ENVIRONMENTAL ASSESSMENT OF
SEISMIC EXPLORATION ON THE SCOTIAN SHELF

by

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INTRODUCTION

The offshore oil and gas industry uses seismic exploration techniques to evaluate the geology that underlies the sea. These techniques involve beaming powerful sounds into the ocean bottom and monitoring the return patterns. Incidentally, large amounts of energy (noise) enter the water column where marine animals live. There is a concern that these animals may be negatively affected by this energy. This report examines the likelihood that negative effects will occur.

The Canada/Nova Scotia Offshore Petroleum Board (CNSOPB) has responsibility for regulating offshore oil and gas exploration on the Scotian Shelf. Thus, the Board issues permits to allow seismic exploration and it determines the operating conditions that are applied. Since the oil and gas industry wishes to conduct seismic exploration for the next several years, the CNSOPB is interested in having an assessment of the available information on the biological effects of seismic exploration on the Scotian Shelf. This report was prepared for Mobil Oil Canada Properties Ltd., Shell Canada Ltd., and Imperial Oil Ltd. to provide such an assessment to the CNSOPB.

This document is a *Class Assessment* as defined by the CNSOPB. According to CNSOPB Policies and Procedures (CNSOPB 1996:3),

> "A class assessment may be conducted by the Board when a particular activity or type of project, and the full range of its potentially adverse environmental effects, have been identified. A representative project is then assessed and thoroughly documented. Once completed this class assessment will be applied to future projects or activities, conducted within the same defined parameters."

The present assessment is meant to address marine environmental effects of seismic operations on the Scotian Shelf that might occur over the next 5 to 7 years, with emphasis on seismic operations to be conducted in summer of 1998.

The Environmental Assessment is designed to meet the requirements of a *Class Assessment* in that

- it follows the precepts of the Canadian Environmental Assessment Act (CEAA),

- it is meant to evaluate impacts of seismic exploration that will be carried out over a period of several years, in a similar manner within a defined area,

- potential impacts of this activity are known or can be predicted and would be similar regardless of where it occurs within the defined area,

- it focuses on a representative project, which is seismic exploration to be conducted during summer 1998, and

- it considers the environmental effects, cumulative environmental effects, calculates the significance of these effects, includes public consultation, addresses comments from the public, and discusses the need for mitigation measures.

The report begins with a discussion of the impact assessment methodology to be used in the study. This is followed by a description of typical seismic programs that might be conducted on the Scotian Shelf. The levels of underwater noise produced are evaluated along with information on rates of transmission loss with distance, ambient noise, and the levels of noise received by the animals of concern. The actual impact assessments that follow in subsequent sections are organized by fish and fisheries, marine mammals, birds, sea turtles, and special areas. The final sections discuss cumulative effects, mitigation measures and monitoring.

IMPACT ASSESSMENT METHODOLOGY

The impact assessment is conducted in accordance with the CNSOPB Class Screening guidelines and the Canadian Environmental Assessment Act (CEAA) and its associated Responsible Authorities Guide. The methods used to assess the potential impacts of seismic activities are similar to those that we have used in

- Seismic monitoring programs for BP Exploration (Alaska) Inc., which were conducted under Incidental Harassment Authorizations issued by the U.S. National Marine Fisheries Service under their guidelines;

- Environmental Assessments of the effects of underwater sound on marine mammals and fish for 4 projects done for the U.S. Department of Defense; and

- Up-to-date reviews of the literature on effects of underwater noise (e.g. Richardson et al. 1995).

Impact Analysis Methods

In the following sections, we describe our approach to each phase of the impact assessment process.

Environmental Descriptions

The environmental descriptions contained in this document are based on reviews of published and unpublished reports, compilations of data, consultations with experts, and the professional experience of the assessment team. The environmental descriptions are focused on Valued Ecosystem Components (VECs). Particular attention is paid to those life-cycle phases that could be affected by seismic operations. For example, the distributions of whales when they are not on the Scotian Shelf are not emphasized.

The literature on the VECs that inhabit the Scotian Shelf was reviewed. The literature provides sufficient information on the general distribution, life history and behaviour of most VECs and on the magnitude of the fish harvest. However, comprehensive site-specific information is lacking for both fish and marine mammals. Fisheries experts were brought onto the project team to map site-specific data on fish catches and to compile landings data. Marine mammal distributional information was reviewed but quantitative data are usually lacking.

Evaluation of Impacts

The preparation of interaction matrices is the first stage in the preparation of the EA. An Interaction Matrix is usually used to identify all potential interactions between project activities and VECs. The matrix identifies potential interactions only and makes no assumptions about actual impacts of the interactions.

Potential project/environment interactions were identified by comparing the timing and areas used by VECs and the timing and areas subject to seismic exploration, taking account of the experience and expertise of the disciplinary experts, results of public consultations, and results of studies done for seismic operations in other areas.

Interactions identified in the Interaction Matrices were then evaluated to determine whether they could lead to impacts. An interaction was considered to be a potential impact if it could cause a change in the abundance or distribution of species that are valued ecosystem components, in the prey species and/or habitats used by VECs, or in fishing activities.

The methods of impact assessment described in the Canadian Environmental Assessment Act (CEAA) Responsible Authorities Guide were used. However, the guide does not provide details for some of the steps to be taken, such as matrix preparation. Those gaps were filled by using relevant Federal Environmental Assessment Review Office (FEARO) documents, Canadian Environmental Assessment Research Council (CEARC) publications, and other related material. The present EA uses the methodology of other EISs while following the precepts laid out in the CEAA and associated documents.

The evaluations of interactions follow the descriptions of the VECs; they begin with brief descriptions of project activities that could interact with the VEC. Brief but comprehensive reviews of the literature on the effects of these types of interactions were conducted and summarized for inclusion in the report. The impact evaluations were based on the abundance of the VEC, the likelihood of the interaction occurring, the known and predicted effects of these types of interactions, past experience, and expert opinions. The impact assessments were done by experts in their fields, using professional judgement and up-to-date knowledge of the published and unpublished literature.

The impact assessment sections integrate the descriptions of the proposed project, the descriptions of the VECs, the concerns identified during workshops and agency consultations, and review of related EISs and IEEs. Written descriptions of the nature of the potential impacts are

presented as are magnitude ratings using the terminology, definitions, and ranking system developed for other EISs and IEEs conducted by LGL Limited. At this stage, impacts were assessed assuming that general industry mitigation measures were in place but that project specific mitigation measures were not in place.

Mitigation Measures and Residual Impacts

In subsequent sections, mitigation measures appropriate for predicted impacts were recommended, and impacts were re-evaluated after the mitigation measures were considered. The expected impacts after mitigation were considered unavoidable residual impacts of the project.

Impact Summary

Lastly, an Impact Summary Table that summarizes predicted impacts before and after mitigation was prepared. Each interaction identified in the Interaction Matrix is listed in the summary table. The following information is included for each interaction: The project activity; the VEC; the potential interaction (e.g., noise disturbance); ranking of the potential impact before mitigation according to magnitude, direction (+ or -), scale, duration, and likelihood of occurrence; a brief description of the mitigation measures (e.g., scheduling, use of equipment); and ranking of the predicted residual impacts after mitigation. Impacts deemed unlikely to occur or rated as negligible are also listed.

Evaluation of Cumulative Impacts

The final step is a discussion of the cumulative effects of the project. Cumulative effects may be additive or synergistic. Cumulative effects include the combined effects of the entire project plus the effects of other existing or planned activities for the area. The Impact Summary for the project was used as the basis for the assessment of cumulative impacts.

Impact Definitions

It is important that the terminology used to describe potential impacts be clear and easily understood. Words such as minor, moderate, and significant are subjective and their meaning differs depending on the context in which they are used and the experience of the reader. Therefore, precise definitions for the ranking of potential impacts have been used in this EA.

The first step in the assignment of impact definitions is to define impact criteria. Seismic exploration has the potential to affect VECs directly and has little or no potential to affect the physical habitat. We have used impact criteria that are specific to each group of VECs to determine whether there was a potential for impacts to occur. These criteria are discussed in the impact assessment sections for Fish and Fisheries and for Marine Mammals. Once it was determined that there was a potential for impact, then the following definitions were used.

Magnitude of Impacts

Major Impact - An impact on a VEC is rated major if it is judged to result in a 10%, or greater, change in the size or health of a population, the carrying capacity of its habitat, a commercial harvest, or in an attribute of another VEC. A change in a population can result from an absolute reduction in population size or from displacement of animals to areas outside the area of consideration.

Moderate Impact - An impact on a VEC is rated moderate if it is judged to result in a 1% to 10% change in the size or health of a population, the carrying capacity of its habitat, a commercial harvest, or in an attribute of another VEC.

Minor Impact - An impact on a VEC is rated minor if it is judged to result in a less than 1% change in the size or health of the population, the carrying capacity of its habitat, a commercial harvest, or in an attribute of another VEC.

Negligible Impact - Negligible impacts are those that are judged to have essentially no effects.

Scale of Impacts

Regional Impact - A regional impact is an interaction that is judged to have an impact at the regional level. For the purposes of this EA, the region is defined as those parts of the Scotian Shelf of interest for oil and gas exploration - an area of about 150,000 km² (see following section 'Spatial and Temporal Boundaries').

Local Impact - A local impact is an interaction that is judged to have an impact at the local level, defined here as an area comprising 5% of the Scotian Shelf region described above. For this assessment, the size of the local area would be about 7,500 km².

Sub-Local Impact - A sub-local impact is an interaction that is judged to have an impact on the biophysical environment involving 1% or less of the Scotian Shelf region described above. For this assessment, the size of a sub-local area would be about 1,500 km² or less.

Duration of Impacts

Long-Term - Impacts that last for more than five years.

Medium-Term - Impacts that last for periods of one to five years.

Short-Term - Impacts that last for a period of less than one year.

Likelihood of Occurrence

The impact definition will include an estimate of the likelihood of an impact occurring.

Significance of Impacts

The terms defined above can be combined, as appropriate, to define an impact. For example, a potential impact can be rated positive, minor, medium-term, local and likely to occur. The most serious impact (positive or negative) in this rating system is major, regional and long-term; the least serious is negligible. These terms define the level of the potential impacts. However, it is also necessary to define what level of impact constitutes a significant impact.

Not Significant Impact means that an impact is negligible or is minor, short-term, and local or sub-local in nature, and

Significant Impact means that the impact rating is major or moderate or that it is minor with a medium or long term and a regional impact.

When evaluating the significance of predicted impacts, certain VECs had special status. For example, impacts on endangered northern right whales were given more weight than were similar impacts on other species. Mortality of one northern right whale would be considered a significant impact while mortality of one individual of an abundant species would be considered a minor or negligible impact. Impacts in ecologically significant areas, such as the Gully, were also given more weight than impacts in another area.

Spatial and Temporal Boundaries

The temporal boundaries of this EA encompass seismic exploration conducted during the period from May through October. The document is designed to be valid for a period of about five years, beginning in summer 1998. After five years, the report should be updated to reflect any new information is developed during the five-year period. Also, any new techniques for seismic exploration would be included in the 5-year review.

Exploration will be conducted on the Scotian Shelf in the area outlined in Figure 1. The outer boundary of the survey area will be the shelf break. The inshore boundary is shown in Figure 1. It should be noted that these are the boundaries for seismic exploration. Sounds made by seismic exploration and hence, effects, could occur outside of these boundaries and are dealt with in this EA.

The oil industry plans to use airguns as the energy source for seismic exploration for the near future; thus, this EA only examines potential effects of the sounds made by airguns. Non-seismic noise sources, such as ship noise, are not considered. The assessment of cumulative effects does, however, consider the effects of shipping, pipeline construction, and the construction and operation of offshore oil and gas facilities.
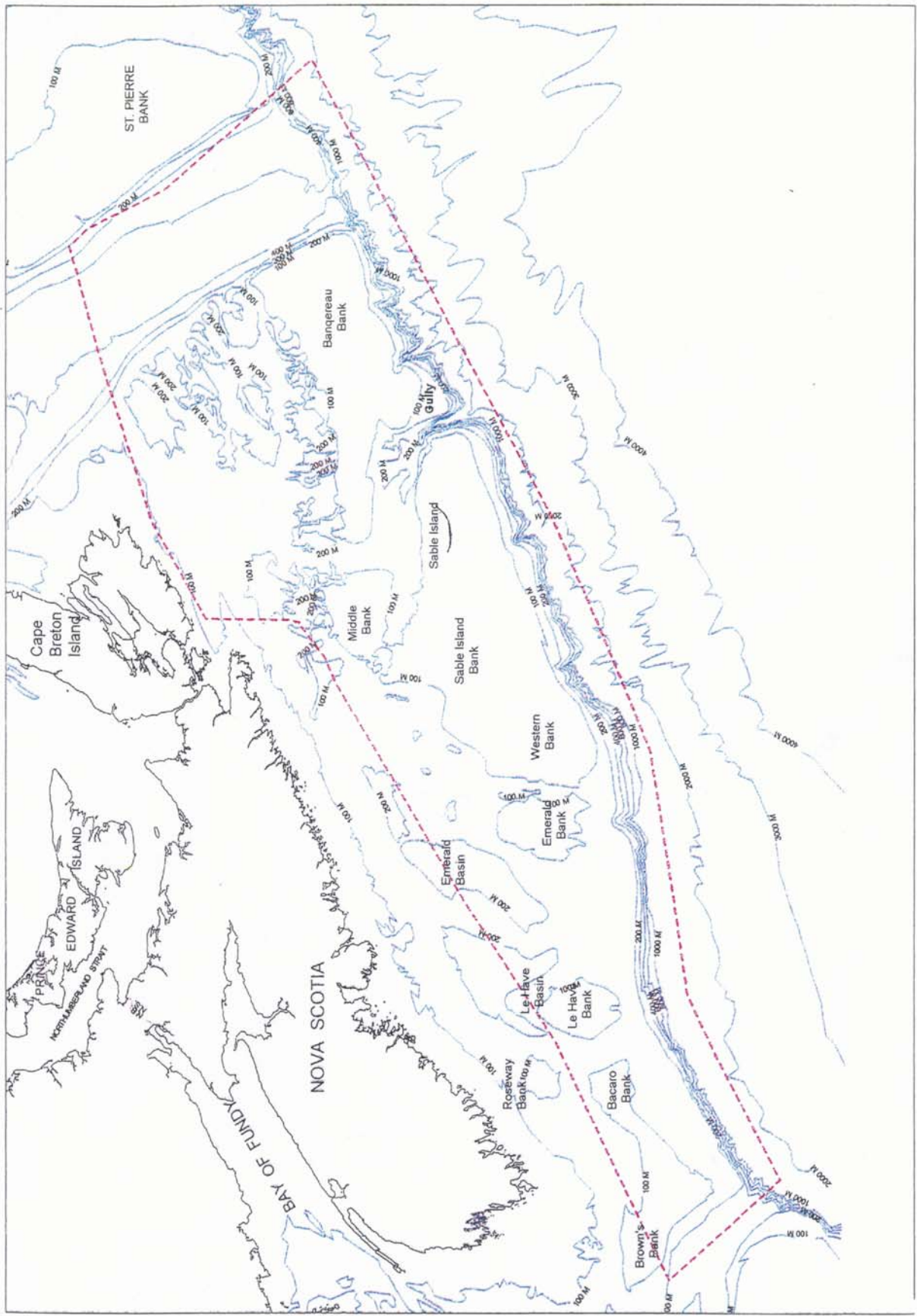
Figure 1. Study area for the Class EA of Marine Geophysical surveys on the Scotian Shelf.

Public Consultation

Workshops and Public Consultation

The Canada/Nova Scotia Offshore Petroleum Board has attempted to insure that the development of this Class EA is an open process with adequate opportunity for various government agencies and interest groups to provide input. To this end, two workshop meetings were held at the CNSOPB offices in Halifax prior to the preparation of this report. The invitation list for these meetings was prepared by the CNSOPB.

The first meeting was held on 18 November 1997 to introduce the project and to discuss the approach to be taken. Issues of concern to the participants were identified. The second meeting was held on 27 February 1998. The meeting discussed the methods to be used, the detailed approach to the assessment, and the preliminary results of the underwater acoustics modelling. The schedule for completion was also discussed.

In addition to project and board staff, a variety of groups were represented at one or both meetings. The oil and gas industry was represented the project sponsors Mobil Oil Canada and Mobil E&P (Dallas), Shell Canada Ltd., Imperial Oil Resources Ltd., and by Geophysical Services Inc. Government agencies participating included Department of Fisheries and Oceans, including Canadian Coast Guard; Environment Canada; Transport Canada, Canadian Environmental Assessment Agency; N.S. Fisheries and Agriculture; and N.S. Petroleum Directorate. Non-government organizations participating included the Native Council of Nova Scotia, National Sea Products Ltd., Seafood Producers Association of N.S., Atlantic Herring Co-op, marine mammalogists from the Biology Department at Dalhousie University, World Wildlife Fund Canada, Ecology Action Centre, SPANS, ESFPA, and Gadus Associates.

Agency Consultation

The relevant government agencies were attended the above-noted workshops. In addition, **DREA (Defence Research Establishment Atlantic)** of the Department of National Defence was approached. DREA has conducted years of research on the acoustic environment of the Scotian Shelf in conjunction with anti-submarine warfare objectives. Under contract to LGL Limited, DREA has kindly assisted in the preparation of the underwater acoustic portions of this EA, particularly the modelling of sound transmission loss.

Valued Ecosystem Components (VECs)

It is not possible, or necessary, to address the potential interactions between project activities and every component of the natural and human environment. Thus, the EA focuses on Valued Ecosystem Components (VECs). VECs include rare or threatened species or habitats; species or habitats that are unique to an area, or are valued for their aesthetic properties; and species that are

harvested by people. The VECs examined in this EA were identified based on the EIS for the Sable Offshore Energy Project (SOEP) and during the workshops and agency consultations.

Fish Larvae

The larvae of many species of commercial importance are found on the Scotian Shelf during the period of proposed seismic operations. Herring spawn in nearshore waters and so will be absent over most of the shelf except for the Sable Island Bank. Larval fish that will be common on the shelf include Atlantic mackerel, redfish, Atlantic cod, silver hake, white hake, haddock, skates, witch flounder, American plaice and yellowtail flounder. Common invertebrate larvae include those of American lobster, northern shrimp, snow crab, and deep sea scallop,

Fish and Invertebrates

The Scotian Shelf supports an important commercial fishery for both finfish and invertebrates. The species considered as VECs are those that accounted for 1% of more of the total 1996 catch biomass for the Scotian Shelf and those that accounted for 1% or more of the value of the catch.

Pelagic species that are considered to be VECs are Atlantic herring, Atlantic mackerel, bluefin tuna and swordfish.

Demersal and benthic species that are considered to be VEC's are Atlantic cod, Atlantic halibut, cusk, flounder (spp.), haddock, pollock, redfish (spp.), silver hake, white hake, and skates (spp.).

Invertebrate species of commercial importance that are VECs include American lobster, deep sea scallops, northern shrimp, snow crab, and Stimpson's surf clams.

The remaining species can be grouped as other pelagic species, other demersal species, and other invertebrates. They are not considered to be VECs.

Fisheries

Fishing on the Scotian Shelf is considered to be a VEC as are the fisheries for each of the species mentioned above. Particularly important fishing areas are also VECs.

Marine Mammals

The Scotian Shelf region, including submerged banks, inter-bank basins, shelf-edge and slope waters, and canyons, is thought to constitute an important feeding area for numerous marine mammal populations, including right, humpback, blue, fin, sei, and minke whales; sperm, northern bottlenose, and long-finned pilot whales; harbour porpoises; white-beaked, Atlantic white-sided, striped, and short-beaked common dolphins; and harbour and grey seals. Additional dolphin and beaked whale species probably forage in the Gully and deep slope waters off the shelf edge but their low numbers and

irregular occurrence mitigate against their inclusion as VECs in this EA. Thus, the list of marine mammal VECs includes 8 species of odontocete cetaceans, 6 species of baleen whales, and 2 species of seals.

Marine Birds

Sea-associated birds are considered to be VECs. However, because of the low potential for interactions with seismic, birds are treated generically rather than creating a long list of individual VECs.

Sea Turtles

Three species of sea turtles occur over the Scotian Shelf. Their status in these waters is poorly understood. Since all three species are considered to be endangered or threatened, they are considered to be VECs in this assessment.

Special Areas

Fish Nursery Areas

Information to be provided by DFO

Sable Island Bank is an important spawning area for herring, Atlantic cod, mackerel, silver hake, white hake, haddock, winter flounder, yellowtail flounder and deep sea scallop.

Key Fishing Areas

Information to be provided by DFO

The Gully

The notable importance of the Gully as foraging habitat for squid-feeding cetaceans, particularly sperm and bottlenose whales, has been noted frequently (Faucher and Weilgart 1992; Whitehead et al. 1992, 1997a, 1997b). Kenney and Winn (1987) were unable to confirm the hypothesis that cetacean biomass is higher in canyon areas than in adjacent shelf edge and slope areas off the U.S. east coast. No similar comparative analysis based on quantitative data has been possible for the Gully, in relation to the adjacent Scotian Shelf edge and slope regions. It appears, however, that the composition of species using the Gully may differ from that using the shelf and shelf edge.

Right Whale Habitat

From a conservation perspective, the Scotian Shelf is exceptionally important insofar as it provides critical habitat for right whales. Historical data suggest that a substantial proportion of the

endangered right whale population uses (or did use) the southwestern Scotian Shelf as a foraging site and possibly also as a migration corridor and an area for nursing calves and socializing.

OVERVIEW OF UNDERWATER ACOUSTICS

Most treatments of the effects of underwater noise are based on the Source:Path:Receiver concept. The elements of this concept are straightforward. In the present case, the noise source is an airgun array that generates large amounts of underwater noise. Noise from the array radiates outward and travels through the water as pressure waves. Water is an efficient medium through which sounds can travel long distances. The receiver of these sounds is a marine animal of interest--i.e. a Valued Ecosystem Component. The sounds received depend upon how much propagation loss occurred between the source and the receiver. The ability of the receiver to detect these signals depends upon the hearing capabilities of the species in question and on the amount of natural ambient or background noise in the sea around the receiver. The sea is a naturally noisy environment and this noise can "drown out" or mask weak signals from distant sources.

The source : path : receiver concept will be used to illustrate the main points needed to evaluate the possible effects of seismic pulses.

Source

Humans hear sounds with a complicated non-linear type of response. The ear responds logarithmically and so acousticians use a logarithmic scale for sound intensity and denote the scale in decibels (dB). In underwater acoustics, sound is usually expressed as a Sound Pressure Level (SPL):

$$\text{Sound Pressure Level} = 20 \log (P/P_o)$$

where P_o is a reference level, usually 1 μPa. Other reference levels have been used in the past and so the reference level needs to be shown as part of the SPL unit. A sound pressure (P) of 1,000 Pascals (Pa) has a SPL of 180 dB re 1 μPa and a pressure of 500 Pa has a SPL of 174 dB. In this scale, a doubling of the sound pressure means an increase of 6 dB. In order to interpret quoted sound pressure levels one must also have some indication of where the measurement applies. SPLs are usually expressed as received sound level at the receiver location or the sound at the source. A source level is usually calculated or measured as the SPL at 1 m from the source. A complete reference to a source level should read as 180 dB re 1 μPa at 1 m. The unit of distance is necessary for comparison of source levels. Geophysicists usually refer to source levels of airguns in the units bar-m. In this document all units have been standardized to dB re 1 μPa.

All seismic noises discussed in this document refer to those made by airguns only, unless otherwise specified. A seismic impulse is created by a burst of compressed air; it is composed of a positive pressure pulse followed by a negative pressure pulse. The difference in pressure between the highest positive pressure and the lowest negative pressure is the peak to peak pressure (P-P; Figure 2). The peak positive pressure, usually called the peak or zero to peak pressure (0-P), is
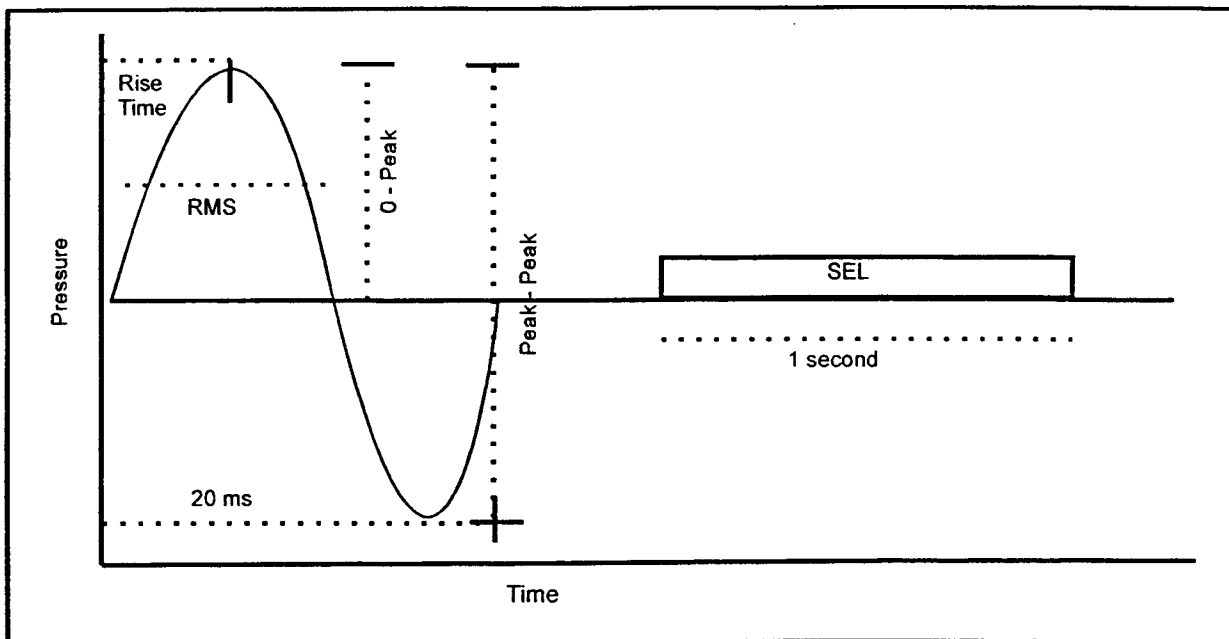
Figure 2. Terms used to define pressure levels of a seismic pulse.

approximately half the peak to peak pressure. Thus, the difference between the two is approximately 6 dB (6 dB = twice the pressure). The average pressure recorded during the pressure pulse can be expressed as the root mean square (rms) or average pressure. The rms pressure is integrated over the duration of the pulse. For seismic sounds, the rms pressure is usually about 10 dB lower than the peak pressure (Greene 1997). To compare pulses of various types, sound pressure can be integrated over a standard unit of time, usually 1 second, to obtain the Sound Exposure Level (SEL). For a seismic sound, the SEL is usually about 20 dB below the zero to peak pressure and about 10 dB below the rms pressure.

An understanding of these different methods of expressing sound pressure is necessary because one needs to compare different measures of sound pressure reported in the literature and because different kinds of effects are related to different aspects of a sound pressure wave. Severity of physical damage is often related to peak pressure. Much of the literature on potential effects on fisheries express sounds as peak pressures. In contrast, disturbance criteria for marine mammals are often based on rms pressures. However, some new criteria for marine mammal impacts are expressed as Sound Exposure Levels. Most reports on the effects of sounds on marine mammals express sound as average (rms) pressures.

Peak pressures should only be compared among similar sources. Physical damage is caused by both the peak pressure and the rise time. The rise time is the amount of time required for a sound pulse to reach peak pressure from the zero (baseline) pressure. A diver can easily sustain a change of 5 atmospheres (515,000 Pa, 234 dB re 1 µPa) during a slow descent. However, a change of 5 atmospheres occurring during a period of less than a millisecond would cause death. High explosives detonated underwater produce pulses with very fast rise times (microseconds) compared to a seismic sounds (milliseconds). Thus, the large body of literature on explosives effects cannot be used to estimate the effects of airgun sounds.

Sound measurements are often expressed as broadband, meaning the overall level of the sound over a range or band of frequencies. The level at a specific frequency will be lower than the broadband sound level for some band containing that frequency because the broadband sound includes the components over a wide range of frequencies. Sound signatures from airguns consist of measurements of the sound level at each frequency--a sound spectrum. Sound level can also be measured and summed over groups or bands of frequencies (e.g., octaves or third octaves).

Comparison of In-Air and Underwater Sounds

It is not possible to directly compare in-air with in-water sound levels because the constants of proportionality between intensity, power and pressure are not the same. Also, different reference pressures are used by underwater acousticians (1µPa) and airborne acousticians (20 µPa).

Characteristics of Seismic Noise Sources

An airgun array is towed behind the boat at a depth of 6 m. Shots typically are fired every 25 m, or about once every 10 sec. For 3D seismic shooting programs, the zero to peak overall source level of the array is about 64 bar m (256 dB re 1 μPa_{0-p} at 1 m) or 128 bar m peak-peak (262 dB re 1 μPa-m_{p-p}) in the downward direction. This is approximately equivalent to an overall broadband rms source level of 246 dB re 1 µPa and a sound exposure level (SEL) of 236 dB re 1 µPa. Because the array is configured to focus sound toward the bottom, effective source levels for propagation in the horizontal direction are lower than those straight down from the array.

	dB re 1 µPa at 1 m	
	Down	Side[1]
Peak to Peak	262	249
Zero to Peak	256	248
RMS	246	235
SEL	236	227

[1] 10° down from horizontal

The source levels for 2D arrays are often slightly higher than those used in 3D surveys. The difference is usually 0 - 3 dB, although the maximum difference of 3 dB would be unusual.

Path

The pressure of a seismic pulse diminishes with increasing distance from the source. Most of the loss in pressure is due to spreading. The diminishing of pressure with increasing distance
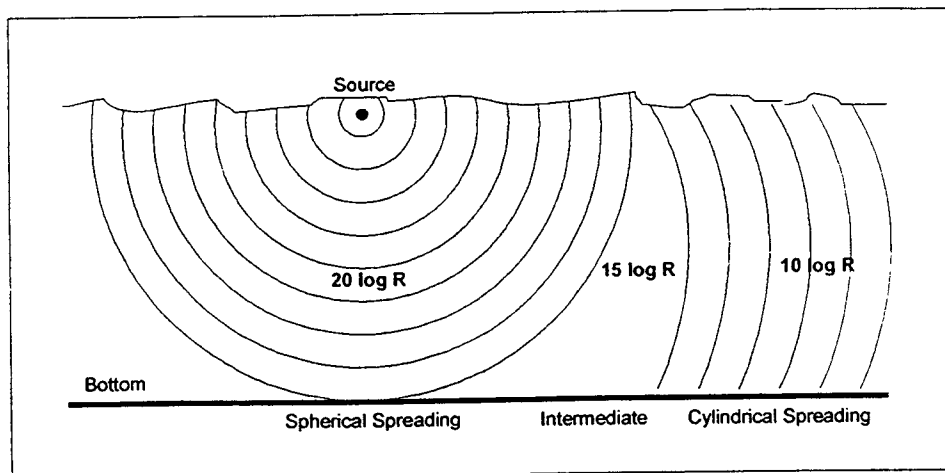
Figure 3. Schematic representation of spreading loss.

from the source is spherical to a distance that is approximately equivalent to the water depth (Figure 3). The loss in dB resulting from spherical spreading is expressed as:

$$20 \log R \text{ dB}$$

The transmission loss is 6 dB with each doubling of the distance. That is to say, pressure decreases by one half with each doubling of the distance. At distances much greater than bottom depth D, sound propagates through a channel bounded by the bottom and the surface and spreading is often assumed to be approximately cylindrical, with loss in dB expressed as

$$10 \log R/D \text{ dB}$$

When spreading is cylindrical, the spreading loss is 3 dB with each doubling of the distance, or one half that of spherical spreading. A simple model of spreading would use spherical spreading to distances equal to that of the bottom and then cylindrical spreading. At ranges intermediate between spherical and cylindrical spreading, loss is often assumed to be 15 log R dB.

In many cases, observed and modeled spreading losses do not agree well with the simple spherical/cylindrical spreading model. The estimation of spreading is complicated by many factors. These include reflections from the surface and bottom and sub-bottom layers, and differences in propagation for different frequencies. Sound speed varies with water temperature, salinity, and pressure, and thus there can be reflection and/or refraction at water mass discontinuities such as the seasonal thermocline. Sound waves can be channelled within a water mass and propagate long distances within a good sound transmitting channel. Received levels are generally lower in surface waters than deeper in the water column, especially for the lower frequency component. These and other factors complicate the estimation of transmission loss and necessitate the use of sophisticated models, such as the ones used later in this report.

The initial pulse emitted by an airgun array is of 10 to 15 milliseconds duration. As it propagates, the pulse duration increases and its frequency spectrum changes. At distances of a few km, pulse length can be ¼ to ½ sec in duration.

Receiver

For an animal to hear a seismic sound, the received level of the underwater sound within a particular bandwidth relevant to the animal's hearing processes must, to a first approximation, be greater than the absolute hearing threshold of the animal of interest. Received sounds below this threshold are not detectable by the animal. The hearing threshold varies with frequency and the frequencies of greatest sensitivity vary among species. Hearing thresholds are known for some species of seals and odontocetes, but not for baleen whales. Some of these audiograms are presented in the marine mammal section later in the report.

An animal's ability to detect sounds produced by seismic exploration also depends on the amount of natural ambient or background noise in the waters in which it is swimming. If background noise is high, then the array noise will not be detectable as far away as would be possible under quieter conditions. The open sea is a naturally noisy environment. Typical open water ambient noise spectra are discussed later. Wind, thermal noise, precipitation, ship traffic and biological sources are all major contributors to ambient noise. However, ambient noise is highly variable resulting in much variation in the detection range of seismic pulses.

Once source levels and propagation loss have been evaluated, the question becomes, 'what are the effects of noise on marine animals?' This is clearly the most complicated and least understood component of the source : path : receiver model. The effects question is addressed in the remainder of this assessment. There are many gaps in the information on hearing capabilities and on the responses of animals to sounds that they hear. Thus, it is not yet possible to establish unequivocal criteria for determining the zone of influence or zone of effects around a noise source.

A hierarchy of criteria for establishing zones of influence can be used for discussion purposes. These criteria are based on

- ambient noise,
- absolute hearing thresholds,
- changes in behaviour
- disturbance effects (e.g. avoidance),
- temporary hearing loss, and
- permanent damage.

Based on the six criteria, one can define a series of zones of potential noise influence of generally decreasing size. The zones within which seismic noise levels exceed ambient levels and absolute hearing thresholds are often large. However, the zones within which there is disturbance and especially auditory impairment will be much smaller (Figure 4).
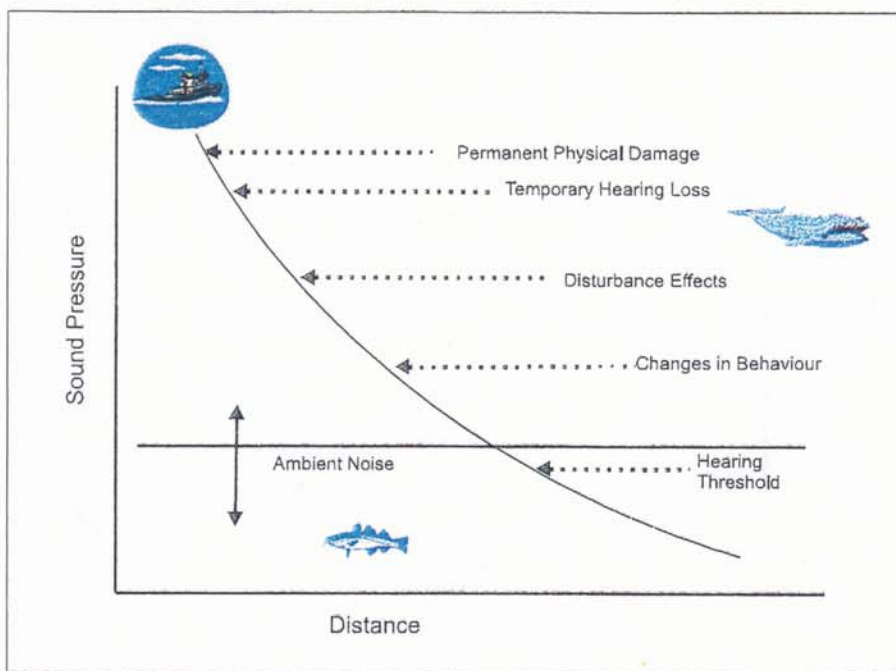
Figure 4. Zones of potential influence of sound.

The maximum possible radius of influence of seismic noise is the distance at which its received level falls substantially below that of the ambient noise in the corresponding frequency band. Once the noise falls substantially below ambient, marine animals will not be able to detect the presence of the industrial source. Ambient noise levels vary over time and season and among geographic areas. Thus, the radius of the zone of detection is also variable.

It is not realistic to use an ambient noise criterion alone to determine a zone of influence. In some cases, an industrial noise level may diminish below the animal's hearing threshold before it reaches ambient levels. Even when this is not the case, detectable but weak seismic pulses probably do not affect marine animals significantly. It is necessary to distinguish between a zone of potential influence and a zone of actual effects. The former is a zone within which the animal might be aware or react mildly to of seismic noise. The latter is the zone, generally much smaller, within which the animal might be detrimentally affected (see Figure 4).

Underwater seismic noise above a particular received level may disturb marine mammals (Richardson et al. 1995). However, the levels of seismic pulses that elicit specific disturbance or other effects have not been studied in detail in very many species. For man-made sounds in general, the levels, frequencies and types of noise that cause disturbance vary from species to species, and perhaps with area and season for a given species. Habituation (diminishing sensitivity during repeated exposures) and possibly sensitization (increasing sensitivity during repeated exposures) are additional sources of variability in responsiveness.

Disturbance is sometimes evident from changes in the behaviour of the animals in question. Behavioural changes can be subtle, such as a slight change in respiration rate detectable only by statistical analysis. Other behavioural changes can be conspicuous, such as moving out of an area to reduce exposure to noise. There may be some situations in which movements to other areas will not detrimentally affect the population. However, the safest assumption is that a population occupies optimum habitat and movement away from the habitat is likely to be detrimental, at least if the animals are displaced for more than a brief period.

Temporary threshold shift (TTS) is the lowest level of physical damage. Brief exposures to loud sounds can temporarily increase the hearing threshold of an animal. This effect is temporary and reversible. Prolonged exposure to continuous loud sounds can cause permanent hearing damage. TTS is an important effects criterion because some individuals of some marine mammal species (seals) do not seem to avoid seismic arrays and thus, may be exposed to very high levels of noise.

PROJECT DESCRIPTION - PROPOSED SEISMIC EXPLORATION

Survey Vessel and Equipment

Modern vessels conducting 3D marine seismic surveys using the streamer method are 80-95 m in length and have a crew of about 40 people. The vessels are capable of travelling at about 14 knots (26 km/h) when in transit with no equipment deployed. When surveying equipment is in the water, vessel speed must be no less than 3.5 kts (6.5 km/h) and no more than 5.5 kts (10 km/h) in order to avoid damage to the towed equipment. Seismic vessels towing streamers have very limited

manoeuvrability when the equipment is deployed, require a minimum of 45 minutes to safely execute a 180° turn, and cannot change course faster than 5° per minute. Deployment and retrieval of the equipment is a very time consuming process, and cannot be accomplished safely when significant wave heights exceed 3 m. Retrieval of the equipment in good weather conditions can be accomplished in about 12 hours, but more often requires a minimum of 24 hours. Deployment of the equipment takes a minimum of 24 hours, and more often several days. If sea conditions are expected to reach and remain above Sea State 6 (Beaufort Force 9 winds) for more than 24 hours, it is likely that the in-sea equipment will be retrieved.

Marine 3D seismic surveys are carried out using high pressure "airguns" for the sound source. The returning signals (echoes) are recorded, during typical streamer surveys, by almost 3000 hydrophones (microphones) which are towed behind the survey vessel. For typical operations off the east coast of Canada, the seismic vessel tows 8 streamers. Each streamer is 4600 m long with 368 hydrophones spaced 12.5 m apart. The streamers are towed at a water depth of 7 or 8 m, and they are about 100 m apart; thus, the swath of towed equipment will be ~700 m wide. The location of the hydrophones at any time can be determined using sophisticated positioning equipment (which includes magnetic compasses, acoustic pingers and satellite navigation units), but cannot be controlled. The position and shape of the streamers behind the seismic vessel is strongly dependent upon currents, and at times, the farthest hydrophone may be more than 1.5 km to the side of the vessel track.

During 2D marine seismic surveys, the survey vessel tows a single streamer of between 4500 and 6000 m in length. Recovery and deployment of the 2D seismic equipment can normally be accomplished in 12 hours or less.

Specific site survey operations require that the survey vessel tow a single streamer of 300-1200 m at about 3 m depth.

For vertical seismic profile (VSP) operations, no streamer is deployed.

3D Versus 2D Seismic Surveys

In areas where hydrocarbons are known to exist in economic quantities, it is usually cost-effective to acquire a 3D seismic survey prior to the design and construction of production facilities. A 3D seismic survey provides a detailed 'picture' of the sub-surface, allowing the geoscientists and engineers to make realistic estimates of the amount and distribution of hydrocarbons within the reservoir. This knowledge allows for better planning of the locations and numbers of production wells and platforms.

A 2D seismic survey is typically more regional in nature than a 3D seismic survey. Survey lines tend to be much further apart (rarely closer than 1 km); and often are laid out in a number of different directions. The information that can be extracted from a 2D seismic dataset is much more limited than that available from a 3D seismic survey, but the 2D is appropriate for exploring large areas relatively inexpensively with the intent of identifying areas that warrant further exploration, perhaps the drilling of an exploration well or acquisition of a 3D survey.

The major difference between 2D and 3D seismic surveys is one of sampling. The 3D dataset provides information about the sub-surface on a very tight grid, usually 25 m in each direction, while 2D data provides information every 25 m in one direction but rarely less than every 1 km in the other, leaving it entirely to the imagination what happens between adjacent survey lines. Figure 5 simply illustrates this concept. The true sub-surface structure is shown in Panel A. The sub-surface structure which might be interpreted from a 2D survey with adjacent lines 800 m apart is shown in Panel B by the dashed line. The small geological feature in the centre is missed entirely. Panels C through G show how the interpretation of the sub-surface structure changes when the spacing between survey lines is decreased from 400 m to 25 m, the latter being what is typically realised with a 3D survey. Clearly, the subtleties of the structure are increasingly better imaged as the interval between measurements decreases. This has important ramifications for planning the development of an oil and/or gas field.

In addition to the simple issue of sampling, much more sophisticated data processing can be applied to 3D datasets than can be applied in 2 dimensions. These data processing techniques allow much better resolution and consequently give the geoscientists and engineers increased confidence in their interpretations of the areal distribution of reservoir rocks within the field.

The Seismic Energy Source

The seismic source currently employed for marine seismic operations is an array of airguns of varying sizes that simultaneously and instantaneously release high pressure air (2000 psi). The rapid expulsion of compressed air causes the water around the airgun to accelerate rapidly outward, creating a pressure wave (sound wave) which serves as the seismic energy source.

A typical marine seismic airgun source (both 2D and 3D) has a volume of 3000-4000 cu in and a peak-to-peak pressure output of ~262 dB re 1μPa at 1 m. The array will typically be made up of 30-40 guns, strategically arranged to beam most of the energy vertically rather than sideways. It is necessary to employ a source with this level of output in order to map sub-surface structures that may be 5000 m below the sea floor. Because both the source and the receivers are towed near the surface, the seismic sound waves must travel both down through the earth and then back up. The layers of rock below the sea floor cause much of the energy to be absorbed; thus, a powerful source is necessary to ensure penetration to the desired depths. In addition, the towed hydrophones are in an environment with relatively high ambient noise levels (due to wave action and propeller noise, etc) making it difficult to detect the desired geophysical information above the noise if the signal strength is weak.

Vertical Seismic Profiles (VSPs) are typically acquired using a cluster of medium sized airguns with a total volume of 450-1500 cu in and a peak pressure output of ~240-250 dB re 1μPa at 1 m. The depth of penetration required for a VSP is similar to that required for conventional 2D and 3D surveys, but during a VSP the detectors are deployed in the well-bore, in an extremely quiet environment, and the seismic sound waves must only travel in one direction through the earth before they are recorded. These two factors allow sufficient data quality to be achieved with a significantly smaller source than is required for 2D and 3D seismic survey operations.
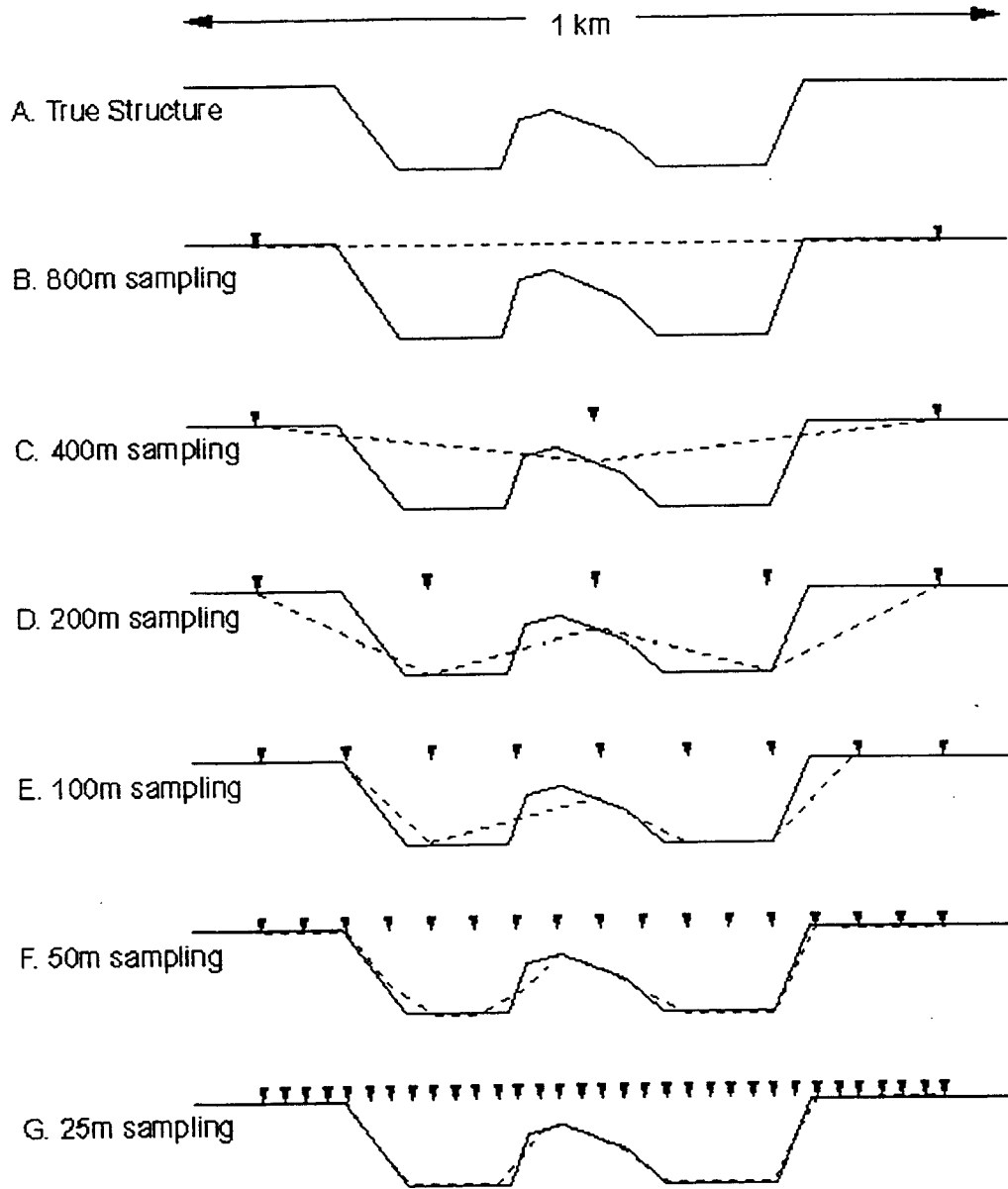
Figure 5. Schematic showing the increased precision resulting from closer spacing of seismic survey lines associated with 3D surveys.

Site surveys are acquired with a much smaller, higher frequency airgun source, typically a cluster of small airguns with a volume of 160-300 cu in and a peak pressure output of ~230 dB re 1μPa at 1 m. This small airgun source is appropriate for site survey investigations since the maximum penetration required is typically less than 1000 m in the search for shallow hazards.

Airguns are the only practical source currently available for deep-penetration marine seismic operations. For very shallow site survey work, sparkers are also used. However, there is ongoing research in the industry into alternative seismic sources. Some experimental work has been carried out using a marine vibrator, a source that delivers a similar amount of energy as an airgun array, but delivers the energy over a 5 or 6 second time window rather than instantaneously. This results in lower peak acoustic pressures and slower rates of change in pressure compared to airguns, and consequently eliminates or at least reduces potential damage to marine life very close to the source (e.g. fish larvae and juveniles). This technique is not commercially proven and it is not considered in the present document.

Types of Seismic Surveys

3D Seismic Surveys

When acquiring a 3D seismic streamer survey, the survey vessel sails many parallel lines, usually about 400 m apart for a dual source/eight streamer configuration (2 sources x 8 streamers = 16 sub-surface lines 25 m apart). Approximately 20 to 30 minutes prior to arriving at the start of a line, the airgun array is slowly brought up to maximum power, firing at first just one or two small airguns and then slowly adding guns until the whole source array is firing. This procedure is known in industry as a "soft start" or "slow start". A soft start is designed to allow mobile marine animals sufficient time to move away if they are disturbed by the sound waves generated by the airguns. The airguns are fired approximately every 12 seconds during acquisition of a line. After completing a line, the vessel is on line change for approximately 2.5 hrs, during which time the seismic source will not be active, and equipment maintenance and repairs will be carried out. Averaged over one month of 3D seismic operations, the airguns will be active 30-40% of the time.

How a given 3D survey will actually be acquired depends upon the size and shape of the area to be surveyed, giving consideration to the influence of the tidal cycle. Best efforts are made to minimize the number of boundaries between lines sailed in opposite directions, and to acquire adjacent lines during the same portion of the tidal cycle. This minimizes the amount of infill which is required in order to completely cover the survey area (infill being data over and above what would theoretically be required to cover the survey area if the streamers were completely straight behind the vessel at all times). Infill for marine seismic operations in the Sable Island area in 1997 was in the order of 30% of the theoretical effort required.

Survey operations can continue without degradation of data quality and without endangering personnel or equipment in up to Sea State 5 or wave heights of about 2.5-3.0 m, after which time operations will normally be suspended for weather. The conditions under which survey operations must cease are very dependent upon the direction of the sea and wind relative to the seismic vessel track, and the period of the waves.

2D Seismic Surveys

When acquiring a 2D seismic survey, the survey lines may be at various orientations and the line lengths may vary from 20 km to perhaps more than 100 km. The seismic source is fired at the same interval as for 3D surveys, approximately every 12 seconds, and a soft start of the airguns prior to commencing acquisition on a line is practised. During a month of 2D seismic operations, the airguns may be active for 50% of the time, the higher percentage being possible because with less equipment in the water, cable repairs and maintenance take less time. Also, line changes are less frequent when survey lines are long.

Site Surveys

The area covered by a site survey is rarely more than 4 km in each direction. Within this area, adjacent survey lines may be spaced as closely as 50 m and as far apart as 400 m, depending upon the type of drilling operation anticipated, and how accurately the proposed location is known. The majority of lines will have a single orientation, although a few tie lines will be acquired which are oriented 90 degrees to the rest. Site surveys generally take no more than a few days to complete, and during that time the source will be fired every 5 or 6 seconds for perhaps 80% of the time. Site surveys must be acquired in very calm sea conditions, but once the weather cooperates, production rates can be high. With a short streamer and close line spacing, line changes can be accomplished very quickly, and there is a minimal amount of equipment to maintain.

Vertical Seismic Profile

The degree of complexity for VSPs can vary significantly, with the total number shots taken ranging from a few hundred to tens of thousands. Thus, the time taken to acquire a VSP can range from 24 hours to more than a week. The airgun cluster may be deployed from the drilling platform itself and remain in one place while the VSP is acquired, but in other cases, the source may be deployed from a vessel and fired in a pattern all around the drilling platform but rarely more than 500 m away.

UNDERWATER SOUND, PROPAGATION LOSS, AND RECEIVED LEVELS

Characteristics of Noise Sources

The discussion of the acoustic components of this assessment follows the source, path, and receiver concept which, as noted earlier, is useful for organizing acoustically related documents. The reader is referred to the earlier section 'Overview of Underwater Acoustics' to provide any needed explanation of the terminology used. The following section describes the temporal and frequency-dependent acoustic features of the seismic array. The physical arrangement and operational features have been described previously.

Pressure Waveform

The arrangement of the individual airguns in the array is designed to produce a coherent addition of the seismic energy from all of the guns into a single N-shaped waveform as shown in Figure 6. This time-pressure waveform is typical of most seismic arrays as observed on the array axis at a point in the far-field directly beneath the array. The "N" shape is produced by the initial positive pressure pulse arriving first at the observation point followed a few milliseconds later by the negative reflection from the water surface. The depth of the array determines the reflected pulse timing and is selected to optimize the dominant frequency of the array. The gun firing sequence is controlled to provide the maximum output in the downward direction for optimizing sub-bottom penetration.

The energy from all of the airguns is not coherent (does not arrive concurrently) at points not on the axis of the array so the peak pressure received at off-axis locations is diminished. When the observation point is sufficiently off the array axis, such as for points well to the side of the array, the pulses from the various airguns arrive individually and provide a much lower and broader peak level than is observed on the array axis. For the special case of an observation point located on a plane normal (at a right angle) to the midpoint axes of the sub-array lines, four individual peaks are seen (Figure 7). These peaks and the peaks observed at endfire aspect (0° and 180° azimuth) have the highest observed pressures off the main array axis. The broadside signal (90° azimuth) provides about 10 dB greater energy level than endfire. Because of this, the effective source level of the array was estimated using the broadside signature when predicting lateral sound exposure levels in areas off the side of the array - the usual geometry in most potential acoustic impact scenarios. The reference pressure level of acoustic sources is usually specified as a "source level" implying that it is the effective sound level that would be measured at 1 m from the acoustic center of the sound source. Since it is usually impractical to locate a reference sensor 1 m away from a large source such as a seismic array, the source output sound level is measured in a nearby region free from reflections, and then corrected for spherical spreading to derive an equivalent 1-m reference location. The nominal source level at 1-m is the level that would occur 1-m from a theoretical point source emitting the same sound as the whole array of airguns.

Frequency Bandwidth

The signature shown in Figure 7 was selected as a representative source signature. It is the model-predicted signature for the selected array as observed at 90° to the array axis (to the side of the trackline) and 80° away from the array's vertical axis (10° down from horizontal)[1]. The time waveform shown in Figure 7 was Fourier-analyzed to determine the frequency dependence of the signature. The amplitude spectrum levels (approx. 2-Hz bandwidth) are shown in Figure 8. Since the hearing characteristics of most species have proportional bandwidth sensitivity (approximately 1/3-octave wide for several marine mammals, and man), the fixed bandwidth spectrum of Figure 8 was converted to a 1/3-octave proportional bandwidth (Figure 9) for use in estimating sound exposure levels.

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[1] This signature does not contain surface-reflected pulses since these will be provided by the sound propagation model used in the transmission loss predications.
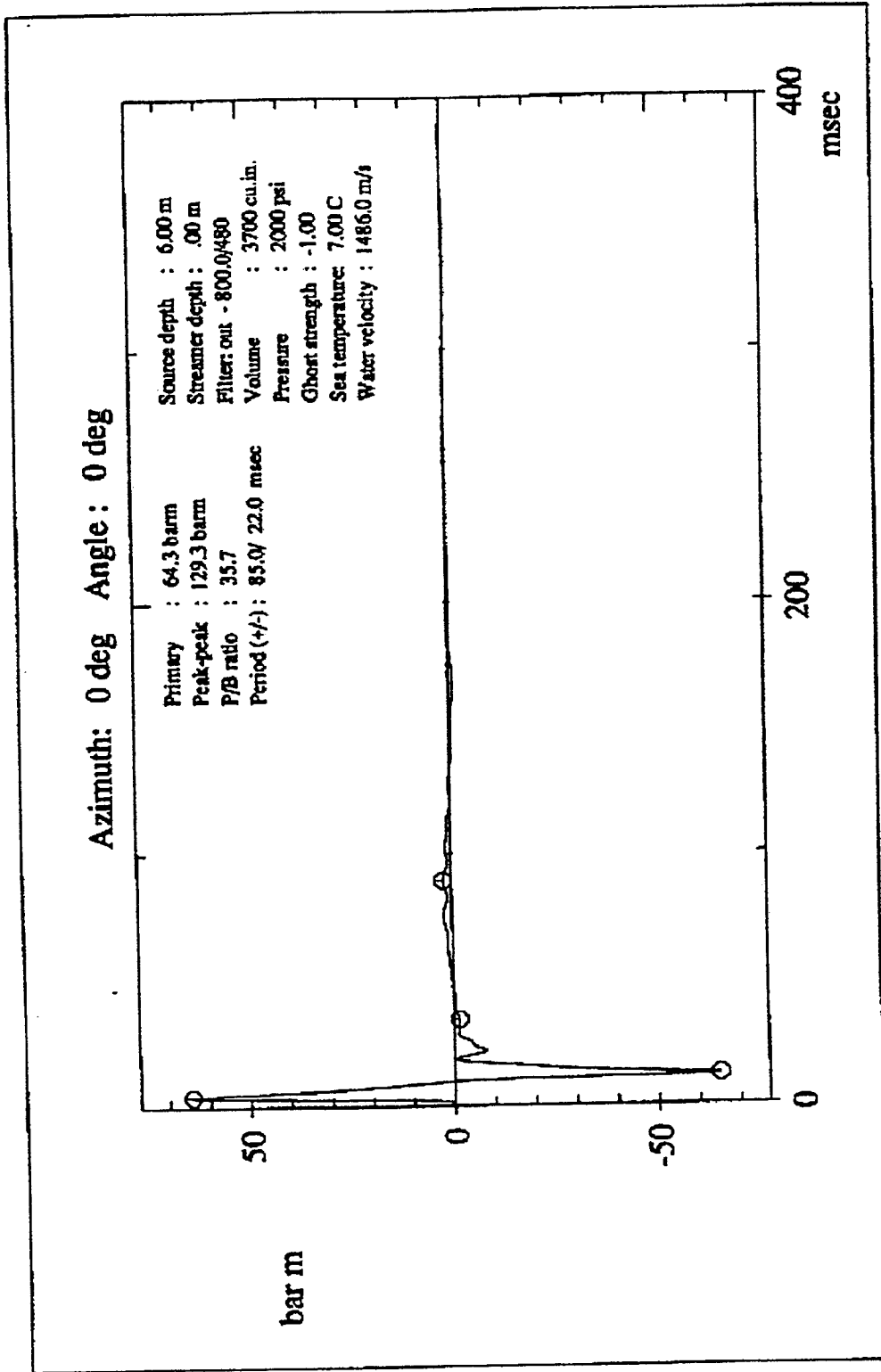
Figure 6. Far-field signature of array: SABLE-GECO98

Figure 7. Array Signature, 90 az, 80 ang

Peak Pressure Level, 247.8 dB re 1 microPa
Avg.rms Pressure Level, 237.4 dB "
Sound Exposure Level, 228.6 dB "
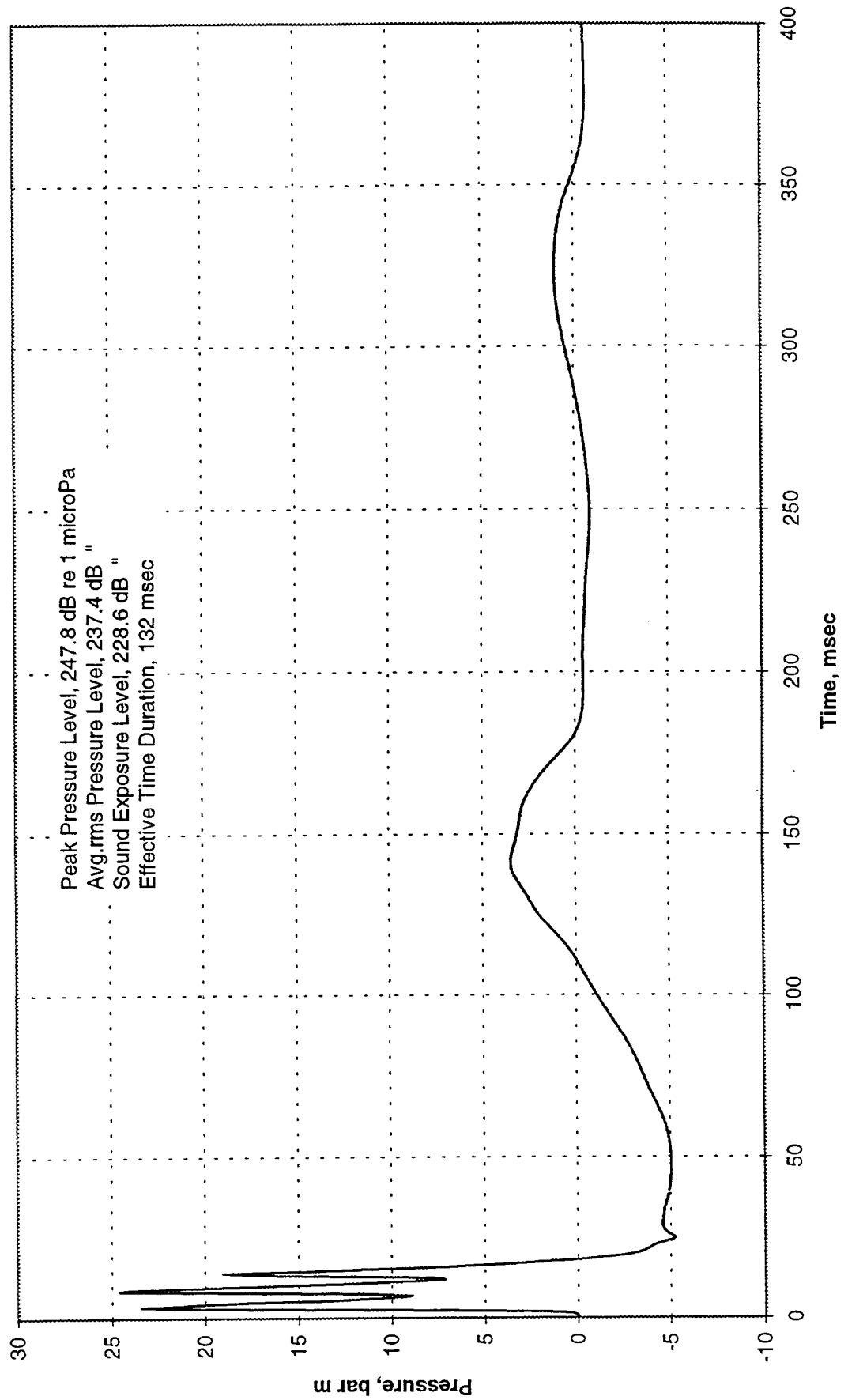Effective Time Duration, 132 msec

Figure 8. Seismic Array Amplitude Spectrum

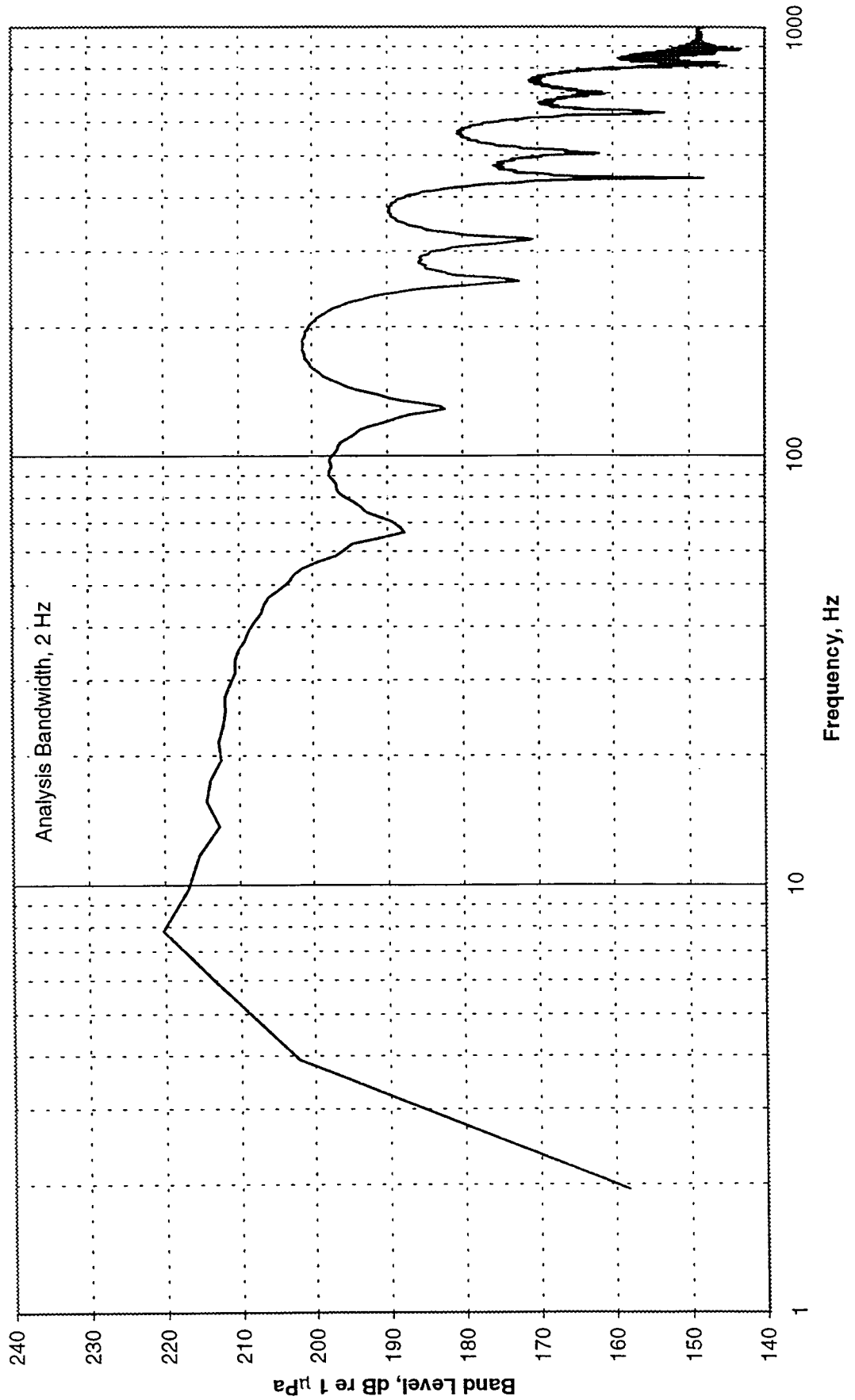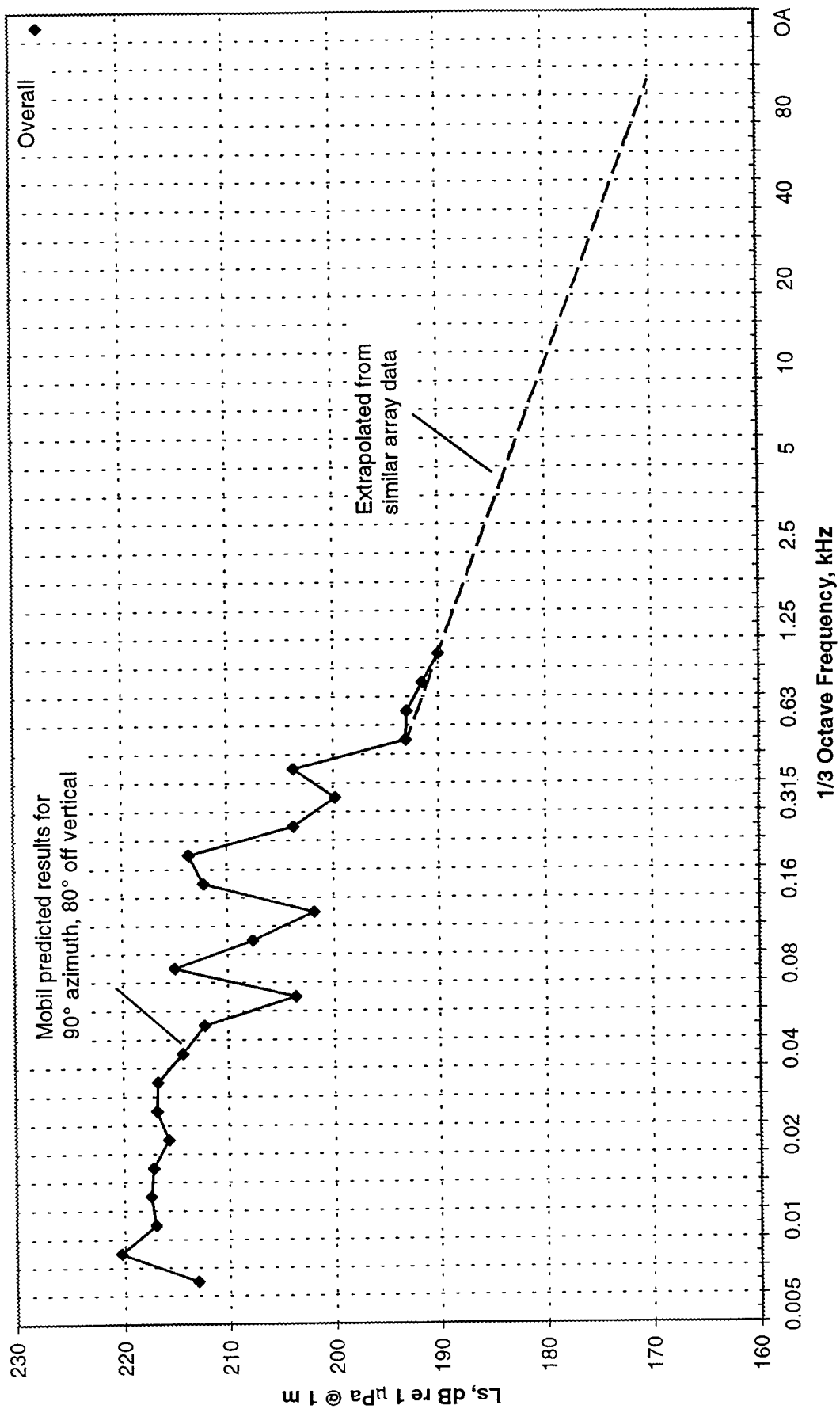Azimuth 90°, 80° off vertical (from Mobil Model)

Figure 9. Seismic Array Amplitude

1/3 Octave Source Spectrum

The spectrum can be seen to have broad peak beginning at 8 Hz with secondary peaks at 80 and 200 Hz. The sampling rate used for the low-frequency signature model was 2 kHz which limited the estimates of the upper part of the array output spectrum to up to 800 Hz. An estimate was made of the expected array output at higher frequencies by using measured data from an array of similar size and output. The data showed that the high frequency spectrum falls off at a rate of 20 dB/decade in energy spectrum level (1 Hz bandwidth) or 10 dB/decade for a 1/3-octave proportional bandwidth spectrum (in accordance with theory). The expected spectrum envelope at high frequencies is shown by the dashed line in Figure 9.

Sound Propagation

Sound exposure levels produced by an acoustic source are estimated as a function of frequency and range by subtracting transmission loss (TL) from the acoustic source level. This section contains a discussion of the process used in estimating transmission loss in selected areas on the Scotian Shelf. The work has been focussed on the Sable Bank permit areas planned for survey work beginning in the spring of 1998 and will be extended to the Laurentian Channel and other areas planned for near-term survey work.

Transmission Loss Components

In unbounded deep water sound transmission characteristics are determined by geometric spreading loss and molecular absorption of the sound energy in the same manner as in atmospheric transmission. Molecular absorption losses are much smaller underwater, however, and are not significant for frequencies less than 5 kHz and ranges less than 5 km. Sound transmission in shallow water is influenced by reflection losses from the bottom and surface, refraction from sound speed gradients, reflection and refraction from sub-bottom layers, and scattering from rough surfaces. All these effects must be considered along with geometric spreading loss to obtain estimates of the received levels at various distances from a source.

The large variability in temperature characteristics of the coastal waters of the Scotian Shelf has a significant influence on sound propagation. A strong surface layer condition occurs in many areas during July-October when solar heating is high. The higher temperature region near the surface is often associated with a lower salinity layer produced by runoff that floats on top of the denser ocean water. While the sound speed in fresh water is slower than that in ocean water, the temperature difference near the surface more than compensates for the effect of the lower salinity. Since sound travels faster in warm water than cold, the net effect is a downward refraction of horizontally travelling sound rays. This produces more bottom reflections per kilometre and higher transmission loss than would be the case if the high sound speed surface layer did not exist.

During the period of November-May when the surface is generally colder than the water at depth, the sound speed profile tends toward neutral and upward-refracting conditions. Under these conditions sound is not refracted, or is refracted upward, and the influence of the bottom on the transmission loss is highly reduced.

Transmission Loss Modelling

Many interacting influences need to be considered in studying underwater sound propagation, especially in shallow water. Several analysis techniques and computer-based models have been developed to aid in the prediction of acoustic transmission loss (TL) characteristics. These procedures use measured sound speed profiles, bottom-loss parameters, and bottom stratigraphy information, in addition to spreading loss calculations, to obtain their results. Several models have been developed for Navy and commercial applications. Most of these are intended primarily for application to deep water areas or to low frequency propagation in shallow water. However, a recently developed model which is based on an efficient procedure for solving the parabolic wave equation (Collins 1993) can be applied to shallow water transmission. Moreover, it has provision for range-dependent parameters such as a sloping, non-uniform bottom, and range-varying sound speed profiles. This "Range-dependent Acoustic Model" (RAM Model) was used to compute transmission loss characteristics for selected transmission paths for frequencies of 800 Hz and below.

Sound transmission models that are based on the parabolic solution to the acoustic wave equation typically use an algorithm which computes the acoustic field incrementally from a starting field with a spherical source. The program "marches" the computed acoustic field out in range and depth using step sizes based on wavelength and input data requirements. Above mid-frequencies such as 800 Hz, the bottom profile details and the short incremental computation step sizes require too much computer time (and analyst patience) to be practical. Consequently, in the higher frequency range from 800 Hz to 100 kHz, a semi-empirical analytic model was used. This model is based on a shallow water sound propagation analysis by Weston (1976) as expanded and formulated by Smith (Malme, Smith, and Miles 1986). The relationships were incorporated into an application program (Weston/Smith Model) that has been used for TL analysis and prediction studies in the Beaufort Sea and other shallow water areas (Malme et al. 1989).

The detailed information needed for the TL analysis was obtained by running the computer models using frequencies spaced at octave intervals from 12.5 Hz to 100 kHz in order to cover the extremes in the hearing ranges from large baleen whales to fish, pinnipeds, and odontocetes. The computed TL vs. range and frequency information was placed in a spreadsheet and extrapolated into 1/3 octave spectra to match available source level and hearing sensitivity data. This provided a matrix that was used with the seismic array source level spectrum to estimate received level spectra vs. range and also the overall total sound exposure level. The TL matrix can also be used with other sources of interest by simply substituting a different source spectrum.

Transmission Loss Test Tracks

The initial areas selected for the model application are shown in Figure 10. On Sable Bank, four test tracks were established. Track S1 begins in 40 m water depth at the eastern edge of the planned 1998 seismic survey area and extends 70 km ENE to the Gully. The bottom along this track has a gentle downward slope until it plunges down into the Gully. As shown in the Scotian Shelf Surficial Geology Atlas from the Bedford Institute of Oceanography (BIO), there are three significant bottom layers: Sable sand or silty sand, 20 m; silty-clay and glacial till, 50 m; and sedimentary bedrock.

The thickness of the sediment layers decreases as the edge of the Gully is approached. The Gully slope has thin till and occasional exposed bedrock with a deep till layer at the bottom of the Gully. An example the bottom profile information necessary for the RAM Model input files is shown in Table 1.

Tracks S2 and S3, extending south off the shelf edge and WSW parallel to the shelf edge, have similar stratigraphy. Track S2 extending 50 km south was designed to predict TL for sound transmitted from the survey area toward the shelf edge. Track S3 extended 200 km along Sable Bank parallel to the shelf edge and was the longest range modeled. The S4 track north of Sable Island begins in 80 m water depth at the northern edge of the 1998 seismic survey area and extends N for 50 km across the basin at the termination of Gully. The stratigraphy for this track is not specifically covered in the BIO atlas, but is believed to involve primarily a shallow layer of silty-sand (5-15 m) over the bedrock. There are several deeper basins which are indicated by chart information as having a mud (silt) bottom. From information for similar regions in the atlas, the mud/silt in these basins is probably much deeper (40 -70 m) than the silt-sand layer thickness in the shallower portions of the track.

Seasonal Dependence of Sound Speed Profiles

Sound speed profile data have been collected for most of the earth's ocean areas for many years. The assistance of the Defence Research Establishment Atlantic (DREA) at Dartmouth, NS, was obtained to assemble and analyze data for the areas of interest. An example of the data available for the Sable Island area for the month of July is shown in Figure 11. The wide variation of the calculated mean profile for each of the survey season months is shown in Figure 12. The profiles for April and May are nearly isospeed, but the profiles for summer and early autumn months show very strong downward refraction. This is helpful since it produces higher TL (greater attenuation of transmitted sound) during the seismic survey season.

Not only does the sound speed profile in a given area vary on a month-to-month basis, it also has been found to vary on a shorter term basis depending on local weather conditions and variations in nearby ocean currents. This produces variations in TL that can result in considerable variation from values predicted by a computer model using fixed mean values in its input data. The influence of these variations in the sound speed profile was estimated by statistically analyzing a set of profiles collected over a selected month for specific areas near Sable Island to determine the mean and +/- standard deviation profiles for the month. The months of May, July, and October were selected as representative of the May to October survey season. These analyses were performed by DREA under a sub-consulting agreement. The results show a standard deviation about the mean of about 5 to 10 m/sec near the surface, with a smaller variation below 30 m in May (Figure 13A). A much wider variation of up to about 15 m/sec is seen below 40 m in the October data (Figure 13C). In areas with water depths greater than 80 m, a sound channel with an axis at 60 m can be seen in the July and October data (Figure 13B,C). This is a layer where sound can be trapped and travel with lower TL than would occur at shallower depths.
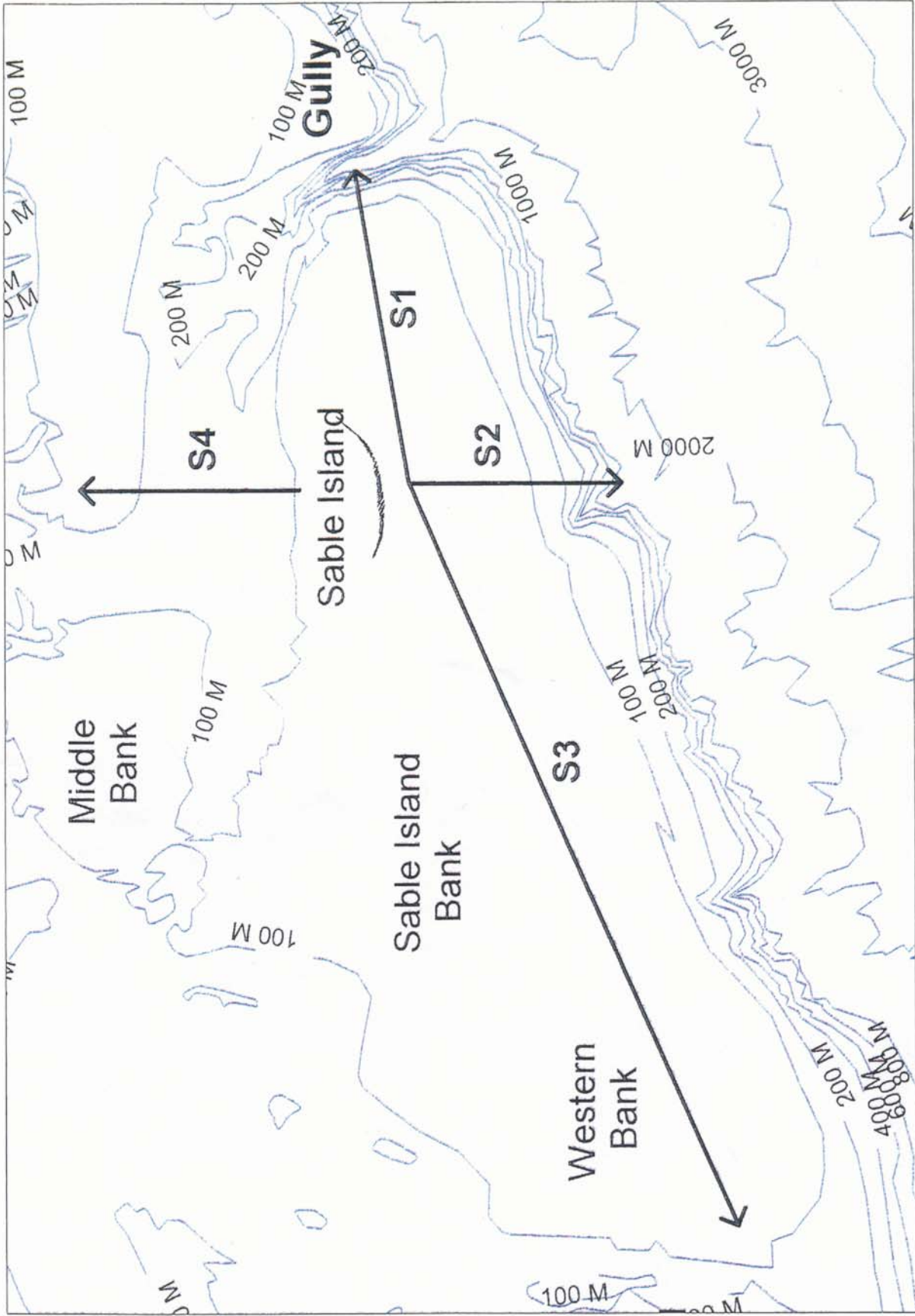
Figure 10. Acoustic propagation paths modelled near Sable Island.

Table 1. Profile for Sable Island Track S1.

Depth to Bottom of Layer							Range (km)										
	0	15	20	27	30	34	40	44	46.5	50	52	53.5	54.5	55	58.5	59.5	60.8
Water	40	43	47	51	54	57	60	65	70	82	90	100	120	200	500	1000	1600
Sand	60	63	67	71	74	77	80	85	90	92	95	100	120	200	500	1000	1600
Till	110	110	110	110	110	110	110	112	115	120	120	120	125	205	515	1010	1700

Bedrock to 2500 m --

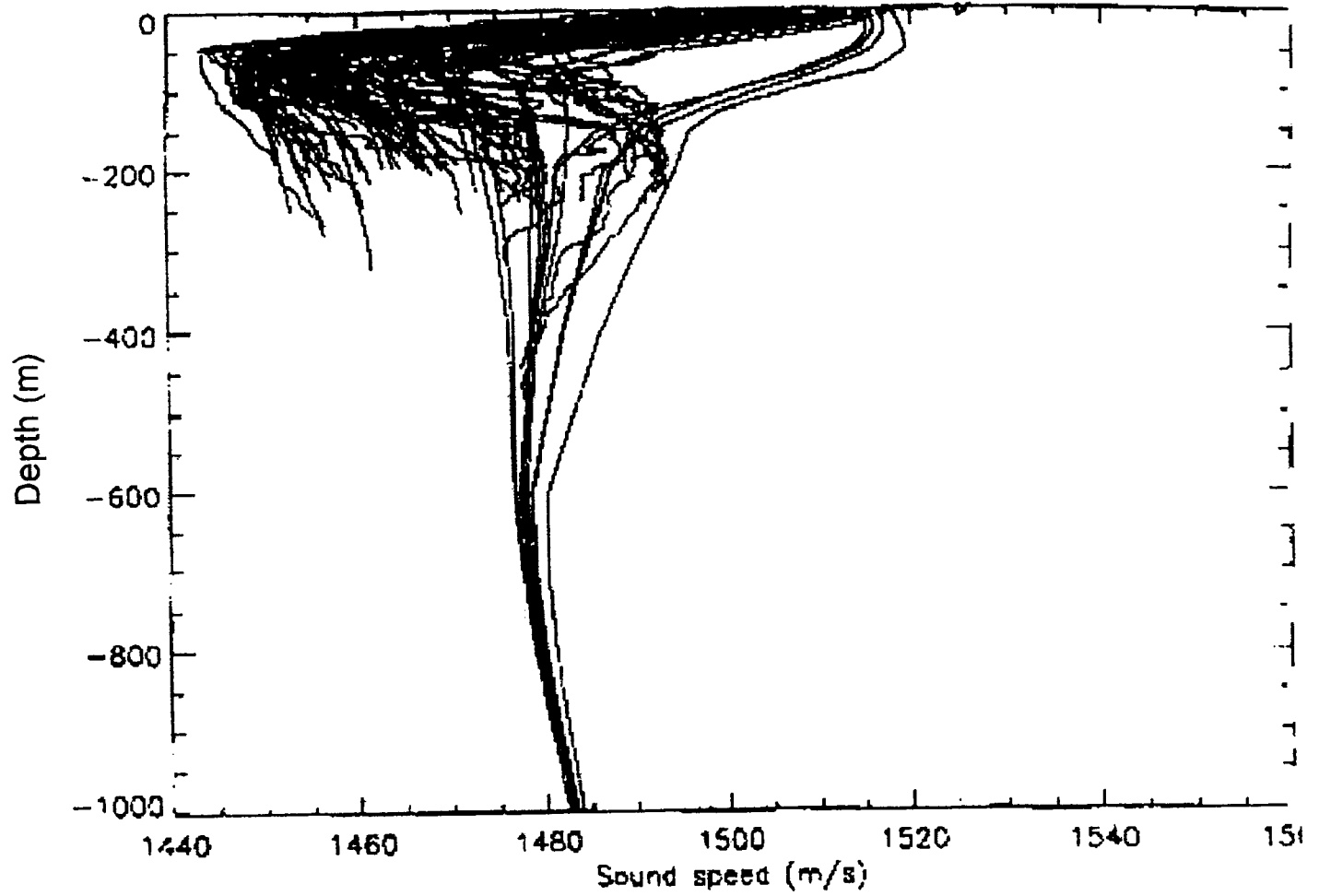| Bottom Material Parameters*	Comp. Wave speed	Density	Attenuation
Sable Sand	1750 m/sec	2.06 gm/cc	0.455 dB/wavelength
Glacial Till	1900	2.1	0.057
Bedrock (sedimetary)	2050	2.2	0.103

* From Chapman and Ellis (1980)

Figure 11. Collected sound speed profile data from Sable Island area for July (from DREA).

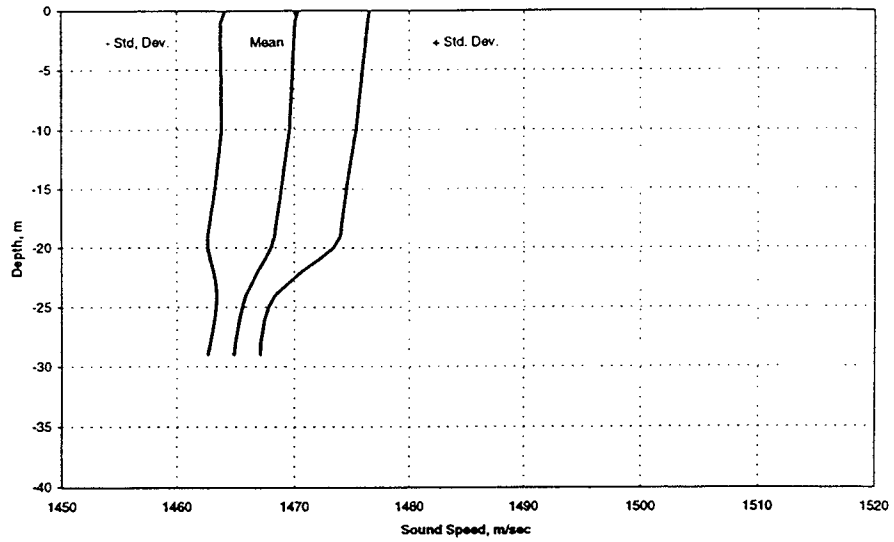Figure 12. Average Sound Velocity Profile near Sable Island

Figure 13 A. Sable Island, Location 1, May
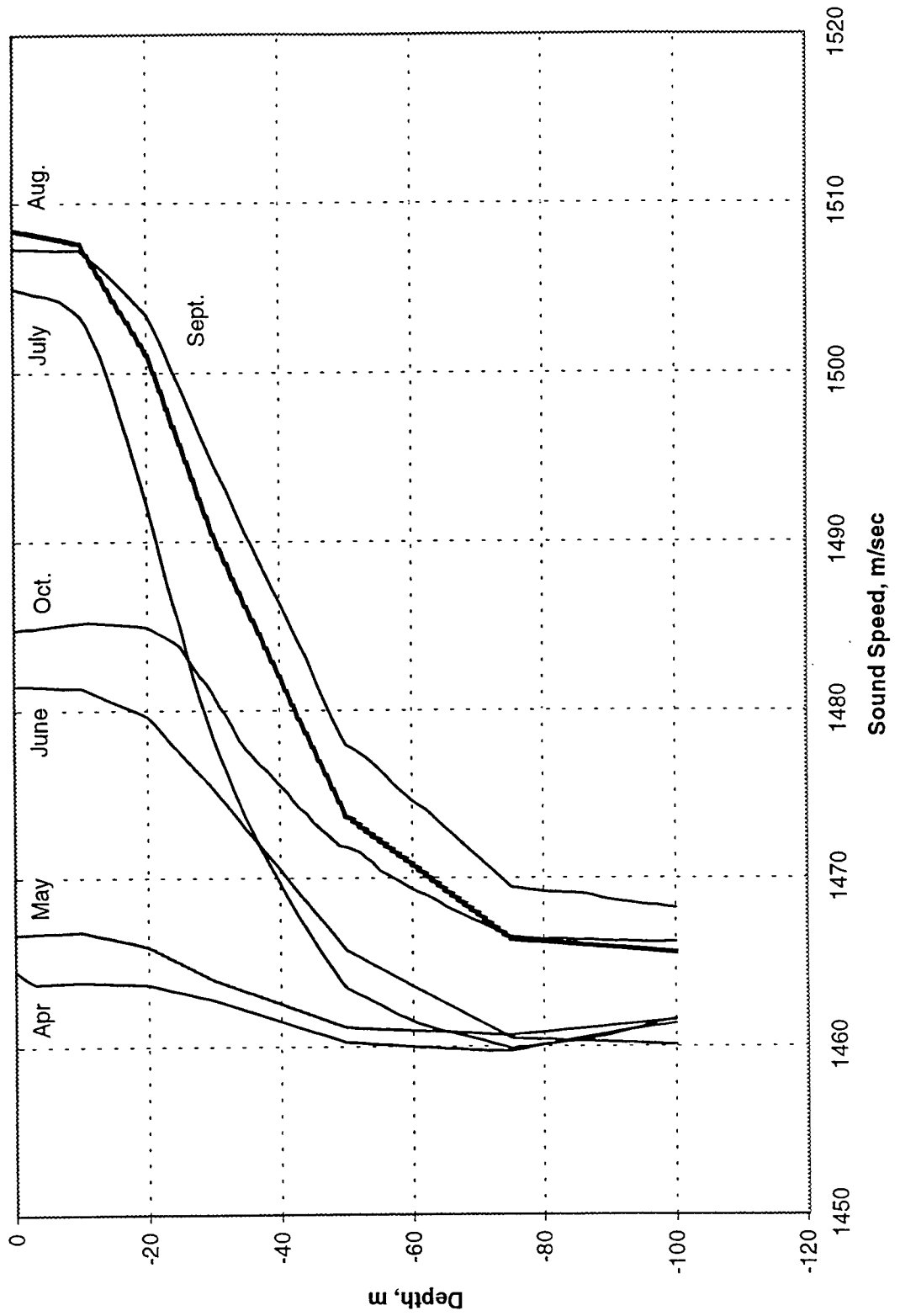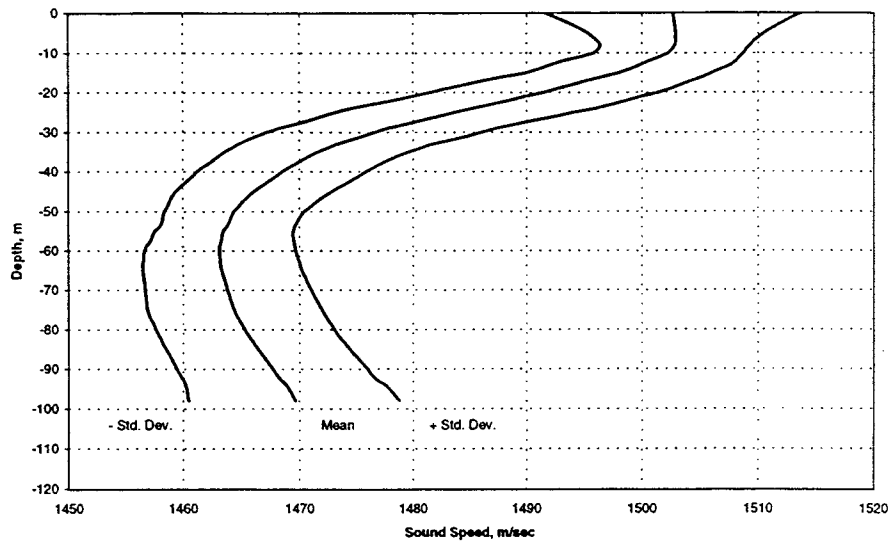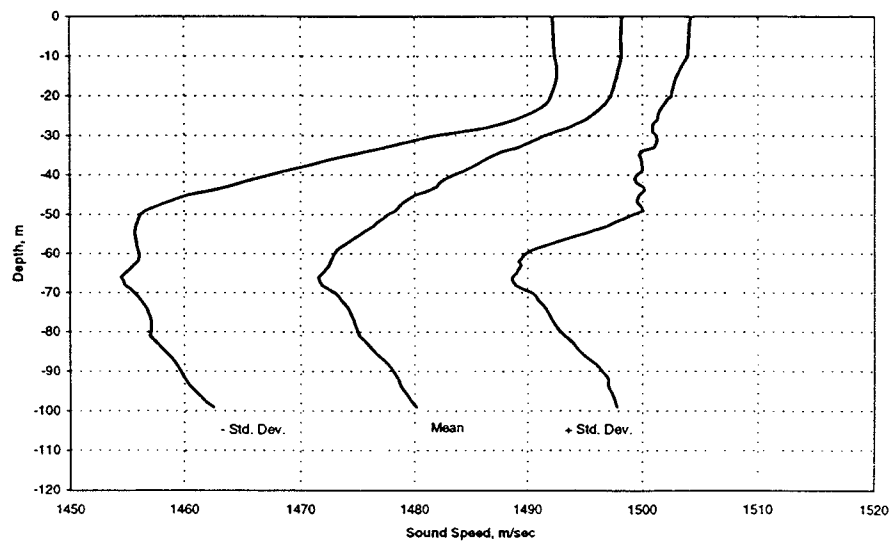
Figure 13B. Sable Island, Location 3, July

Figure 13C. Sable Island, Location 3, October

Calibration of the RAM Model

The accuracy of computer modelling of sound transmission depends not only on the correct theoretical formulation of the model but also on the accuracy of the input data. In addition to the sound speed profile data for the water column (discussed above), it is necessary to supply profiles for the acoustic parameters of the bottom material; typically density, sound speed, and attenuation. These profiles also provide the model with the depth and thickness of each bottom layer. Typically, the input file consists of a sequential set of profiles for both the water and bottom at each range where a significant difference occurs. Geological Survey maps, data provided by DREA, and data provided by Mobil were used to set up the input files. The model was initially calibrated at DREA against an acoustic "Benchmark" established by the Acoustical Society of America, and also by testing against data obtained by Ellis and Chapman (1980). A comparison of model predictions and measured data showed good agreement at low frequencies. At 800 Hz the RAM model tended to predict somewhat lower TL than was measured. This is about the upper limit of the RAM Model's capability because of the large number of computations needed. The Weston/Smith model was used for the higher frequency range.

The Weston/Smith Model

Weston's formulae for transmission loss divide the transmission path into four regions, each of which has a characteristic range dependence. The regions are, in order of increasing range,

- spherical spreading, where bottom-reflected rays are steeper than the critical angle;
- a transitional, reverberant cylindrical spreading region;
- a "mode-stripping" region, wherein energy striking the bottom at steeper angles is attenuated more rapidly than that at shallower angles;
- the "lowest-mode" region, wherein only the fundamental mode carries significant energy.

Only in the last region is the transmission dependent on frequency, so long as the sand layer is either thinner or thicker than ½ wavelength at all frequencies of interest.

The Weston formulae noted previously apply to areas with either uniform upward or uniform downward bottom slopes as well as to the constant depth case. A short computer program was designed by P.W. Smith, Jr., at BBN Systems and Technologies which incorporates these formulas, yielding a value of TL (dB re 1 m) when given a value of range. The program does not include refraction effects produced by sound velocity gradients and, as a result, is usually appropriate only for conditions where gradients are small or neutral. Within this limitation, it has been found to provide good predictions in shallow water conditions and has the advantage of being able to run on small computers.

The Weston/Smith TL model has been incorporated in a computer-implemented automatic least-squares analysis procedure to derive the parameters of the best-fit transmission loss curve for field data from specific sites. This procedure was used to develop a transition from the RAM results at low frequencies to the needed high frequency TL predictions. The output of the RAM Model at 400 and

800 Hz was used as synthetic "data" to have the W/S Model determine the parameters of an "effective bottom" which incorporated the effects of the velocity gradients that had been included in the RAM Model Input file. The W/S model parameters were adjusted to obtain a best-fit for the synthetic data and the results were then used to run the W/S Model to obtain the desired high frequency TL predictions.

Transmission Loss Modelling Results

The goals for the analyses of transmission loss along the 4 selected tracks near Sable Island (and 3 in Laurentian Channel - Appendix 4) were

1. Predict the characteristics of the radiated sound levels from the seismic survey activities as a function of range and frequency.

2. Estimate the effects of seasonal sound speed gradient variations on the radiated sound levels.

3. Estimate the influence of short-term variations in sound speed gradients on the accuracy of the long term predictions.

4. Examine the variation of received sound level with depth as a function of range and season.

The multidimensional nature of the modelling activity required that the most important parameters affecting transmission loss be identified early in order to provide efficient use of available analysis time. Initial studies using track S1 showed that, as expected because of strong downward refracting conditions, the highest TL values were predicted for July. The lowest TL values were predicted for May (with near neutral gradients); October produced intermediate values. The largest amount of modelling effort was required to produce the TL characteristics showing the range and frequency dependence. In previous work, a technique for displaying this interdependence was developed using a TL spectra vs. range matrix in the form of a spreadsheet (Malme et al. 1989). This technique was also used here to organize the results of the modelling work. Transmission loss spectra vs. range and an associated set of received sound exposure level (SEL) spectra were obtained for tracks S1, S2 and S4. This detailed analysis was not carried out for Track S3 because it was similar to track S1 for the first 50 km, although the strongest influence of seasonal and short-term sound speed gradient variations was observed at longer ranges along this track.

The results of the range and frequency analysis are summarized in the following discussion with figures showing the characteristics for the three tracks analyzed. The results of the study of seasonal and depth dependence are summarized here with details presented in Appendix 1.

Track S1

The RAM Model provides a single frequency output using phase-coherent processing. This results in an output file which often has large amplitude fluctuations because of phase interference effects. At low frequencies this effect is not as pronounced, but at higher frequencies, it becomes a

problem that requires data averaging to get meaningful values. This can be done by running the model several times using closely-spaced frequencies to simulate a 1/3-octave signal bandwidth. However, it is much more efficient to use spatial averaging in range over several phase interference cycles. This was accomplished with minimum loss of range resolution by using a moving window with a cosine weighting function. The center of the window was moved along over each range value for a given frequency using a width limited to less than 10% of the total range at short ranges and much less than that at longer ranges. The averaging process produced power-averaged rms TL values which were used in the spreadsheet spectra and related figures.

An example of the averaged model output for Track S1 is shown in Figure 14. Frequencies below 100 Hz are seen to have the highest TL values. This is beneficial in providing the highest attenuation rates for the frequencies with the highest energy output from the seismic array. Frequencies of 100 Hz and above are seen to have similar TL values, particularly at ranges less than 10 km. A corresponding set of computed TL values are shown in Figure 15 for the W/S Model output at 800 Hz and above. The synthetic data points generated by the RAM Model and used for "tuning" the W/S Model are also shown. The rapid increase in TL at high frequencies due to molecular absorption and scattering losses can be seen in the figure.

The TL vs. frequency spectra as a function of range are shown in Figure 16. These are obtained by combining the data shown in the previous two figures in a spreadsheet. Bottom reflection interference effects produce the apparently anomalous results seen at short ranges and low frequencies where the TL at 80 Hz is lower at 0.2 km than it is at 0.1 km. The TL matrix shown in Figure 16 is applied to the seismic array source level spectrum and shown as Sound Exposure Level (SEL) spectra in Figure 17. This figure shows that the high TL values at very low frequencies rapidly attenuate the strong 8 Hz component in the source spectrum so the peaks at 80 and 200 Hz (Figure 9) become the dominant components in the radiated noise at relatively short ranges. At ranges less than 1 km, the 80 Hz band is the highest component, but for longer ranges out to 40 km, the 200 Hz band dominates. The overall SEL levels vs range are also shown in the figure. The overall SEL at each range is the power sum across all of the 1/3 octave bands as received at that range.

While it is difficult to directly compare the SEL value for an impulsive source with the continuous rms level of a ship, if an assumption is made that the noise of a tanker could be produced for one second and then measured as function of range, some subjective conclusions can be made. A comparison between the array pulse SEL at long range and the estimated output of a large tanker is shown in Figure 17. The spectrum shape differs from the array output but the overall level of the tanker at 5 km is seen to be comparable with the overall level of the array at 30 km. Ambient noise data reported for the Scotian Shelf region by Zakarauskas et al. (1990) are also shown in Figure 17.

Track S2

The TL and SEL spectra vs range were also obtained for Track S2 using the previously described modelling and data assembly process. Figure 18 shows the TL spectra vs. range for track S2. This track originates at the same point as Track S1 but proceeds 50 km south over the shelf edge. The

Figure 14. Sable Bank Track S1
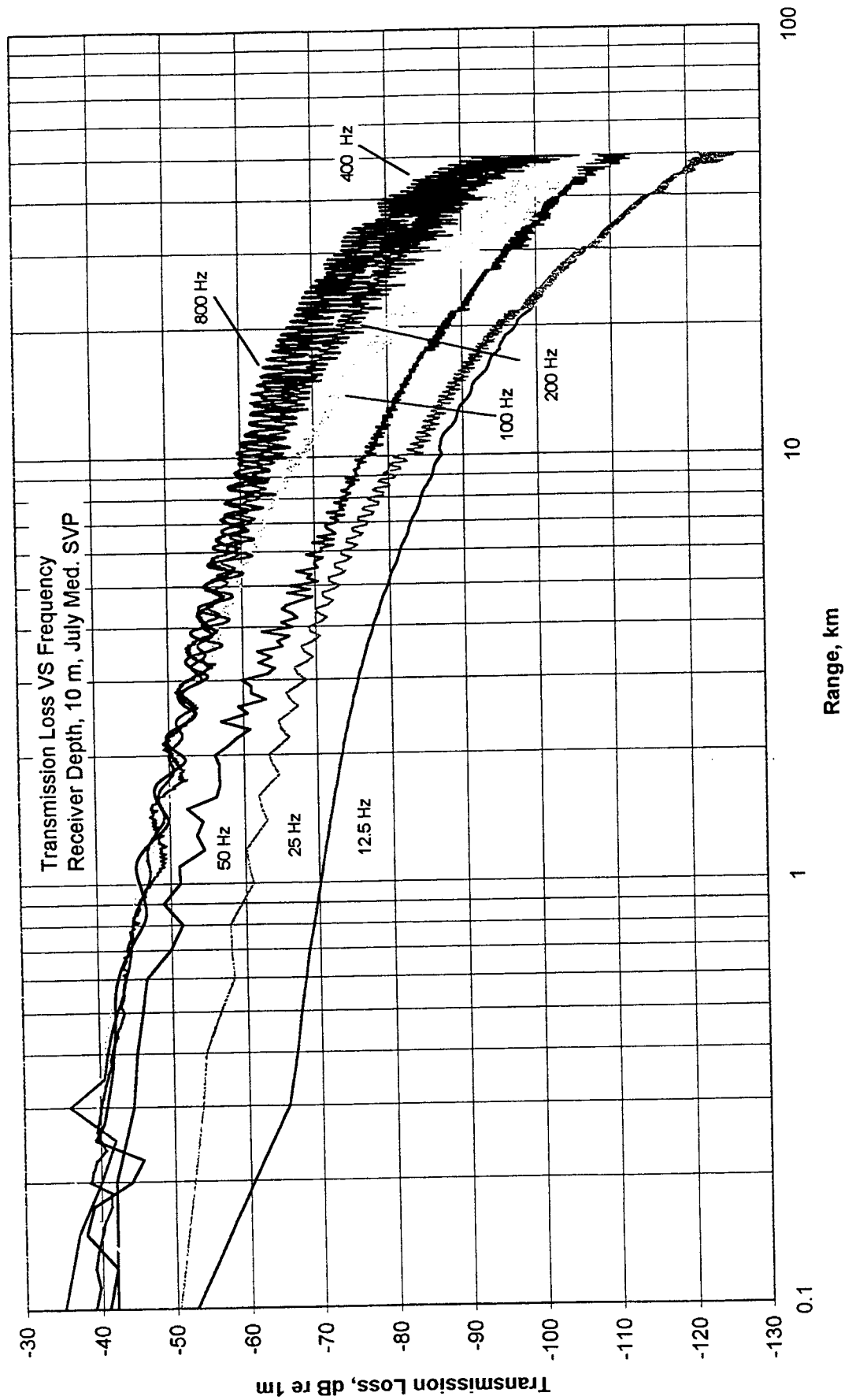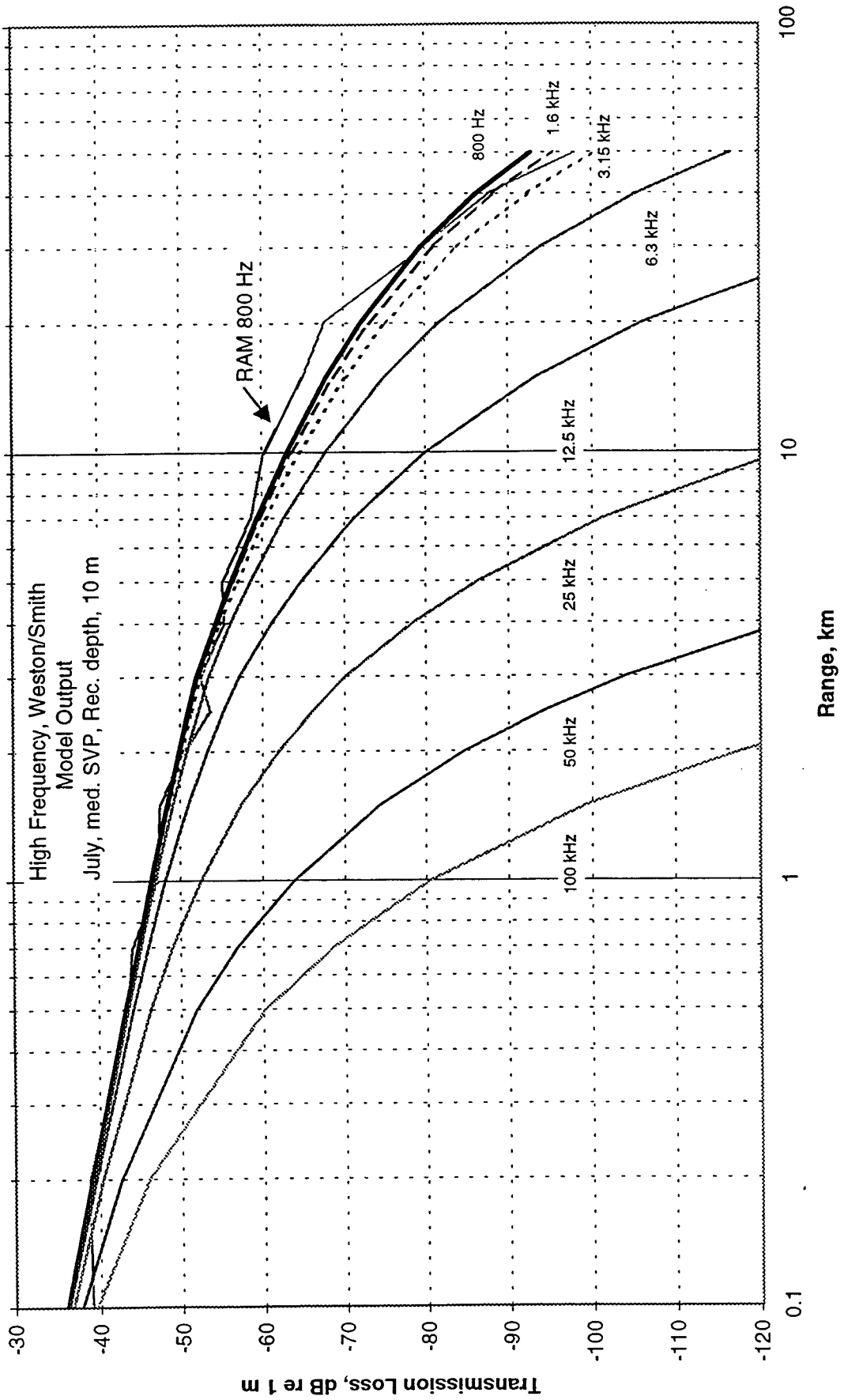
Transmission Loss VS Frequency
Receiver Depth, 10 m, July Med. SVP

Figure 15. Sable Bank Track S1

High Frequency, Weston/Smith
Model Output
July, med. SVP, Rec. depth, 10 m

Figure 16. Sable Bank Track S1

Seismic Array, Transmission Loss Spectra

Receiver Depth, 10 m, July Med. SVP

Figure 17. Sable Bank Track S1

Seismic Array, Sound Exposure Level Spectra

Receiver Depth, 10 m, July Med. SVP

Figure 18. Sable Bank Track S2

Seismic Array, Transmission Loss Spectra
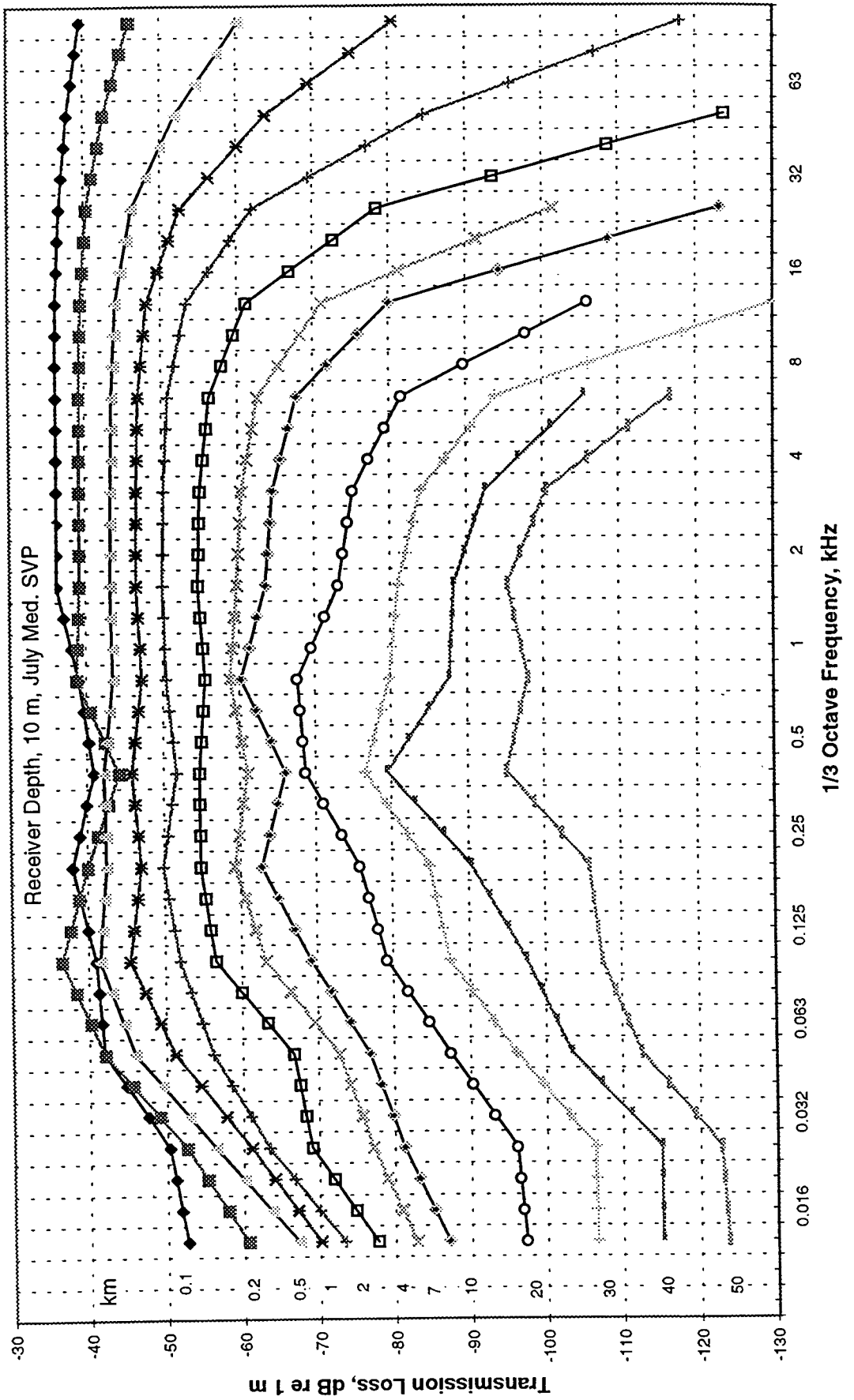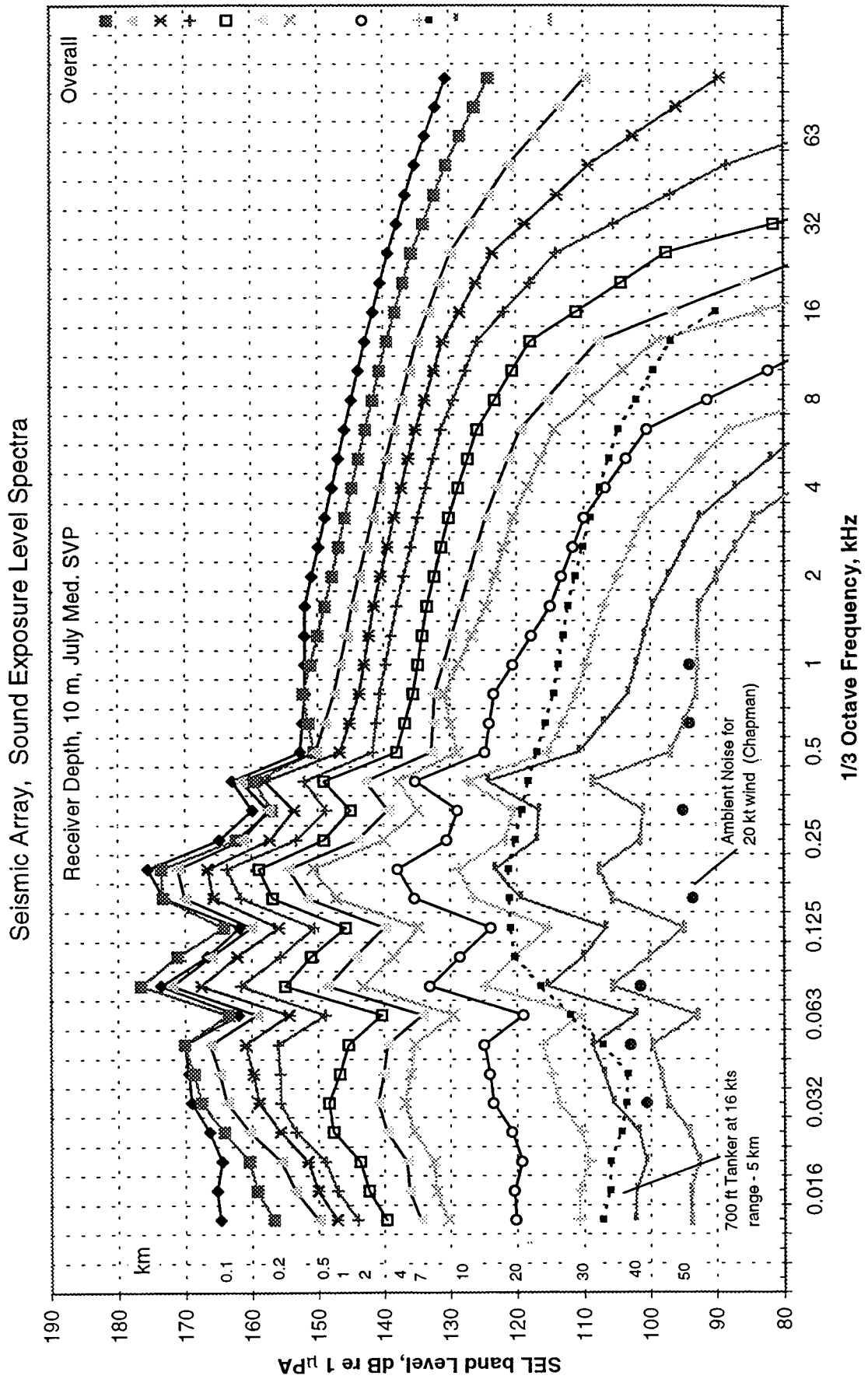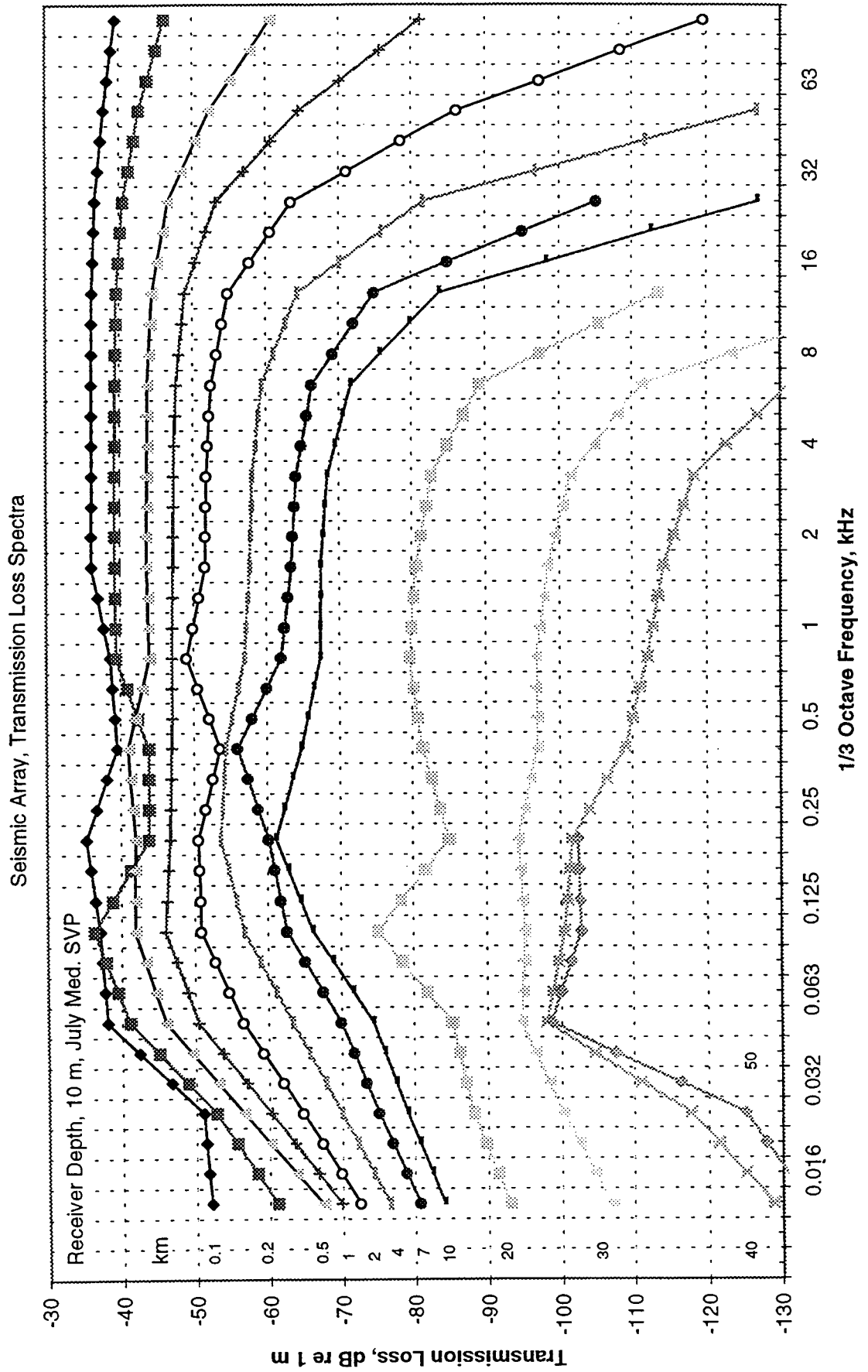
depth contour increases with range more rapidly than occurs for track S1. Comparing Figures 16 and 18, the TL characteristics for Tracks S1 and S2 are seen to be similar out to about 10 km, beyond which the rapidly increasing slope off the shelf begins to have an effect. The entire spectrum is attenuated more rapidly with range for S2, with the exception of the mid-frequency band from 40 to 200 Hz which has lower TL at long range than is seen in the S1 spectra. Figure 19 shows the corresponding SEL spectra for Track S2. Differences in the detailed spectra (Figures 19 vs. 17) are again evident at ranges greater the 10 km, but the overall SEL values are similar even though S1 has considerably shallower depths at 50 km (80 m vs. 1800 m).

Track S3

Track S3 was not analyzed by deriving the TL and SEL vs. range spectra because of its similarity at shorter ranges to S1 and S2. The TL models were used for S3 to extend the analysis at 200 Hz (the dominant frequency in the radiated array noise) out to 200 km. The effects of sound speed gradient changes and receiver depth position vs range were examined by running the models with appropriate input files. The results of this analysis are summarized here with the detailed plots presented in the Appendix.

Depth Effects

The effect of increasing the receiver depth is more apparent at longer ranges. For receivers within 10-20 km of the source, there is about a 3 dB reduction in sound level in going from 10 m to 5 m depth. In going from 10 m to a location near the bottom there is about a 2 dB reduction. At larger ranges beyond 30 km, sound levels near the bottom can be 5-10 dB higher than at a 10 m depth.

Sound Speed Gradient Effects

The effects of seasonal changes in the sound velocity profiles (SVP) are also more apparent beyond 50 km. At 20 km, the TL in July is 4 dB higher than in May, with October being 2 dB higher than May. This translates into about a 4 km shorter acoustic range in July as compared with May (using a 70 dB TL criterion for May). The short term fluctuations in the SVP were also influential primarily at ranges beyond 50 km. The month with the highest variation in TL caused by SVP fluctuations is May with a fluctuation of about 2 dB. This results in only about a 2 km variation at 20 km.

Track S4

Track S4 differs from the previous three tracks in that it begins in deeper water (80 m) north of the Sable Bank and extends north through the basin at the upper end of the Gully. The sediments here are thinner than at the other sites (~5-10 m) over basement rock. The terrain also is irregular with pockets of deep silt and mud. The depths along the track vary from 55 m to 165 m.

The results of the Ram Model TL predictions are shown in Figure 20 as a function of frequency. The low frequencies are not attenuated as quickly as at the other sites with deeper sand layers. The hard bottom can also be seen to provide a strong reflection interference effect at 0.3 km for the 100, 200 and

Figure 19. Sable Bank Track S2
Seismic Array, Sound Exposure Level
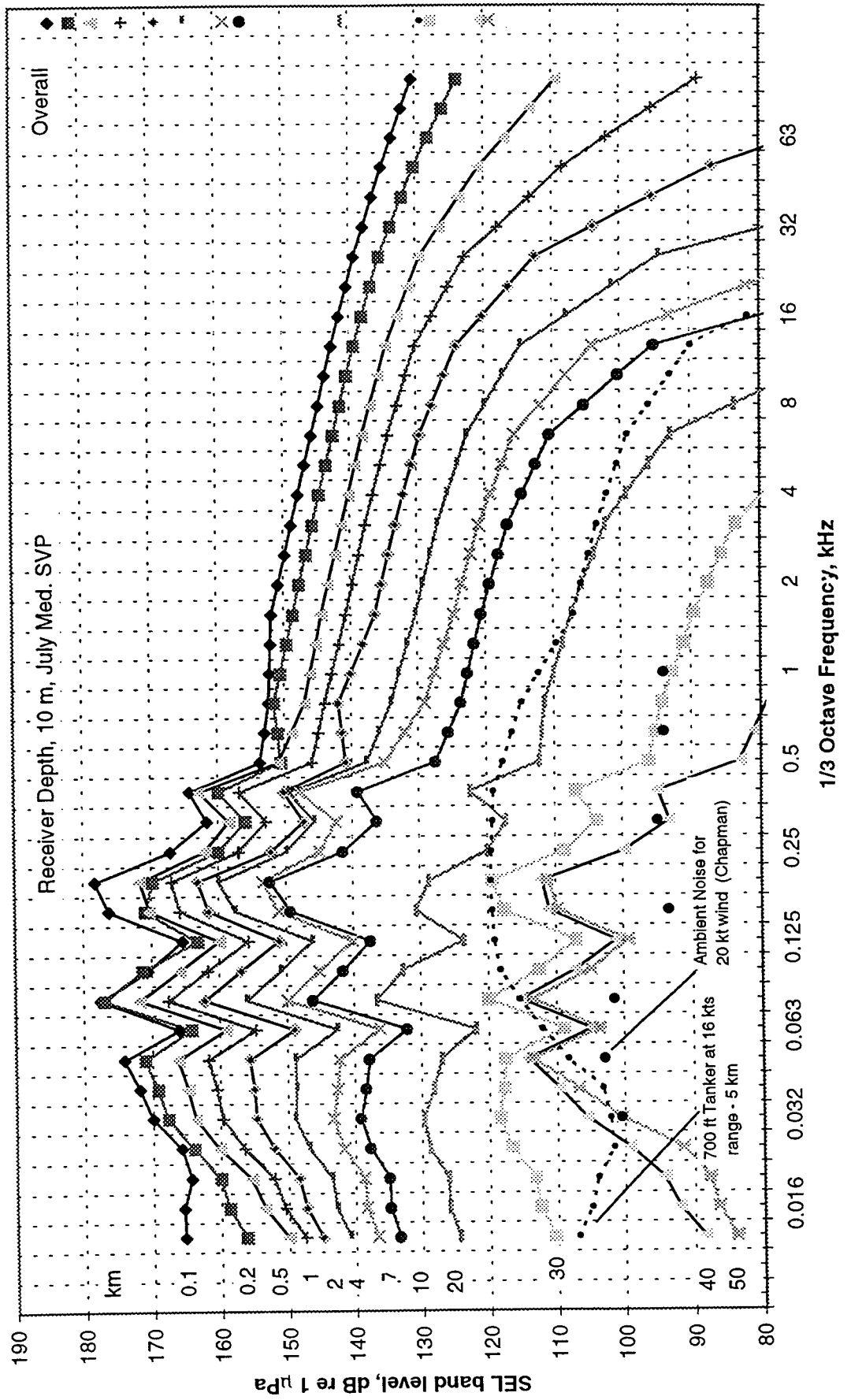
400 Hz TL curves. The track passed over a deep pocket with silt and mud at a range of 22-28 km. The effect of the added absorption can be seen in the TL curves at this range. The TL and SEL spectra were also developed for this track as shown in Figures 21 and 22. The influence of the strong bottom reflection can be seen in the spectra at ranges of 0.1 to 0.5 km. The model predicted that sound travels better to long ranges in this area than on Sable Bank. The overall SEL at 50 km is about 130 dB as shown in Figure 22, as compared with about 115 dB at the same range for track S1 (Figure 17). The SEL of the array pulses at 50 km is predicted to be about 3 dB higher than the rms level from a large tanker at 5 km.

Summary of Overall SEL vs Range for all Tracks Analyzed

Summary curves showing the predicted SEL values for all three tracks analyzed are shown in Figure 23A. If overall SEL values of 150 to 160 dB are estimated to be the levels where potential reactions might occur for large whales and fish (see later sections), these levels can be seen to occur at 4.5 km to 14.5 km with S4 indicating the shortest range and all three tracks providing close agreement at the longest range. The curve for S4 shows that, while it provides the lowest sound level near the source, it also provides the highest sound levels at longer ranges. Figure 23B shows the average SEL vs. range curve for the three tracks analyzed along with approximate rms and peak levels (+10 dB and 20 dB, respectively, relative to SEL).

Ambient Noise on the Scotian Shelf

Above 500 Hz, deep ocean ambient noise is produced primarily by wind and sea state conditions. Below 500 Hz, the ambient noise levels are strongly related to ship traffic both near and far. In shallow water, near continents and islands, surf noise is also a significant factor. Wenz (1962) and Urick (1983) are among many contributors to the literature on underwater ambient noise. Figure 24, based on these two sources, was adapted by Malme et al. (1989) to show ambient noise spectra in 1/3-octave bands for a range of sea state and ship traffic conditions. A recent paper by Zakarauskas et al. (1990) reported ambient data obtained by DREA for several regions on the eastern Canadian continental shelf. Some data reported for the Scotian Shelf have been included in Figure 24.

Wind

On a 1/3-octave basis, wind-related ambient noise in shallow water tends to peak at about 1 kHz. Levels in 1/3-octave bands generally decrease at a rate of 3-4 dB per octave at progressively higher frequencies and at about 6 dB per octave at progressively lower frequencies. Sound levels increase at a rate of 5-6 dB per doubling of wind speed. Maximum 1/3-octave band levels of about 95 dB re 1 μPa are frequently observed at about 1 kHz for sustained winds of 34-40 knots and about 82 dB also at 1 kHz when the winds are in the 7-10 knot range. Since ambient noise related to wind is caused primarily by wave action and spray, the wind-related noise component is strongly dependent on wind duration and fetch as well as water depth, bottom topography and proximity to topographic features, such as islands and shore. A sea state scale which is related to sea surface conditions as a function of wind conditions is commonly used in categorizing wind-related ambient noise. The curves

Figure 20. Sable Bank Track S4
Transmission Loss VS Frequency

Receiver Depth, 10 m, July med. SVP

Transmission Loss, dB re 1 m
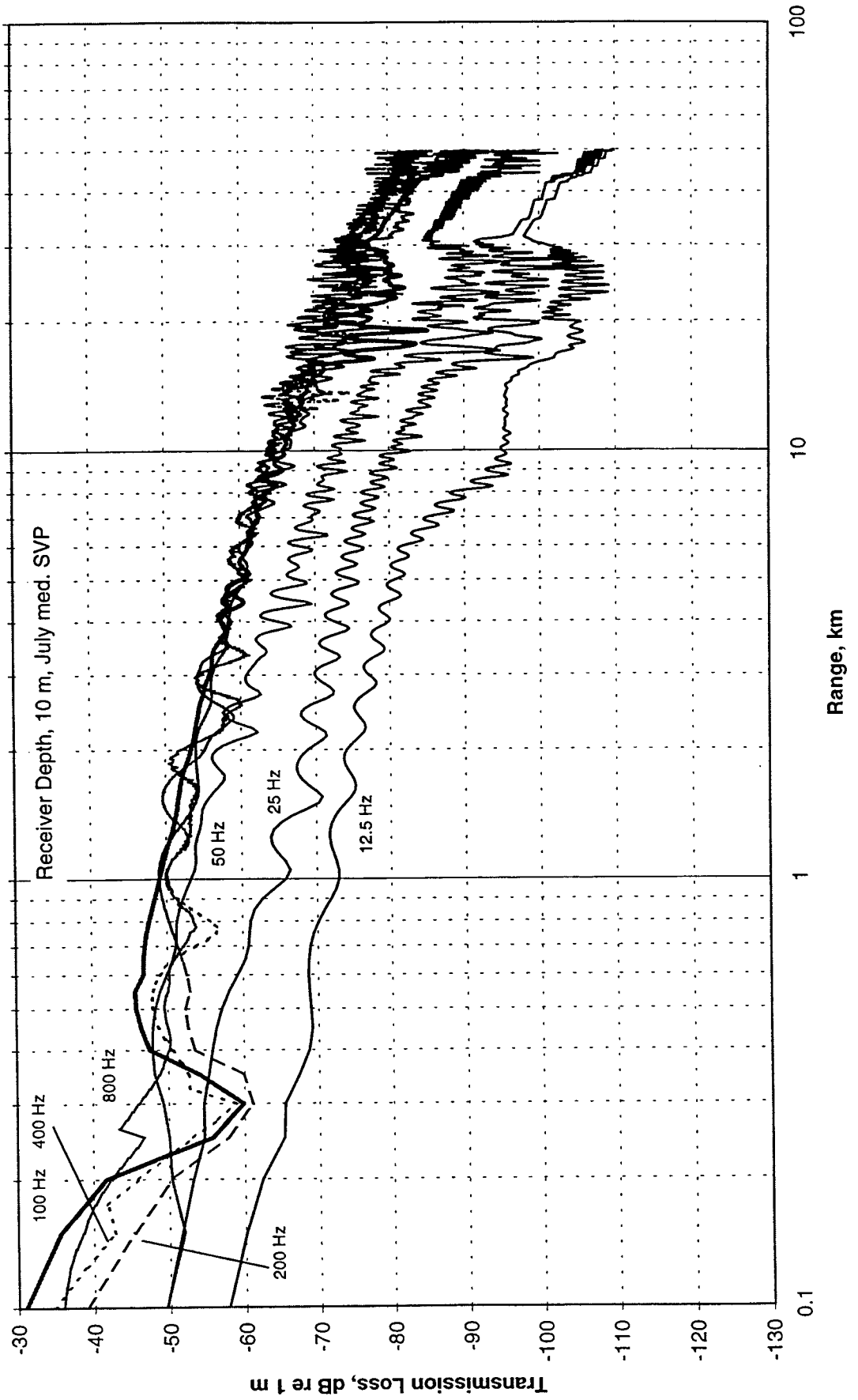
Range, km

Figure 21. Sable Bank Track S4
Seismic Array, Transmission Loss Spectra

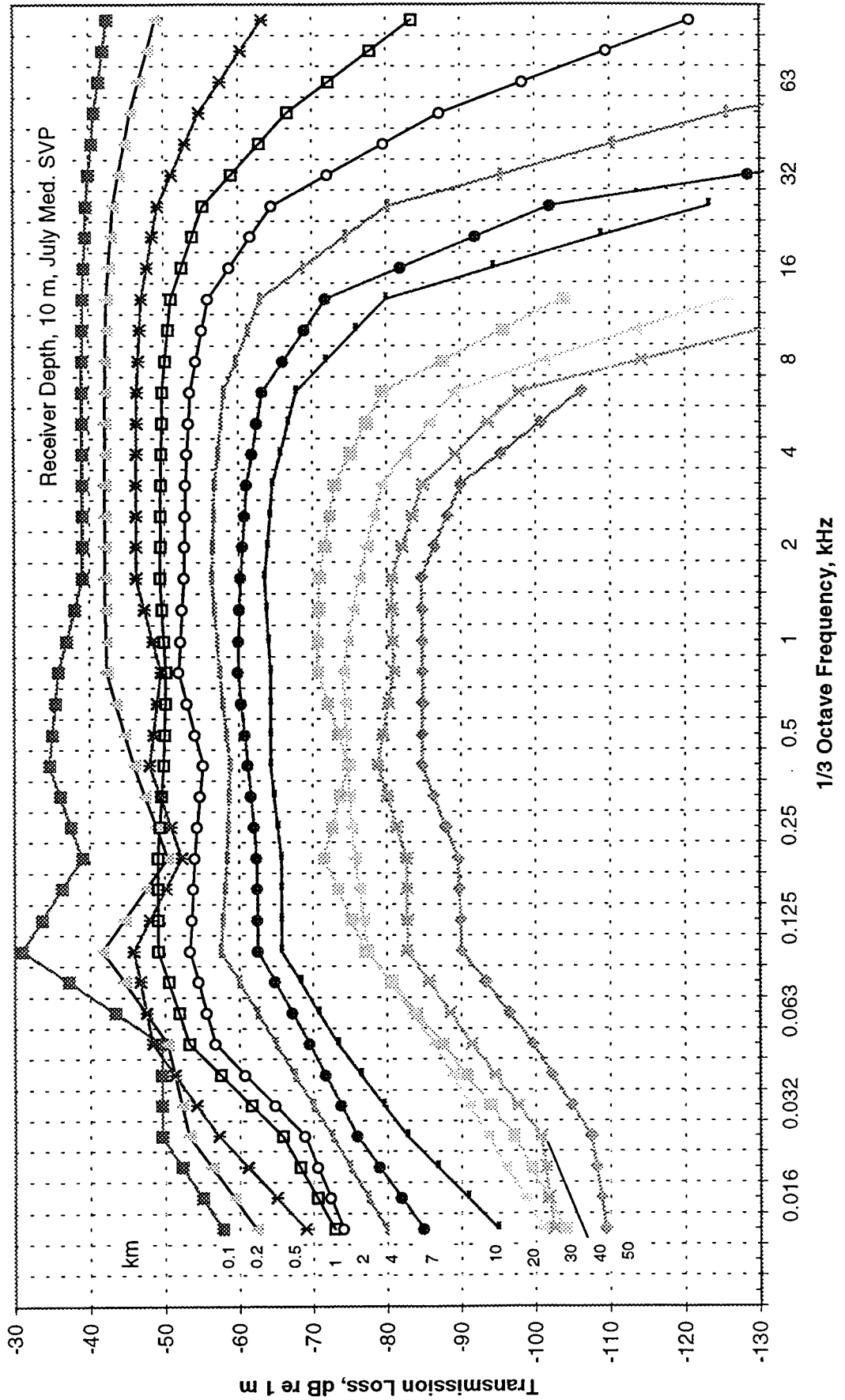Figure 22. Sable Bank Track S4

Seismic Array, Sound Exposure Level

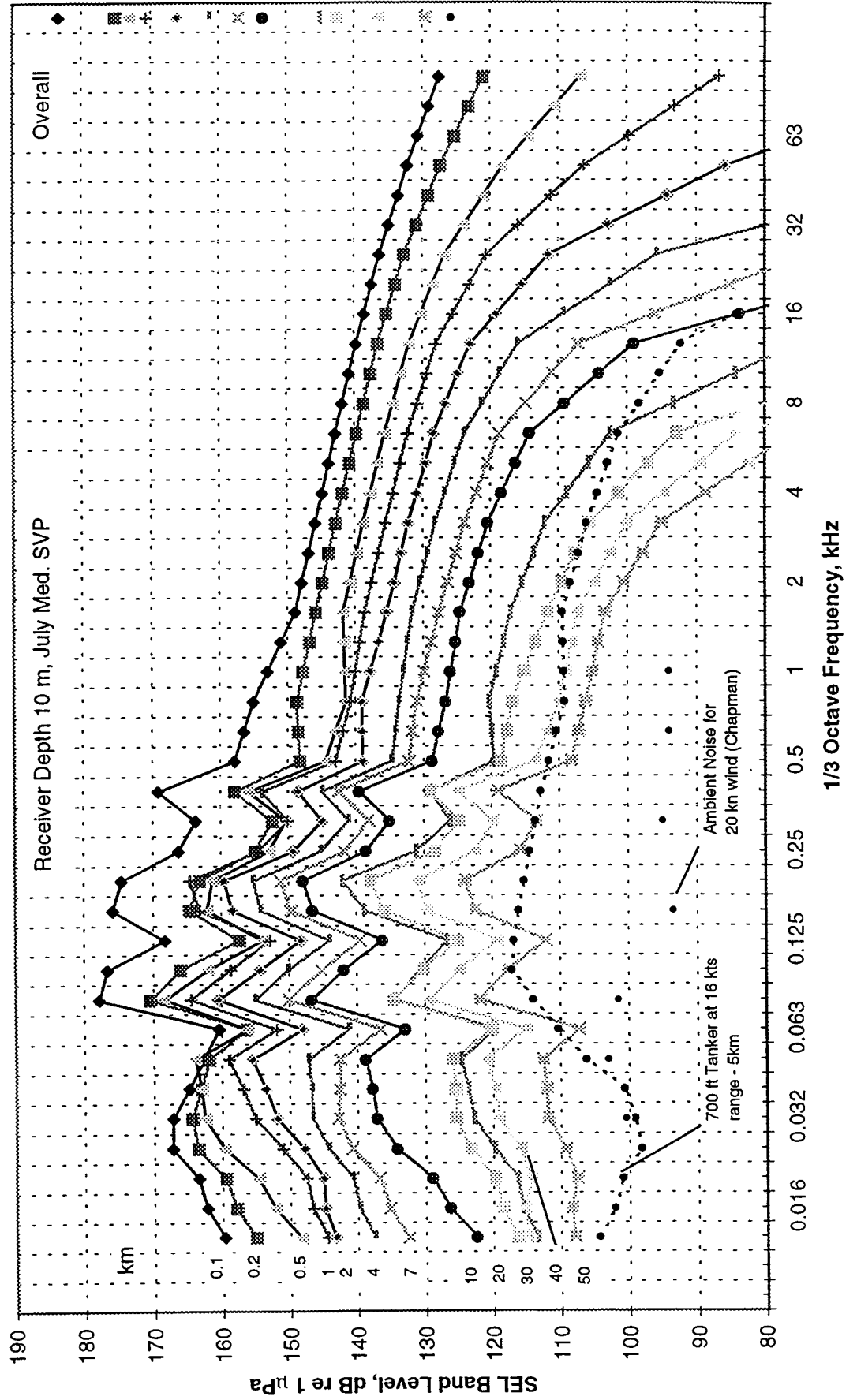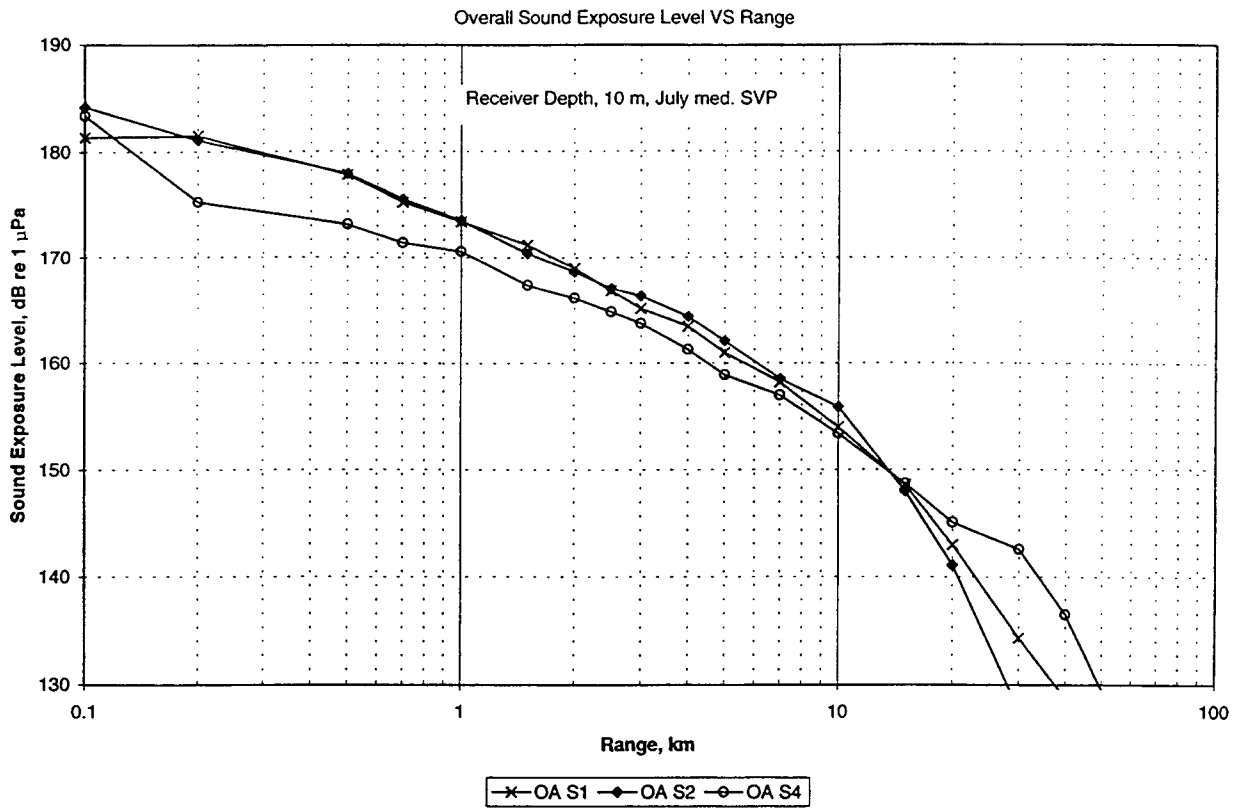**Figure 23A. Sable Bank Track Comparison**

Overall Sound Exposure Level VS Range

Figure 23B. Average SEL, RMS and 0-Peak Levels on Sable Tracks S1, S2 and S3
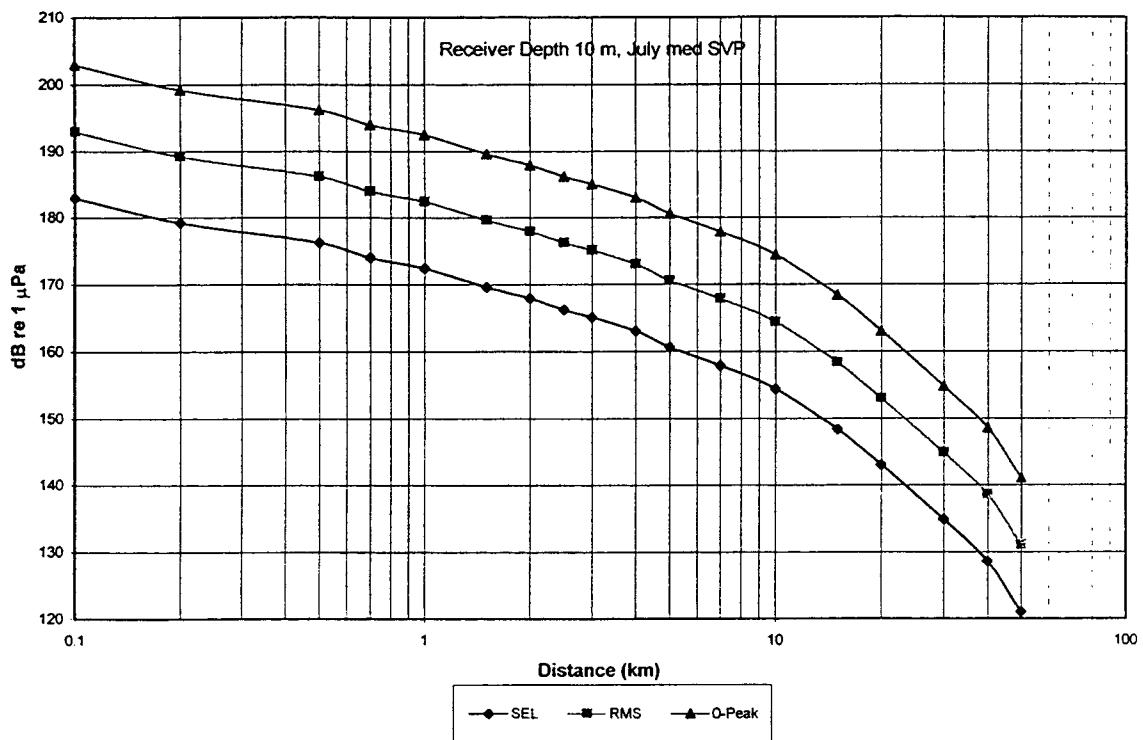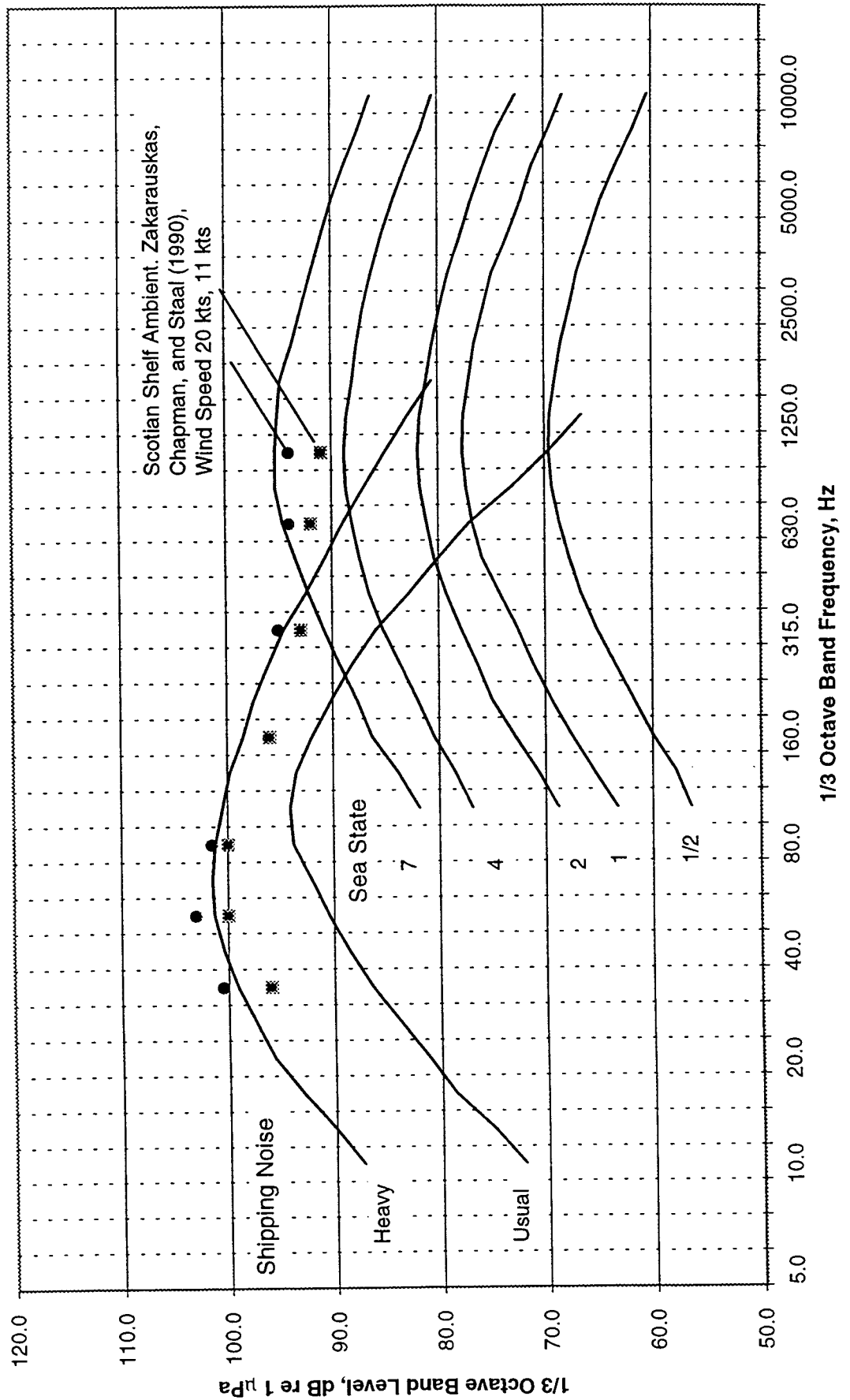
Figure 24. Underwater Ambient Noise
From Wenz (1962), Urick (1983)

for wind-related ambient noise shown in Figure 24 are reasonable averages, although relatively large departures from these curves can be experienced depending on site location and other factors, such as bottom topography and proximity to island or land features.

Distant shipping

The presence of a relatively constant low frequency component in ambient noise within the 10-200 Hz band has been observed for many years and has been related to distant ship traffic as summarized by Wenz and Urick. Low frequency energy radiated primarily by cavitating propellers and by engine excitation of the ship hull is propagated efficiently in the deep ocean to distances of 100 n.mi. (182 km) or more. Higher frequencies do not propagate well to these distances due to acoustic absorption. Also, high frequency sounds radiated by relatively nearby vessels will frequently be masked by local wind-related noise. Thus, distant shipping contributes little or no noise at high frequency. Distant ship-generated low frequency noise incurs more attenuation when it propagates across continental shelf regions and into shallow near-shore areas than occurs in the deep ocean.

Figure 24 provides two curves which approximate the upper bounds of distant ship traffic noise. The upper curve represents noise at sites exposed to heavily used shipping lanes. The lower curve represents moderate or distant shipping noise as measured in shallow water. As shown, highest observed ambient noise levels for these two categories, on a third-octave basis, are 102 dB and 94 dB, respectively, in the 60-100 Hz frequency range. In shallow water, the received noise from distant ship traffic can be as much as 10 dB below the lower curve given in Figure 24, depending on site location on the continental shelf. In fact, some near-shore areas can be effectively shielded from this low frequency component of shipping noise due to sound propagation loss effects.

Note that the shipping noise curves shown in Figure 24 show typical received levels attributable to *distant* shipping. Considerably higher levels can be received when a ship is present within a few miles. The data for the Scotian Shelf area are shown to have higher levels than the expected sea state 2–4 range for the wind speeds shown. This indicates that the ambient noise levels in this area are heavily influenced by shipping noise. The relatively low transmission loss in this area is also a factor since it permits noise to propagate further from the source zone.

Surf Noise

Very few data have been published relating specifically to local noise due to surf in near-shore areas along mainland and island coasts. Wilson et al. (1985) presented underwater noise levels for wind-driven surf along the exposed Monterey Bay coast, as measured at a variety of distances from the surf zone. Wind conditions varied from 25-35 kt. Noise levels varied from 110-120 dB in the 100-1000 Hz band at a distance of 656 ft (200 m) from the surf zone, down to levels of 96-103 dB in the same band 4.6 n.mi (8.5 km) from the surf zone. Assuming that these data are also representative of levels near shorelines in the Sable Island area, surf noise in the 100-500 Hz band some 200 m from shore will be 15-30 dB above that due to wind-related noise in the open ocean under similar wind speed conditions.

IMPACT ASSESSMENT

This document is designed as a class environmental assessment of seismic exploration on the Scotian Shelf. The document also evaluates the 1998 seismic exploration program proposed by Mobil Oil Canada and partners. The specific areas within which 3D seismic surveys are proposed are depicted in Figure 25.

Level I Interaction Matrix

Usually, the first step in an impact assessment is the preparation of an interaction matrix showing all possible interactions between the project and the environment. This Level 1 Matrix shows interactions only and makes no assumptions about possible impacts of the interactions. Interactions that are considered to be important environmental issues can be highlighted in the matrix. Not all interactions could occur throughout the proposed period of operation and so the matrix often includes a timing component.

In the present Class EA, there is only one project activity to be considered and that is the energy and noise produced by seismic operations. From a potential impact point-of-view, there is little basis for treating 2D and 3D seismic separately. Typically, a 2D survey will be somewhat less intensive in a particular area but it will cover a larger area. The available quantitative information on seismic effects does not yet allow precise predictions. Thus, there is effectively only one project activity under consideration. Therefore, an interaction matrix has not been produced.

All VECs previously identified are considered in the assessment of potential effects of seismic operations contained in the sections that follow. An evaluation and description of interactions and resulting impacts, if any, are included in the impact assessment sections. Results of these evaluations and impact predictions are summarized in the Impact Summary Table.
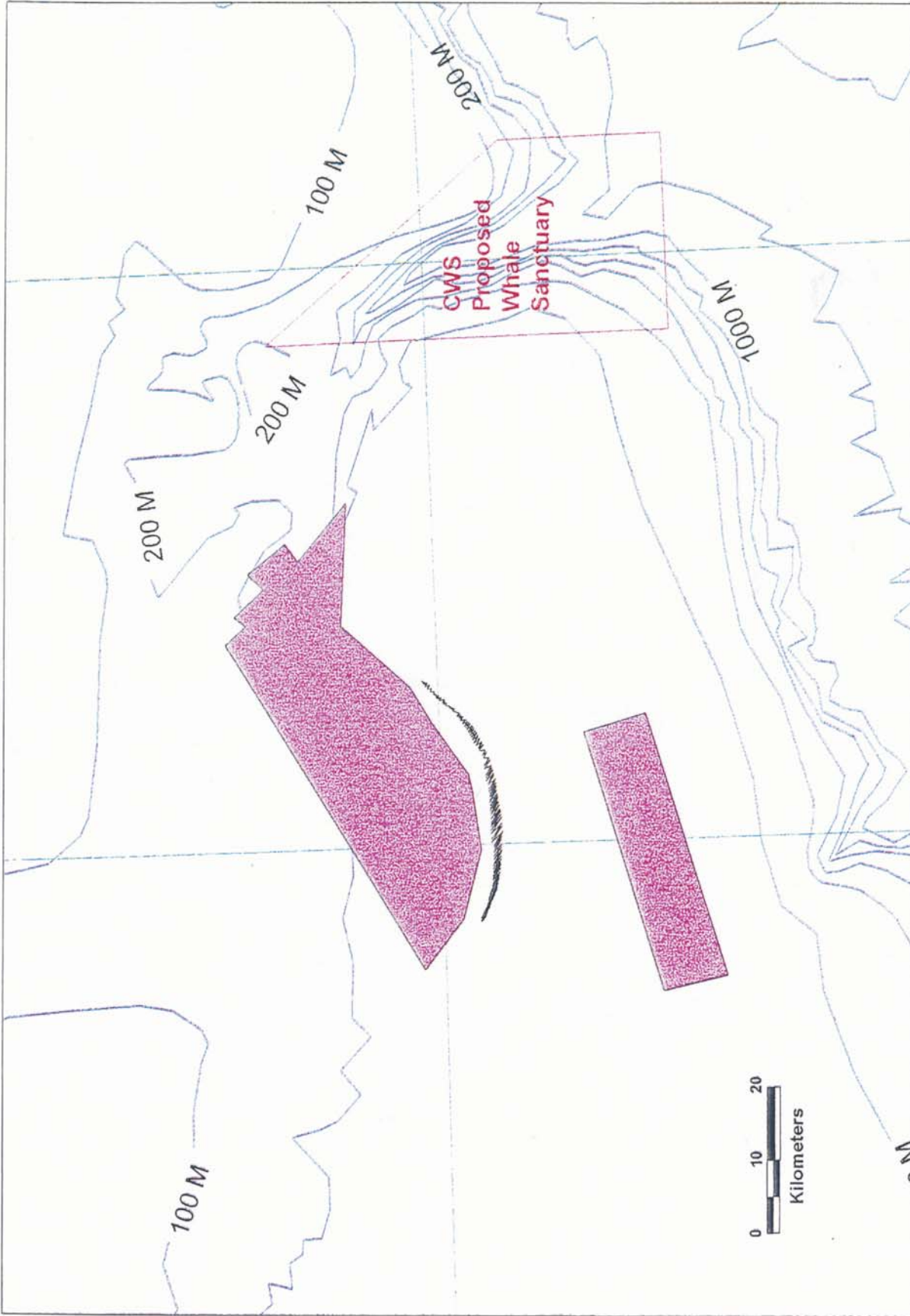
Figure 25. Locations of proposed seismic exploration by Mobil Oil Canada and partners for 1998.

Fish and Fisheries of the Scotian Shelf

The sections dealing with the fisheries resources of the Scotian Shelf were prepared by Trevor J. Kenchington of Gadus Associates, Musquodoboit Harbour, Nova Scotia and John Christian of LGL Limited, St. John's Newfoundland. Catch data were collected and assembled by Canning & Pitt Associates of St John's Newfoundland.

In this section we first review the Valued Ecosystem Components related to fish and fisheries, then define the impact criteria for fish and invertebrates. This is followed by a review of the effects of seismic sounds on fish, their eggs and larvae and invertebrates. Predictions about impacts of seismic exploration on the fisheries resources on the Scotian Shelf are then presented. The section concludes with mitigation and monitoring methods that could be used.

As shown in the following section, sounds produced by seismic surveys can affect the behaviour of some types of fish and can alter their availability to commercial fishing operations. An examination of impacts and evaluation of mitigation measures requires knowledge of which grounds are fished at various times of year and a detailed understanding of the spatial and temporal distribution of different types of fishing effort. Not all exploited species are likely to be equally affected by seismic sound and not all fishing methods are equally influenced by changes in fish behaviour.

The commercial fishery of the Scotian Shelf includes pelagic and demersal fish and invertebrates and a few species of algae. The fishery is described in this section based on catch statistics for the fourteen North Atlantic Fisheries Organization (NAFO) Unit Areas that are within the area of interest (Figure 26). Only the period April to October, when seismic activities are planned, is considered. Individual catch locations from the NAFO database were plotted on maps by species and month, combinations of species, and combinations of months. Most of the catch biomass data are for the year 1996. Data on the value of the catch were not available for 1996, so catch value data for 1995 were used. During the period April to October 1996 over 50 species and/or taxonomic groups were harvested on the Scotian Shelf (Table 2; Scott and Scott 1988).

Sixteen fish and invertebrate groups accounted for over 86% of the total biomass landed; no other species or group accounted for more than 1% of the total biomass (Tables 3 and 4; DFO 1996). An important consideration in comparing the importance of different species is commercial value. Catch value data for the 1996 season are not yet available, however, the 1995 data show that 15 species/groups accounted for over 92% of the total value of the catch (Table 5). Rankings differ markedly between catch biomass and catch value data. In fact, four of the groups which accounted for more than 1% of biomass contributed little to the total value of the catch (Atlantic herring, silver hake, skates, and cusk; Tables 4 and 5). Swordfish, bluefin tuna, and Atlantic halibut contributed significantly to catch value but accounted for a low percentage of total biomass (Tables 4 and 5).

All species that are major contributors to both biomass and catch value are considered to be VECs and are discussed below.
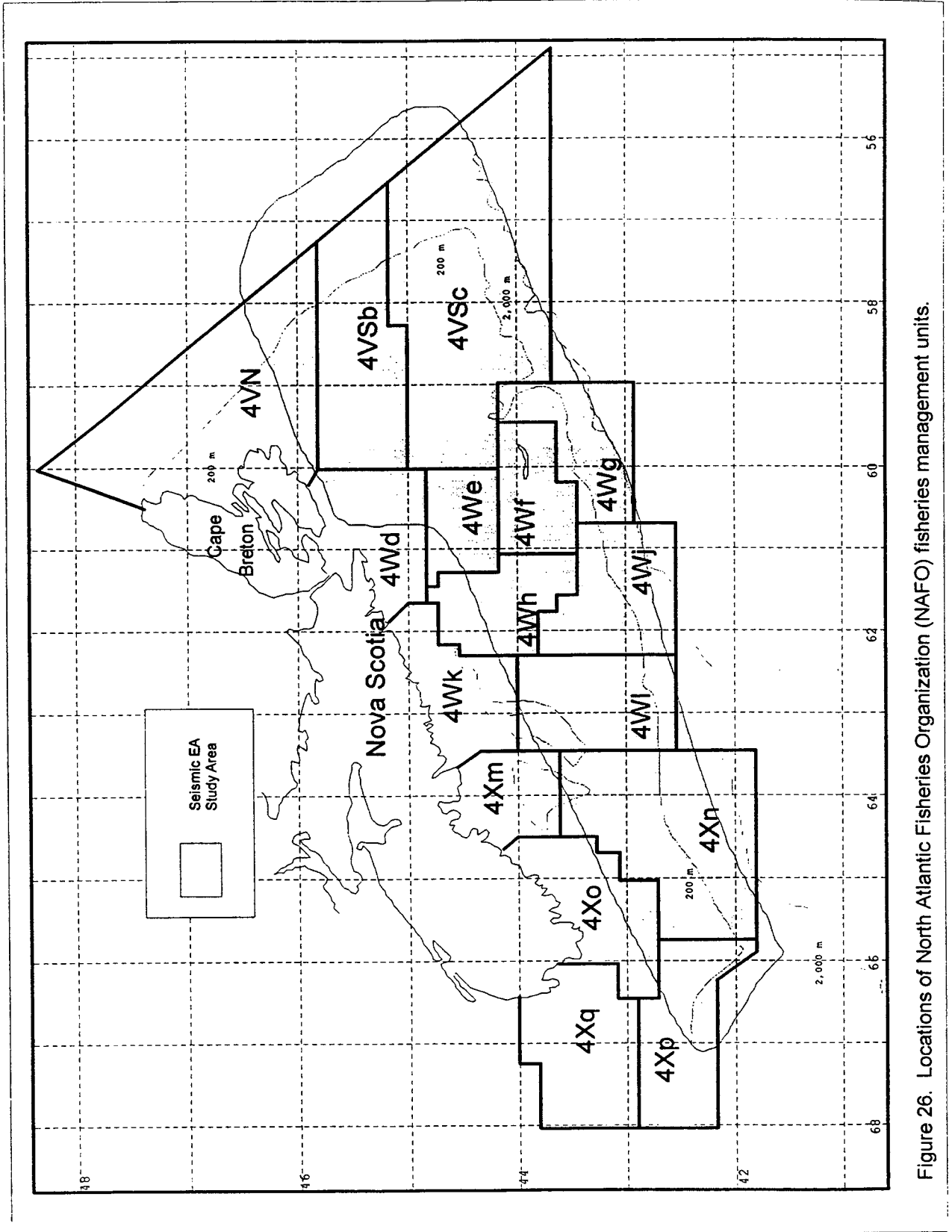
Figure 26. Locations of North Atlantic Fisheries Organization (NAFO) fisheries management units.

Table 2. Common names and scientific names of all species considered in the catch biomass data for the Scotian Shelf, April to October 1996.

Common name	Scientific name
Skates (unspecified)	*Raja sp.*
Porbeagle shark	*Lamna nasus*
Dogfishes	*Squalus sp.*
Mako shark	*Isurus oxyrinchus*
Blue shark	*Prionace glauca*
Sharks (unspecified)	
Bigeye tuna	*Thunnus obesus*
Yellowfin tuna	*Thunnus albacares*
Albacore tuna	*Thunnus alalunga*
Swordfish	*Xiphias gladius*
White marlin	*Tetrapturus albidus*
Atlantic herring	*Clupea harengus*
Atlantic mackerel	*Scomber scombrus*
Redfish	*Sebastes sp.*
Alewife	*Alosa pseudoharengus*
Bluefin tuna	*Thunnus thynnus*
American eel	*Anguilla rostrata*
American shad	*Alosa sapidissima*
Mahi mahi (dolphin)	
Atlantic argentine	*Argentina silus*
Sturgeons (unspecified)	
Atlantic cod	*Gadus morhua*
Silver hake	*Merluccius bilinearis*
Pollock	*Pollachius virens*
Haddock	*Melanogrammus aeglefinus*
White hake	*Urophycis tenuis*
Flounder (unspecified)	
Cusk	*Brosme brosme*
American plaice	*Hippoglossoides platessoides*
Yellowtail flounder	*Limanda ferruginea*
Atlantic halibut	*Hippoglossus hippoglossus*
Witch flounder	*Glyptocephalus cynoglossus*
Wolffish	*Anarhichas sp.*
Monkfish	*Lophius americanus*
Winter flounder	*Pleuronectes americanus*
Roundnose grenadier	*Coryphaenoides rupestris*
Turbot	*Reinhardtius hippoglossoides*
Tilefish	*Lopholatilus chamaeleonticeps*
Groundfish (unspecified)	
Sculpin (unspecified)	
Red hake	*Urophycis chuss*
Squids (unspecified)	

Common name	Scientific name
Stimpson's surf clam	*Mactromeris polynyma*
Deep sea scallop	*Placopecten magellanicus*
Soft shell clam	*Spisula solidissima*
Propeller clam	
Winkles	
Oyster	*Crassostrea virginica*
Molluscs (unspecified)	
American lobster	*Homarus americanus*
Northern shrimp	*Pandalus borealis*
Snow crab	*Chionoecetes opilio*
Red crab	*Chaceon quinquedens*
Rock crab	*Cancer irroratus*
Jonah crab	*Cancer borealis*
Stone crab	*Neopanopeus sayi*
Crabs (unspecified)	
Green sea urchin	*Strongylocentrotus droebachiensis*
Rock weed	*Ascophyllum nodosum, Fucus sp.*
Irish moss	*Chondrus crispus*

Table 3. Catch biomass statistics of all finfish and invertebrate species (first grouping) which accounted for at least 1% of total catch biomass (kg) during April to October 1996 in indicated NAFO Unit Areas (UA) of the Scotian Shelf Region. Species listed in descending order of percentage of total catch biomass. Swordfish, bluefin tuna and Atlantic halibut are included in this table due to their commercial value indicated by the 1995 catch data.

Species	All UAs	4VN	4VSb	4VSc	4Wd	4We	4Wf	4Wg	4Wh	4Wj	4Wk	4Wl	4Xm	4Xn	4Xo
Atlantic herring	16,918,739	939,687	•	•	46,973	1,241,000	•	•	679,536	•	10,846,049	295,909	196,960	4,756	2,667,869
Stimpson's surf clams	5,040,037	•	3,981	5,034,219	•	•	•	•	•	•	•	•	•	•	1,837
Atlantic mackerel	4,438,415	1,590,386	•	•	473,732	•	•	•	4,210	•	138,779	1,024	2,233,633	755	106
Redfish (spp.)	4,290,377	1,092,919	32,074	53,704	6	•	115	1,225	•	49	784,249	15,661	618,369	285,676	1,402,120
American lobster	3,660,906	1,518,091	•	•	282,467	•	•	•	•	•	286,132	•	117,211	68,633	1,388,372
Atlantic cod	3,479,482	52,568	3,229	48,113	3,155	170	1,066	8,250	5,425	1,879	48,242	14,461	388,397	519,267	2,385,260
Silver hake	3,372,056	303	•	730	•	•	•	•	413,130	•	1,867,437	951,079	4,111	135,194	72
Northern shrimp	2,984,913	24,378	85,479	1,905,865	435,176	527,923	5,877	•	•	215	•	•	•	•	•
Pollock	1,840,785	29,563	30,432	198,826	35,228	11	•	6,092	39,483	237	242,209	58,352	217,165	596,288	386,899
Snow crab	1,488,238	593,074	266,518	10,047	503,298	92,031	•	11,091	1,629	•	•	•	1,504	372	8,674
Deep sea scallops	1,374,544	15,796	•	•	14,917	71,773	111,196	66,018	26,003	751,473	742	4,336	•	•	312,290
Haddock	1,337,185	797	240	21,976	951	92	79	645	5,337	855	30,425	7,716	61,937	411,445	794,690
Skates (unspecified)	1,117,296	•	2,663	947,587	•	41,486	59,722	28,373	•	23,195	1,319	871	2,091	4,452	5,537
White hake	996,877	17,681	241	81,678	1,103	21	1,663	9,655	14,104	11,819	161,054	94,998	81,841	314,605	206,414
Flounder (unspecified)	609,004	181,507	18,734	312,329	•	1,358	1,182	•	2,560	•	5,617	4	3,348	8,308	74,057
Cusk	591,792	45	•	25,600	15	230	3,373	18,967	930	10,240	27,881	42,830	47,747	210,184	203,750
SUBTOTAL	53,540,646	6,056,795	443,591	8,640,674	1,797,021	1,976,095	184,273	150,316	1,192,347	799,962	14,440,135	1,487,241	3,974,314	2,559,935	9,837,947
Swordfish	373,020	1,634	•	66,725	•	•	3,731	62,586	8,000	57,891	22,689	87,619	3,056	58,889	200
Bluefin tuna	215,148	•	774	•	39,361	113	•	117	•	•	7,313	•	131,890	28,669	6,911
Atlantic halibut	336,926	8,685	128	63,798	262	5,513	4,910	17,543	16,530	10,673	36,848	37,272	12,252	66,580	55,932
SUBTOTAL	925,094	10,319	902	130,523	39,623	5,626	8,641	80,246	24,530	68,564	66,850	124,891	147,198	154,138	63,043
Remainder of species	7,476,125	681,229	7,719	821,106	139,191	2,133	5,125	21,733	24,186	67,602	1,142,767	168,173	168,023	501,247	3,725,891
TOTAL	61,941,865	6,748,343	452,212	9,592,303	1,975,835	1,983,854	198,039	252,295	1,241,063	936,128	15,649,752	1,780,305	4,289,535	3,215,320	13,626,881

Table 4. 1996 catch biomass statistics of all finfish and invertebrates which accounted for at least 1% of the total catch biomass (kg) during April to October 1996 or at least 1% of the total catch value during April to October 1995 in the fourteen NAFO unit areas considered on the Scotian Shelf. Only the unit areas for each species in which most of the catch biomass was landed is presented by month.

Species	Unit Area	April	May	June	July	August	September	October	Total
Atlantic herring	4Wk	4,536	2,948,711	6,635,349	•	2,957	•	1,254,497	10,846,050
	4Xo	•	45	167,000	1,980,730	3,734	45,820	470,540	2,667,869
	4We	•	•	1,241,000	•	•	•	•	1,241,000
Stimpson's surf claı	4VSc	756,247	1,156,186	•	1,074,924	935,031	857,347	254,484	5,034,219
Atlantic mackerel	4Xm	•	286,055	1,040,549	507,652	319,178	55,222	24,977	2,233,633
	4VN	•	43,567	827,529	117,323	163,691	124,167	314,109	1,590,386
Redfish (sp.)	4Xo	17,183	144,727	230,431	743,436	149,958	33,925	82,459	1,402,119
	4VN	•	204	221	601,038	270,576	91,069	129,811	1,092,919
	4Wk	176,963	157,329	99,520	1,367	202,869	36,667	109,535	784,250
	4Xm	7,738	111,073	173,878	36,930	47,601	76,340	164,809	618,369
American lobster	4VN	1,327	629,253	748,363	139,148	•	•	•	1,518,091
	4Xo	406,058	980,677	1,289	•	•	•	348	1,388,372
Atlantic cod	4Xo	9,118	173,395	760,713	660,771	350,339	192,234	238,690	2,385,260
	4Xn	26,512	57,204	98,378	94,844	92,130	47,519	102,680	519,267
	4Xm	9,725	17,160	71,675	69,468	89,554	94,906	35,909	388,397
Silver hake	4Wk	3,876	992,989	846,387	22,524	•	•	1,661	1,867,437
	4Wl	3,491	357,316	406,755	183,504	14	•	•	951,080
Northern shrimp	4VSc	284,095	684,733	721,991	98,160	42,538	25,572	48,777	1,905,866
	4We	33,854	196,036	117,947	109,345	17,674	20,184	32,884	527,924
	4Wd	987	82,005	132,108	106,804	65,086	22,946	25,239	435,175
Pollock	4Xn	121,268	68,469	204,248	74,401	48,757	24,813	54,332	596,288
	4Xo	7,044	28,215	75,447	97,112	90,964	51,173	36,944	386,899
	4Wk	100,855	20,210	6,486	28,642	62,509	20,876	2,631	242,209
	4Xm	18,889	11,708	30,460	38,158	49,163	40,779	28,009	217,166
	4VSc	280	93,361	70,646	28,005	4,918	1,616	•	198,826
Snow crab	4VN	•	•	•	286,599	283,752	7,019	15,704	593,074
	4Wd	•	•	•	37,714	433,949	31,635	•	503,298
	4VSb	•	•	•	118,922	143,514	4,082	•	266,518
Deep sea scallops	4Wj	•	564,475	88,152	•	36,964	•	61,882	751,473
	4Xo	11,412	•	120,856	55,872	•	124,151	•	312,291
	4Wf	•	13,313	14,895	10,820	15,842	•	56,326	111,196
Haddock	4Xo	4,646	35,628	228,275	197,961	118,743	90,961	118,477	794,691
	4Xn	97,299	26,811	68,129	50,779	62,188	37,566	68,673	411,445
Skates (unspecified	4VSc	209,352	90,089	72,980	280,395	141,317	31,915	121,539	947,587
White hake	4Xn	25,762	209,564	11,774	35,886	14,377	7,278	9,965	314,606
	4Xo	203	23,487	11,104	77,174	32,145	36,795	25,506	206,414
	4Wk	150	999	5,128	60,935	79,794	9,421	4,626	161,053
	4Wl	1,775	21,525	29,203	22,024	17,074	2,421	975	94,997
	4Xm	8,352	2,019	1,843	35,621	19,909	10,118	3,980	81,842
	4VSc	6,799	20,537	12,790	19,610	19,159	1,507	1,276	81,678
Flounder (unspecifı	4VSc	14,108	27,035	148,972	65,726	32,712	6,387	17,389	312,329
	4VN	5	58,114	55,458	20,188	21,564	15,822	10,356	181,507
Cusk	4Xn	14,141	75,910	26,340	25,678	31,097	17,372	19,647	210,185
	4Xo	2,365	13,017	36,817	38,954	44,714	35,762	32,120	203,749
	4Xm	2,397	6,248	6,703	8,258	10,173	10,117	3,851	47,747
	4Wl	1,504	10,945	12,959	6,926	9,725	701	71	42,831

Species	Unit Area	April	May	June	July	August	September	October	Total
Swordfish	4Wl	•	•	•	36,600	36,548	13,162	1,309	87,619
	4VSc	•	•	•	1,551	27,694	35,488	1,992	66,725
	4Wg	•	•	•	1,186	31,972	21,158	8,271	62,587
	4Xn	•	•	•	1,812	22,171	29,857	5,049	58,889
	4Wj	•	•	•	4,673	42,340	10,510	368	57,891
Atlantic halibut	4Xn	2,795	14,615	15,608	11,492	10,594	5,566	5,910	66,580
	4VSc	6,395	20,376	26,726	4,161	5,608	182	351	63,799
	4Xo	19	2,047	7,480	9,280	7,850	14,206	15,049	55,931
	4Wl	1,836	8,516	5,872	4,793	13,538	1,565	1,151	37,271
	4Wk	2,636	8,960	3,187	11,814	9,075	923	254	36,849
Bluefin tuna	4Xm	•	•	•	7,349	29,055	28,626	66,861	131,891
	4Xn	•	•	•	•	25,668	1,658	1,344	28,670
	4Wd	•	•	•	•	1,818	20,288	17,525	39,631

Table 5. Finfish and invertebrate species which accounted for at least 1% of total catch value ($) during April to October 1995 in NAFO Unit Areas 4VN, 4VSb, 4VSc, 4Wd, 4We, 4Wf, 4Wg, 4Wh, 4Wj, 4Wk, 4Wl, 4Xm, 4Xn and 4Xo (Scotian Shelf). Species listed in descending order of value.

Species	Catch Value ($)	Percent of Total Value	Catch Biomass (kg)	Percent of Total Biomass
American lobster	48,604,874	41.3	4,311,575	8.0
Snow crab	11,485,518	9.8	1,486,166	2.8
Swordfish	8,592,972	7.3	1,035,295	1.9
Northern shrimp	6,062,905	5.2	3,025,909	5.6
Bluefin tuna	5,034,395	4.3	173,794	0.3
Deep sea scallops	5,016,993	4.3	3,810,518	7.1
Stimpson's surf clams	4,658,805	4.0	4,700,861	8.7
Redfish (spp.)	3,331,043	2.8	6,769,859	12.6
Atlantic cod	3,244,471	2.8	2,225,002	4.1
Atlantic mackerel	2,584,223	2.2	5,998,497	11.1
Haddock	2,582,889	2.2	1,318,813	2.4
Atlantic halibut	2,117,965	1.8	273,278	0.5
Flounder (unspecified)	1,699,802	1.4	998,482	1.9
White hake	1,448,956	1.2	1,361,995	2.5
Pollock	1,354,915	1.2	1,805,447	3.4
TOTAL	**107,820,726**	**92**	**39,295,491**	**73**

Groundfish Fisheries

Until the end of the 1980s, the major fisheries in the area of present concern were for groundfish. Several species were and are harvested, including the three major gadoids (cod, haddock and pollock), redfish, some small flounders (plaice, yellowtail, witch, winter flounder), halibut, white hake, silver hake and assorted minor species[1]. Most of these are represented by more than one (officially-recognized) stock per species within the Scotian Shelf area, leading to a large number of different biological units. A variety of gears are used in their capture, ranging from otter trawls, Danish and Scottish seines, through gillnets and longlines to handlines and jigs. There is a complex groundfish fleet, subdivided into sectors by boat size, gear used and the location of home ports. It includes everything from large stern trawlers (around 50 m in length) to small open boats less than 10 m long. These fisheries are almost exclusively Nova Scotia-based, with the exception of the silver hake fishery which continues to be primarily carried out by foreign vessels. In 1990, boats of less than 11 m length were fishing the outermost banks of the Scotian Shelf with hook-and-line gear (Kenchington *et al.* 1994), while the large trawlers would sometimes work to the innermost margin of the present study area.

Most parts of the Scotian Shelf have been fished by one or another component of this complex of fisheries, though not all are equally important. The tops of the various banks are noted, in season, as grounds for cod, haddock and flounders, among others. The slopes around them and the deep "holes" between also hold cod, plus redfish, halibut, white hake, witch flounder and more. The halibut fishery extends deepest of all, sometimes reaching 900 metres on the continental slope (Kenchington & Halliday 1994). The only substantial areas that do not appear to have been heavily fished for groundfish in the past are the flat bottoms of the major deep basins, particularly the LaHave and Emerald basins, and those of the two main deep channels, the Laurentian and the Fundian. Those areas are not unexploited but neither have they received the degree of fishing effort applied elsewhere.

Through the later 1980s, many of Atlantic Canada's groundfish stocks were increasingly depleted. Beginning in the fall of 1993, the directed fisheries for some previously-important stocks on the eastern Scotian Shelf, including the cod and haddock there, were closed, while strict limits were placed on other fisheries that took fish of these stocks as bycatch. The affected fisheries have yet to be re-opened, though that might happen as early as 1999 and is quite likely to do so by 2002. Naturally, these closures have resulted in the withdrawal of groundfish effort from some grounds eastward of Halifax. Even to the westward (in NAFO Division 4X), where limited cod and haddock fisheries have continued, effort has shifted to the west, the small quotas being taken off southest Nova Scotia and in the Bay of Fundy while there has been little activity on, for example, LaHave Bank.

Atlantic Cod

Cod landings were reported from all fourteen of the unit areas under consideration and totalled over 3.4 million kg (Table 3). Unit area 4Xo had the highest catch biomass (68% of the total). Catch

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[1] For example: Skate, dogfish, cusk, wolfish, monkfish and turbot. These minor species have become of increased importance as the supply of the traditional major species has declined.

in this area peaked during June and July (Table 4). Landings in UAs 4Xn and 4Xm accounted for another 26% of the total catch biomass. Catches in the latter two areas peaked slightly later in the year than in 4Xo. Landings in all three areas were recorded throughout the August to October period.

Cod landings were concentrated in Unit Area 4Xo, especially during the months of June, July and August. Catches in this unit area were concentrated on Roseway Bank, northwestern Baccaro Bank and northern Browns Bank (Appendix Figures 2-1 to 2-7).

Atlantic cod catch biomass on the Scotian Shelf ranked eighth during April to October 1995 (4.1% of total) while its catch value ranked ninth (2.8% of total; Table 5).

Atlantic cod are distributed across the entire Scotian Shelf with highest concentrations on Sable Island Bank, Middle Bank, Emerald bank, Banquereau Bank and off eastern Cape Breton (Simon and Comeau 1994).

Pollock

Pollack landings were reported from 13 NAFO Unit Areas. Landings in areas 4Xn, 4Xo, 4Wk, 4Xm and 4VSc accounted for 89% of the 1.84 million kg of landings on the Shelf (Table 3). Peak timing for the fishery varied among the unit areas but when considered together, a significant pollock fishery extended from April through to October in 1996 (Table 4).

In June, catches were concentrated at the southwestern end of the Shelf. The majority of catch locations in 4X and 4W occurred inshore from the Seismic EA Study Area in the regions of Roseway Bank, La Have Basin and Emerald Basin. Most of the catches made in areas 4VN and 4VS occurred in July and August at the shelf edge (Appendix Figures 2-8 and 2-9).

In 1995, pollock biomass ranked ninth (3.4% of total catch) and only fifteenth with respect to commercial catch value (1.2% of total; Table 5).

Pollock are concentrated on the western and central Scotian Shelf with highest concentrations on northern Browns bank and inshore of La Have and Emerald Basins. Intermediate concentrations of pollock were found on Emerald Bank, Western Bank and Sable Island Bank (Simon and Comeau 1994).

Haddock

During 1996, each of the 14 unit areas reported haddock landings totalling over 1.3 million kg in total catch biomass. Landings in 4Xo and 4Xn accounted for over 90% of the total biomass reported (Table 3). Catch biomass peaked during April in the offshore unit area 4Xn but remained relatively high until October. In inshore unit area 4Xo, landings were relatively low during April and May, peaked in June and July and then remained strong through to October (Table 4).

During April, most effort was in the offshore region of the southwestern Shelf on Baccaro and La Have Banks and then during May, shifted to inshore areas, mainly Roseway Bank (Appendix Figures 2-10 to 16).

Haddock landings ranked fourteenth in terms of biomass during 1995 (2.4% of total) and eleventh in catch value (2.2% of total; Table 5).

Haddock are occur across the entire outer Scotian Shelf with highest concentrations on Browns Bank to Sable Island Bank, and on Middle Bank and southern Banquereau Bank (Simon and Comeau 1994).

Silver Hake

Landings of silver hake were reported from 8 of the NAFO unit areas. Almost 84% of the 3.4 million kg of silver hake landed were taken in UAs 4Wk and 4Wl (Table 3). Peak catches occurred during the months of May and June and in area 4Wl, good catches persisted into July (Table 4). Most catches were made in the vicinity of Emerald Basin (Appendix Figure 2-17).

The 1995 catch biomass for silver hake (0.5% of total) ranked the species twenty-seventh compared to seventh in 1996 among finfish and invertebrates. Its catch value in 1995 was insignificant (0.1% of total; Table 5).

Silver hake are distributed mainly on the central Scotian Shelf from La Have Bank to Sable Island Bank. Smaller concentrations were also reported on Browns Bank (Simon and Comeau 1994).

White Hake

The catch of 997,000 kg of white hake landed in 1996 was spread over all fourteen unit areas. Landings in 4Xn, 4Xo, 4Wk, 4Wl, 4Xm and 4VSc accounted for 94% of the total (Table 3). The offshore areas (4Xn and 4Wl) on the southwestern Scotian Shelf showed peak catches in May, while inshore regions (4Xo, 4Xm and 4Wk) had peak catches during the summer months. Catch biomass on the eastern Shelf (4VSc) was distributed from May to August (Table 4).

During April and May catches were concentrated between Baccaro Bank and La Have Bank, and along the shelf edge south of the two aforementioned Banks. Inshore catches were concentrated on Roseway Bank and in the regions north of La Have Basin and Emerald Basin. Northeastern Shelf catches occurred mainly at the southern and eastern edges of Banquereau Bank, and the shelf edge due east of Cape Breton (Appendix Figure 2-18).

In 1995, white hake landings ranked twelfth in biomass (2.5% of total) and fourteenth in catch value (1.2% of total; Table 4).

White hake are distributed along the entire shelf edge from Browns Bank to eastern Cape Breton, in the Gully, and around the La Have and Emerald Basins (Simon and Comeau 1994).

Redfish

Landings were recorded in 13 of 14 unit areas between April and October 1996. UAs 4Xo, 4VN, 4Wk, and 4Xm accounted for 90% of the more than 4 million kg landed during that time (Table 3). Catches in UAs 4VN and 4Xo peaked in July, but there was no such trend in the other two unit areas. Catches in UAs 4Wk and 4Xm were bimodal with peaks in the spring and in late summer/early fall (Table 4).

Catch locations were concentrated in the southwestern shelf between April and October and on the northeastern shelf in July and August. Southwestern catches were concentrated in the region of Roseway Bank and inshore from La Have and Emerald Basins. The 4VN catches were concentrated at the shelf edge (Appendix Figures 2-19 and 2-20).

The 1995 catch data indicate that redfish ranked first in catch biomass (12.6% of total) and eighth in catch value (2.8% of total; Table 5).

Summer groundfish surveys from research vessels conducted from 1988 to 1992 showed that redfish were distributed over much of the Scotian Shelf with highest concentrations at the Gully, along the eastern and southeastern shelf edges, Browns Bank, and inshore from the La Have and Emerald Basins (Simon and Comeau 1994).

Highest catches of redfish in small and large otter trawlers in July 1996, and research surveys during 1992-96 were also recorded over northern Browns Bank, Roseway Bank, inshore from La Have and Emerald Basins, and along sections of the shelf edge (Branton 1996).

Flounder (spp.)

In 1996, eleven of the unit areas reported landings of flounder species totalling slightly more than 600,000 kg (Table 3). UAs 4VN and 4VSc accounted for approximately 81% of the total weight landed, most of that being landed during May, June and July (Table 4).

Appendix Figures 21 and 22 indicate that most catches were made on the eastern portions of Banquereau Bank with scattered catches on the southern and northwestern edges of the same bank, and on the shelf region due east of Cape Breton.

Flounder ranked fifteenth in terms of landed biomass in 1995 (1.9% of total). These species accounted for 1.4% of the total catch value, ranking them thirteenth (Table 5).

Winter flounder are concentrated on Sable Island Bank and yellowtail flounder are concentrated over Sable Island Bank and Banquereau Bank (Simon and Comeau 1994).

Halibut

All unit areas reported landings of Atlantic halibut during 1996 and these totalled just under 340,000 kg. Those areas where catches exceeded 35,000 kg include 4Xn, 4VSc, 4Xo, 4Wl and 4Wk (Table 3). Depending on inshore or offshore location, unit area peaks in catch occurred from May through to October, with catch in inshore areas peaking later in the season (Table 4). DFO (1980) reported the key fishing areas for halibut to be along the entire shelf edge region (Appendix Figures 2-23 to 2-29).

Cusk

Thirteen of fourteen unit areas reported cusk landings during the spring to fall period in 1996. Total catch was less than 600,000 kg. Most of the catch occurred in UAs 4Xn and 4Xo (70%) and much of the remainder in 4Xm and 4Wl (Table 3). As has been apparent with some other species, the offshore areas (4Xn and 4Wl) had peak catches in spring/early summer while the inshore areas (4Xo and 4Xm) peaked during summer/early fall (Table 4).

April catches were mainly distributed in the Baccaro Bank and La Have Bank region while subsequent catch distributions (May-October) were mainly inshore around Roseway Bank and inshore from La Have and Emerald Basins (Appendix Figures 30 and 31).

Cusk landings ranked seventeenth in catch biomass in 1995 (1.3%) and accounted for under 1% of the total catch value (Table 5).

Cusk were sparsely distributed on the southwestern Scotian Shelf with highest concentrations inshore from La Have and Emerald Basins, on Roseway Bank, and along the shelf edge from Browns Bank to Emerald Bank (Simon and Comeau 1994).

Skate (spp.)

The species comprising this group were landed in eleven of the fourteen unit areas during 1996, with almost 85% of the 1.1 million kg total being caught in area 4Vsc (Table 3). The harvest of skates was relatively high throughout the seven month period with the highest catches recorded in July (Table 4). Catches were concentrated at the eastern edge of Banquereau Bank (appendix Figures 32 and 33).

During 1995, skate landings ranked eleventh in biomass (2.6%) and accounted for only 0.7% of total catch value during the April to October period (Table 5).

Smooth and winter skate are concentrated primarily toward the east-central and eastern portions of the Scotian Shelf. Smooth skate were concentrated around the Gully area and along the shelf edge in unit areas 4VN and 4Vsb, while winter skate were found primarily on Sable Island Bank, the Gully and Banquereau Bank (Simon and Comeau 1994) .

Other Demersal Species

The concentration of catch locations for the demersal fish species that each accounted for < 1% of total catch increased from April to June and remained fairly steady until October. Most of the catches occurred at the western and eastern ends of the Shelf (Appendix Figure 34).

<u>Pelagic Fisheries</u>

There are substantial fisheries for herring around Nova Scotia, though the principal fishing grounds do not overlap with the seismic-survey assessment area. Most of the herring are caught by large purse seiners (supplemented by a small amount of midwater trawling). Those may sometimes fish within the study area where it approaches the mouth of Chedabucto Bay, which is one of their winter grounds. There is also a limited offshore herring seine fishery on the Scotian Shelf itself which, in 1996, took most of its catch from "The Patch" (northwest of Western Bank). The principal herring seiner grounds are, however, in the Gulf of Maine and the Bay of Fundy, with other grounds along the Nova Scotian coast inshore of the seismic-survey area. The other herring fisheries are carried out by inshore fishermen using gillnets, weirs, "shutoffs" and traps. All of that effort is confined to coastal waters[2].

There may be an opportunity for major expansion of the herring fisheries over the coming years. At least, there is presently a major debate over the potential for a new midwater-trawl herring fishery on the United States side of Georges Bank and that idea may yet move to Canada and the Scotian Shelf.

No other small pelagic fish are currently harvested to any great extent on the Scotian Shelf, though there is potential for the small, inshore mackerel fishery to expand if market conditions improved. There is also some interest in an offshore fishery for saury (or "billfish"), which has to date seen only inshore experimental fishing.

Fisheries for large pelagic species include the bluefin tuna, swordfish longline, swordfish harpoon and "other tuna" fisheries. All are strictly limited under international management agreements covering these highly-migratory species and, in Canadian waters, all are restricted to the warmer months. The highly-valuable bluefin fishery is a small-boat fishery. Its effort can be widespread but in recent years has included a concentration of activity in the "Hell Hole" off the southern tip of Browns Bank. The swordfish harpoon fishery includes many licensed participants with small boats who engage in it as a seasonal alternative to other fisheries. They range widely over the central Scotian Shelf in the search for fish. The pelagic-longline swordfish fishery involves a small number of large (sometimes over 30 m) specialist boats. They can set gear over a wide area but seem to concentrate along the shelf break (the extreme edge of the continental shelf). Even fewer Canadian boats are licensed for tuna longlining. They mostly seek yellowfin and are required to avoid bluefin. As with the swordfish fishery, gear can be set in many areas though there appears to be some concentration of activity along the edge of the Gulf Stream, out over deep ocean and well beyond the seismic-survey study area. Some foreign boats are

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[2] DFO Science Stock Status Report B3-03 (1997).

licensed to take their (internationally set) quotas of tuna within Canada's 200 mile zone and may sometimes do so within that study area.

Swordfish and bluefin tuna are species of significant commercial value. The 1995 data indicate that the three species accounted for a total of a large proportion of total catch value of landings within the fourteen unit areas but accounted for a small percentage of the total catch biomass (Table 5).

Approximately 370,000 kg of swordfish were landed in eleven of the unit areas during the April to October 1996 period. Highest landings of this species were in 4Wl, followed by 4VSc, 4Wg, 4Xn, and 4Wj. These five unit areas accounted for 89% of the total catch biomass (Table 3). Peak catches for swordfish were in July, August and September in the five offshore unit areas (Table 4). DFO (1980) reported that swordfish catches were concentrated on Browns Bank, Emerald Bank, and along the shelf edge, specifically at the Gully and off eastern Cape Breton (Appendix Figures 2-23 to 2-29).

Slightly more than 200,000 kg of bluefin tuna were landed in eight of the unit areas in 1996 with most of the landings from UA 4Xm. Landings in 4Xn and 4Wd are also worthy of consideration (Table 3). August, September and October yielded the highest catch biomass in the three unit areas (Table 4). DFO (1980) reported that the general summer distribution of bluefin tuna covers the entire Scotian Shelf and that catch areas tend to be in inshore regions, especially inside of La Have and Emerald Basins (Appendix Figures 2-23 to 2-29).

There is a small longline fishery for porbeagle shark in the northwest Atlantic that has fluctuated between foreign and Canadian involvement and between directed and bycatch fishing[3]. Its specific grounds are not immediately known. There are smaller landings of blue and mako sharks, apparently mostly from bycatches in the swordfish and tuna longline fisheries though there is a growing sport fishery for them nearer to land.

All of these fisheries for large pelagic species are more likely to contract than expand over the coming years as on-going international over-fishing, the resulting restrictive regulations and increasing pressure from environmentalists all influence the industry. More pronounced changes in the grounds fished may result from the notoriously-fickle behaviour of these fish. Bluefin tuna, in particular, have been known to abandon areas where they were once regular visitors, resulting in fisheries disappearing while new ones appear elsewhere.

Atlantic Herring

In terms of catch biomass, more Atlantic herring were harvested than any other species during April to October 1996 (~17 million kg; Table 3). Nine of the fourteen NAFO unit areas reported herring landings during that time period. Over 64% of all herring were landed within the NAFO Unit Area (UA) 4Wk while an additional 23% were caught in UAs 4Xo and 4We. More than 90% of the 4Wk and 4We

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[3] DFO Atlantic Fisheries Stock Status Report 96/33E (1996).

landings were made in spring (May and June) and almost 75% of the landings in UA 4Xo occurred in July (Table 4).

Geographically, catch locations were concentrated in UA 4Wk, specifically in the Emerald Basin region (Appendix Figure 2-35). The mapped catch information indicate that most of the herring are taken outside the study area for this project.

Herring ranked fifth in catch biomass in 1995 (7.4% of total) yet accounted for only 0.5% of the total catch value in that year (Table 5).

Summer groundfish surveys conducted from 1988 to 1992 showed a sparse herring distribution on the central Scotian-Shelf with highest concentrations inshore from La Have and Emerald Basins, Emerald Bank, Western Bank, northern Sable Island Bank and immediately north of the Gully (Simon and Comeau 1994). Concentrations of herring were lower on Browns Bank during the research surveys.

Stephenson et al. (1996) reported considerable annual variation in herring abundance and distributions but they indicated that the main herring concentrations are on Browns Bank, Emerald Bank, Sable Island Bank, and off eastern Cape Breton.

Atlantic Mackerel

Over 4 million kg of this species were landed in seven of the unit areas under consideration. Eighty-six percent of the catch was landed in UAs 4Xm and 4VN (Table 3). In each UA, landings peaked in June but were high throughout the seven month period (Table 4).

Most catch locations were not mapped because they were inshore and not recorded (Appendix Figure 2-36). Most of the mapped locations were inshore of the Study Area.

In 1995, mackerel ranked second in catch biomass (11.1% of total) but only tenth in catch value (2.2% of total; Table 5).

Remaining Pelagic Species

Most catches of pelagic fish species that each accounted for < 1% of the catch occurred during July to September along the southern edge of the Scotian Shelf (Appendix Figure 2-37).

Crustacean Fisheries

The crustacean fisheries of the Scotian Shelf are dominated by the lobster fisheries, though there is also a very significant shrimp fishery, plus a number of established, developing and experimental crab fisheries. A proposal for a krill fishery is under consideration by the Department of Fisheries & Oceans at the present time. Should the latter develop, it would likely include fishing over in the deep water of the Emerald Basin.

The lobster fishery comprises an "inshore" fishery, using boats of less than 45 ft (13.72 m) in length, and an "offshore" fishery in larger vessels. The inshore fishery east of Cape Sable is largely confined within 20 km of the coast by the limited distribution of lobsters, while a closed area on Browns Bank ("Lobster Fishing Area 40" Appendix 3 Figure 4) keeps it away from the westernmost part of the seismic study area (Pezzack *et al.* 1992). Only off Canso and south-eastern Cape Breton is there any overlap between that area and the inshore lobster grounds. The inshore fishery operates under regulated seasons, which vary along the shore. Off Canso (LFA31a; Appendix 3 Figure 4), the season is open from late April to the end of June, while further east (LFAs 27, 29 & 30; Appendix 3 Figure 4), it is open from mid-May to mid-July.

The offshore lobster fishery operates year-round. The eight boats involved are licensed to fish widely across the outer Scotian Shelf but, in the seismic survey area, the fishery is largely confined to the Fundian Channel and along the shelf break (or uppermost slope) as far east as the tail of Baccaro Bank (Pezzack *et al.* 1992). Only in the mid-1990s were these grounds extended somewhat, with fishing along the shelf break to LaHave Bank plus a little on the continental shelf itself east of that bank[4]. Lobster are known to live along the shelf break as far east as the Sable Gully, so the fishery may expand to there in time. It is not, however, likely to extend much onto the shelf.

The shrimp fishery mainly takes place in summer in the small but deep basins southeast of Cape Breton (known as "Louisbourg Hole", "Misaine Hole", "The Big Hole", "Canso Hole" and "The Noodles"). It may expand into the Sable Gully in time. This is primarily an otter trawl fishery, though there is a recently-developed inshore trap fishery for shrimp in the Chedabucto Bay area. Scotian Shelf shrimping has increased dramatically since 1990 and seems likely to remain at high levels for at least a few more years, though there are expectations that it will decline when the eastern Scotian Shelf cod stock recovers[5].

The main crab fishery on the Scotian Shelf is for snow crab. This fishery has grown since the mid-1980s and been stable, under quota controls, since the early 1990s. The main grounds lie largely outside the seismic survey area, only overlapping along in waters close to the coast of Cape Breton and Canso[6]. There is, however, some fishing in the deep "holes" further south, extending almost to Sable Island, plus a small experimental fishery on the western Scotian Shelf. This fishery is carried out with small boats, often those used in the inshore lobster fisheries.

There is a long-established fishery for red crab on the continental slope (380 to 760 m deep) west of 61°W longitude, with grounds which extend as a narrow strip as far as Georges Bank[7]. Other

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[4] DFO Science Stock Status Report C3-14 (1998).

[5] DFO Science Stock Status Report C3-15 (1997).

[6] DFO Science Stock Status Report C3-02 (1998).

[7] DFO Science Stock Status Report C3-11 (1998).

exploratory or developmental crab fisheries include ones for stone, toad, rock and Jonah crabs in various waters off Nova Scotia.

American Lobster

Lobster were landed in six of the unit areas during April to October 1996. The largest catch was recorded in UAs 4VN and 4Xo (~ 79% of the 3.7 million kg; Table 3). The most productive months for the lobster fishery in these two unit areas were May and June on the northeastern shelf and April and May on the southwestern shelf (Table 4).

Most of the lobster landings occur inshore and not recorded on the NAFO maps. Some lobster fishing occurs throughout the period on the southwestern Scotian Shelf (Appendix Figure 2-38).

American lobster catch ranked fourth in biomass during the April to October 1995 period (8.0% of total). The commercial catch value of this species was worth over 48 million dollars and ranked first by a wide margin (41.3% of total; Table 5).

DFO (1980) reported that lobster were distributed along the entire Nova Scotia and Cape Breton coastline as well as on the southern part of Browns Bank.

Northern Shrimp

Seven of the NAFO unit areas reported northern shrimp landings during April to October 1996. Approximately 64% of the landings occurred in UA 4VSc while catches in 4We and 4Wd accounted for another 32% of the total catch biomass of just under 3 million kg (Table 2). Landings in 4VSc were highest during the April to June period. Landings in 4We and 4Wd, which are closer to shore, peaked during the May to July period (Table 4).

Essentially all of the landings occurred in the northwestern Banquereau Bank and Middle Bank regions at the eastern end of the Scotian Shelf (Appendix Figures 2-39 and 2-40).

Northern shrimp catch biomass ranked seventh in 1995 (5.6% of total) but ranked fourth with respect to catch value (5.2% of total; Table 5).

DFO (1980) reported northern shrimp concentrations on Middle Bank, western Banquereau Bank, and Misaine Bank.

Snow Crab

Ten unit areas reported landings of snow crab during the period of April to October 1996. A total of just under 1.5 million kg of crab was landed (Table 3). Almost 92% of the biomass of the catch was landed in unit areas 4VN, 4Wd and 4VSb, primarily during July and August (Table 4).

The heaviest concentration of landings occurred off the east and south coasts of Cape Breton Island (Appendix Figures 2-41 and 2-42).

Snow crab landings accounted for 2.8% of the total catch biomass during April to October 1995 and ranked tenth in this category. However, from a catch value perspective, this species of crab was worth over 11 million dollars and represented almost 10% of the 1995 total catch value in the considered unit areas (Table 5).

Snow crab are distributed primarily along the east and south coasts of Cape Breton (DFO 1980).

Mollusc Fisheries

There are a number of mollusc fisheries in the waters around Nova Scotia but only two are of much significance in the seismic-survey area. They are respectively the offshore scallop and offshore surf clam fisheries. The scallop fishery is the older of the two. It uses draggers of 27 to 46 m length. The major catches have traditionally been taken from Georges Bank but in recent years more has come from Browns, though it is unclear whether or not this is a long-term change. The exact grounds on the latter bank have varied from month to month since the fishery developed there but they have generally encompassed the north-western part of the Bank (west of the "Cove of Browns"). There are also some scallop beds of secondary importance on the eastern Scotian Shelf (which provided 150 tons of meats in 1995, in contrast to the 2000 tons from Browns). Those eastern beds are found around Western Bank and along the southern flank of Sable Island Bank, plus in areas on Middle Bank and around Sable Island itself[8]. There has been some recent exploration further afield on the Scotian Shelf but, thus far, little sign of commercially-promising beds.

The surf clam fishery is prosecuted by three large factory boats that fish with hydraulic dredges. It began in the 1980s and, on the Scotian Shelf, has always been confined to Banquereau, with different parts being fished as the boats slowly crop the existing resource. (The same boats also fish on Grand Bank.)

Stimpson Surf Clam

A catch biomass total of just over 5 million kg of this species was reported from only three unit areas during April-October 1996 with over 99% of all catches being made in UA 4VSc (Table 3). Catch was quite evenly distributed among months during the April to September period, except during June when no landings were reported (Table 4). Catch locations were concentrated in the central and western parts of Banquereau Bank (Appendix Figure 2-43).

In 1995, this clam species ranked third in catch biomass (8.7% of total) and seventh in catch value (4.0% of total; Table 5).

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[8] DFO Science Stock Status Reports C3-18 & C3-19 (1997).

Roddick (1996) stated that there was a lack of knowledge about the biomass and production of the Stimpson surf clam and this remains a concern during the ongoing development of the fishery.

Deep Sea Scallops

Over 1.3 million kg of scallops were landed in ten of the fourteen NAFO unit areas during 1996. Catches in areas 4Wj, 4Xo, and 4Wf accounted for more than 85% of the total biomass landed (Table 3). Different areas were fished at different times; in 4Wj, effort was concentrated in May, in 4Xo most fishing effort occurred primarily in June and September, and the activity in 4Wf was highest in October but also occurred from May to August (Table 4).

Catches in 4Wj occurred mainly on Western Bank, in 4Xo mainly on northern Browns Bank, and in 4Wf on Sable Island Bank (Appendix Figure 2-44).

Deep sea scallops ranked sixth in both catch biomass (7.1% of total) and catch value (4.3%) during April to October 1996 (Table 5).

According to DFO (1980), scallops are concentrated on Western Bank, Browns Bank, and Sable Island Bank.

Other Fisheries

A valuable sea urchin fishery has emerged in recent years along the coast of Nova Scotia. It is, however, confined to very shallow waters that do not overlap with the seismic survey area. There is some possibility of a sea cucumber fishery offshore, though experiments to date have not shown commercial promise. Finally, there are some important marine plant industries but they are necessarily confined to shallow coastal waters, outside the area of present interest.

Distributions of catch locations for the remaining molluscs and crustaceans were sparse for the entire period of April to October 1996. Highest concentrations of catches were along the southern Shelf edge from Baccaro Bank to Emerald Bank (Appendix Figure 2-45).

Distribution of the Combined 1996 Catch

All species caught within the considered unit areas during the period of April to October 1996 were categorized as demersal fish, pelagic fish and molluscs/crustaceans. Catch locations during the entire period were mapped for each of the three groups (Figures 2-46 to 2-48).

Pelagic finfish catches were concentrated along the shelf edge from Browns Bank to northern Banquereau bank, Roseway Bank, inshore from La Have and Emerald Basins, on northern Sable Island Bank, and just off the northeastern tip of the Nova Scotian mainland.

The main concentration of demersal finfish catch locations was obviously on the western Shelf and inshore regions inside La Have and Emerald Basins. Catch concentrations on the eastern Shelf occurred on the eastern and southern edge of Banquereau Bank, and the shelf edge in unit areas 4VSb and 4VN.

Most mollusc and crustacean catches were made on Banquereau Bank and Middle Bank with lesser concentrations of catches on Browns Bank, Baccaro Bank, Western Bank, Sable Island Bank, and on the shelf off eastern Cape Breton.

Fishery Effort, April to October, 1993-1996

Catch locations for all species were mapped by year and by month to give some indication of changes in catch patterns in recent years (Appendix Figures 2-49 to 2-84).

The catch location patterns in April and May have not changed noticeably between 1993 and 1996. The most obvious year-to-year change during June occurred after 1994 with fewer landings were made on the eastern Scotian Shelf, specifically along the shelf edge in unit areas 4VN and 4VSb. The maps for June 1995 and 1996 when compared to June 1993 and 1994, show a substantial increase in catch locations on the western shelf, particularly in the region of La Have Basin.

Between 1993 and 1996, the number of catch locations for the July to October period steadily increased on the Scotian Shelf, particularly in the western and eastern regions, and along the entire southern shelf edge. The area inshore of La Have and Emerald Basins was fished much more heavily during 1995 and 1996.

Areas With Fishing Restrictions

Some fishing restrictions on the Scotian Shelf include:

- Large trawlers may not work within 12 miles of the coast.
- Otter trawlers directing for hake may use small mesh nets, seaward of the continental shelf break (the Silver Hake Box; Appendix 3 Figure 6).
- Offshore lobster area 40 (Appendix 3, Figure 4) is closed to lobster fishing all year, but not to other kinds of gear.

Fishing Season Restrictions

The swordfish fishery opens on 1 June east of 65°30'W and on ! August to the west of this line (Most of the Scotian Shelf). Harpoon boats may only work east of this line.

Opening and closing dates for crab and lobster described in Appendix 3.

Areas with some type of fisheries restriction are shown in Figure 27 and described in detail in Appendix 3. The areas shown on Figure 27 are:

1. NAFO area 4Vsb closed to groundfish fishing between 1 January and 30 April each year.

2. Haddock nursery area on Western and Emerald Banks. This an important nursery area for haddock. Closed to all goundfish gear fishing year round.

3. Haddock spawning area on Brown's Bank. This is an important spawning area for the western Scotian Shelf haddock population. The closure is from 1 February to 15 June.

4. White Head Hole is closed to otter trawling by vessels > 19.8 m in length between 1 January and 30 June.

5. Swordfish spawning area is closed to all swordfish fishing from 1 September.

6. Redfish-directed fishing using otter trawls with codend mesh < 130 mm is permitted but not in areas < 50 fathoms deep or in the Brown's bank haddock spawning area between 1 January and 30 June.

7. "Hell Hole" closed to swordfish longlining, as required.

8. Shelburne Gill Net Box is closed to groundfish gillnetting throughout the year.
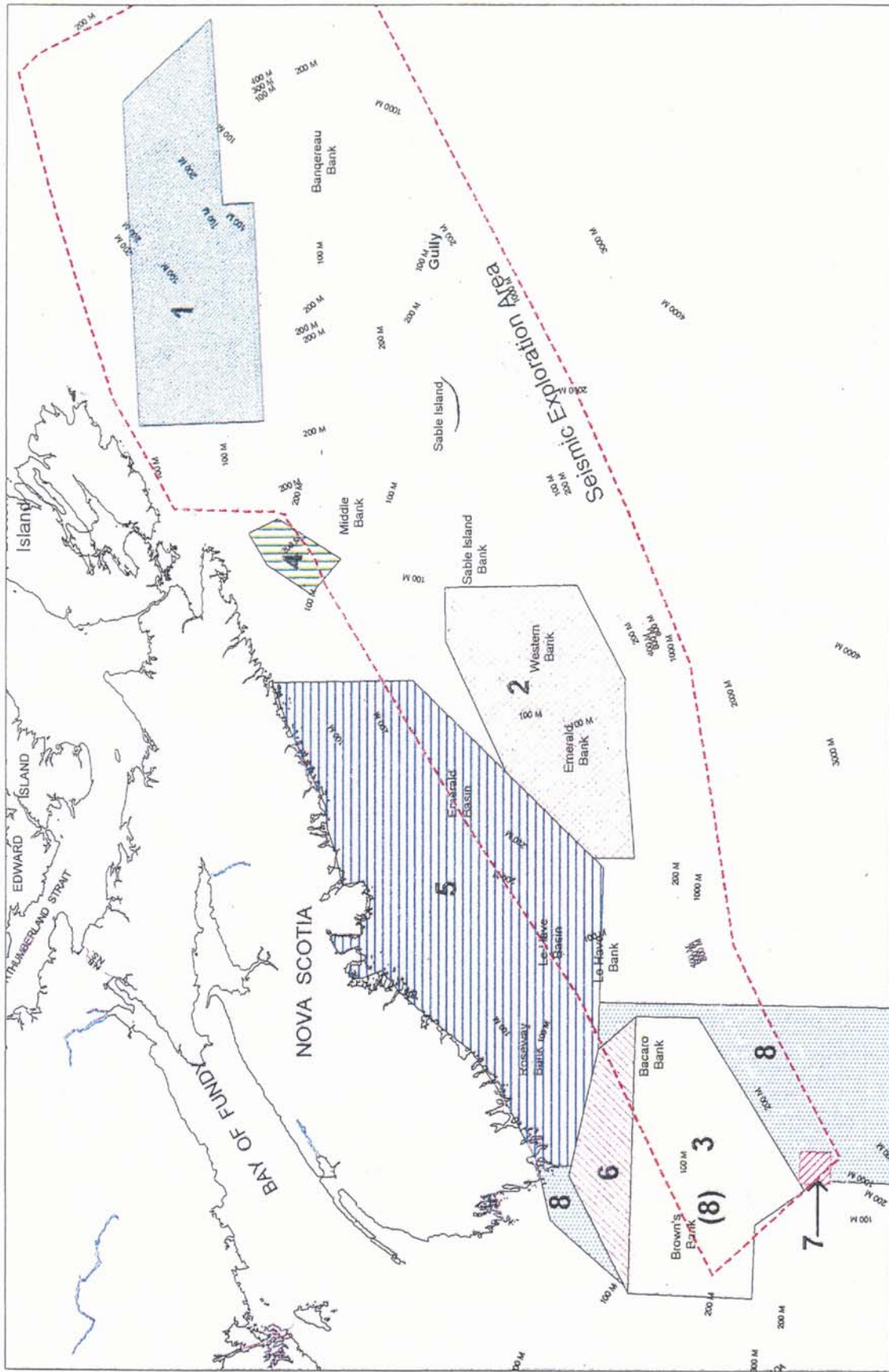
Figure 27. Areas where fishing restrictions apply. See text for details.

Distribution of Eggs and Larvae of Commercial Species

Neilson and Perley (1996) examined whether ichthyoplankton distribution data can be used to describe spawning areas of marine species. They concluded that the available Scotian Shelf Ichthyoplankton Program (SSIP) data are somewhat imprecise for the purpose of describing well-defined spawning areas due to low station density. The SSIP does, however, provide relatively good temporal coverage. Other programs used higher station density but temporal and spatial coverage were limited.

Herring

The 4VXW management unit (=Scotian Shelf) is known to contain a number of herring spawning areas. Spawning units in close proximity, with similar spawning times and which share a larval distribution area are considered part of the same complex.

Key herring spawning areas are as follow: [1] southwest Nova Scotia fishery component - coastal regions of 4Xq and 4Xo; [2] south shore, eastern shore and Cape Breton - coastal regions of 4Xo, 4Xm, 4Wk, 4Wd and 4VN; [3] offshore (> 25 km) Scotian Shelf banks - 4Wh and 4Wl (Stephenson 1997). Herring spawning has been recorded on Sable Island Bank and Banquereau Bank (DFO 1980). Herring nursery areas have been reported in coastal regions of 4Xq and 4Xo (DFO 1980).

Sameoto (1971) reported the results of a study on Scotian Shelf herring larvae in the spring and fall of 1969. No herring larvae were found at either 10 m or 27 m during the late May/early June survey but during the September/October survey, herring larvae between 7 and 12 mm in length were caught along the entire coast of Nova Scotia within the 100 m contour. These surveys found that fall spawning beds were all between the intertidal low watermark and depths of 4 m. The relatively few spring spawning beds were found in much shallower water of 2 to 7 m deep. No strong evidence was found to suggest that much herring spawning occurs at any great distance from shore. The number of herring larvae per 100 m^3 at the 10 m depth inshore sampling ranged from 0 to 25.6.

Scotian Shelf Ichthyoplankton Program (SSIP) data collected with at- and near-surface samplers in 1978 contained very few Atlantic herring larvae or juveniles (Kohler and Waite 1982).

Arctic (Stimpson) Surf Clam

Relatively little is known about the biology of this species of clam, especially its reproductive biology.

Mackerel

Most spawning by the northern component of the Northwest Atlantic mackerel stock takes place in the southern Gulf of St. Lawrence from early June to mid-August. Some spawning does take place on the Scotian Shelf (Sette 1943; Berrien et al. 1981).

Fortier and Villeneuve (1996) reported the capture of mackerel larvae over Sable Island Bank during July 1991. These larvae were estimated to be 4 to 16 days old which strongly indicated that the shallow waters west of Sable Island constitute a spawning ground for the species. The mackerel larvae appeared to aggregate in the upper 20 m of the water column at night but moved deeper during daylight hours. During the morning and afternoon, Atlantic mackerel larvae were concentrated in the thermocline at 10 to 20 m. The mean density ($\pm$ sd) of mackerel larvae at fourteen stations southwest of Sable Island was $11 \pm 23/100$ m^3 and accounted for 24% (by abundance) of all ichthyoplankton collected.

SSIP surface collections in 1978 found the highest catches of mackerel eggs and larvae to be over the Emerald Bank and Sable Island Bank regions, especially during hours of darkness.

Redfish

Redfish on the Scotian Shelf release their larvae from March to September, with most spawning occurring from May to August (Kenchington 1984). In April, the releases are primarily along the shelf edge but by May they begin to release their larvae throughout the Scotian Shelf. During April and May 1991, a field study which included work over Western Bank and southern Sable Island Bank, found redfish larvae concentrations in the upper 10 m of the water column as high as 27/100 m^3 (Drinkwater et al. 1996).

Fortier and Villeneuve (1996) reported the capture of redfish larvae over Emerald Bank, Western Bank and much of Sable Island Bank during July 1991. The redfish larvae appeared to aggregate in the surface layer (< 20 m) at night and moved deeper in the water column during the day. In the morning and afternoon, redfish larvae were found in or below the thermocline which occurred at 10 - 20 m depth and concentrated in the thermocline at 10 to 20 m depth. The mean density ($\pm$ sd) of mackerel larvae at fourteen stations southwest of Sable Island was $4 \pm 10/100$ m^3, accounting for 10% of abundance of all ichthyoplankton collected.

SSIP metre and neuston net data collected in 1978 contained very little in terms of redfish eggs and larvae.

American Lobster

During the Scotian Shelf Ichthyoplankton Program in the late 1970s and early 1980s, lobster larvae were sampled with neuston nets over the entire Scotian Shelf region at distances greater than 30 km from shore (Watson and Miller 1991). With the exception of a few samples taken east of Cape Breton in 1978, only 20 larvae were collected in approximately 1,000 samples taken east of Halifax. Most of the larvae found on the Scotian Shelf were collected primarily over Browns Bank and secondarily over La Have Basin during August and September 1979-1981. Despite the large number of samples collected during the SSIP, Watson and Miller (1991) could not conclude whether larvae from Browns Bank area ultimately seed inshore grounds in southwest Nova Scotia and east to Halifax.

Lobster larvae probably spend approximately 30% of their pelagic life in the surface metre (Stage IV) of the water column, and the remainder at depth of between 5 and 20 m (Stages I-III) (Harding et al. 1987).

Atlantic Cod

Spawning by this species is widespread on the Scotian shelf but occurs mainly on the offshore banks. Timing of spawning occurs earliest in the southwestern end and progressively later to the northeast. Brander (1991) presented distribution maps of cod eggs from SSIP surveys in 1979-81. These figures indicated peak concentrations of the cod eggs on the Scotian Shelf during the months of April and May. Eggs were most numerous during April on the southwestern and central portions of the shelf, especially over Browns Bank, while in May concentrations were primarily over the northeastern portion.

Some spawning also occurs during the fall (October and November) along the Nova Scotian coast from Halifax around into the Bay of Fundy (DFO 1997).

Twenty-nine cruises were conducted on the Scotian Shelf from March 1991 to May 1993 to provide detailed information on all life-history stages of Atlantic cod. This research program was known as Ocean Production Enhancement Network (OPEN). One of its specific objectives was to quantify the variability in cod eggs and larvae in time and space (Miller et al. 1995). On Sable and Western Banks, cod spawning was prolonged and the bimodal spawning distribution found in the SSIP was not evident. During the OPEN program autumn spawning was clearly of greater magnitude than was spring spawning.

Between May and July 1978, metre net collections during the SSIP had the highest numbers of cod eggs at those stations located towards the southwestern portion of the shelf (i.e., 4Xn, 4Xo, 4Wl). Collections at the surface in August and September contained few cod larvae which appears to support the belief that summer spawning of cod is negligible on the Scotian Shelf.

Silver Hake

During July 1991, Fortier and Villeneuve (1996) caught silver hake larvae over Emerald Bank, Western Bank and much of Sable Island Bank, but primarily over the shallow area of Sable Island Bank. The larvae of this species appeared to aggregate in the surface layer (< 20 m) during the day. The mean density ($\pm$ sd) of silver hake larvae at fourteen stations southwest of Sable Island was $17 \pm 52/100$ m^3, accounting for 37% of abundance of all ichthyoplankton collected.

Concentrations of eggs and larvae of silver hake are observed annually over the Sable Island and Emerald Bank shoals. Generally, in late June to early July as the shallow water of the banks gets warmer and the warm slope water begins to penetrate into the area, the spawning concentrations of silver hake leave the slope area for the shoals and the females spawn their first batches of eggs. Around the end of July, a second spawning event occurs and this is usually the peak period for silver hake spawning. A third spawning event in mid-September marks the end of the spawning season (Sherstyukov 1991).

The 1978 SSIP data tend to support the above generalized spawning schedule for silver hake, especially if the data for unspecified hake species actually apply to silver hake. The highest abundance of unspecified hake eggs was found during early summer in areas which included Emerald Bank, Western Bank, Sable Island Bank, and Middle Bank. The highest numbers of unspecified hake larvae were collected by at the surface during late August, 1978 in unit areas which included the banks listed above.

Northern Shrimp

Spawning begins in late June-early July and runs through to August/September in both inshore and offshore waters. The eggs are brooded by the females over the winter and then released as larvae in late winter/early spring, depending on prevailing water temperature and food availability. The larvae spend 3 to 4 months in the plankton, feeding near the surface (Koeller et al. 1996).

The main concentrations of northern shrimp are found on the eastern Scotian Shelf (4Wd, 4VN, 4VSb, and 4VSc) (Koeller 1996).

Pollock

Markle and Frost (1985) collected pollock eggs in March, September and November on the Scotian Shelf and confirmed Steele's (1963) conclusion that this species spawns on the shelf. Neilson and Perley (1996) found concentrations of pollock eggs on Browns Bank, Emerald Bank, Western Bank and parts of Sable Island Bank in autumn. Few pollock were collected at the surface during collections made by SSIP in 1978 during the May to June period. Only two juvenile fish were collected.

Snow Crab

Sampling during July to September in 1977 and 1978 found snow crab larvae all along the Scotian Shelf up to 230 km from shore (Roff et al. 1986). The larvae were most abundant around Cape Breton and off southwest Nova Scotia, reaching concentrations of up to $40/100 \ m^3$.

It is suspected that the larvae found off southwestern Nova Scotia might originate from the population off Cape Breton, because of the lack of snow crab zoea larvae found off southwest Nova Scotia and the existence of a major stock to the northeast of Cape Breton. Roff et al. (1986) admits that little is known of Brachyura larval recruitment mechanisms in Atlantic Canada.

The biomass of larval crab on the southwestern Scotian Shelf reaches a peak between mid-July and mid-September.

Nighttime sampling with neuston nets caught many crab larvae and showed that they occur in surface waters during hours of darkness (Roff et al. 1984).

Deep Sea Scallop

Deep sea scallop larvae on the Scotian Shelf tend to be concentrated on the eastern shelf (Sable Island Bank, Middle Bank, Western Bank) and on Browns and German Banks situated on the western shelf (Robert and Butler 1997).

Numbers of sea scallop larvae in the plankton tend to peak during October. During autumn surveys for scallop larvae conducted between 1985 and 1987, the mean abundance of sea scallop larvae on the southern Scotian Shelf ranged from 5 to 240 per m^2 (Tremblay and Sinclair 1992). Most sea scallop larvae were concentrated at depths of 10 to 45 m (Tremblay and Sinclair 1990) but factors influencing their aggregation depths appear inconsistent and are not well understood. Aggregations of larvae tend to exist in stratified waters and larvae tend to be dispersed where stratification is low. There is substantial conflict in the literature regarding the 'usual' position of scallop larvae in the water column.

Haddock

Major spawning areas/times of haddock on the Scotian Shelf include Browns Bank during April to June (Hurley 1997), and on the eastern shelf over Emerald Bank, Western Bank and Sable Island Bank during the spring months (Frank 1997).

May to July 1978 SSIP net collections at stations towards the southwestern portion of the shelf (i.e., 4Xn, 4Xo, 4Wl) contained the highest numbers of haddock eggs. August and September collections with the neuston net contained few haddock in the plankton and supported the belief that summer spawning of this species is negligible on the Scotian Shelf.

Skate (spp.)

The distributions of winter skate and thorny skate overlap on the offshore banks of the eastern Scotian Shelf (Simon 1996). Winter skate are the primary focus of the commercial fishery.

Peak spawning of winter skate west of Sable Island occurs during late summer while timing of spawning of skate found on Banquereau Bank may differ (Simon and Frank 1996).

White Hake

Spatial and temporal aspects of white hake spawning on the Scotian Shelf are not well understood. There appear to be two spawning components; late spring/early summer, and late summer/early autumn (Sinclair 1996). Fowler et al. (1996) also concluded that based on SSIP surveys, Scotian Shelf white hake are recruited from two spawning periods; early spring spawning along the continental slope and shelf spawning in August. Markle et al. (1982) speculated that Gulf of St. Lawrence early summer spawning may also contribute to Scotian Shelf May-June larval distributions. The eggs and larvae drift primarily in the upper 50 m of the water column.

SSIP metre net samples collected during May to September 1978 included white hake juveniles; larvae of this species were only present in the neuston sampling during the latter part of August. The highest abundance of hake (spp.?) eggs occurred during early summer sampling in unit areas which included Emerald Bank, Western Bank, Sable Island Bank, and Middle Bank. The most unspecified hake larvae were collected by neuston during late August 1978 in unit areas which included the same bank areas as listed above.

Flounder (spp.)

The three commercially important species on the eastern two thirds of the Scotian Shelf (4VW area) include witch flounder, American plaice, and yellowtail flounder (Annand 1996a), while a secondary fishery on the western third (4X area) includes these three species, as well as winter flounder (Annand 1996b).

Based on the 1978 SSIP metre net and neuston net sampling during May to July, the highest numbers of winter flounder and yellowtail flounder larvae were collected over the Sable Island Bank region. American plaice and witch flounder larvae were also collected but in much lower abundances.

Fortier and Villeneuve (1996) reported the capture of yellowtail flounder larvae over Emerald Bank, Western Bank and much of Sable Island Bank during July 1991, but primarily over the shallow area of Sable Island Bank. The larvae of this species appeared to aggregate in the surface layer (< 20 m) during the night and moved to deeper areas of the water column during the day. The mean density (± sd) of yellowtail flounder larvae at fourteen stations southwest of Sable Island was $12 \pm 30/100 \ m^3$, accounting for 27% of abundance of all ichthyoplankton collected.

Cusk

This species is found primarily in 4X on the southwestern Scotian Shelf and Slope in water depths ranging from 50 to 200 m. The reproductive biology of the cusk is not well known for the northwest Atlantic although studies by Oldham (1972) suggested that spawning on the Scotian Shelf takes place during May to August, primarily in June. The eggs and larvae are pelagic (Zwanenburg 1996), and most probably remain well below the surface regions of the water column.

SSIP collections by metre net in June and July 1978 did include a few cusk eggs which were found in unit area 4Xn but generally speaking, they occurred very infrequently in sampling near the surface regions of the water column.

Effects on Fish

Impact Criteria

The following impact criteria will be used to determine what is and is not an impact on fish. The impact criteria are based on the review of the literature that is summarized below.

There are two main criteria for impacts on fish: (1) direct physical injury and (2) detrimental behavioural effects.

(1)   We will use death, injury, or failure to reach (or retardation in the time needed to reach) the next developmental stage as the criterion for impact on fish eggs and larvae. Data are available to enable some predictions about the likelihood and extent of these kinds of effects.

(2)   Exposure to seismic pulses sometimes elicits behavioural reactions by fish, but there is little information on the effect of noise-induced behavioural changes on the well-being of fish. Also, there are no data on behavioural effects of seismic pulses on fish eggs and larvae. Most of the information indicates that effects of noise on fish are transitory, so obvious changes in behaviour may have inconsequential biological effects on the fish. In most cases, it appears that scaring effects on fish should translate into negligible impacts on individuals and populations. However, using the precautionary approach, we will identify behavioural effects that could constitute an impact.

Even if behavioural reactions are not indicative of significant negative impacts on the fish, these behavioural reactions might lead to significant impacts on a fishery if the catchability of fish is reduced. The criterion for impact on fisheries will be behavioural effects on fish that reduce the catchability of fish and, thus, have a negative impact in the fishery.

Hearing in Fish

Fish vary widely in their ability to hear sounds. Some fish have very good auditory capabilities. In many of these fish, such as the herring, the swim bladder is connected directly to the inner ear. For herring, the upper frequency limit of hearing ranges from 4,000 to 13,000 Hz (Enger 1967). The upper limit of hearing in fish without this type of connection is only about 1000 to 1200 Hz (Enger 1967). The herring is also relatively sensitive to sound. At 50 to 1200 Hz its hearing threshold is about 75 to 80 dB re 1 μPa (Enger 1967). In contrast, cod do not have a direct connection between swim bladder and inner ear, and are less sensitive to sound than are some other species of fish (Olsen 1969).

Some other fish have no direct connection between the swim bladder and ear but have other adaptations to enhance hearing. These fish, along with those having a direct connection between swim bladder and ear, have been called "hearing specialists". Although it is difficult to compare hearing

capabilities in air and water, the hearing sensitivity of hearing specialists is similar to that of other vertebrates after standardization of units (Popper and Fay 1993).

Most of the acoustic energy from airgun arrays is at frequencies below 200 Hz, with significant energy up to at least 500 Hz (Greene and Richardson 1988). As shown below, the lowest (best) hearing thresholds for some of the kinds of fish occurring in the study area are below 500 Hz (Fay 1988). There is great diversity in the hearing abilities of different species of fish (Table F5; Popper and Fay 1993). Some of this is no doubt real, but some is attributable to differences in measurement procedures. Three audiograms are available for cod; the sound pressure levels at the most sensitive frequency varies by 30 dB. Yellowfin tuna may not be very sensitive to sound; their threshold is 110 dB, a high (poor) value (Table F5).

TABLE F5.   Best hearing thresholds (in dB re 1 μPa) for various species of fish in the 100 to 400 Hz range (compiled from Fay 1988).

Species	Best Threshold <400 Hz	Hearing Threshold at Best Hearing
Cod	95 dB	95 dB @ 283 Hz
"	75 dB	75 dB @ 160 Hz
"	65 dB	65 dB @ 150 Hz
Pollack	81 dB	81 dB @ 160 Hz
Plaice	100 dB	100 dB @ 160 Hz
Dab	89 dB	89 dB @ 110 Hz
Yellowfin Tuna	110 dB	107 dB @ 500 Hz

Because of this diversity in hearing abilities, one cannot make all-encompassing statements about the ability of fish to detect sounds at a particular frequency and/or received level. However, it is clear that many species of fish, including some of those occurring in the study area, can hear low-frequency sound pulses such as those created by airguns.

Review of Known and Potential Effects

Physical Effects on Fish

Shock waves can injure or kill both invertebrates and fish. The damage caused by a shock wave varies greatly with the source and with the type of animal. The shock waves produced by high explosives are more damaging than are those produced by airguns.

It is the very short rise time of the overpressure caused by high explosives that kill fish and other marine animals. Most blast injuries in fish and other marine animals involve damage to air- or gas-containing organs (Yelverton 1981). Many species of fish have a swim bladder, which is a gas-filled organ used to control buoyancy. Fish with swim bladders are vulnerable to effects of explosives while fish without swim bladders and invertebrates are much more resistant (Yelverton 1981; Young 1991). During exposure to shock waves, the swim bladder oscillates and may rupture, in turn causing haemorrhages in nearby organs. In the extreme case, the oscillating swim bladder may rupture the body wall of the fish (Yelverton 1981). After a blast, most fish that die do so within 1 to 4 h, and almost all do so within 24 h (Yelverton et al. 1975; Yelverton 1981).

Pressure pulses from black powder and airguns have slower rise times and cause relatively little injury to fish (Hubbs and Rechnitzer 1952). Non-explosive seismic energy sources and black powder produce pulses with rise times of about 5 to 8 ms (Hubbs and Rechnitzer 1952; Parrott 1991; McCauley 1994). High explosives have shorter rise times of < 0.2 ms and pulse durations of about 2 ms (Hubbs and Rechnitzer 1952; Wiley et al. 1981). For high explosives, mortality of fish correlates better with impulse, measured in units of pressure·time (Pa·s), than with other blast parameters (Yelverton 1981). The received impulse depends on the mass of the charge, the depth of the charge, the distance from charge to fish, and the depth of the fish. The peak pressure generated by an airgun array is smaller than that produced by small charge of high explosive, but the duration of the pulse is much longer. Hence, the impulse in Pa·s, which integrates pressure over time, cannot be used in comparisons of airgun and high explosive sources. Experiments with airguns have shown that energy flux density ($Pa^2 \cdot s$) usually is a better predictor of effects on fish eggs and larvae than is peak pressure; however, peak pressure is a good predictor of effects on swim bladders (Holliday et al. 1987). For these reasons, the large amount of literature on effects of high explosives cannot be applied seismic pulses. However, information based on tests with black powder is at least partly relevant.

Hubbs and Rechnitzer (1952) conducted a series of 67 experiments on the effects of black powder explosives on caged fish of various sizes. Anchovy, the smallest species tested, were killed in 3 of the experiments; four of five anchovy on the bottom 4.3 m from a 4.5 kg bottom explosion were killed and 2 of 7 anchovy on the surface 10 m from this blast were killed. Eight of nine anchovy on the surface were killed by detonation of an 18 kg charge on the bottom at 29 m depth. Peak pressure was measured in 17 of the experiments. No mortality of caged fish (including anchovy) was observed at received peak pressures (0-p) of up to 241 dB re 1 µPa (1,103 kPa; 160 psi).

Falk and Lawrence (1973) exposed adult Arctic cisco and other small coregonids with swim bladders to a 300 in³ airgun operating at 2,000 to 2,200 psi. No mortalities were observed, but some fish sustained damage to the swim bladder. Based on this damage, they concluded that the lethal radius of the airgun was between 0.6 and 1.5 m (226 - 234 dB r 1 µPa; Turnpenny and Nedwell 1994).

Weinhold and Weaver (1982) tested effects on salmon smolts (130 mm, 25 g). Nineteen of twenty fish survived exposure to pressures of 70 to 166 psi (483-1,144 kPa; 234 to 241 dB re 1 µPa) at a distance of 1 m from airguns.

Holliday et al. (1987) conducted experiments on larval and adult anchovies that included examination of lethal and other effects. Yolk sac larvae (2 d old) were the most sensitive stage to the release of seismic energy. The results showed that peak (0-p) pressures of 217 to 220 dB re 1 μPa (75 to 100 kPa) had detrimental effects on anchovy.

Stage	Effect	Notes	Peak Pressure[1] (kPa)
Larvae	50% Mortality	2 d old	100
		4 d old	75
Adults (100 mm)	Swim bladder Damage	none	40
		damage	90

[1]. Approximate values

Dalen and Knudsen (1986) exposed Atlantic cod eggs, larvae and fry to airguns. There were no effects on eggs, larvae and fry at a distance of 1 m from a 640 cm^3 (40 in^3) airgun where received levels were 222 dB re 1 μPa_{0-p} (126 kPa). Only fry that were 110 days old were exposed to received levels of 231 dB re 1 μPa_{0-p} (355 kPa·m) from a 8610 cm^3 (525 in^3) airgun; all survived.

Kostyuchenko (1973) exposed eggs and fish larvae to a 5 L (305 in^3) airgun operating at 2,000 psi (source level ≈230 dB re 1 μPa_{0-p} or 316 kPa·m; received level 216 dB re 1 μPa or 63 kPa at 5 m). Pulses from the airgun damaged larvae mainly within a radius of 5 m. Eggs of the anchovy, the most sensitive species tested, were much affected at distances of 0.5 m from the source. There was some damage to anchovy eggs exposed at 5 m distance, but survival of those at 10 m distance (≈210 dB re 1 μPa_{0-p}) was close to that of control eggs.

In a review of the subject, Turnpenny and Nedwell (1994) summarize physical effects of noise on fish as follows:

Effect	dB re 1 μPa_{0-p}
Transient stunning	192
Internal Injuries	220
Egg/larval damage	220
Fish mortality	230-240

From the viewpoint of a fish or other sound receiver in the far field, an airgun array can be considered as a point source. However, when considering effects in the near field, each airgun is a separate source. Airguns in the array are typically spaced 3 m apart along a cable, and the different cables are typically 8 m apart. The smallest single airgun in the array may be about 30 in^3 and the largest about 290 in^3. There are sub-arrays of three airguns at the head of each cable. The largest of these subarrays consists of three 235 in^3 airguns arranged 0.8 m apart. This subarray produces 236.6 dB re 1 $\mu Pa·m_{0-p}$. From the above discussion, lethal effects on eggs, larvae and adult fish can be expected at the following peak pressures. The distances at which these pressures can be expected from the 3 x 235 in^3 sub-array and 300 and 30 in^3 airguns are also shown.

Fish Life Stage	Pressure $_{0-P}$		Airgun Size		
			3x235 in^3	300 in^3	30 in^3
	kPa	dB re 1 µPa	Dist(m)	Dist (m)	Dist (m)
Eggs	65	220	6.5	3	1.5
Larvae	65	220	6.5	3	1.5
Adult fish	1100	240	<1	<1	<1

Adult fish would not be injured by the airguns in the array unless they were immediately adjacent to an airgun. Prior to coming that close to the airguns, it is likely that fish would be driven away by the approaching noise source (Turnpenny and Nedwell 1994). Small fish could be injured at distances up to 1.5 to 3 m from individual airguns.

Direct impacts of seismic exploration on adult fish should be *negligible*.

Females of most commercial species produce 10s to 100s of thousands of eggs (Cushing 1968). For example, a female cod can produce 500,000 to 1,000,000 eggs. Natural mortality of fish larvae is very high. A small change in the survival rate of larvae can have a very large effect on recruitment to the adult population. The concern is that seismic exploration could kill a significant number of fish larvae and affect populations.

Eggs and larvae could be damaged at 1.5 to 3 m below individual airguns. Some mortality of eggs and larvae could occur up to 5.5 m below the largest sub-array. Assuming the lethal peak levels cited above, a lethal range for eggs and larvae was computed for each gun in the array. The lethal radii overlap along a string of airguns and between the two largest guns at the head of each string. Allowing for this overlap, the combined volume of water containing lethal sound levels for larvae was estimated at 1,965 m^3 per shot. Assuming that a shot was fired every 12 s and that the array operated for 35% of the time over a 150 d field season, then a total of about 743 km^3 of water would be affected by impulses lethal to fish eggs and larvae. Given an average depth of 50 m, the approximate volume of water in the 1998 exploration area is about 63,500 km^3. A volume of water equivalent to about 1 % of the volume of water in the study area would contain impulses lethal to fish larvae. During the 7 month operating season the array would be towed through dense patches of fish larvae and also though water with few or no fish larvae present and so, on average, the array will pass through an equivalent of 'average' concentrations of fish larvae in the area. Fewer than 1% of fish larvae in this volume of water would be exposed to lethal peak levels. Herring spawning occurs close to shore in very shallow water and eggs would not be affected by seismic exploration. Very few herring larvae are found on the shelf. During the day, pollock, redfish, flatfish and mackerel larvae tend to be found at or below the thermocline and few would be found in surface waters. Summer spawning of haddock may be negligible on the Scotian Shelf. At night, the larvae of mackerel and redfish and other species do rise in the water column and are found in surface waters. Silver hake larvae are concentrated in surface waters, but cusk larvae are not. Lethal ranges for flatfish larvae, which have no swim bladders, would be considerably less than those used in these calculations. Thus, considerably fewer than 1% of fish larvae in the potentially affected water mass would be affected by seismic pulses.

Impacts on fish larvae, including those in nursery areas, would be *minor, sub-local* and *short-term* and *likely* to occur.

Exposure to continuous sounds of 180 dB re 1 μPa $_{rms}$ for 1 to 5 h at an individual frequency between 20 and 400 Hz can cause damage to the sensory hair cells that are the fundamental sound receptors in fish (Enger 1981; Hastings et al. 1996). Hastings et al. (1996) found that continuous exposure to 300 Hz sounds at this received level caused damage to the sensory hairs. There was no damage to the lateral line or to other hearing structures. Exposure to sounds at 60 Hz or to pulsed sounds (20% duty cycle) of 180 dB re 1 μPa for 1 h did not have this effect. The array produces a 20 ms pulse every 12 s (0.2% duty cycle) while the array is operating. The array operates about 30 to 40% of the time. Broadband sounds at or above 180 dB re 1 μPa $_{rms}$ would be experienced within 1,500 m of the array. The array is towed at a speed of 6.5 to 10 km/h. Stationary fish would be exposed to broadband sounds of 180 dB or greater with a 0.2% duty cycle for about 20 to 25 minutes.

Impacts on fish hearing are likely to be *negligible.*

Effects on Invertebrates

Single airguns of 1,000 to 3,000 cm^3 (60 to 180 in^3) and arrays of these airguns with source levels of 220 - 240 dB re 1 μPa·m$_{0-P}$ had no effect on phytoplankton or benthos at distances of 1 m or more (Kosheleva 1992 cited in Turnpenny and Nedwell 1994). Stage II zoeae of the Dungeness crab were not affected by exposures up to 231 dB re 1 μPa $_{0-P}$ (Pearson et al. 1988). Exposure did not affect survival, development or behaviour.

Direct physical impacts on invertebrates and their larvae are likely to be *negligible.*

Most invertebrates may have vibration sensors and do react to vibration and pressure changes (Horridge 1966; Frings and Frings 1967; Lenz et al. 1996; Wiese 1996). Schooling species, such as euphausiids, use these receptors to maintain school structure (Wiese 1996). Many invertebrates produce sound (Moulton 1964) and have receptors that can detect sounds. Invertebrates may not be able to hear in the strict sense of the word, but they sense the associated particle motion (Budelmann 1996). Seismic pulses may trigger escape responses from zooplankters. Sound pressure levels necessary to elicit such a response are unknown. Reactions are likely to decrease as the rise time of the pulse increases with increasing distance from the source.

Impacts on invertebrate larvae and plankton as they relate to feeding by fish are likely to be *negligible.*

Most invertebrates may only perceive pulses in the near field at distances within about 20 m (McCauley 1994). Behavioural reactions by invertebrates that react to the pulses may be limited to a tail flip or closing of the shell in molluscs (McCauley 1994). Steffe and Murphy (1992 cited in McCauley 1994) found no gross effects on the catch rate of shrimp before and after seismic shooting off Australia.

Copepods use well developed 'hearing' receptors to detect predators and flee (Hartline et al. 1996; Wong 1996). They may be able to detect far-field sounds emitted by a seismic array. One species of squid was attracted by 600 Hz pure tones at a source level of 160 dB, increasing the catch (Maniwa 1976 cited in McCauley 1994). Their response to seismic sounds is unknown (McCauley 1994).

Impacts on invertebrate behaviour and related impacts on fisheries are likely to be *negligible*.

Disturbance Effects on Fish

Underwater noise can scare some fish. Sudden changes in noise level can cause fish to dive or to avoid the sound by changing direction. Time of year, whether or not the fish have eaten, and the nature of the sound all may determine whether fish will react to underwater noise.

Short, sharp sounds can startle herring. In one study, the fish changed direction and moved away from the source, but schooling behaviour was not affected (Blaxter et al. 1981). The fish reacted to sounds of 144 dB re 1 µPa at 80 or 92 Hz. However, when the sound was "ramped up", sounds needed to be 5 dB higher to elicit the same response.

Schwarz and Greer (1984) studied the responses of penned herring to vessel and echosounder sounds. Recorded sounds were played back from a projector just outside of a 3.3 x 3.3 m experimental pen. Received sound levels in the center of the pen were 105 to 111 dB re 1 µPa. The kinds of responses noted by Schwarz and Greer (1984) were

- avoidance, in which the fish formed a compact school and moved slowly away from the sound source,

- alarm, in which the school packed, fled at high speed, dove repeatedly, and quickly changed directions, and

- startle, in which fish flexed their bodies powerfully and then swam at high speed for 5 to 10 s without changing direction, school formation was not affected.

Schwartz and Greer did not observe startle response to any playback sounds. The sounds of large vessels or accelerating small vessels mainly caused avoidance responses among the herring. The startle response was occasionally observed in response to other stimuli. Avoidance ended within 10 s of the "departure" of the vessel. When sounds were of equal received level, sounds of a larger vessel (dominated by lower frequencies) elicited a stronger reaction. The herring did not react to a 28 kHz echosounder or a 165 kHz sonar. Twenty five percent of the fish groups habituated to the sound of the large vessel and 75% of the responsive fish groups habituated to the sound of the small boat. Chapman and Hawkins (1969) also noted that fish adjust rapidly to high sound levels.

The reactions of fish to ship sounds in the field have been measured with forward looking sonars and downward looking echosounders. The results of these experiments are of considerable value in estimating the responses of fish to seismic sounds. The broadcast pattern for ship sounds is similar to that of sounds emitted by a seismic array. Sound produced by a ship varies with aspect and is lowest directly ahead of the ship and highest within butterfly-shaped lobes to the side of the ship (Misund et al.

1996). Because of this directivity, fish that react to ship sounds by swimming in the same direction as the ship will be guided ahead of it (Misund 1997). In other instances, fish will avoid the ship by swimming away from the path and will become relatively concentrated to the side of the ship (Misund 1997). Most schools of fish will not show avoidance if they are not in the path of the vessel. When the vessel passes over fish, some species, in some cases, show sudden escape responses that include lateral avoidance and/or downward compression of the school (Misund 1997). Avoidance reactions are quite variable and depend on species, life history stage, behaviour, time of day, whether the fish have fed, and sound propagation characteristics of the water (Misund 1997).

Effects of Seismic Sounds on Fisheries.--Chapman and Hawkins (1969) tested the reactions of whiting (hake) in the wild to an airgun emitting low-frequency, high-amplitude pulses (220 dB re 1 $\mu Pa \cdot m_{0-p}$). The research vessel was anchored and the school of whiting was observed with an echosounder. The airgun fired intermittently. Before the airgun was fired, the fish were at 25 to 55 m depth. In response to the sound pulses, the fish dove and formed a compact layer below 55 m water depth. By the end of an hour of exposure to the sound pulses, the fish had habituated; they rose in the water despite the continued presence of the sound pulses. The airgun was switched off and, when it resumed firing, the fish began to descend again. The habituation seems to have been of short duration. The behaviour of the fish in diving and forming a compact layer resembles the alarm response described by Schwarz and Greer (1984). Assuming spherical spreading from the single airgun, received levels would have been 192 dB re 1 μPa at 25 m and 185 dB at 55 m.

Pearson et al. (1992) conducted a controlled experiment to determine the effects of airgun noise pulses on several species of rockfish off the California coast. They used an airgun with a source level of 223 dB re 1 μPa (0-pk). They noted

- startle responses at received levels of 200-205 dB re 1 μPa and above for two sensitive species, but not for two other species exposed to levels up to 207 dB;

- alarm responses at 177-180 dB for the two sensitive species, and at 186 to 199 dB for other species;

- an overall threshold for the above behavioural response at about 180 dB_{0-p};

- an extrapolated threshold of about 161 dB for subtle changes in the behaviour of rockfish; and

- a return to pre-exposure behaviours within the 20-60 min exposure period.

The startle response was as noted above, but in some cases, fish also shuddered with each pulse.

In a concurrent experiment, Skalski et al. (1992) used a 100 in^3 airgun with a source level of 223 dB_{0-p} re 1 $\mu Pa \cdot m$ to examine effects on catch per unit effort (CPUE) of rockfish. The ship with the airgun traversed the trial fishing area and then stood off while the fishing vessel deployed a set line, did three echosounder transects, and then deployed two more set lines, each for 20 min. Each fishing experiment lasted 1 h 25 min. Received levels at the base of the rockfish aggregations were 186 to 191 dB re 1 μPa_{0-p}. Skalski et al. noted that the catch per unit effort (CPUE) of rockfish declined by an average of 52.4% when airgun pulses were emitted. They believed that the reduction in catch resulted from a change in behaviour of the fish. The fish schools descended to near the bottom when the airgun

was firing, and the fish changed their swimming and schooling behaviour. The fish did not disperse, but the authors hypothesized that dispersal could have occurred at a different location with a different bottom type.

Skalski et al. (1992) did not continue fishing after airgun firing ceased. They speculated that CPUE would return to normal quickly in their experimental area because fish behaviour returned to normal minutes after the sounds ceased. However, in an area where sound had caused the fish to disperse, a lowered CPUE might persist.

Løkkeborg (1991; cited in Turnpenny and Nedwell 1994) investigated longline catches off Northern Norway in the presence of a two-week seismic survey over 185 m of water that used 4 sleeve guns with peak source levels of 238 dB re 1 µPa·m. Catch was reduced by 55 to 80% within the survey area and there was some reduction in catch to a distance of 5 km (estimated received levels of 161 dB). Catches returned to normal with 24 h. In the same area, over water depths of 150-300 m, Løkkeborg and Soldal (1993) investigated effects of seismic shooting with arrays having source levels of about 239-250 dB re 1 µPa·m, as estimated by Turnpenny and Nedwell (1994). Trawls were made before and during shooting. Cod catches during shooting were reduced by 79-83% compared to pre-shooting levels within the exploration area and within 9 km of it (Turnpenny and Nedwell 1994 estimated received levels of 160-171 dB). In another area, catch of cod increased by a factor of three during shooting in the exploration area when bad weather caused a reduction in shooting time to only a few hours. The fish may have been driven to the bottom and more easily caught by the trawl. Catches returned to normal within 12 h of cessation of seismic operations.

Turnpenny and Nedwell (1994) report on effects of seismic shooting on inshore bass fisheries in shallow U.K. waters (5-30 m). They used tagged fish and catch records. There was no reduction in bass catch on days when shooting took place. Results of the tagging study showed no migration out of the area. The array had a peak output of 250 dB re 1 µPa·m. Received levels in the fishing areas were estimated to have been 163 - 191 dB_{0-p}.

Dalen and Knutsen (1986) examined the effects on fish of a 4,752 in^3 airgun array operating at 2,000 psi with a peak output of 250 dB re 1 µPa·m. Estimated peak pressures at bottom depths of 100 to 300 m were 200 to 210 dB re µPa. Shooting was conducted over a period of 6 d within an area of 6 x 10 nmi. Fish were sampled with an echosounder along 105 transects before shooting and 110 transects after shooting in the exploration area and in eight adjacent blocks. In contrast to results of the study described in the following paragraph, there was no significant difference in abundance of small pelagic fish, blue whiting or demersal fish before and after shooting in all areas combined. Within the exploration area, there was a marked reduction in echosounder abundance of demersal species. However, the two trawl catches made within the exploration area after shooting caught 34 and 290 % more fish than the pre-shooting trawls, indicating that the fish were forced to the bottom and had not migrated out of the area. Blue whiting, a pelagic species, migrated out of the exploration area into blocks immediately adjacent to it. There was no discernible change in the distribution of small pelagic fish, possibly because the overall abundance of these fish was low throughout the period.

Experiments on the effects of seismic shooting on abundance and catch of cod and haddock were conducted in the Barents Sea by Engås et al. (1993, 1996). The exploration area was 3 x 10 n.mi. in size at the centre of a 40 x 40 n.mi. (74 X 74 km) study area over water depths of 250 to 280 m. The array consisted of 18 airguns with a total volume of 5,000 in^3 operating at 2,000 psi and a depth of 6 m. The maximum downward source level, corrected for directivity based on field measurements, was 253 dB (± 3 dB) re 1 μPa_{0-p} at 1 m. Shooting was conducted for 5 d. Fish abundance was measured with longlines, trawls and echosounders for 7 d prior to shooting, during the 5 d with shooting, and for 5 d after shooting ceased.

Acoustic density of cod and haddock combined decreased over the entire study area by 45% during the shooting and 64% during the 5 d period after shooting ceased. More than 90% of the trawl catch was cod. During shooting, catch in the shooting area decreased by 60%, and catch in the other areas (up to 18 km from the exploration area) decreased by 45 to 50%. Catch rates did not recover during the 5 d period after shooting ended. For haddock, the trawl catch in the exploration area declined by 68% and that in other areas by 56 to 71%. The longline catch for cod declined by 45% in the exploration area, but the decline was smaller with increasing distance from the exploration area, with no reduction in catch at distances of 16 to 18 nmi from it. Catches increased after cessation of shooting. Declines in the longline catches of haddock were greatest in the exploration area and less so outside of the exploration area. There was a change in the size distribution of fish. Cod > 60 cm in length nearly disappeared from the trawl and longline catches and large haddock became scarcer in the longline catches, but not in the trawl catches. There was no change in the content of food in stomachs of both cod and haddock during the period. Between 91 and 95% of cod in trawls and 73 to 79% of cod in longlines had empty stomachs (Engås et al. 1993). Ignoring bait, the degree of stomach fullness was low (1.1 for cod and 1.55 for haddock, where 5 = full) and did not change for either species over the period of the study. The observed decrease in catch occurred immediately after shooting began. The change in fish distribution was so rapid that it was not observed in the catch data. No outward movement of large numbers of fish were detected. Engås et al. (1996) believed that there was no evident diminution of effect with increasing distance because the study area was too small.

Engås et al. (1996) did not measure received sound levels within their study area. Peak source level was 253 dB re 1 μPa at 1 m. Received levels on the bottom under the array would have been about 205 dB. Sounds from an array are directed downward and effective source levels in the horizontal direction are variable, but at the horizontal azimuth of greatest effective source level, which is abeam of the array, the effective source level would have been about 10 dB lower or about 243 dB re 1 μPa_{0-p}. Assuming simple spherical spreading to a distance equivalent to the depth and then cylindrical spreading, received levels at 18 km could have been about 178 dB re 1 μPa. This would mean a transmission loss of 67 dB over 18 km. Greene and Richardson (1988) added a site-specific term to account for scattering and absorption losses. For water depths of 20 - 100 m this term was 0.61dB/km. If this term also applied in the Norwegian study area, received levels at 18 km would have been 167 dB and the transmission loss would have been 77 dB. In a preceding section, we predict a loss of 72 to 75 dB over 18 km on the Scotian Shelf. Off Australia, transmission loss was 111 dB over 18 km over water depths of 100-120 m from a 2,700 in^3 array with peak output of 252 dB re 1 $\mu Pa \cdot m$ (received level at 18 km was 141 dB re 1 μPa_{0-p}; McCauley et al. 1997). This transmission loss was about 40 dB greater than

that predicted by a simple spherical/cylindrical spreading model. Off California, where transmission loss is very high, received levels from a 4,000 in³ 20 gun array over 3,100 m of water were only 154 dB re $1\mu Pa_{0-p}$ at 18 km (Malme and Miles 1985). Spreading here was further enhanced by the deep water. Given the kind of variability in spreading loss from area to area, it is not possible to estimate what actual received levels could have been using a simple spherical/cylindrical spreading model.

The study conducted by Engås et al. (1996) is the only one to report effects over such a large area and to show no recovery in catches. A standard array was used and shooting was conducted over a 5 d period. Results of this experiment seem to contradict the others cited above, where fish were forced to the bottom and catches returned to normal soon after cessation of shooting. It is useful to compare results obtained by Dalen and Knutsen (1986) with those obtained by Engås et al. (1996). Array size, shooting time, water depth, size of the exploration and study areas, and methods were similar in the two studies. Dalen and Knudsen showed migration of one of three species groups out of the seismic exploration area. However, abundance of this species was high in areas immediately adjacent to the exploration area. Demersal species, including cod and haddock, became concentrated on the bottom, but did not vacate the area.

Turnpenny and Nedwell (1994) conclude that effects on fisheries would be smaller in shallow nearshore waters than in deep water because attenuation of sound is more rapid in shallow water than in deep water. As described above, their study of showed no effects on fisheries in nearshore waters.

Only the study conducted by Chapman and Hawkins (1969) addressed habituation. They found that fish habituated to seismic sounds quickly over the long term. The other studies did not address long-term habituation. Only Chapman and Hawkins (1969) and Skalski et al. (1992) followed the behaviour of individual schools of fish and found no short-term displacement. With the exception of the California studies of rockfish, investigators did not measure received noise levels. Thus, it is not possible to say, with any certainty, what sound levels could cause reduction in catchability cod and haddock. Turnpenny and Nedwell (1994) conclude that the results of the studies on rockfish and extrapolated results form other studies indicate that catchability is reduced when received sound levels exceed 160 to 180 dB_{0-p} and that reaction thresholds of fish without swim bladders, such as flatfish, would be about 20 dB higher than 160 to 180 dB. However, this is true only of rockfish for received levels of 180 dB_{0-p}. Given the variability in transmission loss in different areas, we do not know what levels were received by the fish observed in the other studies.

Seismic streamers are several kilometres in length. Fishermen cannot fish in the immediate vicinity of a seismic program or, alternatively, seismic shooting cannot be conducted in the presence of fishing. Overall peak pressures are predicted to fall to 180 dB within 5 km of the airgun array and to 160 dB within 13 km. The streamers are typically about 4.6 km long. Thus, fishing and seismic operations cannot occur in close proximity to each other. There may be some reduction in catch in the vicinity of the exploration area.

Impacts on catch due to presence of the array and associated noise in typical shooting area are predicted to be *minor, sub-local, short-term* and *likely* to occur.

The 1998 seismic exploration program will occur in NAFO area 4Wf. In 1996, this statistical area had the lowest catch of any statistical area on the Scotian Shelf (Table 3). The 1998 exploration area does not appear to have been heavily fished in previous years (Appendix Figures 2-50 to 2-56. The 1998 exploration area is not within any restricted fishing area (Figure 27). Other areas within the overall study area are more heavily fished (Figure 26, Table 3; Appendix Tables 2-46 to 2-48). In 1996, the largest catches were recorded in NAFO areas 4Xo, 4Xm, 4Vn and 4Wk. These areas are largely inshore of the study area (Figure 26). Catches were very high in areas 4VSc and 4Xn (Table 3). There is a greater potential for interactions between fishermen and seismic activities in heavily fished areas such as Brown's and Bacaro Banks (Areas 4Xn, 4Xo; Figures 46 and 47) and on the eastern edge of Banquereau Bank (Area 4VSc; Figures 46 and 47) than in some other areas. There is also a potential for interactions between lobster fishing gear and the physical presence of the large seismic array during the lobster fishing season (Appendix 2, Figure 4). Potential conflicts between fishing and seismic exploration can be resolved through communication as discussed under Procedures for Class Assessments.

Marine Mammals of the Scotian Shelf

The section describing the abundance and distribution of marine mammals was prepared by Randall R. Reeves, Okapi Wildlife Associates, 27 Chandler Lane, Hudson, Quebec, JOP 1H0. It summarizes information on the distribution, abundance, and conservation status of marine mammals on the Scotian Shelf. It is organized as a checklist of species and includes everything from year-round residents to occasional visitors. Each species account contains an overview of total distribution and some specific information about occurrence on and near the Scotian Shelf, brief comments on behaviour and ecology, and a simple assessment of conservation status in the North Atlantic. Katona et al. (1983) is recommended as a good general reference to the marine mammals of the region.

This section relies heavily on the reviews by Reeves and Brown (1994) and Whitehead et al. (1998). The first of these was prepared as background for environmental assessment, monitoring, and mitigation in relation to ship shock trials conducted by the Canadian Department of Defence in an area off the Scotian Shelf in November 1994. The second focuses on the Gully region and was prepared as background for environmental assessment in relation to oil and gas development in that area (also see Gowans and Whitehead 1995).

The present report includes several charts showing locations of observations of certain species. These charts were developed by Kenney (1994) and are re-used here with permission of the author. Robert Kenney, University of Rhode Island Graduate School of Oceanography, maintains a large database of occurrences of marine mammals, especially cetaceans, along the eastern North American continental shelf. This database, together with additional opportunistic data obtained from the Scotia-Fundy Region, DFO, Halifax, was used to plot monthly occurrences of marine mammals in the Scotian Shelf region, defined in this instance as waters west of 58°W, south of 46°N, east of 67°W, and north of 41°N. Further details concerning data sources (e.g., Sutcliffe and Brodie 1977; CETAP 1982; Winn et al. 1986) and chart production can be found in Kenney (1994). R. Kenney (pers. comm., 5 February 1998) indicated that no additional data have been entered into his database since 1994, when the charts

were originally prepared. These charts do not cover the eastern quarter of the Scotian Shelf but few data are available for this area.

Because most of the records plotted on the charts come from effort-biased data, they should not be interpreted as accurately representing marine mammal usage of the area. In other words, the absence of sightings from an area does not necessarily mean that no marine mammals occur there; it could mean only that the area has not been adequately surveyed. Similarly, densely plotted areas could mean that researchers (or whalers) repeatedly visited them, and not necessarily that they are exceptionally densely populated by marine mammals.

The DFO database of marine mammal sightings since 1994 was not accessible. The absence of these anecdotal data does not affect the validity of this environmental assessment.

The marine mammals of the Scotian Shelf region belong to three taxonomic groups: the toothed cetaceans (odontocetes, including the dolphins, porpoises and some whales), the baleen whales (mysticetes), and the true seals (phocids).

Odontocete Cetaceans

Sperm Whale *Physeter macrocephalus*

Sperm whales are the largest toothed whales, with an extensive worldwide distribution (Rice 1989). They are relatively common in the Scotian Shelf region, primarily in water 200-1500 m deep (Whitehead, Brennan and Grover 1992; Figure 28). According to Whitehead et al. (1998), the distinctive clicks of sperm whales can be heard much of the time in the basin at the northern end of the Gully where water is 200-400 m deep. These authors also note that sperm whales are consistently seen in the Gully throughout the summer and that they are probably present in the area during much of the rest of the year as well. Parsons (1995) reported numerous visual and acoustic detections of sperm whales in deep waters off the Scotian Shelf in November.

Mature males generally occur at higher latitudes than females and juveniles. Although immature males and groups of females are at least occasionally present, most of the sperm whales observed in the Scotian Shelf region have been maturing or adult males, 12.5-15.5 m long (Mitchell 1975a; Whitehead et al. 1992, 1998; Reeves and Whitehead 1997).

Sperm whales routinely dive to depths of hundreds of meters and may occasionally dive to more than 3000 m. They apparently are capable of remaining submerged for longer than two hours, but most dives probably last a half-hour or less (Rice 1989). Sperm whales on the Scotian Shelf sometimes spend well over an hour at or near the surface, without diving (Whitehead et al. 1992). The diet of sperm whales is dominated by mesopelagic and benthic squids and fishes.

If the acoustic behavior of two male sperm whales tracked on the Scotian Shelf in June 1986 can be considered typical of the species in this area (see Mullins et al. 1988), then one can expect most individuals to (1) click continuously for periods of 30-50 min while diving, (2) remain largely silent for
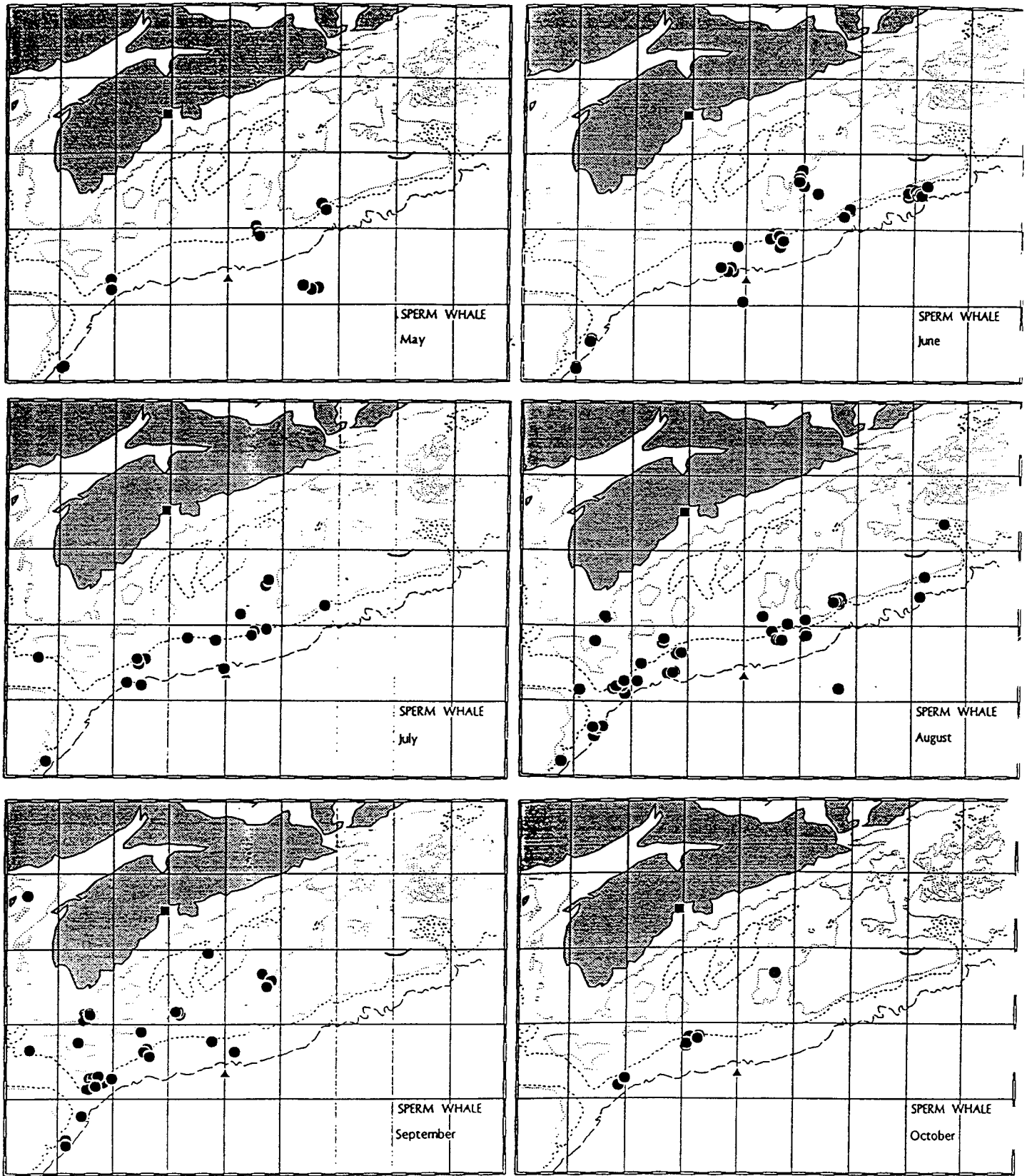
Figure 28. Sperm Whale.

6-30 min between bouts of continuous clicking, and (3) move along depth contours while submerged, at speeds of about 2 knots. The whales may spend about two thirds of their time below the surface, with 30-min dives separated by 9-min periods ventilating at the surface (Mullins et al. 1988; also see Whitehead et al. 1992). Sperm whales respond to man-made underwater sounds (Backus and Schevill 1966; Watkins and Schevill 1975; Watkins et al. 1985; see Reeves 1992 for a review).

The sperm whale is not a biologically endangered species, but some populations have been substantially reduced by whaling (Reeves and Whitehead 1997). No good estimate of the size of the population in the North Atlantic is available, but the total is at least a few thousand and perhaps tens of thousands. Estimates of a few hundred whales have been made for portions of the species' range off the northeastern United States, but these aerial survey estimates are negatively biased because they are not corrected to account for the sperm whale's diving behavior (Blaylock et al. 1995). Whitehead et al. (1998) estimate that 10-30 sperm whales are present in the Gully at any one time.

Pygmy and Dwarf Sperm Whales *Kogia breviceps* and *K. simus*

These two species of small whales are distributed throughout much of the world's ocean area but are poorly known (Caldwell and Caldwell 1989). Both occur on the Scotian Shelf at least occasionally (Baird et al. 1996; Whitehead et al. 1998). Pygmy sperm whales are likely to be encountered mainly in the deeper slope waters along and seaward of the shelf edge, where they feed on mesopelagic squid (McAlpine et al. 1997).

The cryptic behaviour of pygmy and dwarf sperm whales makes them difficult to observe in any but ideal sea conditions.

Although there are few useful estimates of population size for these whales, they are apparently abundant in some areas and are not considered endangered. There is no reason to believe that the Scotian Shelf is a particularly important part of their range.

Northern Bottlenose Whale *Hyperoodon ampullatus*

Northern bottlenose whales are found only in the North Atlantic, with a total population that may be in the tens of thousands (Reeves et al. 1993). They live primarily in deep canyon and slope areas where they prey on squid and deep-sea fishes. The Scotian Shelf has become well known for the bottlenose whales that were once hunted in the Gully by whalers based at Blandford, Nova Scotia, but that are now studied intensively by researchers from Dalhousie University in Halifax. Because this is the only site in the world where a long-term study of ziphiid (beaked) whales is ongoing, the Gully and adjacent Scotian Shelf region have exceptional scientific importance (Whitehead et al. 1997a, 1997b).

Female bottlenose whales are present in the Gully throughout the year, and adult males become common there in August (Whitehead et al. 1998). The deep waters of the Gully canyon (generally deeper than 500 m) are believed to represent the core area of residence for a population of about 230

bottlenose whales. At any one time, about half of that population is thought to be present in the area (Whitehead et al. 1998). Sightings data for other parts of the Scotian Shelf are shown in Figure 29.

Like sperm whales, bottlenose whales can dive for periods well in excess of one hour and to depths of more than 1000 m. They have a tendency to approach and "explore" vessels (Winn et al. 1970), and they also exhibit epimeletic behavior, i.e. they remain near an injured companion until it has died or recovered (Mead 1989a).

Although Reeves et al. (1993) concluded that, as a species, the northern bottlenose whale is not immediately threatened or endangered, the population on the Scotian Shelf, centred in the Gully, is small and potentially vulnerable to the effects of human disturbance associated with gas and oil exploration and development (Whitehead et al. 1997a). It has been forcefully argued that the Gully deserves special protection, in large part because of its importance to bottlenose whales (Faucher and Weilgart 1992).

Cuvier's Beaked Whale *Ziphius cavirostris*

This cosmopolitan species is probably the most widespread species of beaked whale (Heyning 1989). There are no confirmed records from eastern Canada, but the species may be present in the outer Scotian Shelf region in relatively low density. Its inconspicuous blow and deep-diving behavior may help explain the rarity of sightings.

Mesoplodonts - Whales of the genus *Mesoplodon*

Mesoplodonts, as a group, have a cosmopolitan distribution in non-polar waters (Mead 1989b). Of the five mesoplodont species documented from the North Atlantic, only Sowerby's beaked whale (*M. bidens*) is a North Atlantic endemic. Its occurrence on the Scotian Shelf, recently documented through sightings in the Gully and a stranding on Sable Island (Whitehead et al. 1998), was expected in view of the earlier published records from Newfoundland and the northeastern United States (Lien and Barry 1990). True's beaked whale (*M. mirus*) has been documented from eastern Nova Scotia (St. Ann's Bay; Allen 1939) and thus may also occur on and seaward of the Scotian Shelf. A sighting was recently made of Blainville's beaked whale (*M. densirostris*; identification tentative) in the Gully (Whitehead et al. 1998).

Very little is known about the behavior and ecology of the mesoplodonts (Mead 1989b). Group size is apparently small (usually less than ten). Acoustic behaviour is largely unstudied. They are probably all deep divers and occur primarily offshore of the continental shelf edge.

Due to its apparent rarity throughout its range and its "limited Canadian distribution coincidental with major shipping lanes and areas of offshore petrochemical exploration and development", Lien and Barry (1990) considered Sowerby's beaked whale "vulnerable" according to the COSEWIC classification scheme. Mesoplodonts are taken regularly in some pelagic driftnet fisheries (Blaylock
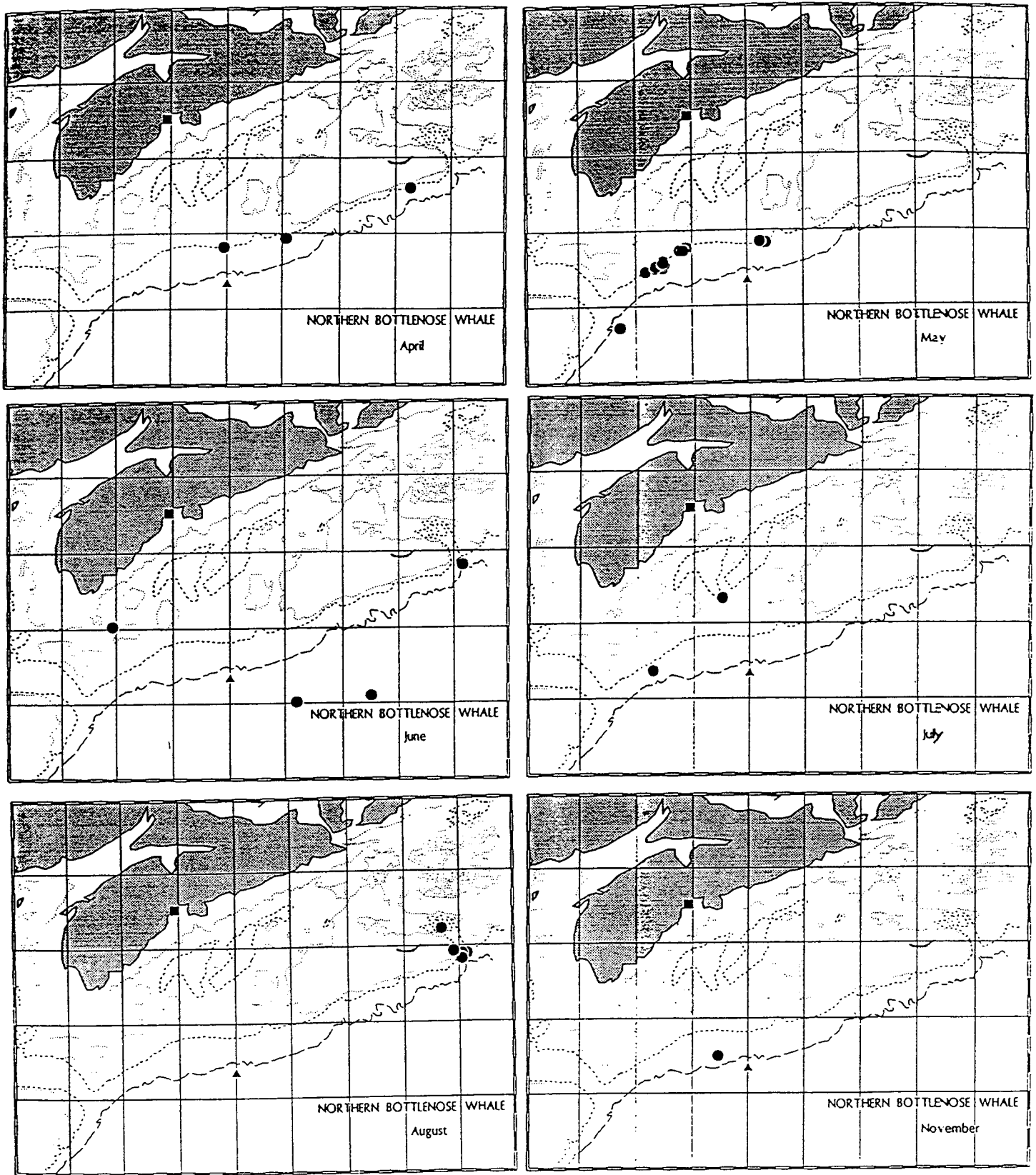
Figure 29. Northern Bottlenose Whale.

et al. 1995). U.S. scientists have estimated that there are at least a few hundred mesoplodonts in Gulf Stream-influenced waters between the 200 and 2000 m isobaths (Blaylock et al. 1995).

Killer Whale *Orcinus orca*

This cosmopolitan species occurs on and near the Scotian Shelf at least occasionally (Mitchell and Reeves 1988). Killer whales appear to be highly mobile and to occur in fairly low density in this region.

Killer whales are large and conspicuous, often travelling in close-knit groups of a few to tens of individuals. They are acoustically active (except when closing on prey), with a large repertoire of sounds (Heyning and Dahlheim 1988). At least some of the killer whales that visit eastern Canadian waters prey on other marine mammals (Whitehead and Glass 1985a; Mitchell and Reeves 1988).

On a global basis, killer whales are not endangered. There are no population estimates for the western North Atlantic, but the species seems to be relatively uncommon and scarce on the Scotian Shelf.

Long-finned Pilot Whale *Globicephala melas*

This abundant and widely distributed species is apparently fairly common on the Scotian Shelf and seaward of the shelf edge (see Figure 30; Gowans and Whitehead 1995; Blaylock et al. 1995; Whitehead et al. 1998). The density of pilot whales in the Gully increases in August (Gowans and Whitehead 1995). Strandings at Sable Island in January and February and sightings near the shelf edge in November (Parsons 1995) have been interpreted as suggesting that pilot whales are present on the Scotian Shelf year-round (Whitehead et al. 1998). In contrast, Nelson and Lien (1996) cited Sergeant (1962) and Lynch (1987) to support the statement that these whales become most common in June and again in October-November along the continental slope from the Gulf of Maine to the Laurentian Channel, along the southwest edge of the Grand Bank, and in the channel between the eastern edge of the Grand Bank and Flemish Cap. These authors suggested that the whales move away from the shelf and shelf edge in winter.

Payne and Heinemann (1993) demonstrated that pilot whales off the northeastern United States occur in shelf, shelf-edge, and slope waters, and Mate (1989) showed that individuals move across depth gradients, probably following concentrations of prey. In some areas, they occupy areas of high relief or submerged banks and are often associated with thermal fronts (Blaylock et al. 1995). In the Gully, however, Gowans and Whitehead (1995) found the distribution of pilot whales to be relatively insensitive to sea floor relief.

It is often stated that long-finned pilot whales in the western North Atlantic prey mainly on short-finned squid (*Illex illecebrosus*) in summer. This statement is based largely on evidence from inshore waters of Newfoundland (Sergeant 1962). However, they are also known to prey on a fairly
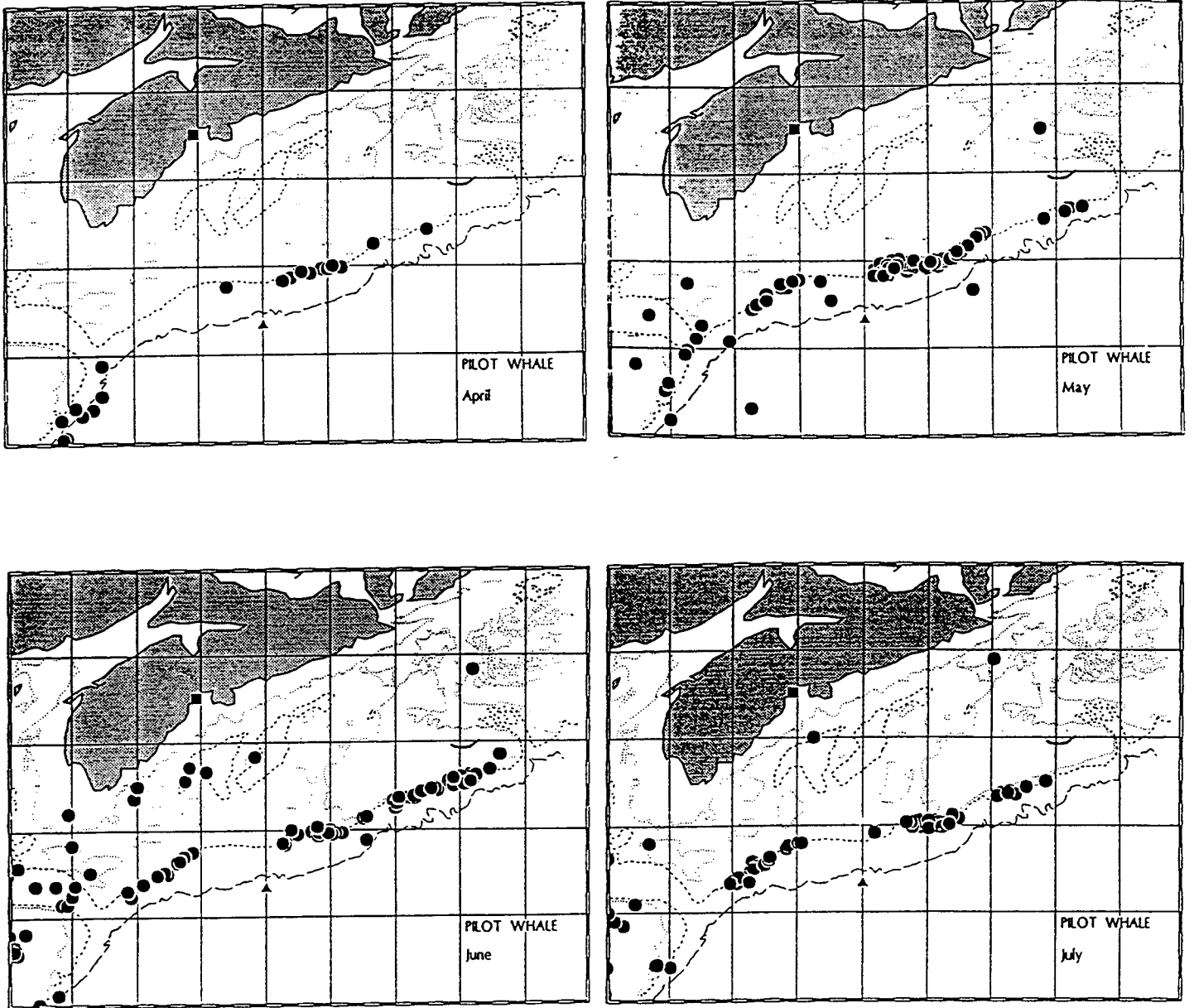
Figure 30. Long-finned Pilot Whale.
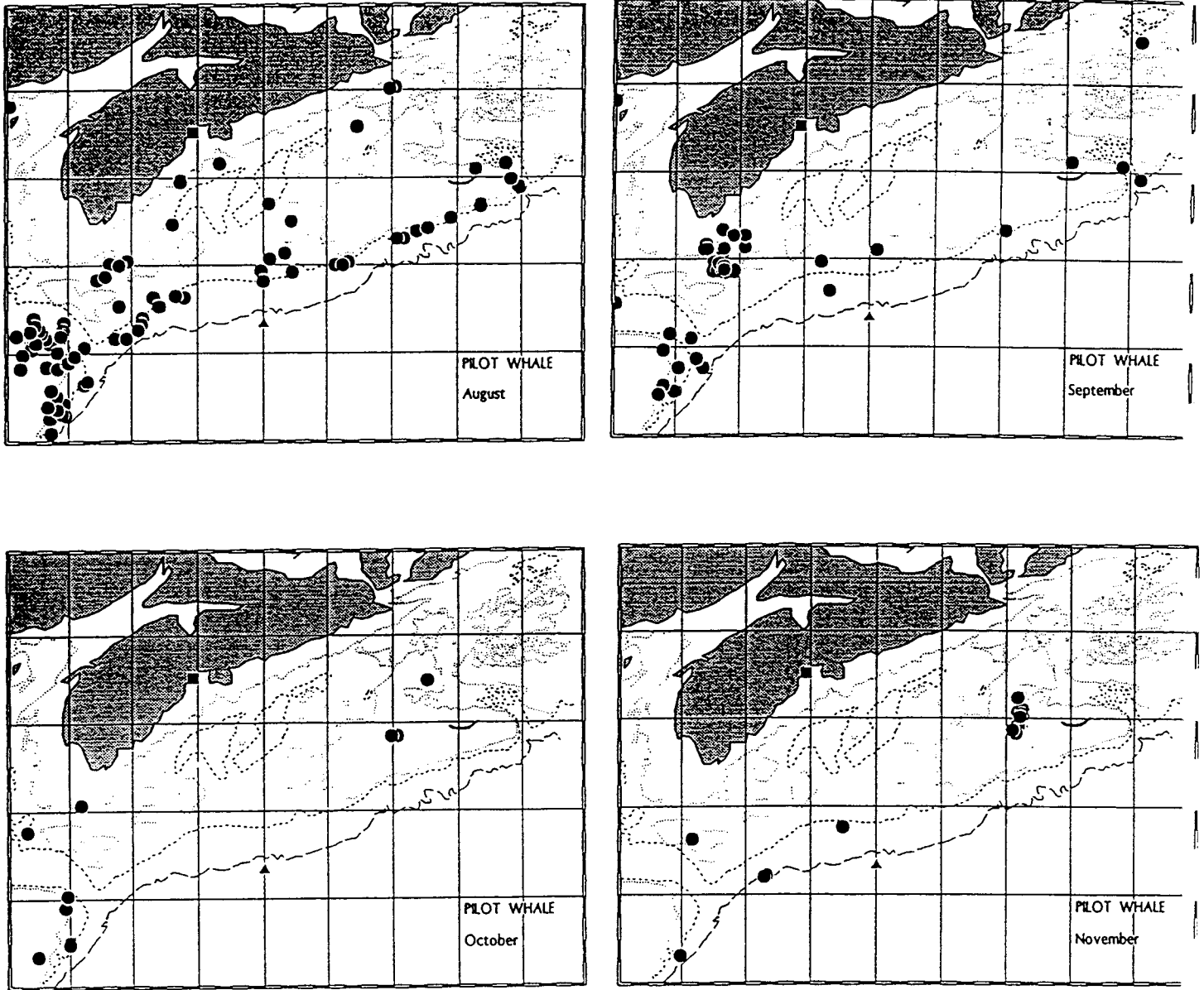
Figure 30. Long-finned Pilot Whale continued.

wide variety of fishes as well as additional species of cephalopods (especially long-finned squid, *Loligo pealei*) at other times and in other areas (Waring et al. 1990; Overholtz and Waring 1991; Desportes and Mouritsen 1993; Nelson and Lien 1996; Gannon et al. 1997).

Pilot whales are gregarious and sometimes occur in large aggregations (hundreds), but pods often consist of five to a few tens of individuals. They are frequently accompanied by cetaceans of other species. Although they are adept divers, pilot whales probably do not usually dive for periods longer than about 15 min. Pilot whales emit high-frequency whistles, usually in the frequency range of 3-5 kHz (Taruski 1979).

The species is not considered endangered even though many hundred to several thousand are killed each year in the North Atlantic by a combination of direct hunting, mainly in the Faroe Islands, and fishery by-catch (see papers in Donovan et al. 1993; Blaylock et al. 1995). An estimate of more than 700,000 animals was recently made for the northeastern Atlantic (Buckland et al. 1993), and current estimates ranging between 4000 and 12,000 have been cited for the northwestern Atlantic (Blaylock et al. 1995; Nelson and Lien 1996).

Short-beaked Common Dolphin *Delphinus delphis*

Short-beaked common dolphins (see Heyning and Perrin 1994) are at least seasonally present on the Scotian Shelf and along the shelf edge (Gaskin 1992b; Parsons 1995; Figure 31). They are considered the most abundant cetacean species in the Gully area during July and August, with numbers estimated in the thousands (Whithead et al. 1998; also see Gowans and Whitehead 1995). A north-south migration has been assumed to occur along the east coast of North America, with common dolphins moving into higher-latitude areas in summer and fall, then moving farther south (or possibly just offshore) for the winter (Selzer and Payne 1988; Gowans and Whitehead 1995). Areas with steep subsurface relief, generally in a broad band paralleling the continental slope (100-200 m depth contour), tend to have relatively high densities of short-beaked common dolphins in U.S. waters (Selzer and Payne 1988), and a broadly similar pattern exists in the Gully (Gowans and Whitehead 1995).

These dolphins often travel in fairly large groups (several hundred animals) that are relatively easy to spot at the surface. Like other delphinids, common dolphins are highly vocal (Evans 1994; also see Schevill and Watkins 1962).

Although there is no meaningful population estimate for the western North Atlantic, short-beaked common dolphins are abundant and not endangered. Estimates of abundance along the eastern United States have been as high as about 30,000 in the early 1980s (CETAP 1982). A more recent estimate for shelf-edge and slope waters from the southern edge of Georges Bank, across the Northeast Channel, to the southwestern edge of the Scotian Shelf was about 1600 (Blaylock et al. 1995). Substantial numbers of common dolphins are taken as a bycatch in offshore mackerel and squid fisheries and in pelagic drift-net and pair-trawl fisheries (see Blaylock et al. 1995).
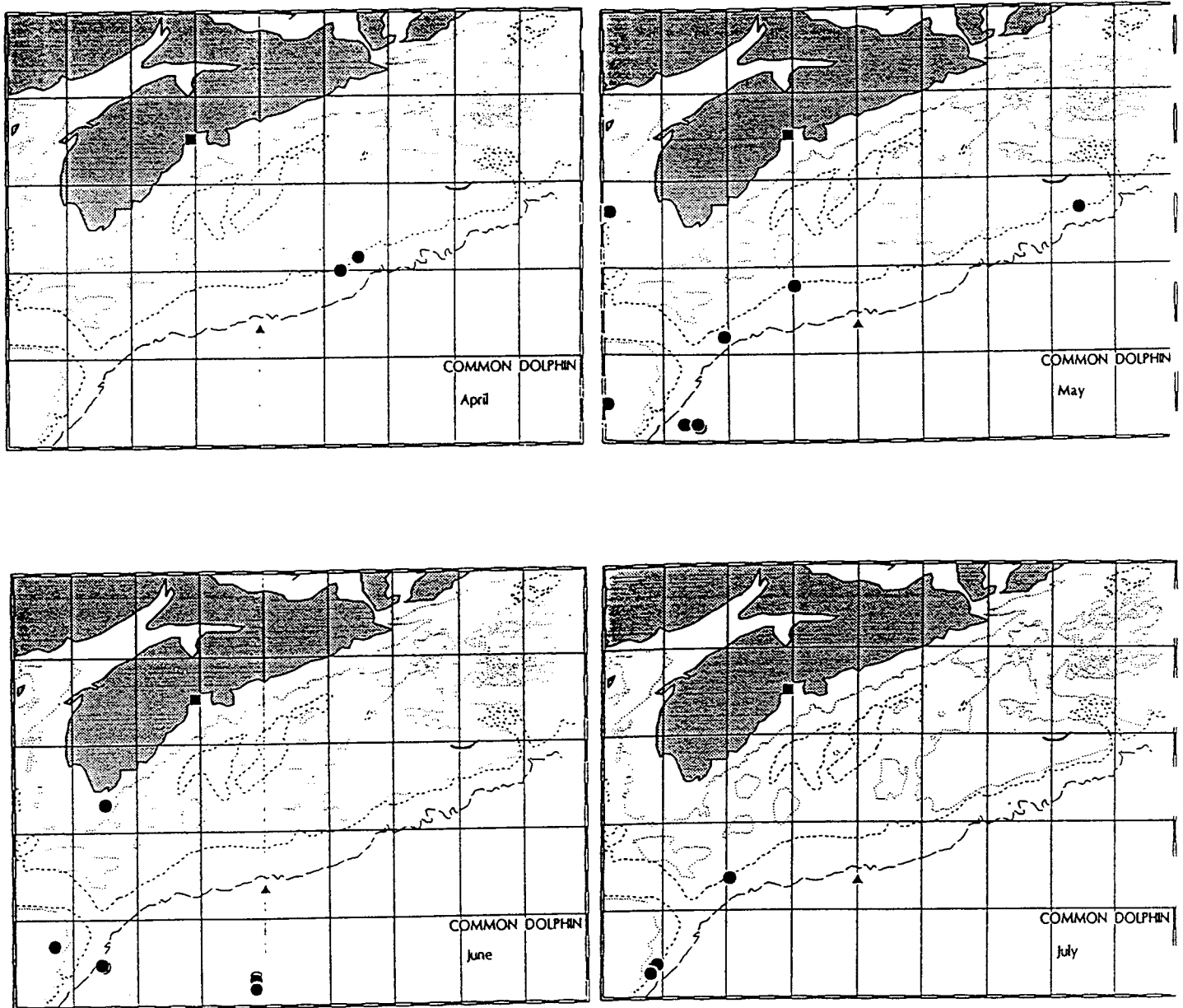
Figure 31. Short-beaked Common Dolphin.
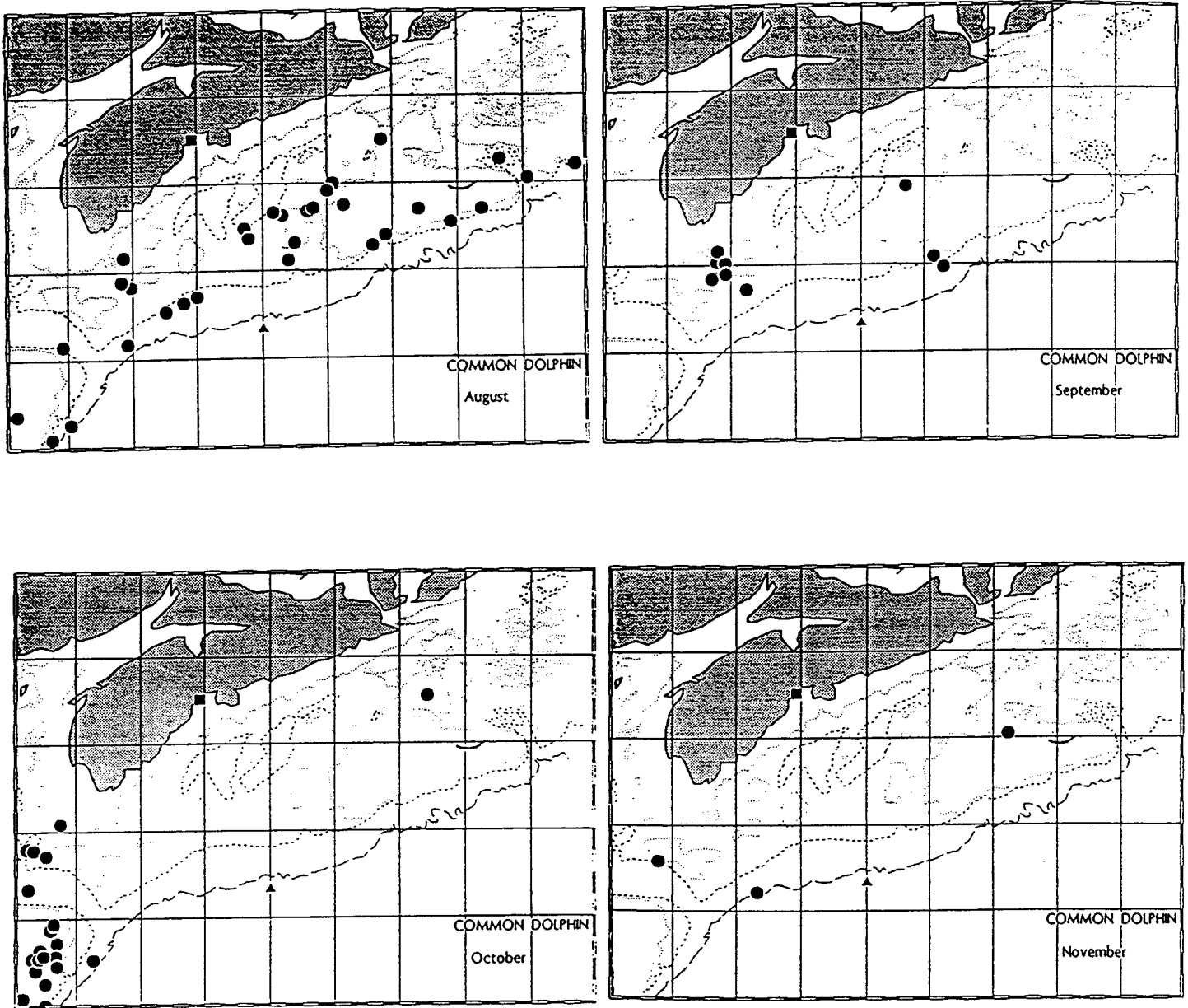
Figure 31. Short-beaked Common Dolphin continued.

Atlantic White-sided Dolphin *Lagenorhynchus acutus*

This species occurs only in the North Atlantic, with a range that includes virtually the entire Scotian Shelf region (Gaskin 1992c; Reeves et al. in press a; Figure 32). Whitehead et al. (1998) described it as "perhaps the most characteristic cetacean of the Scotian Shelf". They noted its preference for deep water, e.g. in and near the Gully, and estimated that there could be thousands in the Gully during the summer. It has been suggested that some white-sided dolphins may overwinter in the Gully (Gowans and Whitehead 1995). Selzer and Payne (1988) described the distribution of Atlantic white-sided dolphins off the northeastern United States as "complementary" to and broadly overlapping that of the short-beaked common dolphin. Their distributions overlap in the Gully as well; in fact, the two species are sometimes seen in the same general area at the same time (Gowans and Whitehead 1985).

Group sizes of white-sided dolphins range from a few individuals to aggregations of hundreds. They are not known to be deep divers even though they inhabit submarine canyon areas where the water is deep. Their known prey include pelagic and demersal fishes and several squid species (Reeves et al. in press a).

Gaskin (1992c) guessed that the total population of white-sided dolphins in the western North Atlantic was at least in the high tens of thousands. Estimates from U.S. waters are in the range of 10,000-20,000 (Blaylock et al. 1995), and Kingsley and Reeves (in press) estimated that there were about 12,000 in the Gulf of St. Lawrence (mainly the northern half) in late August/early September 1995.

White-beaked Dolphin *Lagenorhynchus albirostris*

This species is another North Atlantic endemic. Its range broadly overlaps that of the Atlantic white-sided dolphin, but the white-beaked dolphin tends to be a more coastal, cooler-water species (Reeves et al. in press b). White-beaked dolphins are generally abundant and have an extensive boreal range. They seem to remain at relatively high latitudes throughout the autumn and winter (Lien et al. 1997), but nothing definite is known about seasonal migrations. Lien et al. (1997) suggested that they move northward in summer following spawning concentrations of capelin (*Mallotus villosus*). Ice entrapment is not uncommon in the bays of southern Newfoundland between February and April (Dong et al. 1996).

White-beaked dolphins definitely occur on the Scotian Shelf (Whitehead et al. 1998), but very little is known about their relative density in different parts of it. They are not seen in the Gully. Whitehead and Glass (1985b) encountered them frequently in June on the Southeast Shoal of the Grand Bank, and they are the most common delphinid in summer in the northwestern Gulf of St. Lawrence and Strait of Belle Isle (Kingsley and Reeves in press) and on the Labrador shelf (Alling and Whitehead 1987). The species has become much less common in the Gulf of Maine over the last few decades (Lien et al. 1997) and is now rarely seen in U.S. waters (Blaylock et al. 1995).
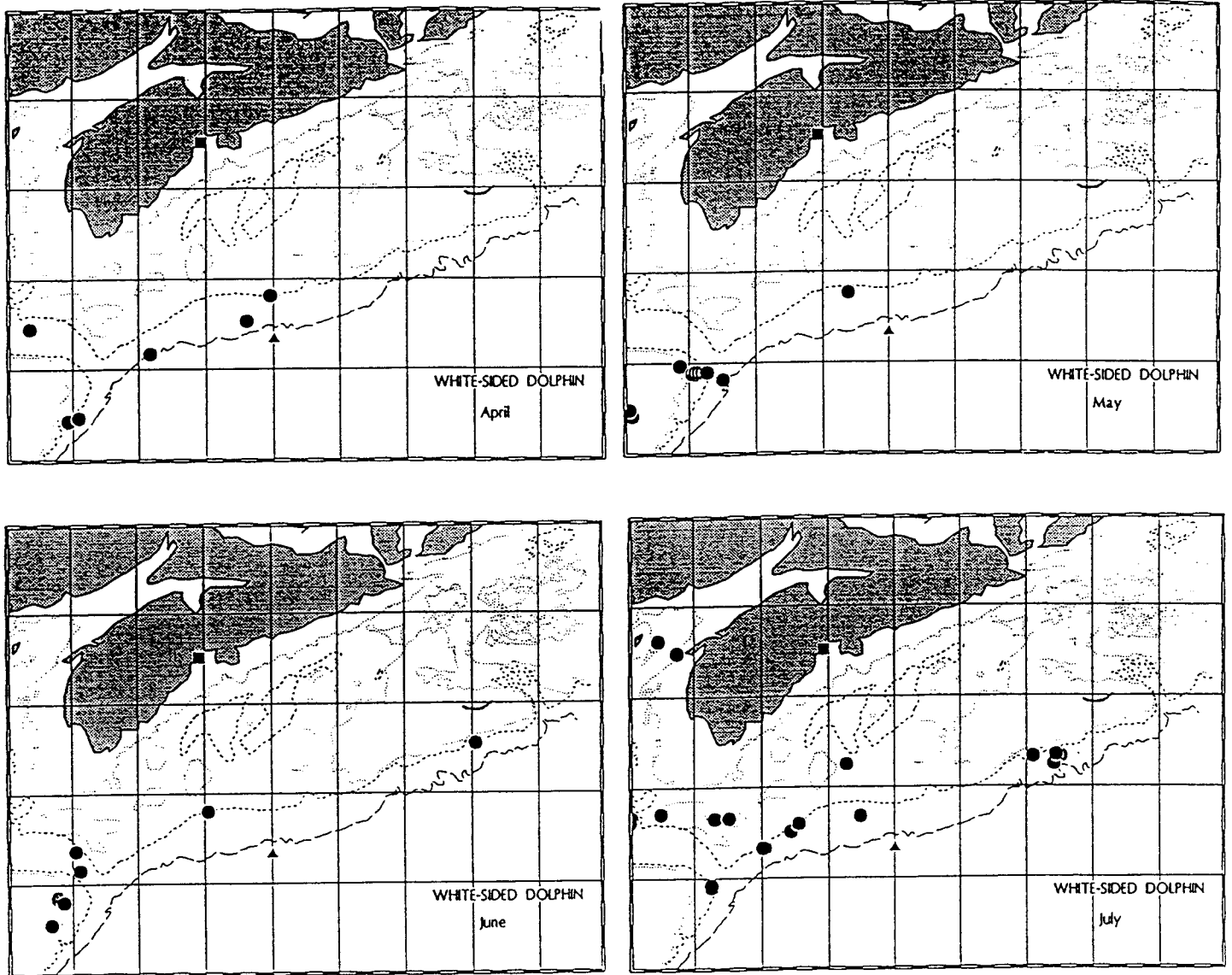
Figure 32. White-sided Dolphin.
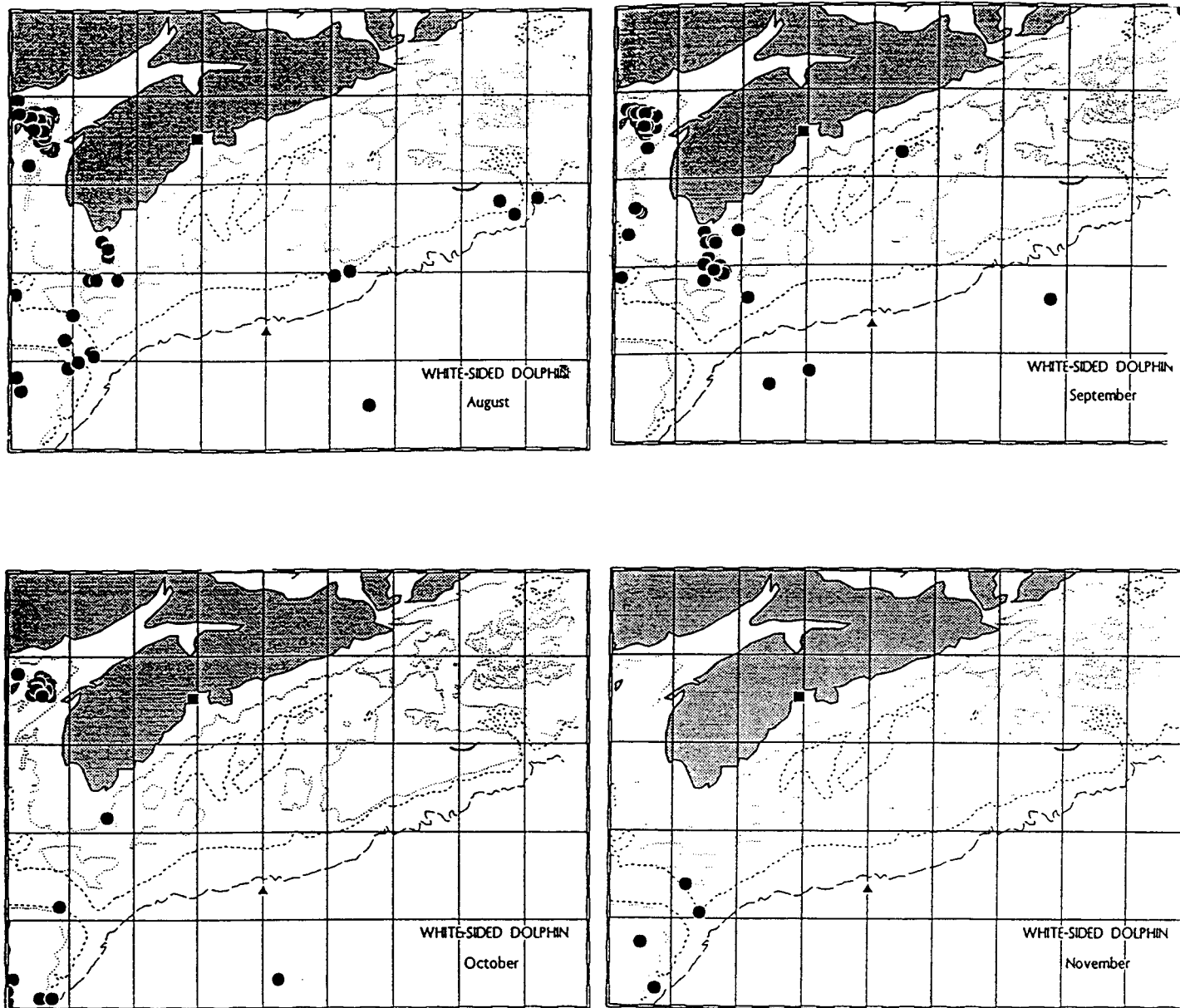
Figure 32. White-sided Dolphin continued.

White-beaked dolphins are not endangered. Reeves et al. (in press b) guessed that the total North Atlantic population might be in the high tens of thousands or low hundreds of thousands, including at least a few thousand along the North American coast from the Gulf of Maine northward.

Striped Dolphin *Stenella coeruleoalba*

Striped dolphins have a cosmopolitan distribution in tropical to warm temperate waters (Perrin, Wilson and Archer 1994). Their preferred habitat seems to be the deep water along the edge and seaward of the continental shelf, particularly in areas influenced by warm currents (e.g. the Gulf Stream; Blaylock et al. 1995). They have been reported on the Scotian Shelf in summer, often in association with other odontocetes (Baird, Stacey and Whitehead 1993; Figure 33). In the deep southern part of the Gully, striped dolphins become common once the water warms to about 15°C in summer (Whitehead et al. 1998; also see Gowans and Whitehead 1995).

Striped dolphins are fairly gregarious (groups of 20 or more are common) and active at the surface. Considering the large size of groups seen in the Gully, Whitehead et al. (1998) suggest that there may be more than 1000 striped dolphins in the Gully, at times.

Although some populations of this species have been seriously reduced by overhunting or habitat degradation (Klinowska 1991; Reeves and Leatherwood 1994), there is no reason to suspect that the striped dolphins in the western North Atlantic face any immediate or serious conservation problem (except possibly the bycatch in offshore pelagic drift-net and groundfish trawl fisheries; see Blaylock et al. 1995). The total abundance of striped dolphins in the western North Atlantic has not been estimated, but estimates for U.S. shelf-edge and slope waters have ranged from about 13,000 to well over 30,000 (Blaylock et al. 1995).

Bottlenose Dolphin *Tursiops truncatus*

Bottlenose dolphins have a worldwide distribution and are abundant on a global scale. They have occasionally been observed in Canadian east-coast waters but are not regularly present there (Baird, Walters and Stacey 1993; Gowans and Whitehead 1995). Occasional sightings are made in the Gully in late summer, often involving mixed schools of bottlenose dolphins with striped or short-beaked common dolphins (Whitehead et al. 1998). It is unlikely that more than a few hundred bottlenose dolphins are present in the Gully at any one time (Whitehead et al. 1998). The Scotian Shelf region is probably best regarded as a marginal part of the bottlenose dolphin's range (Figure 34).

As in the case of the striped dolphin, some populations of bottlenose dolphins are seriously depleted. Stocks off the eastern United States have been affected by large-scale die-offs in recent years (Blaylock et al. 1995). Recent abundance estimates for the "western North Atlantic offshore stock," the one most likely to be represented on the Scotian Shelf, are in the order of 12,000 animals (Blaylock et al. 1995).
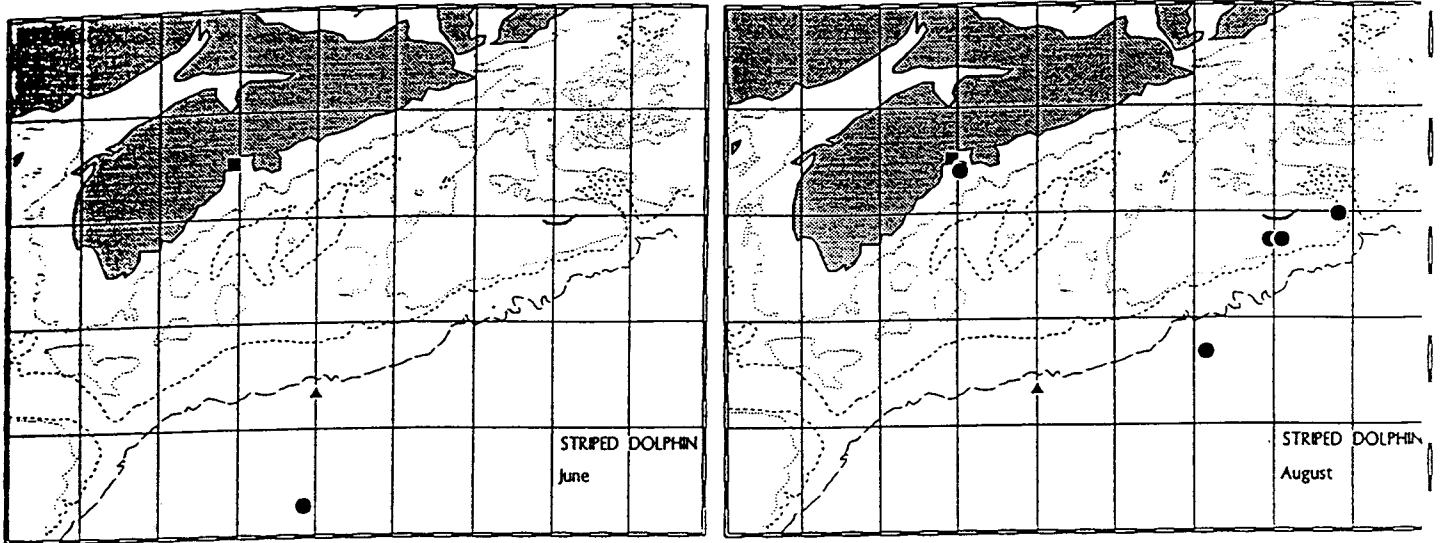
Figure 33. Striped Dolphin.
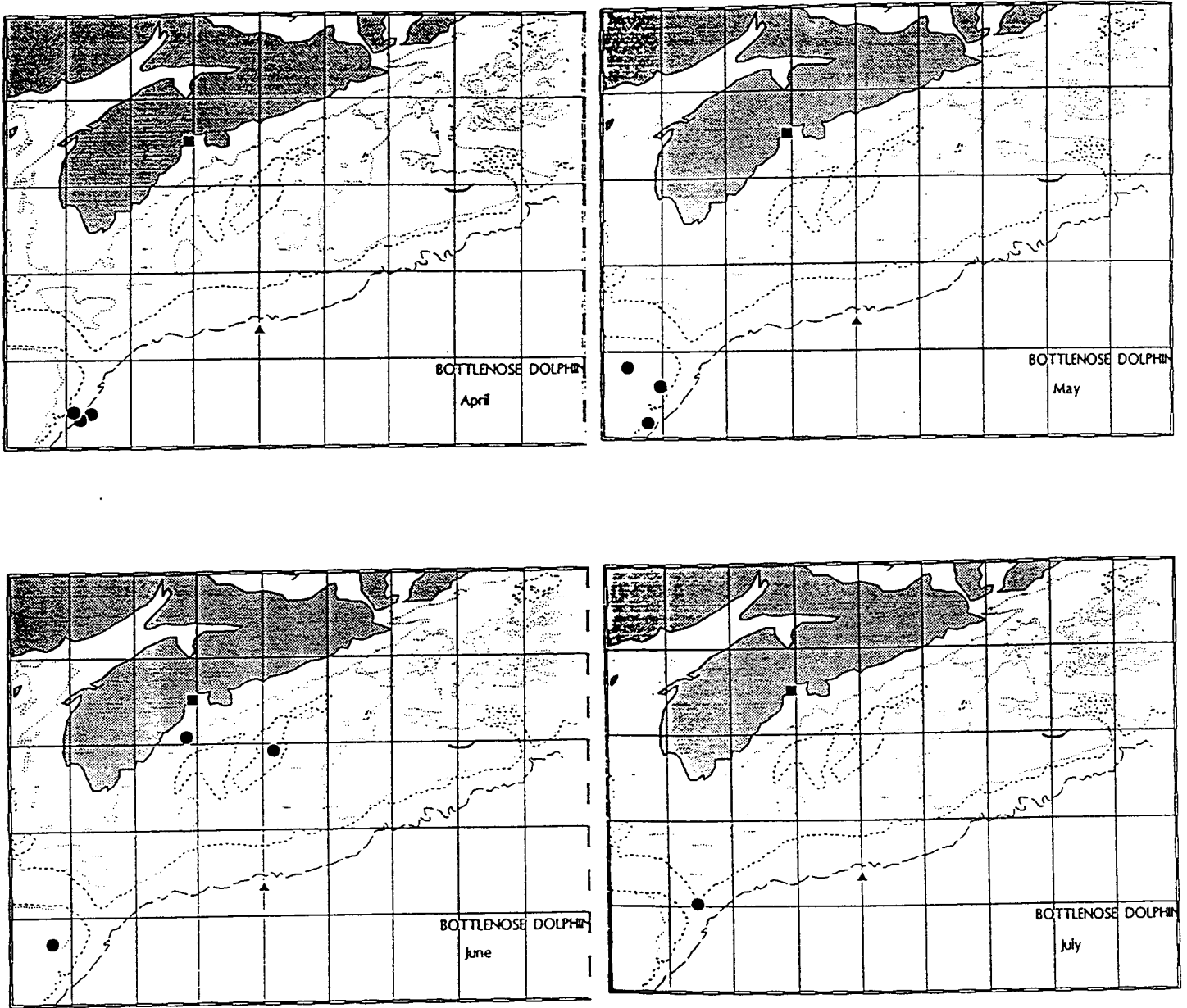
Figure 34. Bottlenose Dolphin.
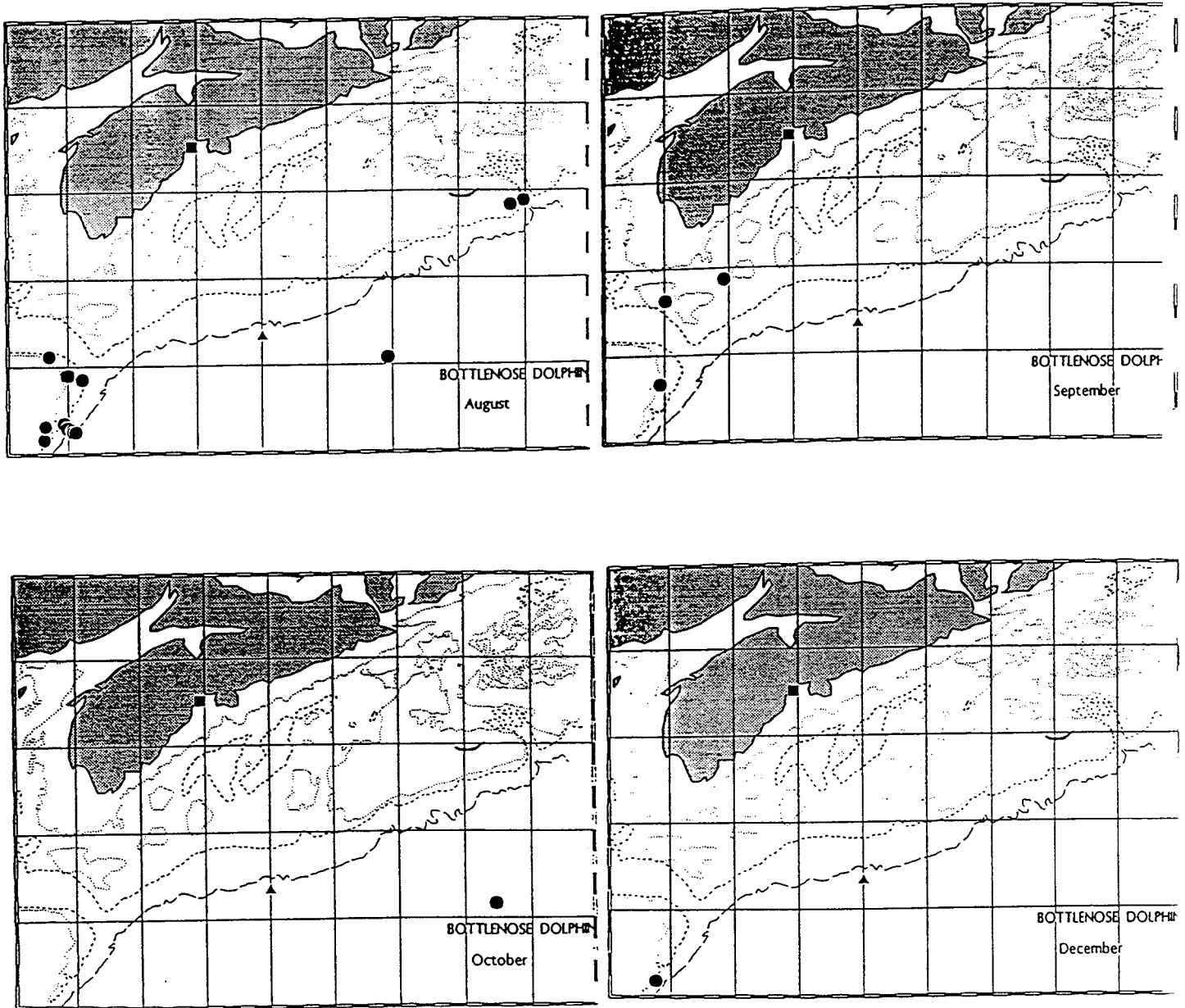
Figure 34. Bottlenose Dolphin continued.

Risso's Dolphin *Grampus griseus*

This cosmopolitan species has been observed a few times in offshore waters of eastern Canada but is not considered a regular inhabitant of the Scotian Shelf (Baird and Stacey 1991). As a deepwater species, it is probably more common seaward of the shelf edge off Nova Scotia, associated with strong bathymetric features and Gulf Stream influence (*cf.* Blaylock et al. 1995). Indeed, small groups of Risso's dolphins were seen off the shelf during the 1994 shipshock trials (Parsons 1995).

Risso's dolphins are abundant and widely distributed globally. Baird and Stacey (1991) concluded that they are "at the margin of their normal distribution in Canadian waters and have always been rare". No immediate conservation problem exists for this species in the western North Atlantic. Recent abundance estimates in U.S. shelf-edge waters were in the range of 10,000-20,000 (Blaylock et al. 1995).

Fraser's Dolphin *Lagenodelphis hosei*

Fraser's dolphin is a tropical species that only rarely occurs in temperate regions, and then only in relation to temporary oceanographic anomalies such as El Niño events (Perrin, Leatherwood and Collet 1994). Whitehead et al. (1998) reported two sightings in the Gully, but on both occasions the species identifications were not confirmed.

Harbour Porpoise *Phocoena phocoena*

The harbour porpoise has a pan-boreal range in the Northern Hemisphere (Gaskin 1984; see papers in Bjørge and Donovan 1995). The Scotian Shelf has long been recognized as an important part of its western North Atlantic range. There is at least a diffuse north-south migration along the east coast of North America, but some individuals may remain in Canadian waters until well into the winter. They may also tend to move offshore in the autumn. Gaskin (1984) refers to "small local 'colonies'" of porpoises inhabiting the Atlantic coast of Nova Scotia. They are present from at least spring through autumn and may move offshore to the Emerald and other banks in the winter. There may also be some movement round the southern tip of Nova Scotia and into the Gulf of Maine, and vice versa. Locations of harbour porpoise sightings are plotted on Figure 35.

Harbour porpoises are difficult to see except in very calm surface conditions. Although they surface frequently (at intervals of roughly 30 to 90 seconds; maximum submergence about 5 min), the time spent ventilating is very short (Westgate et al. 1995). Watson and Gaskin (1983) estimated that individual porpoises were at the surface for no longer than about 7.5% of the time.

Harbour porpoises mainly inhabit shallow waters, and they are not often observed in water deeper than about 125 m (Gaskin 1992a). Monitored dives in the southwestern Bay of Fundy in August and September were mostly to depths of 20-130 m (Westgate et al. 1995). Their sounds span a large frequency range, from perhaps as low as 1 kHz to as high as 100 kHz (Schevill et al. 1969; Watkins 1974). In the summer, harbour porpoises in Canadian waters feed on small pelagic schooling fish,
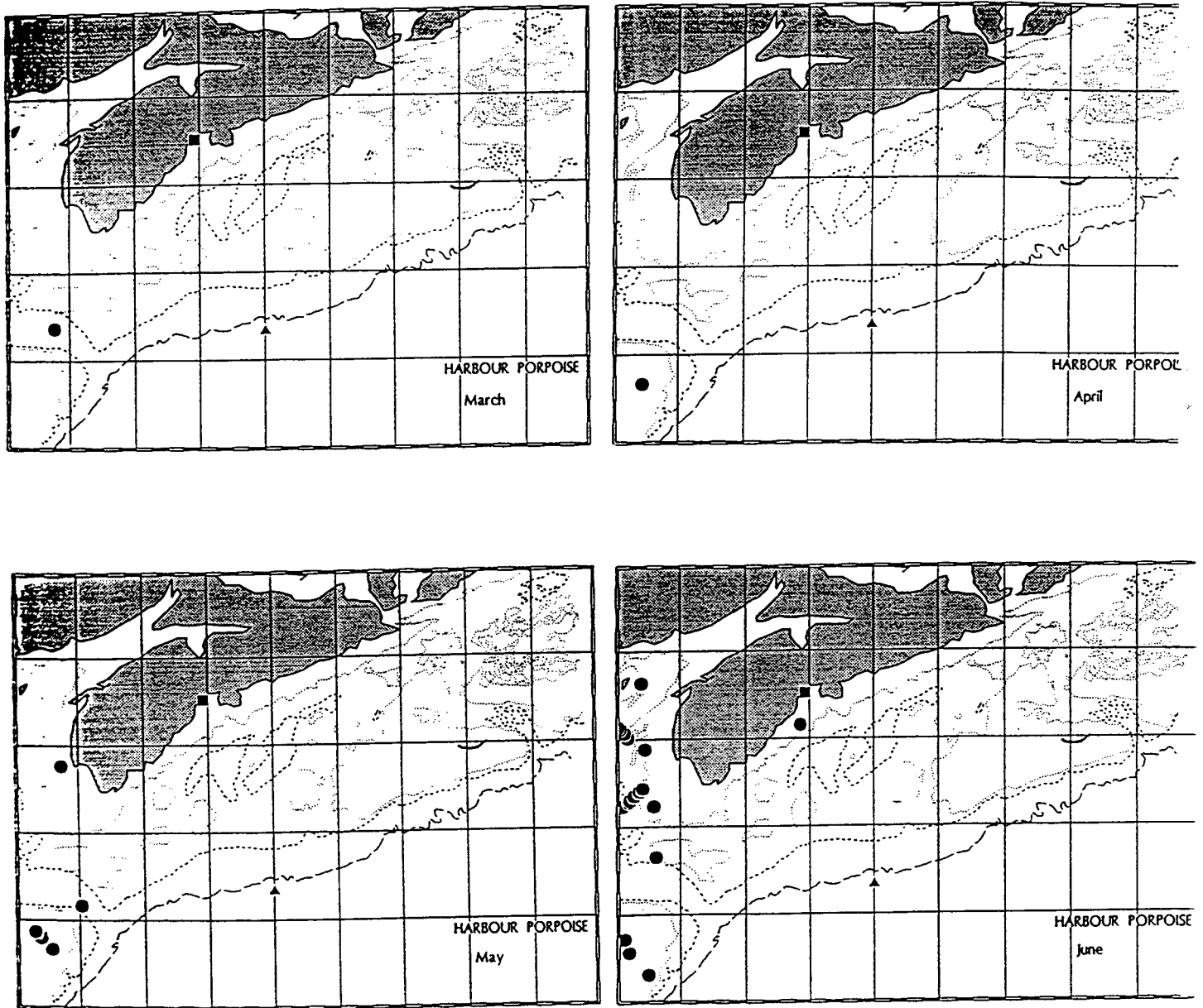
Figure 35. Harbour Porpoise.
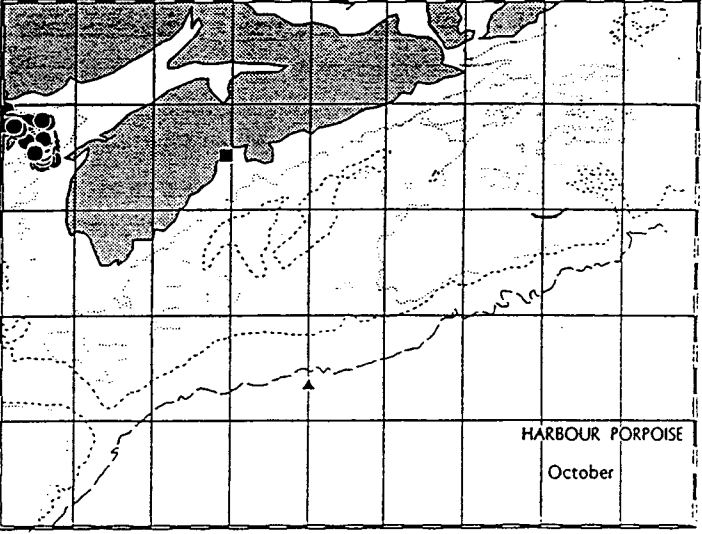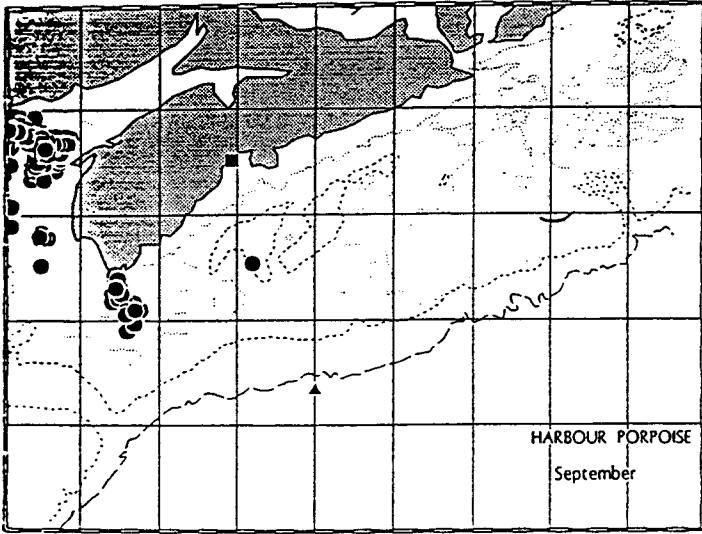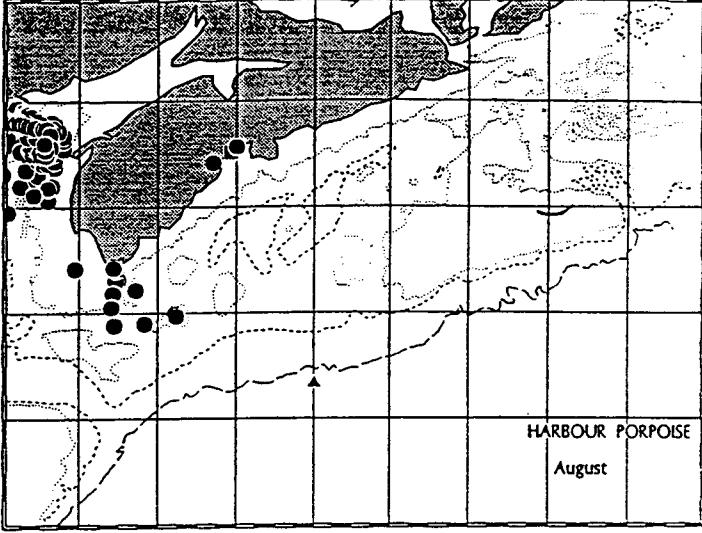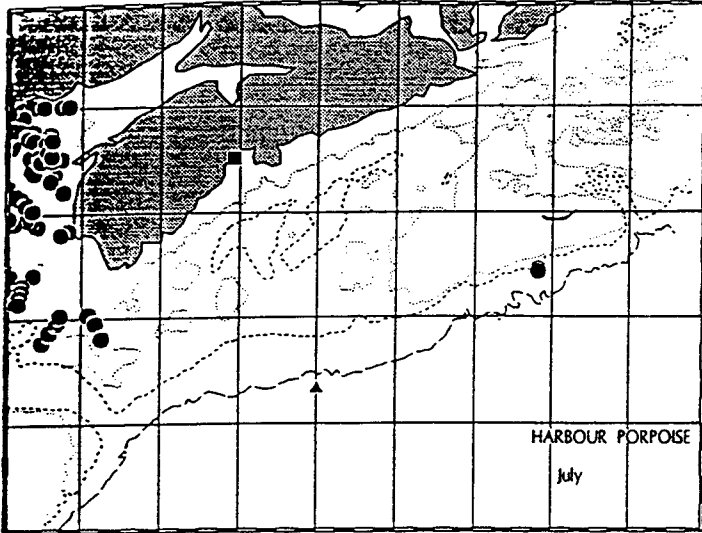
Figure 35. Harbour Porpoise continued.

especially herring (*Clupea harengus*) and capelin (*Mallotus villosus*), with demersal species like silver hake (*Merluccius bilinearis*), redfish (*Sebastes* spp.) and Atlantic cod (*Gadus morhua*) also contributing significantly to their diet (Recchia and Read 1989; Fontaine et al. 1994).

Although the harbour porpoise is numerically abundant and fairly widespread in the North Atlantic, it is highly vulnerable to entanglement in fishing gear. There is concern that bycatch levels in some areas have substantially exceeded the replacement yield, leading to population decline (Bjørge and Donovan 1995). Although the species is not endangered on a global basis, several stocks are officially considered depleted. The harbour porpoise population in the Gulf of Maine and Bay of Fundy (which may be identical to or at least mix with that on the Scotian Shelf) is considered threatened (Gaskin 1992a; Blaylock et al. 1995; but also see Brodie [1995] for a contrary view). Recent abundance estimates for this population have been in the range of 40,000-50,000 (Blaylock et al. 1995). A similarly large population inhabits the Gulf of St. Lawrence in summer (Kingsley and Reeves in press).

Baleen Whales

Northern Right Whale *Eubalaena glacialis*

The historic range of right whales in the temperate North Atlantic was extensive, but their range and numbers are now much reduced. On the western side of the Atlantic, the Scotian Shelf represents an important part of the summer feeding range for the remnant population of a few hundred individuals (Mitchell et al. 1986; Stone et al. 1988; Figure 36). There is a well-documented annual migration between a winter calving area off northern Florida and Georgia and summer feeding areas in the lower Bay of Fundy and the southwestern Scotian Shelf (centred near Browns, Baccaro, Roseway, Lahave and Emerald banks) (Kraus et al. 1986; Winn et al. 1986; NMFS 1991a). At least one additional northern summer feeding area exists, in addition to those in the Bay of Fundy and on the southwestern Scotian Shelf (Schaeff et al. 1993). Some right whales from the western North Atlantic population travel as far to the north and east as Iceland in summer (Knowlton et al. 1992), and others to Newfoundland and the north shore of the Gulf of St. Lawrence (Lien et al. 1989; R. Sears, pers. comm.).

At least a few right whales probably remain on or offshore of the Scotian Shelf during the late autumn and early winter. The relative scarcity of records of right whales on the Scotian Shelf in December-May and June (Figure 36) should not necessarily be interpreted to mean that right whales are scarce in these months because the data are strongly biased by differential effort. The whaling season at Blandford, N.S., never began earlier than 8 May and always closed by the end of November (Mitchell 1974). No recent marine mammal surveys have been done on the southwestern Scotian Shelf in the late autumn and winter months.

Right whales instrumented with satellite-monitored radio transmitters travelled much more widely and rapidly than expected - as much as 500 km offshore, at speeds of up to 10 km/hr, and into waters more than 4000 m deep (Mate et al. 1992; Mate and Nieukirk 1992; Costa 1993). Their movements did not indicate a consistent migratory pattern. Although this peripatetic behaviour may
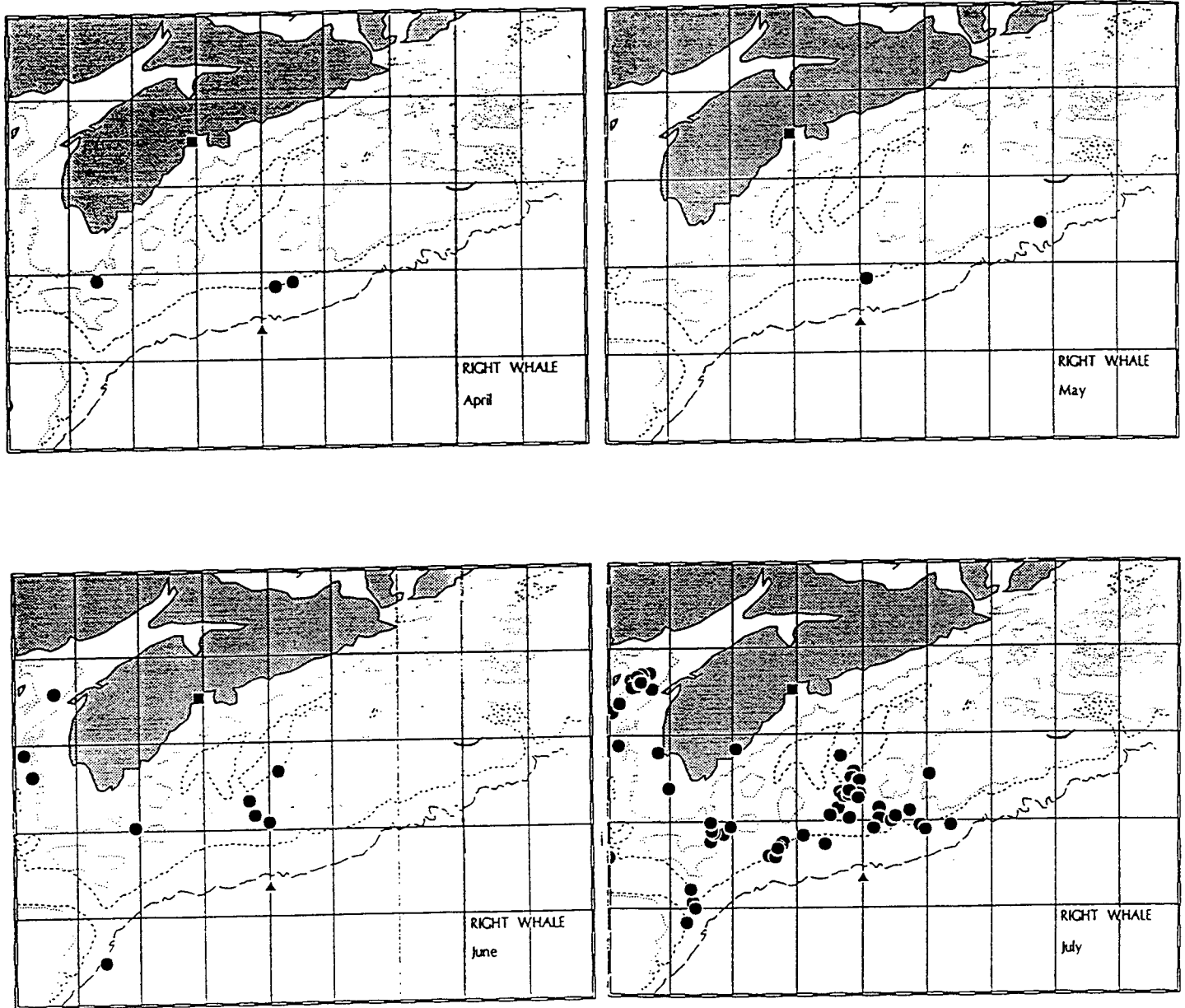
Figure 36. Northern Right Whale.
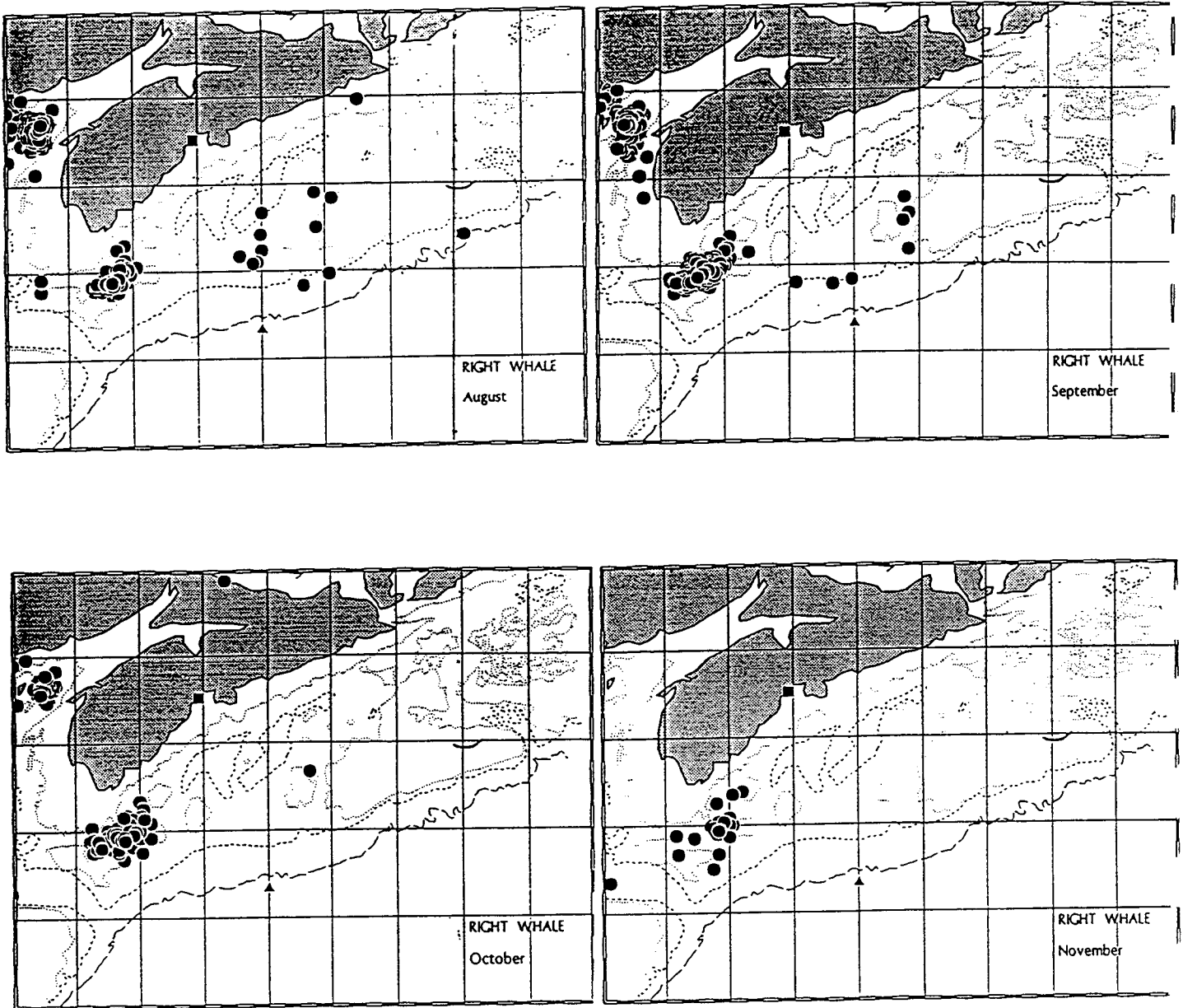
Figure 36. Northern Right Whale continued.

not be random, it certainly presents a much more complex image of right whale behaviour than had been given by previous studies (*cf.* Kraus et al. 1986; Winn et al. 1986). Additional satellite tracking results have yet to be published but include late summer and autumn movement from the lower Bay of Fundy onto the Scotian Shelf (M.W. Brown, pers. comm.). An adult female tagged in the Bay of Fundy in September moved to Emerald Basin where she remained until at least mid-October when the tag stopped transmitting (Chris Slay, pers. comm.). Two or three right whales were seen in Emerald Basin during aerial surveys in early October 1997 (Moira W. Brown, pers. comm.).

An important feature of right whales is that their annual distribution can change dramatically in response to changes in prey densities, which are in turn driven by climatic and oceanographic flux (Payne et al. 1990; Kenney et al. 1995). During the last four years, right whales seem to have greatly reduced their use of the southwestern Scotian Shelf in summer, aggregating instead in unprecedented numbers in the lower Bay of Fundy (M.W. Brown, pers. comm.).

Although right whales are large (adults can be nearly 18 m long) and should be conspicuous, they are often difficult to detect at the surface. The blow is low and bushy, and an animal's body profile at the surface depends on its activity. Although tens of right whales can sometimes be found within an area of a few km^2, they tend to be more solitary than some other baleen whales. The frequency of ship strikes (Kraus 1990; NMFS 1991a) provides indirect evidence of the difficulty of spotting these animals. Whales that were radio-tracked in relatively shallow water (<200 m) spent about 88% of their time submerged and dove for a maximum of 32 min (Mate and Nieukirk 1992), but there is clearly much individual variability in diving and other behaviour (Watkins and Schevill 1982; Watkins and Moore 1983).

Right whales make low-frequency sounds, generally below 500 Hz but possibly up to at least 1500 Hz (Schevill and Watkins 1962; Payne and Payne 1971; Watkins and Schevill 1976; Clark 1982, 1983; Cummings 1985). However their acoustic activity is, in general, directly related to their state of arousal (Clark 1983): resting animals are likely to be silent.

The population of right whales in the North Atlantic is one of the world's most severely endangered whale populations. The Scotian Shelf is known to be an important feeding and socializing area during approximately June through November, and it has been suggested that Roseway Basin, between Browns and Bacarro banks, should be designated as a right whale conservation zone where industrial activities of all kinds should be prohibited (Kraus and Brown 1992; Brown, Allen and Kraus 1995). The population has apparently been growing slowly in recent years (Knowlton et al. 1994), but the incidence of ship strikes and entanglement in fishing gear is alarmingly high (NMFS 1991a). Also, the calving rate of mature females is much lower than would be expected based on observed rates of increase in populations of southern right whales (*Eubalaena australis*) (Knowlton et al. 1994; Brown et al. 1994). The survival and well-being of each individual is important to this small population.

Humpback Whale *Megaptera novaeangliae*

The humpback whale has a cosmopolitan distribution. Its migrations between high-latitude summering grounds and low-latitude wintering grounds are reasonably well known (Winn and Reichley 1985). The total population in the western North Atlantic has been estimated as about 5500 (Katona and Beard 1990) or 7700 (Palsbøll et al. 1997), with the largest component summering off Newfoundland and Labrador. A large proportion of the whales that summer on or near the Grand Bank, in the Gulf of St. Lawrence, or along the coasts of Newfoundland and Labrador probably migrate across or along the edge of the Scotian Shelf (see Figure 37). Photographic matches have demonstrated that whales belonging to Gulf of Maine, Grand Bank, and Newfoundland feeding aggregations visit the Gully on migration (Whitehead et al. 1998).

The peak period for humpbacks in waters of the Canadian Maritimes is July-September, but some individuals remain much longer, even through the winter (NMFS 1991b). Whalers based at Blandford, N.S., took humpbacks in late May, August, September, October and November (Mitchell 1973). Clark (1994) reported that a few sounds of humpback whales were heard in October and November along and south of the Scotian Shelf, and Parsons (1995) found groups of humpbacks to be present in the Gully and on the shelf in mid-November.

The annual distribution of humpback whales in eastern Canadian waters (and the Gulf of Maine) seems to be driven by the availability of schooling fish, most notably capelin and sand lance (*Ammodytes* spp.) (Whitehead and Carscadden 1985; Whitehead and Glass 1985b; Payne et al. 1990). Thus, humpback distribution and movements in any one area are predictable only insofar as environmental conditions are constant from year to year.

Humpbacks are usually fairly conspicuous because of their active surface behaviour and prominent blows. They also often occur in small groups, making them somewhat easier to detect than the more solitary species.

Although humpbacks are famous for their acoustic behaviour, most of their "singing" is done on the winter breeding grounds (Winn and Reichley 1985). However, humpbacks feeding at high latitudes sometimes produce quite different types of calls.

Humpbacks are generally regarded as threatened even though most populations, including that in the western North Atlantic, are known to be recovering rapidly from serious depletion by whaling (see Whitehead [1987]; Campbell [1987, 1991] for COSEWIC listings; NMFS [1991b] and Blaylock et al. [1995] for discussions related to listing under the U.S. Endangered Species Act). There is concern that incidental mortality in fishing gear has slowed recovery (Volgenau et al. 1995).

Blue Whale *Balaenoptera musculus*

The blue whale is widely distributed throughout the world's oceans, but its distribution is specific to areas that provide large seasonal concentrations of euphausiids, its main prey (Yochem and Leatherwood 1985). All populations of blue whales have been exploited commercially, and many have
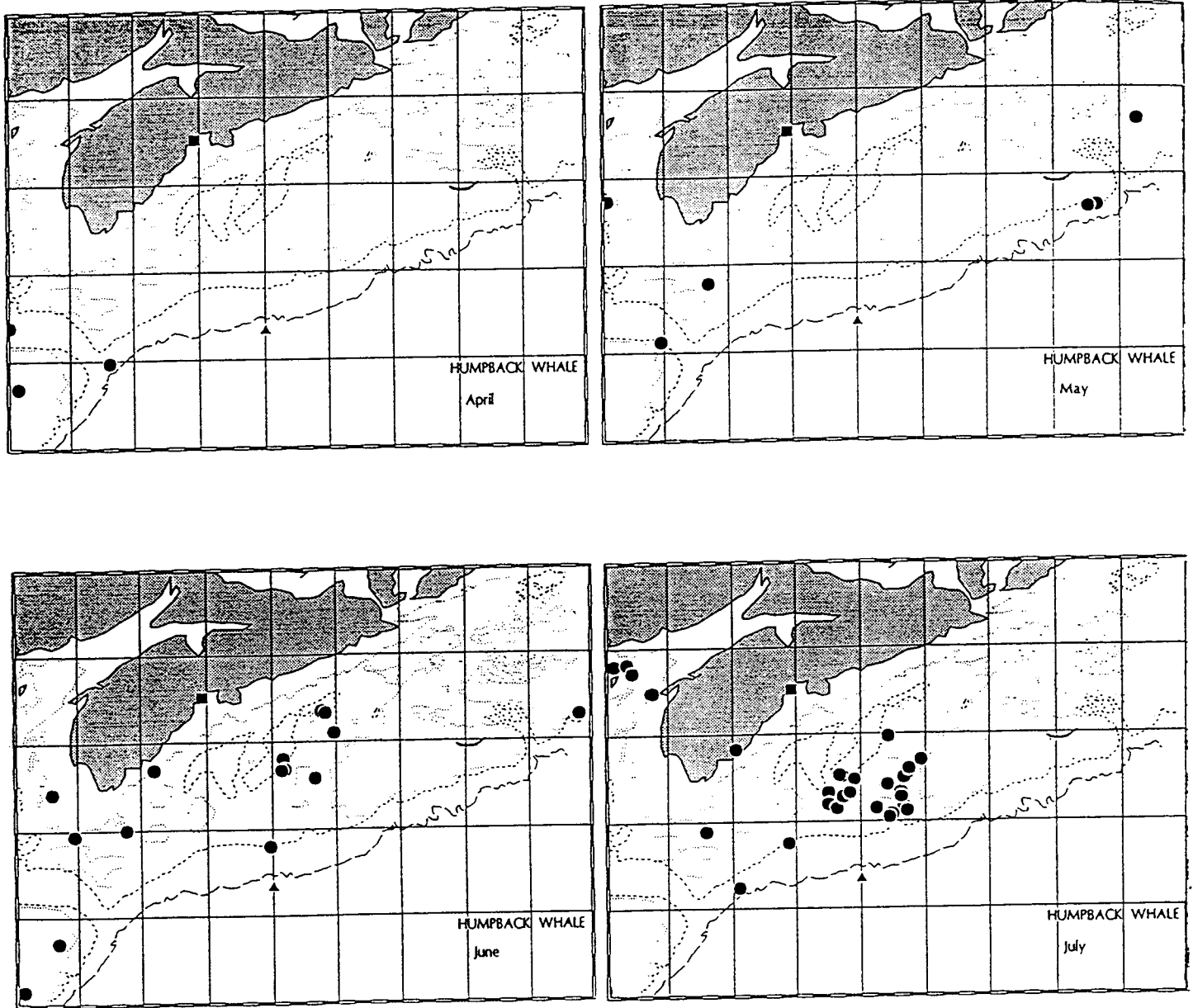
Figure 37. Humpback Whale.
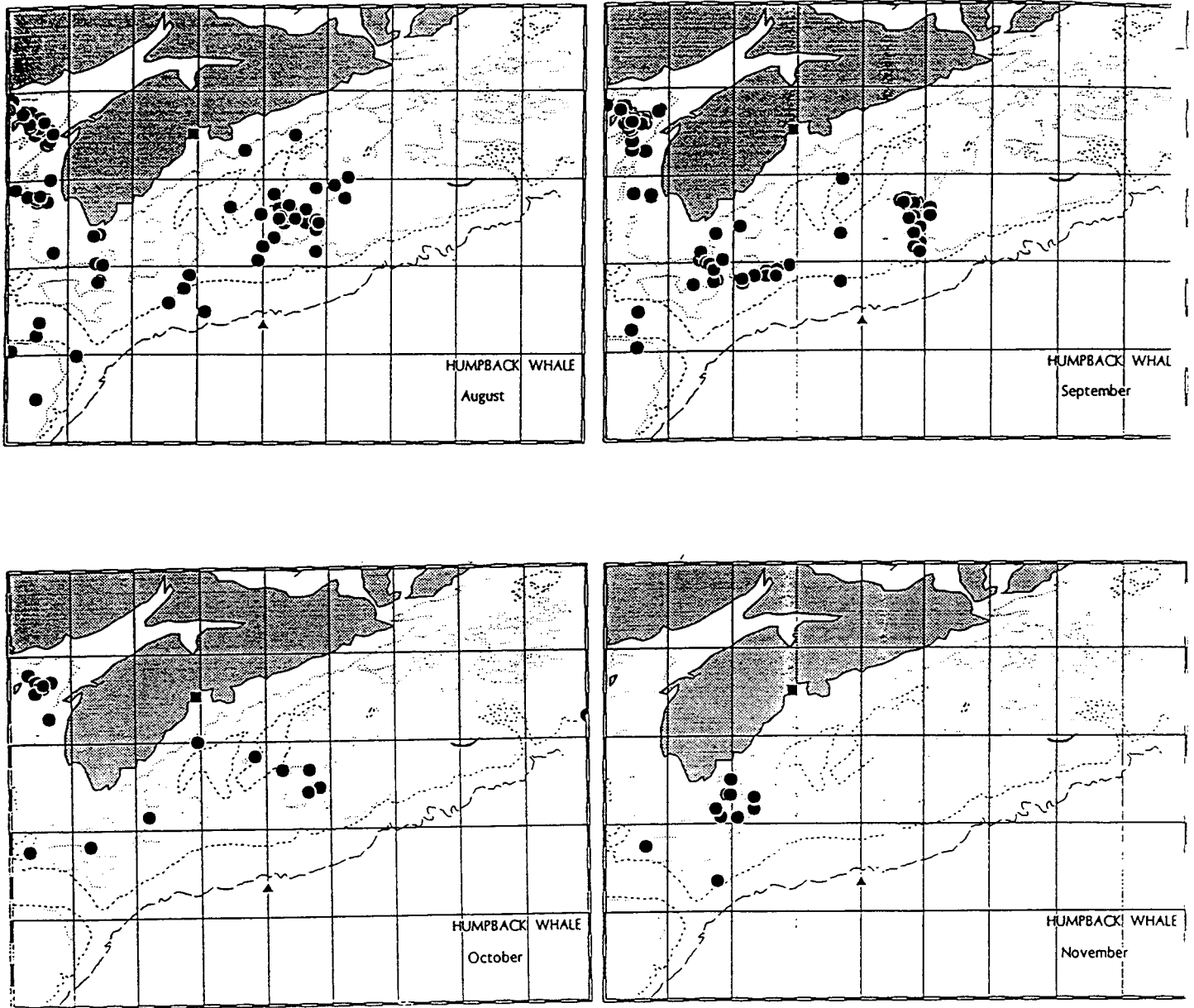
Figure 37. Humpback Whale continued.

been severely depleted as a result. The North Atlantic population is thought to be no larger than 1000-2000 (Sigurjónsson 1995), of which perhaps 200-300 visit the Gulf of St. Lawrence between January and November (*cf.* Sears et al. 1990, R. Sears pers. comm. - see Reeves, Clapham and Brownell 1998). At least some of these whales probably migrate through Cabot Strait while entering or leaving the Gulf, and they are likely to spend some time on the Scotian Shelf en route. Small numbers of blue whales are consistently seen in the Gully in mid to late August (Whitehead et al. 1998). Records plotted in Figure 38 demonstrate that blue whales are present on the southwestern Scotian Shelf from June through November, mostly along or inshore of the 100-fathom contour. Parsons (1995) and Clark (1994) also reported sightings and sounds of blue whales on the Scotian Shelf and in deep water off the shelf edge in October-November.

The "nomadic" nature of blue whales in eastern Canadian waters (Wenzel et al. 1988; Hammond et al. 1990; Sears et al. 1990) means that they could occur in virtually any productive area within their migratory range at any time. The seasonally high primary productivity indicated by remote imagery for the Scotian Shelf and offshore (NSF/NASA 1989) makes this region a likely site for foraging by blue whales.

Blue whales usually occur alone or in small groups. They have a tall and conspicuous blow, and may lift their flukes clear of the surface before a deep dive. Dives can last from 10 to 30 min, separated by series of 10-20 shallow submergences. Swimming speed has been estimated as 2-6.5 km/hr while feeding, and 5-33 km/hr while travelling (Yochem and Leatherwood 1985).

The sounds of blue whales consist mainly of low-frequency "moans" and "long pulses" (Cummings and Thompson 1971; Edds 1982). These sounds are mainly in the range of 14-20 Hz and can have source levels up to 180 dB re 1 µPa·m (Clark 1990).

Blue whales are "endangered" globally (Baillie and Groombridge 1996) and are listed as "vulnerable" in Canadian waters (Campbell 1992). The North Atlantic population is small. Nothing is known about trends in blue whale abundance in the western North Atlantic, but the population that summers around Iceland has been increasing at about 5% per year (Sigurjónsson and Gunnlaugsson 1990). Unlike right whales, blue whales are not known to be subject to frequent ship collisions or gear entanglement (Reeves, Clapham and Brownell 1998), so their prospects for recovery should be better.

Fin Whale *Balaenoptera physalus*

Fin whales are widely distributed in all the world's oceans (Gambell 1985b). This was the main species hunted from the whaling station at Blandford, N.S., from 1966 to 1972 (Mitchell 1974), and the kills and sightings by whalers account for a large proportion of the fin whale records plotted in Figure 39. The extensive data on fin whale distribution from surveys off the northeastern United States indicate a very broad distribution across the continental shelf and extending offshore into water deeper than 2000 m (Hain et al. 1992). Clark (1994) described the fin whale as "by far the most acoustically prolific animal" along the shelf edge and immediately offshore of the Scotian Shelf. He noted that fin whale vocal activity increases from late August and through the autumn, presumably as whales from
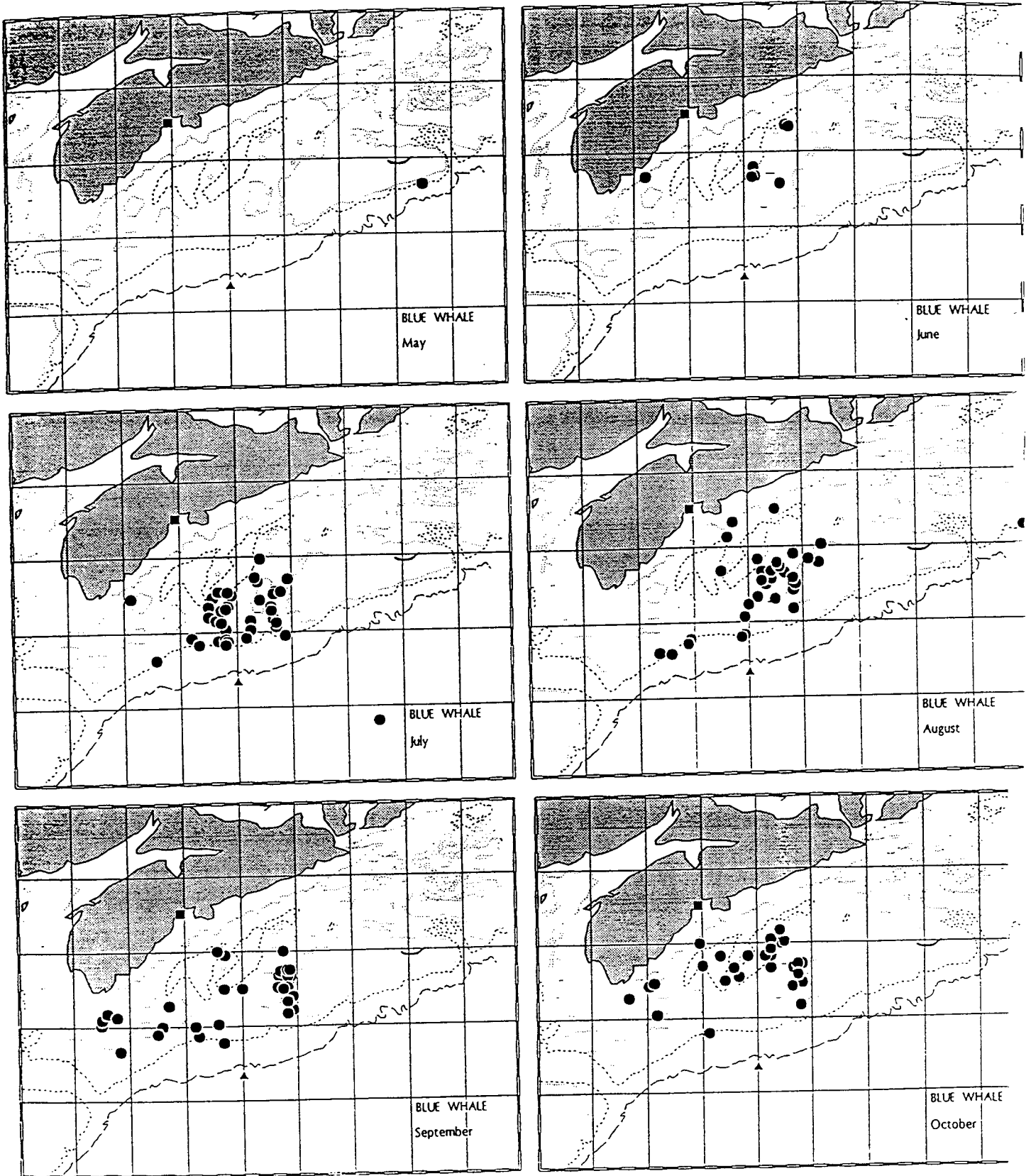
Figure 38. Blue Whale.
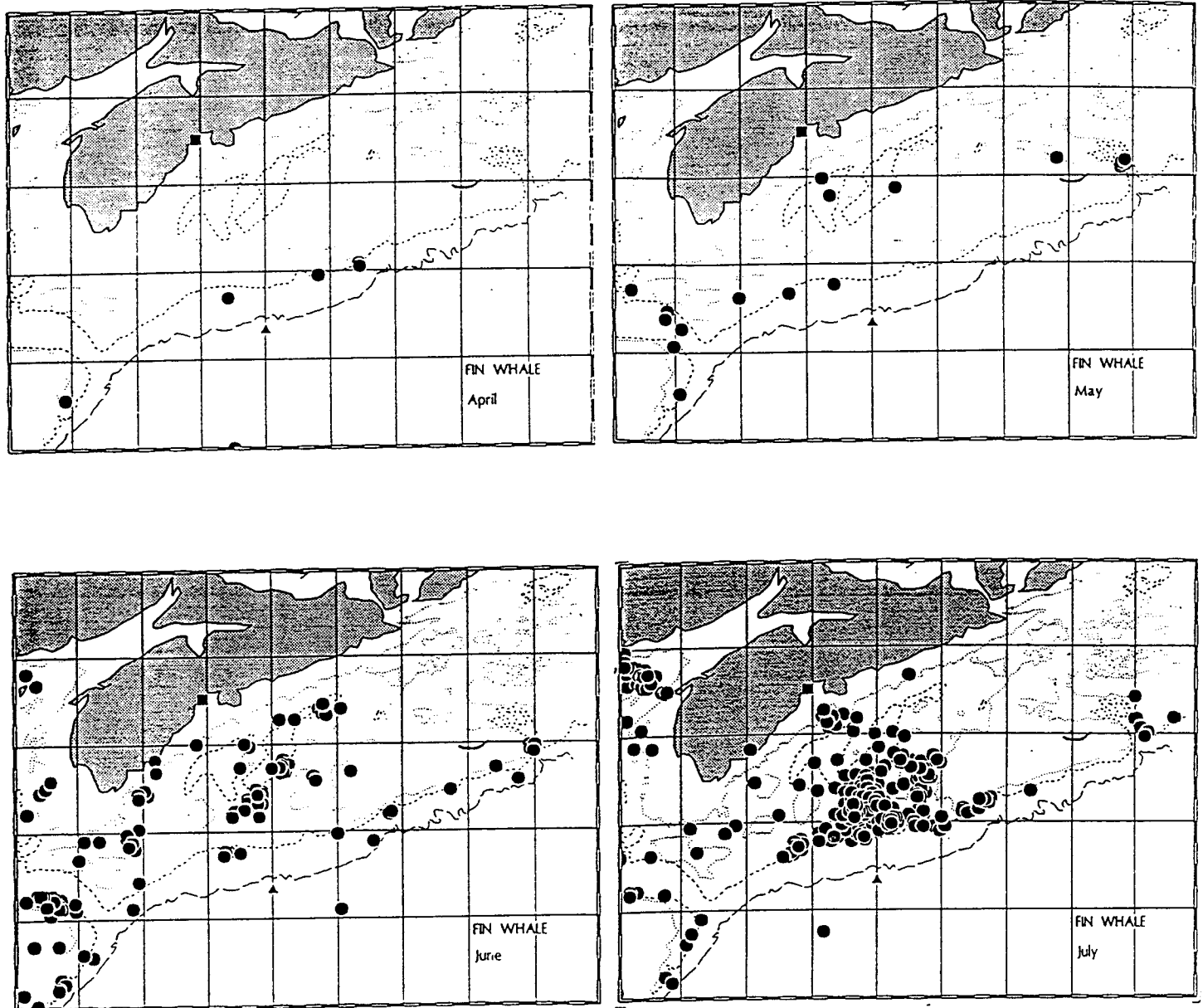
Figure 39. Fin Whale.
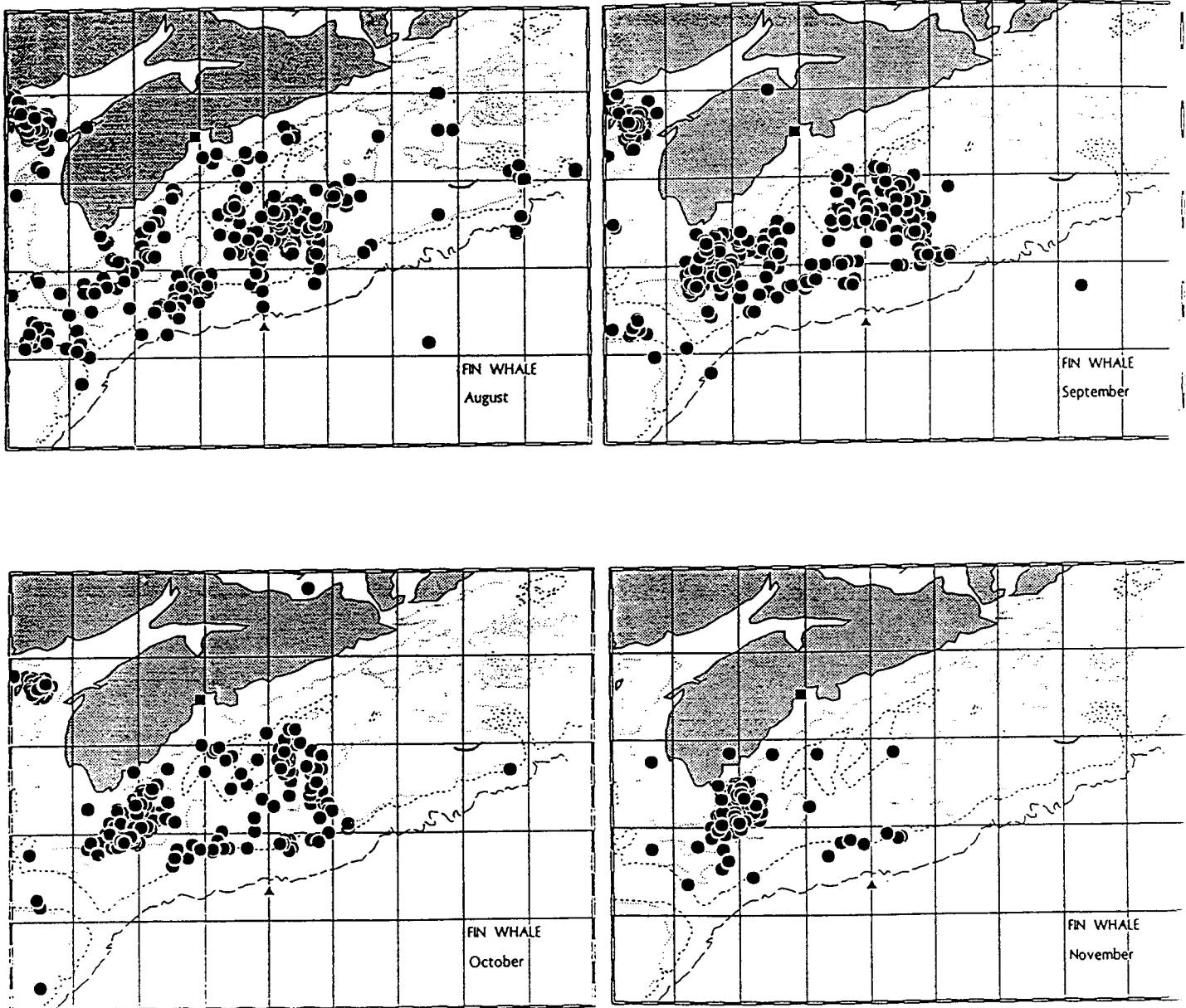
Figure 39. Fin Whale continued.

the Grand Banks area move south and southwestward along the shelf. In mid-winter, the trend seems to reverse as animals move northward. A 2 to 2½ month "acoustic lull" occurs from about mid-June to mid-August, perhaps indicating that animals have either moved north or well inshore of the passive, deep-water hydrophone installations used by Clark (1994) to monitor whale sounds (see distributions on Figure M12). Fin whales are consistently observed in the Gully in July and August (Whitehead et al. 1998), and visual and acoustic observations reported by Parsons (1995) confirmed their presence on the shelf and near the shelf break southwest of Sable Island in November.

The diving behaviour of fin whales in the western North Atlantic was reviewed by Stone et al. (1992) with the explicit objective of evaluating the likelihood of detection by aerial and shipboard surveys. Fin whales in their study area blew about 50 times per hour, and the average dive time was about 3 min. A fin whale radio-tracked off Iceland for 9.5 days surfaced, on average, at 2-min intervals and travelled at an average speed of 7.4 km/hr (Watkins et al. 1984). Since fin whales do not usually remain submerged for long periods, have tall blows and a conspicuous surfacing profile, and often occur in groups of several animals, they are less likely to be overlooked than most other species. They can, however, be missed during periods of inactivity (*cf.* Watkins 1981).

The acoustic behaviour of fin whales has been relatively well studied, especially by Watkins (1981; also see Schevill et al. 1964; Watkins et al. 1987). Their distinctive 20 Hz pulses, with source levels as high as 180 dB re 1 µPa·m, can be heard reliably to distances of several tens of kilometres. These sounds are presumably used for communication. While swimming slowly near the surface or travelling rapidly, fin whales are generally silent (Watkins 1981).

Probably at least in part because of their initially high abundance, wide distribution and diverse feeding habits, fin whales seem not to have been as badly depleted as the other large whales in the North Atlantic (see Reeves, Silber and Payne 1998). They are nevertheless listed as "vulnerable" by COSEWIC (Campbell 1992), and "endangered" globally (Baillie and Groombridge 1996). A recent assessment of fin whales throughout the North Atlantic suggested an aggregate population of a few tens of thousands, subdivided into as many as seven putative stocks (IWC 1992). Approximately 11,000 fin whales were attributed to Canadian east-coast waters. The International Whaling Commission's recent "comprehensive assessment" of fin whales in the North Atlantic (IWC 1992) treated the whales found off Labrador, Newfoundland, and Nova Scotia as a single stock, with a population of at least a few thousand. Recent U.S. surveys of the Gulf of Maine and lower Bay of Fundy resulted in an estimate of at least 2700 fin whales (Blaylock et al. 1995).

Sei Whale *Balaenoptera borealis*

The sei whale has a cosmopolitan distribution, with a marked preference for temperate oceanic waters (Gambell 1985a; Horwood 1987). Its occurrence in different parts of the North Atlantic is somewhat unpredictable, but the Scotian Shelf is one of its few well-documented centres of abundance. Mitchell and Chapman (1977) provisionally recognized the whales on the Scotian Shelf as a separate stock that migrates north along the continental slope in June-July and south on the same route from mid-September to mid-November (see Mitchell 1975b). A total of 825 sei whales were killed by the

whalers from Blandford, N.S., between 1966 and 1972 (Mitchell and Chapman 1977). The distribution on the southwestern Scotian Shelf is mainly in canyon and bank-edge areas or on the slope (Figure 40), but sei whales are rarely seen in the Gully (Whitehead et al. 1998).

Sei whales are known for their high mobility and unpredictable appearance (Horwood 1987; Reeves, Silber and Payne 1998). Incursions into nearshore waters of the Gulf of Maine, associated with exceptional copepod densities, are well documented (Payne et al. 1990; Schilling et al. 1992).

Sei whales usually occur in small groups of up to six individuals. Although their blows are not as high as those of blue and fin whales, they tend to make only shallow dives, which means that they surface relatively frequently. They are fairly conspicuous at the surface. Probably because of their shared preference for copepods, sei whales and right whales are often seen in the same vicinity (e.g. Mitchell et al. 1986). The acoustic behaviour of sei whales has not been studied as extensively as that of most other mysticetes.

Sei whale populations were depleted by whaling, and their current status is generally uncertain (Horwood 1987). Mitchell and Chapman (1977) estimated that there were at least 870, and perhaps as many as 2200, sei whales in the putative Nova Scotia stock, centred on the Scotian Shelf, during the late 1960s. No more recent estimate is available for this area, but Cattanach et al. (1993) estimated that there were about 10,200 sei whales in the central and eastern North Atlantic in 1989.

Minke Whale *Balaenoptera acutorostrata*

Minke whales have a cosmopolitan distribution that spans all ice-free latitudes (Stewart and Leatherwood 1985; Horwood 1990). They are widely distributed on the Scotian Shelf (Figure 41), but their seasonal distribution and migrations are not well known. While some minke whales apparently migrate to low latitudes in winter, others may remain at higher latitudes throughout the year. They have been described as the "most nearly ubiquitous" baleen whales in the Gulf of St. Lawrence (Kingsley and Reeves in press), and this may also apply to the Scotian Shelf. Minke whales occur in shallow near-shore waters, estuaries and bays, and deep offshore waters. They seem able to find and exploit small and transient concentrations of prey (including both fish and invertebrates) as well as the more stable concentrations that attract multi-species assemblages of large predators.

Minke whales are relatively solitary and usually occur in aggregations only when food resources are concentrated. Their small size, inconspicuous blows, and brief surfacing time mean that they are easily overlooked in heavy sea states. Minke whales are known to approach vessels in some circumstances (Stewart and Leatherwood 1985).

A large variety of sounds, ranging in frequency from as low as 60 Hz to as high as 12 kHz, has been attributed to minke whales (Stewart and Leatherwood 1985).
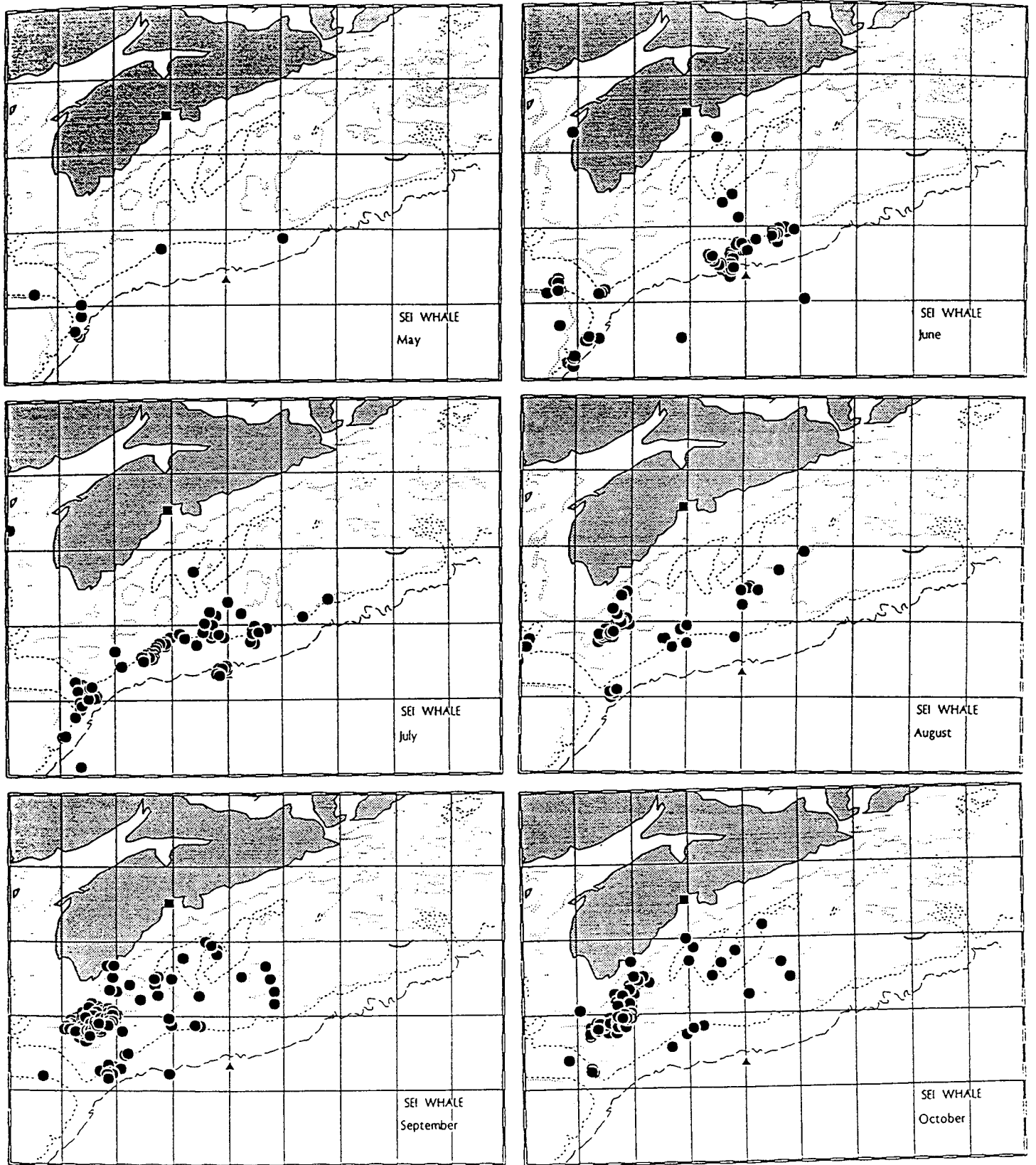
Figure 40. Sei Whale.
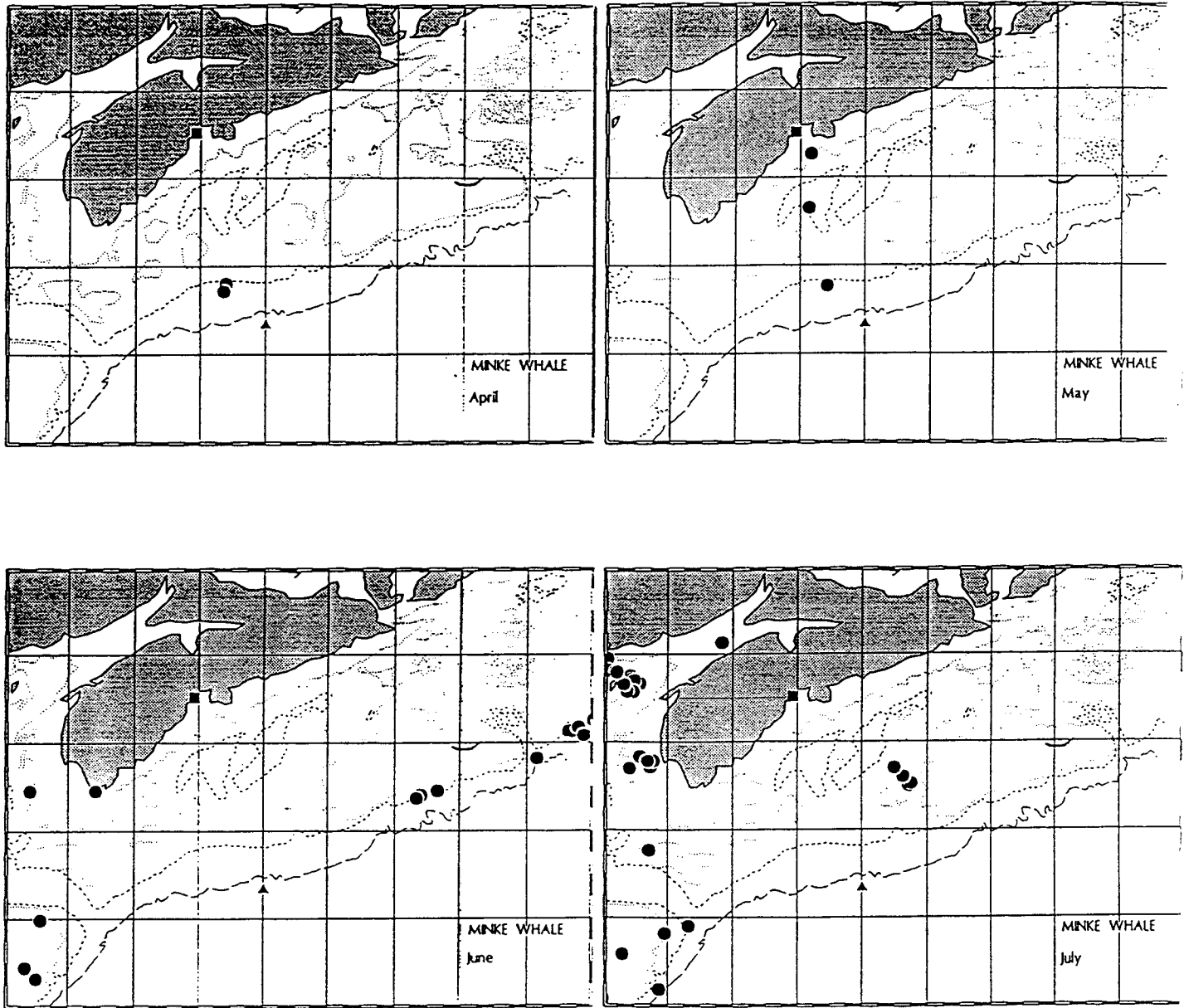
Figure 41. Minke Whale.
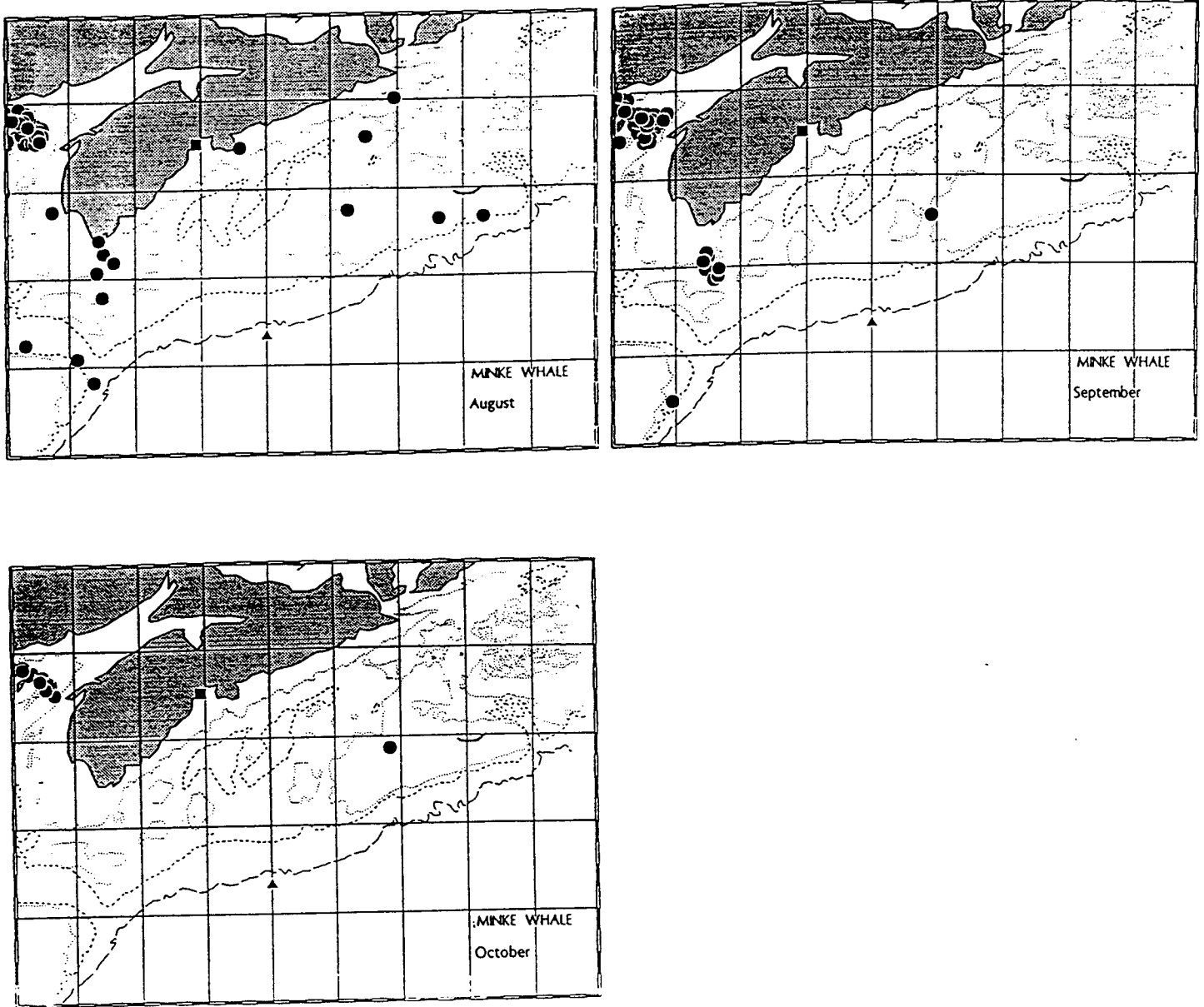
Figure 41. Minke Whale continued.

Minke whales have not been hunted in Canadian or U.S. waters since the early 1970s, and the species is not endangered. However, these whales are killed fairly often in many types of fishing gear (Blaylock et al. 1995), and continued whaling in Greenland and Norway means that populations in the central and eastern North Atlantic require monitoring (Horwood 1990; also see annual reports of the International Whaling Commission). Piecemeal estimates of abundance have been made in recent years in the western North Atlantic, including about 2700 in the Gulf of Maine and lower Bay of Fundy in summer, 300-400 in the shelf edge and slope region from southern Georges Bank, across the entrance of Northeast Channel and to the southwestern edge of the Scotian Shelf (Blaylock et al. 1995), and about 1000 in the Gulf of St. Lawrence (Kingsley and Reeves in press).

Phocid Seals

Harbour Seal *Phoca vitulina*

The range of the harbour seal is mainly coastal but spans much of the temperate northern hemisphere. The distribution in eastern Canada as mapped by Boulva and McLaren (1979), Beck (1983), and Reijnders et al. (1993), includes nearshore waters of the Scotian Shelf and the area around Sable Island. According to Whitehead et al. (1998), genetic data and strong annual fluctuations in pup production indicate that the Sable Island population, once thought to be distinct, does mix with mainland populations. The seals from Sable Island forage in the Gully year-round (Whitehead et al. 1998), but they also probably disperse widely across the shelf during the non-breeding season. Pupping and mating at Sable Island occur mainly in the late spring and early summer (early May through July (Boulva and McLaren 1979).

Harbour seals have a varied diet, including pelagic and demersal fish as well as cephalopods and crustaceans (e.g. Boulva and McLaren 1979; Bowen and Harrison 1996). Local groups of harbour seals, however, tend to specialize on a few prey species, with some variation by season. The seals in the lower Bay of Fundy and near the Atlantic coast of Nova Scotia rely heavily on herring, cod, pollock (*Pollachius virens*) and short-finned squid (Bowen and Harrison 1996). At Sable Island, sand lance are an important element in the diet of harbour seals (W.D. Bowen, unpubl. data, cited in Whitehead et al. 1998).

Harbour seals are not endangered. There are 40,000-100,000 in the western North Atlantic (Reijnders et al. 1993). The number of pups born annually on Sable Island increased from 1978 to 1989 at a rate of 3-5% per year and stabilized at approximately 600 (Reijnders et al. 1993), making it the largest colony in eastern Canada (Whitehead et al. 1998). However, pup production has plummeted since 1992, and only 31 pups were born at Sable Island in 1997 (W.D. Bowen, unpubl. data, cited in Whitehead et al. 1998). Among the explanations suggested for the decline of harbour seals around Sable Island are shark predation on juveniles, reduced female fertility, and insufficient female recruitment (Bowen, as above). The Sable Island population is the only truly offshore breeding group of harbour seals in eastern Canada (Whitehead et al. 1998). There are probably a few thousand harbour seals associated with pupping areas in the lower Bay of Fundy and along the mainland coast of Nova Scotia (e.g. Beck 1983). Counts along the coast of Maine in 1993 totalled just under 30,000 harbour seals (Blaylock et al. 1995).

Grey Seal *Halichoerus grypus*

Grey seals occur only in the northern North Atlantic, with separate populations in European and North American waters. In the western North Atlantic, two main groups of grey seals are distinguished by differences in whelping areas and behaviour (NAMMCO 1996). The larger group pups and breeds on Sable Island in the winter; the smaller group, on the drifting pack ice of the Gulf of St. Lawrence. Sufficient mixing occurs for the two groups to be regarded as belonging to a common stock. Sable Island has the largest single breeding population of grey seals in the world.

The seals at Sable Island disperse widely across the Scotian Shelf for about four months (January-April) after the breeding season, return to moult in May-June, and disperse again from July through September. They return to Sable Island in the late fall and winter to pup and breed (October-December) (Stobo et al. 1990). Adult grey seals from the Gulf of St. Lawrence move onto the Scotian Shelf after breeding, and then return to the Gulf to moult, feed, and breed again the following winter (Lavigueur and Hammill 1993; NAMMCO 1996).

Grey seals are less tied to coastal and island rookeries than are harbour seals. They travel long distances, one individual having been tracked over a distance of 2100 km (NAMMCO 1996). The food of grey seals in the western North Atlantic includes at least 40 species, some of which are commercially important (e.g. Atlantic cod, herring and capelin) (Benoit and Bowen 1990). The diet of seals on the Scotian Shelf varies seasonally and geographically (Bowen et al. 1993). Herring and cod are important at inshore locations in both summer and winter, supplemented by pollock in summer and Atlantic mackerel (*Scomber scombrus*) and squid in winter. Offshore around Sable Island, northern sand lance (*Ammodytes dubius*) are important year-round, supplemented by silver hake (*Merluccius bilinearis*) and squid in summer, and cod in winter (Bowen et al. 1993).

Grey seal populations have demonstrated the ability to recover rapidly from depletion, and fishermen consider them "overabundant" in some areas, including eastern Canada. The Sable Island population was estimated as about 85,000 seals in 1994 and was increasing at about 13% per year (Mohn and Bowen 1996). This population represents more than half of the total eastern Canadian population, estimated at 154,000 in 1994 (Mohn and Bowen 1996).

Harp Seal (*Phoca groenlandica*)

Harp seals are distributed mainly to the north of the Scotian Shelf. They pup and breed on pack ice in the Gulf of St. Lawrence and off the coast of Labrador (Sergeant 1991). Only in recent years have juvenile harp seals become common on Sable Island and farther south. This phenomenon is thought to be related to the rapid increase in the harp seal population (estimated at more than 4 million in the western North Atlantic) or the recent changes in ocean climate (Whitehead et al. 1998).

Hooded Seal (*Cystophora cristata*)

Like the harp seal, the hooded seal is a North Atlantic endemic that pups and breeds on the spring pack ice of the Gulf of St. Lawrence and Labrador coast, then migrates northward to feed. A

recent (1990) estimate of pup production at "the Front" off Labrador was about 83,000 (Stenson et al. 1997), suggesting a current total population of hooded seals in the western Atlantic of 500,000 (Whitehead et al. 1998). Dozens of juvenile hooded seals are seen on Sable Island each year (Whitehead et al. 1998), but the Scotian Shelf is still considered only a peripheral part of the species' range.

Ringed Seal (*Phoca hispida*)

This small arctic seal, which breeds mainly on the land-fast ice, has been reported occasionally at Sable Island (Whitehead et al. 1998). However, it is not part of the normal marine mammal fauna of the Scotian Shelf.

Hearing in Marine Mammals

Marine mammals rely heavily on the use of underwater sounds to communicate and to gain information about their surroundings. Thus, it can be assumed that they also hear many man-made sounds.

Baleen Whales

There is no direct information about the hearing abilities of baleen whales. Baleen whale calls are predominantly at low frequencies, mainly below 1 kHz (Chapter 7 *in* Richardson et al. 1995), and their hearing is presumably good at corresponding frequencies. The anatomy of the baleen whale inner ear seems to be well adapted for detection of low-frequency sounds (Ketten 1991, 1992, 1994). Thus, the auditory system of baleen whales is almost certainly more sensitive to low-frequency sounds than is the auditory system of the small- to moderate-sized toothed whales. Baleen whales are known to detect the low-frequency sound pulses emitted by airguns (see below).

Toothed Whales

Hearing abilities of some toothed whales have been studied in detail (reviewed in Chapter 8 of Richardson et al. 1995). Hearing sensitivity of several species has been determined as a function of frequency. In most of these tests, hearing sensitivity was determined only for frequencies above 1 kHz. However, for two species—the bottlenose dolphin and beluga whale—hearing sensitivity has been extensively studied at low as well as moderate and high frequencies (Figure 42). Similar results have been obtained recently for Risso's dolphin and the false killer whale (Au et al. 1997).

The small- to moderate-sized toothed whales whose hearing has been studied have relatively poor hearing sensitivity at frequencies below 1 kHz, but extremely good sensitivity at, and above, several kilohertz. There are no specific data on the absolute hearing thresholds of the large, deep-diving toothed whales, such as the sperm whale and northern bottlenose whale.

Audiograms of Selected Odontocetes
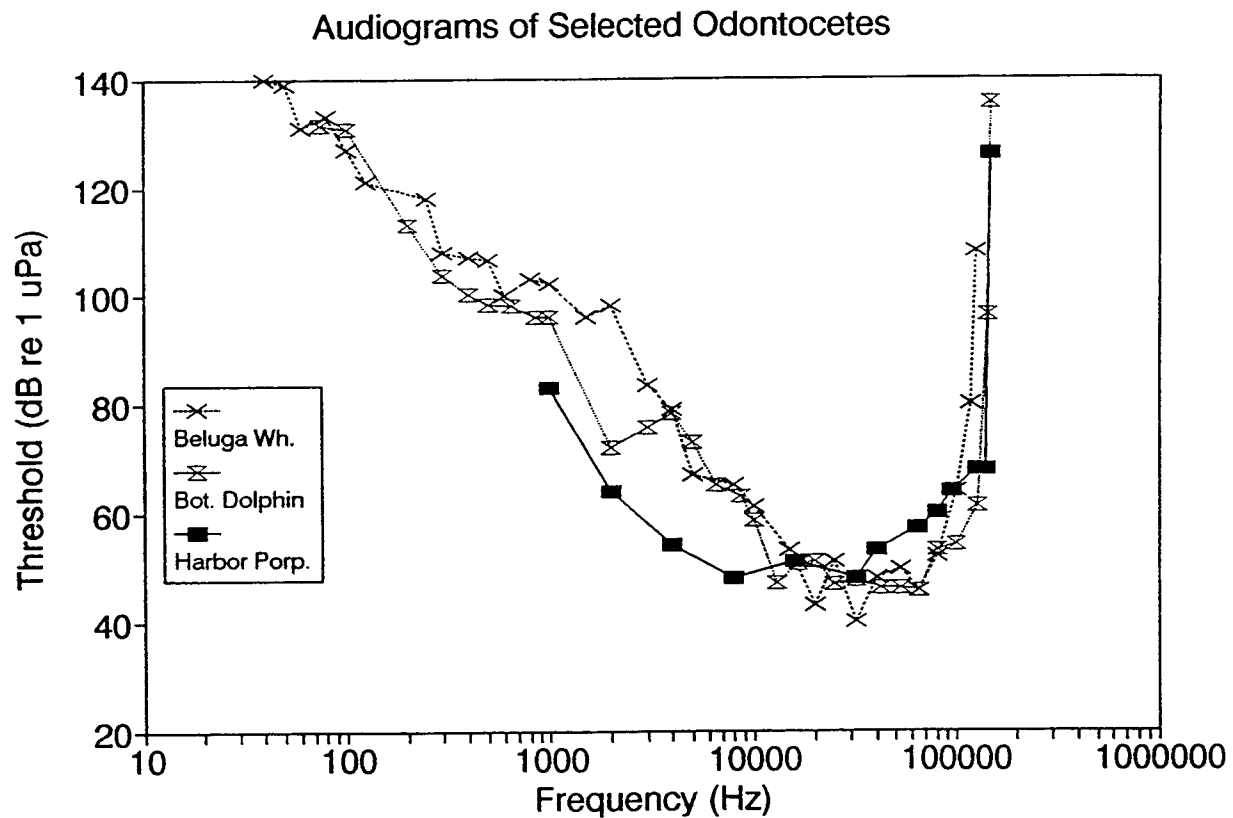
Figure 42. Underwater audiograms of selected toothed whale species, showing the minimum detectable sound level for tonal sounds at various frequencies.

Adapted from Richardson et al. (in press) based on:

- bottlenose dolphin data of Johnson (1967);
- beluga data (averaged) of White et al. (1978, Awbrey et al. (1988),
- and Johnson et al. (1989); and
- harbor porpoise data of Andersen (1970).

The audiograms shown in Figure 42 refer to detection of pure tones of relatively long duration (½-s or more). For pulses less than 0.1-0.2 s in duration, detection thresholds of toothed whales are higher (Johnson 1968, 1991). Underwater noise from airguns is pulsed. However, pulse duration is long (> 0.2 s) at the long distances where received pulse level is approaching threshold level. Thus, the thresholds shown in Figure 42 are applicable.

<u>Seals</u>

Phocid seals have essentially flat audiograms from 1 kHz to 30-50 kHz with thresholds between 60 and 85 dB re 1μPa (Figure 43: data from Richardson et al. 1995). At frequencies below 1 kHz, thresholds increase with decreasing frequency (Kastak and Schusterman in press). For a harbour seal, the 100-Hz threshold was 96 dB re 1 μPa, which is considerably more sensitive than for odontocetes. The functional high frequency limit for the tested species is about 60 kHz (Richardson et al. 1995).

Review of Known and Potential Effects

There have been several recent reviews of the effects of underwater noise, including seismic exploration, on marine mammals. These include Richardson et al. (1989, 1995), McCauley (1994), Turnpenny and Nedwell (1994), Turnpenny et al. (1994), and Gordon and Moscrop (1996). Although there have been several extensive reviews, the same limited experimental and observational data underlie each of the reviews.

To evaluate the potential effects on marine mammals of underwater noise from seismic exploration, it is conceptually useful to define zones or radii within which various effects are expected. These zones include the area within which the underwater noise is audible to the marine mammal, the zones with behavioural responses or auditory masking, and the (theoretical) zones within which there could be hearing loss and physical damage (Richardson et al. 1995). The conceptual zones are discussed in the following sections.

<u>Zone of Audibility</u>

The zone of audibility is the zone within which a marine mammal can hear the seismic pulses. The ability of a mammal to hear the sound depends upon its hearing threshold in the relevant frequency band and the level of ambient noise in that band. For frequencies where hearing sensitivity is good, the ambient noise is usually higher than the hearing threshold, so the ambient noise defines the limit of audibility. [Compare Figure 24 with Figures 42 and 43.] The seismic pulse must be detectable over the background ambient noise. However, for odontocetes with their relatively poor hearing sensitivity at low frequencies, the maximum detection radius for low-frequency sounds like seismic can be determined by absolute hearing threshold rather than the ambient noise level (Richardson et al. 1995: 356; Richardson and Würsig 1997). The radius of the zone of audibility also depends upon the effective source level of the seismic pulse for horizontal propagation and on the propagation loss between the source and the potential receiver.

A. Underwater Audiograms of Hair Seals
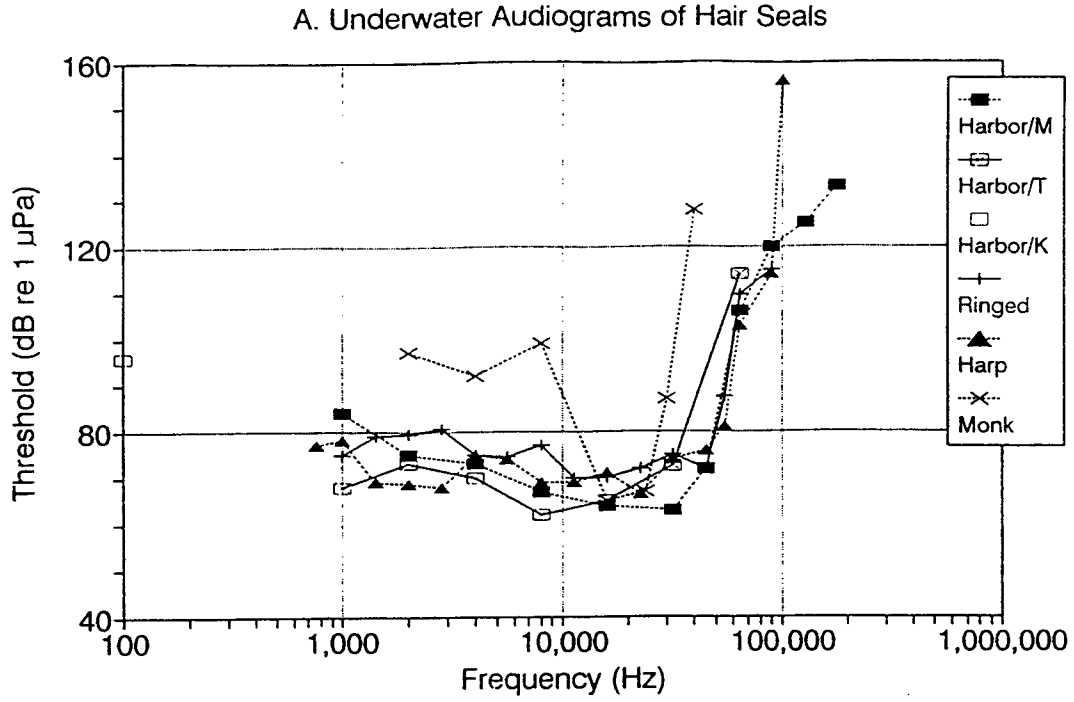
Figure 43. Underwater audiograms of selected species of hair seals (from Richardson et al. 1995).

The zone of audibility for seismic pulses can be quite large, reaching distances of over 50 km on the Scotian Shelf in some circumstances. Although, the zone of audibility establishes the theoretical maximum possible zone of effect, there is no evidence that merely hearing weak seismic pulses from a distant source has any negative effect on marine mammals in their naturally noisy underwater environment (Richardson et al. 1995). For this reason, the zone of audibility on the Scotian Shelf is not discussed further in this document.

Zone of Masking

Man-made noise can interfere with detection of acoustic signals such as communication calls, echolocation calls and environmental sounds important to marine mammals. If the man-made noise is strong enough relative to the received signal, the signal will be "masked" and undetectable. There is very little information about masking of sounds important to marine mammals. However, it is probably safe to conclude that masking will result primarily from continuous noise rather than the short pulses associated with seismic exploration (Richardson et al. 1995). Seismic pulses will have a masking effect for less than 1 second out of every 8-12 seconds (the interval between successive pulses). Thus, for 90% or more of the time, the seismic pulses will not have an appreciable masking effect. Some whales are known to continue to call in the presence of seismic pulses (Richardson et al. 1986). Based on the above, masking is not considered further in this document.

Zone of Behavioural Effects

Studies of marine mammal responses to underwater noise have documented a significant difference in response thresholds for short impulsive sounds from airguns compared to the response thresholds for continuous or slowly varying sound levels (Malme et. al. 1983, 1984). Malme et al. (1984) reported that the probability of avoidance was 50% for migrating gray whales exposed to continuous industrial sound levels of about 120 dB re 1 μPa. However, the avoidance probability when they were exposed to airgun pulses did not reach 50% until the average pulse pressure level was 170 dB re 1 μPa. The average pulse pressure level was defined as the rms level of a continuous sound that provided the same acoustic energy exposure as the actual pulse in the same effective time duration. This procedure of measuring pulse level was found to be more consistent than using the peak of the pressure-time waveform. Peak pressure data were found to be highly variable as a result of multipath propagation in shallow water. Multipath propagation (reverberation) in shallow water also causes pulse duration to increase with range so it becomes necessary to measure both average pulse pressure and pulse duration in order to adequately specify impulse noise. These two parameters can be reduced to one by considering only the total acoustic energy exposure level. This can be done by using a Sound Exposure Level (SEL) approach.

SEL, a measure of the total acoustic energy in a transient sound, has been found to be a useful predictor of the occurrence and degree of annoyance and also of TTS (Temporary Threshold Shift) resulting from human exposure to transient sounds of different durations and repetition rates. SEL is proportional to $10 \log (P^2 T)$, where P is the rms pressure measured over time T, the duration of the transient. SEL is defined as the constant equivalent sound level that supplies the same acoustic energy dose in one second as provided by the actual time-varying transient sound over duration T. For T < 1

s, SEL is less than the rms level; for T > 1 s, SEL exceeds the rms level. It is the total energy content of a short pulse that is likely to be most relevant to an animal, not the details concerning its peak level level, duration, or waveform. Subjective effects of impulsive sounds from different sources can be compared directly using their SEL values.

SEL is an appropriate parameter for the acoustic exposure predictions because the models of transmission loss discussed earlier predict energy loss as a function of frequency and range. The model is a frequency domain program and does not model pulse time spreading. Accordingly, the average pulse pressure levels for observed gray whale responses reported by Malme et al. (1984) have been converted to SEL values using pulse duration data reported by Malme et al. (1986) for the same data set. The received levels at which 10% of the gray whales responded were 174 dB re 1 μPa peak pulse level, 164 dB average pulse or rms level, and 154 dB on the SEL basis. The corresponding figures for 50% response were 180 dB for peak pulse level, 170 dB for average pulse or rms level, and 158 dB for SEL.

The use of SEL measures to define response criteria for airgun pulses should allow the results reported here to be used for short transient signals from other types of seismic sources such as underwater vibroseis. This extrapolation would need to be verified by field observations. The U.S. Navy is presently conducting research on marine mammal responses to low frequency active sonar and other transient sounds. This research should provide data that will be useful in further understanding the responses of various marine mammals in relation to the duration and other properties of strong transient sounds.

Baleen Whales

Specific information about the reactions of some baleen whales to low-frequency noise pulses has been obtained by observing their responses to pulses from airguns and other non-explosive methods of marine seismic exploration. Humpback, gray, and bowhead whales all seem quite tolerant of noise pulses from marine seismic exploration (e.g. Malme et al. 1984, 1985, 1988; Richardson et al. 1986; Ljungblad et al. 1988; Richardson and Malme 1993). The same may be true of fin and blue whales (Ljungblad et al. 1982; McDonald et al. 1993). These species usually continue their normal activities when exposed to pulses with received pressures (in most cases measured on an rms or similar basis) as high as 150-160 dB re 1 μPa, and sometimes even higher. Such levels are 50-70 dB above typical 1/3-octave ambient noise levels. However, subtle behavioural effects are suspected to occur at least some of the time at lower received levels, at least in bowheads and probably gray whales.

In bowhead and gray whales, avoidance reactions are common when rms received levels reach 160-170 dB, as typically occurs several kilometres from a vessel operating a full-scale airgun array. There have been indications that some bowheads may show avoidance at distances as great as 24 km (Koski and Johnson 1987). There is controversy as to whether their migration corridor is diverted somewhat farther offshore during times when seismic exploration is underway in nearshore waters (MMS 1997). A monitoring study is underway to evaluate this (Miller et al. 1997, in prep.). When bowheads are disturbed sufficiently to exhibit strong avoidance, they sometimes swim a few kilometres, and normal activities can be disrupted for an hour or more (Richardson et al. 1986; Ljungblad et al.

1988). The bowhead whale is closely related to the highly-endangered northern right whale which occurs on the southwest portions of the Scotian Shelf.

Before exhibiting obvious avoidance behaviour when approached by an operating seismic vessel, bowhead whales typically show subtle behaviour changes such as reduced surfacing and dive durations, fewer blows per surfacing, and longer intervals between blows. These effects were strongest at ranges less than 5 km, but were evident at 5-10 km (Richardson et al. 1986; Ljungblad et al. 1988). Similar changes in surfacing, respiration and diving cycles were evident when feeding gray whales were exposed to airgun pulses (Malme et al. 1988). The studies of both bowhead and gray whales showed that the seismic pulses were clearly detectable in the water out to distance much greater than those where obvious avoidance reactions became evident. The whales showed considerable tolerance of seismic pulses. However, when the pulses were strong enough, avoidance or other behavioural changes became evident. Because the responses become less obvious with diminishing received sound level, it has been difficult to determine the maximum distance (or minimum received sound level) at which reactions to seismic become evident.

For humpback whales, Malme et al. (1985) also found some tolerance of airgun pulses. More recently (1996-97), McCauley et al. (1998) have conducted studies of the responses of humpback whales off Western Australia to a full-scale seismic survey with a 2678 in^3 array (vertical source level 258 dB re 1 µPa·m (p-p) and to a single 20 in^3 airgun (227 dB, p-p). They found that the overall distribution of migrating humpbacks through their study was unaffected by the full-scale seismic program. McCauley et al. (1998) did, however, document localized avoidance of the array and the single gun. Avoidance reactions began at 5-8 km from the array and these reactions kept most pods about 3-4 km from seismic boat. Corresponding distances from the single airgun were smaller but consistent with the results from the full array in terms of the the received noise levels. For both sources, avoidance became evident when the received level was about 159-162 dB re 1 µPa p-p (5-8 km from array; 2 km from single gun), and pods often manoevered to remain beyond the range where received level was 168-170 dB p-p (3-4 km from array; 1 km from single gun). However, many individual whales approached within 100-400 m of the single gun.

Data on short-term reactions (or lack of reactions) of cetaceans to impulsive noises provide no information about long-term effects. It is not known whether impulsive noises affect reproduction rate or distribution and habitat use in subsequent days or years. Gray whales continue to migrate annually along the west coast of North America despite intermittent seismic exploration in that area for decades (Appendix A in Malme et al. 1984). Bowhead whales continue to travel to the eastern Beaufort Sea each summer despite seismic exploration in their summer and autumn range for many years. Bowheads are often seen in summering areas where seismic exploration occurred in preceding summers (Richardson et al. 1987). They also have been observed over periods of days or weeks in areas repeatedly ensonified by seismic pulses. However, it is not known whether the same individual bowheads were involved in these repeated observations (within and between years) in strongly ensonified areas. It is also not known whether whales that tolerate exposure to seismic pulses are stressed.

Toothed Whales

Seismic operators sometimes see dolphins near operating airgun arrays (Duncan 1985). However, remarkably little systematic information is available about reactions of toothed whales to noise pulses. Few studies similar to the baleen whale/seismic pulse work summarized above have been reported for toothed whales. However, there are some recent observations that suggest that sperm whales in the Southern Ocean ceased calling during some (but not all) times when exposed to weak noise pulses from extremely distant (>300 km) seismic exploration (Bowles et al. 1994). This "quieting" is suspected to represent a disturbance effect, in part because sperm whales exposed to pulsed man-made sounds at higher frequencies often cease calling (Watkins and Schevill 1975; Watkins et al. 1985). Also, sperm whales in the Gulf of Mexico may have moved away from a seismic vessel (Mate et al. 1994). Richardson et al. (1995) concluded that the reactions of odontocetes to seismic pulses deserved detailed study. Despite the relatively poor low-frequency hearing thresholds of small- and medium-sized odontocetes, they should often be able to hear pulses from airgun arrays operating many tens of kilometers away (Richardson et al. 1995:356; Richardson and Würsig 1997). Also, there are no data on the absolute hearing thresholds of the larger toothed whales, such as the sperm and bottlenose whales that occur in the Scotian Shelf region. Their low-frequency hearing may be more sensitive than that of the smaller odontocetes.

Goold (1996a,b,c) studied the effects on common dolphins, *Delphinus delphis,* of 2D seismic surveys in the Irish Sea. Passive acoustic surveys were conducted from the 'guard ship' that towed a hydrophone 180 m aft. In the fall of 1994, the results indicated that there was a local displacement of dolphins around the seismic operation. However, observations indicated that the animals were tolerant of the sounds at distances outside a 1 km radius from the guns (Goold 1996a). Most of the dolphins left the surveyed area during the September to December period. This was thought to be related to a normal southwesterly fall migration of dolphins through the area. This was confirmed during studies conducted in the autumn of 1995 (Goold 1996b,c).

Ridgway et al. (1997) conducted tests of behavioural response and temporary threshold shift in 4 bottlenose dolphins in a captive situation. The dolphins were exposed to single 1-second tones at received levels ranging from 141 to 201 dB re 1 µPa. The TTS results are discussed in the next section. The dolphins exhibited marked changes in their trained behaviour when the loud tones were used. Short-term changes in behaviour were observed above the following levels of the 1-second tone: 186 dB at 3 kHz, 181 dB at 20 kHz, and 178 dB at 75 kHz. It is not clear how these results relate to dolphins in the wild and how responses would change in the presence of the regularly repeated seismic pulses. It is very likely, however, that exposure to seismic pulses with corresponding SEL values would evoke marked avoidance behaviour.

Observations of odontocete responses (or lack of responses) to noise pulses from underwater explosions may be relevant in indicating that odontocetes often tolerate strong noise pulses. During the 1950s, small explosive charges were dropped into an Alaskan river in attempts to scare belugas away from salmon. Success was limited (Fish and Vania 1971; Frost et al. 1984). Small explosive charges were "not always effective" in moving bottlenose dolphins away from sites in the Gulf of Mexico where larger demolition blasts were about to occur (Klima et al. 1988). Odontocetes may be attracted to fish

killed by explosions, and thus attracted rather than repelled by "scare" charges. Hence, scare charges are now not used in the Gulf of Mexico platform removal program (G.R. Gitschlag, pers. comm., 1994). Captive false killer whales showed no obvious reaction to single noise pulses from small (10 g) charges; the received level was ~185 dB re 1 µPa (Akamatsu et al. 1993). Jefferson and Curry (1994) review several additional studies that found limited or no effects of noise pulses from small explosive charges on killer whales and other odontocetes.

Seals

Richardson et al. (1995) noted that very little information has been published on the effects of seismic surveys on seals. An airgun caused an initial startle reaction among South African fur seals, but was ineffective at scaring them away from fishing gear (Anonymous 1975). Gray seals exposed to noise from airguns reportedly did not react strongly (J. Parsons, in Greene et al. 1985) although no details were given.

Recently (1996-97), LGL Limited has been conducting studies of the effects of seismic surveys on ringed and bearded seals in the Alaskan Beaufort Sea (Richardson 1997; LGL and Greeneridge 1997). Observers on the seismic boat kept a continuous watch for seals. In 1996, observers saw seals at nearly identical rates regardless of whether no guns, a single gun, or the full array of 8-11 guns were firing (Harris et al. 1997). However, with full array seismic, seals were encountered less frequently within 150 m of the source vessel and more frequently at distances between 250 m and the limits of vision, estimated at about 500 m for most seals. Thus, some seals avoided the source vessel during operation of the full array. However, some seals remained within 150 m of the array and substantial numbers remained within the 250 to 500 m zone. The overall received rms sound levels from the array were typically about 190 dB at 240 m, 180 dB at 970 m, and 160 dB at 3.6 km (Greene 1997). The preliminary results from 1997 indicate similar patterns of seal distribution in response to a seismic array. Again, the continued presence of seals around the ongoing seismic operation suggested "that seismic operations did not cause many (if any) seals to desert the general area of operations" (MacLean and Harris 1997).

Zone of Physical Effects

In humans, prolonged or repeated exposure to high levels of airborne sound accelerates the normal process of gradual hearing deterioration with increasing age (Kryter 1985). This deterioration is a 'permanent threshold shift' (PTS). In addition, temporary increases in threshold occur during and shortly after exposure to high noise levels. This 'temporary threshold shift' (TTS) can last from minutes or hours to days. The magnitude of TTS depends on the level and duration of noise exposure, among other things.

There has been considerable recent discussion among U.S. regulatory agencies about the use of the TTS threshold (minimum received level eliciting measureable TTS) as an objective criterion for the definition of harassment. This discussion is hindered by the fact that there are almost no published data on TTS in marine mammals. Consideration of TTS studies in humans and terrestrial mammals is helpful, but it is uncertain to what extent these data can extrapolated to marine mammals listening

in water. Aside from an opportunistic observation by Kastak and Schusterman (1996) of TTS in a harbour seal, the only report on a specific study of TTS in marine mammals is Ridgway et al. (1997). For bottlenose dolphins exposed to single 1-sec pulses of underwater sound, TTS became evident at received levels of 194-201 dB re 1μPa at 3 kHz, 193-196 dB at 20 kHz, and 192-194 dB at 75 kHz. Ridgway et al. are also conducting similar TTS experiments on beluga whales.

There is evidence from terrestrial mammals that TTS thresholds are not strongly related to the frequency of the sound. The results for bottlenose dolphins seem consistent with this generalization across a wide range of frequencies (3-75 kHz). Thus, TTS thresholds determined at a few frequencies probably can be assumed to apply, at least approximately, to other similar frequencies. However, the tests on dolphins did not extend below 3 kHz.

It is not known how the fact that seismic pulses occur frequently affects the TTS threshold. The TTS responses measured by Ridgway et al. were based on single 1-s pulses rather than multiple shorter pulses. However, relatively high received levels are needed to elicit TTS (≥192 dB re 1 μPa rms in the case of bottlenose dolphins exposed to single 1-s pulses). The received level of a seismic pulse would need to be about 202 dB re 1 μPa rms in order to have the same SEL as a 1-s 192 dB rms tone of the type used in the Ridgway et al. studies. Received levels of ≥202 dB are restricted to a radius of no more than a few hundred metres around a seismic vessel. A marine mammal near the seismic vessel might be exposed to as many as a few tens of pulses with these levels (or more if the mammal moved with the seismic vessel).

There are major differences in the exposures required to cause temporary and permanent threshold shifts. In humans and other terrestrial animals, sounds that are strong enough to elicit TTS following short-term exposure have been found to be strong enough to cause permanent hearing impairment (PTS) following prolonged exposure. For received levels only slightly above the TTS threshold, very prolonged exposure (e.g. 8 hours per day for at least 10 years) is necessary to cause PTS in excess of that expected from normal aging processes. Received levels well above the TTS threshold are necessary before short-term noise exposure will elicit PTS.

The studies of gray whales (Malme), bowheads (Richardson; Ljungblad) and humpbacks (Malme; McCauley) discussed in previous sections indicate that avoidance responses occur at sound exposure levels of 150-160 dB. TTS thresholds for baleen whales are not known. However, it seems that most individual baleen whales avoid the relatively small zone around a seismic vessel within which effects on hearing might occur.

In assessing the relevance of TTS as a criterion for harassment, it is important to note that marine mammals often exhibit strong behavioural reactions, sometimes including avoidance, when received levels of man-made sounds are well below the anticipated TTS thresholds. For example, the dolphins in the Ridgway et al. experiments exhibited strong behavioural reactions at received levels of 178-186 dB compared to 192-201 dB for TTS onset. If these behavioural reactions are considered to be "harassment", then harassment can occur at received sound levels below the TTS threshold.

At very high received levels, low-frequency underwater sounds can have non-auditory physiological effects on human divers and other submerged terrestrial mammals. These effects can include resonances in the lungs and other body cavities, dizziness, nausea, and visual effects. These phenomena are the subject of considerable ongoing research, mainly in relation to potential effects of powerful low-frequency sonar systems (Cudahy and Sims 1998). These sonars produce transient sounds longer in duration than the brief pulses produced by airgun arrays. Very little is known about the occurrence of noise-induced non-auditory physiological effects in marine mammals. Available data do not allow a meaningful assessment of the circumstances (if any) in which airgun pulses might have effects of these types on marine mammals. If these effects do occur, they would presumably be limited to very short ranges. Marine mammals that show behavioural avoidance of seismic vessels (e.g. most baleen whales) presumably would not be affected.

Predicted Effects on Marine Mammals

It is proposed that two criteria be used to evaluate zones of potential effects of seismic pulses on marine mammals. The first and larger zone is defined by received seismic noise levels that induce behavioural changes. The second (and much smaller) zone is defined by the received levels that would induce TTS. These criteria are applied in the following sections in conjunction with the data on known effects.

Toothed Whales

There is very little information about the behavioural responses of odontocetes to seismic exploration. Goold (1996a) found that common dolphins were tolerant of the noises from an array at distances of over 1 km. The threshold levels for behavioural responses by bottlenose dolphins to single 1-sec pulses ranged from 178 to 186 dB re 1µPa for frequencies from 75 to 3 kHz (Ridgway et al. 1997). The received levels of the seismic pulses on an SEL basis (appropriate for comparison with the 1-s exposures of Ridgway et al.) would decrease to these thresholds at distances of 100 to 500 m depending upon the specific location (Figures 17, 19 and 22). Making an allowance for possible differences between wild and captive animals, and accounting for the observations of Goold, it may be appropriate to conclude that the zone of behavioural effect on the Scotian Shelf for odontocetes may be about 1 km in radius.

This conclusion applies to the dolphins and porpoises whose audiograms are known and that are known to communicate and hear primarily at moderate and high frequencies. Low frequencies predominate in seismic noise, although significant higher frequency noise is also present. The large odontocetes occurring on and near the Scotian Shelf, the sperm whale and northern bottlenose whale, are deep-diving species. They may be more sensitive to low frequency noise and they may make less use of the region of reduced received levels that occurs at and just below the surface. If the cessation of calling by sperm whales exposed to weak seismic pulses as reported by Bowles et al. (1994) was a true cause and effect situation, then sperm whales probably differ from the smaller odontocetes.

Received levels of seismic pulses (SEL basis) would exceed the TTS thresholds (192-201 dB re 1µPa) for bottlenose dolphins only at distances substantially less than 100 m from the beam of the

array (Figures 17, 19 and 22). Animals riding on the bow wave of the seismic boat would not receive levels this high because (1) received levels of low frequency sounds are reduced at and near the surface, and (2) received levels are lower ahead of the array than at corresponding distances and depths to the side of the array. Received levels at the surface close to the array would not likely induce TTS, although strong pulses could be received during dives even to quite shallow depths (Greene and Richardson 1988).

Based on the above review, it is concluded that the effects of seismic pulses on the identified odontocete VECs (long-finned pilot whale, common dolphin, Atlantic white-sided dolphin, white-beaked dolphin, striped dolphin, and harbour porpoise), would be *minor, sub-local, short-term, and likely to occur*. The possibility of non-auditory physiological effects cannot be evaluated with present data. If they occur, they would be limited to animals very close to the operating array.

The situation for sperm whales and northern bottlenose whales is less clear. The available data are not adequate for predictions. It is clear that the proposed program for 1998 is sufficiently far from the Gully to not affect the resident population of northern bottlenose whales and sperm whales present there (see the 40 and 50 km curves on Figure 17). Thus, for the 1998 program the predicted effects are *negligible to minor, local, short-term, and may occur*. If seismic exploration is to occur closer to, or over, the Gully, then an individual assessment would be required to supplement this class assessment. The individual assessment should consider research initiatives to address the question of effects on the sperm whale and the northern bottlenose whale, and enhanced mitigation measures to reduce the likelihood, extent and severity of effects.

Baleen Whales

Thresholds for temporary threshold shift (TTS) in baleen whales are unknown. It is not safe to assume that the measured TTS thresholds for bottlenose dolphins apply to baleen whales, which seem to be much better adapted for low frequency hearing. TTS threshold levels could be important for assessing effects on baleen whales because individuals of some species of baleen whales occur quite close to ships and to seismic operations. For example, one of the main threats to the endangered northern right whale along the Atlantic coast is mortality due to collisions with ships. Also, McCauley et al. (1998) found that some individual humpback whales approached an operating seismic airgun to within 100-400 m. Thus, the received levels that induce TTS may be particularly relevant for baleen whales.

Studies of gray, bowhead, and humpback whales have determined the received levels of seismic noise that induce behavioural responses in whales exposed to operating airguns and airgun arrays. Received levels (rms) of pulses in the 160-170 dB re 1µPa range seem to cause obvious avoidance behaviour in a substantial fraction of the animals exposed. These equate to sound exposure levels (SELs) of 150-160 dB re 1 µPa. Figure 23 presents the sound transmission loss vs. range for the three tracks modelled near Sable Island for the July period. From these data, it is apparent that the seismic pulses will have diminished to 150-160 dB SEL at distances of 4.5 to 14.5 km. Thus, a substantial proportion of the baleen whales within 15 km may show avoidance or other strong disturbance reactions to the seismic array. A minority of the individual whales may show avoidance at somewhat greater

distances, and subtle behavioral effects (e.g. alterations in surfacing-respiration-dive cycles) may extend to well beyond 15 km. The studies to date indicate that such disturbances are likely to be transitory with normal behaviour resuming within an hour or two after ship passage.

It should be pointed out that reactions to seismic pulses have not been studied in any detail in most of the baleen whale species that occur on the Scotian Shelf. (The humpback whale is the one exception.) However, the similar results for the three species that have been studied in some detail suggest that the results may be applicable to most, if not all, baleen whale species.

Although a fairly large area will be affected during the seismic program, individual baleen whales will be disturbed only periodically. The most significant behavioural reactions are likely to consist of short-range avoidance movements. The predicted acoustic impacts on baleen whales (right, humpback, blue, fin, sei and minke) are judged to be *minor, local, short-term*, and *likely to occur*. Non-auditory physiological effects on baleen whales are not likely to occur because of the known avoidance reactions of the species that have been studied at the close distances that are necessary for damage to occur.

Seals

TTS thresholds for seals have not been reported, although preliminary results for a harbour seal suggested that its TTS thresholds might be lower than expected (Kastak and Schusterman 1996). Because seals have been observed close to operating seismic arrays, knowledge of TTS thresholds for pulsed sounds would be very useful. Some seals may occur close enough to the arrays for their hearing to be affected. The studies of ringed and bearded seals in Alaska have indicated that these seals show only very localized displacement in response to an approaching and operating seismic array. Some (not all) seals apparently avoided the area within about 150 m of the operating airguns, but few if any of them moved to distances beyond about 500 m away. Overall received levels diminished to 190 dB and 180 dB (rms) at distances of about 240 m and 970 m, respectively. The ringed seal is closely related to the harbour seal that is common on the Scotian Shelf. Thus, the results may be applied at least to the harbour seal with some confidence.

Based on the apparent tolerance of ringed seals to high levels of noise from seismic operations, the impacts of seismic pulses on harbour and grey seals are judged to be *minor, sub-local, short-term*, and *likely to occur*. The possibility of non-auditory physiological effects on seals cannot be evaluated with present data. If they occur, they would be limited to seals very close to the operating array.

Important Areas

The pelagic distributions of marine mammals on the Scotian Shelf have not been studied systematically. Thus, it is very difficult to identify areas that are particularly important to whales. Nonetheless, there are certain areas on the Scotian Shelf that have been identified by DFO as being important to whales. These areas are the Gully and the Roseway Basin sanctuaries (Figure 44). They are discussed later, in the Section entitled Procedures for Class Assessments.

It is important to note that the lack of synoptic distributional data means that the relative importances of particular areas cannot be assessed properly. Also, it is possible that areas not yet identified might be especially important for marine mammals.

Sea Turtles

Three species of sea turtles are known to occur more or less regularly on the Scotian Shelf: loggerhead, leatherback and Kemp's Ridley sea turtles (Cook 1984). All occur there in summer, but probably not in winter. All are considered to be endangered or threatened.

Leatherback Turtle (*Dermochelys coriacea*)

This is the largest of all the sea turtles, with adult weights over 400 kg not uncommon. The large size and pelagic nature of this species have made it very difficult to study. As a consequence, this is among the least-known species of sea turtles. It feeds primarily on gelatinous animals. Although it occasionally feeds in shallow water (Leary 1957), it is best known for its wide-ranging pelagic migrations. It is not unusual to see the adults in very cold water. Small leatherbacks (post hatchlings) and juveniles are almost never seen, and museum records are rare. Nesting occurs at several locations on both island and mainland beaches in the Caribbean from April to July. There is a small amount of nesting on the east coast of Florida.

This species is found off Atlantic Canada from June to October with peak abundance in August (Cook 1984).

Loggerhead Turtle (*Caretta caretta*)

The loggerhead turtle winters in the south, but some individuals migrate north into Canadian Atlantic waters with the Gulf Stream in summer (Cook 1984). Continental shelf waters are believed to be important feeding areas (Payne et al. 1984). This species feeds on crabs, molluscs, sea pens and various gelatinous organisms.

The loggerhead turtle may achieve sexual maturity at an age of 30-50 years (Magnuson 1990). One of the world's largest breeding aggregations is found on the central Atlantic coast of Florida, with additional nesting occurring along the east coast (mainly on islands) north into North Carolina where there are a small number of nesters each year. Post hatchlings and juveniles stay in the Atlantic gyres for an extended period, probably a number of years. When these turtles approach the 30-50 cm size range, they cross the shelf and begin to forage in the benthic zone of the bays and estuaries. There may be a period of years when they move back and forth between the pelagic and coastal zones. Several satellite tracking projects have shown animals leaving the coastal zone and moving out to sea, particularly as the coastal waters cool in fall (Standora et al. 1992). Sea turtles are not randomly distributed. They commonly associate with convergence zones, drift lines, and downwellings in the open ocean (Carr 1986).

Kemp's Ridley Turtle *(Lepidochelys kempii)*

This is the smallest and rarest sea turtle in the area. Based on stranding records, it is known to occur as far north as eastern Canada; only juveniles have been found along the U.S. Atlantic coast (CeTAP 1982).

The adults of this species, which average about 35-45 kg in weight, are known almost exclusively from the Gulf of Mexico. Since juveniles are commonly found all along the U.S. east coast, it is thought that pelagic-stage individuals are carried by the Florida Current into the Atlantic, where they are picked up by the Gulf Stream and transported north in the western Atlantic. After the pelagic stage, this species feeds primarily on swimming and benthic crabs. Recent satellite tracking shows that even small Ridleys can move into the pelagic zone (Standora et al. 1990). It is likely that there would be a small number of Ridleys in the study area in summer.

Predicted Effects on Sea Turtles

Sea turtles have maximum hearing sensitivity in the 140-500 Hz range (Ridgway et al. 1969) or 100-700 Hz range (Wever 1978, cited in McCauley 1994). The peak sensitivity in the green turtle was 65 dB re 1 µPa at 400 Hz. Outside the above frequency ranges, the hearing sensitivity drops off sharply at 20-40 dB/octave above the range and 35-40 dB/octave below the range, depending upon the study. Likewise, Lenhardt et al. (1983) obtained evidence that loggerhead and Kemp's Ridley sea turtles are sensitive to underwater sounds in the 250-500 Hz range. The frequencies of sensitivity overlap with the seismic noise frequencies that propagate well on the Scotian Shelf. Thus, turtles will certainly hear sound pulses from a seismic program on the shelf.

There is very little information on the effects of seismic exploration on sea turtles. O'Hara and Wilcox (1990) conducted experiments to determine whether airguns would be a suitable means of keeping loggerhead turtles from entering waters that were unsafe for them. Turtles maintained an exclusion zone of at least 30 m around a single 10 in^3 airgun emitting sound at a level of about 220 dB re 1 µPa·m, supplemented by two very small (0.8 in^3) airguns. The highest level of turtle activity in the experimental situation occurred at the maximum distance (180-210 m) from the noise source. These results may not be applicable to open water situations since the turtles would have more choices about moving away from a seismic source. On the other hand, substantial amounts of turtle activity occurred closer to the airgun than was necessary given available quieter habitat.

Given the small numbers of sea turtles expected on the Scotian Shelf and given the tolerance of loud airgun noise indicated by the study of O'Hara and Wilcox (1990), it is likely that seismic effects of sea turtle populations on the shelf will be *negligible*. This conclusion should be revisited in the five-year review of this Class EA, particularly if turtles are found to be more common on the shelf than presently thought and/or if new information on effects becomes available from other areas.
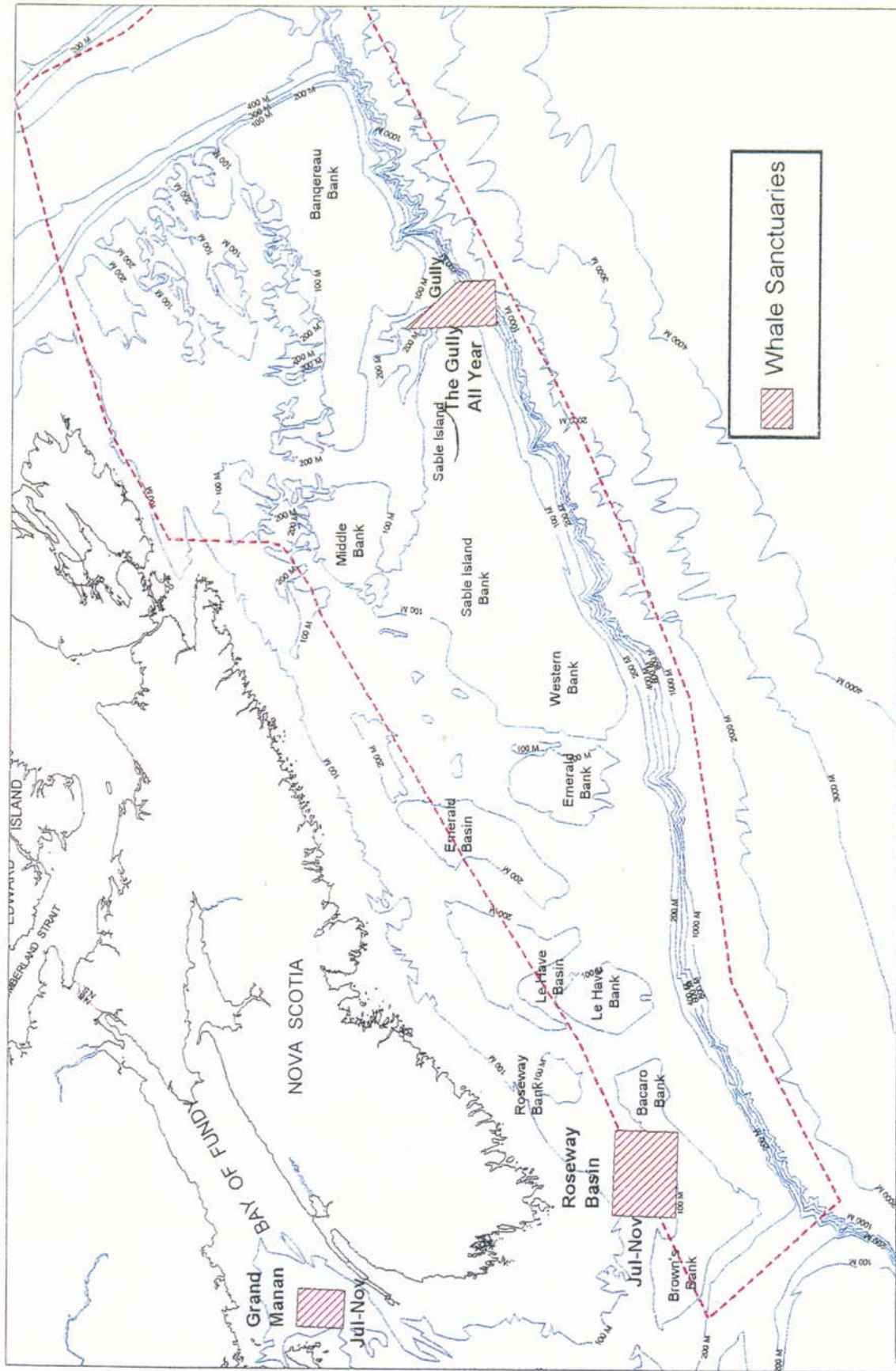
Figure 44. Approximate locations of whale sanctuaries declared by Department of Fisheries and Oceans.

The Gulf of Mexico has major seismic programs and supports substantial populations of sea turtles; thus, if seismic effects on turtles do occur, they should be more evident in the Gulf of Mexico.

Seabirds

Several species of sea-associated birds occupy the Scotian Shelf at various times of year. In addition, species that nest on Sable Island use adjacent waters for feeding. The avifauna of the region was reviewed in SOEP (1996) based primarily on Brown (1986) and Lock et al. (1994). The following brief summary is based on these sources. The summary is not intended to be a complete list of the birds that might occur in the area; rather it mentions the main species that are common in the study area.

Northern fulmars nest in arctic waters and winter offshore in subarctic and cold temperate waters. Some are present on the Scotian Shelf in the late fall through early spring period, mostly outside the period covered by the present assessment. Greater and sooty shearwaters nest on sub-antarctic islands and migrate north in summer into the north Atlantic during the southern hemisphere winter. They can be abundant on the Scotian Shelf during summer. Other shearwater species, Manx, Cory's and Audubon's, occur in much smaller numbers in the study area. Shearwaters are usually considered to feed on surface and near-surface organisms. However, there is recent evidence that sooty shearwaters dive well below the surface (maximum observed depth 67 m) much more often than previously suspected (Weimerskirch and Sagar 1996). The much smaller Leach's and Wilson's storm petrels are also surface feeders that occur on the Scotian Shelf during the spring through fall study period. The Leach's storm petrels nest on coastal islands from Labrador to Maine with most occurring north of the Scotian Shelf. The Wilson's storm petrels are southern hemisphere breeders that are common in the study area during the late spring through early fall period.

The northern gannet nests in large colonies in Quebec and Newfoundland and migrates through the study area. The gannet is a plunge diver that hunts on the wing, diving into the water to feed on fish that occur in near-surface waters. The double-crested and great cormorants are coastal species that feed in coastal and nearshore waters. They swim on the surface and feed by diving to often considerable depths in pursuit of fish.

The alcids are seabirds that feed by diving underwater to catch fish. The black guillemot nests in rocky, coastal areas in Nova Scotia and more northerly areas. Thus, it occurs in coastal and nearshore waters in summer. Other alcid species occur in Scotian Shelf waters mainly in the winter period not covered by this assessment. These include common murre, thick-billed murre, razorbill, Atlantic puffin, and dovekie.

Several species of gulls occur in Nova Scotia waters but only the herring gull and the great black-backed gull occur commonly during the summer period. These are surface feeders that do not dive into the water. The black-legged kittiwake is a pelagic gull that is present offshore of Nova Scotia in the non-breeding (=winter) season.

The roseate tern is classified as a "threatened" species in Canada by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). In Canada, about 30 pairs of roseate terns nest near Country Harbour along the coast and two pairs nest on Sable Island (SOEP 1996). Terns feed by plunge-diving into near-surface waters to catch small fish.

Coastal waterfowl comprise species that dive in search of fish and other marine organisms. The most common marine duck that nests in the area is the common eider. Most eiders in Nova Scotia do not occur within the study area covered by this assessment.

Predicted Effects on Birds

There have been virtually no studies of the effects of airgun-based seismic exploration on birds, perhaps because there has been no evidence to indicate that problems are occurring. Stemp (1985) made observations on the reactions of birds to seismic exploration programs in southern Davis Strait over three summer periods. No distributional or mortality effects were detected in 1982, the only year when an airgun-based program was conducted. John Parsons (*in* Stemp 1985) reported that shearwaters off Sable Island did not respond to underwater explosive charges 30 m away, even though the birds had their heads underwater. Thus, airguns at these distances are unlikely to affect surface-feeding birds. Evans et al. (1993:8) made observations from operating seismic vessels in the Irish Sea. They noted that, when seabirds were in the vicinity of the seismic boats, "there was no observable difference in their behaviour, birds neither being attracted nor repelled by seismic testing".

Bird populations in the offshore study area during the May to October study period are primarily surface feeders and plunge divers. These birds are not expected to be affected by seismic pulses whose levels are reduced in waters within a few metres of the surface. Birds could be affected if their food sources are affected by seismic exploration. Since important food chain effects are not expected (see earlier sections), there are not expected to be any indirect effects on bird populations. Therefore, the effects of seismic exploration on birds in the Scotian Shelf study area are expected to be *negligible.*

IMPACT SUMMARY

The predicted impacts on seismic exploration on marine animals were identified in the preceding sections. Here we present a table summarizing the predicted effects. The impacts identified for invertebrates, fish, fisheries, marine mammals, sea turtles, and seabirds are rated *not significant* according to the definitions adopted earlier in the assessment. There are, however, some special cases that are discussed below under Procedures for Class Assessments.

Valued Ecosystem Component	Interaction	Impact			
		Magnitude	Scale	Duration	Likelihood
Invertebrates					
Commercially important species	Mortality	Negligible			
Invertebrates as food for VECs	Disturbance	Negligible			
Invertebrate Fisheries	Reduction in catch	Negligible			
Fish and Fisheries					
Adult fish	Mortality	Negligible			
Fish eggs and larvae	Mortality	Minor	Sub-local	Short-term	Likely
Fish	Hearing damage	Negligible			
Fisheries	Reduction in catch	Minor	Sub-local	Short-term	Likely
Toothed Whales					
All species		Minor	Sub-local	Short-term	Likely
Baleen Whales					
Right whale		Minor	Sub-local	Short-term	Likely
Humpback whale		Minor	Sub-local	Short-term	Likely
Blue whale		Minor	Sub-local	Short-term	Likely
Fin whale		Minor	Sub-local	Short-term	Likely
Sei whale		Minor	Sub-local	Short-term	Likely
Minke whale		Minor	Sub-local	Short-term	Likely
Seals					
Grey seal		Minor	Sub-local	Short-term	Likely
Harbour seal		Minor	Sub-local	Short-term	Likely

MITIGATION

No moderate or major impacts of seismic exploration were identified on the marine animals of the Scotian shelf. Theoretically, that conclusion should mean that mitigation measures are not required. However, because of the very high noise levels involved and the many gaps in the data, it is prudent to examine the options for mitigation measures and to consider whether to recommend that any be adopted.

The most common mitigation measure for seismic programs is to gradually ramp up the noise of the airgun array until the full array is operating. This is now standard practice with many seismic operations. The rationale for the "ramp-up" of noise is that it warns marine animals and allows them to take evasive action before being exposed to the full array. Most workers agree that "ramp-up" is a good thing. There is anecdotal evidence indicating that some marine mammals move away during ramp ups or when a single airgun begins firing (Richardson et al. 1986, 1995:372). However, there are no quantitative data to document whether the procedure is effective.

There are no widely-accepted standards on how "ramp-up" should be conducted in terms of length of time, initial noise levels, progression of noise levels, and so on. In the U.S., the National Marine Fisheries Service (NMFS) has specified in the permits for some recent seismic programs that each period of airgun array operations should commence at a source level not exceeding 160 dB re 1 μPa. This is impractically low for even the smallest single airgun. In other permits NMFS has specified that operations should commence by firing the smallest airgun in the array. NMFS usually specifies that the rate of ramp up should not exceed 6 dB per minute. There are few specific data upon which to design the most effective protocol. Having said all of this, it is appropriate to continue using a "ramp-up" of about 20-30 minutes duration before beginning full-scale shooting.

When ramping-up is done, there is a need to specify how long the airguns can be silent before a full ramp up must be done. In a recent project in Alaska, ramping-up is called for when the array has been shut down for more than 1 minute under normal conditions, or 2 minutes if the vessel is traveling at no more than 3 knots (p. 2-8 *in* LGL and Greeneridge 1997).

Another type of mitigation is to avoid problems by scheduling. This is appropriate for avoiding seasonal concerns. For example, the Roseway Basin on the SW Scotian Shelf has been identified by DFO as an important area for the endangered northern right whale from July through November. Clearly, the most effective mitigation here would be to conduct any seismic exploration in this area sometime outside the July-November period.

In some jurisdictions (e.g. arctic Alaska and California), seismic operations have, in recent years, been required to shut down if marine mammals are detected within specified distances of the operation. Somewhat different criteria have been used in different projects. NMFS requires more stringent shut-down criteria for baleen whales (with their presumably sensitive low-frequency hearing) than for seals. Shut-down criteria for odontocetes have been variable. Based on present knowledge, this type of mitigation measure is not required on the Scotian Shelf. However, some increased monitoring to document close approaches to marine mammals should be initiated.

RESEARCH AND MONITORING

There has been a large amount of seismic exploration on the Scotian Shelf over the years. In that time, there have been no credible, scientifically-sound studies of the effects of seismic on marine animals. It is recommended that future seismic programs, including the proposed 1998 program, make credible observations of mammals that approach or otherwise occur in the vicinity of the operating array. These observations could be conducted from the seismic boat or the guard boat, depending upon available accommodation. A systematic observation protocol should be adopted and the observer should be a trained biologist with experience observing marine mammals. Although marine mammals should be the focus, the observer should also note turtle and bird observations. Data analysis should be professional and the data should be archived in a user-friendly retrieval system. At the end of the five-year period of this Class EA, the combined data should be analyzed to determine if any changes are required during the update of the Class EA. If several seismic programs have been conducted, it might be appropriate to analyze the data after 2 or 3 years.

As discussed under Mitigation, there is a need for experiments to determine the most appropriate protocols for the "ramp-up" phase of full-scale array operation. This research is more appropriate on an industry wide basis rather than being related to the Scotian Shelf where serious problems have not been identified. The need for tests of ramp-up efficacy and protocols has been identified elsewhere, e.g. Richardson (1998).

As discussed later, if seismic exploration is to be conducted in the Gully or the Roseway Basin whale sanctuaries, then a more intensive research program would be appropriate.

CUMULATIVE EFFECTS

Assessment of cumulative effects is always a very difficult task since there are few relevant data from existing situations and it is difficult to know what effects might be expected from planned or future projects. Cumulative effects may be additive or synergistic. In the present case, they include the combined effects of seismic exploration plus the effects of other existing or planned activities for the area including fishing and the Sable Offshore Energy Project.

The Scotian Shelf has been exposed to heavy commercial shipping, intensive fishing activities, and extensive amounts of seismic exploration over the past decades. Much of the earlier geophysical exploration used much more destructive explosives techniques. Seismic exploration is temporary and the resulting impacts on marine animals also appear to be temporary. The areas surveyed are usually covered over a period of a few weeks and then are not surveyed again for several years. Impacts of seismic operations are not cumulative from year to year. The impacts are all predicted to be short-term. Once an operation is complete, effects would not persist into following years.

Impacts of two or more seismic exploration programs conducted concurrently may or may not have cumulative impacts. If the operations are conducted in areas adjacent to one another or if the boundaries of the exploration areas are within a few km of one another, then impacts would probably be additive and somewhat greater than those predicted here. If the operations are conducted on separate parts of the Scotian Shelf, then they could be treated as separate projects and overall impacts of the projects would be as predicted here.

Shipping is known to affect the behaviour of fish and marine mammals. Ship traffic is heavy on the Scotian Shelf and affects a much greater area than does seismic operations. The addition of the temporary effects of seismic noise to effects of existing shipping noise is probably not significant.

The presence of offshore oil and gas structures has a negligible impact on fish distributions. In fact, fish tend to concentrate around such structures. The impact of seismic exploration on fish behaviour would be independent of the presence of offhsore oil and gas installations.

PROCEDURES FOR CLASS ASSESSMENTS

This document assesses potential impacts that can be expected from seismic exploration on the Scotian Shelf. It is designed to provide a framework against which applications for permits for individual seismic programs can be evaluated. This assessment covers only the area shown in Figure 1. It does not apply outside the May through October period. The assessment covers 2D and 3D seismic programs using airgun arrays. It also covers, by analogy, the localized Site Surveys and Vertical Seismic Profiles that utilize much less power. Thus, the applications for individual seismic programs that fall outside any of these parameters would require a program-specific assessment that focused on those aspects of the proposed program that differ from the parameters of the present document.

The Class Assessment does not cover Ocean Bottom Cable (OBC) seismic surveys that are conducted in many areas. In these programs, the hydrophone cables are laid on the bottom rather than being towed by the seismic boat. The seismic boat tows a typical airgun array, but it is has a much shorter turning radius than a boat towing a full streamer of 4.6 to 6 km in length. As a result, the seismic program can shoot more quickly because it spends much less time in line changes. The OBC technique is not included in the present Class Assessment. Therefore, any OBC program would require specific treatment of OBC in its individual EA. The principal novel component being the cables laid on the bottom.

There are some situations where the program-specific assessment is particularly important, even when the proposed program meets the criteria of this class assessment. These are related to areas that are known to be particularly important and/or species for which seismic effects are poorly understood. Situations that have been identified to date include the whale sanctuaries at the Gully and Roseway Basin (Figure 44). The Gully supports significant populations of sperm whales and northern bottlenose whales. These large, deep-diving odontocetes may be more susceptible to seismic noise than other species of toothed whales. Thus, expanded treatment should be required for an individual EA for a seismic program in the Gully. The Roseway Basin whale sanctuary is designed to protect the highly endangered northern right whale during the July-November period. Any seismic program planning to operate in this sanctuary during this period should complete an expanded individual EA for the program. Seismic programs in the Gully and Roseway Basin should have specific monitoring and research components.

Seismic programs conducted adjacent to a whale sanctuary will transmit substantial noise into the sanctuary. Now, each sanctuary already includes a buffer zone around its core area. In addition to the built-in buffer, it is recommended that any seismic program that wishes to come within 10 km of a sanctuary boundary be required to conduct an expanded individual assessment, as discussed above. The 10 km distance was chosen because noise from a seismic array decreases to threshold sound exposure levels of 150-160 dB at distances of 4.5 to 14.5 km depending upon the specific location. At these levels, some baleen whales exhibit temporary behavioural changes. The 10 km zone is thought to be conservative for the following reasons: it is based on overall received levels rather than 1/3-octave band levels, the sanctuaries, such as the Gully, already have built-in buffer zones, and the mere fact that whales temporarily change their behaviour in response to distant seismic does not necessarily indicate a significant effect.

The CNSOPB needs to consider the number of concurrent seismic exploration programs that can be conducted on the Scotian Shelf. Projects on separate parts of the Scotian Shelf would have negligible impacts on fisheries or other VEC's. However, if overlapping or adjacent programs are proposed by different proponents, then an individual EA may be necessary.

A seismic survey hydrophone streamer may be up to 6 km long and 700 m in width. When working, the vessel towing the array travels at 6.5 to 10 km/h, can change course only at a rate of 5°/min and requires 45 min to execute a 180° turn. A fishing trawler can have several hundred m of cable out and is also limited in manoeuverability. Lobster pots and longlines are set on the bottom, but

have lines rising to the surface. There is a potential for interaction and conflict between fishermen and seismic operations, especially in heavily fished areas and lobster fishing areas.

In order to resolve potential conflicts between fishing and seismic operations, individual screenings under this Class EA process should include consultation with the fishermen in the designated exploration area. The consultations should be facilitated by the CNSOPB Fisheries Advisory Committee and should include any other representatives of the fishing industry and persons who would be fishing in the specific exploration area. Given the long operating season for seismic activities, conflicts can be resolved through spatial and temporal planning of both fishing and seismic operations. Operators should insure early consultations, notices to mariners, and a fair and efficient damage claim process.

This Class EA should be updated for the 2003 seismic season; i.e. after a five year period. The update should focus on new information on seismic effects and on new and refined seismic survey techniques and mitigation measures. If a new seismic survey technique is introduced before 2003, then this Class EA should be updated to assess the new technique. Similarly, an update may be necessary if significant new data on the resources or on the effects of seismic exploration become available.

Applications for individual seismic programs should document that they meet the parameters of this Class Assessment. If all parameters are met, then little else need be required unless mitigation and research/monitoring requirements are adopted by the Board. If the proposed seismic programs do not meet all of the parameters, then an individual assessment should be prepared to address those aspects not covered by the Class EA.

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APPENDIX 1. ACOUSTIC MODEL PREDICTIONS

This appendix contains the model predictions of the variation of sound level with depth for seismic array operation at a depth of 6 m in the Scotian Shelf area. Detailed results from the model study are also included showing the influence of seasonal and short-term changes in sound speed profiles.

Results for Track S1

The model results for Track S1 using the May mean sound velocity profile (SVP) are shown in Figure I-1. The TL was predicted for several selected receiver depths. The initial depth at the beginning of the track was 40 m. Thus, a depth of 50 m was not available until about 25 km from the source. The TL can be seen to be lower (sound levels higher) at mid-depth and near the bottom than it is near the surface. This is a consequence of the shallow source depth and slightly downward refracting SVP. In the Gully, the TL at a depth of 100 m can be seen to be about the same as it is at 50 m. The TL at a depth of 10 m over the Gully can be seen to be higher than it is at 200 m down. Overall, the total TL levels along track S1 from a source south of Sable Island to the Gully are about 90 dB and greater. For a seismic array at this source location, the overall sound levels in the Gully would be less than 130 dB.

The TL frequency dependence for a receiver depth of 10 m is shown in Figure 1-2, again for the May mean SVP. The TL vs frequency analysis presented in the main acoustic section did not include S1 ranges beyond 50 km, to be consistent with the analyses for the other tracks. Figure 1-2 shows extended TL model results including the Gully area. Low frequencies below 50 Hz are seen to be attenuated quite rapidly, with high frequencies, 400 and 800 Hz, propagating best. The implications of this for seismic array sound is that the high sound levels below 50 Hz will be limited in range with the energy above 100 Hz tending to dominate the received level at ranges beyond a few kilometres. The added attenuating influence of the Gully on TL for a shallow receiver at 10 m can be seen to be significant at most frequencies except around 100 Hz.

Results for Track S3

Figure 1-3 shows the predicted TL at 200 Hz (May mean SVP) for the WSW track over the Sable Bank. The water depth along this track increases slowly from 40 m to 90 m at a range of 200 km. A frequency of 200 Hz was selected because this was shown to be the dominant frequency in the radiated noise spectrum beyond a few kilometres from the array. Again the TL is highest for shallow receivers and can be seen to be lowest near the bottom. The effect of changing the receiver depth can be evaluated from these data. For example, assume that a TL of about 70 dB is required to reduce a SEL below a specific reaction criterion. The effect of a change in receiver depth from 5 to 30 m can be seen to result in about a 5 km change in range that 70 dB TL occurs at 200 Hz. Alternately, there is about a 4 dB decrease in TL at 30 m depth compared to 5 m depth at a range of 20 km.

Figure 1-4 provides the same information as Figure 1-3, but for the July mean SVP. Here, as expected, the TL is higher at all ranges and depths because of the strong, downward-refracting profile. The example 70 dB TL range varies from about 13 km to 17 km with a change in receiver depth from 5 to 10 m, but is predicted to be about 13 km for both the 5 and 30 receiver depths. For a fixed range of 15 km, a variation of about 3 dB in TL is seen with change in receiver depth.

Figure 1-5 shows the frequency dependence of the TL for the May mean SVP. The results are similar to those shown in Figure 1-2 for Track S1. The low frequencies below 50 Hz are not shown but would attenuate rapidly as in the previous results for Track S1. Figure 1-5 demonstrates that it is necessary to consider all of the frequency components in the received signal from the array when estimating the effective zone of influence. A TL of 70 dB can be seen to be reached at a range of 6 km at 50 Hz, but requires a range of about 40 km at 400 Hz. It is expected that a dominant frequency band of 100-200 Hz will control the effective range of the signal.

The influence of short-term fluctuations in the SVP is shown in Figures 1-6, 1-7 and 1-8. Here the TL characteristics at 200 Hz for the mean and standard deviation profiles are shown for the months of May, July, and October. This is an estimate of the change in expected sound level that would occur at a given range caused by short term changes in SVP. It is surprising that the May conditions produced the greatest estimated TL fluctuations. These can be seen to be higher at long ranges than those for July and October, which had the strongest downward refraction conditions. However, at shorter ranges which are of more interest, the influence of SVP fluctuations is not as pronounced; i.e., for an example TL value of 70 dB, the variation is seen to be less than 3 DB for all 3 months.

A summary of the 200 Hz TL predictions for the mean gradient conditions is plotted using a 100 km logarithmic scale in Figure 1-9. At 200 Hz, the 70 dB TL level can be seen to be at a range of about 21 km in May and about 14 km in July. Specific estimates of the effective zone of influence ranges are made elsewhere using the full source spectrum and broadband TL characteristics for the criteria selected.

Figure 1-1. Sable Bank Track S1

100 Hz, Source Depth 6 m
Receiver Depths as shown
May, med. SVP
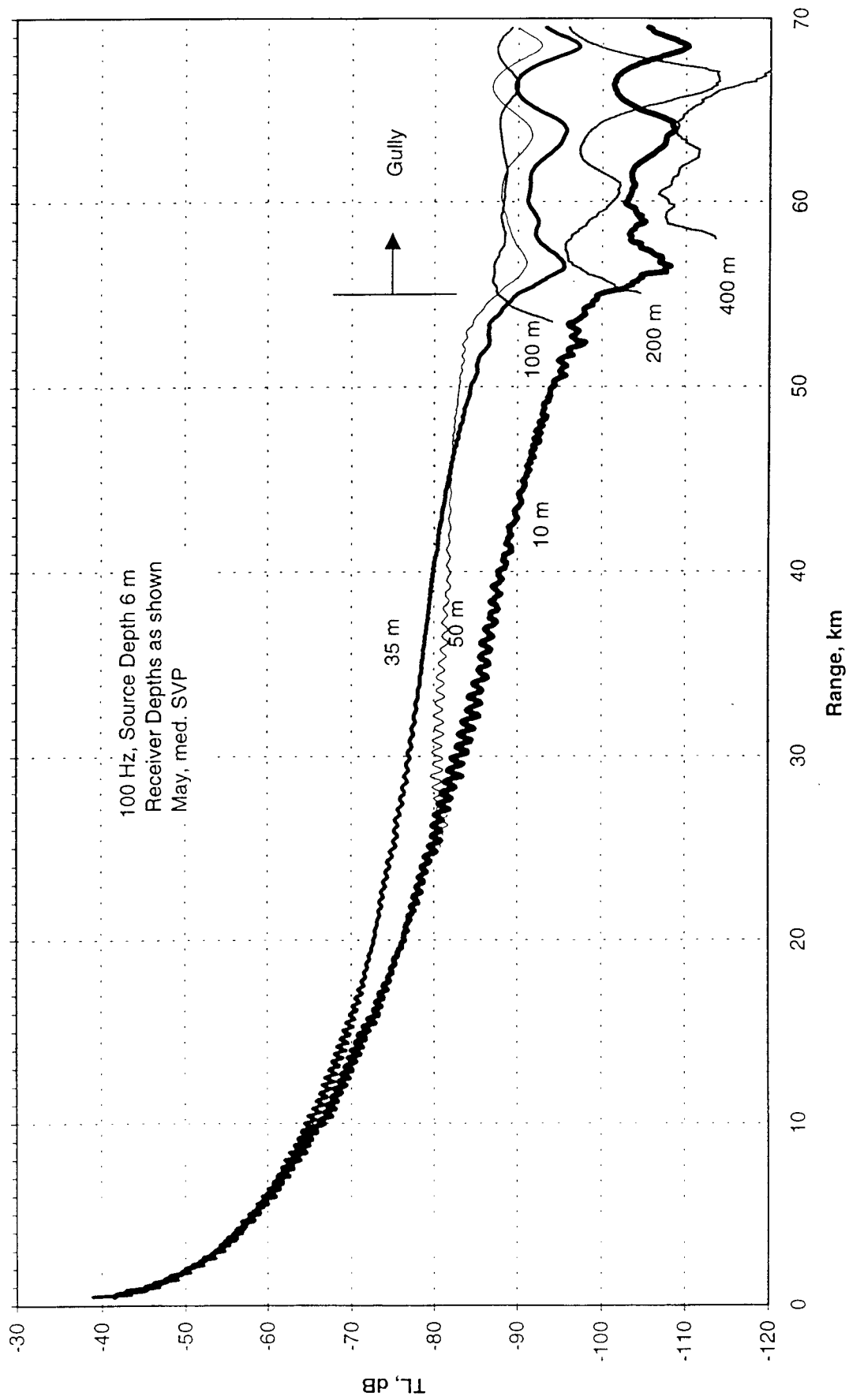
Figure 1-2. Sable Bank Track S1

Transmission Loss vs. Frequency
Rec. Depth, 10 m; May, Mean SVP
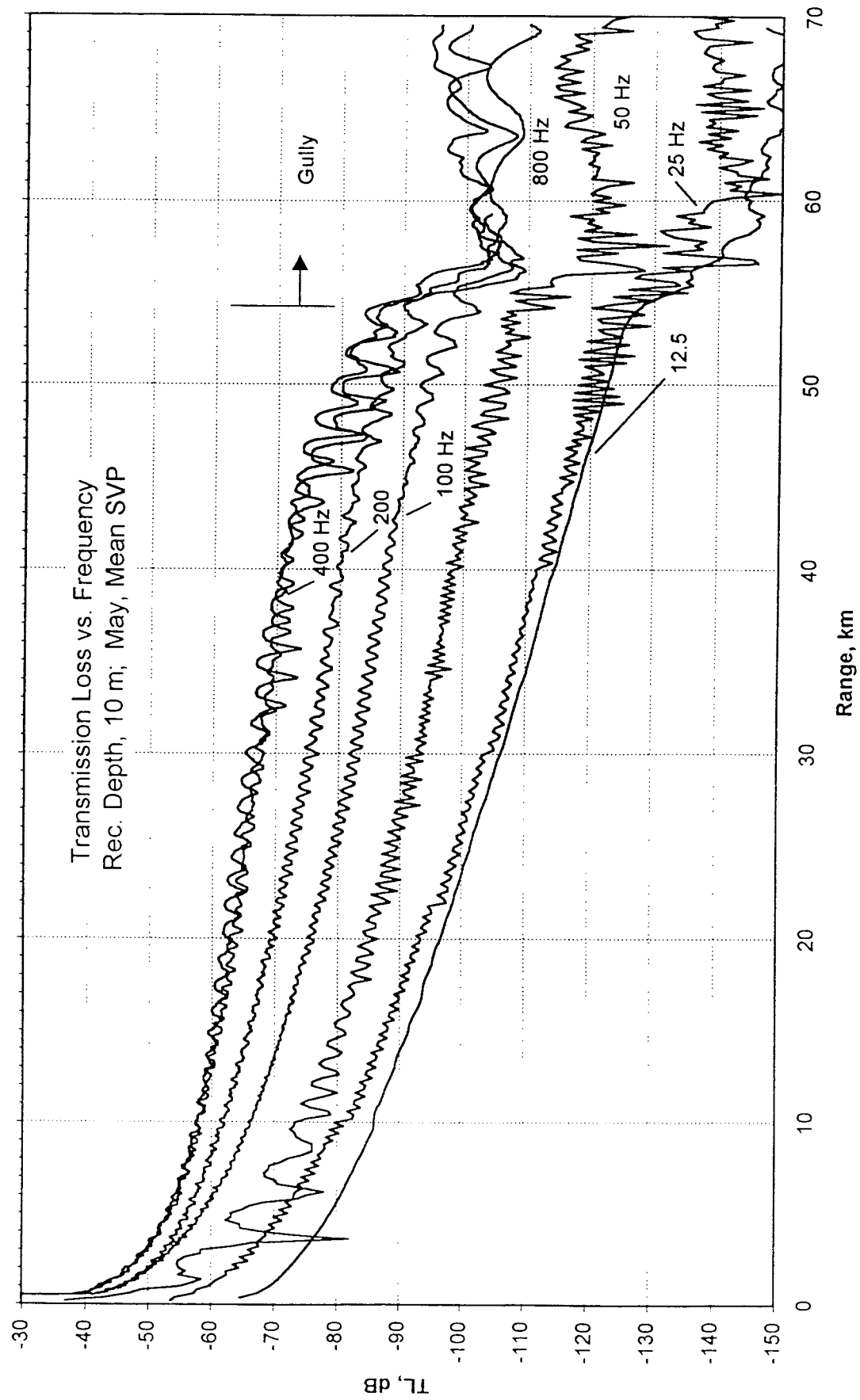
Figure 1-3. Sable Bank Track S3

200 Hz, May, Mean Sound Profile,
Receiver Depths as Shown

Figure 1-4. Sable Bank Track S3

200 Hz, July, Mean Sound Profile,
Receiver Depths as Shown

Figure 1-5. Sable Bank Track S3

Transmission Loss vs. Frequency
Rec. Depth, 10 m; May, Mean SVP
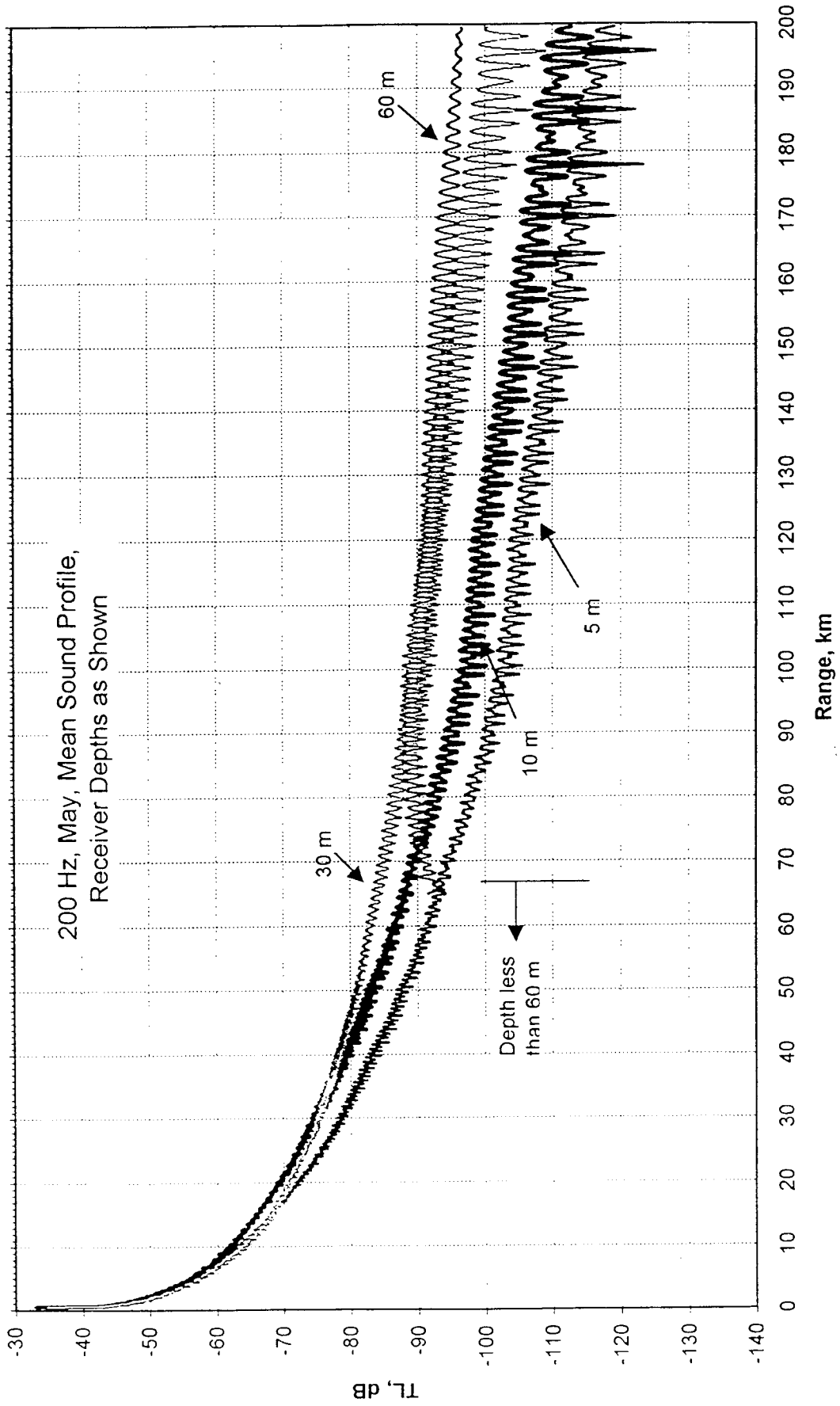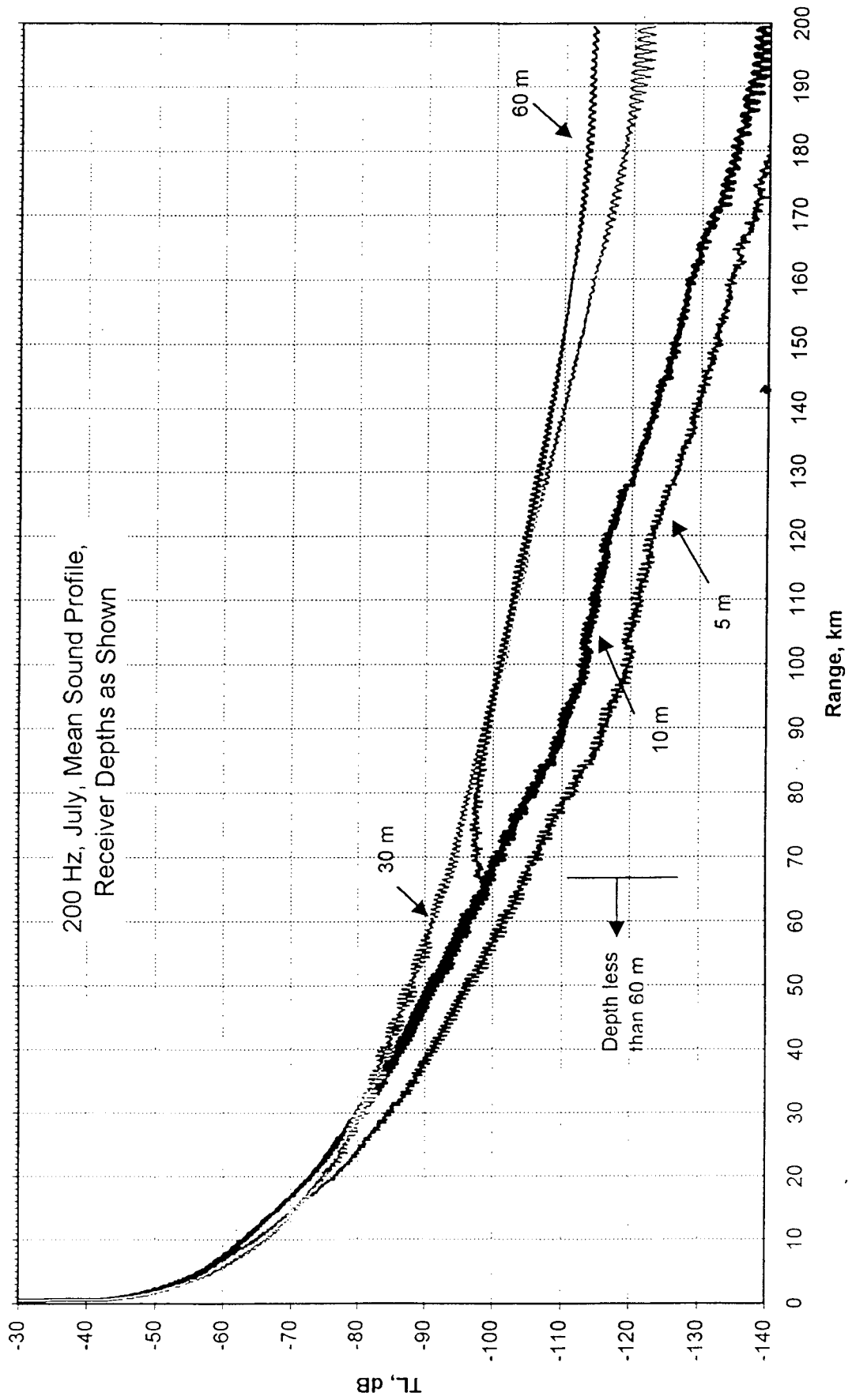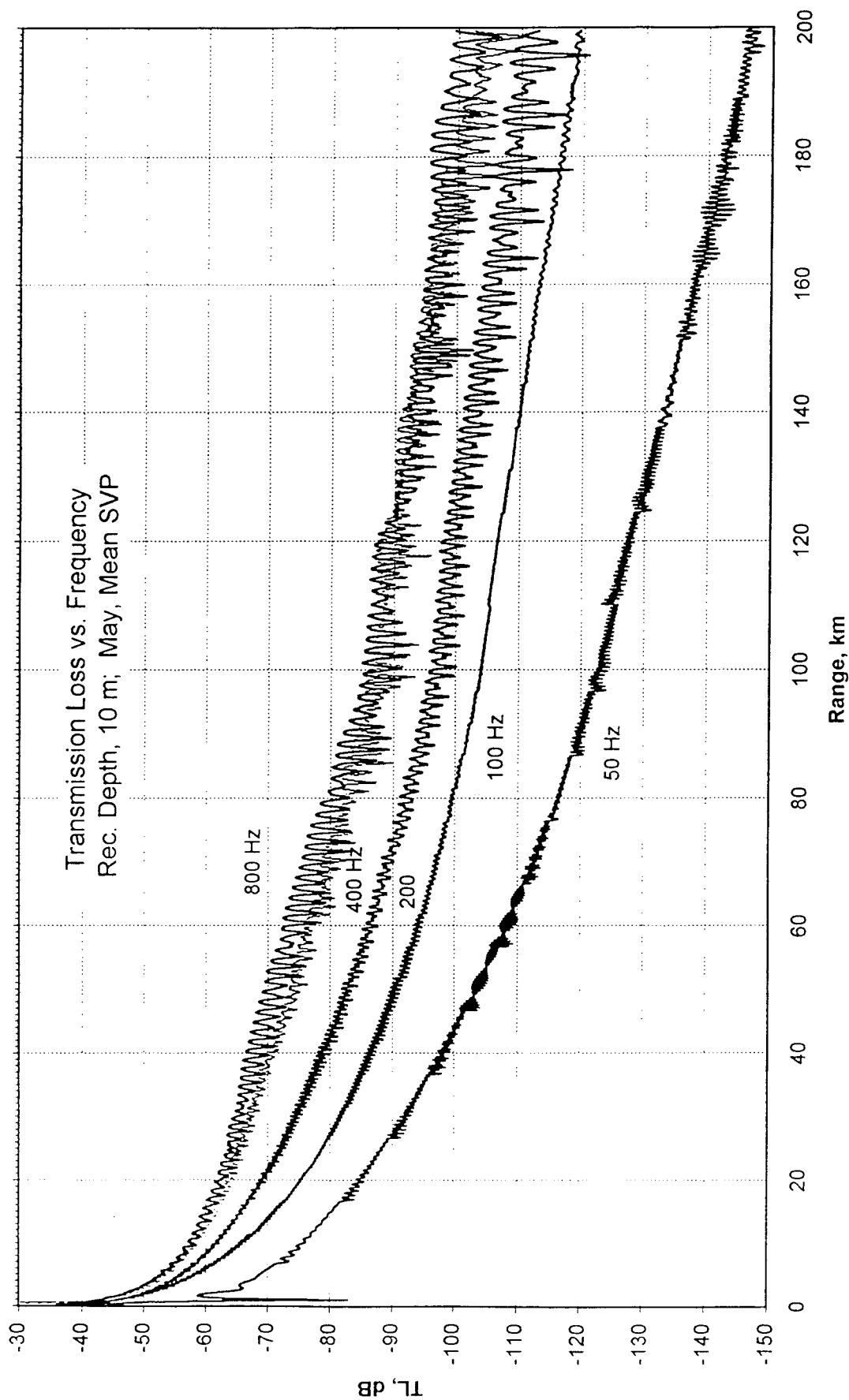
Figure 1-6. Sable Bank Track S3
May, Receiver depth 10 m

Sound Speed Gradient Variation Effect at 200
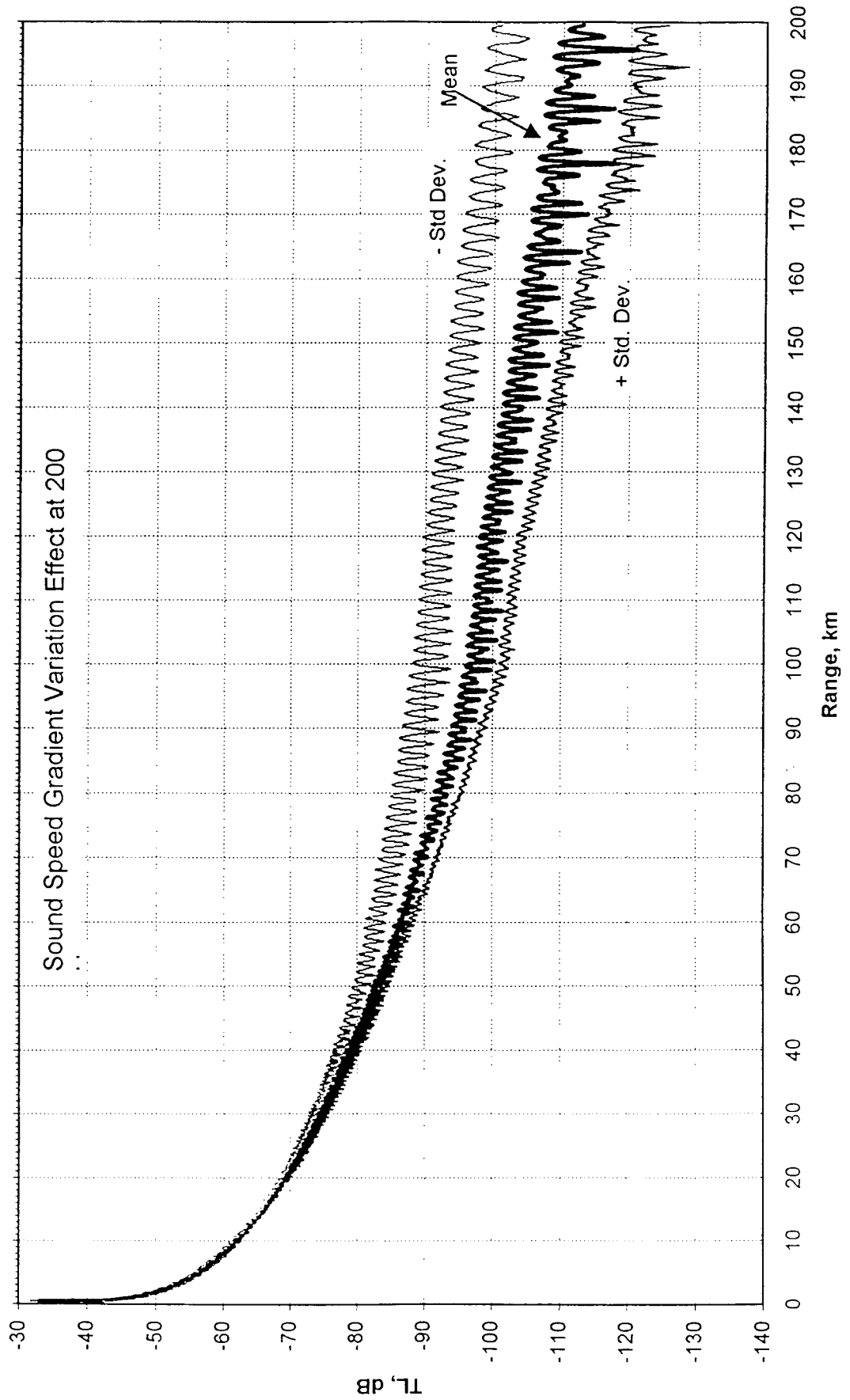
Figure 1-7. Sable Bank Track S3

July, Receiver depth 10 m

Sound Speed Gradient Variation Effect at 200

+ Std. Dev.

- Std Dev.

Mean

Range, km

TL, dB
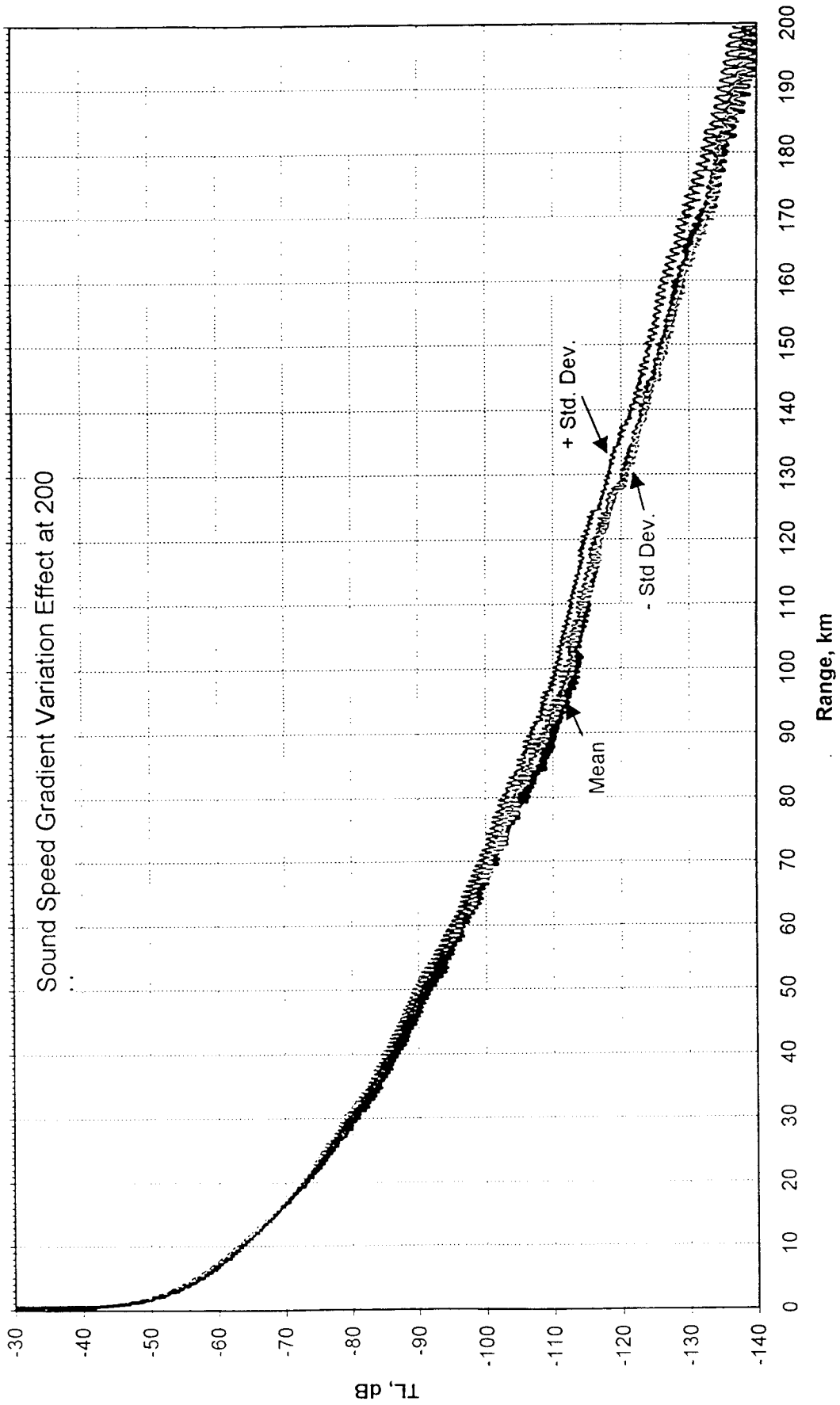
Figure 1-8. Sable Bank Track S3

October, Receiver depth 10 m

Sound Speed Gradient Variation Effect at 200 Hz
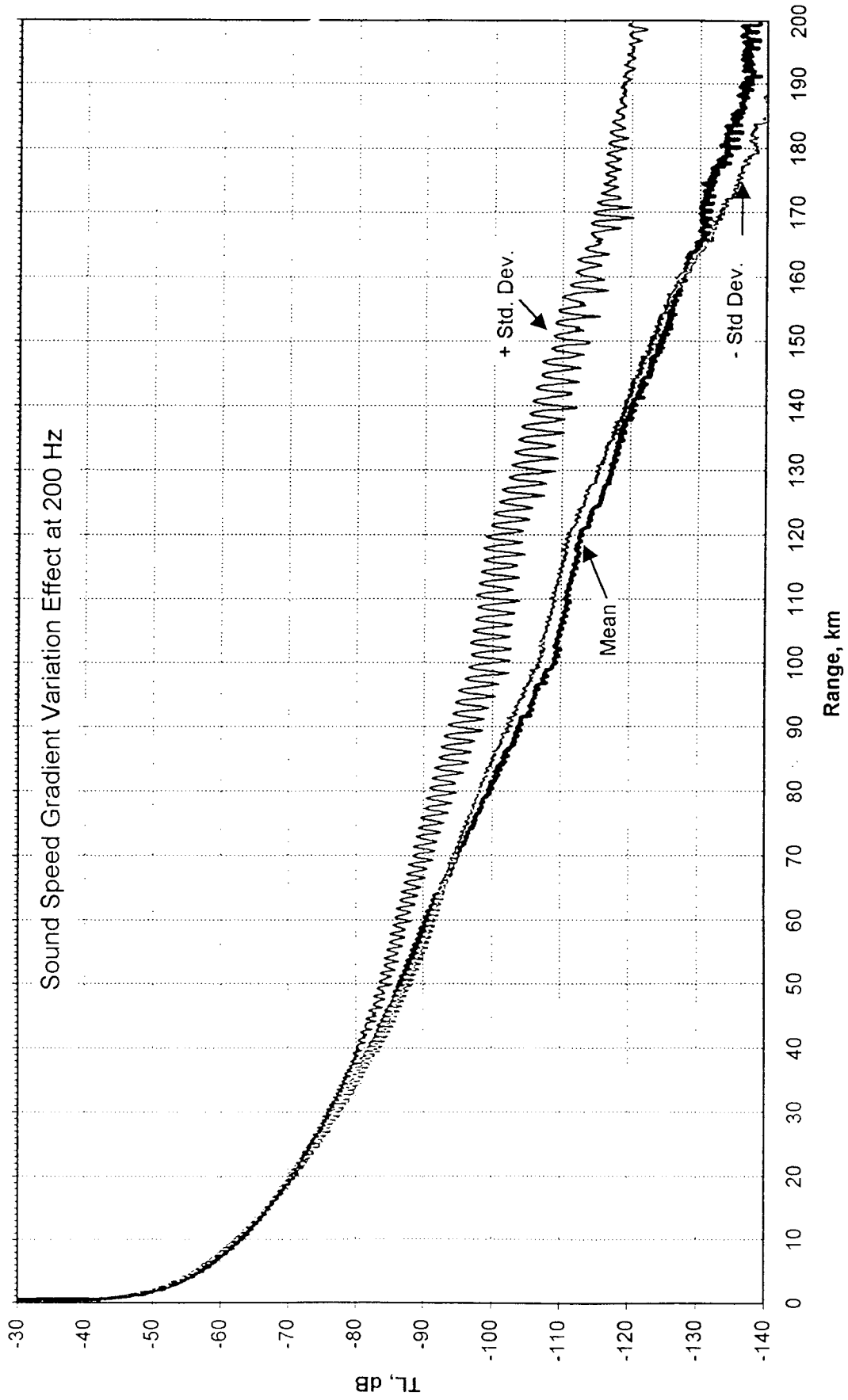
Figure 1-9. Sable Bank Track S3

Receiver depth 10 m

Sound Speed Gradient Variation Effect at 200 Hz
Comparison of seasons, mean gradient
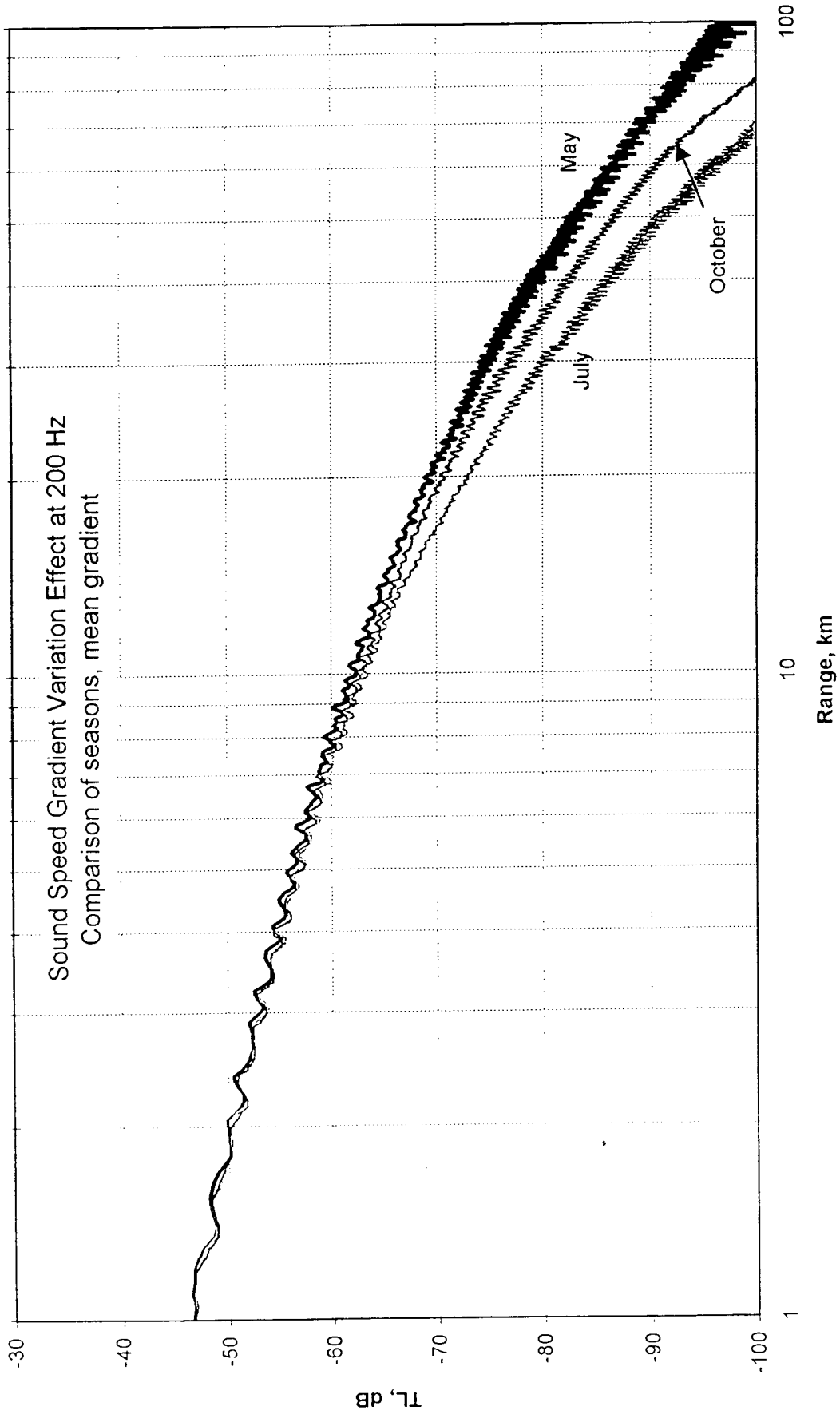
APPENDIX 2

FISHERIES CATCH LOCATIONS

Figures in this appendix were prepared by Canning & Pitt Associate, Inc., 36 Monkstown Road, St. John's, Newfoundland.

Each dot on a map represents a catch of fish and makes no assumptions about the size of the catch. If several catches were reported for the same location, then only one dot was plotted. See text for data limitations.

1996 Catch Data

Figures	Species
1-7	Cod
8-9	Pollock
10-16	Haddock
17	Silver Hake
18	White Hake
19-20	Redfish
21-22	Flounder
23-29	Halibut, swordfish, tuna
30-31	Cusk
32-33	Skate
34	Other Demersal Species
35	Herring
36	Mackerel
37	Other Pelagic Species
38	Lobster
39-40	Shrimp
41-42	Snow Crab
43	Surfclam
44	Scallops
45	Other Molluscs and Crustaceans
46	All Demersal Species
47	All Pelagic Species
48	All Molluscs and Crustaceans

1993 to 1996 Catch Data - All Species Combined

Figures	Years and Month
49	1993-1996 April-October
50-56	1993-1996 All Species by Month
57-63	1993 by Month
64-70	1994 by Month
71-77	1995 by Month
78-84	1996 by Month
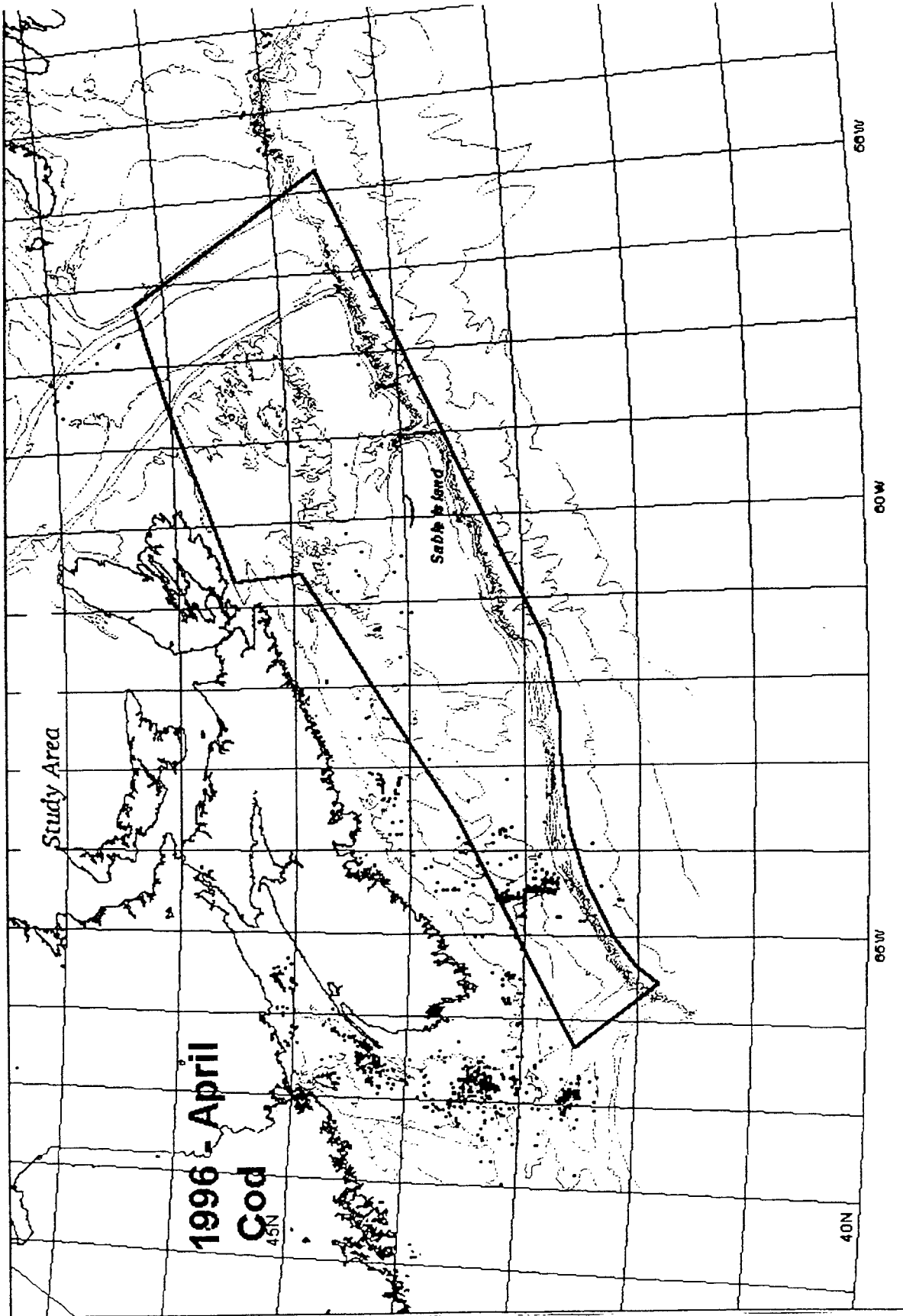
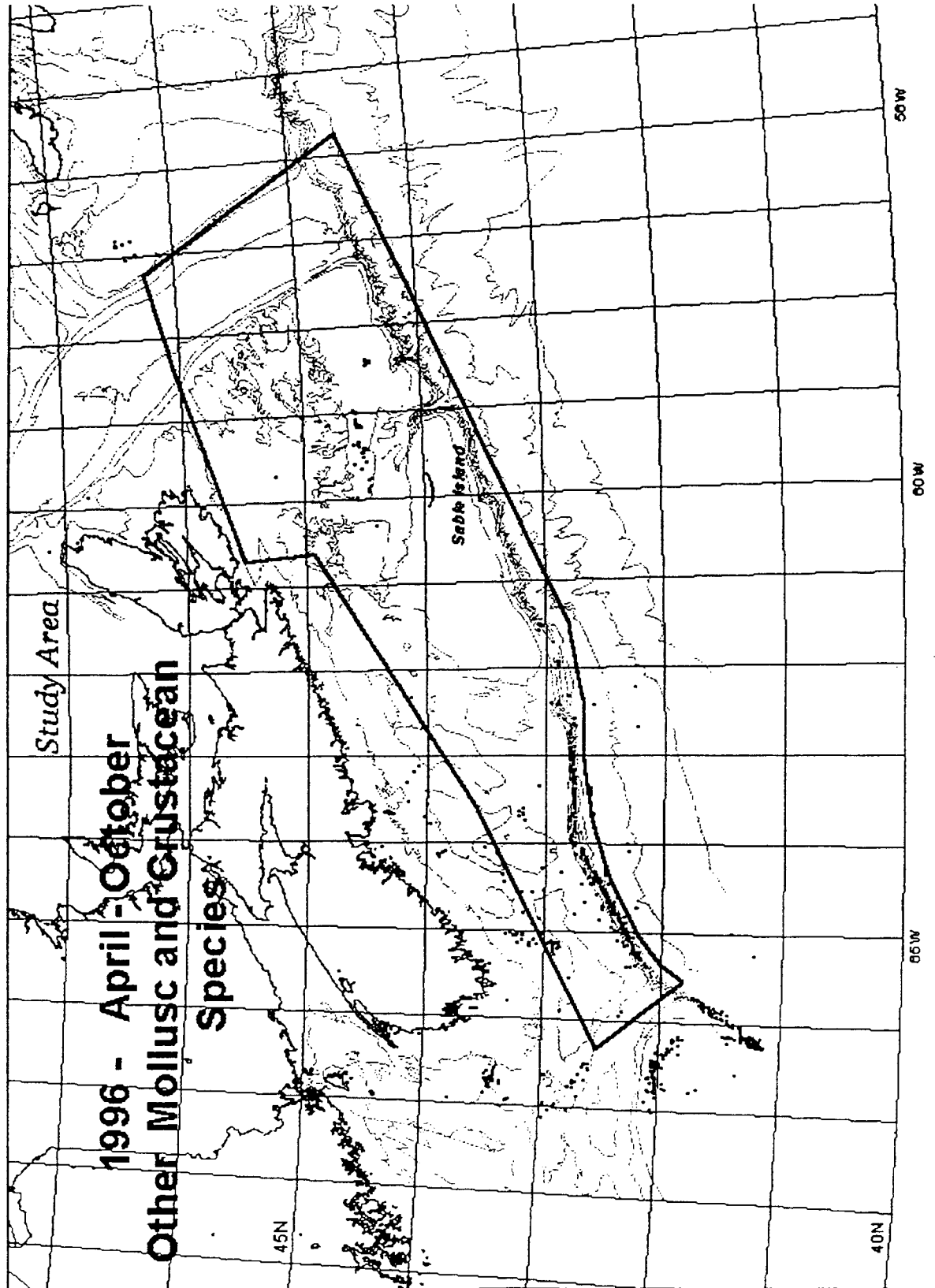Appendix Figure 2 - 1.   Fisheries catch locations on the Scotian Shelf.
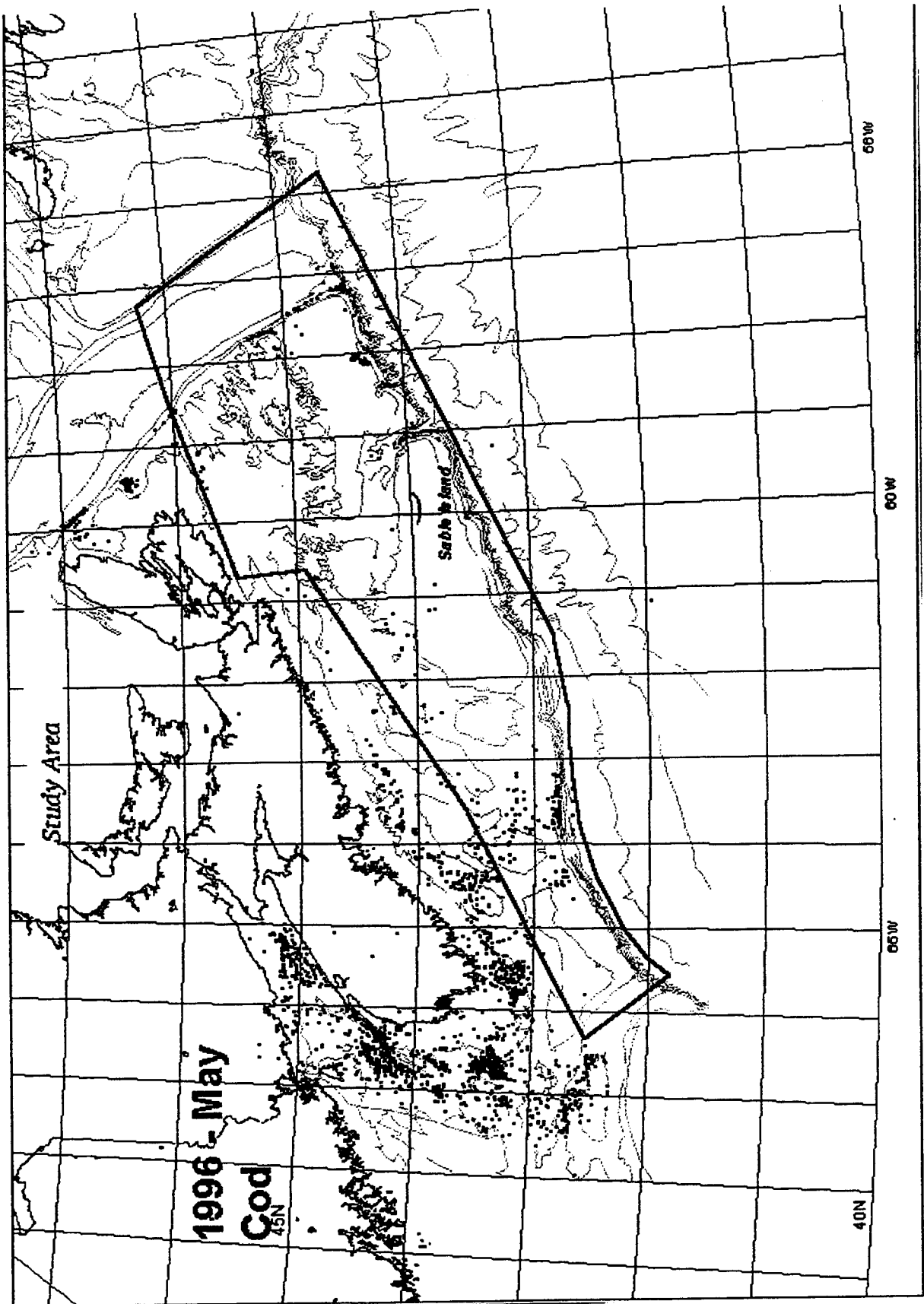
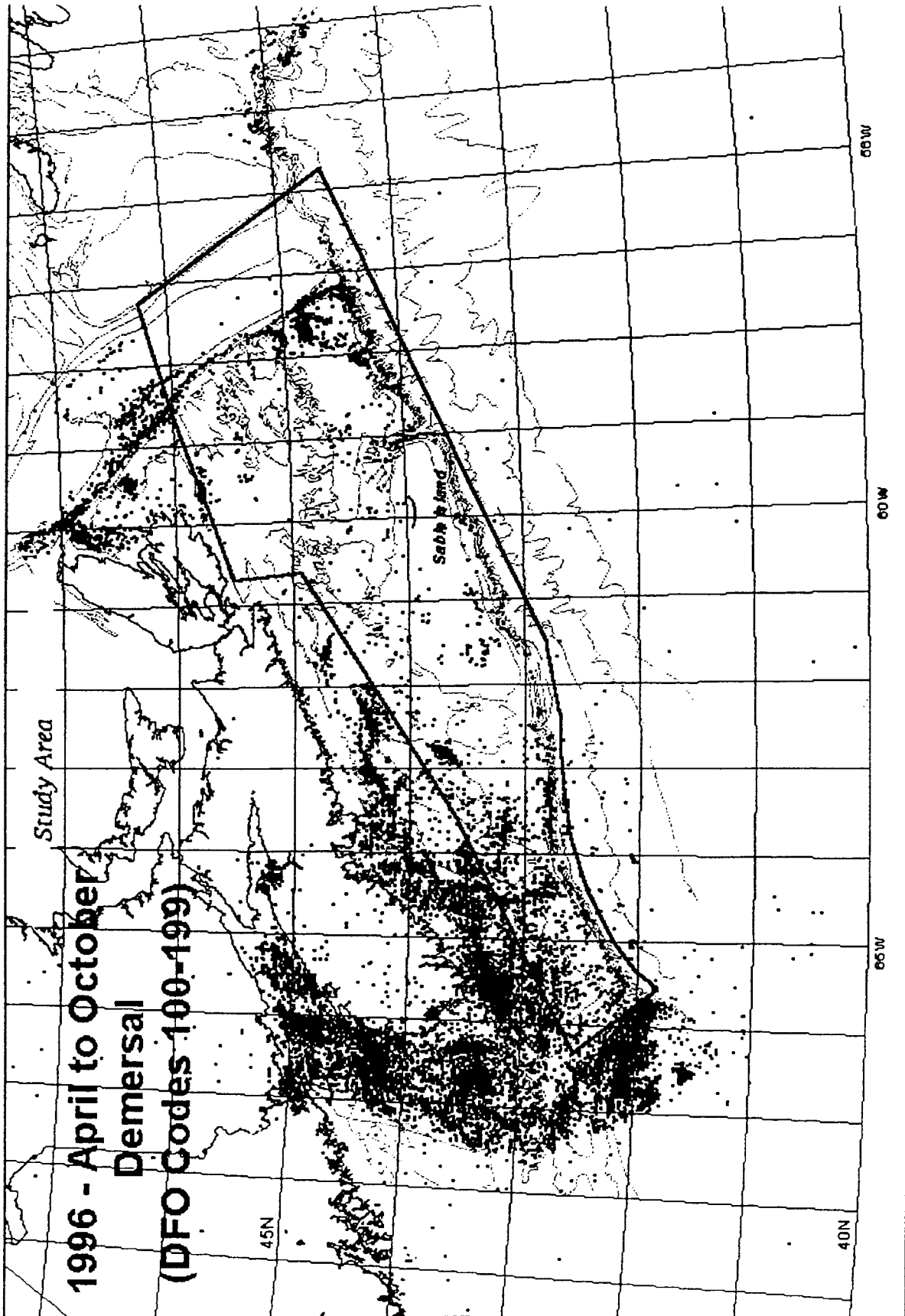Appendix Figure 2 - 2.   Fisheries catch locations on the Scotian Shelf.
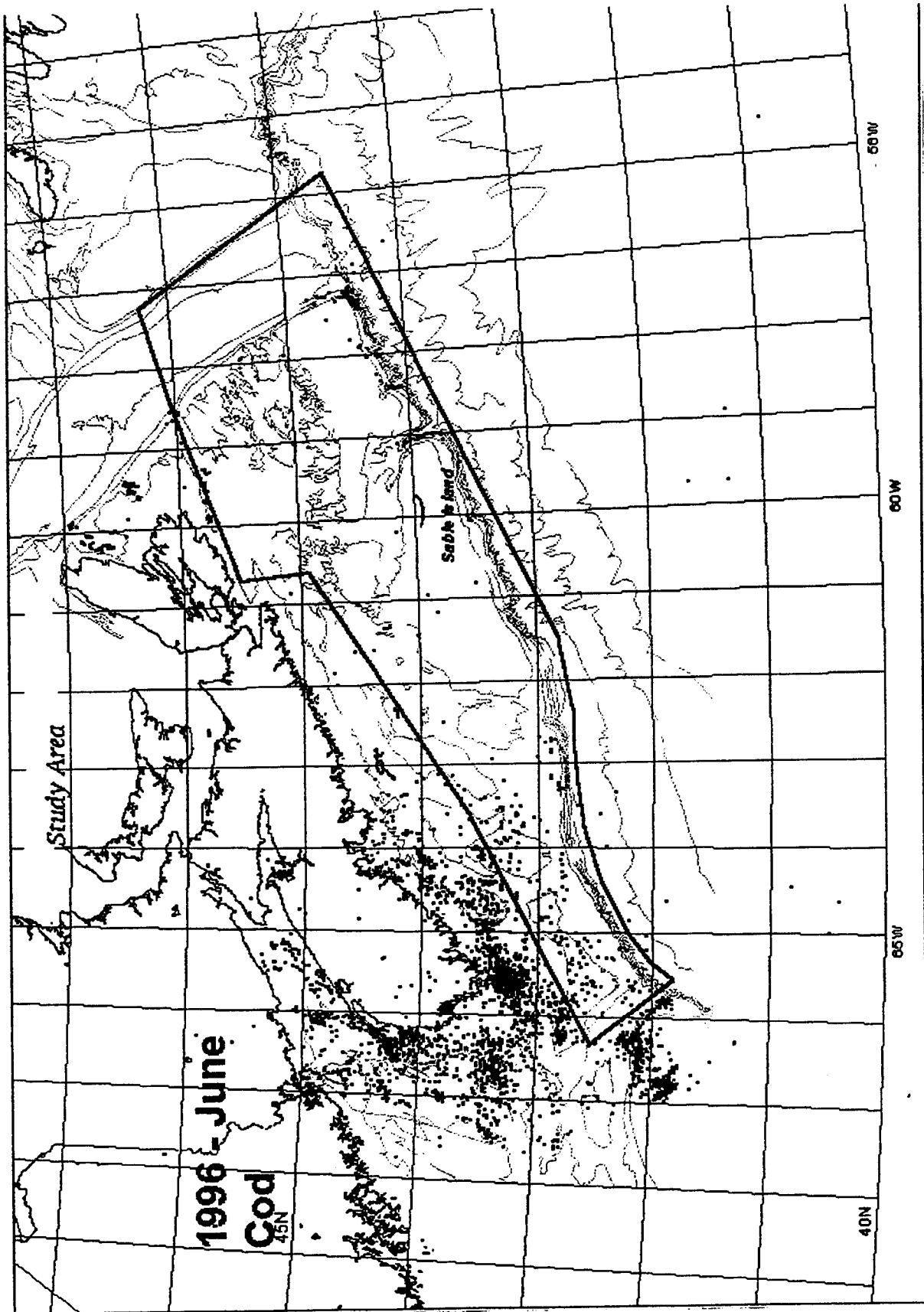
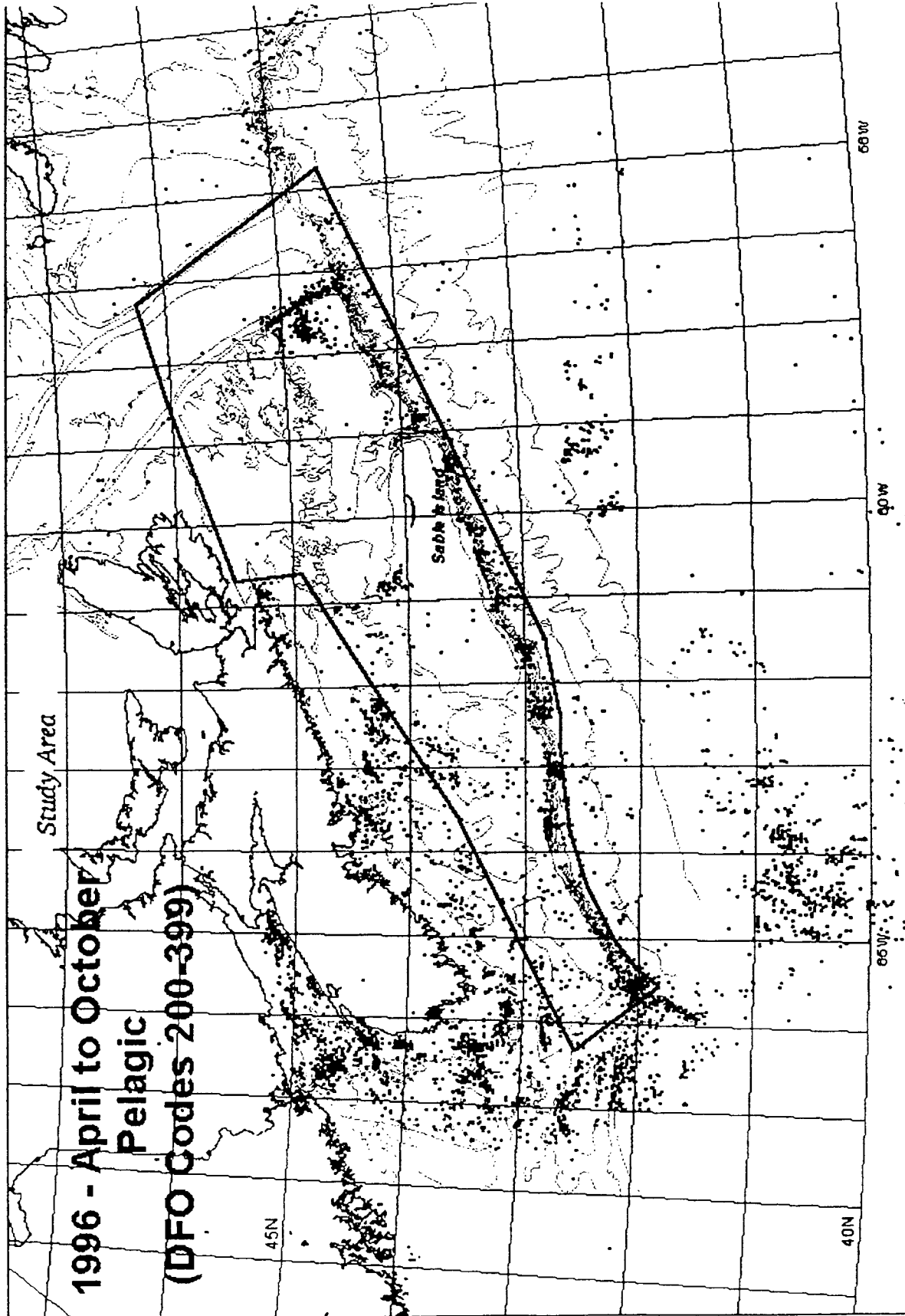Appendix Figure 2 - 3.   Fisheries catch locations on the Scotian Shelf.
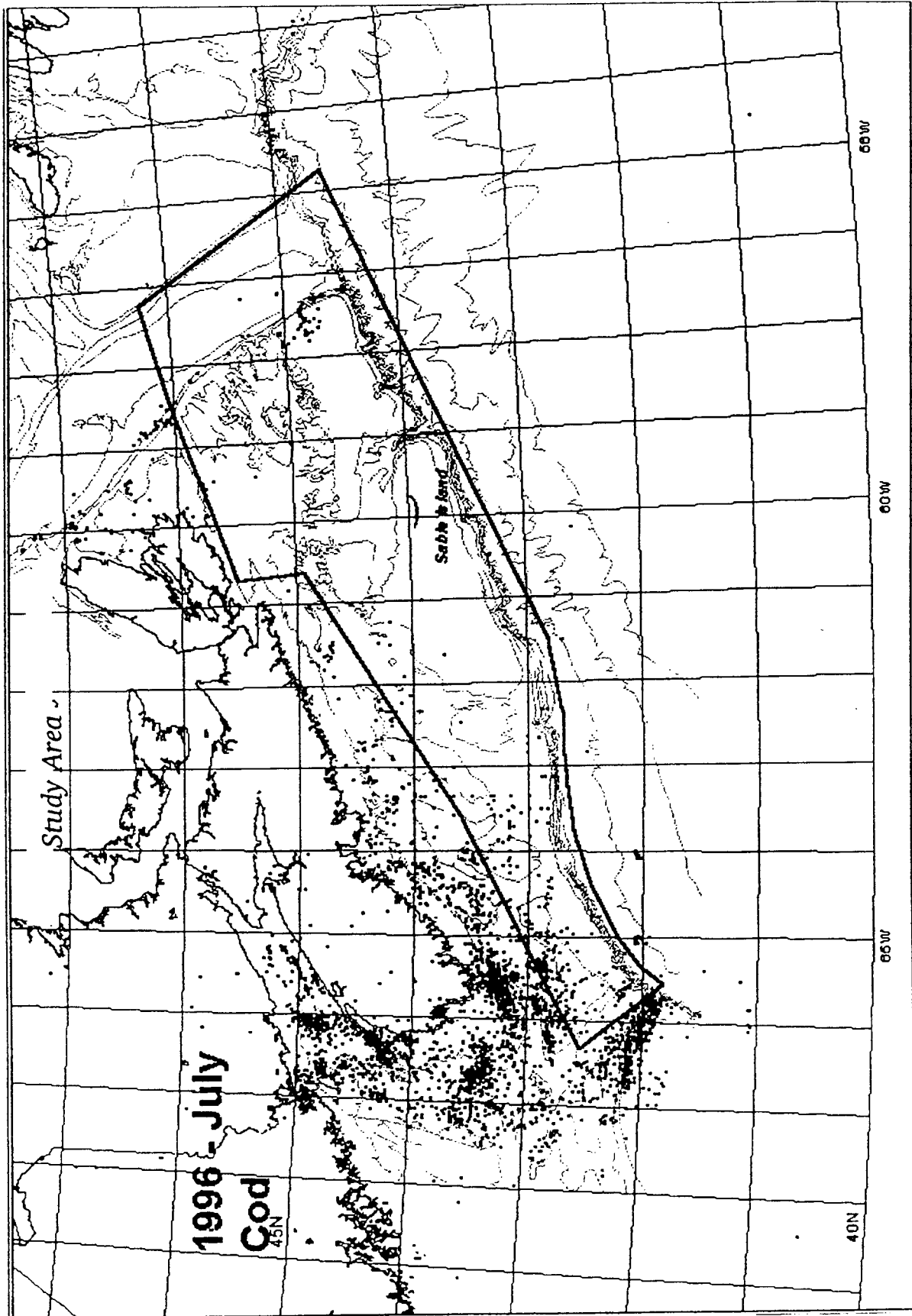
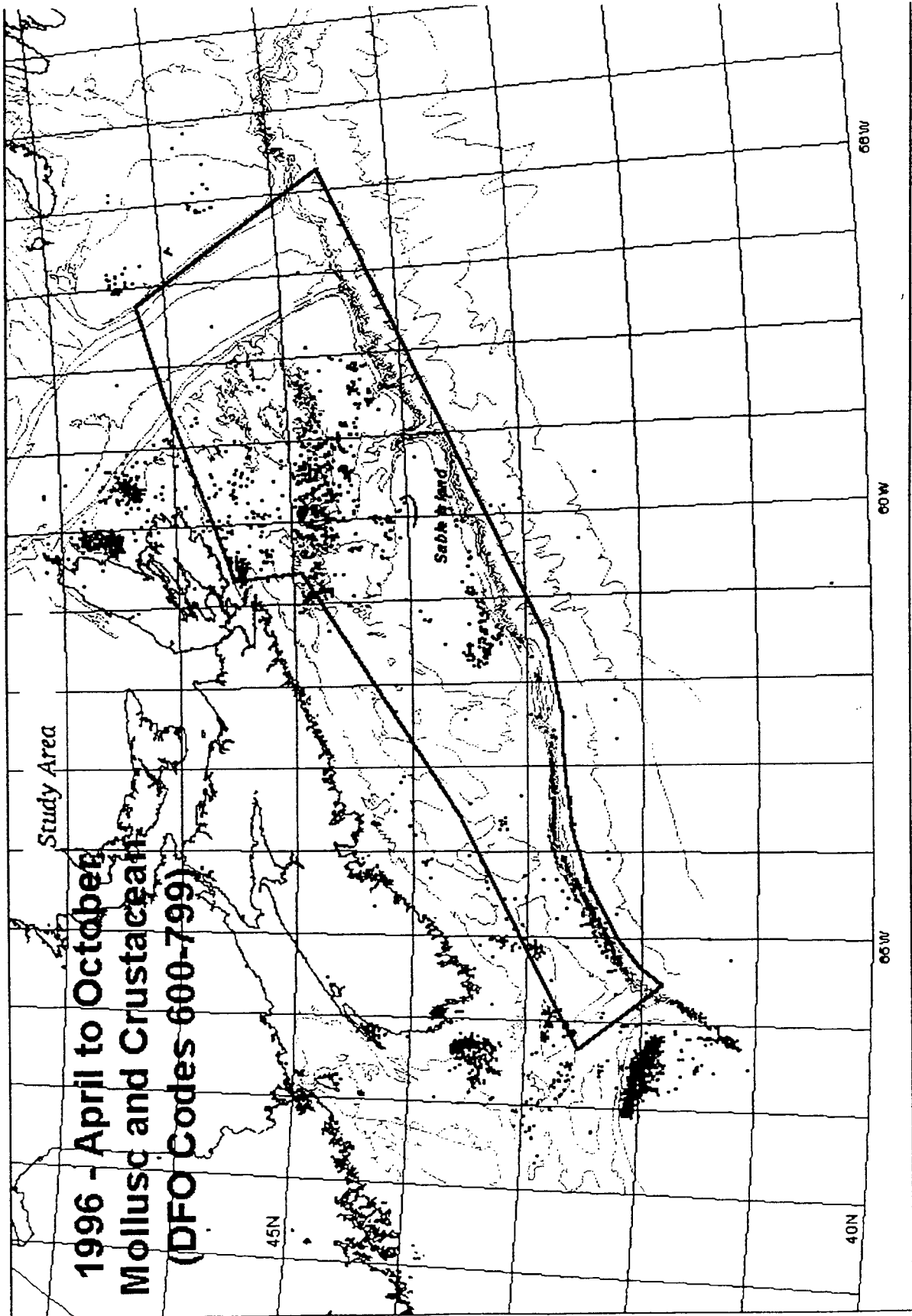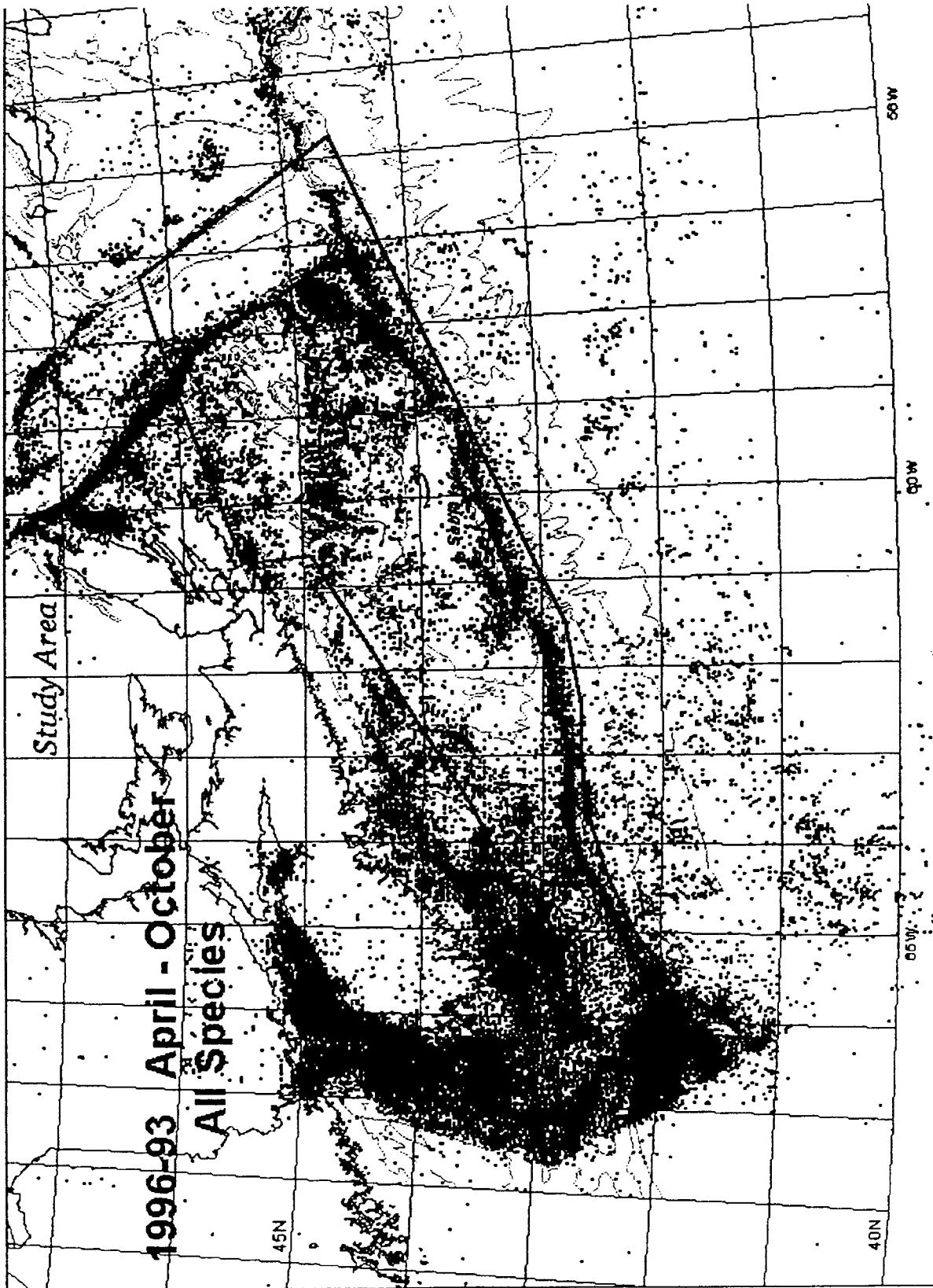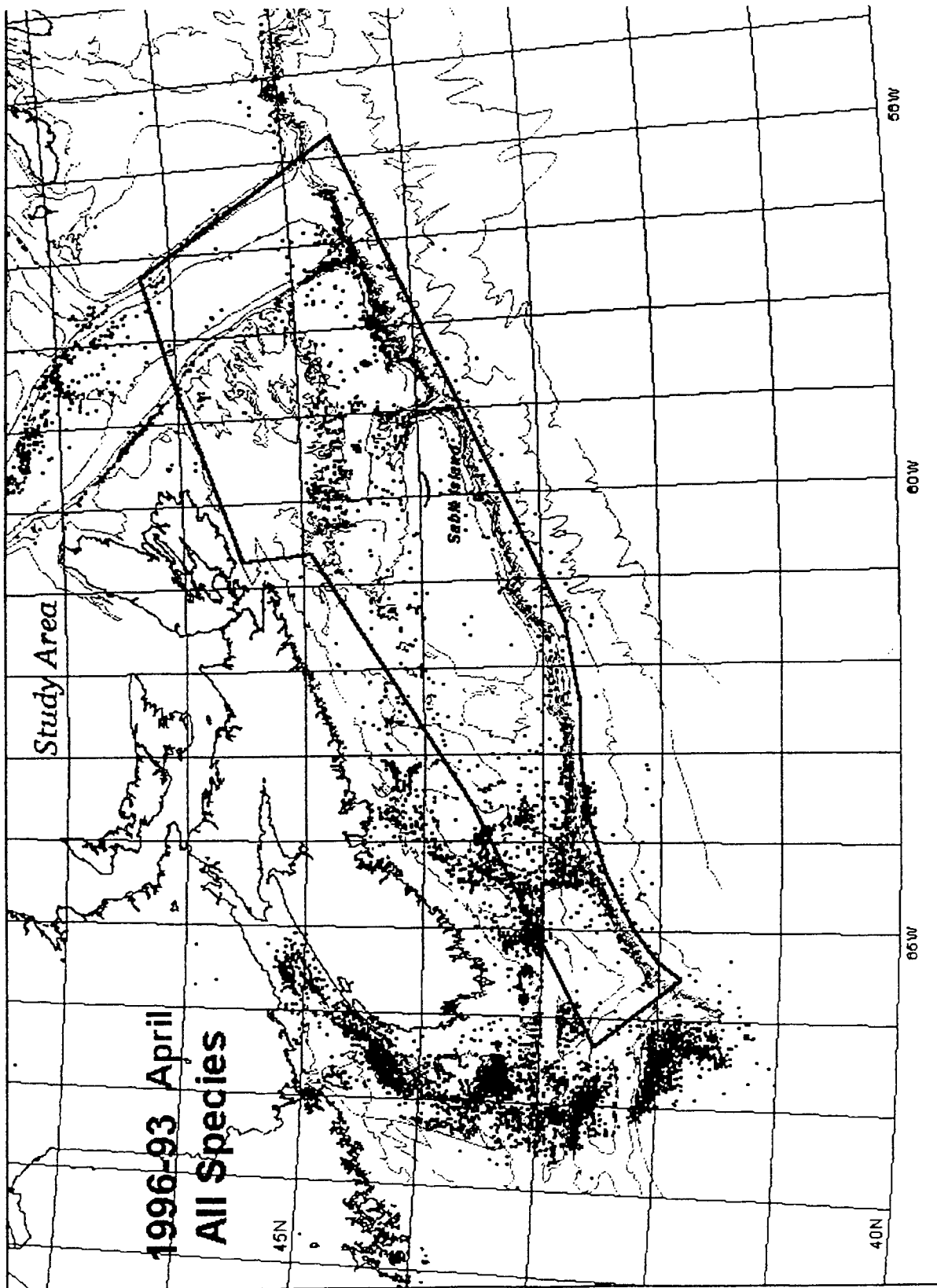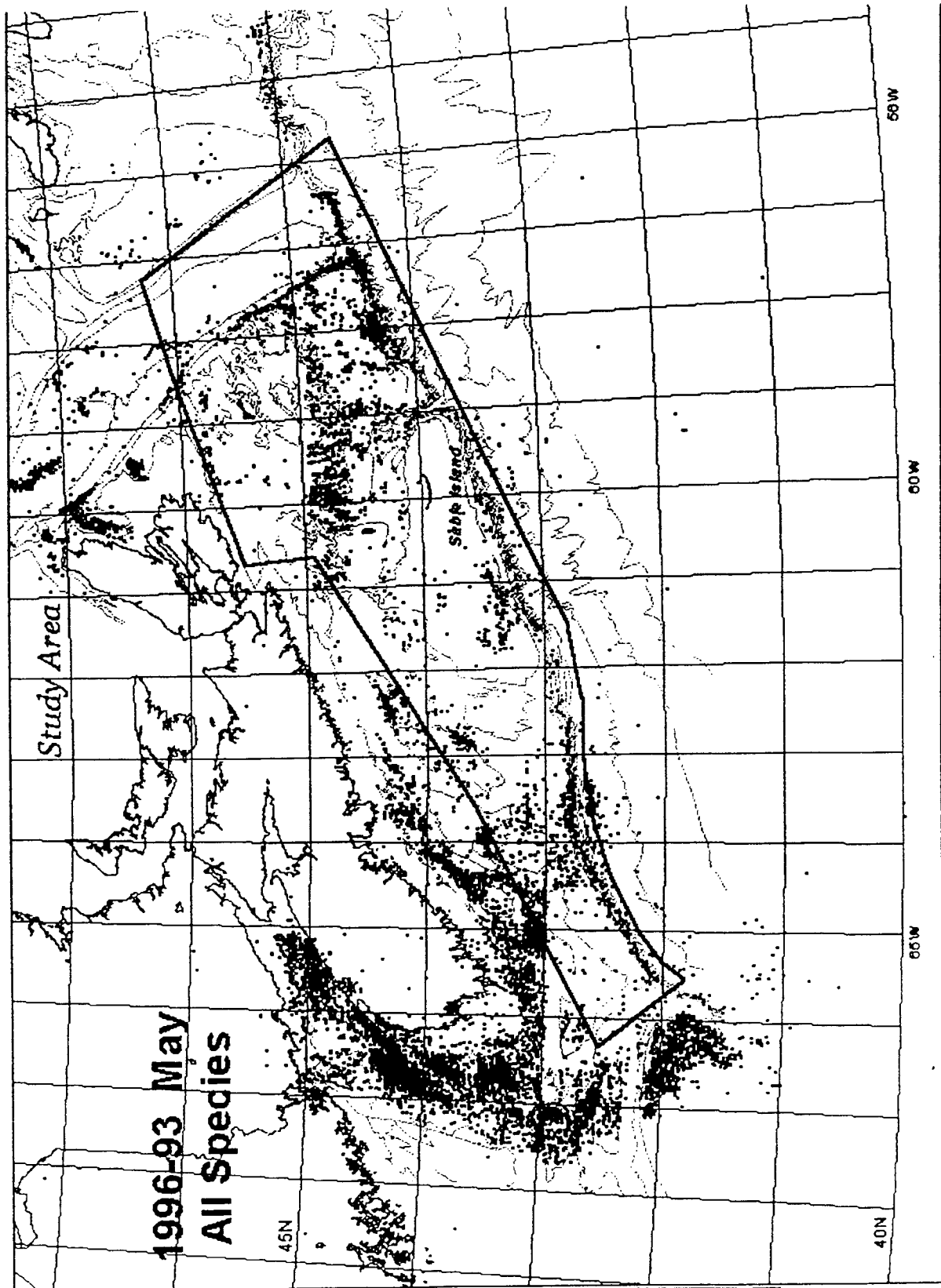Appendix Figure 2 - 4.   Fisheries catch locations on the Scotian Shelf.
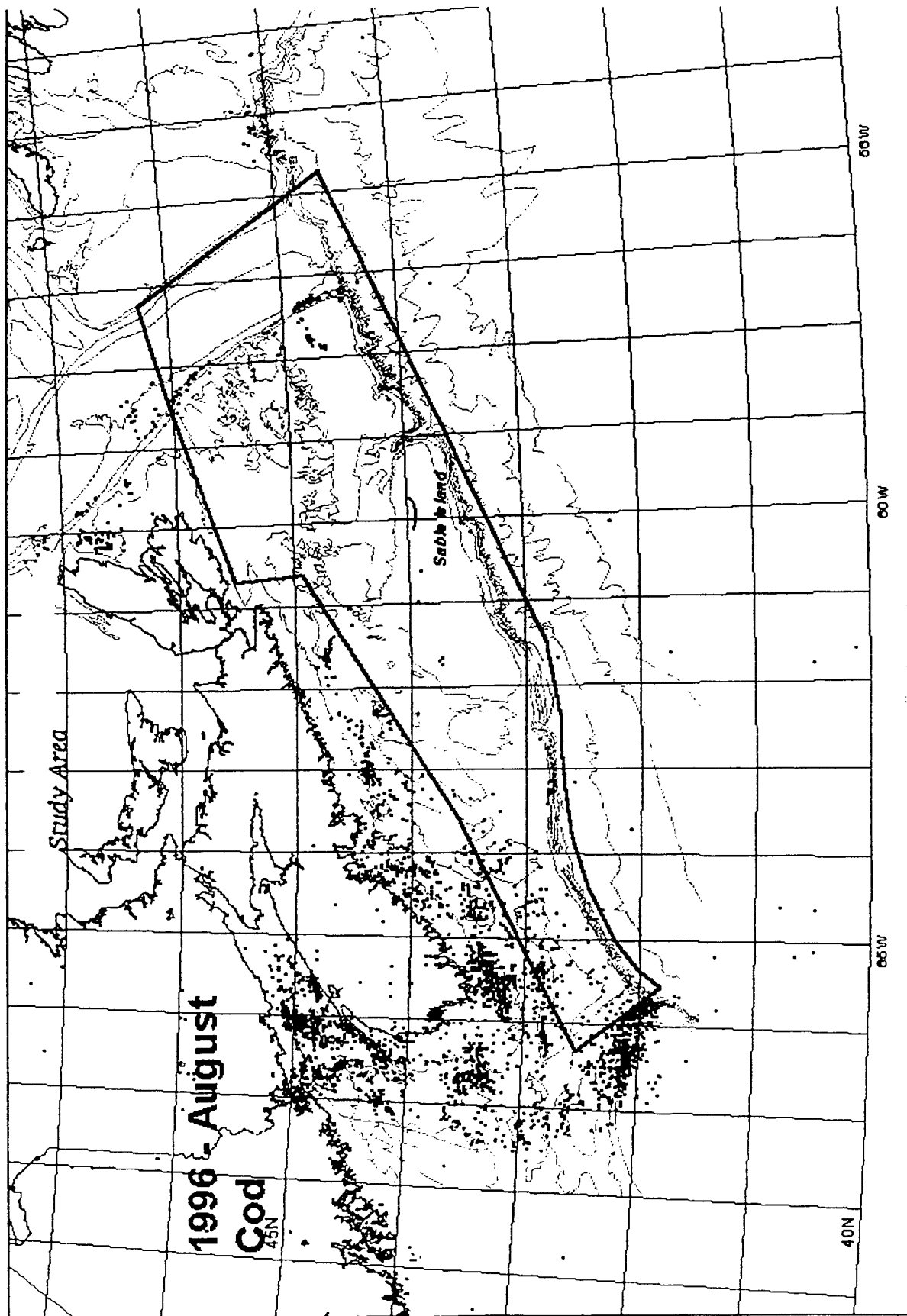
Appendix Figure 2 - 5.   Fisheries catch locations on the Scotian Shelf.
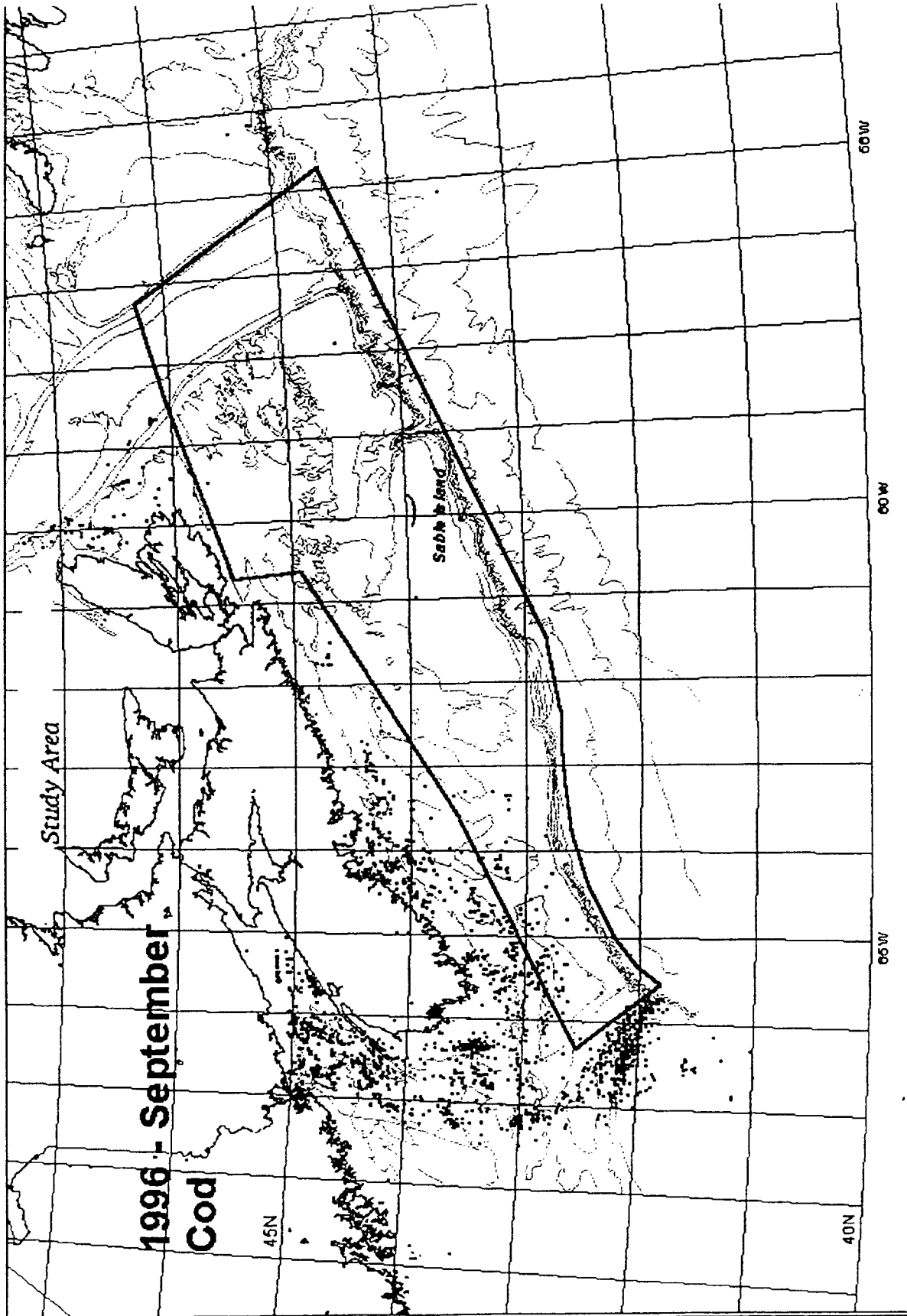
Appendix Figure 2 - 6.   Fisheries catch locations on the Scotian Shelf.
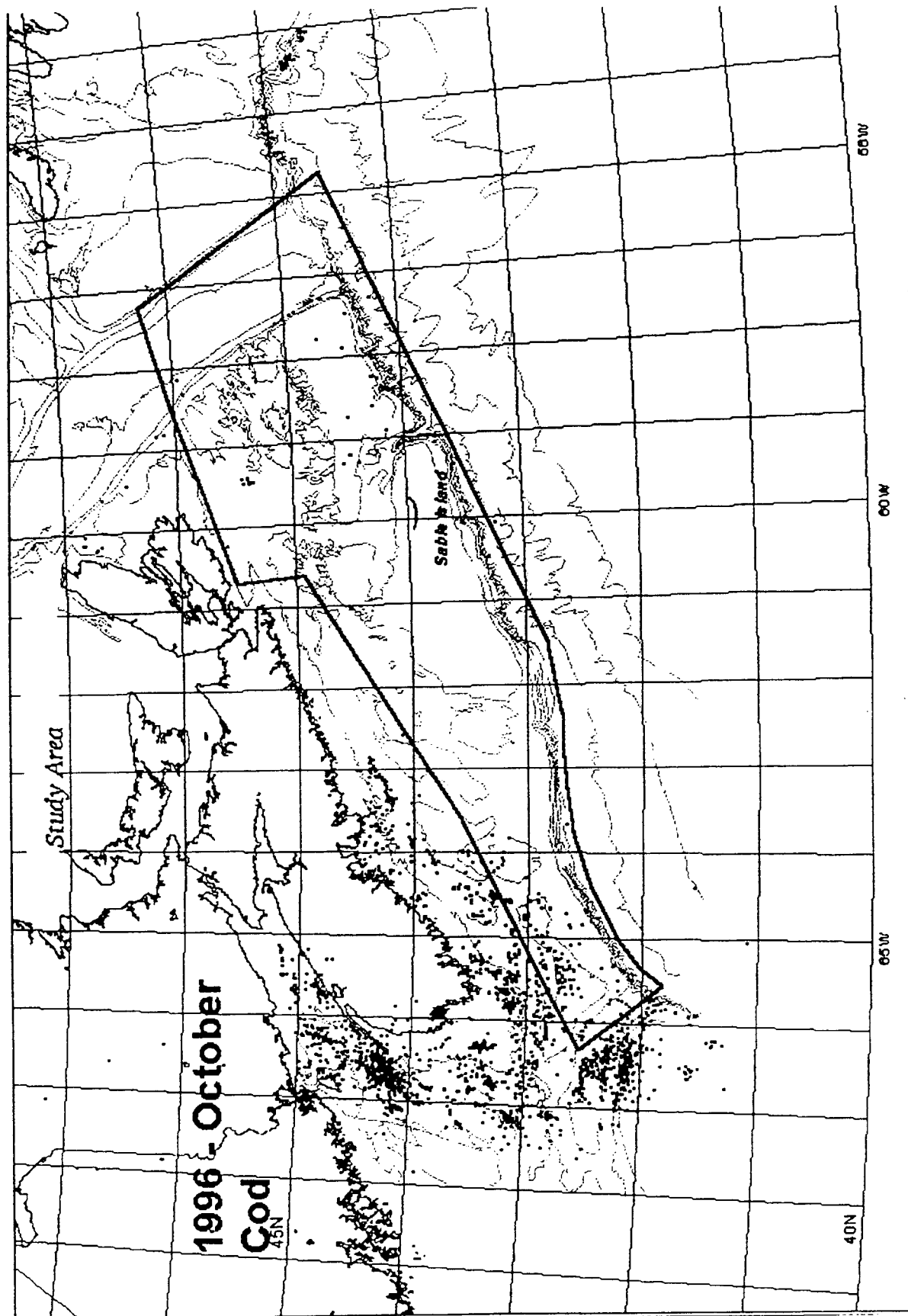
Appendix Figure 2 - 7.   Fisheries catch locations on the Scotian Shelf.
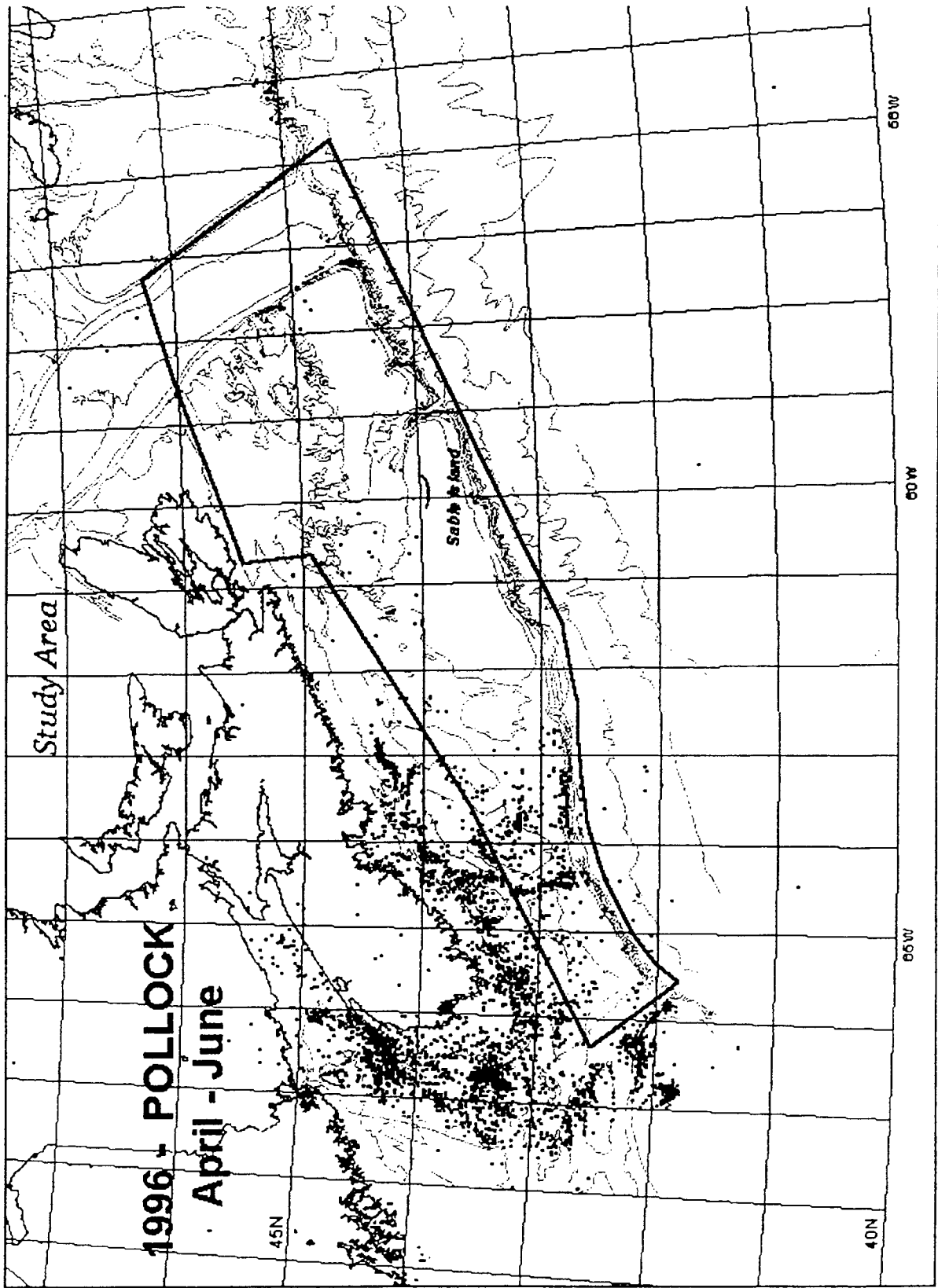
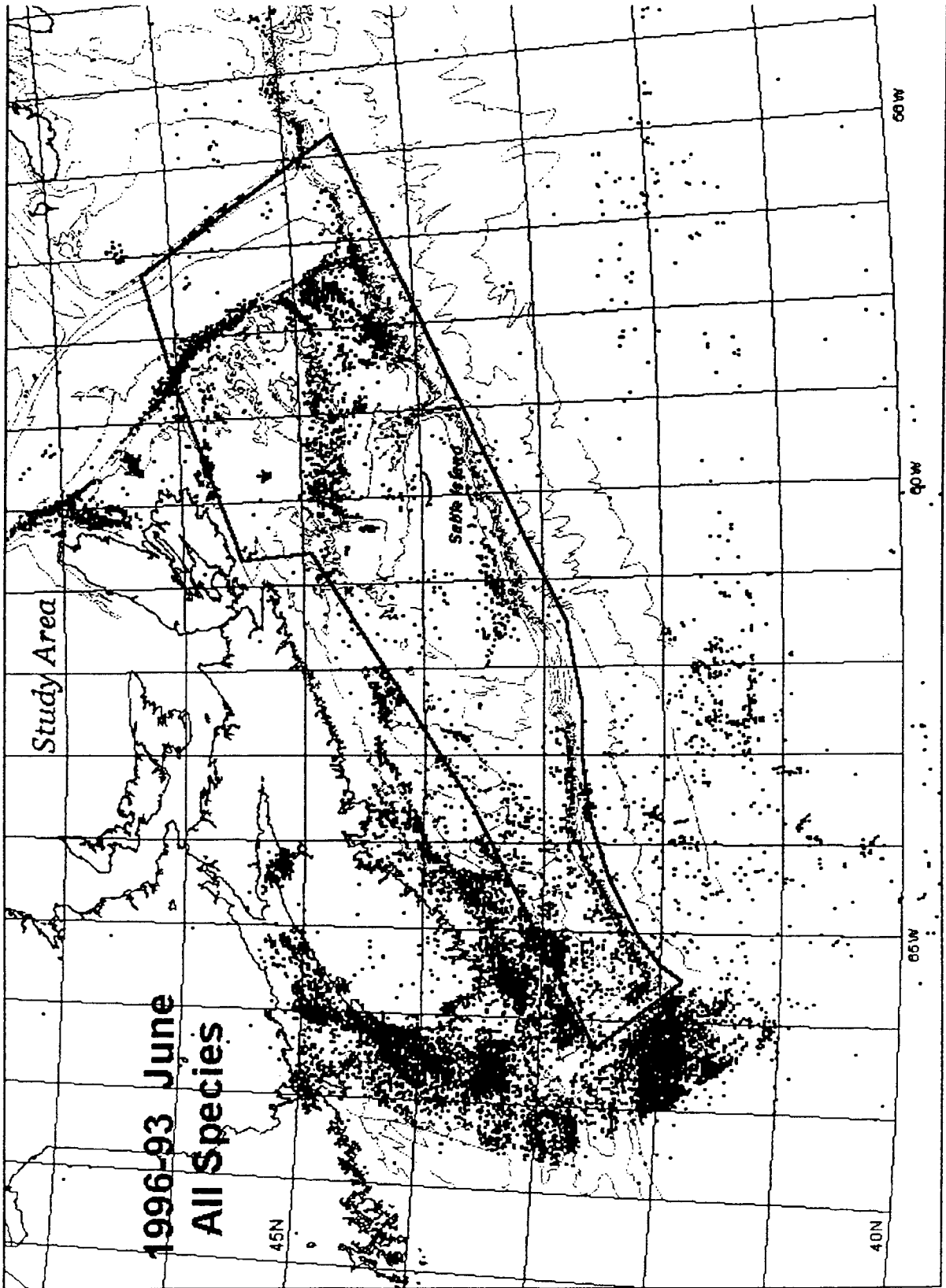Appendix Figure 2 - 8.   Fisheries catch locations on the Scotian Shelf.
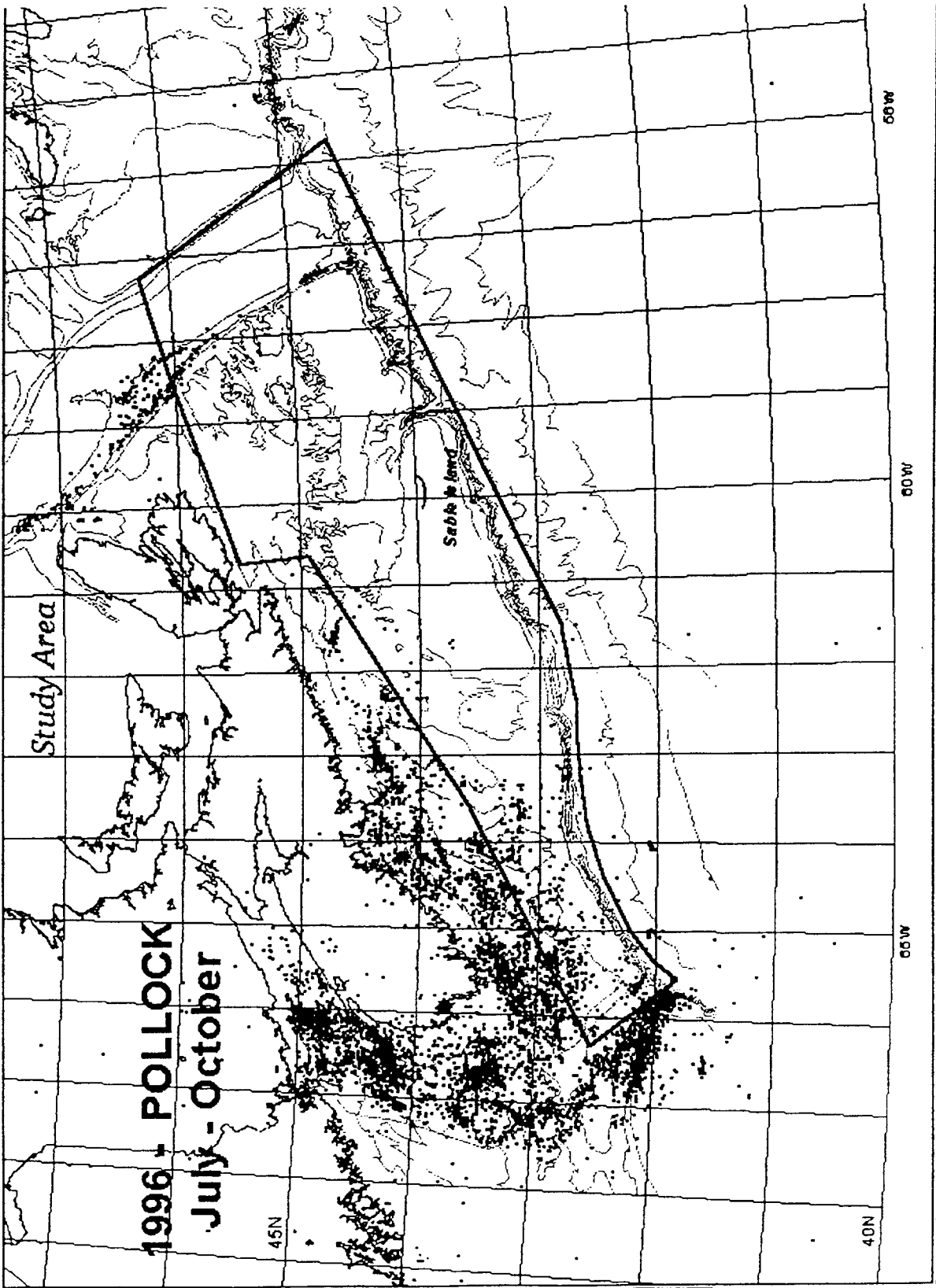
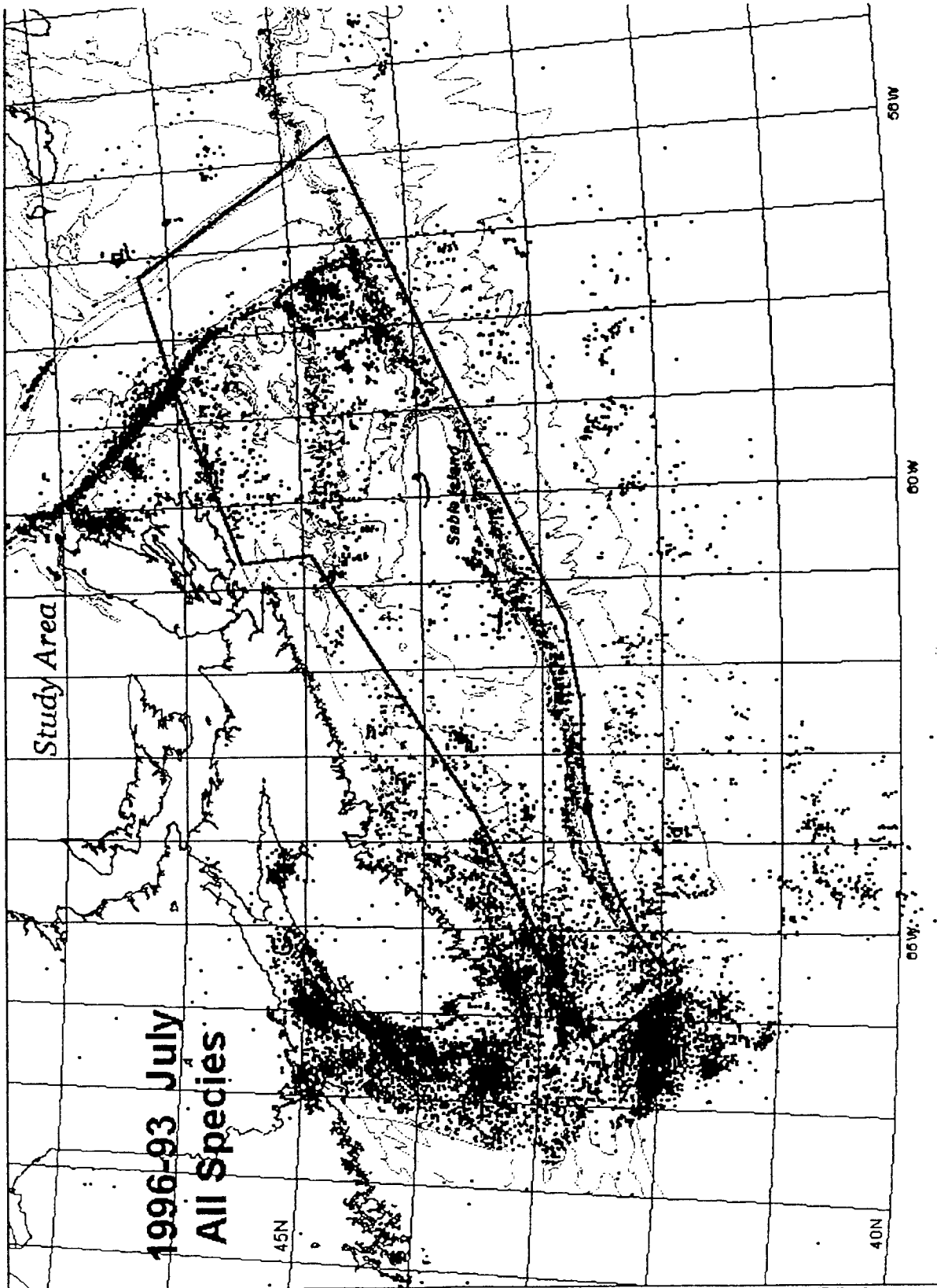Appendix Figure 2 - 9.   Fisheries catch locations on the Scotian Shelf.
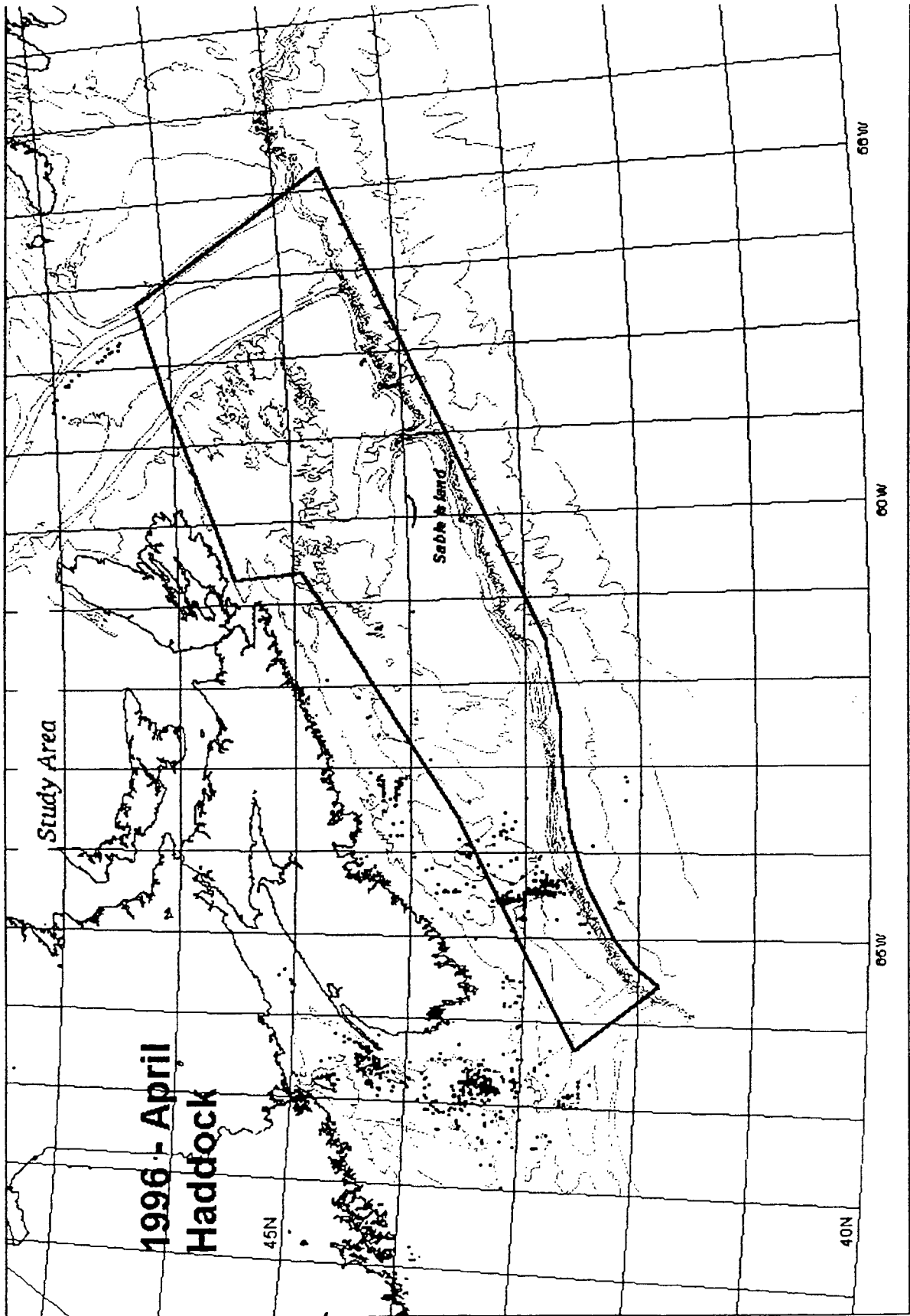
Appendix Figure 2 - 10.   Fisheries catch locations on the Scotian Shelf.
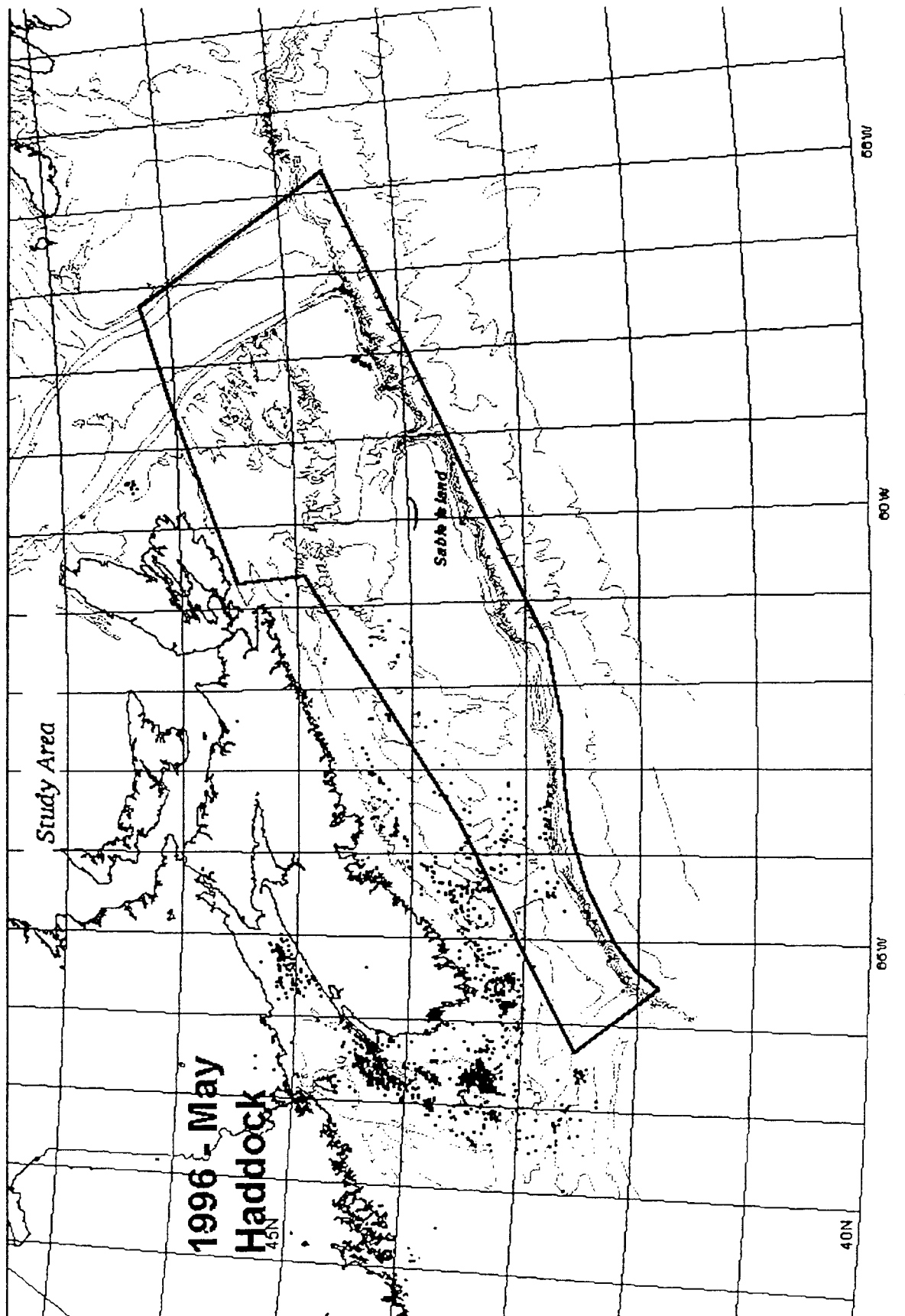
Appendix Figure 2 - 11. Fisheries catch locations on the Scotian Shelf.

Study Area

1996 - June
Haddock

Sable Island
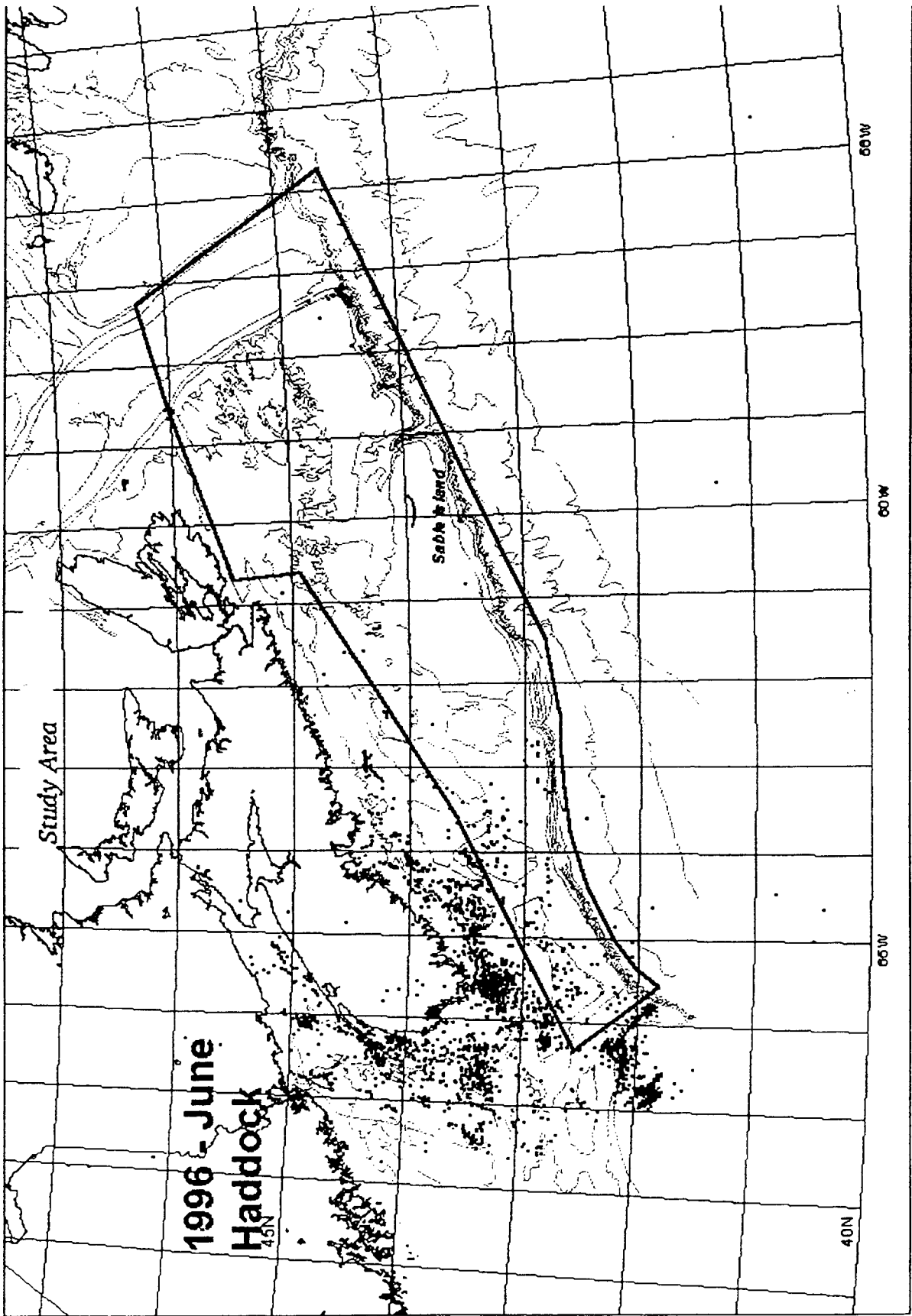
Appendix Figure 2 - 12.   Fisheries catch locations on the Scotian Shelf.
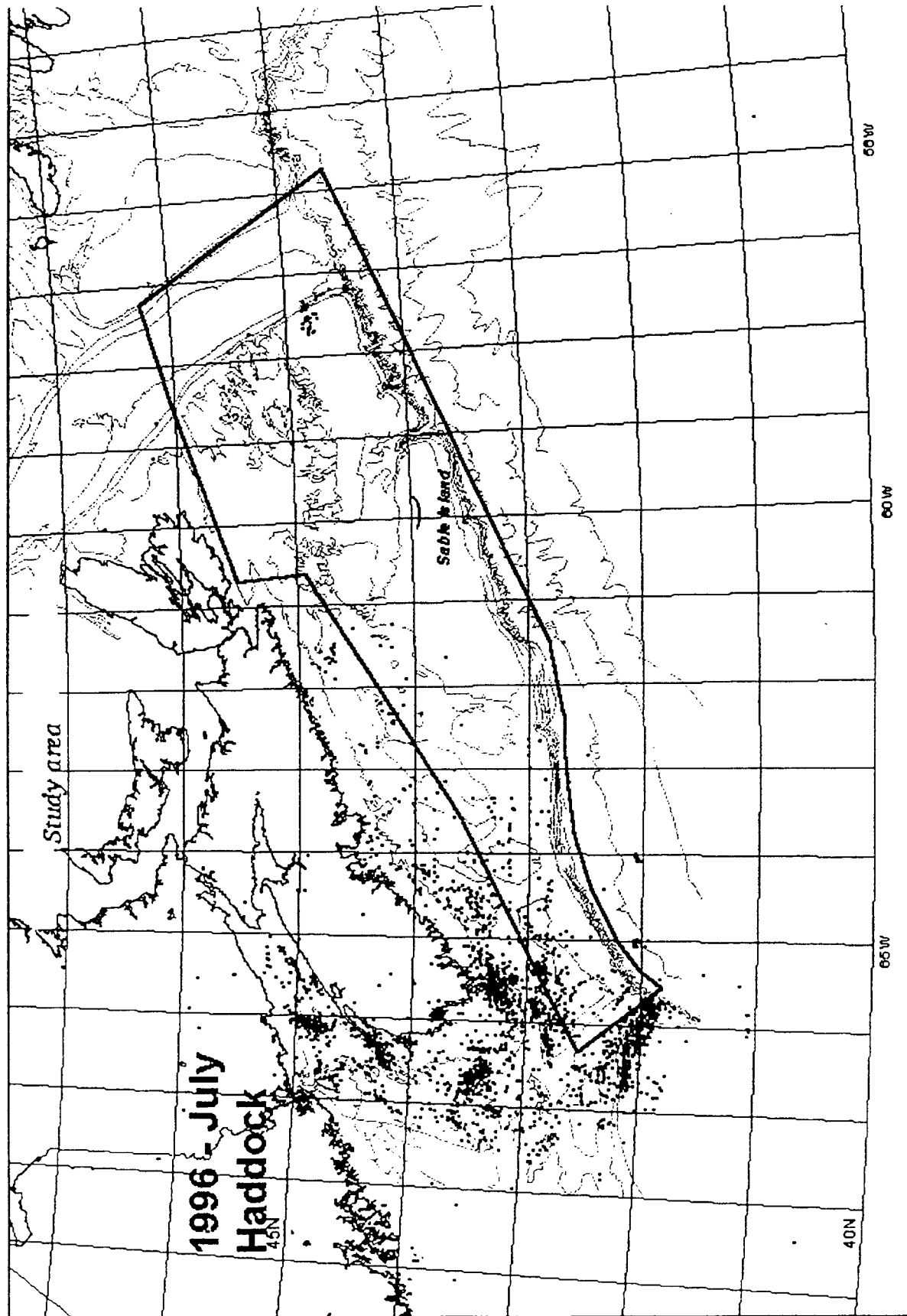
Appendix Figure 2 - 13.   Fisheries catch locations on the Scotian Shelf.
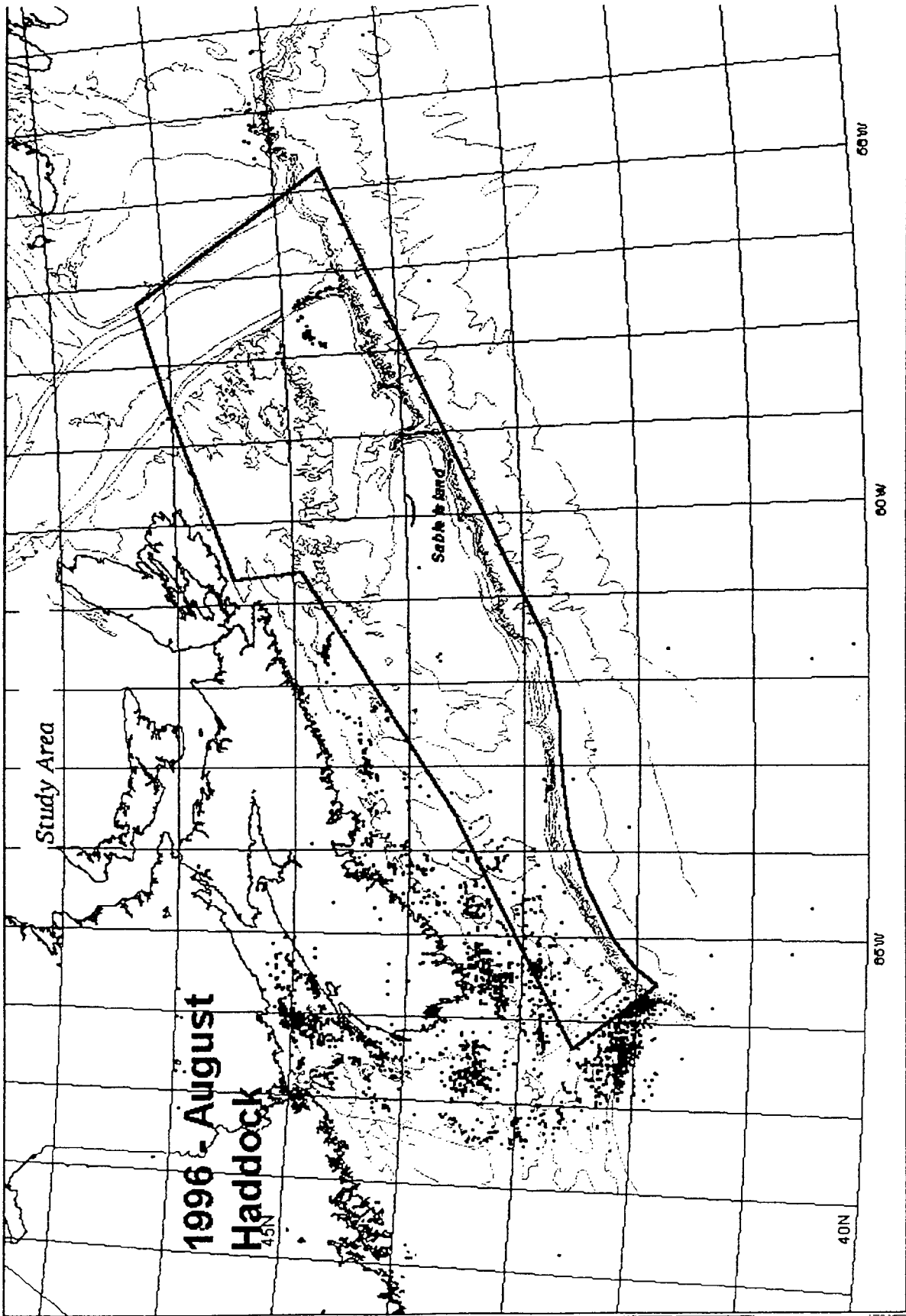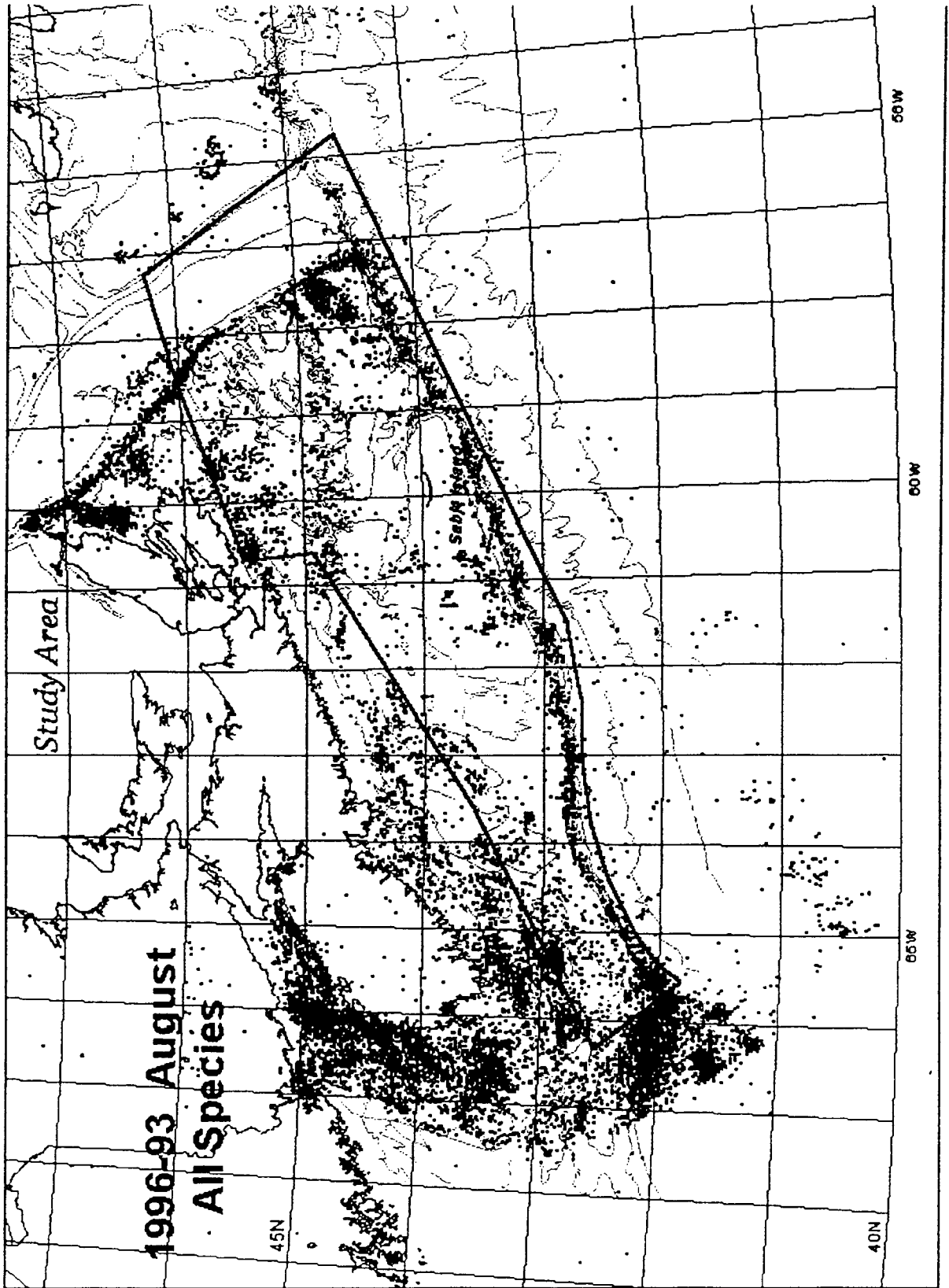
Appendix Figure 2 - 14.   Fisheries catch locations on the Scotian Shelf.
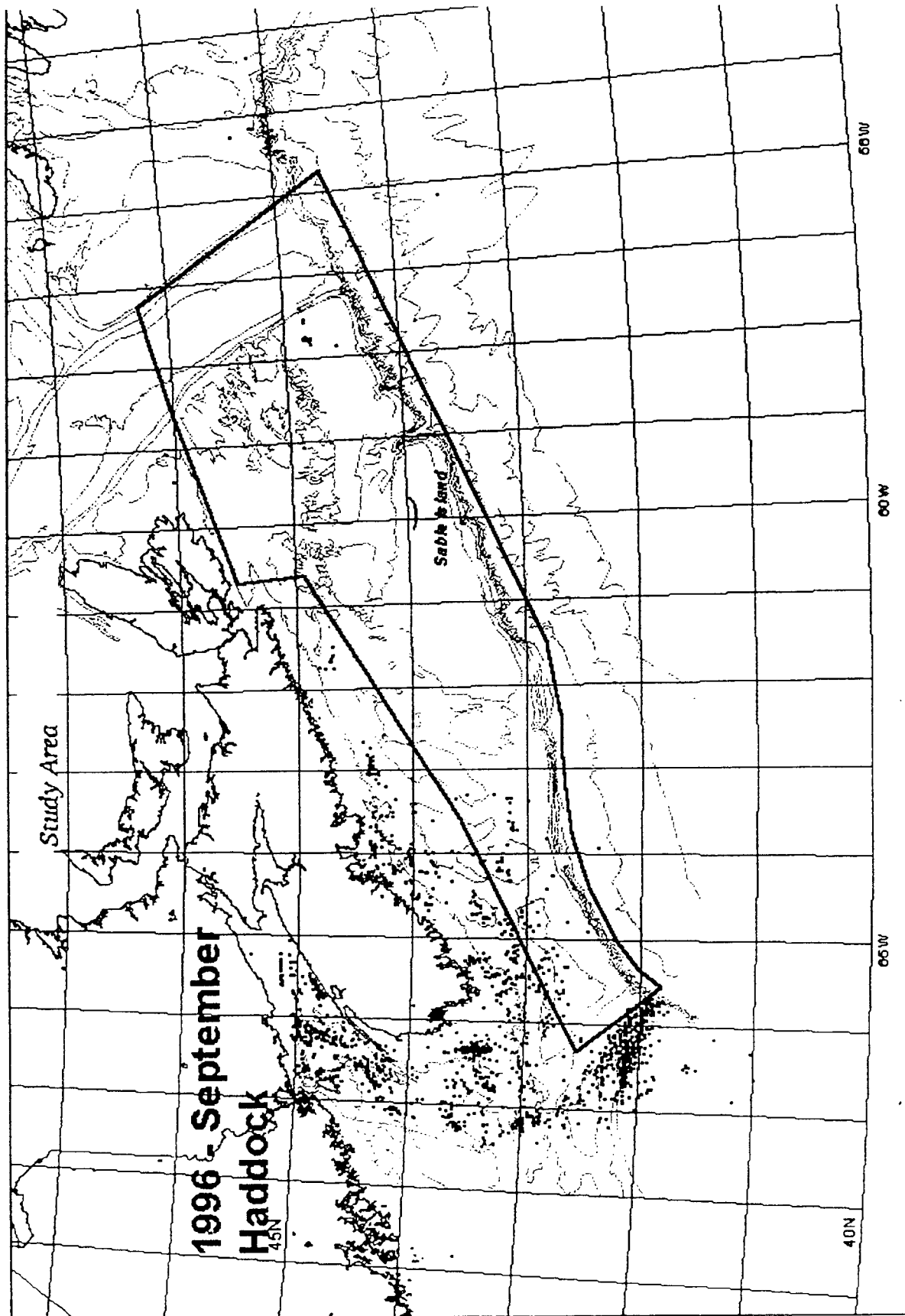
Appendix Figure 2 - 15.   Fisheries catch locations on the Scotian Shelf.
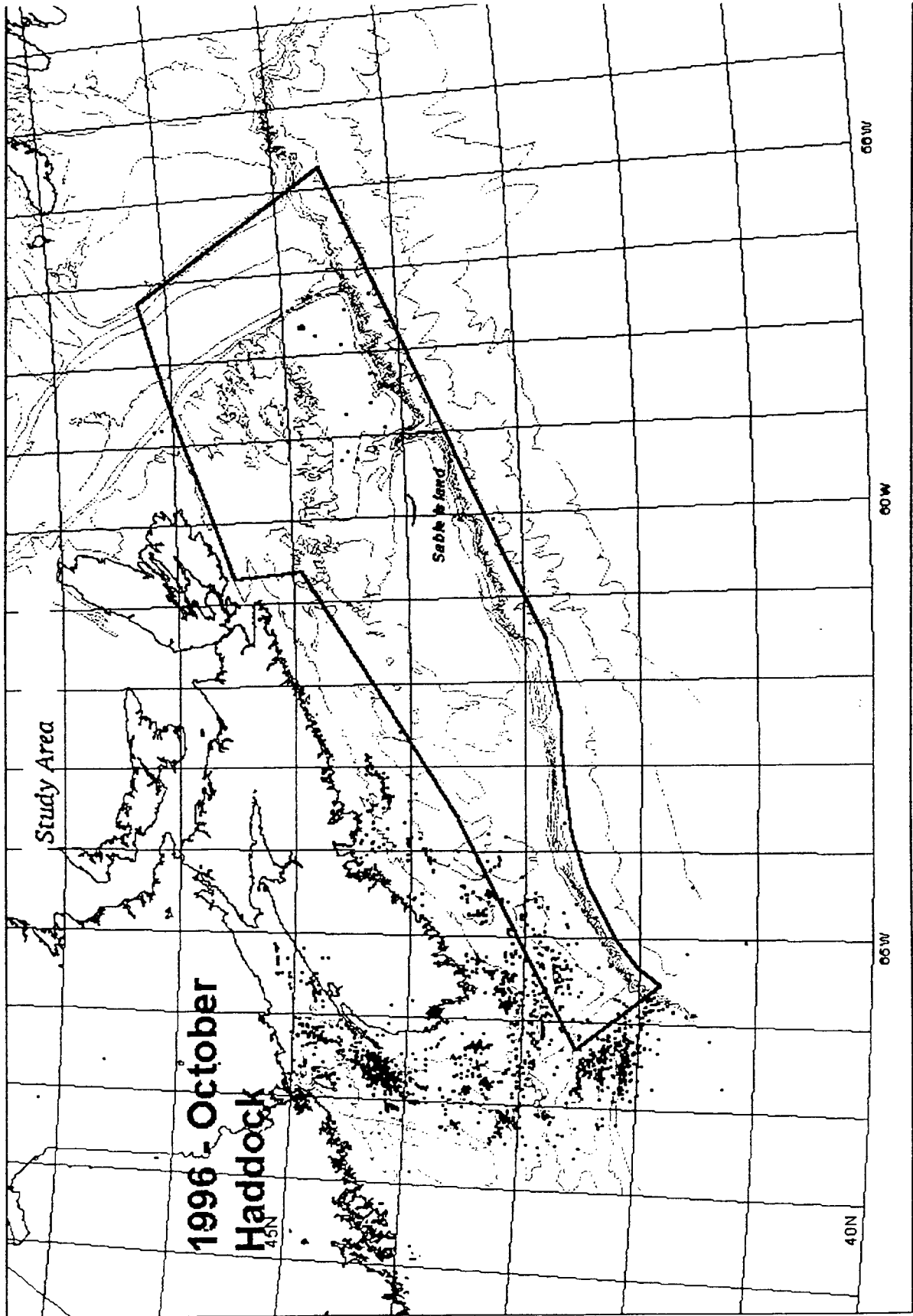
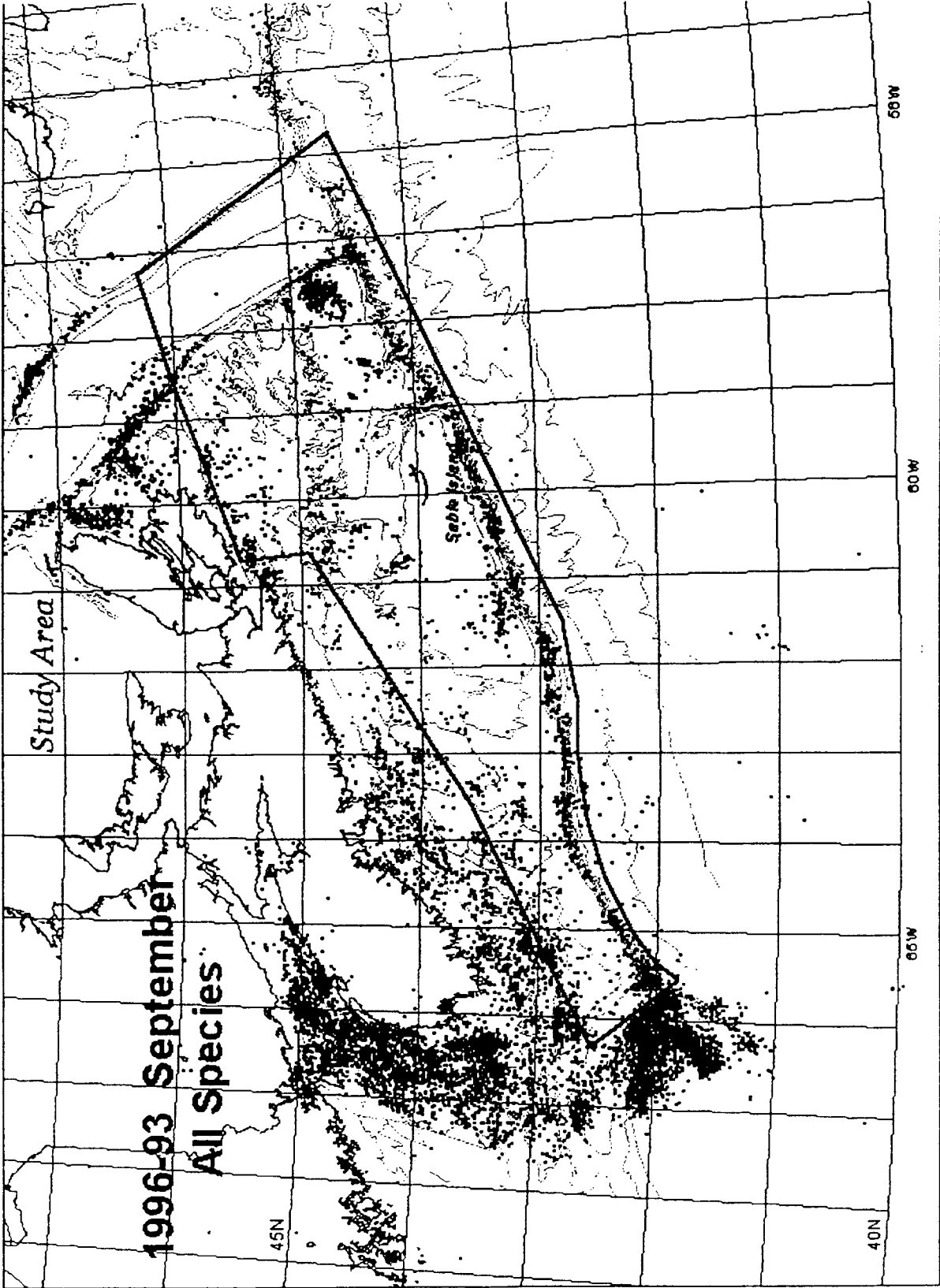Appendix Figure 2 - 16.   Fisheries catch locations on the Scotian Shelf.

1996 - Silver Hake
April - October

Study Area
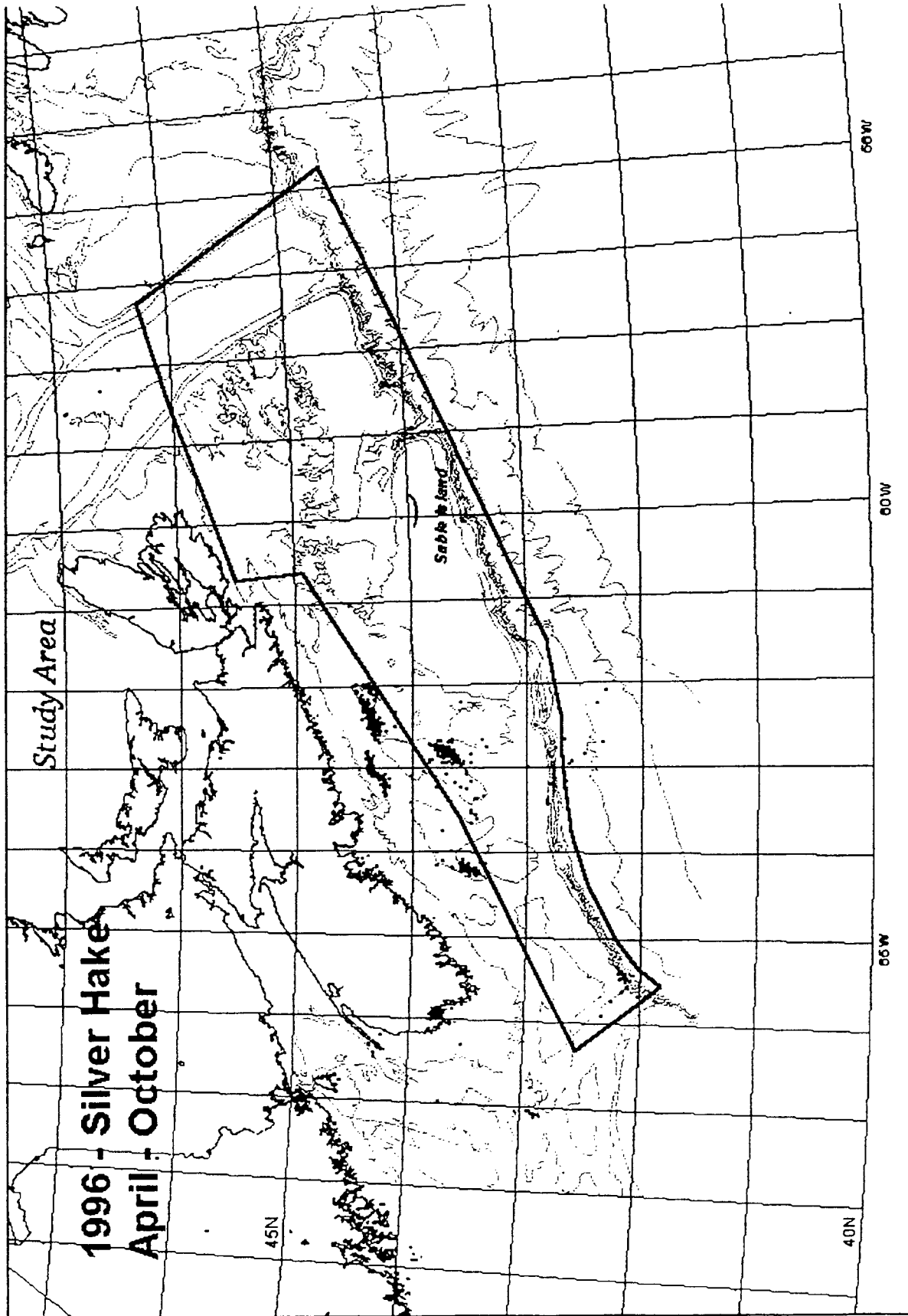
Appendix Figure 2 - 17.   Fisheries catch locations on the Scotian Shelf.
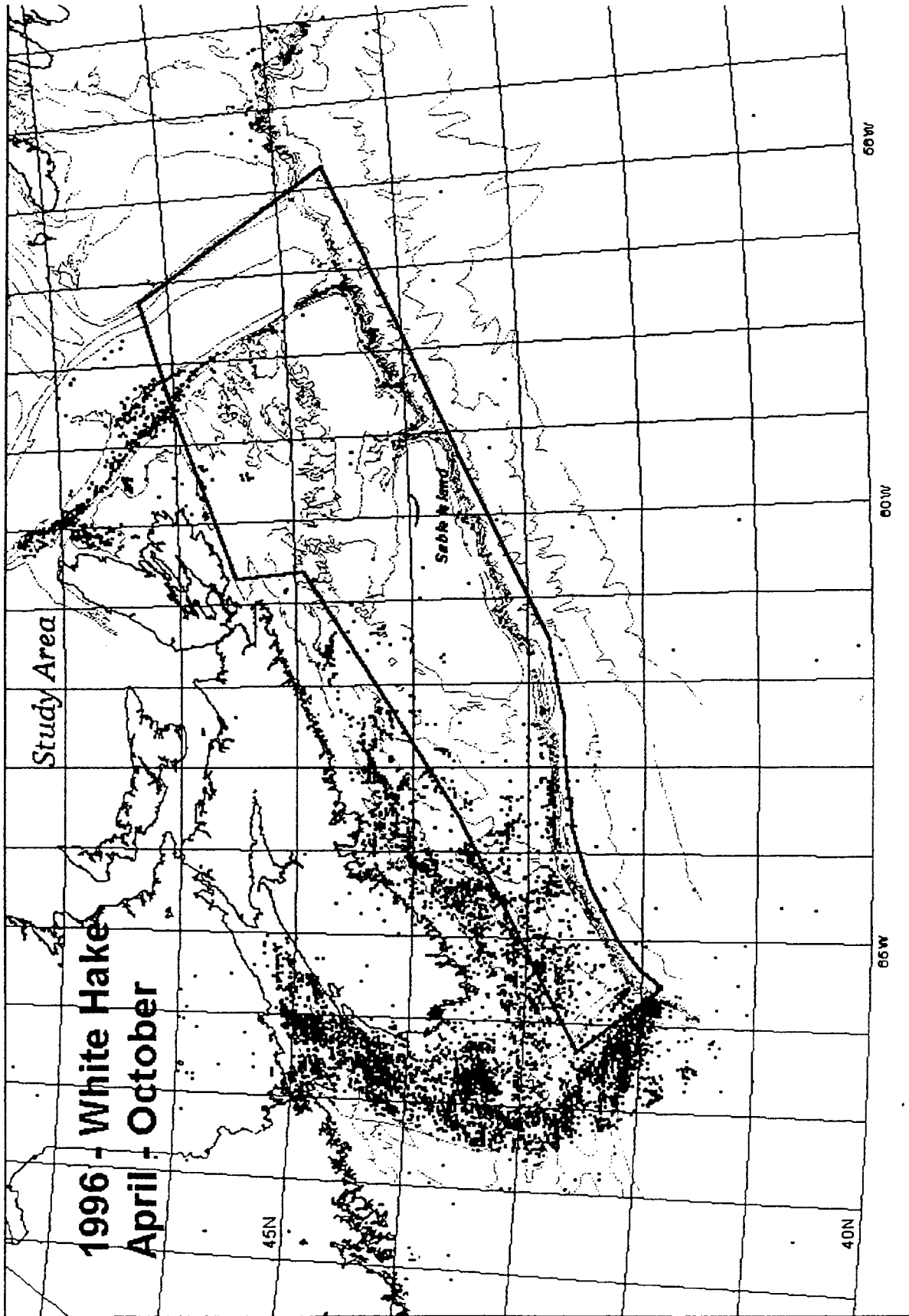
Appendix Figure 2 - 18.   Fisheries catch locations on the Scotian Shelf.
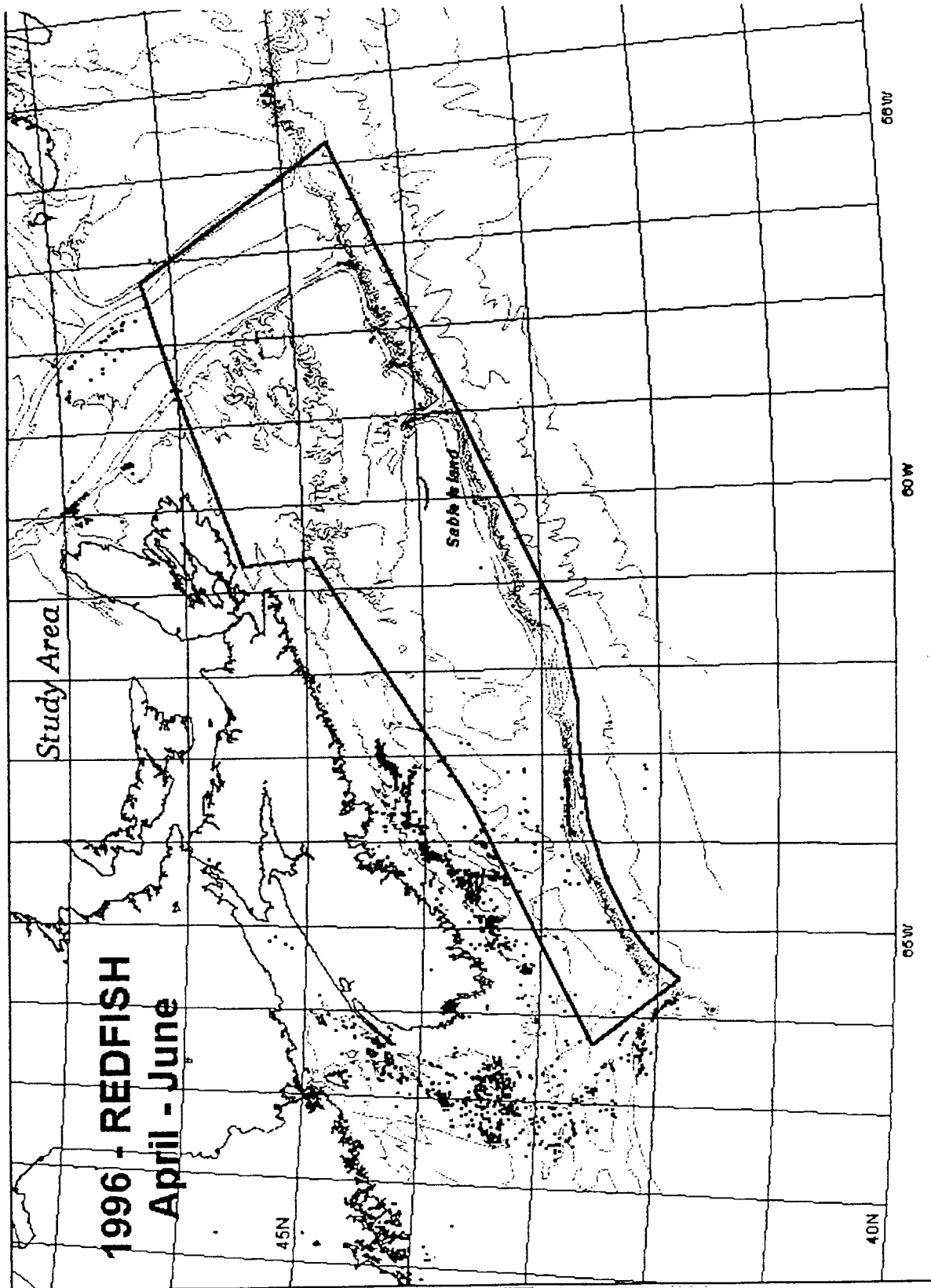
Appendix Figure 2 - 19.   Fisheries catch locations on the Scotian Shelf.
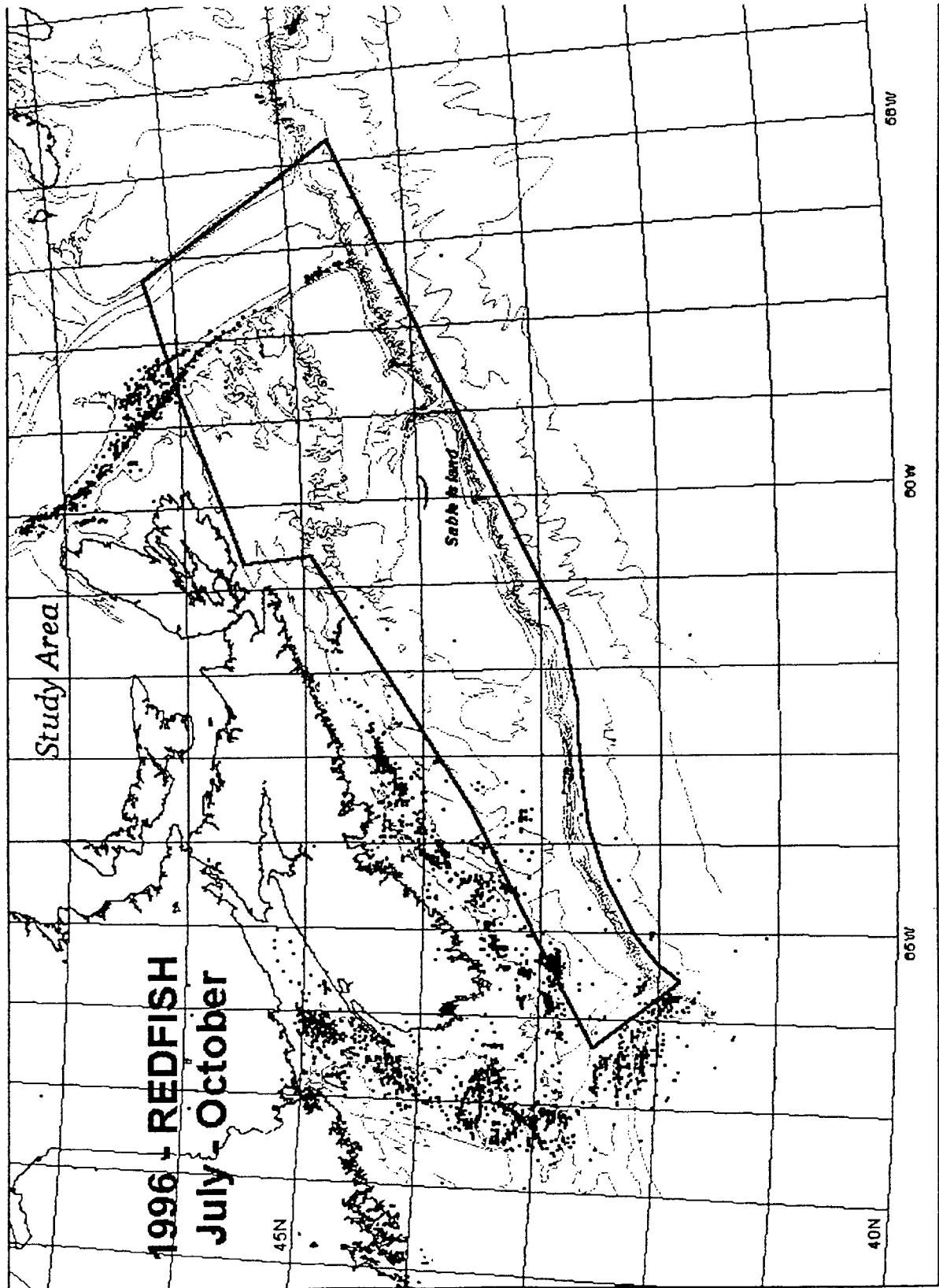
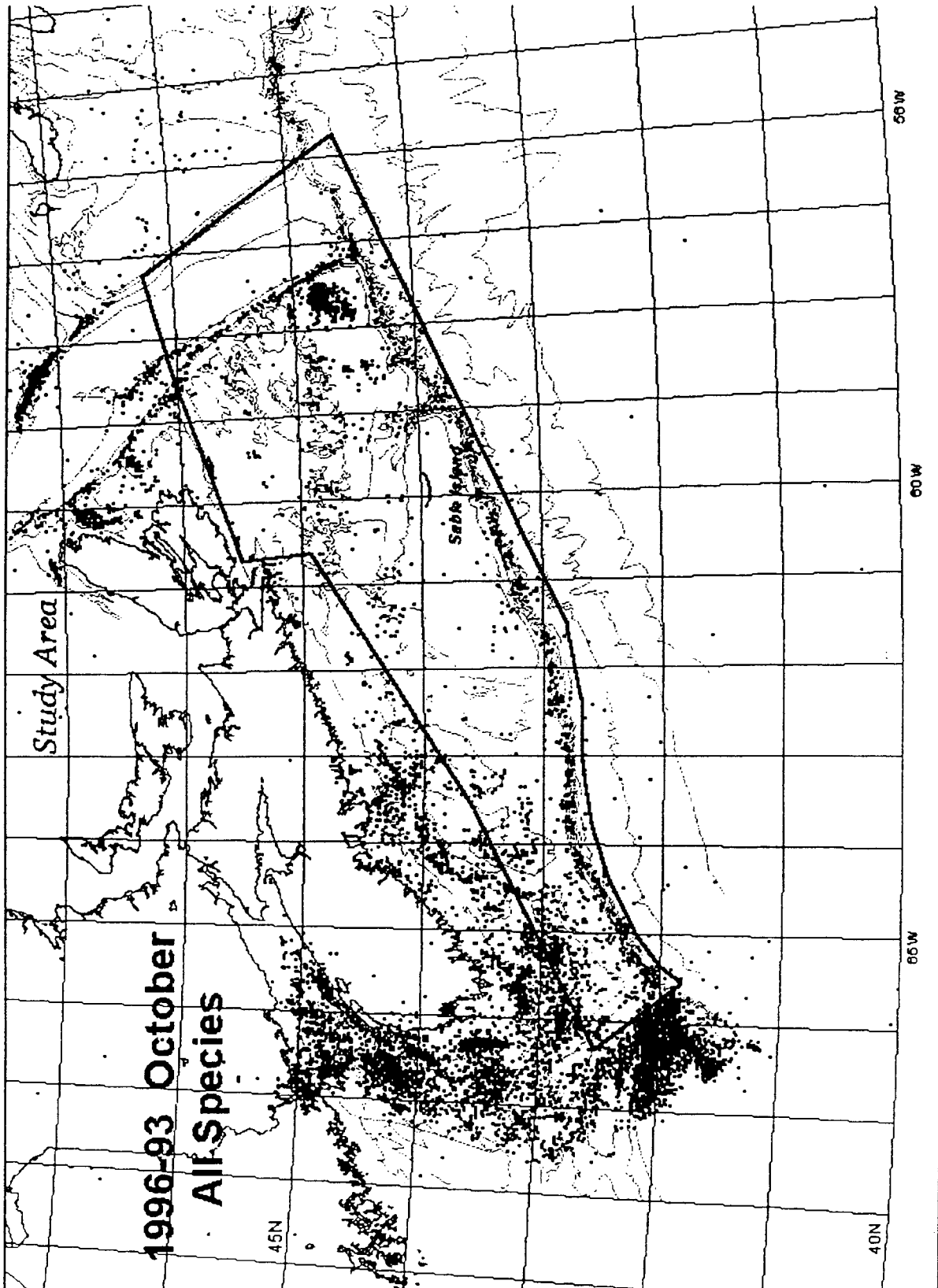Appendix Figure 2 - 20. Fisheries catch locations on the Scotian Shelf.
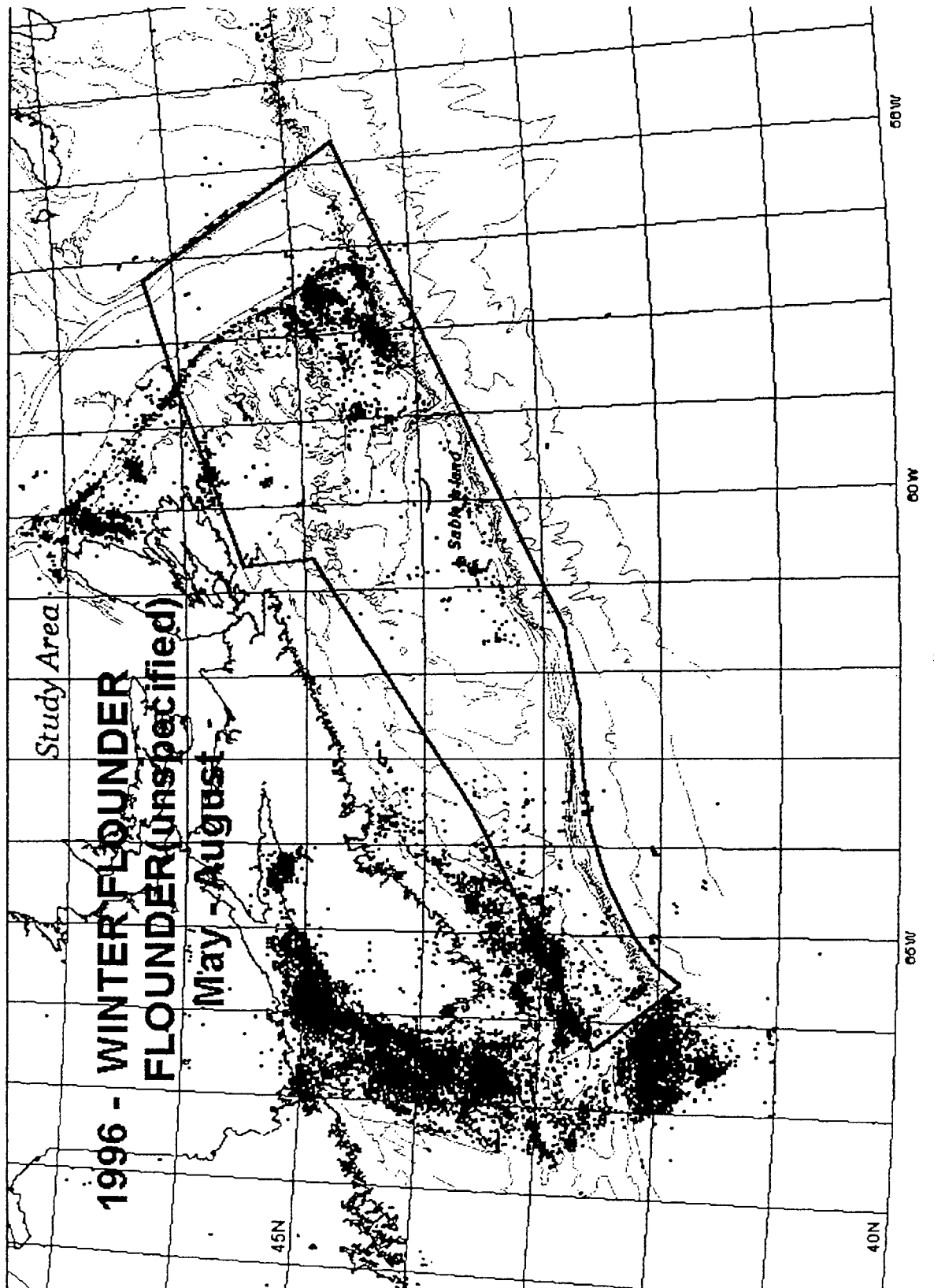
Appendix Figure 2 - 21.   Fisheries catch locations on the Scotian Shelf.
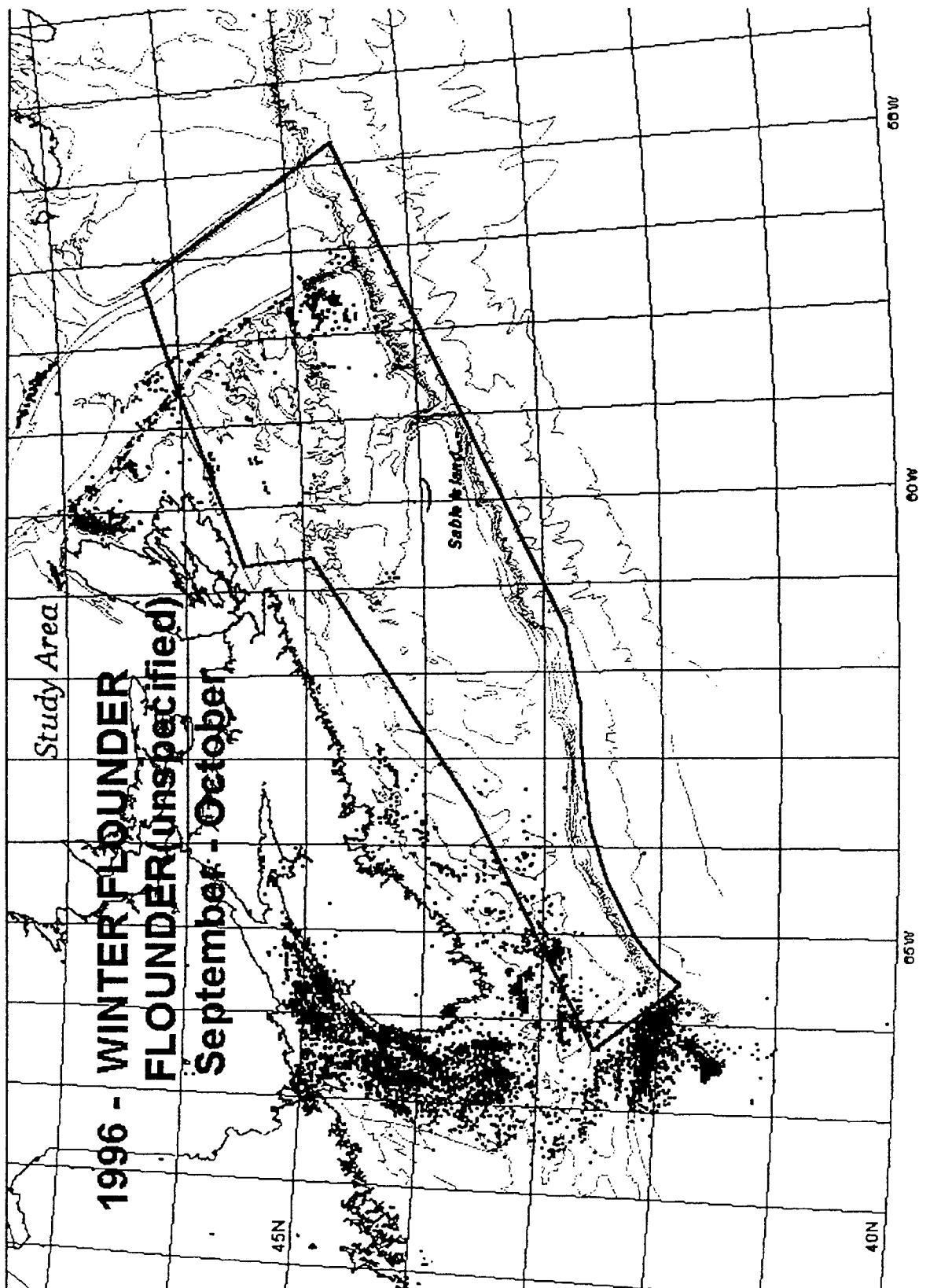
Appendix Figure 2 - 22.   Fisheries catch locations on the Scotian Shelf.
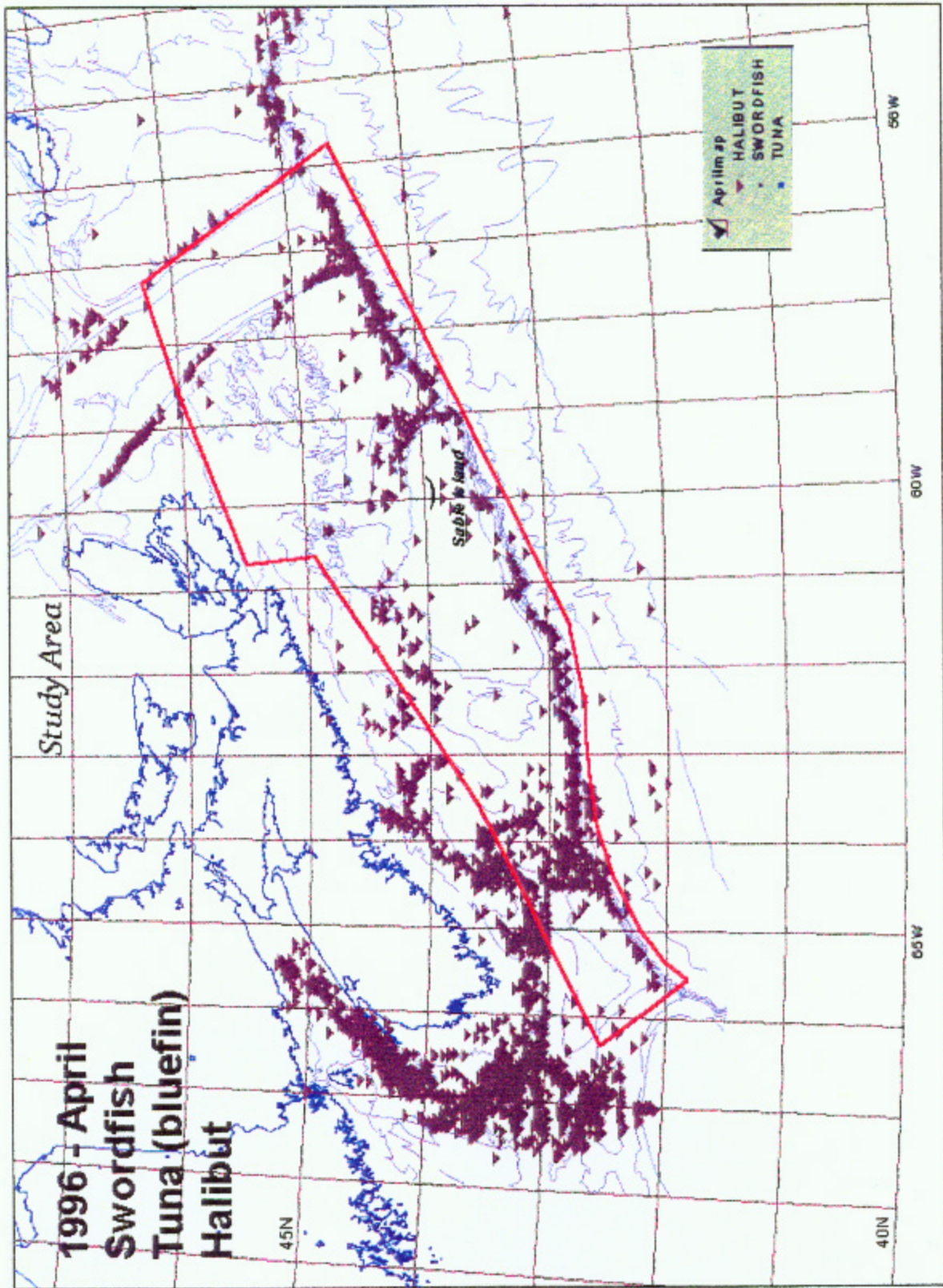
Appendix Figure 2 - 23.   Fisheries catch locations on the Scotian Shelf.
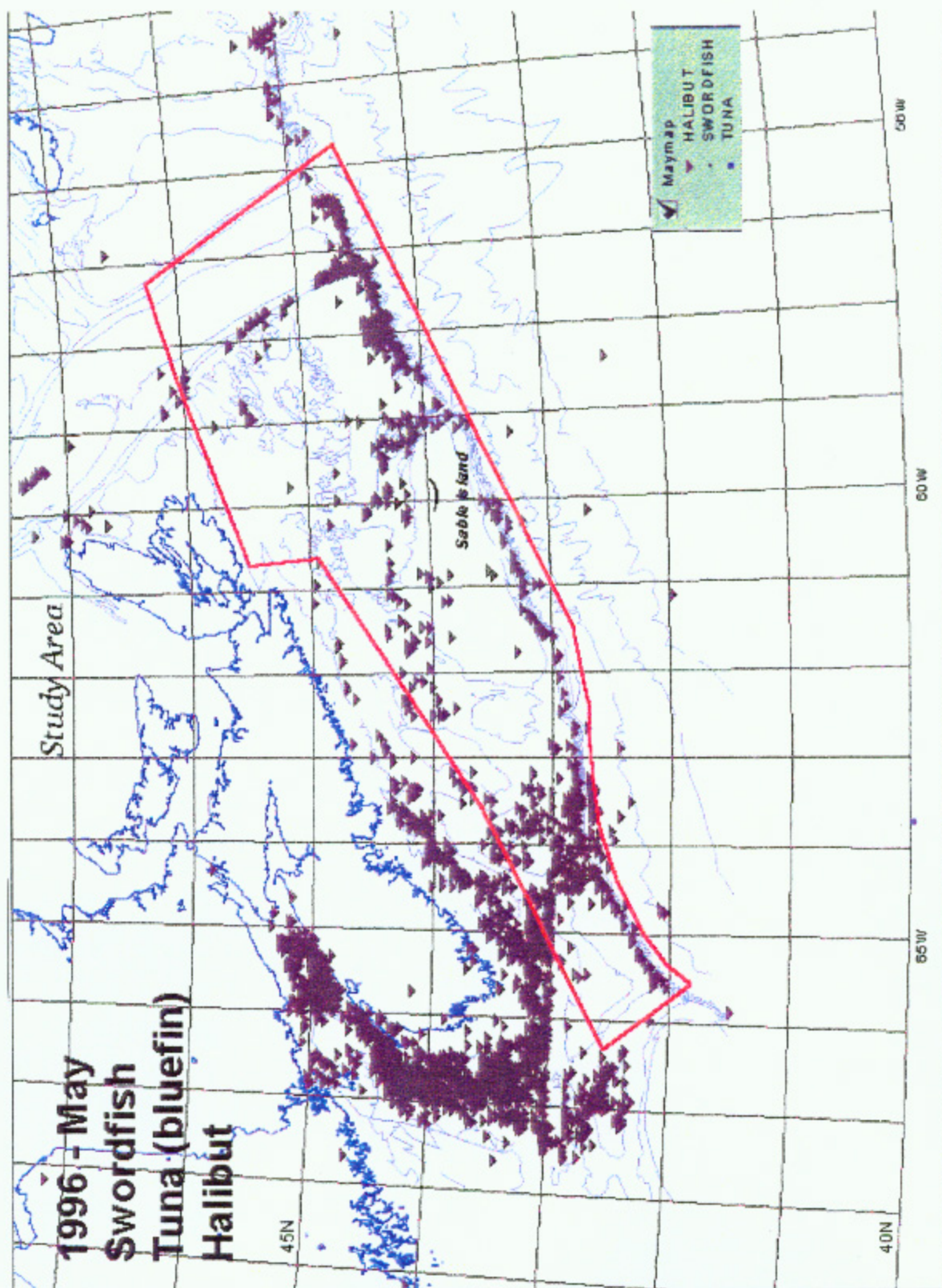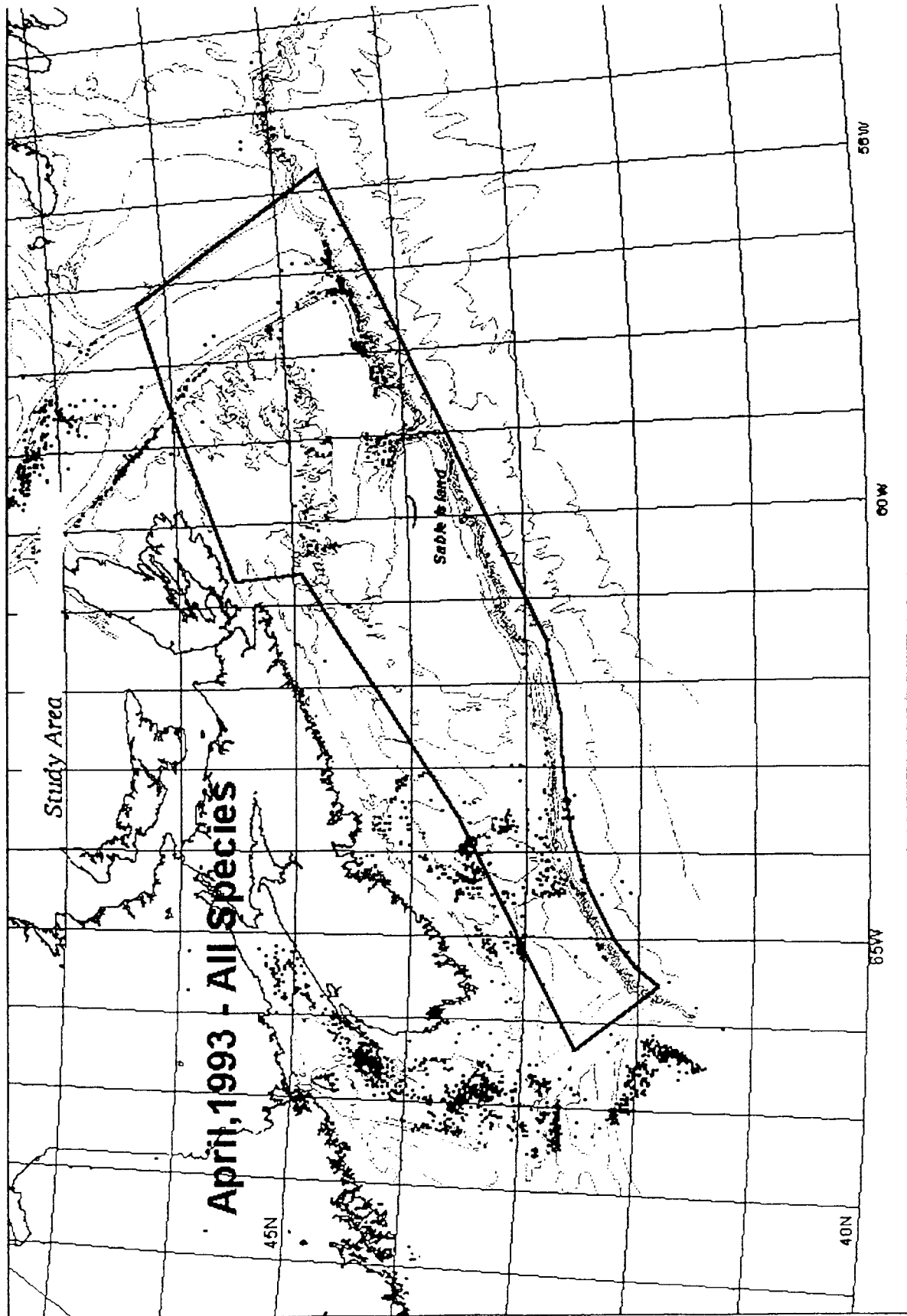
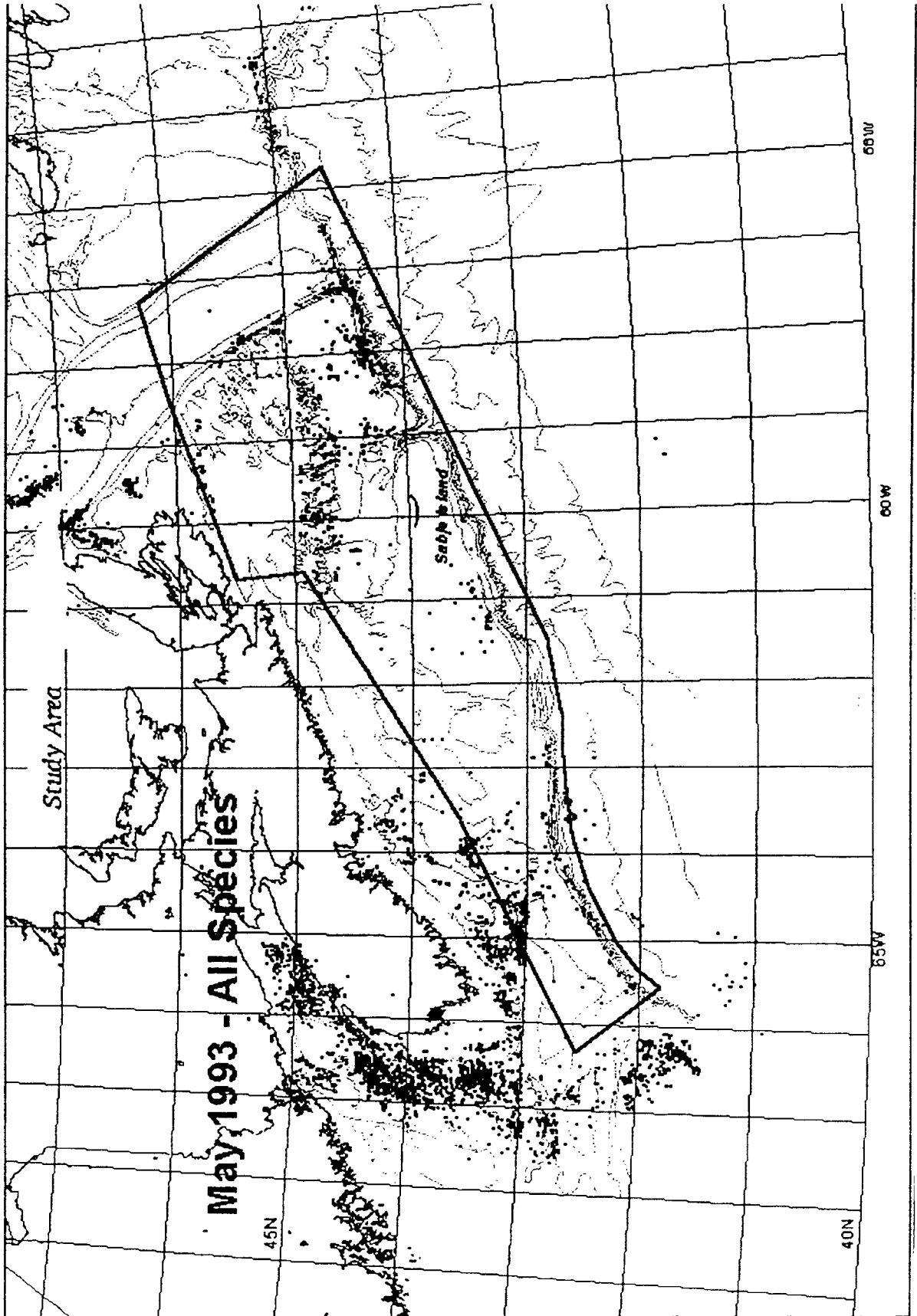Appendix Figure 2 - 24.   Fisheries catch locations on the Scotian Shelf.
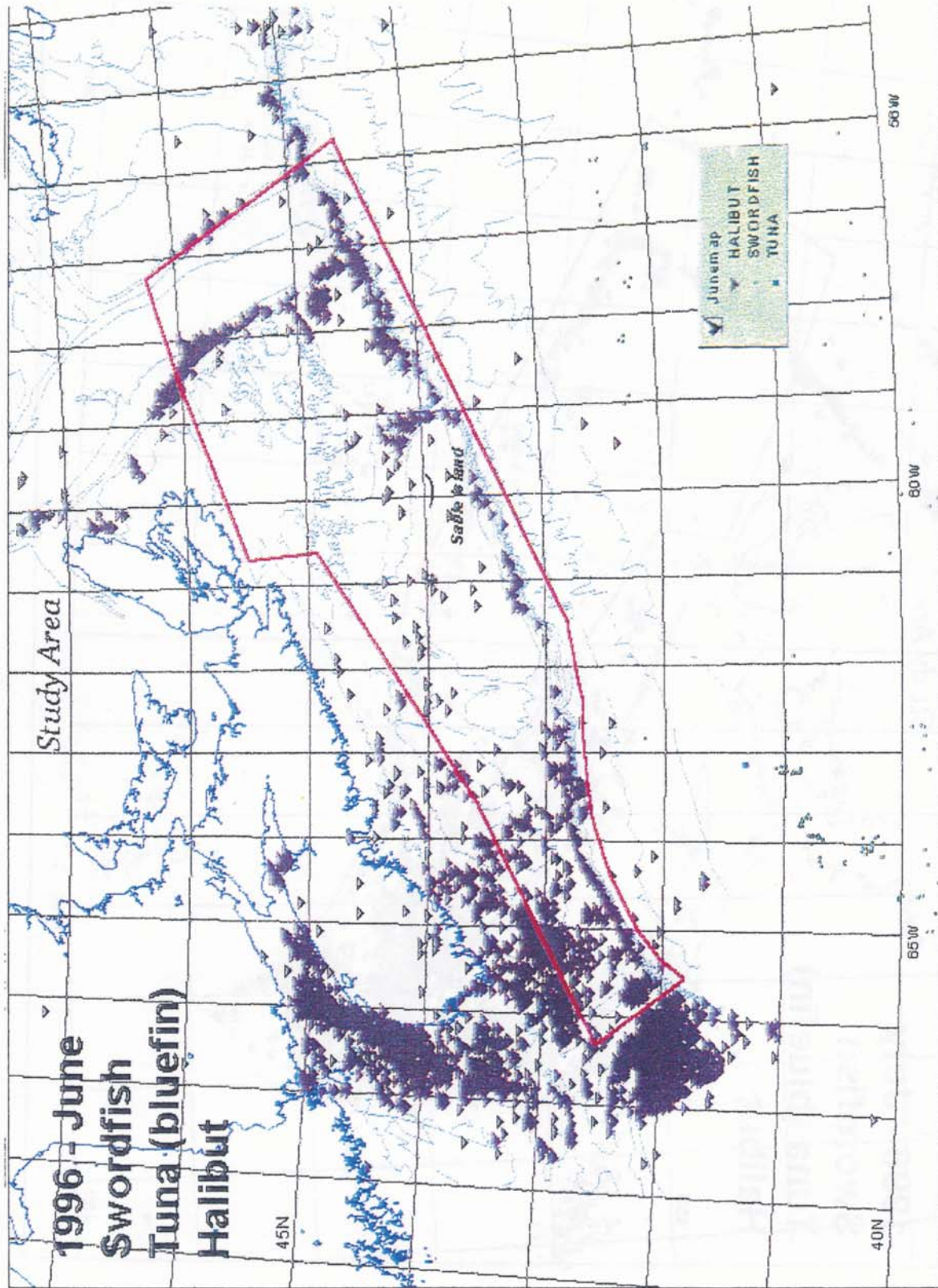
Appendix Figure 2 - 25. Fisheries catch locations on the Scotian Shelf.
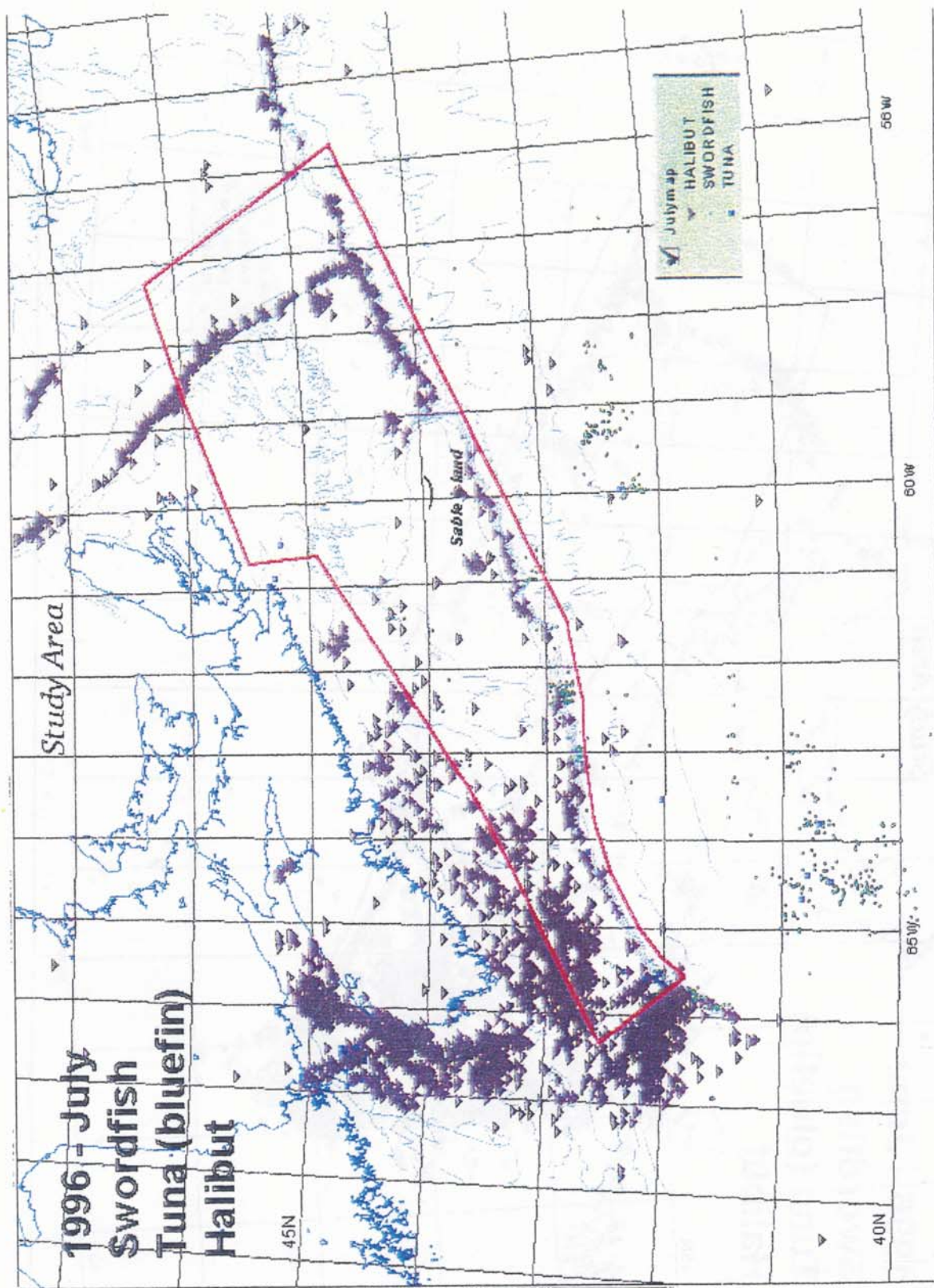
Appendix Figure 2 - 26.   Fisheries catch locations on the Scotian Shelf.
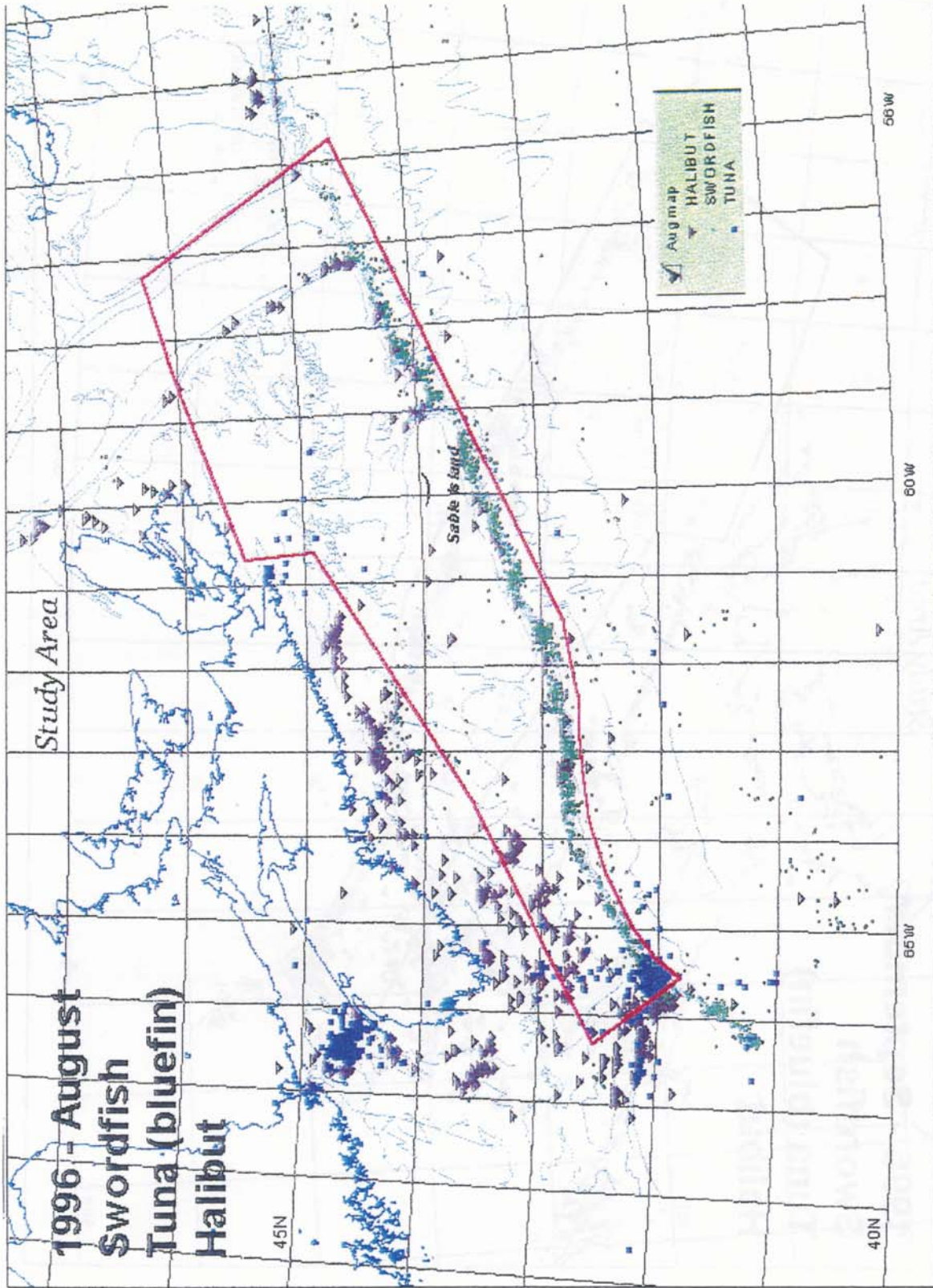
Appendix Figure 2 - 27. Fisheries catch locations on the Scotian Shelf.
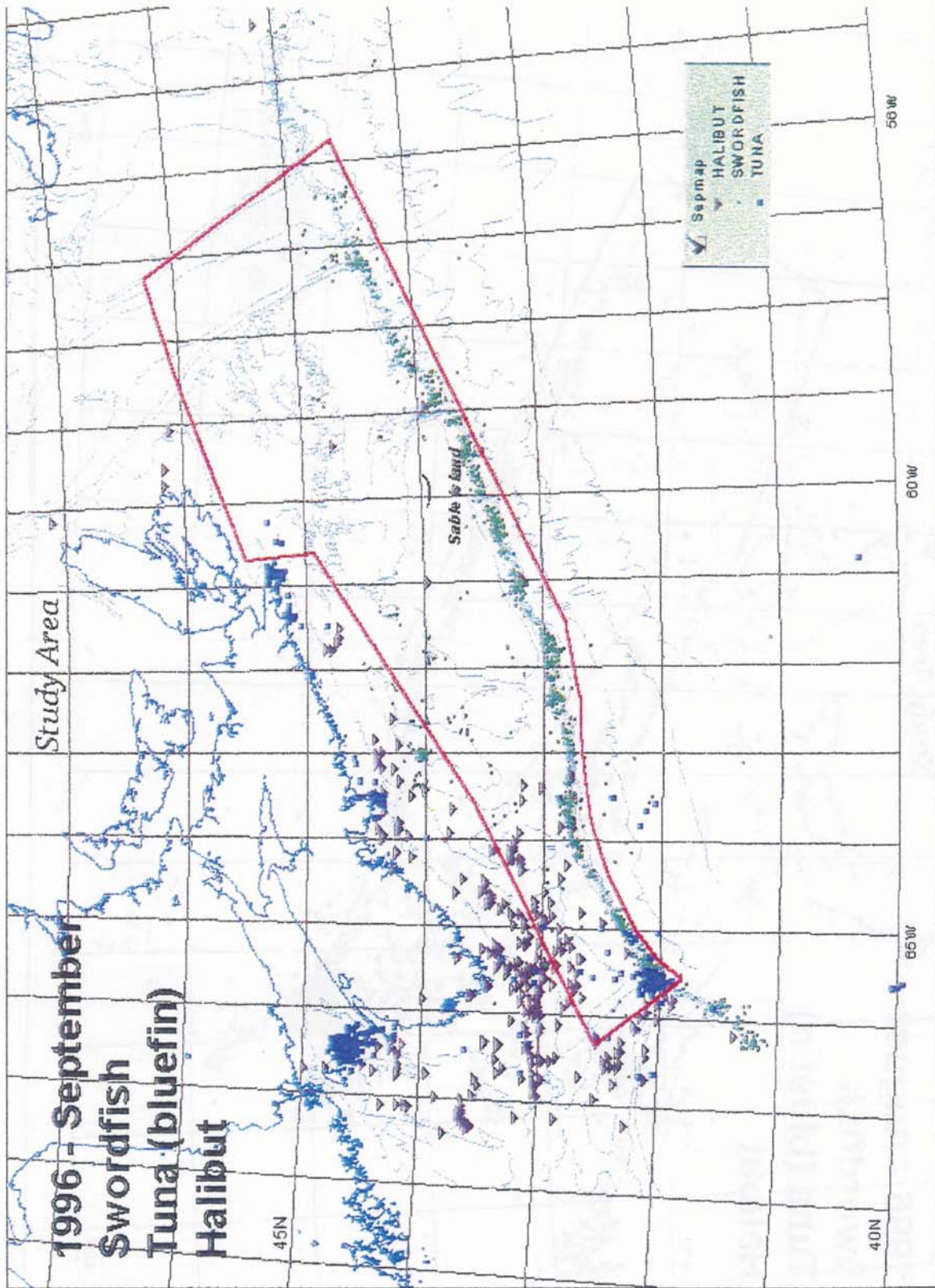
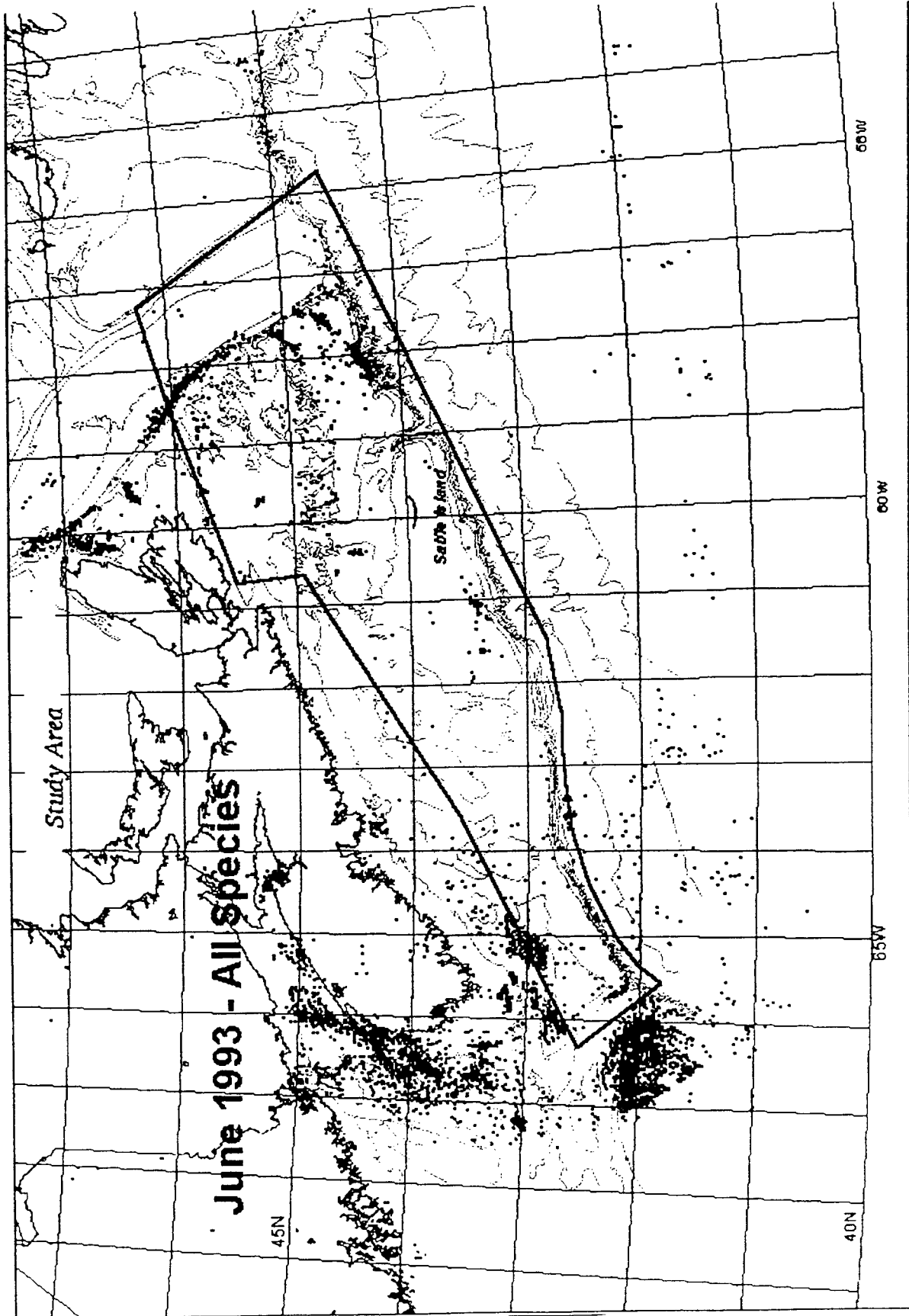Appendix Figure 2 - 28.   Fisheries catch locations on the Scotian Shelf.
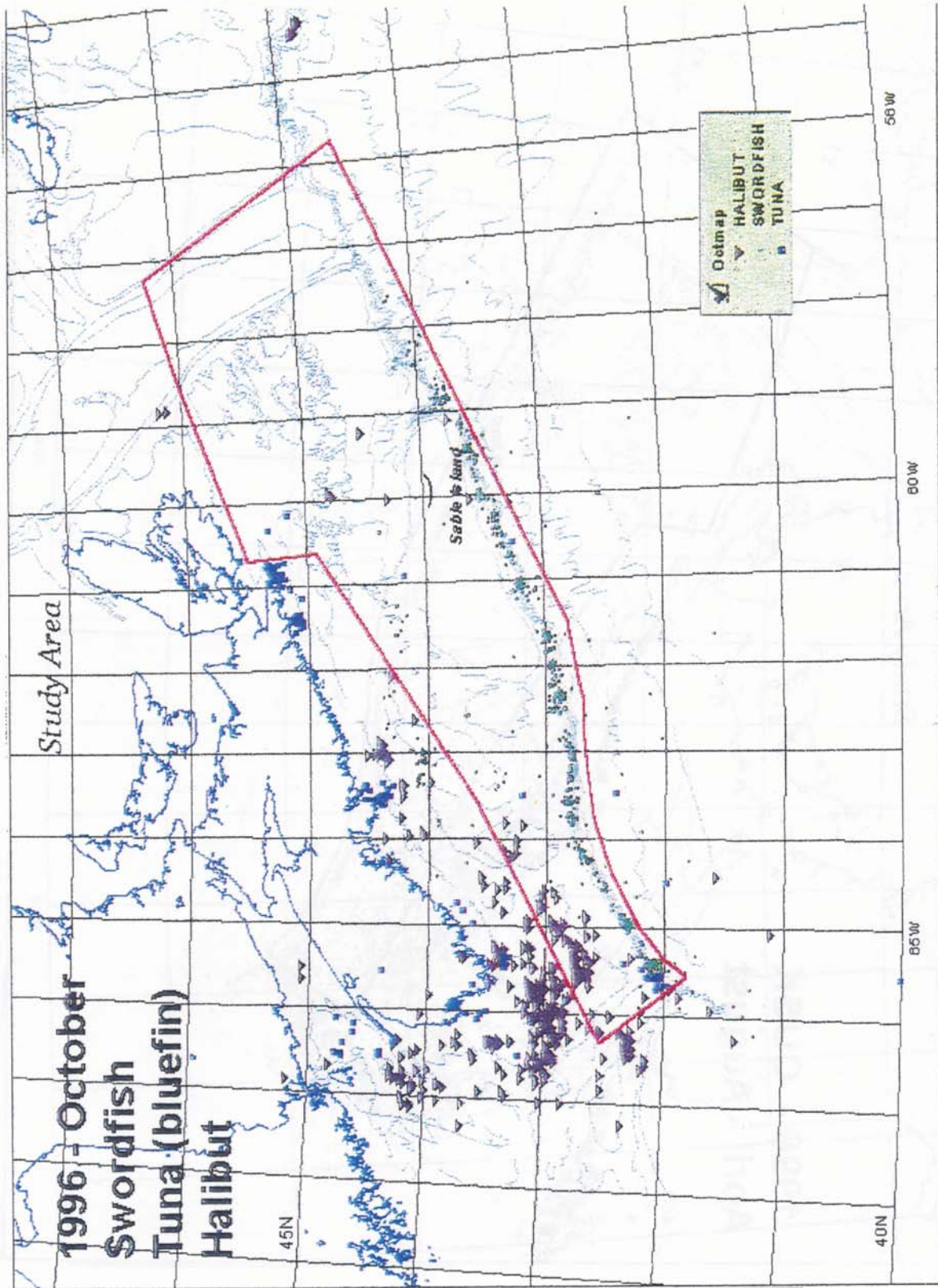
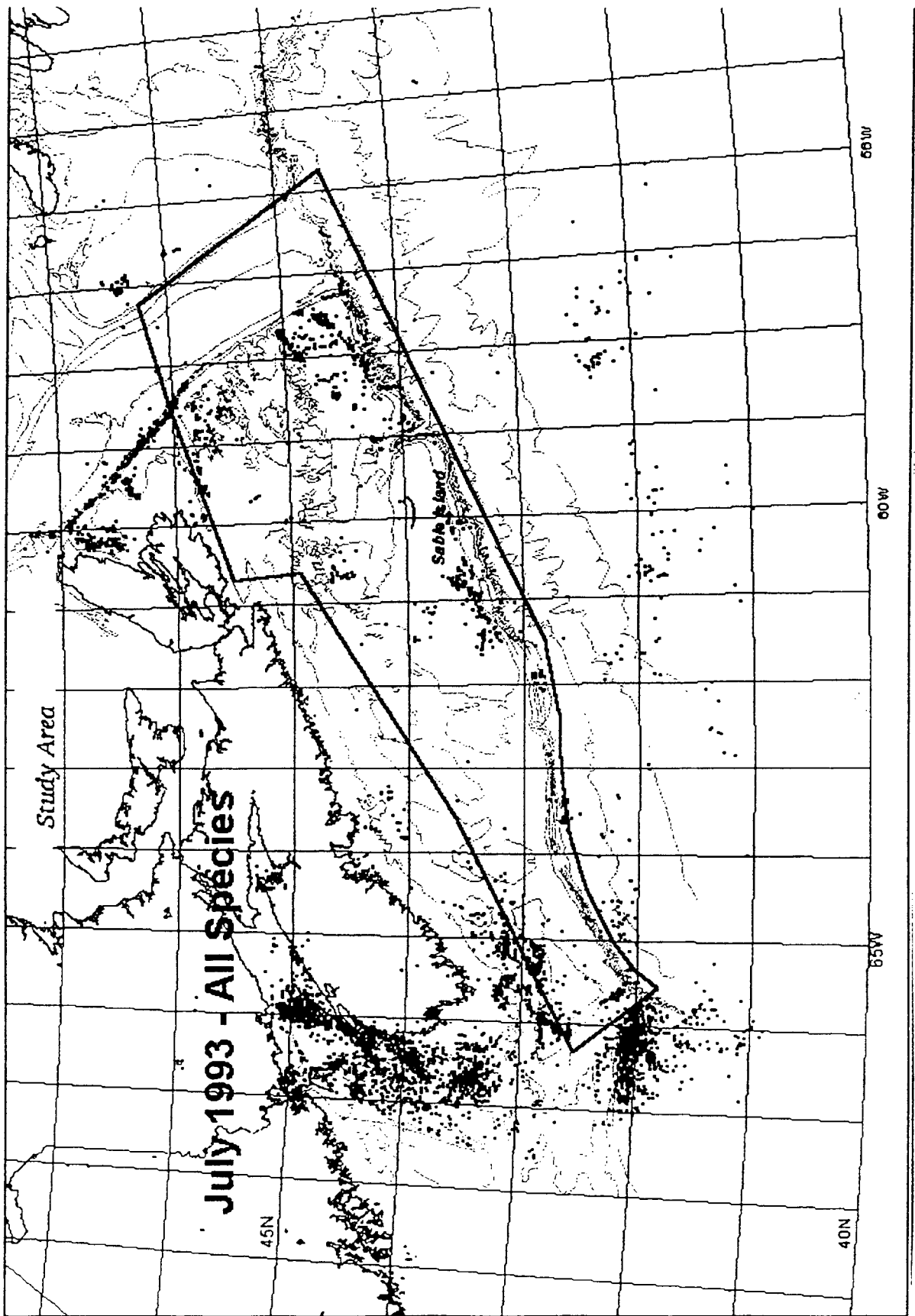Appendix Figure 2 - 29.   Fisheries catch locations on the Scotian Shelf.
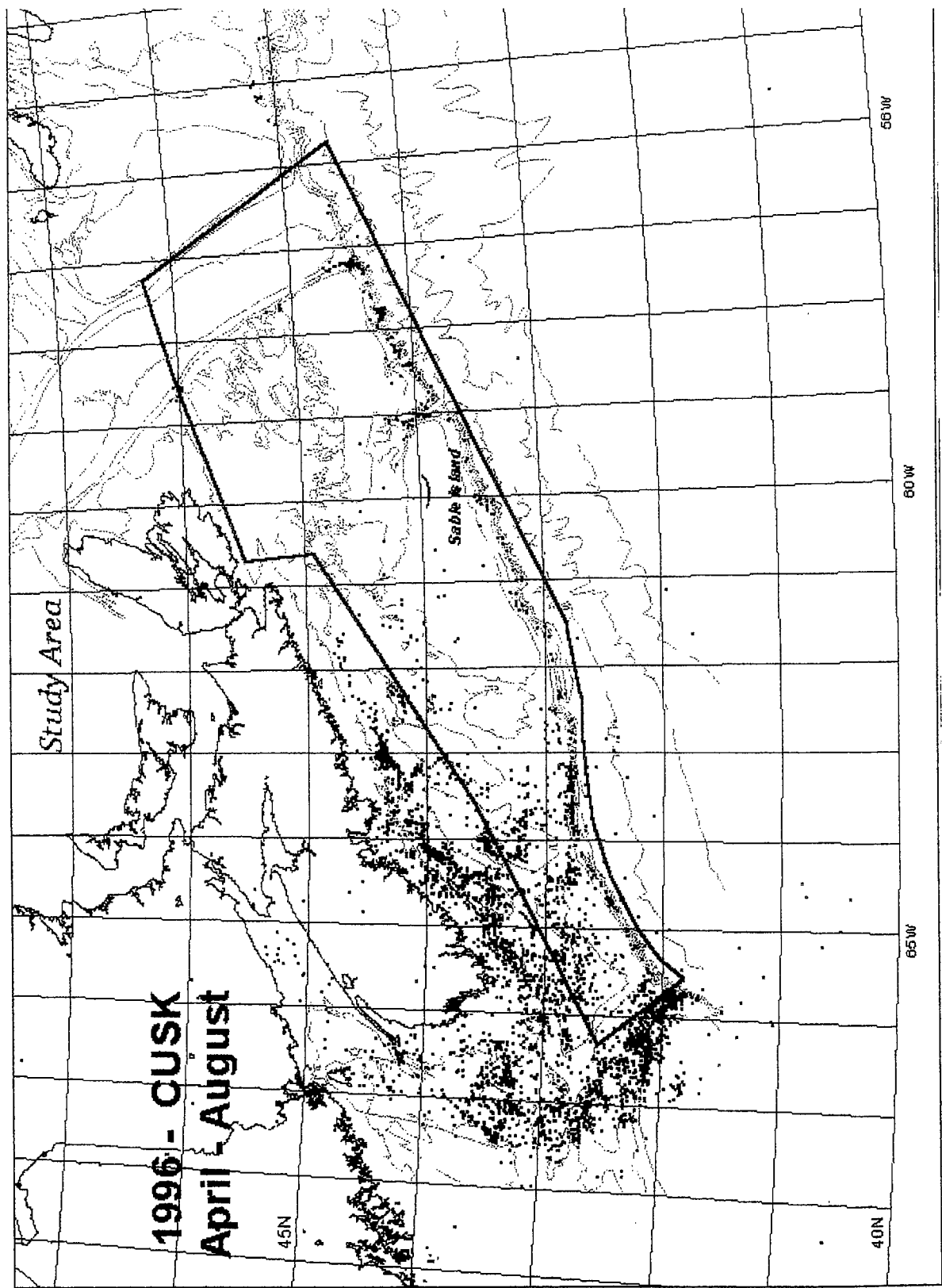
Appendix Figure 2 - 30.   Fisheries catch locations on the Scotian Shelf.
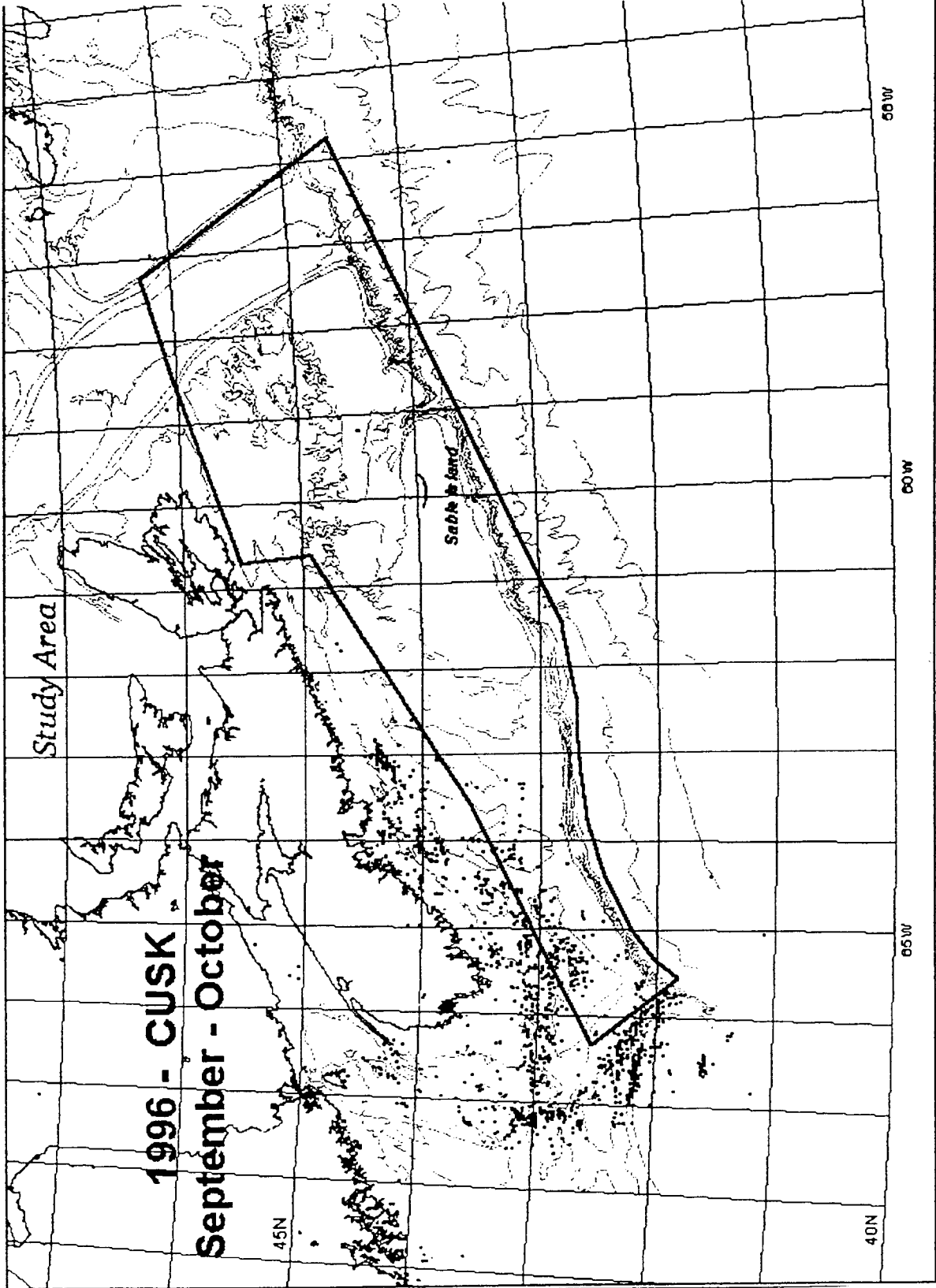
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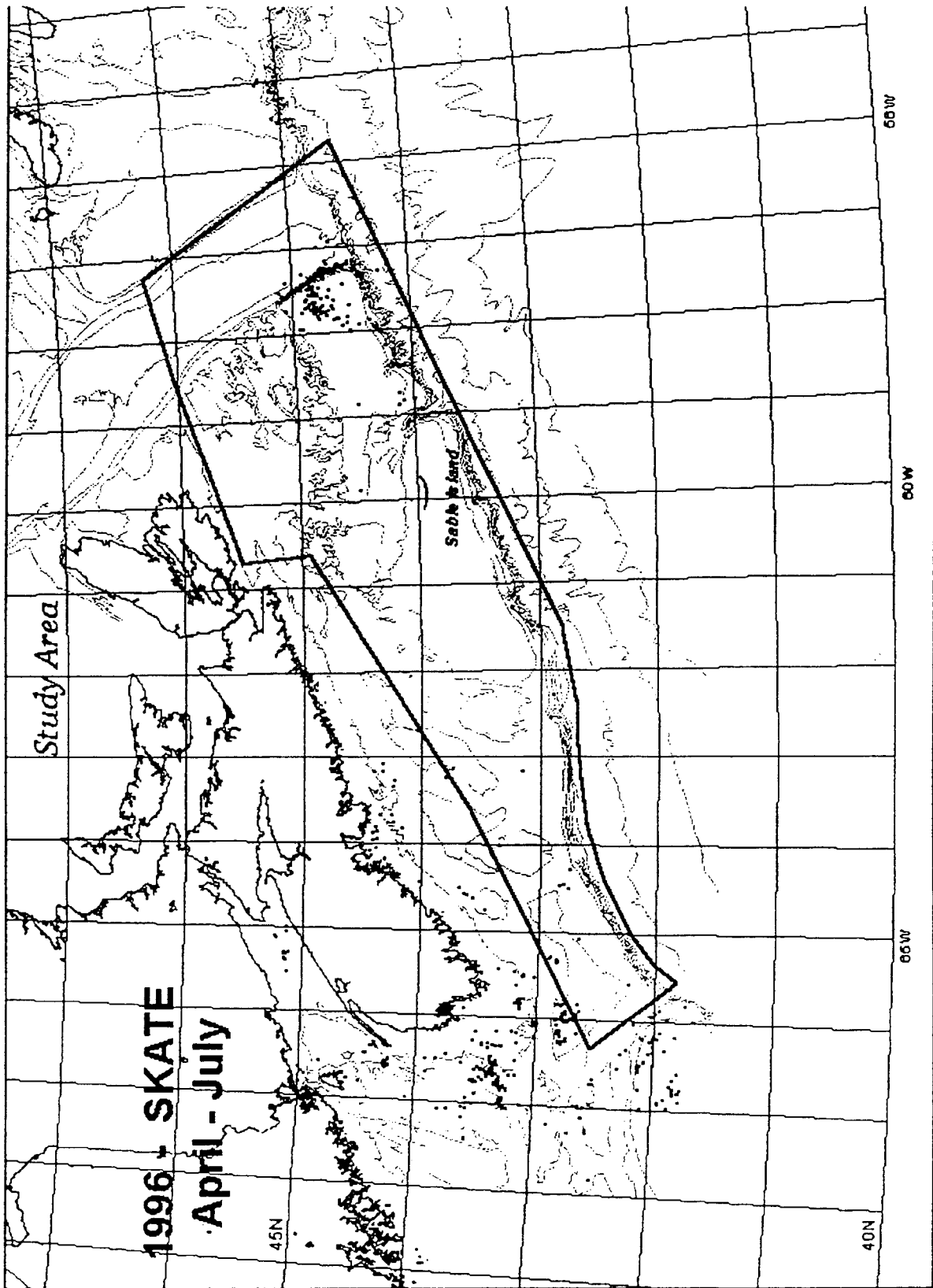
Appendix Figure 2 - 32.   Fisheries catch locations on the Scotian Shelf.
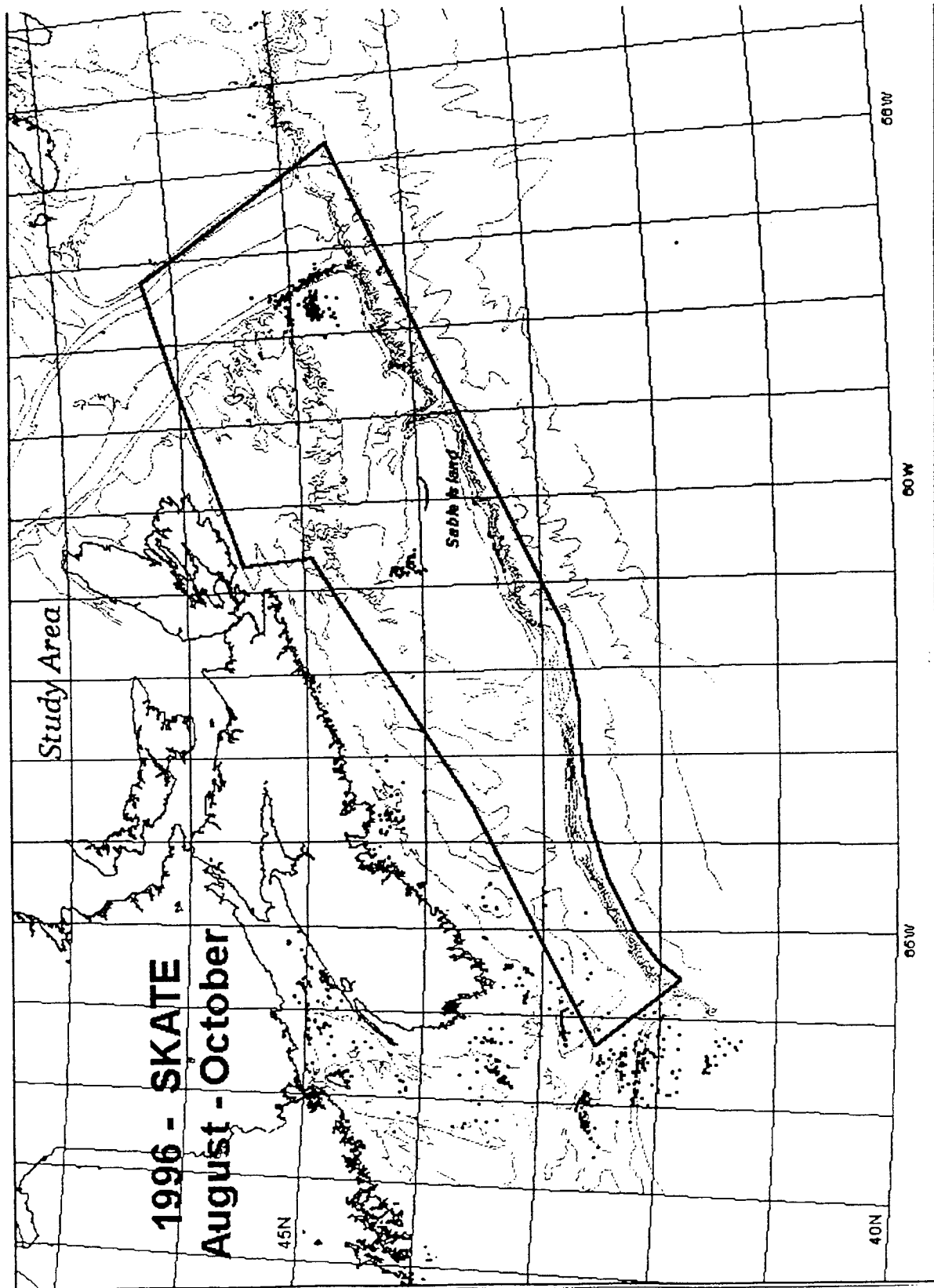
Appendix Figure 2 - 33.   Fisheries catch locations on the Scotian Shelf.
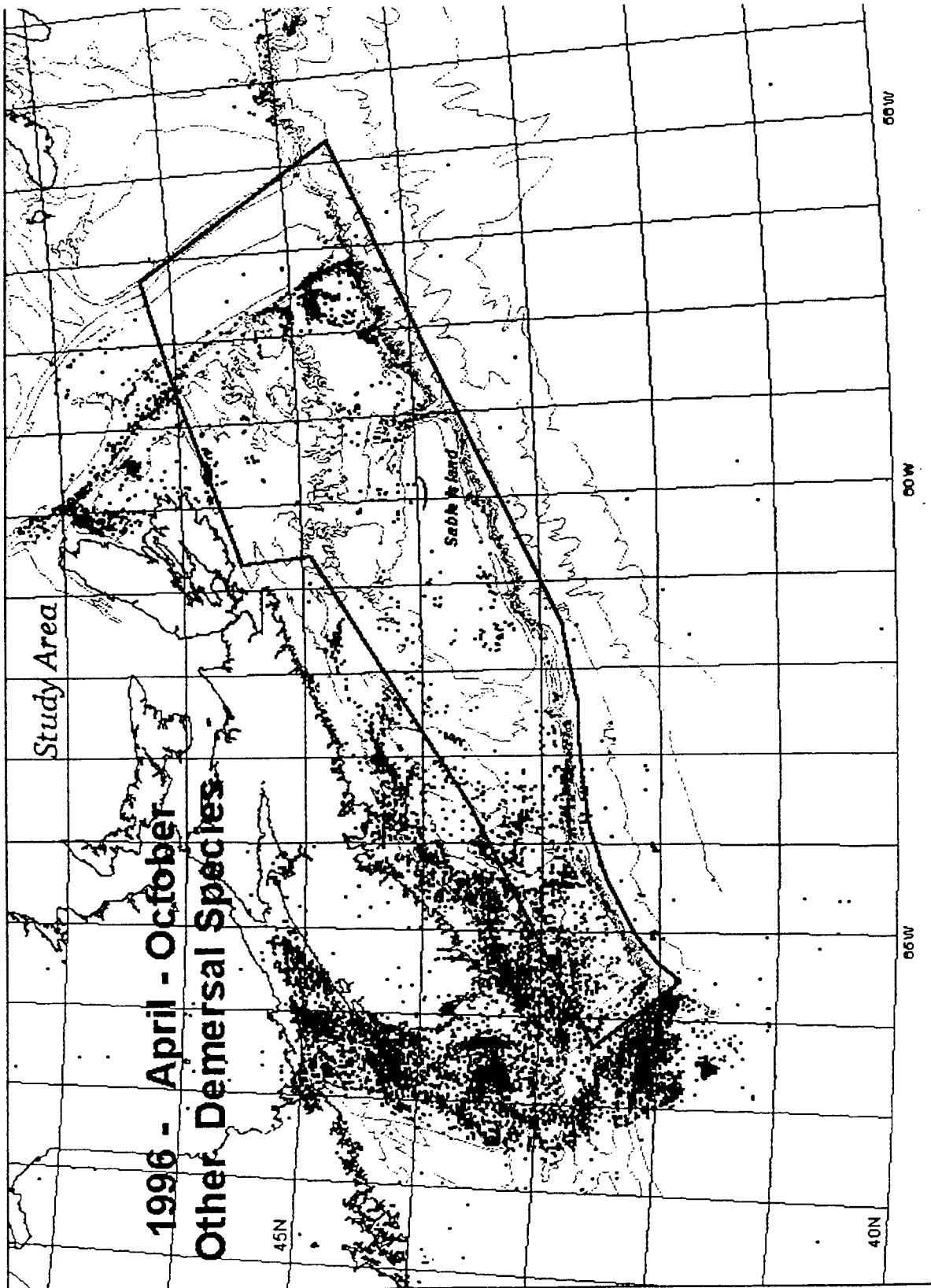
Appendix Figure 2 - 34.   Fisheries catch locations on the Scotian Shelf.
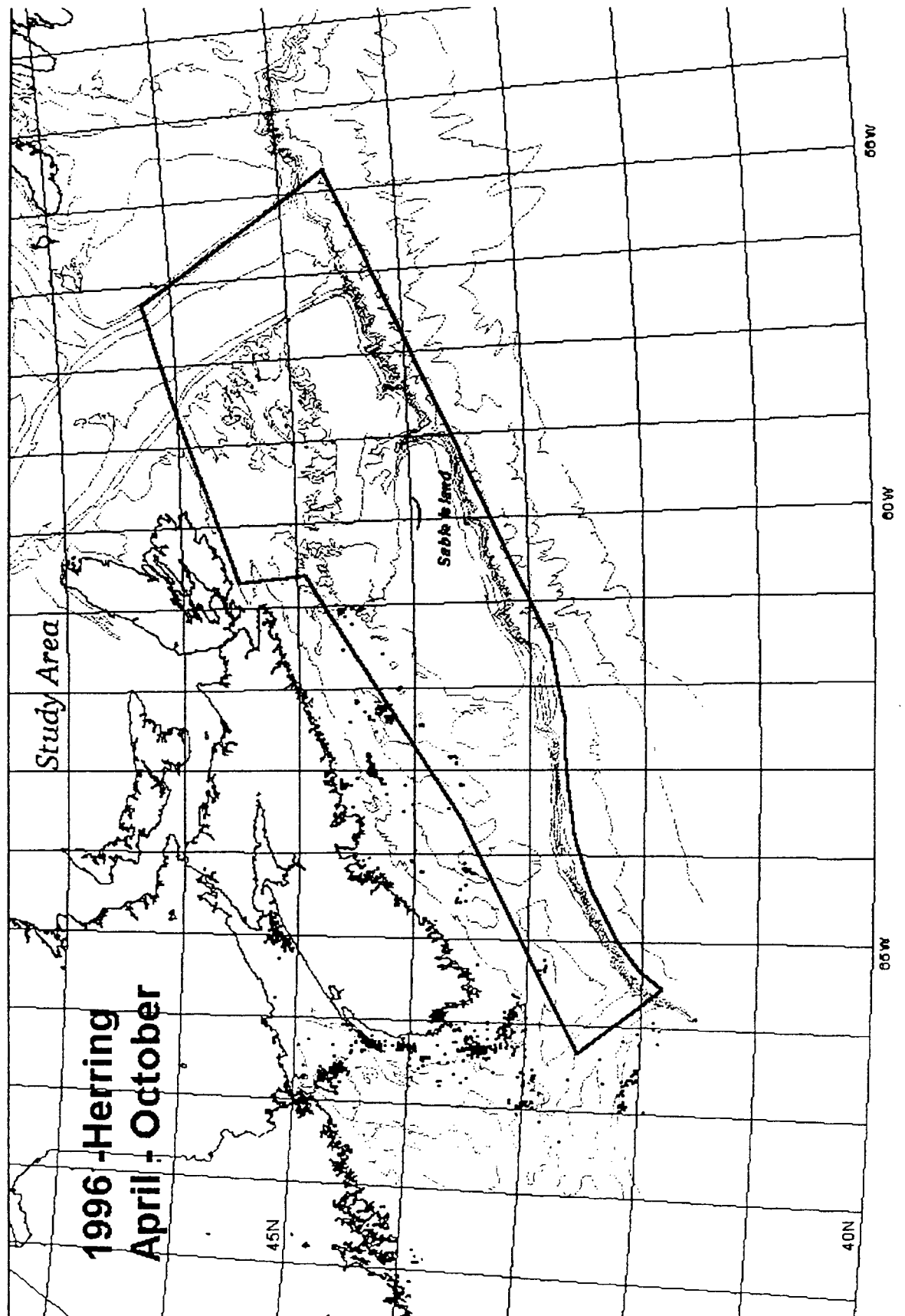
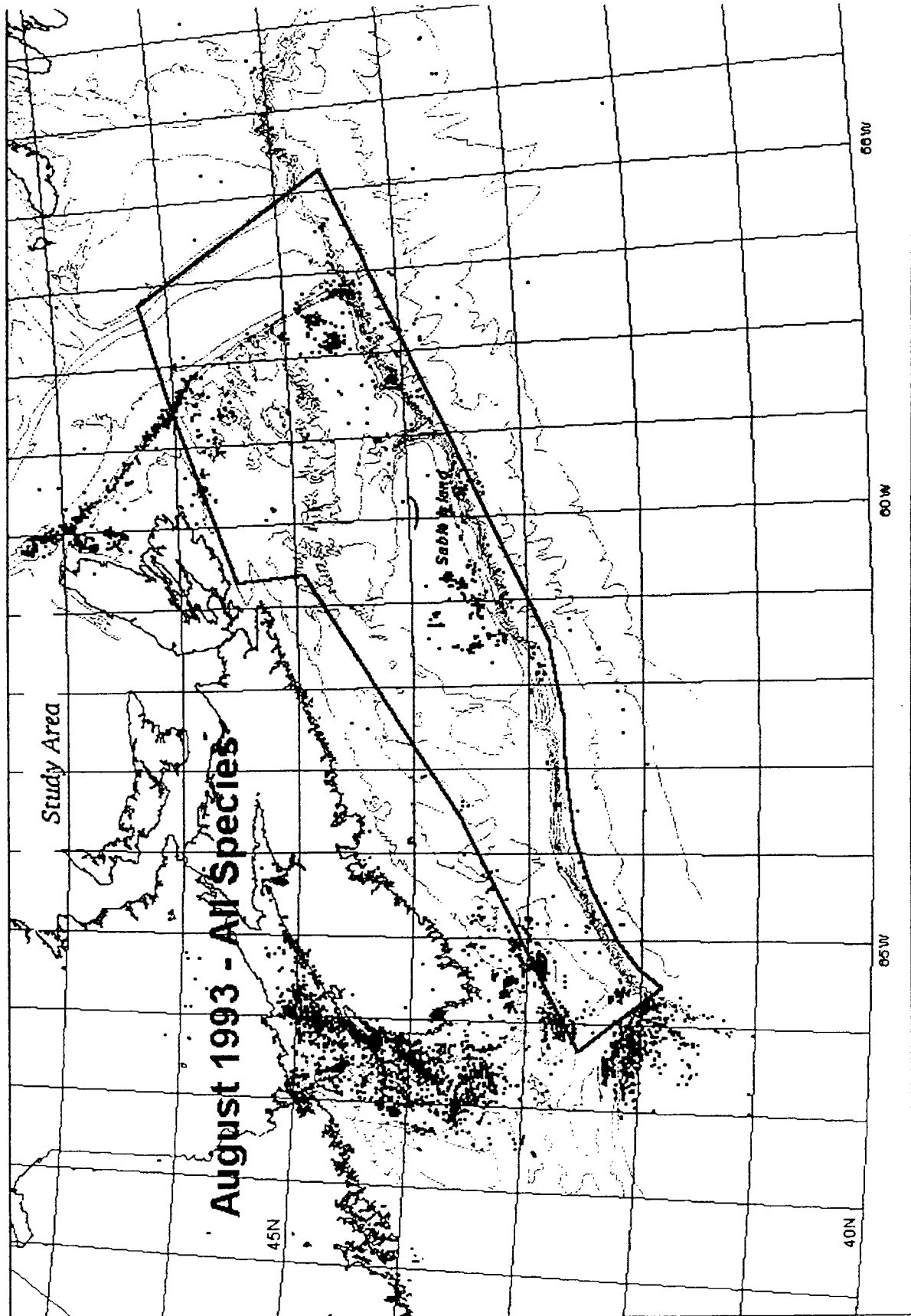Appendix Figure 2 - 35.   Fisheries catch locations on the Scotian Shelf.

1996 - Mackerel
April - October

Study Area

45N

40N

55W

60W

65W

Sable Island
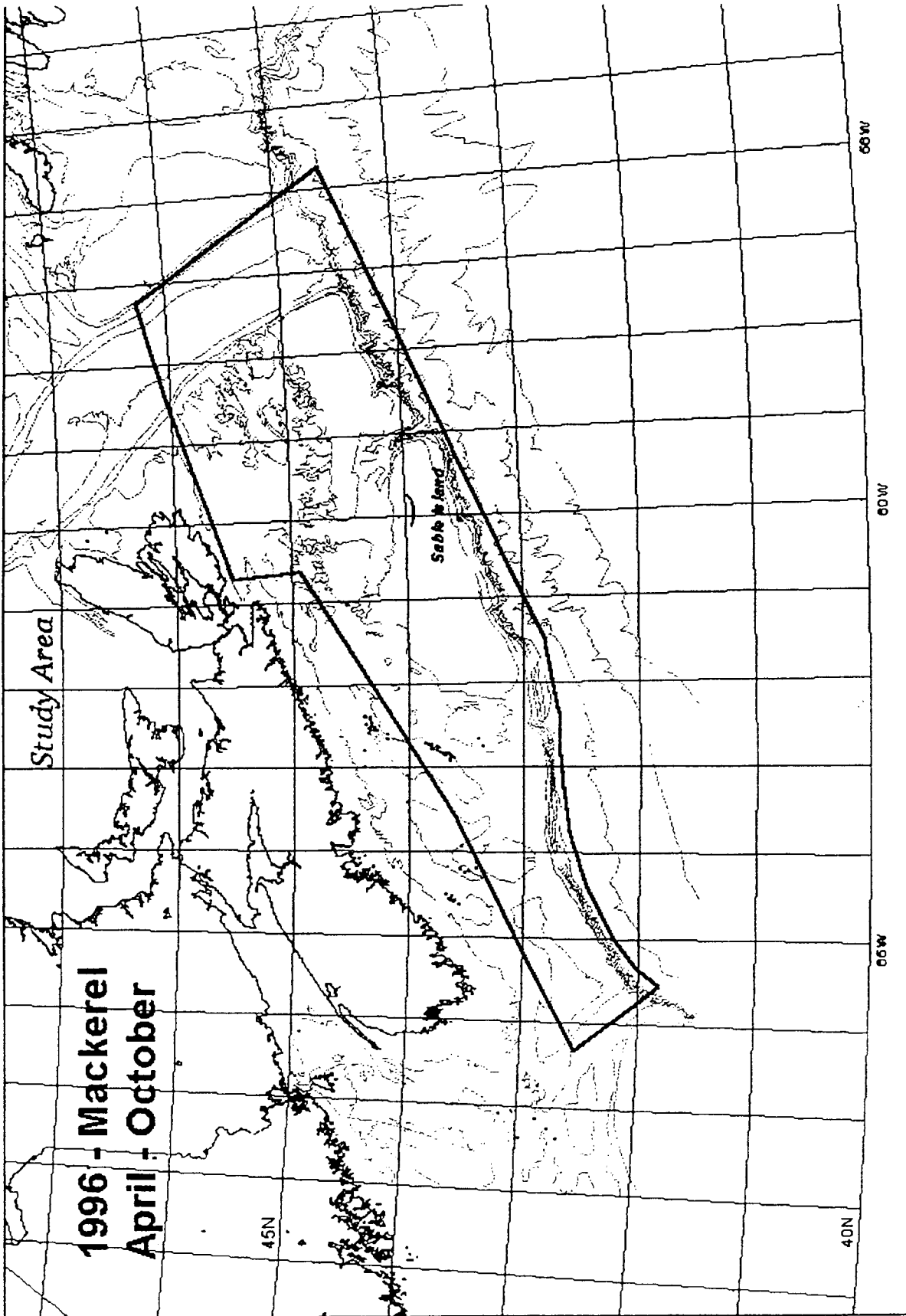
Appendix Figure 2 - 36.   Fisheries catch locations on the Scotian Shelf.
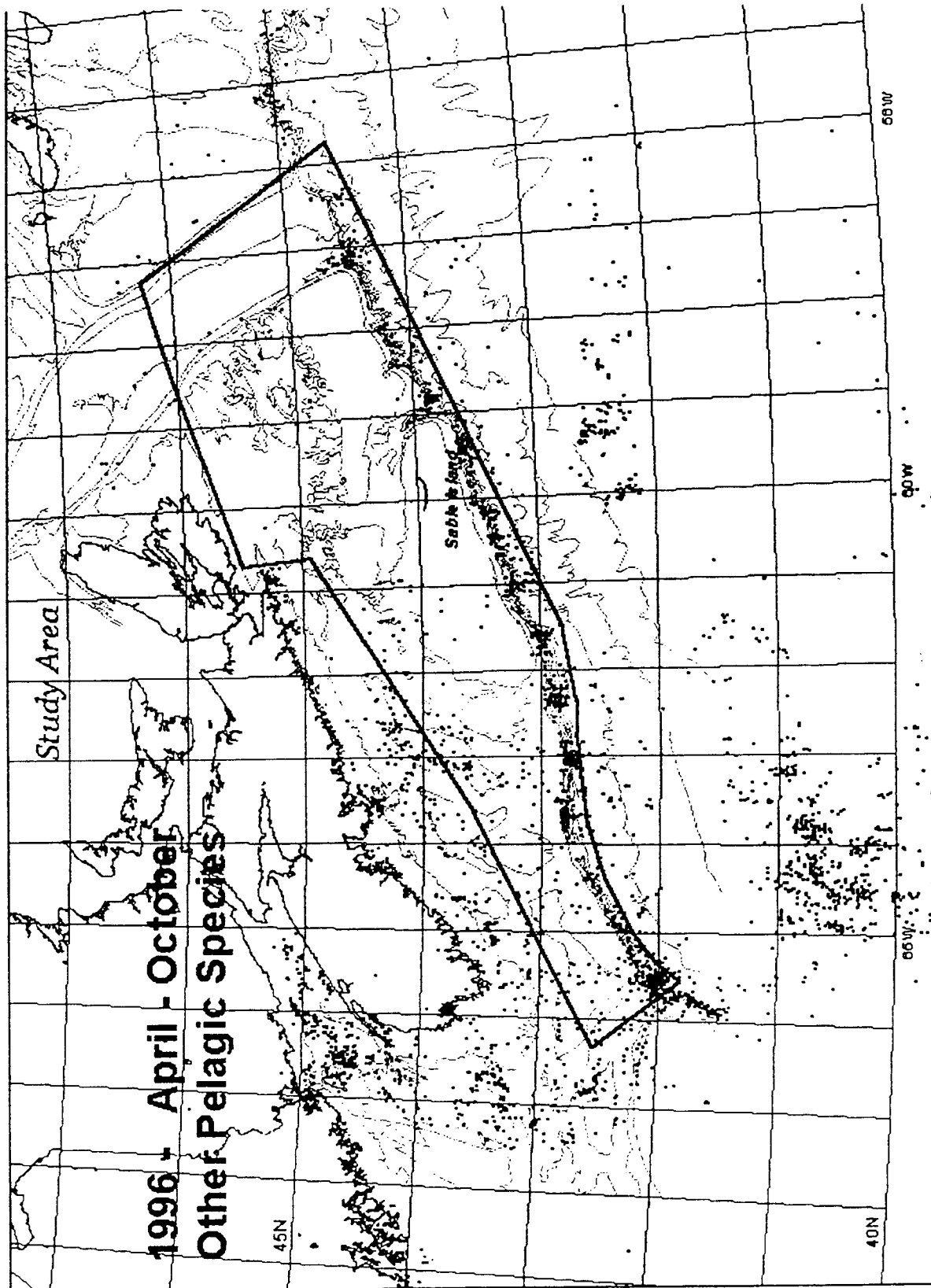
Appendix Figure 2 - 37. Fisheries catch locations on the Scotian Shelf.

1996 - Lobster
April - October

Study Area
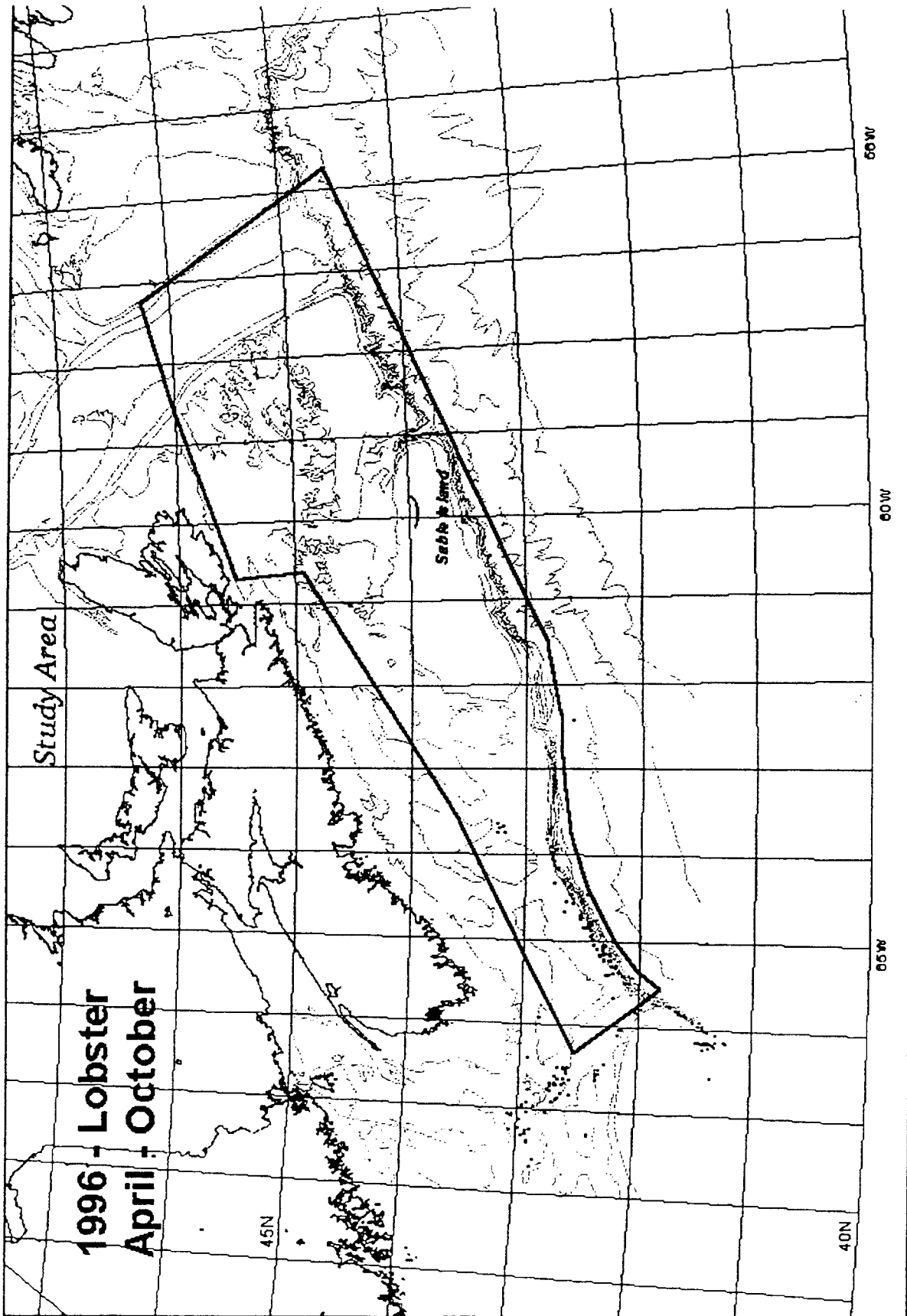
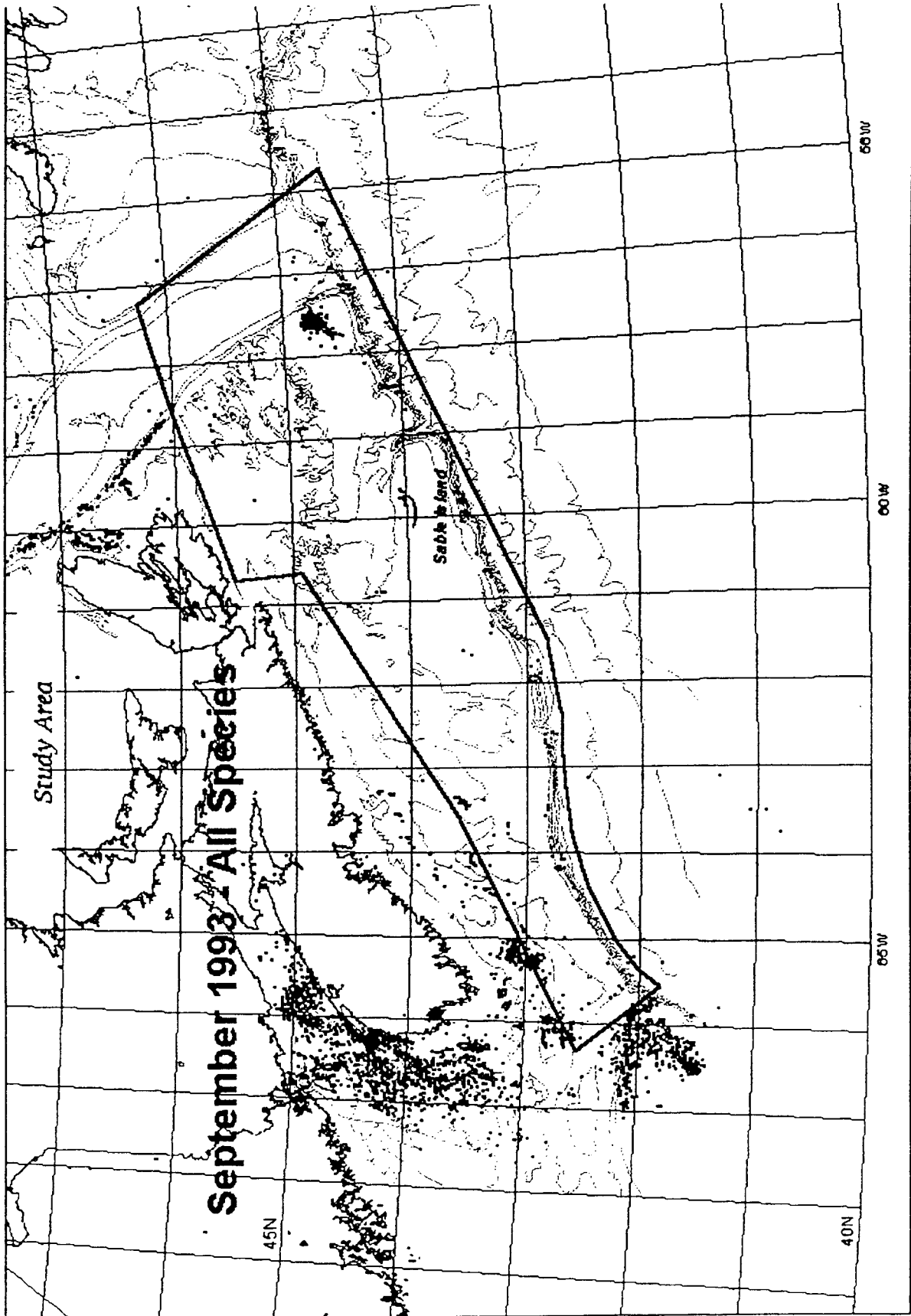Appendix Figure 2 - 38.   Fisheries catch locations on the Scotian Shelf.
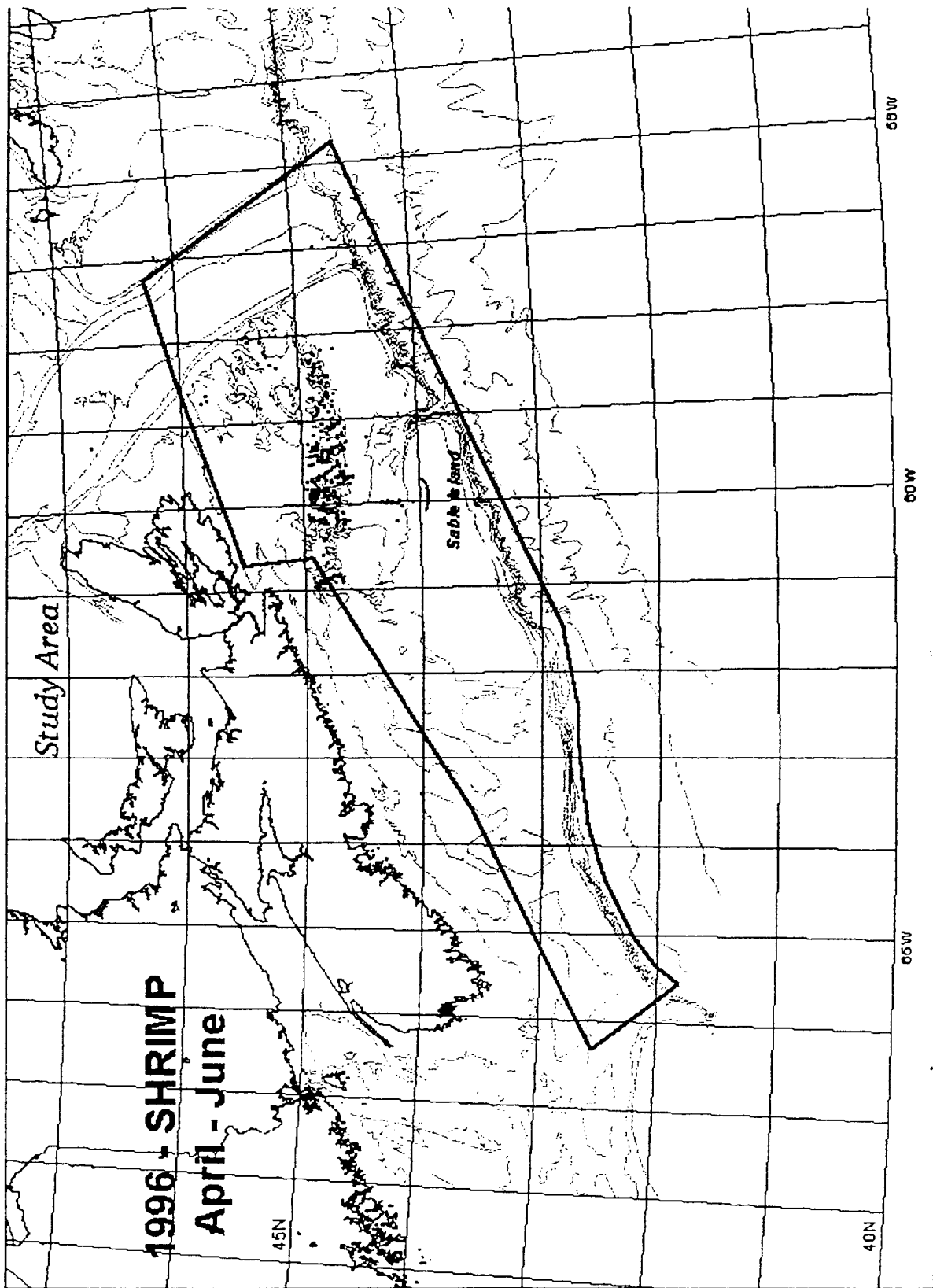
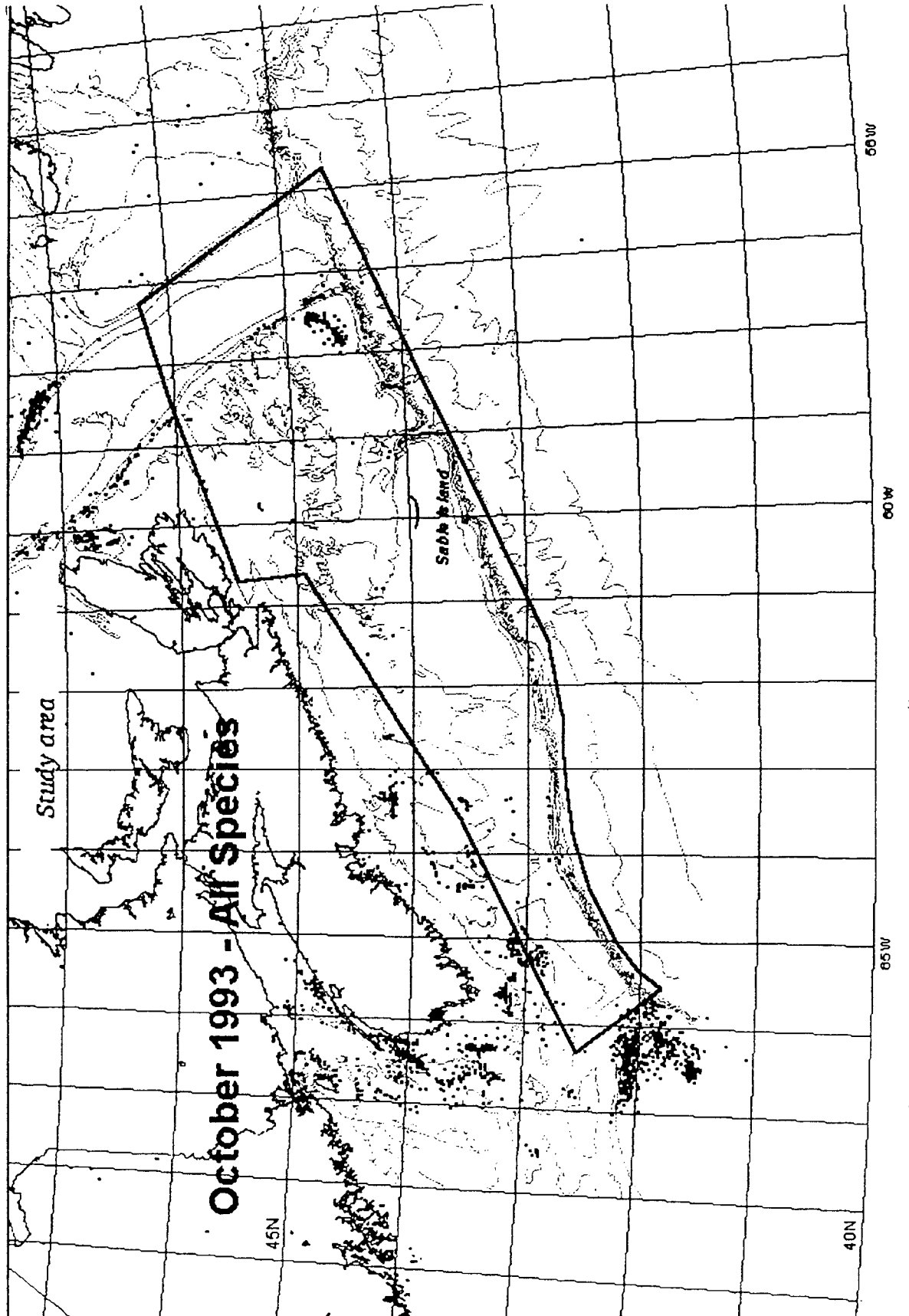Appendix Figure 2 - 39.   Fisheries catch locations on the Scotian Shelf.
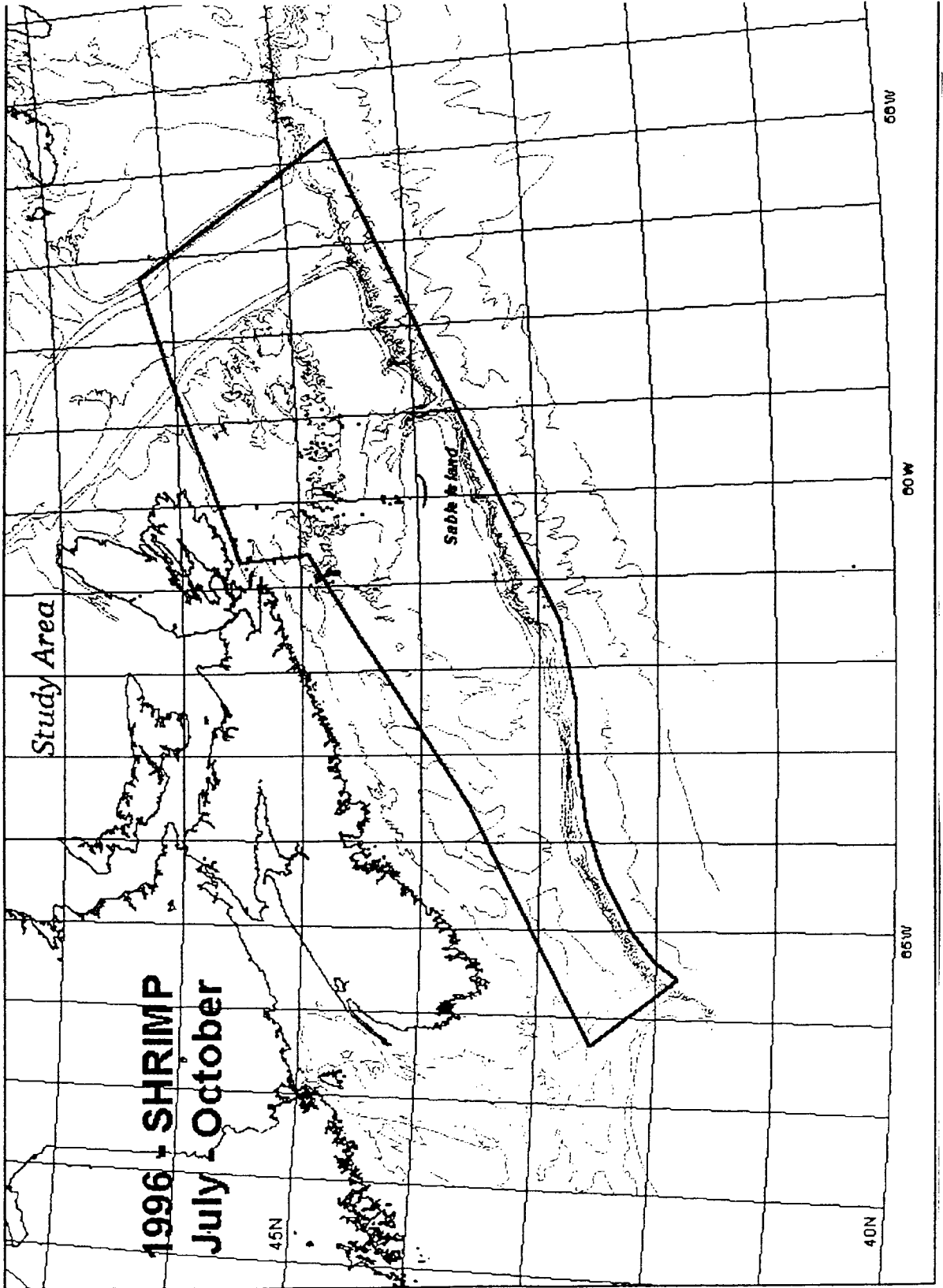
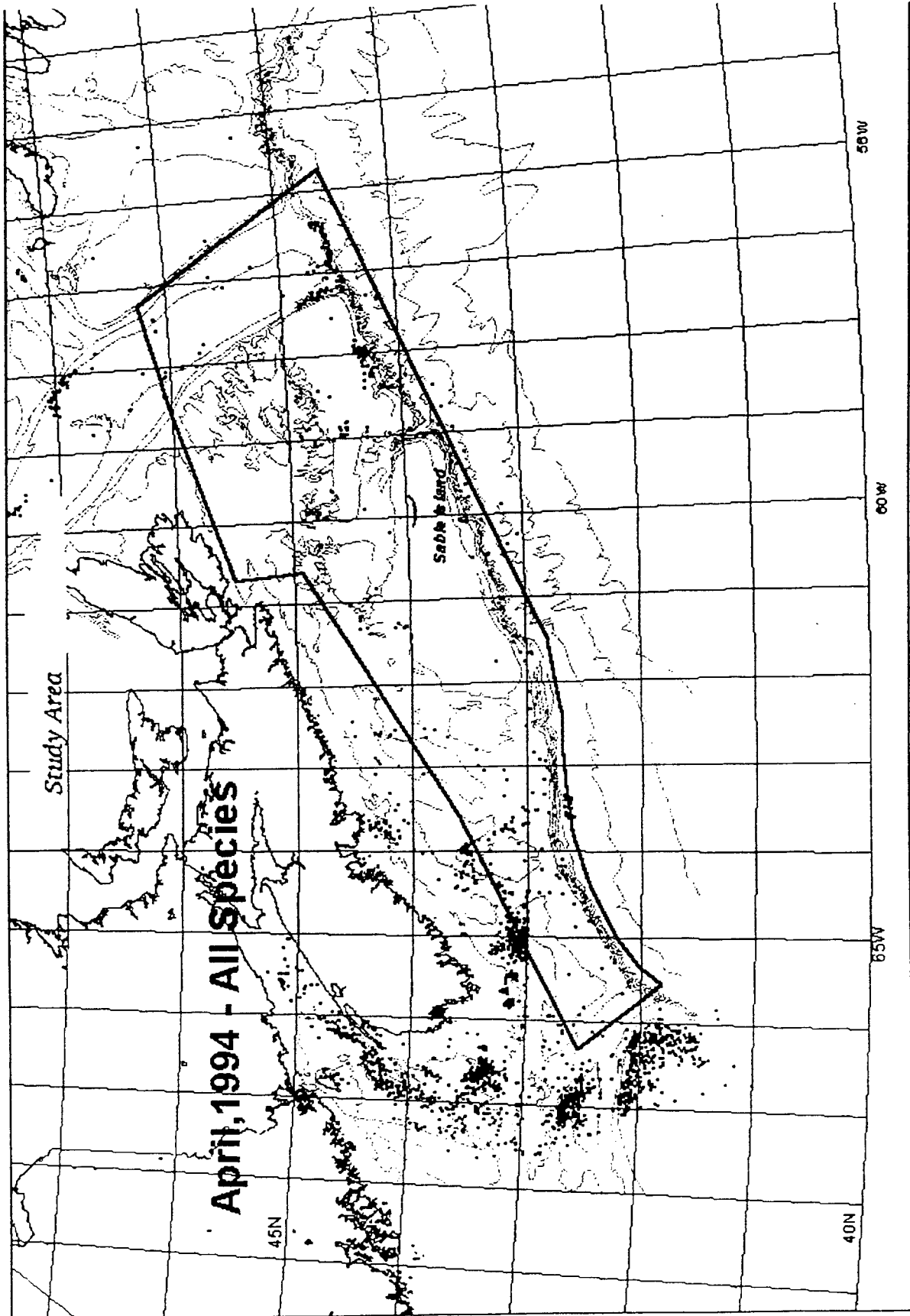Appendix Figure 2 - 40. Fisheries catch locations on the Scotian Shelf.
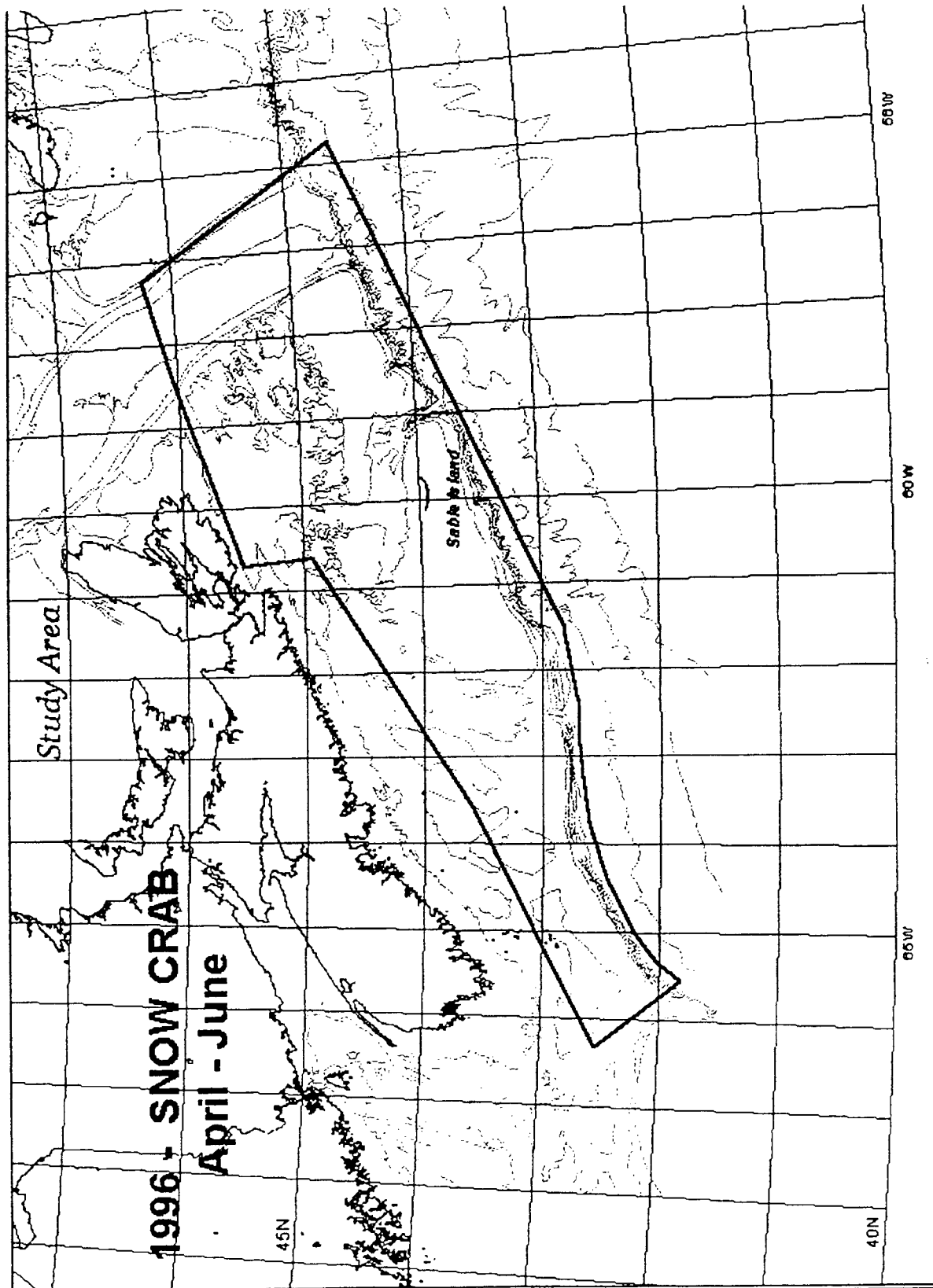
Appendix Figure 2 - 41.   Fisheries catch locations on the Scotian Shelf.
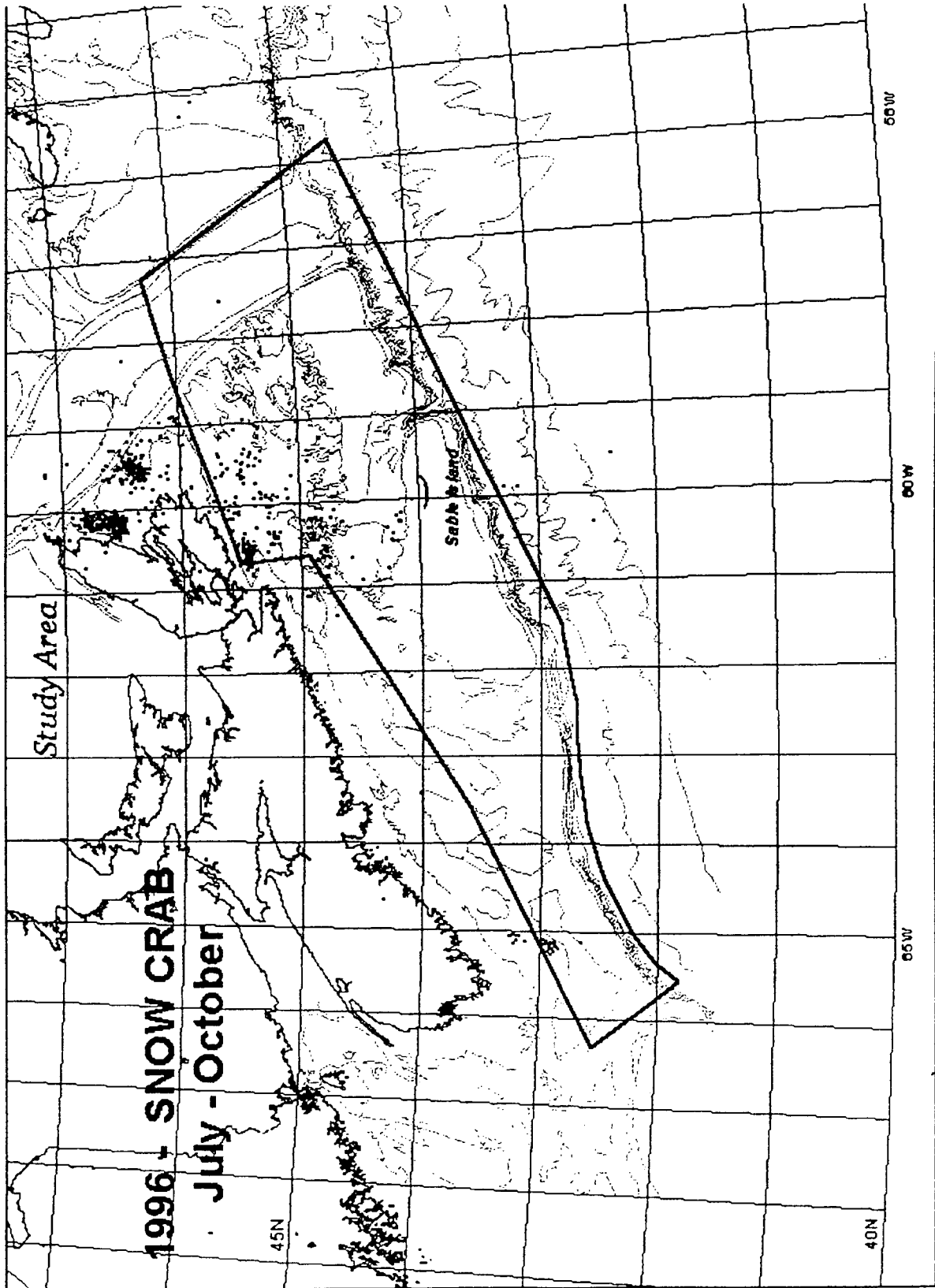
Appendix Figure 2 - 42.   Fisheries catch locations on the Scotian Shelf.
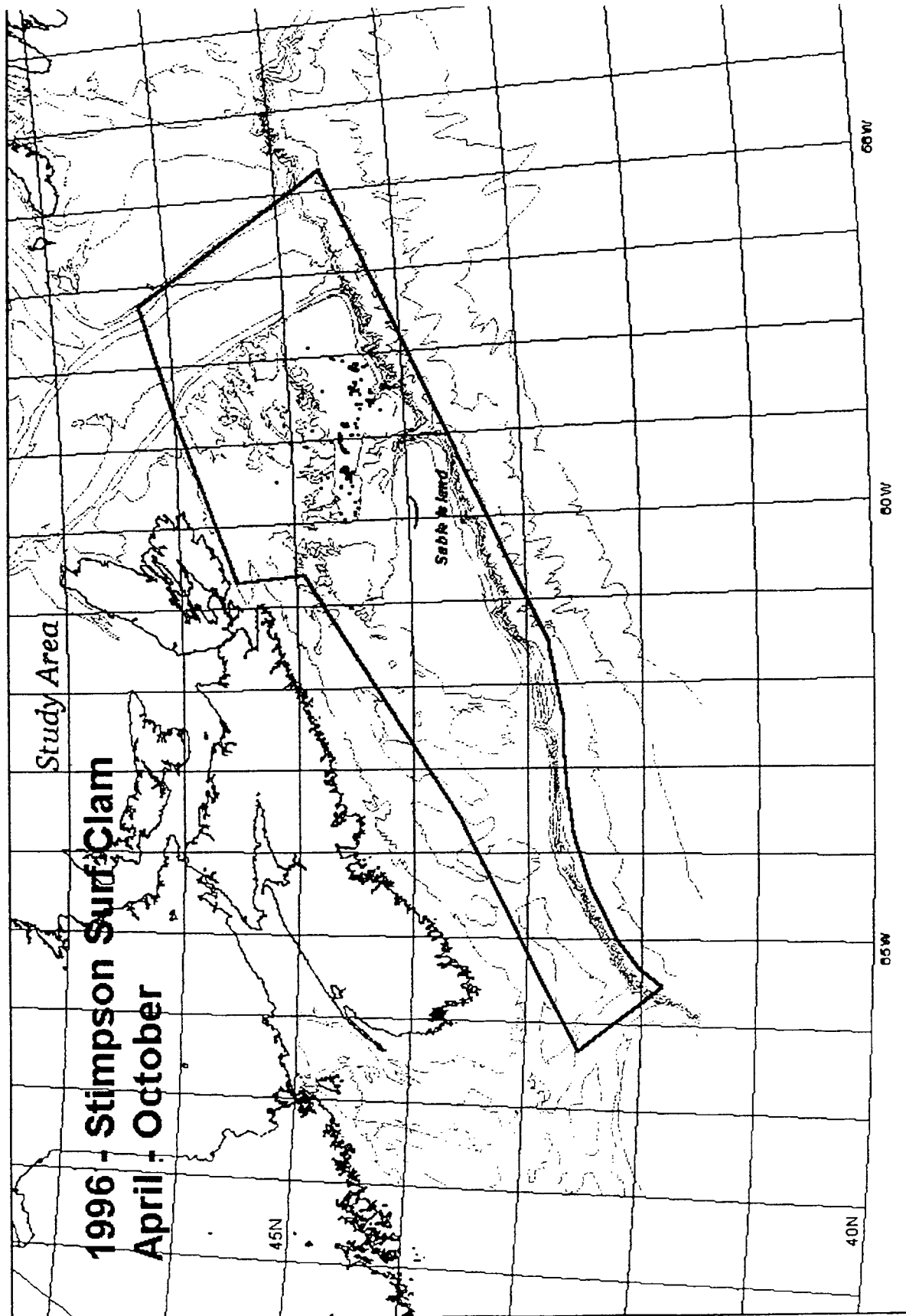
Appendix Figure 2 - 43.   Fisheries catch locations on the Scotian Shelf.
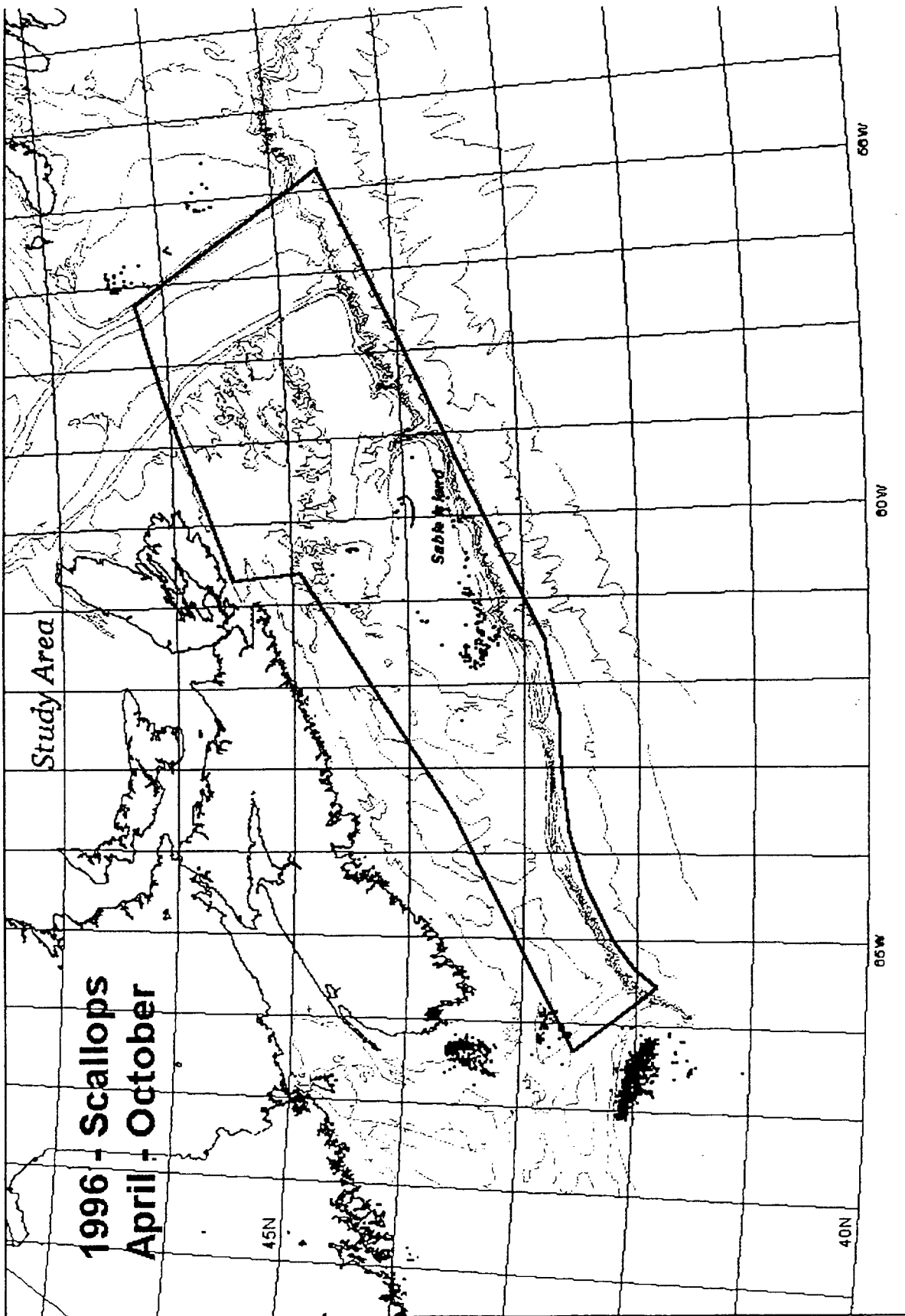
Appendix Figure 2 - 44.   Fisheries catch locations on the Scotian Shelf.

1996 - April - October
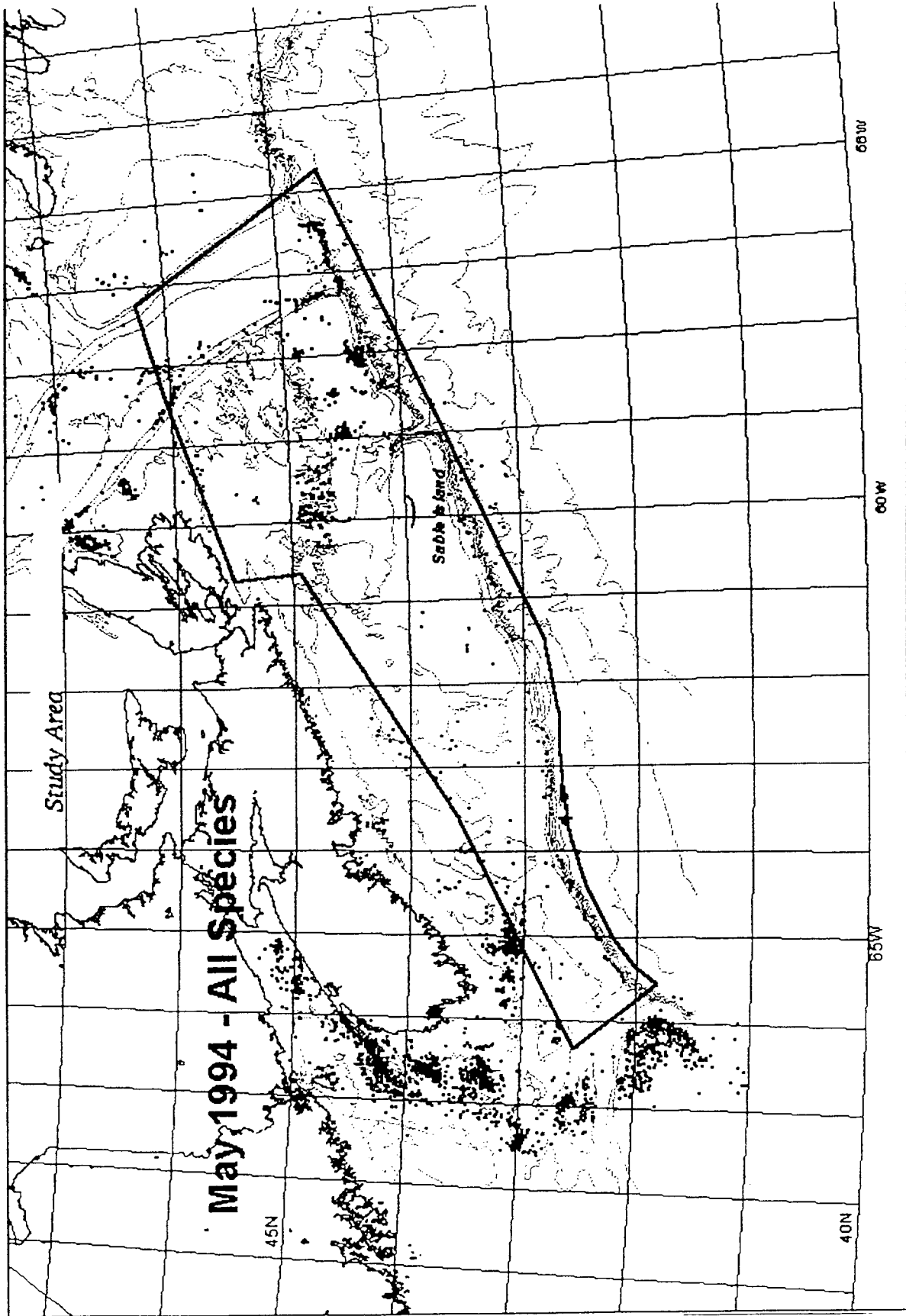Other Mollusc and Crustacean Species

Study Area

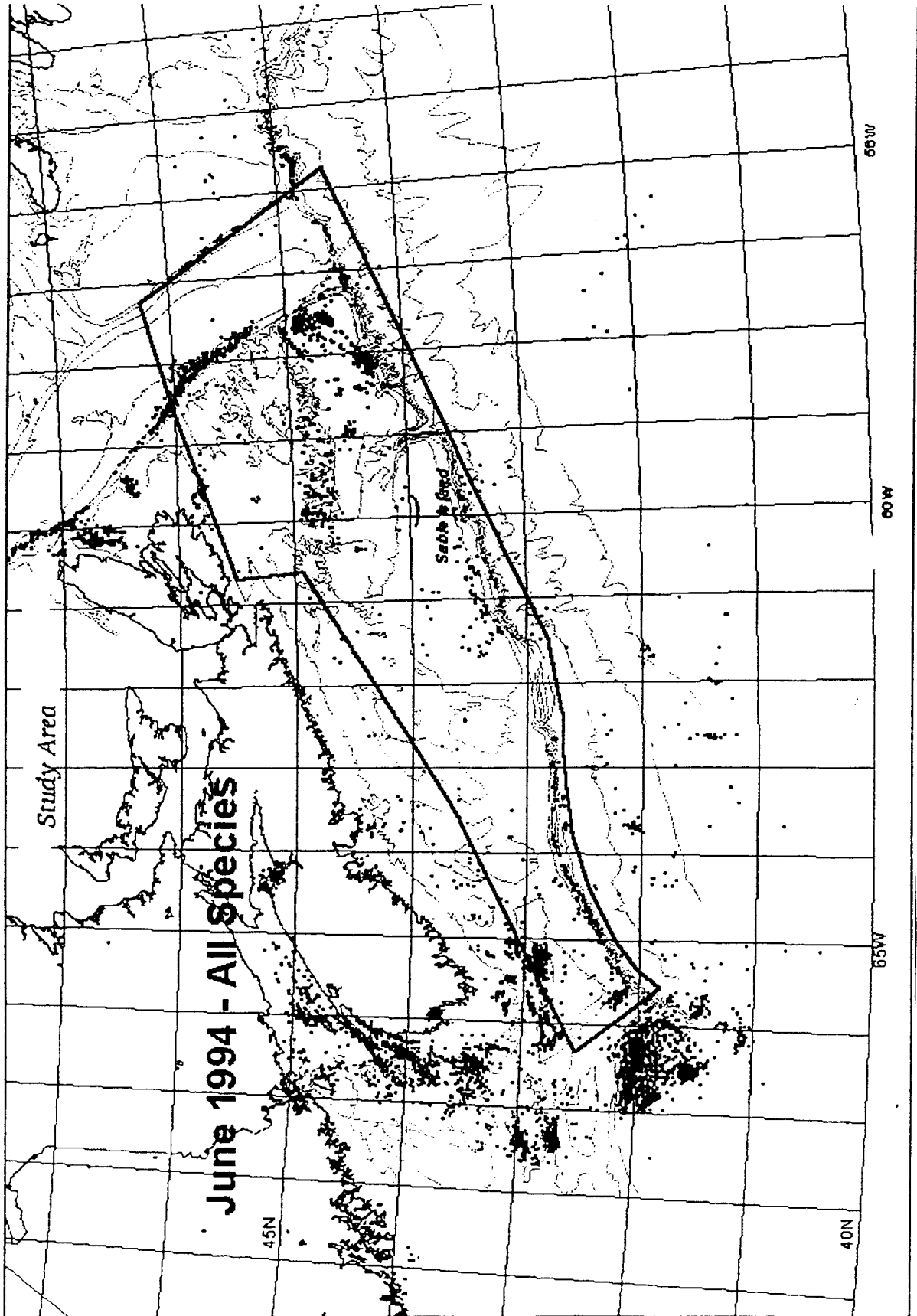Appendix Figure 2 - 45.   Fisheries catch locations on the Scotian Shelf.

Appendix Figure 2 - 46. Fisheries catch locations on the Scotian Shelf.

Appendix Figure 2 - 47.   Fisheries catch locations on the Scotian Shelf.

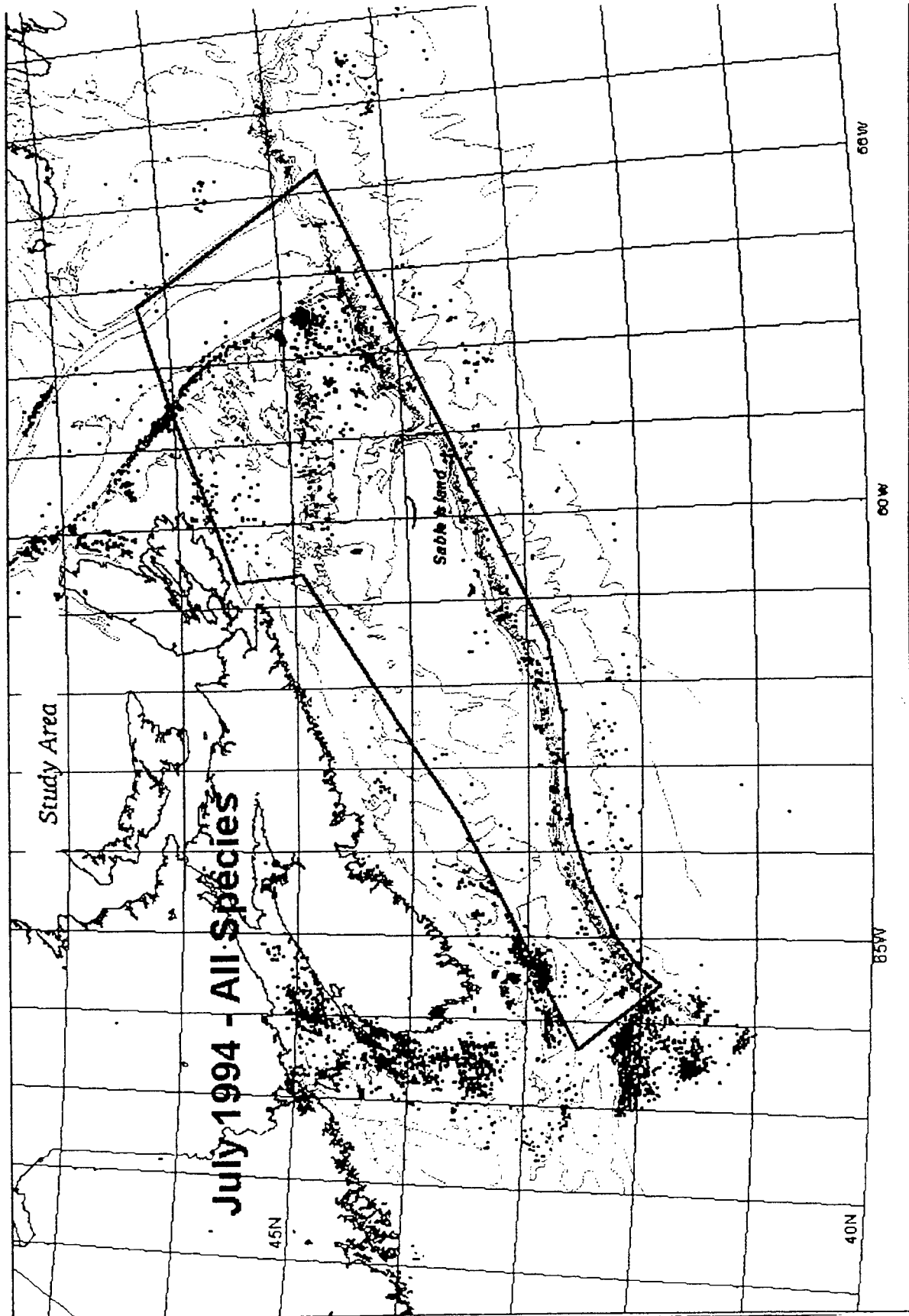Appendix Figure 2 - 48.   Fisheries catch locations on the Scotian Shelf.

Appendix Figure 2 - 49.   Fisheries catch locations on the Scotian Shelf.

Appendix Figure 2 - 50.   Fisheries catch locations on the Scotian Shelf.

Appendix Figure 2 - 51.   Fisheries catch locations on the Scotian Shelf.

Appendix Figure 2 - 52.   Fisheries catch locations on the Scotian Shelf.

Appendix Figure 2 - 53.   Fisheries catch locations on the Scotian Shelf.

Appendix Figure 2 - 54.   Fisheries catch locations on the Scotian Shelf.
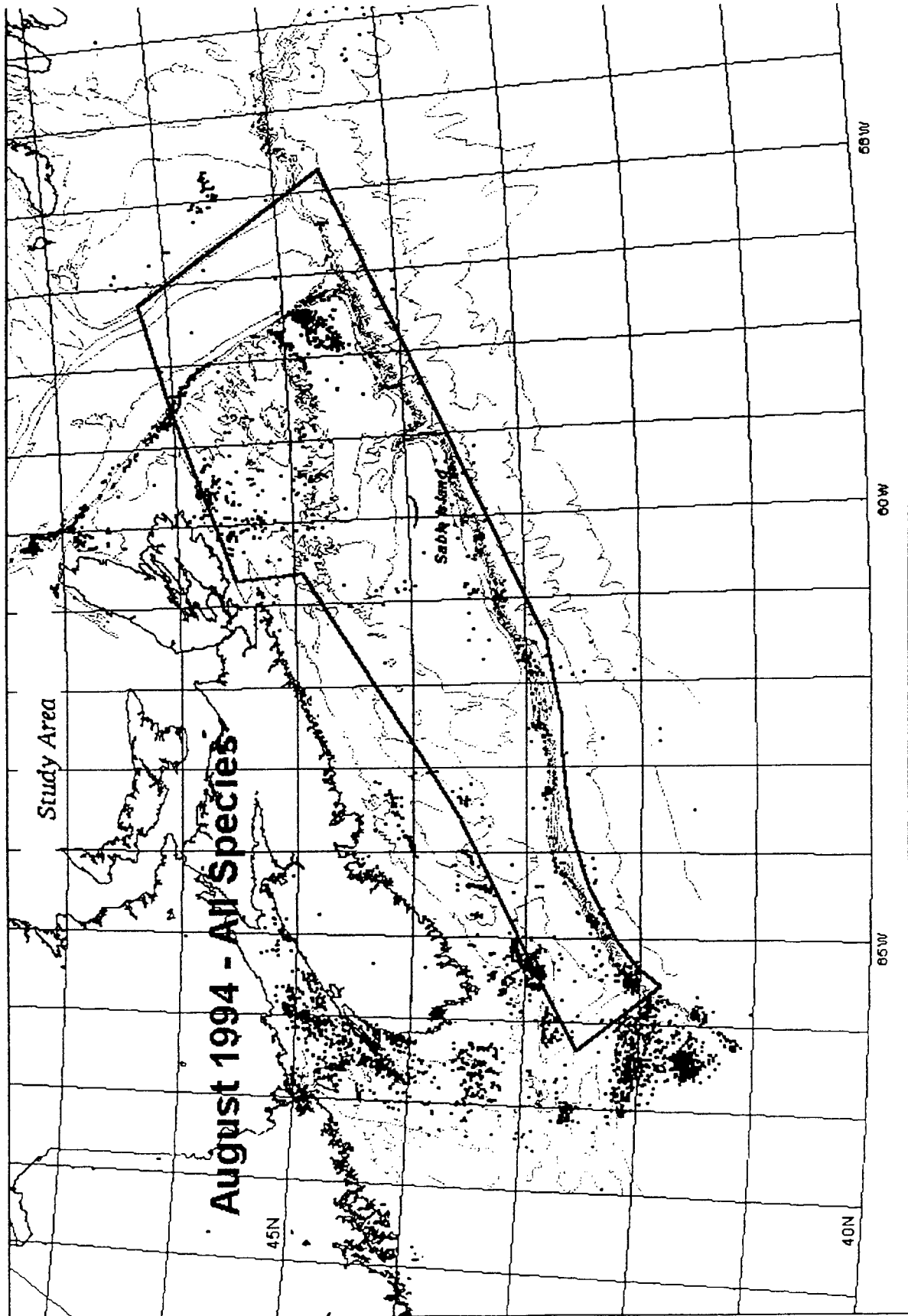
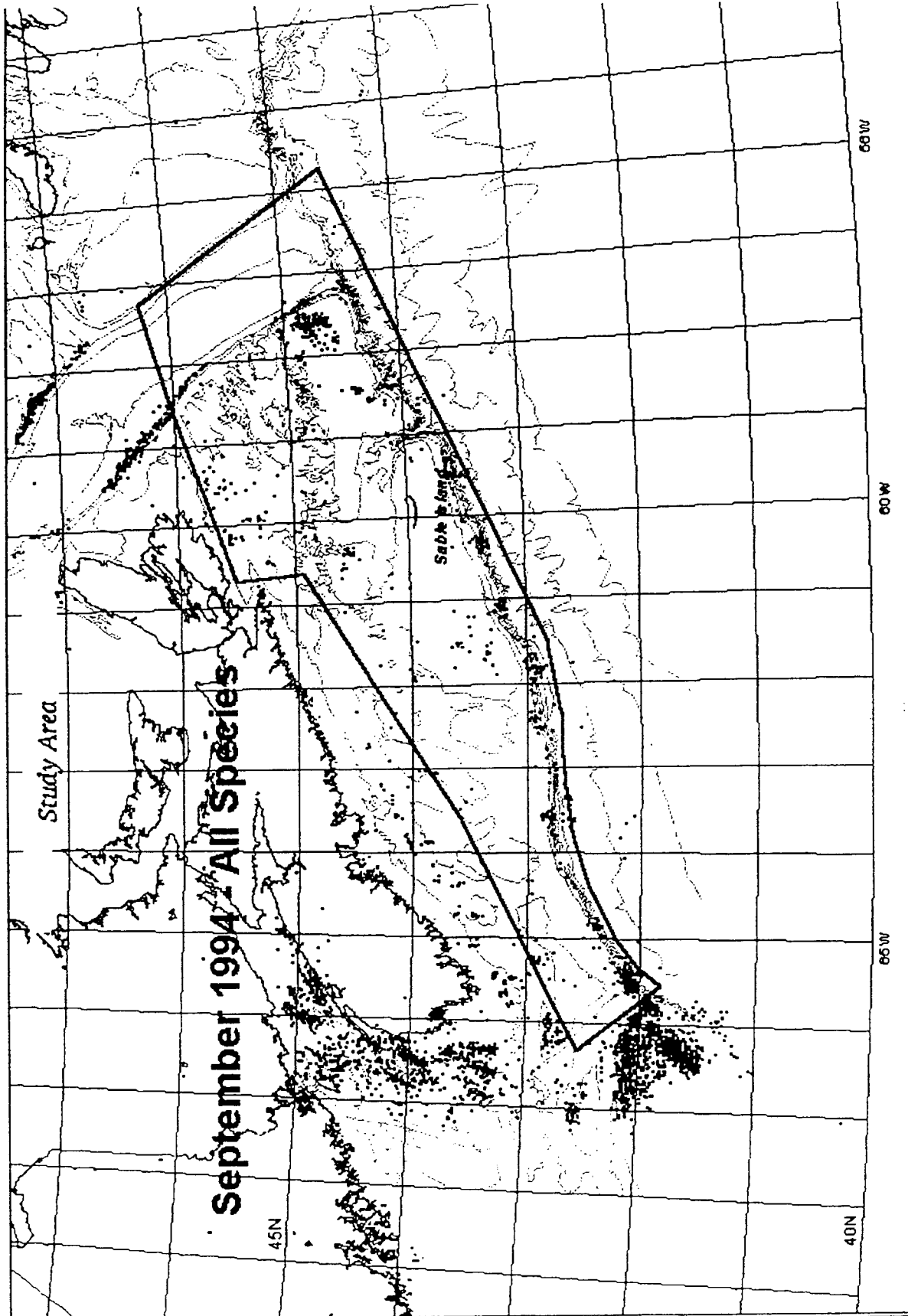Appendix Figure 2 - 55.   Fisheries catch locations on the Scotian Shelf.

Appendix Figure 2 - 56.   Fisheries catch locations on the Scotian Shelf.

Appendix Figure 2 - 57.　Fisheries catch locations on the Scotian Shelf.

Appendix Figure 2 - 58.   Fisheries catch locations on the Scotian Shelf.

June 1993 - All Species

Study Area

Sable Island

45N

40N

65W

60W

58W

Appendix Figure 2 - 59.   Fisheries catch locations on the Scotian Shelf.
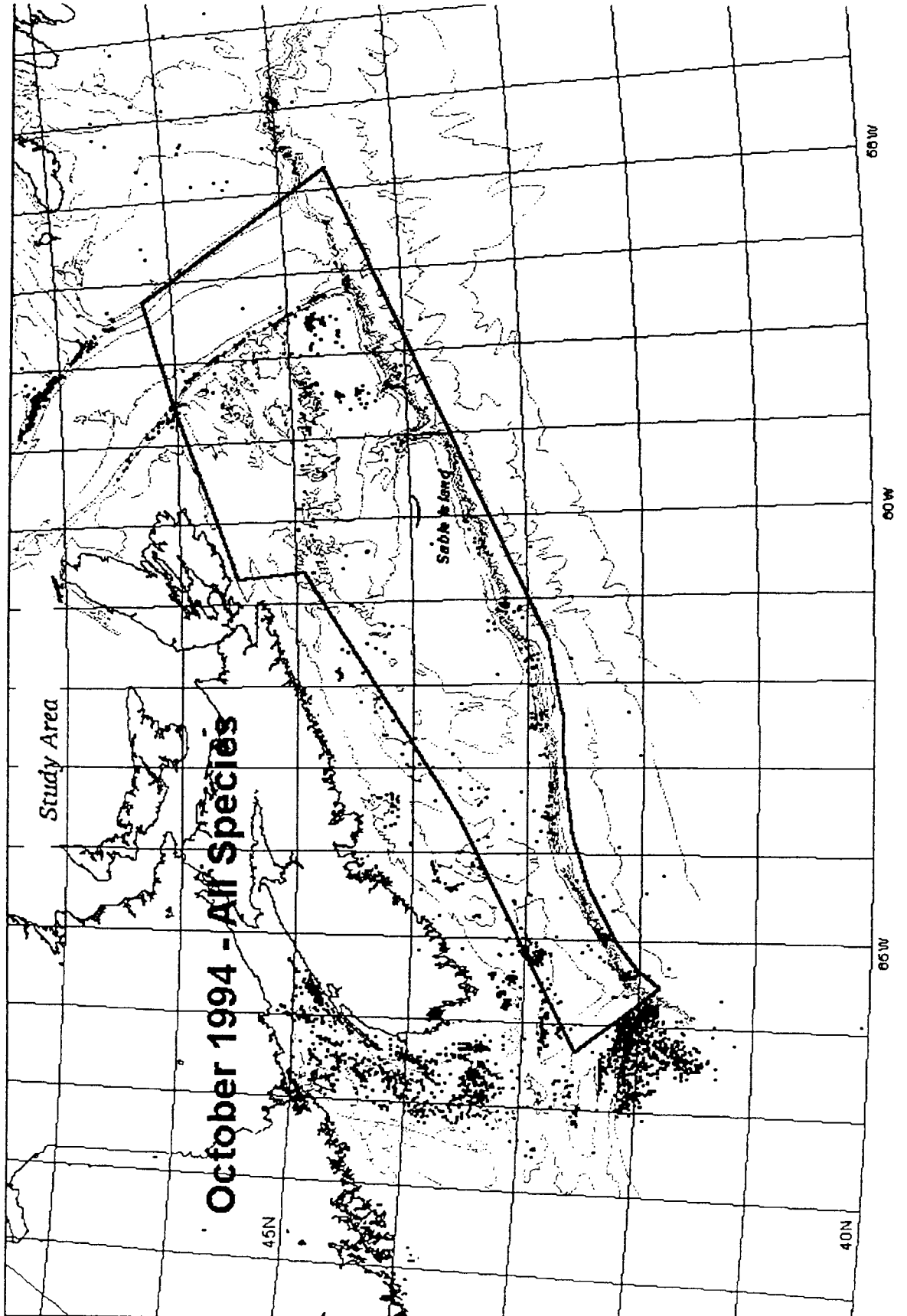
Appendix Figure 2 - 60.   Fisheries catch locations on the Scotian Shelf.

Appendix Figure 2 - 61.   Fisheries catch locations on the Scotian Shelf.
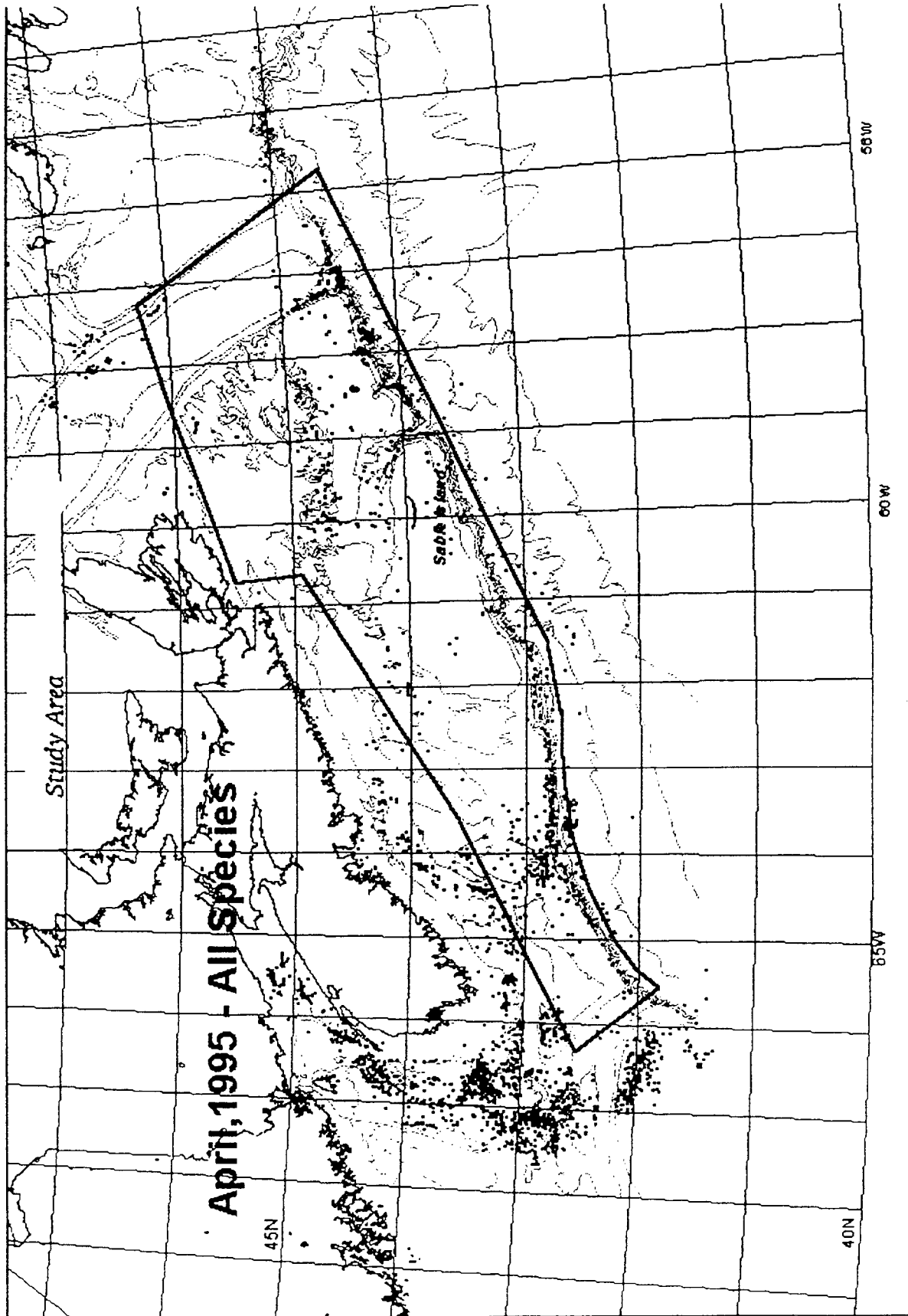
Appendix Figure 2 - 62.   Fisheries catch locations on the Scotian Shelf.

Appendix Figure 2 - 63.   Fisheries catch locations on the Scotian Shelf.

Appendix Figure 2 - 64.   Fisheries catch locations on the Scotian Shelf.

May 1994 - All Species

Study Area

Sable Island

45N

40N

65W

60W

58W

Appendix Figure 2 - 65. Fisheries catch locations on the Scotian Shelf.
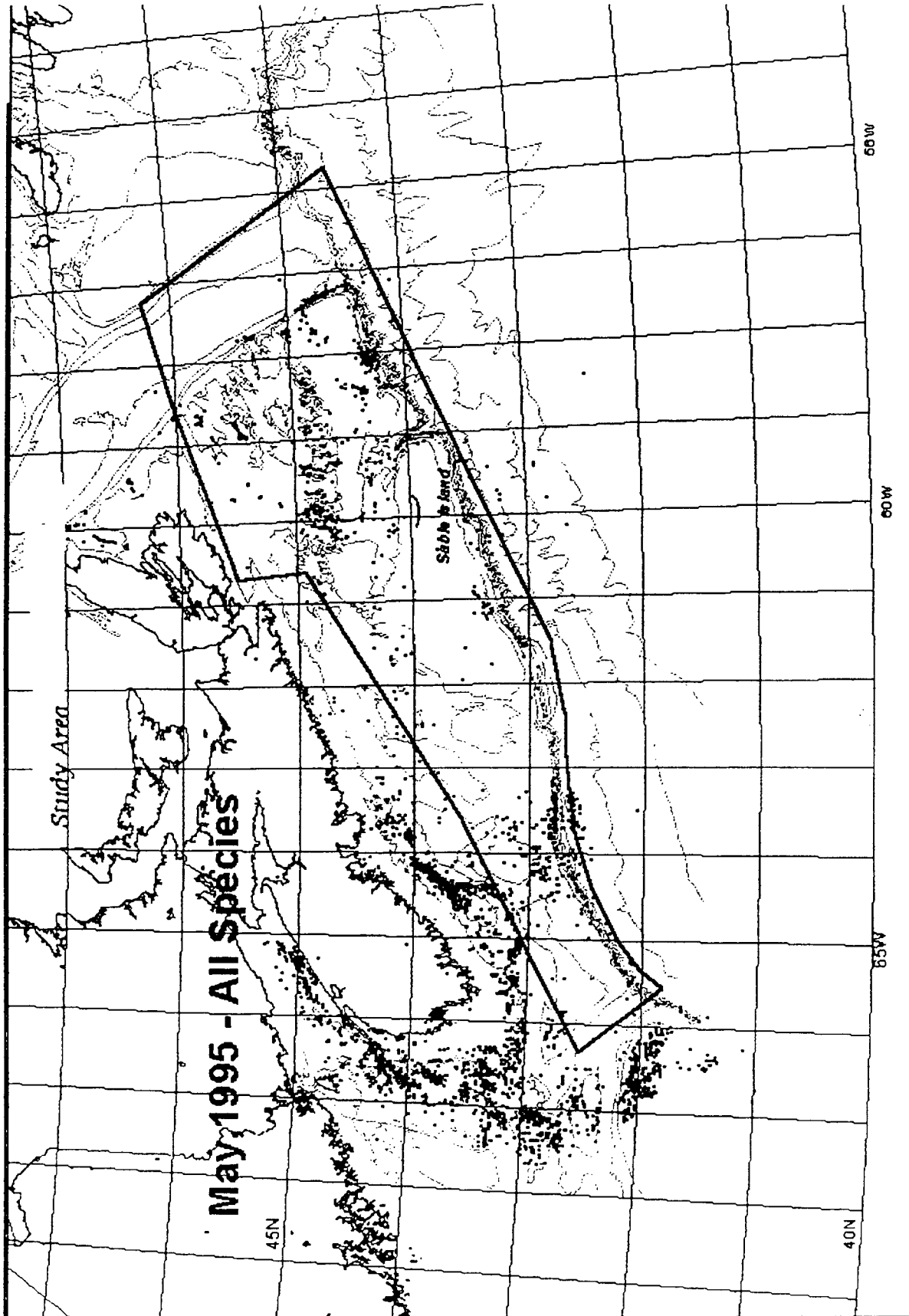
Appendix Figure 2 - 66.   Fisheries catch locations on the Scotian Shelf.

Appendix Figure 2 - 67.   Fisheries catch locations on the Scotian Shelf.

Appendix Figure 2 - 68.   Fisheries catch locations on the Scotian Shelf.

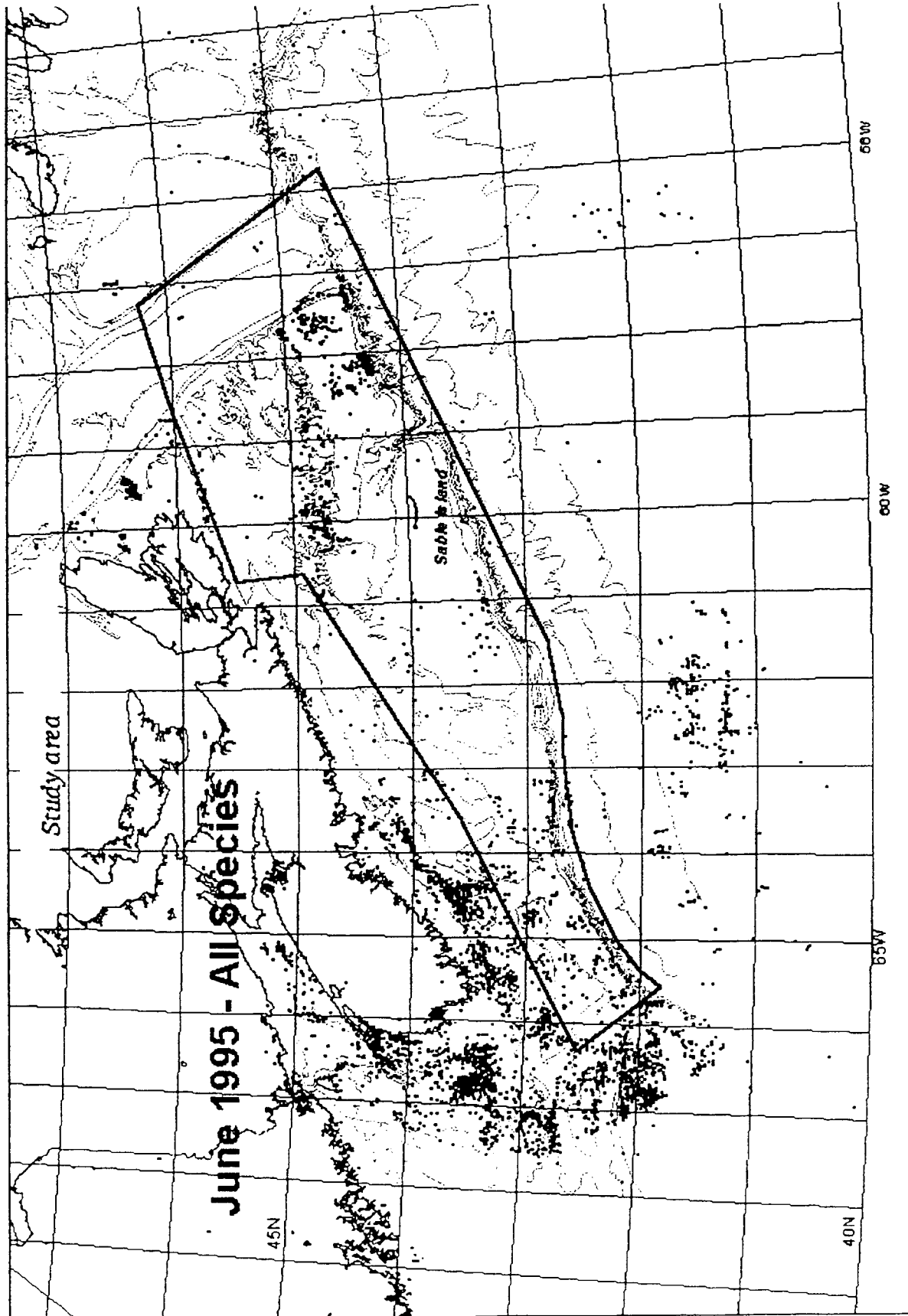Appendix Figure 2 - 69.   Fisheries catch locations on the Scotian Shelf.

Appendix Figure 2 - 70. Fisheries catch locations on the Scotian Shelf.
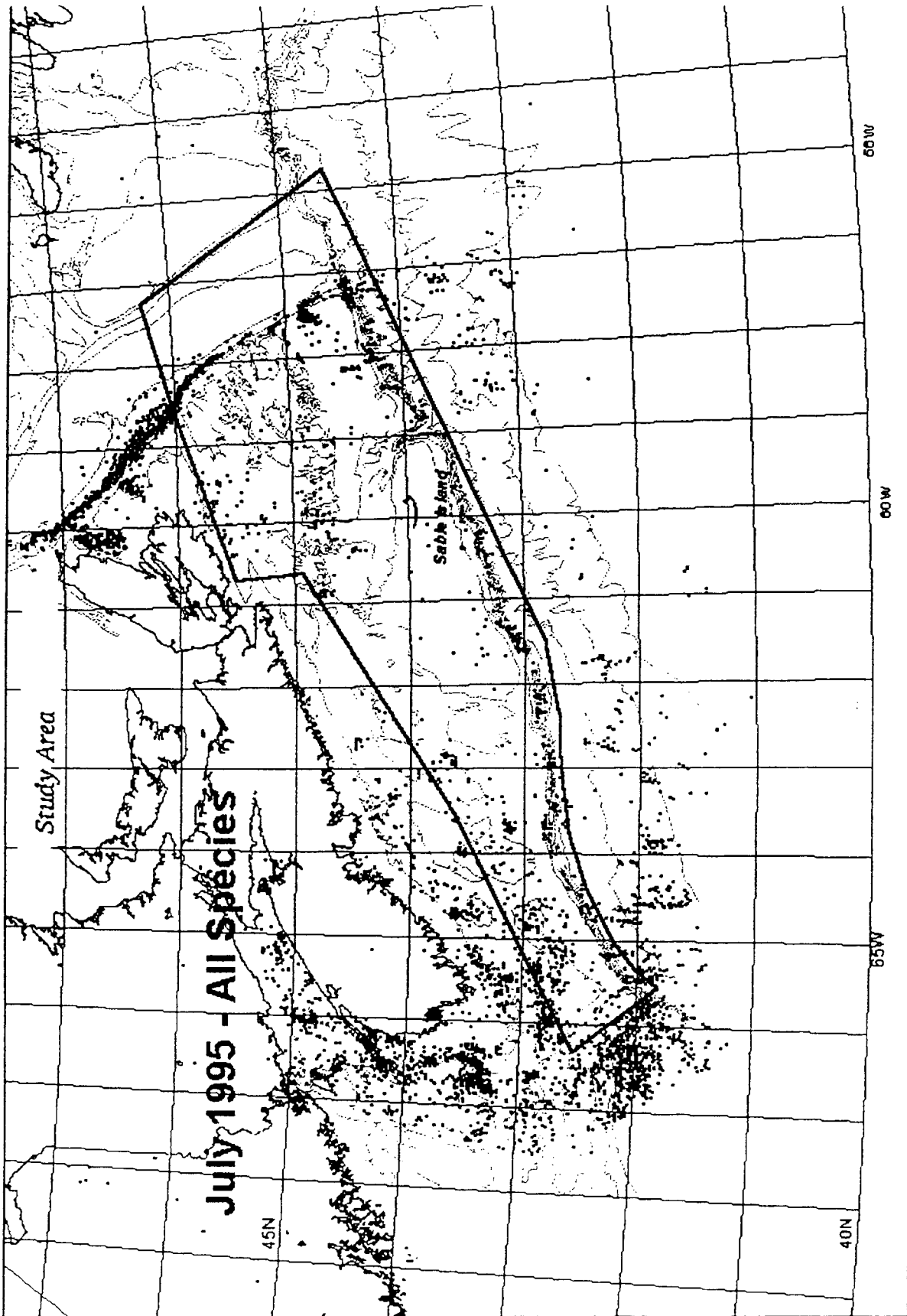
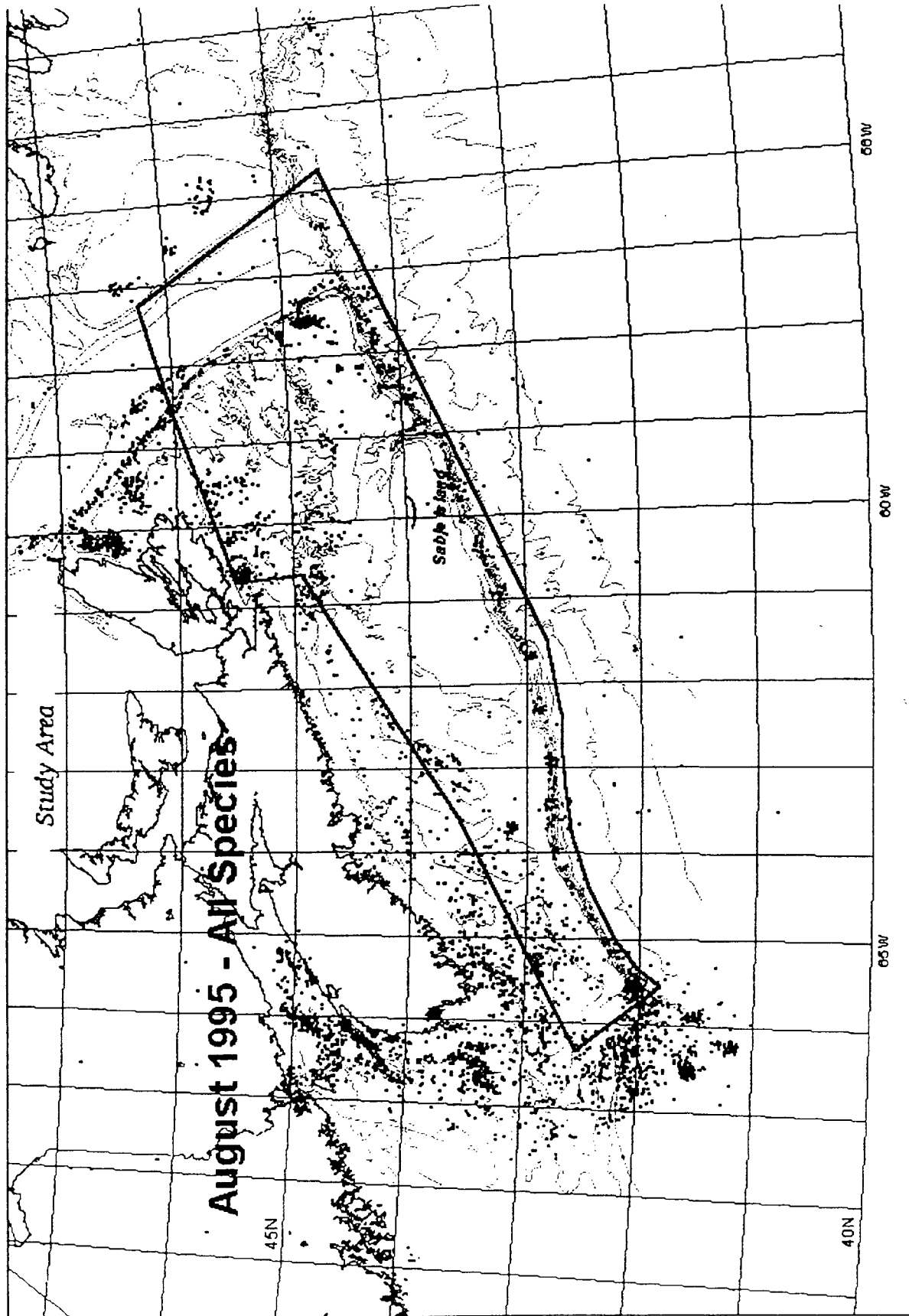Appendix Figure 2 - 71.   Fisheries catch locations on the Scotian Shelf.

Appendix Figure 2 - 72.   Fisheries catch locations on the Scotian Shelf.

Appendix Figure 2 - 73.   Fisheries catch locations on the Scotian Shelf.

Appendix Figure 2 - 74.   Fisheries catch locations on the Scotian Shelf.

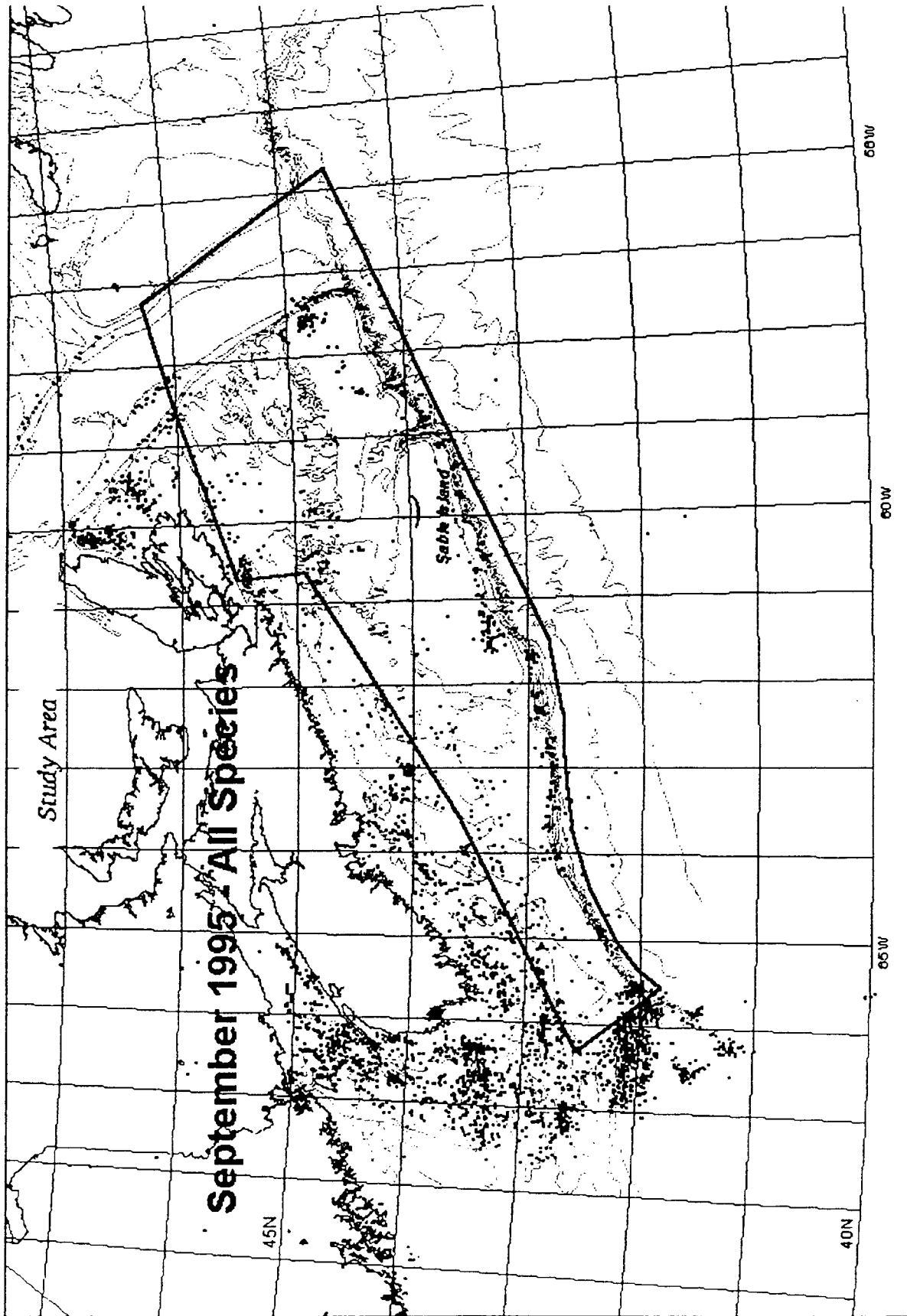Appendix Figure 2 - 75.   Fisheries catch locations on the Scotian Shelf.

Appendix Figure 2 - 76. Fisheries catch locations on the Scotian Shelf.

Appendix Figure 2 - 77.   Fisheries catch locations on the Scotian Shelf.

Appendix Figure 2 - 78.   Fisheries catch locations on the Scotian Shelf.

Appendix Figure 2 - 79.   Fisheries catch locations on the Scotian Shelf.
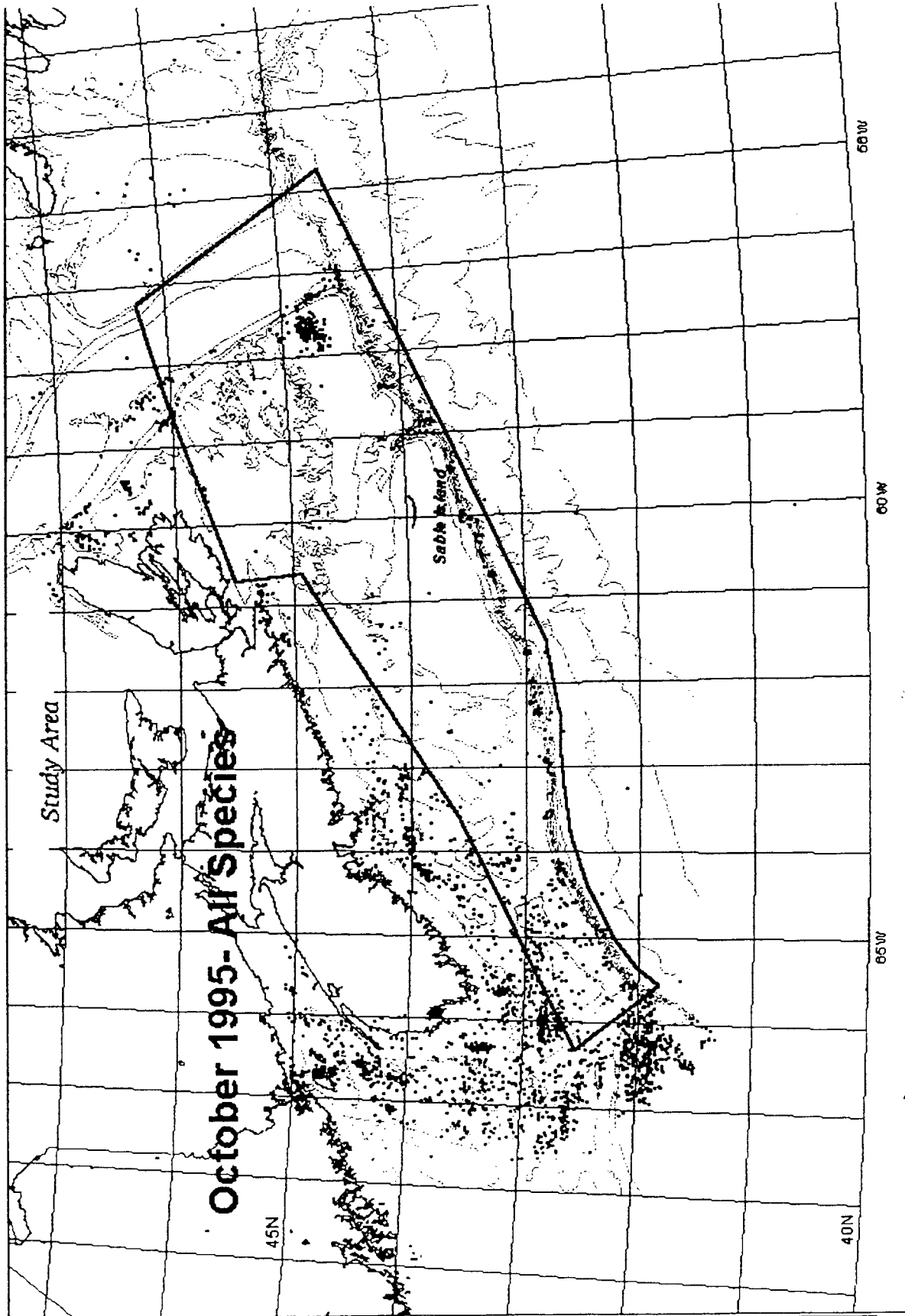
Appendix Figure 2 - 80.   Fisheries catch locations on the Scotian Shelf.

Appendix Figure 2 - 81.　Fisheries catch locations on the Scotian Shelf.

Appendix Figure 2 - 82. Fisheries catch locations on the Scotian Shelf.

Appendix Figure 2 - 83.   Fisheries catch locations on the Scotian Shelf.

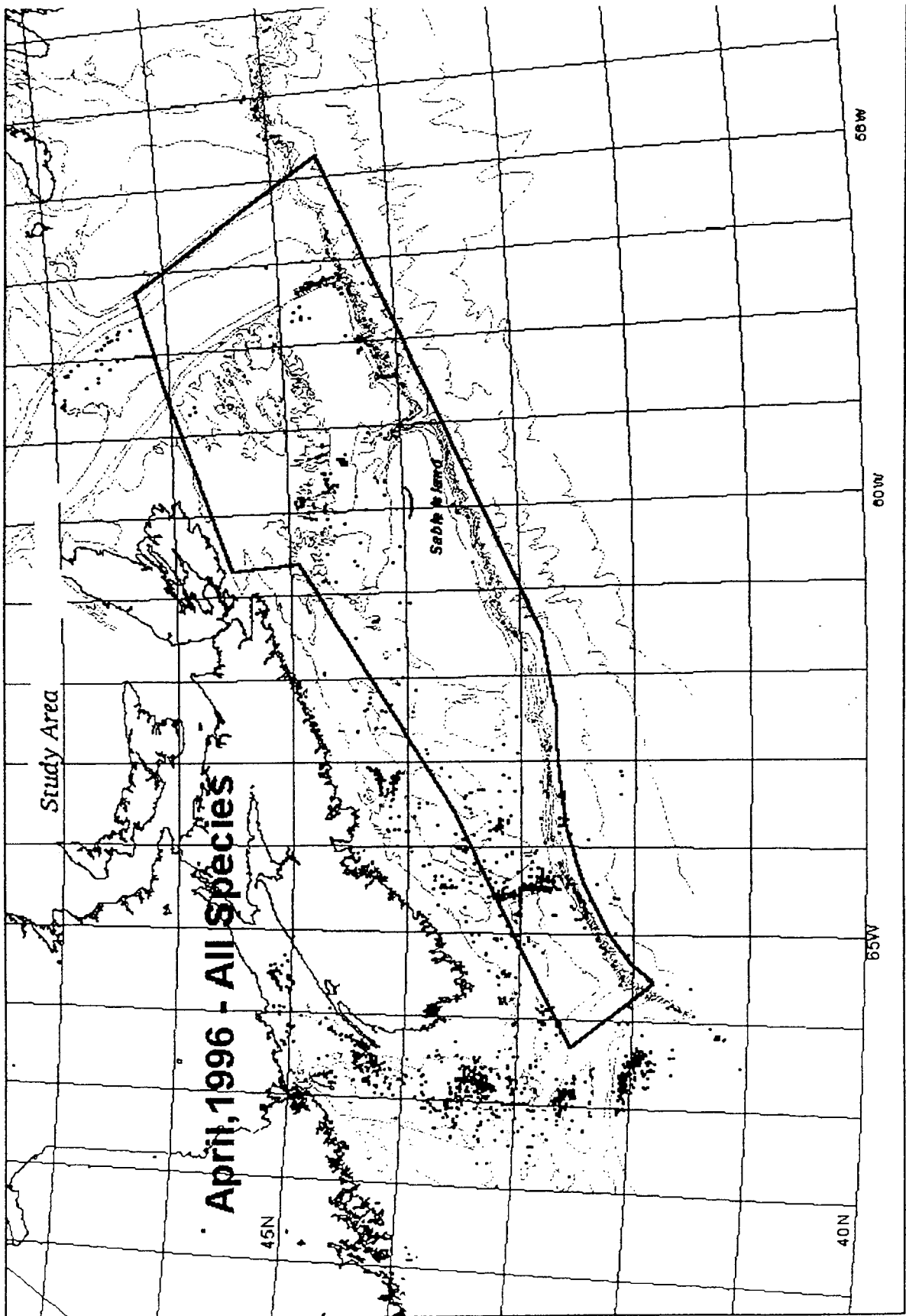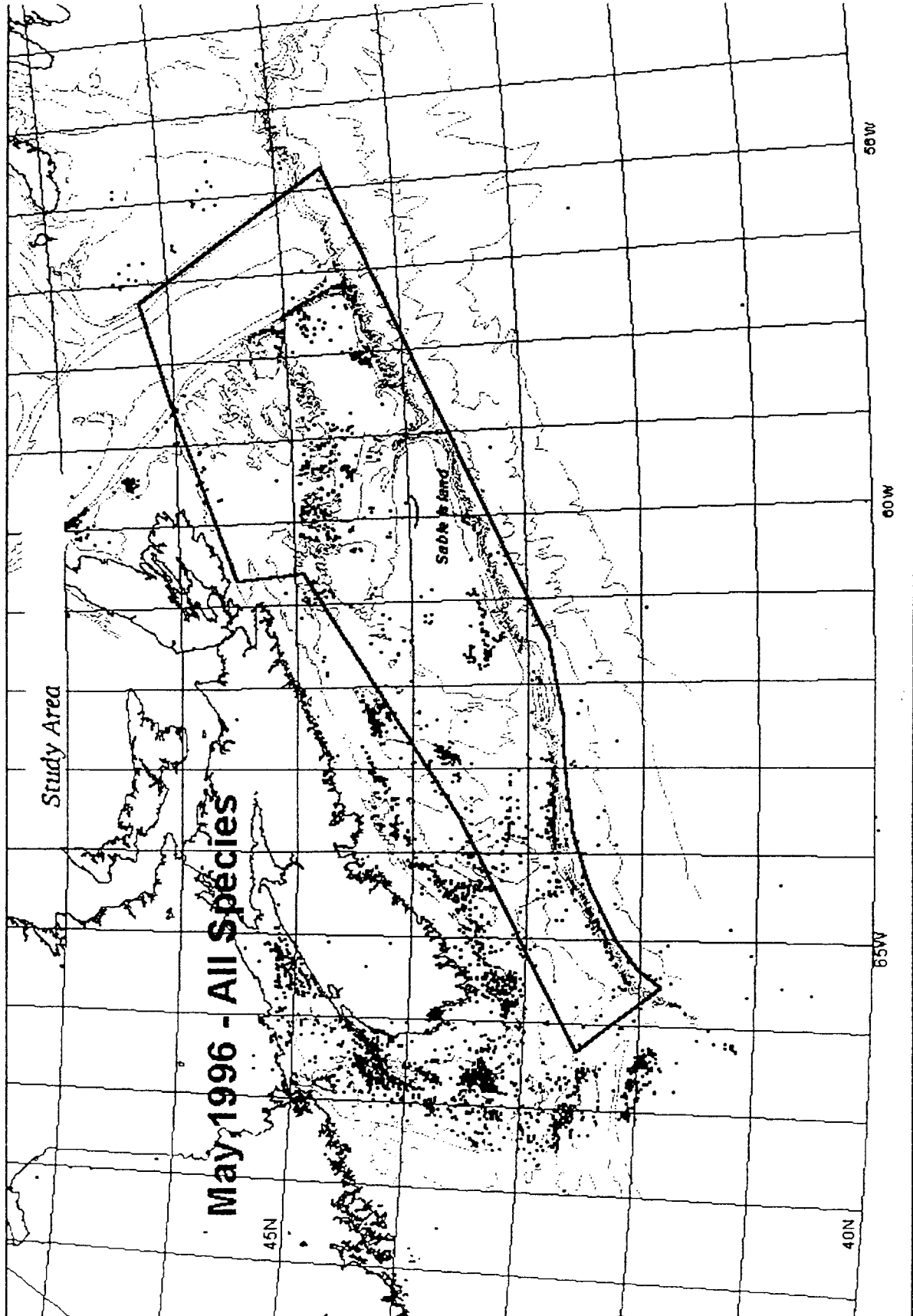Appendix Figure 2 - 84.   Fisheries catch locations on the Scotian Shelf.
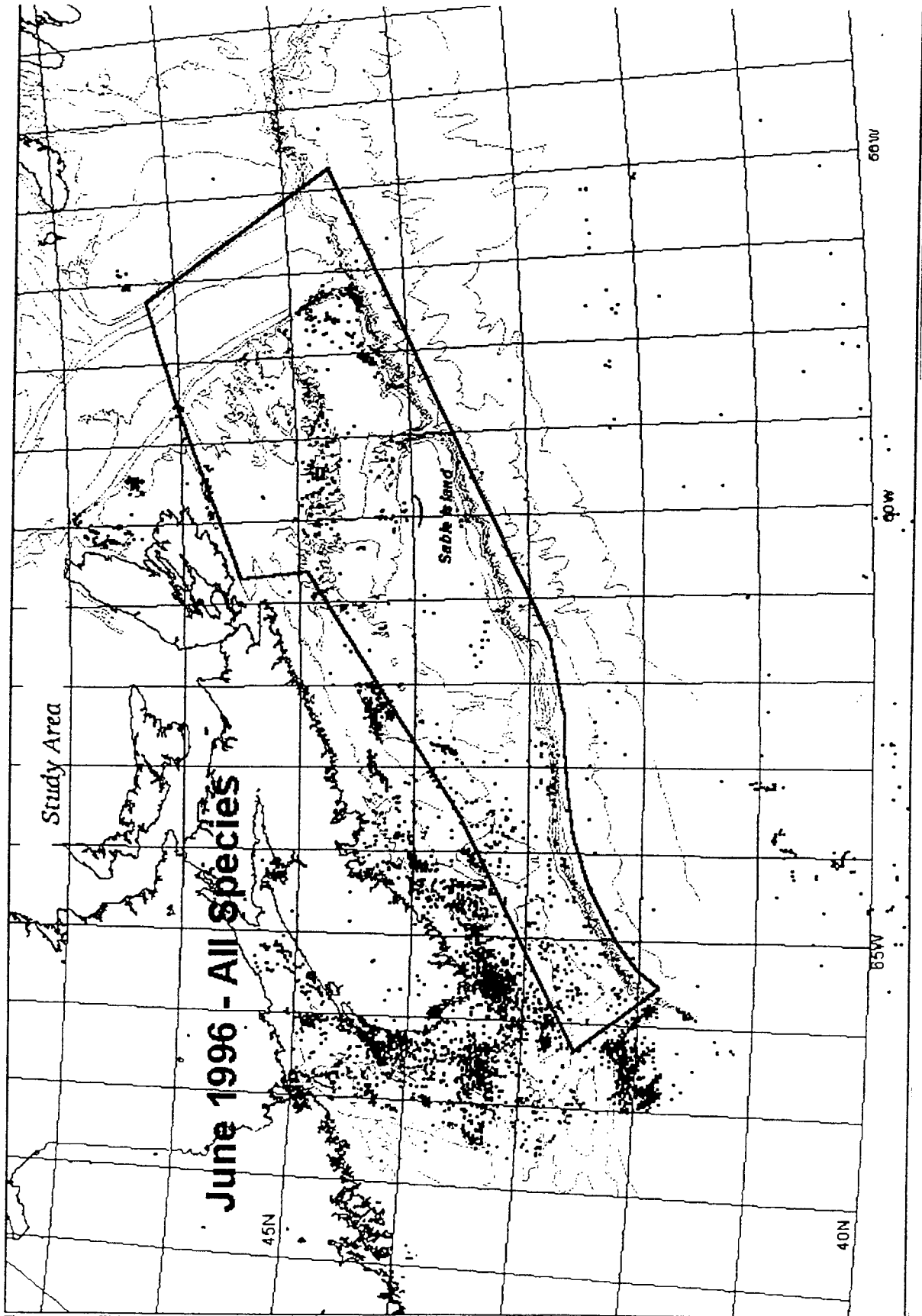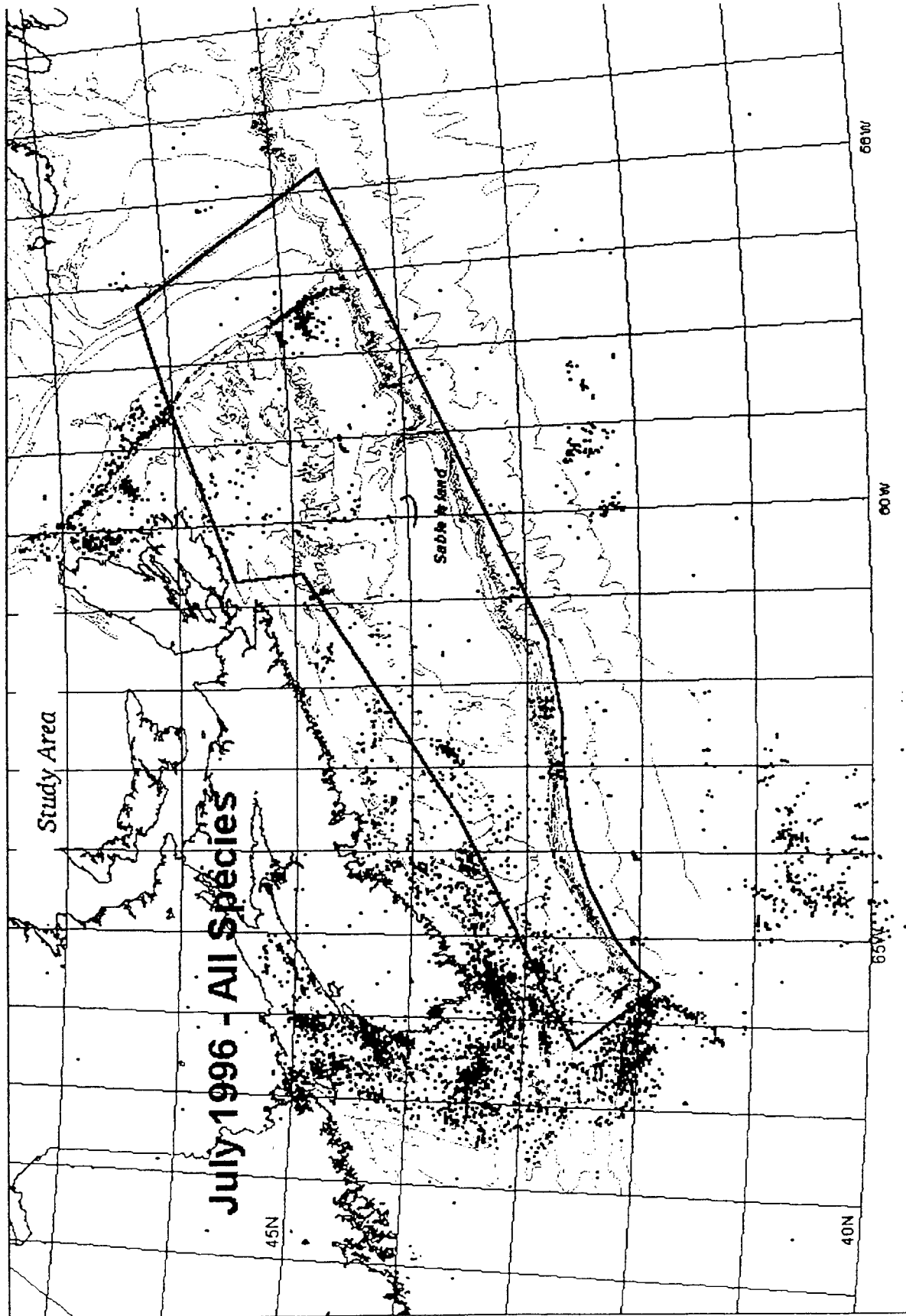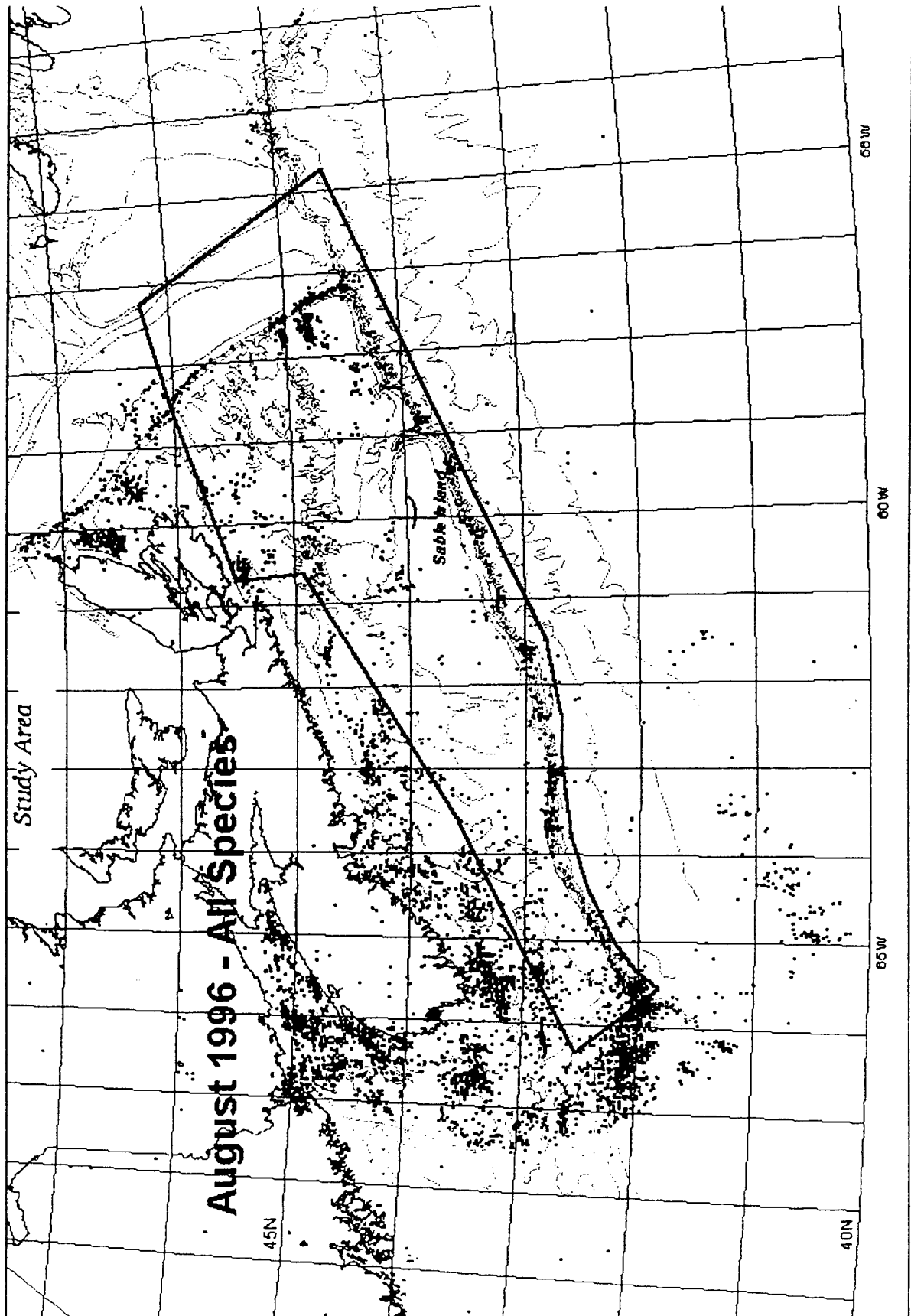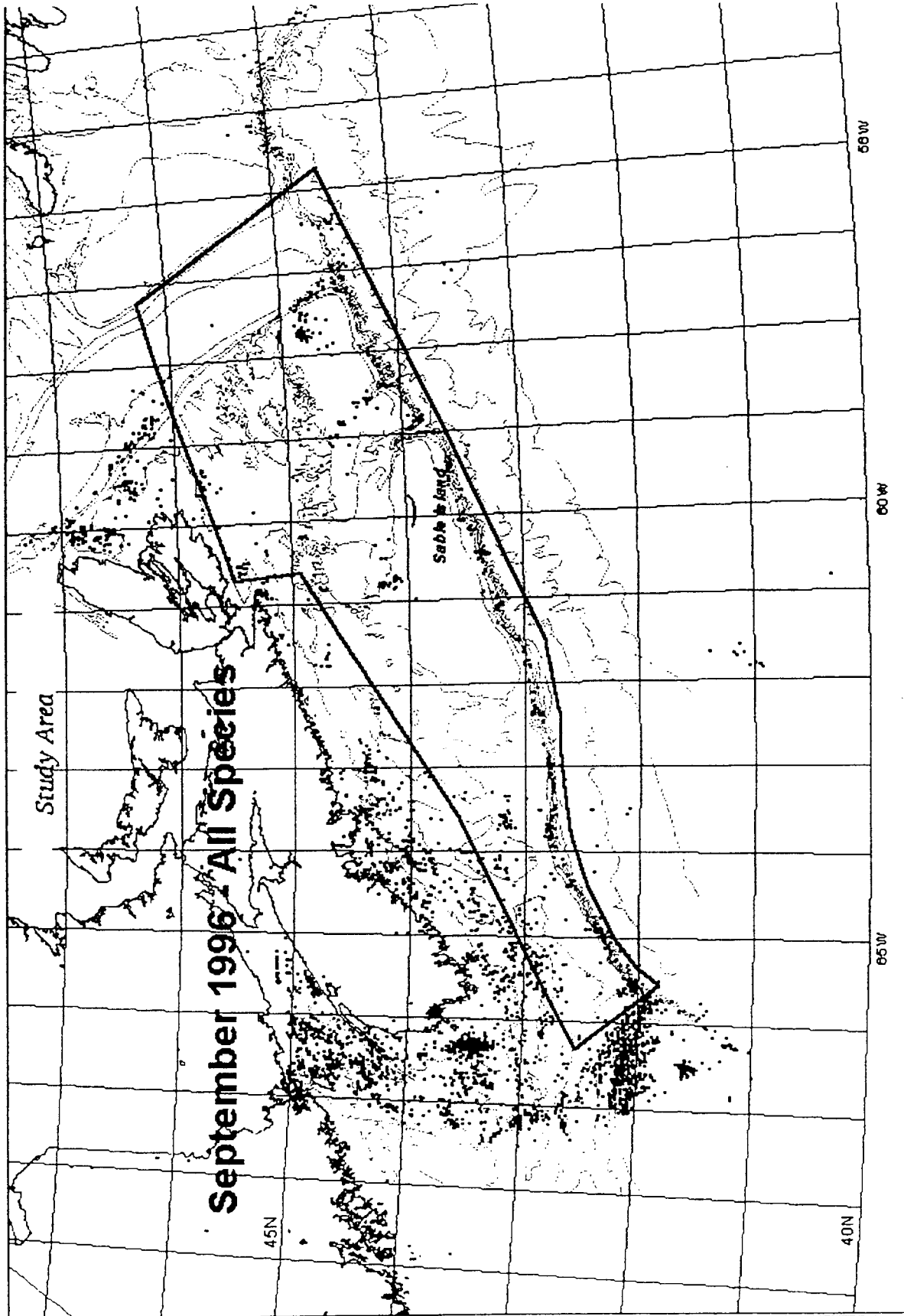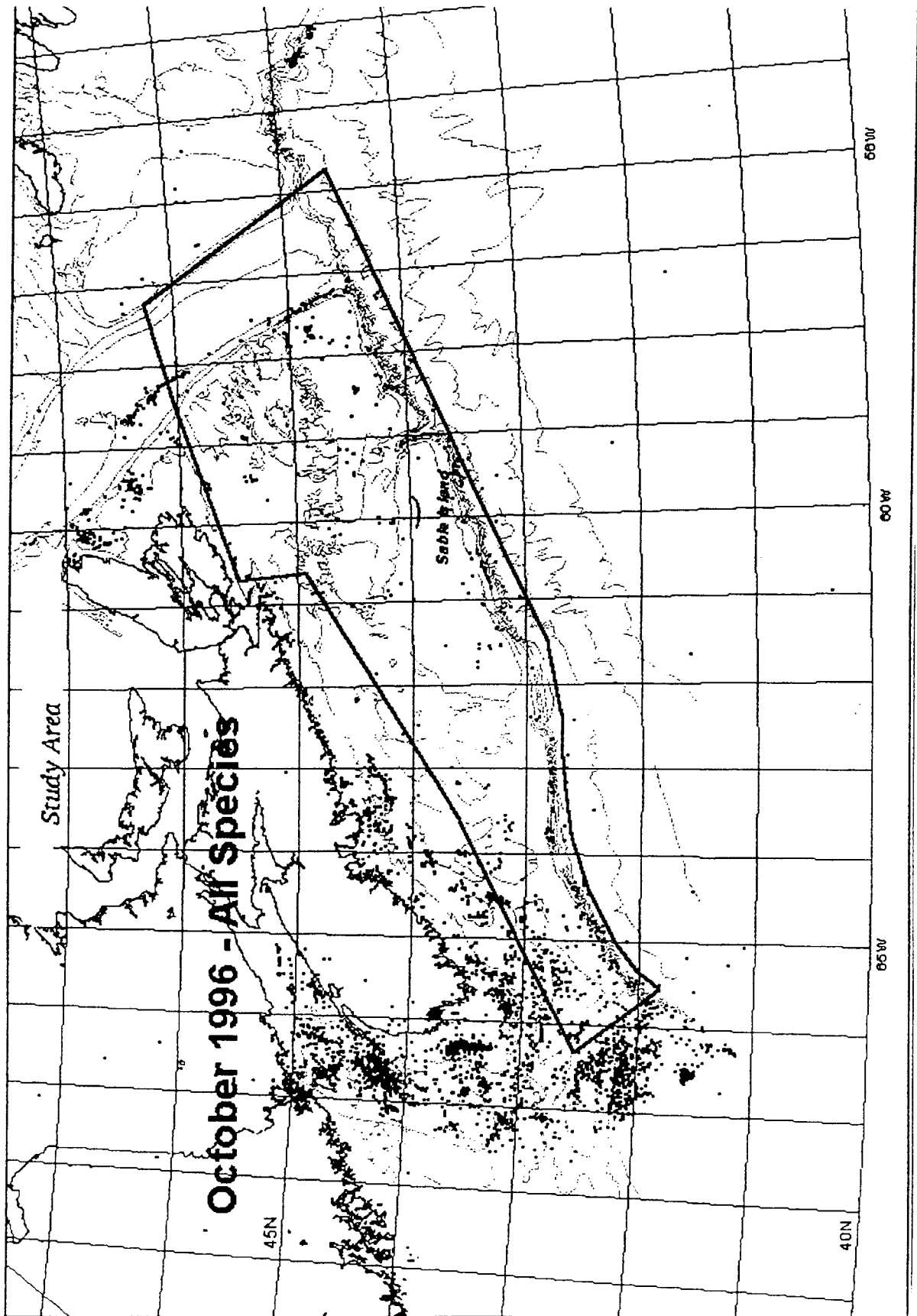
Appendix 3

Fisheries Closed Areas and Closed Seasons
on the Scotian Shelf

prepared by

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King City, Ontario

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INTRODUCTION

Canada's fisheries are managed under a complex array of Acts of Parliament, Orders-in-Council, Regulations, Variation Orders and other instruments. Many of these apply restrictions to specific areas or else permit activities only in certain areas, either for entire years or for some seasons. They thus, directly or indirectly, create fisheries "closed areas" and "closed seasons". Certain of these closures are of interest to environmental managers and to users of Canada's oceans other than the directly-managed fisheries, either as indications of the times and places at which there may be no major fishing activity or else as markers of some recognized times and places of particular sensitivity, such as fish spawning grounds.

This brief report presents a classification and summary of the fisheries closures that apply to the Scotian Shelf, which is defined for present purposes as NAFO Divisions 4VWX (Figure 1: roughly the waters delimited by the Laurentian Channel, Cabot Strait, the coastline of Canada and the Fundian Channel), less Sydney Bight, the Bay of Fundy, that portion of the Gulf of Maine north of the latitude of Cape Sable, all inshore waters immediately adjacent to the coast of Nova Scotia and deep-ocean areas seaward of the continental slope. Details are provided here of the current (1998) extent of, and restrictions applied within, those closures that are of primary importance to interests outside the fisheries. However, this report does not attempt to be a compilation of all the area-based fisheries-management measures applied on the Scotian Shelf. Such a compendium would require a massive, and constantly changing, database and would be of limited relevance other than to fisheries managers themselves.

TYPES OF FISHERIES CLOSURES ON THE SCOTIAN SHELF

There are no areas on the Scotian Shelf that are closed to all types of fishing, even seasonally, with the possible exception of the small exclusion zones (usually 500 metres in radius) around the few offshore oil and gas installations. However, there are a great many areas of the Shelf that are closed to certain types of fishing at certain times, sometimes for partly-biological reasons, sometimes to prevent conflicts among fishermen who use different types of gear and sometimes simply because a particular sector of the fishing industry has temporarily exhausted its quota for certain resource in a certain area. Indeed, there are many fisheries that are only opened on a seasonal basis and many areas in which a fishery might potentially be prosecuted but for which no licences or quotas have been issued, resulting in extensive areas that are not so much "closed" to a particular fishery as "not open"; the onus in fisheries for regulated species being that all areas and seasons are closed unless someone has an appropriate licence (with necessary endorsements and conditions) allowing them to fish.

These many kinds of closures can be summarized as follows:

- Restrictions not related to fisheries management or marine conservation
  Apart from the exclusion zones around offshore oil and gas installations, which apply to all vessels, there are some areas in which all seabed activity, including
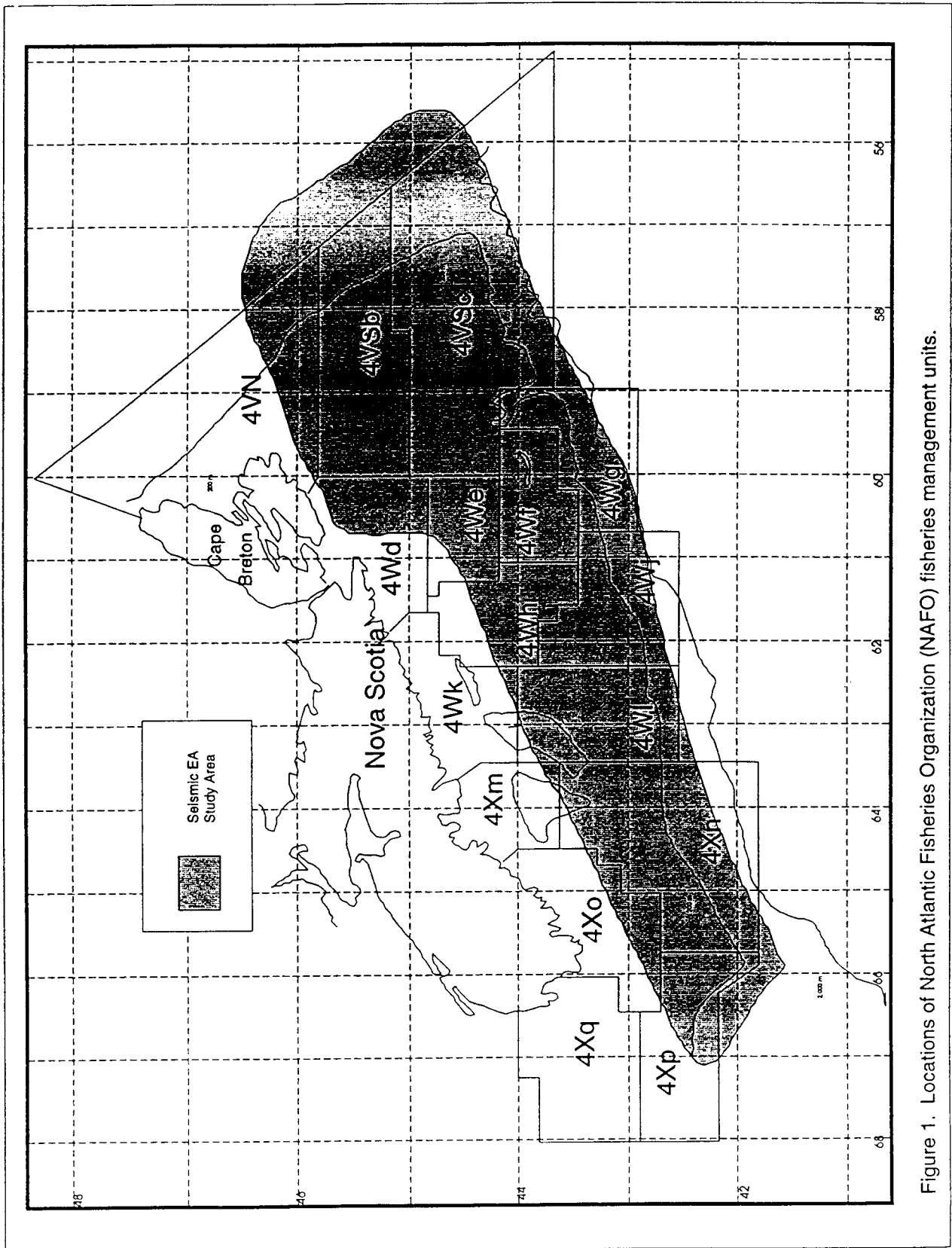
Figure 1. Locations of North Atlantic Fisheries Organization (NAFO) fisheries management units.

bottom fishing, is theoretically restricted. Those include former explosives dumping areas and narrow corridors for telecommunications cables. In coastal waters near the major ports, there are traffic separation arrangements which serve to restrict certain types of fishing, particularly by larger boats. Whether any of these, apart from the offshore exclusion zones, actually restrict fishing activity is debatable.

- Whale Sanctuaries

  Two areas on the Scotian Shelf, plus a third in the Bay of Fundy (Appendix 1), have been designated by the Department of Fisheries & Oceans as "Whale Sanctuaries". That designation is promulgated in the Canadian Coast Guard's *Notices to Mariners Annual Edition* each year. The Sanctuaries are, however, only protected by voluntary guidelines designed to reduce the risk of impacts between ships, including fishing vessels, and whales. There are no mandatory, area-specific limitations. (The *Marine Mammals Regulations* under the Fisheries Act apply throughout Canada's waters, though they might be more strictly interpreted in the event of an infringement within a Sanctuary.) The guidelines may serve to reduce fishing activity within the Sanctuaries but there is little evidence of any such effect.

- Haddock Nursery Area

  There are only two areas on the Scotian Shelf that resemble archetypal fisheries "closed areas" in that they are subject to year-round closures to all kinds of fishing for a particular class of resource, with that closure being intended as indefinite in duration. The larger of the two such areas is the "Haddock Box" or haddock nursery area covering Western and Emerald banks. It is currently closed to all forms of groundfish fishing, while new exploratory or developmental fisheries are also sometimes excluded from it by the terms of the licences issued for such activity. However, the long-established fisheries for resources other than groundfish are still free to work in the nursery area and some, most notably the offshore scallop fishery, do so.

  The haddock nursery area is considered in more detail belo

- Lobster Fishing Area 40

  The other near-archetypal "closed area" is Lobster Fishing Area 40 ("LFA40"), a roughly rectangular patch on the northern part of Browns Bank which is closed year-round to all lobster fishing. It remains open to most other kinds of fishing, except when the same area is covered by other restrictions such as the Browns Bank haddock spawning closure (see below). LFA40 is also discussed below.

- Inshore Year-Round Closures

  There may be some small areas in inshore waters, and hence outside the Scotian Shelf as here defined, that are likewise indefinitely closed year-round to fishing for one or another resource, with that closure having a conservation objective (rather than one related to marine traffic or human health concerns). However, no attempt

has been made, during the preparation of this report, to confirm the existence of such areas since they are outside its offshore focus.

There certainly are many small coastal areas that are permanently closed to mollusc harvesting as a consequence of concerns over contamination and its implications for the health of the (human) consumer, while yet more such areas are closed seasonally for the same reason. Such closures are not considered further here.

- Browns and Georges Bank Haddock Spawning Closures

    The principal seasonal closure on the Scotian Shelf of fisheries that are otherwise open concerns an area on Browns Bank that is closed to all groundfish fishing in late winter and spring of each year. Beyond the limits of the Scotian Shelf, there is a closely-similar seasonal groundfish closure on Georges Bank. Both originated in the 1970s as haddock spawning closures and they are expected to continue indefinitely (though seasonally). These closures do not apply to established non-groundfish fisheries, such as the offshore scallop fishery which drags intensively in the closed areas when groundfish boats are excluded. Nor of course are the areas in question closed to groundfish fishing outside of the closed season.

    These haddock spawning closures are considered in more detail below.

- 4Vsb Groundfish Closure

    A further little-known seasonal groundfish closure exists on the eastern Scotian Shelf in a part of NAFO Subdivision 4Vs known as "4Vsb". This closure would be functionally identical to the haddock spawning closure on Browns Bank were it not that most of the groundfish fisheries in Subdivision 4Vs were reduced to zero quotas in 1993 only shortly after the 4Vsb closure was introduced. However, this functional similarity overlies a very different objective: where the haddock spawning closures were designed to protect the resource, the 4Vsb closure was strictly intended to control which fishing interests had access to cod spawned in the Gulf of St. Lawrence.

    It too is considered in more detail below.

- Limited Fishing Seasons

    The complex groundfish fisheries, involving many different fleets, gear types and target species with fishing spread over various grounds, tend to be managed (conceptually, if not legally) on the basis of being open unless they are closed, leading to notions such as the haddock spawning closures. Many other Scotian Shelf fisheries, however, have limited open seasons, with the specific openings in different areas often, though not always, occurring on different dates. In some cases, the dates of these openings are a matter of annual agreement between the fishing industry and the Department of Fisheries & Oceans, making them nothing more than ephemeral fisheries-management controls. Others, however, are long-established and relatively constant, producing a recognizable patchwork of "open areas/seasons" for various

resources, which implies that there are also "closed" areas and seasons for the fisheries concerned. Whether the latter are best regarded as fisheries closures or simply periods and places where a specific fishery is "not open" depends on the intent behind the limitation on the fishing season – if it is to prevent fishing during a spawning season, one might reasonably see a "closure", whereas if it is simply to control the total fishing effort that the fleet can exert during a year, it would be more appropriate to see the lack of an open period.

The system of Lobster Fishing Areas ("LFAs") and their various open seasons is the best developed of these area-based seasonal opening arrangements on the Scotian Shelf. It is discussed in more detail below, along with the equivalent system for the management of the snow crab fishery.

There is a rather similar system of Scallop Fishing Areas, though most of them lie in the Bay of Fundy, Gulf of Maine or Gulf of St. Lawrence. On the Scotian Shelf, the scallop fishery is carried out either by very small boats working close to shore or else by the offshore fleet working beyond 12 miles from land. The latter is not subject to area-based seasonal management, only to area-specific catch quotas. Some of the minor crab fisheries (i.e. for species other than snow crab) do have lobster-like arrangements of areas and seasons, as do such experimental fisheries as that for whelks, while many of the finfish fisheries are subject to seasonal limitations that differ among areas.

No attempt is made here to compile all of the areas and seasons invoked in the management of every Scotian Shelf fishery. However, as an example of the sorts of complexities that can arise and as a contrast with the arrangements for the lobster fishery, area-based aspects of the 1998 Integrated Management Plan for the swordfish fishery are examined below.

- Gear-Specific Closures

  The above closures involve all forms of fishing for a particular class of resource, within some area and season. There are, in addition, a large number of areas or area/season combinations within which fishing for a resource with one type of boat or gear is forbidden, while fishing for that same resource in other ways is permitted. These gear-specific closures are usually designed to minimise conflicts between different groups of fishermen but they are sometimes also intended to protect some sub-group of a resource (such as small fish) without obstructing the activities of fishermen who do not catch that sub-group. Indeed, there was formerly a gear-specific aspect to the haddock spawning closure on Georges Bank. It took the form of a "large hook exemption" to the closure and allowed hook-and-line fishermen to continue targeting large cod and halibut when the area was closed to all gear that could catch haddock. Similarly, the haddock nursery area on Western and Emerald banks was once open to all hook-and-line fishing when it was thought that such gear would not take large numbers of juvenile haddock. (See details below.)

Examples of other gear-specific groundfish closures are given in detail below.
Although they are not considered at length here, similar rules apply in the herring
fisheries with purse seiners being excluded year-round from waters within 25 miles
of the Atlantic coast of Nova Scotia and from Herring Fishing Area 18 ("HFA18",
the waters off Cape Breton from Point Aconi to about Gabarus; except that the
seiners can enter HFA18 as far as a "Scaterie Island Line" if test-fishing shows that
there are few local fish among the catches of the larger migrant stocks). There is also
a seasonal exclusion of herring seiners from Chedabucto Bay, west of a "Green
Island Line", in November and December, which is intended to protect the local
fixed-gear fishery from competition with the mobile boats (Mr. K. Rodman,
Department of Fisheries & Oceans, *pers.comm.*). A similar array of restrictions
probably applies in every fishery where different gear types are used to catch the
same resource, though not in such homogeneous fisheries as that for lobster.

• Quota Closures

Besides all of the above types of specific closures of areas and seasons to particular
types of fishing, a fishery can only operate on the Scotian Shelf if someone has an
appropriate licence (with any necessary endorsements and conditions) which, in
quota-managed fisheries, also requires that they have some quota for the stock or
stocks in question.

In general, licences exist for fishing every viable resource (and some that are no
longer viable). There are a few potential resources for which no licences have (yet)
been issued, either because no-one has developed a proposal for fishing them or
because such a fishery is considered undesirable for one reason or another. There
are, for example, no krill licences for the Scotian Shelf at present because some
interests see krill filling a more valuable role in the ecosystem as support for other
exploited species than they could have as a resource in their own right. At the same
time, there are some resource species which occur in small numbers outside the
areas for which licences have been issued and thus in places where they cannot be
fished. In such cases, the absence of licences amounts to a form of closure or,
perhaps more accurately, the lack of an opening.

Even given licences, many areas can be closed to certain types of fishing, certain
fleet sectors or even certain individual boats for lack of quota. The latter, which can
only apply where individual quota management schemes are in operation, clearly
does not amount to a "closure". The exclusion of an entire fleet sector, however, is
functionally the same as a temporary gear-specific closure, while the elimination of
all quotas can effectively close an entire fishery. Quota closures can apply for only
a few weeks, until the next quarterly release of quota for example, or they may run
until the end of the current management year. In some cases, the release of quota to
particular fleet sectors can be timed in such a way as to create an open fishing
season (and hence also a closed season), perhaps allowing small boats to avoid
competing for fish during winter weather. However, in the case of many groundfish

stocks on the eastern Scotian Shelf, all quotas for directed fishing were reduced to zero in the fall of 1993 as an emergency conservation measure and that closure has been extended annually ever since. Thus, quota closures can become *de facto* long-term (though not explicitly indefinite) fishery closures.

Quota closures differ from the other types considered above in that there is no specific intention to continue them indefinitely, even though some have now extended for a number of years or have been repeated annually at the same season. They also differ in that they are specific to particular stocks and hence, in any one area, to specific species. In, for example, the scallop or the herring fisheries, this makes no difference since the resource is composed of a single species. With groundfish, however, the eastern Scotian Shelf is currently closed to directed cod or haddock fishing but there are still limited quotas available for redfish and halibut, for example. It is thus the species, and by implication the grounds on which it predominates, rather than the area which is closed.

No attempt is made in this report to map the spatially- and seasonally-intricate quota closures on the Scotian Shelf.

- Small-Fish Closures

  In some fisheries, the Department of Fisheries & Oceans has taken to temporarily closing specific areas to particular kinds of fishing when catches from those areas by those gear types are found to contain too many small fish. This is considered to be a preferable alternative to setting minimum fish-size regulations that only promote unreported dumping of small fish. These small-fish closures are fluid and constantly changing. They will defy any cataloguing and no attempt to do so is made here.

- Shellfish-Contamination Closures

  The closures of some inshore areas to mollusc harvesting as a result of contamination has been noted above. Only one offshore fishery on the Scotian Shelf is subject to equivalent restrictions, that being the "roe-on" fishery for whole scallops. It is only open for a brief period each year and in a limited area where the concentration of Paralytic Shellfish Poisoning ("PSP") toxins in the scallops' internal organs is low enough for safe human consumption. Other areas and times can be regarded as "closed" to this specialized fishery, though not to scallop harvesting.

Haddock Nursery Area

The first northwest Atlantic fishery-resource species to show signs of a severe decline was the haddock, beginning in the late 1960s. From 1970 to 1972, Canada proposed that an area west of Sable Island Bank (Figure 2) should be closed seasonally to protect spawning haddock. (Similar closures on Georges and Browns banks were being introduced at that time: see below.)

This idea did not gain international acceptance, however, as it would have interfered with the fisheries for other species, particularly cod and silver hake. The eastern Scotian Shelf haddock stock was thus managed under only catch quotas and similar restrictions (Halliday 1988).

In the mid-1980s, a renewed decline in this same stock became evident and, in 1986, it was decided to close the stock's nursery areas to all groundfish fishing year-round, with effect from 1987. As an emergency measure, two areas were closed, the larger covering Western and Emerald banks (including much of the area proposed for a seasonal closure in 1970-72) and the other encompassing the southernmost tip of Banquereau, the adjacent continental slope and the edge of the Sable Gully (Figure 3). After further analysis (Fanning *et al.* 1987), the second area was re-opened and the boundaries of the Western/Emerald area were slightly re-drawn (see Appendix 2). For a number of years, that latter area was closed only to "mobile gear" groundfish fishing (i.e. otter trawling, Danish seining and Scottish seining), as it was thought that hook-and-line fishing posed no threat to juvenile haddock. That lead to the growth of a flourishing local longline fishery, using small hooks to target the haddock (Kenchington & Halliday 1994) and, in 1993, the area was closed to all groundfish fishing on an indefinite basis. A few months later, the directed fisheries for cod and haddock in the area (part of NAFO Division 4W) were in any case closed for lack of quota. Both forms of closure have remained in effect to date.

The areas closed in 1987 were based on initial analyses of the catches of young haddock (from young-of-the-year to 3 year-olds, with an emphasis on the latter) in the routine July groundfish research-vessel surveys (which have been run since 1970) and on records, compiled by the International Observer Program from 1981 to 1986, of haddock discarded from commercial vessels. Three of the regular survey strata were found to have both a high frequency and large numbers of young haddock in July and those three became the basis for the closed area covering Western and Emerald banks. The observers had seen concentrations of discarding within that same area but also on the eastern side of the Sable Gully in 1985 and 1986. That led to the latter area being closed also (Fanning *et al.* 1987).

The subsequent and more detailed analysis confirmed the general importance of the Western and Emerald banks area to juvenile haddock in July, while also showing that the distribution of those fish was similar in the catches of a brief program of fall surveys in 1978-1981. It also showed, however, that the young haddock live deeper (about 100 m) in the spring; or at least that they were taken there in the few spring surveys run in 1979-1981. One seasonal spring concentration lay within the western closed area but others did not. This detailed analysis also showed that the waters around Sable Island, while having few young haddock in most years, sometimes had very high densities of them. (The relative significance of average and occasional densities in this situation is still a matter of scientific debate.) Observer data was used as it had initially been to map the distribution of young haddock but only to examine the grounds fished by the Canadian groundfish fisheries in the general area, despite the limitation that almost all of the observed trips in the 1980s were on large stern trawlers. That analysis showed that there

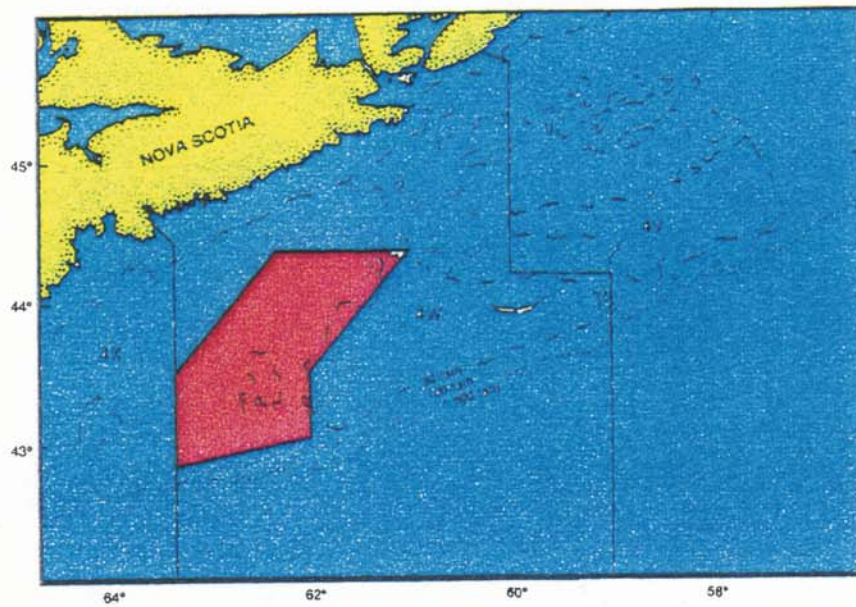**Figure 2: Haddock Spawning Area Closure in Division 4W
Proposed by Canada in 1970-72 but not adopted by ICNAF**
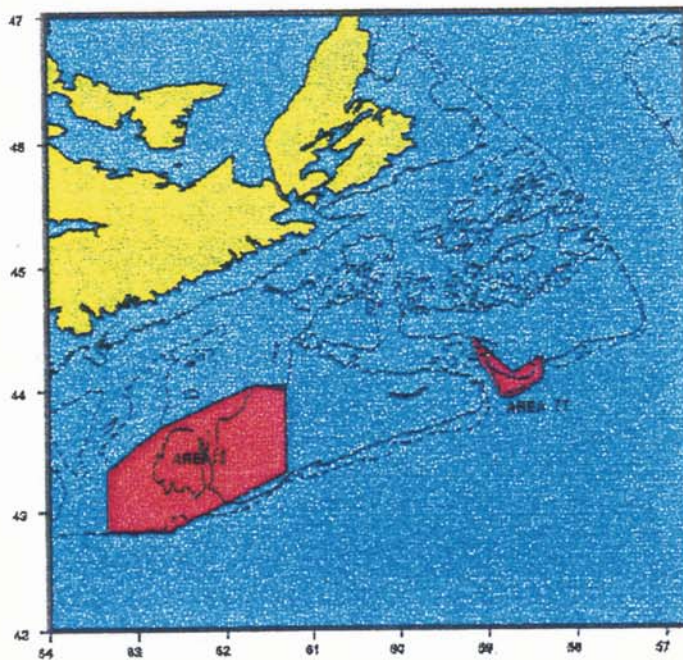(Source: Figure 1 of Halliday 1988)

Figure 3: Haddock Nursery Areas Closed in 1987
(Source: Figure 2b of Fanning *et al.* 1987)

was little fishing for cod or flounder and not much for pollock in the closed area covering Western and Emerald banks, while a small adjustment in its boundaries would prevent it interfering with the silver hake fishery in an area where the latter caught few small haddock. The small closure on the southern tip of Banquereau, in contrast, had a significant impact on some fisheries while it did "not include any detectable [haddock] nursery areas" (Fanning *et al.* 1987). On the basis of this scientific advice, the nursery-area closure was amended to its current boundaries, with effect from 1988.

Whether this closure has been an effective haddock conservation measure is not a question that can be considered here. What must be is whether or not the boundaries of the closed area are to some degree indicative of the area that provides important nursery grounds for the eastern Scotian Shelf (formally the "Divisions 4TVW") haddock stock:

- It must first be noted that the delimitation of the closed area was based on the distribution of young haddock in July, though the available evidence suggests that their distribution in fall is little different. In spring, however, with the surface waters at their coldest, the haddock seem to live deeper and a substantial proportion may be outside the closed area.

- Secondly, even the mapped distribution of median July research survey catches, which was the data presentation which most strongly supported the originally-chosen closed area, showed a substantial concentration of fish on Sable Island Bank east of 61°W longitude and thus outside the closure (Figure 6 of Fanning *et al.* 1987). The emphasis of the original analysis on the strata used in the design of the groundfish surveys deflected attention from this concentration, which spans two strata while filling neither of them.

- These median catches, moreover, emphasized the regular occurrence of the haddock whereas most successful fisheries are primarily dependent on occasional strong year-classes. In "good" years, when such year-classes should be generated, large numbers of young haddock were recorded well to the eastward of the closed area, around Sable Island and even as far as Banquereau.

- Moreover, the fisheries closure was designed around the distribution of three year-old haddock, those being the ones large enough to be caught commercially but still too small to have reached their optimal size. It was haddock of that age which were particularly important in survey strata 63, 64 and 65 (roughly equivalent to the closed area). The young-of-the-year haddock, which might be expected to be the most vulnerable to many environmental insults, were about equally densely distributed in all of strata 55, 56 (Sable Island Bank), 62 (Middle Bank), 63, 64 and 65 (Figure 1a of Fanning *et al.* 1987), though the inefficiency of the survey gear for such small fish meant that all of these catches were low. When a separate series of surveys, specifically directed towards these very young haddock, was conducted close around Sable Island in the early 1980s, very dense concentrations were found

there (though without comparative data from other areas that would support conclusions of relative importance: Scott 1982, 1984, 1987).

- Next, the groundfish survey stations are necessarily far apart, since a single ship must survey the entire Scotian Shelf in a month, and they can easily miss small but dense concentrations of fish. Thus, it is not surprizing that the well-known concentration of young haddock on the southern tip of Banquereau in some years, in the area that saw sufficient discarding of them for it to have been closed in 1987, was not detected in Fanning *et al.*'s (1987) later analysis of the research-vessel survey data. The lack of attention to the distribution of young haddock in commercial catches in that later analysis led directly to the down-grading of the importance of that nursery area; indeed, to denial of its existence.

- Needless to say, the concern for impacts of a closure on other fisheries, which contributed to the re-opening of that area on Banquereau in 1988, has no bearing on its importance to the haddock resource, though it clearly is a vital consideration for fisheries management.

Thus, the analysis which led to the delimitation of the present haddock nursery closed area was far from being a mapping of areas of importance to the young haddock. Perhaps the safest overall conclusion is that the currently-closed area is important as a nursery ground for the eastern Scotian Shelf haddock but that it is not uniquely so. Nor, of course, does it serve as a principal nursery for the, even more valuable, western Scotian Shelf stock. While conservation considerations have not yet led to any nursery closure in that area (NAFO Division 4X), somewhere within it are important grounds utilized by juvenile haddock.

Lobster Fishing Area 40

When an offshore lobster fishery was added to the long-established inshore one, beginning in 1971, the inshore fishermen strongly objected to the competition for their resource. This was particularly so in southwest Nova Scotia where the range of lobster is continuous from the coast out to the continental slope. (To the eastward, there was little potential for interference.) In 1978, the available evidence pointed to a summer-time migration of female lobsters from the inshore grounds, where they were fished in the fall, winter and spring open season (see discussion of lobster fishing seasons below), to Browns Bank. There, it was thought, they could release their larvae into a current flowing back towards the land, thus supplying young lobsters to the inshore grounds. Subsequent analysis has cast doubt on this idea but at the time it gave sufficient foundation for inshore fishermen to demand that an area on Browns be closed to offshore lobstering. In the event, a new near-rectangular area (Appendix 3, Figure 4) was selected, spanning the inshore/offshore dividing line of lobster management (Pezzack *et al.* 1992). That area is now designated Lobster Fishing Area 40 ("LFA40"). It has been closed to all lobstering, though not to other fishing gear, since 1979.
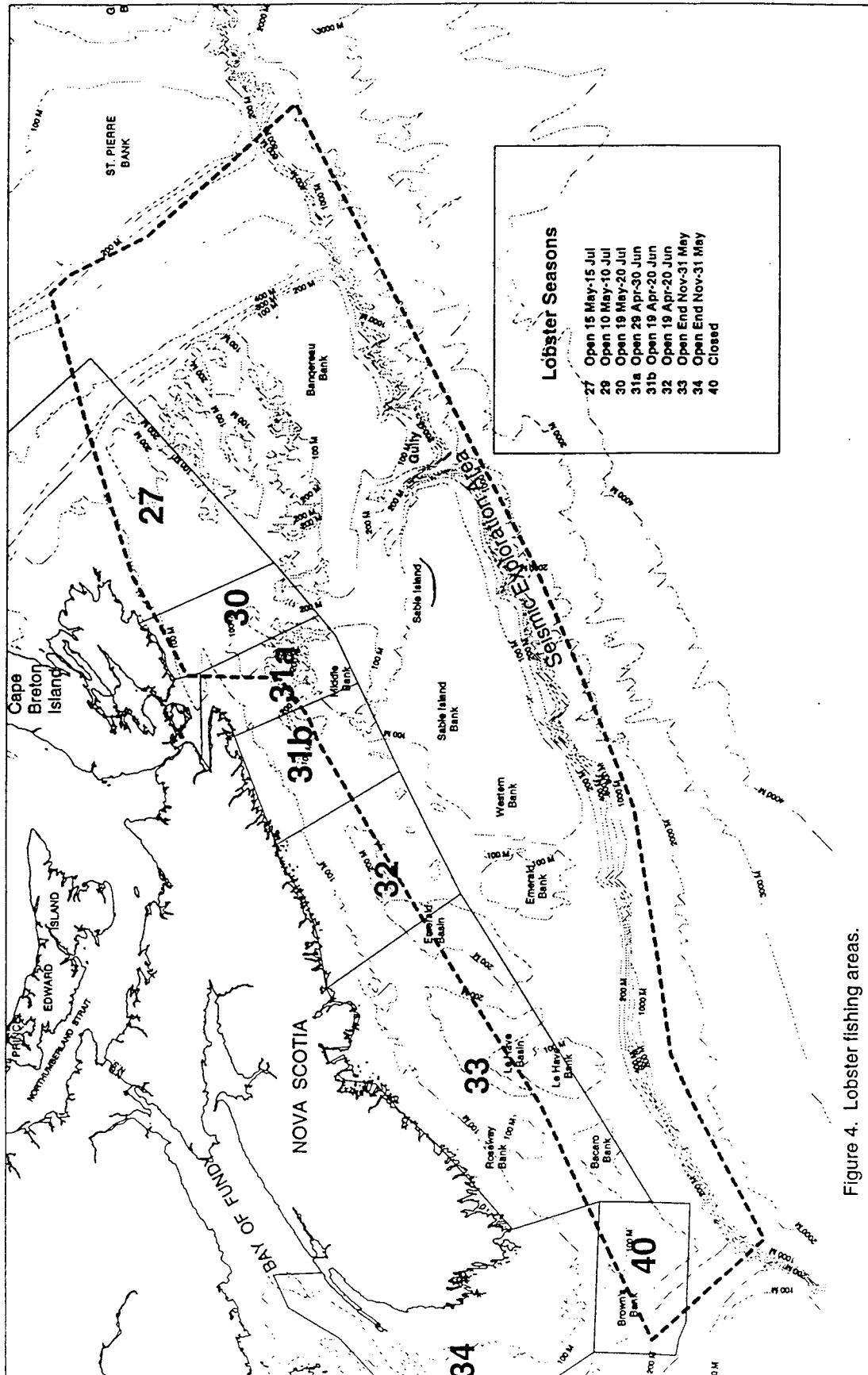
Figure 4. Lobster fishing areas.

The lobsters in LFA40 are no doubt perceived as being important by lobster fishermen, if only because they will quite reasonably object to any action that kills lobsters that they have had to forego catching in the interests of resource protection. However, there does not seem to be any evidence that lobsters are especially abundant in LFA40 and the idea that adults migrate there from inshore waters in order to release their larvae in the summer seems to have been discarded. There is still reason to think that whatever lobsters do find themselves on Browns Bank when they have larvae to release will contribute to the inshore resource (Pezzack *et al.* 1992) and that issue continues to give the area some importance, especially considering the current critically-low levels of spawning biomass in the lobster populations.

In short, the closure of LFA40 may be a valuable fisheries-management tool and the closed area may have an importance to the lobster fishery at least equal to that of some heavily-fished grounds. However, the borders of LFA40 do not seem to delimit an area of unique importance to the fishery nor to the Scotian Shelf ecosystem.

Haddock Spawning Closures

When the northwest Atlantic haddock stocks first showed signs of severe depletion, in the late 1960s, the United States and Canadian governments moved to reduce international fishing pressure on those resources. The scientists concerned saw the primary requirement as one of limiting the Fishing Mortality rate (effectively the percentage of the stock caught each year) for haddock, and the two governments attempted to do that without excessively constraining the important fisheries for cod and pollock. They set out to use the full suite of management measures permitted by the convention governing the then-International Commission for the Northwest Atlantic Fisheries (ICNAF), which included provisions for closing spawning and nursery areas, as well as for limiting the total international catch (through a "TAC" or "Total Allowable Catch") but not for national catch quotas. It was thought that a closure during the spawning period, when the haddock were most concentrated, would not only help to reduce the total catch of that species but would also prevent the annual TAC from being caught in a few weeks, thus allowing the available haddock to be taken over a longer period by the mixed cod, haddock and pollock fisheries (Halliday 1988). Many fishermen, in contrast, believed then (Halliday 1988), as their successors do now (Kenchington & Halliday 1994) and as their forefathers have done for centuries (e.g. Hoffmann 1996), that leaving fish alone during their spawning time has a direct effect on the future size of the resource, quite apart from questions of the percentage of the fish caught per year. The combination of the scientists' and the fishermen's demands for spawning closures led ICNAF to introduce three of them, one on Browns Bank, one on Georges and one near Cape Cod (Figure 5). In the event, the boundaries of those areas were drawn following a study of the distributions, in space and time, of spawning haddock and of their newly-spawned eggs. Thus, scientists drew those boundaries following the conceptual basis for a closure that was espoused by fishermen, while themselves rejecting that basis and warning that the important thing was the reduction in Fishing Mortality (Halliday 1988).

The haddock spawning closures were first introduced in 1970 and both their boundaries and the seasons to which they apply have undergone assorted changes in the years since. Those changes were primarily driven by the conflicting desires to afford more protection to haddock while reducing the impacts on other fisheries of these closures. One distinctive change was introduced in 1972, when an exemption from the closure (which otherwise applied to all groundfish fishing) was introduced for hook-and-line boats fishing with large hooks, which rarely catch haddock. That exemption initially applied to both the closed area on Georges Bank and the one near Cape Cod but, from 1973 to 1981, was then confined to the latter. Thereafter, conversion of the formerly-international regulations into post-1977 Canadian rules applicable to the national 200-mile fishing zone, led to this exemption also being provided for fishing on the Canadian portion of Georges Bank (Halliday 1988). It remained in force for that area into the 1990s but has been deleted in the last five years (J. Hansen, Department of Fisheries & Oceans, *pers.comm.*). It never applied to the Browns Bank spawning closure.

In the 1990s, worsening conservation problems in U.S. waters on Georges Bank have led to extensive closures that are functionally equivalent to the Canadian quota closures on the eastern Scotian Shelf. Matching, though less severe, Canadian restrictions have seen the "spawning closure" on Georges extended in both area and season such that, in 1998, it will last from 1 January to 31 May and will apply to the entire Canadian portion of NAFO Division 5Z (i.e. all Canadian waters west of the Fundian Channel: J. Hansen, Department of Fisheries & Oceans, *pers.comm.*). That has clearly expanded the closure far beyond being a measure to protect spawning haddock and has made it more akin to the long-term quota closures in force elsewhere, though Canada considers that some limited groundfish fishing on Georges is acceptable from the late spring to the fall.

On Browns Bank (and hence on the Scotian Shelf), in contrast, the area covered by the spawning closure (see Appendix 4) in 1998 is identical to that which first applied in 1972 (though larger areas were used in 1970, 1971 and 1975: Halliday 1988). The closed season is longer than it was ten years ago, however – that extension being in part a support to quota reductions but in part also a reflection of some fishermen's belief that the actual haddock spawning season is longer than the original closure period.

As with LFA40, the spawning-closure area on Browns Bank is important in part because many fishermen see it as being so. It is also an area where, at the appropriate season, there is a considerable amount of spawning activity by the valuable (and vulnerable) western Scotian Shelf haddock population. Conversely, its boundaries were originally drawn on the basis of the scientific knowledge of nearly 30 years ago, before any comprehensive surveys of groundfish or their eggs had been undertaken on the Scotian Shelf. Even those boundaries would have been drawn more widely if it were not for conflicts with other fisheries. Indeed, modern knowledge might well suggest that there is at least some haddock spawning throughout the Scotian Shelf and that there certainly are important centres of such spawning far to the eastward, where the "Divisions 4TVW" stock lives. Moreover, haddock is no longer the most severely depleted
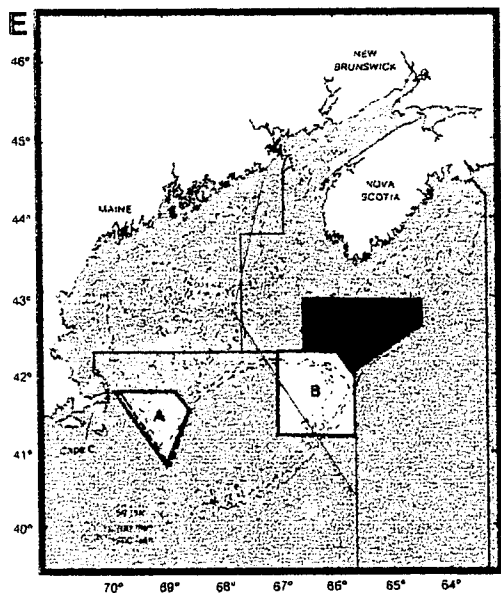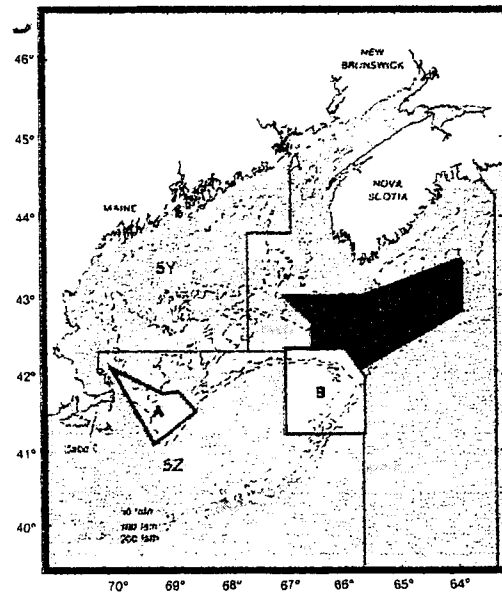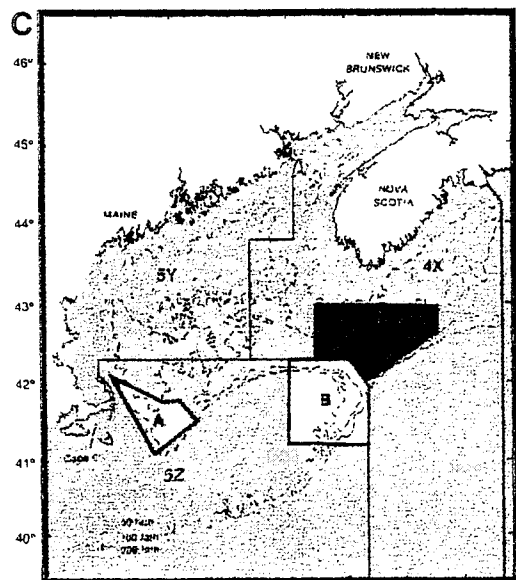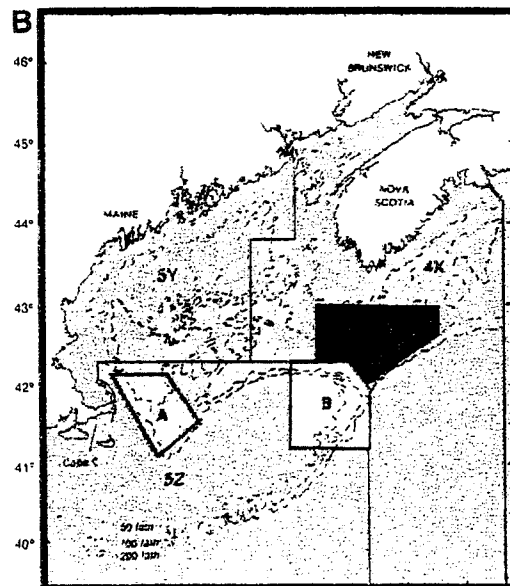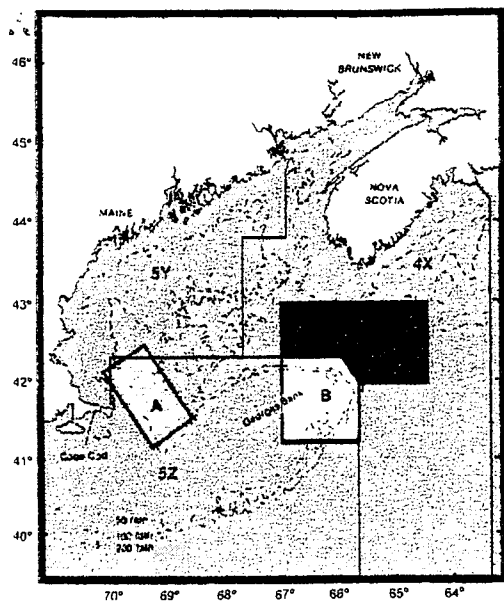
Figure 5: Haddock Spawning Closure Areas
1970-1987

A: 1970 & 1971
B: 1972,
C: 1973, 1974 & 1976-1982,
D: 1975,
E: 1983-1987

After 1987, these areas were continued with few changes into the 1990s. Thereafter the closed areas on Georges Bank have been substan ially increased.
(Source: Figures 2 to 6 of Halliday 1988)

resource on the western Scotian Shelf (it is currently in a better state than the cod resource in that area) and there is no close link between the spawning areas of other valuable species and the existing haddock spawning closure area. Finally, the importance of protecting a stock from fishing during its spawning period continues to be disputed. Whether it needs special protection from other impacts at such a time would, of course, depend on the nature of the impact.

In short, the Browns Bank spawning closure delimits an especially valuable time and place on the Scotian Shelf but not a uniquely valuable one.

4Vsb" Groundfish Closure

When the northwest Atlantic groundfish management system was being developed, it was known that southern Gulf of St. Lawrence (NAFO Division 4T) cod migrate into Sydney Bight (NAFO Subdivision 4Vn) for the winter. The fish were therefore managed in two groups: the "Divisions 4TVn (January to April)" stock represented the migratory Gulf cod plus those resident Sydney Bight fish that were caught during the winter, while the "Division 4Vn (May to December)" stock included the Sydney Bight residents through the rest of the year. The eastern Scotian Shelf, or "Divisions 4VsW", stock was considered to be separate and was exploited by a different fleet, most of which did not have access to the Gulf of St. Lawrence under existing licensing rules. In the later 1980s, it was realized that the Gulf fish actually migrate past Cape North, into Sydney Bight, in the fall and that a proportion of them then move past Cape Breton and far onto the Scotian Shelf. To resolve the ensuing argument between different fleet sectors over access to these Gulf-spawned fish, and following some other attempted solutions, part of NAFO Subdivision 4Vs, denoted "4Vsb" was closed to groundfish fishing from 1 January to 30 April each year (see Appendix 5).

The significance of this closure has been much reduced by the long-term closures of directed fishing for all of the cod, and some of the other groundfish, on the eastern Scotian Shelf which began in the fall of 1993. Should those fisheries later be re-opened while this "4Vsb" closure is maintained, it will have much of the same significance for the fisheries as do the "haddock spawning closures" to the westward and yet its origin will still lie in the avoidance of conflicts over access to fish spawned in the Gulf of St. Lawrence (and hence to long-standing inter-Provincial and Gulf/offshore rivalries) rather than in any conservation issue. For other users of the eastern Scotian Shelf, this closure simply represents and area and a season where there should be no groundfish fishing, without there being any special concentration of fish.

Lobster Fishing Areas and Seasons

The Atlantic Canadian lobster fishery is managed using a system of "Lobster Fishing Areas" or "LFAs" (Appendix 6, Figure 4), with different seasons and other rules (such as a maximum number of traps) for the many LFAs. Each lobster licence and hence (in theory) each lobster boat is confined to a single, specified LFA. The offshore lobster fishery (in LFA41) is

open year-round but the other areas have restrictive seasons, with the lobstermen usually being involved in other fisheries outside of their local lobster season. The timing and duration of the season in each LFA is more or less constant from year to year (aside from some small adjustments that are sometimes necessitated by bad weather). The overall scheme evolved many years ago to ensure a year-round supply of Maritime lobster on the Boston market, while allowing the fishermen to avoid the worst of the weather in more northern areas, to avoid periods when a high proportion of the lobsters are in "soft shell" or moulting condition, to take advantage of periods when they are available to trapping and so forth.

The periods when local lobster fisheries are closed give little indication of increased sensitivity of lobsters, in the sense that a groundfish spawning closure may suggest greater sensitivity of haddock. Rather, it is the open periods that show the presence of important lobster fishing activity along each part of the coast. Yet the areas actually fished are generally far smaller than the LFAs in which they are set. Along most of the Atlantic coast of Nova Scotia, the inshore lobster fishery is confined to a strip within about 20 km of the coast and only in LFA34 does it extend out more-or-less to the margins of the regulated area. The offshore fishery is likewise confined to the continental slope and the shelf break, except in the Browns Bank and Fundian Channel areas where it extends landward to the inner margin of LFA41 (Pezzack *et al.* 1992). Thus, the area/season management system for the lobster fishery gives some indication of the timing of the fishing but little of the areas fished at those times.

Crab Fishing Areas and Seasons

The areas and seasons by which the snow crab fishery on the Scotian Shelf is managed are presented in Appendix 7. The management concept is generally similar to that applied to the lobster fishery, though the Crab Fishing Areas ("CFAs") do not follow the boundaries of the LFAs. The very few licences issued for CFA24 cannot, apparently, be freely fished throughout that large area, though details of the specific restrictions on areas that can be fished are not immediately available.

Area-Based Management of the Swordfish Fishery

The Atlantic Canadian swordfish fishery provides an interesting example of a widespread fishery for a highly-migratory (ocean-wide) resource that nevertheless involves some area-based management measures on the Scotian Shelf. As such, its management contrasts with that used for the lobster fishery and is indicative of the kind of complex area and seasonal closures that are used in the management of still other fisheries.

Canadian swordfish licences are valid for the entire northwest Atlantic (technically: the NAFO Convention Area), except for the Gulf of St. Lawrence, the Bay of Fundy and the waters of other coastal states (the U.S.A., France and Greenland). However, to minimize bycatches of

bluefin tuna, the fishery opens (or will do so in 1998) on 1 June east of longitude 65°30'W and on 1 August to the westward of that meridian. Harpoon boats are confined to the area east of 65°30'W throughout the year, though swordfish longliners can work both east and west. Should bluefin bycatches become excessive despite the later opening, the area of the "Hell Hole", the prime bluefin ground, will be closed to swordfish longlining. Such a closure will be applied to the rectangle delimited by:

NW	42°06'N	65°41.4'W
NE	42°06'N	65°27.5'W
SE	41°55.8'N	65°27.5'W
SW	41°55.8'N	65°41.4'W

Further, to protect large swordfish spawners, an area delimited by:

1	43°23.3'N	65°37.2'W
2	43°12'N	65°36'W
3	43°11'N	63°24'W
4	44°13'N	62°00'W
5	45°00'N	62°00'W

and the coast of Nova Scotia between points 1 and 5 will be closed to all swordfish fishing from 1 September. The swordfish 1998 Integrated Management Plan, from which these restrictions have been extracted, contains additional provisions for closing small areas, either temporarily or for the remainder of the season, in the event of either unacceptable bycatch levels or the capture of too high a proportion of small swordfish[1].

Clearly, something can be deduced about the areas and seasons in which particular types and sizes of large pelagic fish are expected to occur from these various closures. However, their indicative value is low and the distribution of fish and fishing could be more efficiently found elsewhere.

Gear-Specific Groundfish Closures

There are a considerable number of areas on the Scotian Shelf where certain kinds of groundfish fishing are permitted, while others are forbidden (even if the quota closures that exclude specific fleet sectors for particular periods are ignored). Some of these gear-specific closures (though by no means a comprehensive list) are presented in Appendix 8. Besides those listed, there is also the "Silver Hake Box", extending seaward from the break of the continental shelf (Figure 6), within which otter trawlers directing for hake are permitted to use small-mesh nets that are otherwise forbidden. There is another, more general restriction that prevents large trawlers from working within 12 miles of the coast – a rule that has its origin in the inshore fishermen's objections to trawlers in the early decades of this century.

The logic underlying these various gear-specific closures varies from simply the avoidance of conflicts among fishermen in different fleet sectors (e.g. the White Head Hole), through a combination of conflict concerns and area-specific conservation measures, based on the relative distributions of different species (e.g. the Silver Hake Box), to an attempt to minimize catches of undersized fish of the target species (e.g. the "Bowtie"). Each closure has some obvious (and sometimes some not-so-obvious) relevance to the distribution of fishing activity but not necessarily much to that of fish or the relative sensitivity of the marine ecosystem.

Conclusion

While no substantial area on the Scotian Shelf is closed to all fishing, even seasonally, nor is any part open to all forms of fishing throughout the year. Rather, a very large number and a great diversity of areas are closed to certain types of fishing at particular times and a few of them are so year-round. The reasons for these closures are varied but all are designed as instruments of fisheries management, save for the few small areas that are closed because of vessel traffic concerns or the reserved occupancy of the seabed for non-fishing uses. Some of the closures, particularly the haddock nursery area covering Western and Emerald banks and the haddock spawning closure on Browns Bank, have a greater link to wider environmental management concerns, in as much as those areas are closed to fishing to protect valued and vulnerable components of the marine ecosystem (respectively: juvenile haddock and spawning adult haddock). However, the dictates of fisheries management have so shaped the boundaries of even these closures that they should not be treated as delimiting areas of unique importance – not even as indicators of the full area important to spawning or juvenile haddock.

Thus, for those concerned with the environmental management of the Scotian Shelf, some fisheries closures indicate areas of above-average sensitivity and importance but not all do so. Nor are all such sensitive and important areas within the boundaries of closed areas.
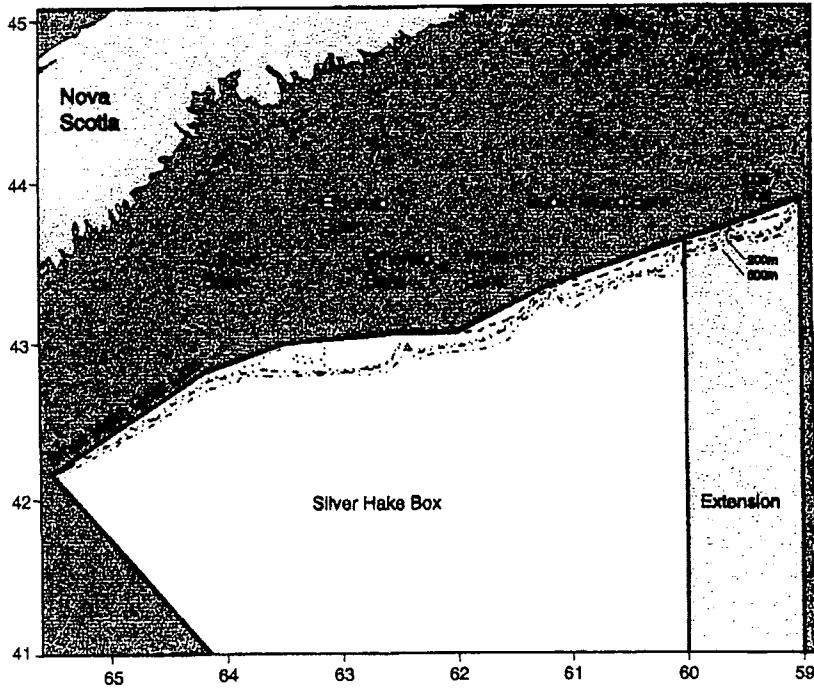
**Figure 6: The "Silver Hake Box" and the "Small Mesh Gear Line"
which delimits its landward edge.**
(Source: DFO Industry Services Project Summary No. 47)

ACKNOWLEDGEMENTS

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Appendix 1: Whale Sanctuary Coordinates

Whale Sanctuary #1: Grand Manan Basin
Season: July to November

NW	44°45'N	66°35'W
NE	44°45'N	66°18'W
SW	44°30'N	66°35'W
SE	44°30'N	66°18'W

Whale Sanctuary #2: Roseway Basin
Season: July to November

NW	43°05'N	65°40'W
NE	43°05'N	65°03'W
SW	42°45'N	65°40'W
SE	42°45'N	65°03'W

Whale Sanctuary #3: Sable Island, The Gully
Season: Year Round

NW	44°12'N	59°08'W
NE	43°54'N	58°48'W
SW	43°42'N	59°08'W
SE	43°42'N	58°48'W

Source: Canadian Coast Guard *Notices to Mariners 1 to 46: Annual Edition 1996* pp. A5-1 to A5-2. The coordinates of these Whale Sanctuaries have not changed since they were first introduced and in 1998 they remain as they were in 1996 (J. Conway, Department of Fisheries and Oceans, *pers.comm.*).

Appendix 2: Haddock Nursery Area Coordinates

Season: Year Round

1	43°21'N	63°20'W
2	43°01'N	63°20'W
3	43°04'N	62°30'W
4	43°04'N	62°00'W
5	43°19'N	61°18'W
6	44°02'N	61°18'W
7	44°02'N	61°42'W
8	43°42'N	62°44'W

Source: Copy of official compilation of fisheries regulations, provided by Mr. J. Hansen, Department of Fisheries and Oceans.

Appendix 3: Lobster Fishing Area 40 Coordinates

Season: Year Round

1	42°55'N	66°30'W
2	42°55'N	65°13'W
4	42°21'N	66°13'W
3	42°21'N	65°13'W
5	42° 23.22'N	66°21'W
6	42°24.25'N	66°30'W

Source: Department of Fisheries and Oceans page on the world Wide Web (URL: http://www.gfc.dfo.ca/licensing/lobzones.htm).

Appendix 4: Browns Bank Haddock Spawning Closure Coordinates

Season: February 1 to June 15

1	42°04'N	65°44'W
2	42°40'N	64°30'W
3	43°00'N	64°30'W
4	43°00'N	66°32'W
5	42°20'N	66°32'W
6	42°20'N	66°00'W

Source: Copy of official compilation of fisheries regulations, provided by Mr. J. Hansen, Department of Fisheries and Oceans.

Appendix 5: Coordinates of the 4Vsb Closure

The area contained by the points:

1	45°10'N	56°55'W
2	45°10'N	58°20'W
3	45°00'N	58°20'W
4	45°00'N	60°00'W
5	45°40'N	60°00'W
6	45°40'N	57°30'W

is closed to groundfish fishing between 1 January and 30 April.

Source: Copy of official compilation of fisheries regulations, provided by Mr. J. Hansen, Department of Fisheries and Oceans.

Appendix 6: Coordinates of the Lobster Fishing Areas
of the Scotian Shelf

Lobster Fishing Area 27

The area contained by the coast of Cape Breton and the points:

1	46°58'42"N	60°40'W
2	47°02'18"N	60°45'W
3	47° 50'N	60°00'W
4	46°00'N	57°50'W
5	44°56'N	59° 42'W
6	45°47'N	60°11'W
7	45°57'25"N	60°47'32"W
8	45°57'32"N	50°48'32"W

Open Season: May 15 to July 15.

Lobster Fishing Area 29

The area bounded by the coasts of Cape Breton and mainland Nova Scotia and the points:

1	45°39'25"N	60°52'30"W
2	45°39'25"N	60°51'45"W
3	45°34'N	60°41'W
4	45°24'40"N	60°38'W
5	45°24'40"N	61°23'W
6	45°38'10"N	61°25'45"W
7	45°38'30"N	61°24'15"W

Open Season: May 10 to July 10.

Lobster Fishing Area 30

The area bounded by the coast of Cape Breton and the points:

1	45°47'N	60°11'W
2	44°56'N	59°42'W
3	44°40'N	60°10'W
4	45°24'40"N	60°38'W
5	45°34'N	60°41'W

Open Season: May 19 to July 20.

Lobster Fishing Area 31a

The area bounded by the coast of Nova Scotia and the points:

1	45°24'40"N	61°23'W
2	45°24'40"N	60°38'W
3	44°40'N	60°10'W
4	44°34'N	60°21'W
5	44°26'N	61°46'W
6	45°12'36"N	61°11'36"W

Open Season: April 29 to June 30.

Lobster Fishing Area 31b

The area bounded by the coast of Nova Scotia and the points:

1	45°12'36"N	61°11'36"W
2	44°26'N	60°46'W
3	44°11'N	61°32'W
4	44°57'18"N	62°09'05"W

Open Season: April 19 to June 20.

Lobster Fishing Area 32

The area bounded by the coast of Nova Scotia and the points:

1	44° 57' 18"N	62°09'05"W
2	44°11'N	61°32'W
3	44°56'N	62°18'30"W
4	44° 38' 48"N	63°25'W

Open Season: April 19 to June 20.

Lobster Fishing Area 33

The area bounded by the coast of Nova Scotia and the points:

1	44°38'48"N	63°25'W
2	43°56'N	62°18'30"W
3	44°57'18"N	62°09'05"W
4	42°35'N	65°13'W
5	42°55'N	65°13'W
6	43°26'59"N	65°28'17"W

Open Season: Last Monday in November to May 31.

Lobster Fishing Area 34

The area bounded by the coast of Nova Scotia and the points:

1	43°26'59"N	65°28'17"W
2	42°55'N	65°13'W
3	42°55'N	66°30'W
4	42°38'40"N	66°30'W
5	42°49'20"N	66°50'W
6	43°05'45"N	67°04'W
7	43°48'50"N	67° 25'W
8	43°51'20"N	67° 24'W
9	44°30'30"N	66° 27' 30"W
10	44°50'N	66° 12' 30"W
11	44°56'N	65° 55' 30"W
12	44°37'39"N	65° 53' 40"W

Open Season: Last Monday in November to May 31.

Lobster Fishing Area 40

See Appendix 3.

Lobster Fishing Area 41

All Maritime Canadian waters outside the other LFAs.
Open year-round.

Source: Department of Fisheries and Oceans pages on the world Wide Web (URLs: http://www.gfc.dfo.ca/licensing/lobzones.htm and http://dfomr.dfo.ca/fisheries/reg/ seasen.html).

Appendix 4. Acoustic Model Predictions for the Laurentian Channel

This appendix contains the model predictions for two selected transmission tracks in and near the Laurentian Channel. The procedure developed for the predictions made near Sable Island (see main text) was followed in the Laurentian Channel.   Acoustic transmission characteristics were modeled for a 100 km track running along the channel axis and for a 50 km transverse track beginning at the 400 m contour at the west edge of the channel and running up the wall of the channel onto the Banquereau Bank. The results of the study were predicted overall sound exposure levels versus range for representative seismic array operations in the Laurentian Channel.

Environmental Description

Bottom Features

The study area and the transmission tracks selected for modelling are shown in Figure 4-1. Tracks L2 and L3 were the primary focus of the study. Track L1 was regarded as similar to L2 with the exception of the down slope propagation near the edge of the continental shelf. This type of propagation was previously modeled for Track S2 south of Sable Island and thus was not repeated here. The portion of Track L3 between the channel edge and the channel axis was regarded as similar acoustically to Track L2. As a result, the modelling of Track L3 was started at the 400 m depth contour, rather than at the channel axis. This provided transmission loss predictions appropriate for array operation near the edges of the study area.

Data on the Laurentian Channel used in this study were derived from Mobil's physical environmental review[1]. The bottom of the channel at an average depth of 460 m is nearly level for a width of about 50 km. The axis of the channel extending for several hundred kilometres between the Grand Banks and Banquereau Banks presents a nearly uniform acoustic transmission path. For a cross-axis traverse, the sides of the channel rise about 300 m in a distance of about 10-20 km depending on location along the channel. This rise provides a contrasting set of acoustic transmission conditions compared with the uniform depths of the channel.

Bottom material and layer thickness data were also obtained from the Mobil report cited previously. A diagram of the interpreted channel cross-section for the location shown in Figure 4-1 is presented in Figure 4-2. As shown in the figure, the bottom of the channel has a generally smooth surficial clay layer, but the lower layers and the bedrock have been deeply channelled by the original glacier activity. The details of the channelling were not modeled but were approximated using average depths for the sub-bottom and basement rock interfaces. The resulting bottom profile for the Track L2 model is shown in Table 4-1. Four bottom layers were included in a range-independent model with an averaged bottom depth of 460 m.

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[1] Preliminary Physical Environmental Review for Mobil's Artimon Block in the Laurentian Channel. Prepared for Mobil Oil Canada, P.O. Box 800, Calgary, AB T2P 2J7, by Seaconsult Marine Research Ltd., 8805 Osler Street, Vancouver, BC V6P 4G1, January, 1993.

The bottom profile used for Track L3 is shown in Table 4-2. The information for this profile was obtained using the cross-section shown in Figure 4-2 as modified using depth information for the track location from the Canadian Hydrographic Service chart. Supplementary bottom stratigraphy data were obtained from the Scotian Shelf Atlas of the Bedford Institute of Oceanography. As shown in Table 4-2, 12 range steps were used in the model to accommodate the depth changes along the track. Three bottom layers were used in the model for this track, with only two, glacial till and bedrock, for the steepest part of the channel wall rise. The Bedford Atlas showed that an upper sand layer occurs when the wall merges with the bank. This sand layer becomes thicker with distance away from the channel edge. In this area the sound propagation on the Banquereau Bank would be expected to be similar to that modeled near Sable Island.

Sound Speed Profiles

The sound speed data obtained for this area were analyzed by Defense Research Establishment Atlantic (DREA) under a sub-consulting contract to derive the mean and standard deviation profiles for each of the months planned for seismic operations. The results for May, July and October are shown in Figure 4-3. The most conspicuous feature of these plots is the extreme gradient developed between the surface and a depth of about 60 m. This is the result of strong surface warming during the summer months with a minimum of mixing with the colder layers below 100 m. A strong sound channel develops with a minimum sound speed (channel axis) between 50 and 100 m. Figure 4-4 shows that this channel persists into October. Since the profile for October can be seen to be similar to that for July, the model study used the sound speed profile data for May and July as representing the extremes of sound transmission variation expected during the survey season.

Track L2 Acoustic Model Results

The mean sound speed profiles (Figure 4-4) show similar sound channel development for May and July with the most pronounced effect in July. Thus, most of the modelling effort was concentrated on the July period with low frequency modelling from 12.5 Hz to 800 Hz for May to examine sound transmission seasonal effects.

May

Seismic array sound exposure level octave band spectra for a receiver depth of 10 m at selected ranges are shown in Figure 4-5. These spectra were derived using the RAM Model together with the techniques employed for the Sable Island modelling procedure. The dominant frequencies are again 100 and 200 Hz as was observed for the Sable Island results. A check of received levels vs range at 200 Hz for receiver depths of 10, 60 and 450 m did not show significant depth dependence.

The overall sound exposure levels versus range are shown in Figure 4-6. The level can be seen to remain relatively constant for ranges from 1 to 4 km suggesting that acoustic channelling or multipath transmission is overcoming the normally expected spreading loss. This may be the

result of sound becoming trapped in the sound duct and then being scattered out by small inhomogeneities. Even though the array at a depth of 6 m and the receiver at a depth of 10 m are well off the duct axis, there may be enough energy scattered into the duct to account for the anomalous results seen. Overall levels in the 150 to 160 dB range are predicted for ranges of 3 to 15 km. While these ranges are similar to those predicted for the Sable Island tracks (see Figure 23A), the levels at shorter ranges (< 10 km) are 10 dB or more below those predicted in the Sable Island results. This is discussed more fully following the July results.

July

The 200 Hz RAM Model predictions for the July mean sound speed profile are shown in Figure 4-7. The results are shown for receiver depths of 10, 60, 225, and 450 m. The shallow receiver depths show that a region of high transmission loss (TL notch) occurs at ranges of 400 to 1200 m. This is likely the result of the strong downward refraction of the direct path from the source which cuts off transmission rapidly until energy from reflected and scattered sound paths begins to become dominant beyond 1500 m. This effect does not occur below the sound duct at depths of 225 and 450 m. Data obtained from DREA for a source depth of 100 m can be seen to compare reasonably well with the model predictions even though the source in the present study is at a depth of 6 m.

The results of the RAM Model predictions for octave-spaced frequencies from 12.5 to 800 Hz for a constant receiver depth of 10 m are shown in Figure 4-8. The TL notch occurs at a range of about 800 m for all frequencies except 50 Hz. Beyond 1 km, the TL characteristics show cyclic irregularities suggesting that duct transmission or phase interference between several acoustic paths is dominant beyond this range[2]. The transmission loss above 800 Hz was modelled using the Weston/Smith Model. This model provides for adjustment of the bottom parameters to match data. Here the "data" used for this match were the RAM Model results for 800 Hz. The output of this Model for octave-spaced frequencies from 800 Hz to 100 kHz are shown in Figure 4-9.

Transmission loss predictions from both models were combined to obtain TL spectra for selected ranges as shown in Figure 4-10. The fluctuations in TL at low frequencies seen previously in Figure 4-8 result in the irregularly spaced spectra in Figure 4-10 (compare with Figure 4-5 for May). These TL spectra were combined with source level spectra for the seismic array to obtain sound exposure level spectra shown in Figure 4-11. The 1/3 octave band sound exposure levels for each range were then summed to obtain the predicted overall levels shown on the right side of the figure. Ambient noise data reported by Zakarauskas, Chapman, and Staal (1990) for the eastern Canadian continental shelf are also shown in Figure 4-11 to provide a comparison with the sound exposure levels for the survey source. If the reported ambient noise

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[2] The RAM Model is a single frequency, phase-coherent model. Broadband signals such as from an airgun array would not be expected to produce the large short-range level variations shown in the model results.

levels for 20 kt wind conditions are relevant in this area, the sounds from the survey source would be audible beyond 50 km along Track L2.

Track L3 Acoustic Model Results

The acoustic modelling work for Track L3 was performed using the July sound speed profile. As shown previously in Figure 4-1, Track L3 begins at the 400 m depth contour and continues WSW up the side of the channel to extend along the Banquereau Bank for a total distance of 50 km. It represents sound transmission from a survey vessel working at the edge of the channel. The track profile versus range (Table 4-2) shows that the steepest rise occurs at ranges of 6 to 8 km where the water depth decreases from 200 to 80 m.

Figure 4-12 was obtained using the bottom profile of Table 4-2 with the RAM Model at selected frequencies for a constant receiver depth of 10 m. The fluctuations in TL shown in the figure are not as large as those seen for Track L2. The decrease in bottom depth between 6 and 8 km produces a rapid increase in TL at all frequencies. The highest frequency used for the RAM Model for this track was 750 Hz since 800 Hz did not provide acceptable results for the bottom profile conditions. The Weston/Smith Model was again used for higher frequency TL predictions resulting in the curves shown in Figure 4-13.

The TL predictions from both models were again combined to produce TL spectra for selected ranges as shown in Figure 4-14. These spectra are more orderly than those obtained for July conditions along Track L2 (Figure 4-10). Combining the source level spectra with the TL spectra produced the sound exposure level spectra shown in Figure 4-15. The ambient noise data for 20 kt wind conditions compared with the seismic array spectra suggest that the survey sounds from an array operating at the edge of the Laurentian Channel may not be audible at a range of 50 km on the Banquereau Bank.

Comparison of Overall Sound Exposure Levels for Tracks L2, L3 and S1 (Sable Bank)

The overall sound exposure levels were calculated for the spectra shown in Figure 4-15 and compared with levels from Track L2 and also with levels from Track S1 on the Sable Bank. The S1 results were representative of the results obtained for the other Sable Bank tracks (see Figure 23A in the main report). Figure 4-16 presents the combined track results.

The predictions for May and July along Track L2 are comparable except for ranges less than about 1.3 km. The TL notch observed for the July conditions produced anomalously low sound levels near the source. The levels rise and generally agree with the May results beyond a range of about 1.3 km. The levels along L2 are between 160 and 150 dB SEL at ranges from 3 km to 15 km for May and about 3.5 to 13 km for July (neglecting the low level region near the source).

The results for July conditions along Track L3 show higher SEL levels near the source than seen for L2, but the SEL drops rapidly beyond 5 km due to the rapid decrease in water depth. The levels are more that 10 dB lower than those for Track L2 beyond 10 km. The ranges

for 160 and 150 dB SEL are 5 and 7.4 km respectively. These ranges are not expected to change very much for May since downward refracting conditions are also present during this time period and high bottom reflection losses along the channel edge will control transmission conditions.

The predicted SEL for the Sable Bank track is seen to be generally higher than levels predicted for the Laurentian Channel tracks except at ranges greater than about 15 km. The flat region in the Laurentian L2 track SEL between ranges of 1 and 4 km becomes very evident when compared with the more normal TL characteristic of the Sable S1 curve. However, beyond 10 km the L2 and the S1 curves can be seen to agree with a SEL from the seismic array of 150 dB at about 14 km. These modelled results should eventually be compared to measured data.

Table 1.   **Laurentian Channel Track L2 Profile**

Range (km)	Water Depth (m)*
0	418
40	433
85	453
140	502
200	450

Avg. Depth   460
(Range-independent model used)

* From chart soundings

Bottom Material	Avg. Bottom of Layer Depth (m)	Parameters: Comp. Wave Speed	Density	Attenuation
LaHave Clay*	467	1513 m/sec	1.4 gm/cc	0.085 dB/wl
Emerald Silt**	482	1615	1.74	0.162
Till***	510	1900	2.1	0.057
Bedrock (sedimentary)***	to 2000	2050	2.2	0.103

* Parameters from J.H. Beebe, S.T. McDaniel, and L.A. Rubano (1982). J. Acoust. Soc Am. **71** p.1417-1426.
** from E.L. Hamilton (1980). J. Acoust. Soc. Am. **68**(5) p. 1313-1340
*** from D.M.F. Chapman and D.D. Ellis (1980). *Bottom-Interacting Ocean Acoustics*, p. 525-539.

Table 2.   **Laurentian Channel Track L3 Profile**

Depth to Bottom of Layer (m) ↓   Range (km) >

Material	0	4.3	6.4	6.8	7.3	7.7	8.1	9.8	13.7	33	37.2	50
Water	400	300	200	150	100	90	80	70	60	50	40	33
Sand	400	300	200	150	100	95	90	85	80	70	65	60
Till	500	470	360	270	150	120	105	100	100	100	100	100

Bedrock to 3000 m ---

Bottom Material Parameters*	Comp. Wave speed	Density	Attenuation
Sable Sand	1750 m/sec	2.06 gm/cc	0.455 dB/wavelength
Glacial Till	1900	2.1	0.057
Bedrock (sedimetary)	2050	2.2	0.103

* From Chapman and Ellis (1980)
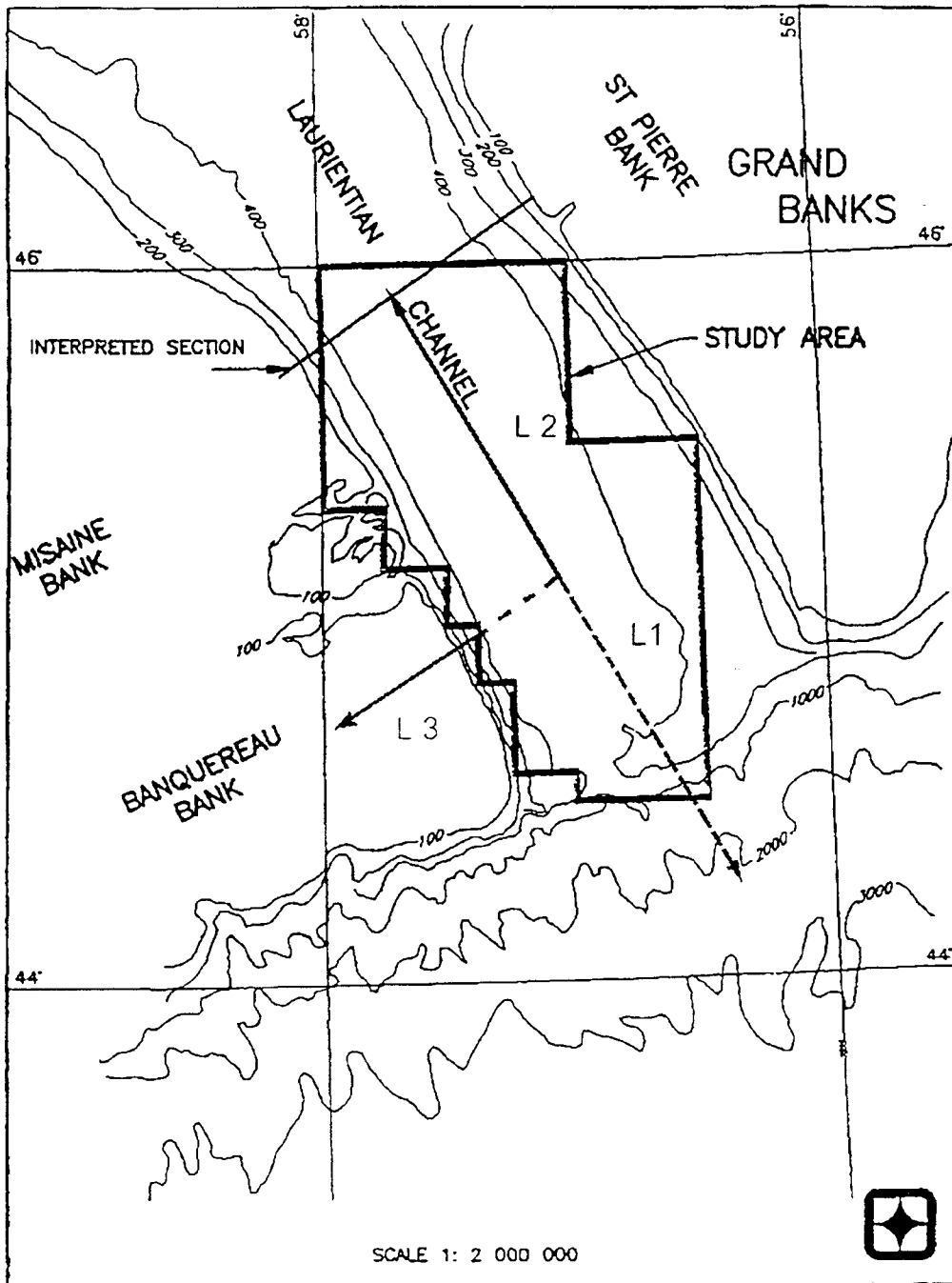
Laurentian Channel TL Transects

Figure 4-1. Sound Propagation Paths Modeled in the Laurentian Channel.
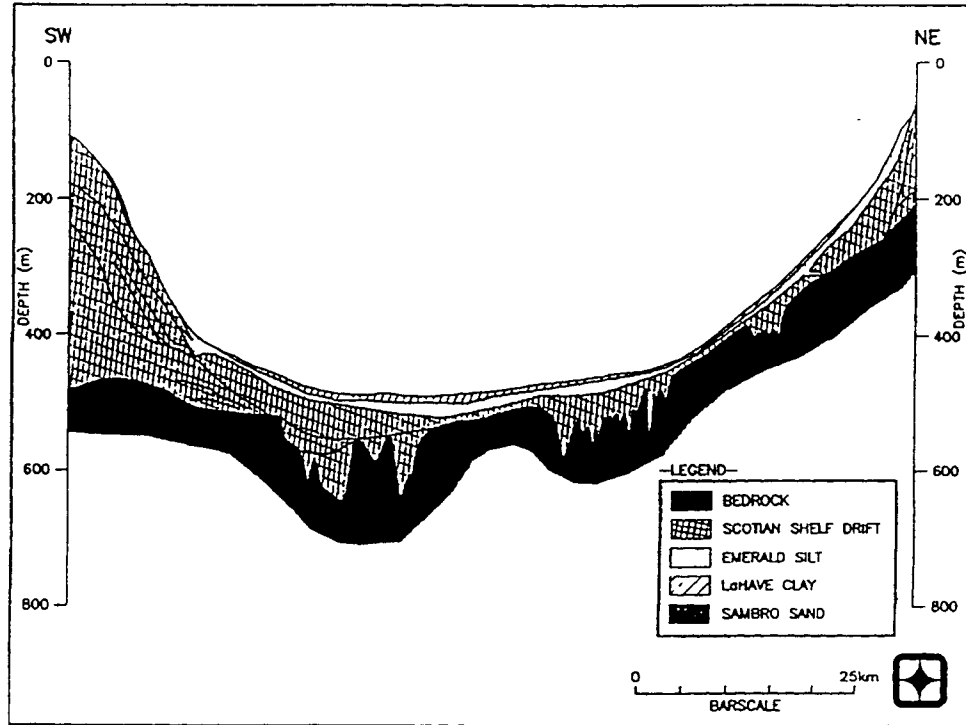
Figure 4-2.   Bottom material and layer thickness
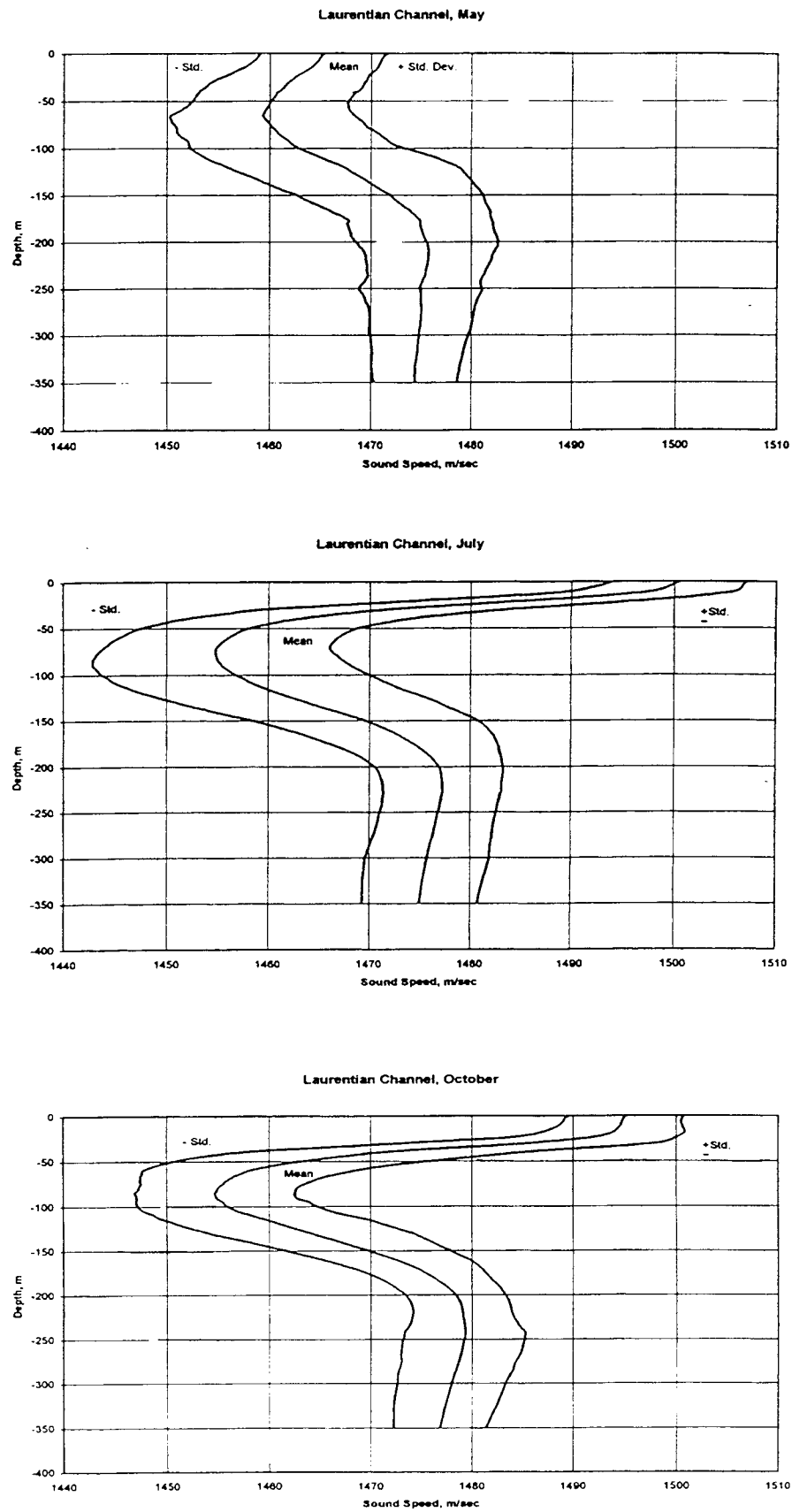for the Laurentian Channel.

Figure 4-3. Average Sound Speed Profiles in the Laurentian Channel in the Months of May, July and October.
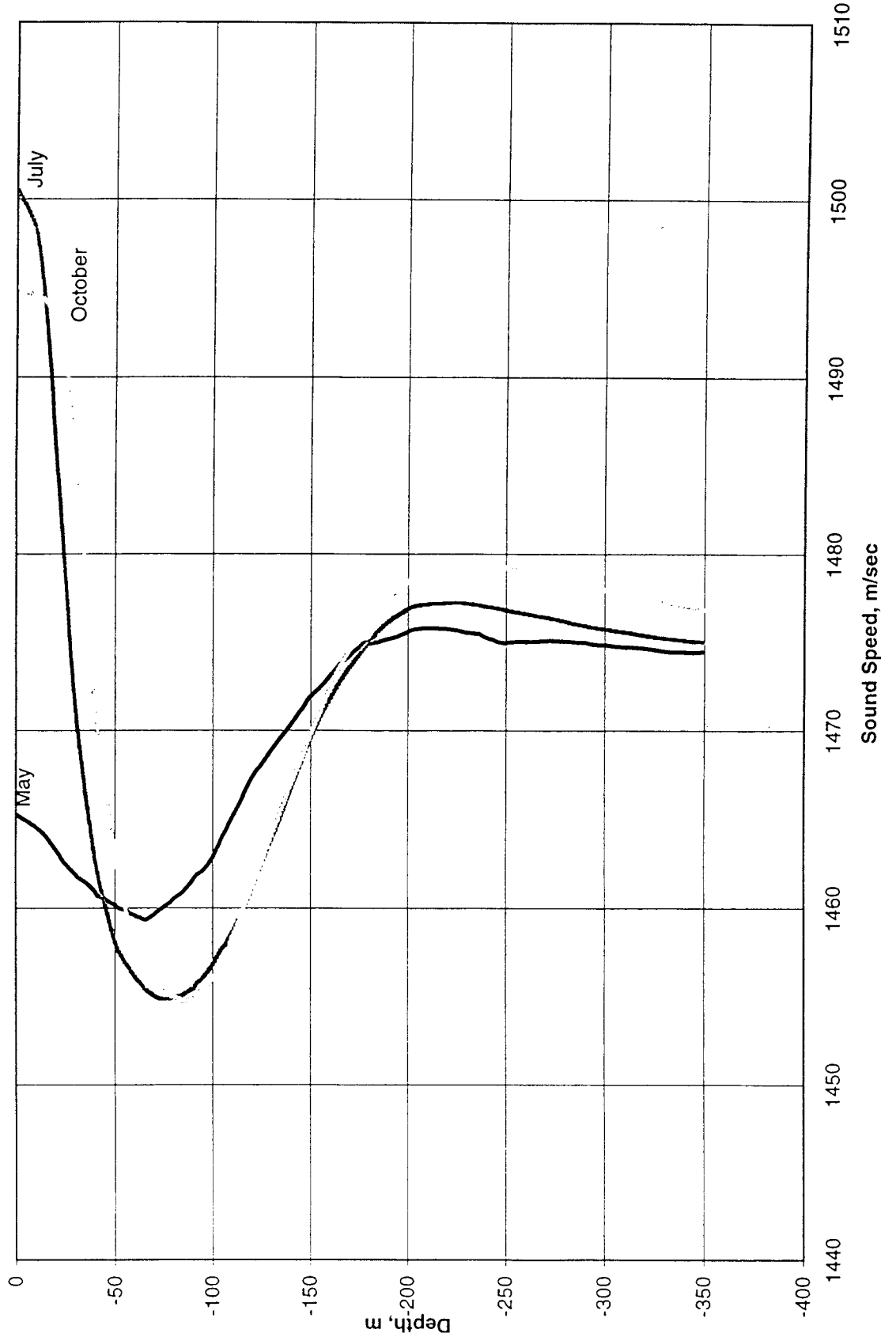
Figre 4-4. Laurentian Channel, Mean SVP

July

October

May

Sound Speed, m/sec

Depth, m

Figure 4-5. Seismic Array Sound Spectra VS Range

Laurentian Channel, Track L2

Receiver Depth, 10 m, May. Mean SVP
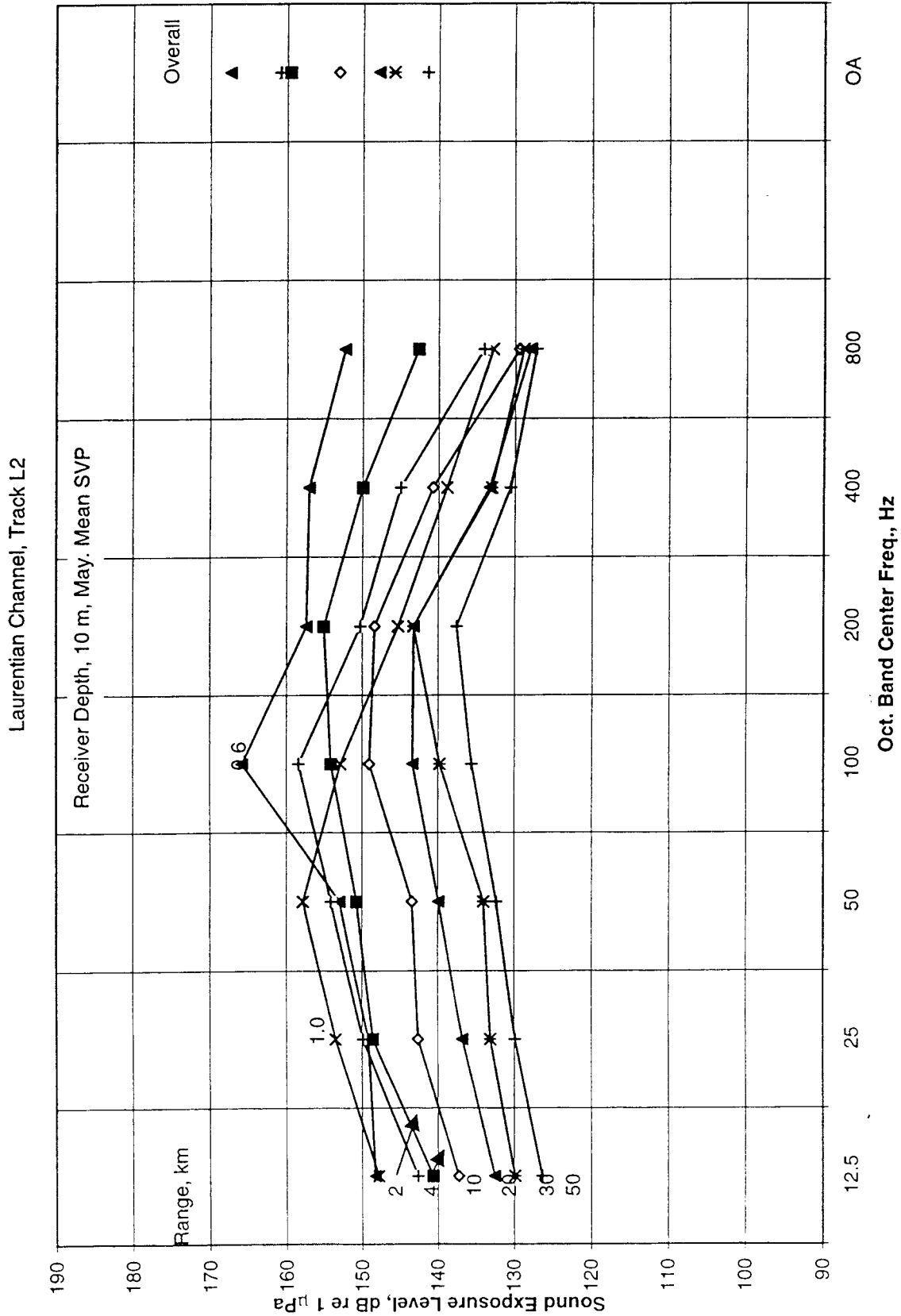
Figure 4-6.   Predicted Seismic Array Sound Exposure Level
Laurentian Channel, Track L2
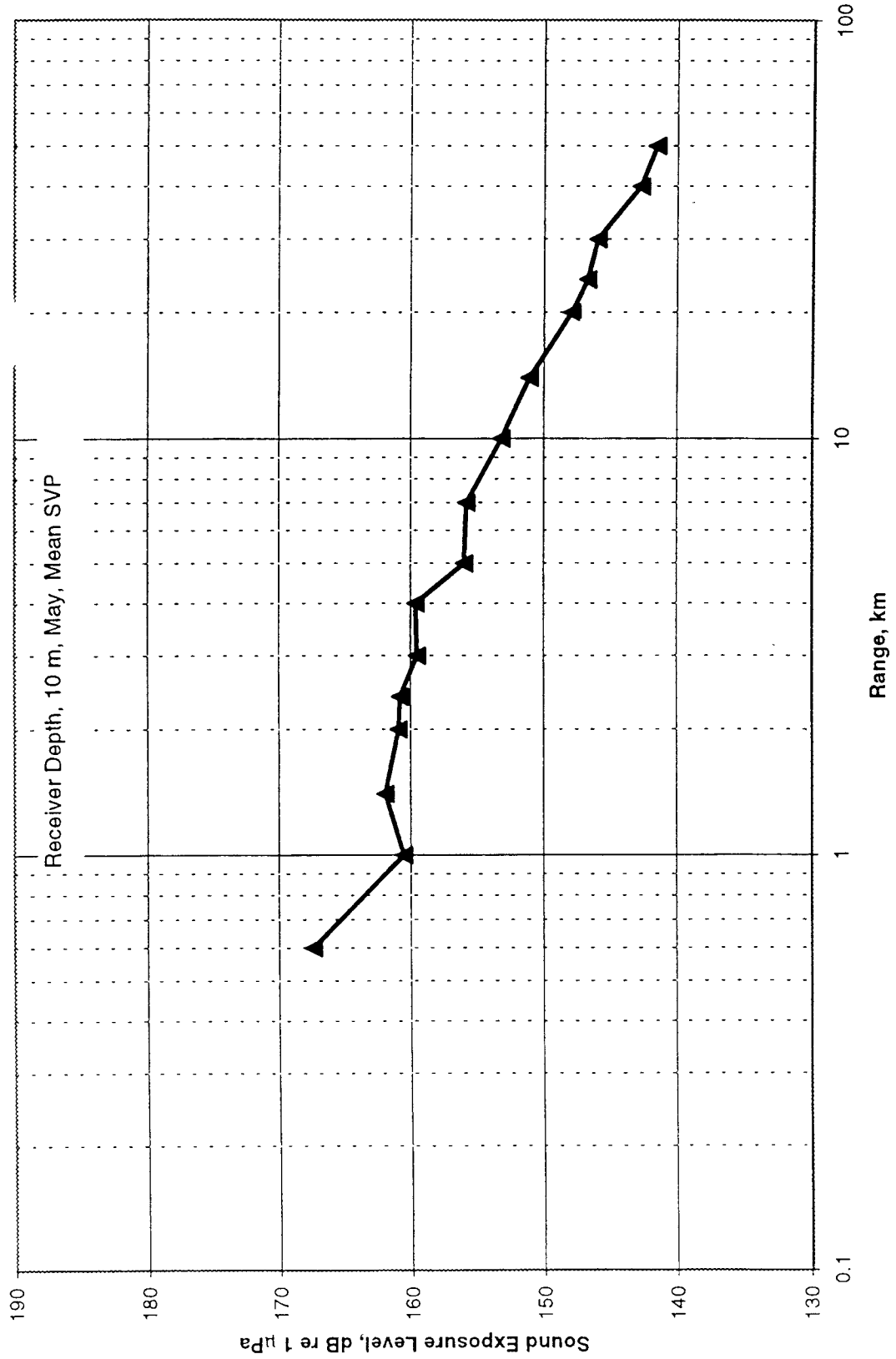
Figure 4-7. Laurentian Channel Track L2
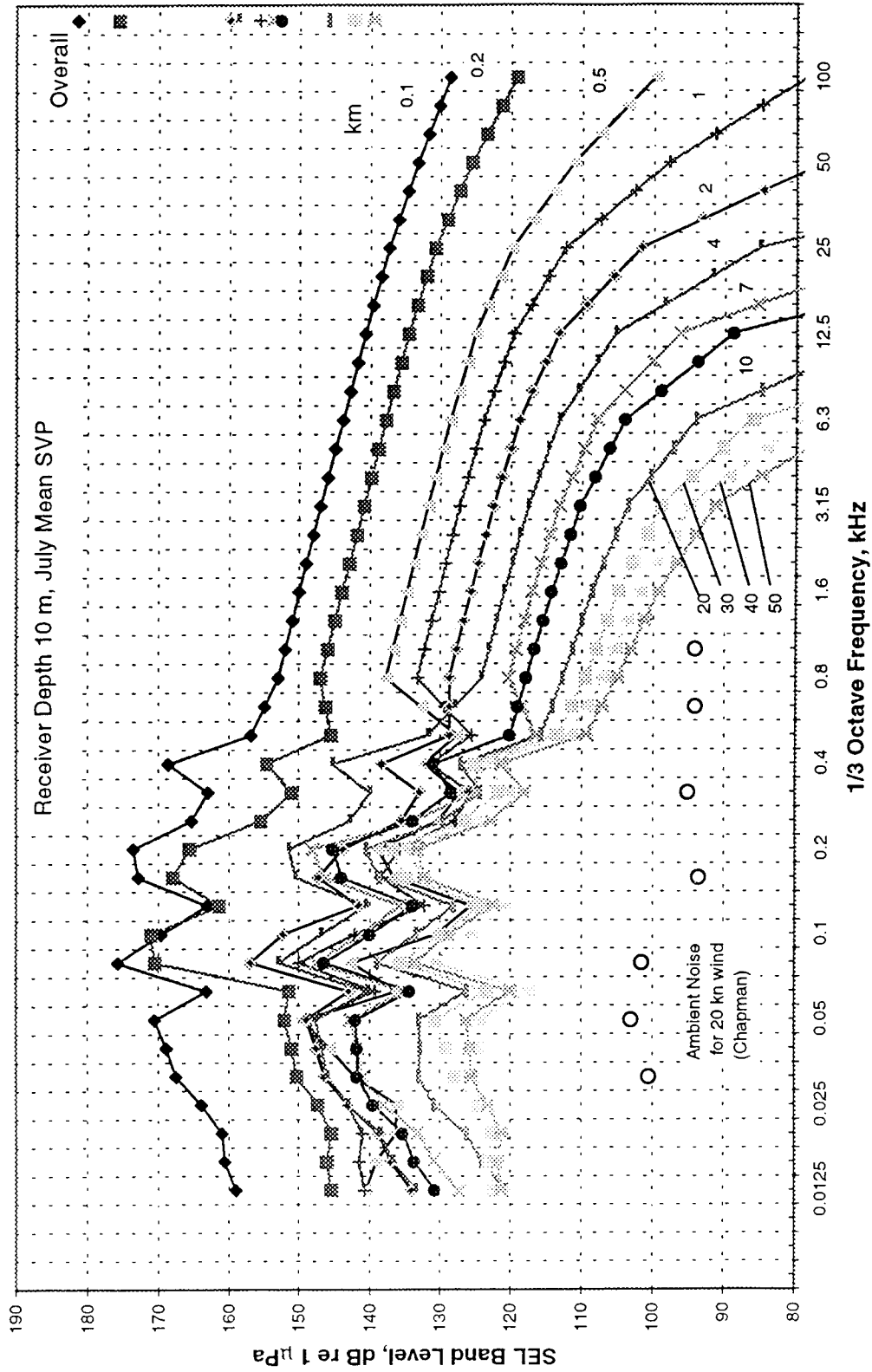Receiver Depths, 10, 60, 225 and 450 m
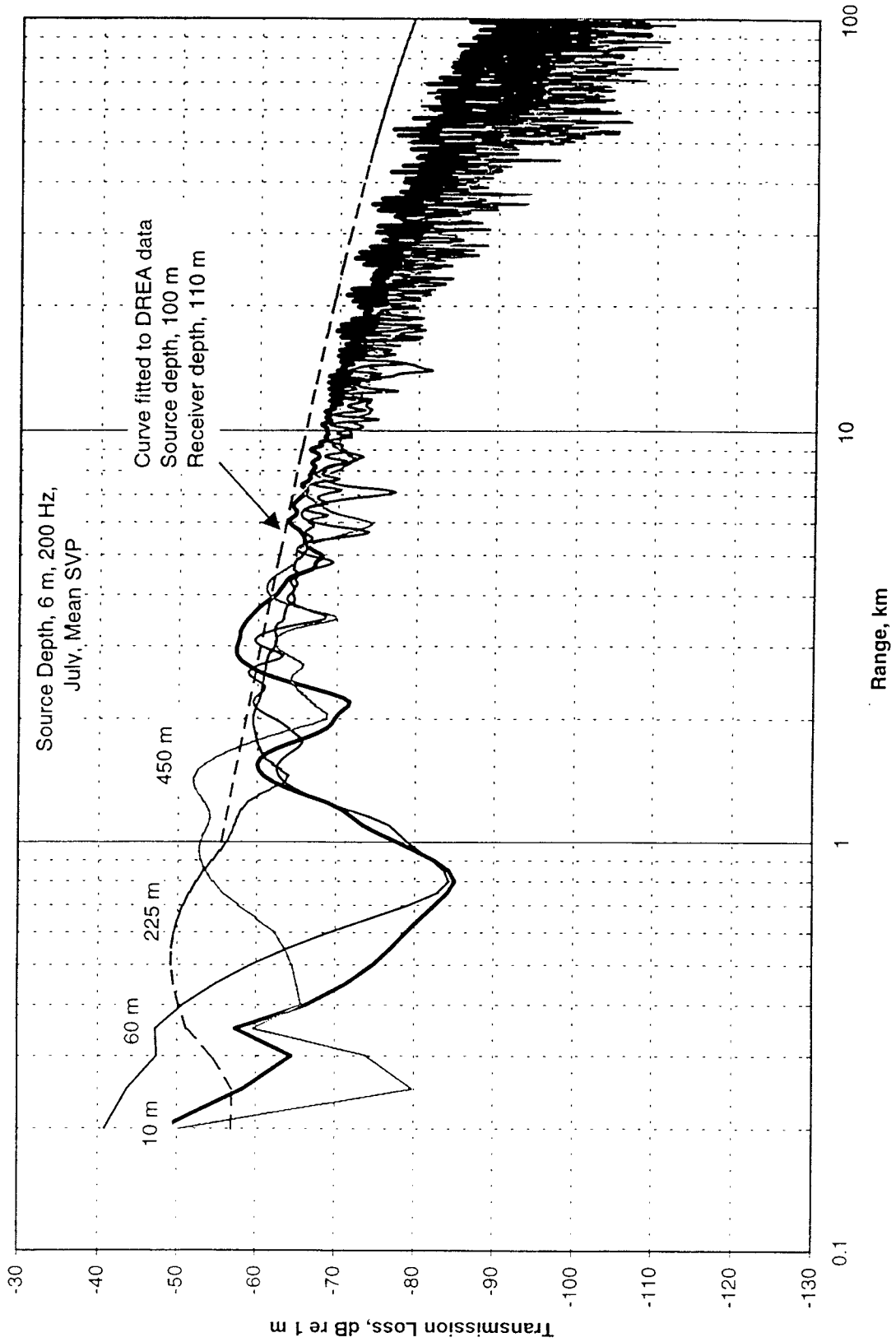
Figure 4-8. Transmission Loss VS Frequency

Laurentian Channel Track L2
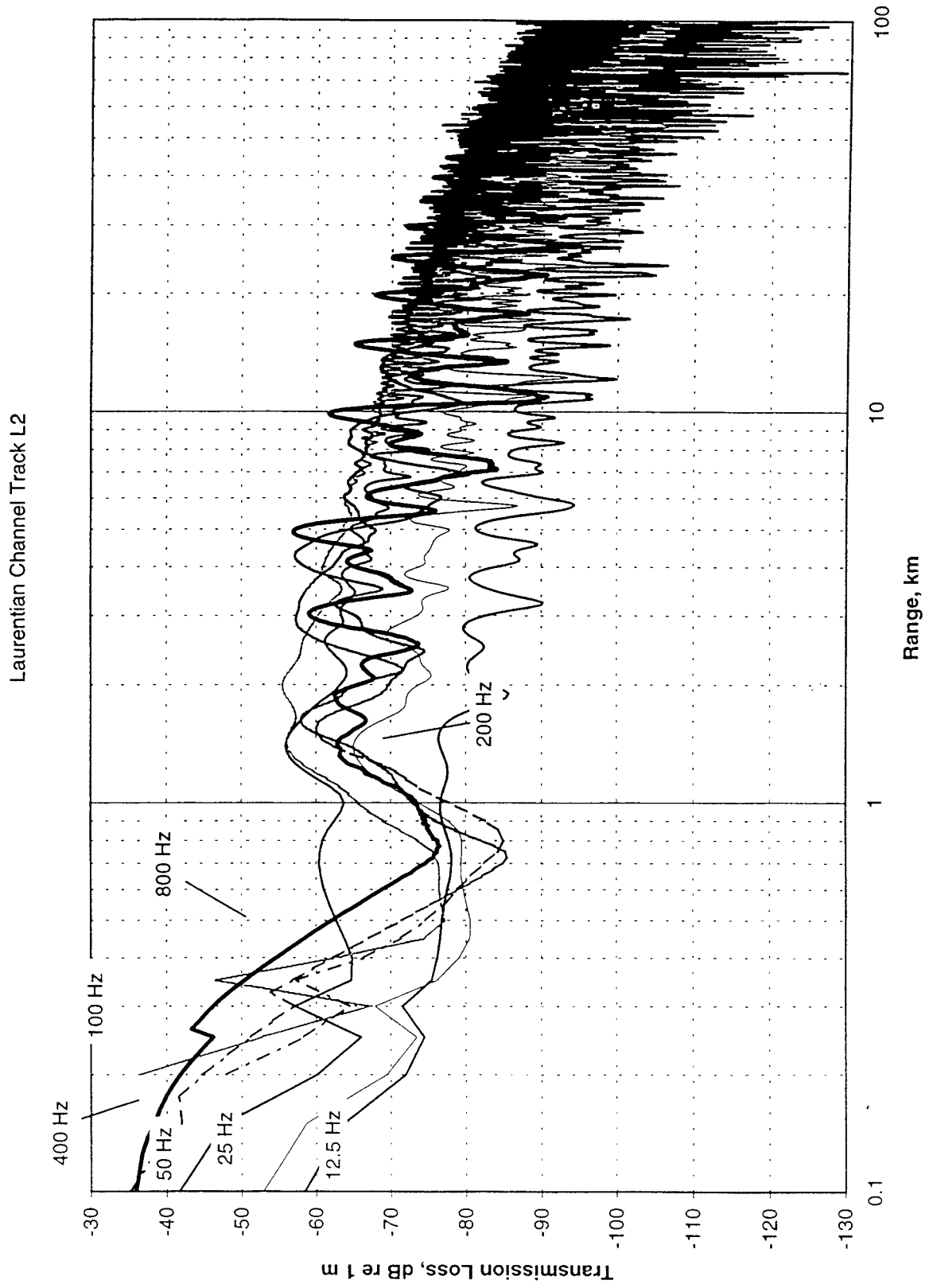
Figure 4-9. Laurentian Channel Track L2

Weston/Smith Model results for high frequencies

Transmission Loss VS Frequency
10 m Receiver Depth, July mean SVP
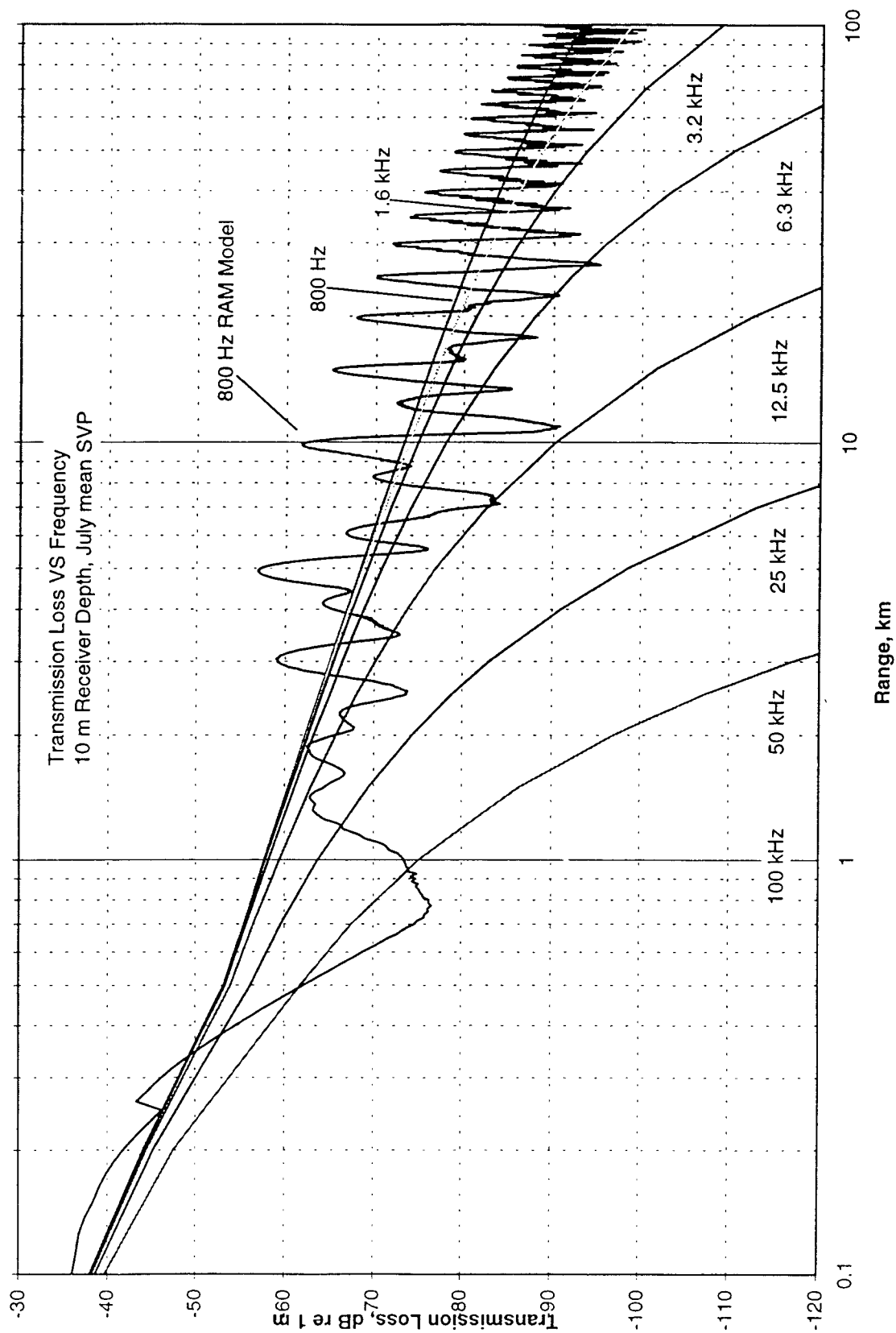
Figure 4-10. Laurentian Channel Track L2
Transmission Loss Spectra
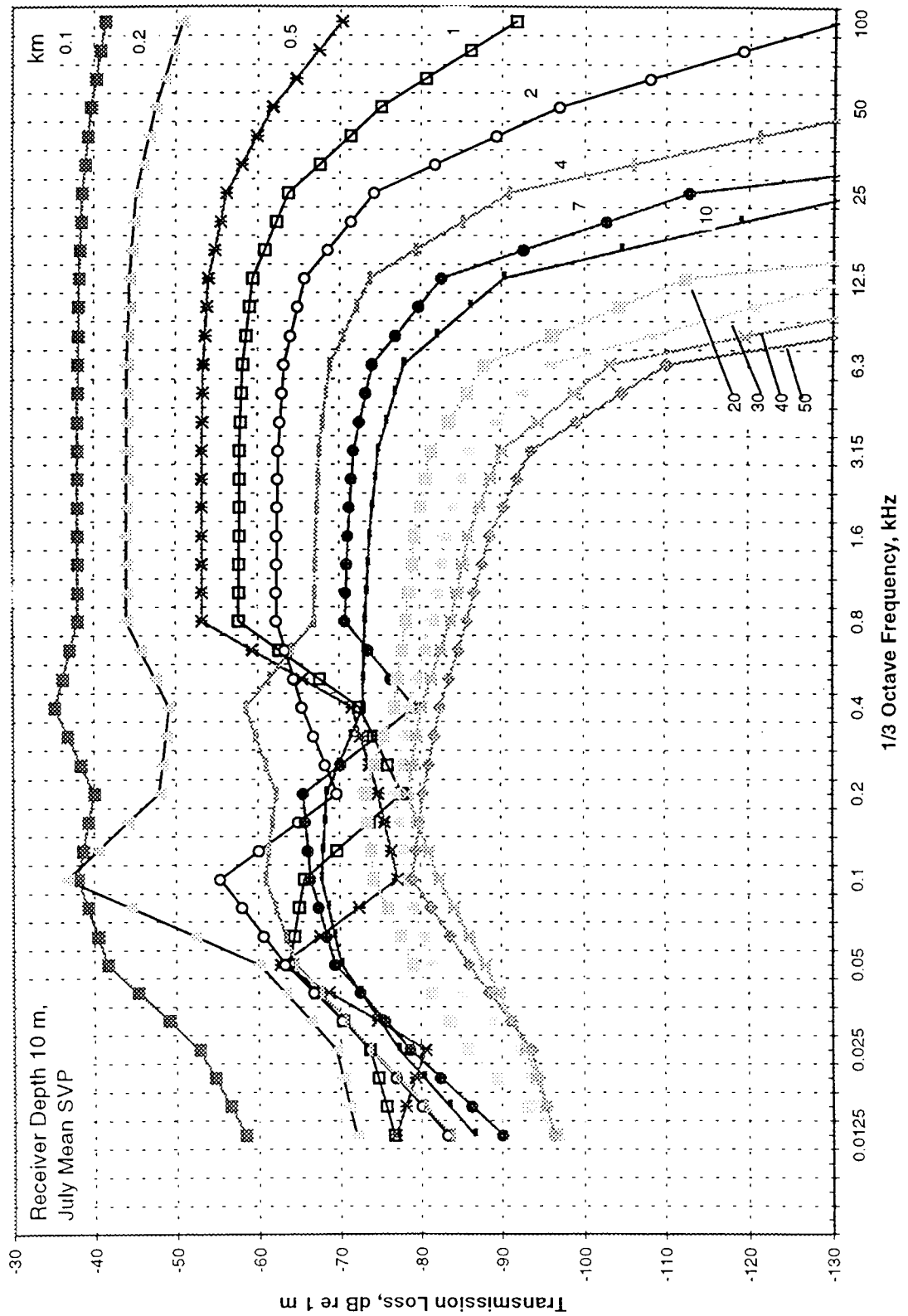
Figure 4-11. Laurentian Channel Track L2
Seismic Array, Sound Exposure Level

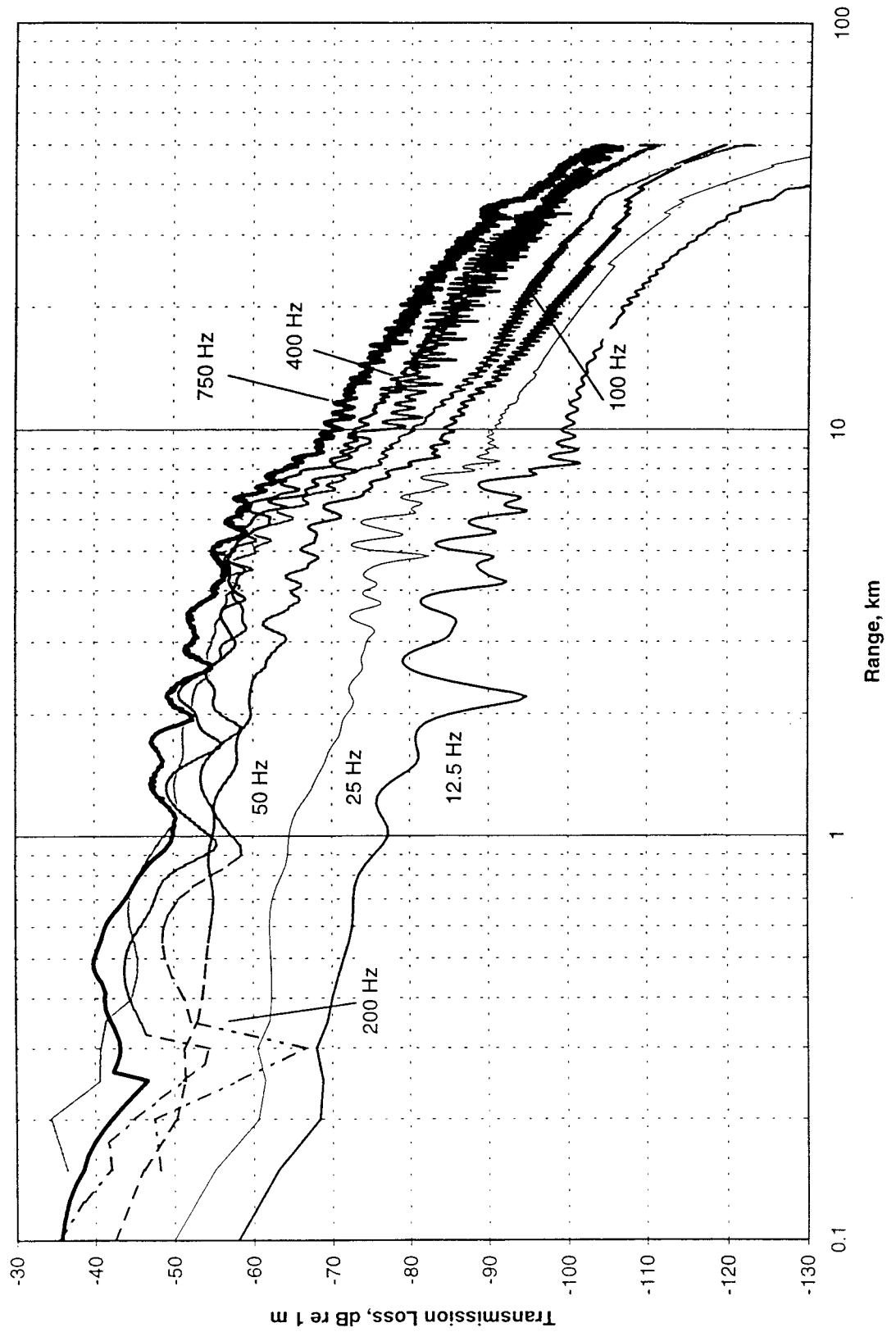**Figure 4-12. Transmission Loss VS Frequency**

Laurentian Channel Track L3

Figure 4-13. Laurentian Channel Track L3
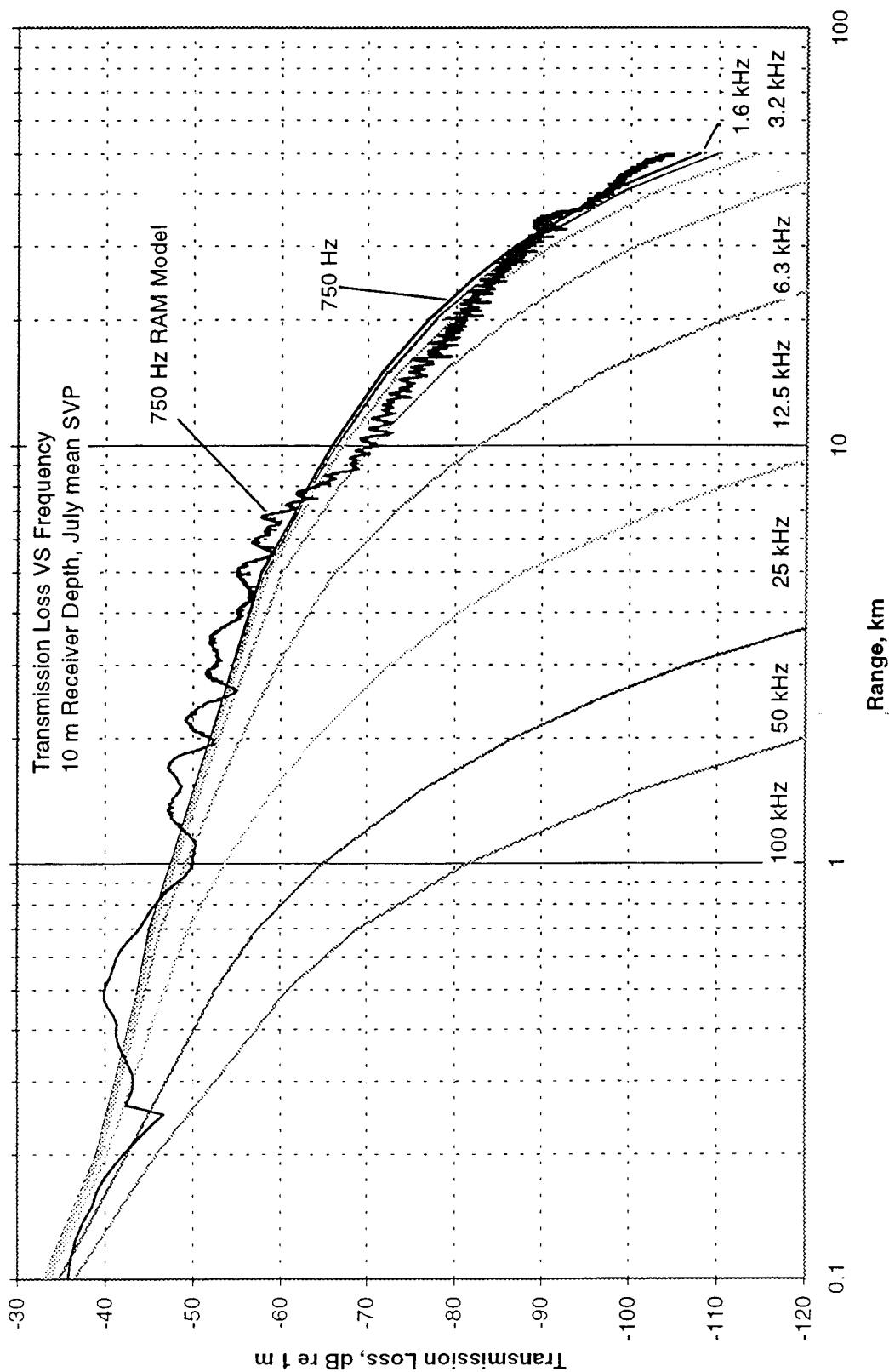Weston/Smith Model results for high frequencies

Transmission Loss VS Frequency
10 m Receiver Depth, July mean SVP

Figure 4-14. Laurentian Channel Track L3
Transmission Loss Spectra
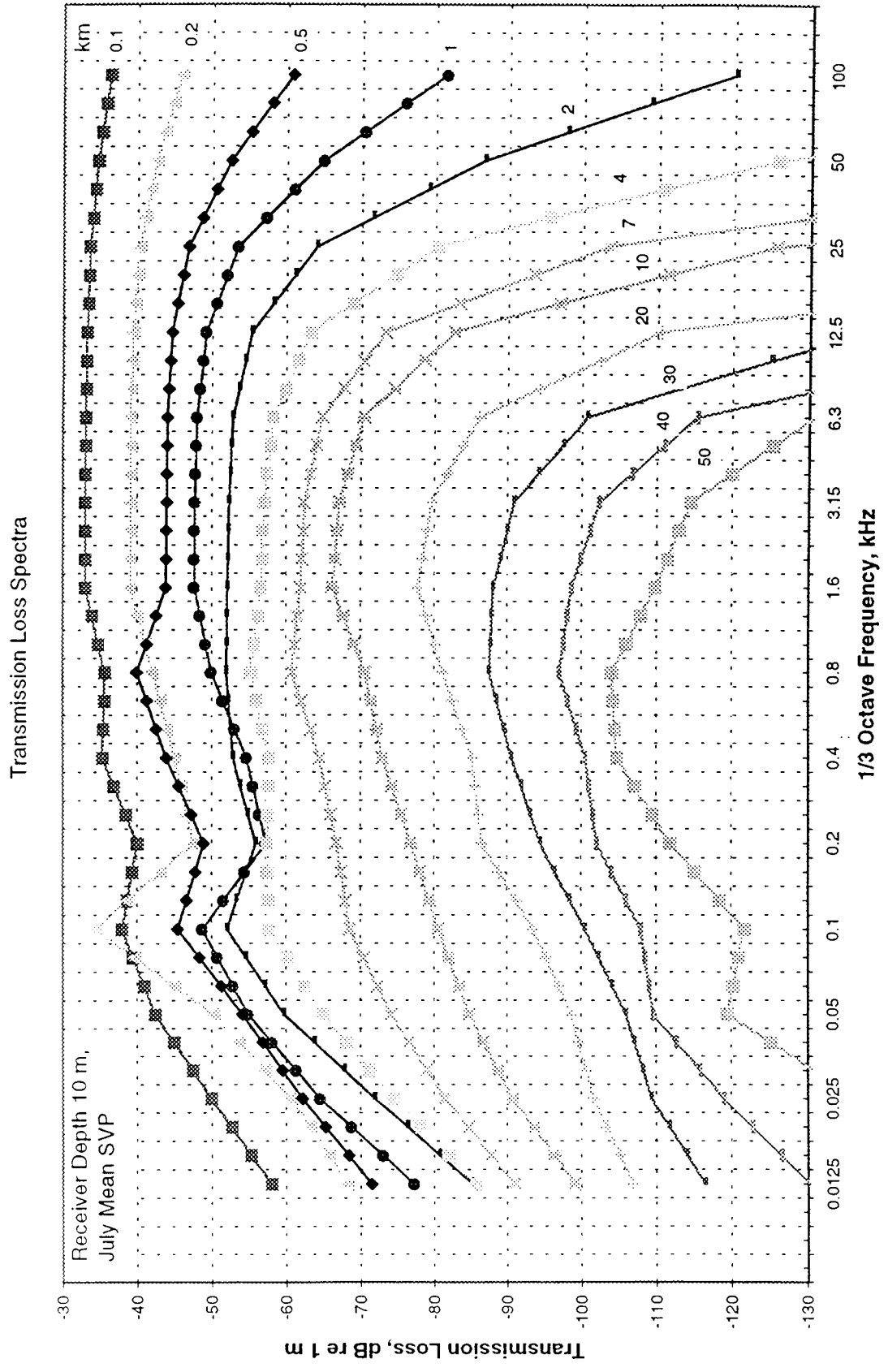
Figure 4-15. Laurentian Channel Track L3
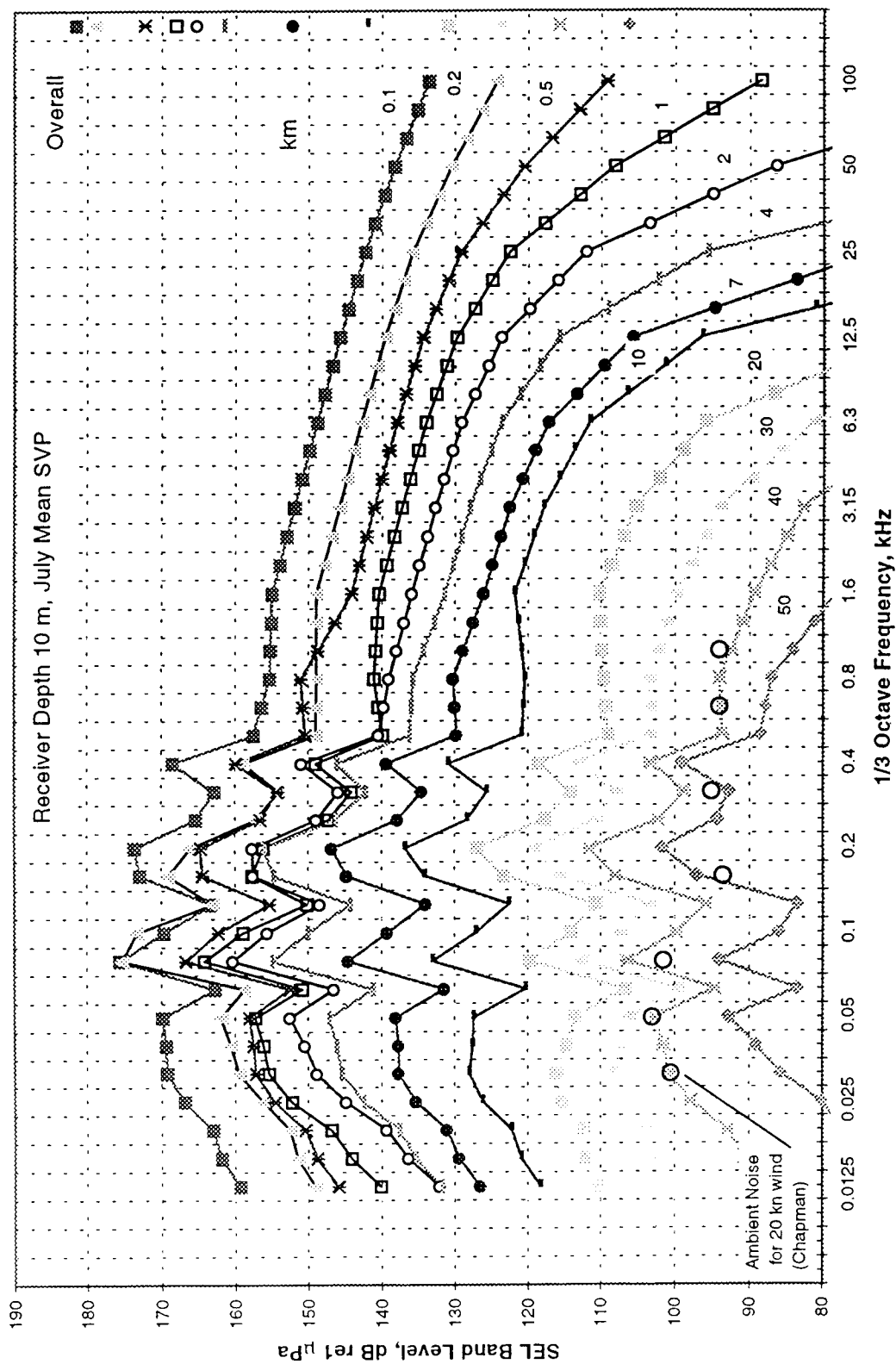
Seismic Array, Sound Exposure Level

Receiver Depth 10 m, July Mean SVP

Figure 4-16. Laurentian Channel Track Comparison
Overall Sound Exposure Level VS Range