Advances in Understanding The Gully Ecosystem: A Summary of Research Projects Conducted at the Bedford Institute of Oceanography (1999-2001)

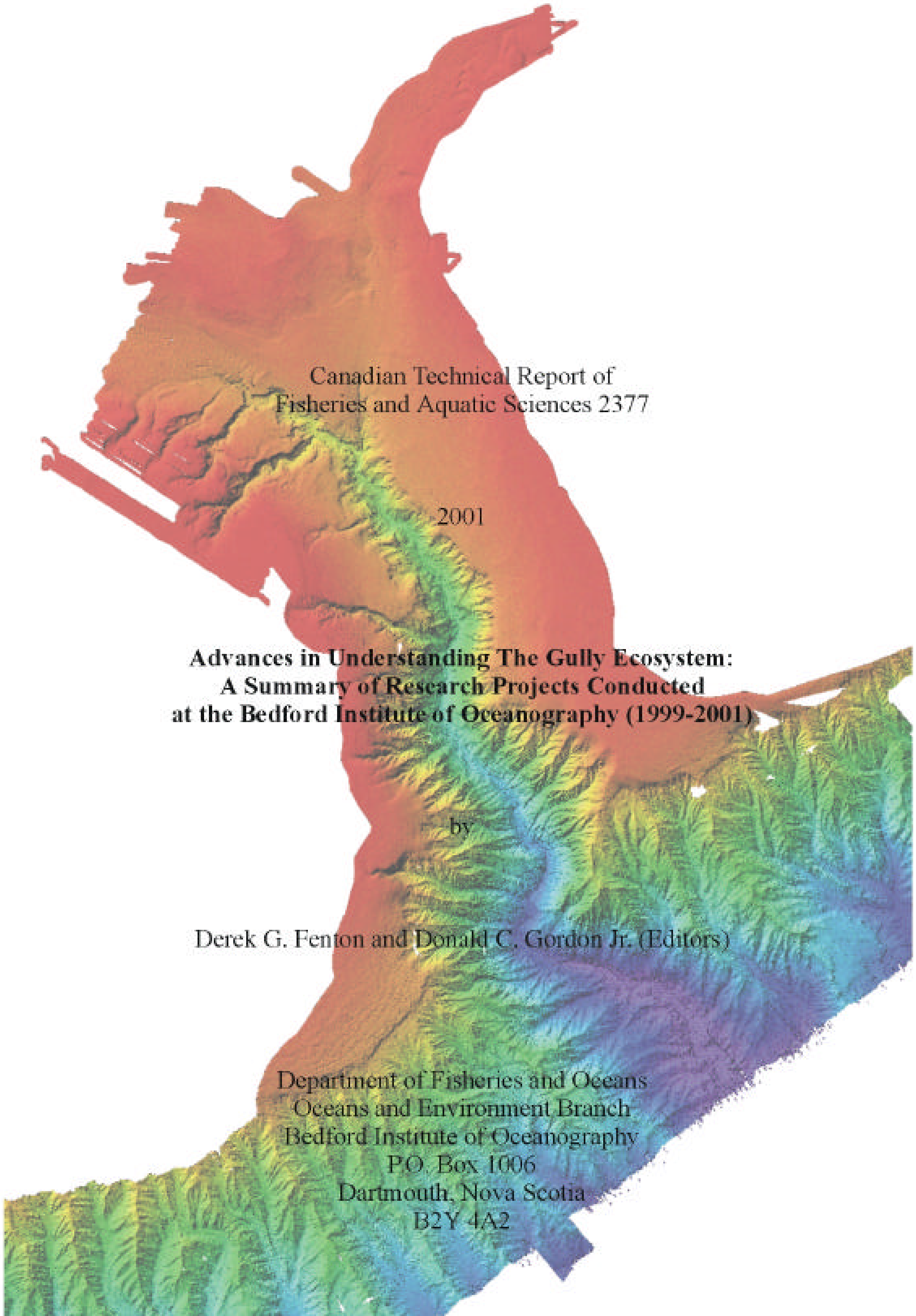
Donald C. Gordon Jr. and Derek G. Fenton (Editors)

Department of Fisheries and Oceans
Oceans and Environment Branch
Bedford Institute of Oceanography
P.O. Box 1006
Dartmouth, Nova Scotia
B2Y 4A2

2001

Canadian Technical Report of Fisheries and Aquatic Sciences 2377

Fisheries and Oceans Canada   Pêches et Océans Canada
Canada



Canadian Technical Report of
Fisheries and Aquatic Sciences 2377

2001

**Advances in Understanding The Gully Ecosystem:
A Summary of Research Projects Conducted
at the Bedford Institute of Oceanography (1999-2001)**

by

Derek G. Fenton and Donald C. Gordon Jr. (Editors)

Department of Fisheries and Oceans
Oceans and Environment Branch
Bedford Institute of Oceanography
P.O. Box 1006
Dartmouth, Nova Scotia
B2Y 4A2

Cat. No. Fs   ISSN

Correct citation for this publication:

Gordon, D.C. and Fenton, D.G. 2001. Advances in Understanding The Gully Ecosystem: A Summary of Research Projects Conducted at the Bedford Institute of Oceanography (1999-2001). Can. Tech. Rep. Fish. Aquat. Sci. 2377: 87p.

TABLE OF CONTENTS

ABSTRACT

The Gully is a large submarine canyon off the coast of Nova Scotia, and is an area of considerable conservation effort. Most recently The Gully became an 'Area of Interest' under the DFO Marine Protected Areas (MPA) Program. Successful marine conservation efforts require a foundation of scientific knowledge. A thorough review of the available information on The Gully ecosystem was conducted in 1997/1998 and numerous information gaps were identified. In 1999, DFO funded a two-year research program to help fill some of these information gaps. Funded projects investigated seasonal and tidal circulation, internal waves, nutrients, primary production, zooplankton, benthic habitat and communities. On 2 May 2001, a Gully Science Review Meeting was held at the Bedford Institute of Oceanography, and participating scientists presented and discussed the available results. This report is a summary of the proceedings. While we are not yet in the position of being able to construct a balanced synthesis of the Gully ecosystem, as a result of the research conducted over the past two years we are further along the road to this ultimate goal. Of particular note is the advancement in our knowledge of geological processes through the participation of Natural Resources Canada in benthic habitat studies.

RÉSUMÉ

Le goulet de l'île de Sable (Gully) est un vaste canyon sous-marin situé au large de la côte de la Nouvelle-Écosse, qui fait l'objet d'efforts considérables de conservation. Tout récemment, le Gully est devenue une « zone d'intérêt » dans le cadre du Programme des zones de protection marine (PZPM) du MPO. Pour être couronnés de succès, les efforts de conservation doivent reposer sur de solides connaissances scientifiques. Lors d'un examen approfondi des renseignements dont on disposait au sujet de l'écosystème du Gully, réalisé en 1997-1998, on a mis en évidence de nombreuses lacunes dans nos connaissances. En vue de les combler, le MPO a financé en 1999 un programme de recherche de deux ans. Ce financement a permis de réaliser des études de la circulation saisonnière, de la circulation due aux marées, des ondes internes, des matières nutritives, de la production primaire, du zooplancton ainsi que des habitats et des communautés benthiques. Le 2 mai 2001, au cours d'une réunion sur l'examen scientifique du Gully tenue à l'Institut océanographique de Bedford, les scientifiques participants ont présenté et commenté les résultats obtenus. Le présent document est un bref compte rendu des discussions tenues à cette réunion

INTRODUCTION

D.C. Gordon Jr.[1] and D.G. Fenton[2]

[1]Marine Environmental Sciences Division, Fisheries and Oceans Canada, Bedford Institute of Oceanography, P.O. Box 1006, Dartmouth, NS, B2Y 4A2

[2]Oceans and Coastal Management Division, Fisheries and Oceans Canada, Bedford Institute of Oceanography, P.O. Box 1006, Dartmouth, NS, B2Y 4A2

The Gully is the largest submarine canyon in eastern North America. Located to the east of Sable Island, it bisects the Scotian Shelf between Banquereau and Sable Island Bank. It has been an important fishing area for many years. Over the past ten years, The Gully has been the subject of heightened conservation interest from numerous agencies and organizations. Primary factors for this interest in recent years include a resident population of Northern bottlenose whales and proximity to oil and gas development.

Important events in the development of a conservation strategy for The Gully have been summarized by Fenton *et al.* (2001). Participants have included Parks Canada, the Canadian Wildlife Service of Environment Canada (EC), Dalhousie University, fisheries organizations, the oil and gas industry, environmental organizations (*e.g.* Ecology Action Centre, World Wildlife Fund, and the Department of Fisheries and Oceans (DFO). In 1998, the Oceans Act Coordination Office (OACO)[1] of DFO released the Sable Gully Conservation Strategy (DFO, 1998a). The intent of this strategy is to identify the conservation objective and goals for protecting The Gully ecosystem and to propose management actions will help guide decisions on the future uses and protection measures. The proposed conservation objective is to “conserve and protect the natural biological diversity and integrity of the Sable Gully ecosystem to ensure its long-term health and sustainable use”. This report also recommended that The Gully be identified as an ‘Area of Interest’ under the newly formed DFO Marine Protected Areas (MPA) Program.

Various scientific studies have been conducted in The Gully over the years. In 1997, a review team of DFO, Natural Resources Canada (NRCan), university and non-governmental organization (NGO) scientists was assembled and asked to review existing information, describe the ecosystem of The Gully and surrounding area, and characterize any special features. All major scientific disciplines were considered including geology, hydrography, ambient noise, physical oceanography, chemical oceanography, plankton ecology, benthic ecology, fish and fisheries (both finfish and shellfish), seabirds, marine mammals, and ecosystem classification. Their report, with extensive references, was released in January 1998 (Harrison and Fenton, 1998). Immediately after, DFO conducted a regional advisory process (RAP) on The Gully. The review include participants from DFO, NRCan, EC and university scientists, NGOs, representatives from the fishing and oil and gas industries, consultants, and three external reviewers from the United Sates. They reviewed The Gully Science Review and produced a Habitat Status

[1] In January 2001 the Oceans Act Coordination Office (OACO) was renamed the Oceans and Coastal Management Division (OCMD)

report (DFO, 1998b). In addition, the Maritimes Region Habitat Subcommittee released a report on The Gully RAP (Keizer, 1998).

The major conclusions of the RAP (DFO 1998b) were:

- The Gully is unique among canyons of the eastern Canadian margin because of its great depth, steep slopes, and extension far onto the continental shelf (*i.e.* connecting the continental slope to the inner shelf).
- Patterns of circulation in The Gully suggest that it may play an important role in two ways: 1) in the localized retention of materials, and 2) in the larger scale transport of materials onto and off of the shelf.
- Plankton dynamics in The Gully exhibit features which are characteristic of both shelf basin and shelf break habitats.
- Given the abundance of silver hake eggs and larvae in the region, it is reasonable to conclude that The Gully was an important spawning area for this species at the time these samples were collected (1978-82).
- The Gully and adjacent area has a relatively high demersal finfish diversity relative to the eastern Scotian Shelf.
- The diversity of benthic species and their abundance is generally greater in submarine canyons than adjacent slope waters.
- Corals are recognized as an important part of the benthic biota of The Gully, providing habitat for a variety of additional species.
- Aside from corals, there are no data that suggest The Gully is of special significance to the populations of any benthic invertebrate species.
- There is not enough evidence to assess whether submarine canyons have any major effect on seabird distributions at the surface.
- The Gully/Sable Island area is an important habitat for both cetaceans and pinnipeds on the Scotian Shelf. The most significant marine mammal habitat within the area for pinnipeds is Sable Island and surrounding waters. For cetaceans, the deep canyon and northern basin of The Gully (>200 m) is the most important habitat.
- An integrated ecosystem description of The Gully is not possible now. However, the same could be said for our understanding of the environment and ecosystems of the Scotian Shelf in general.

General recommendations from the Habitat Subcommittee (Keizer, 1998) included:

- Further research is needed to establish a baseline of information on the distribution and structure of benthic communities of The Gully.
- Surveys are required to collect current information on variables susceptible to change with time.
- More widespread use of technology that permits rapid, high spatial resolution sampling will be required.
- All stakeholders should commit resources for more focussed, coordinated and comprehensive research to develop a better understanding of The Gully's abundant and diverse biota.

- Where crucial scientific information is lacking, a precautionary approach should be taken in management decisions.
- A systems planning approach to ecosystem classification should be implemented by DFO.

In March 1999, DFO Minister Anderson announced a two-year marine science project in the Maritimes Region in support of the oceans challenge. Each year, 1.3 M was available for running the CCGS *Hudson* and 700 K was allocated to research and data base management. From the latter, 100 K (for two years) was allocated for research on The Gully ecosystem to help resolve some of the important information gaps identified in The Gully Science Review. A call for proposals was issued to DFO staff at the Bedford Institute of Oceanography (BIO) and seven projects were approved and funded in May 1999. They (and project leaders) were:

- Modelling of season and tidal circulation (J. Loder)
- Internal waves (J. Elliott)
- Nutrients (P. Yeats)
- Primary production (P. Kepkay)
- Zooplankton (D. Sameoto)
- Benthic habitat and communities (D. Gordon)
- Benthic communities and metabolism (B. Hargrave)

Because of the short notice in establishing this program, and the limited funding available, most of the approved projects were extensions of existing work, made use of shiptime already scheduled, and/or planned to use existing data. Soon after the work got underway, the benthic habitat project expanded to include a geological perspective through collaboration with NRCan. In addition, under the leadership of NRCan, the OCMD, and the Canadian Hydrographic Service (CHS), the benthic habitat project expanded even further to include a multibeam mapping component using funding from other sources. A progress report on The Gully ecosystem program was prepared October 1999, and a full day review session was held at BIO in January 2000 to assess progress during the first year and discuss plans for the second year of the program.

On 2 May 2001, a Gully Ecosystem Review Meeting was held at BIO. The prime purpose of this meeting was to present the available results from this two-year research program (funding ended 31 March 2001) to an open audience of those interested in The Gully ecosystem. In the opening remarks, it was emphasized that:

- The focus of the meeting was on reviewing the research results, not its specific application to key management issues.
- Projects were put together on short notice, funding was very limited and there was limited program coordination.
- This was the first time that participating scientists had come together in over a year to discuss results.
- The work was very much in progress, many conclusions were tentative, and lots of new information was being presented for the first time.

- No attempt has yet been made to develop a synthesis of The Gully ecosystem.

This report presents the extended abstracts of the presentations given at the review meeting by participating scientists. It also includes a summary of presentations, an overview of The Gully ecosystem, and conclusions prepared by Dr. K.H. Mann, as well as a summary of the concluding discussion. It is expected that the results of individual research projects will be reported in greater detail in future publications. In the meantime, more detail can be obtained by contacting the appropriate authors.

This report is not an all-encompassing update on scientific research in the area, as was done in the 1998 Gully Science Review. Other ongoing Gully science activities not reported at this review meeting include groundfish and directed halibut surveys being conducted by DFO, whale research by Dalhousie University, acoustic research by the Defense Research Establishment Atlantic (DREA), and various monitoring programs being funded by Sable Offshore Energy Incorporated (SOEI).

References

DFO. 1998a. The Sable Gully Conservation Strategy. unpublished report of the Oceans Act Coordination Office, Maritimes Region, 51 p.

DFO. 1998b. The Gully – a scientific review of it environment and ecosystems. Maritimes Regional Habitat Status Report 98/1 E.

Fenton, D.G., P.A. Macnab and R.J. Rutherford. 2001. The Sable Gully marine protected area initiative: history and status. Proceedings from *Managing Protected Areas in a Changing World (Fourth International Conference on Science and Management of Protected Areas, May 2000)* Science and Management of Protected Areas Association. In press.

Harrison, G. and D. Fenton (eds.). 1998. The Gully science review. DFO Can. Stock Assessment Sec. Res. Doc. 98/83.

Keizer, P.D. (ed.). 1998. Maritimes Regional Advisory Process Habitat Subcommittee Gully Science Review. DFO Can. Stock Assessment Sec. Proceed. Ser. 98/2.

EXTENDED ABSTRACTS

An interpretation of multibeam bathymetry from The Gully, outer Scotian Shelf: materials, habitats, slopes, features and processes

G. B. J. Fader and J. Strang

Natural Resources Canada, Geological Survey of Canada (Atlantic)
Bedford Institute of Oceanography, Box 1006,
Dartmouth, Nova Scotia, Canada, B2Y 4A2

The first comprehensive scientific review of The Gully, a large submarine canyon on the edge of the Scotian Shelf, was conducted in 1998 by Fisheries and Oceans Canada. In that report Fader *et al.*, (1998) summarized the existing knowledge on the surficial, bedrock geology and morphology of the canyon region. They concluded that existing geoscience information was limited and patchy and that the collection of multibeam bathymetry would provide a significant advance in morphological characterization leading to a better understanding of seabed processes. Only limited multibeam data existed at this time confined to an area of the inner western part of The Gully extending to Sable Island Bank. In 2000, multibeam bathymetry was collected by both Canadian Government and industry in deep and additional shallow water areas to provide a comprehensive assessment of Gully attributes.

This digital bathymetric data base has been processed to produce a colour shaded-relief image (Figure 1) of morphology as well as seabed slope (Figure 2). The multibeam data have been integrated with previously collected seismic reflection air gun profiles, sidescan sonograms, bottom sample information, video and photographic information, mostly collected in the under 400 m water depth zones of the inner Gully. A preliminary interpretation of Gully materials, seabed features, and processes has been undertaken on the basis of this information (Figure 3). The surficial sediments of the Gully region are classified in a formational framework consistent with published maps on the surficial geology of the Scotian Shelf by the Geological Survey of Canada. Figure 4 a is a grey scale shaded-relief multibeam map with an index of a selection of extracted bathymetric profiles (Figure 4b) to illustrate the morphology of many of the features and terrains interpreted in this paper. The following is a brief discussion of the major findings from such an interpretation.

<u>Channels</u>

Seismic reflection profiles show the presence of generations of buried and infilled channels in the subsurface throughout The Gully area. Some of these buried channels are deeper than the present Gully and indicate it has likely shifted its location many times in the past. The thalweg (deepest channel floor profile) of The Gully presents a remarkably uniform, sand-covered surface, sloping at approximately 2 degrees seaward from its head, (Profiles 13 and 18). Only at 2700 m water depth does the slope of the thalweg begin to decrease slightly in slope angle. No overdeepening of the present channel floor occurs along the thalweg, suggesting minimal glacial erosional effects in the deep channel and uniform processes of sediment deposition in recent time.

The head of The Gully is sand-floored and occurs within a large area of bedforms, Profile 1. A large megaflute (triangular–shaped current-scoured depression) occurs on the seabed to the northwest of The Gully head, suggesting formation by periodic, high velocity, bottom water flows (Figure 3). The sediment at the head is similar in texture and lithology to fine-grained sand found on Sable Island Bank. The head of The Gully is bifurcated into two channels, a minor one which extends to the north and the major channel extending to the northwest, profile 14. Based on photographic observations, the deep water channel floor of The Gully to 600 m water depth consists of rippled sand with accumulated organic floc in the troughs of the bedforms.

Feeder canyons

Nine major canyons or channels (termed feeder channels or canyons) and many other smaller associated channels occur on the west flank of The Gully extending from Sable Island Bank (Figure 1). This is in contrast to the west (Banquereau) flank of The Gully where no feeder canyons extend to Banquereau. The feeder canyons on the Sable Island side are asymmetric with gentler and longer slopes on their south side. This suggests that sand on Sable Island Bank may be in active transport moving from south to northeast along the southwest flank of Sable Island Bank and entering the feeder canyons from the south. The two most northerly of the nine feeder canyons are relict and do not have a continuous path to the main Gully channel. Channel 1, Figure 1, the most northerly, appears blocked by glacial material which is in turn overlain with sand waves. Channel 2 has a shallow sill near the connection with the main channel of The Gully. The northernmost 6 feeder canyon heads extend on Sable Island Bank to present water depths of 100 m or less. Such a shallow depth suggests that they were connected to the subaerially exposed part of Sable Island Bank during the post-glacial low sea level stand. All of the feeder canyons have sand filled catchment basins at their heads which give way to bedrock controlled walls in deeper water toward The Gully. Ledges, terraces and down slope minor gullies are characteristics of the feeder canyons. Apart from the area of their heads, the feeder canyon lips are generally represented by abrupt terminations of flat seafloor.

Glacial influence

At 800 m water depth there is a major change in morphology within The Gully. In shallower depths to the northwest, The Gully has many linear scarps oriented parallel to the long axis of The Gully (Figure 1). They cut and block some of the feeder channels to the north and south of feeder canyon 5 with sill-like ridges. Broad terraces are common in depths shallower than 800 m. This morphology is interpreted to have formed directly as a result of erosion and sedimentation by grounded glaciers during the maximum extent of the last glaciation (Wisconsinan), approximately 20 000 ybp, and perhaps during earlier glaciations.

In areas deeper than 800 m, The Gully does not show any of these linear ridges and consists of a uniform ridge and valley morphology suggesting that ice was not grounded in depths deeper than 800 m and that the deeper areas of The Gully formed in response to submarine erosion. Supporting this interpretation is the slope map of the seabed (Figure 2) which shows a series of greater than 50 degree, linear Gully-parallel scarps in depths shallower than 800 m.

The slope map also indicates many areas of 50 degree and greater slopes within The Gully in contrast to the adjacent areas of continental slope off Sable Island Bank and Banquereau. This suggests that erosional processes have been different and more intense within The Gully than on the adjacent continental slope.

Moraines

There are several types of moraines within The Gully (Figure 3). A series of curvilinear ridges up to 10 m in height (Profile 9) occurs on western Banquereau. These are interpreted as recessional glacial moraines, demarcating a northwesterly sequential retreat of grounded ice in The Gully region. Their presence on the southwest corner of Banquereau suggests that the last ice (Wisconsinan) advanced to the edge of the continental shelf. These moraines likely consist of till and are gravel covered at the seabed. They only occur on Banquereau, as the ice was likely floating over The Gully in depths greater than 800 m. A similar set of recessional moraines would be expected to occur on the Sable Island side of The Gully, but none are evident. We interpret that moraines likely occur on Sable Island Bank but are buried in the subsurface covered by more recent sediment.

In the shallower northern part of The Gully are several subparallel ridges of lobate moraines (Profile 3) similar to retreat moraines of the inner basins of the Scotian Shelf. In the distal area of these moraines the seabed is flat and featureless consisting of glaciomarine sediment while proximal to the moraines the seabed is hummocky and rough, and likely formed at the sole of the glaciers. This seabed is gravel covered till.

Bedforms

Large areas of bedforms (sandwaves, megaripples) occur in the inner Gully mostly in water depths between 200 and 400 m (Profiles 1 and 2). These bedforms occur in the northwest and northeast area of the inner Gully. The largest of the sandwaves is over 11m in height (Figure 4b). Most of the bedforms are asymmetric with the steepest flanks downslope to the east, indicating net transport directions down The Gully. The bedform areas continue down the actual geomorphic head of The Gully supporting an interpretation of active and continuous sand transport from shallower areas. The bedforms in the northeast area of The Gully indicate sand transport down the north arm of The Gully. They occur in water depths too deep to be influenced by waves and are therefore interpreted to be current generated. The role of internal waves in their formation is not understood.

Iceberg furrows and pits

On the southeast flank of Sable Island Bank and the west flank of Banquereau are large areas of iceberg furrows and iceberg pits (Profiles 12, 6 and 8). They result from grounding by icebergs and reach depths of 10 m. Iceberg pits form as a result of bearing capacity failure of the seabed as grounded and more or less stationary icebergs change draft and roll over or terminate upslope in response to currents and winds. Iceberg pits are isolated semicircular, amphitheater-shaped, boulder rimmed depressions. Iceberg furrows in contrast, are linear bermed trenches which can extend for tens of kilometres in length. The area of The Gully has a preponderance for iceberg pits versus furrows. Other areas where such a preponderance occurs are interpreted to arise from very hard seabeds or a lack of propelling currents and winds which prevent the icebergs from moving laterally while grounded. The pits and furrows in The Gully are interpreted as mostly forming in late glacial time during the late Wisconsinan ice recession with preservation to the present. The material in which they formed is largely coarse-grained glacial material (till). None occur on the east flank of Sable Island Bank opposite the dense distribution on Banquereau supporting an interpretation of Holocene and recent sand transport to the east on Sable Island Bank to bury such features.

Pockmarks

North of the southwest Gully area of iceberg furrows and pits, is a large zone of circular non-rimed depressions interpreted as pockmarks, (gas-escape vents), Profile 7. Several hundred of these features occur and extend to over 2 m in depth and several hundred metres in diameter. Pockmarks do not form in only sand-sized material and require a mud component (cohesive character) to develop and preserve the passage of gas. The gas is likely hydrocarbon gas and not biogenic because of the close proximity of discovered gas fields (Primrose wellsite) up dip to the north. Upon closer examination, some of the pockmarks appear to continue to the south in the adjacent area of iceberg pits and furrows but are hard to differentiate in this terrain. It is not known if the pockmarks are actively venting gas. If actively venting, they could contain enhanced biological communities at their base resulting from chemosynthetic processes. Our interpretation is that gas is actively venting from the pockmarks due to their fresh appearance and the presence of similar fields of active pockmarks in the large basins of the central Scotian Shelf.

Gully width

The steep-walled “ridge and valley” core area of The Gully widens seaward (Figure 3) until the shelf break where it narrows farther seaward (Profiles 15, 16 and 17). This narrowing suggests that the processes that have eroded The Gully originated on the shelf and not on the adjacent slope of the Scotian Shelf. This also supports the concept of major erosion during glaciation.

Slumps

In the inner part of The Gully near the head, and in feeder channels 3 and 4 are areas of interpreted slides and slumps (Profiles 4, 5 and 14). These are associated with large isolated slump blocks, debris fields in deeper water, circular headwall scarps and sharp well-defined canyon edges. The slumping history is not understood including the mechanisms for initiation.

Limits in bathymetric distribution of deep water corals

Grounded glacial ice and the deposition of coarse glacial debris appears to have occurred in water depths of less than 800 m. This limit may provide an explanation for the distribution of larger gorgonian corals within The Gully. Video observations indicate the presence of coral in Hells Kitchen, the inner area of The Gully between feeder canyons 4 and 5, with water depths of less than 800 m. Many of the observed corals appear attached to boulders of hard lithology. This is in contrast to exposed steep walls of unconsolidated siltstone, mudstone and sandstone which do not appear to have dense populations of attached coral. Therefore a correlation of coral and glacial material may exist, thus limiting the zone of greatest coral concentration to the Hells Kitchen area and other areas shallower than 800 m with coarse grained substrate. Such a correlation may exist for other areas of the Scotian Slope and Northeast Channel where deep water corals are known to occur.

Uniqueness of The Gully

Prior to these studies, the uniqueness of The Gully was never clearly demonstrated, but considered an important aspect for assessment. Based on an interpretation of the multibeam bathymetry, it is clearly evident that The Gully is unique both morphologically and geologically, characterized by the presence of steep bedrock-walled exposures of semi-consolidated siltstone, sandstone and mudstone of Tertiary age. This is quite different from most areas of the Scotian Shelf where the seabed is generally flat without steep slopes, resulting from glacial deposition which tends to infill rough and irregular topography. In areas above 100 m water depth, subsequent processes of marine transgression in post-glacial time produced flat surfaces and well-sorted sediment covering shallow banks. In contrast, The Gully exhibits large areas of exposed semi-consolidated bedrock of varying lithology. Very few areas of the Scotian Shelf expose similar bedrock. The exception occurs in the nearshore where much harder lithologies are commonly exposed at the seabed.

In the areas of bedrock exposure with steep slopes within The Gully, submarine erosion likely continues through the generation of localized slides, slumps, downslope grain flows and failures on the steep canyon walls. Benthic communities also contribute to this erosion and bottom currents likely play an as yet undefined role. As a result of these erosional processes, many near vertical cliffs and local slopes steeper than 50 degrees have formed. Continued submarine erosion has developed much of the present Gully ridge and valley morphology. The steep slopes likely result in local current velocity increases possibly including the generation of turbidity currents, that can redistribute nutrients and transport sediments. Favourable conditions of slope, materials, local currents and nutrients may result in conditions that attract demersal fish. Thus, there may be a direct connection between morphology, seabed materials, physical processes, habitat types, and biological diversity. It is this complex relationship that requires additional understanding.

Recommendations

Based on the above preliminary interpretations of seabed sediments, processes and slopes, several recommendations can be made for additional research. It is essential to process the multibeam bathymetric data for backscatter information to portray and extract data on sediment type. This will allow a refinement of the seabed geological and habitat map interpretations. There is a need to understand sediment transport down The Gully both for sandy sediments and organic materials. In particular there is a need to understand the relationship between sediment on Sable Island Bank and transport to The Gully. This can be accomplished by detailed modeling of transport pathways, currents and sediment budgets within The Gully.

Despite the welcomed addition of the 2000 multibeam bathymetric data to the study, there remains a need for more multibeam in the shallower bank regions as well as to the northwest in the inner part of The Gully. This would allow a more comprehensive connection with the adjacent bank areas and an understanding of the relationship between sediment transport on the banks and The Gully. Terraces that occur on both Sable Island Bank and Banquereau need to be assessed in terms of the sea level history and modern processes of sediment transport.

At present only regional assessments of the current regime exist. There is a need to assess the role of local currents in individual feeder canyons on Sable Island Bank and in the complex minor rills, gullies and valleys in feeding sediment and organic materials to the deep Gully channel floor. It is not known if internal waves could act as a triggering mechanism for sediment resuspension and erosion in deeper water contributing to downslope movement. An assessment of the rate, extent and amount of sediment transport down The Gully thalweg, connecting the shelf to the abyssal plain, is also required.

More site and feature-specific samples and photographic data are required to provide the groundtruth essential for interpretation of the backscatter information (sediment distributions) and to assess facies variations in sediment units and benthic fauna distributions. Such a groundtruth program must also be extended to the deeper areas of The Gully as very few samples and observations presently exist in depths greater than 600 m, yet the bulk of The Gully lies well below this depth limit. This will provide a detailed map of seabed habitats and related benthic communities.

A comprehensive geophysical and geological program has never been conducted in The Gully. It is essential to design and undertake a program to understand the geoscience framework and to assess processes such as slumping, sediment transport, and gas-venting, and to understand the evolution of The Gully through time. The fact that many of the feeder canyons on Sable Island Bank extend to the former shoreline of the Scotian Shelf (100 m water depth) during lowered sea levels, suggests that the formation of The Gully could have been initiated by subaerial erosion on the outer shelf banks.

It is also important to undertake an assessment of the non-fuel mineral resource potential in The Gully and adjacent areas. Data collected in a comprehensive geological assessment can form the basis for such an assessment.

References

Fader, G.B.J., Piper, D.J.W. and Amos, C.L. 1998. Surficial, bedrock geology and morphology of The Gully, *in* The Gully Science Review, 1998. Editors G. Harrison and D. Fenton. Fisheries and Oceans Canada, pp. 7 – 12.

King, L.H. and Fader, G.B.J. 1986. Wisconsinan glaciation of the Atlantic continental shelf of southeast Canada. Geological Survey of Canada Bulletin #363.

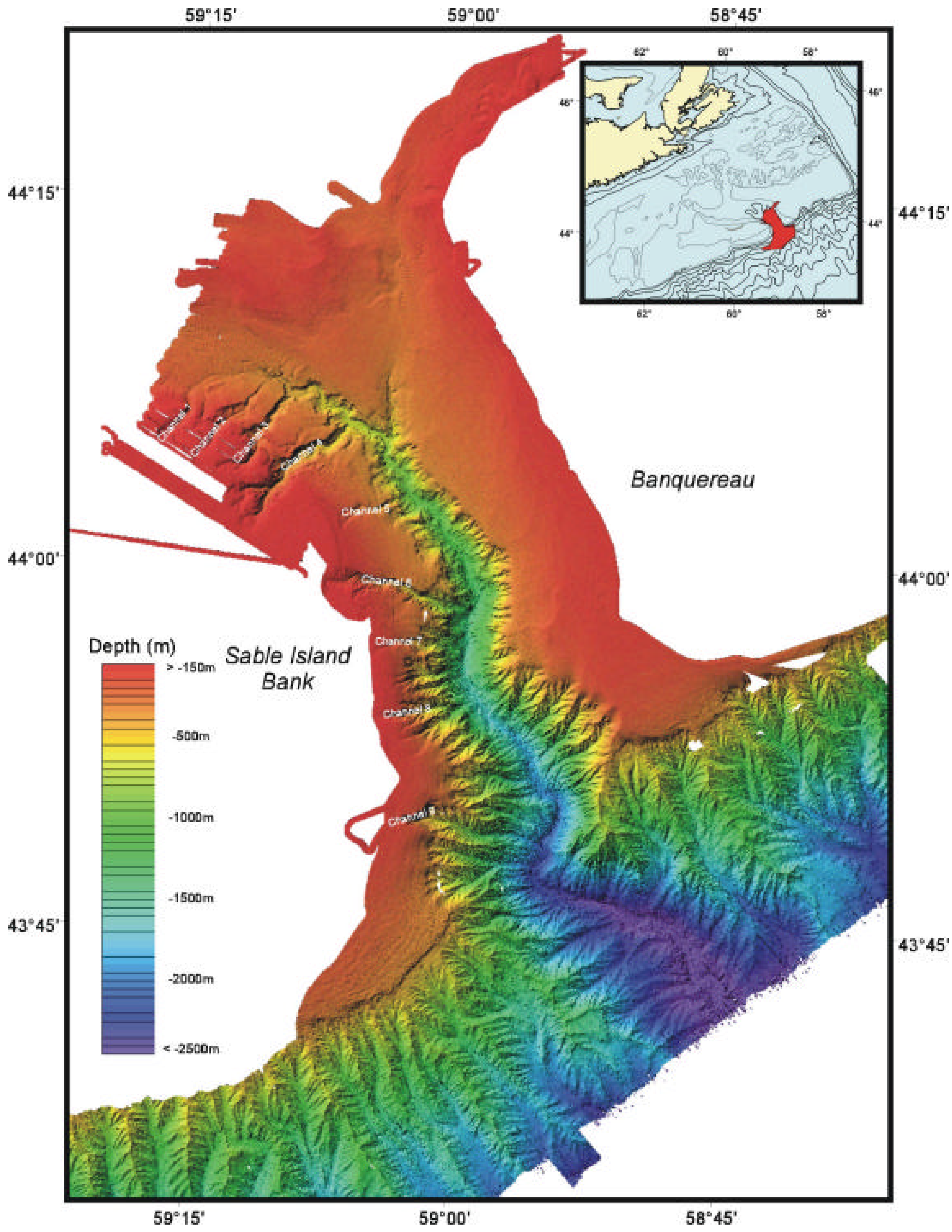


Figure 1*. Colour coded shaded-relief image of The Gully, outer Scotian Shelf, based on multibeam bathymetry collected by the Canadian Hydrographic Service, the Geological Survey of Canada (Atlantic) and industry. A suite of channels (numbered 1 – 9) extend from Sable Island Bank to the western flank of The Gully.*

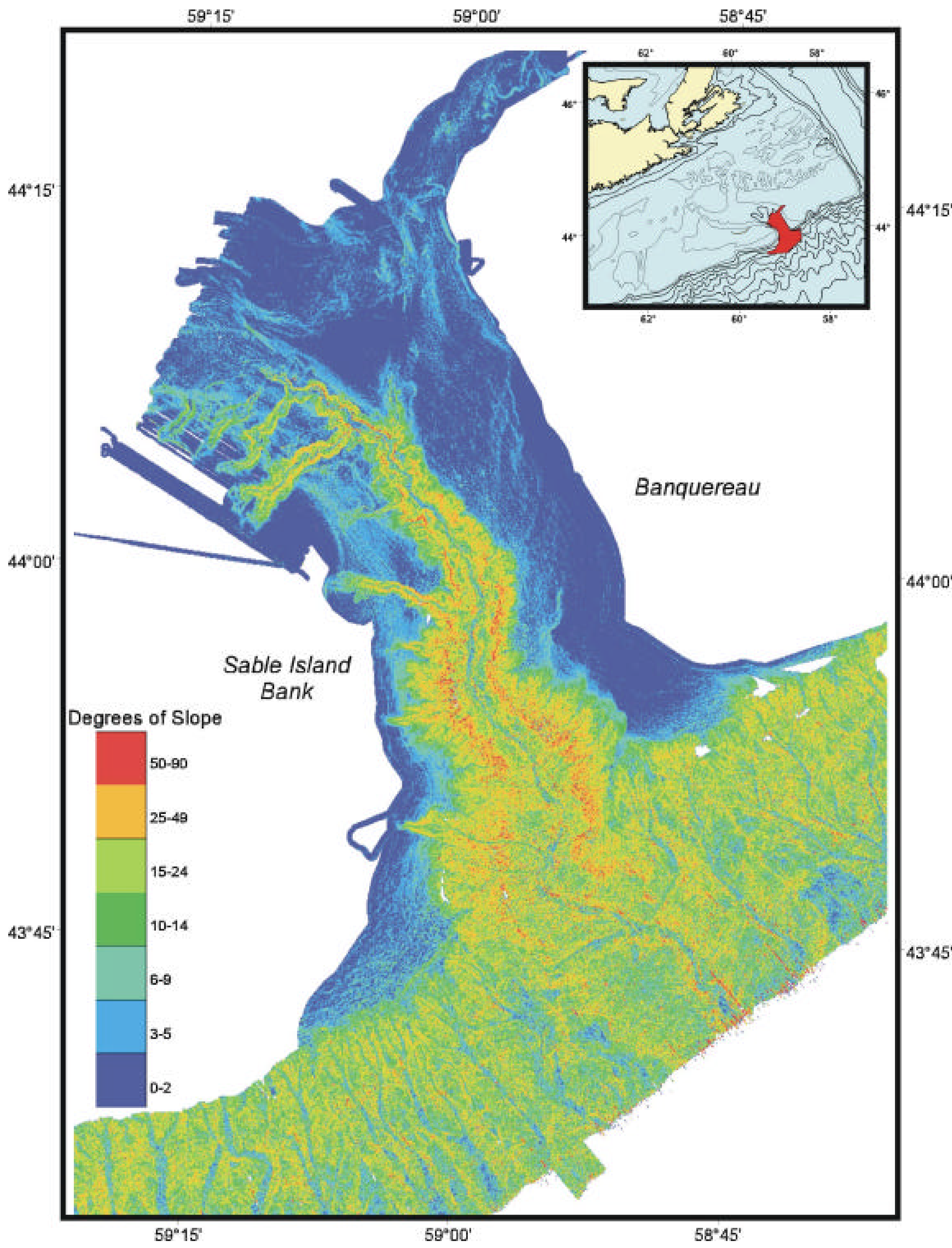


Figure 2*. A seabed slope map of The Gully based on processing of multibeam bathymetry. Seabed slope is expressed in ranges of degrees with the steepest slopes in the region (50 – 90 degrees) occurring within the deeper water areas of The Gully.*

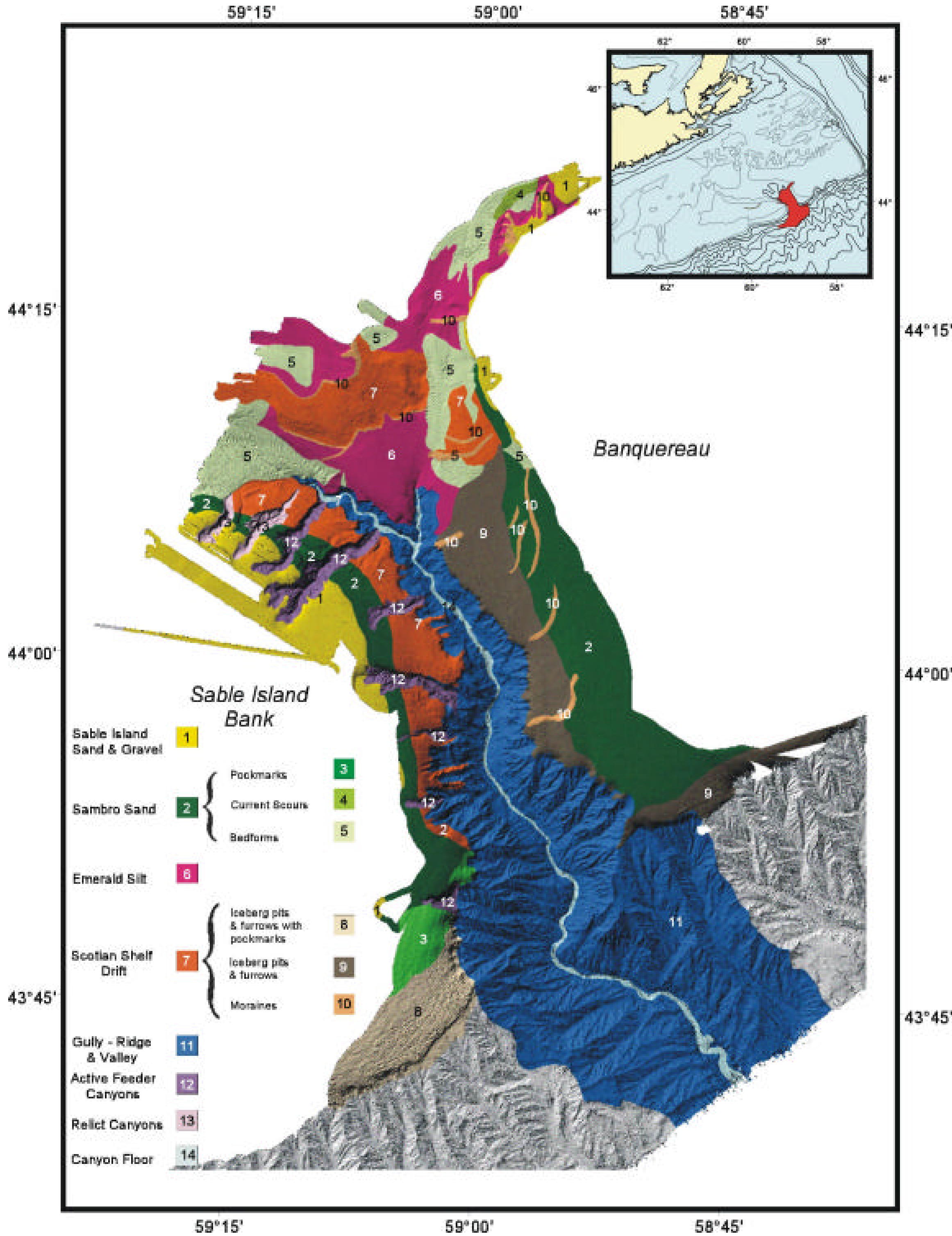


Figure 3. *A geological interpretation of sediment distributions, morphological components and features of The Gully region. The sediment classification is based on a Scotian Shelf wide formational system of King and Fader, 1986. The sediment distributions can form the basis for habitat mapping.*

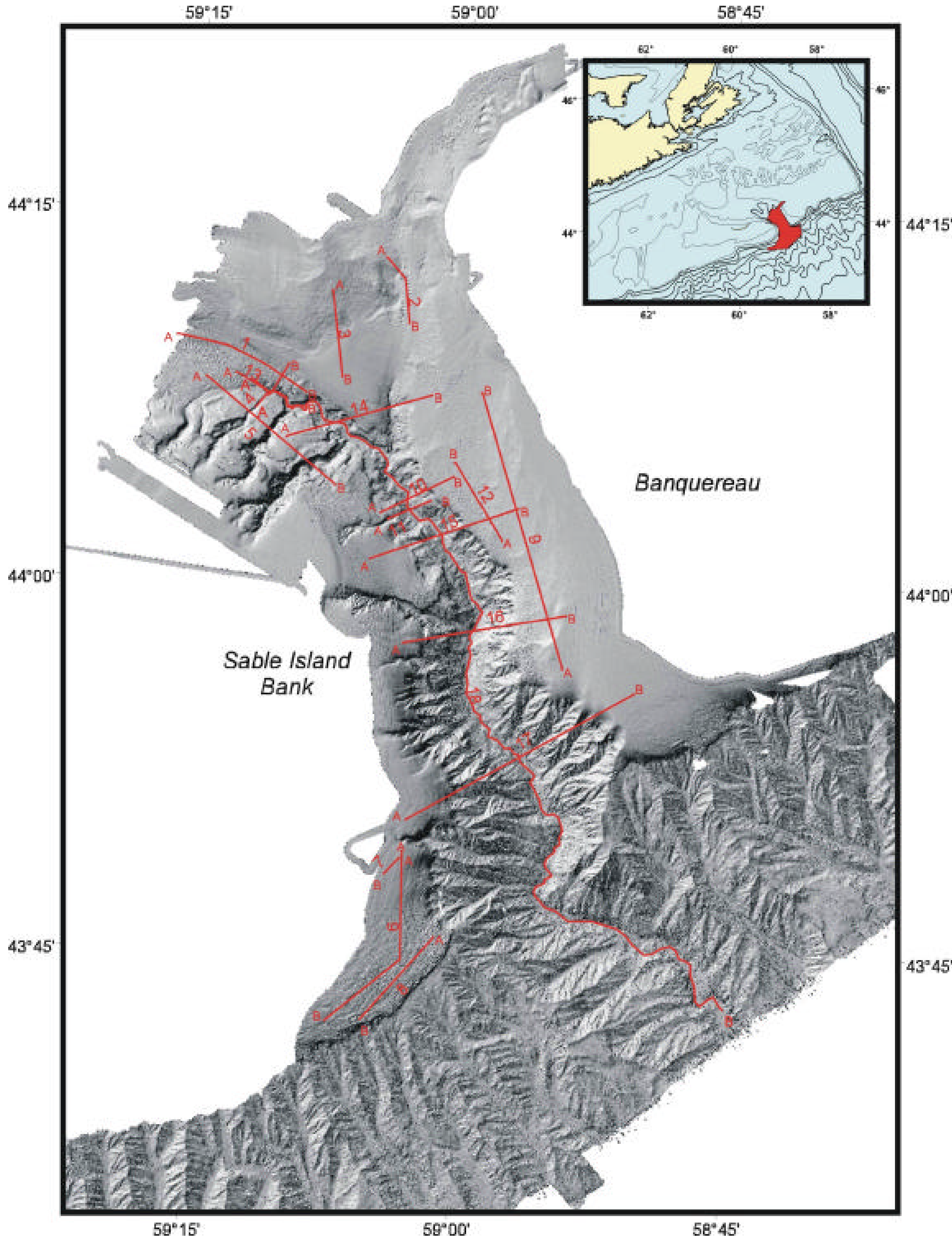


Figure 4a. *A grey scale shaded-relief image of The Gully with the location of selected bathymetric profiles illustrated in Figure 4b. Bathymetric profiles are linear crossections with the exception of profile 13 a-b which follows the deep water thalweg of The Gully.*

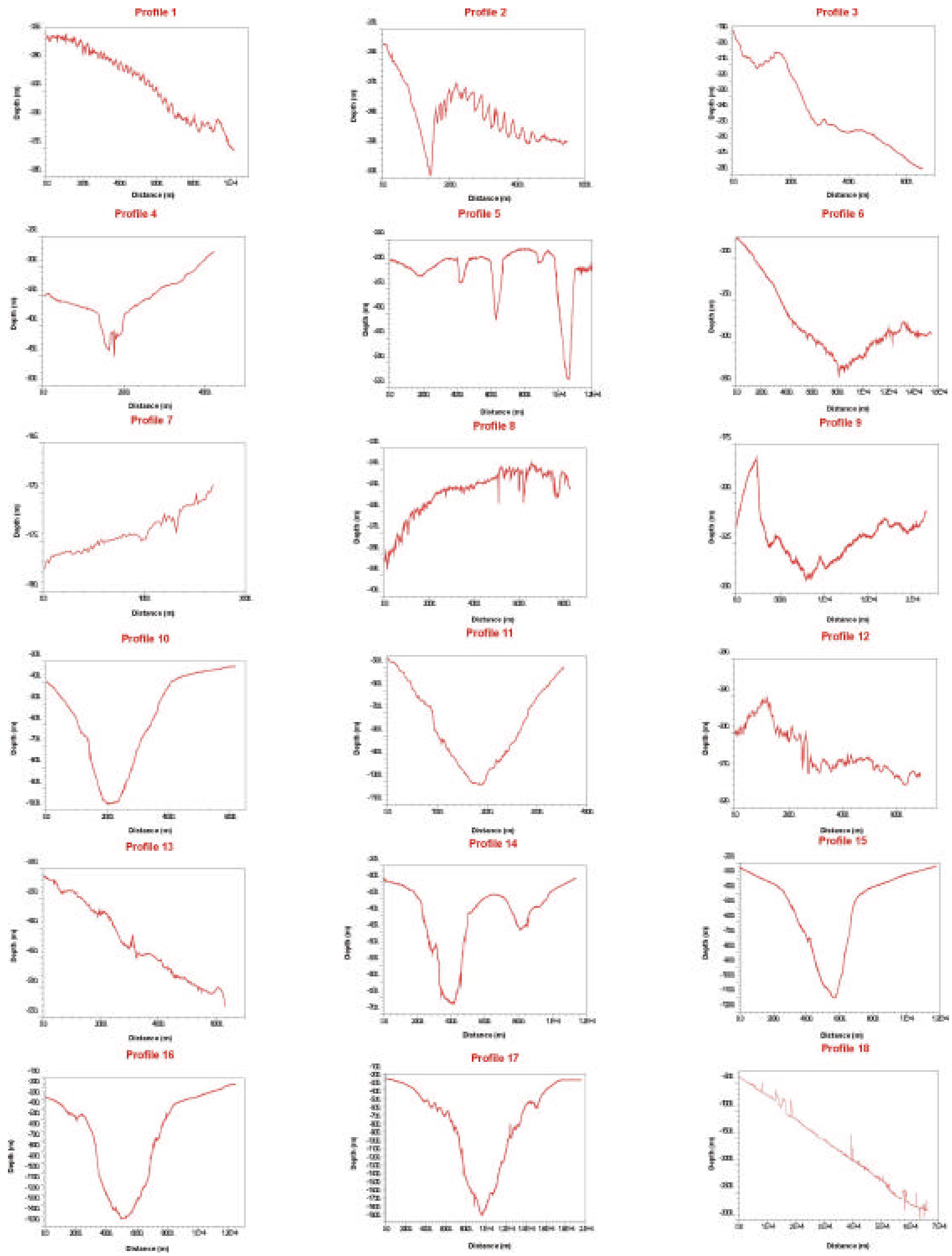


Figure 4b. *Selected bathymetric profiles extracted from the multibeam bathymetric data to illustrate various features and terrains of The Gully. Note the vertical scale for the profiles varies considerably. Profiles 1 and 2 are across fields of sandwaves; profile 7 is across an area of pockmarks; profile 8 is across iceberg furrows; and profile 18 is along the axis of The Gully presenting a uniformly sloped surface.*

Benthic assemblages and habitats of The Gully

V. E. Kostylev

Natural Resources Canada, Geological Survey of Canada (Atlantic)
Bedford Institute of Oceanography, Box 1006,
Dartmouth, Nova Scotia, Canada, B2Y 4A2

The Gully is a unique topographic feature of the sea floor separating Sable Island Bank from Banquereau on the continental shelf of Nova Scotia. This underwater canyon exceeds 2500 meters in water depth, cutting westward through the upper shelf slope cutting deep into the shelf. The size and topography of The Gully suggests the possibility of existence of various and probably distinctly different habitats, which could support diverse benthic fauna. The objective of this study was to describe and classify benthic habitats, and to distinguish and analyze the distribution of benthic assemblages.

Methods

Video and photographic imagery was collected from The Gully in 1997 – 2000 by DFO and NRCan along with all the necessary navigational data. All available video footage was viewed and fauna identified to lowest possible taxon. General remarks on sediment type and habitat were made. Representative oblique shots were collected for each benthic station (where available). A FileMaker database was created, which contains descriptions of 92 stations (79 Campod stations, 8 Benthos camera stations and 5 Videograb stations). Each record contains station coordinates, water depth, date the sample was taken, representative vertical and oblique underwater shots, description of habitat and associated fauna, bathymetry map of the surrounding area and the location map.

The dataset used in the statistical analysis consisted of the total of 462 Campod slides and 125 Benthos camera slides, after discarding duplicates and inadequate (e.g. obscured by turbidity) slides. All fauna was identified to the lowest possible taxon. Presence or absence of each species (recognized taxon) was recorded for each slide. For each station, frequency of occurrence of each taxon was calculated as a ratio of the number of slides where the species is present, to the total number of slides at the station. The use of frequency of occurrence for quantitative analysis was justified by a strong positive relationship between frequency of occurrence and average abundance of benthic species. The relationship is approximated by logarithmic function, and it is asymptotic, because the frequency of occurrence can not exceed 1, which makes variance of observations more homogeneous.

Similarity between frequencies of occurrence of different taxa was calculated using a Bray-Curtis similarity index. Rare species, which were met at less than 3 stations, were omitted from the analysis. Cluster analysis was performed on a dissimilarity matrix and Ward's method of linkage was used to distinguish groups of co-occurring of taxa.

Physical variables describing the benthic environment in The Gully were obtained from the following sources: water depth – from ship log, sediment type – from underwater photographs and multibeam interpretation, and local slope – from multibeam bathymetry. A grid of seasonal oceanographic variables (temperature, salinity, current speed and RMS in nearbottom layer) was obtained from Coastal Ocean Sciences Division (courtesy of G. Han and J. Loder). In order to obtain values of oceanographic variables at each station, kriging was performed on the gridded data, and the interpolated data were queried for values at the coordinates of interest. Additionally, average seasonal values and variables describing variability of temperature and salinity were constructed from seasonal data as a simple variance of the four seasonal values. From all available physical variables only 9 were chosen for further analysis in order to decrease redundancy caused by high correlation between seasonal values. These were depth, sediment type, local slope, average yearly temperature, variance of temperatures based on the four seasons, average yearly salinity, salinity variance, average yearly near-bottom current strength and average yearly RMS of local current. Sediment type was interpreted from bottom photographs and coded from 0 to 7 based on the relative hardness in the following manner: 0 – mud, 1- silty sand, 2 – fine sand, 3 – medium sand, 4 – coarse sand, 5 – winnowed till, 6 – sand and gravel, 7 – lag gravel. This coding system tried to account for and balance both average particle size and sediment sorting. Morphodynamic interpretation of geological setting in the area was provided by G. Fader. Cluster analysis of stations was performed based on these physical variables, which were standardized (by mean and variance) prior to the analysis. Pearson's r was used as a similarity metric, with Ward's agglomeration method.

In order to distinguish the set of physical factors which has the largest influence on composition of benthic assemblages, non-parametric correlation analysis on dissimilarity matrices was performed in the following manner. Two sets of data were compared - Bray-Curtis dissimilarity among stations based on species, and dissimilarities among stations based on all possible combinations of the nine physical factors mentioned above. All physical variables were normalized from 0 to 1 prior to construction of Euclidean dissimilarity matrices. The resulting non-parametric correlation coefficients (Spearman's Rho) between biotic dissimilarity and habitat dissimilarities based on different combinations of descriptors were ranked, and the highest correlation was considered indicative of the combination of variables that best defined community structure. Electivity indices for different habitat types were calculated for each assemblage as (FOhab-AvgFO)/AvgFO, where FOhab is a frequency of occurrence of species of an assemblage in a particular habitat and AvgFO is the average frequency of occurrence of the species through all stations. The index varies from –1 (complete avoidance of the habitat) through 0 (indifference) to indefinitely large positive numbers (preferred habitat).

Results

Classification of physical habitats

The classification clearly distinguishes at least 6 different types of benthic environment. Distribution of different clusters in the Gully is shown in Figure 1. A brief description of the clusters follows:

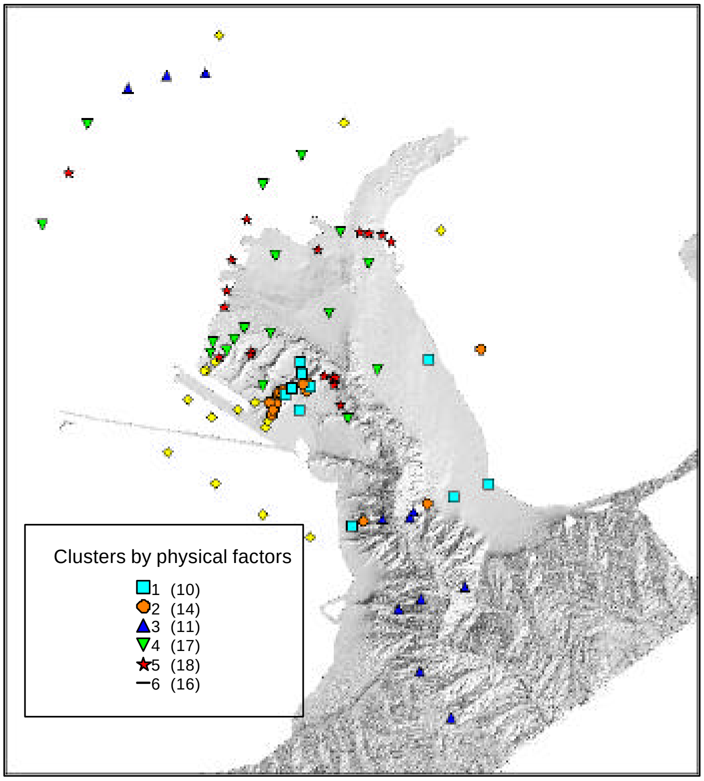


Figure 1: *Distribution of stations belonging to six clusters defined on the basis of the characterization of physical habitat.*

1) Stations within a depth range from 100 to 450 meters, silty sand to medium sand, even terrain, rather constant average water temperatures of 5.4 °C, high and constant salinity, high and variable current strengths, located in the areas adjacent to canyon slopes and tributary channels

2) Stations within similar depth range, silty sand, variable terrain and usually high local slope, and generally similar oceanographic conditions with more variable temperatures, located at the upper slopes of canyon walls and corresponding to inner parts of the tributary channels

3) Stations located in the deeper part of the Gully on mud or silty sand. The cluster includes however 3 stations from the shallow silty sediments. Temperatures are generally low (3.7 – 4.9 °C) and very constant, currents high on average, but variable among stations and seasonally, salinity is the highest compared to other clusters.

4) Stations within 100 – 400 meters depth range, mud to medium sand, even terrain, high and constant temperatures, high and constant salinity, low and constant currents.

5) Stations within 100 – 450 meters water depth, medium sand to lag gravel, varying terrain, relatively high constant temperature and salinity, low and moderately variable currents. These are stations found mostly on hard glacial substrates in the upper Gully

6) Stations from the surrounding banks, with shallow depths, sediments varying from silty sand to winnowed till, but mostly coarse sand, even landscape, low average temperatures and salinities, but highly variable seasonally, moderate but highly variable currents.

This classification generally outlines the location of distinctly different benthic environments in terms of properties of water masses, substrate type and bathymetry. The deeper canyon part of the Gully (3) is well-defined, as well as tributary channels (2), glacial till (5) and banktop environment (6).

Four out of nine tested physical factors appear important for definition of species composition at different stations in The Gully. Similarity analysis showed that the combination of depth, substrate type, variance of temperature and average yearly salinity exhibits the highest non-parametric correlation with community composition. The approach used here relies on the assumption that pairs of samples, which are rather similar in terms of physical variables, would be expected to have rather similar species composition if the relevant variables determining community structure have been included in the analysis. Therefore, these four physical factors will be used for definition of benthic habitats in The Gully at the current state of knowledge about its environment.

Benthic assemblages and habitats

Cluster analysis distinguished 7 groups of co-occurring common species. A brief description of each group is supplemented by data on the physical environment where these assemblages are typically present:

1) The first assemblage includes deep-water species, mostly found in the mouth of The Gully, on canyon walls at water depths 600 meters and deeper. The most common species here are large deep-water brittlestars of genus *Ophiomusium*, banded coral (*Keratoises ornata*), sea whips (likely *Balticina* sp.), solitary hydroids, soft alcyonacean corals (*Anthomasthus* sp.) and several species of anemones. A conspicuous species of probable gorgonian coral (white calcified spiral tube, protruding from sediment) is common in low abundances. This assemblage appears on soft muddy sediments, in high salinity water masses with low variability in temperature, and generally stable environment. Micro-scale variability in this habitat is defined by presence of ridges and valleys, populated by different species. Deep-water ridges are dominated by suspension feeders (*Lima* sp., and stalked crinoids or solitary hydroids). Depositional valleys are typically populated by deposit-feeding brittlestars and biogenic structures (such as amphipod colonies) are increasingly important there in providing small-scale habitat heterogeneity.

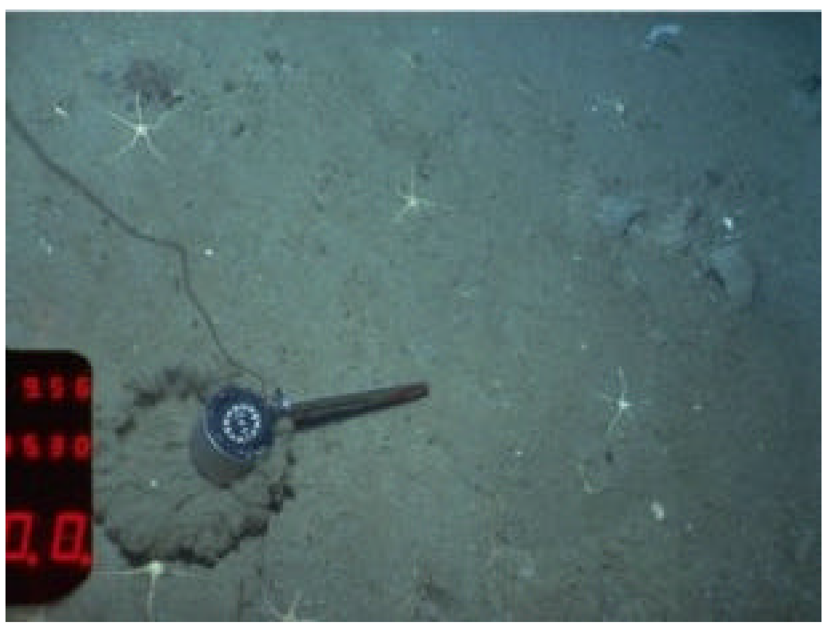


Photo 1: *Deep-water fauna of the main canyon channel of the Gully is affected by upper slope water masses and is distinctly different from the fauna of other habitats.*

2) The second assemblage is represented by species which are characteristic for deep-water gravelly substrate. An infaunal brittlestar (*Ophiopholis aculeata*) is very common, along with daisy-top anemones (*Stomphia* sp.), several species of sponges, chitons, and crinoids. This assemblage is found on till in water depths of 250 – 650 m, in areas affected by slope water masses, with relatively constant temperature and high salinity. These species co-occur only at a small number of stations along the edge of the main canyon.

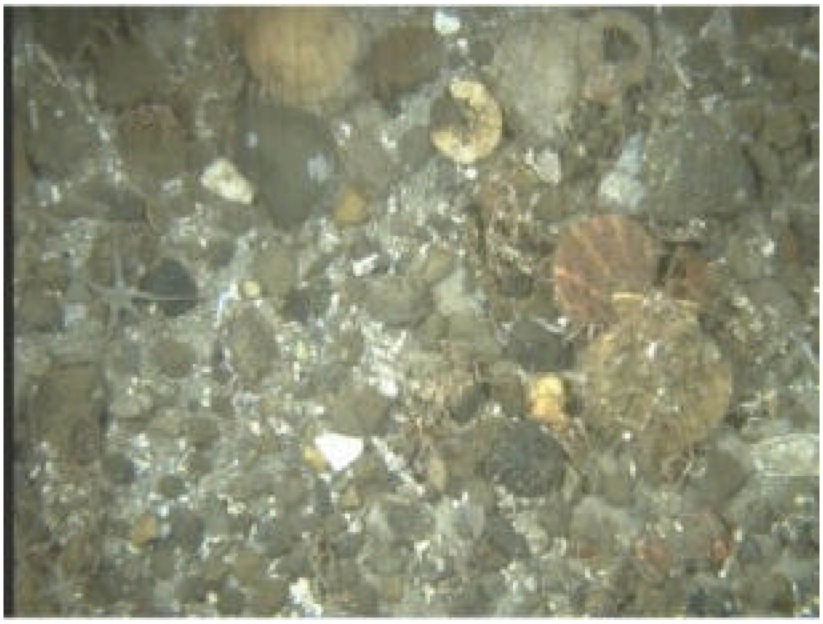


Photo 2: *Fauna characteristic for gravel substrates in the deeper parts of the Gully.*

3) The third assemblage is typical for fine-grained sediments, and is easily recognizable by the presence of cerianthid anemones (*Cerianthus borealis*) and often associated shrimp (Pandalidae spp. and Crangonidae spp.). Patches of thin tubes and polychaete plumes are visible on the surface of sandy silt, as well as several species of burrowing anemones. Several pelagic species such as krill (*Meganyctiphanes norvegica*), grenadier and flounder are associated with this group. A species of deposit-feeding brittlestar (*Ophiura* sp.) is common on the surface of sediment. Species of this assemblage are found at depths of 130-410 m, in moderate salinity and moderately varying water temperature. This assemblage is characteristic for glaciomarine sediments of the upper Gully, and exists in microhabitats created on terraces of bedrock outcrops in the tributary channels.

Photo 3: *Silt dominated glaciomarine sediments in the upper Gully. Cerianthid anemones, snow crabs and shrimp are abundant in this habitat.*

4) The fourth cluster is represented by sand-dwelling fauna, such as sand dollar (*Echinarachnius parma*), very abundant *Ophiura sarsii*, and tube-bearing polychaetes of the family Nothriidae. The hermit crab (*Pagurus* sp.) and spider crab (*Hyas araneus*) are present. Small epifaunal anemones are found where attachment substrate is available. A species of burrowing anemones (likely *Edwardsia* sp.), gastropods of family Trochidae and polar seastars (*Leptasterias* sp.) are also members of this assemblage. Sand lance is commonly observed on video footage. These species are typically present at shallow depths 50- 300m, at the bank tops, in highly variable oceanographic conditions.

Photo 4: *Sable Island sand varying in grain size from coarse to fine on the bank slopes is dominated by sand dollars and brittlestars.*

5) The fifth cluster is typical for soft sediments of tributary canyons and includes protozoan *Bathysyphon* sp., burrowing brittlestars *Amphioplus* sp., soft corals (Alcyonacea spp.), several species of anemones, sponges (most notably *Polymastia* sp.) and sea feathers (*Pennatula* spp.). This assemblage is found at water depths of 200 - 600 m in areas with steeper slopes than for other hard substrate communities. These are the topographically variable habitats along the fringe of the main canyon and tributary channels. Noticeably, the substrate is varying from silty sand to till, with softer sediment covering areas between patches of cobbles and boulders. This substrate heterogeneity defines two types of fauna that are merged into this cluster of species – common soft sediment animals, such as burrowing brittlestars and sea pens, and diverse epifaunal fauna attached to gravel. Higher than average salinity and moderate variability in temperature is characteristic for the stations where this group of species is found, and indicates that oceanographic conditions here are affected by slope waters.

Photo 5: *Substrates of glacial origin surrounding the channels of the Gully are heterogeneous and complex, providing suitable habitat for many epifaunal species including deep-water corals.*

6) The sixth cluster is represented by another assemblage of species typical for gravelly habitats. Sixteen taxa are common here, - sponges (*Halichondria* sp., *Scypha ciliata* and unidentified white globular sponge), tunicates (both encrusting and solitary, likely Molgulidae spp.) and bryozoans (anascan and ascophoran). Stalked hydrozoa (*Sertullaria* like) are present and several types of sabellid tubes and phoronid plumes are protruding from the surface. Mobile fauna is represented by *Buccinum* sp. and terebellids. This assemblage is found on winnowed till, in the middle of the 100 - 500m water depth spectrum, in water masses affected by shelf waters with lower salinity and moderate variability in temperature.

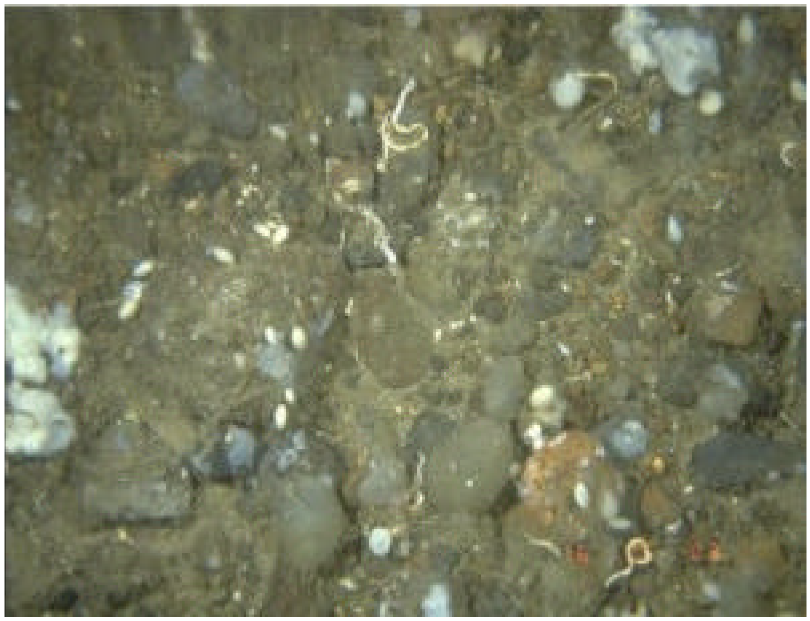


Photo 6: *Brachiopod-sponge assemblage and it's varieties is common on modified till of the shallow banks in the upper Gully.*

7) The seventh assemblage is closely associated with the sponge and tunicate dominated assemblage (6) and share many species. Both assemblages are characteristic for glacial till and are known in other areas of the Scotian Shelf (Kostylev *et al.* 2001). Dominant species are brachiopods (*Terebratulina septentrionalis*), white encrusting sponges, very abundant epifaunal anemones (*Fagesia* sp.), several species of serpullid worms (*Filograna implexa*, *Protula tubularia*) and a species of tube building polychaetes of family Nothriidae (smaller than the species found in sandy habitats). Substrate is poorly sorted gravelly sediment, within water depths of 100 – 500 m, mostly on the top of deeper banks with average salinity, moderately variable temperatures and strong currents.

A summary of habitat preferences for the distinguished assemblages is presented in Figure 2. Note large overlap in sediment type, which is likely the effect of co-occurrence of hard and soft substrate fauna at stations with poorly sorted sediments (e.g. cobbles in silty sand). Therefore, substrate preference was reviewed using a geomorphodynamic classification of the area.

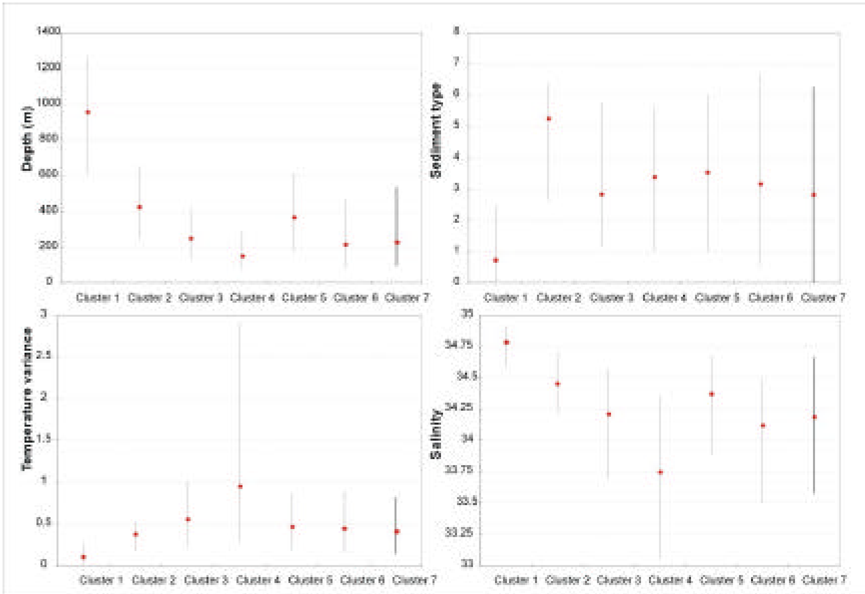


Figure 2: *Ranges of the four physical factors estimated for each assemblage. The bars indicate average minimum and average maximum values for all species of each assemblage.*

The table below presents habitat electivity indices for the 5 categories of geomorphology. Cells in reversed color correspond to the preferred habitats. Grey cells show habitats where an assemblage is likely to occur more often than elsewhere, but not as often as in the preferred habitat. BED – bedforms, CHNL – channel environment (canyon and tributary channels), GLA – glacial deposits and glacially modified terrain (till, iceberg pits and furrows), SAND – sandy sediment excluding major bedforms, SIS – silty sand.

	BED	CHNL	GLA	SAND	SIS
Assemblage 1	-1	2.1	0	-1	-1
Assemblage 2	-1	-1	2.6	-1	-1
Assemblage 3	0	0.1	0.0	-1	0.7
Assemblage 4	0.2	-1	0	1.3	0
Assemblage 5	-1	0	1.9	-1	0
Assemblage 6	0	-1	2.4	-1	-1
Assemblage 7	-1	-1	2.9	-1	-1

Table 1*: Habitat electivity indices for 5 classes of geomorphology in the Gully. The index takes a value of -1 if the assemblage avoids the habitat completely, 0 - if it is as likely to be present in the habitat as in any other, and any positive value shows the preference for the habitat (indicated in reversed color).*

Four assemblages are strongly dependent on glacial deposits, and their spatial distribution can be differentiated by depth range and water masses. The remaining three assemblages are distinctly associated with channel environment, sand and silty glaciomarine sediments.

Biodiversity

One of the major questions related to an evaluation of the uniqueness of The Gully and the development of a management strategy is the question of biological diversity. A total of 175 taxa and features were distinguished from the imagery. It is important to recognize however certain limitations of our data. Firstly, we can only discuss the diversity of megabenthos (animals discernable by naked eye from the photographs) and taxonomic resolution is limited. Photographic analysis deals mostly with epifauna, although some indications of infauna can be discerned from underwater imagery as well. Secondly, different tools were used for optical sampling in different part of The Gully (Campod and Benthos camera), and thirdly different areas of the sea floor were surveyed at different stations. The latter two problems were dealt with by correcting the number of recorded species to standard sample area which allowed comparisons of different stations.

Separate survey area/number of taxa regressions were fitted for hard and soft substrates and for the benthos camera stations for this purpose. The general patterns of diversity are the following. Hard substrate, namely glacial deposits and glacially modified substrate seems to play a major role in supporting biodiversity of megafauna (Figure 3).

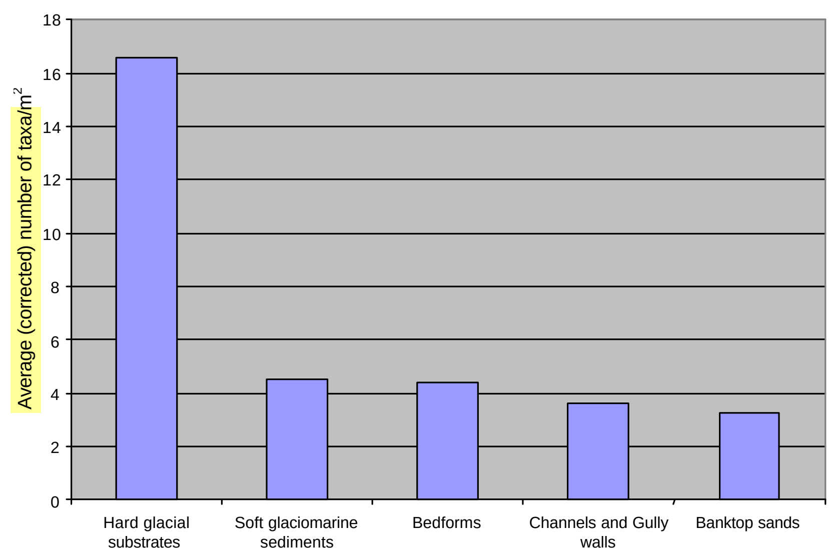


Figure 3: *Average species richness (number of taxa per square meter corrected for the total surveyed area at each station) at different types of geomorphology.*

The channel environment (tributary channels and the main canyon) did not appear exceptionally rich in megafauna and is similar in the number of observed taxa to banktop areas and bedforms. The reason for this could be the active sediment deposition on the ledges and terraces of bedrock outcrop, and transport along the main axes of channels. In addition, bedrock outcrops are easily eroded, and do not provide a stable habitat for large benthic species. On the contrary, hard substrates of glacial origin surrounding the channels, along their edges, were populated with diverse epifauna that included soft alcyonacean and hard gorgonian corals. The same areas, possibly due to their effect on turbulent exchange, attract large populations of groundish species, which often find refuge within sparse coral colonies. The species richness is at its maximum around 180 m water depth and gradually declines towards a 800 m mark, after which the decline is even steeper. The species richness is also highest in the areas affected by slope waters with relatively high salinity (34.5 ppm) and stable temperature regime. Keeping in mind that we are discussing only epibenthic megafauna, it is necessary to mention that infauna of the deeper parts of the Gully can potentially be more diverse because of the dominance of soft sediments.

<u>Conclusions</u>

- A diagram summarizing the distribution of major types of benthic assemblages in The Gully is shown on Figure 4. Based on the data in hand, habitats and epibenthic megafauna are generally more diverse in the middle and in the upper Gully.
- Fauna of the upper Gully and the distinguished benthic assemblages are similar to fauna of the outer banks elsewhere on the Scotian Shelf.
- Geological processes in The Gully play a crucial role in structuring epibenthic communities. For example, sediment transport and depositional processes are likely responsible for the low diversity in the channels. Hard glacial substrates are inhabited by the most diverse and different benthic assemblages whereas soft bedrock outcrops are used to a lesser extent by epifauna.
- Morphology of The Gully is affecting benthic and pelagic processes on a variety of scales. The canyon rim habitat is a good example of how glacial history, and probably topography-induced turbulent water exchange create a habitat essential for the survival of deep-sea corals and redfish stocks.

Deeper parts of The Gully are severely undersampled. This is a distinct environment, however only 8 camera stations were occupied there. Targeted survey of the inner part of the Gully (800 meters and deeper) that will include optical and grab sampling is necessary in order to provide valid conclusions about this habitat that can be used for ocean management.

Identification of benthic species from optical sampling and conclusions about biodiversity in the area can be significantly improved by collecting voucher specimens. Sampling design can be greatly improved by establishing standard underwater survey techniques. Video sampling should be standardized to a set transect length (e.g. 10 minutes at average drift speed) and number of replicate photographs (at least 15 at each station) taken at a constant scale. Interpolation of distribution of benthic assemblages must be based on hypothesis-testing approach and interpreted geology. An integrated study of The Gully should be developed between NRCan and DFO.

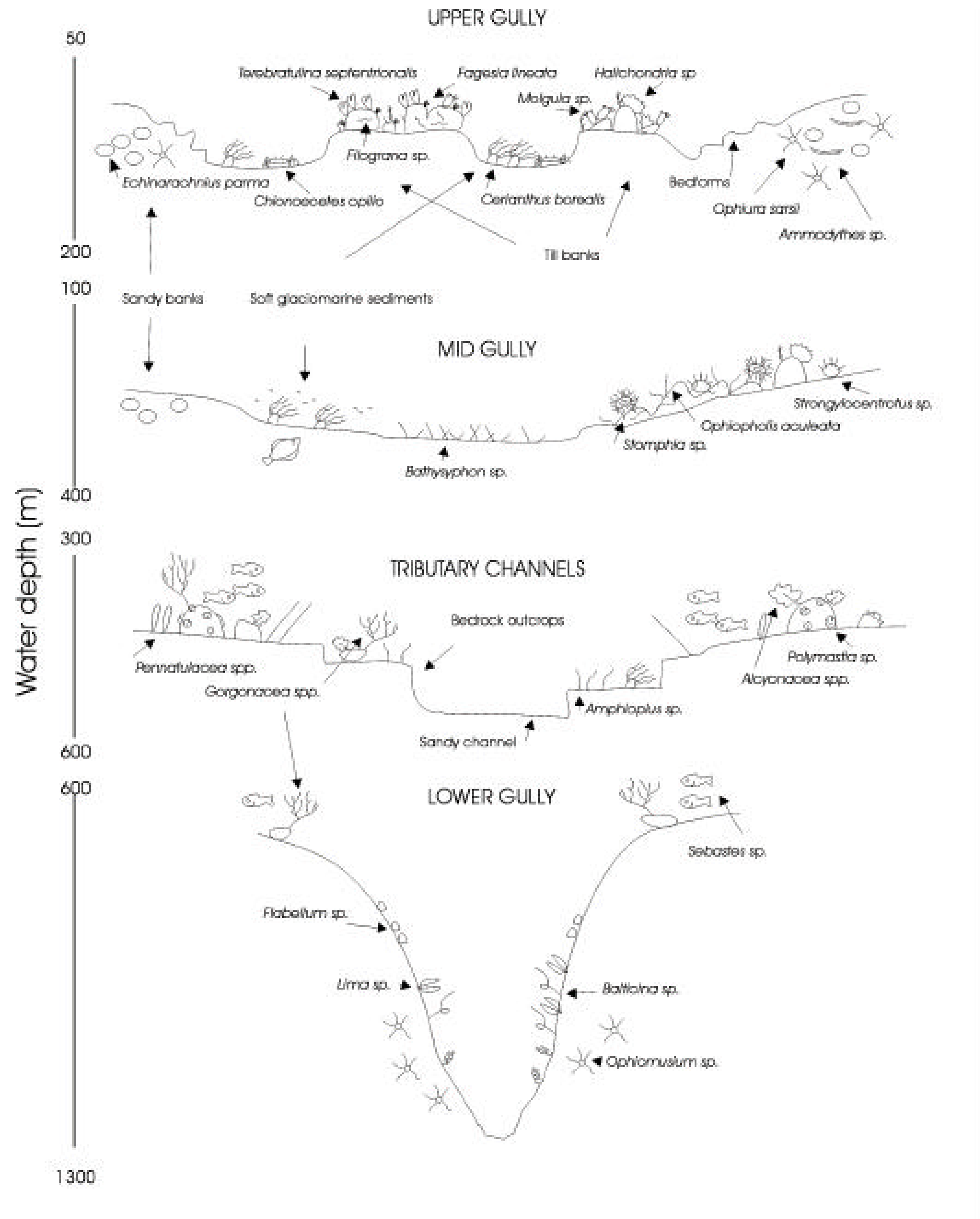


Figure 4: *Schematic distribution of major benthic assemblages in The Gully. Bathymetric ranges are approximate*

References

Kostylev, V.E., Todd, B.J., Fader, G.B.J., Courtney R.C., Cameron, G.D.M. and Pickrill, R.A. 2001. Benthic habitat mapping on the Scotian Shelf based on multibeam bathymetry, surficial geology and sea floor photographs. *Marine Ecology Progress Series.* 219: 121-137.

Patterns of Epifauna Biomass and Respiration in The Gully Region of the Scotian Shelf

B.T. Hargrave[1] and C.M. Hawkins[2]

[1]Marine Environmental Sciences Division, Fisheries and Oceans Canada, Bedford Institute of Oceanography, P.O. Box 1006, Dartmouth, NS, B2Y 4A2

[2]C.M. Hawkins, Triton Consultants, 221 Crichton Ave., Dartmouth, N.S. B3A 3R8

Epifauna are benthic species that are attached (sessile) or capable of movement within, on or above the bottom (also referred to as hyperbenthic) and are visible in photographs. Infauna, on the other hand, are animals of any size that live within sediment. They move freely through interstitial (between sediment particle) spaces or build burrows or tubes either within the sediment or at the surface projecting upwards. These species usually cannot be quantified by photography. Very few studies of epifauna distribution exist for the eastern U.S. or Scotian Shelf (Hecker *et al.* 1980, Houston and Haedrich 1982, Stewart *et al.* 2001) and no estimates of biomass or respiration have been made to assess metabolic demand at the community level.

Diversity (species composition) is often thought to be determined by habitat structure (complexity), stability, predation and other factors, while biomass is regulated by food supply. The observations of major epifauna taxa in photographs from the largest canyon on the edge of the Scotian Shelf, The Gully, were used to test the idea that major sedimentary facies determine epifauna community types and biomass. The distribution of metabolic demand was derived from biomass estimates combined with actual measurements of respiration on board ship. The data were used as an indirect means of testing the idea that particulate organic matter is transported from surrounding upper shelf areas to offshore deep slope areas through this continental shelf canyon ecosystem (Keizer 1998).

Methods

35 mm pictures were taken at 31 stations in The Gully in 1997, 1998 and 2000 (Figure 1) using bottom-mounted (Campod) or bottom-triggered (Benthos Deep Sea) cameras. Images analysis was used to determine numbers and sizes of major taxa of visible epifauna (>0.2 cm), bottom type and areal coverage of hard substrate. The full set of images from 92 stations was used by Kostylev (2001) to describe relationships between benthic assemblages and bottom habitat. In our study, images from 31 stations representing inner and outer parts of The Gully were examined. A subjective classification for rock cover was established to examine relationships between numbers of epifauna taxa and biomass distribution and the percentage of hard substrate at each station. Coverage was classified as high (>50 % rock cover), medium (1 to 49 %) or low (<1 %). Linear dimensions and planar areas of organisms and hard substrate features >0.2 cm were measured using an x- y co-ordinate system. Wet weight of recognizable

epifauna were estimated from volume conversion factors measured with freshly or frozen specimens of various taxa.

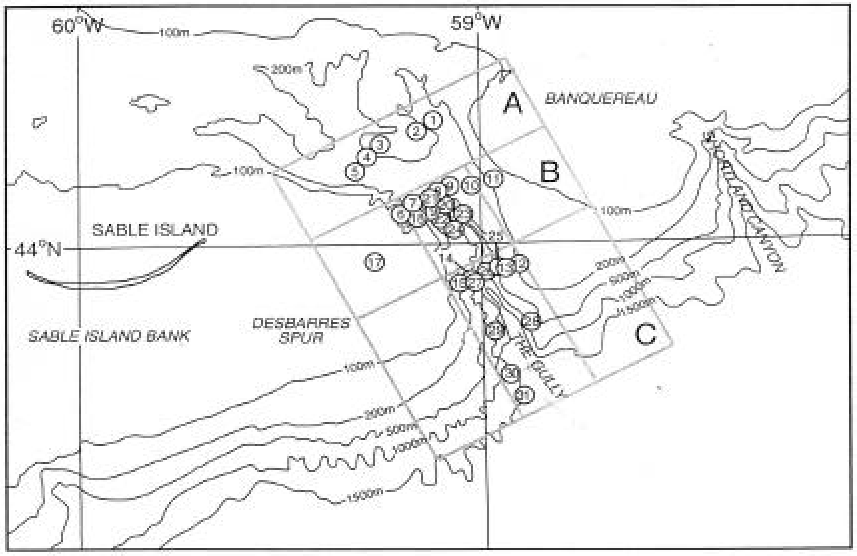


Figure 1*: Station locations for 31 sites in The Gully region photographed for analysis of epifauna taxa, estimates of biomass and respiration and description of bottom type and percentage of hard substrate using Campod and a Benthos Deep-Sea camera system between 1997 and 2000.*

Respiration was measured using fresh specimens collected with the DFO Videograb, a 0.5 m^2 grab and video system developed at the Bedford Institute of Oceanography (Rowell *et al.*, 1997). Specimens were removed from the grab immediately after collection and acclimatized for 6-12 hr at *in situ* temperatures prior to shipboard measurements of oxygen consumption. Individuals were placed in sealed plexiglass chambers and incubated in the dark at ambient temperature (3 to 5º C). Respiration rates over 2 to 4 hr were calculated from differences in initial and final dissolved oxygen concentrations measured using a polarographic oxygen micro-electrode held in a water jacket at the incubation temperature. Weight-specific respiration was expressed on a calorific basis using conversion factors given in Peter (1983)(1 Watt=1J s^{-1}=0.239 cal s^{-1}= 0.05 ml O_2 s^{-1}). Weight-specific standard respiration (R) (Watts kg^{-1}) was calculated from individual body size (W)(kg wet weight) and oxygen uptake measured in the present study using the allometric equation:

$$R=0.023W^{-0.351} \qquad (1)$$

Mean biomass turnover time (TT)(d) was calculated using an average value for invertebrate tissue energy content (7 x 10^6 J kg^{-1}wet weight)(Peters 1983) as the ratio of calories in biomass:calories respired as:

$$TT = (43.5\ W^{0.351}) \times [(7\times10^6)/(8.64 \times 10^6)] \qquad (2)$$

Results and Discussion

Distribution of Bottom Substrate Type, Rock Cover and Epibenthic Fauna Composition

Excluding stations with sand/mud bottom (considered to have no hard substrate), the percentage of hard substrate varied greatly (0.1% to 97.6 %) between stations. There was no consistent relationship between the presence of hard substrate and water depth or onshore-offshore distance along The Gully.

Eleven different taxa of epifauna (sponges, corals, polychaetes, branchipods, custaceans, molluscs, asteroids, ophiuroids, crinoids and tunicates) were observed. The list of recognizable taxa and association of epifaunal groups with hard substrate (glacial till and cobble), sand or mud bottom types is similar to that presented by Kostylev (2001). His statistical analysis was based on all available Campod and Benthos camera images (n=587) from 92 stations collected between 1997 and 2000. We examined 270 images from 31 of these stations distributed throughout The Gully (Figure 1). The taxa present in broad benthic assemblages described by Kostylev (2001) were recognizable in our reduced data set with less resolution due to the reduced number of stations analyzed.

Stations with highest biomass (mean 73.6 g wet weight m^{-2}, SD 17.2, range 6.8 to 306.2) and the greatest number of taxa (mean ± SD = 4.9 ± 2.4) occurred at locations with >50% rock cover in areas of glacial till and gravel (depth range 198 to 922 m) primarily in the upper region (A) of The Gully (Figure 1)(Table 1). Sponges (*Halichondria* spp., *Scypha* and a currently unidentified white encrusting species), *Metridium senile*, *Fraesia lineata*, *Stomphia* spp, brachiopods (*Terebratulina septentrionalis*), polychaetes (free-living and tube forming, Sabellidae and Nothriidae families), tunicates (*Molgula* spp.), and bryozoans (ansascan and ascophoran) were present.

A second mixed assemblage of taxa occurred at stations with medium coverage of hard substrate, clustered in the middle (B) and upper regions of The Gully with coarse cobble and gravel substrates. These stations, with intermediate water depths (152 to 443 m), had a wide range of biomass. The average (mean 52.7 g wet weight m^{-2}, range 1.2 to 81.7 g m^{-2}) was lower than at stations with a higher percentage of rock cover, and the mean number of taxa was reduced (3.0 ± 1.0). Similar species of sponges, brachiopods and tunicates were present with anemones (*Cerianthus borealis*), echinoderms (*Ophiopholis aculeata*), molluscs (bivalves – *Chlamys islandica*, gastropods- *Buccinium* spp., chitons- *Ishnochiton* spp.) and crustaceans (crabs- *Lithodes maja, Pagurus* spp., *Chionoecetes opilio*).

Stations with <1% rock cover occurred over the full range of depths (44 to 1327 m) in all three areas. There was an equally wide range of biomass (2.2 to 147.9 g wet weight m^{-2}) but there were fewer taxa (2.4 ± 1.9). The areas of low rock cover on the banks surrounding The Gully to the north, east and west consisted of sandy sediment with the epifauna community dominated by echinoderms, in particular sand dollars (*Echinarachnius parma*), brittlestars

(*Ophiura sarsi*) and seastars (*Leptasterias* spp.). In deeper water (>600 m) along the central axis and towards the mouth of The Gully, sediments were silty-sand. The epifauna was dominated by brittlestars (*Ophiura sarsi*), stalked crinoids (unkown species, possibly *Lima* spp.), hard corals (*Keratoises ornata*, *Acanella arbuscula*), soft corals (*Gersemia rubiformis*, *Anthomasthus* spp.), anenomes (*Cerianthus borelais*), and sea whips (*Pennatula* spp.).

Distribution of Biomass, Metabolism and Turnover Time

Average values for total numbers of epifauna taxa, community biomass, respiration rates and turnover times ranked by substrate hardness value are presented in Table 1. The maximum total biomass (306 g wet weight m^{-2}) at Stn 3 in region (A) consisted predominantly (93 %) of an unidentified white encrusting sponge. Since respiration rate was calculated from biomass, community respiration was also maximum (132.6 ml O_2 m^{-2} d^{-1}) at this station.

Hardness Value	No. of Stations	No. of Taxa	Biomass (g m^{-2})	Respiration (ml O_2 m^{-2} d^{-1})	TT (d)
1 (>50%)	10	4.9	73.6	32.8	337.9
		(2.4)	(17.2)	(10.7)	(128.7)
2 (1-50%)	4	3.0	52.7	20.4	399.1
		(1.0)	(44.7)	(16.8)	(167.2)
3 (<1 %)	17	2.4	38.5	15.2	616.0
		(1.9)	(50.8)	(25.3)	(335.0)

Table 1: *Comparison of hardness value (percentage of rock cover), mean (±SD) biomass, calculated respiration and turnover time (TT) (ratio of calories respired:calories in biomass) for epifauna observed by image analysis from photographs at 31 stations (Figure 1) in The Gully.*

The data show a decline in biomass from stations with >50% rock cover to those with <1%, as would be expected if the presence of hard substrate is a critical factor for development of diverse epifauna communities. Areas with a higher percentage of rock cover probably experience relatively high bottom currents since there is minimal accumulation of fine-grained sediments. In contrast, areas with minimal hard substrate are those with mostly sand or mud deposits. On the banks, sandy sediments are subject to frequent resuspension and transport when wave motion impacts on the seabed. While the supply of freshly produced particulate organic matter may be high, substrate mobility and the lack of hard substrates for attachment may limit the hinder development of epifauna communities with high biomass.

Deeper (>600 m) areas within The Gully should be subject to lower water currents than occur on the banks or on the upper margins, however internal waves and a clockwise gyre in water circulation may affect water movements within the deeper central areas (Sandstrom and Elliott, 1984). Lower bottom currents reduced the potential for sediment erosion and result in less horizontal transport of particulate matter and lower food supply to filter feeding epifauna.

Stewart *et al*. (2001) reviewed published historic observations of infauna biomass measured using grab samples on Banquereau and Sable Island Banks. Mean values ranged from 204 to 265 g wet weight m^{-2}, close to the range of maximum values that we observed for epifauna (218 to 306 g wet weight m^{-2}). Although mean biomass for the three categories of rock cover (Table 1) was lower (range of 39 to 74 wet weight m^{-2}), from an energetic point of view, large epifauna in The Gully are as important a component of the benthos as are smaller infauna in adjacent shelf sediments.

To examine the hypothesis that transport of particulate matter occurs down-slope from inner to outer regions of The Gully, we grouped stations by the amount of hard substrate and distance (km) from the head of the canyon (Figure 2). Depth (Z_m) increased from 44 to 1327 m along the length of the transect and there was a linear correlation between depth and distance (D)(km) (Z_m =-31.4 + 21.4 D, r^2 =0.53, p<0.05). There were no significant (p>0.05) correlations between biomass and respiration with depth or distance for all stations combined where epifauna occurred (n=24). Logarithmic transformations of variables did not improve regression coefficents. Turnover time was positively correlated with distance (r^2 = 0.36, p=0.002) with a relationship described by:

$$TT = 166.7 + 11.99\ D \qquad (3)$$

A similar comparison of TT with depth showed a slightly reduced but still significant correlation (r^2 = 0.32, p=0.004):

$$TT= 278.7 + 0.37\ (Z_m) \qquad (4)$$

The data for stations plotted in Figure 2 on the basis of the degree of rock cover show different patterns of distribution for biomass, respiration and turnover time for the two groups of stations. A gradient in biomass and respiration occurred at stations with >50% rock cover (Figure. 2A and B) with maximum values at upper Gully stations decreasing with distance. However, there was no clear trend in turnover time with distance (Figure 2C). Stations with <50% rock (with values approximately half of those with >50% rock cover) demonstrated higher biomass and respiration rates at inner and outer ends of the transect (Figure 2D and E). Turnover times were approximately double those at stations with >50% rock cover with a trend to higher values near the outer end of the transect (Figure 2F).

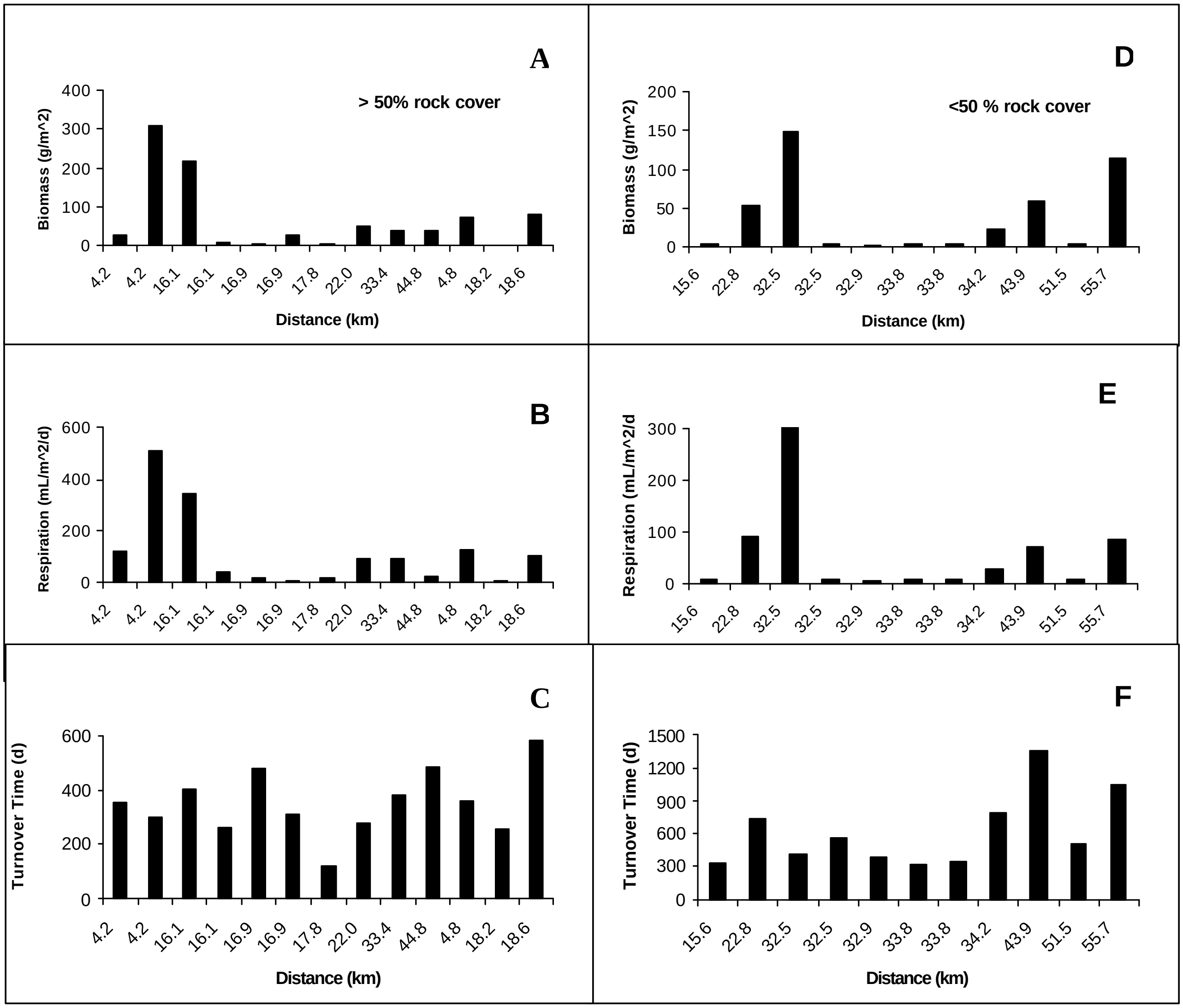


Figure 2: *Comparison of epifauna biomass, respiration and turnover time at stations where epifauna was observed (locations shown in Figure 1) with distance from the head to the mouth of The Gully. Stations were grouped with respect to the amount of hard substrate: left-hand panels >50% rock cover, right-hand panels <50% rock cover.*

Conclusions

The complex bottom topography within The Gully results in a variety of benthic habitat types ranging from steeply-sloped rock outcroppings, cobble/gravel glacial till, fine to medium sand and silty-sand to mud bottom types. In contrast to sediments on adjacent Banquereau and Sable Island Bank, bottom deposits within the canyon are poorly sorted leading to a high degree of substrate heterogeneity. The types and biomass of benthic epifauna communities that form on these substrates in part reflects the amount of hard surface available for attachment and the supply of particulate matter used as food by filter- and deposit-feeding epifauna taxa.

The diverse community of epifauna filter feeders observed in the upper regions of The Gully has a relatively high biomass and corresponding high respiration rates due to the abundance of sponges, anemones and brachiopods that predominate in this region With increasing distance and depth along the axis of the canyon, the amount of rock surface for attachment is reduced. Altered community species composition is evident in a reduced number of taxa with biomass dominated by echinoderms, and hard and soft corals. The lower biomass leads to reduced metabolism towards the outer end of the transect. Turnover times are approximately doubled at these stations indicative of a reduced food supply.

Acknowledgements

We thank the officer and crew of *C.S.S. Hudson*, W. P. Vass, and D. Reimer who helped with field work and C. Bourbonnais and K MacIsaac who confirmed taxonomic identifications and assisted with area/weight determinations. We are grateful to D. Gordon and C. Bourbonnais for providing Campod images for analysis and to K. Bentham and H. Wiele for help with photography.

References

Binyon, J. 1972. Physiology of Echinoderms. Pergamon Press. 264 pp.

Hecker, B., G. Blechschmidt and P. Gibson. 1980. Epifaunal zonation and community structure in three mid- and North Atlantic Canyons. Final Report for the Canyon Assessment Study in the mid- and North Atlantic Areas of the U.S. Outer Continental Shelf. U.S. Dept. of Interior, Bureau Land Management, Washington, 139 pp.

Houston, K.A. and R.L. Haedrich. 1984. Abundance and biomass of macrobenthos in the vicinity of Carson submarine Canyon, Northwest Atlantic Ocean. Mar. Biol. 82: 301-305.

Keizer, P.D. 1998. The Gully Science Review. Canadian Stock Assessment Proc. Ser. 98/2, 40 pp.

Kostylev, V.E. 2001. Benthic assemblages and habitats of The Gully.

Mills, E.L. and R.O. Fournier. 1979. Fish production and the marine ecosystems of the Scotian Shelf. Mar. Biol. 54: 101-108.

Nesis, K.I. 1965. Biocoenoses and biomass of benthos of the Newfoundland-Labrador region. Fish. Res. Bd. Can. Trans. Ser. 1375.

Peters, R.H. 1983. The ecological implications of body size. Cambridge University Press. 329 pp.

Piepenburg, D., T.H. Blackburn, C.F. von Dorrien, J. Gutt, P.O.J. Hall, S, Hulth, M.A. Kenda, K.W. Opalinske, E. Rachor and M.K. Schmid. 1995. Partitioning of benthic community respiration in the Arctic (northwestern Barents Sea). Mar. Ecol. Prog. Ser. 118: 199-213.

Pocklington, P. and M.J. Tremblay. 1987. Faunal zones in the northwestern Atlantic based on polychaete distribution. Can. J. Zool. 65: 391-402.

Rowell, T.W., P. Schwinghamer, M. Chin-Yee, K. Gilkinson, D.C. Gordon, Jr., E. Hartgers, M. Hawryluk, D.L. McKewon, J. Prena, D.P. Reimer, GH. Sonnichsen, G. Steeves, W.P Vass, R. Vine and P. Woo. 1997. Grand Banks Otter Trawling Experiment: III. Sampling equipment, experimental design, and methodology. Can. Tech. Rep. Fish. Aquat. Sci. 2190, viii+36 pp.

Sandstrom, H. and J. Elliott. 1984. Internal tides and solitrons on the Scotian Shelf: a nutrient pump at work. J. Geophys. Res. 89: 6415-6426.

Stewart, P.L., H.A. Levy and B.T. Hargrave. 2001. Database of benthic macrofaunal biomass and productivity measurements for the eastern Canadian continental shelf, slope and adjacent areas. Can. Tech. Rep. Fish. Aquat. Sci. 2336: vi + 31 p. + A1-6.

Seasonal-Mean Circulation and Tidal Currents in the The Gully

G. Han[1], P. Roussel[2] and J. W. Loder[1]

[1] Ocean Sciences Division, Fisheries and Oceans Canada, Bedford Institute of Oceanography, P.O. Box 1006, Dartmouth, N.S. B2Y 4A2

[2] Coastal Ocean Associates Inc., 7 Canal Street, Dartmouth, N.S. B2Y 2W1

Currents, mixing, temperature and other physical oceanographic conditions play important roles in the structure of The Gully ecosystem, its interconnections with ambient regions, and the potential for interactions among various materials and organisms. Petrie *et al.* (1998) provided a broad summary of physical oceanographic information for The Gully region, primarily drawing on water property data, short-term current meter measurements, and shelf-scale numerical modelling results. Notable features included the relatively-strong tidal currents over shallow banks versus weak tidal currents in deep areas according to a 2-D tidal model (de Margerie and Lank, 1986), internal tides and waves on The Gully flanks from Batfish survey data (Sandstrom and Elliott 1984), and a cyclonic partial gyre over The Gully from historical current meter data and circulation models (Han *et al.*, 1997; Hannah *et al.*, 2001). However, there were large information gaps including no current measurements in water depths greater than 200 m and no systematic studies of The Gully's circulation.

As part of the 1999-2001 Gully Ecosystem program, numerical modelling studies of currents on the Eastern Scotian Shelf (ESS) funded by the Panel for Energy Research and Development (PERD) were extended to include additional focus on The Gully. The objectives were to obtain improved quantitative descriptions of 3-D tidal currents and seasonal-mean circulation in The Gully region, for input to other Gully Ecosystem studies and to evaluations for Marine Protected Areas by DFO (OCMD).

Approach

Our approach is hydrodynamics modelling, initialized and constrained with observational temperature and salinity data, and evaluated against moored current measurements. Two 3-D finite-element (FE) circulation models were used: a linear diagnostic model (Naimie and Lynch, 1983) in a mode similar to that in Han *et al.* (1999) to provide initial conditions; and a nonlinear prognostic model with advanced turbulence closure (Lynch *et al.* 1996), in a mode similar to that in Hannah *et al.* (2001), to provide dynamically self-consistent current, hydrographic and turbulence fields. The temperature and salinity fields in the diagnostic model were specified from seasonal climatologies. The prognostic model was initialized with barotropic tidal solutions and the seasonal-mean currents from the diagnostic model, and forced by M_2 and K_1 tides, density gradients, boundary inflows and observed seasonal-mean wind stress.

Two variable-resolution triangular FE meshes were used, allowing increased spatial resolution in target areas as well as inclusion of influential ambient regions. The base mesh (ss3) has a typical horizontal resolution of 5-10 km over the shelf and 21 vertical levels with highest resolution near the sea surface and seafloor. Studies were also initiated on a new high-resolution mesh (ss4) with typical horizontal resolution of 2 km for The Gully and its vicinity, and 61 vertical levels with increased resolution of the pycnocline to resolve internal tides. In the ss3 prognostic solutions, temperature and salinity were restored to the observational climatology with a time scale of half a day, whereas they were allowed to adjust freely with dynamics and topography in the ss4 prognostic solutions. The prognostic simulations were run for 6-8 M_2 cycles, with results presented here for cycles 3-4 (ss3) and 2-3 (ss4).

The seasonal-mean model currents were compared with observational estimates from the Bedford Institute current meter archive using months with at least 15 days of data, while the tidal currents were compared with published tidal analyses and new 30-day analyses of archived current records. Further information on the approach will be provided in Han and Loder (2001).

Results

Tidal Currents

The horizontal structure of the M_2 and K_1 tidal currents is illustrated by the near-surface ellipses (Figure 1) from the low-resolution prognostic model (ss3P). Both the M_2 and K_1 currents are relatively strong over Banquereau and Sable Island Bank, and weaker in the deep Gully. Compared with observational estimates, there is approximate agreement for M_2, but significant overestimation for K_1. The base and high-resolution models show similar barotropic patterns for M_2, but the high-resolution solution has greater K_1 amplification on the flanks of The Gully (not shown). The strong sensitivity of the K_1 solutions is attributable to the probable occurrence of near resonant continental shelf waves at (subinertial) diurnal frequencies (*e.g.* Crawford and Thomson, 1982) on the ESS and to the proximity of a K_1 amphidrome in Laurentian Channel (Han *et al.*, 1996).

Prognostic solutions show more vertical structure, than their diagnostic counterparts, especially on the high-resolution mesh. The high-resolution prognostic solutions allow the generation of internal tides over sloping bottom topography through coupled evolution of the density and current fields. An indication of the distribution and amplitude of the internal tides is provided in Figure 2 by the vertical displacements at 50 m (or mid-depth if the water depth is shallower than 100 m) associated with the M_2 and K_1 vertical velocities in the summer solution. The largest displacements are in and around The Gully, including along the shelf-edge approaches to its mouth, over its main canyon and along the northern edge of Sable Island Bank. There are widespread displacements in excess of 10 m for the M_2 tide and 15 m for the K_1 tide, pointing to a regular physical mechanism for transient vertical movement of water properties, organisms and near-buoyant materials in the interior water column.

The sensitivity of the tides in The Gully region to model dynamics, resolution and bottom topography is consistent with the strong, irregular and unusual temporal variability in observational data from the region. Current meter records from spring-fall generally do not have the slow and regular tidal amplitude modulations (*e.g.* fortnightly) typical of most shelf locations, but rather generally have irregular modulations and sometimes show intermittent shifts from diurnal dominance to semidiurnal dominance. Some records also show marked phase differences between the near-surface and near-bottom currents, indicating the presence of internal tides at the M_2 and K_1 frequencies. Harmonic analysis on successive 2-day blocks of a 12-day record from the eastern flank of The Gully in summer 1994 showed highly-variable amplitudes and phases of the M_2 and K_1 tides, indicating a sensitive nonlinear tidal regime. The combination of spatial and temporal complexity in the tidal dynamics, including strong horizontal and vertical gradients, points to the potential for above-normal rates of energy transfer from tidal to smaller scales throughout the water column in The Gully region.

Seasonal Circulation

The horizontal structure of the seasonal-mean circulation in The Gully region is illustrated in Figure 3 which shows the currents at 25-m depth from the ss3P solutions for spring and summer. The primary shelf-scale circulation features (in all seasons) are the large shelf-edge flow carrying water from the Newfoundland Shelf/Slope and Gulf of St. Lawrence, and the Nova Scotian Current on the inner shelf, both of which are generally directed southwestward. These and other model solutions (*e.g.* Hannah *et al.* 2001) indicate that the Nova Scotian Current on the central Scotian Shelf off Halifax is supplied by both flow along the inner ESS and onshore meanders of the shelf-edge flow particularly around the western end of Sable/Western Bank. There is a cyclonic partial gyre over The Gully in summer, fall and winter associated with topographic steering of part of the shelf-edge flow onto the shelf around the southwestern edge of Banquereau, and the northeastern (southwestward-flowing) limb of an anticyclonic gyre over Sable Island/Western Bank.

The ss3 and ss4 model solutions together with those from other recent studies (Han *et al.* 1997; Hannah *et al.* 2001) indicate that the strength and details of the circulation pattern vary with season. The shelf-edge flow and the Nova Scotian Current on the inner ESS are strongest in winter and fall. The largest seasonal change in The Gully circulation is an increase in the strength and extent of onshore flow in spring, such that this flow (partly) supplies the Nova Scotian Current and disrupts the northeastern limb of the Sable gyre (Figure 3, upper panel). Recent analysis of SeaWiFs data by Harrison and Petrie (*pers.comm.*) indicates that the distribution of the spring phytoplankton bloom on the ESS has its offshore limit coinciding approximately with this spring flow path. In summer and the other seasons when much less of the shelf-edge flow penetrates into The Gully basin to the north and northeast of Sable Island, the cyclonic partial gyre is more prominent although its position and structure tend to vary with season and solution.

The structure and inter-relation of currents and water properties in The Gully is illustrated in Figure 4 which shows the normal component of the seasonal-mean current, temperature and salinity on a southwest-to-northeast section across The Gully east of Sable Island. The increased extent and strength of the onshore flow in spring is apparent. The net (averaged over the entire section) transport in spring is 0.4 Sv which is about one-half of the spring transport of the Nova Scotian Current off Halifax. In contrast, the net transport across The Gully section is close to zero in summer and fall when the subsurface-intensified onshore flow on The Gully's eastern (Banquereau) side is compensated (in volume but not necessarily in property fluxes) by surface-intensified offshore flow on the its western (Sable) side. The flow in these solutions is driven by horizontal density gradients associated primarily with salinity variations and by sea surface slopes associated with the overall regional hydrodynamics. Strong salinity stratification is present year-round in The Gully. Lowest near-surface salinities occur in fall associated with the arrival of the Gulf of St. Lawrence outflow, and highest near-bottom salinities occur in summer and fall suggesting peak onshore penetration of Slope Water at depth in these seasons. The largest cross-channel salinity differences occur in spring, resulting in the intensified onshore flow. The temperature structure evolves from an approximate two-layer structure in winter to a pronounced three-layer structure in summer and fall, with the cold intermediate layer concentrated on the Banquereau side associated with the onshore flow of the shelf-edge current.

The main spatial structures in these model solutions are in approximate agreement with the available observational data and existing knowledge. However, it should be emphasized that there are local discrepancies and some suspicious features in the model solutions, and the observational data are generally not adequate to provide a statistically reliable description of the circulation or to validate the model solutions. Available current meter records are generally of short (couple months) duration and there are no moored current measurements in The Gully area of primary interest.

Conclusions

- The primary features of the model solutions for seasonal-mean circulation in The Gully region are: strong southwestward flow along the shelf edge with greatest strength in fall and winter, topographic steering of some of the shelf-edge flow onshore in The Gully, a persistent tendency for anticyclonic circulation around Sable Island/Western Bank, a cyclonic partial gyre over The Gully with greatest prominence in the summer-to-winter period, and intensified onshore flow in The Gully in spring.
- Tidal currents in The Gully region have strong spatial variations and greater temporal variability than on most other parts of the Atlantic Canadian shelf. This is associated with the dual importance of the semidiurnal and diurnal tides, the complex topography of the Banquereau-Gully-Sable region, complex dynamics of the diurnal tide, and internal tides. As a result, discrepancies remain between models and observations particularly for the diurnal tides, and there is the potential for important influences of tides on mixing and exchange throughout the water column in The Gully.

- The physical oceanography of The Gully region is complex, with pronounced spatial strucure associated with topography, highly variable tides, strong influences from the ambient shelf and slope dynamical regimes, and nonlinear interactions among currents, hydrographic properties and topography.
- There are no observational data (*e.g.* moored measurements) from the deeper parts of The Gully that resolve the spatial and temporal variability in the currents and hydrography that are critical to the structure of its ecosystem. Such data in conjunction with improved models are needed to provide a basic description and understanding of The Gully's physical oceanography which would serve as a framework for addressing various interdisciplinary and applied issues in the region.

References

Crawford, W.R. and R.E. Thomson, 1982. Continental shelf waves of diurnal period along Vancouver Island. *J. Geophys. Res*. 87, 9516-9522.

de Margerie, S. and K.D. Lank, 1986. Tidal circulation of the Scotian Shelf and Grand Bank. Canadian Contractor Report of Hydrography and Ocean Science, 30, 43pp. Han, G., C.G. Hannah, J.W. Loder, and P.C. Smith, 1997: Seasonal variation of the three-dimensional mean circulation over the Scotian Shelf. *J. Geophys. Res.,* 102(C1), 1011-1025.

Han, G., M. Ikeda and P.C. Smith, 1996: Oceanic tides from TOPEX/POSEIDON altimetry over the Scotian Shelf and Grand Banks, *Atmosphere-Ocean*, 34.

Han, G., J.W. Loder, and P.C. Smith, 1999: Seasonal-mean hydrography and circulation in the Gulf of St. Lawrence and eastern Scotian and southern Newfoundland Shelves. *J. Phys. Oceanogr.,* 29(6), 1279-1301.

Han, G. and J.W. Loder, 2001: Three-dimensional seasonal-mean circulation and hydrography on the eastern Scotian Shelf, *in preparation*.

Hannah, C.G, J. Shore, J.W. Loder, and C.E. Naimie, 2001: Seasonal circulation on western and central Scotian Shelf. *J. Phys. Oceanogr*., 31, 591-615.

Lynch, D.R., J.T.C. Ip, C.E. Naimie, and F.E. Werner, 1996: Comprehensive coastal circulation model with application to the Gulf of Maine, *Continental Shelf Research*, 16, 875-906.

Naimie, C.E., and D.R. Lynch, 1993: FUNDY5 Users' Manual. Numerical Methods Laboratory, Dartmouth College, N.H., 40 pp.

Petrie, B., J. Shore, C.Hannah and J. Loder, 1998: Physical Oceanography. In: The Gully: A Scientific Review of its Environment and Ecosystem, editors: W.G.

Harrison and D.G. Fenton, *Canadian Stock Assessment Secretariat Research Document* 98/83., 20-57.

Sandstrom, H. and J. Elliott, 1984: Internal tides and solitons on the Scotian Shelf: a nutrient pump at work*.* *J. Geophys. Res*., 89, 6415-6426.

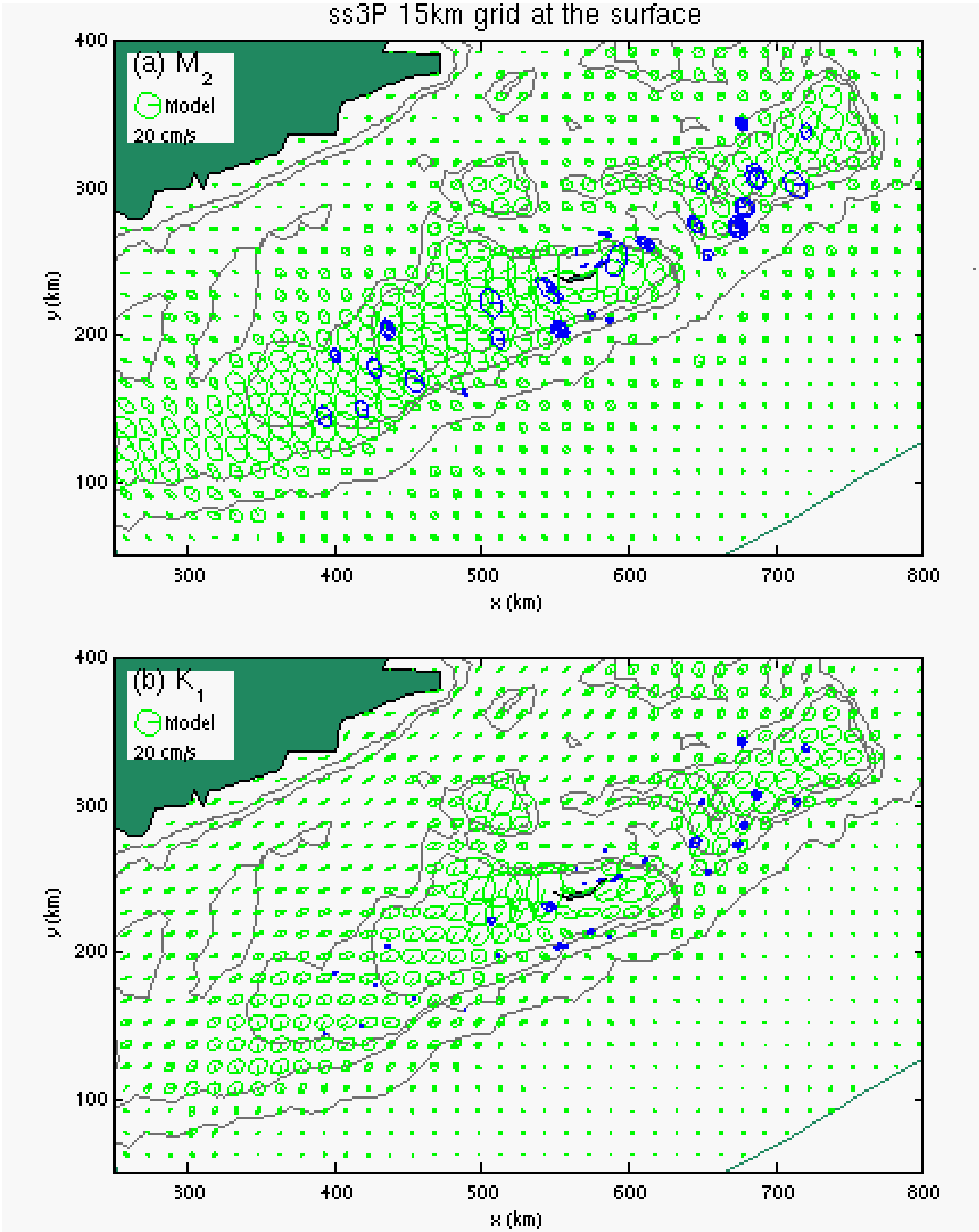


Figure 1: *Near-surface current ellipses (green) for (a) the M_2 tide and (b) the K_1 tide from the base prognostic model for summer, interpolated to a 15-km grid. Ellipses (blue) from tidal analyses on observed data are included for comparison.*

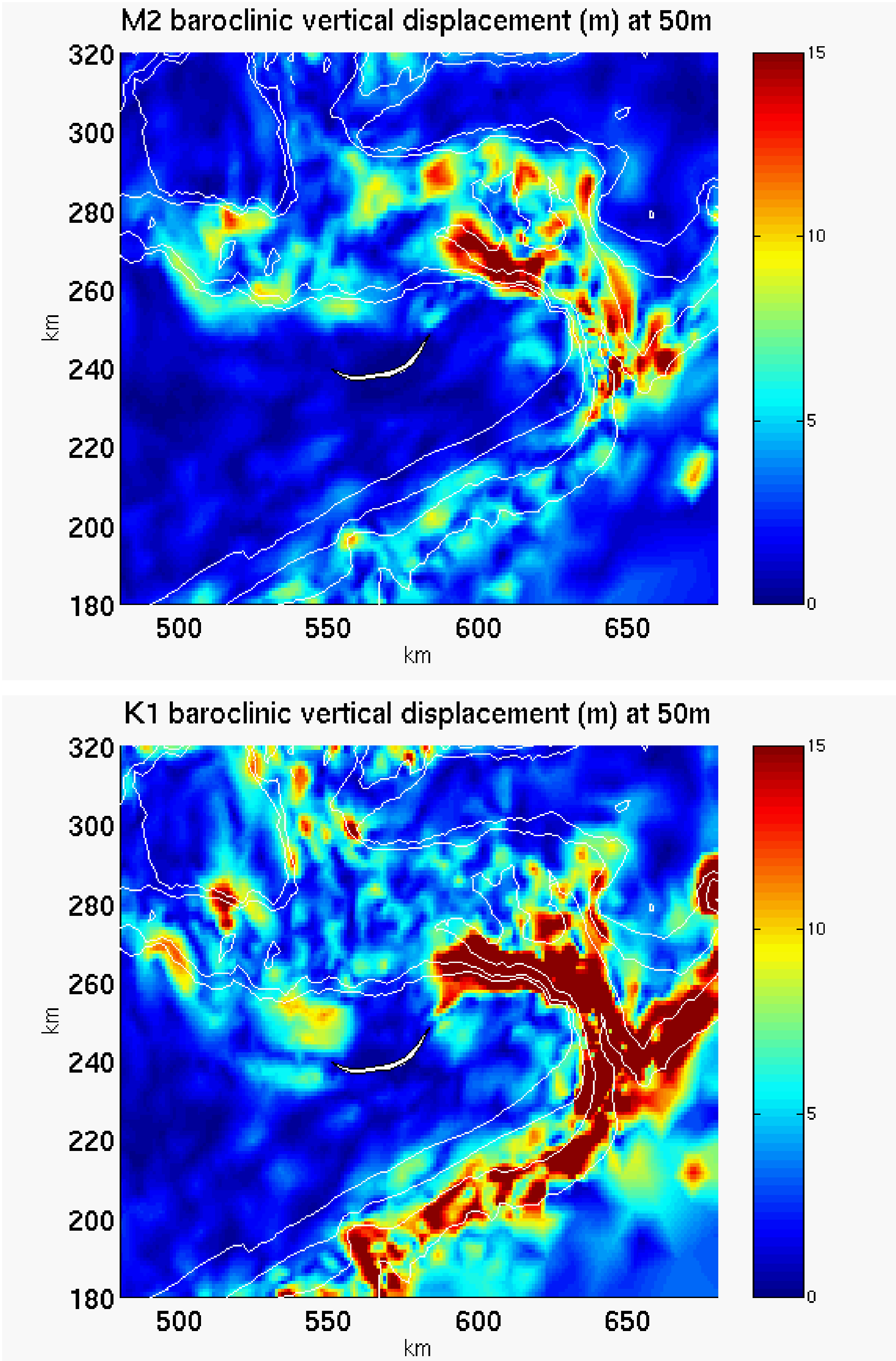


__Figure 2:__ Range of vertical displacements at the shallower of 50 m below surface or mid-depth associated with the M_2 and the K_1 tide in the high-resolution prognostic model solutions for summer. The 70-, 100-, 200- and 1000-m isobaths in the model are included.

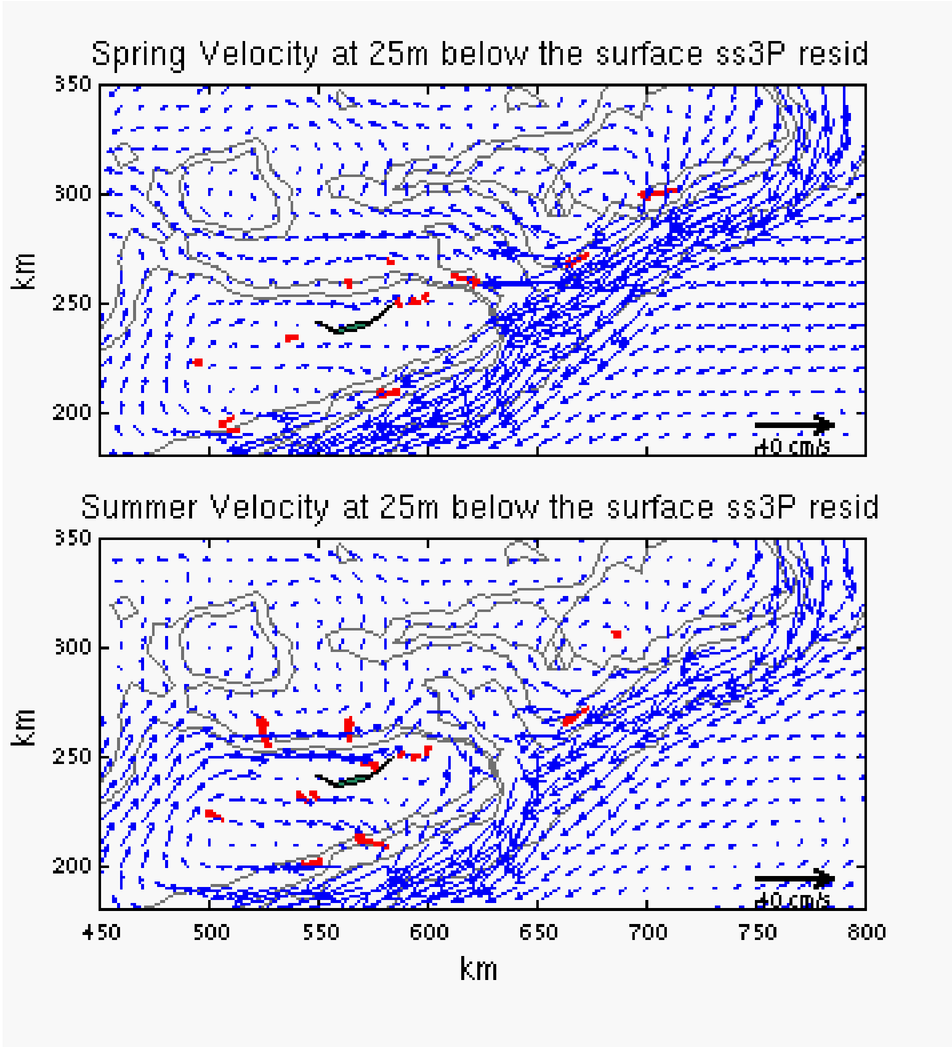


Figure 3: *Seasonal-mean currents (blue) at 25 m below the surface for spring (upper panel) and summer (lower panel) from the base prognostic model, interpolated to a 10-km grid. The seasonal-mean currents from moored measurements (red), and the 70-, 100-, 200- and 1000-m isobaths (black) are also shown.*

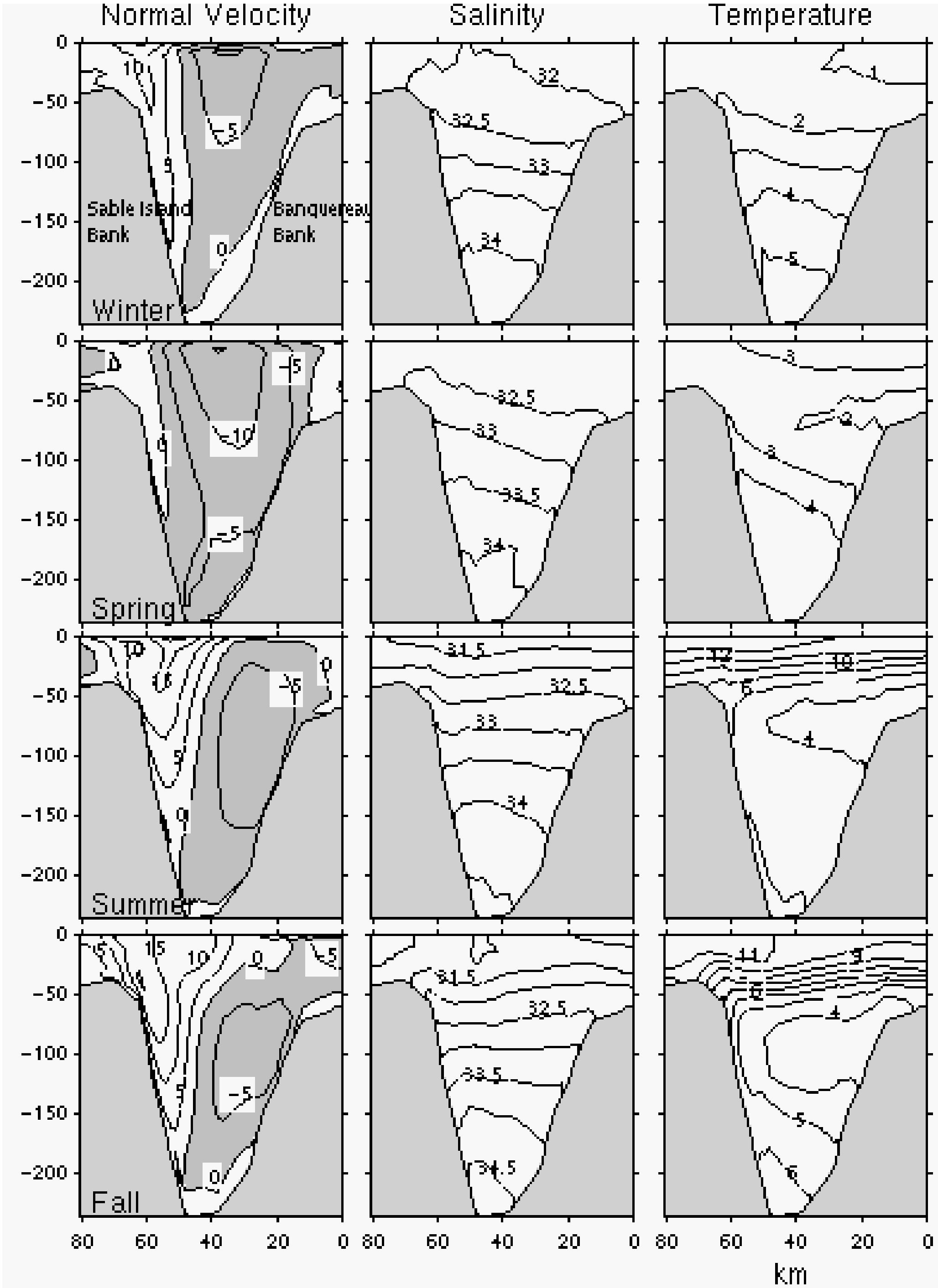


Figure 4: *Vertical distributions of the normal component of seasonal-mean current (left column), salinity (middle column) and temperature (right column) on a section across The Gully starting about 20 km east of Sable Island and extending northeastward to Banquereau Bank. Positive values of current (cm/s) indicate offshore flow, and negative values (shaded) onshore flow.*

Tidal Mixing and The Gully Ecosystem.

H. Sandstrom and J.A. Elliott

Ocean Sciences Division, Fisheries and Oceans Canada, Bedford Institute of Oceanography, P.O. Box 1006, Dartmouth, N.S. B2Y 4A2

Background

In the years of 1981-85, with funding support from PERD, we carried out a field program to study the incidence of large amplitude tidally generated internal waves along the east coast continental shelves. Our interest centered around current surges associated with the large amplitude 'internal solitons'. From August 15 to September 1, 1984, we collected field data in the vicinity of The Gully, east of and adjacent to Sable Island. The bulk of the data collected is ship-based using CTD, BATFISH and an acoustic backscatter system. Two current meter moorings were also deployed. Published results to date focused primarily on describing the role of the dominant groups of solitary internal waves in generating shear instability and hence turbulence. One of the conclusions reached was that the eastern flank of The Gully and the adjacent corner of Banquereau had much stronger internal tides than the western side, and that the energy in the internal tides was sufficient to cause turbulence observable in both temperature fine-structure and acoustic backscatter.

Purpose of study

To answer some questions raised by The Gully Science Review document and in support of the The Gully Ecosystem Program, we undertook a retrospective analysis of the data collected in 1984, in order to obtain more comprehensive estimates of energy in the internal tides and their role in vertical mixing of the water column in The Gully region in contrast to other areas on the Scotian Shelf and Grand Banks. This includes estimates of the size of internal tides generated at the shelf edge, and a description of dissipation and mixing patterns as the internal tides propagate shoreward.

Method

The focus here is on the 226 BATFISH sections collected over a 10 day period (see Figure 1). Two modes of operation were employed: 1) a survey over a fixed path by repeated transects (sections) of approximately one hour duration (= ~ 15 km of track) lasting at least a M2 period, and 2) tracking a wave group as it propagated shoreward by repeated crossings while following the wave group. The latter was made feasible by tracking the bands of surface roughness associated with the waves.

The pertinent BATFISH parameters for our purpose are the depth, density at that depth, horizontal location (lat, long) and time. Using these parameters we determined the displacement of a series of preselected isopycnals in order to calculate the potential energy. To obtain the displacement, we must first estimate the 'mean' density field, *i.e.*

the mean elevation of the isopycnals. This has to be done with care, since the data coverage, even with the relatively good sampling rate of the BATFISH, is sparse. Also, the 'mean' field may be changing due to other longer term variability.

To meet our software requirement, a compendium of Matlab processing routines was compiled for this project. The principal steps in processing are the following:

i) Splitting the BATFISH sections into 'CTD casts'.
ii) Interpolating to obtain the elevations of given isopycnals in each 'CTD cast'. Figure 2 shows one such BATFISH section on the corner of Banquereau.
iii) For the survey mode divide the sections into 3 (or 4) km blocks and assign the casts into a given block according to its geographical location.
iv) For each isopycnal take the mean of the elevations and corresponding times in a block (block averages). A time series of average elevations in a block is thus obtained for the 12+ hour period.
v) A least squares fit to the time series is made with a fitting function consisting of a mean, trend and sinusoids of M2 and M4 period. Figure 3 is an example of block averaged elevation as function of time for three isopycnals and the corresponding fitting functions. The combination of mean and trend yield the mean density field during the tidal cycle(s).
vi) The mean density fields from all tidal cycles are combined into a three-dimensional estimate of the reference field, to which now displacement both from the survey and tracking modes can be referred.

For a given isopycnal the displacement

$$\zeta(z_0) = \text{actual elevation} - \text{mean elevation}(=z_0)$$

The potential energy for a 'CTD cast'

$$PE = ½ \int \rho N^2 \zeta^2 dz_0 = ½ g \sum \zeta^2 \Delta\sigma$$

Where $\Delta\sigma$ is the interval between adjacent chosen ispycnals. If the principle of equipartion of enegy between potential and kinetic holds,

$$\text{Total Energy} = KE + PE = 2xPE$$

Energy production and dissipation in internal tides

The principal characteristics of internal tides are the following:

i. Interaction of surface tides with steep bathymetry at upper continental slope and shelf break displaces the isopycnals, generating both an offshore and shoreward propagating internal tide. The energy in the shoreward moving component is observed to be considerably larger than in the offshore component.

ii. Non-linear effects transform the shoreward propagating internal tide into a ‘sawtooth’ form, as the faster moving isopycnal depressions catch up with the elevations, and short undulations form on the sharpening wavefront. In this process, energy, which originally is distributed more evenly over the internal tidal wave length, becomes concentrated more and more in the short undulations (‘solitons’, ‘undulating internal bores’).
iii. The short undulations also concentrate the shear across the pycnocline, and hence can become unstable. Mixing and turbulence occurs as the short undulations break and dissipate.

With the above concept of internal tides in mind, we have endeavoured to look at the temporal/spatial distribution of energy in The Gully region, and to compare the energy levels and distribution in The Gully region to those in two other locations, namely along longitude 63^{o}30’ W on the Scotian Shelf and along 47^o N on Grand Banks (east of Hibernia site).

The energy is first calculated for each individual cast in a section. There is great variability of energy from cast to cast, especially when the BATFISH is crossing a group of high amplitude waves, whose length scales are typically of order of few hundred metres and similar to BATFISH sampling interval. To smooth out the cast to cast variability, we again average the energy over the same 3 km block length as before and further calculate the mean of the energy in the block over a tidal cycle. It is the geographical distribution of this value that is plotted in Figure 4 for The Gully region, and the same value is compared between different areas.

The energy contours in Figure 4 are in Jm^{-2} and are shown in increments of 1000. Referring back to Figure 1 the values outside the contours are all < 1000. It is obvious that internal tidal energy in The Gully area is largest on the eastern flank of The Gully and the adjacent South West Peak. The maximum value observed exceeds 4000 Jm^{-2}. Across The Gully proper, the values increase from west to east. Typical values across the shelfbreak at 59.50^o W are 200 – 300 Jm^{-2} and approximately twice as large in the easternmost sections. In the Scotian Gulf (63.50^o W) the maximum comparable observed value was 1350 Jm^{-2}, *i.e.* approximately three times smaller than the observed maximum in The Gully area. The observed values on the Grand Banks east of Hibernia are similar to the shelfbreak values at 59.50^o W. The comparison clearly demonstrates that of the three sites considered, the eastern side of The Gully has the largest internal tides, and hence is likely to have highest levels of turbulence and mixing.

Part of the non-linear transformation and dissipation of the propagating internal tide is depicted in Figure 5. In this instance we were tracking a wave group (cf the zig-zag track across the 100 m depth in Figure 1), criss-crossing it at right angles to the wavefront 15 times. In Figure 5 are shown the transects when the ship travelled in the same direction as the waves. Transects in this direction are better sampled and are therefore more reliable. The two curves show the maximum of a 3 km average of energy and the maximum energy in a single cast in the transect. The latter invariably represents the “soliton” of maximum amplitude. We interpret the graphs as showing the concentration of energy in the short undulations (transects 1 – 7), followed by dissipation (transects 7 – 15). The 3 km average and the single cast maximum behave similarly. Between transect 7 and 15 the energy in both has declined by 2/3. The elapsed time between these two transects is ~ 3 h.

Turbulent Dissipation and Mixing

The observed rate of energy dissipation in the most energetic internal tides is

$$0.1\ Wm^{-2} < \text{dissipation rate} < 0.4\ Wm^{-2}$$

Where the lower estimate corresponds to loss of all energy in the course of one tidal cycle, and the higher estimate reflects the energy loss as seen in Figure 5.
Of the above bulk dissipation rate, approximately 20% (Sandstrom and Oakey, 1995) goes into turbulent dissipation. The same authors also found that almost all of the turbulent dissipation took place in the pycnocline, which is typically ~ 10 metres thick. The turbulent dissipation rate

$$\varepsilon = 2 – 8 \times 10^{-6}\ W\ kg^{-1}$$

and the corresponding vertical diffusivity

$$K_z = 1 – 4 \times 10^{-3}\ m^2 s^{-1}$$

From the point of view of mixed layer deepening, the entrainment velocity at the bottom of the mixed layer is related to rate of turbulent dissipation by

$$\text{Rate of turbulent dissipation} = ½\ g\Delta\rho h dh/dt$$

Where **h** is the mixed layer depth. With observed parameters

$$dh/dt = 0.4 – 1.6 \times 10^{-4}\ m/s$$

Referring to Figure 5, between transects 7 and 15, we expect the pycnocline to widen in the 3 hour period by more than a metre. In our previously published work (Sandstrom, Elliott and Cochrane, 1989), the spreading of the turbulent layer had been seen in acoustic backscattering. We note that if we use the lower rate of entrainment (refers to an average over a tidal cycle), it would take approximately one week to exchange the water in the mixed layer (~ 20 metres thick) with water from below the pycnocline.

A comparison with Denman's (1973) estimate of mixed layer erosion at its base by windstress at the sea surface shows that the maximum buoyancy flux in dissipating internal tides is comparable to a 30 ms^{-1} wind blowing. Thus at least in the area of high internal tide energy, as delineated in Figure 4, tidal mixing is the dominant process. The preceding statement applies when conditions for generation of internal tides are favourable, namely the summer/fall season. The water column is then stratified.

Stratification is weak in winter/spring and other mixing processes are expected to dominate.

The vertical diffusivity obtained here is of the same magnitude as the vertical eddy viscosity near the bottom used in tidal model (Han, personal communication), but an order of magnitude greater than what is used at mid-depth.

References

Denman, K. L., A time-dependent model of the upper ocean, *J. Phys. Oceanogr.*, 3, 173-184, 1973.

Sandstrom, H., J. A. Elliott and N. A. Cochrane, Observing groups of solitary internal waves and turbulence with BATFISH and Echo-Sounder, *J. Phys. Oceanogr.*, 19, 987-997, 1989.

Sandstrom, H. and N. S. Oakey, Dissipation in Internal Tides and Solitary Waves, *J. Phys. Oceanogr.*, 25, 604-614, 1995.

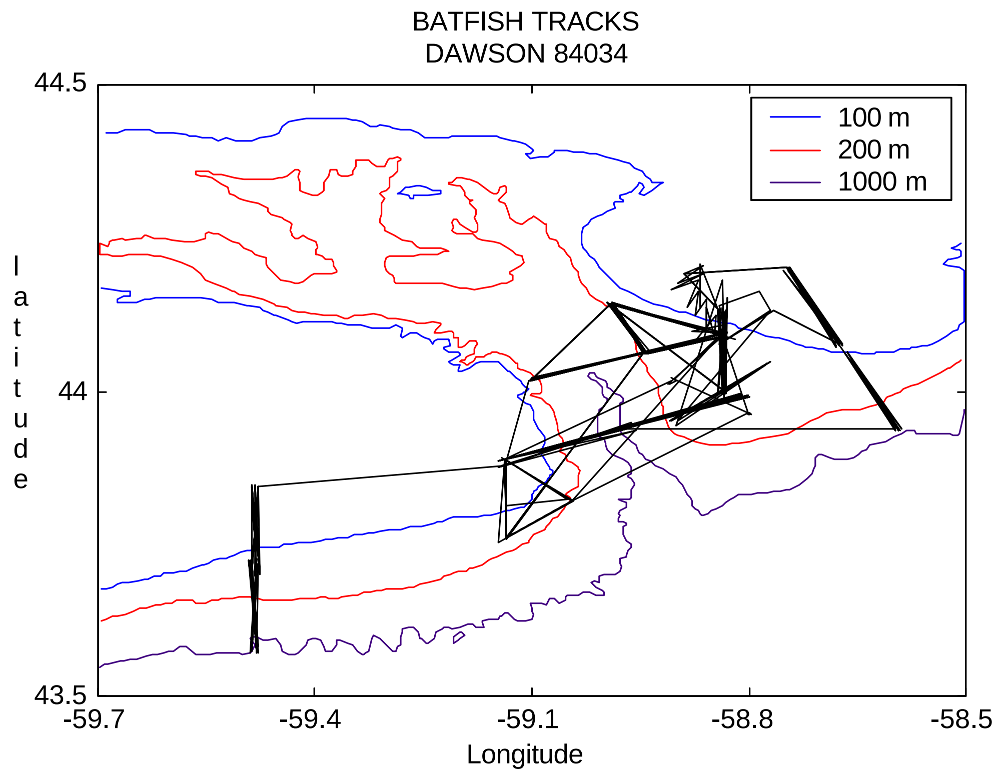


Figure 1: *BATFISH tracks (226 sections) in The Gully region.*

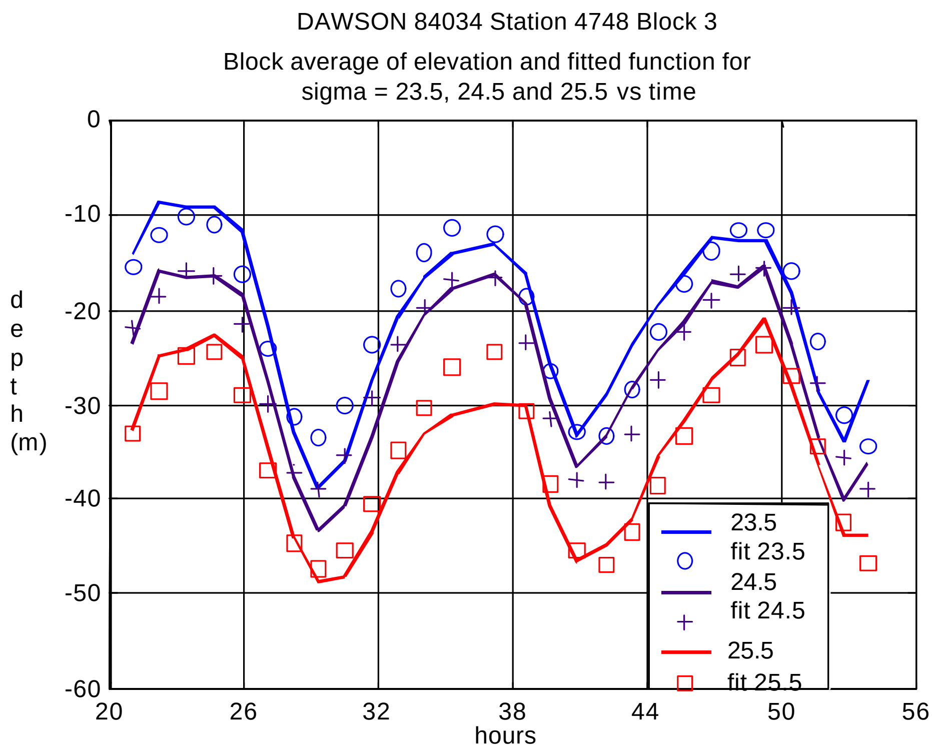


Figure 2: *A BATFISH section on the corner of Banquereau Bank showing the elevation of four isopycnals.*

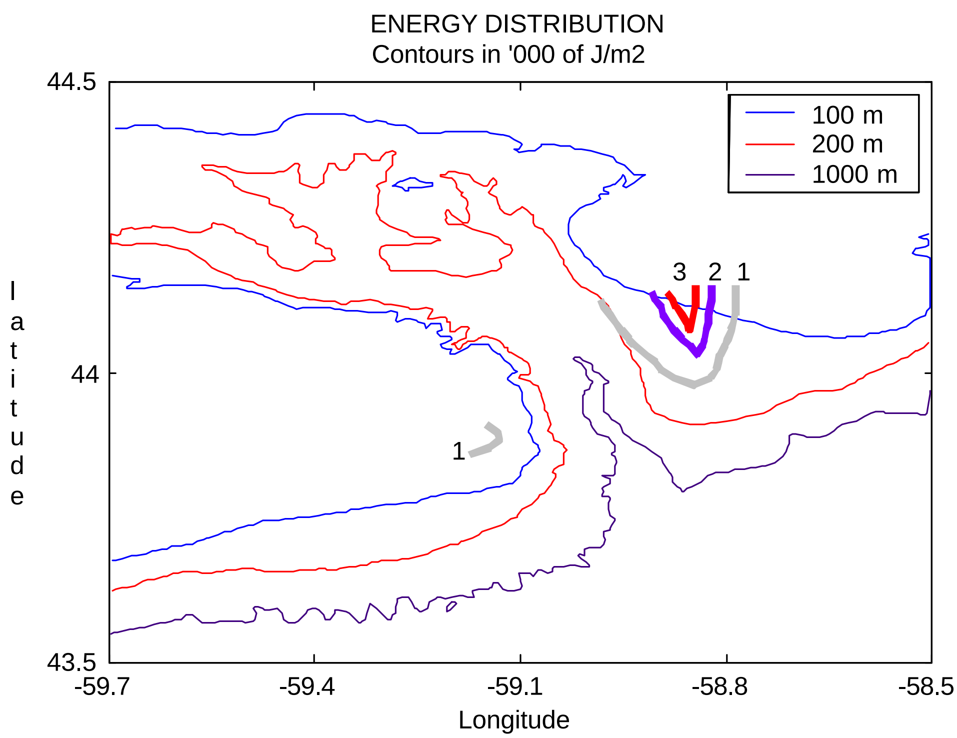


Figure 3: *Time-series of elevations of three isopycnals averaged over a 3 km distance and the corresponding fitting functions*

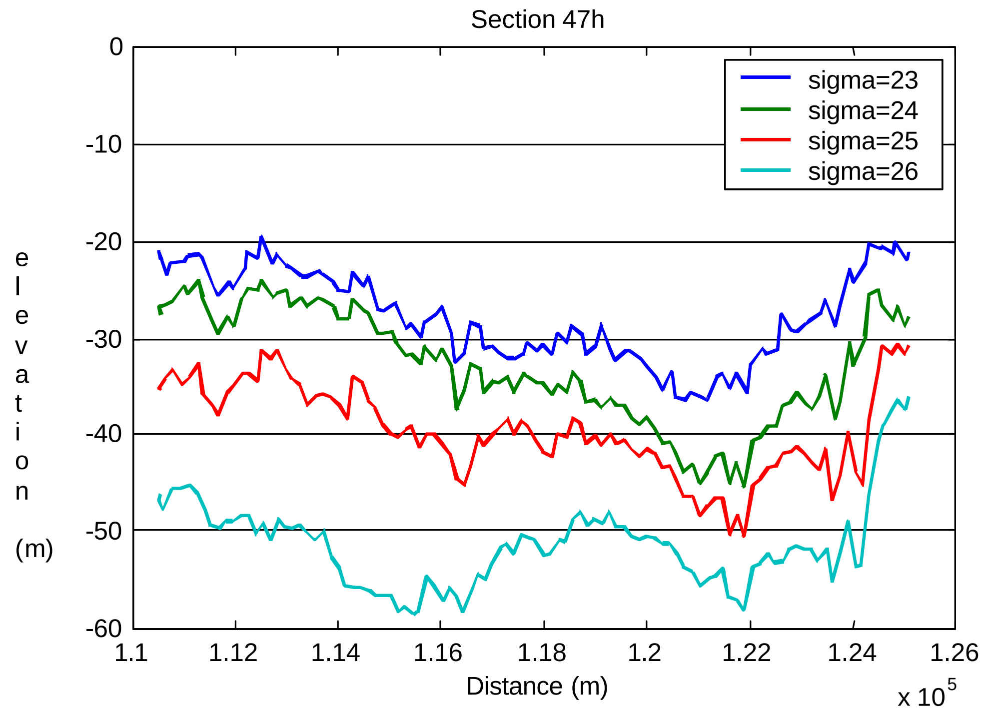


Figure 4: *Energy distribution in and over the flanks of The Gully. Only values exceeding 1000 J/m2 are shown.*

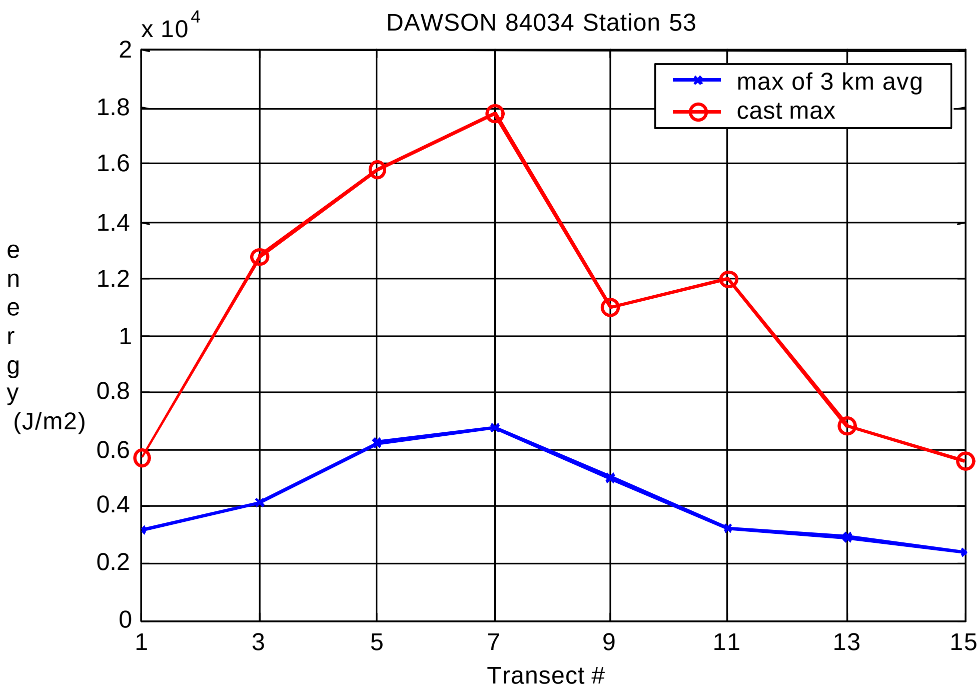


Figure 5: *Growth and dissipation of energy in a group of solitary waves obtained by successive crossings of the waves. Energy maxima are shown for single solitary wave and as averaged over a 3 km distance.*

Nutrient Chemistry in The Gully

P. Yeats

[1]Marine Environmental Sciences Division, Fisheries and Oceans Canada, Bedford Institute of Oceanography, P.O. Box 1006, Dartmouth, NS, B2Y 4A2

The picture of nutrient distributions in The Gully based on data archived in the BIO nutrient database prior to 1997 was described and discussed in The Gully science review (Yeats and Petrie, 1998). A general seasonal description of the nutrient distributions could be developed from the archived data, but variability on small space and time scales could not be assessed. Concurrent physical, chemical and biological oceanographic measurements that would permit an assessment of the role of nutrients in oceanographic processes in The Gully were not available.

An expanded data set for nutrients in The Gully has been collected starting in 1997 using the Atlantic Zone Monitoring Program (AZMP) sampling in The Gully and two cruises conducted by D. Gordon as part of The Gully research program. Both of these programs have also made extensive physical and biological oceanographic measurements. The nutrient data collected in the two year Gully research program are described here.

Surface samples collected while the *Hudson* steamed between stations and traditional hydrographic cast samples were collected on cruises in June 1999 (Cruise 99-012) and June 2000 (Cruise 2000-020). The silicate concentrations observed on the June 2000 surface transects are shown in Figure 1. The figure shows rather uniform concentrations of 0.5 to 0.8 μM silicate concentrations for all of The Gully except for the extreme northwestern region where concentrations reached 1.0 μM. A similar surface transect on the June 1999 cruise showed elevated silicate concentrations (1.1 μM) on the edge of Banquereau at the eastern end of the section, but no elevated concentrations in the inner part of The Gully.

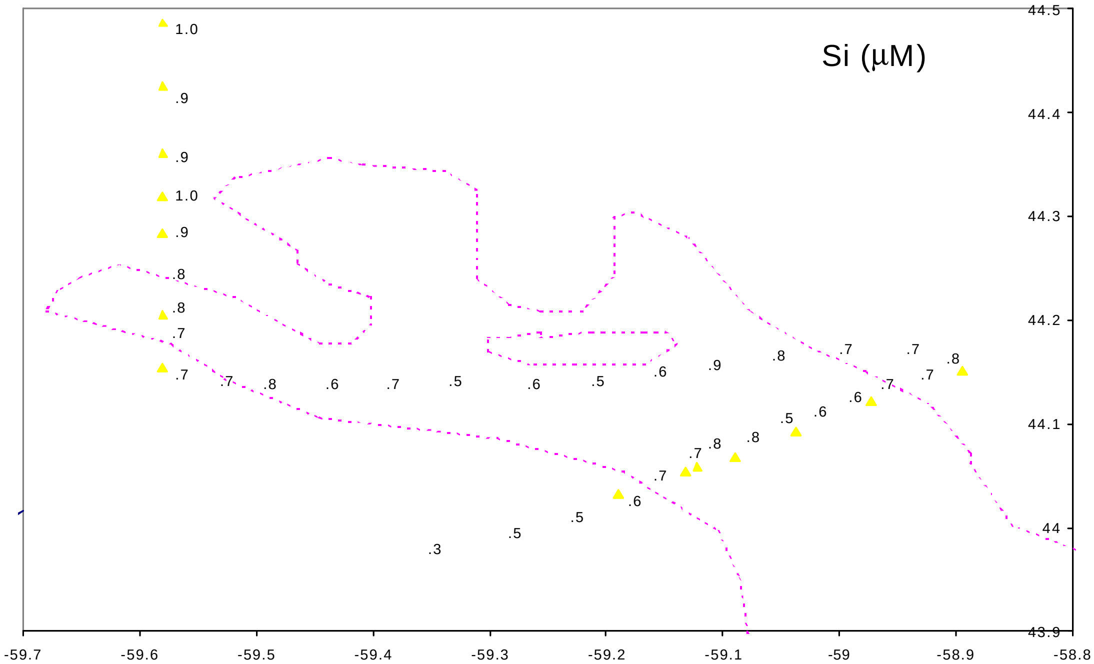


Figure 1: *Surface silicate concentrations in June 2000. Dashed line is 100 m contour.*

The locations for the hydrographic stations on cruise 2000-020 are shown as triangles in Figure 1. Nitrate profiles for stations on the two sections are shown in Figures 2 and 3.

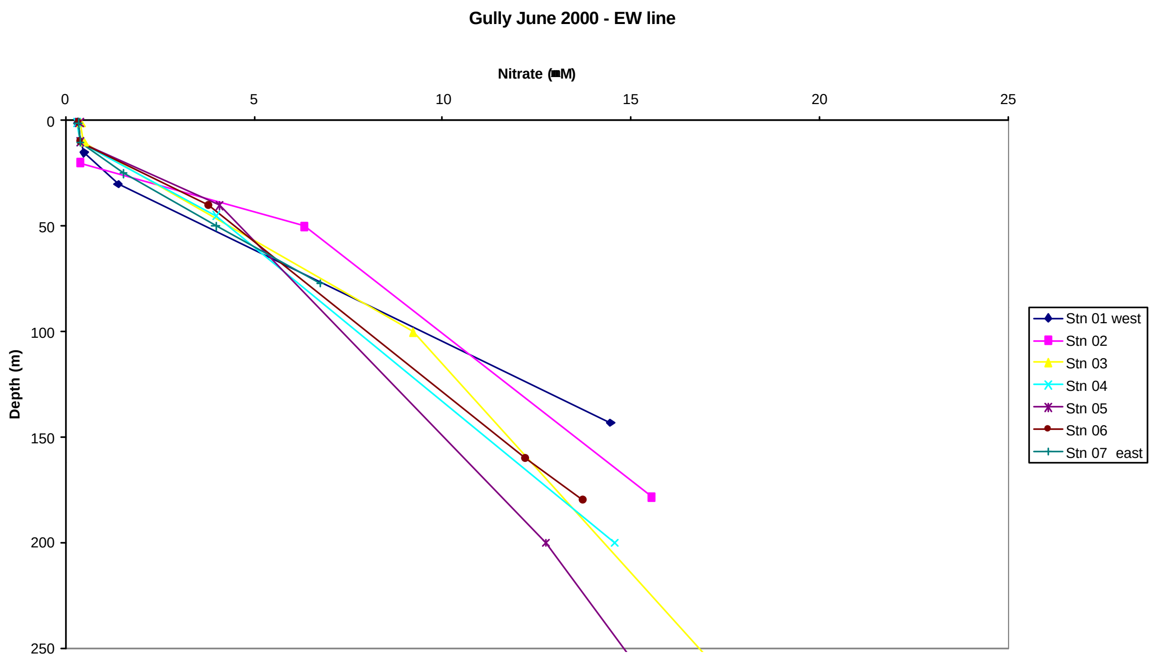


Figure 2: *East-west transect, Cruise 2000-020.*

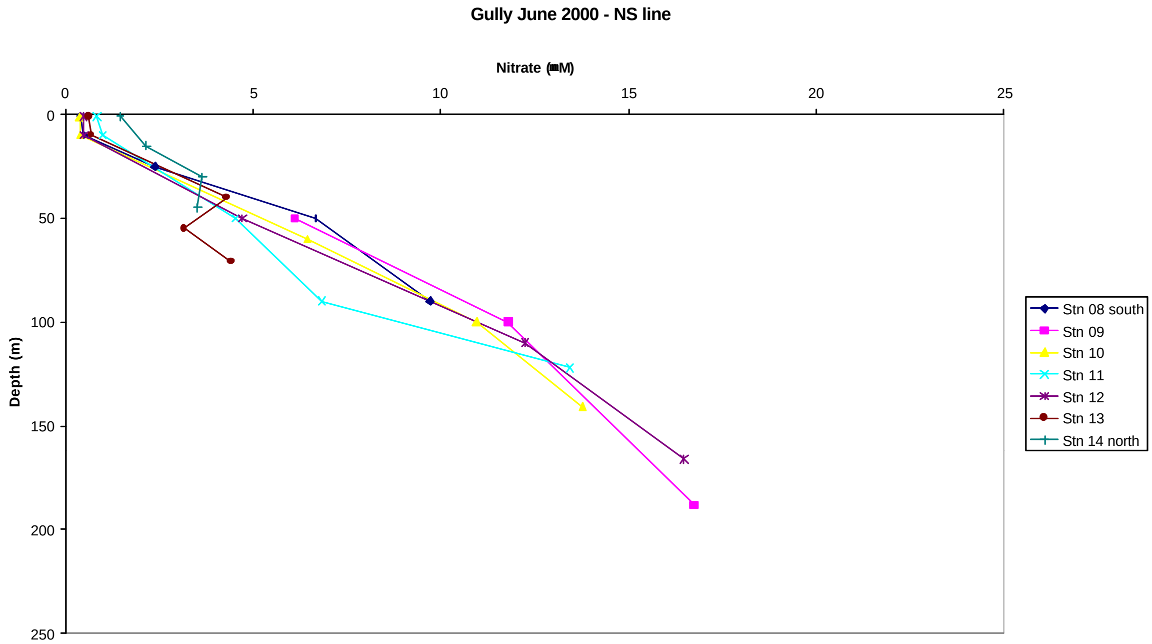


Figure 3: *North-south transect, cruise 2000-020.*

The profiles for the east-west line near the mouth of The Gully (Figure 2) show little indication of any trend across The Gully or any significant difference from the Eastern Scotian Shelf climatological average for June. The north-south line in the inner part of The Gully (Figure 3) shows slightly higher concentrations at any given depth than does the outer line, with the high surface concentrations at the northernmost station consistent with the surface transect results.

Nutrient data were also collected at hydrographic stations on AZMP cruises in April and October of 1999 and 2000. Because the AZMP program also collects samples from the Halifax (Central Scotian Shelf) and Louisbourg (Eastern Scotian Shelf) sections (Mitchell, 2001), these cruises are well suited to comparisons between concentrations in The Gully and those on the adjacent shelves. Nitrate profiles for Cruise 2000-050 are shown in Figure 4. The section runs more or less along the main axis of The Gully from the head of The Gully (Stn 29) to the shelf edge (Stn 32). LL is a composite profile for the stations on the Louisbourg Line around the shelf break. The figure shows the similarity of profiles in The Gully with those on the Louisbourg section.

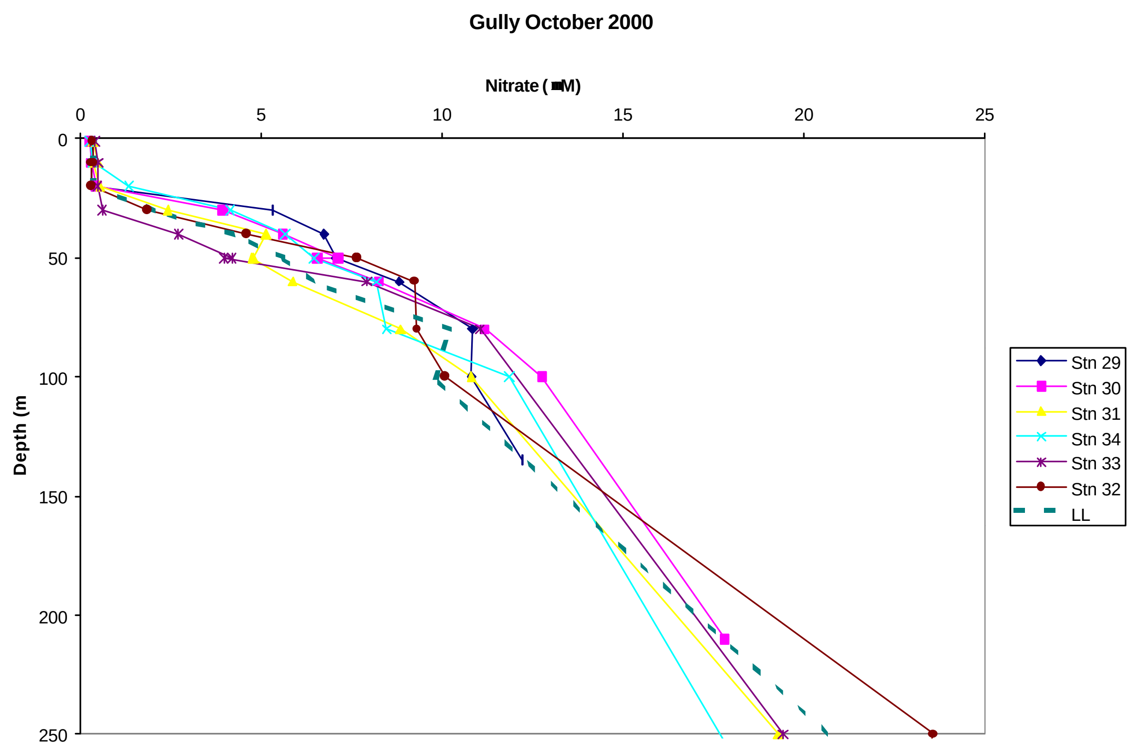


Figure 4: *Nitrate profiles for cruise 2000-050.*

The results presented here are a small fraction of The Gully nutrient data collected in the AZMP and Gully research programs. We now have data for nitrate, phosphate and silicate from 10 cruises covering spring, summer and fall seasons from 1997 to 2000, for an assessment of the variability in nutrient concentrations in The Gully and a comparison of Gully concentrations with those in adjacent shelf edge samples. It should now be possible to assess the importance of nutrient supply to biological production in The Gully.

<u>References</u>

Mitchell, M. 2001. Atlantic Zonal Monitoring Program. In. D. Geddes (ed.). *Bedford Institute of Oceanography 2000*, p. 18-20.

Yeats, P. and B. Petrie. 1998. Chemical Oceanography. In. W.G. Harrison and D.G. Fenton (eds.). A Scientific Review of its Environment and Ecosystem, *Canadian Stock Assessment Secretariat Research Document* 98/83. p. 58-70.

Seasonal Plankton Production in The Gully Ecosystem

P.E. Kepkay, W.G. Harrison, J.B.C. Bugden and C. J. Porter

Biological Oceanography Section, Ocean Sciences Division, Fisheries and Oceans Canada, Bedford Institute of Oceanography, P.O. Box 1006, Dartmouth, NS, B2Y 4A2

Introduction

Ocean ecosystems are responsible for about half of the planet's primary (photosynthetic) production (Hedges 1992; Longhurst *et al.* 1995). A large fraction (70%) of this marine production is concentrated in coastal regions and on continental shelves (Hedges 1992). Given that The Gully has been advanced as a marine protected area (MPA) on the outer edge of the eastern Scotian Shelf, it is important to have an idea of the seasonal variations in production that supply the shelf ecosystem as a whole and The Gully ecosystem in particular.

The primary (light-driven) production of biogenic carbon by the phytoplankton is the foundation of any marine ecosystem. The carbon is food for the animal component of the plankton in the water column (the zooplankton) and for animals in and on the sediment (the benthos). Nearly all estimates of carbon production by the phytoplankton are based on measurements of total or gross production. However, an additional process - respiration - must be accounted for because it can consume a large fraction of the carbon produced. This leads to the requirement that net production be calculated in terms of gross production minus respiration. Net production then becomes the ecologically useful parameter because it is a measure of the carbon that is actually available as food for the rest of the ecosystem.

Three field missions were mounted in the fall of 1999 and during the spring and fall of 2000 to provide information on how much carbon is generated by the phytoplankton to fuel benthic and planktonic ecosystems in The Gully. The data collected on these missions were compared to and contrasted with seasonal estimates of phytoplankton biomass and production by remote sensing. In addition, the balance between gross production and plankton respiration was investigated to provide quantitative estimates of net production that could be compared to independent measurements of carbon inventories in the water column. Together, these data provide some of the basic information required to assess the state of The Gully ecosystem and its capacity to sustain diverse planktonic and benthic communities.

Seasonality of Phytoplankton Biomass and Production

Seasonal composites of SEAWiFs images were created to map surface chlorophyll distribution over the eastern Scotian Shelf during 1998 to 2000 (Figure 1). In terms of the areal distribution of phytoplankton biomass (measured as chlorophyll), The Gully is not appreciably different from the eastern Scotian Shelf as a whole. Composites of earlier CZCS images (dating back to the 1970's) also indicate that the distribution of chlorophyll over the Gully is similar to chlorophyll mapped over a broader scale on the eastern Shelf. Not only does the Gully appear to be part of the general distribution of chlorophyll on the eastern Shelf, it is also included in seasonal variations of surface chlorophyll (Figure 1). One of the most striking features of these variations is the distinct lack of phytoplankton biomass during the summer.

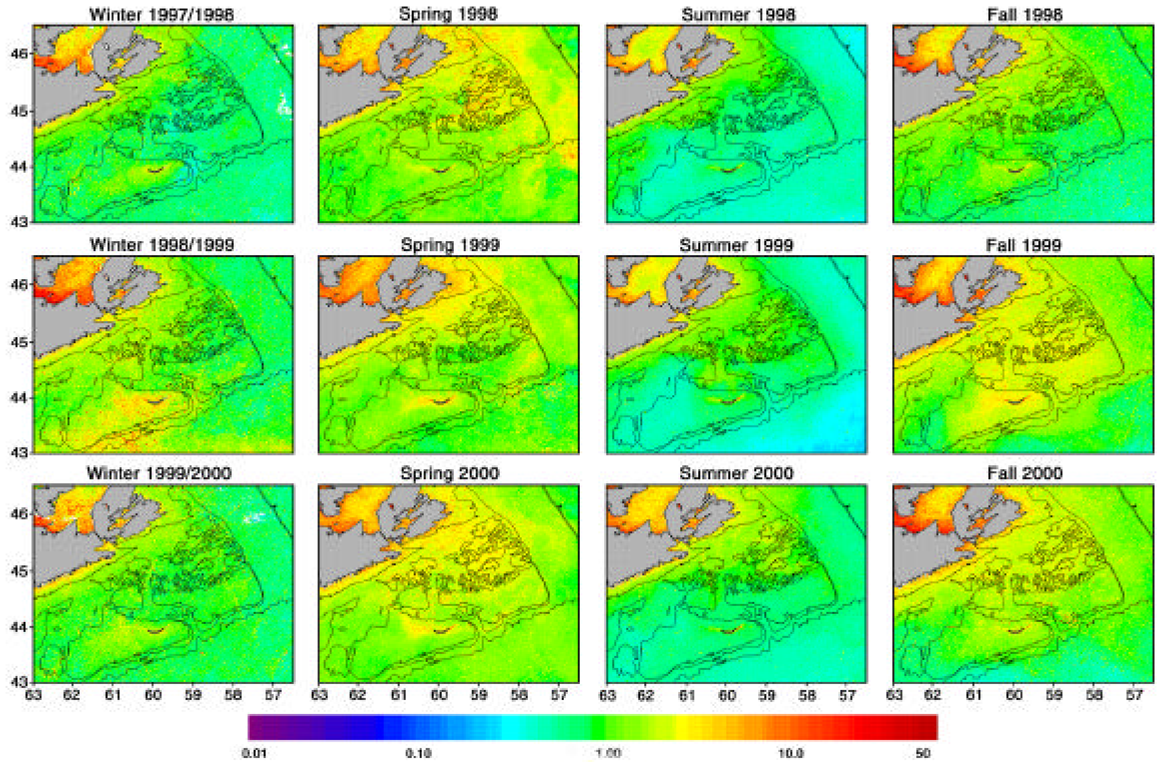


Figure 1: *SeaWiFS satellite seasonal composites of surface chlorophyll concentrations on the eastern Scotian Shelf (1998 -2000). Note the consistent lack of phytoplankton biomass (measured as chlorophyll) in the region during the summer.*

Preliminary and provisional estimates of the seasonal production of phytoplankton are very different from seasonal chlorophyll on the eastern Shelf (Figure 2). Productivity is at a maximum during the summer, whereas chlorophyll is at a maximum during the spring and to a lesser extent during the fall. This leads to the question - Where does the productivity go? A partial answer is that some of the phytoplankton are grazed by the zooplankton (Harrison, 2001). A more complete answer can be obtained if two other factors are taken into account. First, that the seasonal productions in Figure 2 are based on measurements of total, or gross production. Second, that net rather than gross production is the measure of carbon available to fuel the Gully ecosystem. To obtain a quantitative idea of the magnitude of net production, plankton respiration has to be taken into account.

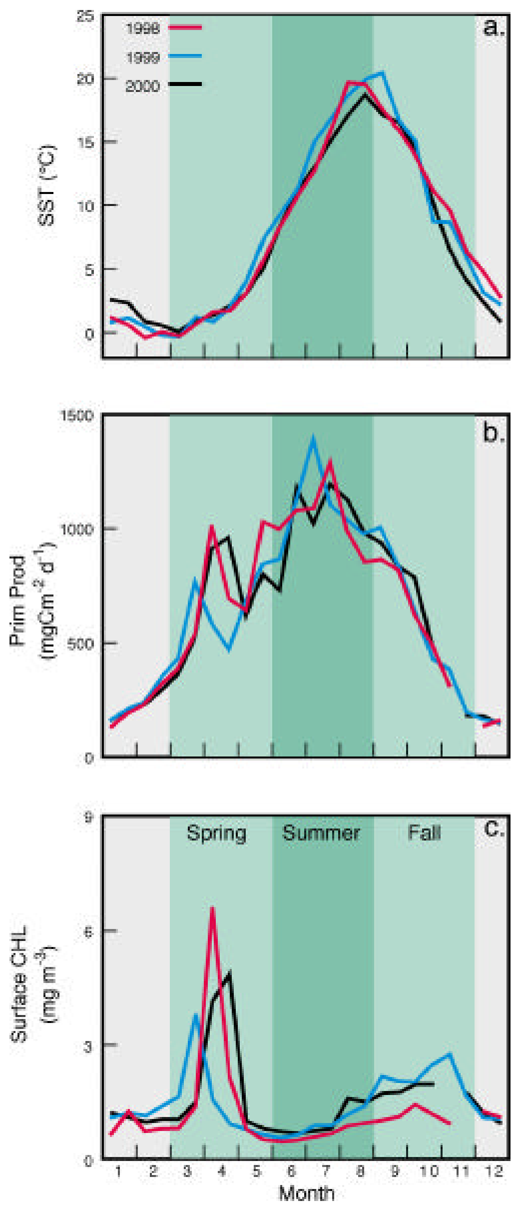


__Figure 2:__ Sea surface temperature (A), phytoplankton production in the photic zone (B) and surface chlorophyll (C) estimated by remote sensing on the eastern Scotian Shelf (1998 - 2000). Note that phytoplankton (chlorophyll) biomass is low when production is high during the summer.

Gross Production, Respiration and Net Production in the Gully

At 4 stations sampled along the axis of the Gully during the fall of 1999, respiration consumed 74 - 93% of the gross production at a depth of 10m (Fig 3). The two processes appeared to be more-or-less 'in balance' with the consumption of carbon by respiration keeping pace with, but not exceeding, the carbon produced (Kepkay 2000). Respiration not only reduced gross production by at least a factor of 4, it also produced a very different distribution of net compared to gross production (Figure 4). On the basis of these calculations, Station 1 (in the trough at the head of the Gully) was the location where net production appeared to be high enough in surface waters to result in the export of relatively large amounts of carbon to the benthos. Farther down the Gully, at Stations 2 and 3 (in the main channel) and at Station 4 (at the mouth), a far smaller fraction of the carbon production was available for export.

Results from 10 m in the fall of 2000 (Figure 5A) were similar to those obtained a year earlier, with net production higher at Station 1. The

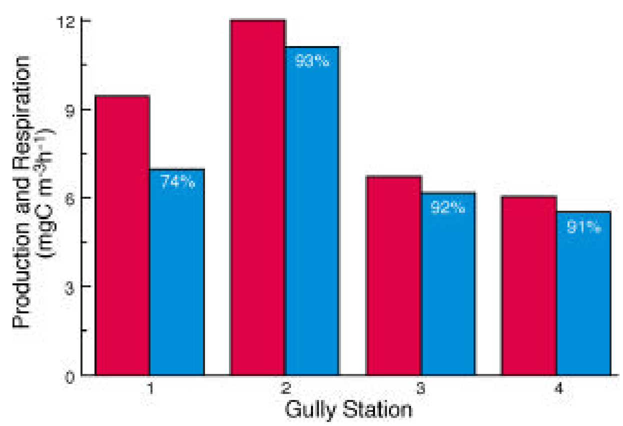


***Figure 3**: Gross production and respiration measured in samples taken from a depth of 10m in Gully surface waters during the fall (Oct 15 and 16) of 1999.*

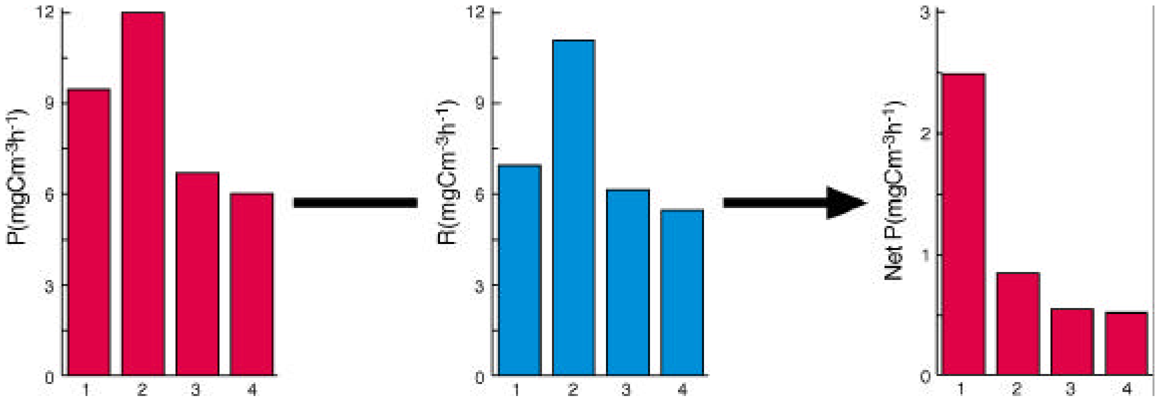


Figure 4: *Net production calculated from gross production minus respiration during the fall of 1999 (data replotted from Figure3). Note the 4-fold decrease and change in distribution of production that is evident when the effect of respiration is taken into account.*

results obtained from light-limited waters taken from a depth of 50 m were very different (Figure 5B). Respiration was predominant throughout, with gross production a small fraction (11 - 39%) of the carbon respired. If nutrients are transported up through similar light-limited regions, they would stand a good chance of first being consumed by respiration before they could fuel production in well-lit surface waters.

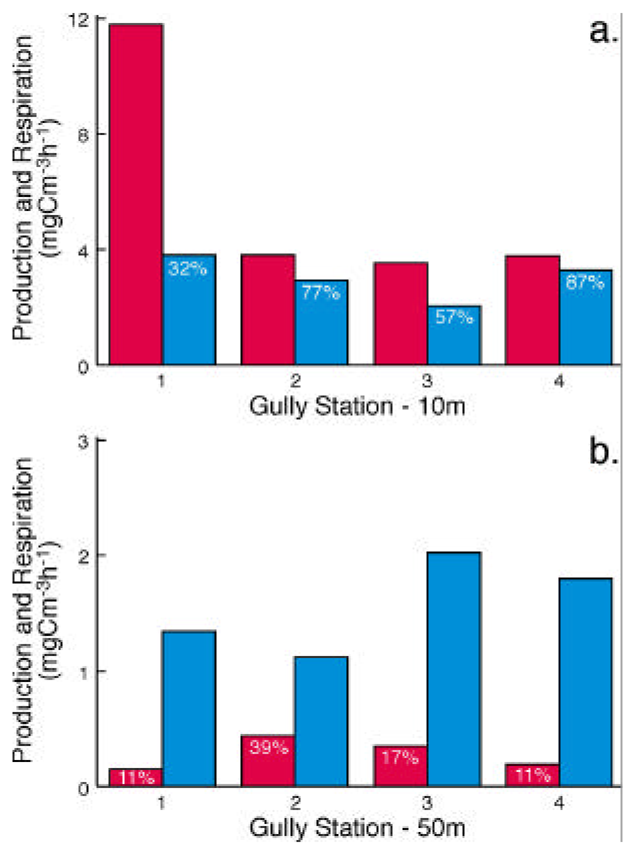


Figure 5: *Gross production and respiration measured in water samples taken from depths of 10 and 50m in the Gully during the fall of 2000. Note the predominance of respiration at 50m where illumination is very low.*

During the spring of 2000, the results from 10 m were very different again from those obtained during the fall. Net production increased from Stations 1 to 3 during the spring (Figure 6), but was high only at Station 1 during the fall. Together, these conclusions lead to one more question - Are seasonal distributions of net production reflected in the carbon inventories of the Gully and the Louisbourg section on the eastern Shelf (Figure 7)?

Carbon Inventories

Total organic carbon (TOC) was identified as the most complete measure of water column carbon inventory. The traditionally-accepted measure of the carbon inventory - particulate organic

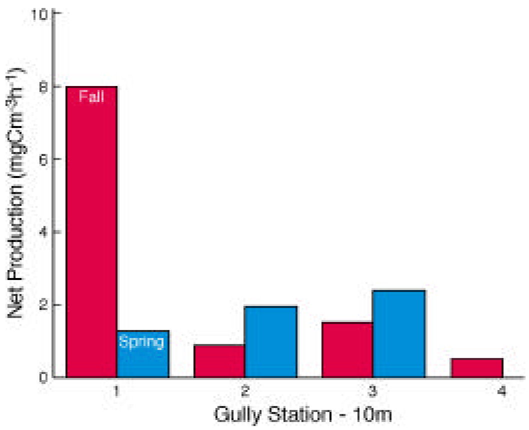


Figure 6: *Net production calculated from measurements made in samples taken from a depth of 10m in Gully surface waters during the spring (April 15 and 16) and fall (Oct 11 and 12) of 2000.*

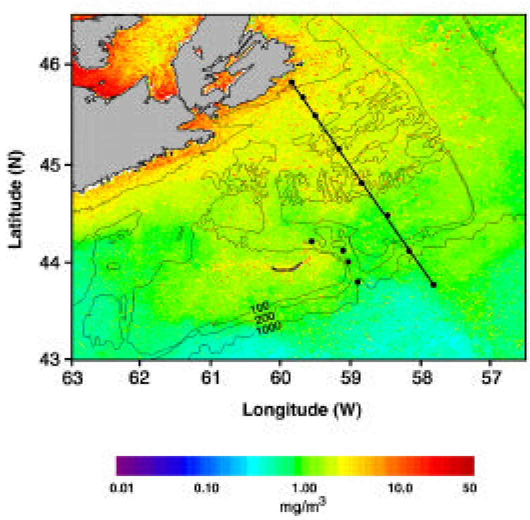


Figure 7: *Location of stations sampled for the total organic carbon (TOC) inventory of the Gully and the Louisbourg section on the eastern Scotian Shelf.*

carbon (POC) - accounted for only 10 - 15% of TOC (Figure 8).

High TOC concentrations in the Gully were confined primarily to the upper 50m of the water column (Figure 9), where phytoplankton production was in operation in the photic zone. Surface water TOCs also followed the seasonality of net production. During the spring, TOC was high along all of the Gully transect (Figure 9A), in agreement with net production increasing from Stations 1 to 3 (Figure 6). High TOCs had retreated shelfwards in the fall (Figure 9B) and were concentrated primarily Station 1 where net production was highest (Figure 6).

TOCs on the Louisbourg section (Figure 10) provided a broader context for interpretation of the Gully results. During the spring of 2000, high TOC extended well out beyond the edge of the Shelf (Figure 10A) and in the fall, retreated back onto the Shelf itself (Figure 10B). This redistribution of TOC would certainly have an affect on the export of carbon to the benthos, with high export over the whole Gully region during the spring and export confined primarily to the trough at the head of the Gully during the fall.

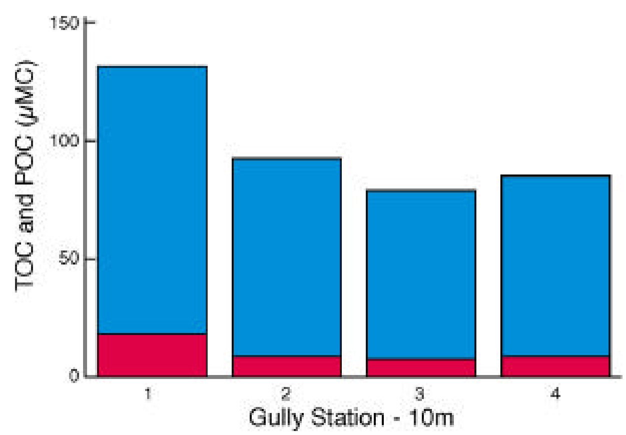


Figure 8: *Total organic carbon (TOC) and particulate organic carbon (POC) in samples taken from a depth of 10m in Gully surface waters. The location of the 4 sampling stations are mapped in Figure 7; POC is delineated in red and the dissolved organic carbon (DOC) component of TOC is delineated in blue.*

Recommendations for Future Work:

1. The physics of horizontal and vertical mixing will be the primary means of moving TOC down and out of the photic zone, just as it would be for moving nutrients up and into the photic zone. Seasonal physical models should include the vertical and horizontal export of TOC out of a zone spanning the upper 50 m of the water column (Figures 9 and 10).

2. In order to calibrate seasonal models of the export of TOC from photic zone to benthos, accurate estimates of vertical particle flux into sediment traps are required, especially during spring and fall blooms.

3. Given that there are now some reasonably good measurements of respiration in surface waters (Figures 3 - 6) and at the sediment-water interface, there is a missing link that should be considered - the effect of mid and deep-water respiration on carbon export.

References

Harrison W.G. (2001). Chemical and Biological Oceanographic conditions in 2000 - Maritimes Region. *DFO Science Stock Status Report* G3-XX(2001), 11 pp.

Hedges J.I. (1992). Global biogeochemical cycles: progress and problems. *Mar. Chem.* 39: 67-93.

Kepkay P.E. (2000). Colloids and the ocean carbon cycle. In: *The Handbook of Environmental Chemistry* Vol. 5 Part D, Marine Chemistry (P. J. Wangersky, ed.), Springer-Verlag, Berlin Heidelberg, pp 35-56.

Longhurst A.L, Sathyendranath S., Platt T., Caverhill C. (1995). An estimate of global primary production in the ocean from satellite radiometer data. *J. Plankton Res*. 17: 1245-1271.

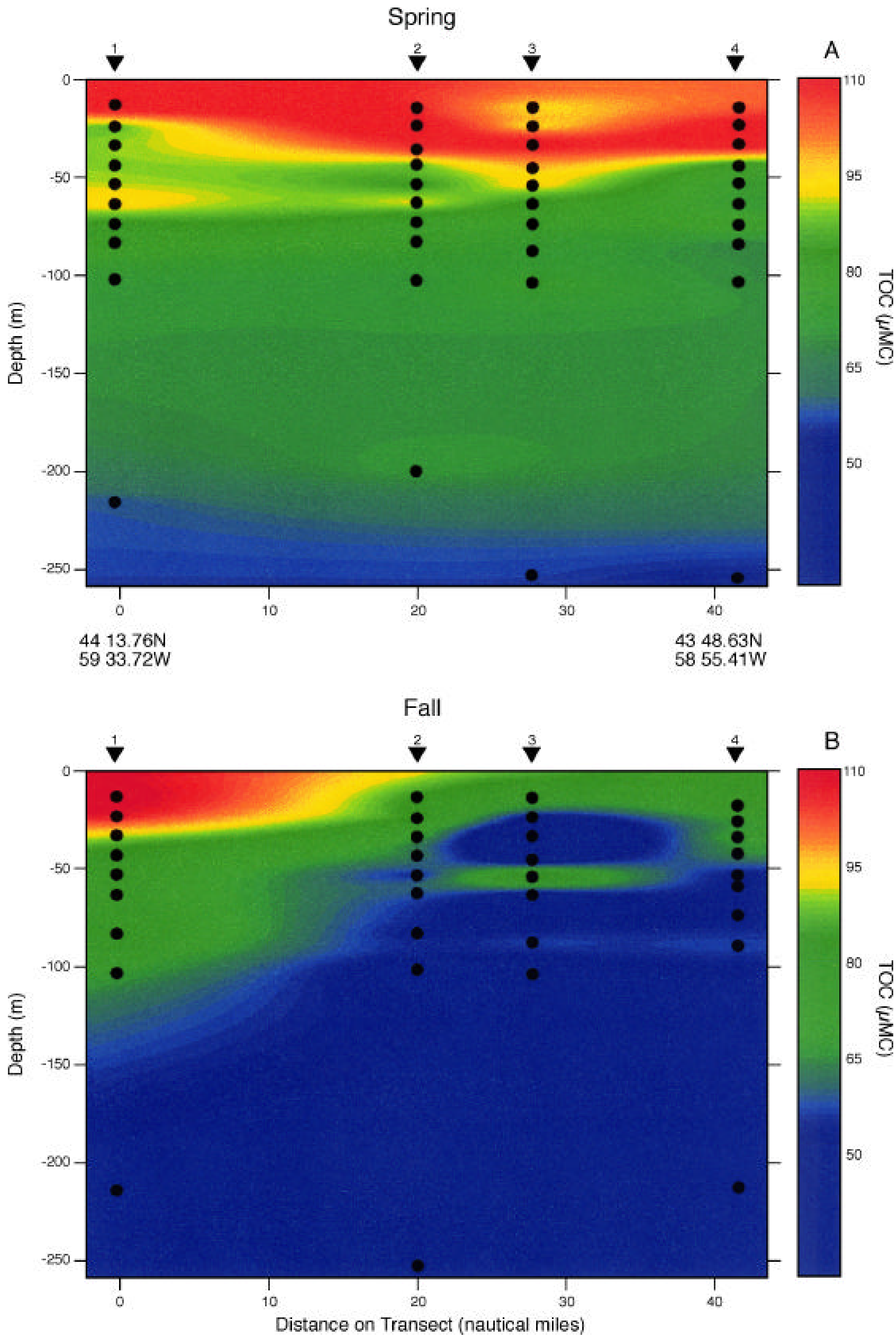


Figure 9: *TOC distributions in the upper 250m of the water column along the Gully transect during the spring (A) and fall (B) of 2000.*

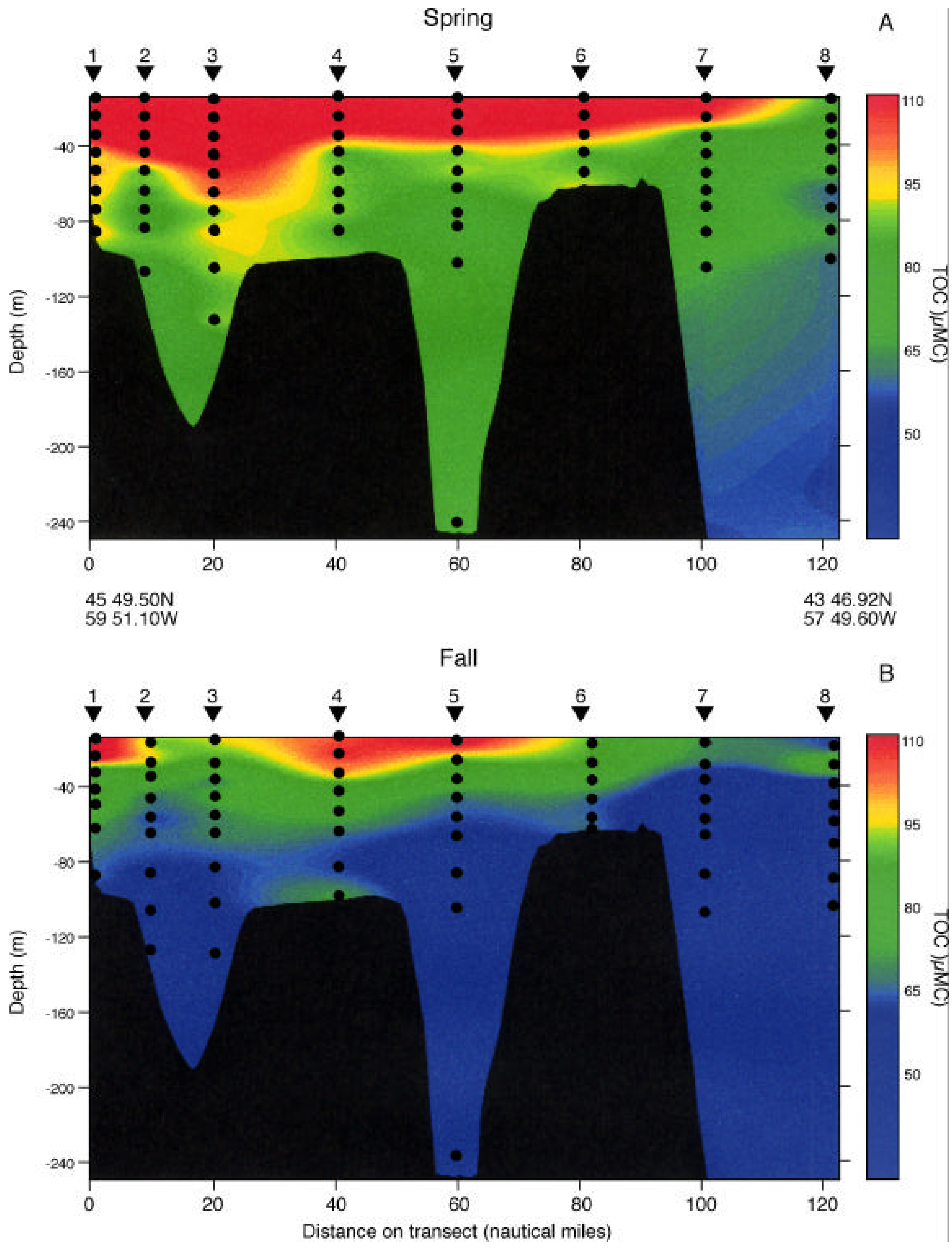


Figure 10: *TOC distributions in the upper 240m of the water column on the Louisbourg section during the spring (A) and fall (B) of 2000*

Seasonal Abundance, Vertical and Geographic Distribution of Mesozooplankton, Macrozooplankton and Micronekton in The Gully

D. Sameoto, N. Cochrane and M. Kennedy

Ocean Sciences Division, Fisheries and Oceans Canada, Bedford Institute of Oceanography, P.O. Box 1006, Dartmouth, NS, B2Y 4A2

Introduction

The purpose of this study was to examine seasonal differences and similarities in the abundance and community structure of the mesozooplankton (animals between 0.2mm and 10mm length), macrozooplankton (animals between 1cm and 4cm) and the micronekton (animals > 4 cm) along the length of The Gully. Comparisons were made between The Gully and regions on the Scotian slope and on the Scotian shelf during the spring (April) and the fall (October/November).

Sampling methods

Acoustic

Gully cruises in Nov. 1999 and Oct. 2000 utilized calibrated hull-mounted transducers on CCGS *Hudson* operating at 12 (EDO 323B, 35^0) and 200 kHz (FURUNO 200B-8, 5.4^0). The April 2000 CCGS *Parizeau* cruise utilized uncalibrated hull-mounted transducers operating at 15 (ELAC LSE 179, 12^0) and 105 kHz (ROSS, 3.5^0). Backscatter data were collected using two DataSonics DFT-210 transceivers incorporating internal TVG and pulse widths of either 2 or 5 ms. Demodulated signal envelopes were digitized 1/10 s at rates of either 2.5 kHz (April & Oct. 2000) or 5 kHz (Nov. 1999). Integrated backscatter levels were computed by echo integration from 20 to 300 m, or to 2 m above bottom if shallower. Each estimate was obtained by averaging over 10 successive transmissions (100 s). The upper integration limit was increased to 30 m when warranted by the appearance of deeply convected surface bubble plumes. For 3-D pictorial backscatter sections, computed levels were averaged in 2 m depth bins and over 10 successive transmissions.

Nets

Three types of zooplankton nets were used to sample the organisms, a 0.75 m diameter 200 µm ring net, 20 cm diameter 200 µm bongo nets, and the BIONESS with 0.5 mouth area and 250 µm mesh nets. The ring and bongo nets were towed in a vertical mode and the BIONESS was towed obliquely at a speed of 1.5 m^{-s}. The BIONESS also contained an Optical Plankton Counter (OPC) that measured the abundance and size distribution of plankton particles during the tows. A strobe light was mounted on the BIONESS. It flashed continuously at a rate of once per 10 sec. with the purpose of blinding organisms and thereby reducing the net avoidance reaction. The ring nets and BIONESS were towed to a maximum depth of 600 m or within 2 m of the bottom. Stratified 50 m interval samples were taken with the BIONESS at four stations in The Gully. All data were entered into the Bio/Chem database.

<u>Results</u>

The high frequency acoustic data (105 & 200 kHz) showed large concentrations of krill in the upper shallow arms of The Gully with lesser concentrations in the central and southern regions of The Gully (Figure 1). The low frequency data indicated large populations of fish in regions where the depth exceeded 500 m (Figure 2). Sampling showed these were the mesopelagic fish *Benthosema glaciale*. Fish echoes were consistently seen near the bottom at depths between 500 and 1000 m. Fish echoes were most concentrated in regions with steep crevices (Figure 2). Sampling showed krill were concentrated in the northern arms of The Gully (Figure 3) while copepods were uniformly distributed throughout The Gully stations. The mesopelagic fish distribution was confined to and centered on the mouth of The Gully (Figure 4). The distribution patterns for these fish were similar in the spring and fall.

Data from other regions of the shelf and slope have not been analysed at this time, therefore it is not possible to draw any conclusions as to the uniqueness of The Gully with respect to the species composition of abundance of animals.

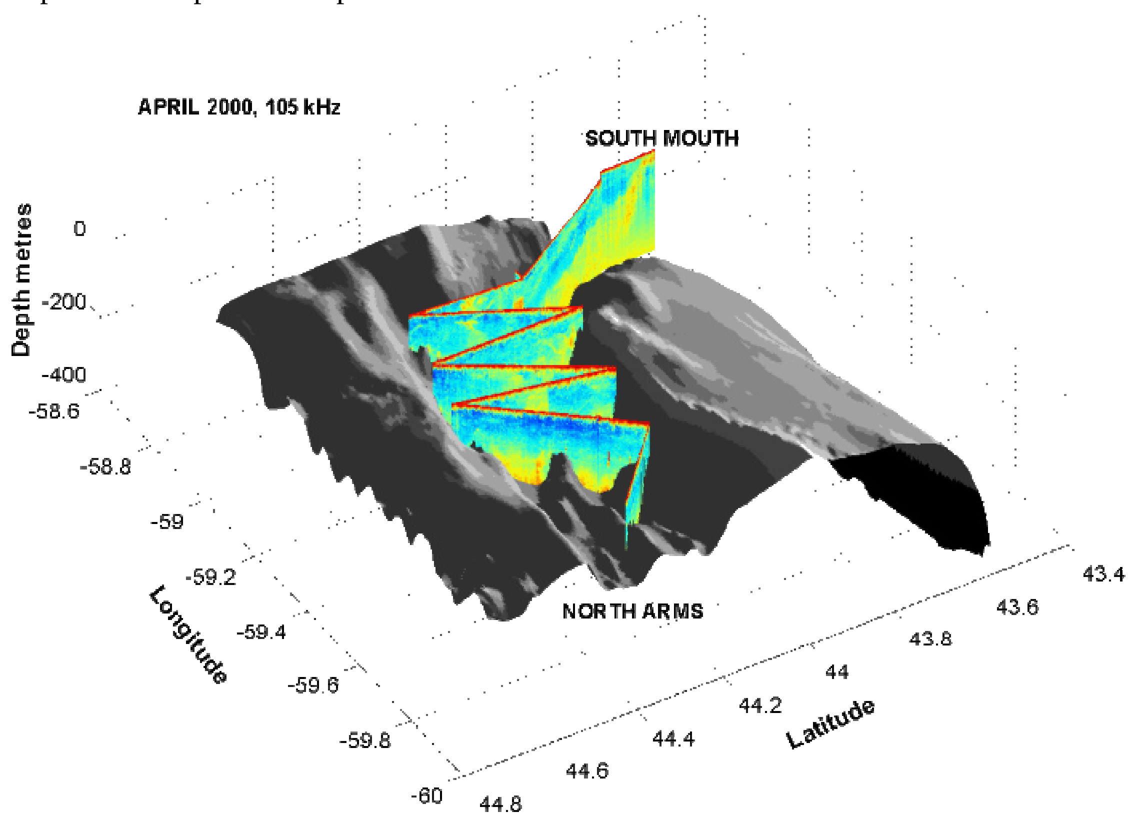


Figure 1: *Acoustic backscattering at 105 kHz shows distribution of krill in the north and mesopelagic fish in the south. Yellow indicates high levels and blue low levels of animals.*

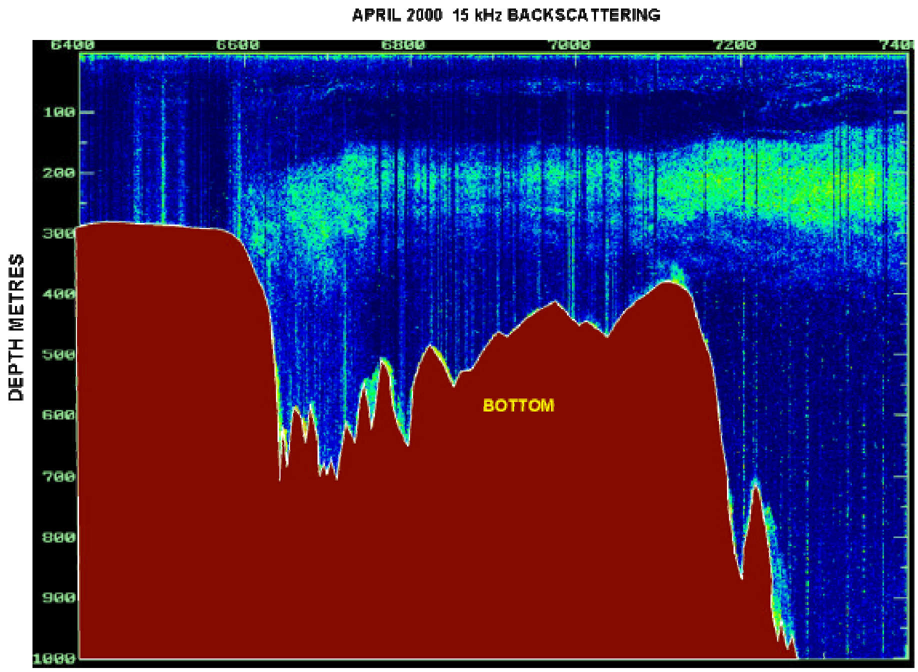


Figure 2*: Acoustic echoes at 15 kHz showing vertical and horizontal distribution of fish in a cross-section of The Gully. Yellow indicates high levels and blue low levels of acoustic backscattering.*

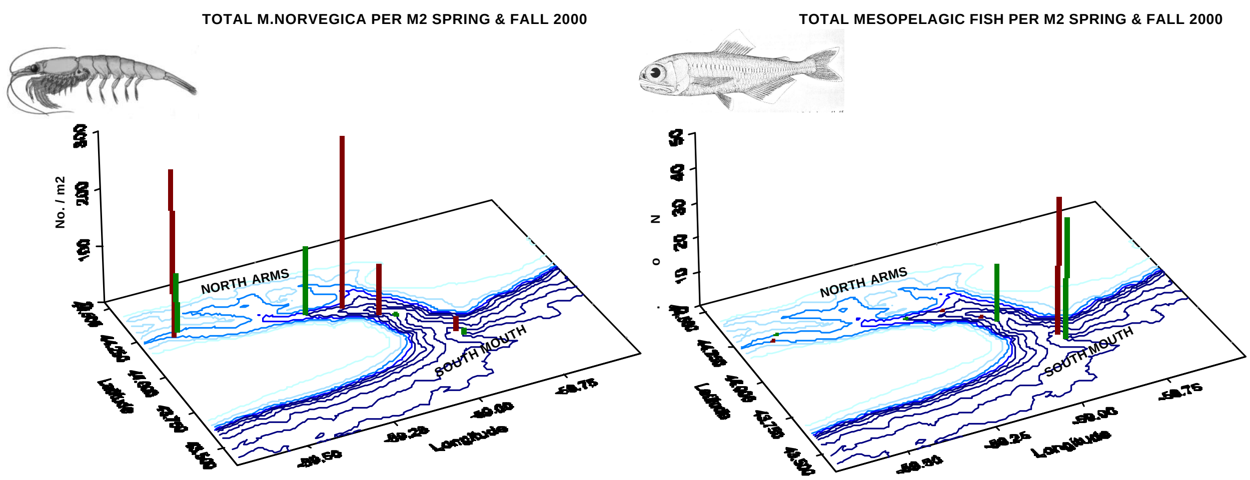


Figure 3: *Abundance of krill and mesopelagic fish on four stations in The Gully in the spring (red) and fall (green).*

OVERVIEW OF RESULTS

K.H. Mann

Emeritus Scientist, Marine Environmental Sciences Division,
Fisheries and Oceans Canada, Bedford Institute of Oceanography, P.O. Box 1006,
Dartmouth, NS, B2Y 4A2

Summary of Presentations

Geology

The Gully is a large shelf-edge canyon on the eastern Scotian Shelf, unique among canyons of the Eastern Canadian margin because of its great depth, steep slopes and extension far back onto the continental shelf. It was formed from a combination of fluvial, glacial ice and glacial meltwater erosion occurring mainly 150 - 450K years ago. It is cut into Tertiary bedrock in the deeper sections, and covered with thick quaternary glaciomarine sediments in the shallower parts.

G. Fader presented results of new multibeam bathymetry data, integrated with previously collected seismic reflection profiles, sidescan sonograms, bottom samples, and video and photographic images. Particular attention was paid to the inner Gully, to depths of 400 m.

The head of The Gully is bifurcated into two channels, a minor one which extends to the north and the major one extending to the northwest. These channels are floored with rippled sand and organic floc accumulated in the troughs of the bedforms. Seismic reflection profiles show many buried and infilled channels, indicating that The Gully has shifted its location many times in the past. Nine major feeder canyons enter The Gully from the Sable Island Bank to the south and show evidence of active transport of sand from the Bank. No feeder canyons enter from the Banquereau to the north and east.

Between 600 m and 800 m depth there is evidence of erosion and sedimentation by grounded glaciers, and in shallower depths there are pits resulting from iceberg grounding. Pockmarks, believed to be gas-escape vents, are particularly abundant in the southwest Gully, north of the area of iceberg furrows and pits. In the northwest and northeast inner Gully between 200 and 400 m, there are large areas of sandwaves up to 11 m in height. Their structure indicates transport of sand down The Gully.

There is much work to be done to ground-truth the interpretations of backscatter information, and to provide a better understanding of sediment dynamics.

Physical Oceanography

Seasonal-mean circulation and tidal currents in The Gully were investigated by means of hydrodynamic models initialized and constrained with observational temperature and salinity data and evaluated against moored current measurements. The main feature of the model solutions for seasonal-mean circulation, as presented by G. Han, was a strong south-westward flow along the shelf edge, with greatest strength in fall and winter. Some of that flow was steered into The Gully along its northern side and out along its southern side, forming a partial cyclonic gyre. The Spring solution showed on-shelf transport extending across most of The Gully and providing a cross-shelf supply to the inner shelf.

The main features of the horizontal tidal current models were that the M2 and K1 currents were strong over Sable Island Bank and Banquereau, but weak in The Gully. The vertical tidal current models indicated great complexity, probably resulting from internal tidally generated waves (see below). There were marked discrepancies between model predictions and observational data. There appeared to be the possibility of strong vertical mixing in the water column of The Gully, but better models and more field data are needed to confirm this.

Tidal mixing and internal waves were investigated by re-analyzing data collected in 1984. The general understanding of internal waves at the shelf edge is as follows. The interaction of tidal currents with the steep bathymetry at the upper continental slope generates both shoreward and offshore propagating waves at the interface between the mixed layer and the deeper water. The energies of the shoreward moving waves are seen to be considerably larger than the energies of the offshore component. The shoreward propagating waves develop a steep leading edge with short undulations known as solitons or undulating internal bores. The latter tend to become unstable and generate mixing across the pycnocline. The internal waves are often of sufficient amplitude to break the surface, giving rise to changed patterns of surface roughness and making it possible to track the wave groups with a ship and run repeated crossings with BATFISH or other instrumentation. Note that these processes only operate as described when the water column is stratified.

H. Sandstrom showed that from the amplitude of the internal waves and accompanying CTD data, the energy of the waves could be calculated. Internal tidal energy was found to be greatest on the eastern flank of The Gully, with a maximum value over 4,000 Jm^{-2}. For comparison, the greatest value observed in the Scotian Gulf was 1350 Jm^{-2}, *i.e.* approximately three times smaller than the observed maximum in The Gully area. In The Gully proper, typical values were 200-300 Jm^{-2} on the western side and approximately twice that value on the eastern side. On the shelf break of the Grand Bank, typical values are about the same as on the western side of The Gully. From these figures it is reasonable to conclude that waters in The Gully experience enhanced vertical mixing in summer and fall as a result of tidally generated internal waves. This leads to the idea that there is vertical transport of nutrients from below the pycnocline during periods of stratification, and that one might expect to find enhanced phytoplankton production.

Nutrient Chemistry

P. Yeats presented a partial analysis of new data on nutrients in the waters of The Gully. Vertical profiles of nitrate along a line near the mouth of The Gully showed little indication of any trend, and no significant difference from the average for the eastern Scotian Shelf. A north-south transect across the inner Gully showed slightly higher concentrations of nitrate for any given depth, compared with the mouth of The Gully.

Samples taken on two occasions along the axis of The Gully showed values similar to those obtained on the eastern Scotian Shelf off Louisbourg. It was emphasized that only a small fraction of the nutrient samples taken between 1997 and 2000 have been analyzed. Clearly, there is as yet no evidence of enhanced nutrient concentration resulting from internal wave activity.

Planktonic Primary Production

Satellite images of chlorophyll over the eastern Scotian Shelf during 1998 to 2000 indicate that the water over The Gully does not show higher phytoplankton biomass than adjacent waters. It is noteworthy that the biomass of phytoplankton is low over the whole area during summer.

P. Kepkay showed that when net production (gross production minus respiration) was calculated for 10 m depth in the fall of 1999 at four stations along the length of The Gully, the station at the head of The Gully has about three times the production of other stations. This indicates a potential for export of organic carbon down the axis of The Gully. Measurements of total organic carbon (POM + DOM) confirmed that in the fall the station at the head of The Gully had the greatest carbon inventory. However, in spring, TOC was high all along the axis of The Gully, as it was along a transect on the shelf off Louisbourg. These features should be considered in attempting to model the fixation and distribution of carbon in The Gully.

Further work suggested by P. Kepkay includes:

- Elucidating the physics of horizontal and vertical mixing in The Gully, in order to be able to make seasonal models of the upwelling of nutrients and the downward export of TOC towards the benthos.
- Calibrating these models by making accurate estimates of vertical particle flux, using sediment traps.
- Studying the effect of mid- and deep-water respiration on carbon export from the mixed layer to the benthos.

Mesozooplankton, Macrozooplankton and Micronekton

D. Sameoto reported on sampling of zooplankton over the size range 0.2 mm to greater than 4 mm in The Gully, using acoustic methods and nets. Similar results were obtained in spring and fall. Copepods were uniformly distributed throughout The Gully. There were large concentrations of krill in the upper shallow arms of The Gully with lesser concentrations in the central and southern regions. At depths greater than 500m, around the mouth of The Gully, there were large concentrations of mesopelagic fish, *Benthosema* *glaciale*. Between 500 m and 1000 m within The Gully, fish echoes were consistently seen near the bottom, and were most concentrated in regions with steep crevices.

Similar samples were taken elsewhere on the shelf and slope, but have not yet been analyzed.

Benthos

V. Kostylev reported an analysis of video and photographic imagery collected at 92 benthic stations in The Gully, (79 Campod stations, 8 Benthos camera stations and 5 Videograb stations). Cluster analysis distinguished seven groups of co-occurring common species:

1. Deep-water species found mostly in the mouth of The Gully, and on canyon walls below 600m. Most common were large brittle stars, banded coral, sea whips, soft corals and anemones.
2. Species characteristic of gravel in deep-water (250-650 m), found along the edge of the main canyon. Most common are an infaunal brittlestar, daisy-top anemones sponges, chitons and crinoids.
3. Species found on fine-grained glaciomarine sediments in the upper Gully at 130-410 m. Most common animals are cerianthid anemones, shrimps, burrowing anemones, brittlestars and tubicolous polychaetes. In the same photographs, krill, flounders and grenadiers are often seen.
4. Sand-dwelling organisms found at 50-300 m depths on top of the banks. The assemblage includes sand dollars, ophiuroids, tubicolous polychaetes, hermit crabs and spider crabs. Sand lance are often present.
5. Species inhabiting the soft sediments interspersed with patches of cobbles and boulders on the fringes of tributary canyons and the main canyon at 200-600 m. Included are protozoan *Bathysyphon* sp., burrowing brittlestars, soft corals, anemones, sponges and sea feathers.
6. A species assemblage found on gravelly habitats on winnowed till, at 100-500 m. Most common are sponges, tunicates, bryozoans, stalked hydrozoans, sabellid worms and phoronids. Whelks crawl on the surface.
7. A community found on poorly sorted gravelly sediment, on tops of deeper banks at 100-500m. There is much overlap with No. 6, and the dominant species are brachiopods, white encrusting sponges, anemones and serpullid worms.

While drawing attention to the limitations of the sampling, (only megafauna visible at the surface were included, and the deep areas were badly undersampled), the author drew some tentative conclusions about diversity. The highest diversity was on hard substrates of glacial origin along the edges of the channels. Soft alcyonacean and hard gorgonian corals were common here. These areas also attracted large populations of groundfish, possibly because they were areas of high turbulent exchange. Species richness was at its maximum around 180 m and declined steadily towards 800 m, after which there was a very steep decline. The beds of the channels and of the main Gully were of low species diversity, possibly because there was movement of sediment down The Gully.

Fauna of the upper Gully is similar to that found on the outer banks elsewhere on the Scotian Shelf.

Biomass and Metabolism of the Benthos

B. Hargrave used a subset of photographic images from 31 Campod and Benthos camera stations, representing inner and outer parts of The Gully, to estimate the biomass of benthic organisms per unit area of bottom. Organism sizes were determined from the images, and relation of biomass to size was determined from volume conversion factors measured with fresh or frozen specimens of various taxa. Respiration was measured on freshly collected specimens on board ship.

The amount of hard substrate in the images varied from 0% to 97.6%. There was a clear correlation between biomass and the amount of hard substrate. When stations were divided into 3 groups, (a) >50% hard substrate, (b) 1-50% hard substrate; and (c) <1% hard substrate, the mean biomasses (g m^{-2}) were (a) 73.6; (b) 52.7; and (c) 38.5. The corresponding amounts of respiration (ml O_2 m^{-2} d^{-1}) were (a) 32.8; (b) 20.4 and (c) 15.2. Turnover times in days (ratio of calories respired to calories in biomass) was lowest in group (a), intermediate in group (b) and longest in group (c) stations. The figures were (a) 338 (b) 399 and (c) 616.

It was postulated that the amount of hard substrate was proportional to the amount of current over the bottom, and that the higher biomasses in the samples with the higher amount of hard substrate could be attributed to a better transport of organic particles into the area for the nutrition of filter feeders.

When stations with >50% hard substrate were grouped according to distance from the head of The Gully, the highest biomass occurred near the head of The Gully, and decreased as one passed down The Gully. The highest biomass values for epifauna were higher than the values for total fauna obtained by grab sampling on the adjacent banks. Sponges, anemones and brachiopods dominated the high biomass communities near the head of The Gully. In deeper water, echinoderms and hard and soft corals dominated the attached epifauna on hard substrates.

Overview of The Gully Ecosystem

We know from previous meetings that The Gully is used by up to 13 species of whales, and that the densities of large whales are higher in The Gully than elsewhere along the edge of the Scotian Shelf. It is estimated that 10-30 sperm whales inhabit the northern end of The Gully at depths of 200-400m. At any given time, over 100 Northern bottlenose whales are in The Gully, and they consistently dive to feed near the bottom at about 1000 m depth. They constitute about half of the total known population of this species. The Gully is known as a rich fishing ground for both groundfish and pelagics.

Doug Sameoto's recent data show that mesopelagic fish and euphausiids are particularly abundant.

This information and other information from comparable canyons indicate that biological productivity is probably higher in The Gully ecosystem than on other parts of the Scotian shelf and slope. How far have we come in explaining this, and how much more information is needed?

The phytoplankton biomass needed to support above-average production in the food web could come either from *in situ* production or from The Gully acting as a trap for phytoplankton transported from outside. The most probable mechanisms for enhanced phytoplankton production *in situ* would be that the upward mixing of nutrients, stimulated by the breaking of tidally-driven internal waves, provides the nutrient base for the phytoplankton. Hal Sandstrom's data show that there is very high mixing energy on the eastern flank of The Gully and on the eastern side of The Gully floor. Satellite images of chlorophyll have not detected any enhancement in surface waters over The Gully, but it is possible that there is enhancement at shorter time scales or at depths too great for the satellites to detect.

Likewise, the water samples that have so far been analyzed show only limited evidence of enhancement of dissolved nitrogen in the water over The Gully. More samples are needed, both from The Gully and particularly from the adjacent shelf and slope, so that detailed comparisons can be made. It is possible that there is enhancement of nutrients on each tidal cycle in summer and fall, and that these nutrients are quickly taken up by the phytoplankton. To test this hypothesis, a series of samples over a tidal cycle would be needed.

Paul Kepkay's study in which he reported on net photosynthesis, the difference between gross photosynthesis and respiration, showed that in the fall the station at the head of The Gully had about three times the rate of net production of stations further down in The Gully. This may be part of the way in which secondary production in The Gully is enriched.

The second possibility is that The Gully acts as a natural trap for primary production transported from outside. Models of the seasonal-mean circulation show a strong south-west flow along the shelf edge, part of which is steered by the topography to enter The Gully on the northern side and out along the southern side. Horizontal tidal currents were shown to be strong over Sable Island Bank and Banquereau, but weak in The Gully. The quieter waters of The Gully may facilitate the settling out of phytoplankton biomass, so that The Gully functions as a trap. As Paul Kepkay suggested, the deployment of sediment traps in The Gully would help determine the input of primary production to the benthos.

Although copepods were uniformly distributed throughout The Gully, there were large populations of krill concentrated particularly in the upper arms, but also in central and southern regions. These may well be an important component of the food web supporting marine mammals.

Hard substrates of glacial origin along the edges of The Gully are the site of communities of benthos with the highest species diversity and highest biomass. It seems likely that these are areas of active water movement, bringing large amounts of food in suspension to filter-feeding organisms including sponges, tunicates, and anemones, with soft and hard corals. These were also sites of aggregations of fish.

One of the notable features of The Gully is the great diversity of habitat, which provides opportunity for a good diversity of benthic invertebrates. An area at mid-depth in the Gully, called Hell’s Kitchen, is well known to fishermen for its assemblages of corals.

Conclusions

The Gully, the largest canyon on the eastern seaboard of North America, is known to be an important habitat for euphausiids, fish and marine mammals, but we do not yet have enough evidence to explain why this site is important for them. To know and understand this site better, it would be good to have more detailed geophysical descriptions.

It seems probable that primary production is enhanced by the mixing action of tidally driven internal waves, and that it traps plankton carried in by the mean flow travelling south along the edge of the shelf. It is important to continue the analysis of water samples and faunal samples taken both on the adjoining banks and in The Gully area, to establish whether the canyon has enhanced productivity. It would be desirable to get more detailed information on the seasonal dynamics of the water in the canyon, with particular reference to the effect of internal waves. To understand the transfer of primary production from the mixed layer to the depths of the canyon, it would be desirable to have a program of sampling with sediment traps at various depths in the water column.

There is still much to be learned about the epibenthos, especially in the seriously undersampled deep waters near the canyon mouth. It would be desirable to have information on the infauna of muddy, sandy and gravelly habitats.

When information is more complete, we can hope to understand what it is about the canyon that is important to the species we especially value, such as whales, fish and the corals. Only then can a well-informed management plan be drawn up that will give priority to protecting the key features of this unique environment.

SUMMARY OF DISCUSSION

D.C. Gordon Jr. [1] and D.G. Fenton[2],

[1]Marine Environmental Sciences Division, Fisheries and Oceans Canada, Bedford Institute of Oceanography, P.O. Box 1006, Dartmouth, NS, B2Y 4A2

[2]Oceans and Coastal Management Division, Fisheries and Oceans Canada, Bedford Institute of Oceanography, P.O. Box 1006, Dartmouth, NS, B2Y 4A2

The open discussion at the end of the day was directed by three general questions posed to the presenters: 1) What have we learned about The Gully ecosystem over the past two years, 2) What are the continuing information gaps, and 3) How can these gaps be filled?

The discussion was broad and diverse and in some cases included differing opinions between scientists and other participants. Not all questions could be addressed during the session given the incomplete representation of expertise on some topics, *e.g.* cetaceans. Individual excerpts from the discussion are highlighted below:

- There is still some debate over the uniqueness of The Gully ecosystem. Participants acknowledged that it clearly is an important habitat for the Northern bottlenose whale and there are a wide variety of contrasting habitats in a relatively small geographic area.
- The benthic assemblages observed in The Gully are not “unique”. The same assemblages are observed in nearby areas. However, more comparative observations are needed from other areas.
- There was discussion of whether The Gully was chosen as a potential MPA for its “uniqueness” or “representativeness”. The question of uniqueness, was one of many deciding factors in the selection of the area as the first offshore ‘Area of Interest’ in the MPA Program in the Maritimes. The *Oceans Act* does not list “representation” as a specific reason for MPA designation.
- A better understanding of sediment transport processes is gradually being developed. There is evidence of sediment moving off Sable Island Bank, through feeder canyons and down The Gully to deep water. It is not clear how active this process is, but it may influence the ultimate fate of wastes released by the oil and gas industry on Sable Island Bank. There are no feeder canyons on the Banquereau side of The Gully which suggests less sediment transport from that side.
- The complex bottom topography of The Gully appears to be unique and probably affects near bottom currents and mixing processes. This complex topography is not taken into account in numerical models and so model predictions may have significant errors. No current meter data are available from The Gully.
- While the focus of recent benthic studies has been on epibenthic forms, which can be readily quantified using video and photographic imagery, it is also

important to study the infaunal benthic organisms that live out of sight below the sediment surface.

- More information is needed on comparing The Gully ecosystem to other canyons and shelf break areas found off Atlantic Canada.
- Most of the biological sampling in The Gully has been conducted in the spring and fall. As a result, there is poor seasonal coverage of important environmental variables.
- Northern bottlenose whales seem to be present in The Gully all year round. Evidence (*i.e.* deep dives) suggests they are actively feeding but the identity of their prey is not fully known. The presence of other marine mammals in The Gully may be more seasonal.
- Most of the benthic samples collected to date in The Gully are from depths less than 500 m. More deep water observations are needed. An opportunity for doing this will be available in August 2001 when the ROPOS ROV will be collecting imagery and samples of corals and their habitat in The Gully.
- Also needed is more information on midwater processes in The Gully (*i.e.* zooplankton, mesopelagic fish, etc).
- There is a need for more research on benthic-pelagic coupling.
- Acoustic and imagery data indicate that The Gully provides important habitat for fish but yet few fisheries ecology studies have been conducted. There is little understanding of what particular habitats are important spawning, nursery, juvenile and feeding areas.
- The food source for the Northern bottlenose whale should be determined. It has been hypothesized that they are feeding on squid living deep in The Gully that might be just seasonal visitors. Appropriate field studies should be conducted to test this hypothesis.
- It was recommended that future geological work should include: processing the multibeam backscatter data to determine sediment type, extending multibeam coverage to include Banquereau and the inner part of The Gully, a dedicated cruise for more precise ground truthing information, and a series of major geological cruises to look at the 3D structure of The Gully and its evolution with time.
- There is need for a long term monitoring program, in particular to measure the effectiveness of any use restrictions that may be implemented in establishing a MPA. Indices for environmental health are required to make sure that conservation strategies are working.
- As a result of recent research activity, The Gully is becoming one of the most studied deep sea ecosystems on the eastern Canadian margin. The findings of this effort will hopefully contribute to the knowledge of similar, but currently unsurveyed ecosystems in the region, including the adjacent submarine canyons on the Scotian Slope.
- There need to develop a broader community of support for research in The Gully ecosystem (industry, NGOs, public at larger, other government departments, etc.).
- At some time in the near future, perhaps a broader Gully science review should be organized. It could include more detailed results from the projects

done under this particular program as well as the results from other scientific studies recently conducted in The Gully.

While we are not yet in the position of being able to construct a balanced synthesis of the Gully ecosystem, as a result of the research presented at this workshop we are further along the road to this ultimate goal. Despite the remaining data gaps, the Gully ecosystem is still one of the better known shelf-break ecosystems in Atlantic Canada. Of particular note is the advancement of our geological knowledge of the Gully during the past two years through the participation of Natural Resources Canada in benthic habitat studies. Geological processes clearly have a profound influence on properties of the Gully ecosystem, especially the benthic components. For example:

- Major erosion took place during glaciation down to depths of about 800 m and may have developed habitats suitable for corals.
- Bedforms (sand waves) have been formed by periodic high velocity bottom currents flowing to the east.
- The floor of the Gully (thalweg) is covered with sand and flocculated organic matter that is being actively transported.
- Sand is possibly eroding from Sable Island Bank and moving to the Gully through the feeder canyons.
- Pockmarks have been observed in some locations. These could be active (i.e. releasing hydrocarbons) and have biological implications.

Despite these recent advances in scientific understanding, there is still much to learn about the Gully ecosystem.

ACKNOWLEDGEMENTS

Funding for the research conducted in this program was provided by the DFO Marine Sciences Project, plus DFO A-Base. In addition, funding for the multibeam bathymetric mapping was provided by the Geological Survey of Canada, Atlantic (NRCan), the DFO Canadian Hydrographic Service (CHS), Oceans and Environment Branch (DFO) and the oil and gas industry. A special thanks goes to Paul Macnab, Bob Rutherford, Denise Mccullough and Lesley Carter of the OCMD for their input into the science program, assistance in organizing the review meetings, and the production of this document. Paul Boudreau and Paul Macnab kindly reviewed this report.

APPENDIX

AGENDA

GULLY ECOSYSTEM SCIENCE REVIEW MEETING

2 May 2001
Main Auditorium
Bedford Institute of Oceanography
Dartmouth, NS

In 1999, funding was provided by DFO to establish a two-year research program to obtain more information about The Gully ecosystem, in particular to address some of the most important information gaps identified in the earlier Gully Scientific Review (Harrison and Fenton 1998). Seven research projects were funded and conducted by DFO and NRCan scientists covering certain aspects of the physical oceanography, nutrient chemistry, primary production, zooplankton ecology, benthic habitat and benthic ecology of The Gully. The new scientific information collected over the past two years will be presented and discussed.

0900 Welcome, background and purpose of this science review (Don Gordon)

0910 Update on The Gully protected area initiative (Derek Fenton)

0915 A morphodynamic interpretation of multibeam bathymetry from the Gully: the first step in habitat classification (Gordon Fader)

0945 Benthic habitat and communities (Vladimir Kostylev)

1015 Health break

1030 Epibenthic biomass and metabolism (Barry Hargrave)

1100 Modelling of seasonal and tidal circulation (Guoqi Han)

1130 Internal waves (Hal Sandstrom)

1200 Lunch

1300 Nutrient chemistry (Phil Yeats)

1330 Seasonal plankton production in The Gully (Paul Kepkay)

1400 Zooplankton (Doug Sameoto)

1430 Health break

1445 Overview of results (Ken Mann)

1500 General discussion on The Gully ecosystem (Don Gordon)

- What have we learned from this scientific program?
- What remain the most critical information gaps?
- How can these information gaps be filled?
- How should the results of this scientific program be reported?