SHADED SEAFLOOR RELIEF AND BENTHIC HABITAT

GERMAN BANK

SCOTIAN SHELF

OFFSHORE NOVA SCOTIA

Scale 1:100 000/Échelle 1/100 000

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This map is not to be used for navigational purposes Cette carte ne doit pas être utilisée aux fins de navigation

Projection transverse universelle de Mercator

Système de référence géodésique nord-américain, 1983

Universal Transverse Mercator Projection

North American Datum 1983

Any revisions or additional information known to the user

would be welcomed by the Geological Survey of Canada

Digital base map (land area) from data compiled by Geomatics Canada, modified by GSC (Atlantic)

Digital bathymetric contours in metres supplied by the Canadian Hydrographic Service and GSC (Atlantic)

Mean magnetic declination 2010, 17°18'W, decreasing 6.0' annually.

Readings vary from 16°59'W in the SW corner to 17°37'W in the NE corner of the map

Depth in metres below mean sea level

DESCRIPTIVE NOTES

INTRODUCTION This map shows 5321 km² of sea floor topography of German Bank, located on the Scotian Shelf off southern Nova Scotia, in shaded-relief view with colour-coded benthic habitat units at a scale of 1:100 000. This map is related to a three-map series of German Bank showing bathymetry, backscatter strength and surficial geology (Todd and Valentine, 2010). This map is the product of a number of surveys (1997-2003) that used a multibeam-sonar system to map of the seafloor. Other surveys collected shown (in white) on the benthic habitat at a depth interval of 20 m. Bathymetric contours (in blue) outside the multibeam survey area, presented at a depth interval of 10 m, are from the Natural Resource Map series (Canadian Hydrographic Service, 1967, 1971a, 1971b, 1972). The interdisciplinary scientific field of benthic habitat mapping has been successfully developed and applied in Canada to provide the knowledge base to effectively manage offshore fisheries, evaluate marine protected areas, minimize the environmental impact of offshore development, and resolve sea floor use conflicts (Pickrill and Todd, 2003; Todd and Shaw, 2009). For example, on German Bank, benthic habitat mapping was the critical underpinning of newly-opened scallop fishing grounds (Smith et al., 2005, 2009) where the resource manager (the Government of Canada) and the fishing industry shared the cost of map development.

Ocean circulation in the region of German Bank has been studied using moored current meters, drifting buoys, and finite-element modelling (Smith, 1983; Page and Smith, 1989; Lynch et al., 1996; Hannah et al., 2001). Seasonal circulation is tidally dominated with a persistent westward and north-westward flow toward the Gulf of Maine. The geostrophic Nova Scotia current flows southwest over the Scotian Shelf against the direction of the main wind stress (Smith and Schwing, 1991). On German Bank the Nova Scotia current mixes with the warmer and more saline water of the Gulf of Maine. The northwest flow of Scotian Shelf water across German Bank contributes to the broad-scale counter clockwise ocean circulation within the Gulf of Maine (Lynch et al., 1996). Seasonal circulation on German Bank is dominated by tidal rectification and baroclinic flow, with smaller contributions from wind stress (Han and Loder, 2003). The current regime on the bank is strongly influenced by tides with the root-mean square (RMS) of tidal current speed reaching 70 cm s⁻¹ over eastern parts of German Bank, signifying well-mixed water (Fig. 1a). The average yearly bottom water temperature on German Bank (Fig. 1b) increases from 4°C in the east to 8°C in the west, varying seasonally from less than 2° in the deeper part of the bank (> 100 m) to almost 10° in the shallow inshore zone (Fig. 1c) (Hannah et al., 2001). Average bottom salinity (Fig. 1d) i 32‰ in shallow eastern waters increasing to 34‰ in the deeper part of the bank to the west (Hannal et al., 2001). Based on the summer water density difference between surface and 30 meters depth, water masses on the bank are well mixed, with stratification slightly higher in the eastern nearshore part of the study area (Fig. 1e). Spring phytoplankton bloom production (Fig. 1f) reaches 6 m kg ml1 (estimated from SeaWifs, G. Harrison, pers. comm., 2004). The bottom waters of German Bank are strongly saturated with oxygen (Fig. 1g), with average saturation 100% to the east near the Nova Scotia shore, decreasing to 60% saturation to the southwest in Georges Basin in July, based on oxygen saturation data from annual summer groundfish cruises extracted for the period 1997–2003 from the BioChem database (Fisheries and Oceans Canada, 2006a).

OCEANOGRAPHY

MULTIBEAM SONAR BATHYMETRY Multibeam sonar bathymetric data were collected over 5320 km2 of German Bank using a Simrad Subsea EM1000 multibeam bathymetric survey system (95 kHz). This system produces 60 beams arrayed over an arc of 150° and operates by ensonifying a narrow swath of seafloor across track and detecting the seafloor echoes. The width of seafloor imaged on each survey line was five to six times the water depth. Line spacing was approximately three to four times water depth to provide ensonification overlap between adjacent lines. The Differential Global Positioning System was used for navigation, providing positional accuracy of approximately 3 m. Survey speeds averaged 14 kno resulting in an average data collection rate of approximately 5.0 km2 hr-1 in water depths of 20 to 70 m. The sound velocity in the ocean was periodically measured during multibeam data collection and was used to correct the effect of sonar beam refraction caused by changes in water density. During the survey, water depth values were inspected and erroneous values were removed. The data were adjusted for tidal variation using tidal measurements and predictions from the Canadian Hydrographic Service and Fisheries and Oceans Canada Coastal Oceanography Group (Dupont et The multibeam bathymetric data are presented at 5 m per pixel horizontal resolution in shaded relief. Topographic features are enhanced by sun illumination on the northwest-facing slopes and by shadows cast on the southeast-facing slopes. Thus, small topographic features are accentuated that could not be effectively shown by contours at this scale. Superimposed on the shaded relief image are colours assigned to benthic habitats (discussed below).

MORPHOLOGY Morphological seabed descriptors (seabed slope and benthic position index) were derived from multibeam sonar bathymetric data gridded at 10 m resolution (Fig. 1h, i). Benthic Position Index was calculated from the bathymetric raster dataset using Benthic Terrain Modeler (http://www.csc.noaa.gov/products/btm/) with the outer radius set to 25 and 100 map pixels; the corresponding terrain classification maps produced have scales of 250 m and 1000 m. The 250 m scale map (Fig. 1j) emphasizes local-scale features (e.g., crests and troughs of sand bedforms) whereas the 1000 m scale map characterizes broad-scale gradients. BIOLOGICAL DATA

igh-resolution sea floor imagery was obtained on German Bank using Campod, an instrumented tripod (Gordon et al., 2007). The system includes forward- and downward-looking video cameras and a downward-looking 35-mm still camera. Campod was allowed to drift across the seabed and was placed, stationary, on the sea floor at locations of interest. Using this system, 97 sea floor video transects, including 1134 sea floor photographs, were collected. Physical habitat characteristics and the type of benthic fauna on German Bank were interpreted from the seafloor photographs. The presence or absence of benthic animals and biogenic seabed features e.g., burrows) were classified. All visible species of megabenthos were identified to the highest possible taxonomic resolution. A total of 127 taxa and biogenic features was described from the analysis of seaber photographs collected at 70 stations. The frequency of occurrence of each species was calculated for Physical habitat at the 70 stations was described in terms of relative abundance of gravel (boulders, cobbles, pebbles, and granules), sand and silt, as well as perceived topographic complexity. Other habitat descriptors were water turbidity, the abundance of shell hash, the presence of small and large burrows, and siphons of infaunal invertebrates. A qualitative estimate was undertaken of the area of sea floor covered by sediment of different grain size classes (i.e., gravel, sand, mud) ranging on a scale from 1 (some cover) to 5 (full cover). BYCATCHANALYSIS

From 2001 to 2005, annual research surveys were conducted by Fisheries and Oceans Canada on a scallop fishing area on eastern German Bank (Fisheries and Oceans Canada, 2006b). An 800 m-long tow using scallop dragging equipment was conducted at survey stations. A random survey design was used in 2001; from 2002 to 2004, a stratified random design was used by area and in 2005 the strata were defined by sea floor sediment type. The total number of tows per sampling year varied from 125 to 169 but not all tows were used for estimating abundance in this study. A number of tows were either exploratory or were used to collect ancillary information on different species and bottom types. Fisheries observers monitored bycatch on commercial vessels with a target of one observed trip for each vessel. Numbers and weights of the fish and invertebrate species in the catch were recorded. For this present study, the weights of the discarded bycatch of benthic invertebrates were normalized and a Bray-Curtis betweenstation similarity matrix was created. This matrix was used for BIOENV and ANOSIM analyses described

Three data groups were analyzed in relation to similarity of benthic fauna: (1) oceanographic data (RMS tidal currents (Fig. 1a), average annual bottom temperature (Fig. 1b), variability in bottom temperature (Fig. 1c), bottom water salinity (Fig. 1d), density difference (Fig. 1e), spring average chlorophyll-a concentration (Fig. 1f), and oxygen saturation (Fig. 1g)); (2) morphological data (water depth (sheet 1), rugosity (Fig. 1h), seabed slope (Fig. 1i), benthic position index at 250 (Fig. 1j) and 1000 metre scales); and (3) textural data (multibeam sonar backscatter (sheet 2), percent seabed surface cover for bedrock, cobbles and boulders, pebbles and granules, shell hash, sand, fine sand, and muddy sand). The values for oceanographic, morphological and textural factors were extracted from data grids in ESRI ArcGIS using the Sample tool. The values were standardized and used in BIOENV (Biota and Environment matching) analysis in Primer (Clarke and Ainsworth, 1993). Similarity between stations was assessed using the Bray-Curtis similarity index for community composition and Euclidean distance for similarity ANOSIM (Analysis of Similarities) was used to check for differences in faunal structure between different seabed types in both bycatch and seabed photo data. The analyses produces the R statistic, which is scaled to lie between -1 and +1, with the value of zero representing the null hypothesis of no

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differences among a set of samples (Clarke, 1993).

Seafloor and associated fauna Photograph and video observations reveal that the German Bank seabed is diverse and heterogeneous. The geological and topographical complexity of the seabed is the result of glacial and modern processes. Structurally, habitats vary from outcropping bedrock to sand wave fields, and in terms of substrate from silt to gravel. Benthic fauna of these habitats is dependent on the types of substrate to which it can attach, In the deeper parts of German Bank (100 to 140 m water depth), muddy sand with patches of amphipod or polychaete tubes dominates a generally flat seabed (Fig. 2a). Sediment varies from gravely sand to mud. Poorly-developed current ripples commonly are observed on the surface of muddy sand. Benthic megafauna include the dominant burrowing anemone Cerianthus borealis and shrimps Pandalus sp., with less common Jonah crabs (Cancer sp.) and hermit crabs (Pagurus sp.). Some Urophycis sp., monkfish and several species of flatfish are found above and on the seabed. Benthic epifauna in this part of the bank is generally scarce. In water depths of 50 to 100 m, topographically complex and heterogeneous seabed varies from exposed bedrock through cobbles and boulders to sandy gravel and shell hash beds. Fauna on hard substrates (exposed bedrock and topographically complex mixed sediments, Fig. 2b, c) include a variety of encrusting and erect sponges, sea stars (Asterias sp., Crossaster papposus, Solaster endeca, Hippasteria phrygiana), tunicates (Boltenia ovifera), brachiopods (Terebratulina sp.) and soft corals (Gersemia sp.). Fish are commonly observed in the complex rocky habitat. Calcareous polychaete tubes, likely of Filograna implexa, and sponges are generally characteristic of poorly sorted sediments. Asterias sp., *Crossaster* sp. and *Hippasteria* sp. are also common on sandy gravel and gravely sand, as well as on shell beds containing populations of horse mussels (*Modiolus modiolus*) (Fig. 2d). Hard substrates are commonly overgrown with dense mats of hydrozoa and bryozoa, but patches of sand and sandy mud occurring among till and bedrock outcrops have scarce fauna, with Hyas aranaeus, Strongylocentrotus Within a similar water depth range of 50 to 100 m in the northwest part of the German Bank, dominated by drumlins, seabed texture varies from gravelly mud to complex cobble and boulder bottom (Fig. 2e). Abundant epifauna with low diversity is commonly observed on hard substrates. Groundfish, Jonah crab

(Cancer sp.) and scallops (Placopecten magellanicus) are common on gravely sand in troughs between drumlins. Anemones and Asterias sp., as well as abundant erect and encrusting (Halichondria panicea) sponges, are common in the complex habitat on the drumlins. On sand deposits in the southeast of the German Bank (Fig. 2f), brittlestars (Ophiura sarsi) are abundant in deeper waters (70 m), along with less frequently occurring Strongylocentrotus sp., Hippasteria phrygiana, Pagurus sp., Colus sp., Buccinum sp., Neptunea sp., hydrozoa, bryozoa and anemones, both burrowing and non-burrowing. Shallower sands (30 to 40 m) usually contain abundant shell fragments and mussel shells (Fig. 2g). These habitats have scarce fauna, which includes *Placopecten magellanicus*, and *Modiolus modiolus* with anemones and sponges (*Polymastia sp.*) In the shallowest waters (20 to 40 m) of German Bank the seabed is dominated by bedrock and boulders with a few patches of sand. Boulders are covered with *Lithothamnium* sp. and densely colonized by fauna typical for southern Nova Scotia nearshore environments (Fig. 2h). The frilled anemone Metridium senile is very abundant along with the stalked tunicate Boltenia ovifera. Prolific fauna includes Modiolus modiolus, as well as encrusting, erect sponges (Haliclona oculata), mound-shaped sponges, Because of the general homogeneity of oceanographic processes on the bank, no distinct broad scale gradients in benthic fauna composition were noticed in the analysis of the bycatch data. Some exceptions are the boreal species such as sea cucumber (Cucumaria frondosa) and basket stars ank; lobsters (Hommarus americanus) and Jonah crab (Cancer sp.) were more abundant in the wester part of the bank, possibly because of the temperature preference of these species. The majority of the species, however, were more dependent on the local habitat structure. Analysis of the distribution of mosaic fashion, often associated with topographic or geological features. For example, an assemblage characterized by high abundance of crabs, skates and lobsters was commonly found in muddy, fla alleys between the sets of moraine ridges. Based on these preliminary observations it is concluded th most of the variability in distribution of commercial species and bycatch is explained by the geological patterns (See Todd and Valentine, 2010).

Statistical analysis of the megafaunal community data and the trawl bycatch data was undertaken to establish the relationship between distribution of benthic fauna and environmental variables. BIOENV analysis of megafaunal community data as assessed from photographs revealed that the single variable which best explains the distribution of bottom fauna is summer oxygen saturation at seabed (Fig. 1g). The best combination of several variables related to benthic community composition is the combination of water depth (sheet 1), oxygen saturation (Fig. 1g), seabed cover by cobbles and seabed cover by sand (Spearman's Rho = 0.174) (Table 1). For the trawl bycatch dataset, the best single variable is the interannual variability in water temperature (Fig. 1c), and the best four are interannual variability in water temperature, water stratification (Fig. 1e), seabed slope (Fig. 1i) and spring chlorophyll-a concentration Fig. 1f) (Table 2). Thus, between the megafaunal community and the trawl bycatch datasets, a number oceanographic and geological variables prove useful for discrimination of different benthic habitats. Among these variables, oxygen saturation, variability in temperature, stratification, and chlorophyll concentration relate to productivity of the environment. All of these variables co-vary, to some degree, with water depth. Also, seabed slope and seabed cover by sand or cobbles reflects the underlying ANOSIM between surficial geology class and benthic community structure based on seabed photographs shows no difference in observed fauna between different geological classes (Global R =

0.027, p = 0.244). However, ANOSIM between surficial geology classes and trawl data show that geological classes have an effect on the type of benthos caught by the trawls where the overall test Global R statistic) was statistically significant at the 0.001 level. Ice-distal glaciomarine silt and postglacial sand and gravel are the most distinct (R = 0.092, p= 0.002) and differ in their fauna from other classes. The silt class is different from metasedimentary rock (R = 0.133 p = 0.001) as well as from igneous rock (R = 0.099 p = 0.015). Postglacial sand and gravel is different from ice contact sediment (till) (R = 0.075 p = 0.001). Tow contents on igneous and metasedimentary rock do not differ significantly (R = 0.049, p = 0.085). Also, these bedrock types are not different from catches on ice-contact sediment or on postglacial sand and gravel. No significant difference is observed between silt and ice-contact sediment, probably because most of the ice-contact sediment has a high silt content. To summarize the statistical analysis, German Bank exhibits four classes of surficial geology which have significantly different fauna as deduced from trawl samples: 1) bedrock (including both metasedimentary and igneous rock), 2) ice-contact sediment, 3) postglacial sand and gravel, and 4) icedistal glaciomarine silt. These four surficial geology classes were used for habitat classification.

The oceanographic factors which were found important for structuring benthic fauna on the bank (oxygen saturation, temperature variability, water stratification and chlorophyll-a concentration) are strongly related to water depth. These factors vary smoothly over the bank and it is not helpful to use the gradients in those factors to define the bank and its not helpful to use the gradients in these factors to define the boundaries of benthic habitat zones. The approach taken here was to designate the water depth of 100 meters as an approximate boundary which separates high from low values for all of the oceanographic factors. The two depth classes, termed shallow (< 100 m) and deep (> 100 m), were combined with the four seabed geology classes of bedrock, till, sand and mud silt to produce the resulting eight habitat types that are relevant to benthic fauna on the bank, namely deep and shallow bedrock, deep and shallow till, deep and shallow sand, and deep and shallow mud.

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ICE-DISTAL GLACIOMARINE SILT

POSTGLACIAL SAND

ICE-CONTACT SEDIMENT

METASEDIMENTARY AND IGNEOUS ROCK

Benthic habitat boundaries (inferred contacts that may be gradational

						Table 1. BIOENV analysis of meg.	afaunal community d	ata
66°30′W	RMS tides cm s ¹	96*30*W	Bottom Temperature	66°30W	Temperature variability	Physical Variable	Spearman Corr. Coefficient	1
	High : 68.46		High : 7.8826		High: 6.74	Oxygen saturation	0.172	
	Low: 38.14		Low : 4.82636	-	Low: 1.55	Water Depth	0.123	
						Sand cover	0.027	
						Cobbles and boulders cover	0.048	
						Shell hash cover	0.047	
			S-10 C			Stratification	0.085	
						Seabed slope	0.065	
	A	-	В		C 1	BPI 100 m	0.081	
	A		D	ı		BPI 25 m	0.054	
I		ı	T			Bedrock cover	0.107	
	Salinity		Density difference (Stratification)	prince have	Chlorophyll-a mg m ³	Variability in temperature	0.068	
	Promille High: 34.08		kg m ⁻³		mg m ³ High: 2.203	RMS tides	0.000	
	Low: 31.71	-	High: 1.11	-	Low: 1.371	Temperature	0.050	
			Low: 0.45			Salinity	0.030	
						Muddy sand cover	-0.002	
		-				•	-0.002	
						Chlorophyll a		
						Backscatter intensity	-0.005	
						Pebbles and granules cover	-0.025	
	D		E		F.	Fine sand cover	-0.072	
	Oxygen saturation Percent High: 100		Rugosity Value High: 6.5		Slope Degrees High: 73	Table 2. BIOENV analysis of bent		T _
	Low: 71		Low: 1.0		Low: 0	Physical Variable	Spearman Corr. Coefficient	Fred 1
			The same of the sa		Contract Security Sec	Variability in temperature	0.151	
						Stratification	0.140	
				- A - 2 - 2 - 3		Seabed slope	0.051	
					No. of Contract	Chlorophyll a	0.149	
	G	The same of the sa		Was a series of the series of		Temperature	0.147	
	G		H			Oxygen saturation	0.147	
1	Т	66°30'W	66°W 65°30°W	66°30′W	66°W 65°30′W	RMS tides	0.147	
NO STORAGE TO STORAGE	BPI 25	Figure 4 Com	man Pank assansarari	nic data plattadit	hin the houndary of the	Salinity	0.146	
TARREST NA	Value Trough	topographic ir	nan bank oceanograpi nage: (A) RMS tidal	currents. (B) a	hin the boundary of the verage annual bottom	Seabed Rugosity	0.146	
200	Flat Ridge	temperature, (C) variability in bottom	temperature, (D) b	ottom water salinity, (E)	Backscatter intensity	0.145	
200		density differ	ence, or stratification	on, (F) spring a	average chlorophyll-a	Water Depth	0.123	
					om seabed topography	BDI 25 m	0.106	

are shown in (H) rugosity, (I) seabed slope, and (J) benthic position index at 250

Physical Variable	Spearman Corr. Coefficient	Frequency in the be	
Oxygen saturation	0.172	1.0	
Water Depth	0.123	0.9	
Sand cover	0.027	0.9	
Cobbles and boulders cover	0.048	0.6	
Shell hash cover	0.047	0.5	
Stratification	0.085	0.4	
Seabed slope	0.065	0.2	
BPI 100 m	0.081	0.1	
BPI 25 m	0.054	0.1	
Bedrock cover	0.107	0.0	
Variability in temperature	0.068	0.0	
RMS tides	0.044	0.0	
Temperature	0.050	0.0	
Salinity	0.029	0.0	
Muddy sand cover	-0.002	0.0	
Chlorophyll a	-0.010	0.0	
Backscatter intensity	-0.005	0.0	
Pebbles and granules cover	-0.025	0.0	
Fine sand cover	-0.072	0.0	

Physical Variable	Spearman Corr. Coefficient	Frequency in the bes 10 combinations	
Variability in temperature	0.151	1.0	
Stratification	0.140	1.0	
Seabed slope	0.051	1.0	
Chlorophyll a	0.149	0.6	
Temperature	0.147	0.5	
Oxygen saturation	0.147	0.2	
RMS tides	0.147	0.2	
Salinity	0.146	0.2	
Seabed Rugosity	0.146	0.1	
Backscatter intensity	0.145	0.0	
Water Depth	0.123	0.0	
BPI 25 m	0.106	0.0	
Bycatch of cobbles and boulders	0.089	0.0	
Bycatch of foreign material	0.041	0.0	

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	OPEN FILE DOSSIER PUBLIC	Open files are product that have not gone through the GSC form publication process.
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