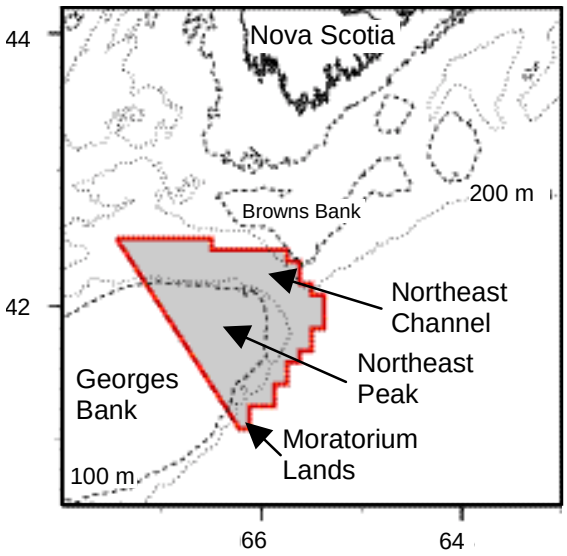
The Possible Environmental Impacts of Petroleum Exploration Activities on the Georges Bank Ecosystem



Background

Georges Bank is a broad offshore bank on the continental shelf of the western North Atlantic, located between Cape Cod and the southwestern tip of Nova Scotia. The international boundary between Canada and the United States crosses the Bank, with the highly productive Northeast Peak belonging to Canada. This Bank has been the location of an intensive fishery for many species of groundfish, invertebrates and pelagic fish. Due to overfishing of some of the resources, severe fishery management measures have been taken in recent years by both the United States and Canada to rebuild and protect fish stocks on the Bank.

In 1981 and 1982, eight exploratory wells were drilled on the southern flank of the U.S. portion of the Bank. Interest was expressed at the time in conducting similar exploration activity on the Canadian portion of the Bank. In response to concerns about potential risks to the Georges Bank ecosystem from petroleum exploration, in 1988 the ministers of Natural Resources for Canada and Nova Scotia placed a moratorium on oil and gas activities on the Canadian portion of the Bank until January 1st, 2000. As a condition of the moratorium, a public review of the environmental and socio-economic impacts of exploration and drilling activity is required by July 1st, 1999. The Georges Bank Review Panel was set up to carry out this review and report to the ministers who are required to make a decision if the moratorium is to continue. The U.S. placed a moratorium on drilling activity on the continental shelf of the U.S., including the American portion of Georges Bank, in 1990. In the summer of 1998, the U.S. President extended this moratorium to the year 2012.

In response to a request from the Georges Bank Review Panel, the Department of Fisheries and Oceans (DFO) has reviewed the biological, physical and environmental status of Georges Bank. The purpose of the review was to assess the potential impacts of petroleum exploration activities on the Georges Bank ecosystem.

This assessment does not include consideration of potential impacts from development and production activity that might result if commercial reserves of hydrocarbons are discovered.

Canada

Summary

- Georges Bank is an important offshore bank that has a number of features, which, in combination with its size, make it unique.

- Routine exploratory seismic activity might have a significant but temporary impact on adult fish behaviour and movement. This might affect fish catch rates and spawning behaviour.

- Routine operational exploratory drilling activity is likely to have only localised impacts on the ecosystem components reviewed. The actual impacts will be dependent on the location, timing of the activities, and the properties of discharges. There does exist a small probability that these impacts will have population and ecosystem level impacts.

- Exploration drilling would lead to a temporary loss of access to some portion of the fishing grounds, although the area lost would be relatively small. Seismic activity would lead to temporary space conflicts with fishing activities that would depend on the timing, location and the gear types involved. This conflict would be greatest during the summer months.

- There is a low probability of a large release of petroleum product from a well blowout. If this were to occur, it might have population and ecosystem level impacts.

- Routine exploratory seismic activity could have a localised impact on eggs and larvae depending on the time of year and location.

- Production activities were not reviewed but the impacts are expected to be different, both in scale and in nature, from those considered for exploratory activities. A review of specific production proposals is needed before any assessment of these can be carried out.

Introduction

The Georges Bank ecosystem supports a productive biological system with complex linkages among its component species. It exists in a dynamic environment and is subject to numerous physical influences having different spatial and temporal scales. Natural events include storms, that can quickly move both water and sediment large distances. Human influences include fishing activity that interact with populations of both harvested and non-harvested species and the benthic habitat supporting them. It is located on the important shipping routes between the U.S., Canada and Europe. In the early 1980s, it was the site of oil and gas exploration activity on the southern flank.

Georges Bank is one of the world's richest fishing banks, characterised by a marine ecosystem of high diversity. It has been heavily fished for more than a hundred years by many nations, and is of major economic and social importance to coastal communities in Canada and the United States. Canada and the U.S. share jurisdiction over the Bank. Both have fisheries management programs aimed at rebuilding and sustaining the fisheries stocks and the supporting ecosystem.

The intent of this review was to provide a peer-reviewed summary of the possible impacts from petroleum exploration on the Georges Bank ecosystem. It updates information published a decade ago

(Gordon, 1988) by incorporating information from DFO and the National Marine Fisheries Service (NMFS) assessment surveys, research activities and new initiatives supported by the Panel on Energy Research and Development (PERD) and the U.S. Global Ocean Ecosystem Dynamics Study (GLOBEC). It is important to note that the results of these two research initiatives are presently being compiled and will provide additional relevant information.

A decision was made at the start of the review to focus on the potential impacts of exploration activity. The exploration scenario considered here as the most likely one, is a seismic survey phase lasting from 20 days to 2 months, followed by the use of one offshore rig to drill 3 or 4 wells in succession. A successful exploration program may lead to proposals to develop identified reserves.

The impacts of development and production activity will depend heavily on the production scenario, which is unknown at this time. The production phase would involve more extensive activities, similar to the exploration phase, as well as some additional activities. Therefore, the potential impacts can be considerably different from the impacts of exploration activity and would require separate consideration.

Description of the Georges Bank Ecosystem

Topography

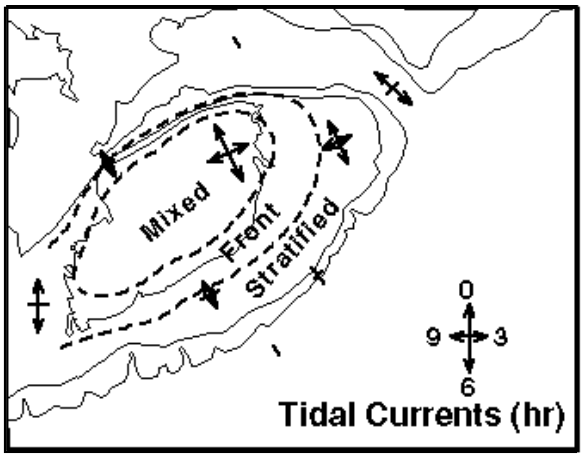
Georges Bank is a broad offshore bank located between Cape Cod and the southwestern tip of Nova Scotia. Its plateau and sloping sides cover an area of more than 40,000 km^2, of which about 7,000 km^2 is under Canadian jurisdiction and is a region known as the Northeast Peak. Water depths on the bank plateau vary from an area of shoals on the U.S. portion to a gentle slope between 60 and 100 m on the Northeast Peak. The Bank is bounded on the west by the Great South Channel with a depth of 70 m, on the north and east by the Gulf of Maine and Northeast Channel with depths near 300 m, and on the south by the continental slope. The latter is cut by rugged canyons. The sides of the Northeast Peak are steeply sloped with depth changes of more than 100 m in less than 10 km.

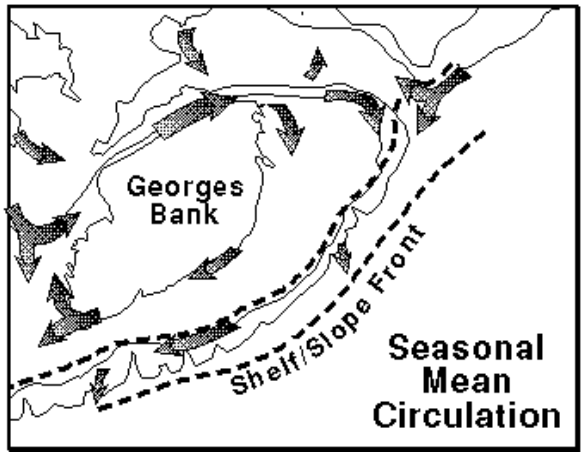
The Canadian moratorium lands cover an area of about 15,000 km^2, extending beyond the Bank and across the Northeast Channel to the southwest edge of Browns Bank.

Circulation, Hydrographic Structure and Mixing

The movement of water and particles on Georges Bank is primarily driven by tides, differences in water density and the wind. Its location at the mouth of the Gulf of Maine-Bay of Fundy tidal system and its shallow depths give rise to strong tidal currents, with peak speeds ranging from 0.2 metres per second (m/s) over its sides to more than 1.0 m/s over the crest. During a single tidal cycle, water moves in an elliptical pattern over distances up to 15 km.

On longer time scales, there is a persistent movement of water in a clockwise gyre around most of the Bank, at speeds of about 0.1-0.2 m/s but 0.2-0.4 m/s along its northern edge. This partial gyre intensifies in summer and fall, but is “leaky”, with significant exchange with surrounding waters. It can be temporarily disrupted by episodic events such as storms and Gulf Stream ring intrusions.





Water and materials typically remain on the Bank for periods of 20-80 days. Materials in the lower water column, or those released on the central Bank, remain on the Bank for the longer periods of time. Materials near the sea surface, or released near the Bank edge, remain for shorter time periods. Water and materials remain on the Canadian portion of the Bank for shorter time periods than those for the Bank as a whole. On the crest of the Northeast Peak, materials released deep in the water column in winter and spring remain for the longest periods. From spring to fall, the gyre provides a mechanism for recirculation of materials and organisms inside about the 80-m contour around the Bank, with a circuit time of about 50 days.

The strong currents result in an area on the crest in which the water is well mixed from surface to bottom throughout the year. This is unusual for offshore areas. Over the sides of the Bank and in most surrounding areas, the water becomes stratified in the summer with warm water on the top and cold water on the bottom. In between the mixed and seasonally stratified waters, is a tidal-mixing front, with an intermediate level of vertical mixing, enhanced gyral circulation and a surface convergence zone. Such fronts are known to be important areas of biological production.

The high levels of turbulent mixing and current shears on Georges Bank provide a general tendency for relatively high rates of dispersion and dilution of materials. However, for materials and organisms near the sea surface, this can be at least partially offset by the concentrating effects of convergence zones at the tidal front and on the central Bank. Similarly, there may be near-bottom convergences associated with sandwaves and other bedforms that locally reduce dispersion rates.

In summary, the physical environment on Georges Bank has both dispersive features, such as the strong currents and vertical mixing, and retentive features, such as the partial gyre and surface convergence zones. The net effect of these contrasting influences on the movement and concentration of materials and organisms depends on the geographic location, vertical position in the water column, time of the year, the effect of storms and Gulf Stream rings, as well as the space and time scales of interest.

Surficial Sediments and Sediment Transport

The seafloor on Georges Bank consists primarily of sand and gravel deposited

during glacial periods. These sediments have been moved around by the strong currents, with much of the finer material being removed from the Bank. The remaining sediments are moved into various wavelike patterns at irregular intervals. Finer materials go into suspension and are redistributed with the water movements. The larger materials are moved along the bottom by bedload transport from the strong water movements near bottom. This is particularly evident over the central crest, where active bedforms, such as dunes and ripples, reach heights of 10's of meters.

An important consideration for the potential impacts of petroleum exploration activities is the movement of water and particles, both natural and human-induced, close to the seafloor. This portion of the water column is called the benthic boundary layer and differs from the overlying waters due to its strong vertical gradients in current speed and higher suspended particle concentration. On Georges Bank, the benthic boundary layer may be up to several tens of meters thick but the greatest changes often occur within just a couple of meters of the seafloor. The vertical sorting of particles, combined with the strong currents, causes "shear dispersion" as particles lifted to different heights above the seafloor are transported horizontally at different rates.

Biological Production

Georges Bank is one of the world's most productive offshore ecosystems. Phytoplankton and fisheries production is higher than in the neighbouring Gulf of Maine. The high phytoplankton production is related to the circulation patterns that import significant amounts of nutrients into shallower water depths where sunlight supports growth for a longer period than in adjacent waters. Growth rates of both cod and haddock on Georges Bank are considerably greater than those of the other northwest Atlantic stocks of these species. A distinctive characteristic of Georges Bank is that populations of bottom organisms are dominated by large filter feeders. Scallops, surf clams and ocean quahogs make up three-quarters of the biomass of the large, bottom dwelling organisms. The importance of filter feeders is related to the high primary production and high concentrations of food in the benthic boundary layer. Up to 15% of the total primary production of the Bank is exported off the Bank into deeper water. These deeper waters support offshore lobster and many demersal fish populations during the winter months.

Biodiversity

Georges Bank is a biogeographical transition area for plankton, benthos and fish associated with influences from both subpolar and subtropical water. For example, the Bank is at the southern limit of the range for north temperate groundfish species and the northern limit for south temperate species. About 100 groundfish species are regularly taken in trawl surveys from Cape Hatteras to Cape Chidley. Of these 60 have been found in the moratorium area. Thus the biodiversity of Georges Bank is high in relation to the contiguous shelf areas in the northwest Atlantic Ocean.

Commercially Important Species

The review primarily focused on the principal commercially important species because those are the species for which we have the most knowledge.

Scallop: The sea scallop is presently the most commercially valuable species on the Bank. This relatively immobile benthic bivalve is found in a number of areas on the

Bank but is most abundant on the Northeast Peak.

This filter feeder relies on phytoplankton and some resuspended detritus for food. The main spawning event takes place late in August to October with a minor one during May to June. Larvae are most abundant in the water column in areas of 60-100 m depth, the same areas where adults are most abundant. However, the depth range where scallops are present extends from 35 to 120 m. Scallops prefer a sandy, gravel bottom but will also settle on sand bottoms with shell debris. Scallops are sedentary once settled to the bottom.

Lobsters: Lobster occur on Georges Bank and adjacent slope and basin areas with the largest concentrations found in the canyons along the outer slope and to a lesser extent along the Bank's northeastern edge. On Georges Bank, the majority of mature lobsters undertake annual migrations between the deeper water (300-700 m) and the shoal waters in summer where they moult, mate and hatch their eggs. The larvae are hatched on the Bank in June and July and are in the water column for about a month before settling and moulting into the early benthic phase on the bottom.

The Gulf of Maine lobster population contains a number of sub-populations linked by movements of larvae and adults. The contribution Georges Bank larvae may make to other portions of the Gulf of Maine or the contribution of those areas to Georges Bank is not known.

Haddock: Georges Bank sustains a population of haddock with adult fish concentrated on the Northeast Peak in the spring, and moving to deeper water on the edge and slopes of the Bank during summer and fall. Most spawning occurs from March to April; eggs and larvae are planktonic. Eggs are most prevalent on the northeastern portion of Georges Bank. As larvae develop, they become distributed from the Northeast Peak along the southern flank of the Bank. Haddock are bottom feeders, with typical prey including crustaceans, molluscs, and annelid worms.

Cod: Georges Bank sustains a population of cod with adult fish concentrated on the Northeast Peak in the spring. Considerable exchange has been demonstrated with other parts of Georges Bank and the southern Scotian Shelf. Spawning activity peaks in February and March; eggs and larvae are planktonic. The distribution of early life history stages is generally similar to, but somewhat broader than, that of haddock. Larger cod are predominately fish eaters, but also include molluscs and crustaceans in their diet.

Pollock: The pollock on Georges Bank are part of a population that extends from southern Georges, through the Bay of Fundy and onto the Scotian Shelf. Spawning occurs from October to March. The planktonic eggs are most prevalent on the northern edge of the Bank. Pollock feed on krill, herring, sand lance and silver hake.

Yellowtail flounder: Georges Bank sustains a population of yellowtail flounder with adults occurring mostly the southern portion of the Northeast Peak. Spawning peaks in May and the eggs and larvae are planktonic. Spawning occurs throughout the Canadian portion of Georges Bank with larvae present on the southern half of the Bank from April to August. Yellowtail flounder is a bottom feeder, preying on polychaetes, amphipods and other invertebrates.

Herring: Atlantic herring are the most abundant commercial pelagic fish species on

the Bank. Although a large portion of the stock migrates to over-winter in the offshore waters south of Cape Cod, both adult and juvenile herring can be found on the Bank throughout the year. With the onset of spring, migratory herring return to the Bank where they remain for summer feeding. Spawning occurs between September and November primarily along the northern edge, from the Great South Channel to the Northeast Peak. In recent years, spawning has also been observed in the central portion near the international boundary that represents the southwest boundary of the moratorium lands. Herring produce demersal eggs, which adhere to the gravel/cobble substrate. The eggs hatch in 10-12 days. After hatching, the larvae, which are planktonic, can be found in the water column over the entire Bank for 4-5 months. Adult fish appear to leave the Bank shortly after spawning.

Mackerel: Adult mackerel occupy Georges Bank for about a month in the spring and the fall during their annual spawning migration to the Gulf of St. Lawrence and return to southern waters.

Tunas and Swordfish: The shelf and slope water of Georges Bank provide important foraging habitat for several large pelagic species (swordfish and tunas, including bluefin, bigeye, yellowfin and albacore) during their seasonal feeding migrations along the edge of the continental shelf. Although few fish are taken on the Bank, more than 25% of Canadian annual landings occur within the moratorium lands. In addition, immature swordfish and bluefin tuna are attracted to the Bank during the summer to take advantage of the plentiful prey.

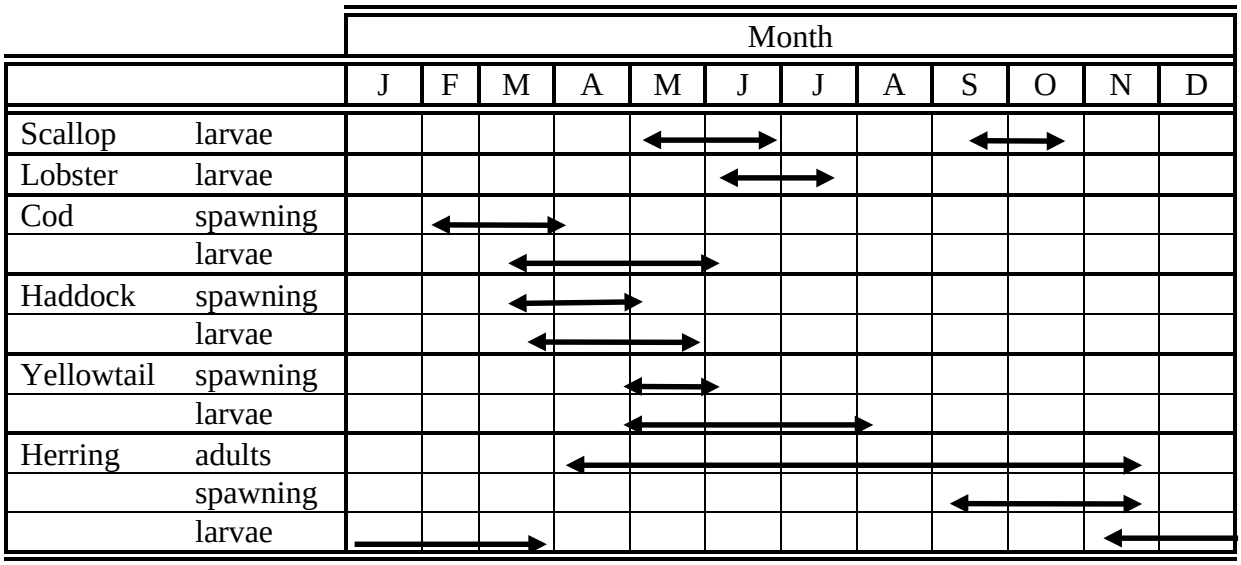
Sharks: Ten species of sharks frequent Georges Bank. Of these the spiny dogfish are the most abundant and are present in large numbers from early spring to late fall. Porbeagle sharks primarily migrate over the Bank as part of their annual migration north, however it is suspected that they over-winter and pup in late winter and early spring on the Bank. Basking sharks, which occur throughout the summer in the Gulf of Maine, including Georges Bank, are thought to utilise the Bank for mating.

Squid: The U.S. has commercially exploited short-finned and long-finned squid in the Gulf of Maine area. Both species migrate considerable distances, and are in the Gulf of Maine area only in summer and fall. The abundance of both species in the Gulf of Maine area is highly variable from year to year due to their short life span and highly migratory nature.

Seasonal Use of the Bank

The species described above spend some or all of their life stages on the Bank. For many of these species, the spawning period is a particularly sensitive time when their eggs and subsequently their larvae are exposed to natural and human-made perturbations. Because of the diversity of organisms that use the Bank, this area is used almost year-round as a spawning habitat.

Approximate peak times when activities or life stages of selected commercial species occur on Georges Bank.



Other Species of Interest

In addition to the species of commercial importance, there are numerous other species that are part of the ecosystem and interact biologically within the system. Some are essential as prey species, such as sand lance. Some are valued for non-commercial reasons, such as right whales, marine turtles and corals. Marine mammals are discussed below. Due to a lack of expertise, some ecosystem components were not considered in this review. Of particular note are seabirds that are an important component of the Georges Bank ecosystem and may be susceptible to the activities under review. There is substantial knowledge about seabirds in this area and the potential impacts of exploration activity on this important and sensitive ecosystem component needs to be addressed.

Marine mammals: Georges Bank is used by over two dozen whale and four seal species. Of the seals, only the grey is common to the Bank. Juveniles and adults forage in this area during the summer and fall. Breeding occurs on the Scotian Shelf and in the Gulf of St. Lawrence. Of the whale, dolphin and porpoise species, only a small number are abundant seasonally on the Bank, which is not a core distribution area for any of them. The range of these species is far broader than the moratorium area. They are observed during all seasons of the year. The relative seasonal abundance of the more common species is summarised here.

Relative seasonal abundance of the more common cetaceans on Georges Bank (adapted from Kenney *et al.* 1997).

	Season			
Species	Winter	Spring	Summer	Fall
Right whale		+	+	
Fin whale	+	++	+	+
Sei whale	+	++	+	+
Minke whale		+++	+	
Humpback whale		+	+	+
Sperm whale	+	+	++	+
Bottlenose whale		+		
Beaked whales		+	+	+
Pilot whales	+	+++	+++	+
Risso's dolphin		+	++	++
Bottlenose dolphin	+	++	++	+
White-sided dolphin	+	++	+++	+++
Common dolphin	+++	++	+	+++
Striped dolphin		+	++	++
Spotted dolphin			+	+
Harbour porpoise	+	+++		
+, ++, +++ corresponds to low, medium and high abundance				

There is particular concern about the right whale that has a population of only about 300 individuals and is endangered. Right whales transit the area during migrations to and from wintering and summer feeding areas. Major feeding areas are to the west, north and east of the moratorium lands. The degree to which the moratorium lands are a regular part of the migration pattern is not known, but sightings have been made in the Northeast Channel in June and July and on the Bank in January. Significant threats to this species include collisions with large vessels and entanglement in fishing gear.

Fishing Activities

Georges Bank is one of the most important fishing areas in the North Atlantic. It supports a very diversified fishery with landings of scallops, lobster, groundfish and large and small pelagics. Recent landings for Canada and the United States exceed $100 million annually. Fishing activity by foreign and domestic fleets intensified in the years following World War II, leaving many stocks near collapse. Recently, both Canada and the U.S., following declaration of their 200-mile economic zones and the settlement of an international boundary dispute, instituted management programs to rebuild the stocks. While some stocks remain in a low or rebuilding state, scallops and lobsters are performing well. However, in general, groundfish stocks remain in a depleted, fragile state. The fishery is being conducted with low quotas, closed seasons and spawning season closures in order to facilitate the rebuilding of the biomass of these species.

Overall fishery yields are considerably less than those that might be expected if stocks rebuild. Examples are provided below for some of the more highly valued fishery resources. The methods of estimating the

potential yield and the uncertainty associated with the estimate vary depending upon the species.

Resource	Potential Yield (t)	Current Yield (t)
Scallops[1] (meats)	6,000	4,100
Lobster[2]	800	1,300
Cod[2]	20,000	3,500
Haddock[2]	45,000	2,900
Yellowtail flounder[2]	13,700	1,800
Herring[2]	100,000	2,900

[1] - Canadian landings
[2] - Canadian and U.S. landings

Uniqueness of Georges Bank

The Georges Bank ecosystem is biologically highly diverse with many distinct physical oceanographic and biological features. In combination, these features make Georges Bank a unique marine ecosystem with:

- a broad and shallow plateau influenced by subpolar and subtropical water masses and organisms, resulting in high biodiversity of species;
- strong and persistent tidal currents, resulting in high mixing rates, nutrient supply and overall dispersion;
- a partial gyre that typically provides a mechanism for recirculation and extended residence of a portion of the Bank's water during part of the year;
- a seasonal frontal system with enhanced around-bank drift, elevated phytoplankton production and near-surface convergence zones that may concentrate organisms;
- high productivity of phytoplankton, and fish;
- a relatively large number of commercially important fisheries on the Northeast Peak with benthic invertebrates including scallops and lobster, dominating the landed value; and,
- the co-occurrence on the Northeast Peak of spawning and nursery areas for many fish species.

There is a sound knowledge and description of most of these features, but their inter-relations, and the overall dynamics and basis for the resiliency of the ecosystem are not fully understood. While the unique features of Georges Bank provide a basis for special concern regarding impacts of petroleum activities, it is not clear whether they make the ecosystem more or less sensitive to such impacts.

Exploratory Activities and Their Potential Impacts

Seismics

Seismic exploration and possible impacts for the Scotian Shelf have been summarised in an assessment document prepared for the Canada-Nova Scotia Offshore Petroleum Board (Davis *et al.* 1998). There is relatively little scientific knowledge available on the potential impacts of seismic activity on marine organisms. Recently, a conference on the subject was convened by the industry but the reports from that conference are not yet available. Based on the above assessment, it is expected that the following issues will be of concern:

- fish movement, such as the potential avoidance of favoured habitat and changes in catchability;
- fish behaviour; such as the potential impacts on spawning behaviour;
- the movement and behaviour of whales; and,

- potential mortalities of planktonic eggs and larvae.

The effects of seismic exploration on fish movement could interfere with commercial groundfish fisheries. During the period of the surveys, fishermen would lose access to the immediate area being surveyed. Fish behaviour is disturbed thereby potentially affecting catchability.

Lethal effects are expected to be limited to early life stages that come within 1-2 metres of the sound source. Thus impacts will be small and restricted to fish stocks with the sensitive life stages present in the upper water column. The acceptable practices of scheduling activity to avoid peak periods of spawning should make potential impacts minimal. However this approach would have to be used with caution on Georges Bank where spawning occurs throughout most of the year on various parts of the Bank as discussed above.

Exploratory Drilling

Exploratory drilling is required to confirm the presence of oil and gas products estimated from seismic surveys. This involves the operation of a drilling rig for a period of usually several months. Potential sources of impacts from routine activity include:

- infrastructure, such as ship movements, anchors, cables, debris, light and sounds;
- temporary loss of access to fishing areas;
- routine operational discharges; and,
- accidental discharges.

This assessment of impacts is based on an exploratory drilling scenario involving one rig drilling 3 or 4 wells, with 3 to 4 months being required to complete each hole.

Loss of Access: Most of the impacts from the infrastructure for the exploration phase will be transient. Exploration activities would lead to a loss of access to some portion of the fishing grounds while the drilling rig is on the site. The exclusion area depends on the type of drilling platform (semi-submersible, jack-up rig, or drill ship) but the area will range from 500 m to 1,000 m in radius around the site.

Operational Discharges: Two types of operational discharges are discussed here: cuttings and drilling muds. Cuttings are the pieces of rock, about the size of sand grains, produced from the drilling. Drilling muds are mixtures of various materials that are used during drilling primarily to seal the hole and to lubricate the drill bit. These discharges have a potential to cause both mortality and sublethal effects on marine biota. Water-based muds would be used during the exploratory phase. Under present Canadian regulations, routine discharges of drilling wastes are allowed during exploratory drilling with water-based muds.

The most direct effect to the ecosystem is smothering of benthic organisms by cuttings that might accumulate below the drill rig. Since the cuttings have a relatively large particle size, they settle rapidly and this impact tends to be localised. Based on the observations and experience at other offshore exploration and production sites, any mortalities due to physical or toxic effects of the cuttings are expected to be restricted to an area less than 0.5 km from the drilling rig. Because of the strong currents on the Bank, the cuttings pile would not be expected to persist any more than a couple of months after drilling ceased.

A recently developed numerical model for benthic boundary layer transport (*bblt*) provides estimates of the movement and

concentrations of drilling mud at various heights above the seafloor and distances from a discharge site. Model simulations have been carried out for different sites and seasons on Georges Bank based on a realistic scenario provided by the oil industry of a total mud discharge of 468 mt over the 93-day period of an exploratory well.

The model simulations and extensive sensitivity studies indicate that the processes affecting drilling mud concentration depend strongly on water depth, current strength at selected locations on Georges Bank and the settling rate of the mud particles in the water column. Highest near-bottom concentrations and hence potential benthic impacts of drilling mud occur in the relatively deep Stratified region, shown previously, as a result of relatively low suspension, dispersion and drift. Lowest near-bottom concentrations occur in the Mixed region on top of the Bank because of high suspension and dispersion. Intermediate concentrations occur in the Frontal region.

The focus of recent DFO research on the biological effects of drilling wastes has been on sea scallops which is the most valuable commercial species on Georges Bank. Studies include the modelling of water and material movement on the Bank and laboratory studies of the sensitivity of adult scallops to drilling muds. Given the nature of the exploration phase of offshore oil production, the risk of impact from drilling activities is greatest for sessile benthic organisms such as scallops. Estimates of near-bottom concentrations from the discharge simulations, together with the results of laboratory experiments, provide a basis for estimating potential impacts on adult scallops.

Laboratory experiments have shown that mortalities occur when adult scallops experience bentonite concentrations of 10 mg/l over periods of 30 days. The *bblt* model simulations provide estimates of the duration of high near-bottom concentrations of drilling mud around release sites in different regions of Georges Bank. The longest duration of concentrations exceeding 10 mg/l occur in the Stratified region, with values reaching 9 days at the release site in that region and falling off to 3 days at 5 km downstream for a relatively high settling velocity. In the Frontal region, the longest duration is about 1 day at the release site. These durations indicate that significant mortality of scallop populations from drilling mud discharges is unlikely for an exploratory well on Georges Bank.

Sublethal Effects of Operational Discharges: Recent research with sea scallops has shown that the growth and reproduction of adult scallops is highly sensitive to particulate drilling wastes as a result of the physical and chemical characteristics of the wastes. Biological responses to major water-based mud constituents, bentonite and barite, were used with the *bblt* model predictions of near-bottom mud concentrations to predict the spatial and temporal extent of impact zones around hypothetical exploratory drill sites on Georges Bank. The predicted zone of impact was highly sensitive to the settling velocity of the drilling waste. A conservative estimate of impact zones was obtained using a relatively high estimate of the settling velocity of flocculated drilling wastes.

The *bblt* model indicates that scallop growth reductions are greatest at the release point, decreasing rapidly within a few km from the discharge in most directions. The model also reveals a primary drift direction away from

the release site along which the impact decreases more slowly over distances between 10 and 40 km. The size of the predicted impact zone depends on the water depth and oceanographic conditions at the particular site.

Estimates of days of lost growth for scallops as a result of the discharge of drilling muds generated using the *bblt* model. Estimates are given for two different settling velocities averaged within circular areas with three different radii around the discharge point. The relative densities of scallops in the regions are also indicated.

Radius (km)	Settling Velocity (cm/s)	Region		
		Mixed	**Front**	**Stratified**
0.5	0.1	0	0	5
	0.5	2	15	40
2.0	0.1	0	0	3
	0.5	1	6	19
10.0	0.1	0	0	2
	0.5	0	3	11
Relative density of scallops		Low	Medium to High	Low to High

Higher bottom stress and stronger dispersion in the Mixed region on top of the Bank result in predicted near-bottom waste concentrations that are very low. This zone does not have commercial scallop stocks and it is highly unlikely that measurable impacts on scallop growth would occur here. The Frontal zone contains the majority of the scallop stocks on the Bank and the model predicts maximum growth losses in this zone, averaged over along the primary drift direction, to be less than five days during drilling of an exploratory well.

The zone of greatest potential impact on growth is along the side of the Bank in the Stratified water at depths greater than 100 m as shown above. The modelling predicts potential impacts in this zone up to 40 km away from the release site in the direction of primary drift. The predicted concentrations at this distance could be sufficiently high to prevent the growth of scallops for up to several weeks during the exploratory well scenario simulated. Scallop stocks along the side of the Bank tend to be less dense than in the Frontal region, but aggregations are found at various locations on the northeastern edge.

The model predictions of a loss of up to 10-20 days of reproductive growth could reduce the reproductive output of scallops by 5-10% within a 100-200 km^2 area on the side of the Bank. It is difficult to predict how this would alter recruitment to the scallop fishery. If such an impact occurred in a region of medium to high scallop stocks, it is possible that it could have a significant impact. However, as noted in the table above, it is probable that the effects will be less than discussed here. It is important to note that the model predictions are specific to the discharge of water-based muds containing equal proportions of bentonite and barite. Differences in the toxicity and

transport characteristics of drilling muds or a change in the timing of waste releases may result in different impacts on scallop stocks.

In established offshore petroleum fields, there has been occasional tainting of fish and shellfish, largely during the production phase and when oil-based drilling muds have been used and discharged into the environment. Tainting should not be a significant concern during routine exploration operations especially if water-based drilling muds are used.

Accidental Discharges: Spills are most often the result of human error and are more often associated with the transport of petroleum products and the operation of vessels than with offshore petroleum exploration. There is always the possibility of a spill from the drilling platform or a supply ship but the probability and potential size of such a spill during the exploratory phase is no greater than that from other vessel traffic in the area.

As with any drilling operation, exploration or production, there is a small chance of a large release of hydrocarbons into the environment as a result of a well blowout. Although all precautions against such an event are recommended, the probability still exists. In such an event, all ecosystem components are expected to be at risk. Due to the concentration of some life stages of certain species on the Northeast Peak and the presence of convergence zones, there is a chance that even a relatively small blowout could result in impacts on a significant portion of the population. Seabirds that frequent Georges Bank would be particularly vulnerable to spilled oil. Also of interest would be an accidental release of petroleum products at a time of strong persistent winds from the south. This could result in the drift of surface slicks toward southwestern Nova Scotia.

Summary: Under the scenarios considered, operational discharges into the water column and on the ocean floor of Georges Bank will result in some impacts on local organisms and there may be some impact on the ecosystem. It is expected that these impacts will be restricted in space to a small area (a few km on the Bank plateau to 10's of km on the side of the Bank) in the immediate vicinity and downstream of the drilling rig, and to a relatively short time (days to months). In particular, if drilling muds are released in areas with high scallop densities, significant loss of growth might occur. The extent of growth loss will depend on the time of year of the discharge and the properties of the discharge. Models, based on laboratory experiments, exist that can be used to quantify the potential impacts on scallops and can be used to evaluate any specific proposed exploration activities if the moratorium was not extended.

Multiple Exploration Wells

Due to the relatively small area of the Northeast Peak, its high productivity, and high fishing activity, the number of drilling rigs that might be used in exploration would be an important factor in potential impacts. While current thinking is that just one rig would be used to drill 3 to 4 successive wells, future circumstances might lead to proposals to have more than one rig drilling at a time, as occurred in the U.S. portion in 1981-82. The general pattern of currents tends to distribute water and particles widely throughout the ecosystem. The location and timing of activities would be critical to determining potential impacts.

Distant Impacts

There is evidence that biological components on the Bank provide contributions to stocks in other areas. This is certainly true with those species that migrate through the area such as the large marine mammals and large pelagic species. It may also be true for herring, cod and lobsters. Caution must be used in these situations and any review of specific exploration activities must consider linkages between the Georges Bank ecosystem and distant areas such as the Gulf of Maine, Bay of Fundy and western Scotian Shelf. It is expected that distant impacts would be less than local ones.

Additional Concerns Related to Production Activity

This review and assessment was limited to petroleum exploration activities. A review of production activities, that are unknown at present, and their potential impacts was not conducted. However it is important to note that there are many aspects of production activity that have potential impacts on the marine ecosystem. Some of these activities are the same as for the exploration phase but are greater in scale. Other activities are unique to the development and production phases. Relative to the exploration phase, these include:

- additional infrastructure, such as more or different platforms in place for a long time;
- new infrastructure, such as pipelines;
- different formulations of drilling muds;
- additional discharges, such as sewage and biocides;
- loss of access for the duration of the project;
- potential release of produced water; and,
- gas flaring.

Uncertainties

As with any complex assessment, there are uncertainties associated with various aspects of this review. However, Georges Bank has been, and continues to be, one of the most extensively studied regions of the world's oceans. Its physical oceanography in particular is generally well described and understood, to the point that numerical circulation and dispersion models are now available that provide realistic quantitative descriptions of the effects of the predominant tidal and seasonal-mean currents, and the unique features identified above. Its biological resources are also generally well described and many of their linkages to the physical environment and other trophic levels have been identified.

However, there remain many areas of incomplete understanding, such as the role of episodic perturbations on the physical regime, some predator-prey relationships, and the overall dynamics and resiliency of the ecosystem.

Recent studies of drilling mud properties, dispersion and impacts on scallops in laboratory experiments, combined with our understanding of the physical environment and description of the scallop resource on Georges Bank, provide a substantial knowledge base for estimating potential impacts on scallop populations. The strong tidal mixing and coarse natural sediments on the Canadian portion of the Bank provide strong support for the dispersion model's prediction of relatively rapid dilution of drilling wastes in the benthic boundary layer. Most of the approximations in the model are conservative, in the sense of

underestimating dispersion, and hence overestimating drilling mud concentrations, so that there is a moderate-to-high level of overall confidence in the predictions of drift, dispersion and mud concentrations. Confidence is highest for the shallower Mixed and Frontal zones where dispersion and suspension are highest, and where the highest density scallop beds occur, that is the Frontal zone. There is less confidence in the prediction for the Stratified zone that borders the densest scallop beds and where dispersion and suspension are lower.

The dispersion of drilling mud in the ocean is a complex phenomenon which is not fully understood and for which there are not adequate observations to validate a dispersion model in any rigorous sense. Thus, there is a small chance that drilling mud concentrations could be higher than predicted by the present dispersion model, but this is considered to be unlikely except for deeper areas away from the scallop beds.

There is uncertainty about the full range and nature of the impacts of drilling discharges on the ecosystem. Extensive studies have been conducted on the acute and sublethal toxicity of drilling muds to adult scallops and limited testing has been done with early life stages of sea scallop, lobster and haddock. These species and life stages are expected to be the most sensitive. However potential lethal and sub-lethal impacts of operational discharges on other marine resources, and the overall ecosystem structure and function, on Georges Bank have not been investigated.

Much of this review deals with average conditions of physical oceanography, biological populations and weather. In reality, there can be significant deviations from the mean that would affect the assessment of potential impacts.

Conclusions

Georges Bank has a number of distinct features which, in combination, result in a unique marine ecosystem. Routine exploratory seismic activity might have a significant impact on adult fish behaviour such as potentially affecting fish catch rates and spawning behaviour, and could also have a very localised impact on fish larvae, depending on the time of year and location. Routine operational exploratory drilling activity is likely to have only localised impacts on the ecosystem components reviewed. Actual impacts will be dependent on the location, timing of the activities, and the properties of discharges. There is a small probability that these impacts will have population and ecosystem level impacts.

There will be some temporary loss of access to fishing grounds during both the seismic surveys and exploration drilling. The total area that would be lost as a result of drilling activity is relatively small. The loss of access due to the seismic surveys will depend on the timing and location of the surveys and the types of fishing gear that are being used. The greatest potential for conflict is in the summer time when fishing activity is high and weather conditions for seismic surveys are optimal.

As with any petroleum exploration or production activity, there is a low probability of a large release of petroleum product from a well blowout that might have an effect on the ecosystem or populations. Current technology helps to reduce this probability but most blowouts are the result of human error, a factor that is difficult to regulate other than through the training requirements specified by Canadian regulations.

Potential impacts from production activities were not included in this assessment but the impacts are expected to be different than those considered for exploratory activities. There is a wide range of production scenarios depending upon many factors, such as the product being produced, the market, available technology and best practices at the time of development. The potential impacts will be dependent, to a large degree, upon the actual production scenario.

For more Information:

Contact: Paul Keizer
Fisheries and Oceans Canada
Marine Environmental Sciences Division
Bedford Institute of Oceanography
P.O. Box 1006
Dartmouth, N.S. B2Y 4A2

Tel: (902) 426-6138
Fax: (902) 426-6695
E-Mail:
keizerp@mar.dfo-mpo.gc.ca

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Suggested Further Reading:

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This report is available from the:

Maritimes Regional Advisory Process
Department of Fisheries and Oceans
P.O. Box 1006, Stn. B203
Dartmouth, Nova Scotia
Canada B2Y 4A2
Phone number: 902-426-7070
e-mail address: MyraV@mar.dfo-mpo.gc.ca

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