Marine Protected Area Design and the Spatial and Temporal Distribution of Cetaceans in a Submarine Canyon

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Abstract: *The Gully, the largest submarine canyon off the coast of eastern Canada, is currently under consideration as a marine conservation area, primarily because of the increasing interest in oil and gas production on the Scotian Shelf. Cetaceans, as a guild of abundant, large organisms that are relatively sensitive to such threats, provide a reliable means to determine the boundaries for a conservation area in this region. We compared the abundance of cetaceans between the Gully and other parts of the Scotian Shelf and Slope and found that abundance was higher in the Gully. We also assessed cetacean distribution and relative abundance within the Gully relative to search effort for several spatial and temporal parameters: depth, slope, sea surface temperature, and month. Distribution within the Gully was most strongly correlated with depth, but was also significantly correlated with sea surface temperature and month. Five of the 11 cetacean species commonly found in the Gully, and all those for which the Gully formed significant habitat on the Scotian Shelf, were concentrated in the deep (200–2000 m) mouth of the canyon. We suggest that a year-round marine protected area is necessary for the Gully. A core protection zone should be defined in the Gully based on depth and bounded by the 200-m isobath. A buffer zone around the core zone should be defined to provide protection from activities with further-reaching effects, such as noise, dredging, and chemical pollution.*

Diseño de Areas Marinas Protejidas y la Distribución Espacial y Temporal de Cetaceos en un Cañón Submarino

Resumen: *El cañon submarino mas largo de la costa este de Canada, el Gully, esta actualmente bajo consideración como área marina de conservación, principlamente debido al creciente interés en la producción de gas y aceites en la plataforma escocesa. Los cetaceos, como grupo de abundantes organismos grandes y relativamente sensibles a este tipo de amenazas, provee un medio confiable para determinar los límites de un área de conservación para esta región. Comparamos la abundancia de cetaceos entre el Gully y otras partes de la plataforma y el talud escoceses y encontramos que la abundancia fué mayor en la región del Gully. También evaluamos la distribución de cetaceos y su abundancia relativa dentro del Gully en relación con el esfuerzo de busqueda para diversos parámetros especiales y temporales: profundidad, pendiente, temperatura de la superficie marina y mes. La distribución dentro del Gully estuvo mas fuertemente corelacionada con la profundidad, pero también estuvo significativamente correlacionada con la temperatura de la superficie marina y el mes. Cinco de las 11 especies de cetaceos comunmente encontradas en el Gully y todas aquellas para las que el Gully representa un hábitat significativo de la plataforma escocesa, se concentraron en la profunda boca del cañón (200-2000 m). Sugerimos que se necesita un área protegida todo el año para la región del Gully. Una zona de protección principal debe ser defínida en el Gully en base a la profundidad y delimitada por la isobata de los 200 m. Una zona de amortiguamiento debe ser definida para proveer la protección contra actividades con efectos de largo alcance, como son el ruido, el dragado y la contaminación química.*

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Introduction

The largest submarine canyon off the Nova Scotia coast is under consideration as a marine conservation area. Known as the Gully, this region, once known to whalers to support a high density of northern bottlenose whales (*Hyperoodon ampullatus*), is now being threatened by offshore petroleum development. To address the potential threats to these important offshore waters, we studied the distribution of 11 species of cetaceans over space and time in the Gully relative to the design of marine protected areas (MPAs).

The Gully lies about 200 km from the Nova Scotia coast (Fig. 1) and is 6–10 km across and 40 km long at its 500-m isobath. Recently the Sable Offshore Energy Project has begun development of gas and oil fields in the area of the Gully, and a plan has been approved to construct a gas pipeline to the mainland (Joint Public Review Panel 1997; Fig. 1). This, together with the likelihood of future developments, may pose several threats to the Gully region, including an increase in ship traffic, noise pollution from ships, seismic operations and drilling, and increased chemical and floating pollution (Faucher & Whitehead 1995; Joint Public Review Panel 1997). Although there has previously been some interest in creating an MPA in the Gully (Shackell et al. 1996), there has been little rigorous investigation of its potential boundaries.

Although an ecosystem approach has been widely advocated over a single-species approach in designing MPAs (Agardy 1994; Jones 1994; Recchia et al. 1995), more is known about the cetaceans of the Gully than about many other components of the ecosystem. As a guild of common to abundant large organisms with a relatively high localized diversity, cetaceans offer a compelling suite of species by which to assess MPA design. In addition, cetaceans are particularly vulnerable to threats such as acoustic and chemical pollution (Simmonds & Hutchinson 1996) and as such are good focal species for this ecosystem (Lambeck 1997).

Species distributions are determined by a combination of spatial and temporal processes (Borcard et al. 1992). In the marine environment, species' spatial distributions may be determined by both fixed spatial features such as topography and variable oceanographic features such as sea surface temperature and salinity. In many systems, for example at thermal fronts, the fluid oceanographic environment rather than the geographically fixed physical features often plays the major role in defining species distribution. As a result the definition of fixed spatial boundaries for protected areas may not be an effective conservation measure (Agardy 1994). It is therefore critical in any assessment of an area for protection that the relative importance of these fixed and fluid environmental characteristics be investigated. We examined how the distributions of several cetacean species changed with time and how they were correlated with depth, slope, and sea surface temperature in and around the Gully.

Methods

Cetacean Abundance

Each summer (June–August) from 1988 to 1990 and from 1993 to 1996, researchers spent varying periods of time (13–65 days) in the region of the Gully observing

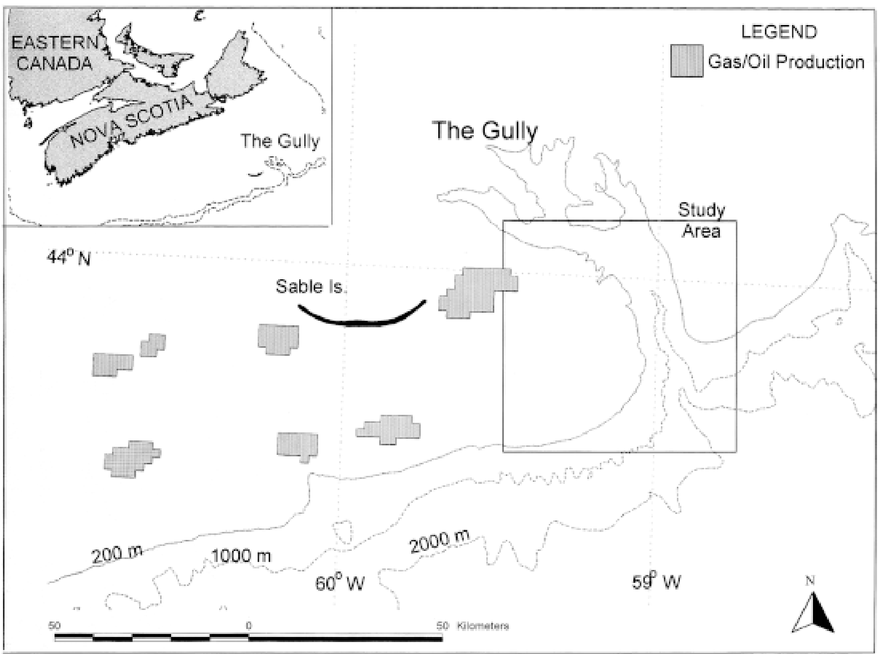

Figure 1. Bathymetry of the Gully, Sable Island, and the oil and gas fields under current production. Inset shows location of the Gully in relation to eastern Canada.

cetaceans from auxiliary sailing vessels (10–12 m length). The primary focus of these research trips was sperm whales (*Physeter macrocephalus*) (1988) and northern bottlenose whales (1989–1996), but all cetacean sightings were recorded in a systematic manner, including species, number, and location. Locational data were also collected on an hourly basis with Loran (SeaPort Loran-C [1988–1990]) or global positioning system (Trimble Transpak GPS [1993–1996] and Garmin 65 Global Navigator [1996]). Environmental data (including sea surface temperature, SST) were recorded every 3 hours. One or more observers were on deck for all daylight hours. We included in this study data presented previously by Whitehead et al. (1992) for sperm whales and Gowans and Whitehead (1995) for dolphins.

For any study of cetacean distribution, effort (i.e., a measure of the locations searched) is crucial in correcting the bias present in sighting locations (e.g., Kenney & Winn 1987; Polacheck 1987; Reilly 1990; Gowans & Whitehead 1995); this is especially so for data collected when a systematic search pattern is not used. For analyses presented here, variables during cetacean sightings were compared to those at positions every hour (depth, slope) or every 3 hours (SST, month). Gowans and Whitehead (1995) found that differentiating sightings according to weather conditions had little effect on results. Sightings and effort recordings in all weather conditions were therefore included in this study.

To compare the relative abundance of whales along different portions of the shelf edge, catches of large whales (blue [*Balaenoptera musculus*], fin [*B. physalus*], sei [*B. borealis*], minke [*B. acutorostrata*], humpback [*Megaptera novaeangliae*], right [*Eubalaena glacialis*], sperm, northern bottlenose, and killer whales [*Orcinus orca*]) from ships operating out of Blandford, Nova Scotia, as tabulated by Sutcliffe and Brodie (1977), were summed for each of 10 approximately equally sized areas on the edge of the Scotian Shelf (Fig. 2). Shore-based whalers preferentially operated close to their base, so catch per unit area generally fell with distance from the whaling station (Mitchell 1974). The total catch of whales in each area (logged) was plotted against its distance from Blandford (logged).

Cetacean Distribution

The study area (Fig. 1) used for these analyses was chosen such that effort was represented over the entire area. We used the geographic information system software IDRISI for Windows 1.1 (Clark University) for calculation of depth and slope at sighting and effort locations and for all spatial analyses.

A digitized bathymetric vector map of the Gully region (Seabed Exploration Associates, Halifax, Canada) was used to interpolate depth for each 500 × 500-m cell within the study area (Fig. 1). We used these depth values to calculate slope values for each cell (calculated as the maximum slope around each cell from the depth difference between it and neighboring cells [not including diagonals]). Sea surface temperature for each sighting was not recorded in the field but was assigned as the closest 3-hour record. Investigation of the difference between consecutive readings shows an absolute mean difference of 0.5° C (SD 0.5° C, $n = 687$), so our method of measuring temperature should not introduce much bias into the data. The SST was not related to time of day at which the reading was taken (no systematic change in SST with time of day). To view general trends in sightings between months, sightings were pooled for month across years.

A Kolmogorov-Smirnov goodness-of-fit test (K-S test) was used to test the hypothesis that the variables (depth,

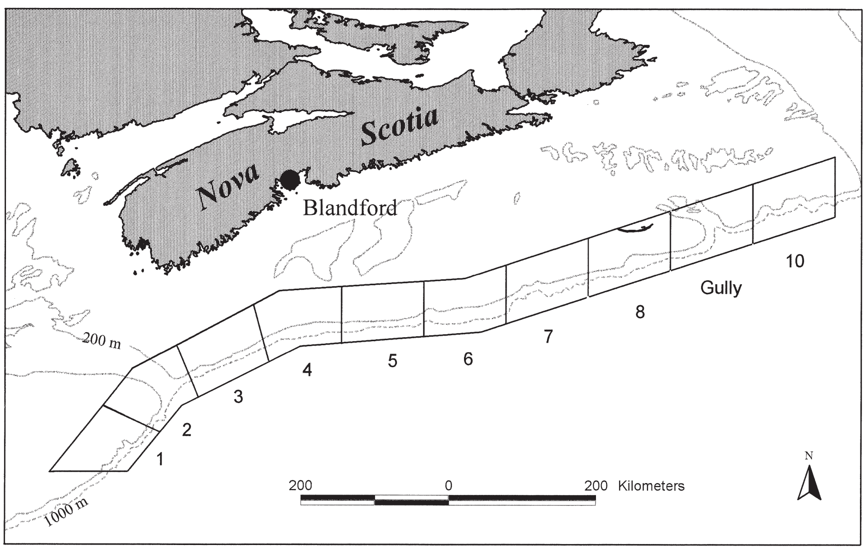

Figure 2. Map of Scotian Slope showing Blandford whaling station and the areas used (marked by integers 1–10) for comparison of numbers of whales killed along the edge of the shelf.

slope, SST, and month) for sightings data had the same distribution as those for the effort data. A general linear model (e.g., variable = constant + depth category + species/effort category) was used to test whether, given the effect of depth, a species then showed a preference for slope, SST, or month. A similar model was then generated to test for an effect of depth, given that of the SST. The relative influences of these variables on cetacean distribution were used as the basis on which to define the boundaries for an MPA in the Gully.

Initial results showed that depth was the best predictor of species distribution. Regions were defined in the Gully according to depth (0–200 m, 200–1000 m, and 1000+ m), the Gully midline, and north-south boundary lines, such that the number of effort hours within each region were approximately comparable (mean = 188.5 hours, SD = 42.2 hours). The number of sightings was calculated for each region, and a corrected species distribution map of sightings per hour of effort for each region was produced. The distribution maps show proportional distribution across the Gully area and are a broad representation of the spatial habitat preferences of each species within the Gully area. Maps were tested to investigate whether the distribution was random with respect to effort (goodness-of-fit *G* test).

Results

Cetacean Abundance

Between 1988 and 1996, 1885 daylight hours were spent in the Gully and 12 species of cetaceans were observed (Table 1): blue, fin, sei, minke, humpback, sperm, northern bottlenose, and long-finned pilot whales (*Globicephala melas*) and striped (*Stenella coeruleoalba*), Atlantic white-sided (*Lagenorhynchus acutus*), short-beaked common (*Delphinus delphis*), and bottlenose dolphins (*Tursiops truncatus*). Several additional species have been documented in the Gully outside the study period, including Sowerby's beaked whale (*Mesoplodon bidens*) and harbor porpoise (*Phocoena phocoena*), and there have been unconfirmed sightings of Blainville's beaked whale (*Mesoplodon densirostris*), and Fraser's dolphin (*Lagenodelphis hosei*). Sei whales were excluded from our analyses due to small sample size.

On the Scotian Shelf during trips to and from the Gully study area (1121 daylight hours), no blue whales, humpback whales, bottlenose whales, striped dolphins, or bottlenose dolphins were seen (Table 1), and all other species except minke whales, white-beaked dolphin (*Lagenorhynchus albirostris*), and harbor porpoise were generally seen at lower rates. Search effort (number of observers) was usually reduced during these trips, so any statistical comparison is not valid. Nevertheless, these data describe the general distribution of cetaceans on the Scotian Shelf and provide a useful comparison.

Results from Blandford whaling data show that the catch of whales (log scale) on the edge of the Scotian Shelf fell approximately linearly with the distance (log scale) from Blandford (Fig. 3; the power relationship has exponent -2.31). The catch of whales in the Gully was approximately twice what would be expected from this relationship (Fig. 3). The Gully area also had the greatest positive deviation from the regression line (studentized residual of 1.99).

Cetacean Distribution

There is wide variation in cetacean species' use of the Gully in terms of depth, slope, SST, and month (Table

Table 1. Number of sightings of cetacean species in the Gully and on the Scotian Shelf, eastern Canada.

Species	Gully total sightings	Year 1988	1989	1990	1993	1994	1995	1996	Group size mean (SD)	Shelf total sightings
Blue whale	8	—	—	—	—	—	3	5	1.4 (0.5)	0
Fin whale	32	6	4	6	5	1	—	10	1.3 (0.8)	1
Sei whale	3	—	—	—	—	—	—	3	1 (0)	1
Minke whale	8	4	—	—	1	—	—	3	1.3 (0.5)	16
Humpback whale	38	2	15	1	2	12	—	6	1.5 (1.1)	0
Sperm whale	92	65	5	1	1	3	1	16	1.1 (0.3)	6
Northern bottlenose whale	577	11	58	180	70	39	12	207	3.3 (2.2)	0
Long-finned pilot whale	54	9	9	7	2	8	8	11	11.4(13.4)	11
Striped dolphin	29	—	5	3	10	7	3	1	13.4 (2.5)	0
Atlantic white-sided dolphin	148	11	15	53	17	7	—	45	8.8 (8.4)	19
Short-beaked common dolphin	104	7	25	11	18	21	—	22	15.6 (25.9)	23
Bottlenose dolphin	7	—	—	2	1	—	1	3	11.3 (13.3)	0
White-beaked dolphin	0	—	—	—	—	—	—	—	—	1
Harbor porpoise	0	—	—	—	—	—	—	—	—	1
Totals	1100	115	136	264	127	98	28	332		79
Effort (daylight hours)	1885	213	215	399	153	170	80	667		1121

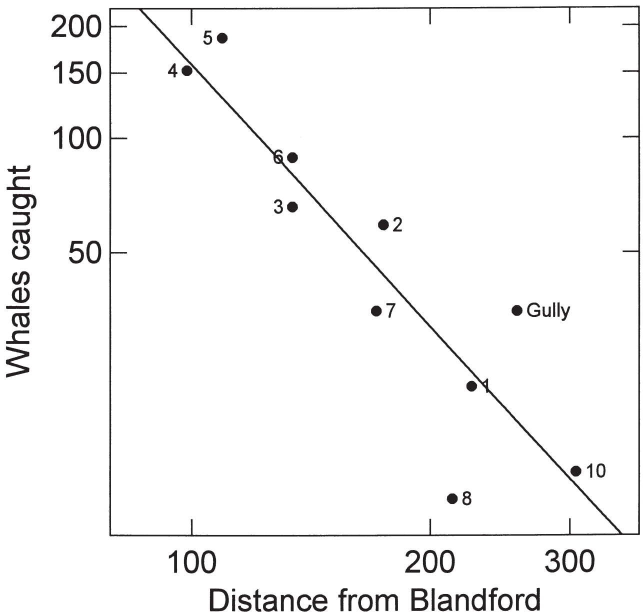

Figure 3. Number of whales killed (log scale) in areas along the Scotian Shelf edge (as shown in Fig. 2) plotted against distance from Blandford (log scale) (regression line shown).

2). These range from minke whales found in shallow shelf waters to striped dolphins in deeper water with higher slope inclines, and from white-sided dolphins found earlier in the summer and at cool SST to blue whales that have been seen only in August and at warm SST (Table 2). Kolmogorov-Smirnov tests (Table 3) indicated that many species had distributions significantly different from the distribution of effort for depth, slope, SST, and calendar month. Such results should be viewed with caution for several reasons: possible Type 1 errors; the inexact nature of the tests, and relationships between variables (particularly depth with slope, Spearman's $r = 0.844$, $n = 14{,}400$; and SST with month, Spearman's $r = 0.837$, $n = 703$).

For seven of the eight species with 20 or more sightings, depth was a better determinant of abundance than slope (comparison of p values, Table 3). Given depth, slope had no significant predictive power of abundance for any species (Table 4). Therefore when the species distributions are related to spatial features, the data suggest that we should restrict our attention to water depth. In contrast, both SST and month were useful predictors of some species distributions given depth (Table 4). The SST and month were strongly correlated with SST rising through the summer. Thus, comparing species distributions to SST is almost equivalent to comparing them to month (significance levels are similar for both of these variables, Tables 3 & 4). The effect of depth on some species distributions is still pronounced given the effect of SST (Table 4), suggesting that depth is of more value than SST in describing certain species' distributions.

Statistically significant depth effects included the preferences of minke whales for shallow water no deeper than than 200 m, of sperm whales for depths between about 250 and 750 m, of northern bottlenose whales for depths between about 750 and 1500 m, of striped dolphins for waters deeper than 1000 m, and of Atlantic white-sided dolphins for water deeper than 200 m. In general, temporal and temperature preferences were shown by blue whales, humpback whales, long-finned pilot whales, striped dolphins, short-beaked common dolphins, and bottlenose dolphins for late summer and warmer waters, and by Atlantic white-sided dolphins for earlier summer and cooler waters (Table 5).

Results of a G test based on the spatial regions defined showed that the spatial distributions of sightings of minke ($p < 0.005$), sperm ($p < 0.001$), and northern bottlenose whales ($p < 0.001$) and striped ($p < 0.05$) and Atlantic white-sided dolphins ($p < 0.005$) sightings were significantly different from the hourly search positions (i.e., they were significantly different from random, Fig. 4). Tests for blue whales, minke whales, and bottlenose dolphins, may not be statistically reliable due

Table 2. Mean (SD) of depth, slope, SST,[a] and calendar month for cetacean sightings and search positions in the Gully.

Species	*Depth (m)*	*Slope (°)*	*SST (°C)*	*Month*
Blue whale	920 (560)	14 (9)	18.0 (1.8)	8 (0)
Fin whale	920 (470)	10 (6)	16.6 (3.2)	7.53 (0.51)
Minke whale	170 (90)	3 (2)	13.1 (3.5)	6.75 (0.46)
Humpback whale	1010 (460)	12 (9)	17.3 (3.2)	7.61 (0.59)
Sperm whale	730 (430)	9 (7)	15.4 (2.2)	7.24 (0.62)
Northern bottlenose whale	1200 (290)	14 (8)	14.5 (3.9)	7.11 (0.77)
Long-finned pilot whale	950 (550)	11 (7)	17.3 (3.1)	7.65 (0.59)
Striped dolphin	1380 (380)	13 (8)	16.8 (3.0)	7.55 (0.51)
Atlantic white-sided dolphin	1170 (410)	13 (7)	13.5 (3.6)	6.88 (0.70)
Short-beaked common dolphin	1100 (480)	12 (7)	16.5 (2.9)	7.49 (0.54)
Bottlenose dolphin	950 (490)	16 (8)	16.0 (2.1)	7.86 (0.38)
Search locations[b]	1030 (500)	11 (8)	15.2 (3.7)	7.27 (0.73)

[a] *Sea surface temperature.*
[b] *Locations every hour (n = 1885) for depth and slope and every 3 hours (n = 703) for SST and month.*

Table 3. Summary of Kolmogorov-Smirnov goodness-of-fit tests (*p* values) of environmental and temporal variables for each cetacean species compared to search effort.

Species	*Depth*	*Slope*	*SST**	*Month*
Blue whale	0.834	0.601	0.027	0.013
Fin whale	0.065	0.042	0.020	0.026
Minke whale	<0.001	0.002	0.424	0.874
Humpback whale	0.089	0.634	0.008	0.047
Sperm whale	<0.001	0.003	<0.001	<0.001
Northern bottlenose whale	<0.001	<0.001	<0.001	<0.001
Long-finned pilot whale	0.107	0.634	<0.001	0.001
Striped dolphin	0.001	0.450	0.074	0.067
Atlantic white-sided dolphin	0.002	0.013	<0.001	<0.001
Short-beaked common dolphin	0.109	0.817	0.001	<0.001
Bottlenose dolphin	0.861	0.257	0.770	0.102

**Sea surface temperature.*

to small sample sizes. Fin whales and short-beaked common dolphins showed a marginal but nonsignificant preference for the shelf edge.

Discussion

The prime objective in the establishment of many marine protected areas is the conservation of biodiversity (Jones 1994). The Gully has a higher diversity and abundance of cetaceans than the adjacent shelf waters (Table 1). The waters around Sable Island and the Gully have previously been noted to have the most diverse cetacean fauna of eastern Canada (Sergeant et al. 1970). Sergeant et al. (1970) attributed this to the proximity of deep water and the mixing of slope water between the Gulf Stream and coastal water. The Gully has a higher diversity of cetaceans than the adjacent shelf waters (Table 2) and many other areas in the northwestern Atlantic (e.g., the Gulf of Maine has six common species, Katona et al. 1983; the Bay of Fundy has six common species, Gaskin 1983). Our analysis of data on whale catches along the Scotian Slope further suggests that the local abundance of whales in the Gully is not due solely to its shelf edge location (Fig. 3). Large whales appear to have been more available in the Gully than in other similar sized areas along the Scotian Slope.

The World Conservation Union has defined an MPA as "any area of inter-tidal or sub-tidal terrain, together with its overlying waters and associated flora, fauna, and historical and cultural features, which has been reserved by legislation to manage or protect part or all of the enclosed environment" (Kelleher & Kenchington 1992). A key word in this definition is "legislation." Previously there have been two protective measures used in the Gully, although neither was legislated. The first was the designation of a shipping exclusion zone for the oil field (Cohasset/Panuke) developed in 1990 (Faucher & Weilgart 1992; Faucher & Whitehead 1995). The boundary of this area extends around both the Gully and Sable Island, from north of the 200-m isobath to south of the 1000-m isobath in the Gully. Although this zone has kept shipping associated with this development out of the Gully, other ship traffic is regularly seen in and around the

Table 4. Results of general linear model (*p* values) testing the effect of slope, sea surface temperature (SST), and month on species distributions given the effect of depth, and of depth on species distributions given the effect of SST.

Species	*Slope given depth*	*SST given depth*	*Month given depth*	*Depth given SST*
Blue whale	0.240	0.046	0.006	0.676
Fin whale	0.447	0.034	0.049	0.500
Minke whale	0.981	0.044	0.014	<0.001*
Humpback whale	0.721	0.001	0.004	0.855
Sperm whale	0.055	0.849	0.439	<0.001*
Northern bottlenose whale	0.133	0.021	0.008	<0.001*
Long-finned pilot whale	0.729	<0.001*	<0.001*	0.488
Striped dolphin	0.840	0.029	0.033	<0.001*
Atlantic white-sided dolphin	0.088	<0.001*	<0.001*	<0.001*
Short-beaked common dolphin	0.923	0.001	0.002	0.028
Bottlenose dolphin	0.007	0.546	0.036	0.875

**Significant effect (Bonferroni correction).*

Table 5. Summary of spatial and temporal results and the importance of the Gully to the species found there.

Species	*Habitat within Gully*	*Seasonal changes*	*COSEWIC* status*	*Importance of Gully*
Blue whale	—	late summer	vulnerable	a few sightings
Fin whale	—	mid-late summer	vulnerable	part of a band of abundance near the shelf edge (Mitchell 1974)
Minke whale	shallow waters	—	—	probably not very important
Humpback whale	—	more in late summer	vulnerable	the only known offshore distribution on the Scotian Shelf
Sperm whale	northern basin	—	not at risk	reliable concentrations, probably the most important habitat on the Scotian Shelf (Whitehead et al. 1992)
Northern bottlenose whale	center of Gully canyon	throughout year	vulnerable	focal habitat of what may be a distinct population (Whitehead et al. 1997*b*)
Long-finned pilot whale	—	more in late summer	not at risk	part of a general distribution on the Scotian Shelf (Sergeant & Fisher 1957)
Striped dolphin	deep waters and in south of canyon	late summer	not at risk	the most significant habitat identified in Canadian waters (Baird et al. 1993*a*)
Atlantic white-sided dolphin	deeper waters	early summer	not at risk	part of a general distribution on the Scotian Shelf, possibly an area of special abundance (Sergeant et al. 1970; Gowans & Whitehead 1995)
Short-beaked common dolphin	—	late summer	not at risk	possibly the most significant habitat in Canadian waters (Gowans & Whitehead 1995)
Bottlenose dolphin	—	late summer	not at risk	occasional sightings of rarely seen species in Canada (Baird et al. 1993*b*)

**The Committee on the Status of Endangered Wildlife in Canada (Campbell 1997).*

Gully area. In 1994 the Canadian Department of Fisheries and Oceans set up a voluntary whale sanctuary in the Gully (Fig. 5; Faucher & Whitehead 1995). Mariners are advised as to the significance of the area, it is recommended that the area should be avoided when possible, and guidelines are given for minimizing hazards to whales when navigating through the area (as announced in "Notices to Mariners"). This sanctuary was set up to minimize the risk of ship collisions with northern bottlenose whales and does not account for other threats, has no legislative authority, and does not aim to protect any other species in the area.

In Canada there are two major federal mechanisms for the establishment of an MPA. The Oceans Act, which came into force on 31 January 1997, states that a marine protected area should conserve and protect an area of the sea for one or more of the following values: (1) commercial and noncommercial fishery resources, including marine mammals and their habitats; (2) endangered or threatened marine species and their habitats; (3) unique habitats; (4) marine areas of high biodiversity or biological productivity; and (5) any other marine resource or habitat as is necessary to fulfill the mandate of the Minister of Fisheries and Oceans (s.35(1), Department of Fisheries and Oceans 1997). Prior to the Oceans Act, the major mechanism for the creation of marine parks was through the National Parks Act, through which Canadian Heritage may protect marine and coastal areas by designation of formal park status. One goal of the National Marine Parks Policy is to establish a national marine park representing each of the 29 marine regions (Waterman 1995). There are currently five national marine parks in Canada, three on the west coast and two in inland waters (Lake Huron and the St. Lawrence River), but there is none on the east coast (Dionne 1995; Waterman 1995). There is also a third federal initiative run by the Canadian Wildlife Service (Environment Canada) that can declare migratory bird sanctuaries or national wildlife areas via the Migratory Birds Convention Act and the Canada Wildlife Act. The foci of these, however, are primarily migratory birds. The Oceans Act and National Parks Act have differing criteria for MPAs. The former recommends protecting unique habitat, the latter representative habitat. The Oceans Act, however, states that the Department of Fisheries and Oceans "will lead and co-ordinate the development and implementation of a national system of MPAs" (s.35(2)), so it appears this act will be Canada's primary legislation for the implementation of MPAs.

The Gully fits all of the criteria listed in the Oceans Act: (1) it includes a high diversity and abundance of marine mammals; (2) the northern bottlenose whale population has been designated as vulnerable by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC; Whitehead et al. 1997*a*); (3) submarine canyons have been identified as one of the habitat classifications recommended for a protected area (Ray 1975), and

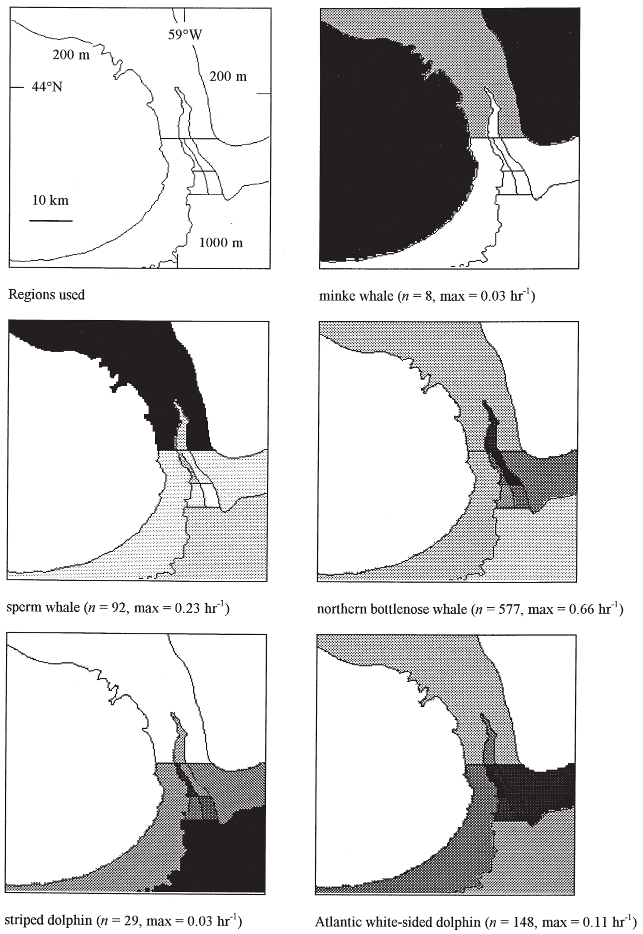

Figure 4. Species' distribution maps in the Gully. Regions are defined primarily by depth (0–200 m, 200–1000 m, and >1000 m) but also by the centerline of the canyon and north-south boundaries. For each species the shading ranges from black for the area of highest sighting per effort hour to white for the area of no sightings per effort hour. The maximum number of sightings per hour (for area of darkest shading) is shown below each species' map.

the Gully is the deepest and largest submarine canyon on the Scotian Shelf; and (4) the diversity and abundance of cetacean species in the submarine canyon suggest its ecological importance.

A major problem in conserving marine habitat is identifying the relevant ecological boundaries and responding to them in the design of the protected area (Agardy 1994; Duffus & Dearden 1995; Recchia et al. 1995). We focused on the cetacean inhabitants of the Gully in order to make initial recommendations for MPA boundaries, but our recommendations should be subject to modification as further research on the Gully ecosystem and its threats is conducted.

Under the Oceans Act, MPA regulations may include zoning, prohibition of certain activities, or any other matter consistent with the purpose of the designation (s.35(3)). The level of protection can therefore vary from a strict no-take area, where access is severely limited, to areas where controlled use or resource harvesting is allowed (Department of Fisheries and Oceans 1997). Zoning may also be temporal in terms of seasonal restrictions. Northern bottlenose whales (Whitehead et al. 1997*a*), sperm whales (resighted between years; J. Christal, personal communication), and Atlantic white-sided dolphins and minke whales (seen in early summer and cold water, Table 5) inhabit the Gully throughout the year. To protect the habitat of these and the other more transient visitors to the Gully, a year-round MPA should be established rather than protection implemented for only the summer months.

The type of protection required in the Gully area depends on the threats to it. In general, threats to marine biological diversity fall into two classes, those that involve overexploitation of living resources and those that destroy or degrade habitat (Sobel 1993). Of threats to cetaceans, the most direct and lethal are from ship collisions and fisheries (in terms of accidental bycatch, Perrin et al. 1994), but within the Gully these currently pose a relatively small threat. Indirect effects include acoustic pollution, chemical pollution, and marine debris (Simmonds & Hutchinson 1996). Of primary concern in the area is the increase in gas and oil production close to the Gully (Fig. 1), which is likely to lead to both increased noise pollution and increased risk of ship collisions. Other threats associated with gas and oil production include the effects of routine operational discharges (drill muds and cuttings or produced water and associated biocides) as well as the potential for accidental spills of oil or other hazardous chemicals into the Gully (Messieh et al. 1991; Joint Public Review Panel 1997). Cetaceans rapidly bioaccumulate even trace toxins and in some cases may suffer immunological and reproductive disorders as a consequence (Simmonds & Hutchinson 1996). The recent discovery of four small feeder canyons into the Gully from Sable Island bank is of additional concern because they may provide a conduit for transport of material into the Gully (Fader et al. 1997). Little is known of the Gully's benthic processes, but at a minimum the local deep sea corals (Breeze et al. 1997) would suffer from an increase in sediment transport into the region. In addition to the current oil and gas development in the region, there are two leases of additional concern: the "Parcel 5" lease, a large area bordering the 500-m isobath in the center of the Gully, and the "Primrose" lease 8 km from the center of the Gully (Canada/Nova Scotia Offshore Petroleum Board, personal communication).

Our results quantitatively demonstrate that cetacean species using the Gully showed significant preferences for certain depths within the region and were seen significantly more often at certain SST than at others (Ta-

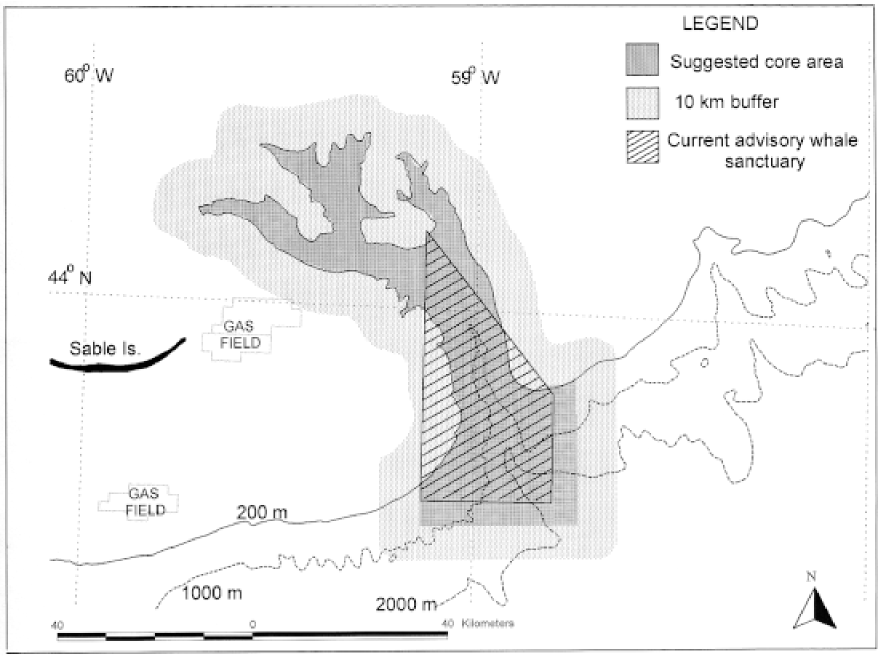

Figure 5. Map showing the current protection in the Gully (an advisory "whale sanctuary"), the core area boundary for a marine protected area (MPA) suggested by this study, and a 10-km buffer zone around this core area.

bles 3 & 4). Most depth trends we found agree with those suggested previously for other areas in the northwest Atlantic (Table 2; see also Hay 1982; Hain et al. 1985; Selzer & Payne 1988; Payne & Heinemann 1993). Although both depth and SST had a significant effect on species distributions, when interactive effects are considered the effect of depth appears to be more significant than that of SST (especially on species thought to live in the Gully year-round, Tables 3 & 4). This suggests that species distributions are better defined by fixed features of the physical environment than by variable aspects of environment (Tables 4 & 5; Fig. 4). Because the ecological processes governing this system are still largely unknown, it would be advisable to take a precautionary approach to MPA designation, as recommended in the preamble to the Oceans Act. A core-area boundary, to protect cetaceans within the Gully against both direct and indirect effects of gas and oil development and the shipping industry, should therefore be established based on the 200-m isobath (Figs. 4 & 5). Species distributions (Fig. 4) suggest that an appropriate southern boundary for the core area is that used in this study to the south and the boundary of the whale sanctuary to the west (Fig. 5).

A buffer zone around this core area would be advisable for protection against threats such as chemical or noise pollution or adjacent dredging (Sobel 1995). Little is known of the effects of many acoustic activities on cetaceans (Richardson et al. 1995), but 10 km is a recommended buffer distance to allow source levels for seismic or tanker traffic to decrease to acceptable levels (160 dB; Davis et al. 1998) (Fig. 5). The effects of chemical pollutants are also not well studied, and the patterns of current flow within the Gully are still being elucidated (Cong et al. 1996). A circular, clockwise current lying just southeast of Sable Island could entrain drilling muds or other seafloor particles (Amos & Nadeau 1988; Amos & Judge 1991), whereas surface particles could become entrained in a retention zone over the head waters of the Gully (Cong et al. 1996). Further study is needed of the indirect effects of these processes. Given these uncertainties, the optimal size and scope of a buffer zone remains undefined.

We have shown that the Gully fits all of the criteria recommended for the establishment of a marine protected area in Canada. Cetacean distribution in the Gully can provide a reasonable and informative basis for drawing the boundaries of a protected area, and within the Gully the primary boundary should be the 200-m isobath. Classification systems to aid in ranking candidate MPA sites are being defined (Davis et al. 1994), but in the interim the Gully has been suggested as a reasonable pilot MPA. Its offshore nature and the minimal fishery there should assure that there are relatively few objections to this site from user groups (Agardy 1995), and given the government's commitment to establishing a system of MPAs (Department of Fisheries and Oceans 1997), we hope the Gully will receive adequate legislative protection in the near future.

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