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CANADA

2009

Canadian Technical Report of
Fisheries and Aquatic Sciences 2853

Canadian Technical Report of Fisheries and Aquatic Sciences

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METHODOLOGY OF THE 2007 SURVEY OF MESO- AND BATHYPELAGIC MICRONEKTON OF THE SABLE GULLY: CRUISE TEM768

by

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Cat. No. Fs 97-6/2853E ISSN 0706-6457

Correct citation for this publication:

Kenchington, T.J., M. Best, C. Bourbonnais-Boyce, P. Clement, A. Cogswell, B. MacDonald, W.J. MacEachern, K. MacIsaac, P. MacNab, L. Paon, J. Reid, S. Roach, L. Shea, D. Themelis and E.L.R. Kenchington. 2009. Methodology of the 2007 Survey of Meso- and Bathypelagic Micronekton of the Sable Gully: Cruise TEM768. Can. Tech. Rep. Fish. Aquat. Sci. 2853: vi+91p.

ABSTRACT

Kenchington, T.J., M. Best, C. Bourbonnais-Boyce, P. Clement, A. Cogswell, B. MacDonald, W.J. MacEachern, K. MacIsaac, P. MacNab, L. Paon, J. Reid, S. Roach, L. Shea, D. Themelis and E.L.R. Kenchington. 2009. Methodology of the 2007 Survey of Meso- and Bathypelagic Micronekton of the Sable Gully: Cruise TEM768. Can. Tech. Rep. Fish. Aquat. Sci. 2853: vi+91p.

A first midwater-trawl survey of the nekton and micronekton at meso- and bathypelagic depths in the Sable Gully, a submarine canyon and Marine Protected Area immediately east of Sable Island, was conducted in September 2007. The survey used an IYGPT net and followed a fixed-station, depth-stratified design, with replicate sampling in each of daylight and night. This report provides a detailed record of the at-sea methodology, as a foundation for later studies of the data obtained and as a basis for further development of the survey methodology. The limited physical-oceanographic data, acoustic records of scattering layers and whale-watch observations obtained during the cruise are fully reported, providing a background for the trawl catches.

RÉSUMÉ

Kenchington, T.J., M. Best, C. Bourbonnais-Boyce, P. Clement, A. Cogswell, B. MacDonald, W.J. MacEachern, K. MacIsaac, P. MacNab, L. Paon, J. Reid, S. Roach, L. Shea, D. Themelis and E.L.R. Kenchington. 2009. Methodology of the 2007 Survey of Meso- and Bathypelagic Micronekton of the Sable Gully: Cruise TEM768. Can. Tech. Rep. Fish. Aquat. Sci. 2853: vi+91p.

Un premier relevé au chalut pélagique portant sur le necton et le micronecton des profondeurs mésopélagiques et bathypélagiques du Gully de l'île de Sable, canyon sous-marin et zone de protection marine situés immédiatement à l'est de l'île de Sable, a été effectué en septembre 2007. Le chalut utilisé était un chalut IYGPT (pour les jeunes gadidés) et le plan de relevé comportait des stations fixes et une stratification selon la profondeur, les opérations d'échantillonnage réalisées à la lumière du jour étant répétées la nuit ou vice-versa. La méthode appliquée en mer est exposée en détail dans le présent rapport, afin qu'il puisse servir de base à l'étude ultérieure des données recueillies et au perfectionnement de la méthode de relevé. En rendant pleinement compte des données physiques et océanographiques limitées, des données acoustiques des couches diffusantes et des données d'observation de baleines recueillies durant la mission en mer, ce document donne un contexte aux prises ramenées par le chalut.

1 INTRODUCTION

The Sable Gully (Figures 1 & 2), cut into the edge of the Scotian Shelf between Sable Island and Banquereau, is the largest submarine canyon on the eastern seaboard of North America. In 2004, much of it was designated as a Marine Protected Area under Canada's Oceans Act. In preparation for that designation, existing knowledge of the Gully ecosystem was compiled in a series of reports by Harrison & Fenton (1998), Gordon & Fenton (2002) and Rutherford & Breeze (2002). Collectively, they showed that the epipelagic waters over the Gully were broadly comparable to those across much of the rest of the eastern Scotian Shelf, with little indication of locally-enhanced productivity. Yet the Gully is notable for supporting deep-diving whales, particularly a population of northern bottlenose whales (*Hyperoodon ampullatus*), one of the signature species of the MPA. The bottlenose whales are known to be specialist predators of armhook squid (*Gonatus* spp.: Hooker *et al.* 2001), diving to the lower mesopelagic and upper bathypelagic zones to feed. Hence, it appears that a canyon with unremarkable surface waters is highly productive at great depth (cf. Hooker *et al.* 2002). With the partial exception of Sameoto *et al.* (2002), however, studies of the pelagic organisms within the Gully have been restricted to the epipelagic and upper mesopelagic layers, leaving a void in understanding of the ecosystem that supports the enhanced productivity and hence the bottlenose whales.

In 2007, we initiated a research program to fill that void with the overall goal of understanding the Gully's pelagic ecosystem, including its biodiversity, both as an aid to management of the MPA and as an example of global canyon ecosystems – the very large size of the Gully allowing space for some kinds of sampling that are not possible in most other canyons. The first cruise, designated TEM768 and conducted in September 2007, was dedicated to a midwater-trawl survey at meso- and bathypelagic depths, designed to generate a quantitative description of the nekton within the canyon, including its spatial and diel variability. The prime focus was on fish, squid and the larger crustacea (including decapods, euphausiids and hyperiid amphipods). While this was a stand-alone survey, it was designed to allow comparison with the results of an extensive series of cruises in the 1980s which mapped the mesopelagic fauna south of Nova Scotia, between the shelf break and the Gulf Stream (Halliday *et al.* 1995; Themelis 1996; Vecchione & Pohl 2002), as well as with recent and on-going research in United States waters (Moore *et al.* 2003, 2004). Secondary objectives of the 2007 cruise included the collection of stomach samples for analysis of food chains and of genetic samples for the *Barcode of Life* program.

The present report documents the at-sea survey methods and presents a cruise narrative, serving as a reference source for detailed studies of the catches of particular taxa and a basis for the development of a standardized deep-pelagic survey methodology. We also present here the data obtained during the 2007 survey other than those derived by trawling, specifically: physical-oceanographic data, sounder records of scattering layers and whale-watch observations. None of those can support independent research, nor were they intended to, but they may assist in the interpretation of the trawl catches in light of other studies of the Gully ecosystem. Minor observations and recommendations on methodological issues are presented in the Methods section, while more substantial issues are taken up in the Results and Discussion.

2 METHODS

2.1 TRAWLING

2.1.1 Fishing Gear & Trawl Instrumentation

The survey was conducted aboard CCGS *Wilfred Templeman*, a 50 m stern trawler of 2,000 HP. To provide inter-comparability with the surveys in the 1980s and with the on-going research in the United States, all fishing used IYGPT midwater trawls. Two nets were taken to sea, differing in the depth specifications of their floats and in that one net (here designated Net #1) had a panel of black mesh, when the trawls were otherwise white. They were both old nets, having previously been used in Halliday *et al.*'s (1995) surveys in the 1980s and not being new even then. They were refurbished before the 2007 cruise, though experience was to show that the repairs had not gone far enough. The nets are assumed to have conformed to the standard design of an IYGPT. The careful examination of the nets that would be needed to confirm that assumption was not attempted nor was it deemed necessary. During the cruise, some points of detail in their construction were found to differ from the standard plan of an IYGPT but there is no specific reason to think that the fishing performance of the nets was affected.

The IYGPT was chosen to provide comparability with the catches of other programs and that objective was achieved. However, the selection of any particular midwater net inevitably strongly influences the catches obtained. In the case of the IYGPT, experience confirmed that almost all plankton and any micronekton smaller than krill and hyperiid amphipods escaped the net, while even the largest krill were likely undersampled. At the other extreme, most large and active pelagic fish and cephalopods can avoid an IYGPT and were undersampled in this survey. In particular, the number of *Gonatus* spp. taken was much less than would be expected from the density thought to be present, based on the expected consumption by bottlenose whales (Hooker *et al.* 2002). Capturing larger and more active animals, other than by rare chance, would require a substantially larger net towed at a higher speed. *Templeman* lacks sufficient engine power for such trawling at the depths of current interest.

While smaller than a commercial midwater trawl, an IYGPT is much larger than any available opening / closing nets and is thus able to catch both somewhat larger animals and a greater number of less-frequent species. As an open net, however, an IYGPT fishes from when it is shot away until it is recovered to the ship, not simply across some selected depth range. Indeed, it is essential to maintain a steady tension on the trawl warps throughout a set, to prevent the otter boards from becoming crossed, and hence the net fishes almost equally whether or not the winches are turning and, if so, whether the warps are being paid out or hauled in.

The trawls were deployed with Scanmar instrumentation sending data to the ship in real time, the sensors providing information on headline depth beneath the sea surface (Scanmar HC4-20/D1800), wingspread, door spread (both HC4-A144 or HC4-A110), headline height above the fishing line (HC4-TS150) and water flow speed (HC4-TSS). The HC4-TS150 additionally monitored the net's altitude above the seabed, though not with sufficient range to be useful during the 2007 survey. A Star-Oddi DST centi-ex depth and temperature recorder was attached to the headrope (except on Sets 74 and 75) to provide backup data on the depth profile of each set, along with the temperatures of the waters fished. The latter were expected to be important if the depth profile of temperature proved so variable in space or time that temperatures at fishing depths could not be inferred from CTD casts made hours earlier or later. Data were stored in the recorder and uploaded to a computer after each set. The nominal accuracy of the Scanmar HC4-20/D1800 is ±3% of measured depth, though the read-out is often unstable with outliers that are very much less accurate. The Star-Oddi DST centi-ex is designed for ±12 m accuracy

Net depth was controlled by varying the length of warp out, the speed of hauling or paying out warp, and the speed of the ship, all with reference to the read-out of the Scanmar net-depth data when that was available. When the data stream was interrupted (through equipment failure or simply because the range from the net weakened the signal received at the ship), adjustments were made based on experience accumulated during the cruise. In practice, for sets following standard profiles, the net could be well controlled without real-time depth information, though such control was deemed too uncertain for near-bottom sets within the confines of the canyon, which were aborted whenever the Scanmar depth read-out failed.

For some sets, an "aquarium codend" (Figure 3) was attached to the conventional twine codend of the net to test its ability to preserve specimens in better condition than was typical of animals taken in the net as normally configured. The "aquarium" was an old unit, originally constructed for surface use in salmon-tagging operations, following the approach of Holst and McDonald

(2000). It was refitted as a prototype subsurface unit, for meso- and bathypelagic specimen collection and was tested in that role. One set (Set 87) was made with a large plastic tub fastened inside the twine codend to test whether such simple gear could improve the condition of the specimens taken without the expense and complications of the "aquarium".

2.1.2 Survey Design

The survey followed a fixed-station, depth-stratified design, using several different tow profiles. The stations were selected, with the aid of detailed bathymetric information for the Gully MPA (Figures 2 & 4), so as to ensure that sets along straight tracks could be completed without encountering the canyon walls or floor. The limited number of places where a large net could be towed at depth inside the canyon determined the choice of a fixed-station design.

<u>2.1.2.1 Stations</u>: There were three stations aligned along the canyon: a "Deep Station", where the canyon cuts through the continental slope, a "Main Station" north of the shelf break and in the area where bottlenose whales have most often been observed, and a "Head Station" as near to the head of the Gully as sufficient depth could be found (Table 1). A fourth "Wall Station" was adjacent to the Main Station but placed over the canyon wall to allow examination of the effects on the mesopelagic fauna of proximity of the seabed. In addition, one set was made in a feeder canyon on the west side of the Gully.

A further station, outside the canyon, was frequently fished during Halliday *et al.*'s (1995) mesopelagic surveys and was selected for trawling in 2007 with the intention of providing a comparison between catches in the Gully and those taken by the earlier program, of examining temporal change over 20 years at the one site, and of describing faunal differences between the canyon and the nearby open ocean. For the present program, it was designated the "Offshore Station".

<u>2.1.2.2 Depth-Stratified Survey</u>: The core of the 2007 survey comprised depth-stratified sets at each of the named stations. The strata fished were nominally 0–250 m, 250–750 m and 750–1250 m, though the deepest of those was unavailable at the Wall and Head stations. (With the IYGPT being an open net, sets designed to sample the deeper strata actually fished from the surface to the maximum depth of their nominal stratum.) Restricting the shallowest stratum to half the depth range of the deeper strata served to distinguish the epipelagic zone from deeper waters without doubling the number of strata and so the number of IYGPT sets required. Before the cruise, there was an option of adding a 1250–1750 m stratum at the "Deep" and "Offshore" stations. In practice, those depths were not fished systematically due to a lack of time. Available warp lengths and trawl-winch power prevented fishing significantly below 1750 m and no attempt was made to do so.

Within each stratum, the survey design called for stepped-oblique profiles since it had been assumed that the ship's trawl winch would be unable to cope with continuous-oblique profiles. In practice, control of net depth below 250 m proved to be too imprecise for stepped-oblique profiles to be achieved but continuous-oblique towing was found to be straightforward and was therefore adopted. Meanwhile, it had been supposed that the net would be dropped to depth and that it would only begin fishing once the maximum depth of the stratum had been reached. In practice, the need to keep tension on the warps to prevent the otter boards from crossing meant that the net fished while being dropped to depth. Hence, sets in the strata below 250 m depth all followed a double-oblique or "V" profile, though hauling was faster after the net left its nominal stratum, producing some irregularity in the "V". All sets in the depth-stratified design saw the net in its nominal stratum for 60 minutes. Total fishing time for the deeper sets was substantially longer.

Sets in the 0–250 m stratum initially followed the intended stepped-oblique design, with steps at 50 m intervals occupying 12 minutes each, including the time to change depth to the next step. The very slow hauling needed in an hour-long continuous-oblique set covering only 250 m depth was deemed impractical and hence the stepped design was retained until Set 43, despite its abandonment for the deeper strata. Subsequent sets in the shallowest depth stratum followed a "W" profile, in which the net was dropped to 250 m, recovered to 50 m depth following a double-oblique track, dropped again to 250 m and then brought to the surface as a second double-oblique track. That profile proved very practical to follow.

No fishing was conducted during dawn and dusk periods so as to avoid the confusions resulting from sampling migratory animals while they were moving in the water column. "Dawn" and "dusk" were arbitrarily defined as periods extending one hour either side of sunrise and sunset, respectively. On the dates and at the locations of the trawling, the time of sunrise varied between 0927 and 0940 UTC, while the time of sunset was between 2158 and 2220[1]. For practical purposes, the non-fishing times were set at 0830–1030 and 2110–2310.

Pre-cruise planning envisioned at least two replicate sets (three on the Main Station) in each stratum on each station in each of daylight and night. In practice, daylight catches above 250 m were minimal and only a single set of that type

[1] All clock times presented in this report are in UTC (synonymous with GMT). While at sea, the ship's clocks were maintained on ADST (Z+3 or 3 h slow of UTC) but the computers logged data in UTC. Local Apparent Time (i.e. time relative to the Sun) in the Sable Gully during the survey was within a few minutes of being 4 h slow of UTC, while Zone Time for the area is AST (Z+4).

was made on each station, aside from the Main Station, where a full three sets were made. Otherwise, the design was achieved at all stations in the Gully (with one extra set on the Wall Station) but only one V-profile set was made in each stratum in each of daylight and night on the Offshore Station (Tables 2 & 3).

2.1.2.3 Other Trawling: With the exception of the Wall Station, where the 250–750 m stratum closely approached the seabed, one set was made on each station below the depth of the deepest stratum routinely fished. Those were generally "V"-profile sets but on the Deep Station (Set 73) the net was held at about 1500 m depth for an hour before hauling back, in an unsuccessful attempt to collect more specimens of bathypelagic species. The extra-deep set on the Main Station (Set 80) was made with the "aquarium" codend attached to the net.

Halliday *et al.* (1995) had used a wide variety of tow profiles in their surveys of mesopelagic species but had primarily relied on stepped-oblique sets, made at night, with one ten-minute step at each of 200, 100 and 50 m depths. In order to obtain comparative data, the cruise plan for 2007 envisioned that three sets would be made at the Offshore Station following that Halliday *et al.* (1995) profile. In practice, two such sets were completed (Sets 4 & 5).

The cruise plan also called for at least one targeted set, at each station, to be made in each persistent scattering layer observed on the echo sounder trace. In practice, a great many scattering layers were observed (up to about 20 at one time) but they were not spatially persistent. They did form an extensive band of acoustic scattering, generally distributed from about 350 to 750 m depth, but that was well sampled by the oblique sets in the 250–750 m depth stratum. In the event, there were only two occasions when well-defined scattering layers invited targeted fishing. Only one of the two sets (Sets 37 & 55) produced a markedly enhanced catch, suggesting that the other missed the scattering layer to which it was directed, though it is also possible that the scatterers were too small to be retained in the IYGPT and that they were not then accompanied by larger predators.

Sets 81 and 84 were made on the Head Station with the "aquarium" codend mounted on the net, to gather catches comparable to the regular depth-stratified sets in the same strata and hence to provide an indication of the effects of the "aquarium" on the efficiency of the trawl. Set 79 was towed up a feeder canyon west of the Main Station with the "aquarium" codend fitted. It followed a "V" profile similar to those of standard sets in the 750–1250 m depth stratum but constrained by bottom depth. It was intended to sample any benthopelagic fauna and was thus fished as close to the seabed as prudence allowed – the net being at times deeper than was the seabed beneath the ship, which was more than a kilometre further up the canyon.

Other IYGPT sets included a mixture of gear trials and aborted sets (Table 2).

A further pre-cruise proposal was to repeat the depth-stratified fishing on the Main Station one week after it was first done, in order to distinguish diel changes in distributions from any driven by tidal streams, the timing of semi-diurnal tidal phenomena changing by six hours (or 180° of phase) per week. In the event, the available fishing time did not permit such a repetition.

2.1.3 Catch Processing

2.1.3.1 From Codend to Sorted Taxa: When each IYGPT set, aside from those that used the "aquarium", was recovered to the deck, the codend contents were dumped into a plastic tub and the codend hosed down, washing any residual catch into the same or an additional tub. The net was then searched from wings to codend, all animals found being extracted and added to the catch. During daylight, that picking of the net appeared highly successful, with little left in the meshes to contaminate future catches, aside perhaps from small *Cyclothone* spp. Searching the net under the deck lights at night could not be equally comprehensive. When the "aquarium" codend was fitted to the net, the catch was mostly bailed out and kept in water until sorted, though the "aquarium" and the twine codend leading to it were then hosed down and the net picked as usual.

Provisions were made in the cruise planning for recording large volumes of gelatinous plankton on deck and discarding them immediately, while retaining other catch from the same sets. In the event, no such large catches were taken and all material from the net was taken below for sorting in the ship's laboratory.

The protocols for subsequent processing evolved during the cruise, as was expected during what was, in part, a trial of a new kind of survey. It had proven impossible to fully anticipate, in advance, the best means of handling the catches while ensuring that all required data were collected. The end result was less than ideal but did yield valuable experience as a foundation for designing a standard protocol for future surveys. Presentation of the evolving methods in this report is necessarily complex. The approaches most commonly applied are described in this section, while all exceptions are specified in Table 2.

The catch from each set was sorted by taxon in a multi-step process, with the finer sorting undertaken by specialists, most animals being ultimately sorted into individual species or at least genera. Catches from sets that were aborted for various reasons, along with those from gear trials and the like, were generally picked over for interesting taxonomic specimens but otherwise discarded without full sorting or data recording. However, the catches from some non-standard IYGPT sets were fully processed (see Table 2).

Halliday *et al.* (1995) had recorded their catches by displaced volume and the intention in 2007 was to record both the total volume and total weight (per set) of each of the fish, cephalopods, crustaceans, gelatinous plankton and other invertebrates, thus generating data for volume / wet-weight conversions. In practice, efficiency in catch sorting demanded that the major taxa were partially subdivided during the initial sort, which then made determination of volumes a laborious, multi-step process. It was largely abandoned during the cruise, in order to focus the available manpower on maximizing the number of sets that could be processed. In the event, only a few displaced volumes were recorded (Table 4).

When volumes were measured, the animals were placed in containers of known volume and seawater added until the marked volume was reached. The water in the container was then poured off into a graduated funnel, the animals being left on a mesh surface while the residual water drained. Subtracting the volume of water from that of the container provided the displaced volume of the animals. With gelatinous plankton, the water volumes were often large and were sometimes determined by weighing, the weights subsequently being multiplied by the density of seawater, rather than by direct measurement. The weights corresponding to the volumes were reconstructed ashore from the recorded weights of individual taxa.

2.1.3.2 Fish: All fish caught by regular IYGPT sets were sorted and identified at sea to the lowest practical taxonomic level (usually species), the scientific personnel on the cruise including a fish specialist on each watch who coordinated their use of designations for those taxa that could not be identified to species while at sea. The catch (from each set) of each taxon was weighed (wet weight to 0.1 g precision for smaller weights, otherwise to 1 g, using a motion-compensating balance) and, in general, the number of individuals was counted. For the purpose of those counts, an “individual” was defined as a complete vertebral column, whether or not that was part of an intact fish. In cases where a significant amount of material could be identified to some taxon but not assigned to a counted individual, the counts made at sea were subsequently expanded by the total weight of that taxon (per set) and the weight of all counted individuals[2].

[2] That adjustment of the counts was an unanticipated effect of the GSE (“Groundfish Surveys Entry”) software used for recording the IYGPT catches at sea. While fully appropriate for neritic fish surveys, in which damaged individuals are unusual and usually distinct from the animals measured, it will have produced errors when used in the present deepwater survey. Catches from meso- and bathypelagic depths include many specimens with soft bodies and weak skeletons which can lose much of their weight to damage in the trawl and yet can still be measurable. The difference between total catch weight and the weight of measured carcasses is, therefore, partially a matter of tissue broken away from

Likewise, if only a subsample of the fish was measured (see below), the overall count was obtained by expanding the number of measured individuals by the ratio of total weight of the taxon caught to the weight of the measured subsample. No attempt was made to count the numbers of *Cyclothone* spp., which were too small for quantitative sampling by the meshes of the IYGPT net and which were usually taken only as naked vertebral columns. When more than insignificant quantities of unidentifiable fish tissue were taken, the weight of that material was recorded as "unidentified fish and remains"[3].

By intention, every individual fish caught (except *Cyclothone* spp. after the first two sets) was measured (standard length, in millimetres), up to a maximum of about 200 individuals per taxon per set – a limit only reached with *Benthosema glaciale*. When greater numbers of fish were taken, a subsample should have been extracted, weighed and all individuals within it measured but it appears that, for many sets, individual fish were extracted and measured until 200 lengths had been recorded, after which those measured fish were weighed as a group. That process will have biased the recorded length frequencies.

In practice, many individuals were too damaged for useful measurement. Unfortunately, for some sets there was a mistaken attempt to measure 200 individuals of *B. glaciale*, even when too few undamaged specimens were available. As a consequence, some measurements of lengths shorter than the standard length (some as short as the length of the vertebral column alone) were introduced into the database, with the extent of the bias differing from set to set and station to station. The resulting data are adequate as indicators of the size of the fish taken but should not be used in comparisons of size distributions among the stations or depth strata of this survey.

Individual fish were not routinely weighed, except where samples were retained for specific studies (see below). Such fish weights as were taken were recorded to 0.1 g precision. Unfortunately, it was discovered during the cruise that the catch-recording software used ("Groundfish Surveys Entry", hereafter "GSE") was truncating the entered values to whole numbers of grams. From Set 23 onwards, the data were entered as ten times the true weight and subsequently scaled down. Shortly before that change in procedure, some weights were

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those individuals that were measured and only partially of additional individuals too damaged to measure. The extent of the errors in the 2007 catch data resulting from this inappropriate adjustment are currently unknown.

[3] During the cruise, considerable quantities of a white substance of unknown origin were found in the catches. Only when the "aquarium" codend was fitted and examples of that substance were found *in situ* as the scales of *Scopelogadus beanii* was its origin discovered. The scales taken in earlier sets were therefore not included in the weights of unidentified fish remains.

rounded to the nearest whole gram before entry to the GSE. Subsequent to the cruise, all individual fish weights of less than 10 g recorded from Sets 1 to 22 were discarded, to avoid excessive errors from the rounding down – the alternative of adding 0.5 g (to halve the maximum error from the rounding) being prevented by some data having been rounded up before data entry. Other weights from those sets were retained, to a precision of 1 g.

Following identification, counting, weighing and measuring, the first claim on fish specimens was for DNA “barcoding”. The aim was to select one or two specimens of any fish species caught that had not previously been collected for the *Barcode of Life* project. Specimens selected for genetic sampling were photographed before a muscle-tissue sample was extracted and preserved. The residue of each specimen was, by intention, then individually fixed in formalin. In practice, some were frozen and others fixed in jars containing more than one individual specimen. In the event, 205 tissue samples were taken for DNA sequencing, including examples of some 90 different species according to at-sea identifications. Following *Barcode of Life* protocols, DNA sequences were subsequently prepared ashore and the remainder of the fish archived at the Atlantic Reference Centre, St. Andrews, N.B.

From the remaining catch, specimens were selected for stomach-contents analysis, with the intent that other biological data might be taken from the same individuals at a later date. Those species which were the first, second or third most abundant fish in a set were considered for such analysis, though a species which had achieved that status in one set would then be considered for sampling from all other sets at the same station. Non-myctophid species that were consistently frequent, though never among the three most abundant in any set, were also considered for sampling. Among qualifying species, samples were only to be retained if at least 30 individuals could be accumulated from the sets made in a particular depth stratum at a particular station. In the event, only *Benthosema glaciale* met the latter criterion more than occasionally, though specimens of other species were sometimes retained for exploratory analysis of diets. Up to 100 individuals were to be preserved from each species and each set, with a directive to include large individuals while haphazardly selecting the remainder, though the common procedure was to retain only 30 individuals per set. Each selected specimen was measured, if that had not been done previously, most were individually weighed and the specimens were individually bagged in brine and frozen.

The remaining fish specimens were fixed in formalin if they could not be identified to species or if they were specimens of rare or otherwise interesting species. All other fish caught were then discarded. Many specimens were photographed. Subsequent to the cruise, all preserved specimens (aside from those frozen for stomach analysis) were re-examined to confirm and, where possible, refine their taxonomic identifications.

For efficiency in the laboratory at sea, the work flow was not as described above. Rather, the common species were swiftly sorted from the mass and checked for identification by a specialist. The samples for stomach analysis were picked out, weighed as a group (for subsequent summation with the weight of other fish of the same species from the same set), measured, individually weighed and then bagged. The remainder of the common species were then weighed, with each taxon as a unit, and the lengthy process of measuring individuals commenced. The combined weight of the individuals measured was recorded separately from the weight of all other members of the taxon, for subsequent summation. Meanwhile, less-common species were identified by a specialist, weighed and counted. The first and second specimens of each taxon that were encountered during the cruise were handed to the "barcoding" specialist for tissue sampling.

2.1.3.3 Cephalopods: Most cephalopods were identified at sea by a taxonomic specialist, usually to the species level, and their dorsal mantle lengths (in millimetres) and individual wet weights (0.1 g precision, with the same caveats as applied to fish for catches before Set 23) were recorded. Where possible, disarticulated heads and bodies were reunited for weighing. Bodies without heads were measured for mantle length but no weights were taken of headless bodies or heads without bodies. The combined weight of the catch of each taxon (from a single set) was recorded, either by summation of individual weights or by a separate weighing but excluding all body parts that could not be united into discrete individuals. The count of measurable mantles was recorded for each taxon, as was the total weight of all cephalopods taken in each set (including all unattached body parts) summed across the taxa.

Many specimens were photographed and / or fixed in formalin and returned to shore, either for identification or as specimens for collections. When the cephalopod specialist was off watch and unavailable, the bulk weight of the cephalopod catch from each set was typically recorded and the entire catch, (occasionally less the common and easily-identified species, which were discarded after recording), was fixed for identification ashore. When the specialist was able to sort the catches herself, the bulk of the cephalopods, comprising many individuals of only a few species, was discarded after the data had been recorded.

Stomachs were extracted from some specimens, particularly *Gonatus* sp. that appeared to have recently eaten, and preserved for a potential study of food types. Some tissue samples were retained for genetic analysis while many specimens were photographed.

Subsequent to the cruise, the cephalopod specimens were transferred to alcohol and sent to the Delaware Museum of Natural History for further study, including any necessary confirmation of identifications. On completion of that work, certain of the specimens will be returned to Canada for archival storage.

2.1.3.4 Crustaceans: At sea, the crustacean catch was sorted to the lowest taxonomic level possible, which was often generic, with the final sorting by a taxonomic specialist. For most groups, the wet weight caught in each set was recorded, samples were fixed in formalin and the remaining catch, if any, was frozen (as a bagged sample of one taxon from one set) for further examination ashore. For taxa requiring special care in subsequent laboratory identification, the entire catch was fixed but for those identified with confidence to the species level at sea, most of the catch was frozen and only single specimens from some sets were fixed. Many photographs were taken before specimens were fixed. No counts of abundance were made at sea, though some were reconstructed subsequently when either the entire catch of a taxon or else a quantitative subsample was preserved.

For the euphausiid krill, the decapods *Sergestes* spp. and the hyperiid amphipods, catches were typically large, in abundance terms. Following the extraction of all other taxa, the total weight of the three groups combined was recorded for each set, after which one or more weighed subsamples were sorted into the three groups. For much of the cruise, the subsampling was continued until a minimum of each of 1000 ml of *Sergestes* spp., 500 ml of krill and 250 ml of hyperiids had been obtained. (Those volumes were intended to secure minimum preserved samples of 200 to 400 individuals per taxon per set.) Latterly, the hyperiids became so scarce that very large amounts of krill were being sorted to achieve the required minimum amount of amphipods, leading to a decision to sort only a single 1000 ml subsample. The sorted animals from the subsamples were weighed (per taxon and set) before being fixed in formalin. The remainder of the krill, *Sergestes* spp. and hyperiid catches were then discarded.

Some samples of crustaceans were retained for genetic study, by informal extension of the fish “barcode” sampling. No special samples were retained for work on stomach contents, the specimens frozen whole being adequate for that purpose.

Preserved and frozen material was subsequently examined in laboratory ashore to provide species level identifications, counts and weights. Weights of fixed material were corrected to wet weight, using correction factors for the same or similar species fixed in formaldehyde. Abundance and biomass estimates were calculated for euphausiid krill, *Sergestes* spp. and the hyperiid amphipods by expansion from the counts and weights of the fixed subsamples.

2.1.3.5 Gelatinous Plankton: The gelatinous plankton from each set was weighed as a single bulk item and, in some cases, its displacement volume was also determined. In general, the material was then discarded. For some sets, the gelatinous catch was sorted into five recognizable taxa, after which the count of individuals in each taxon was additionally recorded, as were (later in the cruise) the taxon weights. Specimens of all five taxa were retained for subsequent identification ashore, while some were photographed to aid those identifications.

2.1.3.6 Other Invertebrate Species: Few specimens of other species were taken and they tended to receive individual attention. Each was recorded, weighed and preserved in alcohol or formalin, or else by freezing. The exceptions were the large chaetognaths that were regularly seen during catch sorting later in the cruise[4]. It appears that those, even after extraction from the remainder of the catch, were frequently either combined into the gelatinous plankton (making a negligible contribution to its recorded weight) or else discarded without being recorded at all. Records of chaetognath catches certainly severely underestimate the amounts caught.

2.1.4 Photography

Multiple photographic systems were used to produce visual records of both individual specimens and shipboard operations. For small specimens and detailed features on larger ones, a camera-equipped microscope was hardwired to a computer to capture imagery through an already-tested system. Larger whole specimens were photographed using either a developmental lighting and camera system or else simply a hand-held digital camera.

Shipboard operations, including details of handling the trawl and its “aquarium” codend, were mostly recorded using the private cameras of members of the scientific party, though the camera provided for whale observations (see below) was also used. The records included video, digital-still and slides.

[4] It is uncertain whether this apparent increase in abundance was real. During rough sorting, the chaetognaths were easily confused with the naked vertebral columns of *Cyclothone* spp. and the collections of the latter were not closely examined before being discarded. Many chaetognaths may have been recorded only as a minor contribution to the weight of *Cyclothone* spp.

2.2 DATA RECORDING & EDITING

2.2.1 Bridge Data

Pre-cruise planning had supposed that the very large amounts of data generated on the ship's bridge could be captured to a single database in real time using ClassActMapper software. In the event, the system could not cope with the volume of data and other arrangements had to be substituted while the work was on-going.

In practice, the ship's Aldebaran II navigational computer logged basic navigational data (date, time, position, heading, speed and usually bottom depth) every two seconds, with values for the intervening seconds being subsequently interpolated. Bottom depth was sometimes unavailable, when the seabed was beyond the detection range of the EK500 echosounder, and was sometimes erroneous when the instrument "white lined" on a scattering layer for want of a stronger echo. When trawling, the Scanmar output was recorded by another computer, under the control of the ship's watchkeeping officers. Both the navigational and the Scanmar data were periodically copied to a data-management computer and were backed up daily.

One member of the scientific party was present on the bridge during all trawling operations, with the dual roles of directing the fishing (through the ship's officer of the watch) and maintaining, on hard copy, a descriptive record of events, such as shooting the net, applying the winch brakes or commencing hauling, as well as any gear damage. In the absence of ClassActMapper, that was the sole record of the activity of the trawl winch, including times of starting and stopping, rates of paying out and hauling, as well as lengths of warp out[5]. The records maintained on the bridge by scientific personnel were also the primary logging of times of shooting and hauling (summarized in Table 5).

A parallel record of events was maintained by the ship's officers in the form of a "Station and Set" record for each set. Those required a standardized data format which was demanded by the GSE software and subsequently by the standard databases in which the data were to be archived. However, the "Station and Set" format was too rigid to capture the subtleties of this midwater-trawl survey and the data obtained were only of use for corroboration of the records kept by the scientists observing the trawling. Archived data from the "Station and Set" records should not be used in future analyses.

[5] Electronic recording of winch activity would be advantageous on future surveys.

2.2.2 Laboratory Data

Data generated in the ship's laboratory were variously recorded in logbooks and directly to the GSE software. The latter is the standard system used for the capture of catch data during routine groundfish surveys in DFO's Maritimes Region. While well suited to its designed purpose, the software proved to have severe limitations for deep, midwater work. Besides the already-noted inability to record weights to fine precision and the unanticipated adjustment of numbers of individuals caught, it could not record lengths of more than three figures (which is no restriction when measuring in centimetres on a groundfish survey but did cause problems with the millimetric precision required when so many species taken have small maximum sizes). A greater problem arose because GSE cannot accept data from a new set until entry of all data from the previous set has been completed – a major disadvantage with the complex workflows that arise when specimens require expert identification. The software required keyboard entry of data, lacking direct connection to the electronic balances, while length measurements were taken on manual (not electronic) measuring boards. The system was expected to demand that all key data fields were completed but frequent gaps in the resulting data suggest that that feature did not function as intended.

Subsequent to the cruise, the catch data recorded through GSE were subjected to a standard battery of checks, particularly for null values and outliers. Anomalies were identified and the data edited as necessary. The dataset was additionally updated to incorporate all catch records that, at sea, had been logged in hard copy only.

2.3 ACOUSTICS

CCGS *Wilfred Templeman* was equipped with a Simrad EK500 echosounder, with a 38 kHz transceiver, 4 kilowatts of transmission power (source level: ≈126 dB ref 1µPa at 1m) and a hull-mounted transducer. The focus of the cruise was on trawling and no attempt was made to run acoustic-survey transects. However, the sounder was kept in continual operation and was used to observe scattering layers as well as the seabed.

The sounder menu settings were largely left to those standard in acoustic surveys of fish biomass. Time Varied Gain ("TVG") was consistently set at 20 Log R. The ping interval was frequently left set to automatic, leading to variable rates of generation of output display (i.e. millimetres of paper trace per minute of time). The degree to which received sound was displayed as scattering layers was optimized by adjusting the minimum displayed Target Strength (TS) and Scattering Volume (Sv). At continental-shelf depths, the *Templeman's* EK500 has been shown to work well at TS_{min} = -51 dB and Sv_{min} = -71 dB. Trials at the greater depths fished during September 2007 led at first to a preferred settings of TS_{min} = -55 dB and Sv_{min} = -68 dB in order to both detect the seabed and display the scattering layers. Between Sets 35 and 36, the settings were further amended to TS_{min} = -70 dB and Sv_{min} = -75 dB. However, the sounder was sometimes adjusted to meet the needs of the ship's watchkeeping officers and was not always promptly reset to match scientific requirements. The changing echosounder settings were not consistently logged, nor did the instrument display them outside of its menu field, save only for the depth range selected.

The EK500 had a colour video display but also produced permanent paper records by sending its output to an inkjet printer. The printer was in continuous operation whenever the ship was over water deeper than 200 m and sometimes when over the banks. However, there are breaks in the record resulting from various failures of the printing process. Aside from logged seabed depths, all extant information gleaned from the sounder was taken from the printed records and thus suffers from the same breaks. Since the printer only recorded the time at the start of each new page, while the rate of printing varied with the ping interval, there is some uncertainty as to exactly when particular echo traces were recorded and hence as to where the ship was at the time.

Subsequent to the cruise, the printed echograms were scanned into electronic images. An ArcView file was prepared from the ship's navigational data, showing the cruise track subdivided into time periods corresponding to each printed page, with the individual segments hyperlinked to the scanned images. It was thus possible to identify either the location of some feature identified on an echogram or else the echo traces corresponding to some location, subject to the uncertainty in timing of recorded echoes. The approach did not allow the detailed interpretation of scattering layers that an acoustic survey, running straight transects, would have done but it did greatly facilitate the use of echograms recorded as the ship undertook other functions.

2.4 PHYSICAL OCEANOGRAPHY

The ocean waters off the mouth of the Sable Gully are exceptionally variable, due to the movements of Gulf Stream meanders and eddies. To support *post hoc* interpretation of trawl catch data, AVHHR satellite imagery of sea surface temperature ("SST"), downloaded from Rutgers University's Coastal Ocean Observation Laboratory, for the period before and during the cruise was examined. While informative, SST has a severe limitation for the immediate purpose in as much as the Scotian Shelf Water and Slope Water have very similar surface temperatures (though different salinities) in late summer, preventing detection of the biogeographically-important shelf / slope front in SST imagery. Those images were therefore supplemented with interpretations developed by the U.S. Navy's Naval Oceanographic Office (routinely captured and archived at BIO) which utilize a wider range of data sources. The satellite data were not examined at sea as there was no intention of, and very limited opportunity for, altering the trawl-survey design to match particular water masses.

CTD casts were made whenever practical during the dawn and dusk periods between daylight and night trawling operations, usually near the station last trawled (Table 2). No attempt was made to deploy the CTD near the canyon walls and hence, when fishing the Wall Station, the casts were made on the Main Station. This limitation was essential to the security of an expensive instrument when the ship was drifting across the canyon with the hydro wire displaced laterally by an unknown amount. However, it prevented observations of any near-bottom upwelling or downwelling, which may have great importance to bentho-pelagic species. Deployment of a cheaper and more robust, albeit less precise, sensor (such as an XBT) might be considered, though the homogeneity of water properties below about 500 m depth in the Gully would prevent detection of most water movement by such means, while deployment of expendable instruments within the MPA would raise concerns over the discarding of sensors and wire[6].

The CTD used was a Sea-Bird SBE25, bearing an oxygen sensor as well as the temperature, conductivity and depth sensors. After each cast, the data were uploaded to a dedicated computer and backed up to the data-management computer. Each cast carried a single NIO bottle used to collect a salinity sample for on-shore calibration of conductivity readings. Subsequent to the cruise, the CTD data were subjected to standard quality-control steps and uploaded to the Integrated Science Data Management (ISDM) national archive. Locally, vertical profiles of temperature, salinity, density and oxygen concentration were generated for each cast, as were temperature / salinity plots.

The data from the downward leg of each CTD cast were plotted and examined. To aid comparisons among the casts, the depths (in units of decibars, here interpreted as metres) of selected isotherms below the subsurface temperature maximum were read from the data file for each cast (downward leg only). Where an isotherm was crossed more than once, the measured depths were averaged. With the exceptions of Sets 40 and 82, which proved to be anomalous, the isotherm depths on the casts at each station were then averaged.

The Star-Oddi recorder attached to the IYGPT's headline recorded temperature as well as depth. However, there was an appreciable lag in its temperature response, reducing the value of the data in the top 200 m of the water column, where there were pronounced thermoclines. Below 200 m depth, the CTD data showed great stability in temperature profiles, such that the temperatures fished

[6] XBTs were carried as backup for the CTD but were neither required nor used.

could be determined, with fully-adequate precision for biological purposes, from information on net depth and the results of the CTD casts. Hence, the Star-Oddi recorder's temperature-sensing capability was a potential (though, in the event, unneeded) backup to the CTD but otherwise of limited value on this survey.

2.5 WHALE & SEABIRD OBSERVATIONS

The limited number of berths for scientific personnel aboard CCGS *Wilfred Templeman*, coupled with the heavy workloads processing trawl catches, precluded maintaining a continuous whale watch during daylight. Whales were nevertheless recorded when seen, the initial sighting being most often by the ship's watchkeeping officers and lookouts. Records were maintained on standard *Marine Mammal Encounter Record* logsheets. The *ad hoc* nature of the observations, the inexperience of the observers (requiring much consultation of reference books) and the impossibility of recording data while continuing to keep a whale in sight conspired to degrade the quality of the records. Should berthing space permit on future surveys, a dedicated whale watcher (supported as necessary by the scientist posted to the bridge to direct the trawling) would result in a marked improvement in data quality.

The cruise carried a camera with 300 mm telephoto lens for whale photography, especially for recording the identifying colour markings of individuals. In the event, whales very rarely approached the ship closely enough for photography and, when they did so, the visit was fleeting and did not provide opportunities to unpack the camera from its safe storage before the encounter was over.

No formal observations of seabirds were made but occasional notes were kept on those seen.

3 CRUISE NARRATIVE

CCGS *Wilfred Templeman* secured alongside at BIO to load scientific equipment at 1530 UTC on 5 September and departed for sea at 1715 next day. Passing south of Sable Island, the ship crossed Logan Canyon at 1120 on 7 September, when recording began with the EK500 echosounder. At 1400, it was decided to test deep-fishing capabilities by shooting the IYGPT on 2,500 m of warp, while heading east to keep the wind on the stern. That became Set 1 of the cruise. The ship then proceeded to the Offshore Station, in 15 knots of wind and a slight sea, to commence work.

Templeman remained on the Offshore Station until 0200 on 10 September, the weather first improving to 5 knots, with a smooth sea and a low swell, before the wind picked up again. In that time, one IYGPT set in each depth stratum during each of daylight and night was completed, as were one set below 1250m, two stepped-oblique sets mimicking the design used by Halliday *et al.* (1995) and three CTD casts. There were a further five IYGPT sets that were either aborted or deemed unrepresentative (Table 2). During Set 8, likely as the net was being recovered up the stern ramp, one of the combination ropes around the mouth of the trawl parted –the second such failure since the start of the cruise– requiring a change to Net #2.

By the end of Set 18, the work offshore was far from complete but progress had been slow, with only nine valid, quantitative sets completed, and a decision was made to move into the Gully before more time was lost. The steaming distance then precluded a return to the Offshore Station when work at other stations went more swiftly. At 0446 on 10 September, Set 19 was shot away, commencing operations on the Main Station. *Templeman* continued to work that station (aside from Set 38 on the adjacent Wall Station) until 0700 on 13 September, when Set 43 was completed. Those 24 sets included three IYGPT sets in each depth stratum and in each of daylight and night, one set (Set 37) targeted on a scattering layer at 450m depth, plus four CTD casts. The only aborted set was a CTD cast that had a technical failure. During the three days, the weather was initially as fine as it had been on the Offshore Station but the wind picked up to 20 knots late on 11 September, producing moderate seas. Trawling was suspended for six hours between Sets 34 and 35 but then resumed. Conditions improved again on 13 September.

The ship then moved to the Head Station for Sets 44 to 52, the latter being completed at 0730 on 14 September. Only five of the nine sets were successfully-concluded IYGPT sets, while one other was a successful CTD cast. Two of the remaining sets were lost to equipment failure: In one case, the Scanmar depth read-out was lost, posing unacceptable risks in the confines of the canyon head, and in the other the starboard trawl winch developed a slack turn in the warp, requiring priority attention.

The final set, Set 46, was the sole case during the cruise of any gear contacting the seabed. At 1610 GMT on 13 September, the IYGPT net was shot away with the intent of fishing the 250–750 m stratum, the winch brakes being applied at 1642, with 1600 m of warp out on each side. Perhaps under the influence of wind and tide, the ship veered to the north of the intended track of the Head Station, though it is likely that the set would have been successfully completed if that course had been maintained. However, some 40 minutes into the set, *Templeman* altered course further to the north. Hauling back commenced as intended at 1657, by which time the net would have sunk to about 750 m but, with the ship heading towards the Banquereau side of The Gully, contact with the canyon wall on was by then almost inevitable. It happened at 1705, as logged on the bridge, though likely some 15 seconds earlier, judging by a sharp change in the ship's recorded positions at that instant. The ship's DGPS position was then 44° 03.7' N 59° 02.2' W. Net depth was approximately 700 m, based on Scanmar data, and the contact, far astern of the ship, likely occurred a little to the north of 44° 03.0' N 59° 02.2' W. The net was very badly damaged but all parts were recovered, including the Scanmar sensors, which were found in the remnant of the codend. The catch was not fully processed but the weight was recorded by major taxon. The corals and some other benthos taken incidentally were returned to shore for further investigation (Table 6). The damage to the trawl necessitated a change back to the repaired Net #1 from Set 48 onwards.

Sets 53 to 61 were made on the Wall Station. Combined with the earlier Set 38, those served to complete the survey design on the Station and added an extra set between 250 and 750m. In addition, Set 55 was targeted on a scattering layer at 390m while Set 57 was a CTD cast.

By 1100 on 15 September, *Templeman* was commencing Set 62 on the Deep Station. By 1500, the wind had risen to 25 knots from the southeast, producing a moderate sea. Although the wind went no higher, a heavy swell rolled in and the sea became rough over the following twelve hours. Fishing ceasing after Set 64 was completed at 1807. Following the processing of the catch from that set, scientific operations were suspended until Set 65 was shot away at 1000 on 16 September. The wind and sea continued to drop away, such that the early hours of 17 September saw only light airs, a smooth sea and a low swell. Work on the Deep Station continued to Set 77, which was concluded shortly before 0300 on 18 September. In that time, the regular survey sets on the Station were completed. In addition, two CTD casts were performed while Set 73 was an extra-deep set.

Having almost completed the intended quantitative survey work in the Gully, it was decided to test the prototype "aquarium" codend, even at the risk of damaging the one remaining usable IYGPT net. Set 74 was the initial trial, merely testing the handling of the equipment. No catch was taken. The gear was then deployed in a test of its effectiveness in lessening damage to the specimens caught. That set, Set 75, was made away from the Deep Station to the southwest. It followed the depth profile of the survey sets in the 250–750m stratum.

Following the two remaining sets back on the Deep Station, *Templeman* then worked back to the northward, fishing with the "aquarium" codend mounted on the net. Set 78 was an attempt at an extra-deep set on the Main Station which had to be aborted when the ship veered too far west. The intended set was successfully performed as Set 80. In the meanwhile, Set 79 was towed up one of the feeder canyons on the flank of Sable Island Bank.

At the Head Station, Sets 81 and 84 mimicked regular survey sets but with the "aquarium" codend fitted so as to test its effect on the quantities of animals caught. Set 83 was an "extra-deep" set, in as much as it went below the 750 m maximum depth of the strata regularly fished at the Head Station. However, its maximum depth was only 900m, that being sufficient for it to take benthopelagic species in the relatively-shallow area. Sets 82, 85 and 86 comprised a CTD cast and the two regular survey sets needed to complete the survey design at the Head Station. Finally, Set 87 replicated Set 83, except that a large plastic tub was fastened inside the cod end, instead of fitting the "aquarium", to see whether the simpler approach would have equally-beneficial effects on the quality of the specimens taken. In the event, the catch in the tub resembled what would have been taken with a mesh codend alone and the idea was abandoned.

Meanwhile, the weather had continued ideal since late on 16 September, with never more than 10 knots of wind rippling the surface over a low swell. The last set was completed at 1500 on 19 September and the ship headed for Halifax. Shortly after departing the Head Station, *Templeman* passed over the 200 m contour on Sable Island Bank and the recording of echosounder traces ceased. The ship secured alongside the BIO wharf at 1500 on 20 September.

4 RESULTS & DISCUSSION

4.1 SUMMARY OF THE TRAWL CATCHES

The survey's principal results, which take the form of the data on trawl catches, will be the focus of subsequent publications and are reported here only in the briefest outline. As identified at sea, they comprised members of 229 recorded taxa, including at least 115 different species of fish, 25 of cephalopods and 20 of crustaceans. As expected when sampling with an IYGPT net at mesopelagic depths north and west of the Slope Water, by far the most abundant fish was the glacier lanternfish, *Benthosema glaciale*, with up to 1300 individuals (1.6 kg) recorded from a single set. Summed across the entire cruise, that one species accounted for 30 kg of the 125 kg fish biomass taken and 22,000 of the 31,000 individual fish recorded. Other myctophids added a further 12 kg and 4,000 individuals. The dragonfish *Stomias boa* was the second species in biomass, at 17 kg, though only 1,000 individuals were caught. It was followed by the stout sawpalate, *Serrivomer beani*, at 13 kg and 670 individuals. *Cyclothone* spp., although substantially under-represented in IYGPT catches, totalled 6 kg.

The most numerous cephalopods were *Brachioteuthis* spp., with 735 individuals recorded, though the greatest biomass taken was of the large, bottom-associated *Stauroteuthis syrtensis*, with a total recorded catch of 28 kg (100 individuals). Of particular interest, as they are thought to comprise the primary food of the bottlenose whales, 113 *Gonatus* spp. were recorded, including individuals identified to each of the two species (*G. fabricii* and *G. steenstrupii*) recognized from the North Atlantic. Their mantle lengths were between 26 and 270 mm, though most were under 100 m and only one individual exceeded 200 mm. It is likely that the larger size classes of such an active squid are severely under-represented in IYGPT catches.

Much the greatest biomass in the catches and almost certainly the greatest abundance of any one taxon comprised krill, primarily *Meganyctiphanes norvegica*, with up to 25 kg being taken in a single set and nearly 180 kg in all. Decapods of the genus *Sergestes* were second at 54 kg summed over the cruise.

Many of the invertebrate taxa other than cephalopods and crustaceans were benthic species tangled in the trawl when Set 46 contacted the canyon wall. The major quantity of material, however, comprised assorted gelatinous plankton, which totalled over 200 kg recorded biomass – though the proportion of water content is very high in such animals. The catches also included a large pelagic nemertean that awaits definitive identification, a few specimens of the pteropod mollusc *Clione* sp., numerous giant chaetognaths and a single benthic gastropod which had perhaps been swept away from the canyon wall by a swift tidal current. (Among the fish taken was a lone witch flounder, *Glyptocephalus cynoglossus*, which may have suffered a similar fate.)

Diversity, measured as the number of taxa recorded, was generally highest at the Offshore Station and decreased progressively up the canyon to the Head Station. Biomass was, however, high in the Gully. *Benthosema glaciale* showed its maximum biomass on the Main Station, with night catches from the 250–750 m stratum (which included fish taken in surface layers during haul-back of the open net) averaging 0.8 kg – in contrast to 0.5 kg on the Deep Station, 0.3 kg on the Wall Station and 0.1 kg on the Head Station. *Stomias boa* was similarly distributed, with the same selection of sets showing 0.7 kg at the Deep Station, 0.6 kg at the Main, 0.3 kg at the Wall and 0.1 kg at the Head Station. *Meganyctiphanes norvegica* was considerably more abundant, at night, in the 0–250 m stratum than in the deeper tows. In that stratum, catches averaged 13.8 kg on the Main Station and 7.6 kg on the Wall but 6.4 kg and 5.2 kg on the Deep and Head stations respectively – though the limited catches of other species at the canyon head made it appear exceptionally rich in krill. Thus, overall biomass was highest where bottlenose whales were seen most often during the cruise (see below).

Catches on the Wall Station were markedly different from those on the nearly Main Station – differences seen in the biomasses of the principal taxa noted above but also in many other species. The two stations were less than a mile apart, hence the distinctions between them can be ascribed to the proximity of the canyon wall, rather than to any geographic changes.

4.2 TRAWLING OPERATIONS

4.2.1 IYGPT Performance

CCGS *Wilfred Templeman* proved well able to handle the IYGPT net to depths below 1500 m. The maximum depths that might have been achieved remain unknown but there is little doubt that routine trawling to 1750 m would be possible. The Scanmar sensors provided invaluable information on the performance of the net but the signals from them were frequently lost. The Star-Oddi recorder thus proved to be an essential backup for data on the depths fished.

The Scanmar sensors showed that the net's wingspread was variable but usually in the range 11 to 15 m (Figure 5). Headline height was similarly variable but about 6 m, meaning that the mouth area of the net was approximately 60 m^2. Door spread was about 50 m but varied in proportion to wingspread. More detailed study of the IYGPT's dimensions and the volumes of water filtered is in progress and will be reported elsewhere.

Above 250 m, the depth of the net could be controlled, with reasonable effectiveness, by paying out and hauling the warps. Stepped-oblique sets did not exactly follow the angular profiles of theoretical survey designs but did achieve reasonable approximations (Figure 5). After some experimentation early in the cruise, the ship's officers chose to pay out about 625 m of warp when trawling at 250 m depth (Table 5), for a warp-to-depth ratio of 2.5:1.

At 750 m and greater depths, in contrast, the relationship between the length of warp out and the depth of the net was by no means constant. The warps were payed out to a warp-to-depth ratio of about 2.1:1 for a set to 750 m or 1.85:1 for one to 1250 m, but when the winch brakes were locked the net continued to sink, following the same near-parabolic trajectory and showing no evident response to the lack of additional warp – possibly because the ship's speed was cut as the brakes were applied, maintaining a constant speed of the net through the water. When the IYGPT reached the nominal maximum depth for the set, hauling began and net depth showed an almost-instantaneous response: even if the net continued to sink for a time, its rate of falling was abruptly reduced. Hence, the maximum achievable warp-to-depth ratio was never found.

With experience, and at the cost of great concentration by the ship's officers, it proved possible to tow the IYGPT horizontally at depth (Set 73) and to work the trawl up a feeder canyon, keeping it close to the seabed (Set 79). A total of 43 trawl sets were made within the canyon proper (excluding those on the Offshore and Deep stations), only one of which touched bottom – the consequence of a lapse in concentration. While they proved very demanding for the *Templeman*'s bridge personnel, particularly the Fishing Officer and Bo's'un who operated the trawl winch, the double-oblique, "V" set profiles developed during the cruise and the "W" profiles used above 250 m depth on later sets could be routinely followed with fully acceptable accuracy.

In future surveys, the "V" profiles should be adjusted, such that a set in the 750–1250 m stratum does the same fishing above 750 m as a nominal 250–750 m set. Likewise, a set in the 250–750 m stratum should fish above 250 m depth for one half the time of a 0–250 m "W" set. With large, non-closing trawls, such as the IYGPT, it is not possible to avoid contaminating deep catches with animals caught at lesser depths. Nor is it possible to haul the net through the overlying waters so rapidly as to reduce contamination to negligible levels. Instead, during shooting and hauling, the deeper sets should mimic the fishing of shallow sets sufficiently that the contamination may be assumed to equal the average catch of the latter. That design was approximated by the "V" sets in September 2007 but not as closely as it could have been.

The sole attempt at a deep (1500 m) horizontal set (Set 73) produced only a disappointing catch, little different to what was typically taken by the 1250 m "V" sets, though possibly with some larger individuals of frequently-taken species. As a result of a communications failure at sea, the catch was discarded without comprehensive recording but its initial inspection gave no encouragement to include similar profiles in the regular survey design.

4.2.2 Aquarium Codend

The "aquarium" codend used in September 2007 was only an initial prototype. Its performance in practice raised no concerns: although a substantial structure when seen on deck, it was but a small addition to the IYGPT and did not appear to alter the net's behaviour at the surface in any way. It was far too small to affect the rate of sinking of the net, which was dominated by the weight of the otter boards.

When shooting the gear, the "aquarium" was placed on the ship's hydraulic wave gate, at the top of the stern ramp, once that had been lowered to horizontal. The unit was then filled with water by hose, the gate lowered until flush with the stern ramp, and the "aquarium" slid into the sea. On recovery, admittedly under calm conditions, it rode up the ramp without difficulty, save once: At the end of Set 79, as the gear was being recovered, the "aquarium" rolled heavily and it came up the stern ramp on its side, thus pouring the catch into the mesh top of the unit and negating some of its intended effects. Future designs should use sufficient floats, mounted high enough, to ensure that the “aquarium” remains upright. Care will continue to be needed in bringing the unit onto the stern ramp, especially when the ship is pitching.

The effects of the “aquarium” on the quality of the specimens that were caught appeared comparable to those seen in other meso- and bathypelagic sampling (Dr. M. Fogarty, North East Fisheries Science Centre, Woods Hole, *pers.comm.*; Dr. O.-A. Bergstad, Institute of Marine Research, Flødevigen, *pers.comm.*). Much of the catch was in the same condition as seen when fishing with the IYGPT alone but a few specimens were obtained in a very much better state, some of the invertebrate taxa (notably hyperiid amphipods and scyphozoan jellyfish) showing particular improvement. It is hypothesized that those few fish which chanced to pass into the “aquarium” without contacting the IYGPT survived with little harm, while those which struck the mesh suffered major damage before reaching the “aquarium” itself. To reduce, though not eliminate, that damage, it is recommended that future nets for meso- and bathypelagic sampling use knotless mesh – the resulting reduction in strength being of little account with the small catches taken in such fishing. It is further recommended that a new “aquarium” be so designed as to guide the catch into still water with the minimum of contact with rough surfaces or turbulent water flows.

The improved condition of some taxa suggests that crushing of the catch within a mesh codend can be much alleviated by the use of an “aquarium”. Whether that advantage may be realized with fish and squid, once damage in the IYGPT itself has been reduced, remains to be determined. Further development may be needed to ensure some water exchange within the “box” portion of the codend, without inducing turbulence that would damage specimens once caught. It did appear, during the cruise, that fish taken in sets which also caught large amounts of krill suffered severe abrasion from contact with the crustaceans’ exoskeletons. It is unclear whether an improved “aquarium” could reduce that damage.

Two sets (Sets 81 & 84) were made with the “aquarium” codend attached to the trawl that were in other respects comparable to regular sets of the depth-stratified survey at the Head Station (respectively Sets 44 & 86, to 750m depth, and Sets 51 & 85, to 250m). So few sets cannot, in the face of the expected variability, support rigorous analysis of the effects of the “aquarium” on the catches obtained. However, a comparison of those catches (Table 7) gives little indication of any effect on the amount or species composition of the fish. There is a trend towards a higher weight of *Benthosema glaciale* with the “aquarium” in use. That species, and the other myctophids, frequently suffered severe damage and it is possible that the increased weight resulted from a reduced loss of tissue from the same number of animals taken. If so, the trend will have appeared in *B. glaciale* because its higher abundance served to smooth out chance variations.

Cephalopod catches were distinctly higher when the “aquarium” was used, though the increase was seen in *Stauroteuthis syrtensis* in Set 81 but in *Brachioteuthis* sp. in Set 84. Since squids were only counted if at least their mantles were intact, a reduction in damage to the specimens many have contributed to the higher recorded catches.

Set 81 produced a general increase in the quantity of crustaceans caught but no marked difference in the catch of any particular taxa, when compared to Sets 44 and 86. However, a decrease in crustacean catch when the aquarium was used was seen among the shallow sets (Sets 51, 84 & 85). The latter was largely a decline in the weight of krill – a taxon that (recorded as “Euphausiacea”) also showed a rather lower catch than expected in Set 81. The mesh size of the codend liner used in the IYGPT, which was the same as the mesh size of the water-filtering top cover of the “aquarium”, was large enough for most krill to pass. That they were nevertheless caught on regular survey sets was partly because individuals became trapped amongst the mass of other animals in the twine codend. Use of the “aquarium” would have reduced that trapping effect, which may account for the reduced catches. The reduction in krill in the catch from Set 81 means that the increase in the overall crustacean catch in that set arose from greater retention by the aquarium of deep-living decapods. Those were largely absent from the shallow depths fished by Set 84.

The amount of gelatinous plankton taken in 250–750 m depths was substantially greater when the “aquarium” was fitted. However, that trend was not seen above 250 m. Those trends may be artefacts generated by chance effects but it is possible that some deep-living species tend to be broken and lost from a twine codend when they survive when fishing with the “aquarium”.

It is recommended that an improved “aquarium” codend be constructed and deployed routinely in future meso- and bathypelagic trawling. The catches taken will not, however, be fully quantitatively comparable to those of the 2007 survey.

4.2.3 Instrumentation

A major limitation of the instrumentation available on this cruise was the lack of data on the position of the net relative to the ship or the seabed. The ship’s position was known with great accuracy from DGPS. Seabed depth is known with high precision from past multibeam bathymetric survey. However, the only firm data on the net’s position relative to either of those were the length of warp out and the headline depth. The distance astern of the ship could be estimated but the lateral displacement, to port or starboard of the ship’s track, was quite unknown. It would be highly desirable for future canyon-fishing cruises if the net could be equipped with an acoustic-positioning system. An acoustic altimeter, giving the net's height above bottom, would be a valuable addition if it had a range of several hundred metres.

The multibeam bathymetric survey data was of great value when planning the survey but was of limited use on the ship's bridge as it was only available in the form of a hard-copy map, lacking navigational information. The high-resolution bathymetry should be combined with GPS position in a display on the bridge, either on the ship's navigational system or on a separate computer. Ideally, the same display would show the net's position with its depth indicated.

4.3 DISPLACED VOLUMES

The limited number of displaced-volume determinations that were made (Table 4) were sufficient to demonstrate the high additional workload involved. The incompatibility of such measurements with the multi-stage sorting protocols that were required by the intensity of the fishing is also shown by only one volume measurement of fish having been attempted. Table 4 further shows that either the measurement of volume or that or weight was too uncertain for inter-calibration of the two to be worthwhile.

Future surveys should focus on determining catch weights accurately, using motion-compensating balances. If there is a need to relate those weights to the volumes recorded during Halliday *et al.*'s (1995) surveys, the latter could be converted to weights using assumed densities with no loss of precision compared to developing new calibration relationships.

4.4 SOUND-SCATTERING LAYERS

Some 270 pages of echograms were printed during the cruise, of which 241 contained usable information on scattering layers in waters deeper than 200 m (see Figure 6 for examples). The sounder proved able to detect the seabed at depths of more than 2,000 m but below about 1,000 m any midwater scatterers were obscured by noise (probably generated on board the ship) which was amplified by the TVG. The instrument was therefore usually used to display only the upper 1,000 m of the water column.

The scatterers formed a large number of more-or-less distinct layers – once reaching twenty at one time on the Offshore Station. They were, however, highly spatially variable. When *Templeman* was drifting, the layers appeared steady on the echograms but, as soon as the ship began to move, they broke up, typically taking on a "wavy" appearance. (That "waviness" was seen less when outside the canyon and was not always present within it.) In some cases, the ship turned and ran a reciprocal course, close alongside its previous track. The "waves" could then appear on an echogram as "mirror images", again suggesting that they were spatial rather than temporal features. In a few cases, the “waves” appeared to be associated with water flowing over bathymetric features, such as the edge of a bank, and similar relationships might have been more evident if it were possible to record the scatterers in three dimensions. However, there were some occasions when the ship crossed the edge of a bank and yet the scattering layers were seen to be undisturbed. It is possible that variable tidal and wind-driven water movements were involved in the production of the “waves”.

The sounder detected some isolated epipelagic schools and sometimes thin scattering layers in near-surface waters. However, the major amount of scattering was at 350 to 750 m, with the exact depths varying with time and location. The echoes usually printed in grey (rather than colour), indicating that their S_v values were not much above the threshold set for display, typically -75 dB. Some scattering layers had rather higher echo intensities within them[7].

Review of the echograms in relation to the cruise track showed considerable variation in the scatterers among various locations. A particularly-dense mass was repeatedly detected at depths of about 400 to 500 m in the vicinity of the spur that projects southwest from Banquereau, immediately southeast of the Main Station (Figure 6b). Both the density of scatterers and apparently the degree of “waviness” decreased southwards from there, through the Deep Station and on to the Offshore Station. The gradient in the density was sufficiently sharp for the echograms to show noticeably more scattering at the northwestern end of the Deep Station than at its southeastern extremity.

The density of scatterers also fell off northward from the Banquereau spur, particularly from about the northern ends of the Main and Wall stations north to the Head Station. The latter had only very thin traces of scattering and most of those were over the canyon walls to either side of the station itself. The IYGPT catches indicate that krill were less abundant at the Head Station than on the Main Station but only by a factor of about three – suggesting that krill were not the principal scatterers.

When compared to the Main Station, the Wall Station generated very similar echograms, though with a tendency towards even greater densities. The strongest scattering recorded (though possibly affected by unknown adjustments to sounder settings) was seen at depths below 300 m, over a 700 m-deep seabed, a little east of the Wall Station.

Diel vertical migration was clearly seen only at the Offshore Station and once within the canyon near the south end of the Main Station. The ship was offshore

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[7] While temperature microstructure in the water column can return echoes similar to those observed, the CTD data showed no such structure (see below).

through dusk of 7 September and both dawn and dusk of each of the next two days. Of the five potential migrant periods, movement was only well recorded by echograms on two occasions but portions of two others were detected, while no echoes were printed during the dawn period of 8 September. Thus, it appears that such migrations were normal on the Offshore Station, albeit not normally recorded.

At dusk on 8 September, a scattering layer centred at about 275 m depth appeared to begin moving upwards at about 2000 UTC – some two hours before sunset (Figure 6d). It accelerated sharply at about 2230, when it was centred on 250 m depth, and passed 100 m at about 2300. By 2330, the scatterers had reached 25 m depth, where they remained as a dense layer. Next morning, at about 0815 UTC, the dense, shallow layer became more diffuse and began to drop downwards (Figure 6e). At sunrise, around 0930, the scatterers were passing 200 m depth. They passed 300 m at about 1130 and stabilized around 325 m about half an hour later. It is hypothesized, based on preliminary examination of the IYGPT catches, that these migratory scatterers were myctophid fish.

The only other well-recorded vertical migration was seen at dusk on 12 September, when the ship was in the canyon, west of the south end of the Main Station. An upward movement from below 250 m was in progress by 2100 and was most rapid at about 2230, when the layer was at about 125 m depth. The scatterers settled at about 30 m around 2315 UTC. From the IYGPT catches, they may have been myctophids or krill, though the lack of evident migratory behaviour in echograms from areas with high krill densities, notably the Wall and Head stations (where high catches above 250 m at night indicate that diel vertical migration was happening) suggest that the krill were not well detected by the *Templeman*'s 38 kHz sounder.

From time to time, the sounder showed scattered, high-intensity “flecks” (Figure 6c). Those were seen in the vicinity of every station, though they appeared particularly common around the Head Station. While an origin in some sort of interference cannot be ruled out, it is hypothesized that these “flecks” were traces of whales – either reverberating echoes when the animals’ lungs were insonified by the narrow side-lobes of the sounder’s beam (producing the irregular records as the ship pitched and rolled while passing each whale) or, more likely, the result of whale vocalizations being received by the sounder’s transducer when the animal chanced to be oriented towards the ship. Each “fleck” on the echograms corresponded to sound received over about 25 to 30 µs, which corresponds to the length of a bottlenose whale’s foraging click, while they emit frequencies approaching, of not exceeding, 38 kHz (Hooker & Whitehead 2002). On two occasions, both at the Head Station, some “flecks” were arranged to form parabolic traces on the echograms, reaching an apparent maximum range from the ship (not necessarily a depth below the surface) of about 800 m. Once, on the Wall Station, an echogram showed an inverted parabolic trace of the same kind, with a minimum range from the ship of about 550 m. Rather than echoes from diving whales, those traces may represent whales emitting sound with inter-click intervals matched to the ping interval of the sounder, while oriented steadily towards the ship – meaning a deliberate response by the whale to the emissions from the sounder. Inspection of the echograms suggests an inter-click interval of about 10 s, in contrast to the 0.4 s of bottlenose whale foraging clicks (Hooker & Whitehead 2002).

While the migratory scattering layer and “flecks” are interesting, the principal scatters seen in and near the Gully in September 2007 were the non-migrators at 350 to 750 m. Their identification can only be speculative at present. Similar layers have not often been noted off Nova Scotia. Specifically, they were not seen during a 2002 cruise that included transects across the Gully with 15 kHz and 105 kHz sounders, though a layer was found between 300 m depth and the limit of detection (below 500 m) off the mouth of the Gully in 1984, with a 50.5 kHz sounder (N. Cochrane, Bedford Institute of Oceanography, *pers.comm.*). Deep scattering layers closely similar to those in the Gully have, however, been seen elsewhere in the North Atlantic. They were first described from the Irminger Sea by Magnússon (1996) and subsequently by Sigurdsson *et al.* (2002), Anderson *et al.* (2005) and Gislason *et al.* (2007). In that area, they are continuous, both spatially and temporally, usually at depths of 400 or 500 m down to 700 or 800 m, with some components showing clear diel migration but much being non-migratory. The scattering is usually denser over Reykjanes Ridge and the continental slopes than it is over deep water between Iceland and Greenland. So similar is this scattering to our observations that some of Magnússon’s (1996) 38 kHz echograms are almost indistinguishable from those obtained in the Gully in 2007, though he also saw pronounced vertical “eruptions” rising to 200 m depth in March 1995 which have no known parallel in the Gully. To date, these Irminger Sea scatterers remain unidentified. Magnússon (1996) suggested that they are small crustaceans which escaped through the 5 mm codend mesh of his trawl. Subsequent authors have supposed, from the acoustic frequency used in surveys, that the scatterers are small fish but that has not been confirmed by trawling. Sigurdsson *et al.* (2002) took rather small numbers of mesopelagic species, even though they sampled with an extremely large Gloria trawl. Gislason *et al.* (2007) named only the migratory *Benthosema glaciale* and *Maurolicus muelleri* as fish species abundant in their catches.

Orlowski (1990), using a 38 kHz sounder, found a diffuse layer, extending from about 400 to 800 m depth and showing little vertical migration, to be generally distributed east and north of the Azores. It was particularly dense north of the islands –an area surveyed during September– where S_v reached values comparable to those seen in the Gully. Orlowski (1990) was not able to offer much identification of the scattering organisms. Opdal *et al.* (2008) worked an acoustic and trawl survey along the Mid-Atlantic Ridge from Iceland to the Azores using 18 and 38 kHz sounders. Their published paper reported only the results from the 18 kHz instrument but noted a similarity of their 18 and 38 kHz echograms over the limited depth range of the latter. They found a diffuse, non-migratory scattering layer at depths of several hundred metres, similar to that reported by Orlowski (1990). Taken together, those studies suggest that the layer is broadly continuous over 30 degrees of latitude.

Opdal *et al.* (2008) noted five non-migratory species among nine that they identified as “likely primary sound-scatterers” on the basis of their abundance in trawl catches and their assumed high target strengths. The five were *Bathylagus euryops*, *Maulisia microlepis*, *Scopelogadus beanii*, *Serivomer beanii* and especially *Cyclothone microdon* – which comprised 88% (by number) of all of the fish caught below 750 m depth, even though it may have been undersampled by the nets used. Opdal *et al.* (2008) acknowledged the probability that other scatterers, not vulnerable to the trawls, may have been present.

In the Sargasso Sea, Cole *et al.* (1970), using 12 kHz sounders, found a non-migratory scattering layer that was well defined (in contrast to the diffuse layer seen in the Gully and elsewhere) at depths between 400 and 580 m. They described the layer as “ubiquitous” south of the Gulf Stream but ending abruptly at the edge of the Sargasso. Conte *et al.* (1986) found the same layer, or up to three discrete layers in the same depth range, and fished them using a MOCNESS opening / closing sampler. They sought to identify the scatterers by selecting a non-migratory species that was relatively abundant, occurred at the appropriate depth in areas where scattering was detected and not where it was absent, and which scatters sound at 12 kHz. The only plausible candidate in their catches was *Cyclothone braueri*, though Conte *et al.* (1986) acknowledged that they could not reject the possible presence of physonect siphonophores, which would not have been retained by the nets used. *C. braueri* was caught at densities of 7 to 9 m^{-2}, integrated over the upper 1000 m of the water column, or potentially about one per 10 m^3 in the scattering layers. Conte *et al.* (1986) estimated that the swimbladders of those fish should have resonated at frequencies above 19 kHz but they noted that the sharpness of the resonant peak is unknown, meaning that even at 12 kHz target strengths may have been enhanced by resonance.

During September 2007, any non-migratory micronekton scatterers in the 350 to 750 m layer in the Gully should have been well sampled by the 250–750 m IYGPT sets but their catches contained rather limited biomass, particularly once the migratory krill and myctophids are excluded. The observed S_v values might be explained by fish of about 100 mm length if they had gas-filled swimbladders and occurred at densities of about one per 100 m^3 (N. Cochrane, Bedford

Institute of Oceanography, *pers.comm.*). However, the most abundant non-migratory species in the catches were boa dragonfish (*Stomias boa*). They were of an appropriate size: combining specimens from throughout the cruise, those that were caught averaged about 200 mm in length. They, however, lack any swimbladders (Marshall 1962) and the catch only reached a maximum of 75 individuals in a single set or about 0.02 fish per 100 m^3. Meanwhile, the diffuse nature of the echoes argues against most of the scatterers being animals large and active enough to avoid the trawl. Hence, it seems likely that they were small enough to pass through its meshes – or else that they were siphonophores fragile enough to have been broken up by the net with no detectable remains in the catch.

Of the non-migratory species that are known to be present but which were under-represented in the IYGPT catches, the most likely candidate for the principal scatterer is *Cyclothone* spp. The members of the genus have small but functional swimbladders as postlarvae which some species retain into adulthood, though most replace them with fat bodies before they become sexually mature – the final loss of a gas-filled structure occurring at about 35 mm length in *C. braueri* (Marshall 1962). The species present in the Gully are not yet known but *C. microdon* was the most abundant member of the genus found north of the Slope Water in one survey off Grand Bank (McKelvie & Haedrich 1986) and likely dominates along the edge of the Scotian Shelf. It would require an extremely large biomass of adult *Cyclothone* spp., lacking swimbladders, to account for the observed scattering. Even juveniles with bladders might have to be very abundant to produce the recorded S_v values. However, a 0.5 mm air bubble (approximately the size of a *Cyclothone* swimbladder) at 400 m depth in seawater would resonate at 38 kHz, meaning that it is possible that what were recorded were resonant echoes from a comparatively sparse distribution of fish – supplemented by low levels of energy returned from the other organisms in 350-750 m depths in the Gully.

The extent of the deep scattering layer observed in 2007 suggests that the scatterers may be a critical link in the food chain supporting the northern bottlenose whales, and other toothed whales, in the Gully MPA. Future research is needed to determine whether the scattering layers are a persistent feature and to document the micronekton and macroplankton (below the sizes vulnerable to the IYGPT) which might contribute to the scattering. The use of finer-mesh nets and of more advanced acoustic equipment, including multi-frequency sounders with transducers towed at depth, should be considered.

4.5 PHYSICAL OCEANOGRAPHY

Physical conditions on the eastern Scotian Shelf during 2007 were generally close to long-term means (Petrie *et al.* 2008). However, the volume of the Cold Intermediate Layer ("CIL") was high, though not the highest on record. At its core, that layer had its normal temperature and somewhat elevated salinity, indicating a saltier outflow from the Gulf of St. Lawrence, but its expanded volume resulted in cooler and fresher conditions in areas and depths where it replaced other waters. Near the surface along the shelf break, temperatures were markedly lower than normal in both April and in October, the spring temperature anomaly on the Halifax Line (which passes about 200 km west of the Gully) being as great as –6°C, with a corresponding salinity anomaly in the same area. In the fall, there were similarly-large negative anomalies on the Louisbourg Line (which crosses Banquereau east of the Gully) at about 50 and 150 m depths, corresponding to an expanded vertical extent of the CIL near its southern limits, while the Halifax Line was still cold at about 50 m depth around the Shelf Break (Petrie *et al.* 2008). It is thus likely that both the vertical and the horizontal extents of the CIL observed over the Gully and the Offshore Station in September 2007 were greater than normal.

Another feature of 2007 was an exceptional spring phytoplankton bloom – the strongest yet recorded since present monitoring programs began in 1999. That enhanced bloom was widespread across the Scotian Shelf and lasted longer than normal but post-bloom chlorophyll levels were not elevated. The high levels of phytoplankton were followed by an equally-exceptional abundance of *Calanus finmarchicus*, though the timing of routine surveys is such that it was only directly observed at a fixed station near Halifax. Zooplankton biomass soon dropped to below normal levels, presumably as a result of predation mortality (Harrison *et al.* 2008). Both the phytoplankton and zooplankton blooms were long over, and biomasses had returned to near-typical levels, before the deep-pelagic survey cruise in the Gully, though some enhancement of micronekton predators may have persisted. Of perhaps more importance, the ultimate cause of those blooms is thought to have been a 45 km northward displacement of the Shelf / Slope Front between mid-March and early April, which pushed some 2,000 km^3 of water over the shelf break and onto the Scotian Shelf, leading to broad upwelling of nutrient-rich waters into the photic zone (Petrie *et al.* 2008). Some substantial fraction of that flow may have passed through the Gully and its consequences may have lingered into September.

In October 2007, the temperature anomalies 50 km to seaward of the shelf break were strongly positive, suggesting that the Gulf Stream was pressed northward at that time. As an annual average, however, the position of the Stream south of Nova Scotia in 2007 was very close to its long-term mean, while the Shelf / Slope Front was some 30 km south of its mean position (Petrie *et al.* 2008). During the cruise, AVHHR satellite imagery of the Gulf Stream south of Nova Scotia was much affected by cloud cover. Valuable images of sea surface temperature (SST) were, however, captured on a number of days before and after the cruise. In late August (Figure 7), an elongated meander in the Stream had its northern head directly south of Sable Island and some 110 km from the shelf break (hence about 275 km north of the Stream's annual mean position). In early September, that meander began to break off as a warm core ring, centred off the Gully. During the cruise, the ring moved slowly westwards, while the meander from which it had broken off moved more swiftly to the northeast. As the cruise was ending, the ring was again centred south of Sable Island and was merging into the next meander to the west, which lay roughly south of Halifax. The Naval Oceanographic Office's interpretation for the early part of the cruise (Figure 8) shows the warm core ring and suggests the presence to two fronts between that and the shelf break, lying respectively some 40 and 140 km south of the mouth of the Gully. The first of those was about 10 km from the Offshore Station. By the end of the cruise, that front had retreated somewhat southward but there had not been any major change in the locations of the watermasses.

Twelve CTD casts were made during the cruise (Table 2, Figures 9 and 10). All showed the same basic structure of the water column. There was a well-mixed, warm, low-salinity layer at the surface, extending to about 20 m depth. Offshore, that layer was at about 19℃ and 30 to 32‰ salinity. Within the Gully, it was at 16 to 17℃ and about 31‰. Below the surface layer, there was a sharp thermohalocline leading to the CIL, with salinity around 33‰ and a minimum temperature that was as low as 0℃ on one cast and as high as 6℃ on another. Beneath the CIL was another thermohalocline, which was often unstable (i.e. no increase in density with depth), allowing lenses of warmer, saltier water to overlie parts of the CIL. The subsurface temperature maximum usually lay around 150m depth, though some casts found it around 200 m. The maximum temperature was variable but typically around 8℃, while the salinity at that depth was about 35‰. From about 200 m depth, temperature declined and salinity increased progressively, rather rapidly at first and then more slowly. The maximum depths reached by the CTD were in the range 600 to 1900 m, varying among the casts, where temperatures were around 4℃ and salinities very close to 35‰. All of those values were broadly comparable to the long-term mean conditions for September reported by Petrie *et al.*. (1998)**.** Oxygen concentrations were somewhat less than 5 $ml.l^{-1}$ across most depths. They were higher in the low temperatures of the CIL and notably lower somewhat below the subsurface temperature maximum – the latter presumably as a result of aerobic bacterial breakdown of detritus. Maximum and minimum concentrations were approximately 6 and 3 $ml.l^{-1}$ respectively.

All waters from the subsurface temperature maximum to the greatest depths reached by the CTD were Labrador Slope Water of 4 to 8℃ and 35‰ salinity (Figure 10), derived from the deeper waters of the Labrador Current which flow around Grand Bank and into the volume south of the Scotian Shelf but north of the Slope Water and the North Atlantic Central Water at meso- and bathypelagic depths. However, the migrant animals caught above 250 m depth at night experienced a wider range of conditions, potentially anywhere from 0 to 19℃ and 30 to 35‰, depending on where they migrated up and how far they rose in the water column, along with depressed oxygen concentrations at certain depths.

Three CTD casts were made on the Offshore Station (Sets 3, 10 & 17; Figures 9a, b, c, 10a, b, c). While all conformed to the above generalizations, had surface temperatures around 19℃ and were essentially identical below the subsurface temperature maximum, they differed markedly in their details around the CIL. Set 3 showed little presence of a cold layer at all, with a minimum of 5.8℃ at 48 m depth and a subsurface maximum of 8.9℃ at 166 m[8]. Set 10, in contrast, showed a well-developed CIL, with a minimum temperature of 2.8℃ at 50 m and a subsurface maximum of 11.0℃ at 105 m depth. Set 17 had a somewhat higher minimum temperature but a lower maximum since the CIL was thicker, forcing the subsurface maximum down to 154 m. The three casts were made within 10 km of one another and over a period of less than 48 hours. Sets 3 and 17 differed the most in time but had starting locations within 200 m of each other. It thus appears that the extent of the CIL was highly temporally variable in the vicinity of the Offshore Station – which is perhaps not surprising so close to the shelf / slope front, with the warm core ring moving not far beyond.

Set 3 showed the highest and lowest oxygen concentrations, despite the limited presence of the CIL there, with a maximum of 6.23 ml l^{-1} at 50 m (90% saturation at the temperature and salinity at that depth) and a minimum of 2.76 ml l^{-1} at 245 m (42% saturation). The layering in oxygen was, however, better developed during Sets 10 and 17. Reduced concentrations extended to about 700 m depth on each of those casts. The three casts, especially Sets 3 and 17, also showed narrow bands of somewhat reduced oxygen concentration within the thermocline under the surface layer.

Two CTD casts were made on the Deep Station (Sets 63 & 68; Figures 9j, k, 10j, k). They showed almost identical profiles, with surface water of 17.2℃ or 17.3℃ and 31.5‰ or 31.6‰ respectively, a well-developed CIL at about 1℃ and 33‰ extending from about 30 m depth to 120 m (minimum temperatures 0.9℃ at 64 m and 0.4℃ at 97 m), and a subsurface temperature maximum extending from 150 to 225 m, with a peak of 7.2℃ at 225 m or 7.8℃ at 220 m depth. The oxygen maximum, with concentrations around 5.5 ml l^{-1} (68% saturation), coincided closely with the CIL, while the minimum was centred from about 200 to 300 m depth, with concentrations down to 3.5 ml l^{-1} (50% saturation). From

[8] Quoted CTD data are taken from the down leg of each cast. The up leg produced closely similar but not identical data.

500 m downwards, concentrations were about 5 ml l^{-1} (around 70% saturation). There was a narrow zone of reduced concentration at the immediate base of the well-mixed surface layer.

On the Main Station, a total of five CTD casts were made (Sets 20, 25, 32, 40 & 57; Figures 9d, e, f, g, i, 10d, e, f, g, i). Of those, Set 40 showed a unique profile. The other four all had surface waters of 16.1 to 16.5°C and 31.1 to 31.2‰ and were essentially identical below the subsurface temperature maximum, where they were also identical to the profiles on the Deep Station. The CIL was pronounced in each case though of variable thickness, sometimes extending from 50 to 100 m depth. Minimum temperatures varied from 0.0°C at 93 m to 1.0°C at 76 m, with corresponding salinities of 33.1 to 33.3‰. Subsurface maxima were at 150 to 200 m depth and at temperatures of 7.2 to 7.9°C. Set 20 found one marked lens of warmer, saltier water within the lower portion of the CIL, a phenomenon never as clearly displayed on the Deep or Offshore stations. In the vicinity of that lens, the water had essentially constant density over a temperature range of 4 to 7° (Figure 10d). The differences among these four casts suggest that a spatially-variable CIL was moving across the Gully.

The homogeneity in salinity and temperature characteristics among Sets 20, 25, 32 and 57 was not displayed in their oxygen concentrations. Sets 20 and 25 found a narrow but marked oxygen minimum at the base of the surface layer 4.4 ml l^{-1}, 72% saturation), then a broad layer with concentrations around 5.5 ml l^{-1} corresponding to the CIL. Set 20 showed a narrow layer of very cold, oxygen-rich water (6.0 ml l^{-1}, 77% saturation) not seen elsewhere. Below that was a broad zone of decreasing oxygen concentrations, extending through the subsurface temperature maximum, followed by a return to normal concentrations by about 500 m depth. Sets 32 and 57, however, showed a much broader oxygen minimum, extending from about 200 to around 350 m depth. That lay below the depth of the banks and hence the water was trapped within the Gully canyon. The five casts were made within a period of four and a half days but Sets 32 and 57 were located a few kilometres further north than Sets 20 and 25, suggesting substantial fine-scale spatial structuring of the waters within the canyon.

Set 40, which was located about 7 km further south (and correspondingly closer to the Deep Station casts, which it did not resemble), found very slightly saltier water at about 200 to 400 m depth than did the other casts on the Main Station (35.0‰ *versus* 34.9‰ at 300 m depth), while at lesser depths there was rather less development of the CIL, with a minimum temperature of 2.4°C at 70 m and a corresponding salinity of 33.3‰. The subsurface maximum was about 8.1°C and lay at 164 m depth. The first of the two periods of heavier weather experienced during the cruise fell between Sets 32 and 40 and may have had some role in creating the anomalous conditions in the water column. While it was unique in temperature and salinity, Set 40 showed a similar oxygen profile to sets 20 and 25.

Only two CTD casts were made on the Head Station (Sets 47 & 82; Figures 9h, I, 10h, I), which reached depths of only 850 and 600 m respectively. The surface waters were essentially identical to those seen on the Main Station, while the deepest layers had much the same waters as seen on most of the Main Station casts – though Set 82 found a profile that was subtly anomalous when examined in detail. Set 47 showed a well-developed CIL, spanning 75 to 120 m depth with temperatures below 2℃ (minimum 1.5℃ at 65 m depth) and salinities around 33‰. There was one lens of warmer water in the centre of that layer and a subsurface temperature maximum of 7.7℃ at 193 m depth. Set 82, however had much weaker development of the layering, with a minimum temperature of 2.8℃ at 57 m and a subsurface maximum of 7.2℃ at 165 m depth. Both Sets 47 and 82 found some reduction in oxygen concentrations at the base of the mixed surface layer but the elevated concentrations in the CIL had quite different profiles in the two casts. Otherwise, the oxygen profiles generally corresponded to what was seen at the stations further south.

The Sable Gully has well-developed internal waves, generated by an interaction between the bathymetry and the semi-diurnal tides, which are believed to break, causing turbulent mixing. The region of greatest concentration of energy is on the flank of Banquereau, due east of the location of Set 82, at a depth of about 100 m (Sandstrom & Elliott 2002). It is possible that the weakening of the layering at the Head Station, between Sets 47 and 82, resulted from westward movement of the surface layers, bringing water partially mixed by the breaking of the internal waves. However, it is also possible that the change resulted from wind forcing, which appears to have had a major effect deeper in the water column.

While the major differences among the CTD casts were in and around the CIL, there were also subtle variations in the deeper waters. Below about 1000 m depth and temperatures of about 4.5℃, each isotherm lay deeper within the Gully than it did on the Offshore Station, whereas at lesser depths (though still below the subsurface temperature maximum) the isotherms were elevated within the canyon and were generally higher in the water column as they extended further up the Gully (Figure 11). Some of that elevation was a static balancing of the lesser density of the thick CIL but it seems likely that there was an inflow up the axis of the Gully at mesopelagic depths. The fate of that inflowing water is unknown. It cannot have upwelled into the photic zone as the CIL capped the water column. It may have returned seaward along the canyon walls, where no CTD could be deployed, or it may have flowed into the Gully Trough, though the sill depth at the head of the canyon proper makes that unlikely. Most probably, the uppermost portion of the Labrador Slope Water was entrained into the bottom of the CIL and advected away from the canyon, being replaced by deeper and colder water.

There were two prominent deviations from this general pattern. The anomalous Set 40 found most isotherms depressed relative to those seen on the Main and Deep stations. The 4.0℃ isotherm, in particular, suggests that there was a marked outflow at great depth along the canyon when that cast was made. There had been westerly winds of some 20 knots for much of the preceding day and those may have caused sufficient displacement of waters over the Scotian Shelf to cause this outflow, though it may have alternatively (or additionally) been driven by movements of the Shelf / Slope Front outside the canyon's mouth. Set 82, in contrast, showed that there had been a very marked inflow past the Head Station during the five days since the CTD had last been deployed there. All isotherms below the subsurface temperature maximum were elevated. The 4.2℃ isotherm, which on 13 September lay below the 872 m maximum depth of Set 47 was at 585 m for Set 82 on the 18th of the month. There had been southerly winds of 25 knots on 15 September, accompanied by a mild drop in atmospheric pressure, which may have driven water over the shelf break and hence up the canyon, though once again a cause amongst the movements of watermasses offshore cannot be ruled out.

Further west along the Scotian Slope, pronounced upwelling at the continental slope and on-shelf flows between the shallow banks are known to be generated by westerly and southwesterly winds. The upwelling originates at least as deep as 400 m and the horizontal flows reach 2 knots, even with winds of below gale force (Petrie 1983). In contrast to the broad, if relatively shallow, channels between Western, Emerald, La Have and Baccaro banks that link the basins of the western Scotian Shelf to deep ocean, Banquereau and Sable Island Bank form an almost-continuous wall, reaching to above 100 m depth. Only the deep but narrow cleft of The Gully links its Trough, and hence the basins of the eastern Scotian Shelf, to the open ocean. The different bathymetry can be expected to result in qualitatively different responses to meteorological forcing to those seen to the westward but similar magnitudes of effects would not be surprising. Sets 40 and 82 may have recorded just such effects.

4.6 WHALES & SEABIRDS

Fifty-one encounters with marine mammals, each involving one or more individuals, were recorded in the Sable Gully between 10 and 19 September (Table 8). Some were close and prolonged but others were no more than the sighting of a distant blow. None of the encounters were recorded while the ship was on the Offshore Station, though that may have been because the scientific party was preoccupied with developing protocols for trawling and for handling the catches.

Northern bottlenose whales (*Hyperoodon ampullatus*) were seen frequently, and sometimes in considerable numbers, but only when the ship was on either the Main or Wall stations – in the portion of the Gully where they have been most often seen by other observers. Long-finned pilot whales (*Globicephala melas*) were about equally frequent but were more widespread, being seen throughout the survey area, aside from the Offshore Station. Other species recorded included dolphins (some identified as common dolphin: *Delphinus delphis*) and various large whales, some individuals being identified, more or less tentatively, as sperm (*Physeter macrocephalus*), humpback (*Megaptera novaeangliae*), fin (*Balaenoptera physalus*) and sei (*Balaenoptera borealis*), all of which species have been previously recorded from the Gully. Humpback whales were observed actively feeding on the Head Station, at a time when the echosounder detected small but dense schools of epipelagics, which may have been the whales' food.

Bird life was limited on the Offshore Station and to some extent on the Deep Station but was relatively more prolific within the Gully. Most of the birds present were greater shearwaters (*Puffinus gravis*) or fulmars (*Fulmarus glacialis*). With the passage of time through the cruise, the numbers on the Deep Station increased, though they remained noticeably scarcer than on the Main Station. Beginning during the work on the Deep Station, but continuing thereafter, there came to be an admixture of gulls, primarily greater black backs (*Larus marinus*). Following the heavy weather of 15–16 September, a number of storm petrels (*Oceanites* sp.) were noted. With the exception of the latter, most of the birds seen were clearly following the ship and thus do not give an unbiased indication of the avifauna in the area.

ACKNOWLEDGEMENTS

The work reported here would have been impossible without the extreme efforts of Captain Mary Chislett and the crew of CCGS *Wilfred Templeman* during her cruise to the Sable Gully in September 2007. Additional thanks are due to Cam Lirette for preparing the ArcView file of the cruise track hyperlinked to scanned echograms, to Dr. Norman Cochrane for invaluable advice on interpretation of the acoustic data, Dr. Blair Greenan for interpretation of the CTD data, Dr. Erica Head for advice on the zooplankton of the Gully and to Dr. Brian Petrie and Liam Petrie for provision of archived interpretation charts from the U.S. Navy's Naval Oceanography Office.

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TABLES

Table 1 : Station Positions and Seabed Depths
The positions given define the nominal lines on which the trawling was undertaken, though the actual trawl tracks diverged somewhat. The positions are given as starting at the more southerly end of each line, though IYGPT sets were made in both directions. Latitudes and longitudes are presented in both decimal degrees and degrees plus decimal minutes. (In the case of any disagreements, the decimal degrees are definitive.) Depths are derived from multibeam bathymetric data.

STATION	START			END		
	North Latitude	West Longitude	Depth (m)	North Latitude	West Longitude	Depth (m)
Offshore	43.3000° 43° 30.00	59.0000° 59° 00.00	2790	43.2300° 43° 13.80	59.0000° 59° 00.00	3000
Deep	43.7319° 43° 43.91	58.7647° 58° 45.88	2662	43.7675° 43° 46.05	58.8453° 58° 50.72	2576
Main	43.8470° 43° 50.82	58.9156° 58° 54.94	1966	43.9101° 43° 54.61	58.9641° 58° 57.85	1333
Wall	43.8832° 43° 52.99	58.9040° 58° 54.24	1257	43.9257° 43° 55.54	58.9716° 58° 58.30	1161
Head	44.0195° 44° 01.17	59.0115° 59° 00.69	1156	44.0730° 44° 04.38	59.0678° 59° 04.07	732

Table 2 : List of Sets, with Set-Specific Details of Gear and of IYGPT-Catch Sampling
Dates given are those of the start of each set.

Set	Station	Light	Set Type	Date	Set-Specific Details
1	–	Day	Trial Tow	7 Sept	Commenced fishing with Net #1. Carried six extra trawl floats at Scanmar headline sensors, removed before later sets; Taxon weights recorded but catch incompletely sorted and little other data gathered. Data should not be used in analyses
2	Offshore	–	Halliday stepped	7 Sept	**Aborted** – Lost Scanmar depth; Only selected specimens recorded
3	Offshore	–	CTD	7 Sept	Salinity sample 900 m
4	Offshore	Night	Halliday stepped	8 Sept	No individuals weighed; *Cyclothone* recorded as other fish; Gelatinous plankton counted
5	Offshore	Night	Halliday stepped	8 Sept	Individual weights only for a few cephalopods; *Cyclothone* recorded as other fish; One cephalopod taxon recorded only as taxon weight
6	Offshore	Night		8 Sept	**Aborted** – Engineroom problems; NO CATCH DATA RECORDED
7	Offshore	Night	250m stepped	8 Sept	Individual weights only for two fish and a few cephalopods
8	Offshore	Day	750-1250m	8 Sept	Starboard wing and belly torn when combination rope in wing failed; Only selected fish specimens recorded but all cephalopods were
9	Offshore	Day	250m stepped	8 Sept	Began using Net #2; No individuals weighed
10	Offshore	–	CTD	8 Sept	Salinity sample 900 m
11	Offshore	Night		8 Sept	**Aborted** – Lost Scanmar door-spread data. Otter boards hauled back to gallows. Net not hauled and catch included with Set 12
12	Offshore	Night	750-1250m	9 Sept	Individual weights only for a few fish and a few cephalopods
13	Offshore	Night	Extra-deep	9 Sept	Maximum depth 1694 m; Individual weights only for four fish and four cephalopods; One cephalopod taxon neither counted nor measured

Set	Station	Light	Set Type	Date	Set-Specific Details
14	Offshore	Day	250-750m	9 Sept	Individual weights only for a few cephalopods; Two fish taxa neither counted nor measured; Taxon weights missing for two cephalopod taxa
15	Offshore	Day	750-1250m	9 Sept	No individuals weighed; Two fish taxa neither counted nor measured; Cephalopods recorded only as a single bulk weight
16	Offshore	Day	750-1250m	9 Sept	Doors crossed at end of haulback; NO CATCH DATA RECORDED, except for one cephalopod
17	Offshore	–	CTD	9 Sept	Salinity sample 900 m
18	Offshore	Night	250-750m	9 Sept	Individual weights only for a few cephalopods
19	Main	Night	250m stepped	10 Sept	Individual weights only for two cephalopods
20	Main	–	CTD	10 Sept	Salinity sample 480 m
21	Main	Day	250-750m	10 Sept	Individual weights only for a few cephalopods; Taxon weights missing for two cephalopod taxa
22	Main	Day	750-1250m	10 Sept	Individual weight only for one fish; One fish taxon neither counted nor measured; No data on cephalopods
23	Main	Day	250-750m	10 Sept	Individual weights for fish, including sample of *B. glaciale*; Cephalopods recorded only as zero weight and a null count
24	Main	Day	250m stepped	10 Sept	Individual weights for sample of *B. glaciale*; Cephalopods recorded as a single bulk weight
25	Main	–	CTD	10 Sept	Salinity sample 790 m
26	Main	Night	750-1250m	10 Sept	Individual weights for samples of *B. glaciale* and *M. punctatum*, plus most cephalopods
27	Main	Night	250-750m	11 Sept	Individual weights for samples of *B. glaciale*, *C. maderensis* and *M. punctatum*, plus most cephalopods; Taxon weight missing for one cephalopod taxon
28	Main	Night	750-1250m	11 Sept	Doors crossed at end of haulback; Individual weights for a few fish and most cephalopods; All data missing for one recorded fish taxon; Length data missing for *B. glaciale*; One other fish taxon neither counted nor measured

Set	Station	Light	Set Type	Date	Set-Specific Details
29	Main	Day	750-1250m	11 Sept	Individual weights for most cephalopods but no fish; Taxon weights missing for two cephalopod taxa
30	Main	Day	250-750m	11 Sept	Individual weights for fish, including sample of *B. glaciale*; One fish taxon neither counted nor measured; Cephalopods recorded as a single bulk weight
31	Main	Day	250m stepped	11 Sept	Individual weight for the sole cephalopod caught
32	Main	–	CTD	11 Sept	Salinity sample 600 m
33	Main	Night	250-750m	11 Sept	Individual weights for samples of *B. glaciale*, *C. maderensis* and *M. punctatum*, plus most cephalopods; One fish taxon neither counted nor measured
34	Main	Night	750-1250m	12 Sept	Individual weights for sample of *B. glaciale*, plus most cephalopods; Taxon weights missing for two cephalopod taxa
35	Main	Day	750-1250m	12 Sept	Individual weights for one fish and most cephalopods; Taxon weights missing for one fish and two cephalopod taxa
36	Main	Day	250m stepped	12 Sept	No individuals weighed; Cephalopods recorded only as a single bulk weight
37	Main	Day	Scattering layer	12 Sept	Targeted on layer at 450 m; Individual weights for sample of *B. glaciale*; Cephalopods recorded only as a single bulk weight
38	Wall	Day	250-750m	12 Sept	Individual weights for sample of *B. glaciale*; Cephalopods recorded only as a single bulk weight
39	Main	–	CTD	12 Sept	**Aborted**
40	Main	–	CTD	12 Sept	Salinity sample 300 m
41	Main	Night	250m stepped	13 Sept	Individual weights for sample of *B. glaciale*, plus most cephalopods; Length data missing for one abundant fish taxon; Taxon weight missing for one cephalopod taxon
42	Main	Night	250-750m	13 Sept	Individual weights for samples of *B. glaciale* and *C. maderensis*, plus most cephalopods
43	Main	Night	250m stepped	13 Sept	Individual weights for samples of *B. glaciale* and *C. maderensis*, plus most cephalopods
44	Head	Day	250-750m	13 Sept	Individual weights for sample of *B. glaciale*, plus most cephalopods

Set	Station	Light	Set Type	Date	Set-Specific Details
45	Head	Day	250m W-oblique	13 Sept	No individuals weighed
46	Head	Day	250-750m	13 Sept	**Aborted** – Touched bottom and net badly damaged; Only limited catch data collected
47	Head	–	CTD	13 Sept	Salinity sample 300 m
48	Head	Night		13 Sept	**Aborted** – Depth sensor failed; NO CATCH DATA RECORDED; Began using repaired Net #1
49	Head	Night	250-750m	14 Sept	Individual weights for sample of *B. glaciale*, plus all cephalopods
50	Head	Night		14 Sept	**Aborted** – slack turn on winch; NO CATCH DATA RECORDED
51	Head	Night	250m W-oblique	14 Sept	Individual weights for *B. glaciale*, plus all cephalopods
52	Head	Night	250-750m	14 Sept	Otter board spun on warp when 50 m below surface at end of hauling; Individual weights for sample of *B. glaciale*, plus all cephalopods
53	Wall	Day	250m W-oblique	14 Sept	No individuals weighed
54	Wall	Day	250-750m	14 Sept	Individual weights for sample of *B. glaciale*, plus all cephalopods
55	Wall	Day	Scattering layer	14 Sept	Targeted on layer at 390 m; Individual weights for sample of *B. glaciale*; Most cephalopods recorded only as single bulk weight
56	Wall	Day	250-750m	14 Sept	Individual weights for sample of *B. glaciale*; Cephalopods recorded only as a single bulk weight
57	Main	–	CTD	14 Sept	No salinity sample – Bottle did not close
58	Wall	Night	250m W-oblique	14 Sept	No individuals weighed; Cephalopods recorded only as a single bulk weight
59	Wall	Night	250-750m	15 Sept	Individual weights for sample of *B. glaciale*, plus most cephalopods; One cephalopod taxon neither counted nor measured; Codend was not fully washed out, reducing the recorded catch in this set and transferring some contamination to Set 60

Set	Station	Light	Set Type	Date	Set-Specific Details
60	Wall	Night	250m W-oblique	15 Sept	Individual weights for samples of *B. glaciale* and *C. maderensis*, plus most cephalopods
61	Wall	Night	250-750m	15 Sept	Trawl shot away but hauled back to gallows when otter boards unsteady. Net not brought aboard. Set then fished normally without a new set number being allocated; Individual weights for all cephalopods; Length data missing for one fish taxon
62	Deep	Day	250-750m	15 Sept	Individual weights for sample of *B. glaciale*, plus most cephalopods
63	Deep	–	CTD	15 Sept	Salinity sample 500 m
64	Deep	Day	750-1250m	15 Sept	No individuals weighed; Cephalopods recorded only as a single bulk weight
65	Deep	Day	250-750m	16 Sept	Individual weights for sample of *B. glaciale*, plus most cephalopods
66	Deep	Day	750-1250m	16 Sept	Individual weights for sample of *B. glaciale*, plus most cephalopods; Taxon weight missing for one cephalopod taxon
67	Deep	Day	250m W-oblique	16 Sept	No individuals weighed; Cephalopods recorded only as a single bulk weight
68	Deep	–	CTD	16 Sept	Salinity sample 300 m
69	Deep	Night	250m W-oblique	16 Sept	Individual weights for sample of *B. glaciale*, plus all cephalopods
70	Deep	Night	750-1250m	17 Sept	Individual weights for sample of *B. glaciale*, plus most cephalopods
71	Deep	Night	250-750m	17 Sept	Individual weights for sample of *B. glaciale*, plus most cephalopods
72	Deep	Night	750-1250m	17 Sept	Individual weights for sample of *B. glaciale*, plus most cephalopods; Taxon weight missing for two cephalopod taxa
73	Deep	Day	Horizontal 1500m	17 Sept	NO CATCH DATA RECORDED, except for one cephalopod
74	–	Day	Aquarium Trial	17 Sept	Aquarium on : Otter boards never let go from ship.
75	–	Day	Aquarium Trial	17 Sept	Aquarium on : 750-250m set, southwest of Deep Station; Catch only picked through for selected specimens
76	Deep	Night	250-750m	17 Sept	Individual weights for sample of *B. glaciale*, plus most cephalopods
77	Deep	Night	250m W-oblique	18 Sept	Individual weights for samples of *B. glaciale*, *C. maderensis* and *N. elongates kroyeri*, plus most cephalopods

Set	Station	Light	Set Type	Date	Set-Specific Details
78	Main	Night	Extra-deep	18 Sept	Aquarium on : **Aborted** – Depth sensor failed; NO CATCH DATA RECORDED, except for one cephalopod
79	–	Day	Feeder Canyon	18 Sept	Aquarium on : Individual weights for sample of *B. glaciale*, plus most cephalopods
80	Main	Day	Extra-deep	18 Sept	Aquarium on : Individual weights for sample of *B. glaciale*; Cephalopods recorded only as a single bulk weight
81	Head	Day	250-750m	18 Sept	Aquarium on : Individual weights for sample of *B. glaciale*, plus all cephalopods
82	Head	–	CTD	18 Sept	Salinity sample 300 m
83	Head	Night	Extra-deep	19 Sept	Aquarium on : Individual weights for samples of *B. glaciale* and *M. punctatum*, plus all cephalopods
84	Head	Night	250m W-oblique	19 Sept	Aquarium on : Second part of "W" profile did not get to depth, perhaps because of strong current; Individual weights for sample of *B. glaciale*, plus most cephalopods
85	Head	Night	250m W-oblique	19 Sept	Individual weights for most cephalopods
86	Head	Day	750-250m	19 Sept	Individual weights for sample of *B. glaciale*, plus two other fish and all cephalopods
87	Head	Day	Extra-deep	19 Sept	Plastic tub in codend; NO CATCH DATA RECORDED

Table 3 : Survey Design, showing Sets Completed

Station	Time	Stratum	Sets
Offshore	Daylight	0–250 m	9
		250–750 m	14
		750–1250 m	15
	Night	0–250 m	7
		250–750 m	18
		750–1250 m	12
		Extra Deep	13
Deep	Daylight	0–250 m	67
		250–750 m	62,65
		750–1250 m	64,66
		Extra Deep	73
	Night	0–250 m	69,77
		250–750 m	71,76
		750–1250 m	70,72
Main	Daylight	0–250 m	24,31,36
		250–750 m	21,23,30
		750–1250 m	22,29,35
		Extra Deep	80
	Night	0–250 m	19,41,43
		250–750 m	27,33,42
		750–1250 m	26,28,34
Wall	Daylight	0–250 m	53
		250–750 m	38,54,56
	Night	0–250 m	58,60
		250–750 m	59,61
Head	Daylight	0–250 m	45
		250–750 m	44,86
	Night	0–250 m	51,85
		250–750 m	49,52
		Extra Deep	83

Table 4 : Displaced Volumes of Major Taxa, with Corresponding Weights

In some cases, two different weights were recorded corresponding to the same measured displaced volume, one being a summation of the weights of individual identified taxa within the major taxon, the other being an overall weight for the major taxon that was recorded specifically for comparison with the volume data. In all such cases, the table shows only the larger of the two weights (which could come from either source). With only two exceptions, the larger weight had better correspondence to the recorded volume.

"–" indicates missing data.

Set	Fish Wt	Fish Vol	Ceph. Wt	Ceph. Vol	Crust. Wt	Crust. Vol	Jelly Wt	Jelly Vol	Other Wt	Other Vol
1	–	–	1.39	1.38	3.59	3.42	2.52	2.53	0.92	0.23
4	–	–	0.04	0.05	1.2	1.43	4.0	4.5	0	0
5	–	–	0.92	0.7	0.90	0.9	4.4	4.0	0.002	0
7	–	–	0.21	0.18	0.92	0.73	9.95	9.75	0	0
9	0.16	0.18	0	0	–	–	0.69	0.7	0	0
13	–	–	0.42	0.4	–	–	2.78	2.5	0.001	0.01
14	–	–	–	–	1.46	1.55	5.61	5.12	0	0
22	–	–	1.12	–	–	–	4.73	4.66	–	–
23	–	–	–	–	–	–	7.44	7.27	–	–
24	–	–	–	–	–	–	2.91	2.84	–	–
26	–	–	0.45	1.2	–	–	3.64	3.65	–	–
27	–	–	0.15	0.18	–	–	3.59	3.55	–	–
28	–	–	–	–	–	–	5.45	5.2	–	–

Table 5 : Summary of Trawling Data

For each IYGPT set, this table shows the times (in UTC, to nearest minute) of key events and the maximum length of warp payed out off each drum of the trawl winch. The timed events are:

1: Release of the otter boards from the ship,

2: Net at upper depth of nominal stratum for the set (deemed synonymous with release of the otter boards for 0–250 m sets),

3: Application of winch brakes after warp fully payed out,

4: Net reached maximum depth and hauling commenced (for “V”- and “W”-profile sets) or net reached depth of first step of stepped-oblique set or net settled at planned fishing depth of horizontal set,

5: Net returned to upper depth of nominal stratum (50 m for 0–250 m sets) or net reached end of last step of stepped-oblique set or net reached end of horizontal set – after any of which, the rate of hauling was usually increased, and

6: Otter boards returned to ship.

“–“ indicates missing data. Events not relevant to a particular set are shaded.

Data for “W”-profile sets are presented over two rows of the table, with the time of the net reaching the intermediate 50 m depth being shown in the 3rd column on the 2nd row. Set 61 is also presented over two rows (see Table 2).

	Time (UTC)						
Set	**Doors Away**	**Top of Stratum**	**Winch Stop**	**Start of Step or Haul**	**Start of Final Haul**	**Doors Back**	**Maximum Warp Out (metres)**
1	–		1453	1558	1640	1657	2500
2	–	–	1949	1949	2027	2054	3000
4	–	–	0156	0156	0238	0242	525
5	0355	0355	0404	0409	0451	0453	500
6	–	0607	–	–	–	–	–
7	0727	0727	0734	0741	0841	0843	600
8	1142	–	1215	1232	1355	1413	2500
9	1933	1933	1942	1949	2045	2048	600
11	0049					0058	
12	0059	0128	0133	0152	0227	0247	2300
13	0357	0431	0436	0456	0525	0553	–
14	1037	–	1103	1116	1205	1215	1650
15	1348	1417	1421	1440	1513	1534	2300
16	1720	1747	1748	1816	1847	1943	2301
18	2327	2343	0004	0010	0043	0055	1650
19	0501	0501	0512	0521	0617	0622	600
21	1033	1047	1058	1107	1145	1155	–
22	1308	1341	1346	1402	1440	1457	2500

Set	Time (UTC)						Maximum Warp Out (metres)
	Doors Away	Top of Stratum	Winch Stop	Start of Step or Haul	Start of Final Haul	Doors Back	
23	1625	1642	1659	1712	1740	1748	1600
24	1852	1852	1901	1917	2014	2020	483
26	2308	2343	2348	0006	0044	0104	2500
27	0211	0227	0238	0255	0321	0330	1650
28	0514	0554	0550	0627	0648	–	–
29	–	–	1115	1148	1210	1235	2300
30	1554	1612	1621	1634	1706	1716	1600
31	1824	1824	1834	1854	1954	1957	540
33	2327	2341	2353	0000	0040	0050	–
34	0231	0310	0314	0343	0410	0441	2500
35	1032	1104	1112	1124	1202	1220	2500
36	1305	1305	1317	1327	1417	1421	600
37	1552		1614	1624	1654	1712	1028
38	1840	1859	1911	1923	1954	2007	–
41	0035	0035	0048	0057	0154	0159	625
42	0313	0336	0344	0407	0435	0446	–
43	0538	0538	0557	0606	0647	0651	–
44	1042	1057	1108	1117	1156	1204	1650
45	1303	1303	1314	1328			625
		1343	1350	1357	1413	1416	–
46	1615	1631	1642	–	1725	1733	1600
48	2334	–	–	–	–	–	–
49	0022	0039	0049	0100	0136	0145	1650
50	0252	0252	0259	0311	–	0347	917
51	0413	0413	0426	0435			625
		0450	0501	0507	0520	0524	625
52	0607	0625	0636	0655	0720	0733	1600
53	1031	1031	1042	1053			625
		1109	1116	1125	1141	1144	625
54	1227	1242	1253	1305	1340	1350	1650
55	1423		1437	1447	1517	1535	850
56	1719	1735	1746	1757	1827	1838	1650
58	2333	2333	2344	2348			625
		0005	0012	0017	0034	0039	625
59	0119	0136	0145	0201	0234	0245	1625
60	0337	0337	0350	0356			600
		0411	0422	0430	0443	0447	600
61	0548					0602	
	0639	0658	0707	0725	0755	0808	1600

Set	Time (UTC)						Maximum Warp Out (metres)
	Doors Away	Top of Stratum	Winch Stop	Start of Step or Haul	Start of Final Haul	Doors Back	
62	1053	1111	1119	1129	–	1215	1650
64	1554	1632	1637	1655	1729	1759	2506
65	1048	1103	1115	1122	1200	1207	1650
66	1252	1323	1329	1344	1423	1441	2500
67	1619	1619	1630	1635			600
		1650	1658	1707	1721	1725	600
69	2308	2308	2319	2331			625
		2347	2353	0001	0015	0019	625
70	0116	0148	0154	0209	0248	0318	–
71	0405	0423	0434	0446	0521	0535	1600
72	0617	0656	0701	0717	0753	0823	2500
73	1121	1208	1206	1219	1019	1356	3000
74							
75	–	1954	2006	2023	2055	–	1600
76	2320	2335	2347	2355	0033	2346	1650
77	0138	0138	0150	0201			625
		0218	0225	0232	0247	0251	625
78	0502	–	–	–	0557	0609	2800
79	1052		1130	1136	1243	1243	2300
80	1423	1508	1508	1522	–	1638	2700
81	1807	1823	1833	1843	1915	1928	1600
83	0004	0019	0036	0050	0129	0139	1700
84	0324	0324	0345	0346			620
		0400	0410	0419	0431	0434	630
85	0524	0524	0531	0549			650
		0557	–	0611	0629	0632	–
86	1107	1123	1133	1146	1220	1230	1600
87	–	1403	1411	1427	–	1518	1700

Table 6 : Catch Taken on Set 46[9]
"–" indicates missing data

Taxon or type of catch	Weight Caught (grams)
Cnidaria	
Keratoisis ornata	150
Primnoa resedaeformis	355
Paragorgia arborea (red morph)	1,355
Paragorgia arborea (white morph)	200
Flabellum sp.	27.0
Anthoptilum grandiflorum	38.2
Anemone	25.9
Hydrozoans, growing on *K. ornata*	0.1
Other Benthos	
Sabellid worm, in *Primnoa* base	–
Scalpellid barnacle, on *K. ornata*	3.2
Brittlestars	0.1
Crinoid	0.1
Pycnogonid	0.1
Pelagic Finfish	45.0
Pelagic Crustaceans	56.7
Pelagic Cephalopods	15.2
Sediment: Mud & small rocks	13.5

[9] The names applied to the taxa are subject to revision and refinement following laboratory identification of specimens.

Table 7a : Comparison of Catches with and without the "Aquarium" Codend in 250–750 m Daylight Sets at the Head Station

Cephalopod catches are counts of measurable mantles. All other catches are in kilograms. The taxa are as identified at sea and, apart from the totals, exclude most of those taxa that included more than one genus[10]. "–" indicates zero catch.

Taxon	Set 44	Set 86	Set 81 Aquarium
Total Fish	1.494	0.911	1.331
Total Cephalopods	14	6	24
Total Crustacea	1.412	1.824	2.113
Total Gelatinous Plankton	0.88	0.52	2.365
Fish taxa *Bathylagus euryops*	–	0.0064	0.085
Bathylagus spp.	0.045	–	–
Benthosema glaciale	0.135	0.156	0.277
Borostomias antarcticus	0.0017	–	–
Ceratoscopelus maderensis	0.002	0.0028	–
Chauliodus sloani	0.049	0.0415	0.044
Chiasmodon niger	–	–	0.015
Cyclothone spp.	0.71	0.1764	0.12
Eurypharynx pelecanoides	0.008	–	0.001
Gaidropsarus argentatus	–	0.0218	–
Gigantactis vanhoeffeni	–	–	0.0003
Lampanyctus ater	–	–	0.006
Lampanyctus macdonaldi	0.055	0.161	0.064
Malacosteus niger	0.09	–	0.263
Melanostigma atlanticum	0.0006	0.0197	0.044
Myctophum punctatum	0.056	0.0338	0.044
Nemichthys scolopaceus	–	–	0.026
Notolepis rissoi	0.09	0.244	0.024
Notoscopelus caudispinosus	0.025	–	–
Notoscopelus elongates kroyeri	–	0.0183	0.015
Paralepis atlantica			0.001
Paraliparis copei	0.005	0.0008	–
Polyipnus asteroides	0.0008	–	–
Poromitra megalops	–	–	0.005
Scopeloberyx opisthopterus	–	–	0.003

[10] The names applied to the taxa are subject to revision and refinement following laboratory identification of specimens. These data are presented here as a comparison of the catches obtained with and without the "aquarium" codend attached to the trawl. They should not be used as any indication of the species composition of the pelagic fauna in the Gully.

Taxon	**Set 44**	**Set 86**	**Set 81 Aquarium**
Sebastes spp.	0.001	–	0.003
Serrivomer beani	0.165	0.03212	0.134
Stomias boa	0.054	–	0.157
Synaphobranchus kaupi	–	0.018	–
Triglops spp.	0.001	–	–
Cephalopod taxa			
Brachioteuthis spp.	10	4	4
Gonatus fabricii	–	–	4
Gonatus steenstrupii	1	1	–
Mastigoteuthis agassizii	2	1	2
Stauroteuthis syrtensis	1	–	13
Teuthowenia megalops	–	–	1
Crustacean taxa			
Acanthephyra exemia	0.11	0.45	0.386
Acanthephyra pelagica	0.0038	0.015	0.032
Acanthephyra purpurea	0.0038	0.023	–
Acanthephyra spp.	0.0008	–	–
Eucopia spp.	0.01	0.0053	0.0089
Euphausiacea	–	0.0067	0.032
Gennadas spp.	0.077	0.01	0.0723
Gnathophausia spp.	0.028	0.02	0.0516
Hyperiidae	0.022	0.0117	0.012
Meganyctiphanes norvegica	0.181	0.025	–
Mysidacea	0.0024	0.0195	0.0085
Ostracoda	0.0012	–	–
Parapasiphaea sulcatifrons	0.0025	0.02	0.015
Pasiphaea multidentata	0.607	0.67	0.879
Pasiphaea tarda	0.245	0.345	0.3655
Sergestes spp.	0.048	0.185	0.207
Sergia spp.	0.06	0.01	0.0672
Thysanopoda acutifrons	0.005	0.0043	0.069

Table 7b : Comparison of Catches with and without the "Aquarium" Codend in 0–250 m Night Sets at the Head Station
Cephalopod catches are counts of measurable mantles. All other catches are in kilograms. The taxa are as identified at sea and, apart from the totals, exclude most of those taxa that included more than one genus[11]. "-" indicates zero catch.

Taxon	Set 51	Set 85	Set 84 Aquarium
Total Fish	0.132	0.091	0.232
Total Cephalopods	7	8	24
Total Crustacea	7.594	5.680	4.821
Total Gelatinous Plankton	0.030	0.885	0.140
Fish taxa *Benthosema glaciale*	0.0064	0.0215	0.0613
Ceratoscopelus maderensis	0.00537	0.0032	–
Chauliodus sloani	0.0055	–	–
Cyclothone spp.	–	0.0033	0.0443
Lampadena speculigera	–	–	0.0163
Maurolicus muelleri	0.0004	–	–
Melanostigma atlanticum	–	0.0134	0.0084
Myctophum punctatum	0.00032	0.0067	0.007
Nemichthys scolopaceus	–	–	0.0181
Notolepis rissoi	0.0131	0.027	0.0129
Notoscopelus elongates kroyeri	–	0.0123	–
Paralepis atlantica	–	–	0.024
Polyipnus asteroides	0.0015	–	–
Scomber scombrus	–	–	0.0322
Sebastes spp.	–	0.0032	–
Stomias boa	0.0989	–	0.0078
Triglops pingeli	0.00042	–	–
Cephalopod taxa *Brachioteuthis* spp.	6	8	21
Gonatus steenstrupii	1	–	–
Gonatus spp.	–	–	1
Mastigoteuthis spp.	–	–	1
Stauroteuthis syrtensis	–	–	1

[11] The names applied to the taxa are subject to revision and refinement following laboratory identification of specimens. These data are presented here as a comparison of the catches obtained with and without the "aquarium" codend attached to the trawl. They should not be used as any indication of the species composition of the pelagic fauna in the Gully.

Taxon	Set 51	Set 85	Set 84 Aquarium
Crustacean taxa			
Eucopia spp.	–	–	0.001
Gennadas spp.	–	–	0.0014
Gnathophausia spp.	–	–	0.002
Hyperiidae	0.1027	0.03	0.035
Meganyctiphanes norvegica	5.8041	4.655	3.23
Pasiphaea multidentata	1.675	0.93	1.46
Sergestes spp.	0.0121	0.065	0.09
Sergia spp.	–	–	0.0019

Table 8 : Summary of Marine Mammal Sightings
Species identifications are as recorded at sea, some being very tentative. The numbers given are the total counts of sightings for the species, station and day, sometimes combining the counts from multiple encounters. Hence, it is possible that smaller numbers of individuals were present and were repeatedly sighted.

Date	Station	Species	Numbers
10 Sept	Main	Pilot	16
		Bottlenose	≈40
		Unknown large whale	2
11 Sept	Main	Bottlenose	≈20
		Pilot	1
		Sperm	1
12 Sept	Main	Bottlenose	2
13 Sept	Head and nearby	Pilot	17
		Common Dolphin	7
		Unknown large whale	Unknown
14 Sept	Wall	Bottlenose	4
		Sei	2
		Unknown large whale	6
		Unknown dolphin	≈30
17 Sept	Deep	Pilot	≈10
18 Sept	Feeder Canyon	Pilot	≈5
		Unknown large whale	1
	Main	Bottlenose	4
	Head	Pilot	18
19 Sept	Head	Pilot	5
		Humpback	6
		Fin	2

FIGURES

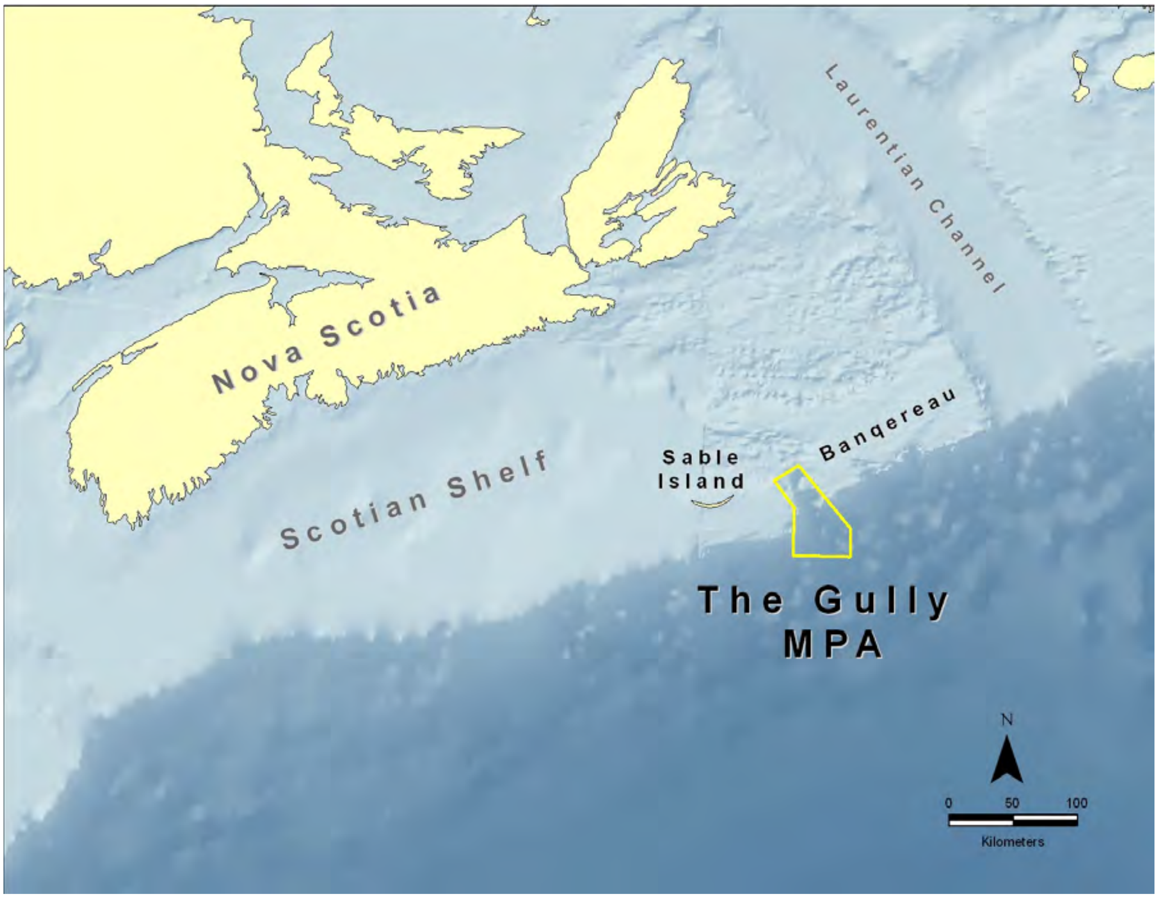

Figure 1 : Location of the Sable Gully

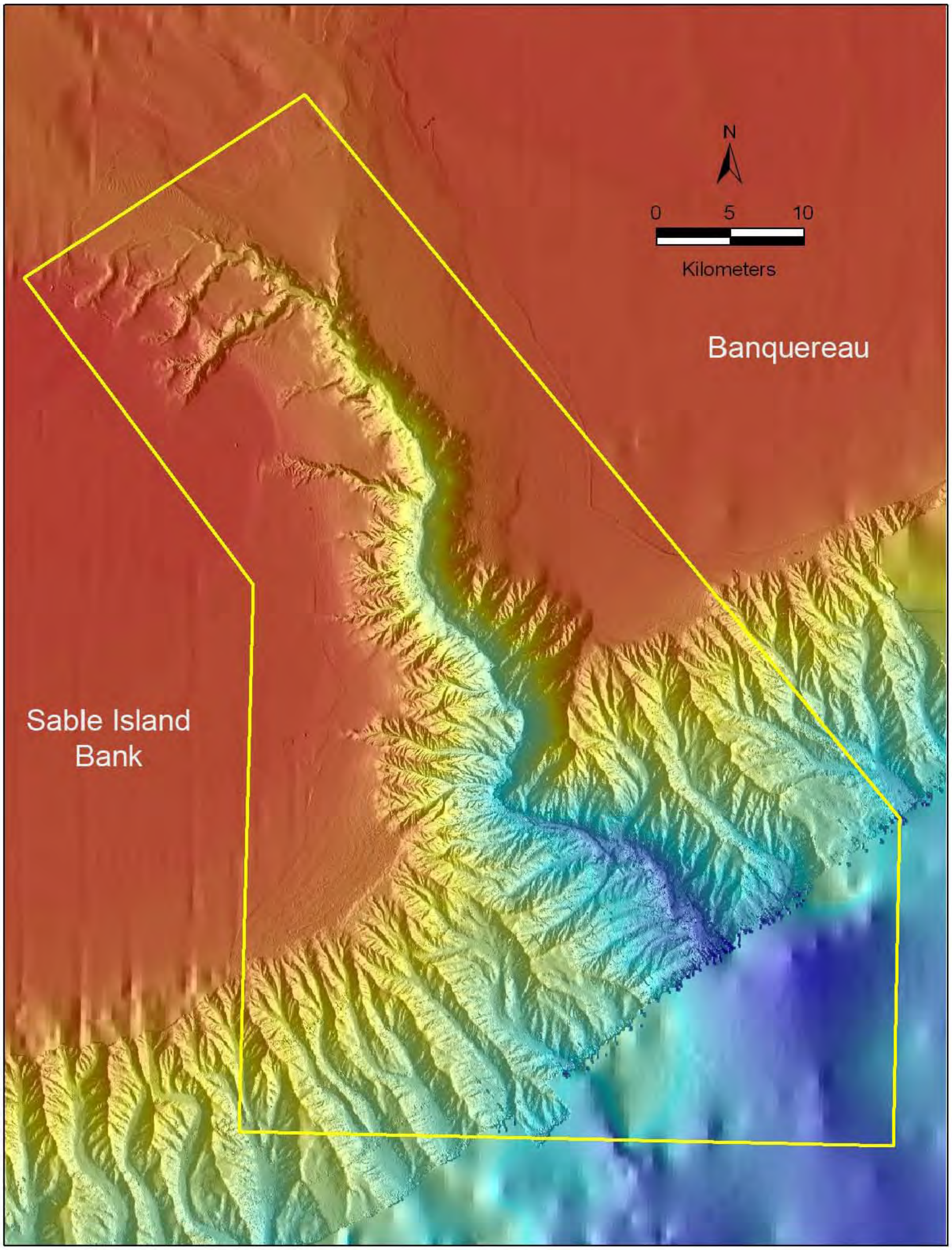

Figure 2 : Multibeam Bathymetry of Sable Gully
Boundaries of the Marine Protected Area are shown. Note that bathymetry of deeper waters to southeast has not been surveyed to the same accuracy

Figure 3 : "Aquarium" Codend, as used in September 2007
The "aquarium" is seen being launched down the stern ramp of *Templeman*, after being filled with seawater (which can be seen flowing out).

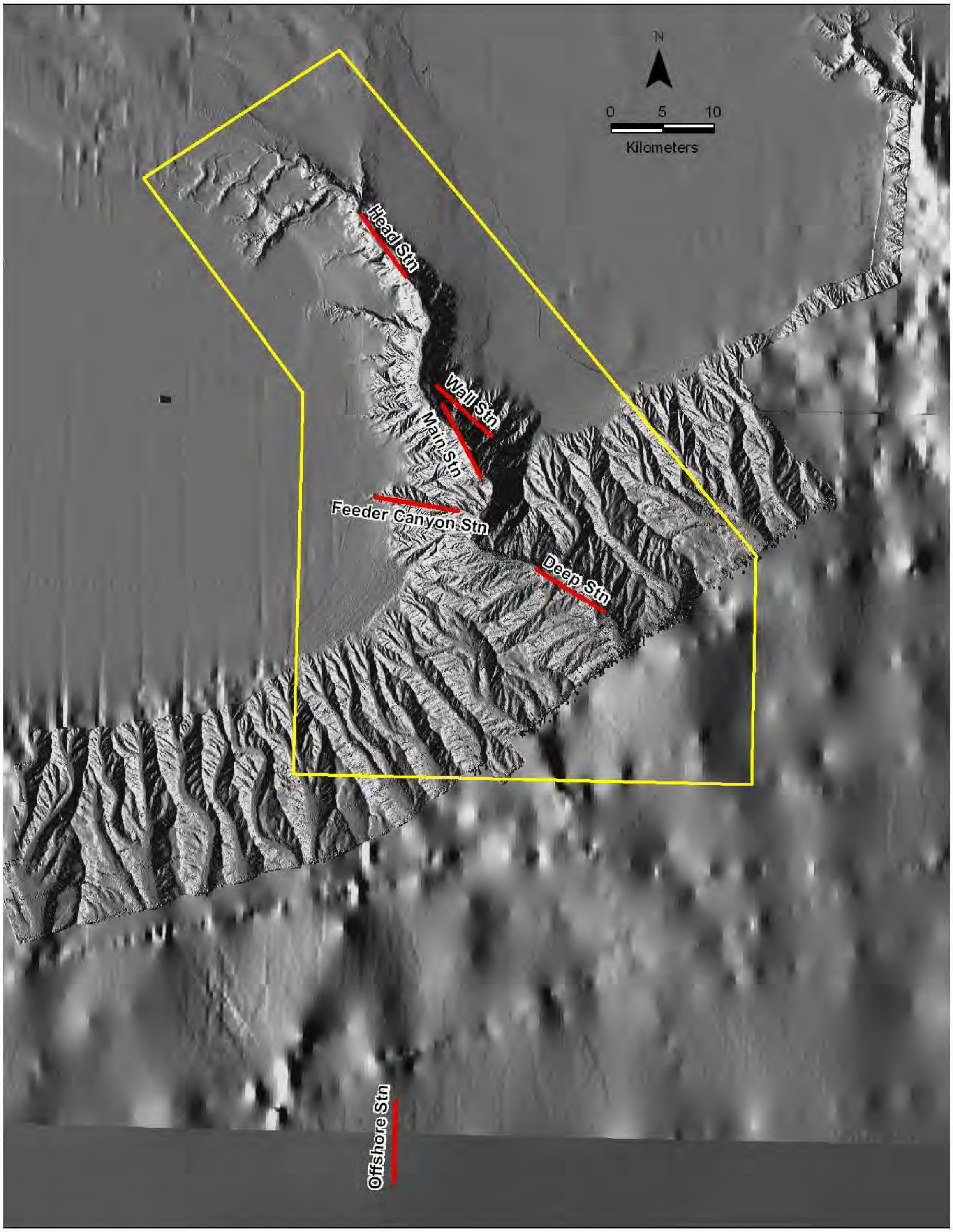

Figure 4 : Locations of the Named Trawling Stations, relative to the Bathymetry and Boundaries of the Marine Protected Area
Detailed bathymetric data unavailable for area of Offshore Station

Figure 5 : Selected Examples of Scanmar Sensor Output
Depths are in green, wingspread in blue and headline height (vertical net opening) in red. For clarity, outliers identified by the Scanmar software have been deleted.

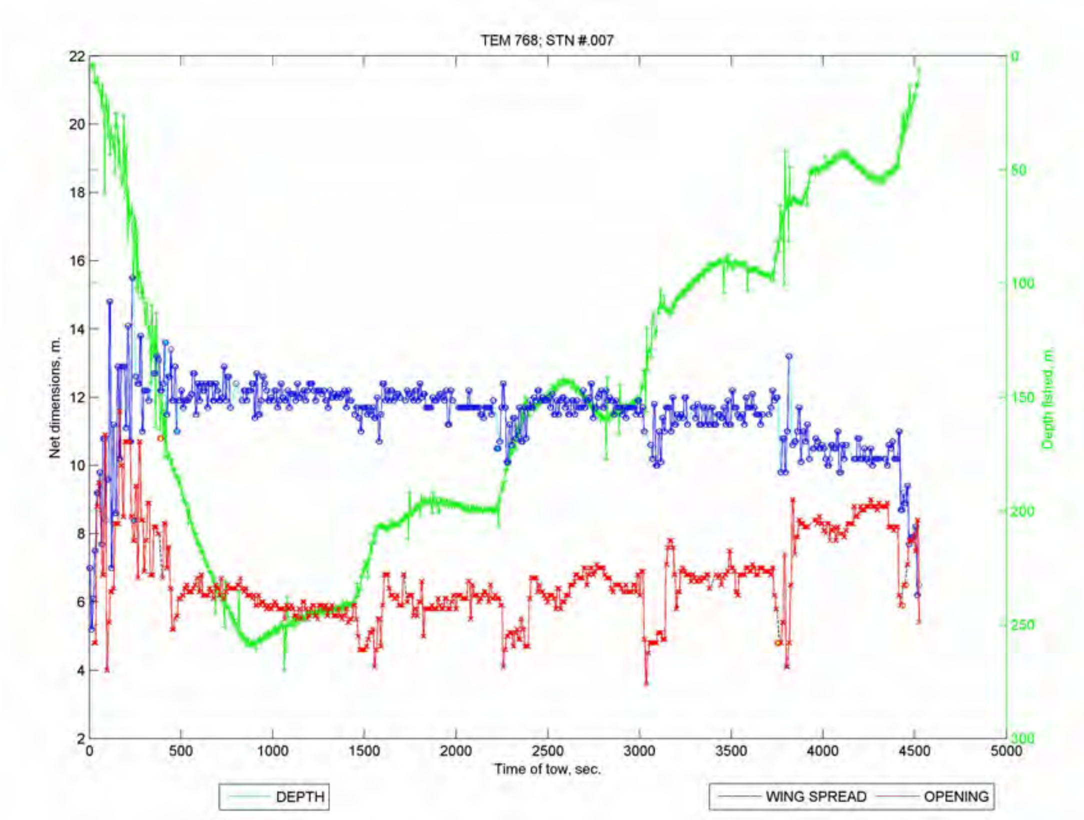

Figure 5a : Set 7, an Example of a 0–250 m Stepped-Oblique Set

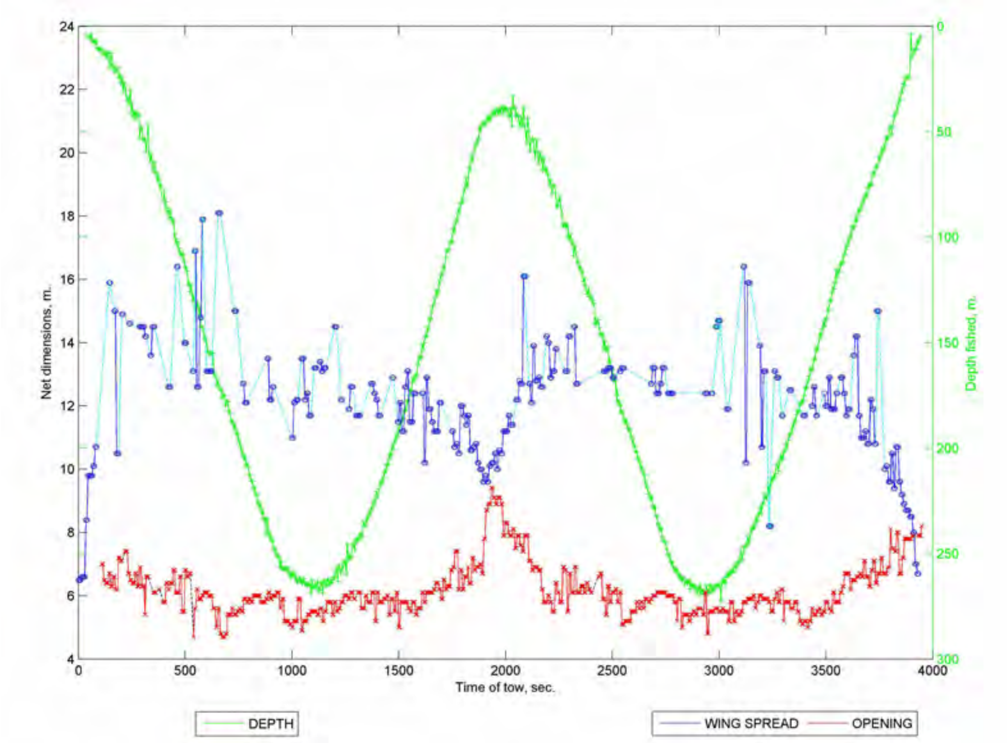

Figure 5b : Set 85, an Example of a 0–250 m “W”-Profile Set

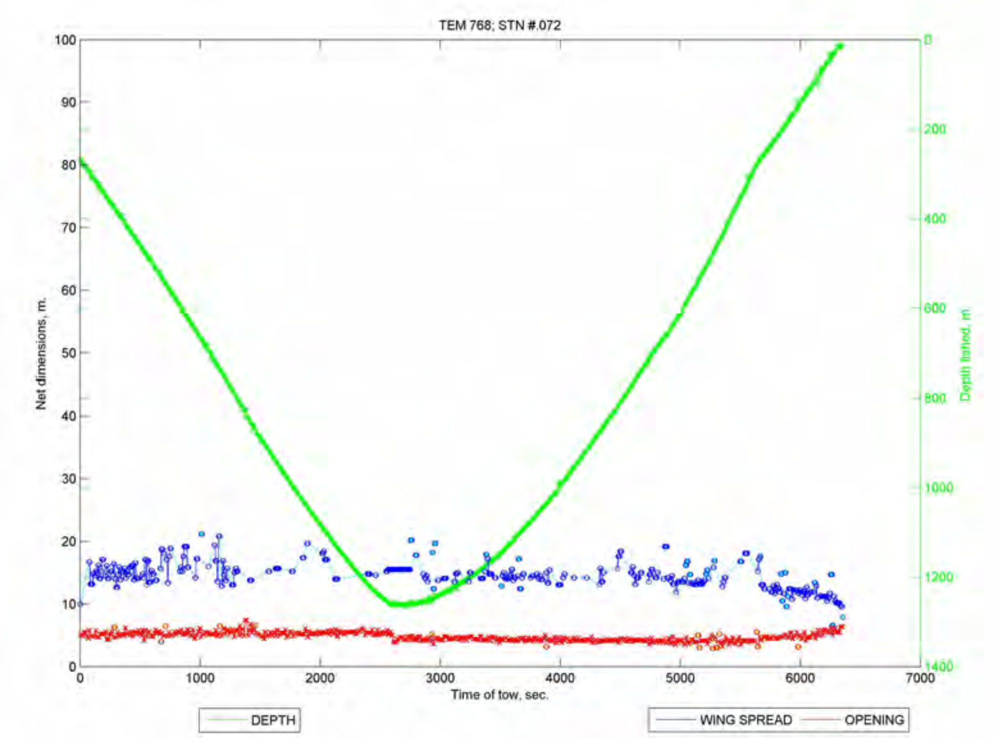

Figure 5c : Set 72, an Example of a 750–1250 m “V”-Profile Set

Figure 6 : Selected Echograms from the Simrad EK500 Sounder

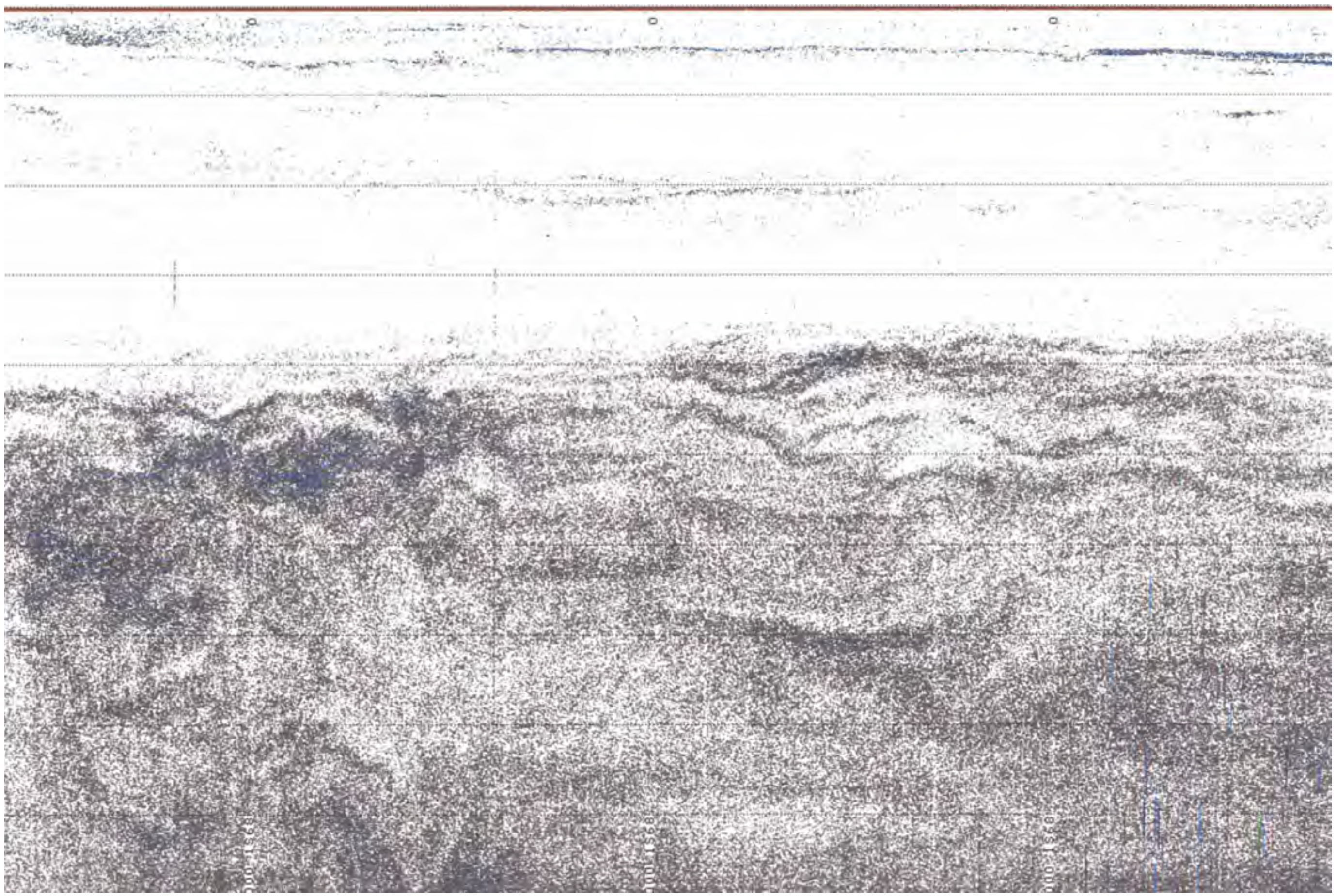

Figure 6a : Typical Echogram from the Main Station, Showing Dense Scattering below 400 m Depth, in Multiple "Wavy" Layers. Depth range displayed: 0 to 1000 m, with 100 m intervals indicated.

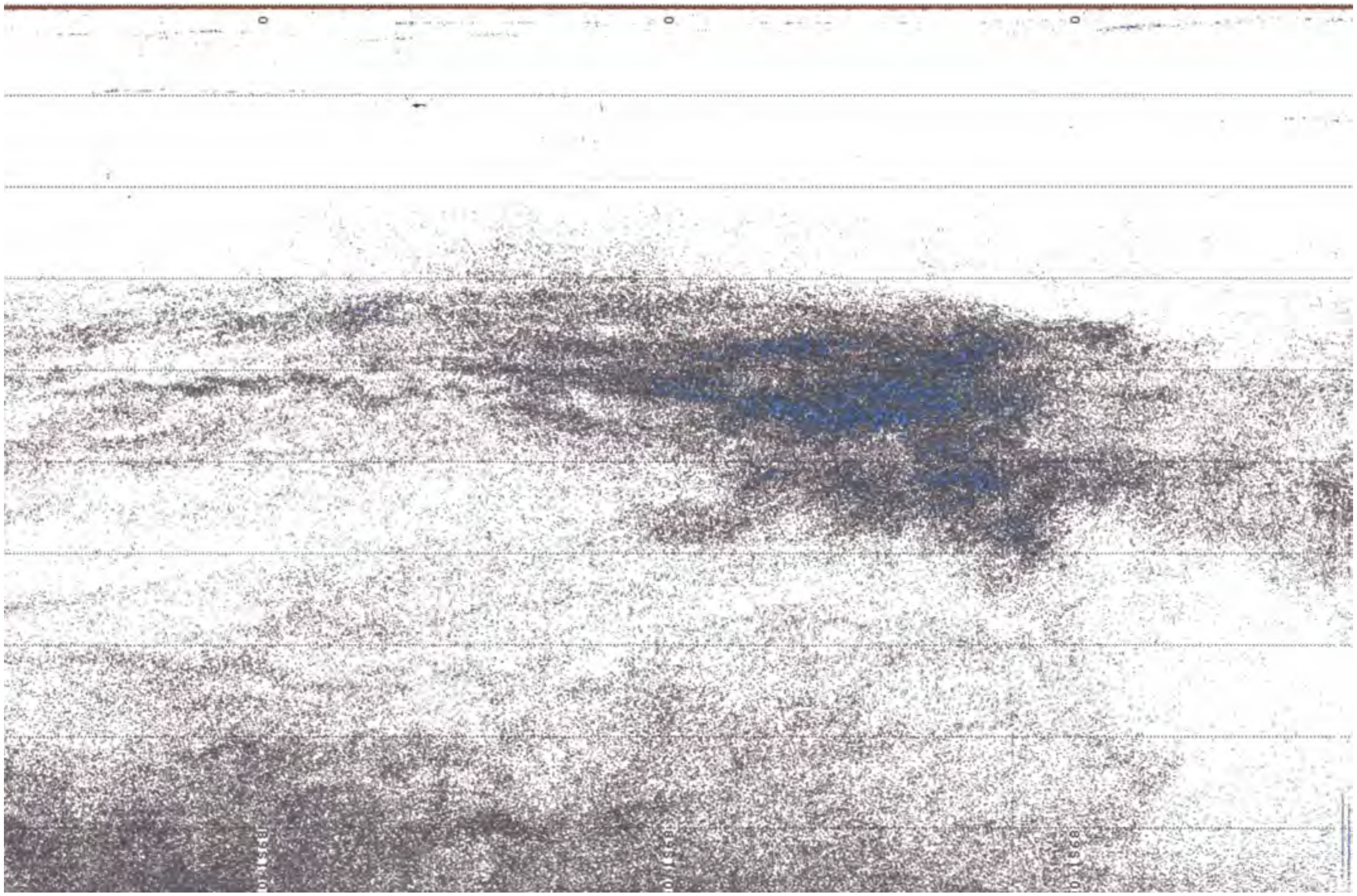

Figure 6b : Echogram Showing Dense Scattering Near the Banquereau Spur
Depth range displayed: 0 to 1000 m, with 100 m intervals indicated.

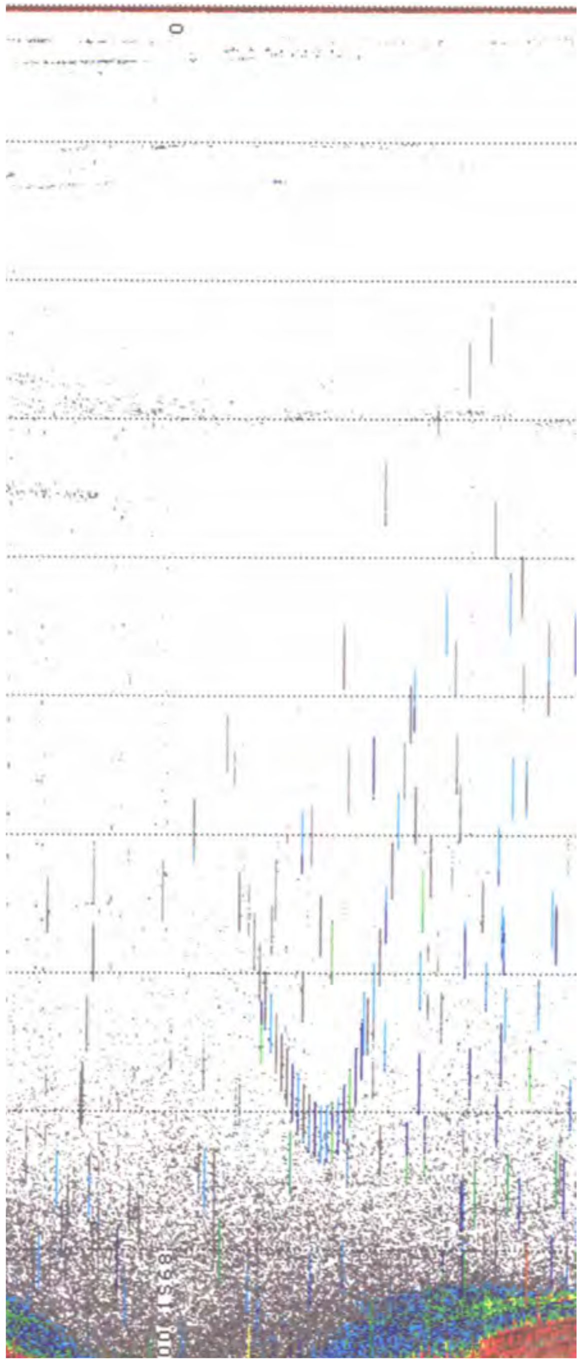

Figure 6c : Echogram from the Head Station, Showing Lack of Dense Scattering, Examples of "Whale Flecks" and Parabolic Trace of a Whale
Depth range displayed: 0 to 1000 m, with 100 m intervals indicated.

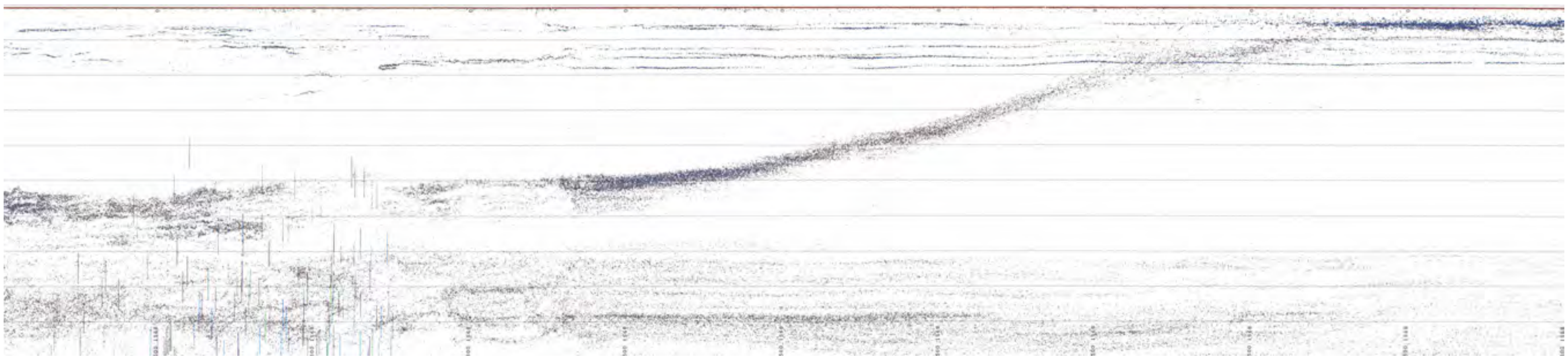

Figure 6d : Vertical Migration of a Scattering Layer at Dusk: Offshore Station from 1940 UTC on 8 September to 0012 UTC on 9 September Depth range displayed: 0 to 500 m, with 50 m intervals indicated.

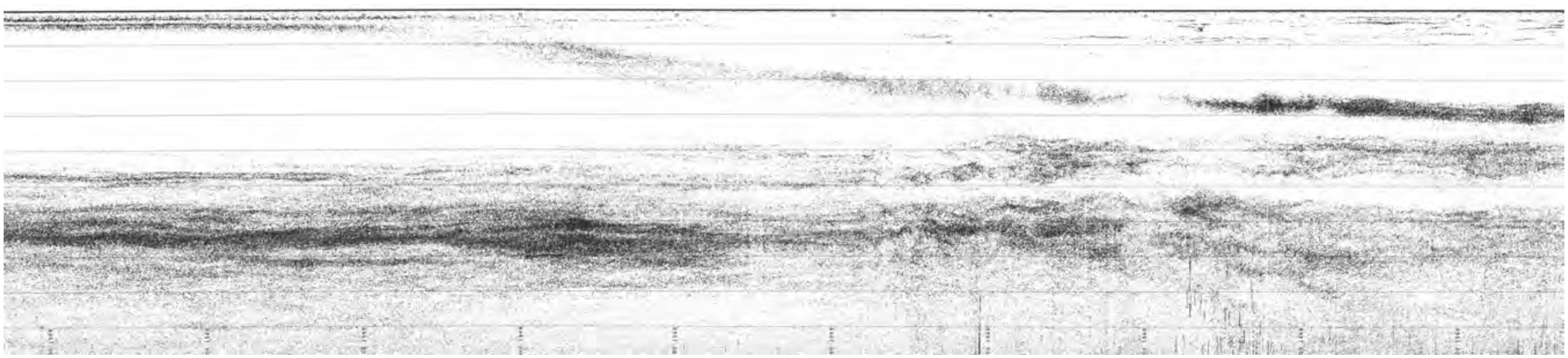

Figure 6e : Vertical Migration of a Scattering Layer at Dawn: Offshore Station from 0719 to 1142 UTC on 9 September Depth range displayed: 0 to 1000 m, with 100 m intervals indicated.

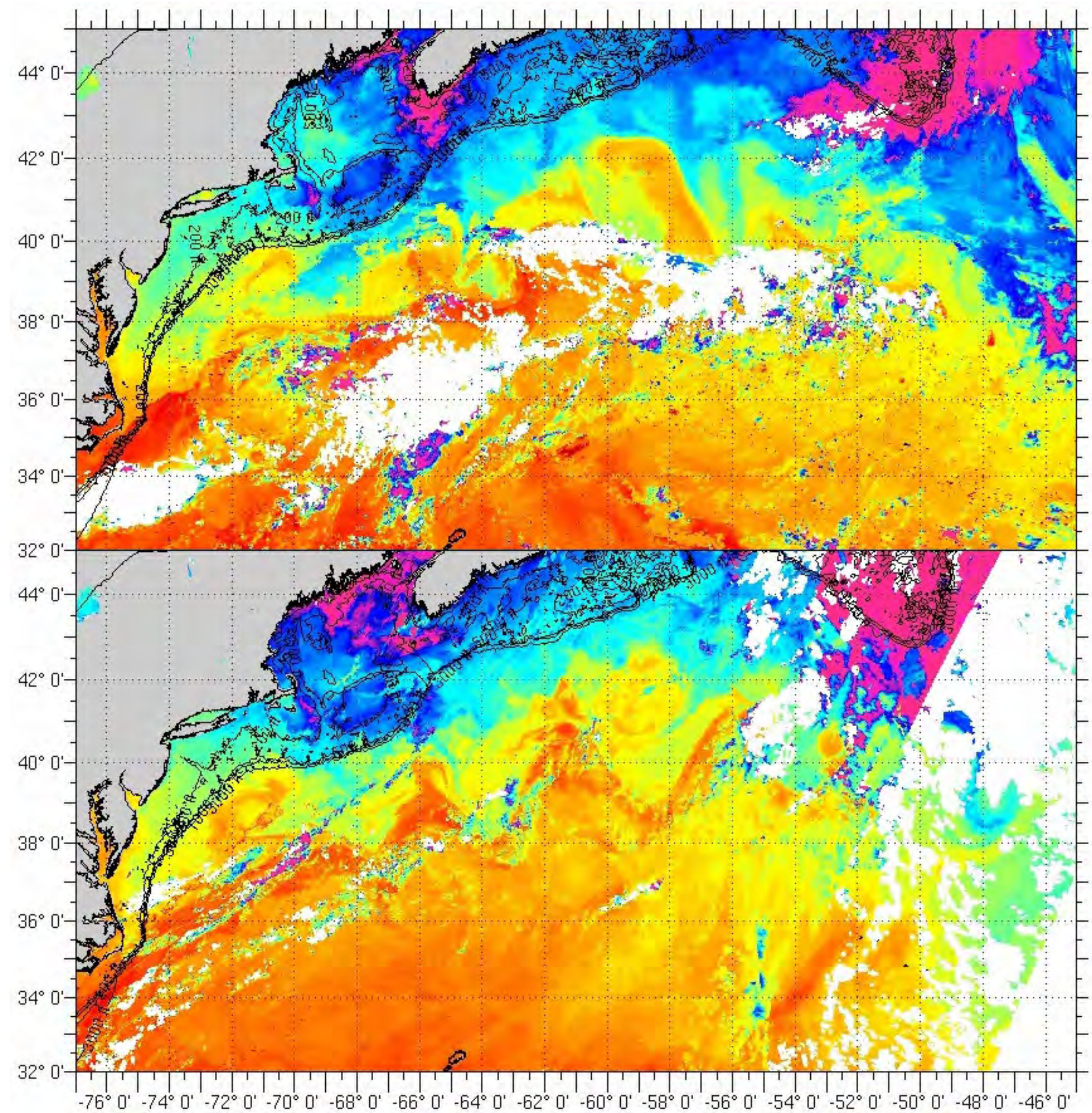

Figure 7 : Sea Surface Temperature from Cape Hatteras to Grand Bank, upper: 28 August 2007, lower 12 September 2007

The Gully lies at about 44°N 59°W. [Images courtesy of Rutgers University's Coastal Ocean Observation Laboratory]

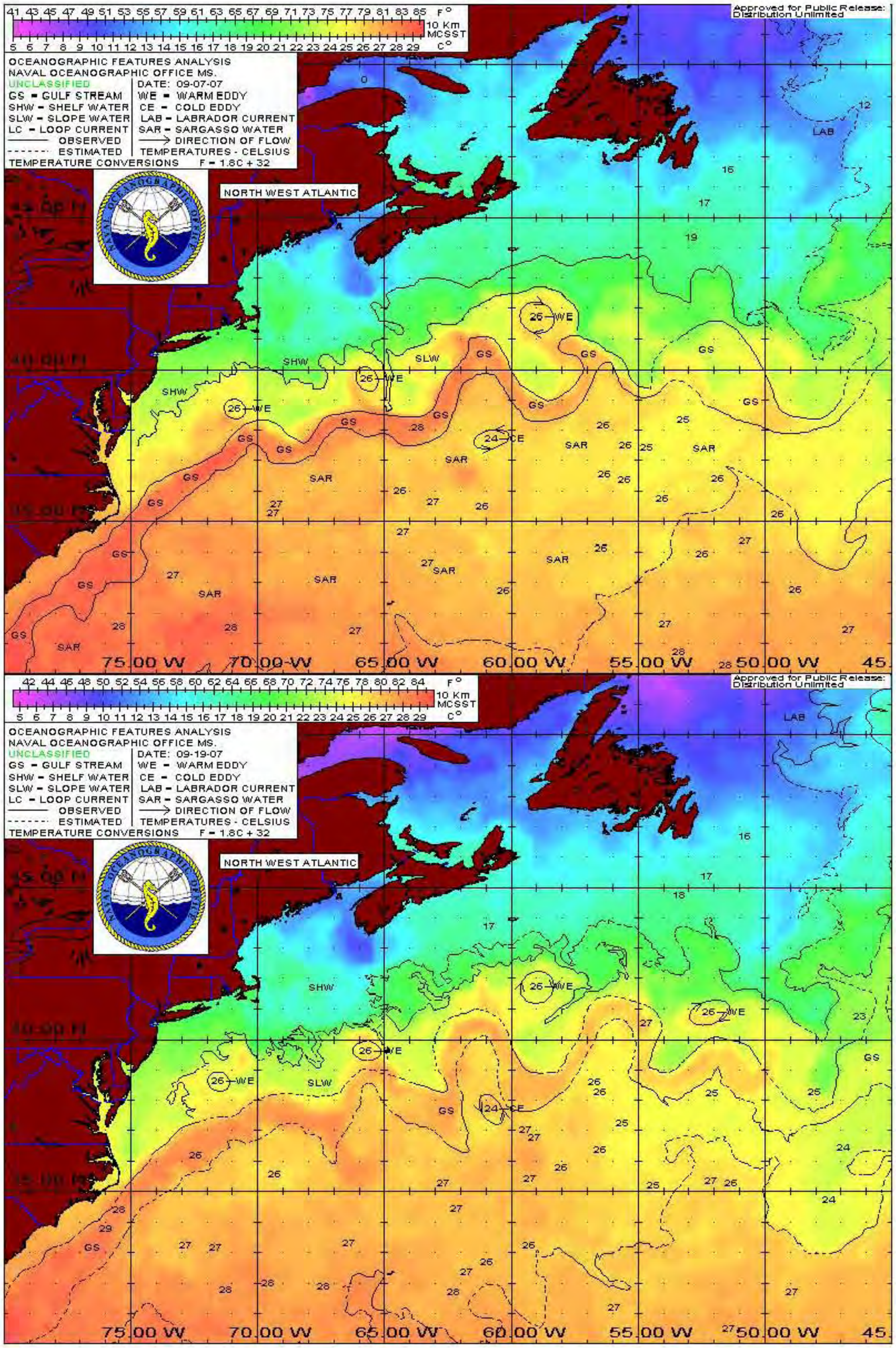

Figure 8 : Interpreted Distribution of Surface Watermasses from Cape Hatteras to Grand Bank, upper: 7 September, lower 19 September 2007
Sable Island is shown at 44°N 60°W. The Gully lies 80 km to the east.
[Images courtesy of U.S.N. Naval Oceanographic Office]

Figure 9 : Depth Profiles of Temperature, Salinity, Density and Oxygen Concentration from CTD Data

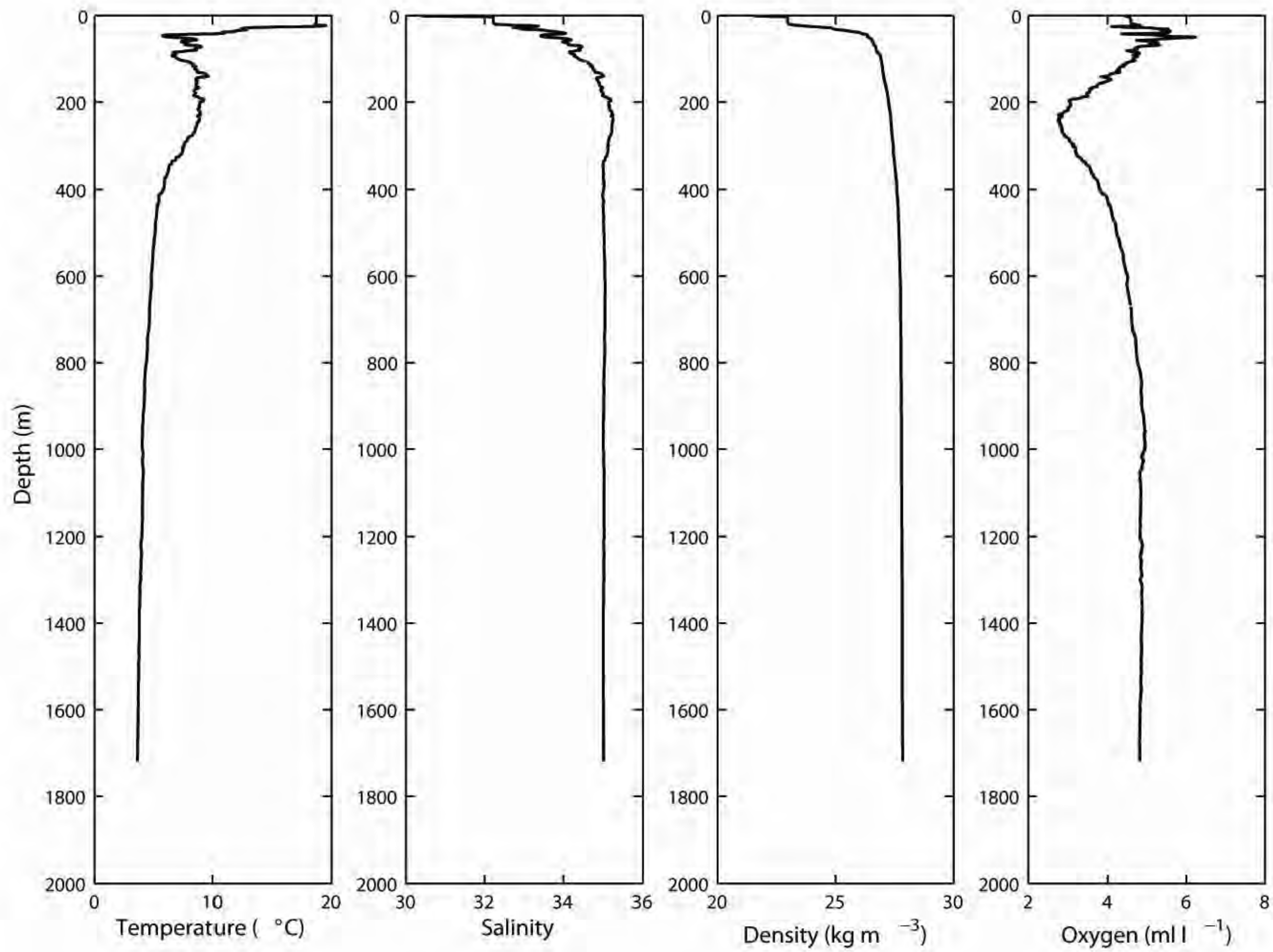

Figure 9a : Set 3 (Offshore Station)

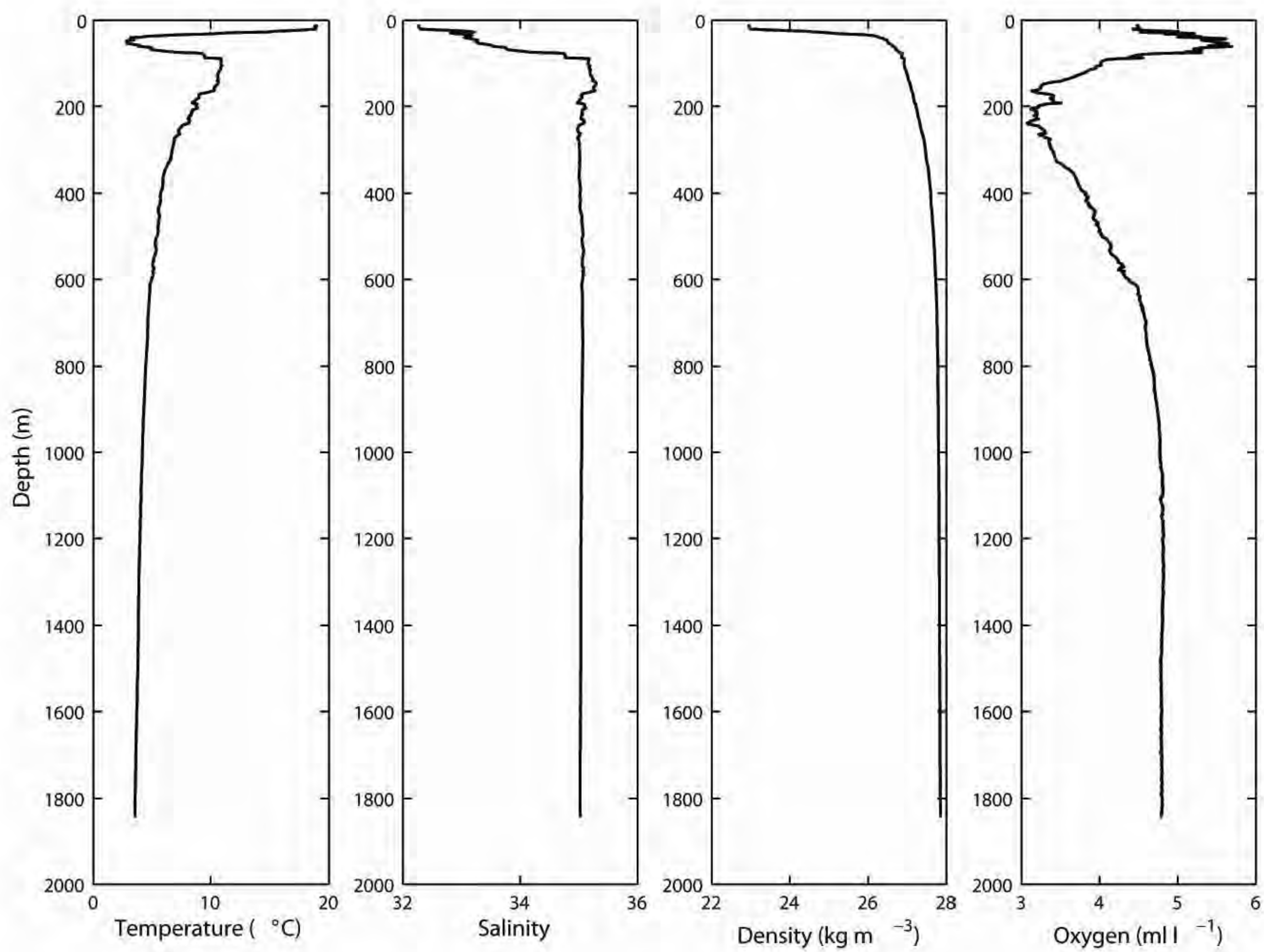

Figure 9b : Set 10 (Offshore Station)

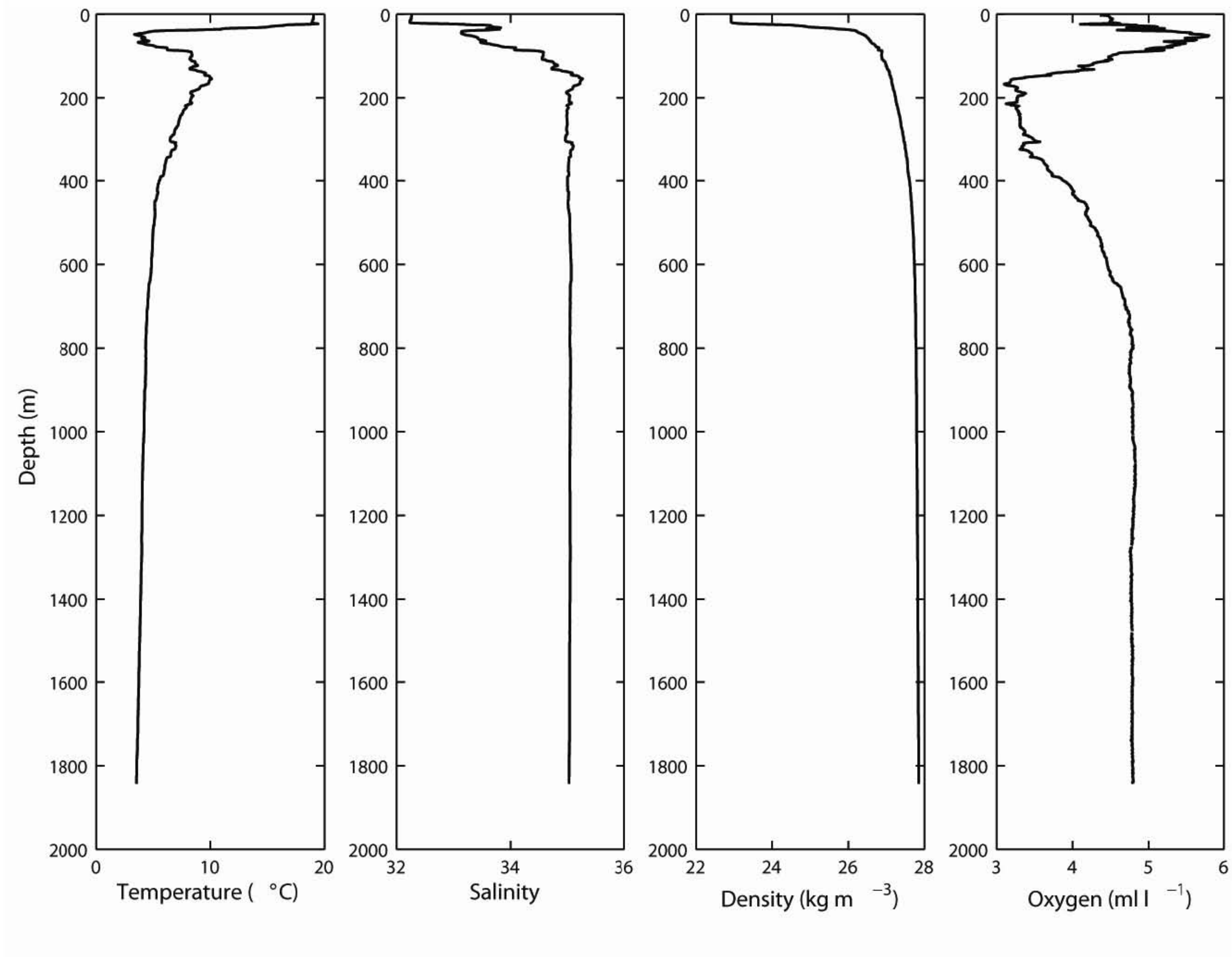

Figure 9c : Set 17 (Offshore Station)

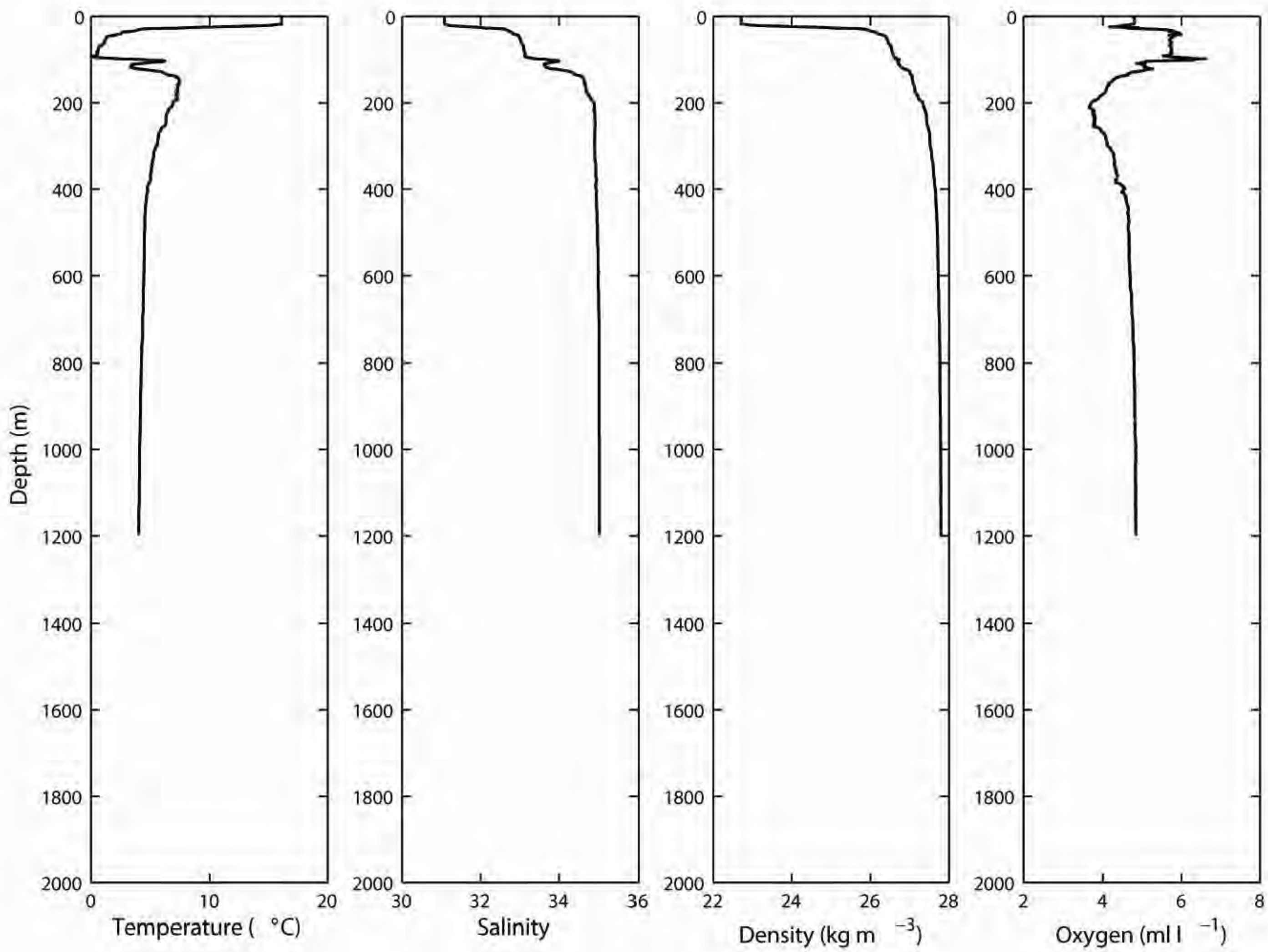

Figure 9d : Set 20 (Main Station)

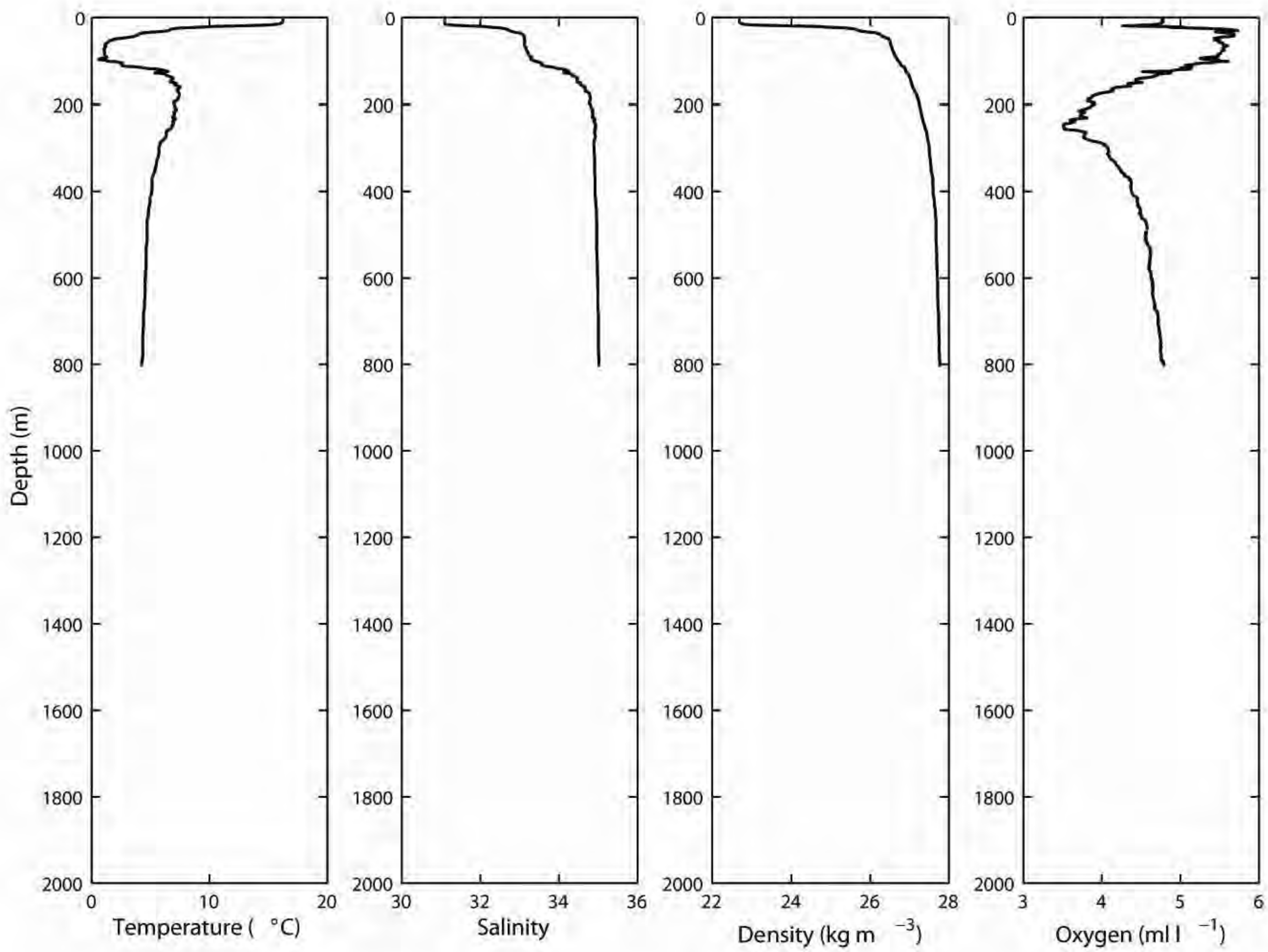

Figure 9e : Set 25 (Main Station)

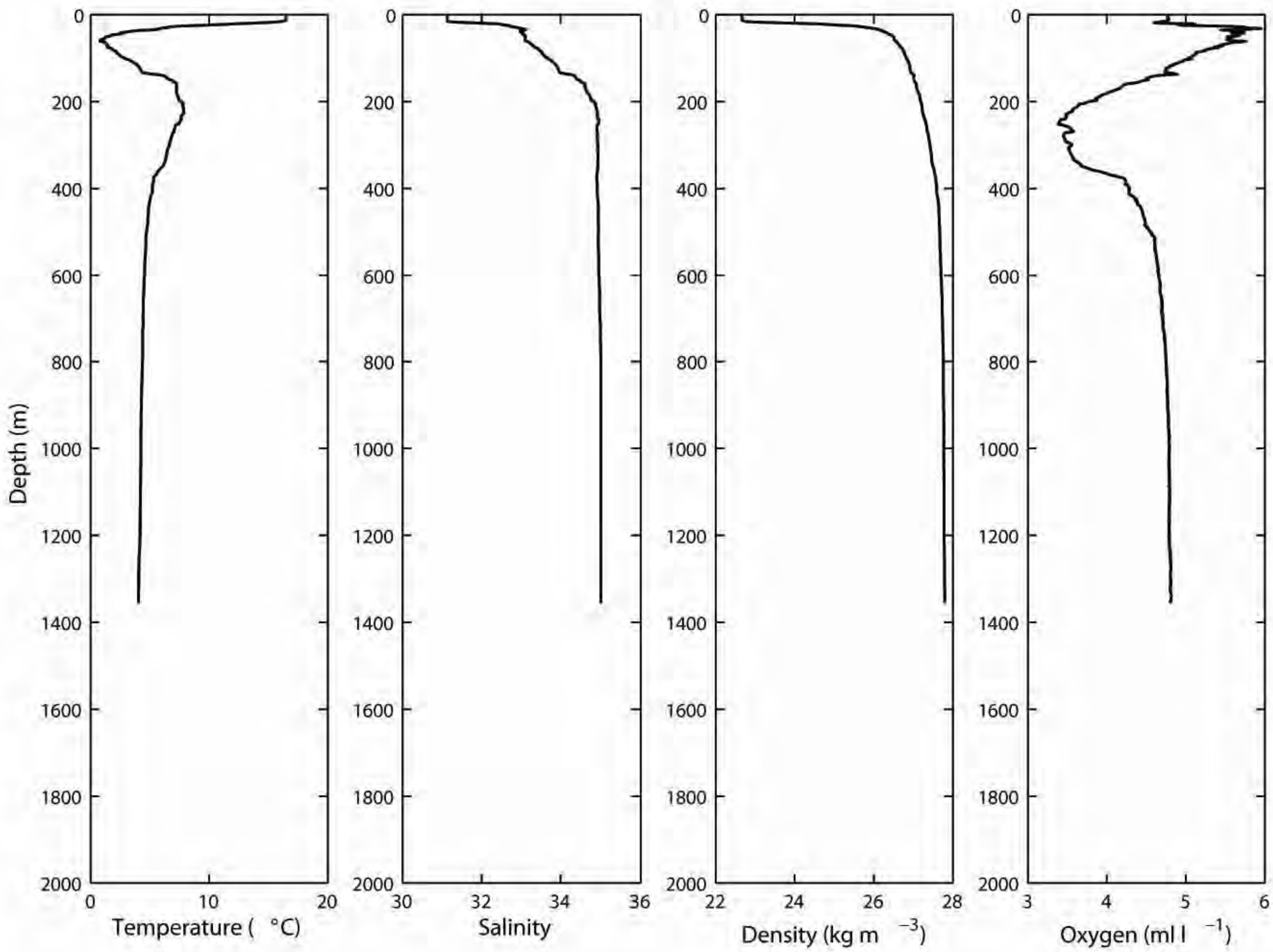

Figure 9f : Set 32 (Main Station)

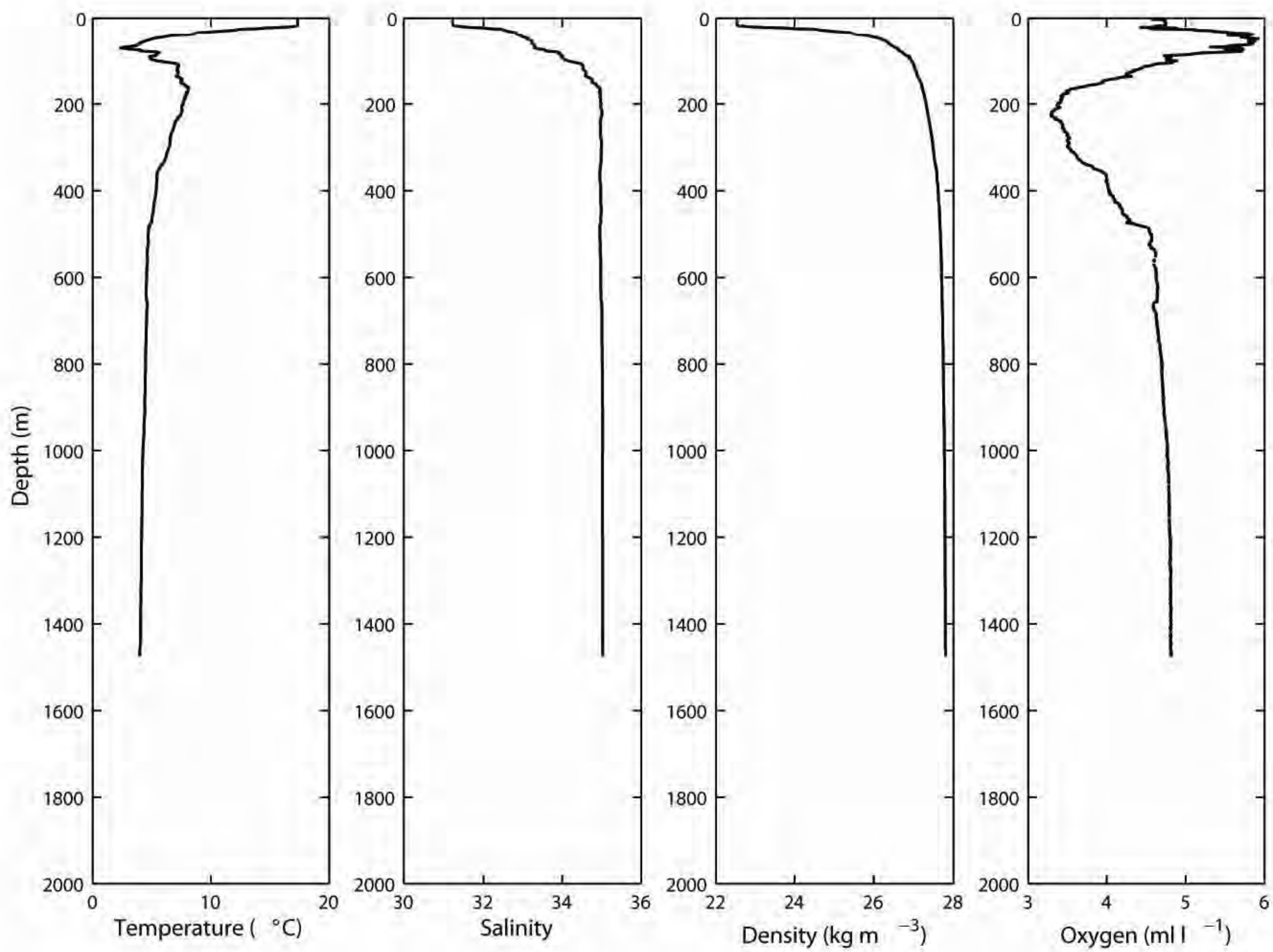

Figure 9g : Set 40 (near Main Station)

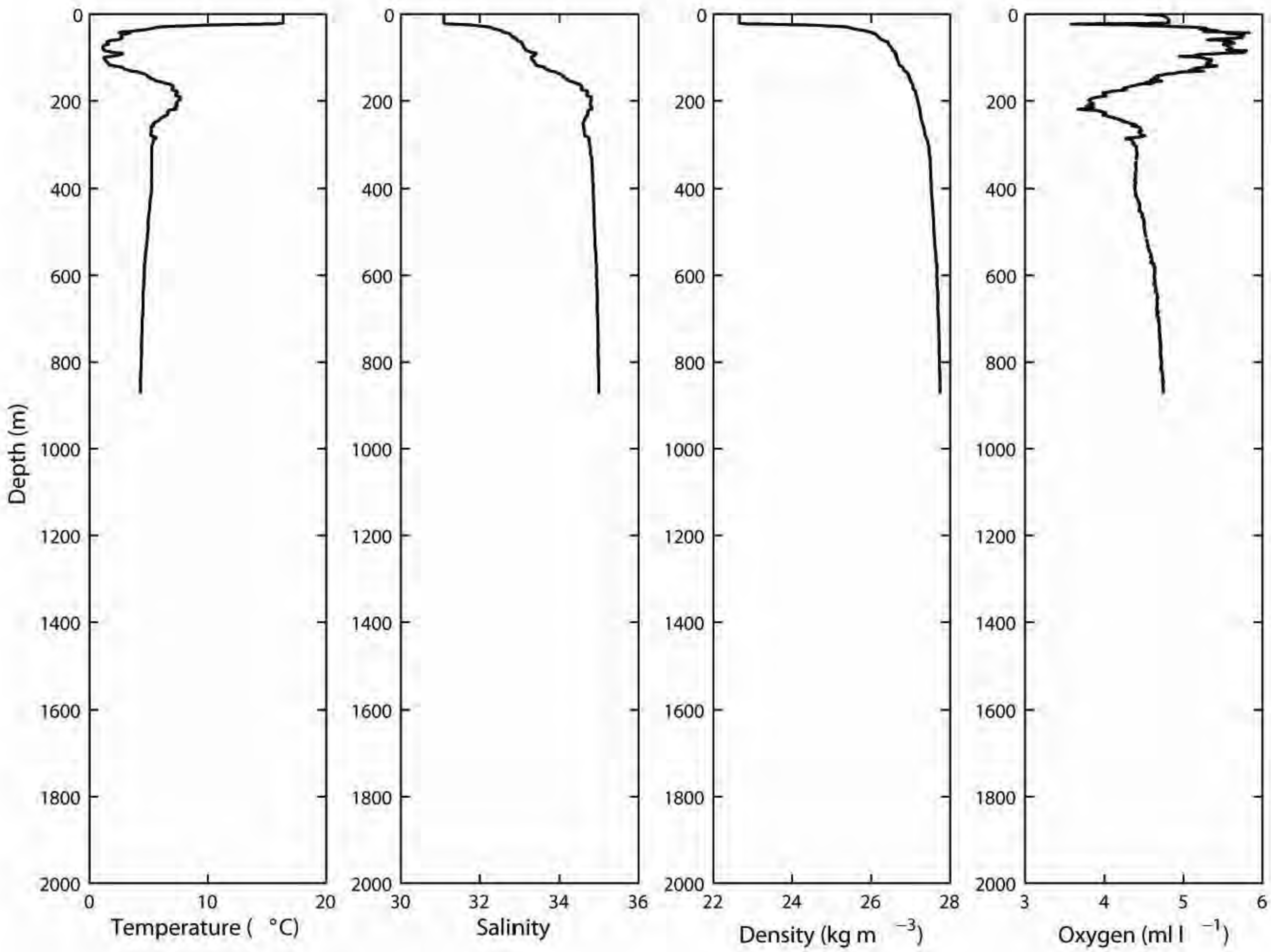

Figure 9h : Set 47 (Head Station)

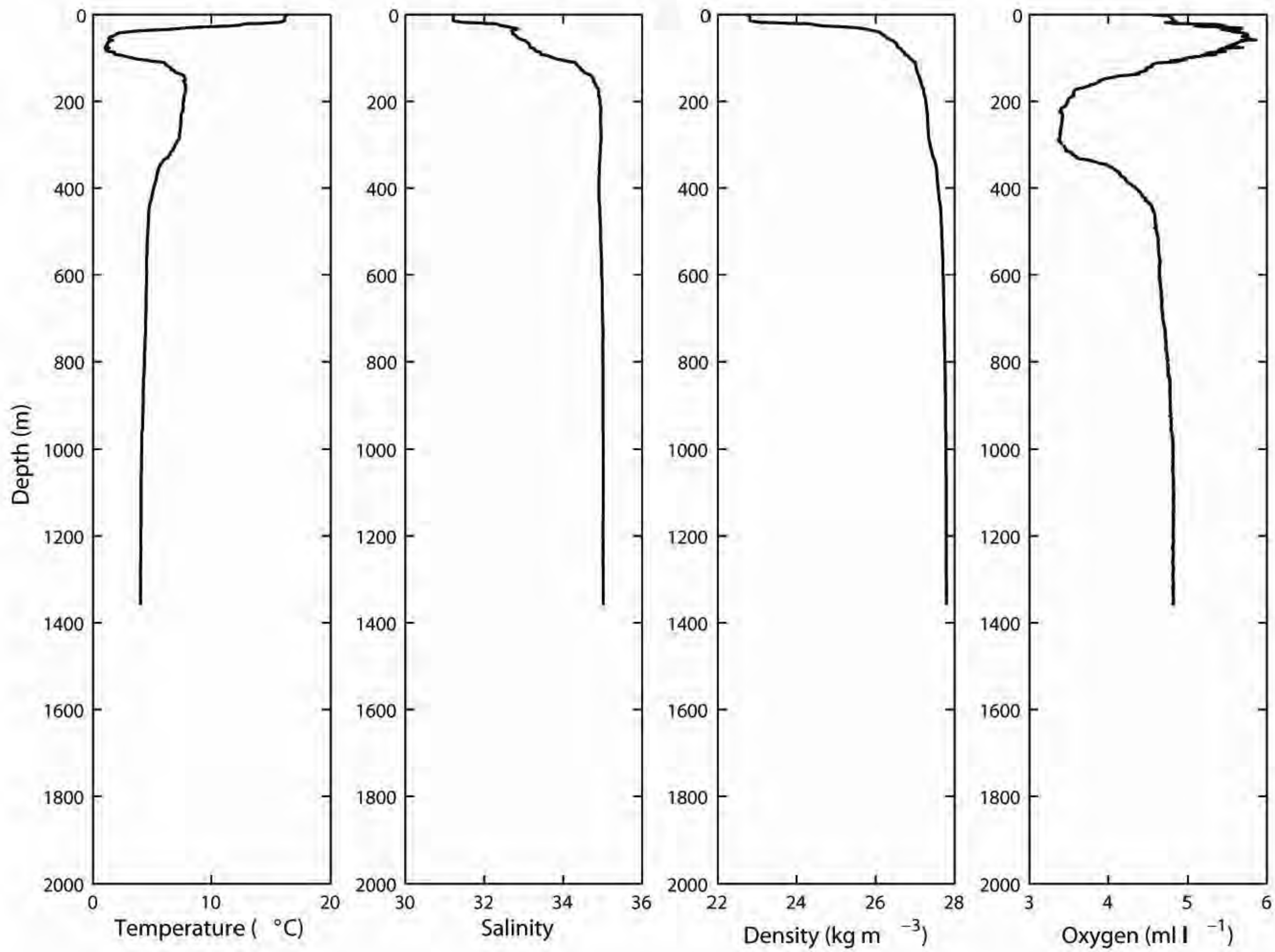

Figure 9i : Set 57 (Main Station)

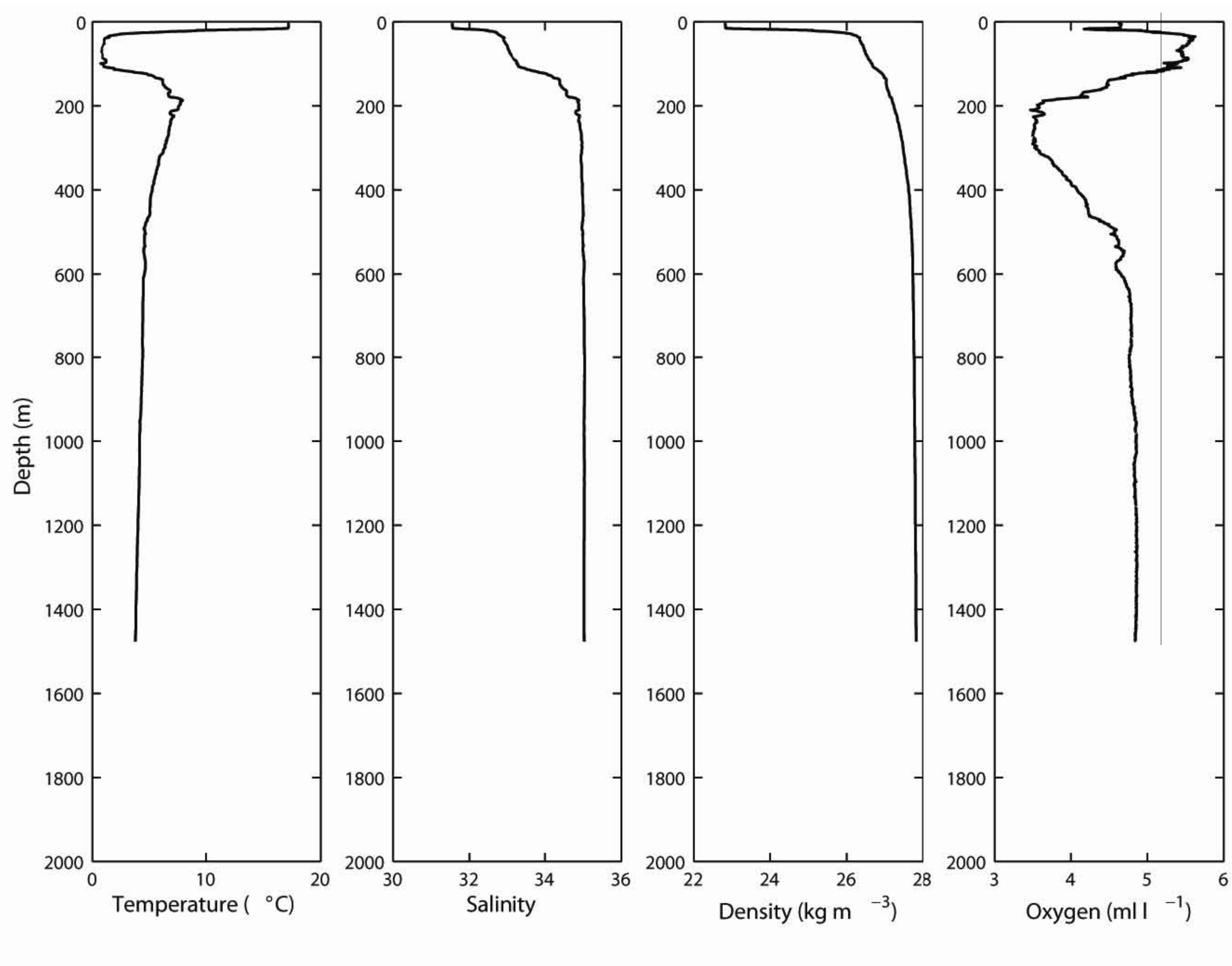

Figure 9j : Set 63 (Deep Station)

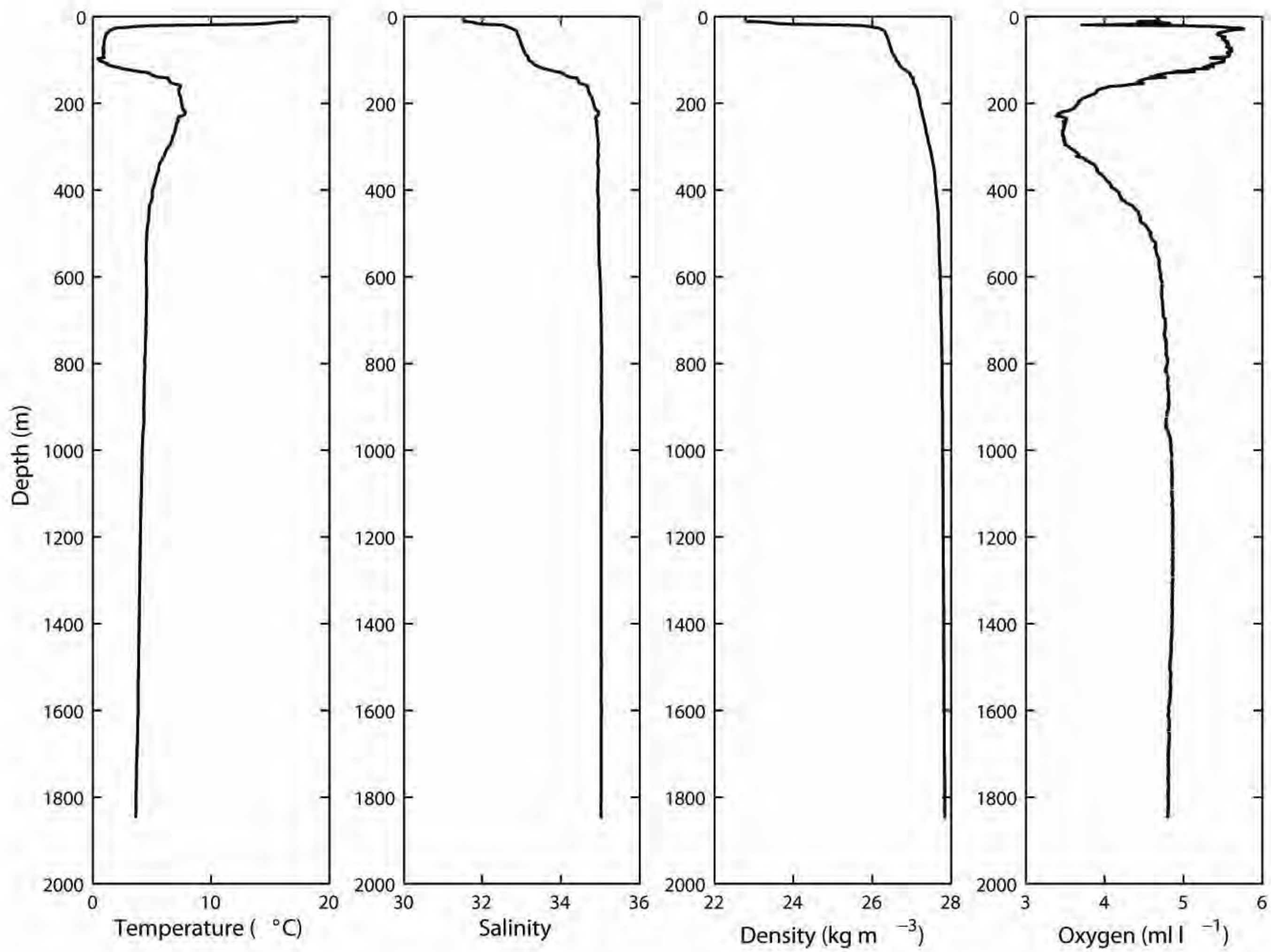

Figure 9k : Set 68 (Deep Station)

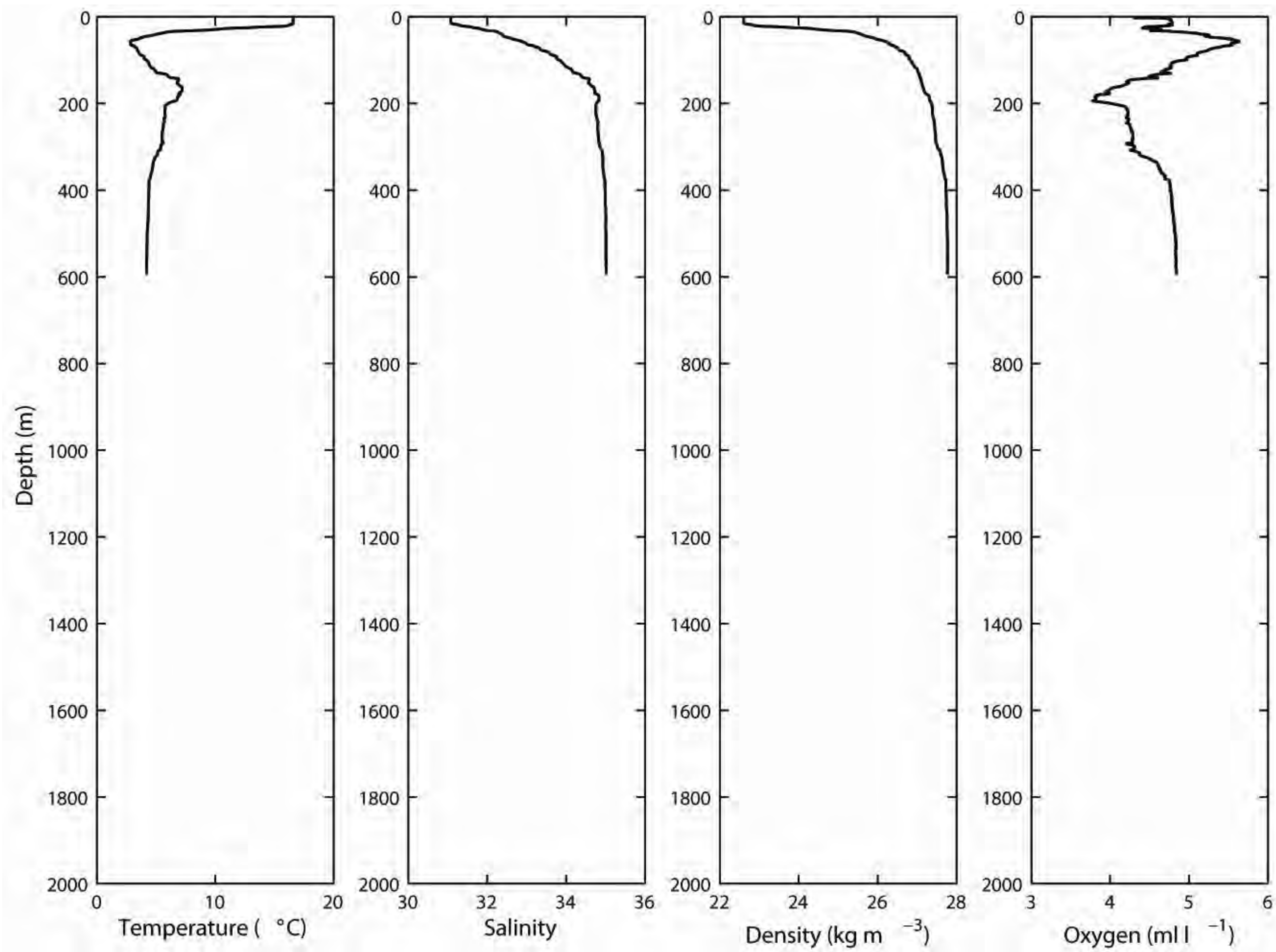

Figure 9l : Set 82 (Head Station)

Figure 10 : Temperature / Salinity Plots from CTD Data
Density contours are labelled in units of σ^T

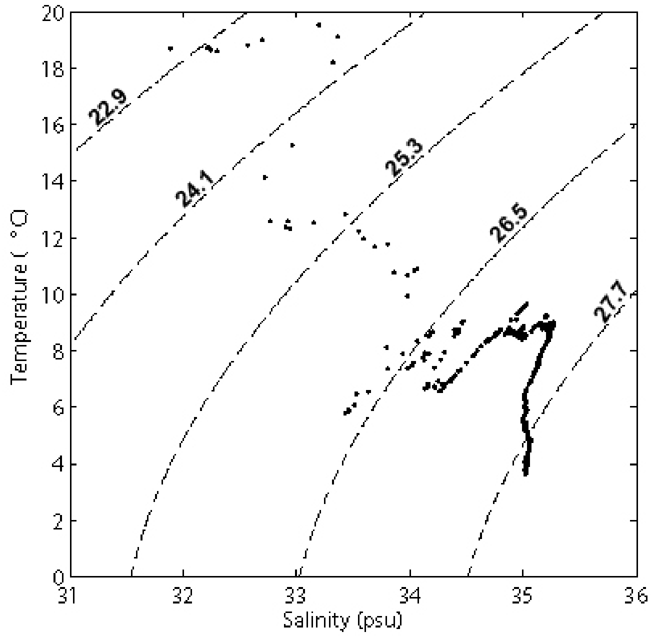

Figure 10a : Set 3 (Offshore Station)

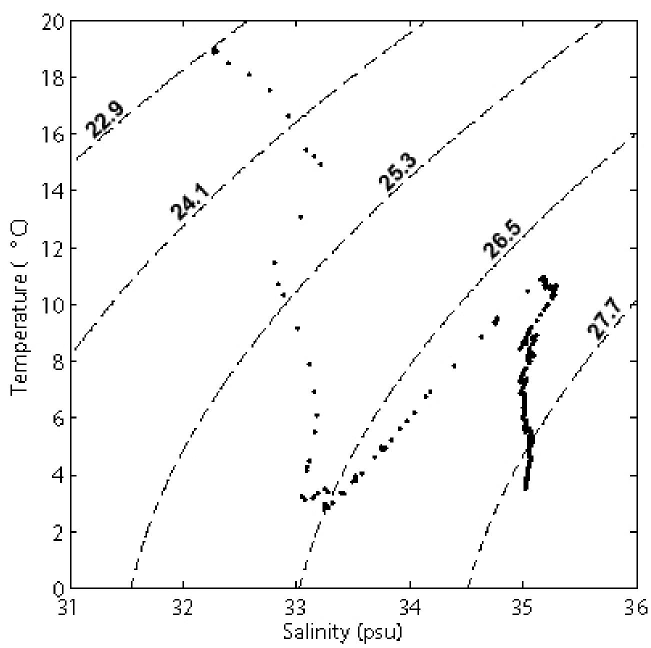

Figure 10b : Set 10 (Offshore Station)

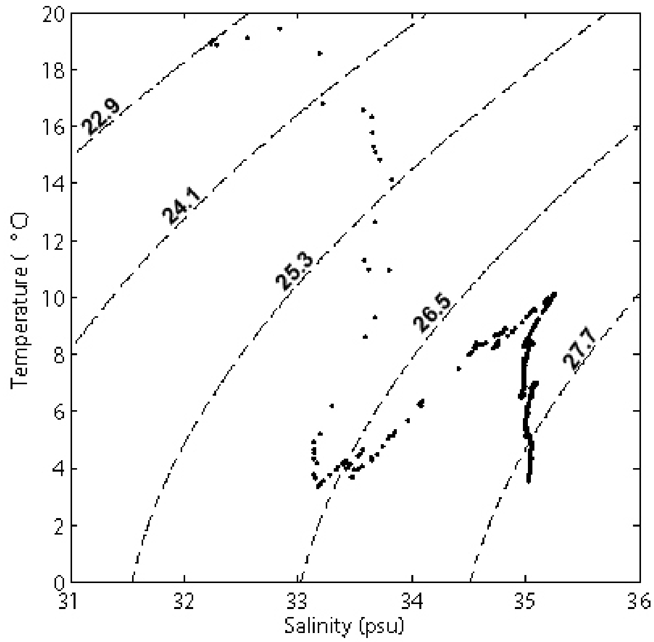

Figure 10c : Set 17 (Offshore Station)

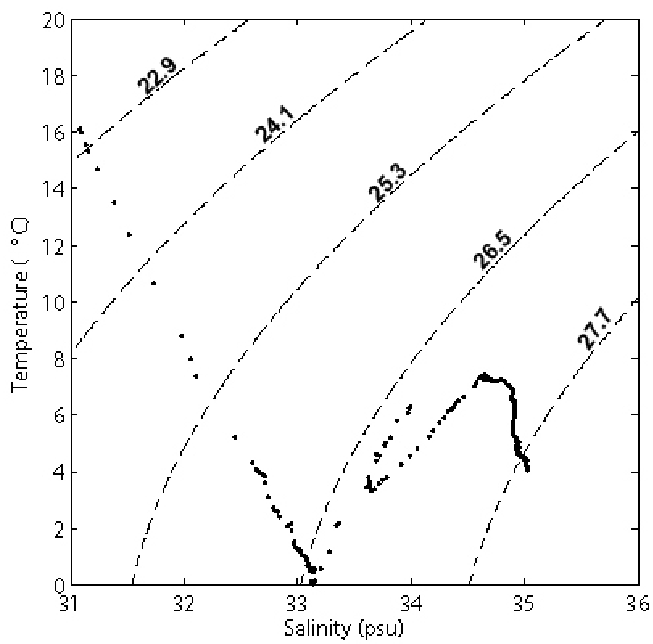

Figure 10d : Set 20 (Main Station)

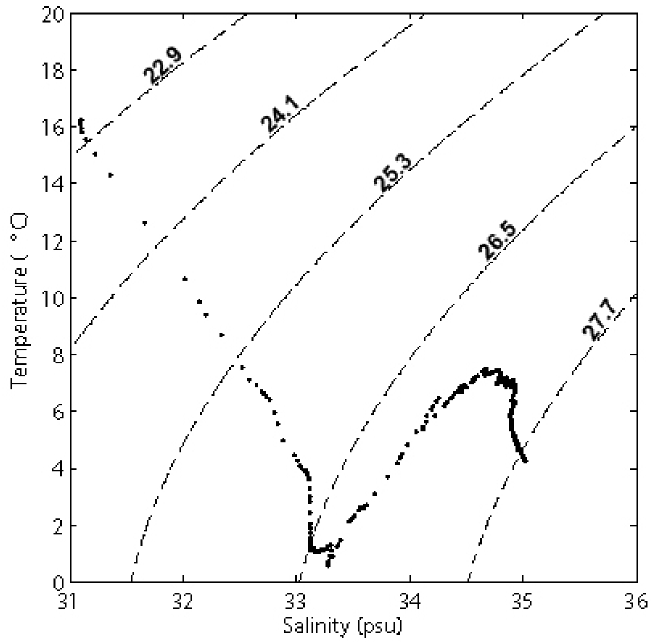

Figure 10e : Set 25 (Main Station)

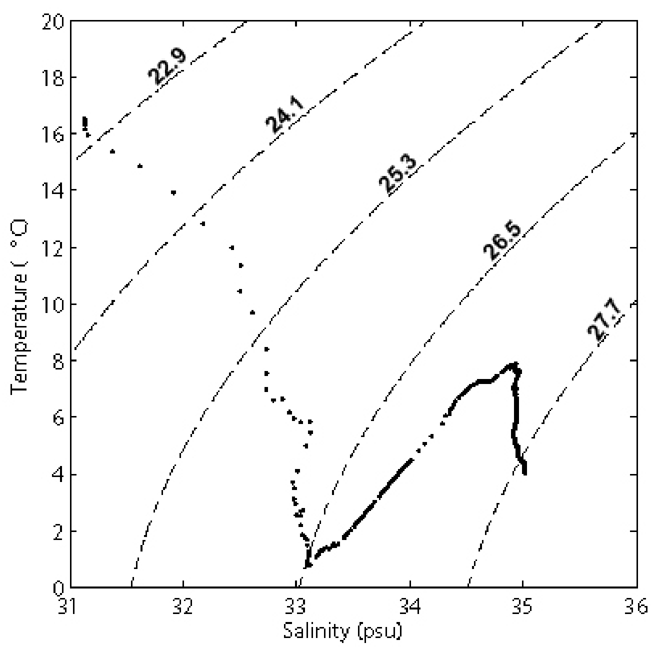

Figure 10f : Set 32 (Main Station)

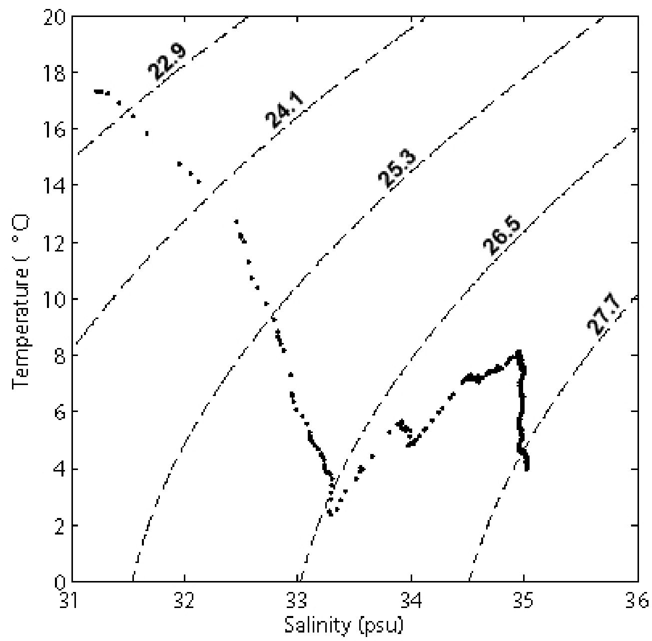

Figure 10g : Set 40 (near Main Station)

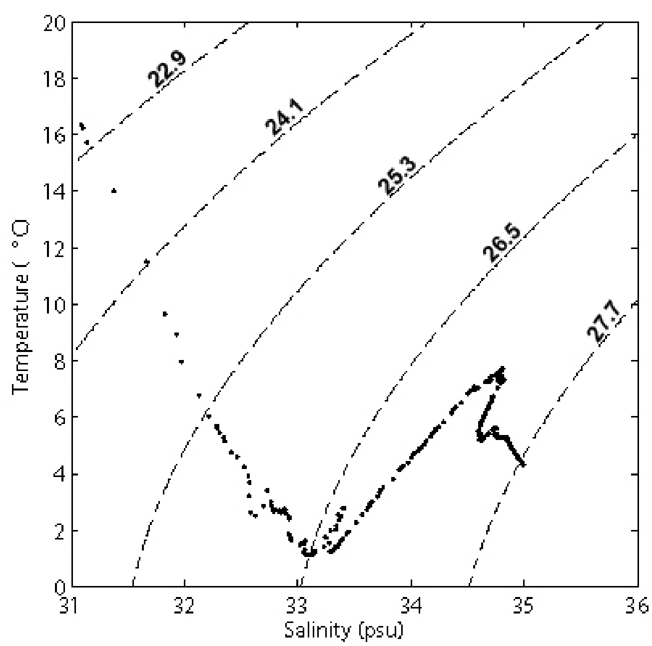

Figure 10h : Set 47 (Head Station)

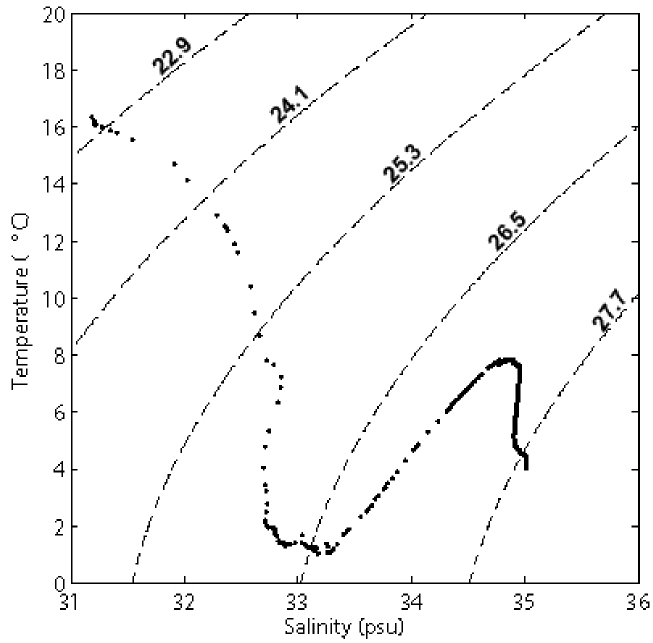

Figure 10i : Set 57 (Main Station)

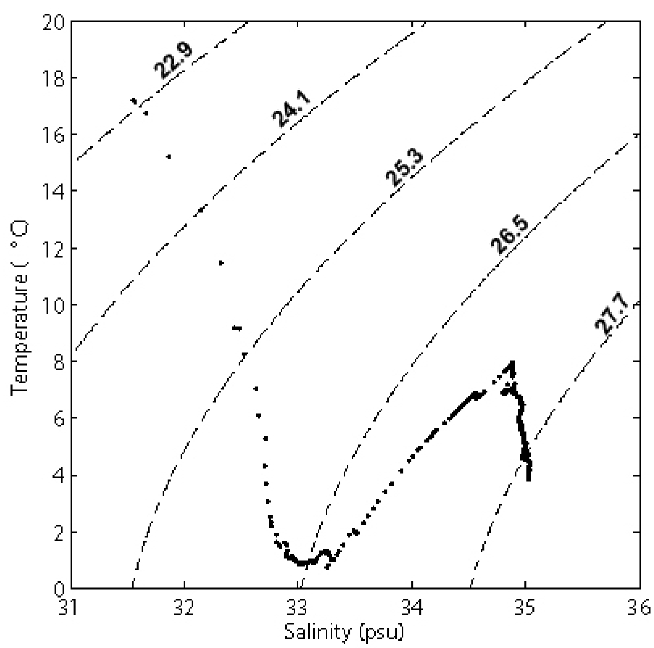

Figure 10j : Set 63 (Deep Station)

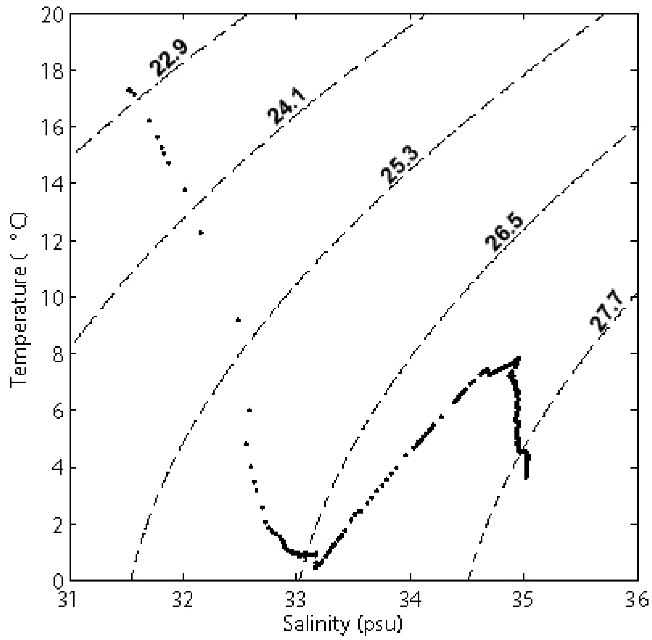

Figure 10k : Set 68 (Deep Station)

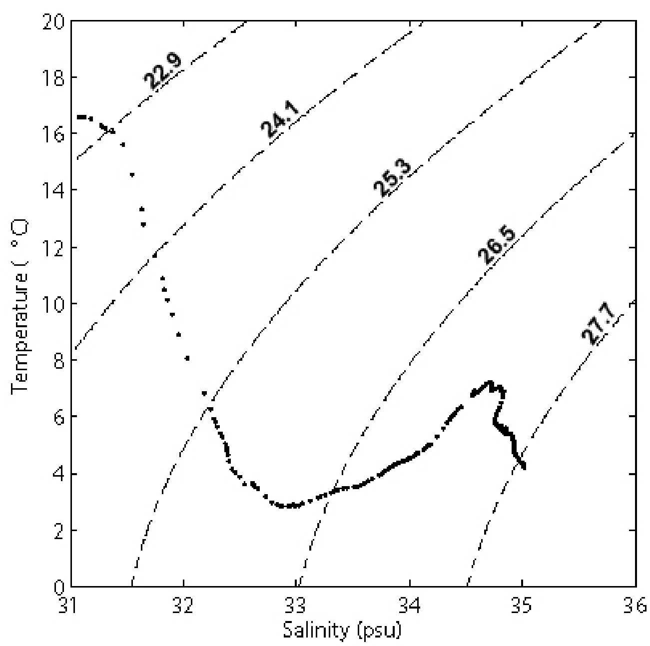

Figure 10l : Set 82 (Head Station)

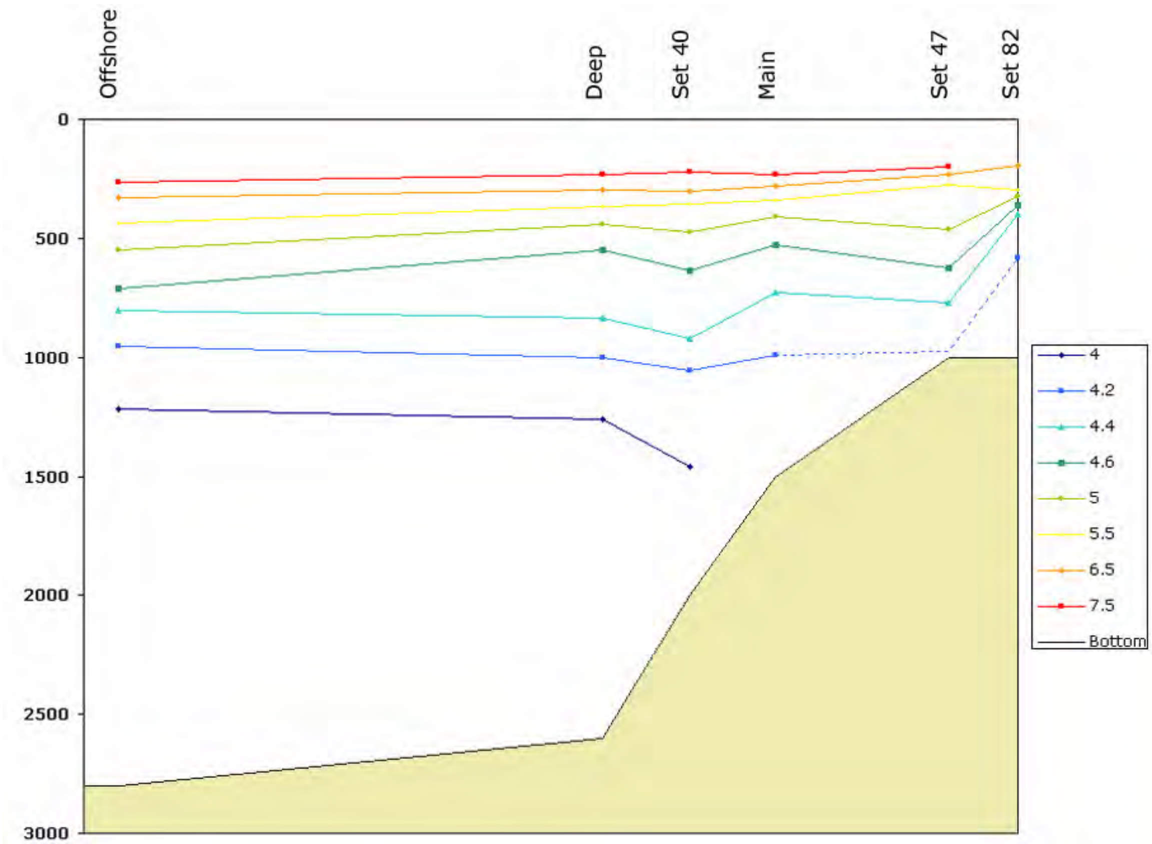

Figure 11 : Depth profile of Isotherms Below the Cold Intermediate Water Along the Axis of the Gully and Seaward to the Offshore Station

Shaded area represents seabed. The 4.2° isotherm on Set 47 was below the maximum depth of the CTD cast and its depth has been estimated. The location of Set 82 has been displaced to the right to illustrate its temporal separation from Set 47.