CONTAMINANT MONITORING IN THE GULLY MARINE PROTECTED AREA

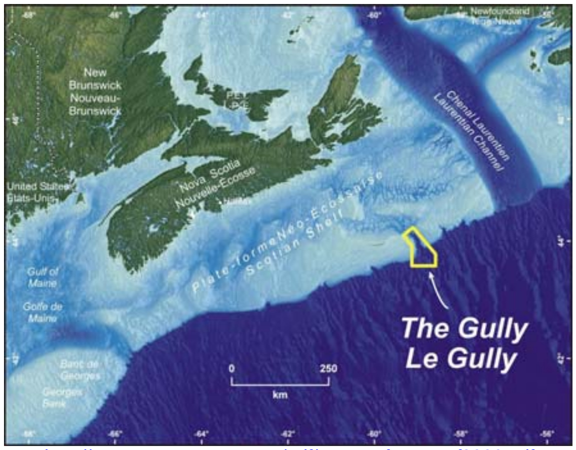

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Figure 1: Location of the Gully Marine Protected Area. For a more detailed map, see Appendix A.

Context

The Gully is the largest submarine canyon in eastern North America. Located offshore Nova Scotia near Sable Island, the Gully contains a rich diversity of marine habitats and species, including deep-sea corals and the endangered population of northern bottlenose whales (Hyperoodon ampullatus). The area is nationally and globally acknowledged as a unique and important marine habitat. The Gully ecosystem has long been important for fishing, and more recently, the surrounding waters have witnessed growth in oil and gas exploration and development. The health of the Gully is closely linked to that of the surrounding area. Large scale currents and smaller scale water movements carry suspended particles into the canyon. Oceanographic processes and retention within the Gully may make it susceptible to accumulation of contaminants.

In May 2004, Canada's Minister of Fisheries and Oceans designated the Gully Marine Protected Area (MPA) through regulations under the Oceans Act. A Gully Management Plan has been developed to support the MPA Regulations and provide guidance to DFO, other regulators, marine users and the public on protecting and managing this important ecosystem. A scientific review of the Gully Ecosystem conducted in 1998 contained little information on contaminants, and additional information has been collected since that time. This assessment will inform management decisions related to monitoring of contaminants in the Gully MPA over the coming years, and it is expected to contribute to the development of a more comprehensive monitoring plan for the Gully MPA.

SUMMARY

- Known **sources of contaminants** for the Gully MPA include dry and wet atmospheric precipitation, transport of river-borne contaminants via coastal currents, transport of contaminants from oceanic waters via shelf edge water exchange, and more localized sources including the offshore oil and gas developments on Sable Bank and marine shipping.

- Some **temporal trends** in contaminants of relevance to the Gully MPA have been detected. For example, decreasing trends in PCB and DDT concentrations have been observed in Sable Island seals, which may spend some of their time in the Gully. However, samples from northern bottlenose whales that spend much of their time in the Gully indicated an increase in 4,4'-DDE and trans-nonachlor from 1996 to 2003. Decreasing trends in dissolved lead and zinc are evident across the Eastern Scotian Shelf, and large floating debris appears to have decreased over time in the Gully. However, no decreasing trend was seen in dissolved copper or smaller plastic debris.

- Dissolved **metals** measured in the Gully MPA are similar to these measured elsewhere on the Scotian Shelf. Chromium, copper, iron, vanadium and zinc in sediments of the Gully area show patterns that are indicative of natural concentrations. A small subset of samples has shown elevated levels of barium and lead.

- Aromatic **hydrocarbons** were not detected in sediment samples collected from feeder canyons to the Gully MPA in 2006, but the samples did contain total alkanes (C_{10}-C_{35}) at low concentrations. The source of these alkanes is unknown, though observations based on the analysis of individual alkanes suggests both biogenic and anthropogenic sources are possible. A small sample of Gully krill contained pristane but no other detectable alkanes and very low concentrations of alkylated and parental PAHs. Measurements of CYP1A1 protein expression in northern bottlenose whales indicated increased levels in 2003, which may be an indication of exposure to hydrocarbon contamination.

- Higher concentrations of a number of **organochlorine** compounds were observed in northern bottlenose whales from the Gully than in a population from the northern Labrador Shelf.

- **Future contaminant monitoring** within the Gully ecosystem should include: continuation of existing time series to establish long-term temporal trends, expanded sampling and analysis of Gully sediments to establish spatial patterns, and opportunistic sampling/analysis of relevant indicator species to determine contaminant levels and investigate potential biological effects. This monitoring should be conducted in conjunction with targeted research to better understand the ecosystem dynamics of the Gully, including geological and oceanographic processes.

- Potential **indicator species** for monitoring of contaminants and their biological effects in the Gully include flounder, snow crab, squid, krill/shrimp, corals and bottlenose whales. However, additional research is required to determine the feasibility of using any of these species for contaminant monitoring in the MPA and the potential usefulness of the results for management.

- There are a number of **sources of uncertainty** to be taken into account when considering the recommendations provided within this report. Only a small number of water, sediment and biota samples have been collected from the Gully MPA, and only a very limited analysis of the dynamics of the system has been conducted to date. Given the limited amount of site-specific data, observations made elsewhere on the Scotian Shelf have been used to provide context for the Gully MPA.

BACKGROUND

For the purposes of this report, a contaminant is considered to be any element or natural substance whose concentration locally exceeds the background concentration, or any substance that does not naturally occur within the environment.

Chemical distributions in the Gully and their relationships to both biological and physical oceanographic processes were reviewed by DFO in 1998; however, the focus of that review was on nutrients, oxygen and chlorophyll rather than on contaminants. Since 1998, a number of other studies and reviews of contaminants on the Scotian Shelf and Sable Island Bank have been conducted. The current review was initiated to compile existing information on contaminant monitoring that has been conducted in the vicinity of the Gully and provide guidance on future monitoring of contaminants and their biological effects in the Gully MPA.

A meeting was held 11 December 2007 to:

- Review existing sources of contaminant data that has been collected to date by DFO and others in the Gully MPA and surrounding waters, and discuss methods that have been used or could be used for analysis;
- Identify sources of information on biological effects of contaminants that may be relevant to the Gully MPA and surrounding waters;
- Review studies that have been conducted elsewhere that may inform the development of a contaminant monitoring framework for the Gully MPA; and
- Identify potential components of a contaminant monitoring program for the Gully MPA in the Maritimes Region.

The information compiled was reviewed at a subsequent meeting on 2 July 2008. This Science Advisory Report, associated proceedings and research document are the products of these two meetings.

ASSESSMENT

Contaminant Sources

Known sources of contaminants for the Gully MPA include dry and wet atmospheric precipitation, transport of river-borne contaminants via coastal currents, transport of contaminants from oceanic waters via shelf edge water exchange, and more localized sources including the offshore oil and gas developments on Sable Bank and marine shipping.

Atmospheric deposition is most important for volatile contaminants (e.g., volatile organic compounds and mercury) and some non-volatile contaminants (e.g., lead). Sources of atmospheric pollution vary and include stacks, vehicles and other non-point sources (so called because they are not traceable to a single geographic location). The main source of river-borne contaminants is the Gulf of St. Lawrence, which is a source for more water soluble heavy metals and organic contaminants. Oceanic water that flows into the Gully at depth is the most important source of contaminants that remain in solution in seawater and have long residence times, such as cadmium. Offshore oil and gas development could be an important source for specific contaminants that are discharged to the water in drilling wastes (e.g., barium) or with produced water and other production wastes. Inputs of contaminants from shipping were not analysed for this review, but it is assumed that ship discharges have occurred within the Gully.

Other potential sources of contaminants include ocean dumping, ship wrecks, and accidental spills. However, there are no known disposal sites in the vicinity of the Gully MPA of materials that have been screened through the Canadian Environmental Protection Act. In addition, no ship wrecks are known to have occurred within the Gully MPA. A spills database maintained by Environment Canada was not analysed for this review.

Estimates of the magnitude of known contaminant transport vectors and the predicted input of three metals onto the Eastern Scotian Shelf (ESS) are provided in Table 1. The relative importance of these contaminant sources for the Gully MPA would be somewhat different from the ESS as a whole. While the input of contaminants from oceanic water would be similar for the Gully MPA (as most of the oceanic water that reaches the ESS flows through the Gully), only a fraction of the input to the ESS from the Gulf of St. Lawrence reaches the Gully. The transport of near bottom particulates and resuspended sediment material from Sable Bank to the Gully via the small canyons on the western side of the Gully may turn out to be an important transport mechanism for contaminants from Sable Bank. Thus, further research on sediment transport in relation to the Gully MPA is recommended.

Table 1. Contaminant inputs to the Eastern Scotian Shelf.

	Cu (tonnes/yr)	**Pb (tonnes/yr)**	**Zn (tonnes/yr)**
Gulf of St. Lawrence	4390	258	7750
Oceanic water	279	37	409
Rainfall	90	90	270
NS rivers	32	30	97
'sewage'	5	3	11
Produced water	<1	23	157
Shipping, dumping, and other sources	?	?	?

Temporal Trends

A study of dissolved and dispersed oil in water conducted in the 1970s indicated a decreasing trend in the Eastern Scotian Shelf (ESS) from 1971 to 1976; however, observations of oiled birds have not shown a decreasing trend.

A study of various chlorinated organics in seals from Sable Island shows decreasing concentrations of PCBs and DDT in seal blubber (decrease from 1985 to 1994 for PCBs and from 1976 to 1994 for DDT). However, resident bottlenose whale samples from the Gully indicated an increase in 4,4'-DDE and trans-nonachlor from 1996/97 to 2002/03.

Decreases in dissolved lead across the ESS are associated with a reduction in anthropogenic releases of lead into the atmosphere, including the elimination of lead from gasoline. Decreases in the industrial discharge of zinc into rivers are likely responsible for the decreasing trend in dissolved zinc. No decrease in dissolved copper has been observed on the ESS.

Significant decreases in concentrations of large floating debris (mostly plastics) were observed in surveys conducted in the Gully in 1990, 1996/97 and 1999, though concentrations of smaller debris collected with plankton nets during these surveys showed insignificant increases.

The global increase in atmospheric and oceanic carbon dioxide (CO_2) is evident in the change in pH on the Scotian Shelf (Figure 2). Increases in CO_2 could stimulate more primary productivity, but decreases in pH will negatively affect the ability of carbonate forming organism to form and maintain their carbonate structures. Deep-sea corals are expected to be particularly sensitive to long-term increases in acidity.

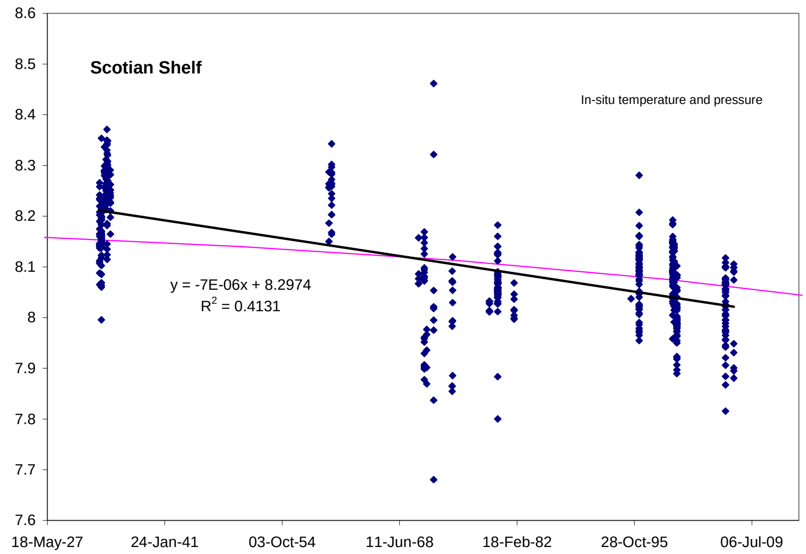

Figure 2. pH trends on the Scotian Shelf

Spatial Distribution

Maps of chromium, copper, lead (Figure 3) and zinc in sediments have been generated for the Scotian Shelf, as have maps of dissolved cadmium and copper (Figure 4). Maps for other metals could be generated as required.

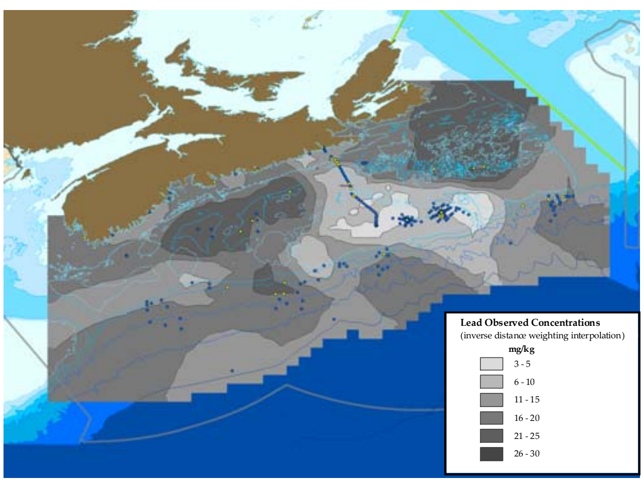

Figure 3. Distribution of total lead in sediments (from Breeze and Horsman 2005).

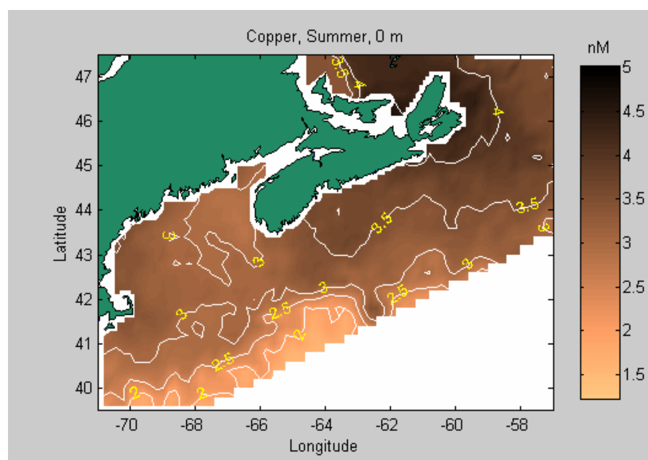

Figure 4. Optimally estimated summertime surface dissolved copper distribution.

Recent Measures of Contaminants in the Gully

In the past decade, a number of measurements have been made of contaminant concentrations in the Gully (Figure 5).

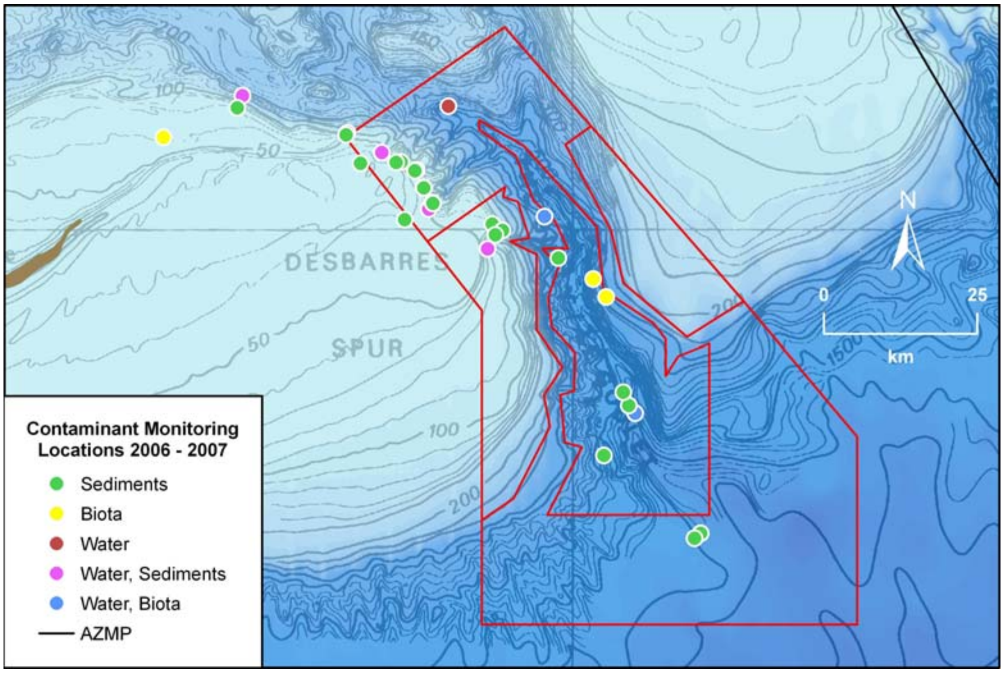

Figure 5. Map showing contaminant sampling locations in the Gully.

Metals

Dissolved metals concentrations measured in the Gully MPA since 1997 are not significantly different from those measured along the Louisbourg Line (a fixed transect that is monitored regularly by DFO, Figure 6).

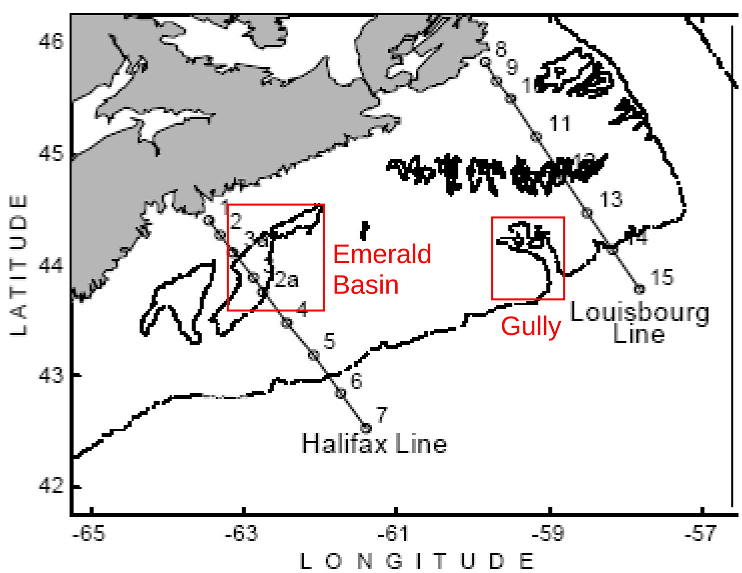

Figure 6. Location of the Louisbourg and Halifax Lines (including station numbers).

Chromium, copper, iron, vanadium and zinc in sediments collected in and near the Gully MPA in 2006 and 2007 all show patterns that are indicative of natural concentrations. The concentrations along Sable Bank are lower than those for the deeper stations, but all are consistent with earlier observations for the Scotian Shelf.

Barium is a well known tracer of drilling wastes and produced waters, and it is seen more frequently in sediments within a kilometer or so of drill sites. Remobilization of barium by storms has been observed, and produced water barium would generate finer-grained particles that would not settle as quickly as drilling mud barium, so transport of barium greater distances from well sites is possible. Elevated levels of barium have only been observed in two samples from one of 20 sampling sites on the eastern end of Sable Bank (Figure 7), and the source of this barium is uncertain as other metals associated with produced water and drilling wastes were not detected. Identification of excess barium in finer sediments from the deeper parts of the Gully will require a better understanding of the barium grain-size relationships for basin/slope sediments.

The concentration of lead (Pb) in nine samples from the finer-grained sediments collected deeper in the Gully also exceeded natural levels (Figure 8). All of these samples were from the top portions of sediment cores from three stations located along the main axis of the Gully, which may indicate more recent deposition. The potential source and transport pathway for lead into the Gully is not clear at present, nor is its potential importance for environmental quality.

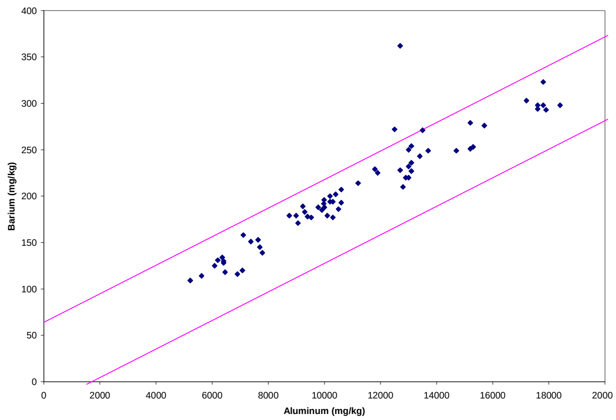

Figure 7. Barium and aluminum concentrations from sediment cores collected on Sable Bank in 2006. The two lines represent the upper and lower bounds of the expected relationship between barium and aluminum in uncontaminated sediments.

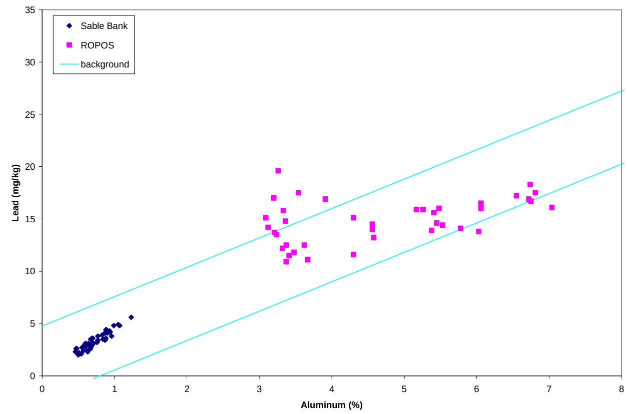

Figure 8. Lead versus aluminum for sediment cores collected in 2007. The two lines represent the upper and lower bounds of the expected relationship between barium and aluminum in uncontaminated sediments.

Metals in Gully krill (Cr, Cu, Pb, Zn, Sn, Fe) have been measured and were found to be lower than samples taken from Emerald Basin (see Figure 6). However, replication is required to test for significance.

Hydrocarbons

Aromatic hydrocarbons were not detected in sediment samples collected from feeder canyons to the Gully MPA in 2006, but the samples did contain total alkanes (C_{10}-C_{35}) ranging in concentrations from 966 to 6486 $ng.g^{-1}$ dry weight (Figure 9). These concentrations and compositions are consistent with observations of hydrocarbons in mostly uncontaminated sandy shelf sediments. However, sediments that are not contaminated with petroleum hydrocarbons have pristane/phytane ratios >1, usually between 3 and 5. Samples from the Gully MPA have a pristane to phytane ratio ranging from 0.93 to 1.08, suggesting anthropogenic sources. The overall distribution of odd/even alkanes (0.91-1.21) reveals no dominance of odd carbon number alkanes, again suggesting the potential contribution of petrogenic (i.e., produced by incomplete combustion) hydrocarbons to the sediments. The ratios of odd/even alkanes for $<C_{24}$

are in the range of 0.91-1.08, while the ratio of odd/even alkanes ≥C_{24} are in the range of 1.18-1.98, which suggests some hydrocarbon input linked to natural production from higher plants. Overall, the results suggest both a biogenic and anthropogenic source of hydrocarbons dominated by the alkane fraction.

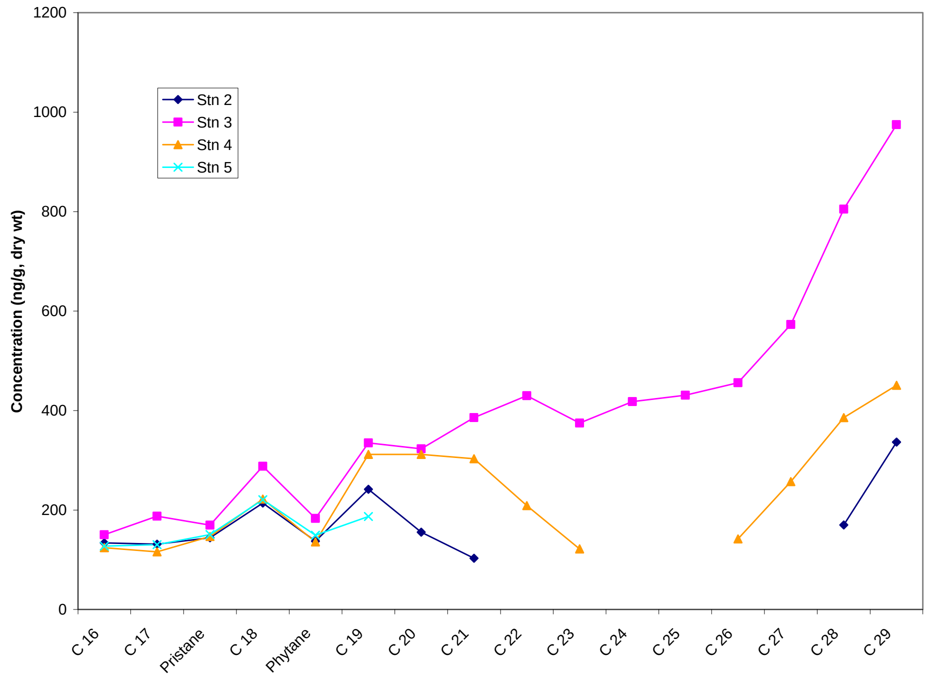

Figure 9. Hydrocarbon concentrations in Gully sediments.

Measurements of organic contaminants in Gully krill indicated the presence of pristane but no other detectable alkanes and very low (few ng/g) concentrations of alkylated and parental PAHs. Given the limited number of samples analysed, caution is warranted and it would be premature to draw any strong conclusions from this result.

Other Organic Contaminants

In a study that is the most comprehensive investigation of contaminants and biological effects done to date within the Gully MPA, Hooker et al. (2008) have shown that concentrations of PCBs, DDTs and several other organochlorine compounds are higher in blubber of northern bottlenose whales from the Gully than in those collected off northern Labrador. Higher concentrations were observed in males than females. Concentrations were generally consistent with concentrations reported for blubber of other large whales in the North Atlantic Ocean.

Biological Effects of Contaminants

A lot of research has been conducted on the toxicity of chemical contaminants to marine organisms, and all of the contaminants discussed in this paper have been shown to cause toxicity. Finding actual field measurements of biological effects, however, is more difficult, and very few toxicological measurements have been made in the Gully. The Hooker et al. (2008) study of organic contaminants in bottlenose whales included measurements of CYP1A1 protein expression in the whales and their results showed increased levels in 2003 samples that could perhaps be associated with spills of kerosene and streamer fluids from seismic surveys. They also observed that CYP1A1 expression was lower in whales from the Gully than in whales from northern Labrador, opposite to the trend in persistent organic contaminant concentrations.

Toxicity of sediments collected from five stations at the edge of the Gully MPA on the eastern edge of Sable Bank has been evaluated as part of the Sable Offshore Energy Project (SOEP) Environmental Effects Monitoring program, including echinoid fertilization assays, Microtox™ luminescent bacteria assays, and amphipod survival assays. More recent SOEP studies have focused on amphipod survival. To date, no acute toxicity has been detected as a result of SOEP-related chemicals in sediments, though produced water is regularly found to be toxic.

Potential Indicators

The Canadian Council of Ministers of the Environment (CCME) has developed Environmental Quality Guidelines that are nationally approved, science-based indicators of environmental quality. They are recommended numerical or narrative limits for a variety of substances and environmental quality parameters, which, if exceeded, may impair the health of Canadian ecosystems. The CCME Guidelines for the protection of aquatic life are based on rigorous analysis of safe concentrations of a single contaminant in the environment which will allow organisms to complete their whole life cycle. A major limitation to the approach is that it does not allow for multiple exposures to the suite of contaminants one could expect to encounter in, for example, the Gully. In the Gully MPA, species or community-level indicators may be more effective measures of environmental quality.

A number of potential indicator species were identified that could be used to measure contaminants and their biological effects in the Gully MPA (Table 2).

Table 2. Potential species for measuring contaminants and their biological effects in the Gully MPA.

Species Used to Date	Benefits	Disadvantages
Northern Bottlenose Whales	A priority within the Gully MPA Management Plan; local distribution; spatial and temporal integrator of contaminants.	Species at risk protection could limit sampling frequency or methods.
Seals	Relatively easy to sample on Sable Island.	Far-ranging.
Krill	Indicator of contaminants in the water column; lipid rich.	Some difficulties with collection to date (various species).
Other Species Considered		
Cod	Have been studied extensively elsewhere; long time series for metals on the Scotian Shelf (70s-80s).	Low abundance.
Flounder	Have been studied extensively elsewhere (including lab studies); suspected localized movement; abundant; biological effects well understood.	May not be present at all depths in the Gully MPA (most abundant in Zone 3).
Sand Dollars	Used elsewhere.	Distribution limited by depth; lipid poor.
Halibut (and associated bycatch)	The current fishery in the Gully may facilitate collection; found in deep waters of the Gully; higher	Far-ranging.

Species Used to Date	Benefits	Disadvantages
	trophic level may facilitate accumulation of contaminants.	
Snow Crab	Active fishery in the vicinity of the Gully; annual research survey; used as indicator species on the Grand Banks; baseline studies proposed; some data (elsewhere) and samples (Gully) available for analysis; hepatopancreas is lipid rich; benthic exposure; relatively sedentary relative to fish; interest from industry.	Better understanding of natural variability (baseline conditions) and relationship between contaminants and biological effects required. Movement outside the Gully MPA is likely.
Other Crab	Current exploratory fishery in the vicinity of the Gully.	Lower abundance than snow crab; contracted distribution.
Coral	Sedentary; may be affected by lower pH; mixed function oxidase induction possible; a management priority within the Gully MPA Management Plan.	Hard corals are lipid poor and may be difficult to analyse for organic contaminants.
Brittlestars	Found at all depths and may be easy to sample.	Limitations on what can be analysed.
Scallops, Quahogs	Research surveys on Banquereau and Sable Bank may facilitate collection; work on biological effects of contaminants on scallops has been conducted on Scotian Shelf.	Located primarily outside of the Gully MPA.
Shrimp	Active fishery outside of the Gully MPA; chemical analysis conducted on Grand Banks and elsewhere; annual research survey to facilitate collection.	The Gully MPA is not currently sampled during the Scotian Shelf shrimp survey.
Birds	Biological effects of contaminants well documented	Far-ranging.
Squid (*Gonatus* sp.)	Important prey species for bottlenose whales.	Work would be required to determine baseline levels and natural variability; poor understanding of movement and distribution.
Anemones and Tube Worms	Present throughout canyon.	
Mesopelagic Fish and Invertebrates	Planned surveys may facilitate collection.	

Sources of Uncertainty

There are a number of sources of uncertainty to be taken into account when considering the recommendations provided within this report. Only a small number of water, sediment and biota samples have been collected from the Gully MPA, and these analysed for only a limited number of contaminants. As a result, inferences are often based on extrapolation of results from the broader Eastern Scotian Shelf. In addition, only a very limited analysis of the dynamics of the system has been conducted to date.

CONCLUSIONS AND ADVICE

Most of the contaminant monitoring conducted to date in the Gully and surrounding waters has focused on contaminant pathways, e.g., transport to sediments, and accumulation in biota. It is recommended that future monitoring include: 1) continuation of existing time series to establish long-term temporal trends, 2) expanded sampling and analysis of Gully sediments to establish spatial patterns, and 3) opportunistic sampling of relevant indicator species to detect and investigate potential biological effects. This monitoring should be conducted in conjunction with targeted research to better understand the ecosystem dynamics of the Gully, including geological and oceanographic processes.

In studies of temporal trends, decreasing concentrations have been observed for Pb and Zn in water and PCBs and DDTs in seals in areas near the Gully, but increasing concentrations of two organochlorines are seen in northern bottlenose whales resident to the Gully. The global-scale decreases in ocean pH are also evident in data collected from the Scotian Shelf. Continuation of periodic surveys of metals in the water, and additional measurements of contaminants in whales would provide on-going data on trends in contaminant exposure and bioaccumulation in the Gully. Because of the potential sensitivity of deep-sea corals to possible pH changes resulting from increases in dissolved carbon dioxide, it may be useful to include sampling stations in the Gully during any larger-scale monitoring of pH change on the Scotian Shelf. Standardized sampling and analytical methods, along with sample archiving, is important in order to enable future temporal and spatial comparisons.

Recent measurements of individual alkanes in sediments from the eastern edge of Sable Bank give some indication of sources for the hydrocarbons observed in these sediments. While not conclusive, the initial survey gives an indication that an anthropogenic source is likely. Collection and analysis of additional sediments from more locations would provide a clearer picture of both the concentrations of hydrocarbons and their sources. Testing for chlorinated hydrocarbons and other contaminants detected in biota would enhance the relevance of these measurements for management. A better understanding of the barium grain-size relationships for basin/slope sediments would assist with interpretation of results of barium sampling in sediments.

Most metal contaminants from land-based sources will eventually be deposited in fine grained sediments. This is the process for accumulation of metals in Emerald and other shelf basins and will also be important for the Gully especially in deeper areas (e.g., Zone 1 of the MPA, Appendix A). The Gully may also be a trap for metals transported from offshore and discharged to and mobilized by activities on the outer banks. It will be important to develop a better understanding of sediment dynamics around the Gully in order to support interpretation of any measured changes that occur.

Based on sediment sampling to date, extent of contamination appears to be small (though some elevated concentrations of lead and potentially barium have been detected). Sediments on the eastern end of Sable Bank have been much better sampled than the deeper areas in the Gully where contaminants may be accumulating. More extensive sampling of metals and other contaminants in finer grained sediments from the Gully MPA, as well as sampling from nearby canyons for comparison purposes placed in the context of a knowledge of sediment dynamics within the Gully, would be required to delineate and understand the extent of any contamination, identify accumulation areas and how to manage protection of the Gully from metals contamination.

Measurements in the Gully MPA of contaminants in biota and their associated biological effects are very limited and contradictory. Very little can be concluded about accumulation of contaminants or their potential for causing effects without additional research that fills in some of the gaps in analytes to be targeted, distributions of contaminants within the organisms, and trophic dynamics and levels within the biota. A geographical comparison would also help interpret the origin of the contamination and place the results in perspective.

It is suggested that opportunistic sampling of potential indicator species be pursued where possible. Potential indicator species for monitoring contaminants and their biological effects in the Gully MPA include flounder, snow crab, squid, krill/shrimp, corals and northern bottlenose whales.

- Flounder have been used extensively for monitoring of contaminants elsewhere, but further work would be required to determine their accessibility, distribution and movement within the Gully MPA.
- Snow crab is a bottom dwelling invertebrate species that may reflect contaminant exposure in the benthic layer and may be a useful organism for contaminant measurements. Some samples of snow crab for contaminant measurements have already been collected and others could be readily available; however, additional research on baseline conditions and natural variability within snow crab is required before its reliability as an indicator species can be determined. Contaminant analysis of archived snow crab samples could be an initial first step.
- Squid (*Gonatus* sp.) are thought to be an important prey item for bottlenose whales and a potential source of contaminants for them. However, additional work is required on the biology and ecology of squid (or their food sources) to determine their feasibility as an indicator species. It is suggested that opportunistic sampling of squid and their prey be pursued where possible.
- A small number of krill from the Gully MPA have already been sampled for contaminants, and additional samples are available for analysis. While a potential indicator of contaminants in the upper water column, krill have been difficult to acquire opportunistically within the Gully MPA and their relevance to management is uncertain.
- Corals and bottlenose whales are of significant management interest in the Gully MPA; however, any sampling of these species should be conducted in a manner that minimizes harm.

With the exception of squid, where sample collection is required, the focus of biological monitoring within the Gully MPA should be on analysis or re-analysis (for an expanded suite of contaminants) of existing samples to investigate feasibility and usefulness of the various organisms for ongoing monitoring of contaminants and their biological effects.

OTHER CONSIDERATIONS

Consideration of contaminant monitoring conducted elsewhere on the Scotian Shelf and the Northwest Atlantic (e.g., use of winter flounder as an indicator species in the U.S. and comparability with monitoring programs such as the NOAA Status and Trends program and the Gulf of Maine Gulfwatch program) during the design of contaminant monitoring programs for the Gully MPA would facilitate comparison of results. Selection of pertinent contaminants from the *Canadian Environmental Protection Act (CEPA)* Priority Substances Lists is another alternate means of selection.

Contaminant monitoring that is designed to detect potential stressors before they lead to irreversible effects (i.e., early warning indicators) is considered to be an appropriate approach for the relatively uncontaminated environment of the Gully MPA.

Recent studies on the geological and oceanographic processes in the Gully can enhance our understanding of the pathways of contaminants from surrounding areas into the Gully.

Data management issues related to the Gully MPA need to be addressed.

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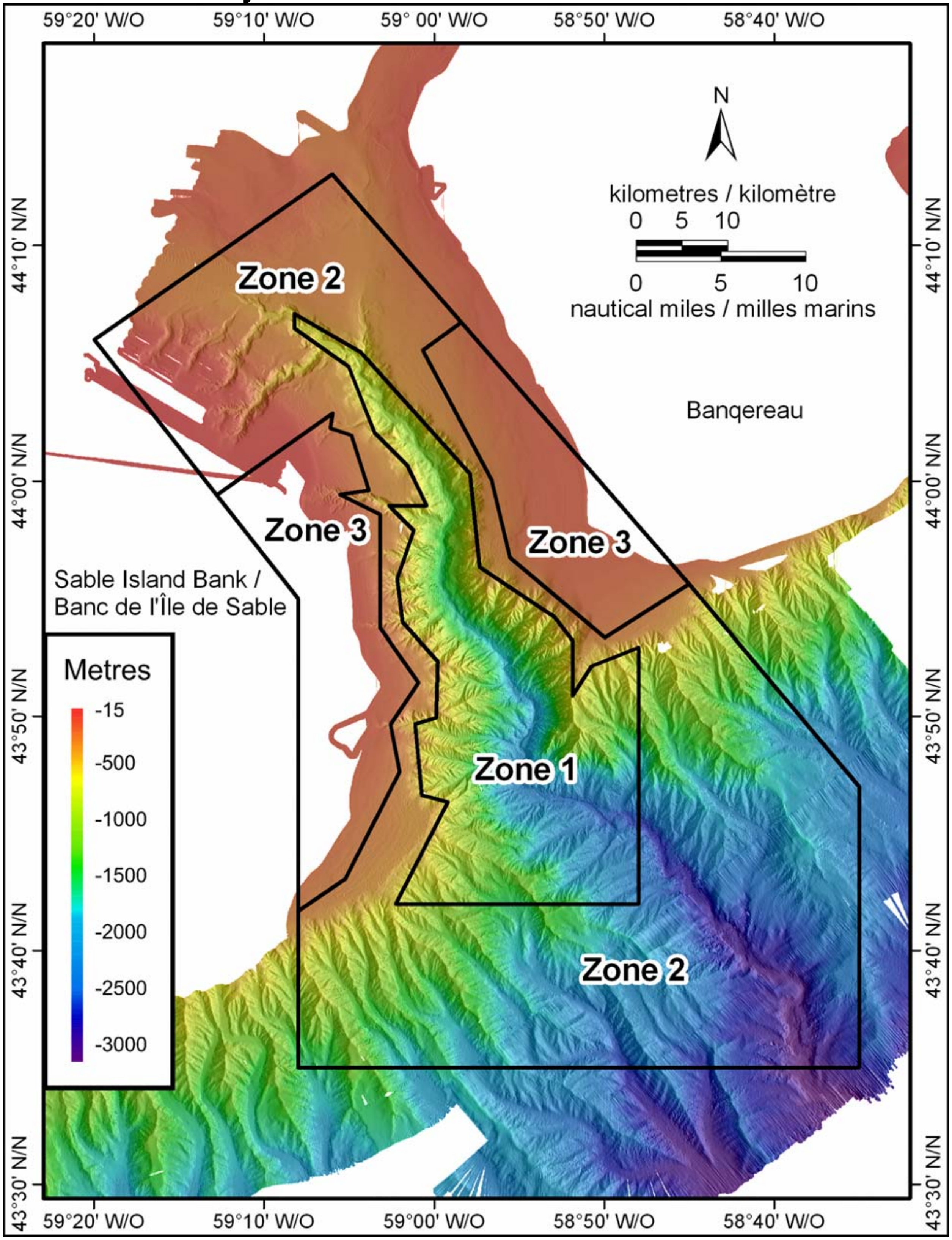
Appendix A. Management Zones and Multibeam Bathymetry of the Gully MPA.



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