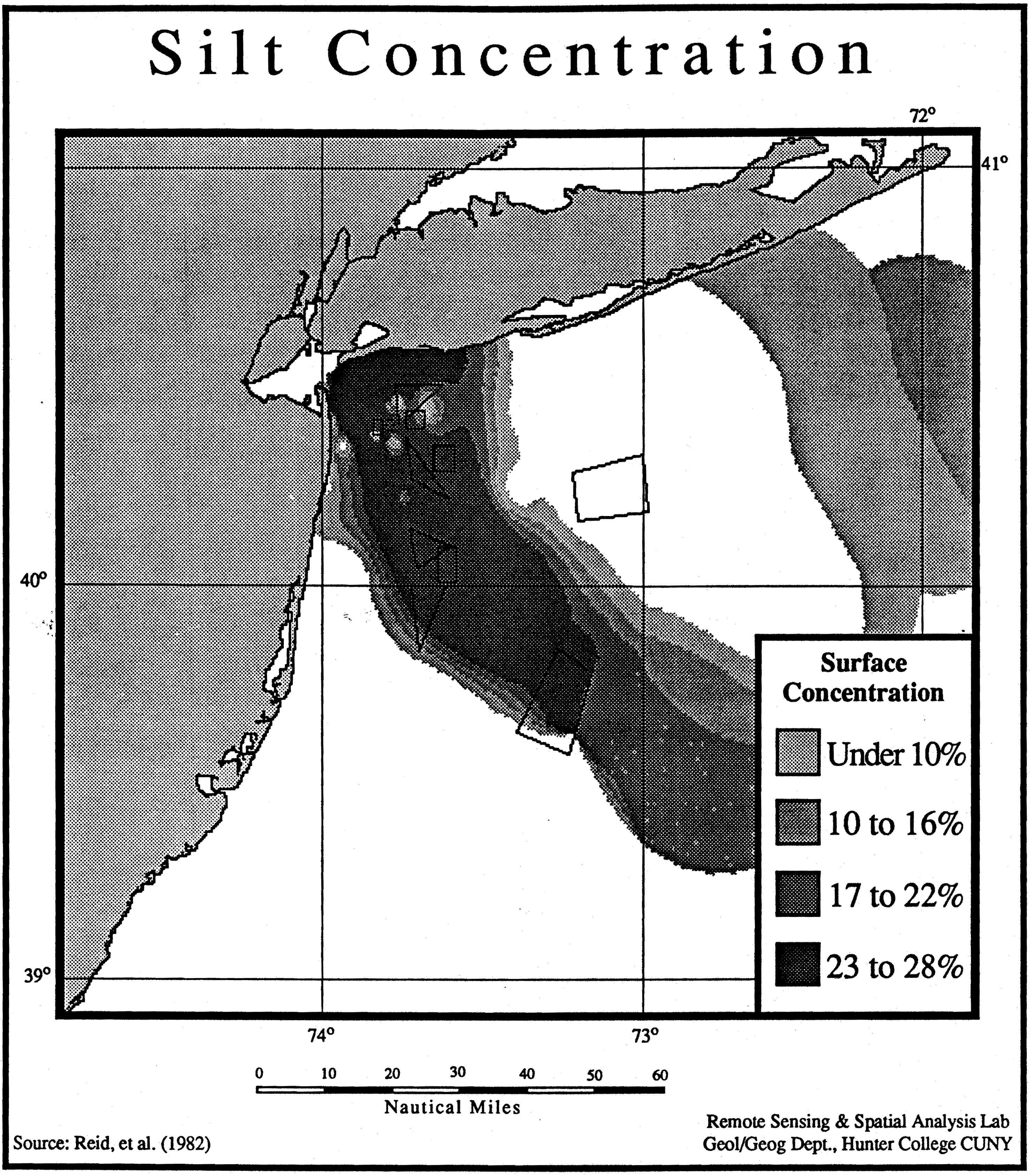
Over Five Percent Gravel
72°
41°
40°
39°
74°
73°
0
10
20
30
40
50
60
Nautical Miles
Remote Sensing & Spatial Analysis Lab
Geog/Geol Dept., Hunter College CUNY
Source: Freedland and Swift (1978)

Figure 41



Surface Clay Sediments
74°
72°
41°
40°
39°
73°
N
Percent Clay
Trace - 20
20 - 25
25 - 50
0
10
20
30
40
50
60
Nautical Miles
Source: Freedland and Swift (1978)
Remote Sensing & Spatial Analysis Lab
Geol/Geog Dept., Hunter College CUNY

Figure 42



Silt Concentration
72°
41°
40°
39°
74°
73°
Surface Concentration
Under 10%
10 to 16%
17 to 22%
23 to 28%
0
10
20
30
40
50
60
Nautical Miles
Source: Reid, et al. (1982)
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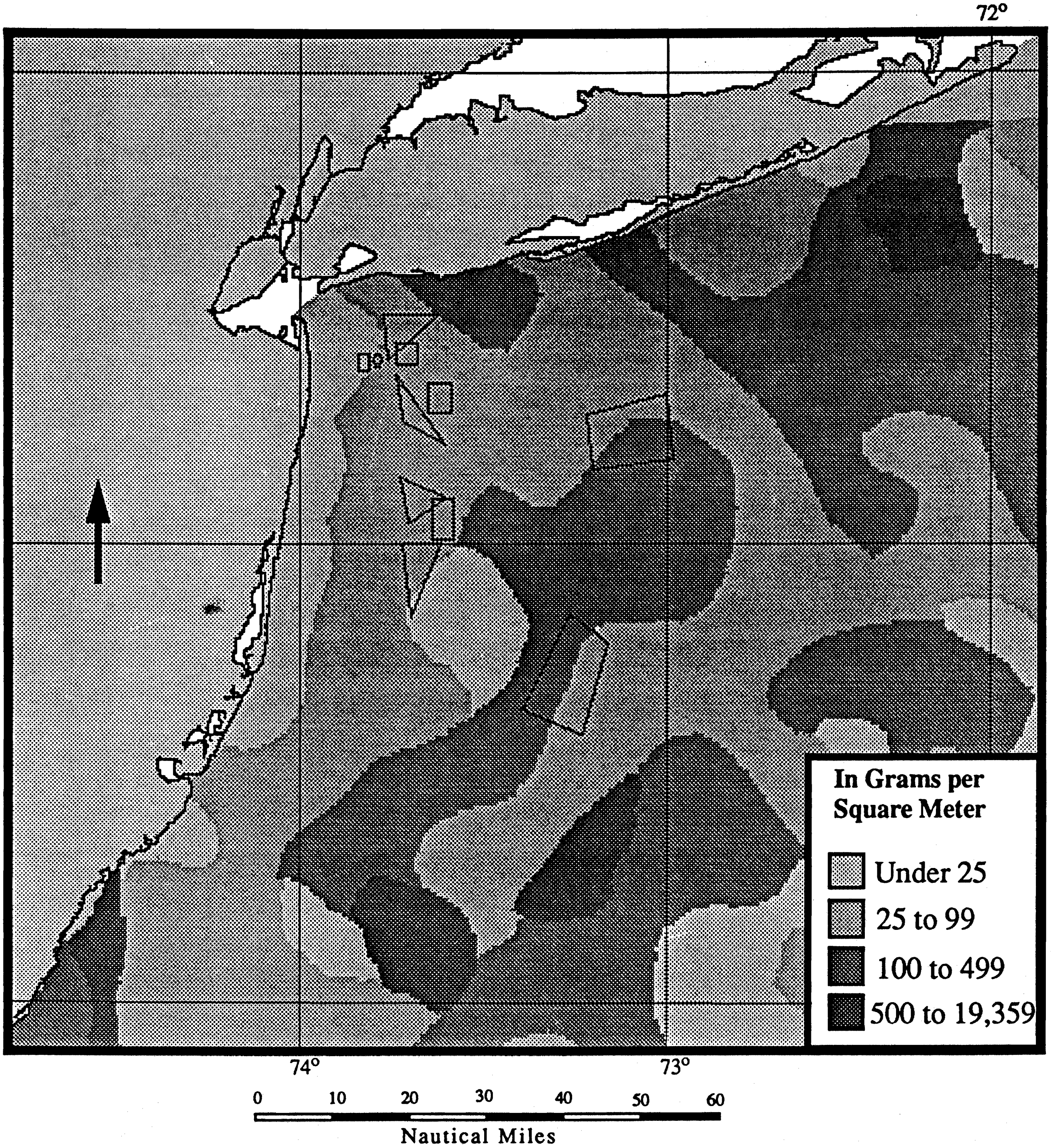
Figure 43

Biomass Density



Source: Wigley and Theroux (1981)

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Figure 44

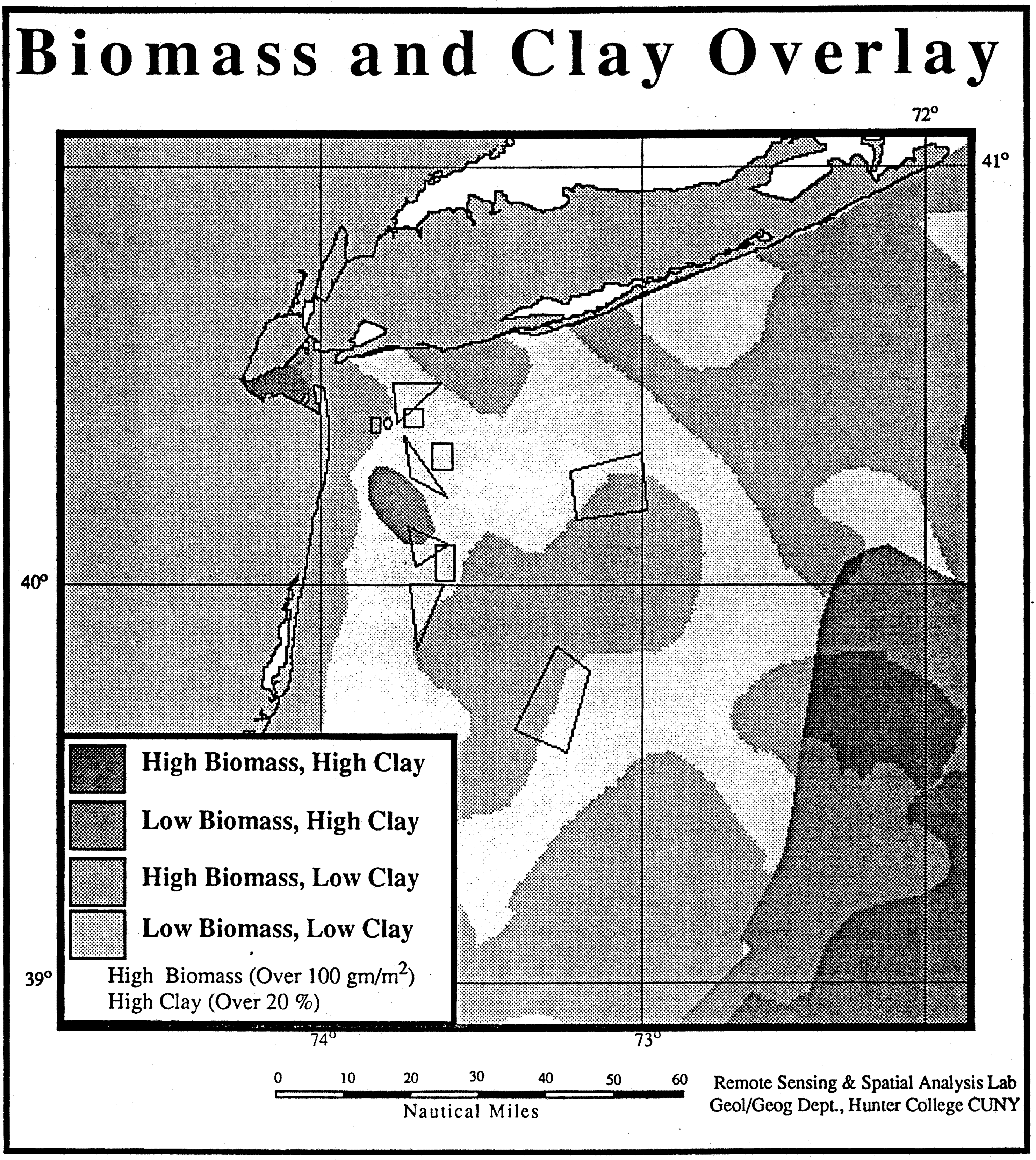
Biomass and Clay Overlay
72°
41°
40°
39°
74°
73°
High Biomass, High Clay
Low Biomass, High Clay
High Biomass, Low Clay
Low Biomass, Low Clay
High Biomass (Over 100 gm/m^2)
High Clay (Over 20 %)
0 10 20 30 40 50 60
Nautical Miles
Remote Sensing & Spatial Analysis Lab
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Figure 45

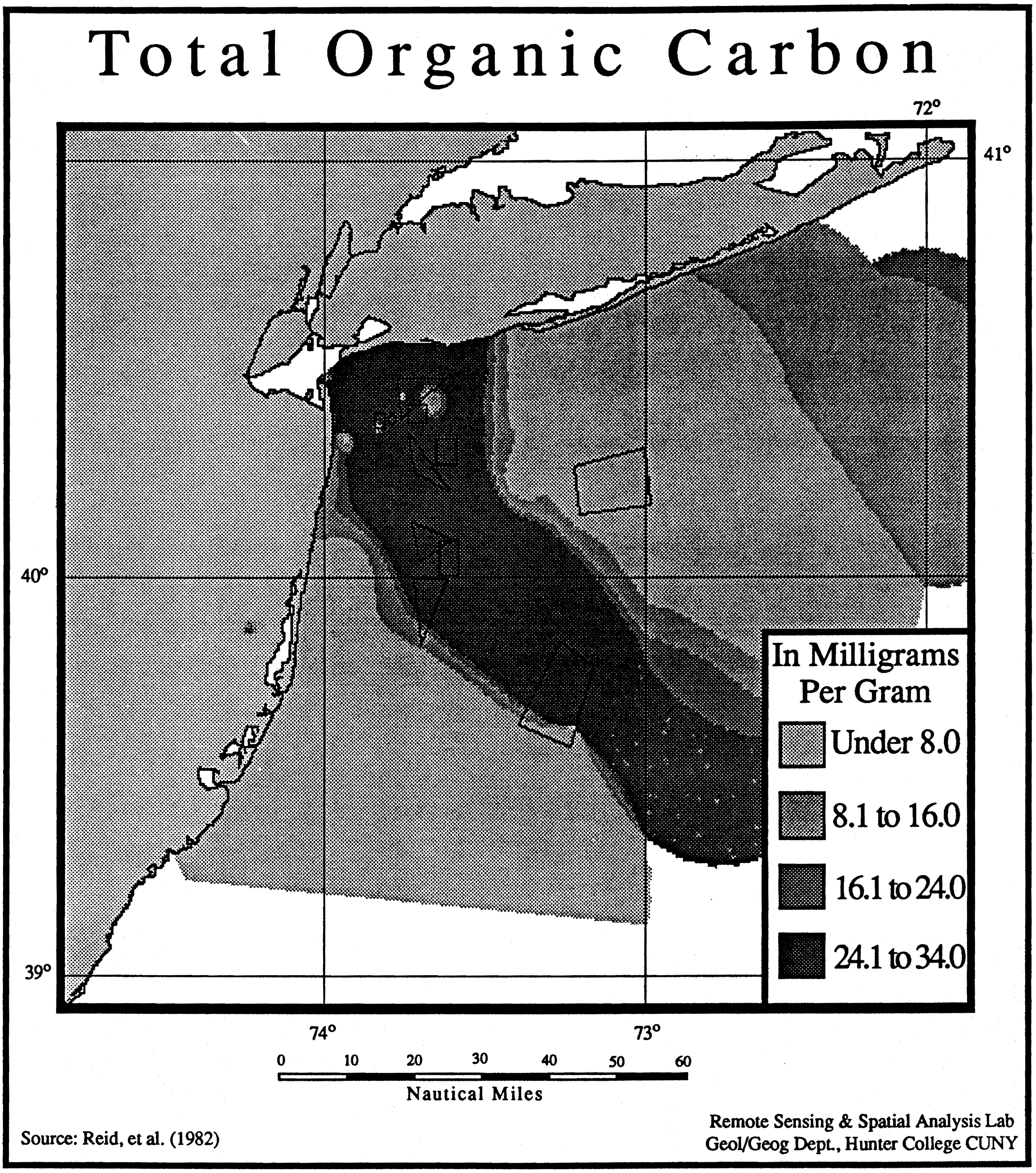
Total Organic Carbon
72°
41°
40°
39°
74°
73°
In Milligrams Per Gram
Under 8.0
8.1 to 16.0
16.1 to 24.0
24.1 to 34.0
0 10 20 30 40 50 60
Nautical Miles
Source: Reid, et al. (1982)
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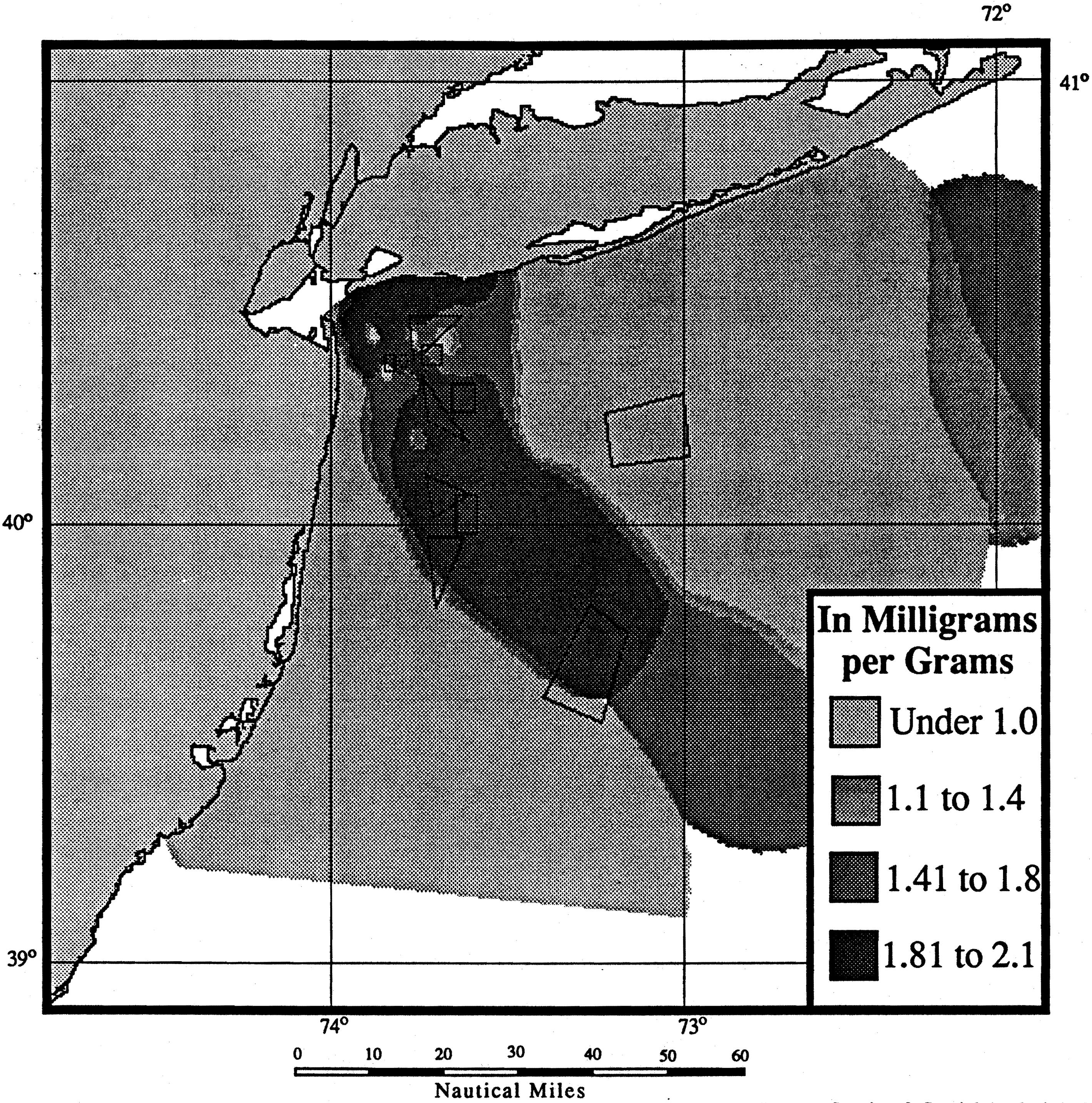
Figure 46

Total Kjeldahl Nitrogen



Source: Reid, et al. (1982)

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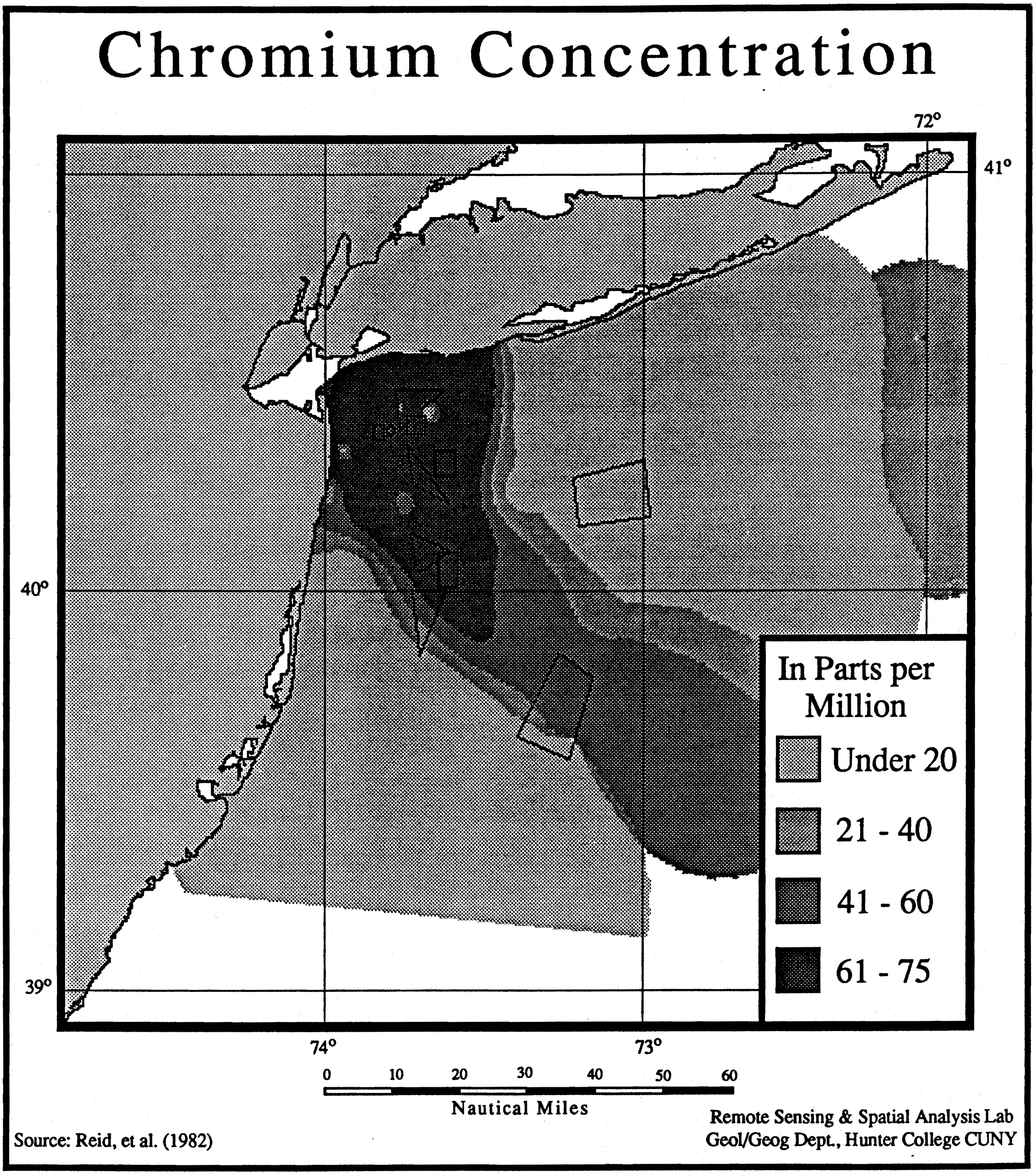
Figure 47



Chromium Concentration
72°
41°
40°
39°
74°
73°
0
10
20
30
40
50
60
Nautical Miles
In Parts per Million
Under 20
21 - 40
41 - 60
61 - 75
Source: Reid, et al. (1982)
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Figure 48

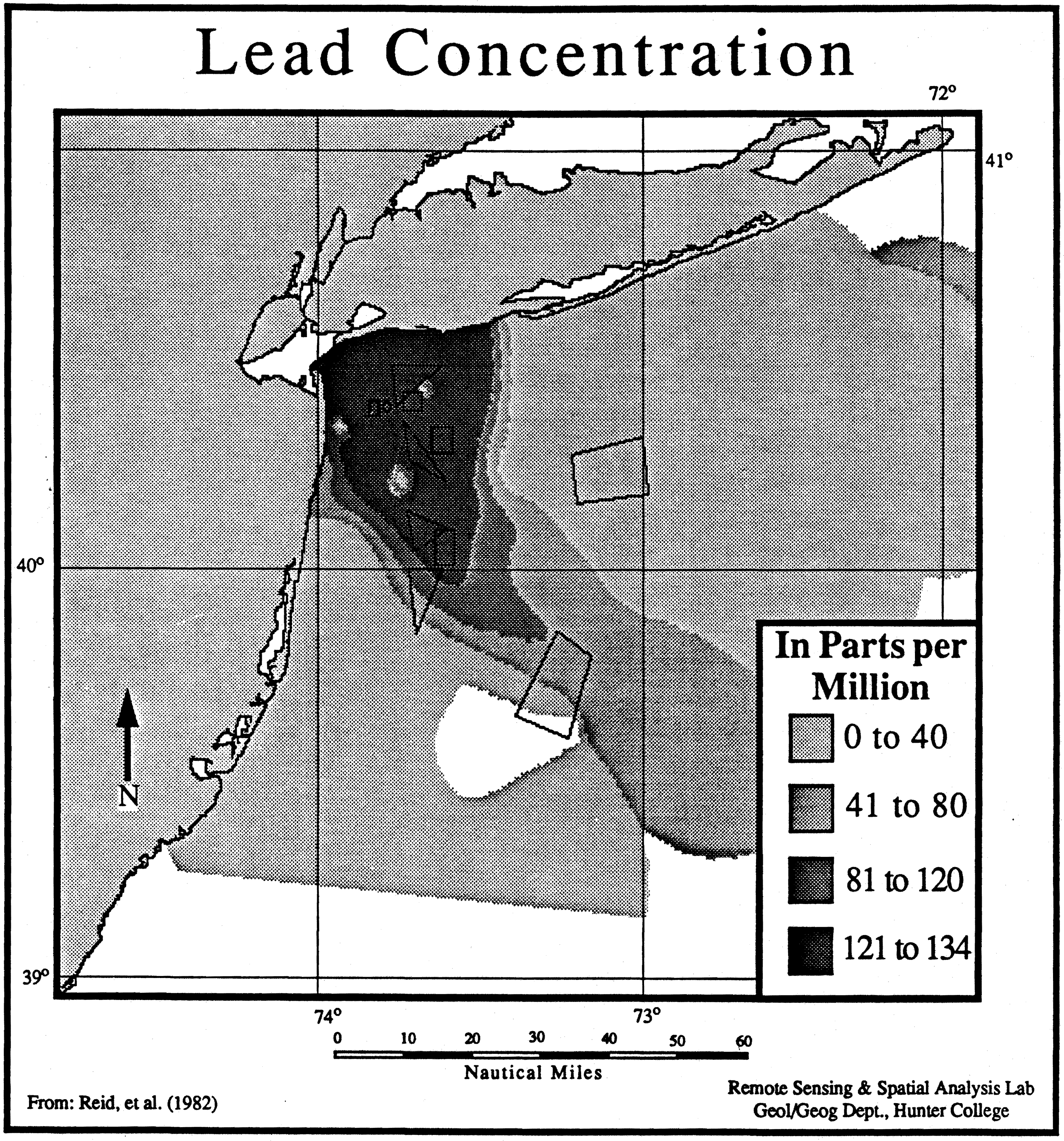
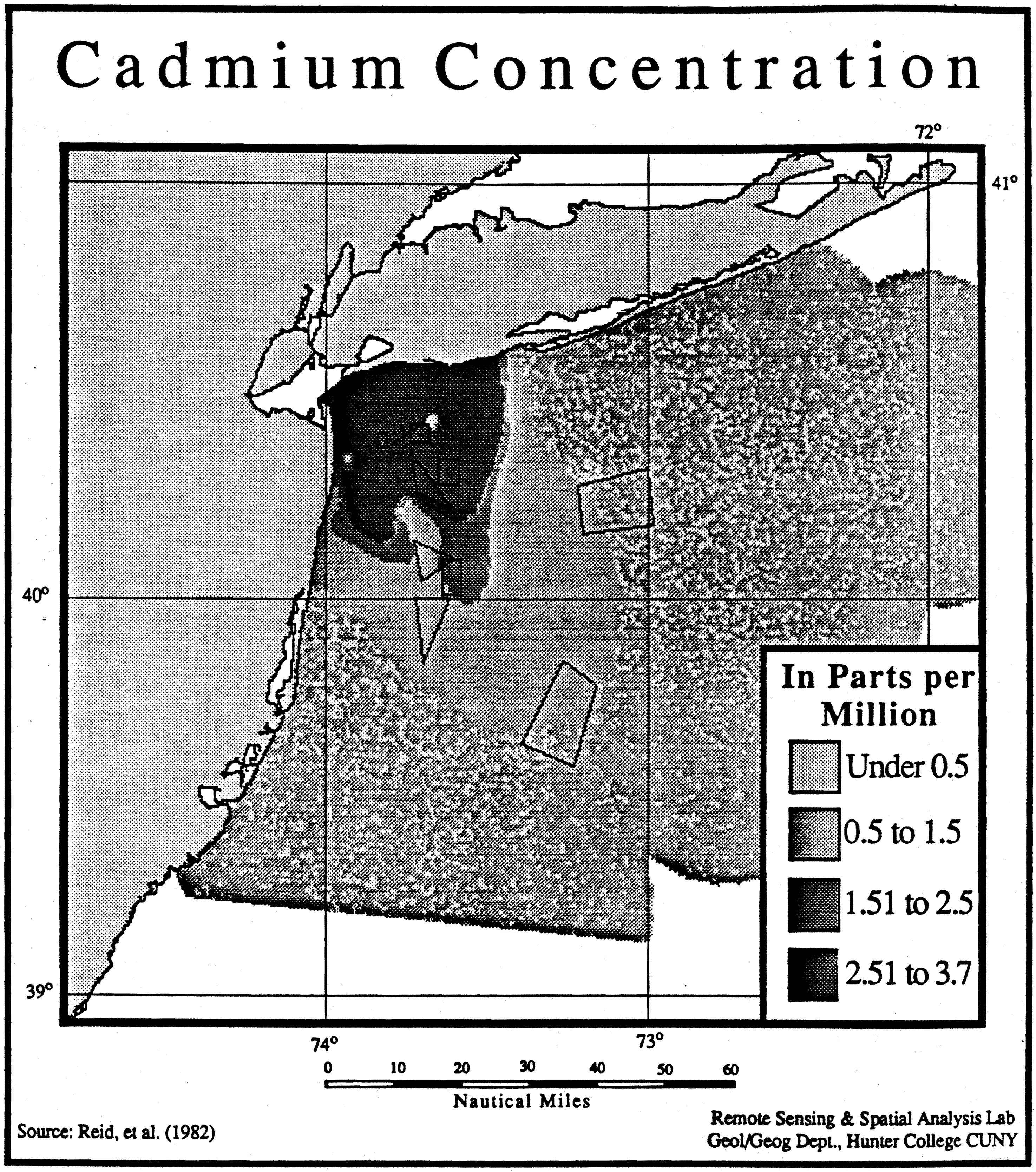

Lead Concentration
72°
41°
40°
39°
74°
73°
N
In Parts per Million
0 to 40
41 to 80
81 to 120
121 to 134
0 10 20 30 40 50 60
Nautical Miles
From: Reid, et al. (1982)
Remote Sensing & Spatial Analysis Lab
Geol/Geog Dept., Hunter College

Figure 49



Cadmium Concentration
72°
41°
40°
39°
74°
73°
In Parts per Million
Under 0.5
0.5 to 1.5
1.51 to 2.5
2.51 to 3.7
0
10
20
30
40
50
60
Nautical Miles
Source: Reid, et al. (1982)
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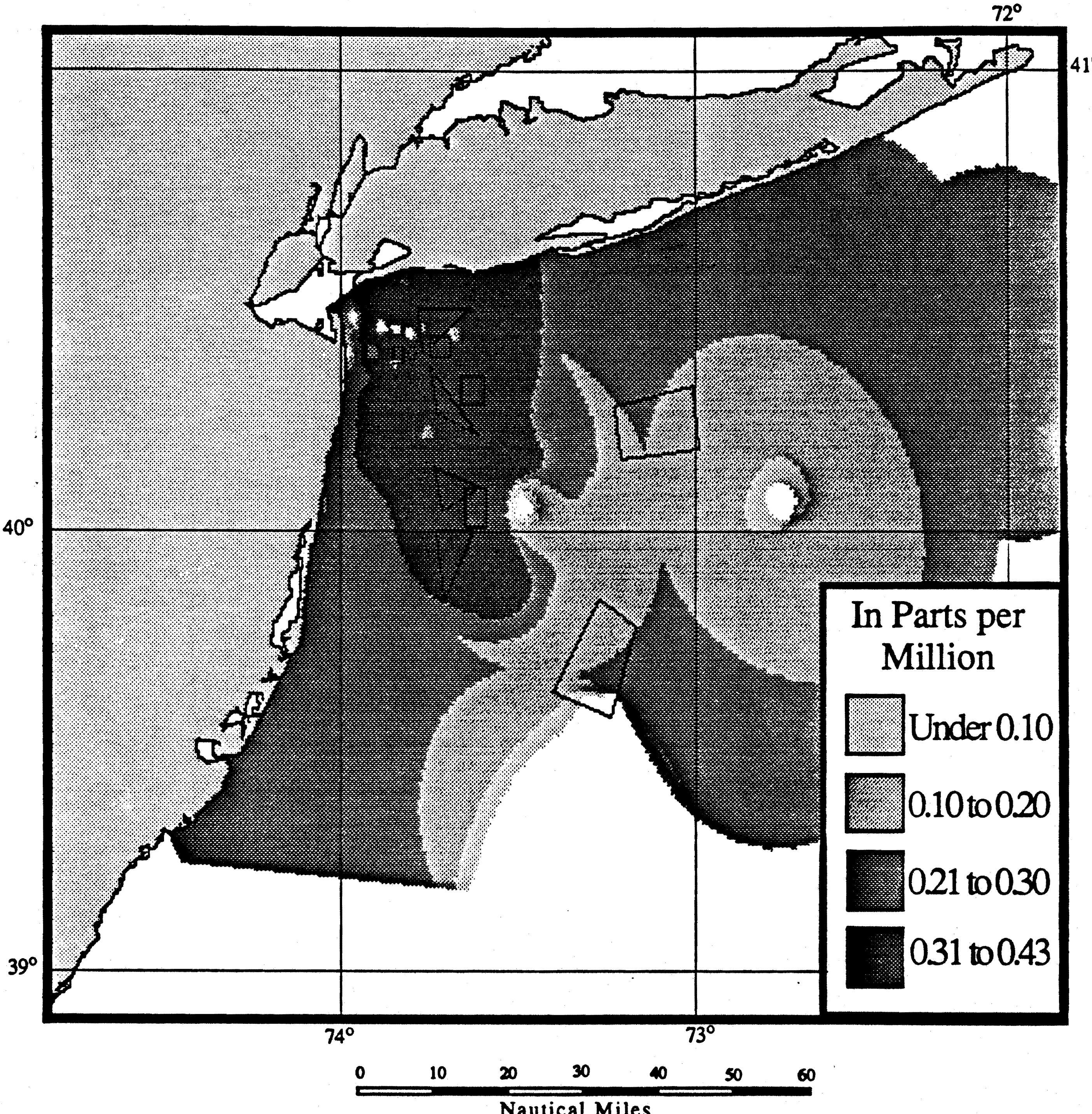
Figure 50

Mercury Concentration



Source: Reid, et al. (1982)

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Figure 51

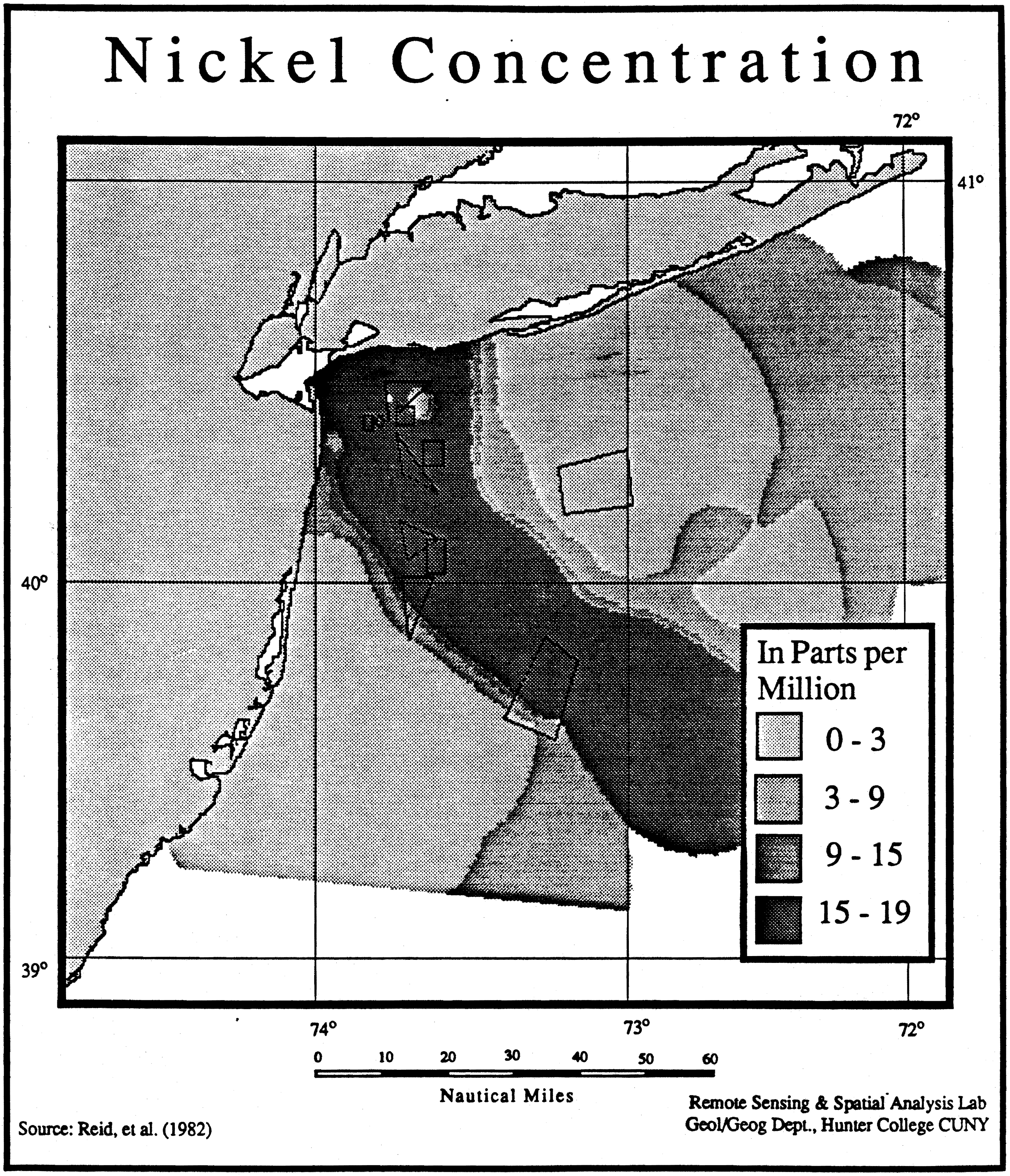
Nickel Concentration
72°
41°
40°
39°
74°
73°
72°
0
10
20
30
40
50
60
Nautical Miles
In Parts per Million
0 - 3
3 - 9
9 - 15
15 - 19
Source: Reid, et al. (1982)
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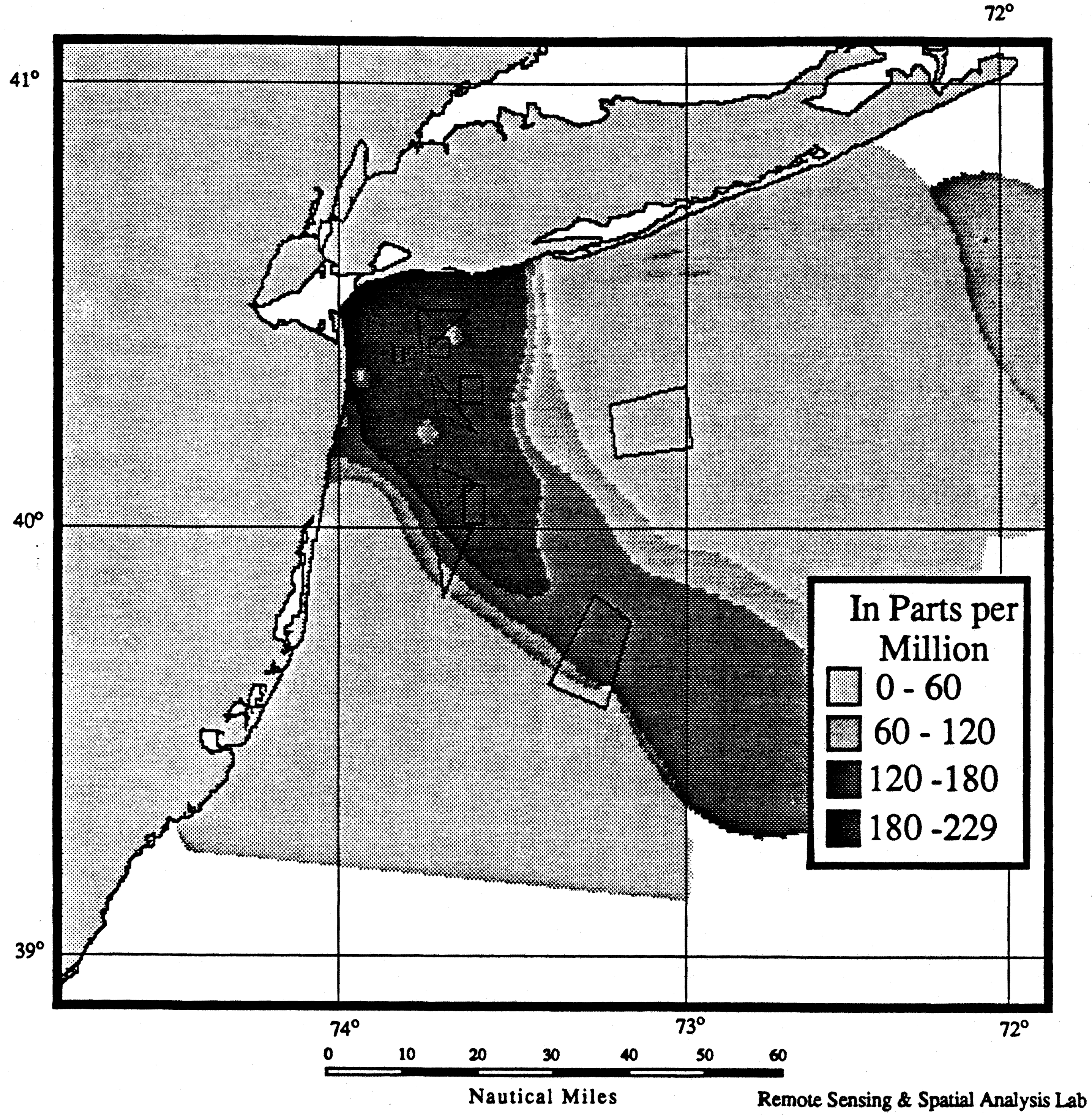
Figure 52

Zinc Concentration



Source: NOAA Technical Memorandum NMFS-F/NEC-16 (1982)

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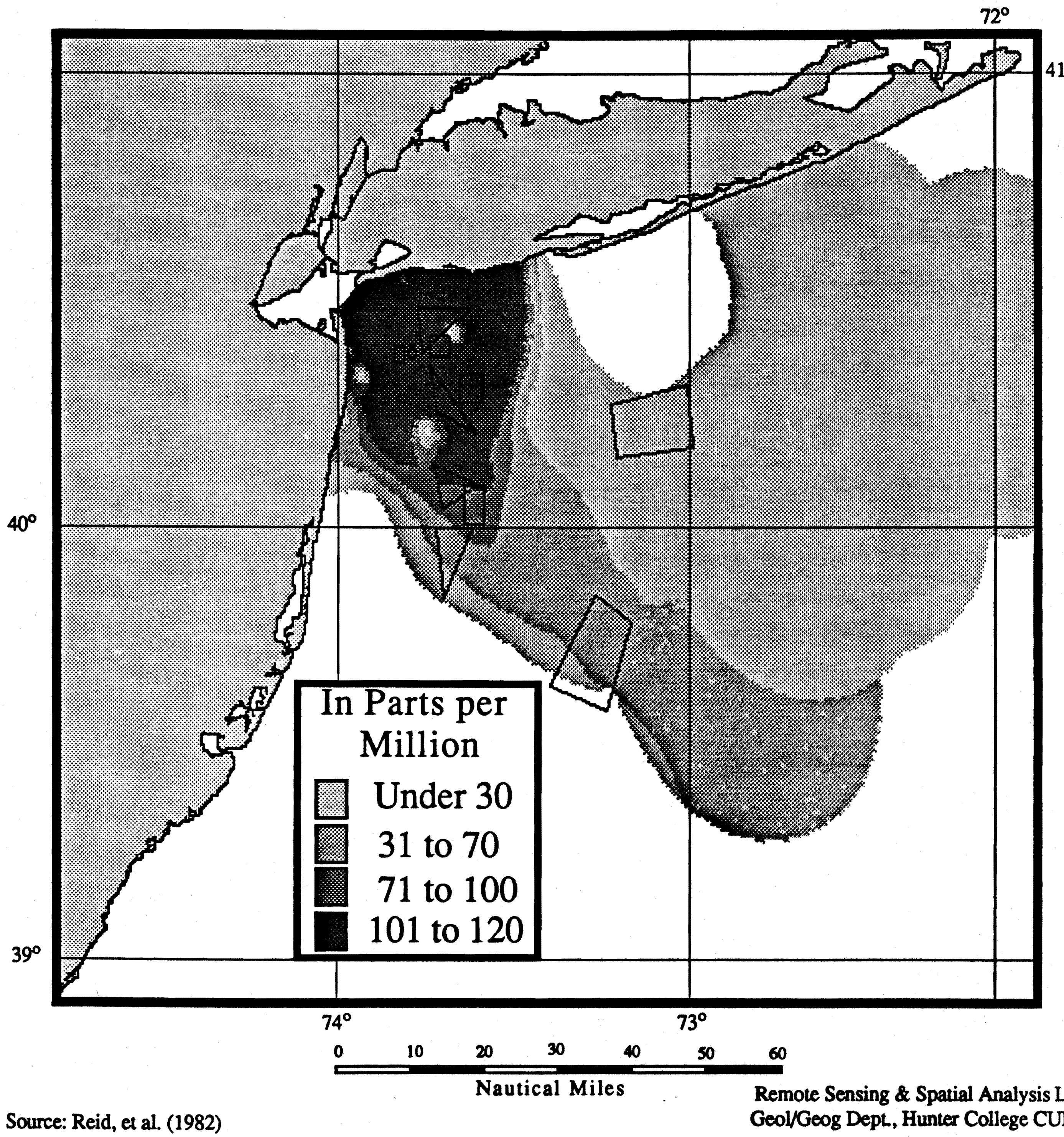
Figure 53

Copper Concentration



Source: Reid, et al. (1982)

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Figure 54

Current Velocity, DIFID Model

Short-term site simulation, combined flood tide and non-storm induced circulation

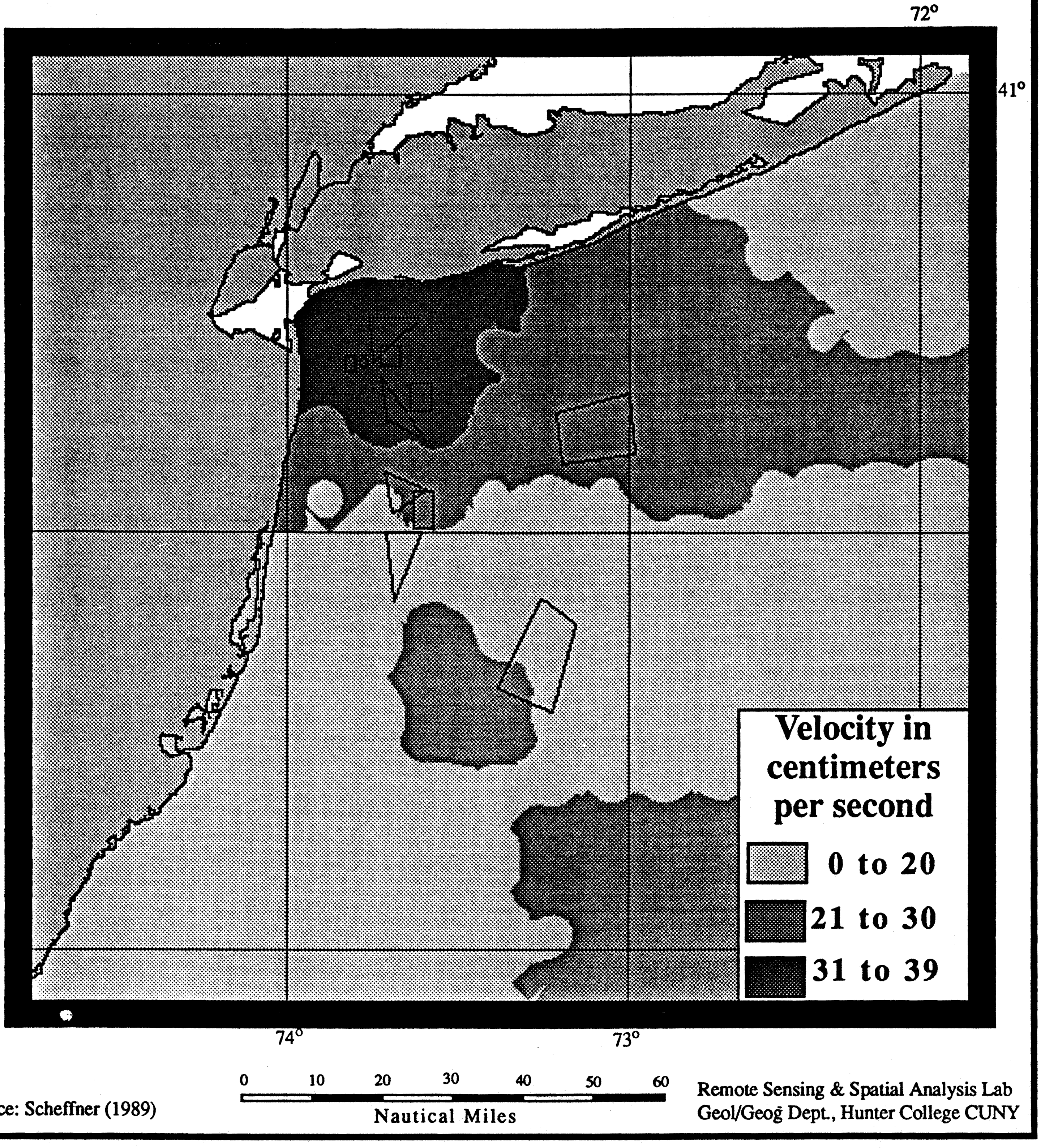

Figure 55

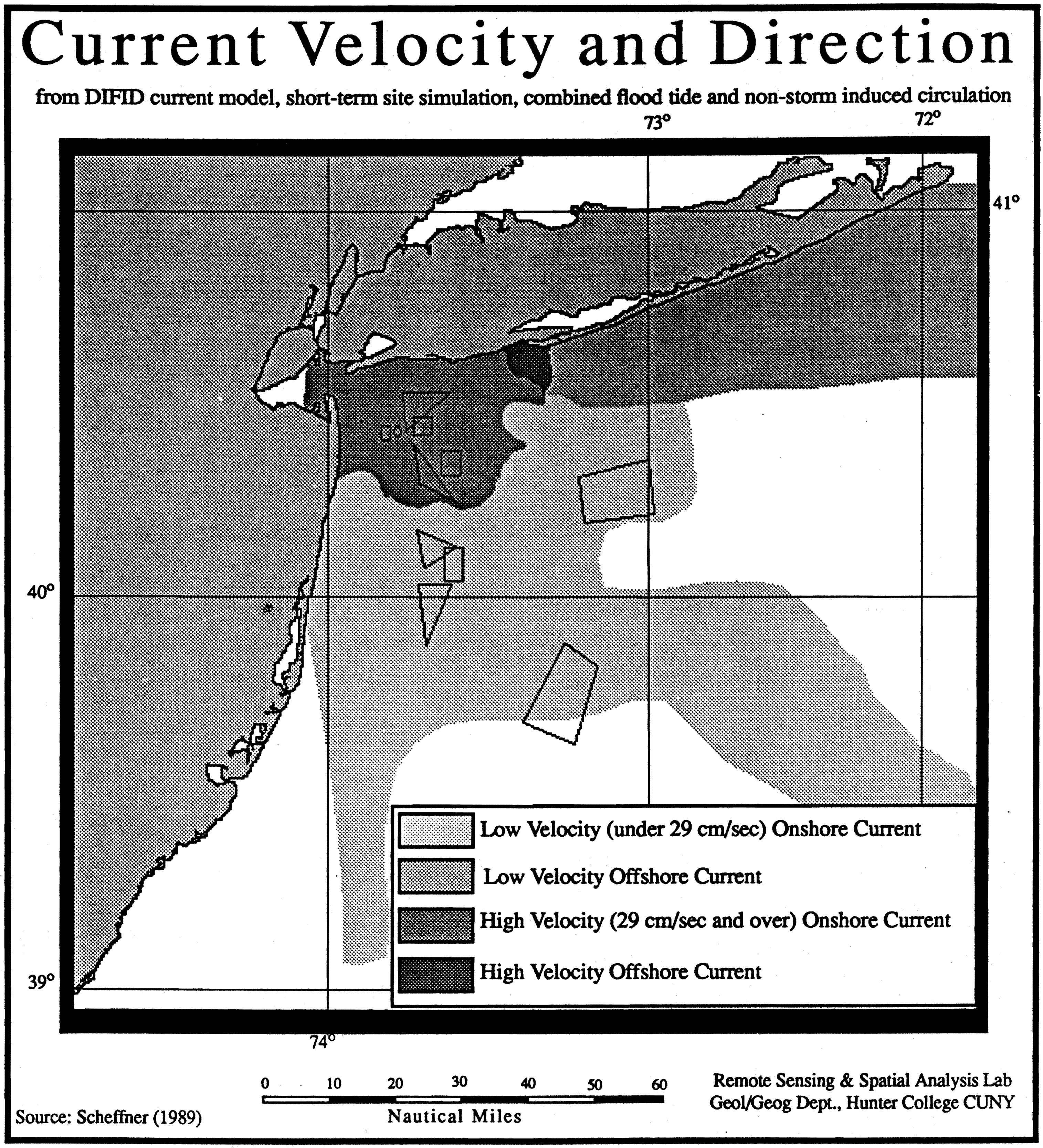
Current Velocity and Direction
from DIFID current model, short-term site simulation, combined flood tide and non-storm induced circulation
73°
72°
41°
40°
39°
74°
Low Velocity (under 29 cm/sec) Onshore Current
Low Velocity Offshore Current
High Velocity (29 cm/sec and over) Onshore Current
High Velocity Offshore Current
0
10
20
30
40
50
60
Nautical Miles
Source: Scheffner (1989)
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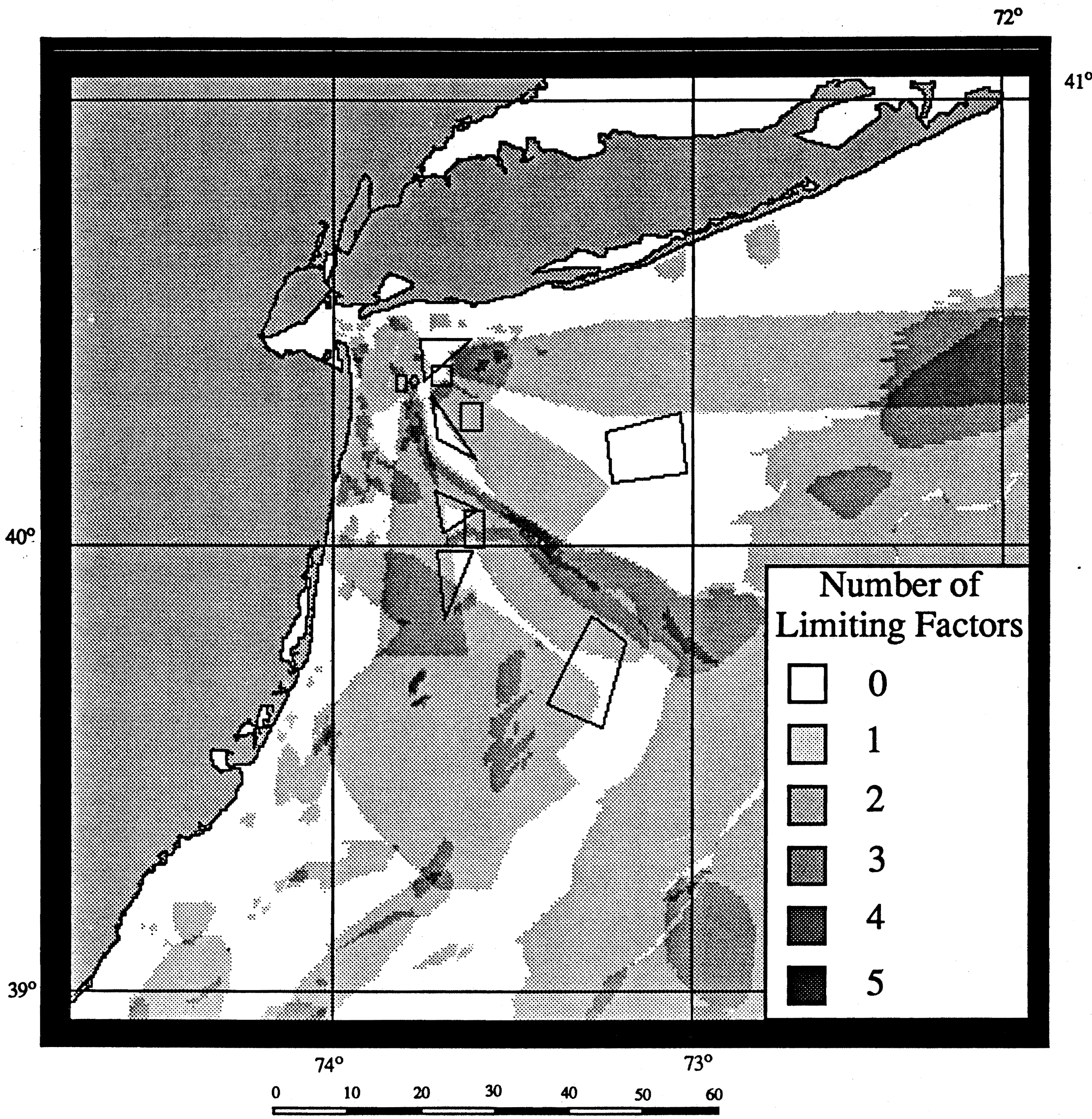
Figure 56

Five Category Overlay

Gravel, Hudson Canyon, Lobster, Recreational Fishing, and Shipping Lanes



Source: Long and Figley (1982)

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Figure 57

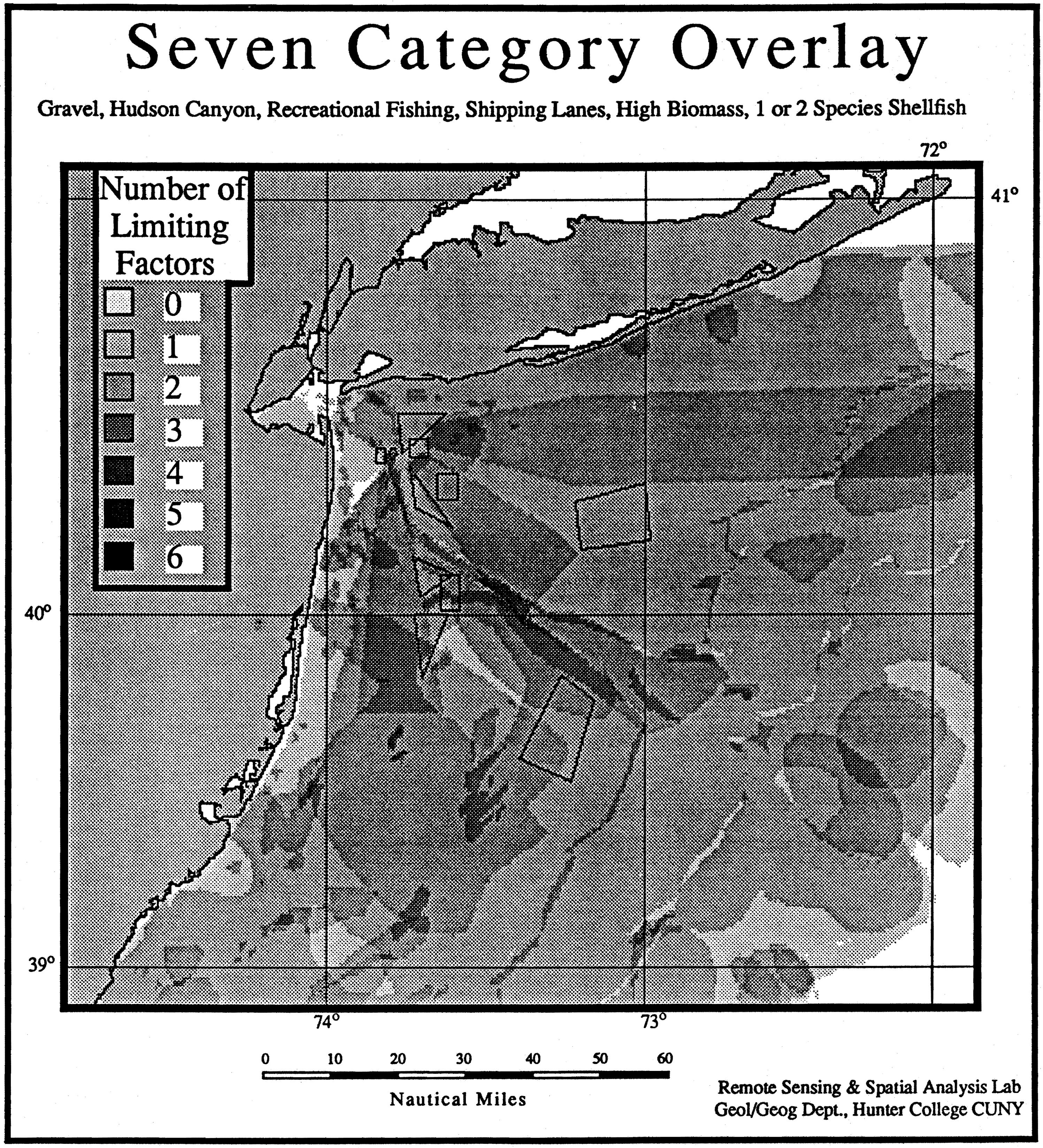
Seven Category Overlay
Gravel, Hudson Canyon, Recreational Fishing, Shipping Lanes, High Biomass, 1 or 2 Species Shellfish
Number of Limiting Factors
0
1
2
3
4
5
6
72°
41°
40°
39°
74°
73°
0
10
20
30
40
50
60
Nautical Miles
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Figure 58

Overlay of Fisheries in Dollar Value per Hectare with Over 5% Gravel and Shipping Lanes

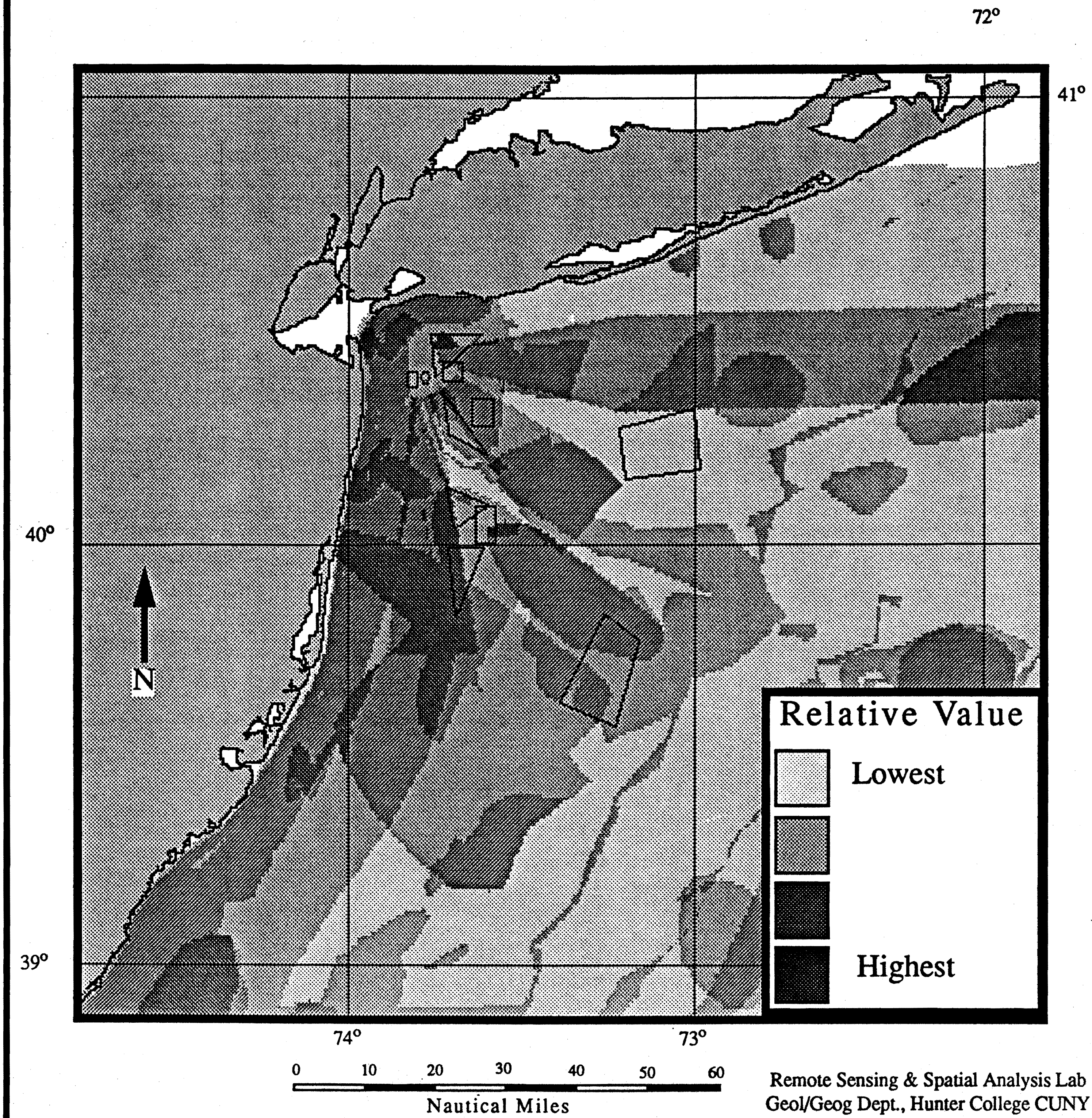

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Figure 59

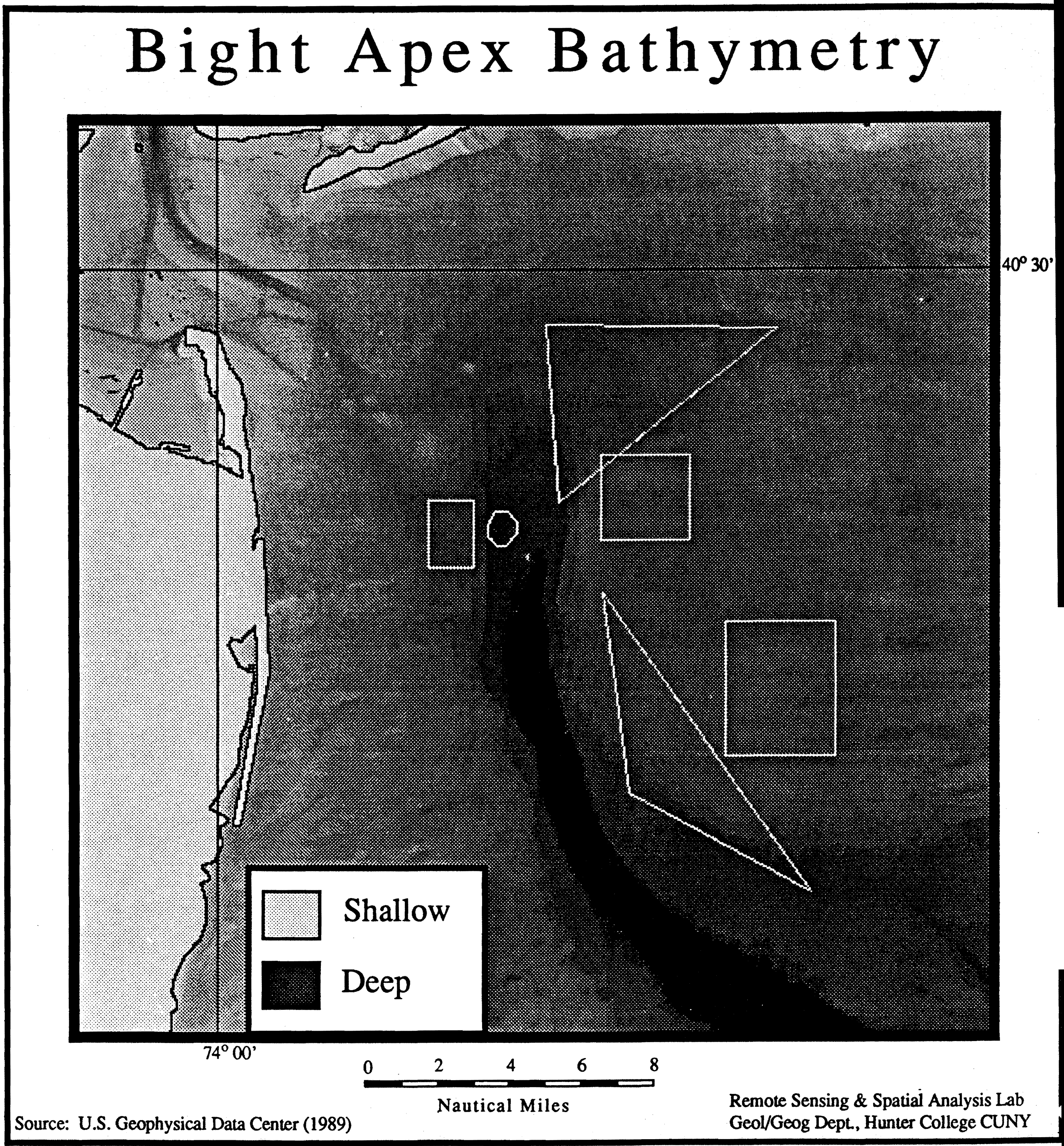
Bight Apex Bathymetry
40° 30'
Shallow
Deep
74° 00'
0 2 4 6 8
Nautical Miles
Source: U.S. Geophysical Data Center (1989)
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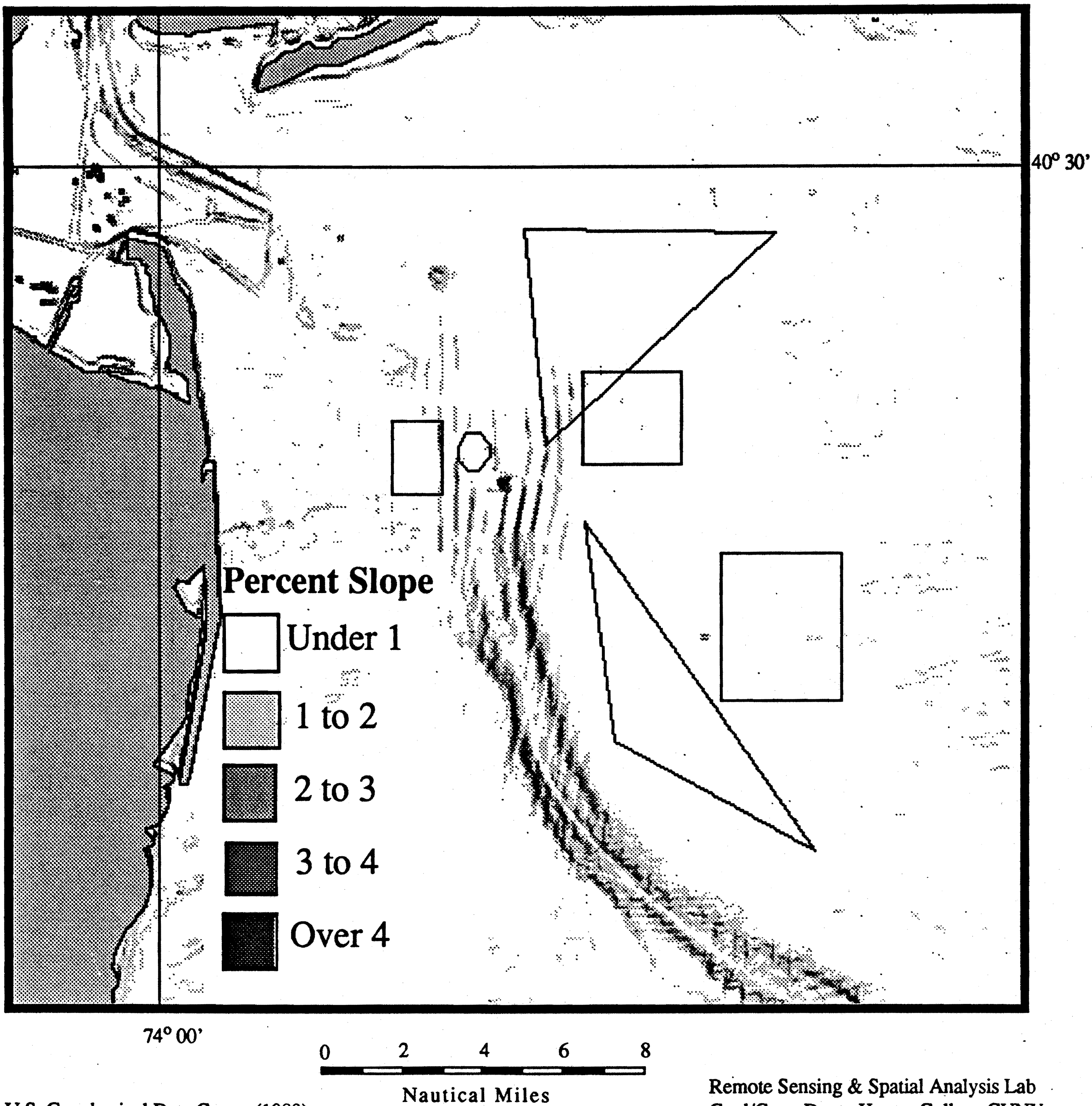
Figure 60

Bathymetric Gradients in the New York Bight Apex



Source: U.S. Geophysical Data Center (1989)

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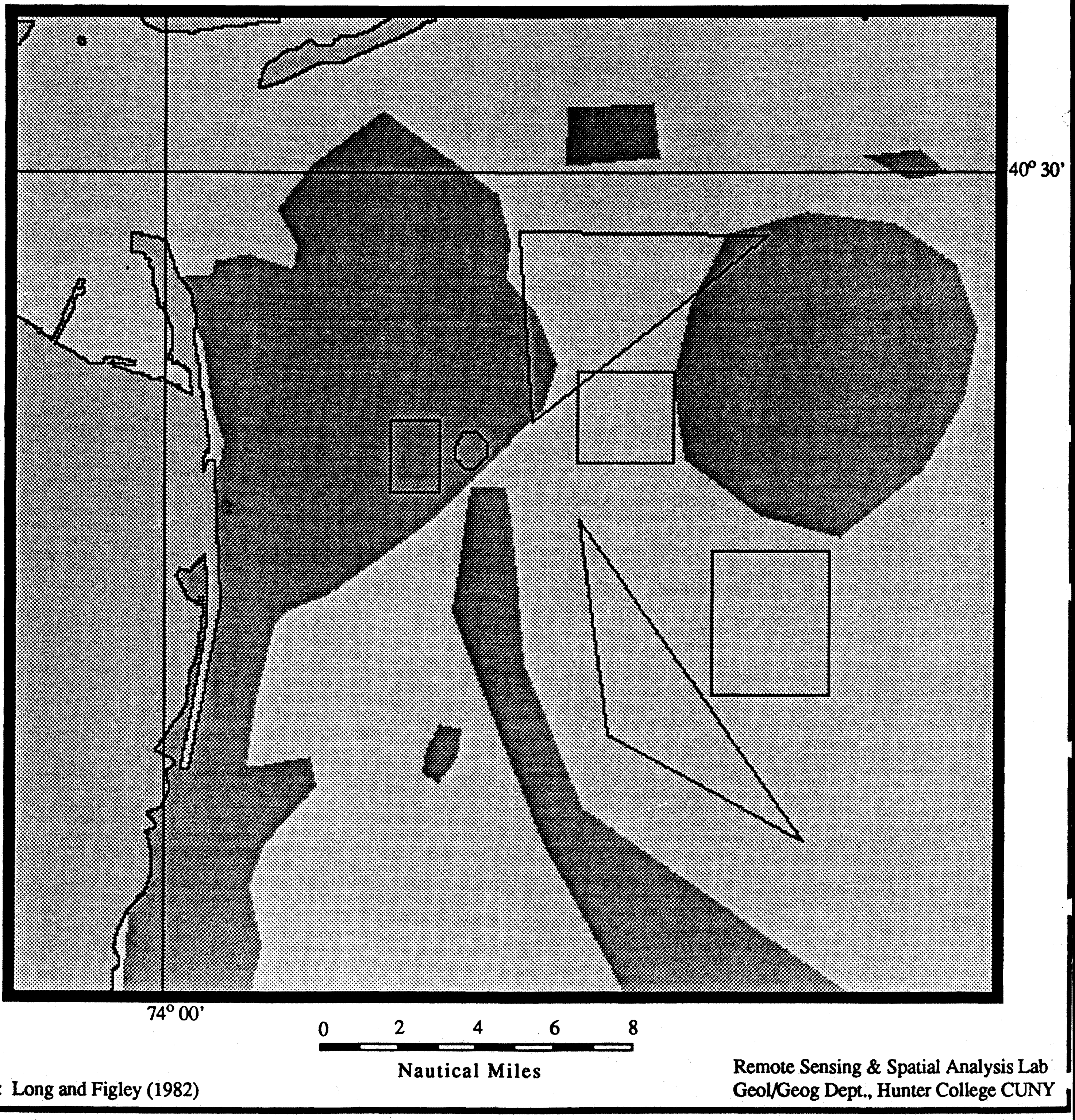
Figure 61

Bight Apex: Lobster Distribution



Source: Long and Figley (1982)

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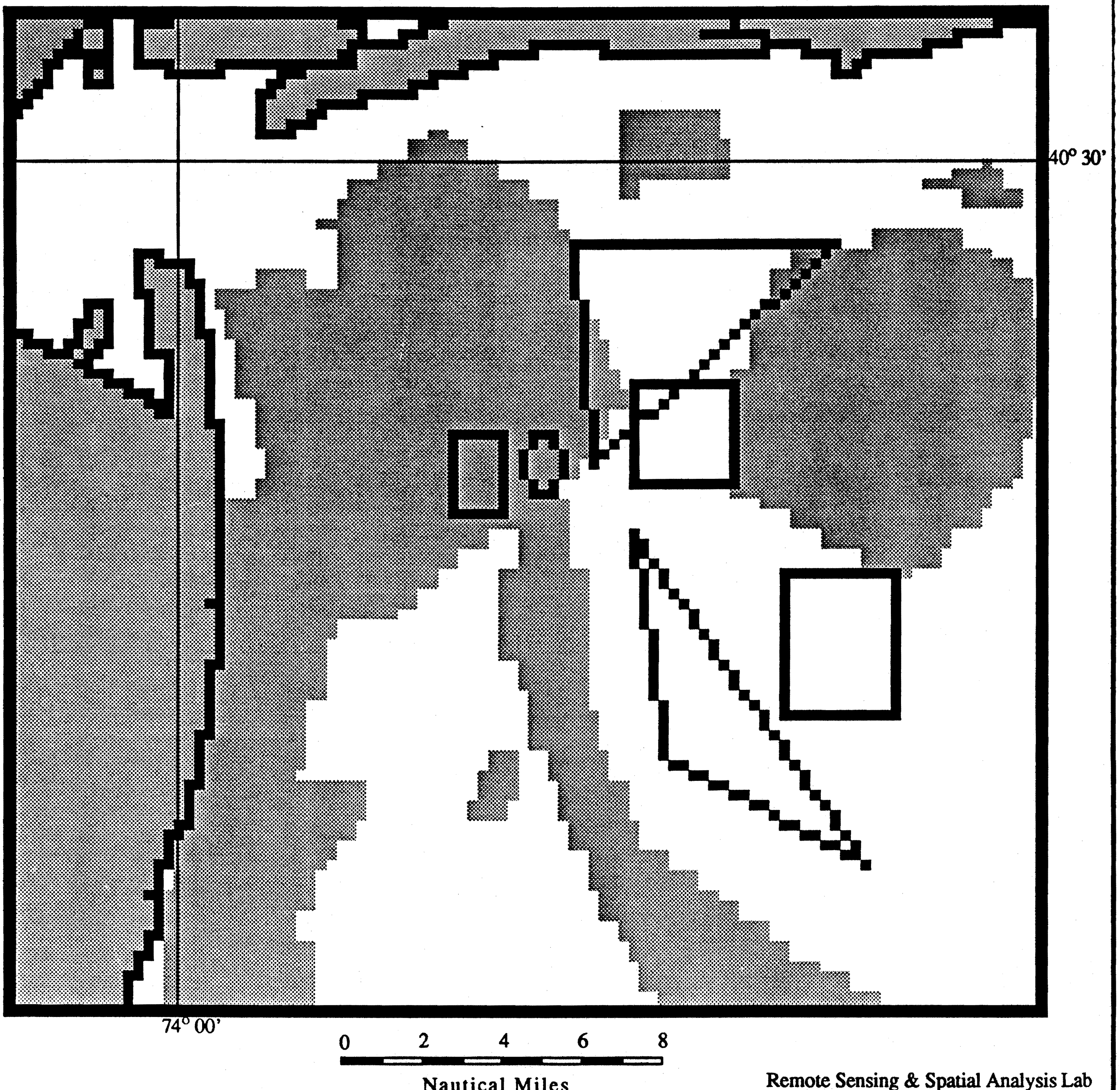
Figure 62

Bight Apex: Lobster Distribution

From N.Y. Bight GIS



Source: Long and Figley (1982)

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Figure 63

Apex Biomass Density

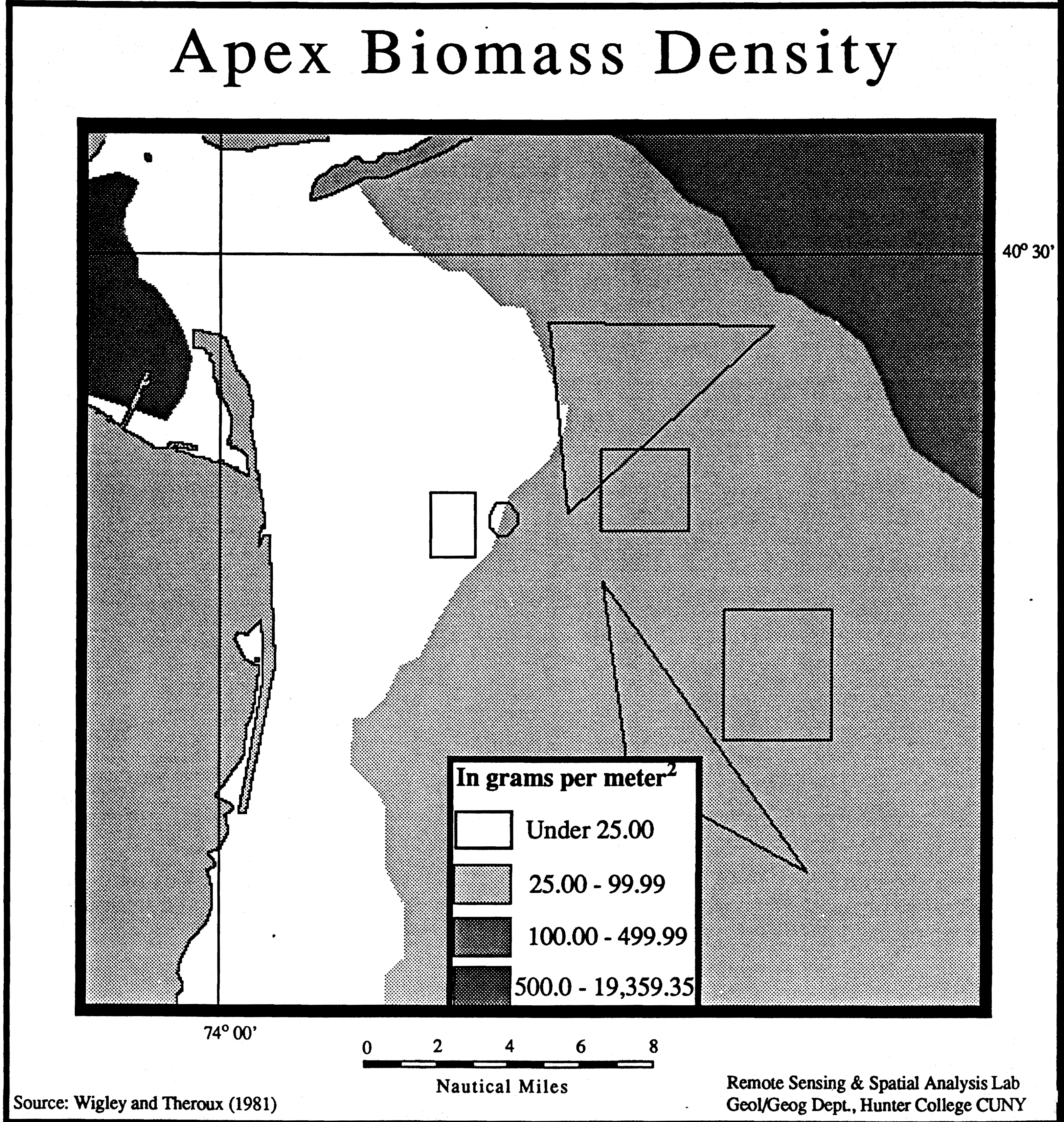
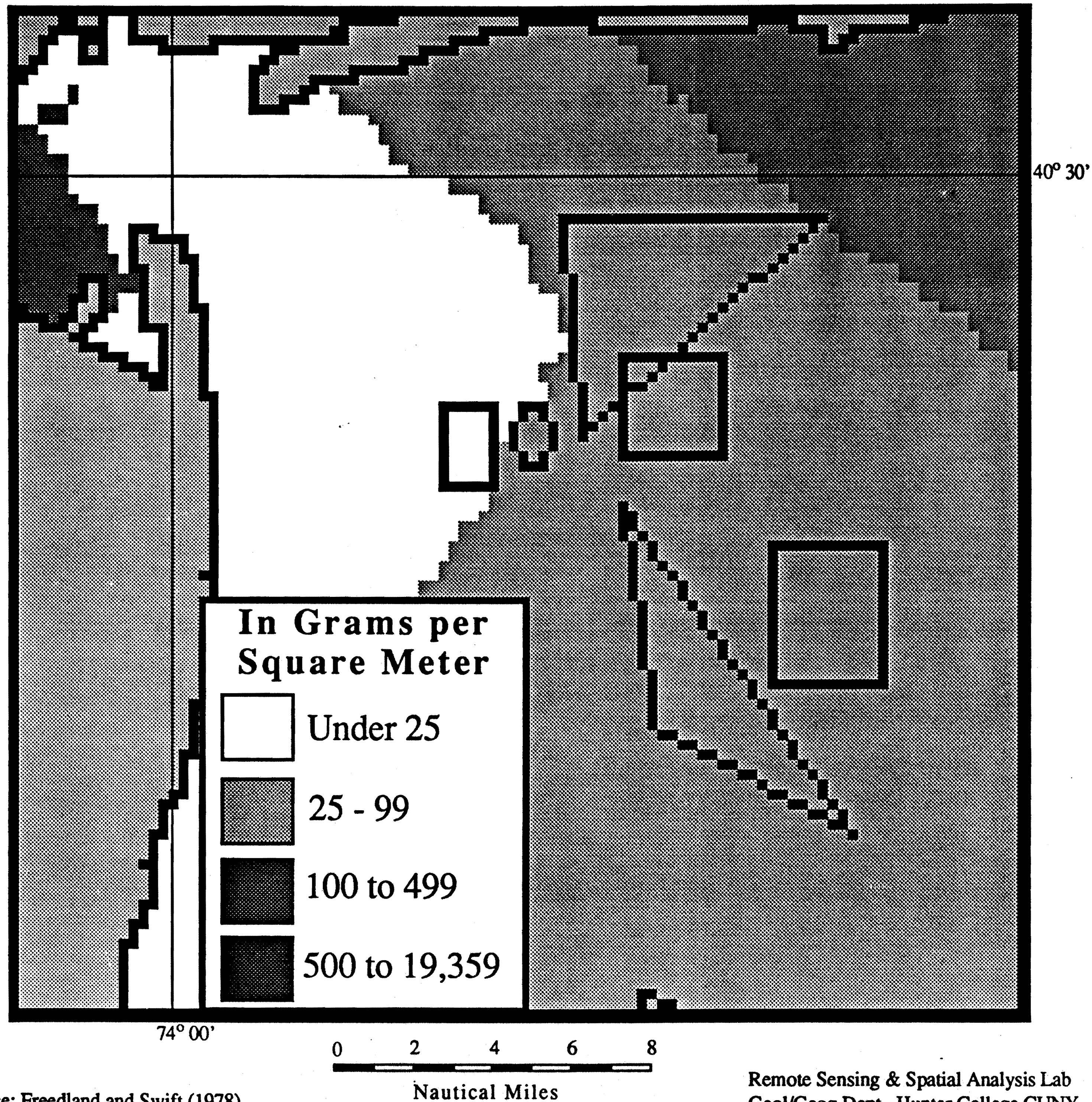


Figure 64

Bight Apex:Biomass Density

Bight Apex, From N.Y. Bight GIS



Source: Freedland and Swift (1978)

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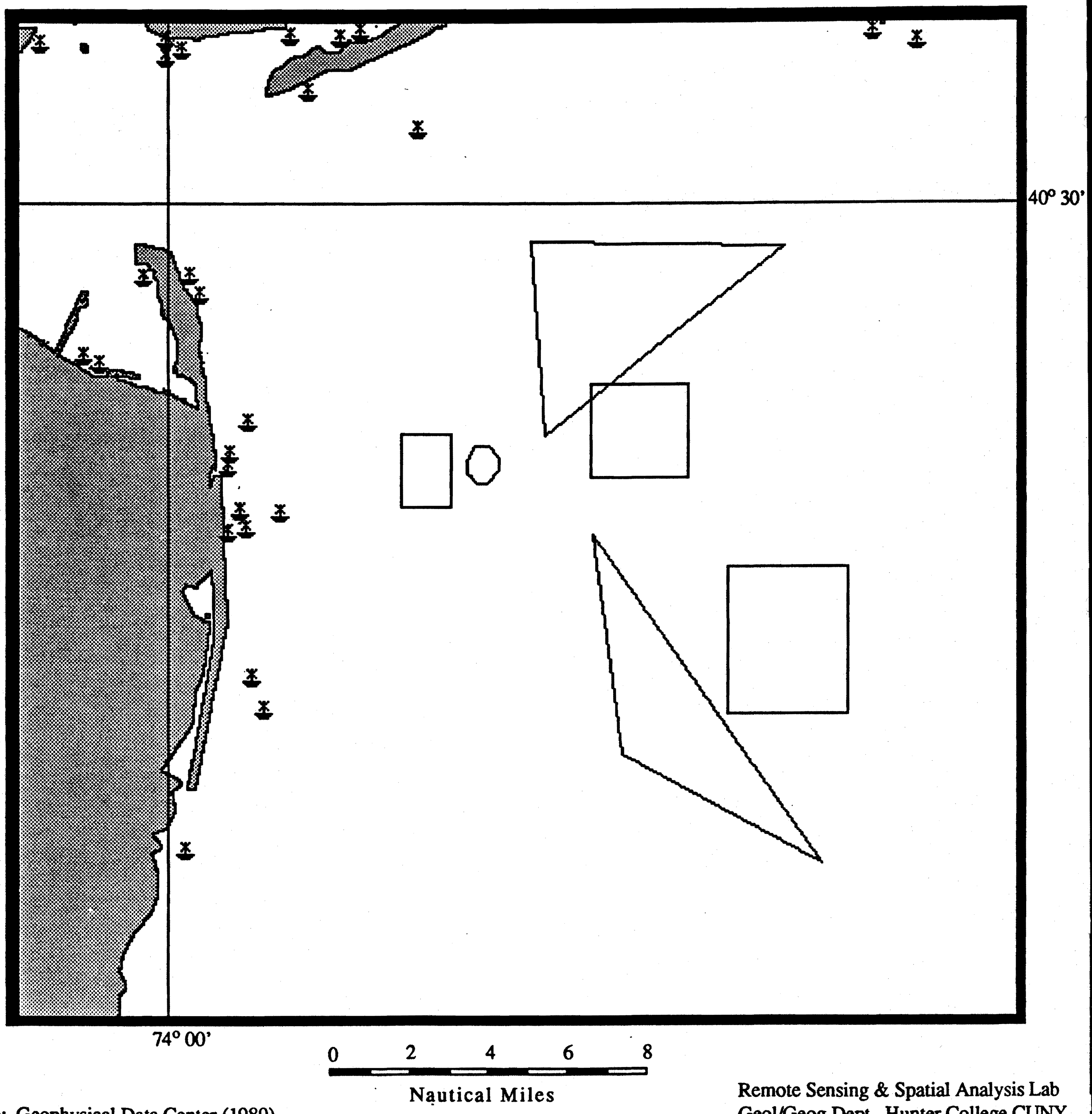
Figure 65

Bight Apex: Shipwrecks



Source: Geophysical Data Center (1989)

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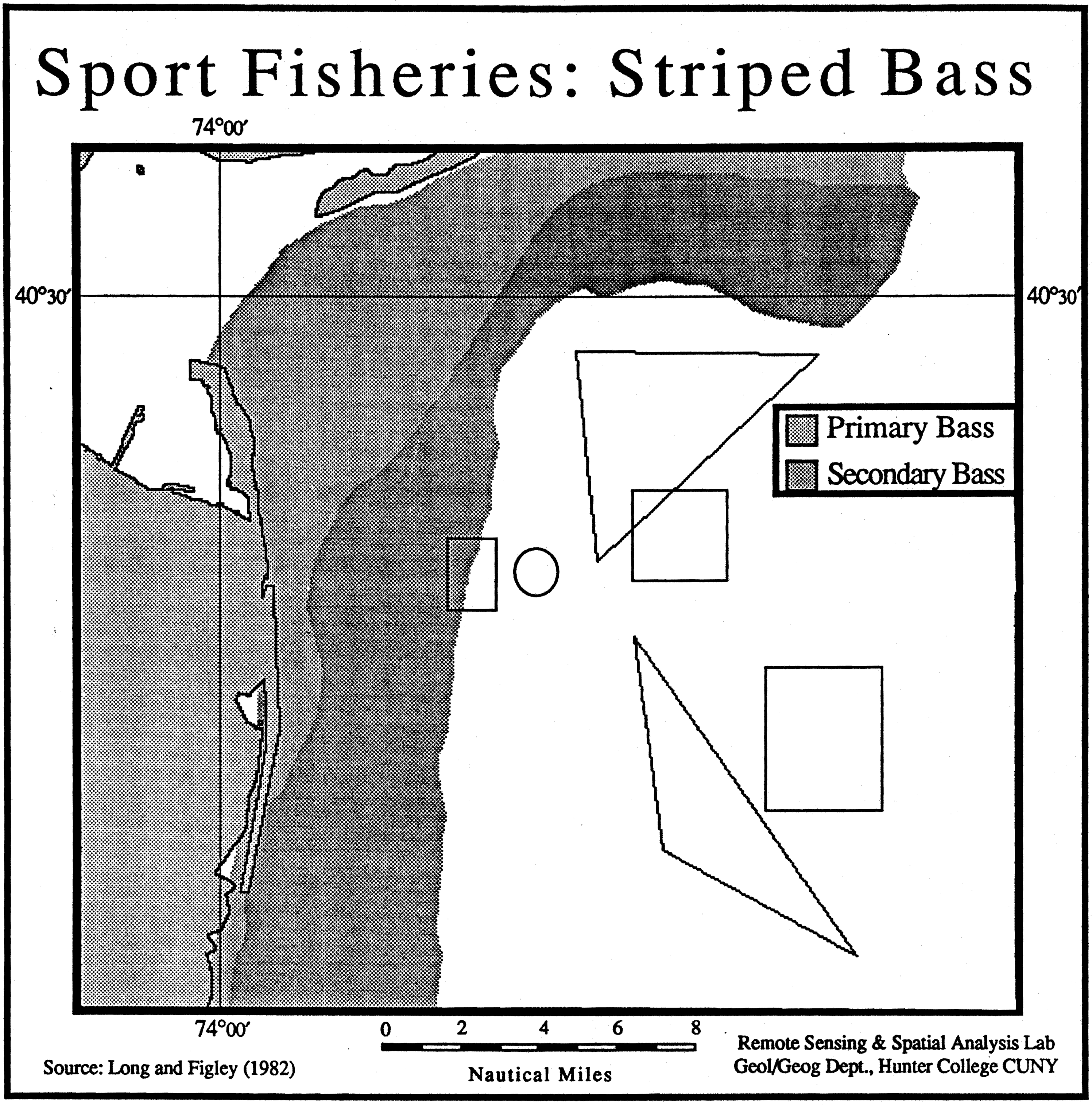
Figure 66


Sport Fisheries: Striped Bass
74°00′
40°30′
40°30′
Primary Bass
Secondary Bass
74°00′
0
2
4
6
8
Nautical Miles
Source: Long and Figley (1982)
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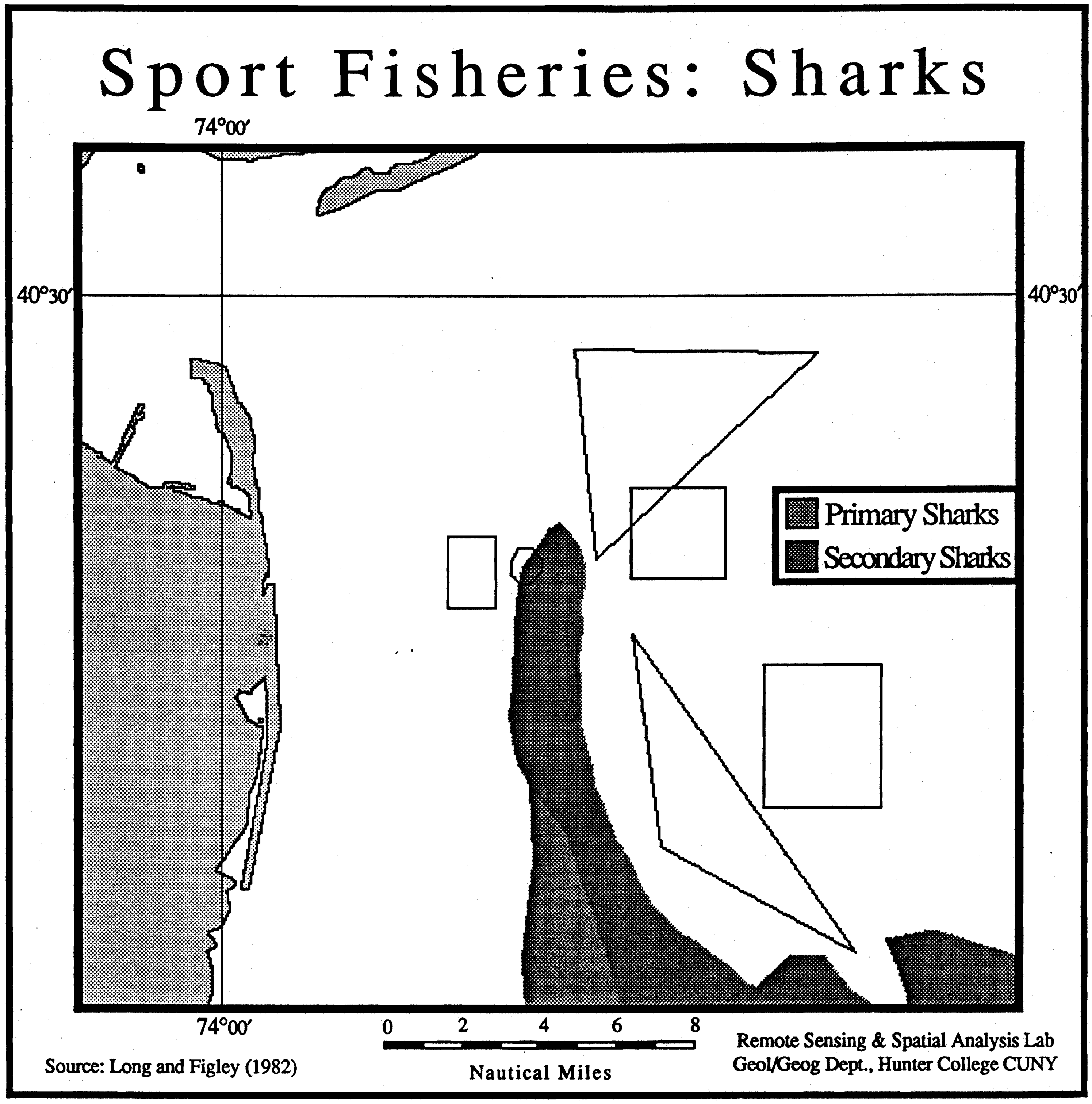
Geol/Geog Dept., Hunter College CUNY

Figure 67


Sport Fisheries: Sharks
74°00′
40°30′
40°30′
Primary Sharks
Secondary Sharks
74°00′
0
2
4
6
8
Nautical Miles
Source: Long and Figley (1982)
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Geol/Geog Dept., Hunter College CUNY

Figure 68

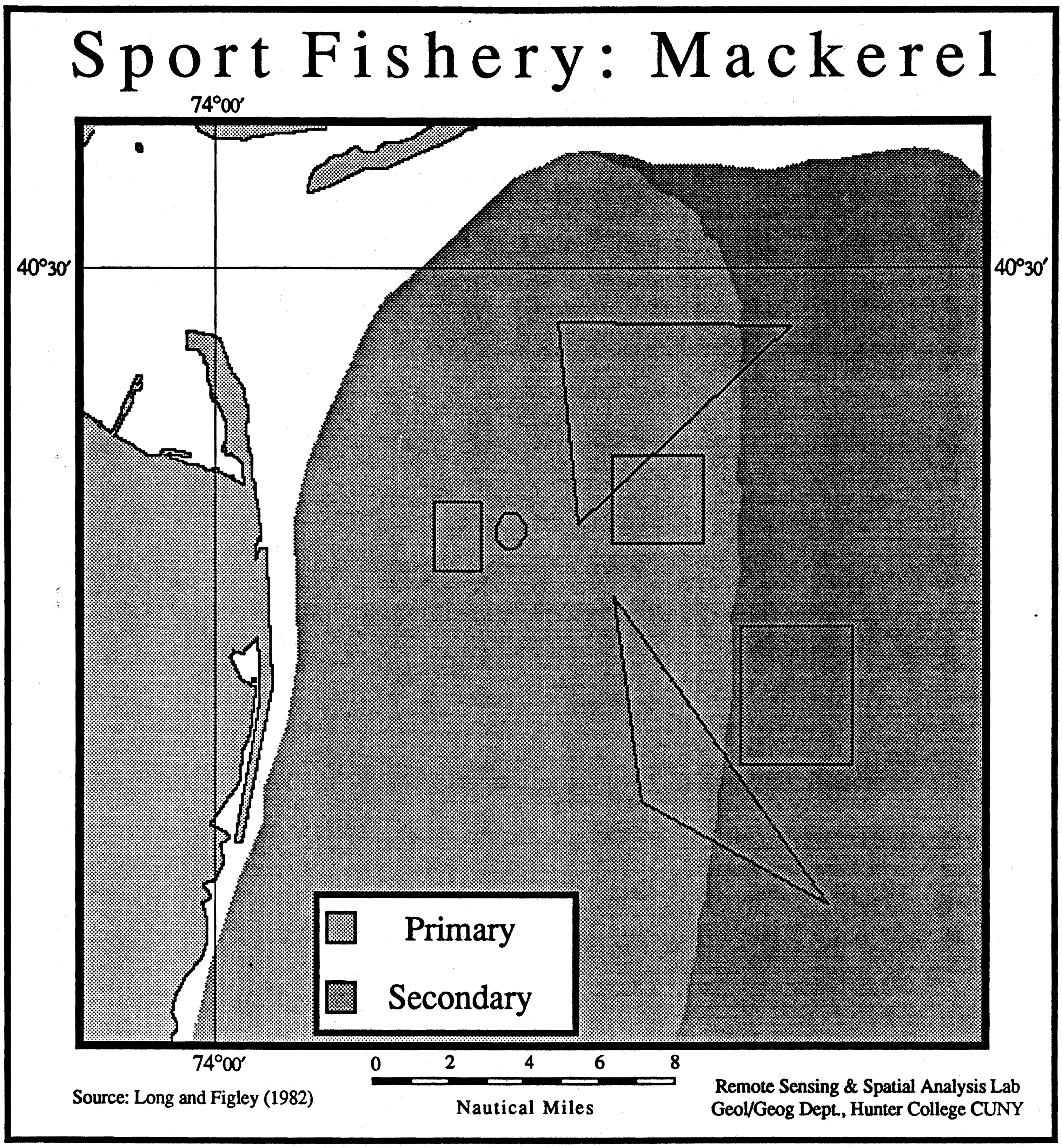
Sport Fishery: Mackerel
74°00′
40°30′
40°30′
Primary
Secondary
74°00′
0 2 4 6 8
Nautical Miles
Source: Long and Figley (1982)
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Figure 69

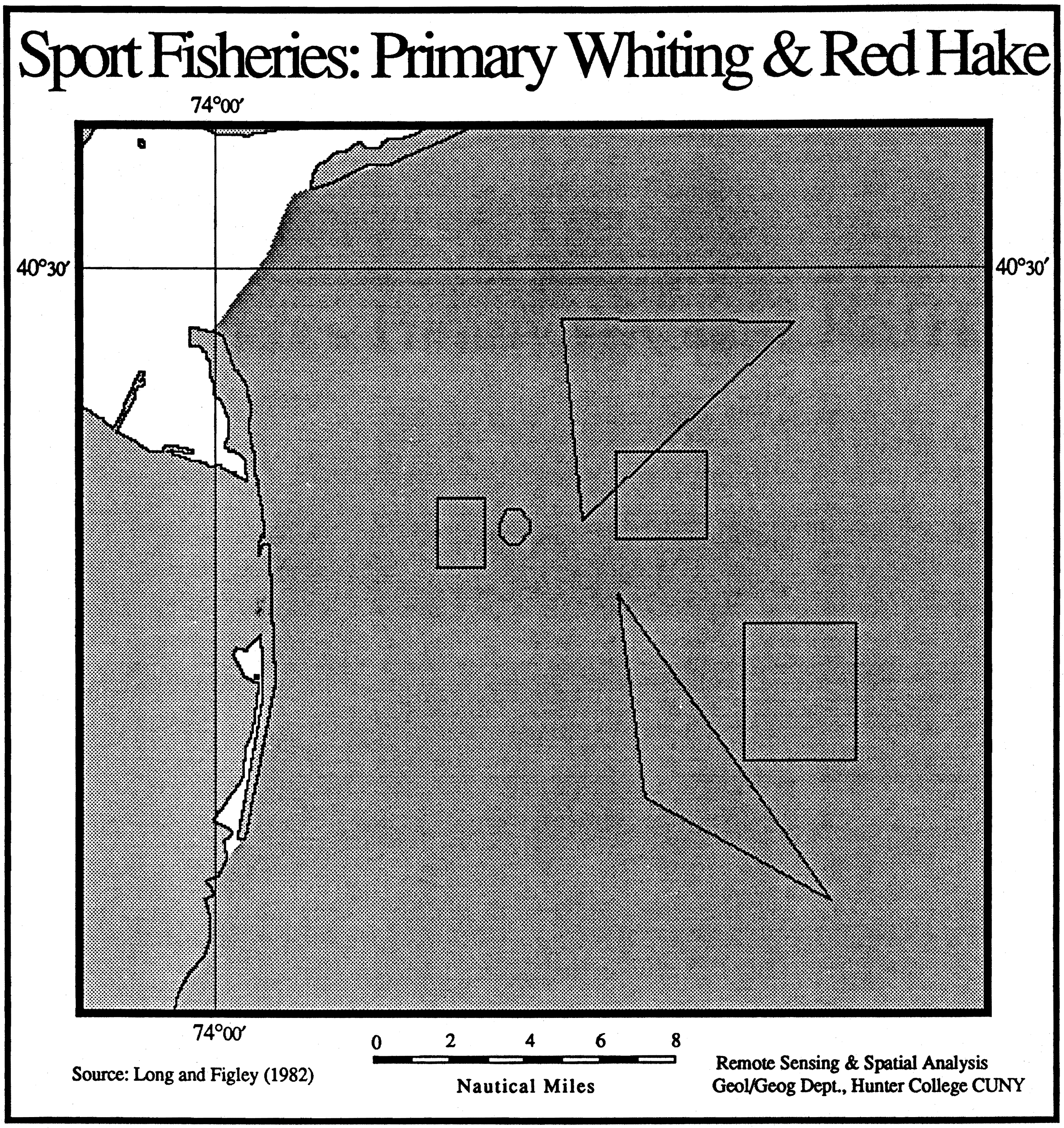
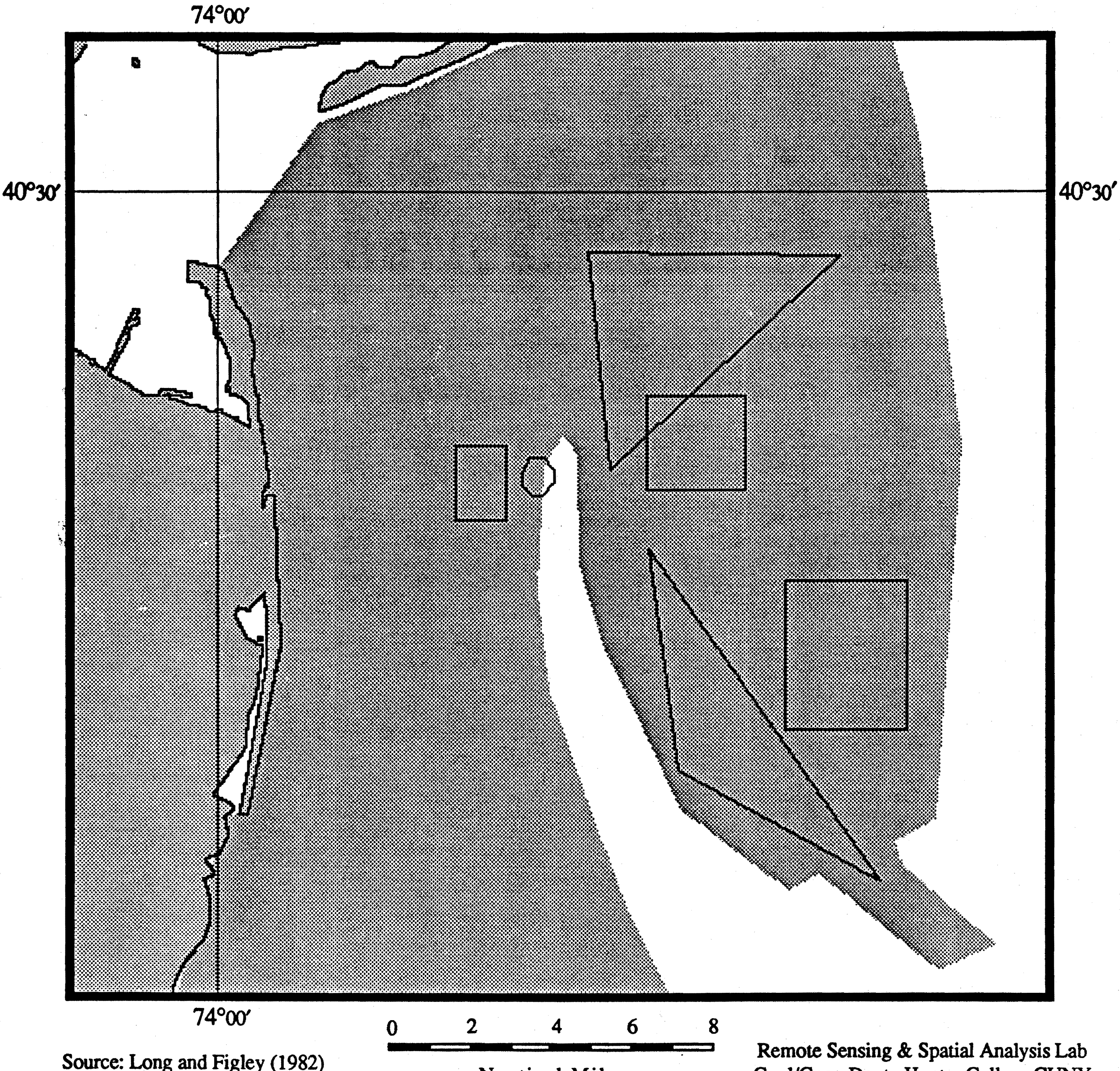

Sport Fisheries: Primary Whiting & Red Hake
74°00′
40°30′
40°30′
74°00′
0
2
4
6
8
Nautical Miles
Source: Long and Figley (1982)
Remote Sensing & Spatial Analysis
Geol/Geog Dept., Hunter College CUNY

Figure 70

Sport Fisheries: Black Sea Bass



Source: Long and Figley (1982)

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Figure 71

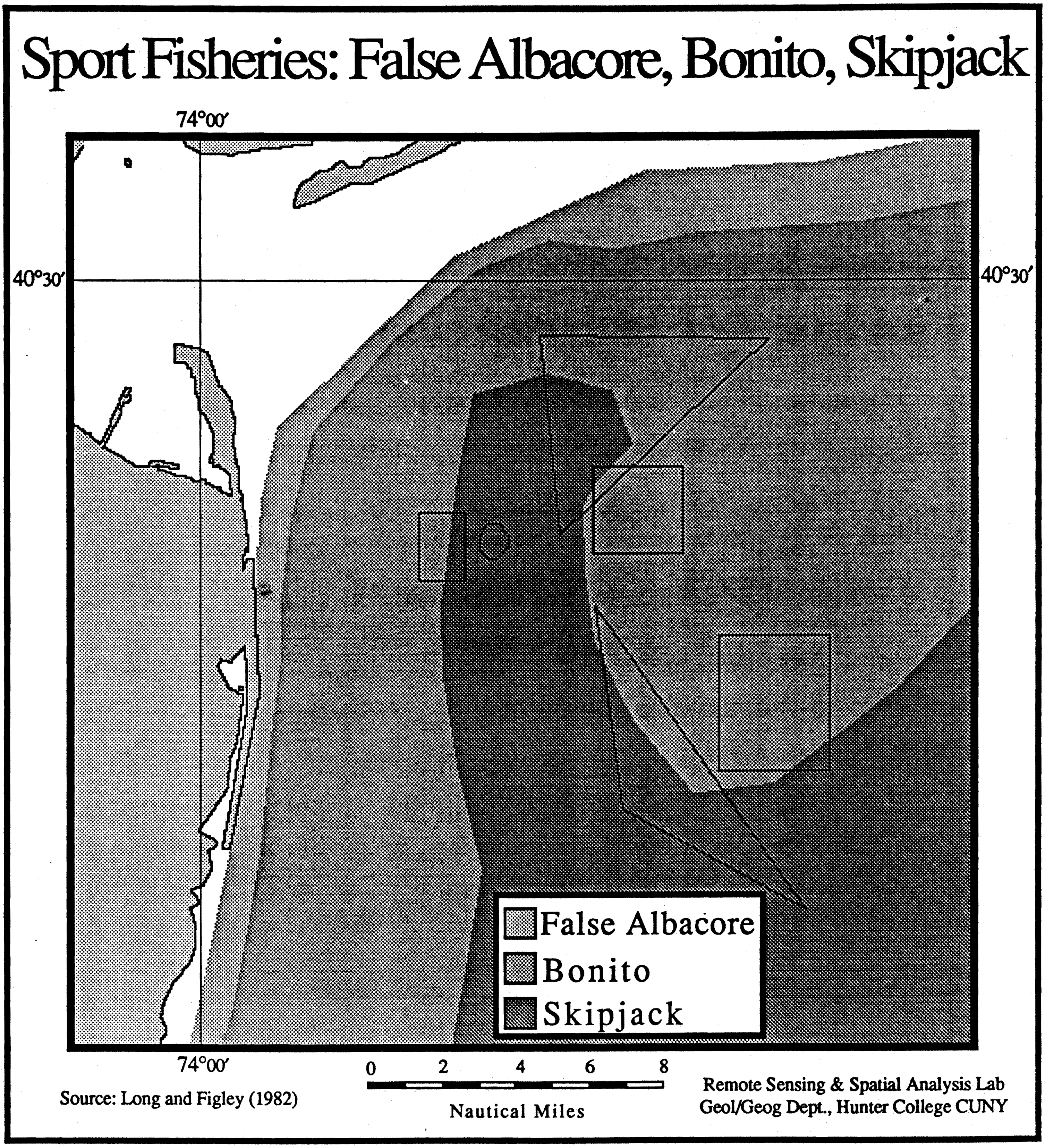
Sport Fisheries: False Albacore, Bonito, Skipjack
74°00′
40°30′
40°30′
74°00′
False Albacore
Bonito
Skipjack
0 2 4 6 8
Nautical Miles
Source: Long and Figley (1982)
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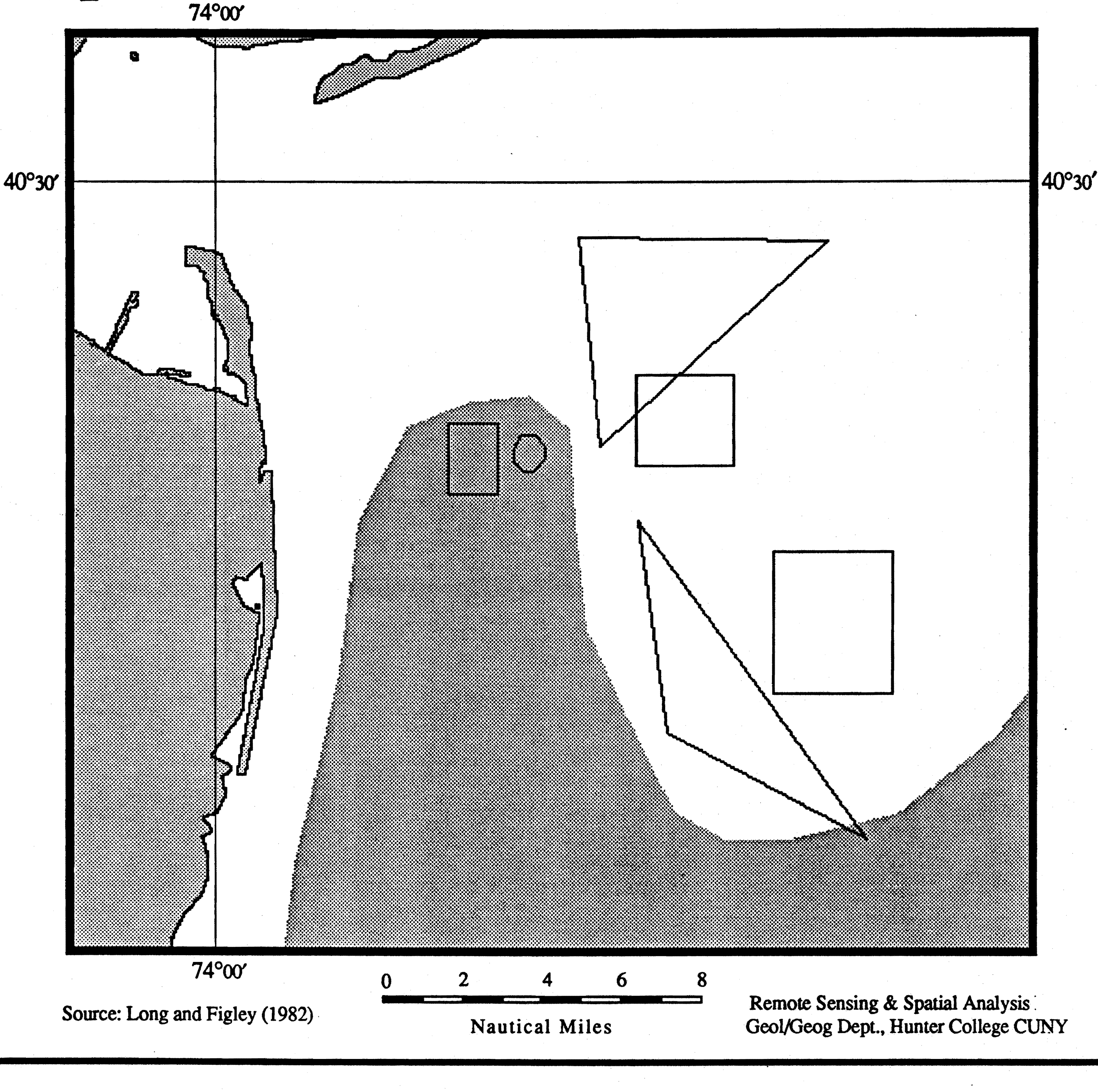
Figure 72

Sport Fisheries: Bluefin Tuna



Source: Long and Figley (1982)

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Figure 73

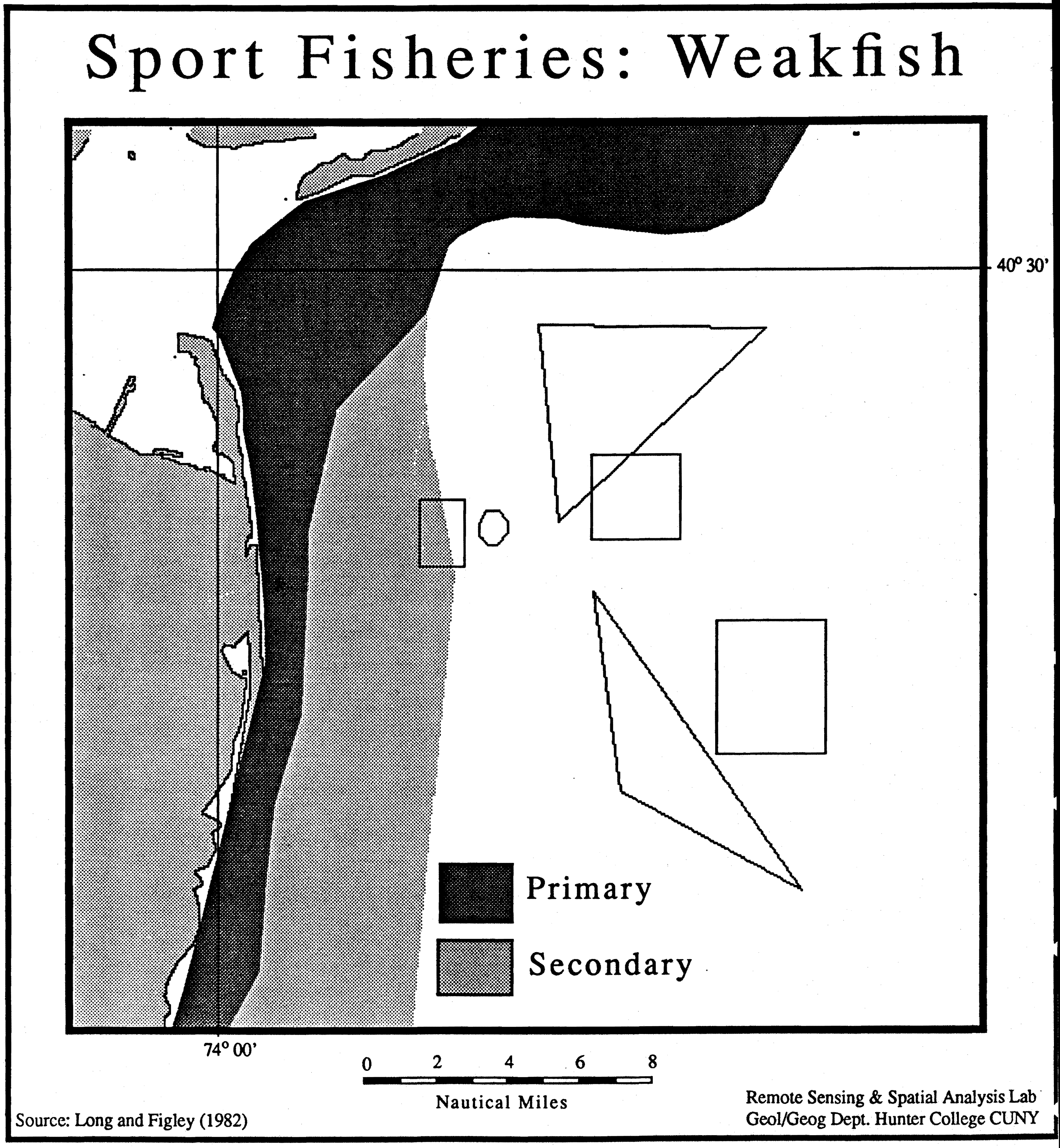

Sport Fisheries: Weakfish
40° 30'
Primary
Secondary
74° 00'
0 2 4 6 8
Nautical Miles
Source: Long and Figley (1982)
Remote Sensing & Spatial Analysis Lab
Geol/Geog Dept. Hunter College CUNY

Figure 74

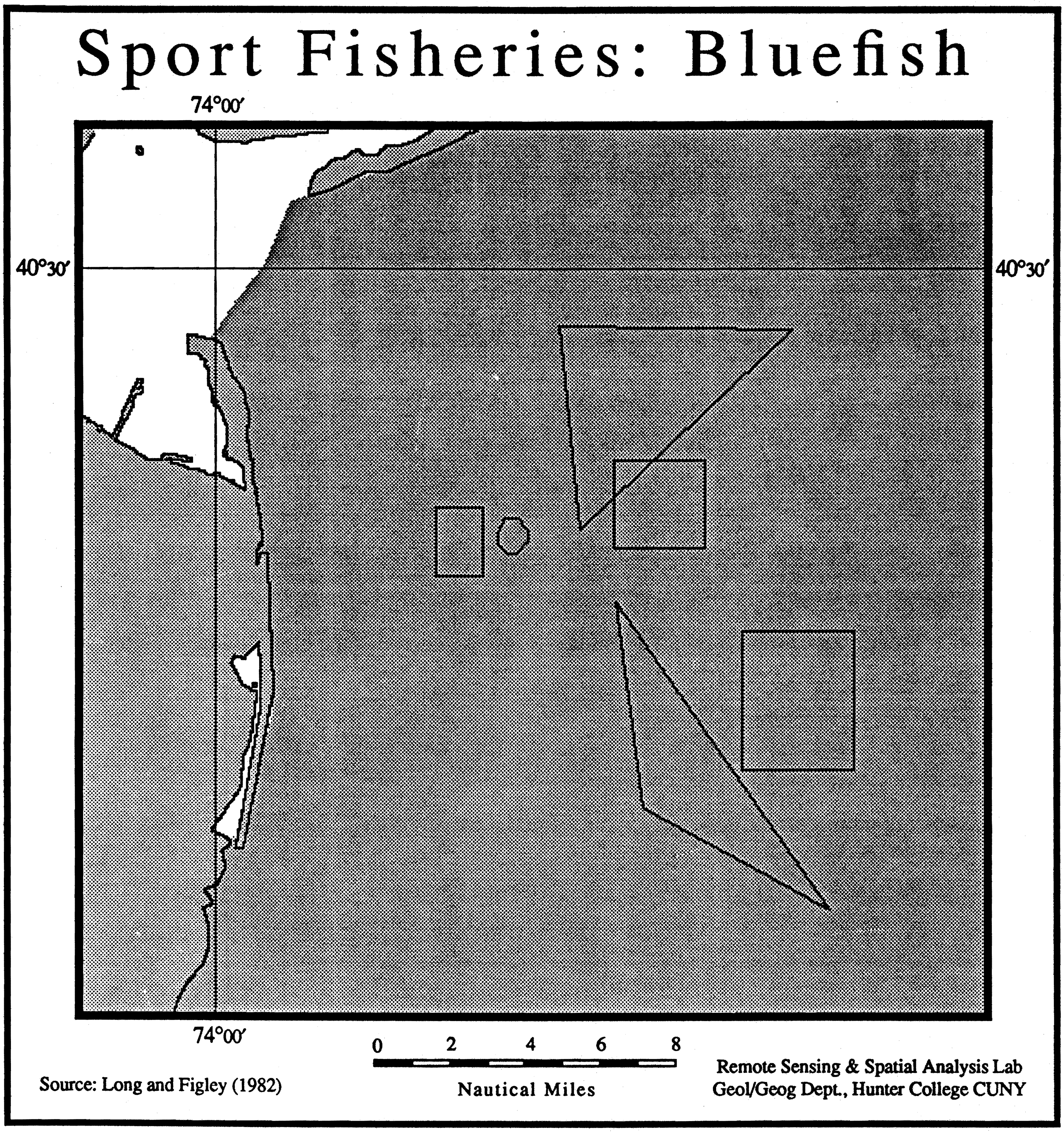
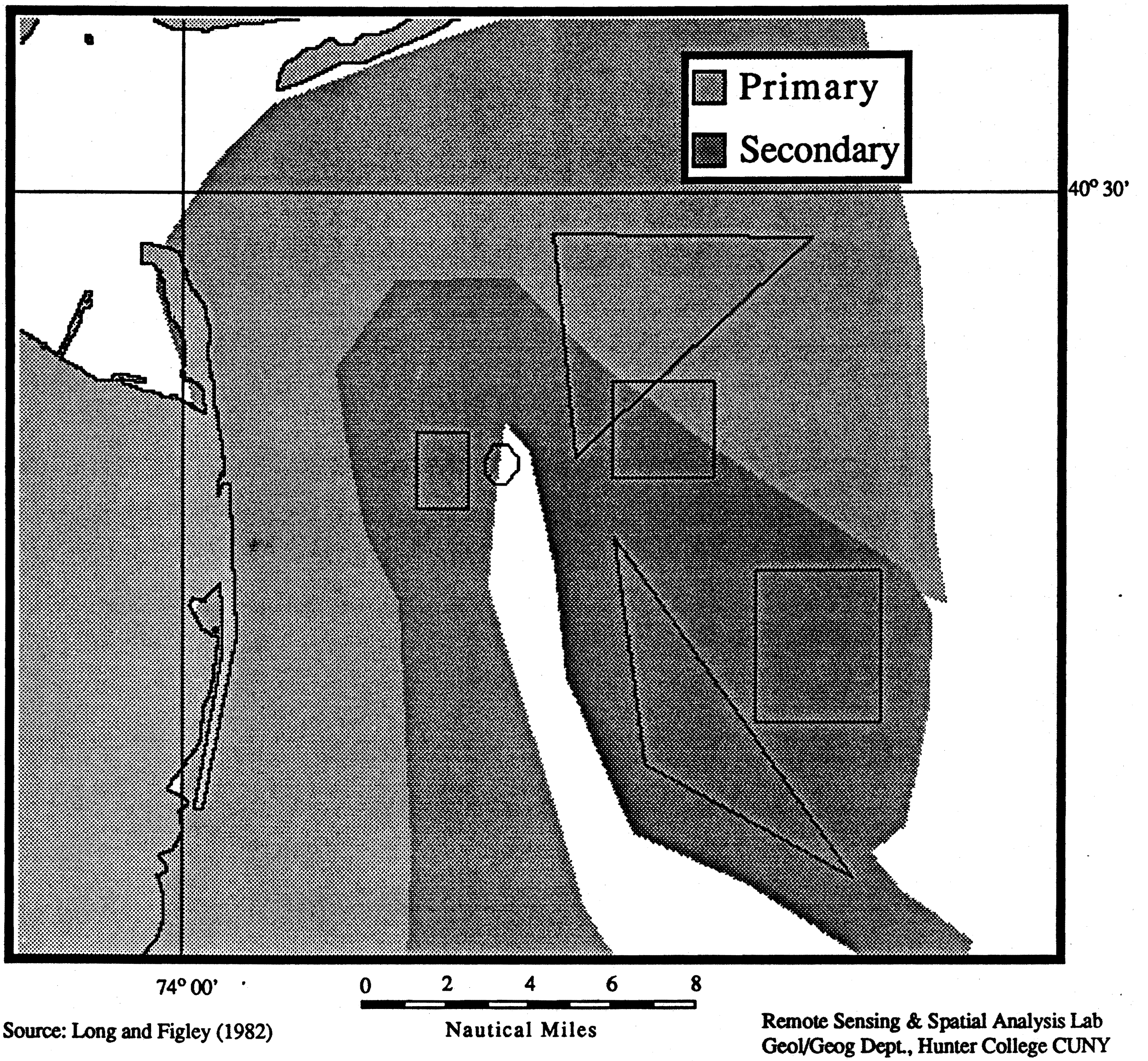

Sport Fisheries: Bluefish
74°00′
40°30′
40°30′
74°00′
0
2
4
6
8
Nautical Miles
Source: Long and Figley (1982)
Remote Sensing & Spatial Analysis Lab
Geol/Geog Dept., Hunter College CUNY

Figure 75

Sport Fisheries: Tautog



Source: Long and Figley (1982)

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Figure 76

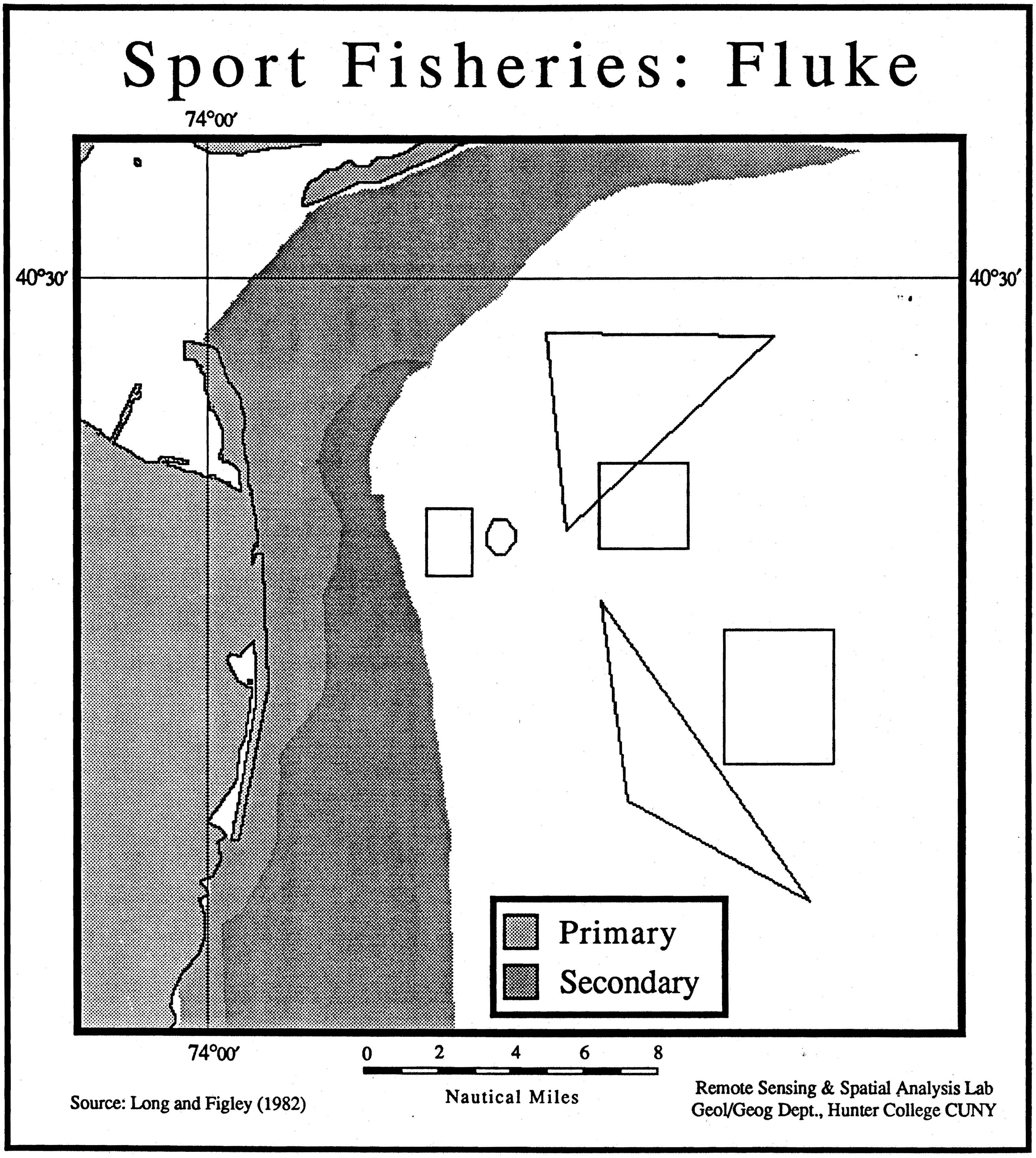
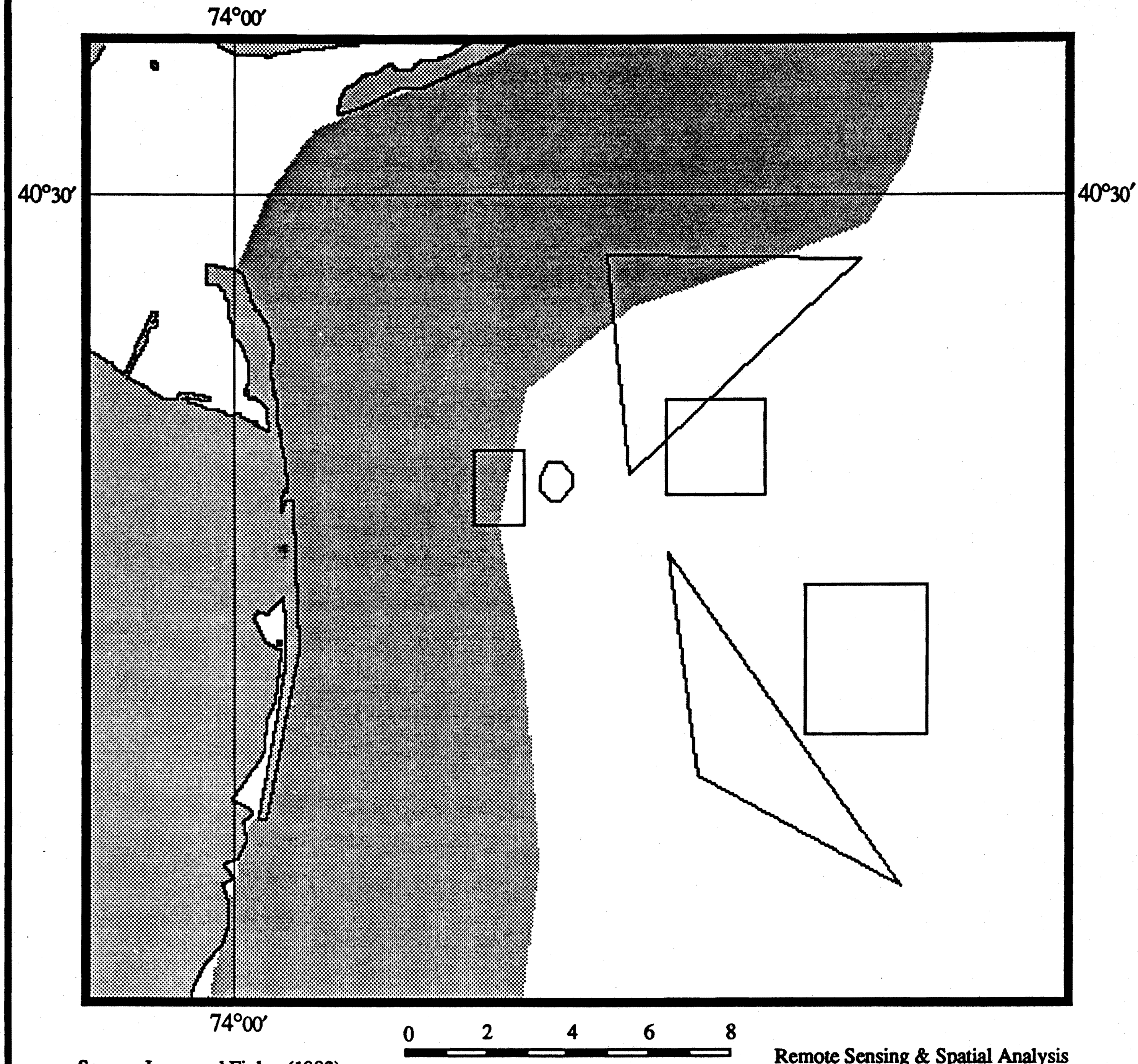

Sport Fisheries: Fluke
74°00′
40°30′
40°30′
Primary
Secondary
74°00′
0
2
4
6
8
Nautical Miles
Source: Long and Figley (1982)
Remote Sensing & Spatial Analysis Lab
Geol/Geog Dept., Hunter College CUNY

Figure 77

Commercial Fisheries: Bluefish & Weakfish



Source: Long and Figley (1982)

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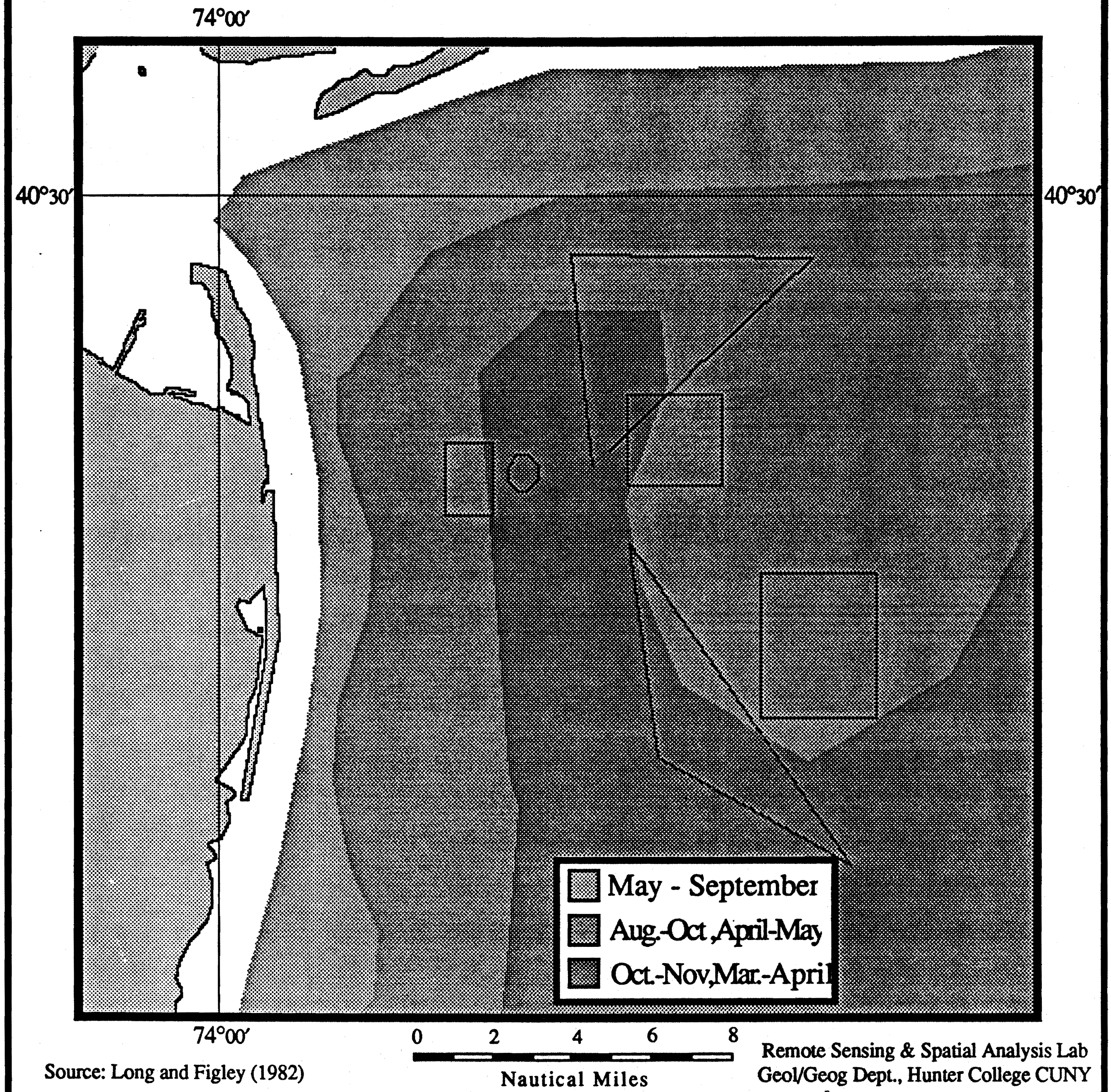
Figure 78

Commercial Fisheries: Fluke



Source: Long and Figley (1982)

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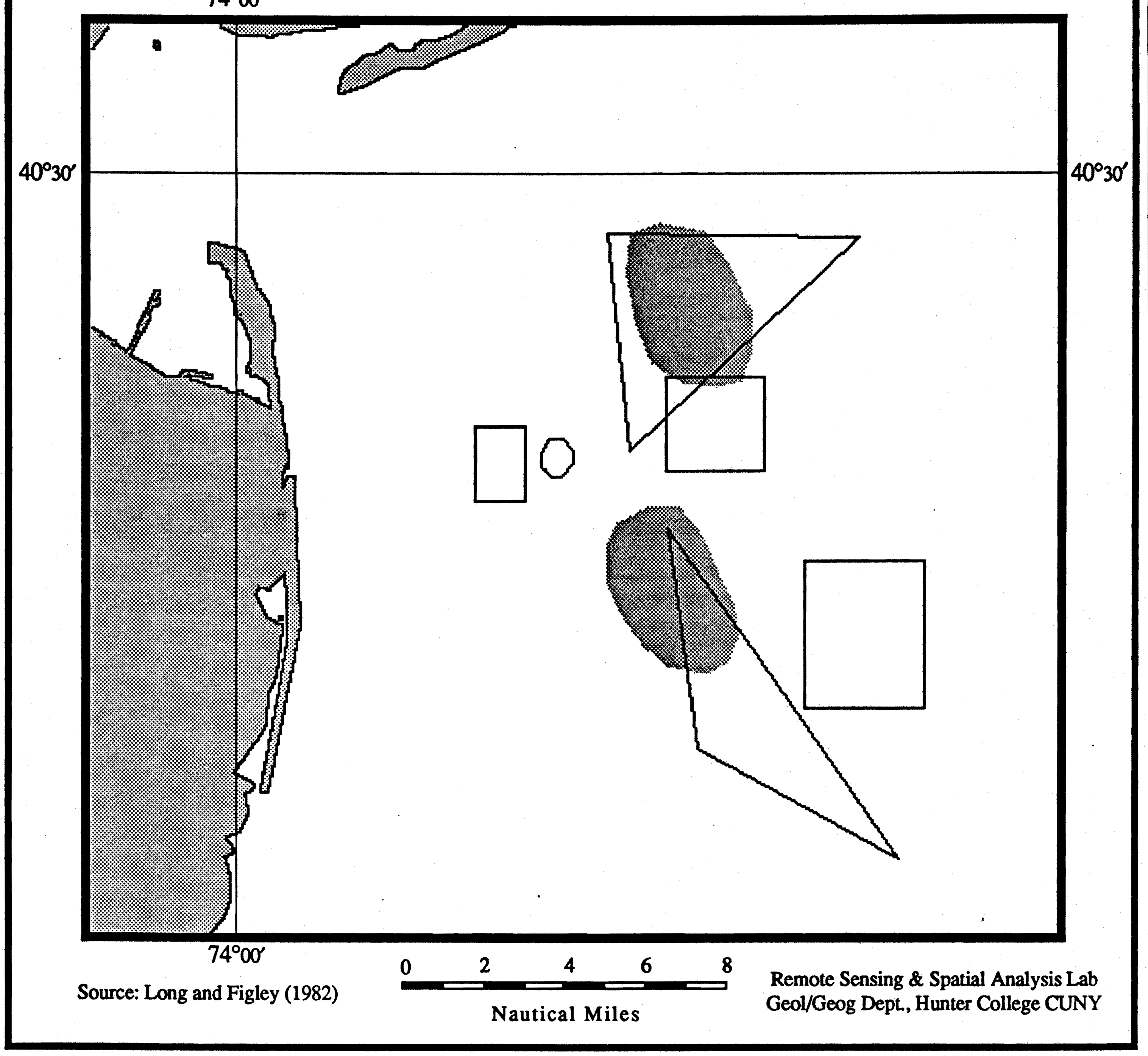
Figure 79

Commercial Fisheries: Yellowtail Flounder



Source: Long and Figley (1982)

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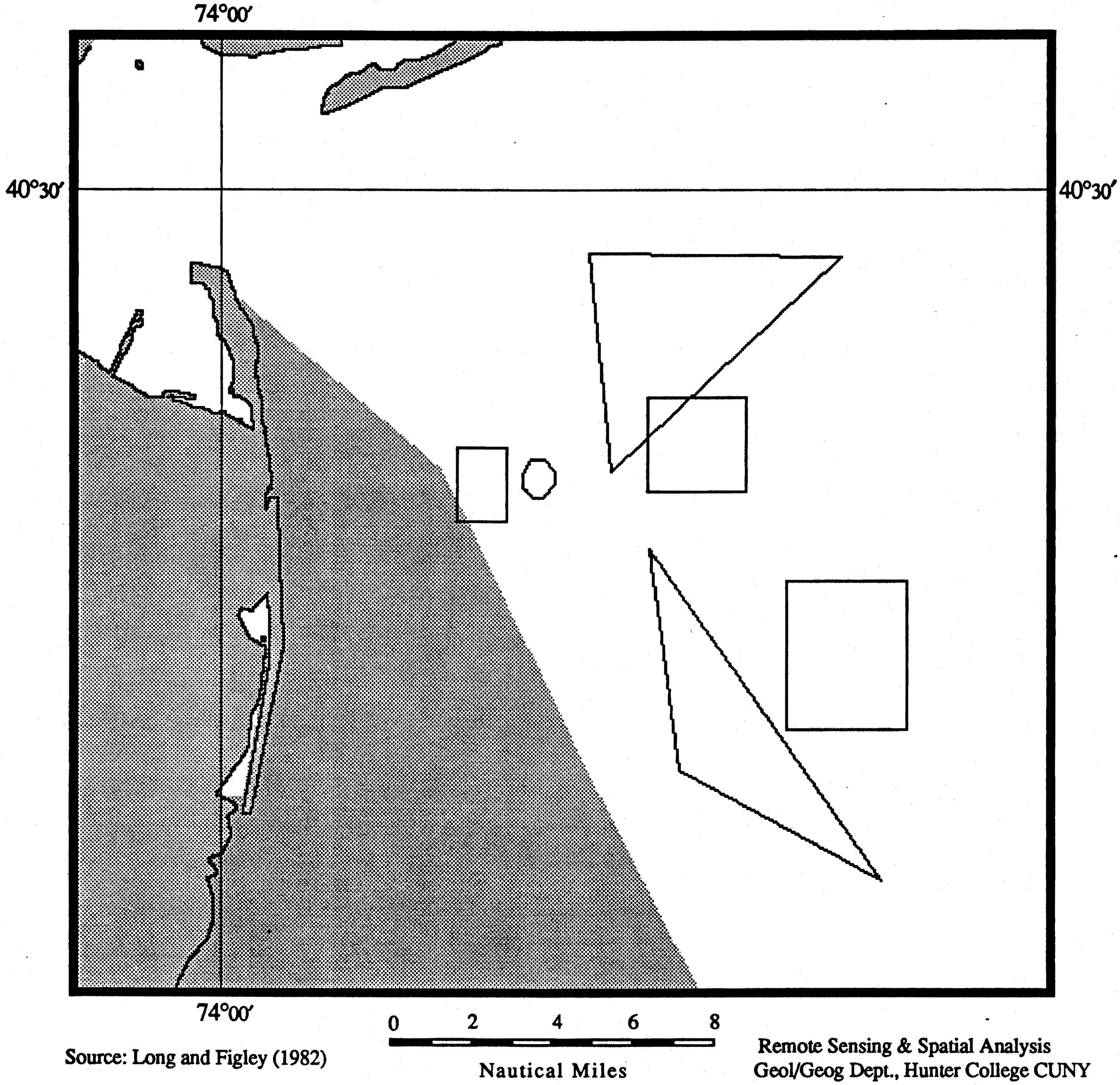
Figure 80

Commercial Fisheries: Mackerel (April-May)



Source: Long and Figley (1982)

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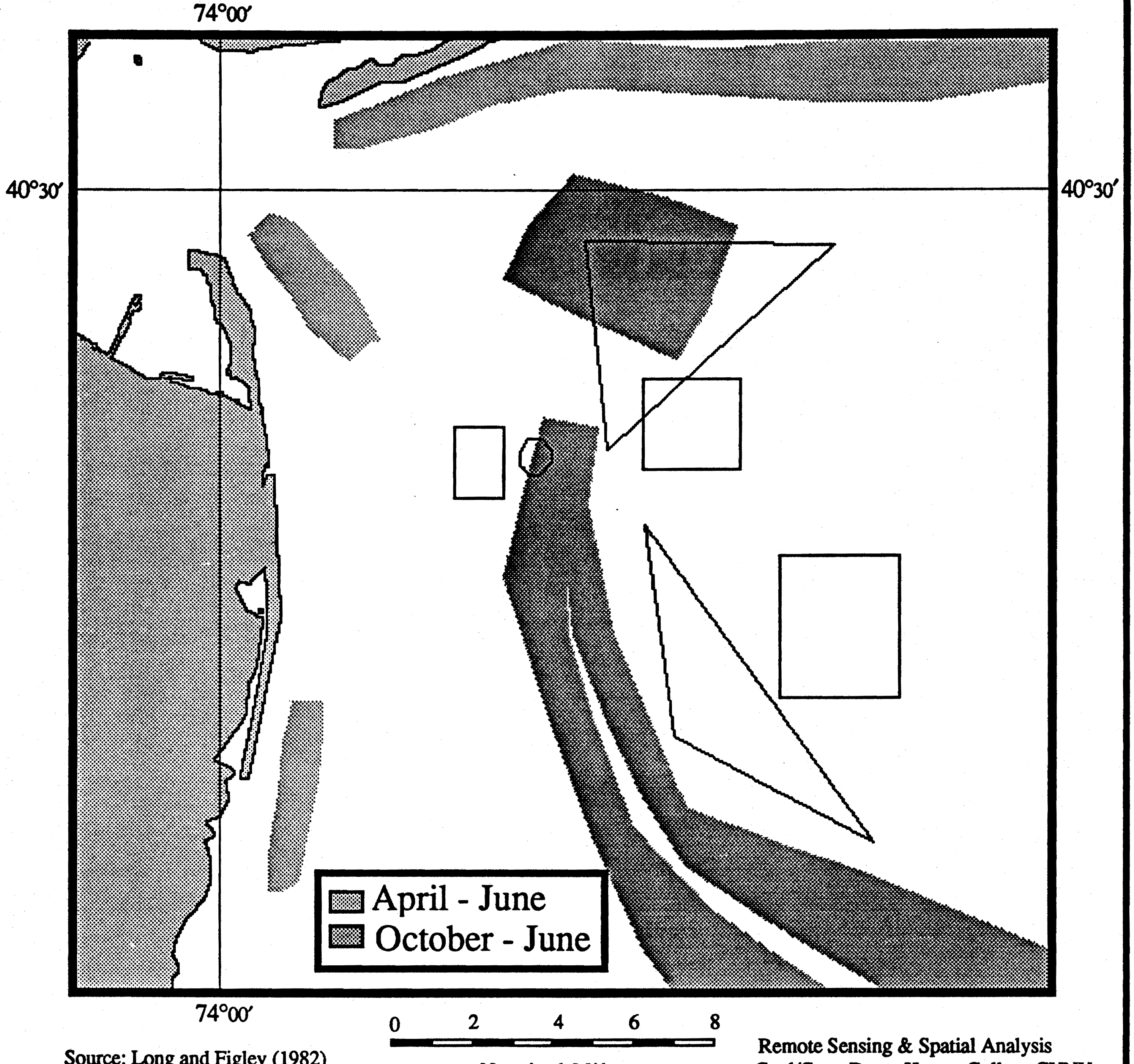
Figure 81

Commercial Fisheries: Whiting & Red Hake



Source: Long and Figley (1982)

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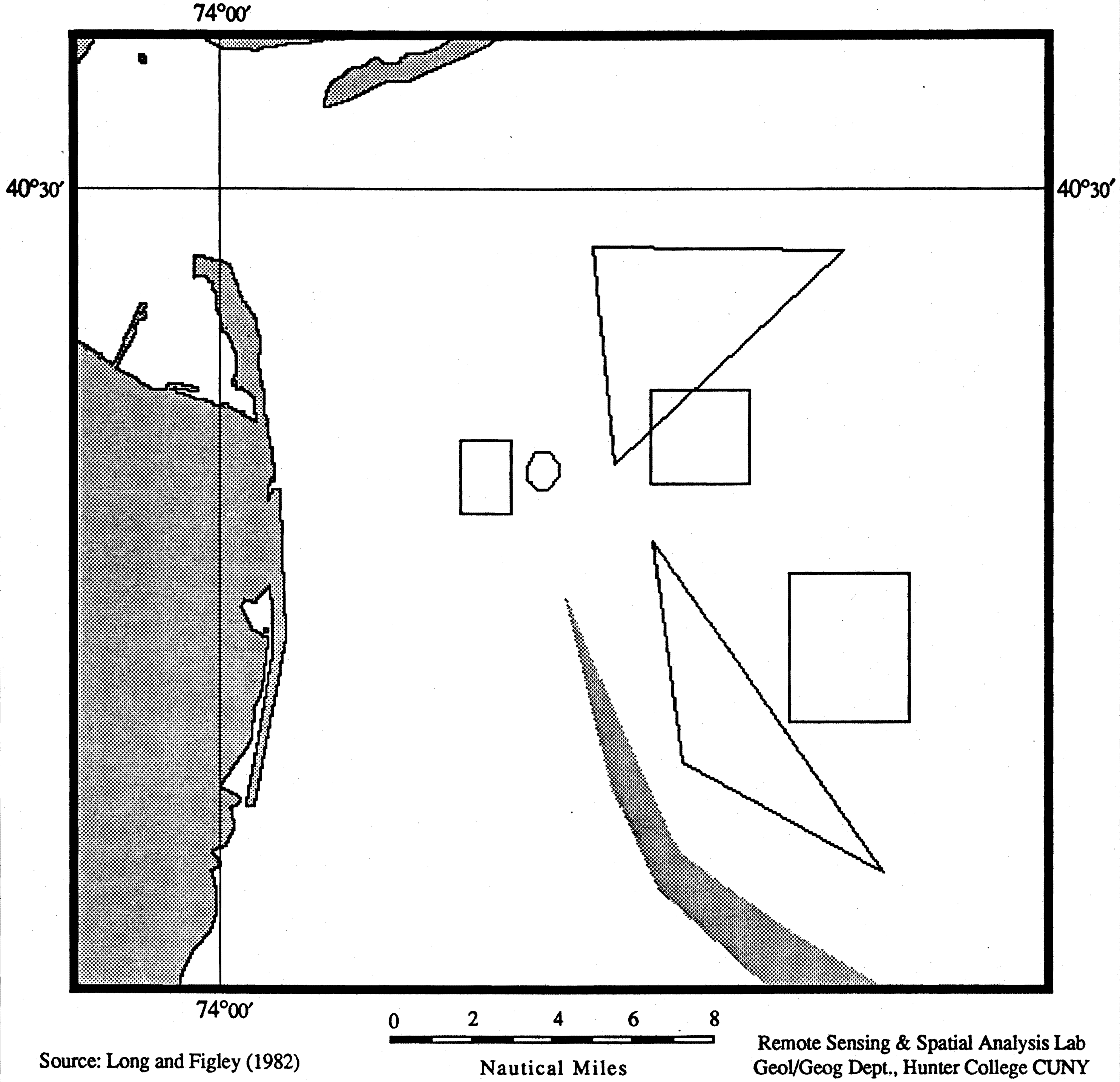
Figure 82

Commercial Fisheries: Black Sea Bass (Trawl Fishery)



Source: Long and Figley (1982)

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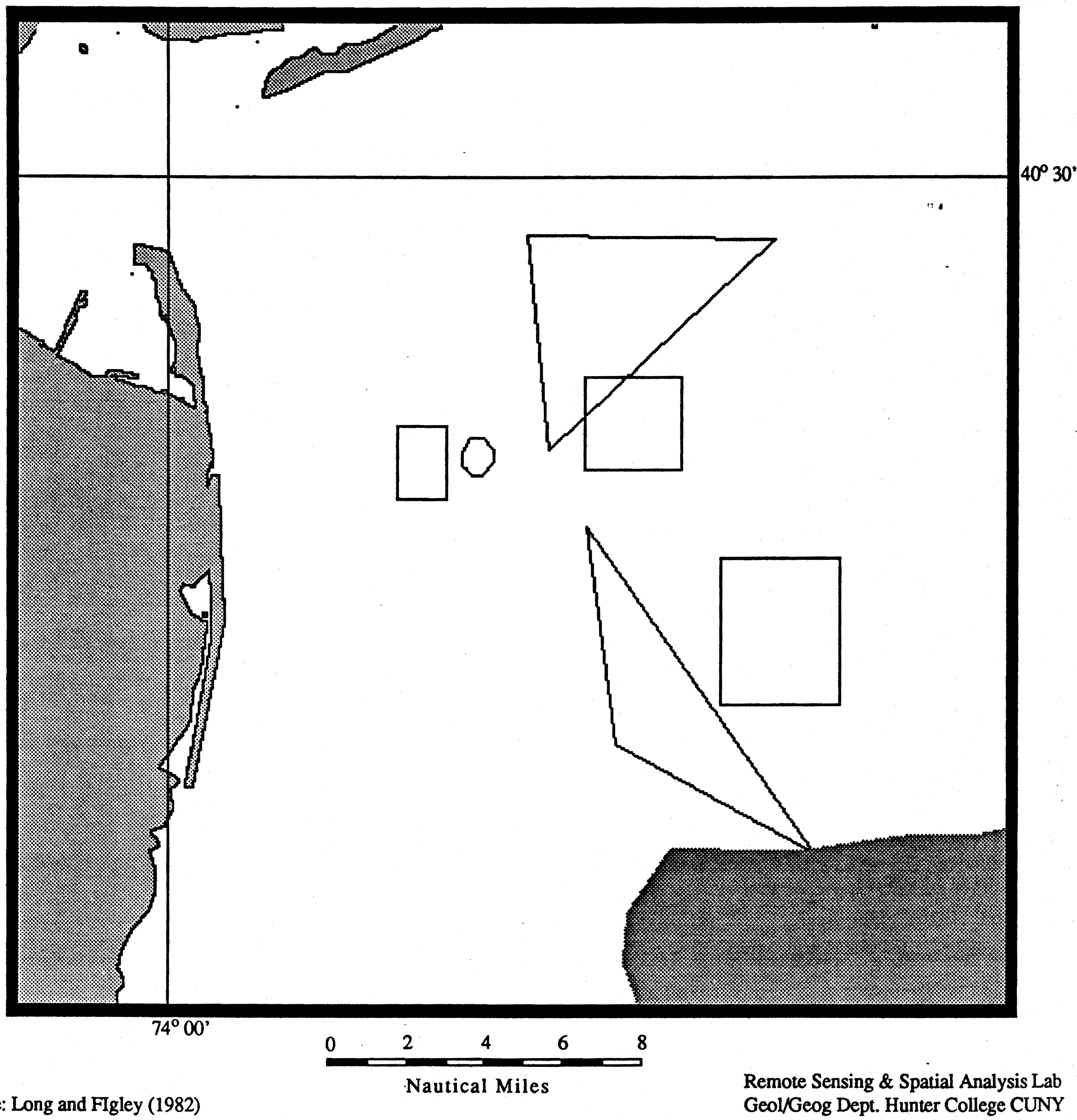
Figure 83

Commercial Fisheries: Scup



Source: Long and FIgley (1982)

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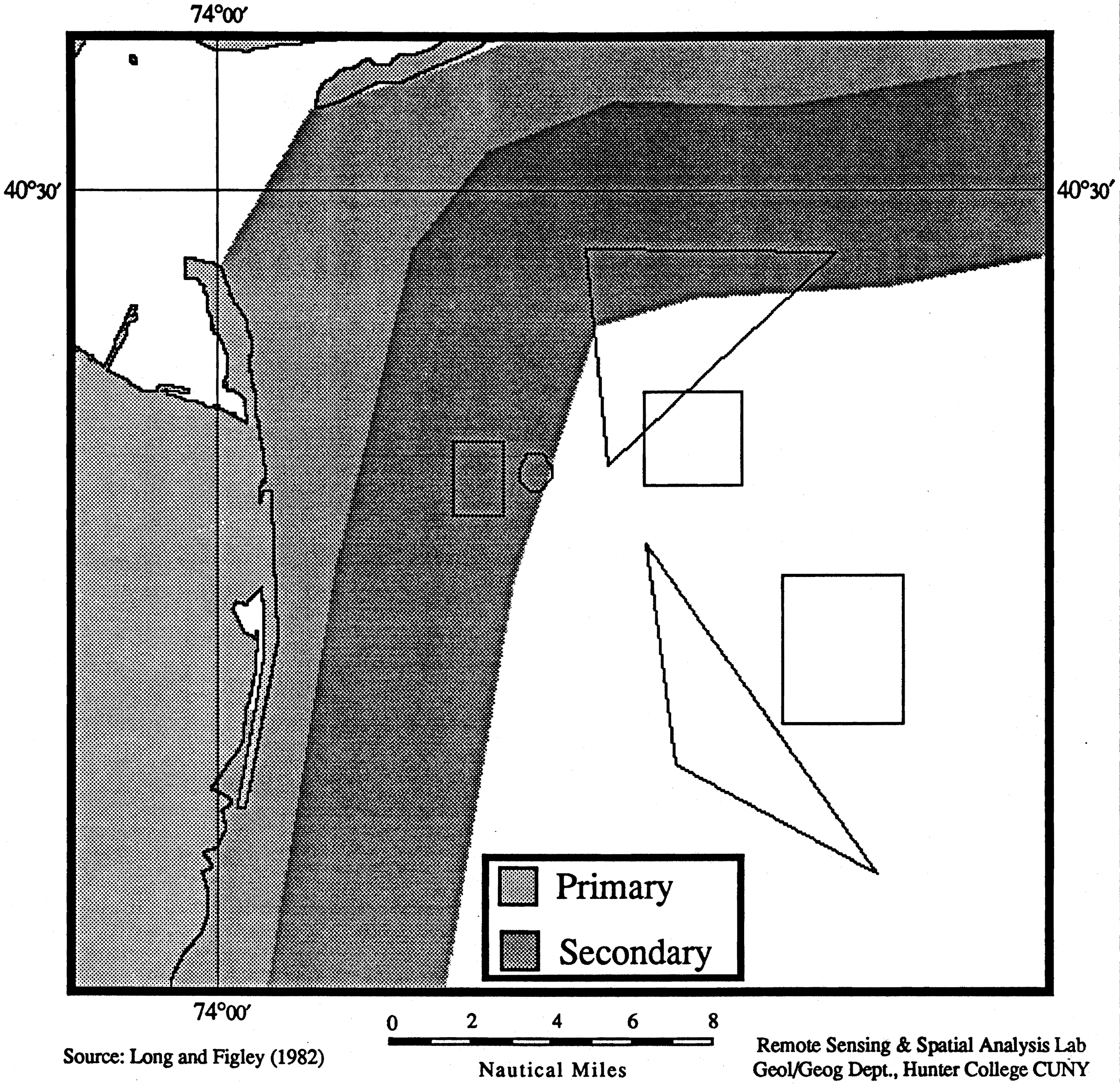
Figure 84

Commercial Fisheries: Menhaden



Source: Long and Figley (1982)

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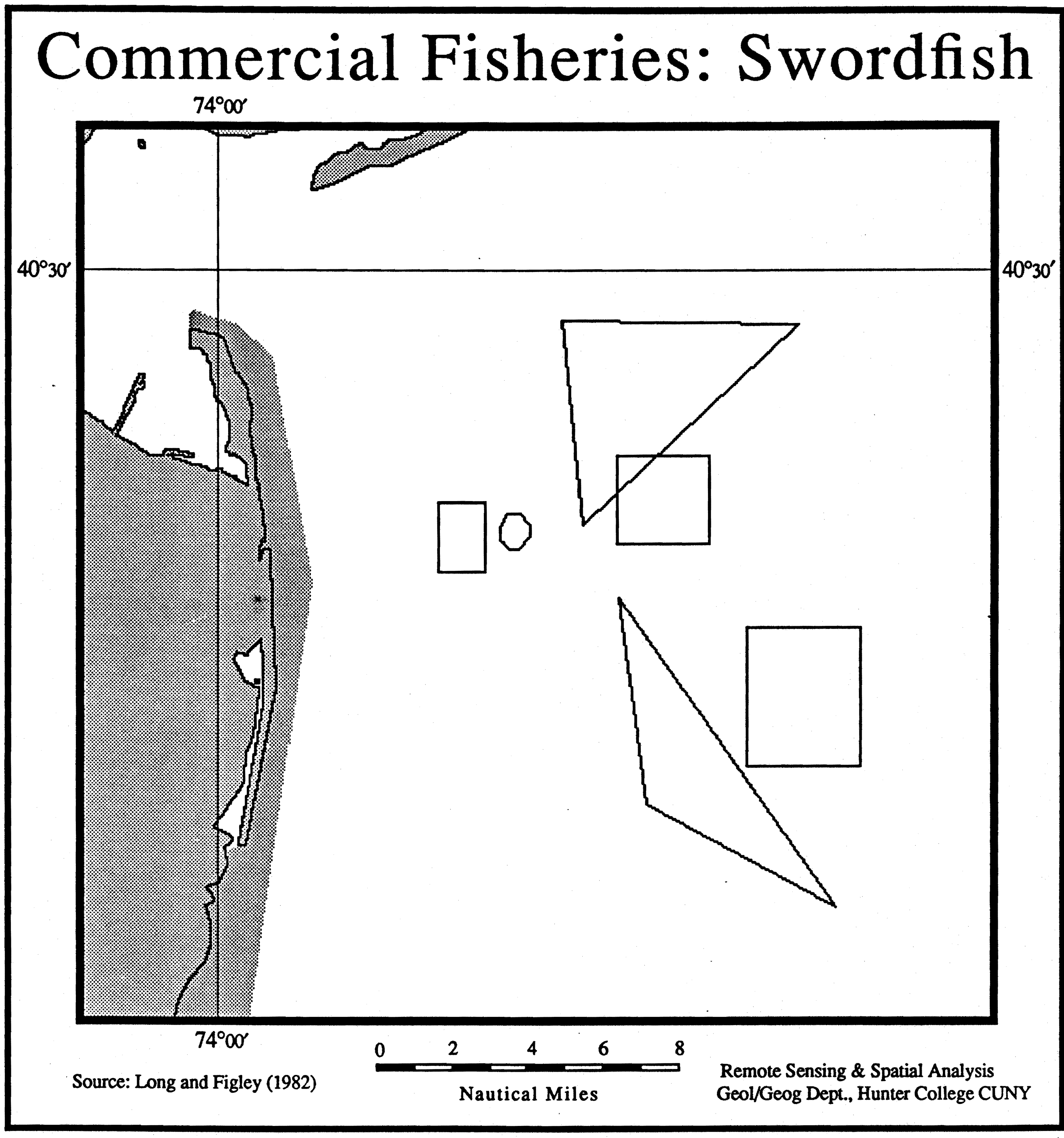
Figure 85


Commercial Fisheries: Swordfish
74°00′
40°30′
40°30′
74°00′
0
2
4
6
8
Nautical Miles
Source: Long and Figley (1982)
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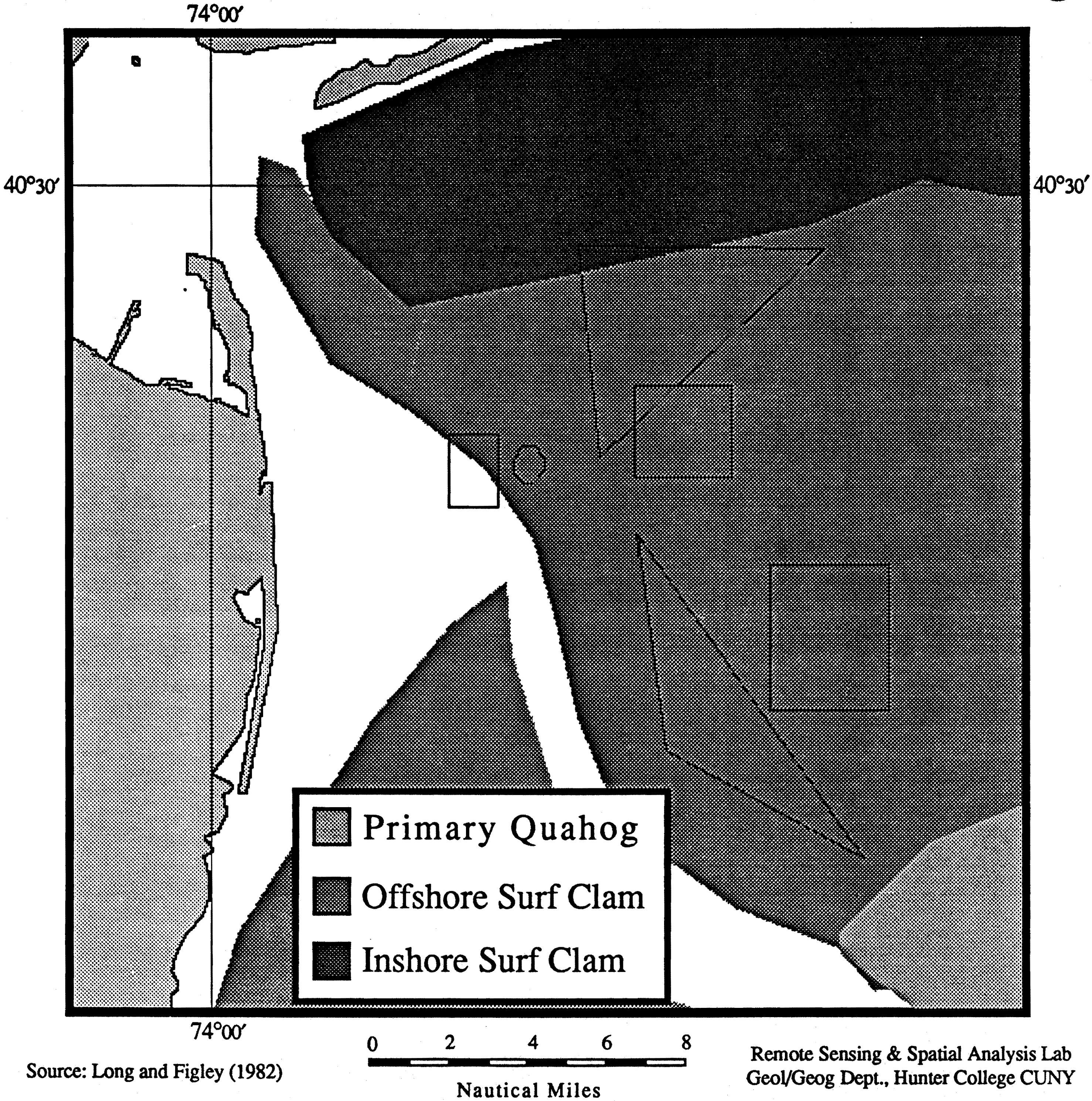
Geol/Geog Dept., Hunter College CUNY

Figure 86

Commercial Fisheries: Surf Clam & Quahog



Source: Long and Figley (1982)

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Figure 87

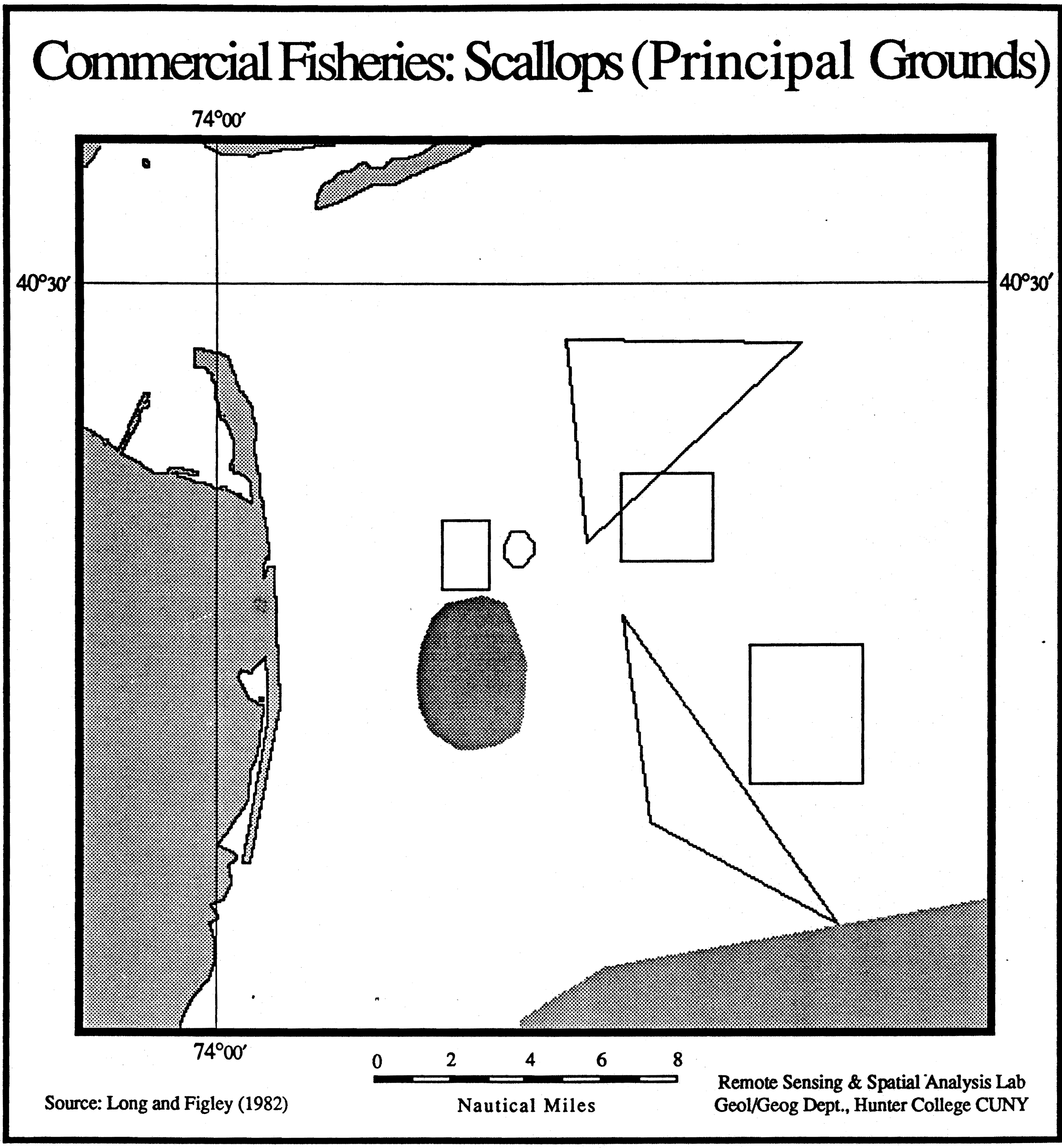
Commercial Fisheries: Scallops (Principal Grounds)
74°00′
40°30′
40°30′
74°00′
0
2
4
6
8
Nautical Miles
Source: Long and Figley (1982)
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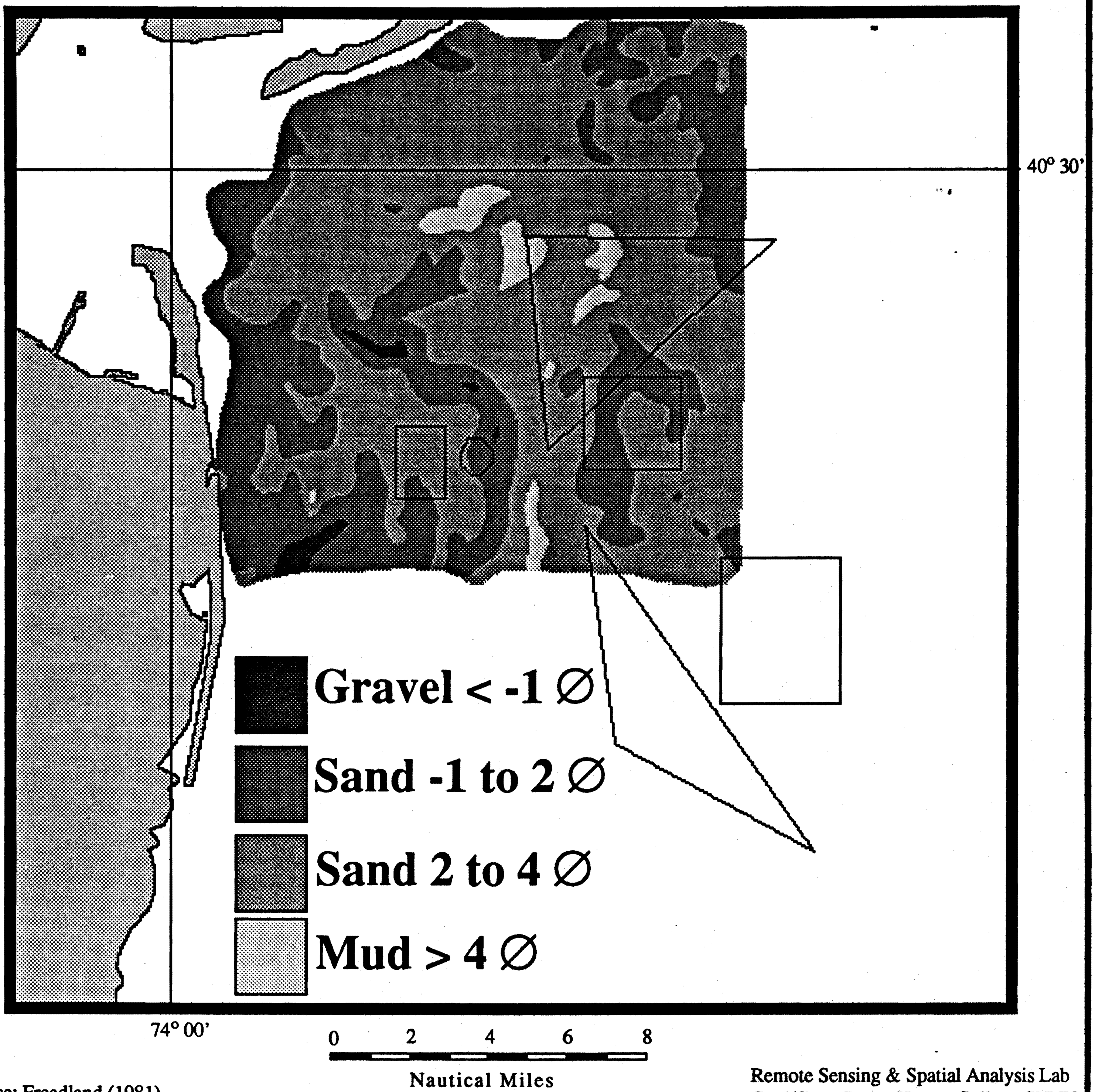
Figure 88

N.Y. Bight Apex Sediment



Source: Freedland (1981)

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Figure 89

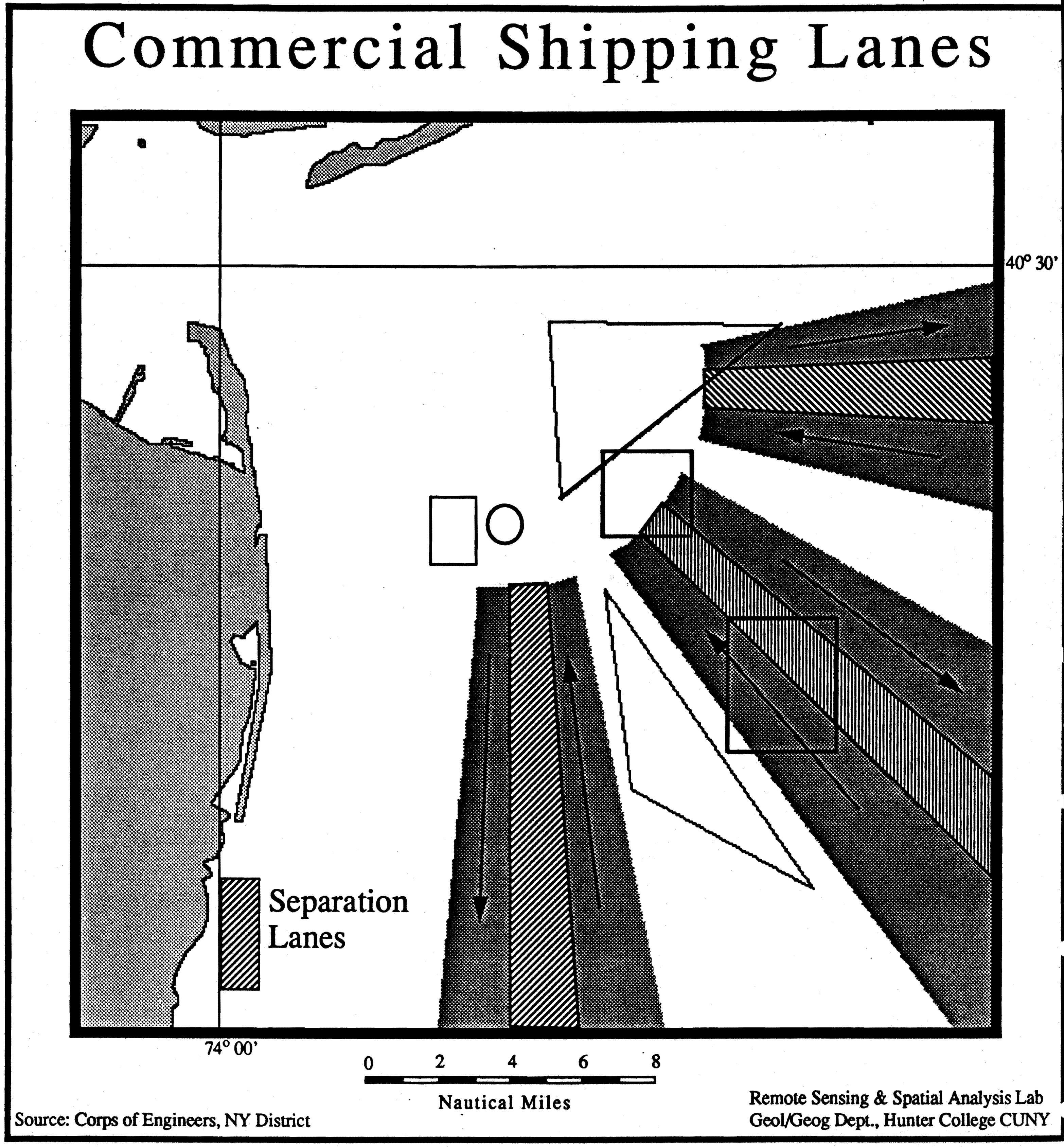
Commercial Shipping Lanes
40° 30'
Separation
Lanes
74° 00'
0
2
4
6
8
Nautical Miles
Source: Corps of Engineers, NY District
Remote Sensing & Spatial Analysis Lab
Geol/Geog Dept., Hunter College CUNY

Figure 90

Five Category Overlay, Bight Apex

Hudson Canyon, Gravel Concentration,Lobster Distribution,Recreational Fishing and Shipping Lanes

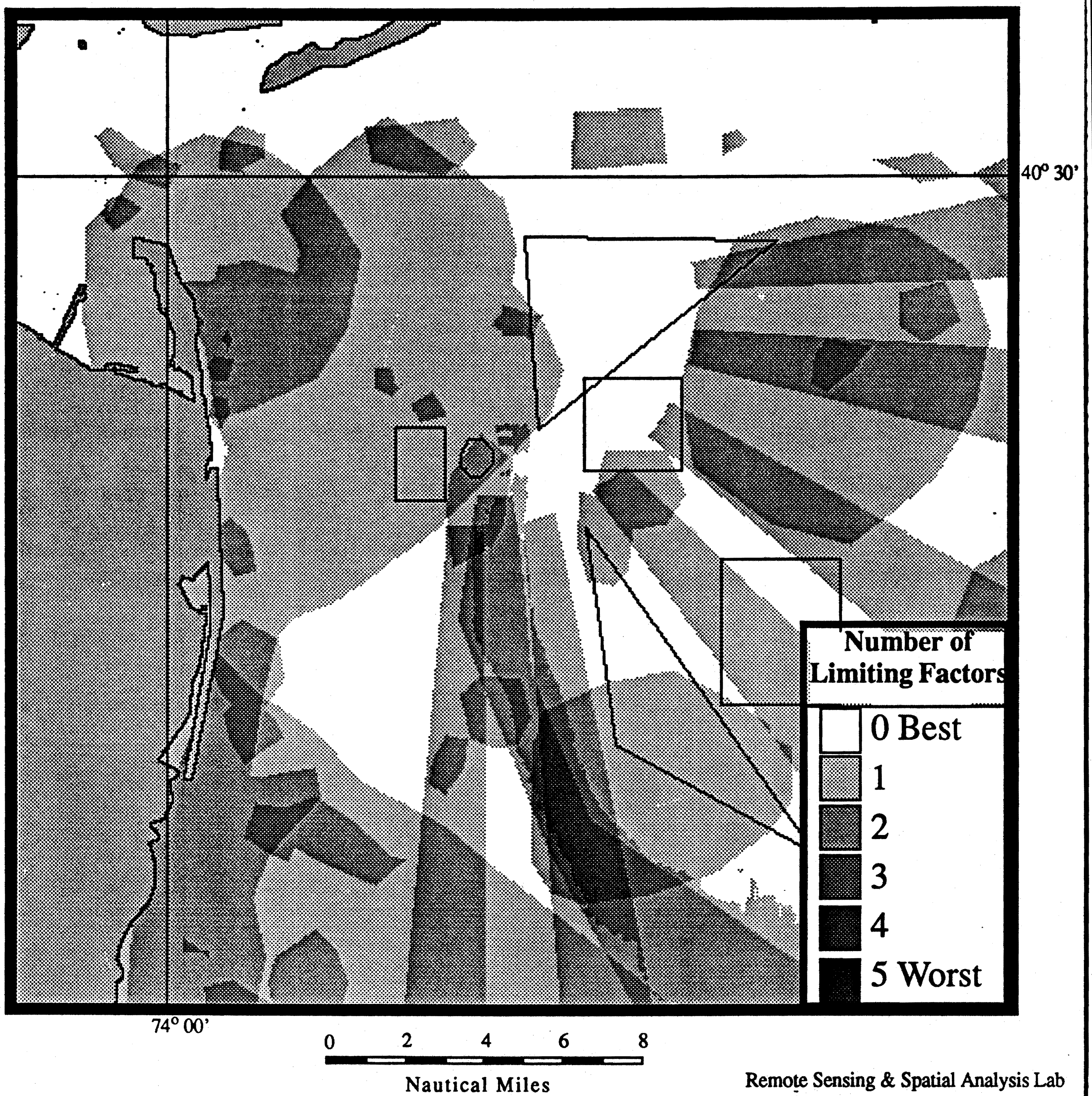

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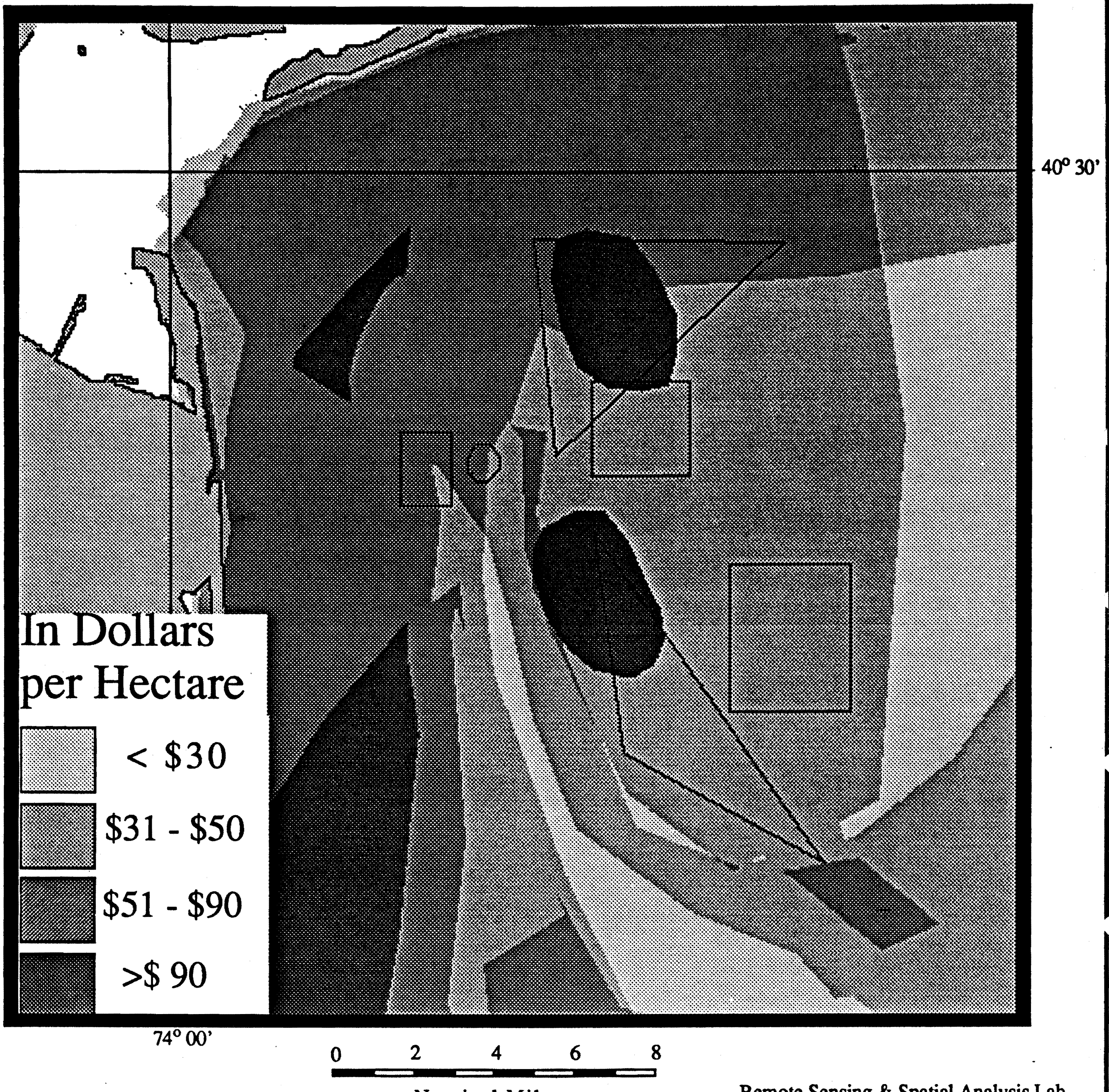
Figure 91

Apex Commercial and Recreational Fisheries in Dollar Value per Hectare



Source: Long and Figley (1982)

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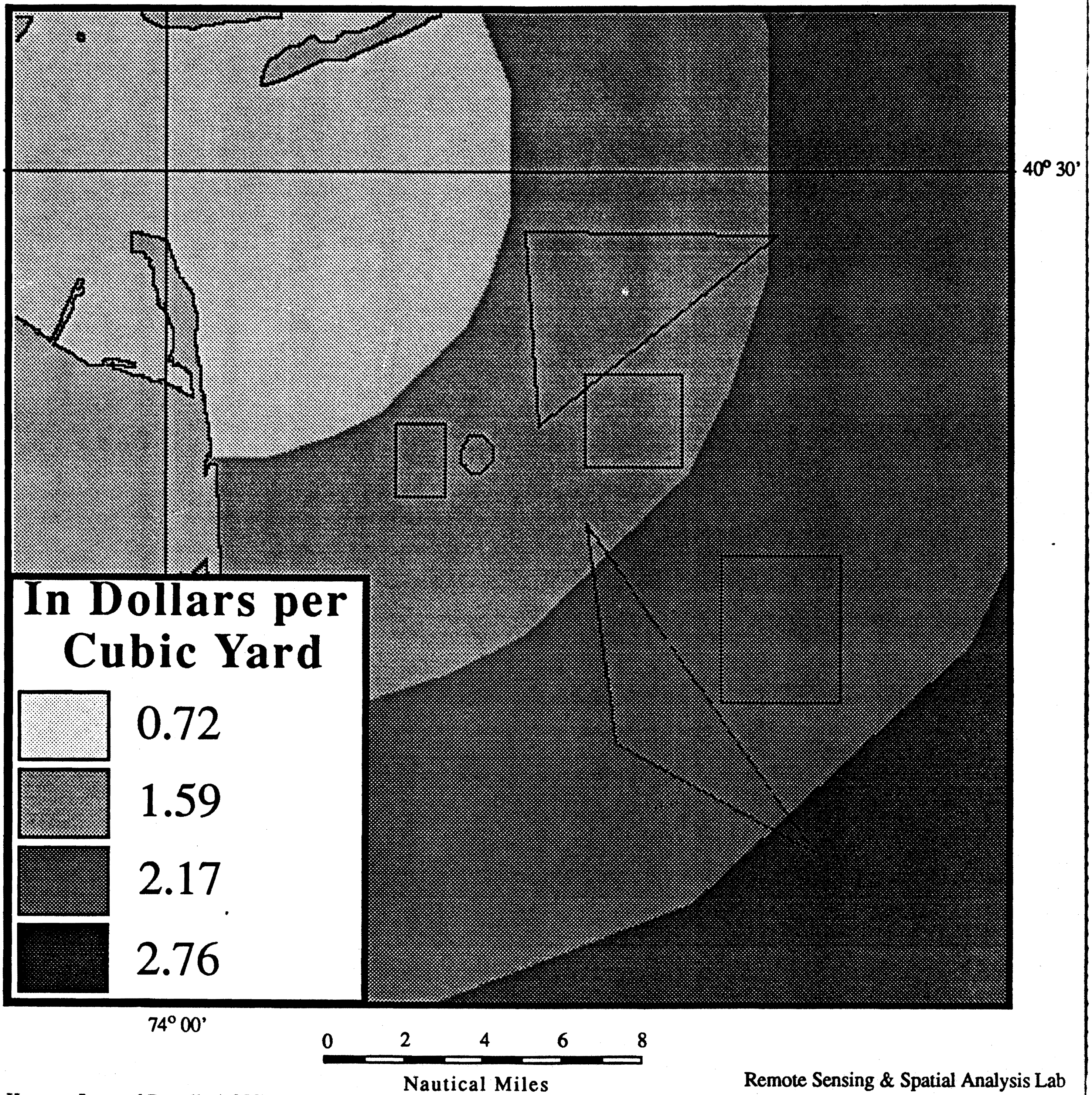
Figure 92

Transportation Cost Distance Analysis for Dredged Sediment



Source: Kearney Inc. and Battelle (1988)

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Figure 93

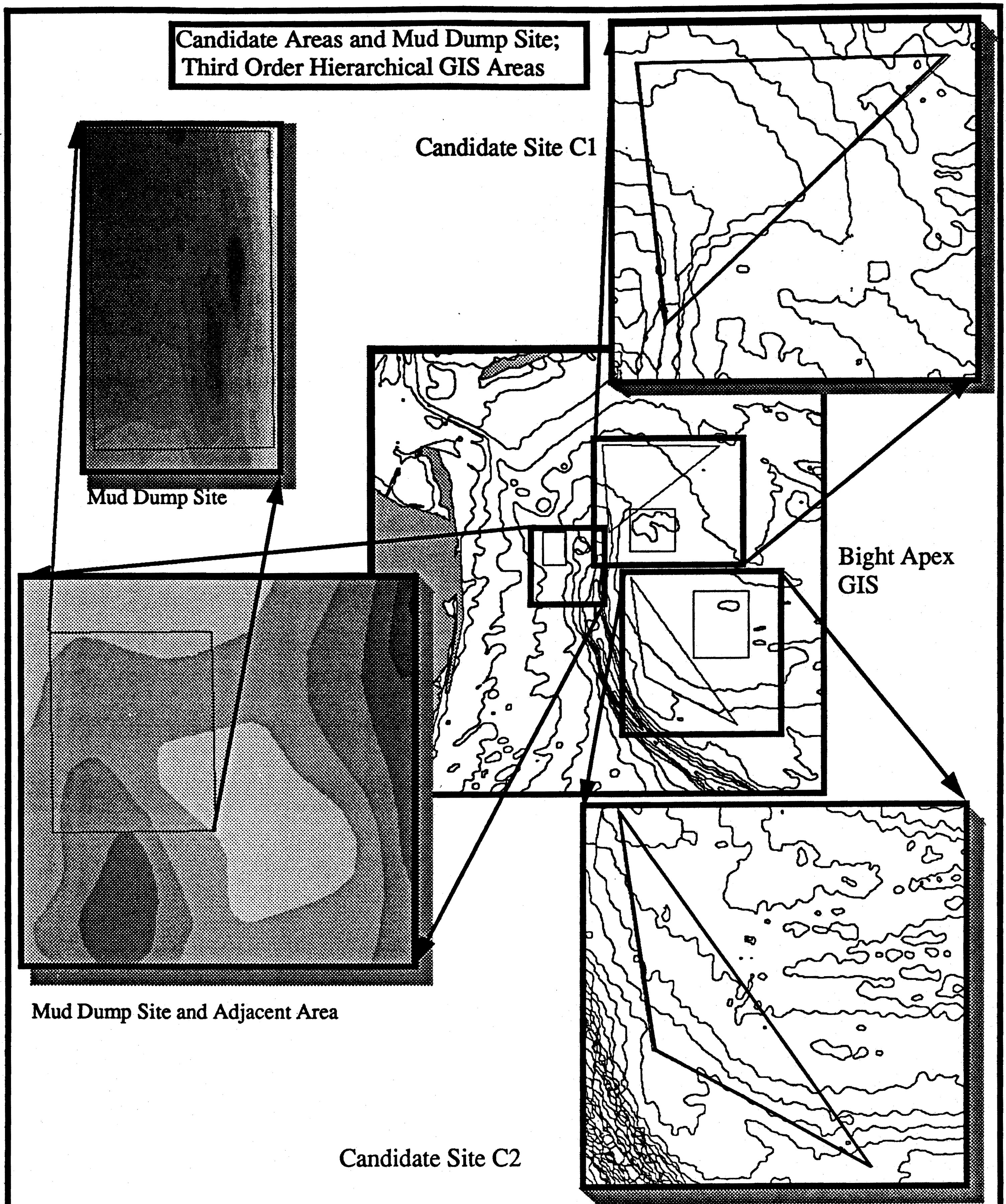
Candidate Areas and Mud Dump Site;
Third Order Hierarchical GIS Areas
Candidate Site C1
Mud Dump Site
Bight Apex
GIS
Mud Dump Site and Adjacent Area
Candidate Site C2

Figure 94