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# GRAND BANKS OTTER TRAWLING EXPERIMENT:
# III. SAMPLING EQUIPMENT, EXPERIMENTAL DESIGN, AND METHODOLOGY

By

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# ABSTRACT

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In order to obtain quantitative information on the impacts of otter trawling on benthic communities, the Canadian Department of Fisheries and Oceans initiated an experiment on the Grand Banks in July 1993. Further work was carried out in September 1993, July 1994 and June/July 1995. The experiment had two components; a major component, which we have termed the "corridor study" and a minor component termed the "long-trawl".

The study site for the primary experiment, the "corridor study", centred at $47^0$ 09' N, $48^0$ 17' W, has an average water depth of about 137 m, a well-sorted sandy sediment, and an extensive benthic fauna. The area was closed to trawling for the duration of the experiment. In 1993, after pre-trawl sampling by the C.S.S. *Parizeau*, three replicate experimental corridors, each 13 km long and approximately 200 m wide, were trawled twelve times by the C.S.S. *Wilfred Templeman* using a commercial Engel 145 otter trawl equipped with rockhopper foot gear. The trawl catch, including captured benthic organisms, was immediately processed and sampled. Immediately after trawling, the area was again sampled by the *Parizeau* to evaluate immediate impacts. The extent and duration of physical disturbance was visually assessed using video imaging by BRUTIV and acoustically assessed using side-scan sonar, DRUMS$^{TM}$, and RoxAnn$^{TM}$. Biological samples, in both trawled and reference corridors, were collected with a newly-developed hydraulically-powered grab (0.5 $m^2$) and an existing epibenthic sled which was modified to provide more quantitative samples. Both the grab and sled are video-equipped. The high resolution acoustic imaging system, DRUMS, was also newly developed for the study. Variables measured included epifauna, macrofauna, meiofauna, bacteria, grain size, organic carbon/nitrogen, and sediment structure. A second sampling was carried out in September 1993, ten weeks after trawling, to evaluate short-term impacts. A third sampling was carried out, in July of 1994, to evaluate intermediate-term impacts one year after the initial trawling; the corridors were then re-trawled and immediately thereafter a fourth sampling, the second for immediate impacts, was carried out. A fifth sampling, in June/July 1995, evaluated intermediate-term and cumulative impacts from the 1993 and 1994 trawlings. The corridors were then re-trawled and immediately afterward a sixth sampling, the third for immediate impacts, was carried out.

The secondary experiment, the "long-trawl", was designed by the Geological Survey of Canada to traverse a range of water depths and sediment types in order to determine decay rates of a trawl-created bottom disturbance, as an analog for an iceberg scour, in these substrates and energy regimes. During the establishment of the "long-trawl" in July 1993, the C.S.S. *Parizeau* accompanied the C.S.S. *Wilfred Templeman* from $47^0$ 04.00' N, $48^0$ 11.00' W to $46^0$ 45.46' N, $48^0$ 46.27'W as the *Templeman* laid down a trawl track over a distance of 60 km and covering a depth range of 75-135 m . The "long-trawl" was resurveyed using side-scan sonar in September 1993, July 1994 and July 1995 by the C.S.S. *Parizeau* and in August 1994 by the C.S.S. *Hudson.*

This report describes both the equipment used, most of it new or highly adapted, and the design and methodology of the experiments.

## RÉSUMÉ

T. W. Rowell, P. Schwinghamer, M. Chin-Yee, K. Gilkinson, D.C. Gordon Jr., E. Hartgers, M. Hawryluk, D. L. McKeown, J. Prena, D. P. Reimer, G. Sonnichsen, G. Steeves, W.P. Vass, R. Vine and P. Woo. 1996. Grand Banks otter trawling experiment: lll, sampling equipment, experimental design, and methodology. Can. Tech. Rep. Fish. Aquati. Sci. 2190: viii +36 p.

Afin d'obtenir des données quantitatives sur les impacts de la pêche au chalut à panneaux sur les communautés benthiques, le ministère canadien des Pêches et des Océans a entrepris, en juillet 1993, une expérience sur les Grands Bancs. D'autres travaux ont été effectués en septembre 1993, en juillet 1994 et en juin et juillet 1995. L'expérience comportait deux éléments, soit un élément principal désigné par l'expression "étude en corridor" et un élément secondaire appelé "long chalutage".

Lors de l'expérience primaire, soit "l'étude en corridor", le site d'étude centré sur $47^o$09'N par $48^o$17'W présentait une profondeur d'environ 137 m et possédait des sédiments sableux bien assortis et une importante faune benthique. La pêche au chalut a été interdite dans cette zone pendant la durée de l'expérience. En 1993, après le prélèvement d'échantillons préalables par le n.s.c. *Parizeau,* le n.s.c. *Wilfred Templeman* a, à douze reprises, procédé au chalutage avec un chalut commercial à panneaux Engel 145, muni sur le bourrelet d'un dispositif permettant d'éviter les roches, dans trois corridors expérimentaux, chacun mesurant 13 km de long et environ 200 m de large. Les prises, y compris les organismes benthiques capturés, ont été immédiatement traitées et échantillonnées. Le *Parizeau* a ensuite prélevé d'autres échantillons en vue d'évaluer les impacts immédiats. On a procédé à une évaluation visuelle de l'importance et de la durée de la perturbation physique par imagerie vidéo de BRUTIV, ainsi qu'à une évaluation acoustique par sonar à balayage latéral, DRUMS$^{MD}$, et RoxAnn$^{MD}$. Des échantillons biologiques ont été prélevés dans les corridors chalutés et dans les corridors de référence, grâce à un grappin hydraulique (0,5 $m^2$) nouvellement mis au point et à un traîneau existant de prélèvement épibenthique que l'on a modifié de façon à obtenir des échantillons plus quantitatifs.

Le grappin et le traîneau étaient, l'un et l'autre, munis d'une caméra vidéo. Le système d'imagerie acoustique à haute résolution DRUMS a nouvellement été mis au point pour l'étude. Les variables mesurées comprenaient les organismes épifauniques, macrofauniques et méiofauniques, les bactéries, la granulométrie, le carbone et l'azote organiques et la structure des sédiments. On a prélevé une deuxième série d'échantillons en septembre 1993, soit dix semaines après le chalutage, pour évaluer les impacts à court terme. On a aussi prélevé une troisième série d'échantillons en juillet 1994 pour évaluer les impacts à moyen terme un an après le chalutage; on a chaluté de nouveau les corridors, puis on a procédé immédiatement à un quatrième échantillonnage, le deuxième destiné à déterminer les impacts immédiats. Un cinquième échantillonnage réalisé en juin et juillet 1995 a permis d'évaluer les impacts à moyen terme et les impacts cumulatifs des chalutages réalisés en 1993 et en 1994. On a encore chaluté les corridors, puis on a immédiatement procédé à un sixième échantillonnage, soit le troisième destiné à déterminer les impacts immédiats.

La Commission géologique du Canada a conçu l'expérience secondaire, soit le prélèvement par "long chalutage", pour prélever des échantillons à diverses profondeurs et sur divers types de sédiments dans le but de déterminer les vitesses de décroissance d'une perturbation du fond provoquée par le chalutage, en comparaison à une cicatrice d'affouillement par un iceberg, dans ces substrats et à ces régimes énergétiques. Durant la réalisation du prélèvement par "long chalutage" en juillet 1993, le n.s.c. *Parizeau* a accompagné le n.s.c. *Wilfred Templeman* à partir de 47°04,00'N par 48°11,00'W jusqu'à 46°45,46'N par 48°46,27'W pendant que le *Templeman* procédait au chalutage sur une distance de 60 km à une profondeur de 75-135 m. Les effets de cette opération ont été évalués grâce à un sonar à balayage latéral, en septembre 1993, juillet 1994 et juillet 1995, par le n.s.c. *Parizeau*, et en août 1994 par le n.s.c *Hudson*.

Dans ce rapport, on décrit le matériel utilisé, dont la plus grande partie est nouveau ou hautement adapté, ainsi que la méthodologie des expériences et la façon dont elles ont été conçues.

# INTRODUCTION

The fishing industry in Atlantic Canada uses a variety of mobile gear types, the most common being otter trawls, scallop rakes and hydraulic clam dredges. Concern as to the possible effects that these harvesting methods may have on fish stocks and the habitat supporting them has increased dramatically in recent years (Haché 1989; Harris 1990). In 1990, these concerns resulted in the initiation by the Scotia-Fundy and Newfoundland Regions of the Department of Fisheries and Oceans (DFO) of a major research project to study fishing impacts.

A review of existing Scotian Shelf side-scan sonar records for evidence of bottom disturbance from mobile fishing gear by Jenner et al. (1991) indicated that less than 2% of available records contained any evidence of physical disturbance by such gear. Most of the observed disturbance was due to groundfish trawls and was restricted to areas of low sediment transport. For the Grand Banks, less than 10% of the total length of record showed any evidence, even slight, of trawling disturbance (re-analyses of data from Harrison et al. 1991). The south and eastern areas of the Banks were more intensively trawled than other areas, but even in these areas over 90% of the line segments with trawl tracks were in the <5% disturbance category. Less than 1% of the length of record showing disturbance was in the heaviest (>25%) disturbance category. These results provided no information on the effects of the physical disturbance observed.

A more detailed analysis of the spatial pattern of trawling on the Grand Banks and Labrador Shelf is available through analysis of commercial trawling effort data collected in the fisheries observer program over the period from 1980 to 1992. From these data, the area of bottom scoured by dragging has been calculated from duration of set, speed of vessel, and type of net used (Schwinghamer and Kulka, unpublished data). The most intense effort was shown to be directed toward the edges of the Banks and especially along the northeast Newfoundland continental shelf; an important spawning area for northern cod. Areas of intense shrimp (*Pandalus*) trawling also occur along the Labrador Shelf up to Cape Chidley. The general magnitude of the percent of bottom area trawled, as determined in this manner, is in accord with the results of the earlier side-scan record analysis. Relatively small areas are intensely trawled, but even in these areas only about 10% of the bottom surface area is trawled annually.

Brylinsky et al. (1994) investigated the impacts of otter trawls on the intertidal sediments of the Minas Basin; with trawling carried out at high tide and observations of effects made at low tide when the trawled area was exposed. Impacts were judged to be relatively minor, especially since the intertidal sediments of this macrotidal area are already exposed to natural stresses imposed by storms and winter ice. In contrast, the benthic communities found on offshore fishing areas have a much richer and morediverse assemblage of organisms, especially epibenthic forms which are much more susceptible to possible damage from mobile gear.

Previous studies and reviews (BEON 1990; BEON 1991; Messieh et al. 1991; Jones 1992) and reports by ICES Working Groups (Anon. 1991; Anon. 1992a; Anon. 1992b; Anon. 1993a; Anon. 1993b) and others had identified or suggested the following possible effects of mobile gear types:

- direct mortality of those organisms harvested, those captured but discarded, and those left on the seafloor;
- indirect mortality of organisms which are exposed to predators or unable to escape predators due to injury;
- alteration of the physical properties of the seafloor;
- alteration of chemical fluxes between sediments and the water column; and
- alteration of the structure of benthic habitat and its suitability for particular species.

We decided to initially restrict our study to the impacts of otter trawls, this being the most widely used form of mobile gear in Atlantic Canada. Preliminary surveys of the Scotian Shelf and Grand Banks, in 1991 and 1992, led to the selection of an area on the Grand Banks for the trawling impact study (Prena et al. 1996). In 1997, it is planned to carry out further trawling impact studies in a different physical regime on the Scotian Shelf so as to make the overall results more broadly applicable. Additionally, it is planned to experimentally examine the impacts of clam and scallop dredges.

Quantitative sampling of the benthos has always proven difficult. Early sampling gears were generally small in size and, in consequence, on each deployment sampled only a very small area of the seabed. Furthermore, these early sampling devices, be they grabs, dredges, or sleds, were in all cases fished or operated with little or no means of determining how efficiently they were sampling. The only criteria for grabs were whether, on retrieval, they appeared to have fully closed and whether the bucket appeared to contain a full or partial sample. If partially full, it was impossible to be sure whether the grab had only shallowly penetrated the sediments, or if a part of the sample had been lost during retrieval. In the case of dredges and sleds for sampling the epibenthos, the nature of the tow could only be assessed by such things as the vibrations of the towing warp, the polishing of the runners or other parts which had come in contact with the seabed, and the catch. Area swept by towed gear was generally estimated based on either time and vessel speed or distance covered by the vessel as determined by navigational systems. The attachment of various types of odometers, initially with mechanical and then with electrical counting systems, to towed samplers gave a direct, although often inaccurate, physical measure of the distance traversed. Although providing some measure of the distance covered, the performance of such odometers is highly dependent on how well the gear itself is fishing; something the odometer itself generally gives no indication of.

The lack of visual information on both the nature of the area being sampled and on the efficiency of the sampling gear itself have long been recognized as major restraints to the quantitative sampling of the benthos. The potential usefulness of such visual information was demonstrated to one of the authors (Rowell) several years ago while attempting to sample juvenile surf clams on Banquereau Bank. Our inability to sample juvenile Stimpson's surf clams (*Mactromeris polynyma*) in areas where they were known to exist, and observations on the highly aggregated assemblages of the Arctic wedge clam (*Mesodesma arctatum*) on the same bank, suggested that the distribution of both these species might be limited to particular seabed features. This idea suggested that, with visual guidance, one should be able to specifically sample features, such as sand ridges, etc., thought to be influencing such highly aggregated assemblages of bivalve molluscs. It was with this in mind that, when first considering the means of conducting a trawling impact study, it was determined to experiment with the use of a video camera in the bucket of a van Veen grab. The information gained in these experiments, during the first cruises to determine suitable study sites for our current trawling impact studies, indicated the value of such video information and the limitations of conventional grabs such as the van Veen (Rowell et al. 1993, Rowell et al. 1994). This led to a decision to develop an entirely new grab and camera system for use in the study. It was also felt essential that any epibenthic sled used should be as quantitative as possible; implying accurate measurement of the distance covered while sampling and a means of monitoring actual sampling performance.

Thouzeau et al. (1991) had successfully used a video-equipped epibenthic sled during work on scallops and benthic community assemblages on Georges Bank. This sled, with its odometer measured distance of tow and its video monitoring of performance, seemed most suited to the study's needs.

It was anticipated that trawling might induce structural changes in surface and near surface sediments as well as break down macrofaunal structures such as tubes and burrows. The need to measure these changes was recognized (Schwinghamer) and resulted in the development of an entirely new sonar array which could provide nondestructive imaging of these structures and the benthos. This array, Dynamically Responding Underwater Matrix Sonar (DRUMS$^{TM}$), was developed by Guigné International Limited (Guigné et al. 1993) to meet the needs of these experiments and future benthic studies.

The Geological Survey of Canada (Atlantic) [GSC(A)] had been interested in DFO's trawling impact studies since their inception because of parallels between seafloor disturbances caused by trawling gear and seafloor disturbances caused by iceberg scouring. The DFO program provided GSC(A) with an opportunity to repetitively and accurately map seafloor sediments and determine any changes indicative of sediment transport or changes or additions to the seabed ice scour record. Throughout the entire program, GSC(A) have provided DFO with seafloor expertise and side-scan equipment to allow for the remote verification of the seabed trawl disturbance. The side-scan data were collected to 1) provide a remote image of the location, dimensions and character of the trawl disturbances; 2) indicate the severity of disturbance as a function of location along each corridor; 3) to ensure that reference samples were collected in areas of undisturbed seafloor, and 4) to observe changes, over time, to the seafloor trawl marks and also to existing iceberg scours.

Within the "corridor" experiment, side-scan surveys were used to measure how the seafloor trawl marks changed over time. Previous investigators (Harrison et al. 1991, Jenner et al. 1991) have calculated the density of seafloor trawl marks on side-scan sonograms as a measure of the intensity of local trawl fishing activity. However, in order to accurately estimate the annual trawling activity, it is important to know how long the features have been accumulating, and whether the seafloor record is complete ( i.e., have any trawl marks been erased). "Residence time" for a trawl mark is expected to vary spatially with changing substrate, seafloor energy environment, and the amount of re-working by benthic organisms. From GSC(A)'s perspective, the same information is necessary (i.e., the residence time for scours on the seafloor) in order to calculate an annual frequency of iceberg scouring. Thus both programs could benefit from information concerning degradation rates for seafloor features. To address the issue of the residence time for seafloor features in different seafloor regimes, DFO agreed to drag an otter trawl along an extended corridor covering a gradient of water depths and sediments of differing grain sizes. This experiment was termed the "long-trawl". Repetitive surveys by both GSC(A) and DFO would then determine whether all or any portions of the trawl marks remained visible on side-scan sonograms from one year to the next. The "long-trawl" would also provide an excellent opportunity to identify changes to the existing ice scour population and any additions over time.

This report has two main sections. The first, SAMPLING EQUIPMENT, describes the sampling gears used, including detailed descriptions of those that are entirely new or highly modified and improved. The second section describes the EXPERIMENTAL DESIGN and METHODOLOGY of the experiments.

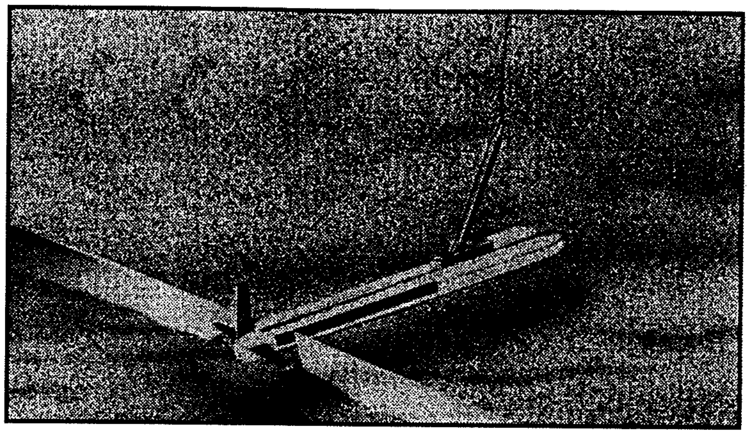
## SAMPLING EQUIPMENT

### SIDE-SCAN SONAR

Throughout the experiments, side-scan sonar was used for the remote verification of the seabed trawl disturbances and the changes to them over time by repetitively and accurately mapping the seafloor sediments and trawl marks.

Side-scan sonar systems consist of a side-scan processor and graphic display system, a hard copy output device and a digital or analog recording system, located in the ship's lab, which is connected by winch and cable to a side-scan towfish (a towed streamlined body with port and starboard acoustic transducers) (Fig. 1A). The towfish transducers transmit high frequency, short acoustic pulses that travel through the water to the seafloor, where they are partly absorbed and partly reflected. The amplitude of each pulse returned is a function of the amount of energy reflected back to the transducer; strong returns (high reflectivity) usually indicate coarser-grained sands and gravel, while weak returns (low reflectivity) indicate finer-grained sands. The side-scan processor then displays, in time, the strength of the signal returned to a hard copy medium and/or digital or analog tape.

**A.**



*Artist's rendition of a Simrad 992 sidescan sonar towfish being used in seabed survey.*

**B.**

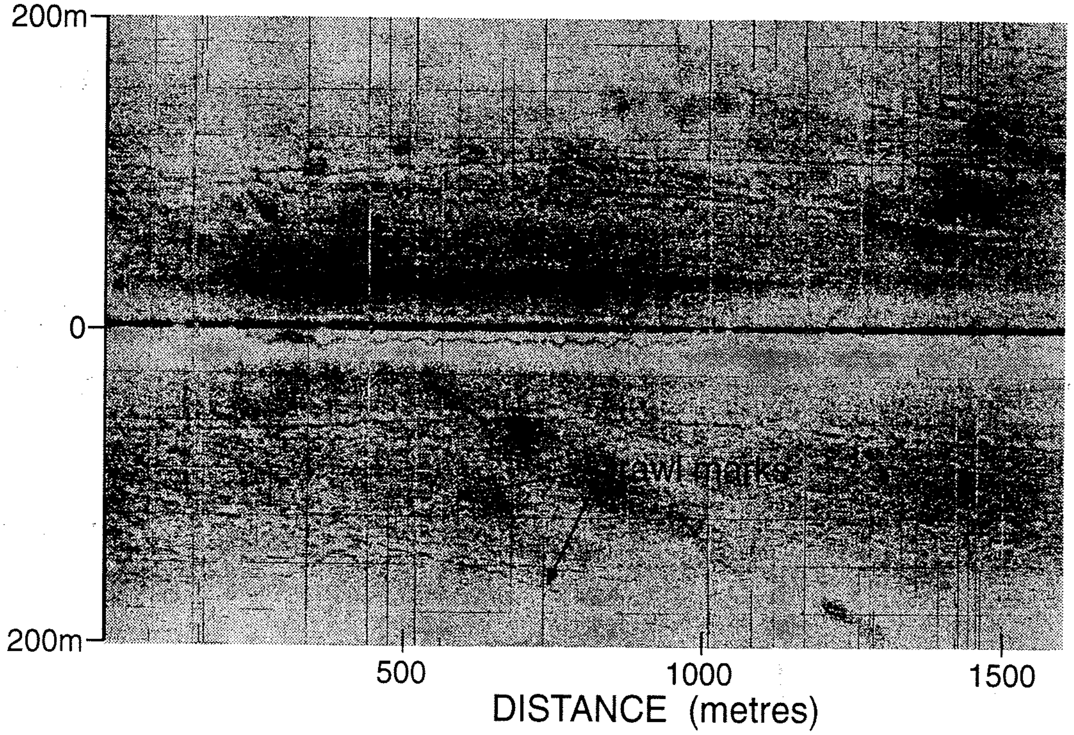


Figure 1: *Representative sidescan sonogram from the corridor survey area illustrating the seabed disturbance created by repetitive trawling.*

Two different side-scan systems were used in the study. A Simrad Mesotech 992 dual frequency (120 and 330 kHz) side-scan was the preferred system and was used during surveys 93-021, 93-029, 94-015 and 94-021. Klein side-scan sonar systems (100 kHz) were used as a replacement for the Simrad M992 on two occasions: a Klein 595 system was used for portions of the corridor surveys during 93-021 when the Simrad M992 was not functioning; the Klein 531 T side-scan sonar system was used for the 95-013 survey because the Simrad was unavailable. The Klein systems provide very good hard copy records but are not as conducive to post-processing because output gains are continually adjusted by the Klein system and written to the tape data.

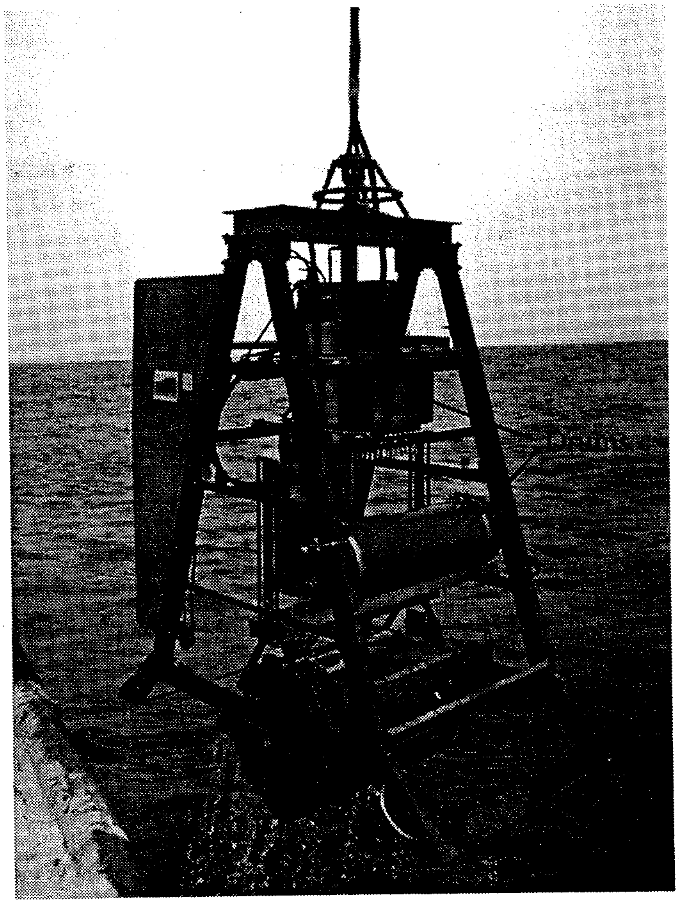


*Figure 2: Video Grab with DRUMS mounted.*

Hard copy paper records were typically collected using an Alden 9315 thermal printer set to record 120 kHz data in two channel print mode with auto-annotation (display times). An example of the seabed record provided is given in Figure 1 B.

During the "long-trawl", on Cruise 93-021 in 1993, subsurface geological features were also recorded using a Huntec high resolution deep towed seismic (DTS) profiling system. Details of this equipment are not included in this report, since the data were collected for other purposes and are of no relevance to the primary purpose of the trawling impact study.

## DRUMS

Dynamically Responding Underwater Matrix Sonar (DRUMS™) was developed by Guigné International Limited (Guigné et al. 1993) under contract to the Department of Fisheries and Oceans for the high resolution measurement of structural changes in near surface sediments caused by the passage of fishing gear, such as otter trawls, over the seafloor (Fig. 2). It was designed to provide non-destructive imaging, within broad frequency spectrum signals, of macrofaunal structures such as tubes, burrows, and mollusc shells as well as epifaunal and infaunal benthos (Schwinghamer et al. 1996). In use, DRUMS is deployed while mounted on the frame of the Videograb immediately above the sampling bucket (Fig. 2). On each deployment of the grab, DRUMS sonically and non-destructively samples the area of seabed which the grab will subsequently physically disturb in taking quantitative samples of the benthos. The DRUMS samples, then, allow quantitative comparisons of acoustic microstructures of the sediments and benthos over areas of seabed; in this case, along the experimental and reference corridors of the trawling impact experiment.

DRUMS was used in all but the first two cruises in July and September of 1993. In operation, the very high resolution broadband parametric, 12 x 30 cm , 40-element acoustic array ensonified the seabed to an average depth of 4.5cm below the sediment surface. The acoustic return signals were Hilbert transformed into five depth strata of approximately 1 cm each.

Details of the design, specifications, and performance of DRUMS are presented in Guigné et al. (1993) and Schwinghamer et al. (1996).

## ROXANN

In 1995, a RoxAnn™ (Marine Microsystems Ltd.) acoustic bottom classification system was used aboard the research trawler *Wilfred Templeman* throughout it's trawling operations in the study area. This system processes reflected hydroacoustic signals and provides a real-time indication of the roughness and hardness of seabed sediments. Details of the system and its operational characteristics are provided by Chivers et al. (1990) and will not be elaborated on here.

## BRUTIV

For rapid video and still camera overview surveys of the study corridors, it was decided to use BRUTIV (Bottom Referencing Underwater Towed Vehicle). BRUTIV (Fig. 3A) was first developed in the 1970s (Foulkes 1984). For this study, the developmental prototype of BRUTIV Mark III was significantly modified and upgraded.

### DESIGN

BRUTIV is a "flyable" underwater vehicle controlled from a mother ship. When under tow, a control system operated from the ship's laboratory allows the operator to set parameters and automatically maintain flight at a constant depth or altitude above the seabed. The terrain-following feature allows BRUTIV to be used as a platform for video and still cameras as well as other instrumentation for examination of the seafloor. Maintenance of a constant altitude off bottom and the sensing and avoidance of obstacles are dependent upon a forward-looking sonar system. Altitude, depth, pitch, roll, and wing angle sensors provide flight control information. Positive bouyancy ensures that the vehicle will passively come to the surface should the cable weak-link break. Tubular runners protect the instrumented underside of the vehicle should it inadvertently be flown into the bottom or strike an unavoidable object. These events can arise when there is a very rapid change in topography, such as a rock wall, when BRUTIV's climb rate is insufficient for complete avoidance.

### SPECIFICATIONS

Control System: Underwater electronics and hydraulic servo-actuator provide automatic terrain following or constant depth flight with surface adjustment and manual over-ride.

Dive Duration: 2-16 hours on one set of batteries. Three sets of batteries accompany the system.

Data Telemetry: A number of on/off analogue and digital (RS-232) data channels are available in both directions. One channel of composite video is available from the vehicle to the surface.

Camera Equipment: Universal mounts are available for a variety of still and video cameras and associated lighting. For the study, the vehicle was fitted with a video camera (Sony

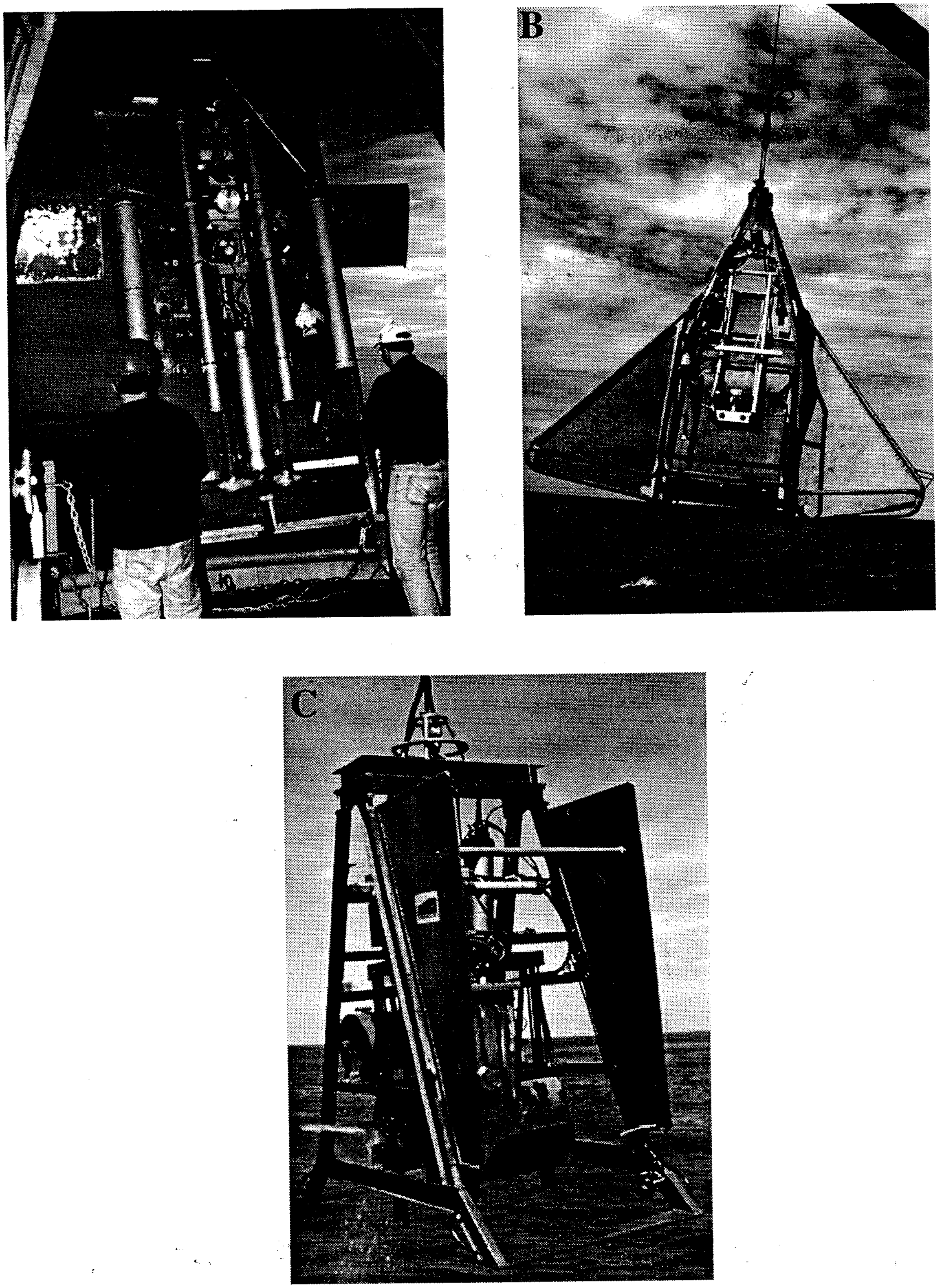


*Figure 3: The Bottom Referencing Underwater Towed Instrumented Vehicle, BRUTIV (A), Epibenthic sled (B), and Video Grab (C) being deployed from the CSS Parizeau.*

AVC-D7 black and white) and 150 watt lighting (Deep Sea Light and Power). The vehicle was also outfitted with a 35 mm still camera and strobe light for this study.

Tow Cable: 1000 m of 10 mm diameter Kevlar covered coaxial cable (RG 59).

Handling System: The vehicle is usually launched and recovered off the after deck. It is easier to slide the vehicle on and off the towing vessel than lifting it. A crane or other support mechanism must be provided to support the towing block. Maximum towing tension is limited to about 350 kg by the weak link. The cable is stored on a winch which requires 10 gpm @ 2000 psi hydraulic supply. The winch is fitted with slip rings.

Construction: Tubular aluminum sections provide a very rugged frame construction and provide buoyancy. Open design allows easy replacement and maintenance of components.

Depth Capability: 400 m (600 m with faired cable).

Scope Ratio: Ratio (cable length/depth) can vary from 2.5:1 to 5:1 without adversely affecting performance.

Speed Range: 2 to 6 knots, depending on depth of operation, height off bottom and quality of visual information required.

Power: 24 V DC on vehicle from on-board 55 amp.hr replaceable battery packs: deck unit 115 V AC.

Dimensions: Length, 3.1 m; span, 2.9 m; height, 1.0 m; width for transport, 1.6 m (wings removed); weight in air (loaded), 270 kg: bouyancy, 5-15 kg.

## PERFORMANCE

Since 1992, BRUTIV has been used to survey seafloor sites associated with the trawling impact studies on the Grand Banks. In 1992, BRUTIV was used to examine several potential study sites. Five tows were carried out on Western Bank, and one on the Grand Banks. In addition to video and still imagery, a high resolution altimeter provided detailed geomorphological information, in particular, during one tow which transected an iceberg scour. In 1993, one successful post-trawling video survey was accomplished with BRUTIV, before control problems removed it from service. Failure of the hydraulic actuator system which adjusts the flight control surfaces prevented any useful data from being obtained during 1994. In 1995, BRUTIV once again successfully collected video imagery. Each of the four tows covered about 8 km of sea floor at a speed of about 2.5 knots and altitude of about 2 metres.

During each tow, an ORE Trackpoint II short-base positioning system was used to determine BRUTIV's position (McKeown and Gordon 1997).

## EPIBENTHIC SLED

It was considered essential that the epibenthic sled used to sample megabenthos in the trawling impact should be as quantitative as possible. This required accurate measurement of the distance covered while sampling and a means of monitoring gear behavior and sampling performance.

The large epibenthic sled AQUAREVE III (Thouzeau and Vine 1991) was considered most suitable (Fig. 3B). Initial performance characteristics of the sled, during gear trials and during preliminary sampling, in 1991 and 1992, in the homogeneous medium-fine Adolphus sand (125-500 µm grain size) found on the Grand Banks study site, did not match the capabilities demonstrated by the sled's designers on the gravel bottom of Georges Bank. The mouth of the sled quickly plugged with a rolling mass of sand and benthos; apparently due to the inability of the sled's collection (sample) box to "filter" or sieve the sediments rapidly enough. The sheet steel collection box has regularly spaced 1 cm diameter sieve holes. Video images clearly showed that a large amount of both sediments and benthos were passing over the top and around the sides of the sled mouth, instead of into the collection box.

The sled retrieval process itself also reduced the quantitative accuracy of the sampler. The sled was originally designed with a mouth-closing door which was activated mechanically when the sled left the bottom; the door being levered opened by bottom contact. In practice, however, when the tow cable was wound back onto the winch, the sled would, after initial lift-off from the seabed, repeatedly regain contact with the bottom, thus opening the mouth door and allowing more sample to enter the collection box. This prevented an accurate determination of the sample "end-point".

### DESIGN

To overcome the above mentioned and other shortcomings, several design changes were incorporated before the sled was used in the trawling impact study.

To eliminate the apparent "filtering" problem, in which sediments and benthos escaped, the sled mouth and blade were reduced in width from 1 m to 0.34 m, while retaining the same filtering area of steel mesh on the collection box. The skids of the sled were also increased in width from 8 cm to 20 cm to reduce any tendency to sink into the seafloor sediments.

In addition, the lever-operated mouth-opening and closing door was replaced with a positively closing door controlled by a stepping motor. The door is now held open prior to and during the tow. When odometer wheel counts indicate that the desired length of tow has been achieved, the door closing mechanism is triggered from the electronic deck unit in the ship's lab. When the sample door closes, the logging of the odometer count is stopped manually by the operator. The operator also monitors the video image throughout the tow and can make a decision as to the sled's performance and the validity of the tow.

A second odometer wheel was added to the sled with the objective of improving distance measurement. This wheel has metal spikes which extend 1.15 cm beyond its flat steel tire surface, while the original odometer wheel has a flat rubber surface. It was felt the spikes would provide more positive traction in the sandy sediment of the study site. The second wheel also serves as a back-up, since small stones and shells occasionally wedge in the forks and stop the wheels from turning. The wheels are approximately 1 meter in circumference and are located in front, and on either side, of the sled's cutting bar and mouth opening. They are hinge-mounted to maximize bottom contact. Both odometers use Hall-effect proximity sensors, with 3 contacts per revolution, to electronically signal the number of revolutions of their wheels.

Wings, shaped to provide stability but not lift or depressive force, were added to the sled to prevent the sled from rotating during its travel to and from the bottom. Rotation of this nature had occurred on the original sled and resulted in damage to the electro-mechanical cable used to tow it.

The sled is equipped with two colour video cameras; one facing forward for reconnaissance and the other facing the sled's mouth and sampling area.

Instrumentation allows the operator to monitor the status of the sled and to control sled functions such as system initialization, video camera, lights, display options, and sample door closing actuation.

The Deck Control Unit includes a microprocessor, a 9600 baud bi-directional 4-wire twisted pair communication link, and a front panel with display and control switches. The Unit receives port and starboard odometer data and information such as the current status of the camera, lights, and sample door from the Underwater Unit. The information is processed and displayed on the front panel display. The operator can select various functions from the front panel switches and visually monitor the status of the sled using the video display and the front panel odometer counter displays. The switches allow the operator to zero or hold computed distance on the counters and to actuate the closing of the sample door.

The Underwater Unit uses similar electronics to communicate with the surface and to monitor the two odometers and to control external devices, i.e. camera, lights, and sample door. The Underwater Unit transmits port and starboard odometer data and status information to the Deck Control Unit at fixed time intervals. The unit receives commands sent by the Deck Control Unit, executes these commands and confirms them.

The Underwater and the Deck Control Units communicate via a 500 meter, 3/4 inch diameter electro-mechanical cable and slip-ring assembly. The cable has 18 copper conductors and a 2 RG-59 co-axial video conductor to supply electrical power and to exchange communication and video signals.

SPECIFICATIONS

| | |
|---|---|
| width of area sampled | 0.34 m |
| sampling depth (depth of cutting bar) | 25 mm |
| diameter of sieve holes in sample box | 1 cm |
| weight of sled | 1 tonne |
| operating depth | 170 m |

Colour Video Imaging System
- two Sony XC-999 colour video cameras
- standard broadcast
- cameras synchronized
- min. illumination 0.5 lux @ f/1.2
- frequency compensating tuned video amplifiers
- two 500 watt quartz-halogen lights

An ORE Trackpoint II short-base positioning system was used to determine the sled's position throughout each tow (McKeown and Gordon 1997).

PERFORMANCE

Changes to the sled's original design have greatly improved its overall performance. Stabilizing wings have eliminated any tendency for it to rotate, and in consequence have saved valuable at-sea sampling time as well as greatly extending the useful life of the towing cable. The widening of the runners and the reduction in fishing area of the mouth have largely eliminated any plugging up of the mouth area and increased the general consistency or smoothness of the tows. The addition of the second odometer has provided a back-up estimate of distance traversed in sampling and the positive door closing has provided a definitive end-point to the effective sampling tow.

During the first two cruises, carried out in 1993, only total counts from the spiked and rubber-surfaced odometer wheels were logged on the Deck Control Unit. The system was modified in 1994 to display both the rate of odometer wheel rotation and time-specific accumulated counts from each odometer wheel. The Deck Control Unit communicates the odometer and control status information directly to a personal computer where it is logged. This allows the identification of count irregularities caused by rocks or shells occasionally jamming a wheel as well as changes in sled movement over the seabed.

## VIDEOGRAB

As earlier noted, the lack of direct visual information regarding the performance of conventional mechanical grabs, such as the van Veen, has long been recognized as a major restraint to the quantitative sampling of the benthos; as has the lack of visual information on the nature of the seabed being sampled. In consequence of the need for verifiably good quantitative sampling for the trawling impact study, it was decided to develop an entirely new grab equipped with a high resolution video camera system.

## DESIGN

The videograb (Figs. 3C, 4, 5) is designed to sample the upper 10-25 cm. of the ocean bottom with minimum disturbance to the benthic organisms and features within a 0.5 square metre sample area. It differs from other similar devices in three important aspects. Firstly, the grab assembly is landed on the seafloor with the bucket poised 20 cm above the bottom. This allows the sample area to remain essentially undisturbed with the grab decoupled from the motion of the ship. Secondly, the high-resolution video camera that is mounted above the bucket gives the operator a real-time view of the area of the seafloor that is about to be sampled. Thirdly, while on deck or on the seafloor, the grab can be opened or closed by the operator who controls the hydraulic actuator from the deck console.

The hydraulic actuator provides a penetration and closing force of up to 1 ton, though most applications will probably require less. With full penetration, the bucket was designed to collect approximately 0.06 $m^3$ of sediment. However, in practice, samples of up to 0.1 $m^3$ have been taken. The videograb system includes 700 metres of kevlar multi-conductor electro-mechanical cable stored on a winch with a large diameter drum, and fitted with NSRF (Focal Technologies) slip rings. The winch was designed and built at BIO specifically for the videograb system.

A heavy galvanized-steel frame, in the shape of a 254 cm high pyramid, provides a stable platform which supports and protects an electro-hydraulically actuated clam type bucket and a video system. The seabed foot-print of the videograb frame is 203cm X 113cm. Large fins allow the grab to align itself with the current and counteract any tendency for rotation. The design attempts to minimize the "frontal" area while the sampler is being lowered with the bucket fully open, so as to reduce disturbance caused by a "bow wave". The bucket has a rectangular bite of 0.5 $m^2$ with an aspect ratio that approximates the viewing area of the high resolution colour video camera. Essential to the proper operation of the bucket is a lid that closes over the bucket as the sample is being taken. This prevents washing out of the sample, and, being directly actuated by the bucket jaws, acts as a visual indicator that the bucket jaws are closing properly. Closing of the lid precludes further direct observation of the sample.

The hydraulic ram which closes and opens the bucket is driven by an electro-hydraulic power pack with a 3/4hp 220v 1ph. 60Hz. electric motor. The entire power pack, including miniature hydraulic pump, electric motor, control valves, filters, and tank, are housed in a stainless steel underwater housing mounted on the frame. Remote operation of the hydraulic system is effected from a ship-board console.

The video system (Figs. 4 & 5) actually consists of two video cameras: i) a colour microlens CCD camera which can function at relatively low light levels for "looking ahead" of the grab as it "flies" over the bottom at altitudes of up to 6 metres; and, ii) a high resolution 3-CCD colour camera looking through the bucket at the sample area. The colour camera has full focus, zoom and macro remote control capabilities. Lighting is supplied by two 500 watt quartz halogen lamps powered by a DC supply at the surface.

The two video cameras are frame synchronized. The video signals (NSTC B&W, S-Video chrominance & luminance) are pre-emphasized by video amplifiers and driven to the surface on RG-59 coaxial conductors terminated by video clamping distribution amplifiers. The S-Video colour signals are recorded along with a longitudinal time-code on one of the linear audio channels. The other audio channel is used to record RS-232 digital data which has been conditioned by a special FSK 1200 baud modem. The digital data contains the navigation information necessary to control the video imagery and the physical samples.

The grab may also be configured to carry the earlier described DRUMS system.

## SPECIFICATIONS

| | |
|---|---|
| sample area | 0.5 $m^2$ |
| sample volume (at full penetration) | 0.06 $m^3$ |
| sampling depth | 10 to 25 cm |
| penetration force | up to 1 ton |
| operating depth | 500 m |

Colour Imaging System

- 3-CCD colour video camera
- picture elements 768 x 494 (horizontal, vertical) (NTSC)
- resolution > 700 TV lines (centre)
- video output: S-Video, RGB, Beta
- focus, zoom, and macro remote controls
- 2 quartz-halogen 500 watt lights

An ORE Trackpoint short base positioning system was used to determine the videograb's position on some deployments (McKeown and Gordon 1997).

## PERFORMANCE

From the very first deployment during initial sea-trials in the summer of 1992, the advantages of the videograb became spectacularly evident (Fig. 5). The ability of the operator to view the ocean floor from an altitude of 6 metres, then to observe the sample area in great detail once the grab was landed on the bottom, prior to deciding whether the sample was to be taken, allowed for selective sampling only achievable before using remotely operated vehicles (ROV) and manned submersibles.

In operation, when lowered to the seafloor, the grab caused very little disturbance of the surface sediments and epibenthos within its sampling area.

In fine grained sand, silt, or mud, the bucket has no trouble taking a full bite. In the presence of gravel and cobble, stones may occasionally prevent the jaws from closing completely and the sample will wash out. However, this condition is easily observed by the video camera and the operator can attempt to collect another sample immediately or search for an alternative location. When necessary, the operator can lift off and "fly" the grab to an alternative site, or discard unwanted samples, or make repeated attempts at sampling a particular area that may prove difficult because of bottom composition.

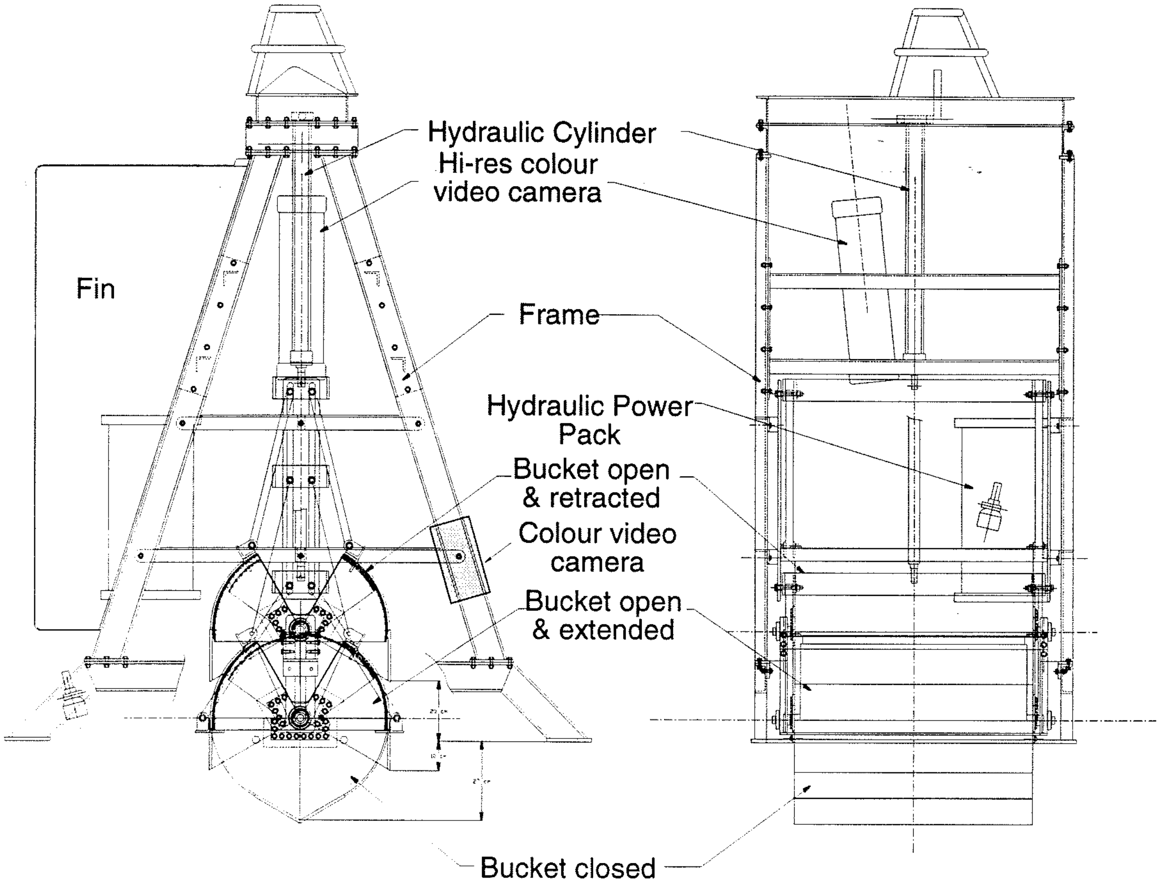


*Figure 4: General assembly drawing of Video Grab*

The videograb may be used either as a visually-directed physical sampler of the seabed and benthos and as a visual and video-imaging tool (Fig. 6) in situations where a physical sample is not required or where, because of the need to cover an extensive area, time constraints restrict the number of physical samples which may be taken. In the latter situation, we have found it extremely useful to drift or move slowly over an area of seabed with the grab system suspended within one or two metres of the bottom. We've termed this the "drift mode". When used in the "drift mode" the system can quickly provide synoptic information as to the variability of the seabed and benthos over an extended area and/or to assess areas prior to physical sampling.

A number of new features were added to the grab's handling system for the 1994 and 1995 cruises. A new winch, with its own self-contained electro-hydraulic power source, was custom designed and built in order to minimize the required deck area and to allow remote control of the winch from the operator's console in the ship's lab during deployment and retrieval operations. Additionally, modifications were made to allow the operator to switch the winch into a constant tension or "auto-mooring" mode when the grab is landed on the seafloor. The intention was to have the winch maintain just enough back tension on the cable to support its weight in water and prevent over-deployment and slackness in the cable. This would allow the grab to remain undisturbed on the bottom; the winch automati-

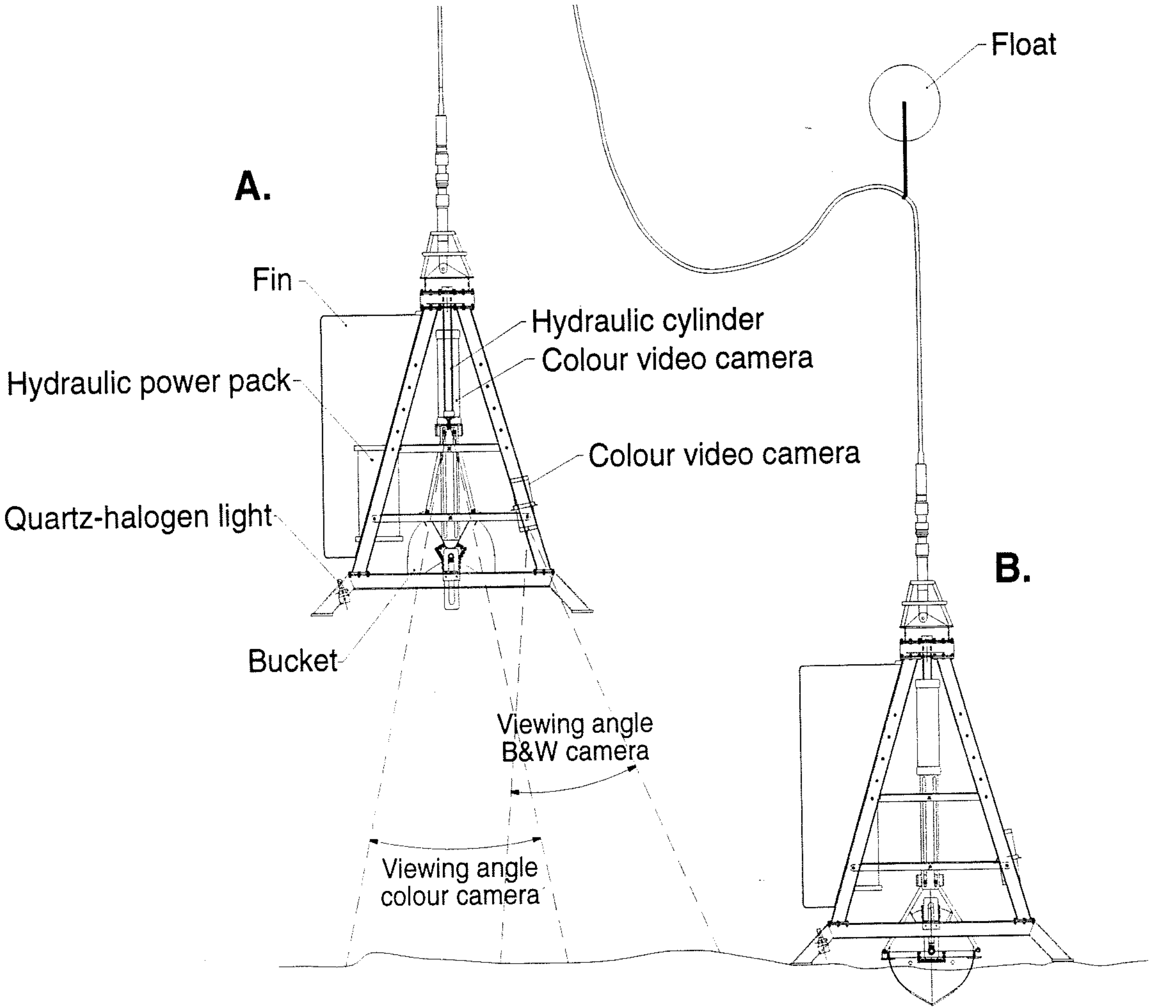


*Figure 5: Video Grab being lowered in survey mode with the bucket open (A) and taking a sample of the seafloor (B).*

cally accommodating the ship's motion and minor manoeuvering operations without constant interactive coordination between winch operator, grab operator, deck crew, and the bridge. Unfortunately, due to mechanical inertia, the "auto-mooring" mode did not work well and attempts at its use were quickly abandoned.

The control systems allow the grab operator, who is monitoring video displays of both winch operations and the grab's camera system in the ships laboratory, to take over control of the winch once he sees the seabed coming into view. The normal operating scenario is as follows: 1) the grab is deployed over the side by the deck crew and lowered until the bottom becomes visible on the video monitors in the lab; 2) the grab operator requests the on-deck winch operator to switch control of the winch to the lab console; 3) the grab operator then takes full control and can land the grab on the bottom whenever he wishes; 4) when the operator has taken a sample by closing the grab bucket, the grab is lifted off the bottom; 5) if the operator is satisfied with the sample, he signals the on-deck winch operator to resume control of the winch and bring the grab to the surface, and then on deck. The on-deck winch operator has an "over-ride" option on the winch control.

# EXPERIMENTAL DESIGN and METHODOLOGY

The study was designed with two components; the "long-trawl" and the "corridor" experiments. The "long-trawl" component was primarily of interest to the GSC(A), with the trawl track serving as an analog for an iceberg scour. DFO's interest in the "long-trawl" related to determining a means of ageing trawl-tracks recorded on previously existing side-scan records for fishing areas.

During the establishment of both the "long-trawl" and the "corridor" experiments, the *Wilfred Templeman* towed a rock-hopper equipped Engel 145 trawl over the seabed laying down trawl tracks made by the net, footgear, and doors. This is the standard trawl of Canadian vessels fishing the Grand Banks and was rigged as in that fishery. Details of the trawl and trawl doors are shown in Fig. 7. The *Parizeau* followed immediately astern and to the side of the *Wilfred Templeman* (Fig. 8), recording the position of the trawl with the ORE Trackpoint acoustic positioning system, for the entire "long-trawl" and during much of the trawling in the "corridor" experiment.

The experimental designs for both experiments required highly accurate positioning of the trawl tracks being laid down and of the survey and sampling gears.

The *Parizeau's* navigation system included a Magnavox model 4200 dGPS receiver, a StarFix II system providing differential corrections from a monitoring station at Long Island, N.Y., an autopilot providing headings, and a ORE Trackpoint II ultra-short baseline acoustic positioning system used with an over-the-side transducer boom for positioning of towed survey systems and seafloor sampling devices. AGCNAV, a custom hardware/software package developed at BIO, provided real-time display and logging of all navigation data. The rate of logging, which is dependent on the source and the user's setup, was generally set for 2 second intervals. Post-processing and database archiving (MULTIP) was carried out at GSC(A).

The dGPS/StarFix system provided very accurate (± 3-4 m) positions relative to the ship's antenna (McKeown and Gordon 1997).

The ORE Trackpoint II system system provided positional accuracy of the gear calculated to range from ± 4 m at the ship to ± 20 m at a working range of 600 m from the ship (McKeown and Gordon 1997). Unfortunately, in side-scanning operations, inaccuracies in the calculations due to the long distance to the towfish and high frequency motion of the towfish made the Trackpoint positioning too inaccurate for use in post-processing of the data. Instead, approximate laybacks between ship and side-scan were calculated from observed offsets in features on overlapping side-scan records.

The *Wilfred Templeman* was equipped with a Furuno GPS navigation system in 1993 and with dGPS in 1994 and 1995. A Scanmar acoustic trawl instrumentation system was used to monitor trawl door, wing spread, and other net characteristics while fishing.

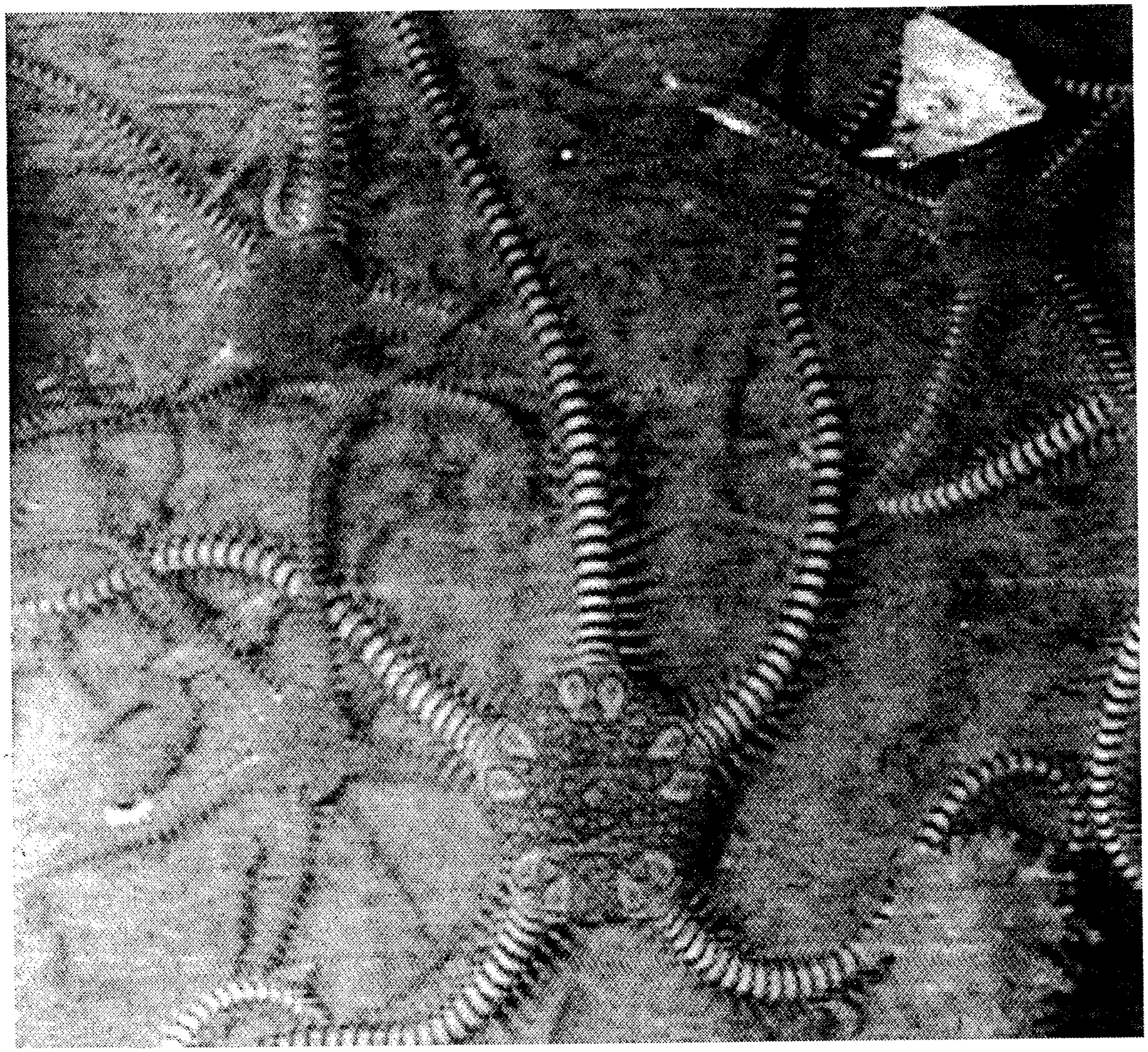


*Figure 6: A typical sea floor image obtained from the Sony colour video camera on the video grab. A Coreco Oculus-300 monochrome frame grabber with 8 bit (256 level) grey scale anf 512 x 512 pixel resolution was used to digitize it.*

## "LONG-TRAWL" EXPERIMENT

The "long-trawl" experiment had as its objective the determination of bottom disturbance degradation rates. The experimental design required the laying down of a continuous trawl track, as an analog for an iceberg scour, extending over a range of depths, and hence energy regimes, and sediment types, for subsequent observation of the rate of degradation over an extended period of time. The region chosen (Fig.9) extends 60 km from near the Hibernia oil production site to the Conquest J-09 well site location and traverses a bathymetric range from 75 to 135 meters. The survey track extends from 47° 04.00' N, 48° 11.00' W to 46° 45.46' N, 48° 46.27' W; perpendicularly crossing isobaths, the prevailing southerly currents, and the drift direction for the majority of icebergs.

Five surveys; four by the *Parizeau* (93-021, 93-029, 94-015, and 95-013) and one by the *Hudson* (94-021) were conducted over the "long- trawl". A summary of equipment and data collection processes is given below, along with the digital procedures necessary to correct the data and produce geo-referenced images of the seafloor.

### *Parizeau* 93-021 (July 1993)

In establishing the "long-trawl" the Engel 145 trawl was fished with the codend open; creating two continuous parallel otter-board scours along the survey track. The *Parizeau*, following immediately astern and to starboard, monitored the position of the trawl with the ORE Trackpoint acoustic positioning system while at the same time side-scanning (Simrad Mesotech 992) the trawl track being created. A second side-scanning run was then made back along the "long-trawl". Data from the side-scan were logged on a Ferranti SE 880 sonar enhancement system. Once side-scan operations were completed, some limited sampling of surficial sediments was carried out at selected stations along the line near Hibernia using the videograb system. During all subsequent cruises, the "long-trawl" was side-scanned in a similar manner.

Concurrently with the side-scan, a Huntec Deep Tow System (DTS) sub-bottom boomer profiler was towed along the "long-trawl" by the *Parizeau*; in a later transit, the DTS was operated with an external sparker as the source.

The side-scan data were of high quality, although hampered by sporadic shutdowns of the Simrad, which created small gaps in the data. Often internal striations could be seen within the trawl scour, probably created by the rock-hoppers along the footrope. The videograb was used to collect three sediment samples near the "Hibernia" end of the "long-trawl".

### *Parizeau* 93-029 (September 1993)

In September, the "long-trawl" corridor was resurveyed with the Simrad M992 using a range per channel of approximately 200 meters (400m swath) and the data digitized to Exabyte tape using a GeoAcoustics SE 880 Digital Acquisition System. No sub-bottom data or videograb samples were collected during 93-029. The two month old trawl track was visible along the entire length of the trawl corridor.

### *Parizeau* 94-015 (July 1994)

Side-scanning of the "long-trawl" during Cruise 94-015 was carried out with the Simrad M992 operated in 120 kHz mode over a range of 200 m per channel. The data were collected on an analog SONY DAT recorder at sea, and subsequently digitized to Exabyte tape at GSC(A) using the GeoAcoustics SE 880 Digital Acquisition system.

### *Hudson* 94-021 (August 1994)

The "long-trawl" was re-run one month later with the Simrad M992 side-scan during Cruise 94-021 of the *Hudson*. The data collected were digitized to Exabyte tape using AGC-DIG, a four channel digital acquisition system. Seven videograb samples and one box core sample were also collected along the "long-trawl".

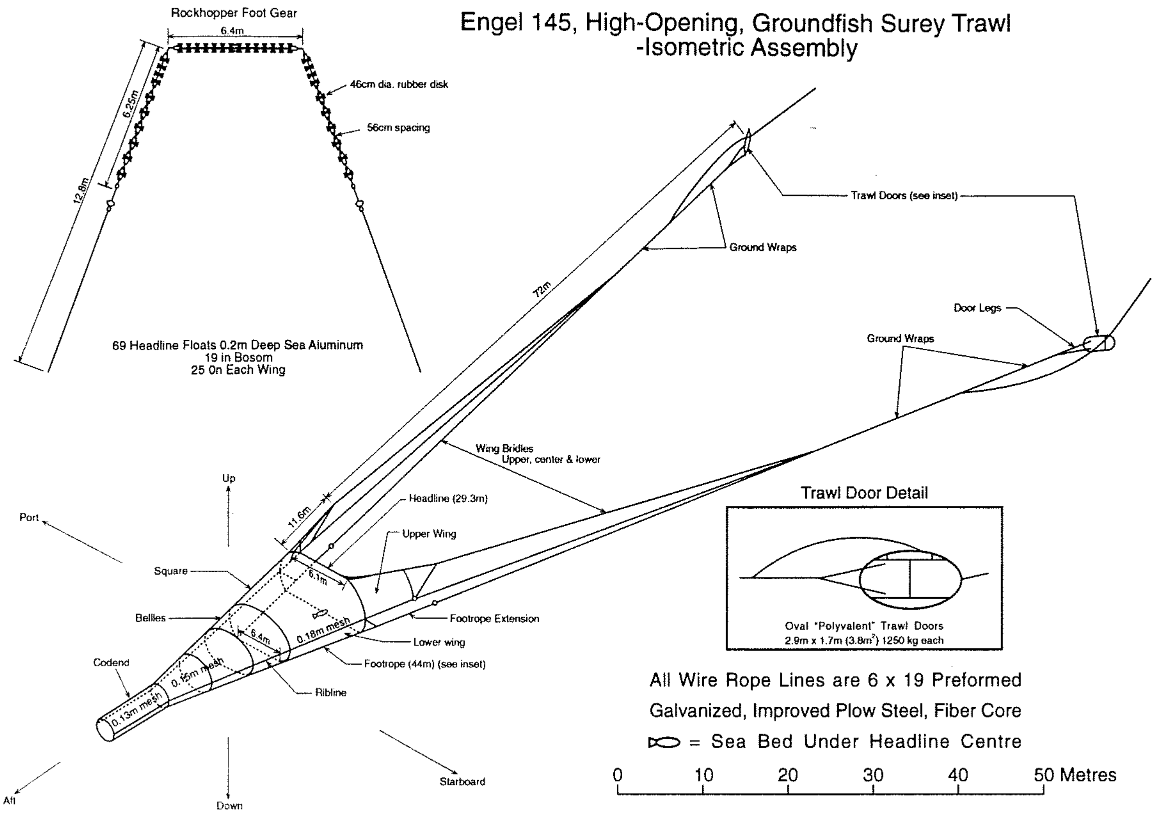


*Figure 7: Detailed drawing of the Engle 145 High - Opening Groundfish trawl.*

## <u>*Parizeau* 95-013 (July 1995)</u>

Side-scanning of the "long-trawl" during Cruise 95-013 was carried out using a Klein 531 T system in place of the unavailable Simrad M922. The data were recorded to a 19 inch (approx. 48 cm) wet paper record. Although the Klein systems provide very good paper records, they are not as conducive to post-processing since the output gains are continually adjusted by the Klein system and written to the tape data. Unfortunately, the starboard transducer was operating at very low output energy which resulted in poor digital data for that transducer. Additionally, the Klein digital data were difficult to gain-equalize. For these reasons, the paper field records proved to be the most useful for analysis of seabed changes. These were of good to very good quality with better small feature resolution than in much of the Simrad data. The videograb was used to collect sediment samples at five stations along the "long-trawl".

## "CORRIDOR" EXPERIMENT

Prena et al. (1996) describe the criteria established for selection of a suitable site for the "corridor study". After assessment of the criteria set out, the Grand Banks site, a 10 nautical mile square area centred at $47^0$ 10' N, $48^0$ 17' W and having an average depth of 137 m, was chosen (Fig.9)

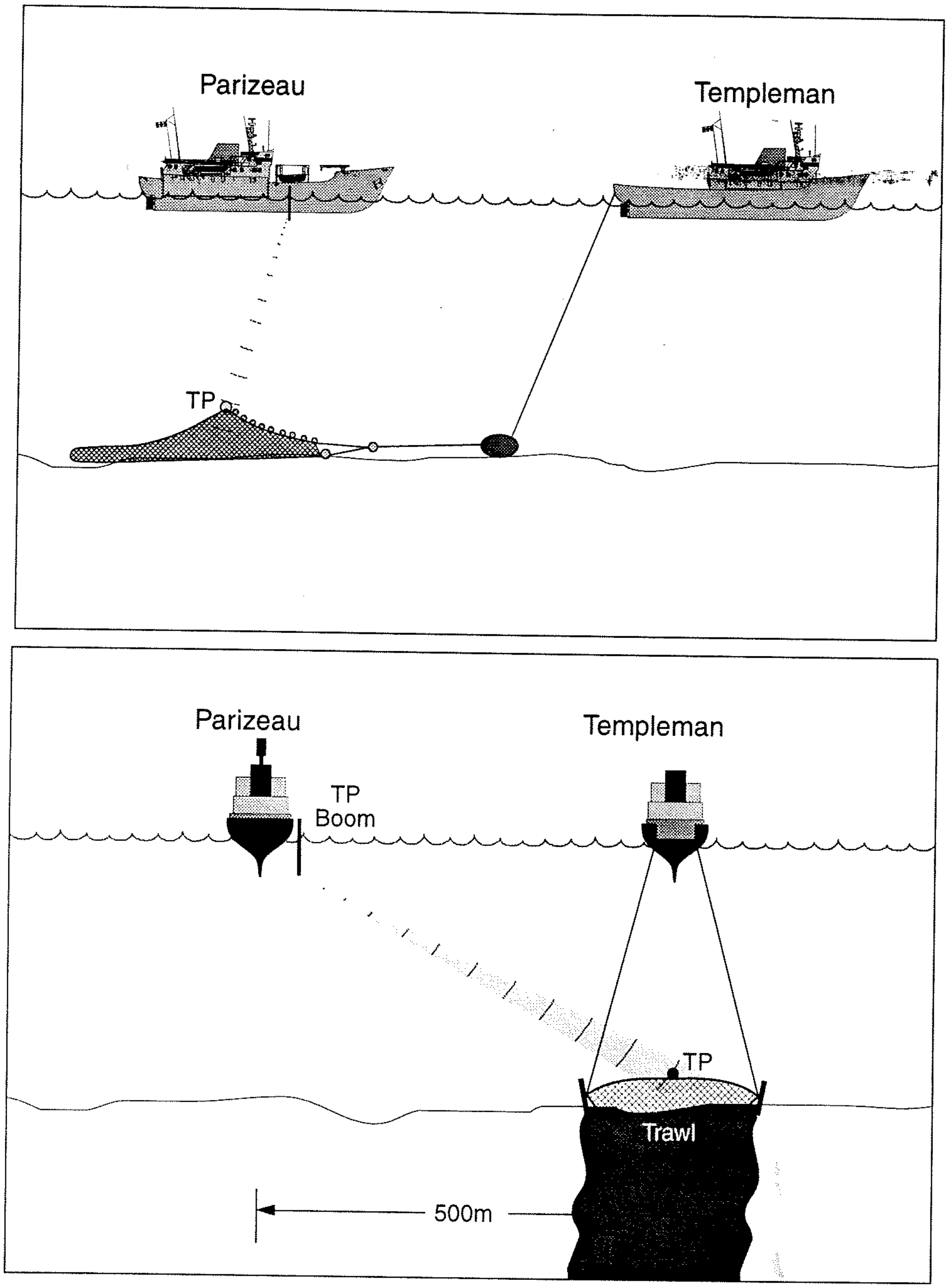


*Figure 8: Relative position of the CSS Parizeau and CSS Templeman during Trackpoint (TP) monitoring of the trawl path in an Experimental Corridor.*

The trawling impact "corridor" experiment had as its objective the determination of the immediate, short-term, intermediate-term, and long-term impacts of otter trawling on the seabed and the benthos. The experimental design called for the establishment of three 7 nm (13 km) long by 200 m wide experimental corridors, all in relatively close proximity but having different compass headings, within which experimental trawl tracks could be laid down and sampled at intervals to determine any resultant impacts (Fig. 10). A 50 m wide reference "corridor" was established parallel to each experimental "corridor".

Each corridor was divided into 260 fifty-metre long blocks, each block being given an individual identifier code (Fig. 11). For each grab sample, the central area in one 50 m block was targeted, and for each epibenthic sled sample five consecutive 50 m blocks were used, with the tow targeted at the central three blocks. For epibenthic sled sampling stations, the identifier code for the central block in the string of five was used to designate the station and sample.

The first two *Parizeau* cruises in the experiment took place in 1993. The first, in which 11 days were spent on-site in July, was directed at establishing the experiment by doing a pre-trawl survey, carrying out the trawling, and then determining the immediate effects on the seabed and benthos. Two months later, in September, a second cruise, in which 10 days were spent on-site, was directed at evaluating the short-term effects. A third cruise, in which 11 days were spent on-site, was carried out in July 1994 to evaluate longer-term (1 yr.) residual impacts of the 1993 trawling and to carry out further trawling and sampling to provide a second data set on the immediate impacts of such disturbances. A fourth, and final, cruise, in which 6 days were spent on-site, was carried out in June/July 1995 to again evaluate longer-term (1 and 2 year) cumulative residual effects of the 1993 and 1994 trawling, and to provide a third data set on the immediate impacts of trawling disturbances.

The three cruises of the research trawler *Wilfred Templeman*, to carry out trawling and re-trawling of the experimental corridors, were concurrent with but timed to follow completion of pre-trawl sampling by the *Parizeau*. The *Wilfred Templeman* did not participate in September 1993, since the experimental design did not call for re-trawling on such a short time frame.

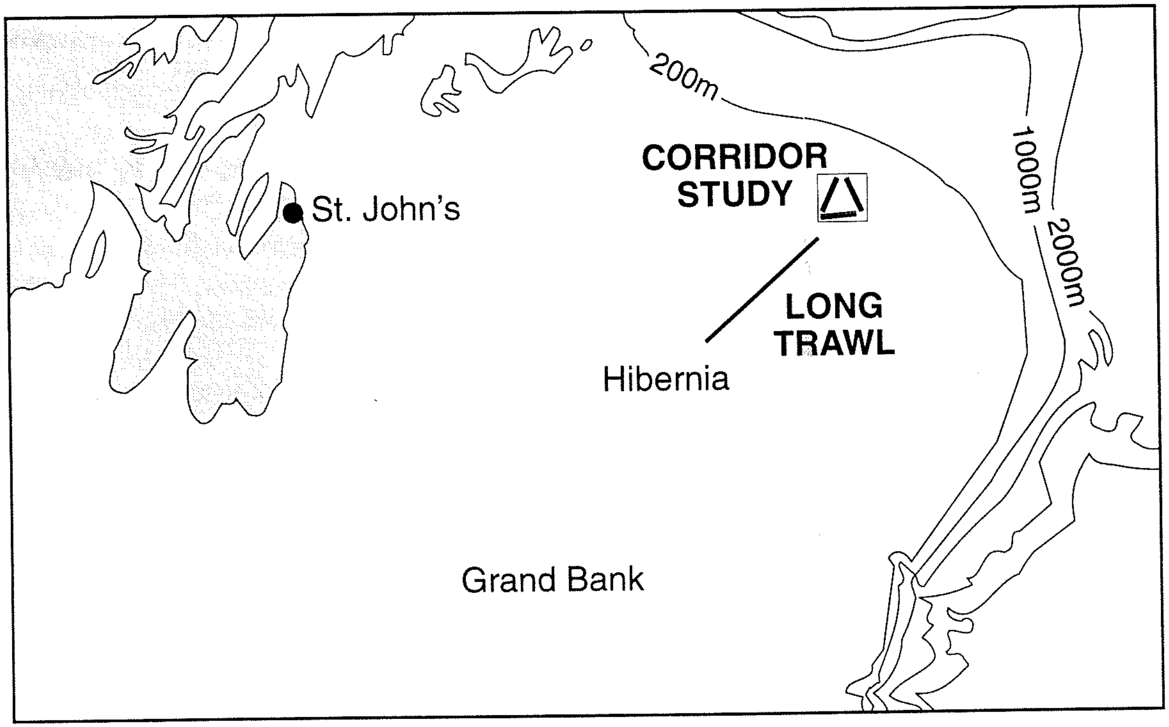


*Figure 9: The Grand Bank showing the east coast of Newfoundland, the site of the "corridor" experiment study area and the track location of the "long trawl".*

The principal biological sampling gears used in the study were the video-equipped 0.5 m$^2$ grab sampler, with hydraulically-powered jaws, and the 1 m wide video-equipped epibenthic sled with a 0.34 m wide operational sampling width (Figs. 2B & 2C). The seabed was acoustically imaged prior to and after trawling using side-scan sonar. During the first and last cruises in the series the seabed was also optically imaged by still and video cameras mounted on BRUTIV (Fig. 3A).

Table 1 summarizes the data sets and numbers of samples collected using the principal sampling gears, the videograb and epibenthic sled, during each cruise.

### *Parizeau* 93-021 (July 1993)

On arrival at the study area, during the first cruise in July 1993, the *Parizeau* made an initial assessment of bottom characteristics within experimental and reference Corridors A and B using side-scan sonar (Fig. 12). One survey line was run along the centre of the 200 m wide experimental (to be subsequently trawled) corridors with the side-scan set at 200 m range (400 m swath); a further two lines were run along the outer edges of the experimental corridors with the side-scan set at 100 m range (200 m swath); and one line was run along the centre of each 50 m wide reference corridor with the side-scan set at the 100 m range (200 m swath). The Simrad M992 dual frequency (120 and 330 kHz) side-scan was used over a range of approximately 200m for much of the survey. Mid-survey a back-up Klein 595 system (100 kHz) towfish was used after the Simrad towfish crashed into the side of the ship. Both 120 and 330 kHz data were collected. Data from the side-scan were digitized to Exabyte tape at sea using a GeoAcoustics SE 880 Digital Acquisition system. Hard copy paper records were typically collected using an Alden 9315 thermal printer set to record 120 kHz data in two channel print mode with auto-annotation (display times). Much of the 1993 "corridor" experiment data were printed in 4-channel (120 kHz and 330 kHz) mode but this greatly compressed observable features. These records are referred to as the "raw" or uncorrected data records (Sonnichsen, 1994).

Pre-trawl sampling of the corridors was then carried out with the grab and epibenthic sled. Time did not permit pre-trawl side-scanning or sampling of Corridor C. Stations for biological sampling were randomly selected from among the 260 blocks along each corridor. Five grab samples each were taken from the reference areas and from the experimental areas of Corridors A and B. Two tows, of approximately 50 m, were made in each of the reference and experimental corridors with the epibenthic sled. Pre-trawl samples from the experimental corridors were considered as reference samples, since the areas were as yet undisturbed. As seen in Figure 11, adjacent blocks in the reference and experimental corridors were numbered the same. In pre-trawl sampling, blocks sampled in the experimental corridors (yet untrawled) were not matched with blocks sampled in the reference corridors. In the subsequent post-trawl sampling, matching blocks of the experimental (trawled) and reference corridors were sampled with the intent of reducing possible environmental variables related to distance between sampling stations. Pre-trawl sampling, with the exception of Corridor C, was completed prior to the arrival of the *Wilfred Templeman* and the commencement of its trawling operations.

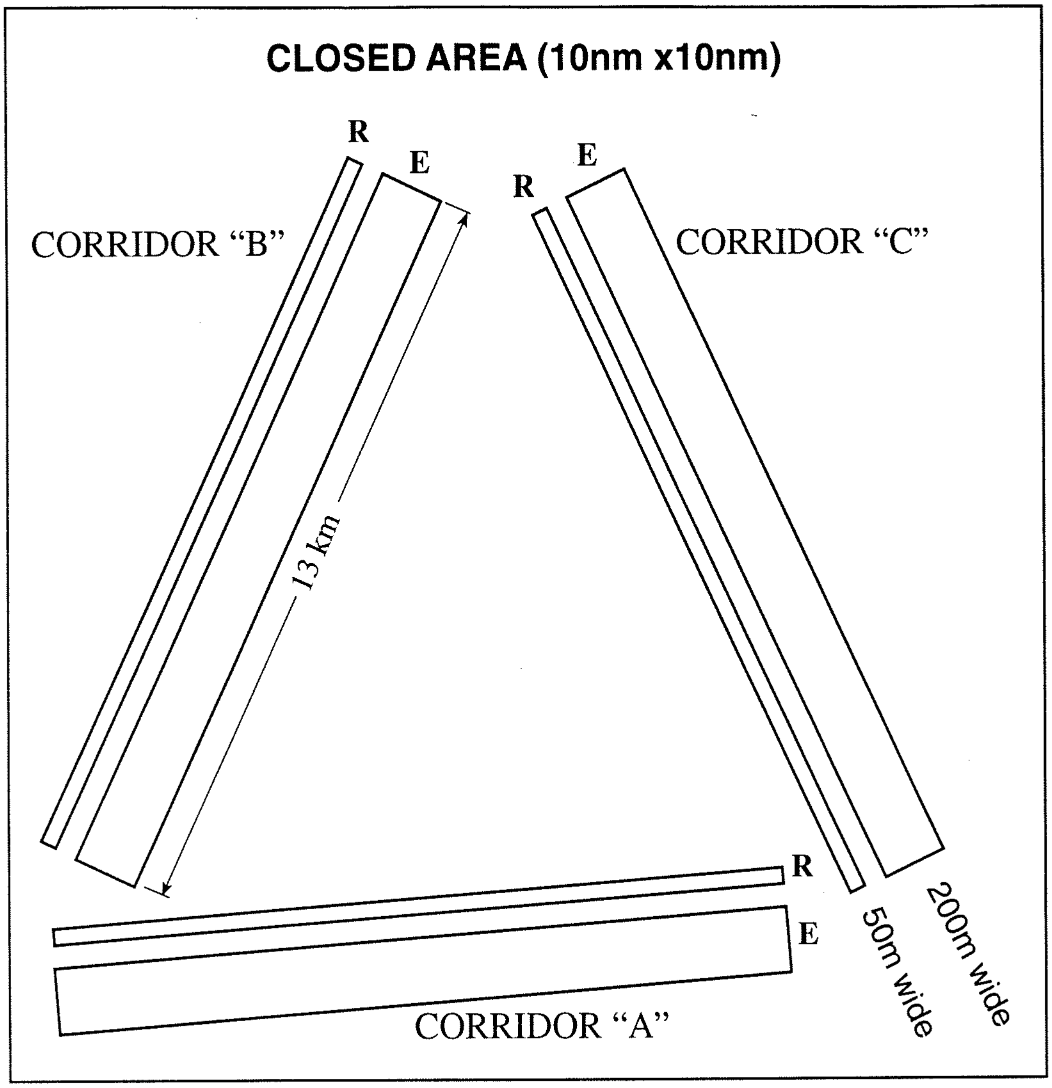


Figure 10: The relative position and orientation of the Reference and Experimental (trawled) Corridors A,B, and C within the "closed" area.

On completion of pre-trawl sampling of Corridors A and B by the *Parizeau*, the *Wilfred Templeman* trawled experimental Corridors A, B, and C with the rockhopper-equipped Engel 145 trawl (Fig. 7). The *Templeman* made 12 trawling passes along the centre line of each corridor. A Trackpoint transponder was fitted to the centre of the headrope for accurate recording of the trawl's position on the bottom throughout the trawling operations. During the trawling of Corridors A and B, the *Parizeau* shadowed the *Wilfred Templeman* and monitored the trawl's position using the Trackpoint system installed aboard the *Parizeau* (Figs. 8 & 13). All 12 trawling tows were monitored in Corridor A and 6 (half) tows were monitored in Corridor B. Trawling operations in Corridor C were not monitored with Trackpoint, since the *Parizeau* was occupied in the post-trawl side-scanning and sampling of Corridors A and B. There was no positional data collected on the net itself during the trawling of Corridor C.

During trawling operations, the catch was sorted at the end of each pass and numbers and biomass of fish and invertebrates recorded. Sub-samples of crabs were frozen for analysis of sex, age, and maturity. Stomachs and otoliths of all species of fish were retained from trawl passes at the beginning, middle, and end of the trawl series in each corridor. Unlike commercial gear, the trawl used was equipped with a codend liner of 30mm mesh.. This liner does not appreciably affect the hydrodynamic characteristics of the net but results in greater retention of benthic megafauna and small fish in the codend. The catch is thus not strictly comparable to a commercial catch but may give a better indication of relative numbers of megafauna that are disturbed by trawling, independent of clogging of the codend

## GRABS

| | Data Set | Corridor A | | Corridor B | | Corridor C | | Total | |
|---|---|---|---|---|---|---|---|---|---|
| | | Exp. | Ref. | Exp. | Ref. | Exp. | Ref. | Exp. | Ref. |
| Cruise 93-021 | | | | | | | | | |
| Pre-trawl | 1 | 5 | 5 | 5 | 5 | 5 | 5 | 15 | 15 |
| Post-trawl | 2 | 10 | - | 10 | - | - | - | 20 | |
| Cruise 93-029 | 3 | 10 | 10 | 10 | 10 | - | - | 20 | 20 |
| Cruise 94-015 | | | | | | | | | |
| Pre-trawl | 4 | 10 | 10 | 10 | 10 | - | - | 20 | 20 |
| Post-trawl | 5 | 10 | 10 | | | - | - | 20 | |
| Cruise 95-013 | | | | | | | | | |
| Pre-trawl | 6 | 10 | 10 | 10 | 10 | - | - | 20 | 20 |
| Post-trawl | 7 | 10 | 10 | | | - | - | 20 | |
| Total | | 65 | 35 | 65 | 35 | 5 | 5 | 135 | 75 |

## SLEDS

| | Data Set | Corridor A | | Corridor B | | Corridor C | | Total | |
|---|---|---|---|---|---|---|---|---|---|
| | | Exp. | Ref. | Exp. | Ref. | Exp. | Ref. | Exp. | Ref. |
| Cruise 93-021 | | | | | | | | | |
| Pre-trawl | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 6 | 6 |
| Post-trawl | 2 | 4 | - | 4 | - | - | - | 8 | |
| Cruise 93-029 | 3 | 3 | 4 | 1 | 1 | - | - | 4 | 5 |
| Cruise 94-015 | | | | | | | | | |
| Pre-trawl | 4 | - | - | - | - | - | - | - | - |
| Post-trawl | 5 | 10 | 10 | 10 | 10 | - | - | 20 | 20 |
| Cruise 95-013 | | | | | | | | | |
| Pre-trawl | 6 | - | - | - | - | - | - | - | - |
| Post-trawl | 7 | 10 | 10 | 10 | 10 | - | - | 20 | 20 |
| Total | | 29 | 26 | 27 | 23 | 2 | 2 | 58 | 51 |

*Table 1. Numbers of Pre- and Post-trawl video grab and epibenthic sled samples taken in the Reference and Experimental Corridors during the four sampling cruises of the C.S.S. Parizeau. Pre-trawl Data Set 1 includes 5 samples from each of the Experimental Corridors. These are used in the data base as Reference samples, since they were taken prior to the occurrence of any trawling disturbance in these corridors.*

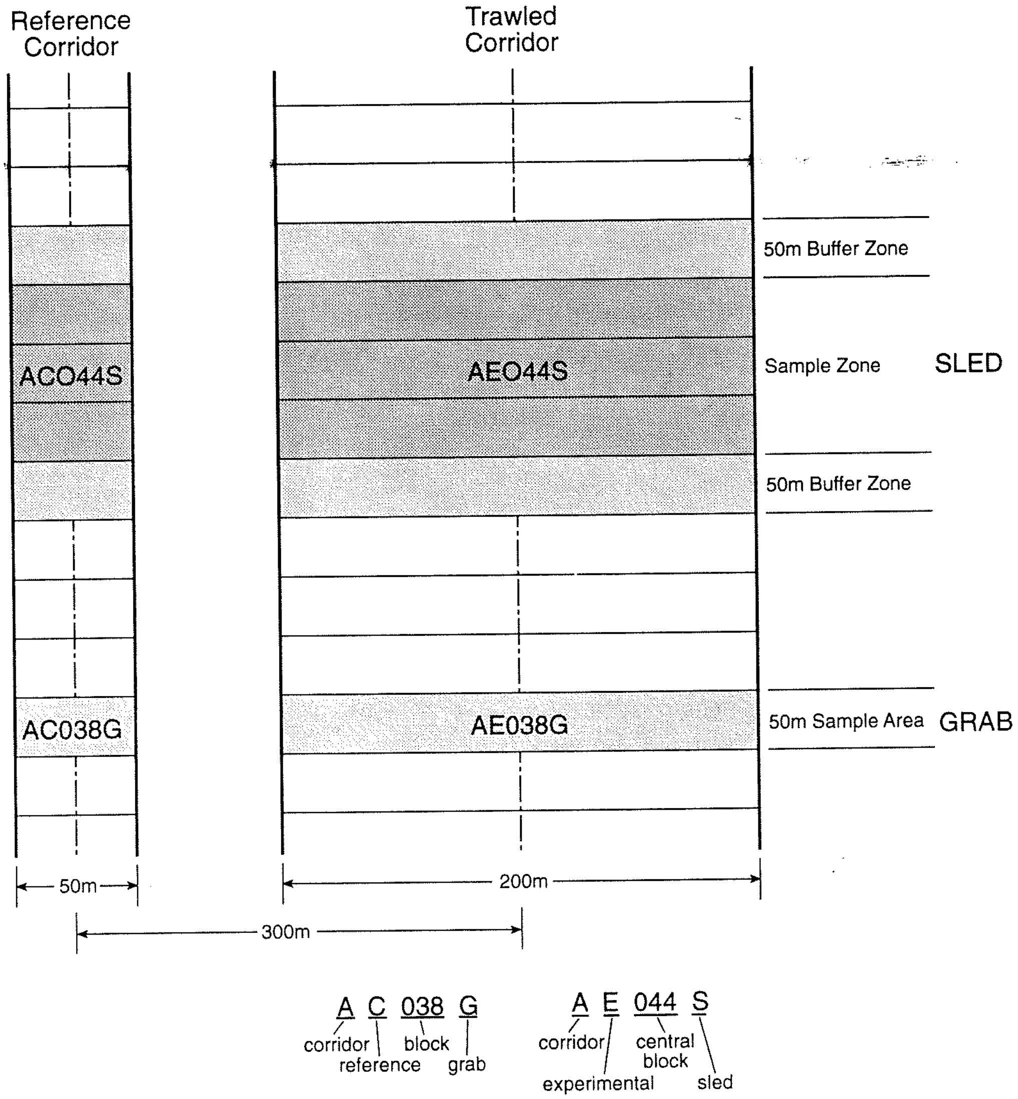


*Figure 11: A portion of a Reference and an Experimental (trawled) Corridor, showing the 50m blocks used individually for grab sampling and in combination for epibenthic sled sampling. Examples of station and sample coding is also given.*

mesh by finfish catch. It was clear from the amount of broken crab, basket star, and other invertebrate parts on the mesh of the trawl belly, ahead of the liner, and the wings, that the megafauna retained in the codend did not represent the major proportion of the invertebrates picked up by the trawl.

Once trawling operations were completed in experimental Corridors A and B, the *Parizeau* conducted immediate post-trawl sampling using the grab and epibenthic sled for biological sampling, BRUTIV and the grab's video system for visual imaging of both biological and physical changes, and side-scan sonar for acoustic imaging of physical disturbances. Within the trawled area, ten randomly selected stations (blocks) were sampled with the grab, and epibenthic sled tows, of approximately 50 m, were made in another four randomly selected blocks. One post-trawl video transect with BRUTIV was made along Corridor A. In this transect, BRUTIV was flown approximately 2 metres above the bottom along the first and last thirds of the experimentally trawled corridor's length as well as along the centre one-third section of the parallel reference corridor. Post-trawl side-scan surveys of experimental Corridors A, B, and C were carried out, as described above, immediately after trawling. There was no post-trawl grab or sled sampling of the reference and experimental Corridors C due to time limitations.

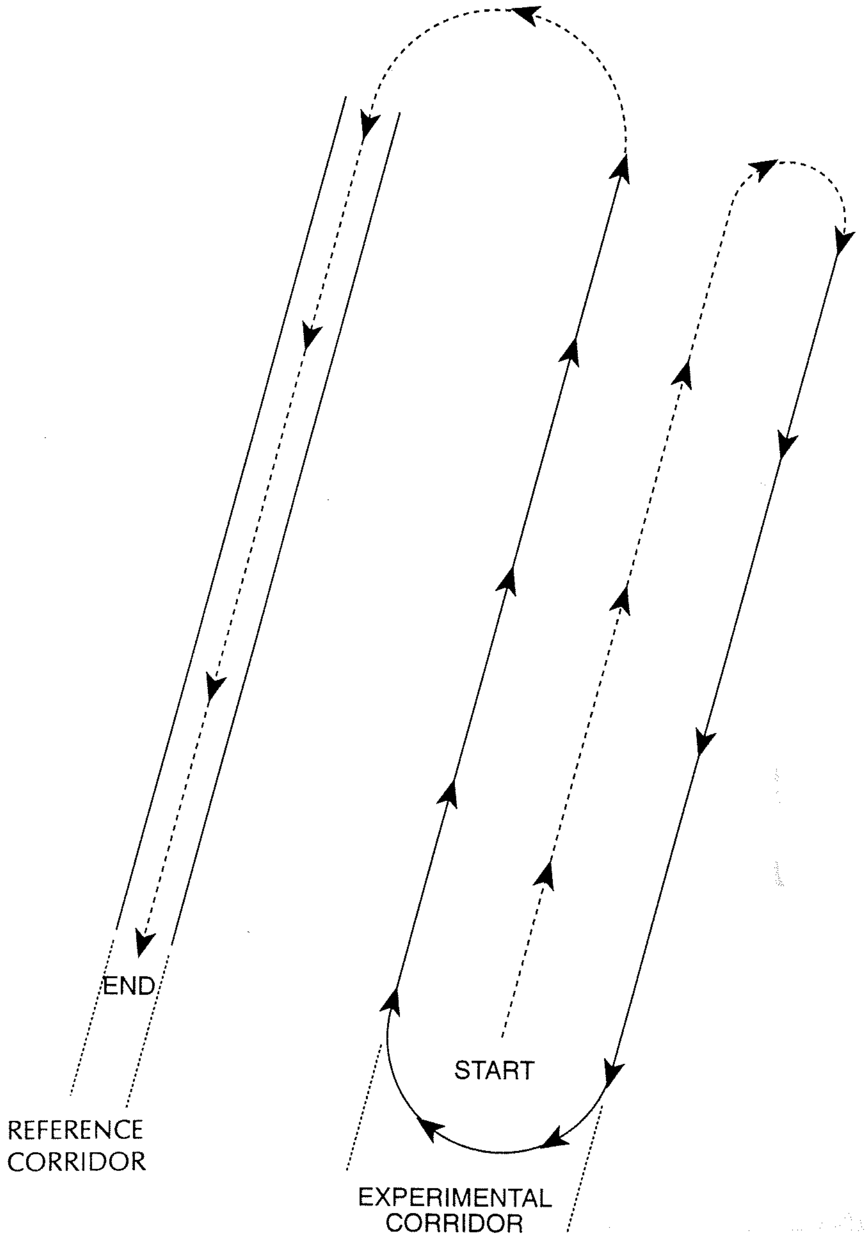


*Figure 12: Vessel track followed on side-scanning operations over one set of Experimental and Reference Corridors. This track provided complete coverage for mosaicing of the Experimental and Reference Corridors and the area of seabed between them.*

On-board treatment of samples: On retrieval of each grab, and prior to dumping and sieving, duplicate 1 ml sediment samples, for bacterial analysis, were removed from the sediment surface with a 3 ml syringe. Five ml of 0.22 µm filtered 2 % gluteraldehyde was then added and the samples frozen. Duplicate 10 cm deep samples were also removed at this time, using a 140 ml syringe, and divided into sub-samples from depths of 0-2 cm, 2-5 cm, and 5-10 cm for meiofaunal analysis. Seven % MgCl$_2$ was added to relax the organisms and 2-24 hrs later, gluteraldehyde was added to a final concentration of 2 %. Duplicate 125 ml sediment samples were removed and frozen for grain size and CHN analysis. The grab was then opened and the sample sieved through a 1 mm screen before being preserved in buffered formalin for later sorting and analysis. This analysis included, where possible, an assessment of damage to the macrobenthos.

Epibenthic sled samples were sieved on the same screen and immediately sorted by species. Large and numerous species were counted and weighed on-board, while smaller and unidentified specimens were separated and frozen for later examination in the laboratory. Apparent damage, or lack thereof, was recorded during the sorting process for three megabenthic species; the sea urchin (*Strongylcentrotus pallidus*), sand dollar (*Echinarachnius parma*), and the brittle star (*Ophiura sarsi*). Molluscs were separated into bivalves and gastropods, bagged, and frozen for laboratory analysis of shell damage caused by the trawl.

Laboratory treatment of samples: The preserved residue of the grab samples was brought into suspension, screened through a 1 mm-mesh, and sorted under a dissecting microscope. The retained sediment was examined under a magnification lens. Specimens were identified to species level when possible and additionally grouped into size classes. As in the sled samples, the damage of sea urchins was recorded; however, this was not possible in the brittle stars which additionally suffered through sieving and handling. Biomass was determined as formalin wet weight (molluscs with mantle cavity liquid and shells). Specimens were subsequently transferred into 70% ethanol.

Molluscan samples from the sled were analyzed for damage after careful thawing. This was to ensure that there would be no handling induced damage. The specimens were then sorted into four categories: 1) no damage; 2) minor damage (considered likely to survive); 3) moderate damage (might survive); and 4) major damage (considered unlikely to survive).

Frozen samples of whole sediment were thawed and subsampled for water content (wet weight minus dry weight after 24 h at 60°C), CHN analysis, and Coulter Counter analysis. The remaining sample (~100 mL) was wet sieved on a stack of circular brass sieves of 63, 125, 250, 500, 1000, 2000, and 4000 um mesh sizes. Wet sieving was used to retain the integrity of the biological structures, aggregates, etc. which would be disintegrated by preparation for dry sieving. The sieved fractions were placed in preweighed aluminum pans. They were then dried at 60°C for 24 h and weighed.

Particulate CHN was determined using a Perkin-Elmer 2400 Series II CHNS/CHN analyzer. Sediment was ground with an alumina mortar and pestle. One-half of the sample was acid treated to remove carbonates prior to analysis, while the other half was not.

Bacteria were counted using the acridine orange epiflourescence method detailed by Schwinghamer (1988a). A Zeiss ICM 405 inverted microscope equipped with a drawing tube and a 486 PC with a Java image analysis system were used to measure bacterial sizes for biomass determination.

Meiofauna were extracted from the sediment using Ludox AM density gradient centrifugation (Schwinghamer 1988b). Meiofaunal organisms were counted and measured using a video-equipped Zeiss ICM 405 inverted microscope and a 486 PC with Mocha image analysis system.

There has not yet been any analysis of samples of snow crabs, fish stomachs, and otoliths collected during the trawling operations.

### *Parizeau* 93-029 (September 1993)

The *Parizeau* revisited both the "long-trawl" and the Experimental Corridors in September to evaluate short-term (after ten weeks) effects of the July trawling.

Navigational aids and positioning systems were as described for the initial July cruise (93-021).

A side-scan survey was again run within the three Experimental Corridors (A, B, and C), in the manner described above and illustrated in Fig. 12, to assess changes in trawl mark characteristics ten weeks after trawling. The Simrad M992 was used and the data digitized to Exabyte tape at sea using a GeoAcoustics SE 880 Digital Acquisition system. Data were of good to very good quality. Trawl marks were still visible along all of the Experimental Corridors.

Biological sampling was again conducted, with the grab and epibenthic sled, at randomly selected stations in the Reference and Experimental Corridors A and B. As in the earlier cruise, there was no sampling of Corridor C due to time limitations. Ten grab samples were taken from each of the reference areas and experimental areas; 40 grabs in all being successfully completed. Nine 50 m (approx.) tows were made with the epibenthic sled; 7 and 2 being completed in the Reference and Experimental Corridors of A and B, respectively. The limited epibenthic sled sampling resulted from the loss of several sampling days due to rough weather. As in the previous cruise, time limitations precluded grab and sled sampling in Corridor C. On-board and laboratory treatment of samples was essentially as described for the previous cruise.

BRUTIV was not available for use on this second cruise.

### Parizeau 94-015 (July 1994)

The Corridors were resurveyed by side-scan three times in 1994; twice in July, before and after re-trawling, and once in August, one month after retrawling. The Simrad Mesotech

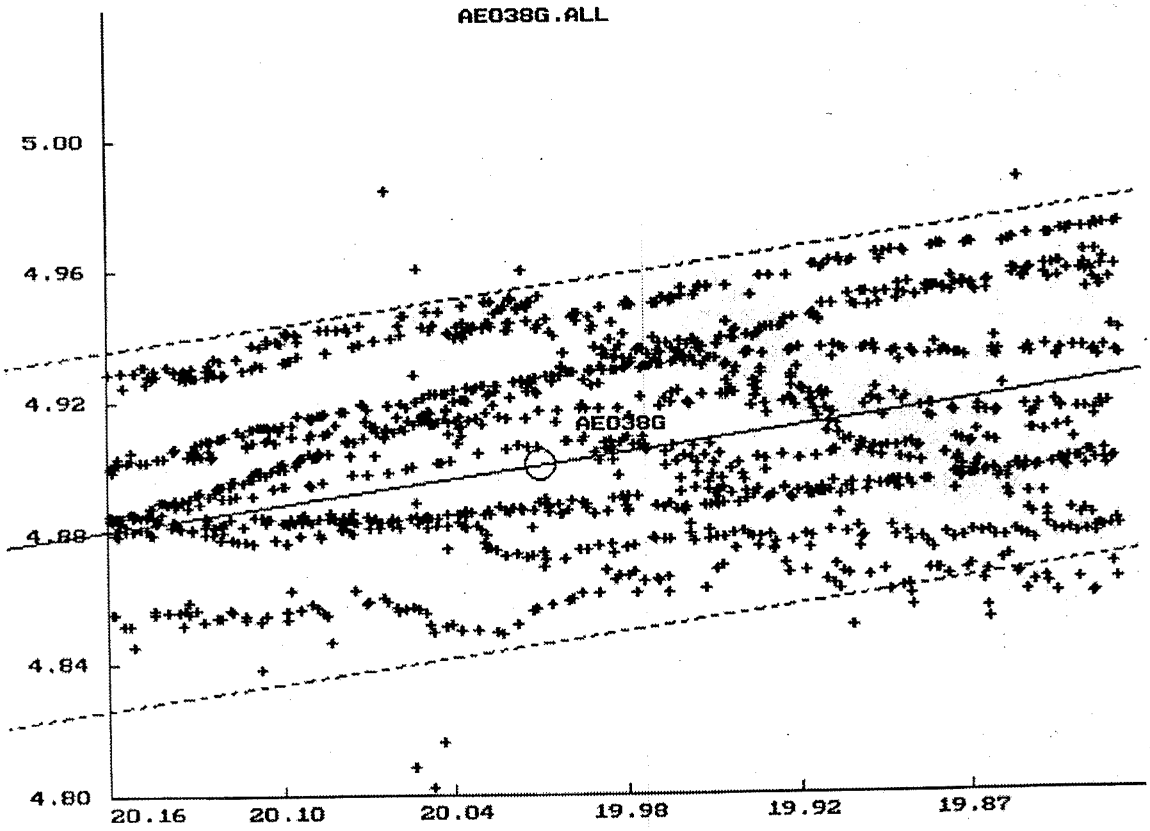


*Figure 13: Trackpoint indicated paths of trawl doors in relation to Grab Station No. 038 in Experimental Corridor A. The centre line and boundaries of the Corridor are also indicated.*

992 dual frequency (120 and 330 kHz) system was used, with the Corridors surveyed at the 50, 100 and 200 m ranges using both 120 and 300 kHz frequencies. The data were collected on an analog SONY DAT recorder at sea, and subsequently digitized to Exabyte tape at GSCA using the GeoAcoustics SE 880 Digital Acquisition system.

Prior to re-trawling the Experimental Corridors, biological sampling was carried out using the videograb to determine any residual effects of trawling one year after the first trawling. Ten grab samples were taken from each of the reference and experimental areas of Corridors A and B. In pre-trawl sampling, adjacent blocks in the Reference and Experimental Corridors were sampled as illustrated in Figure 11. The epibenthic sled was not used prior to re-trawling. Pre-trawl sampling was completed prior to the arrival of the *Wilfred Templeman* and the commencement of its trawling operations.

On completion of pre-trawl sampling of Corridors A and B by the *Parizeau*, the *Wilfred Templeman* trawled Experimental Corridors A, B, and C in the same manner as it had in 1993; again making 12 trawling passes along the centre line of each corridor. A Trackpoint transponder was fitted to the centre of the headrope for accurate recording of the trawl's position on the bottom for 6 (half) of the trawling operations in Corridor B. During these 6 tows, the *Parizeau* shadowed the *Wilfred Templeman* and monitored the trawl's position using the Trackpoint system installed aboard the *Parizeau*. The *Templeman* was equipped with dGPS in 1994, and for the 6 remaining tows in Corridor B, and all tows in Corridors A and C, the position of the net was estimated from the ship's positional data and it's Scanmar net mensuration system. During trawling operations, the catch was sorted at the end of each pass and numbers and biomass of fish and invertebrates recorded as in 1993. Sub-samples of crabs were frozen for analysis of sex, age, and maturity. Stomachs and otoliths of all species of fish were retained from trawl passes at the beginning, middle, and end of the trawl series in each corridor.

The *Parizeau* conducted immediate post-trawl sampling using the grab and epibenthic sled for biological sampling, the grab's video system for visual imaging of both biological and physical changes, and side-scan sonar for acoustic imaging of physical disturbances. Within the trawled area, ten randomly selected stations (blocks) were sampled with the grab. The Reference Corridors had already been sampled prior to trawling. Epibenthic sled tows, of approximately 50 m, were made in ten randomly selected blocks in each of the Experimental and Reference Corridors. Post-trawl side-scan surveys of Experimental Corridors A, B, and C were carried out, as described above, immediately after trawling. As in the earlier cruises, there was no post-trawl grab or sled sampling of Corridor C due to time limitations. On-board and laboratory treatment of samples was essentially as described for the previous cruises.

Failure of BRUTIV's hydraulic actuator system, which adjusts the flight control surfaces, prevented any useful data from being obtained from this equipment in 1994.

### *Hudson* 94-021 (August 1994)

As noted above, the corridors were resurveyed by side-scan in August, one month after retrawling, during a GSC(A) cruise aboard the *Hudson* (Sonnichsen 1994). No biological sampling was undertaken within the corridors during this cruise.

### *Parizeau* 95-013 (June/July 1995)

The corridors were surveyed by side-scan sonar before and after re-trawling in 1995; a Klein 531 T system being used. The resulting paper records were of good to very good quality with better small feature resolution than in much of the Simrad data.
Prior to re-trawling the Experimental Corridors, biological sampling was carried out using the videograb to determine any residual effects of trawling two years after the first trawling and one year after the second trawling. Ten grab samples were taken from adjacent blocks in each of the reference and experimental areas of Corridors A and B. The epibenthic sled was not used prior to re-trawling. Pre-trawl sampling was completed prior to the arrival of the *Wilfred Templeman* and the commencement of its trawling operations.

On completion of pre-trawl sampling of Corridors A and B by the *Parizeau*, the *Wilfred Templeman* trawled Experimental Corridors A, B, and C in the same manner as it had in 1993 and 1994; again making 12 trawling passes along the centre line of each Experimental Corridor. During trawling, the *Parizeau* shadowed the *Wilfred Templeman* for 4 tows in Corridor A and 3 tows in Corridor B. The *Templeman* was again equipped with dGPS in

1995, and for the remaining tows the position of the net was estimated from the ship's positional data and it's net minding system. During trawling operations, the catch was sorted at the end of each pass and numbers and biomass of fish and invertebrates recorded as in 1993 and 1994. Sub-samples of crabs were frozen for analysis of sex, age, and maturity.

Immediate post-trawl sampling was carried out with the videograb and epibenthic sled. Within the trawled area, stations were sampled with the grab. The Reference Corridors had already been sampled by grab prior to trawling. Ten epibenthic sled tows were made in each of the Experimental and Reference Corridors. Post-trawl side-scan surveys of Experimental Corridors A, B, and C were carried out, as described above, immediately after trawling. As in all earlier cruises, there was no post-trawl grab or sled sampling of Corridor C due to time limitations. On-board and laboratory treatment of samples was essentially as described for the previous cruises.

In 1995, BRUTIV once again successfully collected video imagery. Each of the four tows covered about 8 km of seafloor at a speed of about 2.5 knots and altitude of about 2 metres. One experimental (trawled) corridor was surveyed three times: immediately prior to the commencement of trawling; within thirty to sixty minutes of the last pass of the trawl through the area; and, again along the same corridor twenty four hours later. Also, the nearby parallel reference (undisturbed) corridor was surveyed once. Effects of the trawling activity could be readily discerned from the video image during the tow. Further study of the video tapes is planned including experimentation with image processing methodology to quantify before vs. after and trawled vs. untrawled differences in bottom appearance.

## SUMMARY

The "long-trawl" and "closed" area trawling impact studies reported here represent the first such studies of this nature having a longer-term temporal framework. The information gathered in the "long-trawl" has provided a clearer understanding of trawl mark degradation rates in various energy regimes and sediment types and will aid in interpretation of the extensive side-scan records existing for the continental shelf. The "closed" area trawling impact study has provided a unique data base covering the impacts and recovery rates after both single and multiple trawling events.

The studies required the development of new equipment, the videograb and DRUMS, and the modification and improvement of others such as the epibenthic sled and BRUTIV. The videograb, in particular, has greatly enhanced our ability to take quantitative samples of the seabed and benthos and to collect very high quality video images the seabed being sampled. It has also spawned the development of other sampling gear such as the video imaging Campod with its attached slurper system for physically sampling benthic boundary layer waters. The Campod system uses the same winch, cable, and camera system as the videograb.

We are confident that the data collected in this first experiment will, after full analysis, considerably advance our understanding of the impacts of trawling on the seabed in the particular environment studied. A second study, in an area of Western Bank having much coarser sediments, will be initiated in the fall of 1997 using the same Engel trawl. This study is being carried out to provide information as to the variability of impacts on different sediment types. The combined information from the two studies will provide a clearer picture as to the range of impacts which trawling can have and how the nature of the bottom sediments may influence these impacts.

Although the Grand Banks "corridor" experiment was largely concluded in 1995, it is intended to maintain the corridors free of commercial fishing and, should the opportunity arise, resample them in future years to determine longer-term impacts and rates of recovery of both the seabed and the benthos.

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