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The Possible Environmental Impacts of Petroleum Exploration Activities in the Southern Gulf of St. Lawrence and Sydney Bight Ecosystems

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ABSTRACT

There has been offshore oil and gas exploration activity on Canada's East Coast since the early 1970's. During that period considerable knowledge has been acquired about the potential impacts of these operations. In addition knowledge has also been acquired for more advanced offshore oil and gas industries in the Gulf of Mexico and the North Sea. This document provides a brief overview of the types of potential impacts. In the absence of a specific exploration proposal it is not possible to be more specific about potential impacts and the severity of risks. Any proposed activity must submit an environmental assessment that provides a detailed evaluation of potential impacts, identification of proposed mitigation, and assessment of the risk associated with any residual impacts.

The three lease areas under consideration are located in coastal waters of Nova Scotia. Previous exploration activity has occurred farther offshore. The physical and biological characteristics of the coastal environment are significantly different from the offshore and will require special consideration in environmental assessments.

RÉSUMÉ

Il y a eu des activité d'exploration de pétrole et de gaz au large de la côte est du Canada depuis le début des années 1970. Pendant cette période des connaissances considérables ont été acquises au sujet des impacts potentiels de ces opérations. De plus des connaissances ont été également acquise pour des industries plus avancées de pétrole et de gaz au large du Golfe du Mexique et de la Mer du Nord. Ce document fournit une brève vue d'ensemble des types d'impacts potentiels. En l'absence d'une proposition spécifique d'exploration il n'est pas possible d'être plus spécifique au sujet des impacts potentiels et de la sévérité des risques. N'importe quelle activité proposée doit soumettre une évaluation environnementale qui fournit une évaluation détaillée des impacts potentiels, de l'identification de la réduction proposée, et de l'évaluation du risque lié à tous les impacts résiduels.

Les trois secteurs de location à l'étude sont situés en eaux côtières de la Nouvelle-Écosse. L'activité précédente d'exploration s'est produite plus loin en mer. Les caractéristiques physiques et biologiques de l'environnement côtier sont sensiblement différentes de celles en pleine mer et exigeront une considération spéciale dans des évaluations environnementales.

INTRODUCTION

Offshore petroleum exploration activities have been requested by the industry for the Southern Gulf of St. Lawrence and the Sydney Bight areas. In an effort to provide peer-reviewed science information on these ecosystems, and potential impacts, the Department of Fisheries and Oceans (DFO) convened a Regional Advisory Process (RAP) in November 2001. This document is one of a number of documents presented and discussed within the RAP. This document forms the basis for the summary stated in the DFO Habitat Status Report.

The main legislative base of DFO is the *Government Organisation Act* (1979), and the schedule of statutes attached thereto, including the *Fisheries Act*, the *Fisheries Development Act*, the *Fish Inspection Act*, the *Fishing and Recreational Harbours Act*, the *Coastal Fisheries Protection Act*, the *Fisheries and Oceans Research Advisory Council Act*, and the *Canada Shipping Act* regarding charts and publications, regulations and several international treaties and conventions. Under the *Government Organisation Act* the duties, powers and functions of the Minister of Fisheries and Oceans include responsibilities for seacoast and inland fisheries, fishing and recreational harbours, hydrography and marine sciences and the co-ordination of the policies and programs of the Government of Canada respecting Oceans. Its responsibility for habitat protection is clearly described in the "Policy for the Management of Fish Habitat" (Anon. 1986) adopted in 1987 that describes the principle of "No Net Loss." The department also has a responsibility to provide advice to other government departments pursuant to the *Canada Shipping Act*, *TERMPOL*, *Navigable Waters Protection Act*, and *the Canada Oil and Gas Conservation and Production Act*. The Department's mandate in sustainable development has been further expanded by the *Oceans Act* (1997). The details of this responsibility are developed further in the document "Sustainable Development - a Framework for Action" (Anon. 1997).

It is in this legislative context that DFO has a responsibility to provide scientific advice on the possible petroleum exploration activities in the Southern Gulf of St. Lawrence and Sydney Bight areas.

A DFO Regional Advisory Process (RAP) was carried out in November 2001 to:

1) characterise ecosystem features of the southern Gulf and Sydney Bight area that deserve special attention in the context of oil and gas exploration and the potential impact of this activity on the ecosystem; and,

2) identify what issues, if any, are insufficiently understood and need further research before an assessment can be made of the potential impacts of oil and gas exploration on the Southern Gulf ecosystem and the Sydney Bight area.

The other RAP documents describe various components of the ecosystems to be considered.

This document attempts to summarise the possible impacts of exploratory activities on ecosystem components.

EXPLORATORY ACTIVITIES AND THEIR POTENTIAL IMPACTS

Seismic Survey

Seismic exploration has been proposed for the southern Gulf of St. Lawrence and Sydney Bight areas to update information collected on earlier surveys. New surveys would provide more detailed information necessary for planning any future steps in exploration. The general operation is for a vessel to sail along straight-line transects towing a sound source, at a predetermined water depth and a string of hydrophones that record sound reflected from the different geological interfaces. From this information analytical techniques can generate images of the geological strata and identify those with probable oil and/or gas deposits.

A class assessment document, Davis *et al.* (1998), provides a review of the present state of knowledge on the potential impacts of seismic exploration in the marine environment. Although this assessment addresses the activities on the Scotian Shelf, this generic document should be appropriate for considering some of the potential impacts of seismic activities in the southern Gulf of St. Lawrence and Sydney Bight ecosystems.

In the fall of 2000, the Environmental Studies Research Fund (ESRF) sponsored a workshop to consider the effects of seismic exploration for gas and oil deposits and to set priorities for research on Canada's east coast (Thomson *et al.* 2001). It was concluded that most organisms are killed or severely impaired within 1 or 2 m of a seismic gun. There was general agreement among the participants that seismic surveys have been shown to markedly reduce catch (>50%) in fisheries (Engas *et al*., 1996). Engas *et al*. (1996) report the results of a large-scale fishing and acoustic study over an offshore bank in the Barents Sea at water depths of 250 to 280 m seven days before, 5 days during and 5 days following a simulated seismic survey used by the oil industry. Trawl catches of cod and haddock and long line catches of haddock declined on average by about 50% (by weight) after shooting started and this was supported by the acoustic abundance estimates. Reductions in catch rates were observed 18 nautical miles from the seismic shooting area of 3X10 nm, but the most pronounced reduction occurred within the shooting area, where trawl catches of both species and long line catches of haddock and cod were reduced by about 70% and 45% respectively. After the seismic survey concluded, abundance and catch rates did not return to the pre-shooting levels observed during the 5-day period of the experiment. This study, however, cannot be used to predict the duration or distance to which these seismic impacts on fish populations can be expected in other areas.

The known effect of seismic noise in scaring of fish from their usual habitat is of most concern during spawning season, on nursery and foraging grounds and possibly during their seasonal migrations. Apart from the increased stress on fish, seismic activity could have long-term population effects through delayed or displaced spawning, feeding and migratory behaviour to less than optimal times and locations. Fishing catches also would decline because the fish have moved to unknown areas. It is therefore understood that seismic exploration is sufficient, in some situations, to reduce ground fish yield in the short term and may reduce the number of recruits produced, thus effecting the long-term prognosis.

On the other hand, a number of studies have shown that seismic noise does not scare territorial fish very far from their reefs but can result in abnormal swimming behaviour and vertical movements (see Pearson *et al*. 1992. Skalski *et al*. 1992, Wardle *et al*. 2001). In a recent Scottish study, pollock were observed one week before, during and 4 days after an experimental seismic shooting with three gun array (Wardle *et al*. 2001). The fish, equipped with acoustic tags, which stayed near the reef, had their diurnal movement unaffected by seismic shoots (250 m). Fish observed with a TV monitor during seismic firing exhibited momentary startle or escape reflexes but then carried on swimming. This result is very different from the above Norwegian cod and haddock study in the Barents Sea. Wardle *et al*. (2001) suggested that in their experiments, the lack of avoidance by pollock to seismic noise may be a result of their inability to determine direction because a stationary gun array was used. The California study with rockfish resulted in similar findings of behavioural responses with no directed horizontal avoidance observed (Skalski *et al*. 1992). It could be that shelter or reef-seeking fish behave differently from groundfish in the presence of seismic noise. More research is needed to resolve these conflicting studies on fish.

A secondary concern is the potential mortality of fish eggs, larvae and juveniles in areas of seismic surveys. The sound source generates a compression and decompression wave in the water that is sufficient to kill certain life stages, depending on the distance from the air guns. Most of the observed mortalities occur close to the sound source (within metres). Due to the three-dimensional spreading of sound, the impacts decrease quickly with distance from the sound source. Mortality rates can be expected to be low if considered for a species that is evenly distributed over the upper 50 m of the water column, ~1% was the estimate for a typical survey on the Scotian Shelf (Davis *et al*. 1998). Seismic operations in the vicinity of strong seasonal stratification, frontal systems or convergent zones would at certain times of they year impact more eggs and larvae because of their higher densities. However, in the southern Gulf of St. Lawrence more severe losses would occur for species with eggs, larvae, and juveniles that inhabit the seasonal surface layer. Solar heating creates a warm surface layer here starting in late June that gradually deepens to 20-30 m by the end of the summer, before turning over in the fall (Drinkwater 1994). Both mackerel and lobster eggs and larvae appear in this surface layer in late June and are confined to the upper mixed layer throughout their development (Ware 1977, Harding *et al*. 1982). Obviously, mortalities would be highest when the upper mixed layer first forms because of the proximity of the eggs and larvae to the air gun arrays.

The results of a Norwegian risk assessment of the effects of seismic noise on eggs and larvae of fish, spread throughout the water column, showed that effects were indistinguishable from natural variability. The workshop participants concurred that eggs and larvae were not of prime concern for the viability of finfish populations.

The highest research priority for waters off Nova Scotia, identified at the seismic workshop, was considered to be studies of the seismic effects on shellfish, particularly snow crab and lobster, since little is known about their reactions to seismic noise. A skipper in the snow crab fishery, with a licence off Newfoundland, presented anecdotal information indicating that catches of the fleet had declined in the immediate vicinity of a seismic survey the previous fall. No decline in catch was experienced at a distance greater than 50 nm from the “shoot”.

Another potential impact resulting from seismic surveys would be on marine mammals. Recent studies on whales in the Beaufort Sea have demonstrated that migrating bowheads avoided the seismic source by approximately 20 km, with some avoidance evident up to 30 km (Thomson *et al.* 2001). Many marine mammals use the southern Gulf of St. Lawrence and Sydney Bight areas for summer feeding grounds and on their migration routes. Seismic activities would interfere with the normal activities of the large marine mammals that frequent southern Gulf of St. Lawrence and Sydney Bight. The standard practice of having trained observers on the vessels at the time of surveys should minimise direct contact. Grey seals and harp seals also use the Cape Breton coast and the southern Gulf for puping on the ice during the winter when seismic surveys are impractical, so no conflict would be expected.

There is also the potential for space conflicts between the seismic boats and fishing boats in the area. The southern Gulf of St. Lawrence and Sydney Bight is heavily used throughout the ice-free period for fishing. There may be a brief period in late fall when spawning and large concentrations of fish do not occur and fishing activities are reduced.

Impacts on adult invertebrate species such as the commercially important lobster and snow crab are unknown at this time.

In summary, seismic exploration may have a number of possible impacts such as:

- a decreased catch rates possible due to scaring of fish;

- interference with fish migration, spawning and feeding grounds; (interruption of fish migrations;)
- space conflicts with existing fishing activities;
- possible mortalities in a number of species and a number of life stages at close range; and,
- possible changes in marine mammal movements and feeding grounds.

There are a number of important issues that need to be resolved:

The effect of seismic activity on:

- crab and lobster survival and trapability.
- established fish, invertebrate, and whale migration patterns and whether any effect is large enough to interfere with optimal foraging grounds and breeding times and locations;

Exploratory Drilling

Exploratory drilling is conducted to determine whether commercial accumulations of gas and/or oil are present in the most promising geological structures detected by seismic surveys. Drilling methodology in the Southern Gulf of St. Lawrence and Sydney Bight ecosystems will most likely be the same as is used on the Eastern Canadian continental shelf. Thompson *et al.* (2000) provide a generic environmental assessment of exploration drilling on the Scotian Shelf, however it does not include the area considered by this document. Potential impacts from routine exploratory drilling operations may result from:

- Infrastructure - ship movements, anchors, cables, debris, domestic discharges, light and sounds;
- Loss of access - fisheries interruptions; and,
- Operational discharges – mortality, sublethal effects and tainting.

Infrastructure

Service traffic, both vessel and aircraft, should not cause any problems as long as operators respect fishing operations and stay clear of working vessels and unattended fishing gear.

There are three classes of debris generated from drilling operations: solid domestic waste, liquid domestic waste and solid operation waste.

Based on the “Offshore Waste Treatment Guidelines” and the Nova Scotia Petroleum Drilling Regulations, disposal of solid wastes at sea is not permitted. (NEB,1996). Liquid wastes, such as sewage and food wastes, are macerated and treated to some degree before any possible disposal at sea. Providing the treatment technologies recommended by the Department of the Environment (DOE) are followed, the discharge of liquid wastes at sea should not pose significant impacts on the ecosystem.

Solid operational debris, including anchors and chains placed on the sea floor from offshore activities, has been a problem in the North Sea and the Gulf of Mexico. Canadian drilling regulations require that the sea floor be cleared of any material that could interfere with other commercial uses of the area when the well is abandoned. The well casing itself must be sealed at least 1 m below the sea floor to prevent damage to fishing gear. Within a year of the cessation of the United States’ exploration activities on Georges Bank, only four large items remained unrecovered in the area. None exhibited sufficient relief to interfere with commercial fishing activities (Danenberger 1983).

Exploratory rigs are typically on location for about 3-4 months with service approximately every other day by both helicopter and/or supply boat. Activities on the drilling rig, and associated supply vessels will generate significant amounts of light and sound during routine operations. These may have positive and negative impacts. Marine mammals may be scared from the vicinity of the rig due to the unusual and/or increased noise levels, whereas, marine birds may be attracted to the lights of the rig. Some pelagic species, such as squid, are attracted to the lights and may be subject to higher predation due to this increased aggregation. Some species can use the structure as habitat, although the short time period required for an exploration well reduces any long-term habitat creation. There are directed studies underway in the Sable Offshore Energy Project (SOEI) Environmental Effects Monitoring program to study the levels of noise and potential impacts that may be appropriate for application to evaluating potential impacts to the Southern Gulf of St. Lawrence and Sydney Bight ecosystems.

Loss of Access

A direct and quantifiable impact on fishing activities from drilling is the exclusion of the fishing activities from the areas around drilling sites.

While on location, a drilling rig is surrounded by a safety zone that more than covers all underwater equipment, i.e. anchors and cables, and is off-limits to all vessels except supply boats. The size of the zone depends upon the type of rig and depth of water. The radius usually ranges from 500 – 1,000 m. All fishing activity is excluded from this zone (and perhaps from a larger area depending upon type of fishery, fishery methods, topographic constraints, etc.) for the drilling periods of usually 3-4 months.

A rig with a 1.5-km safety zone radius would exclude approximately 7 km^2 from fishing. This is a small percentage of the total area of Southern Gulf of St. Lawrence or Sydney Bight areas, but would increase if there were multiple rigs in the same area. The potential impact on the fishing industry, however, could be greater than this percentage suggests if the areas are not uniformly fished. Any proposal for drilling activities would have to consider the exact location of the rig in reference to the known distributions of commercial stocks and the timing of the fisheries.

Impacts resulting from loss of access will depend upon the time of the year and the species concerned because of the seasonal nature of most fishing activity. Experience shows that fishing activity should be able to resume as soon as the rig leaves the drill site.

Operational Discharges

Hydrocarbon exploration drilling in the Southern Gulf of St. Lawrence and Sydney Bight areas will result in the routine release of operational wastes such as drilling muds and formation cuttings. Muds tend to be fine, dense material while cuttings are generally coarser pieces of rock, about the size of sand grains. Once discharged there are a number of different processes that act on them, determining their fate and potential impacts on the environment.

Before considering environmental impacts of operational discharges, it is important to understand some of the details of drilling procedures, especially the drilling mud circulation system (Figure 1). Drilling muds are a suspension of solids and dissolved material in a carrier fluid of fresh water, or seawater, or oil. The major components of the mud can include barite (barium sulphate), clay (bentonite), lignosulfonate, lignite (soft coal), sodium hydroxide, trace amounts of additives and carrier fluid. Mud composition is continually changed during drilling to adjust to specific down-hole conditions encountered. Initially, this mixture is discharged onto the sea bed. After installation of the well casing, the mud circulates from the rig, down the drill string and back up to the rig. Muds serve several functions including transporting cuttings to the surface, balancing of subsurface and formation pressure to prevent blow-out, and cooling, lubricating and partly supporting the drill bit and drill pipe. They also stabilise the borehole wall and prevent fluid exchanges with the rock formation.

There are three classes of muds: water-based (WBM), diesel oil-based (OBM) muds, and alternative-based muds (ABM). ABM include both mineral oil and synthetics (SBM). It is important to point out that although petroleum extraction activities in many areas of the world, including Canada, have in the past used oil-based drilling muds (OBMs), the Canada- Nova Scotia Offshore Petroleum Board (CNSOPB) now requires that all drilling muds discharged must have hydrocarbon concentrations less than 1%, thus excluding the use of OBMs. The CNSOPB has currently permitted the discharge of 6% SBM on cuttings at one offshore site on an experimental basis.

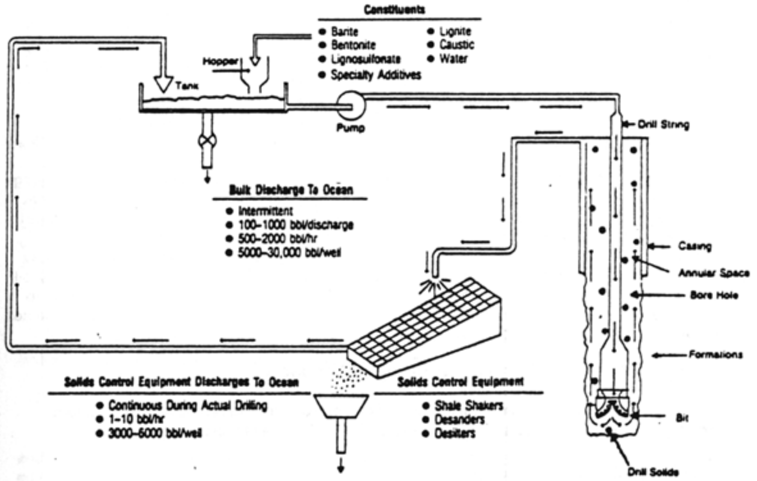

Figure 1**.** Diagram of standard drilling mud circulation system used on exploratory rigs. Source: U.S. National Research Council (NRC 1983)

Conclusions on the Relative Environmental Impacts of WBM and SBM (Cranford *et al.* 2001a):

- Exposure of demersal and benthic organisms to drilling wastes is greatest during the initial part of the drilling, and after bulk dumps.
- The use of SBM over WBM comes with the additional risk of organic enrichment impacts from SBM contaminated cuttings.
- Use of SBM for deeper sections would eliminate bulk WBM dumps that can cause physical effects and heavy metal contamination. Higher concentrations of particulate and heavy metal contaminants are introduced into the environment from drilling with WBM than for SBM.

The first well sections are drilled with a WBM. As the mud cannot be returned to the platform until the well casing is installed, WBM and well cuttings are discharged directly on the seafloor during this period. After installation of the casing (approximately 12 days), the cuttings produced by drilling are circulated with the mud up to the rig platform via the drill string. Cuttings of the rock formation being drilled are mechanically separated from drilling mud on the platform and are continually discharged into the sea from an outfall pipe located 10 m below the surface. Discharge is on the order of 1-10 barrels per hour while drilling is in progress or 3,000-6,000 barrels in total for the average well. Two types of discharges generally occur over time:

- daily discharges consisting of cuttings, associated muds and some fine particles from the formation; and,

- bulk dumps at the completion of the well or well sections.

Field observations made around active drilling platforms indicate that roughly 10% of the discharged wastes are neutrally buoyant and form a surface plume (NRC, 1983). Using standard industry models, simulations have been carried out to determine the depth of descent of the waste discharge plume under different discharge conditions, densities and environmental conditions. The factors that significantly affect the depth of descent were found to be mud density, depth of release, initial downward volume flux of the discharge, current strength and water column stratification (Cranford *et al.* 2001a; Andrade and Loder 1997). These data can be used to estimate the portion of drilling wastes released at or near the sea surface that can be expected to reach the seafloor under different scenarios.

In many cases, the finer components of the discharge may flocculate to form larger particles with higher settling velocities than the original material. Flocculation increases effective particle size and therefore increases settling velocity and greatly influences the final deposition site of the material. Observations by DFO using various oceanographic instrumentation around the PanCanadian CoPan oil field on Sable Island Bank (34 m depth) have confirmed that discharged drilling wastes flocculate, settle rapidly and concentrate in the benthic boundary layer (Muschenheim and Milligan 1996). On certain occasions during developmental drilling, fine particulates from drilling wastes were present up to 8 km from the platform. Field observations around developing sites on Georges Bank indicate the presence of elevated levels of natural suspended matter in the benthic boundary layer, but the absence of fine particulates (Muschenheim *et al.* 1995).

Laboratory experiments carried out with whole water-based mud (WBM); particulate-drilling wastes and two major mud constituents (barite and bentonite) have provided accurate estimates of flocculation and settling rates. These experiments indicated that the settling rates of flocculated drilling wastes under laboratory conditions could be as high as 1.5 cm s^{-1}. However, these flocs were densely packed and did not look like the “fluffy” drilling waste flocs observed at CoPan (Muschenheim and Milligan 1996). On the basis of these results, the observations of drilling waste concentration gradients in the benthic boundary layer at CoPan and literature values, it was decided that a reasonable range of effective settling velocities for flocculated drilling wastes under natural conditions in tidally-energetic environments is 0.1-0.5 cm s^{-1} (assuming a 50/50 mixture of bentonite and barite). These values can be used to model settling in specific oceanographic conditions.

The balance of the wastes (on the order of 90%), along with the resultant floc, is denser than seawater and, if released at or near the sea surface, forms a plume that descends through the water column until it either reaches the seafloor or becomes neutrally buoyant. In shallow water, a large fraction of the discharge will reach the seafloor close to the platform. Resuspension, dispersion, drift and final deposition site of this material will depend upon such physical variables as water depth, currents (tidal and residual), waves and storms. Most of this lateral transport takes place in the water column just above the bottom in the benthic boundary layer. Transport has been modelled using the benthic boundary layer transport model called the *bblt* (Hannah *et al.* 1995).

Discharges are usually contaminated to some degree with hydrocarbons. These discharges may have oil included, either through their addition to the muds or from any crude petroleum in the rock formations. Water-based mud cuttings can contain low levels of hydrocarbons from the formations being drilled as well as those absorbed from any oil added to the mud.

It should be pointed out that crude petroleum, in contrast to synthetic pollutants such as chlorinated hydrocarbons and refined petroleum products, is a naturally occurring substance that is derived from organic matter. Hydrocarbons have been added to the ocean continuously over long periods of geological time by natural seeps without known deleterious effects. Refined hydrocarbons, however, entering the marine environment from routine shipping and land-based activities often somewhat different, having more impact on the environment, than those released from natural seeps.

During the DFO assessment on the possible environmental effects of exploratory drilling on Georges Bank (Boudreau *et al.* 1999), the results of the Panel on Energy Research and Development (PERD) supported science was used to examine the potential impacts of operational discharges in various oceanographic regions. This research program (Gordon *et al.* 2000a) covered a wide range of scientific disciplines including physical oceanography, sedimentology, engineering and ecology. By coupling the biological results with waste dispersion models, the spatial and temporal extent of potential impact zones around a drill site can be predicted. DFO scientists have completed the modelling project and have applied the new models to hypothetical drilling sites on the Georges Bank, in order to predict the extent of the impact zone following mud discharge. This approach would be very useful for analysing potential impacts from exploratory and development activities in Southern Gulf of St. Lawrence and Sydney Bight regions.

The main findings from the Georges Bank work are summarised as follows:

- The predicted near-bottom concentrations are very sensitive to the effective settling velocities of drilling wastes. Those at the higher velocity (0.5 cm s^{-1}) are about an order of magnitude greater than those at the lower velocity (0.1 cm s^{-1}).

- In general, predicted near-bottom concentrations decrease rapidly over distances of 2-10 km from the release point. In some applications, substantial waste concentrations are carried as far as 20-50 km from the release point at the higher settling velocity. These more distant concentrations must be interpreted with caution because the assumptions in local *bblt* (i.e. uniform physical environment over the entire model domain) break down with increasing distance from the release point.

- The predicted near-bottom concentrations are very dependent upon geographic location and oceanographic conditions. The highest concentrations occur in stratified waters. In areas with high bottom stress and stronger dispersion, such as in shallow waters with strong tides and or currents, predicted near-bottom concentrations are much lower. Near-bottom concentrations are also lower in the frontal area (65-100 m) due to higher bottom stress, stronger dispersion and stronger drift.

- Near-bottom waste concentrations can be higher by up to a factor of two for neap tides because of reduced height of bottom-trapped sediment (i.e. in the benthic boundary layer) and reduced dispersion in the water column.

Cranford *et al.* (2001a) provides a more recent summary of DFO research in this field and reached the following conclusions regarding the fate of offshore drilling waste discharges:

- Drilling waste discharges do not always disperse to negligible concentrations on the continental shelf.

- Drilling wastes readily flocculate in seawater in laboratory experiments and form fragile aggregates, on the order of 0.5-1.5 mm in diameter, with high settling velocities > 1 mm s^{-1}.

- Flocs containing drilling wastes have been observed to accumulate on the seabed at distances up to 8 km away from the active drilling platform.

- Drilling waste particles can be concentrated in the benthic boundary layer associated with flocculated wastes being alternately resuspended and deposited over the tidal cycle.

- Physics-based numerical models have provided a tool to estimate the zone of influence for drilling waste at specific drilling sites and for specific discharge scenarios, but further validation studies are desirable.

- Regional and temporal variations in physical oceanographic processes, that determine the degree of initial dilution and waste suspension, dispersion and drift in the benthic boundary layer, have a large influence on the potential zone of influence of discharged drilling wastes.

- The exposure of organisms to potentially deleterious drilling waste concentrations can be expected to vary substantially between drilling sites.

Mortality

Operational discharges can accumulate in low energy systems resulting in the smothering of benthic organisms near the rig. Assuming that a well has a total operational discharge of 20,000 barrels and that 90% of the material reaches the sea floor, the average net bottom accumulation on the bottom, if all discharged material was contained within an area 100 m^2 would be 0.29 m, or 0.29 cm if evenly distributed over 1 km^2. In actuality, it is expected that suspended material will disperse based on the energy level of the environment. Due to the high settling velocity of the cuttings there is reason to believe that smothering might kill significant numbers of slow-moving or sessile organisms living in a small area directly under a drill rig.

Even if physical smothering of benthic organisms does not take place, mortality may result directly from the toxicity or physical interference from; the materials discharged (Cranford and Gordon 1991). The lethal toxicity of over 70 different water-based drilling mud formulations have been tested, using a variety of test species in laboratory experiments. . Most acute toxicity thresholds for muds and their components are much higher than concentrations expected under field conditions. A number of studies have suggested that the observed acute toxicity is primarily due to special purpose additives, such as diesel oil and various biocides. However, Cranford *et al.* (1998) conducted 96-h acute toxicity studies with used WBM obtained from a Scotian Shelf operation and observed that 100 mg L^{-1} caused a 30% reduction in the survival of haddock embryo and yolk-sac stages. In addition a 60% decrease in stage one lobster survival was observed. These results suggest that WBM formulations can be moderately toxic to both these species. The larvae of lobster, (*H. americanus),* have been identified as one of only a few species that are sensitive to used drilling fluids (Neff 1987). The lethal toxicity of several drilling fluids to lobster larvae is also reported by Derby and Capuzzo (1984). The fluids tested by these authors consisted of oil- and water-based muds at concentrations between 1 and 500 mg L^{-1}. A fluid from a well in the Gulf of Mexico, that had low oil content, resulted in an LC_{50} value of 190 mg L^{-1} for stage-one larvae. Stage-three larvae were even more sensitive to toxic effects from this fluid. Acute exposure of embryos and larvae can impact at the population level if critical processes during development are affected, such as the inhibition of transitional development phases, induction of morphological developmental defects and chromosomal aberrations (Raimondi *et al*. 1997). These biological responses have been attributed to anthropogenic contaminants including petroleum hydrocarbons and drilling muds (Cameron and Berg 1992).

It is important to remember that dispersion/dilution processes generally dilute drilling waste discharges at sea to below 10 mg L^{-1} within three hours of discharge (Neff 1987). Any larvae entrained in the convective descent plume would be exposed to high waste concentrations for only a short period. Increasing numbers of larvae will enter the plume during the diffusion phase, but these will also experience limited exposure to concentrations responsible for acute mortalities (> 100 mg L^{-1}). Early life stages would only be susceptible to impacts if the drilling wastes were able to accumulate in convergence zones where the embryos and larvae may also become concentrated.

Prolonged exposure during drilling, on the order of a month, to lower concentrations (>30 mg L^{-1}) of bentonite and barite has been shown to cause mortality of sea scallops (Cranford and Gordon 1992, Cranford *et al.* 1999). The chronic lethality of low levels (<10 mg l^{-1}) WBM, and synthetic based muds (SBM), including a new low viscosity ester-based mud, was very low. However, drilling mud containing a low-toxicity mineral oil caused high mortality at concentrations greater than 0.5 mg l^{-1} (Cranford *et al.* 1999).

The *bblt* model simulations of the fate of WBM discharges on Georges Bank suggest that while near-bottom waste concentrations may reach these high levels close to the discharge point, the short exposure duration would not likely result in scallop mortalities in any of the oceanographic regions studied.

In summary, the toxicity of operational discharges depends primarily upon the type of drilling mud employed and receiving environment. By using appropriate choices of less toxic WBMs and SBMs, and well-contained SBMs, effects from isolated exploratory wells would be limited in space and time to the area under and adjacent to the rig. The importance of such mortalities on the population level is difficult to estimate but is expected to be lower than the sublethal impacts discussed in the next section.

Sublethal effects on growth

In addition to the potential for mortalities resulting from operational discharges, some populations may exhibit sublethal effects that would be reflected in reduced growth rates and/or reproduction in the presence of discharged materials. Derby and Capuzzo (1984) documented effects on the growth, development, respiration and feeding rates of lobster larvae at drilling fluid concentrations as low as 10 mg L^{-1}. While exposure of larvae is likely to be limited by dispersion/dilution processes (above), sessile benthic organisms would be exposed to drilling wastes over the duration of exploratory drilling. Chronic toxicity studies in which sea scallop cohorts were exposed under environmentally relevant conditions to low levels of suspended WBM and ABM for up to 72-days, showed that low levels of drilling wastes can influence food utilisation, growth, and reproduction (Cranford and Gordon 1992; Cranford 1995; Cranford *et al*. 1999). Threshold drilling waste concentrations causing significant impacts to scallop tissue growth varied between 0.07 and 10 mg l^{-1}, depending on the formulation studied (Cranford and Gordon, 1992; Cranford *et al*. 1999; Cranford and Armsworthy, unpublished data). The following ranking of the drilling wastes studied, in order of increasing chronic detrimental effects, was observed: water-based mud and cuttings < bentonite < barite = synthetic-based mud < mineral oil-based mud.

Observed effects of drilling wastes on benthic fauna have generally been grouped as being caused primarily by (1) chemical toxicity from hazardous pollutants and biodegradation products; (2) organic enrichment of sediment that may produce anoxia; (3) physical smothering. Research on the effects of drilling wastes on the sea scallop shows that an additional, and potentially more important, source of toxicity exists. Physical interference from biologically inert components in all drilling fluids (e.g. bentonite and barite) was the major cause of the observed effects from the WBM, and ABM wastes tested (Cranford *et al.* 1999). There is increasing field and laboratory evidence to indicate that oil- and synthetic-base fluids are not the prime factor causing the far-field effects observed around drilling platforms (Cranford *et al.* 1999, Barlow and Kingston 2001).

The following conclusions from DFO studies on the biological effects of drilling wastes were reached by Cranford *et al.* (2001a):

- Chronic exposure of sea scallops to different drilling wastes can significantly affect growth and reproduction at environmentally relevant concentrations (<10 mg l^{-1}).
- A waste containing a mineral oil-based fluid is highly toxic to scallops.
- Chronic sublethal effects of SBM and WBM exposures are similar, as the toxicity of the base-fluids was generally low. Significant impacts on scallop growth and reproduction from SBM and WBM formulations were attributed to physical interference.
- The drilling wastes tested have detrimental effects in the following order of increasing chronic effects: water-based mud and cuttings (impact threshold >10 mg l^{-1}) < bentonite (>2 mg l^{-1}) < barite ≈ synthetic-based mud (>0.07 mg l^{-1}) < mineral oil-based mud.
- Exposure of demersal and benthic organisms to drilling wastes is greatest during the initial part of the drilling and after bulk disposal.
- Chronic toxicity studies with flounder indicate that aliphatic hydrocarbon-based drilling fluids have little potential to affect fish health.

- Studies on organ condition indices, energy reserves and MGO in flounder indicate little potential for toxicity beyond 1-2 km from rig sites.

- Sub-lethal effects have been observed in flounder exposed to sediments containing aromatic hydrocarbons as low as in the 1 ppm range.

- Laboratory studies indicate that very high concentrations of petroleum hydrocarbons in sediment result in little bioaccumulation of polycyclic aromatic hydrocarbons (PAH) in fish tissues.

- A low level of enzyme induction in American Plaice taken near the Hibernia development site was observed. Prolonged or repeated induction of MFO especially to high levels, has the potential to produce a variety of physiological and pathological conditions in fish.

- Chronic toxicity studies with lobster indicate that relatively low concentrations of petroleum hydrocarbons in water (0.04-0.05 ppm range) can affect animal health.

- Only a very small fraction of marine organisms and life stages have been studied with respect to the potential for chronic sublethal effects at low waste levels.

Numerical models were used to simulate the dispersion of drilling wastes around drilling platforms under typical exploration drilling scenarios on Georges Bank (Hannah *et al*. 1995; Loder *et al.* 2001). Predictions of the potential spatial and temporal extent of drilling waste concentrations were coupled with the biological effects information to explore site-specific impacts on sea scallop populations (Boudreau *et al*. 1999; Gordon *et al*. 2000a).

The potential impacts of the discharges predicted by the linked modelling from the Georges Bank situation are as follows:

- In mixed, high energy, areas, model results predict very low near-bottom waste concentrations and the potential growth loss, averaged along the primary drift line, is less than one day, even at the high settling velocity.

- In the frontal zone, near-bottom waste concentrations predicted by *bblt* for the complete waste release scenario would reduce potential scallop growth, averaged along the primary drift line, on the order of <0.1 to 15 days depending on settling velocity and the area over which the data are averaged. The results of laboratory experiments suggest that gonadal growth would be affected more than somatic tissue growth so that the net effect might be reproductive loss that could affect the strength of future year classes. Due to the conservative nature of the parameters used in this modelling, it is expected that impacts would be lower than these predicted

- In areas with stratified water, the model predicted the greatest concentrations and highest potential scallop growth loss. Total growth days lost ranged between 2 and 40 for the full waste release scenario depending on settling velocity and the area over which the data are averaged.

Similar *bblt* applications for hypothetical oil and gas exploration sites have been conducted for the Sable Island Bank, the Northern Grand Bank, Laurentian Channel and the St. Pierre Bank (MacLaren Plansearch 1997; Thompson *et al.*, 2000; Hannah *et al.* 2000). Differences in the local oceanography and water depth have resulted in a range in the predicted zone of influence for drilling wastes; similarly large differences in the biological effects zone would be expected. All of the *bblt* applications performed to date illustrate the importance of site location and waste settling velocity in defining the zone of potential sublethal population effects. Further conclusions based on DFO scallop population risk assessments are as follows (Cranford *et al.,* 2001b):

- Numerical dispersion models, used in conjunction with laboratory data on chronic sublethal effects and field information on population distributions, are valuable tools for evaluating the risk of potential population-level impacts of discharged drilling wastes.

- Near-seabed waste concentrations of WBM have been predicted to extend for large areas around single exploration platforms at levels that are known to adversely affect scallops.

- The predicted biological effects zone can vary greatly with location and season.

- There exists a small probability that changes in reproductive output resulting from exposure to fine particulate matter in WBM could have detectable and significant population and ecosystem level effects in some areas of the Eastern Canadian shelf.

- The use of SBM over WBM comes with the additional risk of organic enrichment impacts from SBM contaminated cuttings.

- Use of SBM for deeper sections would eliminate bulk WBM disposal that can cause physical effects and heavy metal contamination. Higher concentrations of particulate and heavy metal contaminants are introduced into the environment from drilling with WBM than for SBM.

- Unlike synthetic-based fluids which biodegrade rapidly, heavy metal contamination from WBM disposal can be more or less permanent.

- SBM impacts can be mediated by pre-treatment of cuttings.

Tainting

GESAMP (1993) provides an excellent summary of reported tainting from petroleum products. It is possible that certain metals and organic compounds contained in drilling muds or released with cuttings may be concentrated in tissues of exposed organisms, even at relatively low concentrations. One of the possible concerns is whether these contaminants might be transferred through the food web and result in tainting that might affect market value of commercially viable species.

Tainting might result from the use of water-based muds because of the possible oil additives. If tainting was detected under field conditions by a monitoring program, the area around a rig may have to be closed to fishing for a period of time until after drilling ceases.

Canadian laboratory experiments have indicated that scallops have the potential to concentrate both barium and chromium in their digestive tract, as well as clay particles, from water-based drilling muds but again it is difficult to apply these results to natural conditions. In regards to scallops this should not affect their marketability as only the muscle is eaten.

Measurements made during the US Georges Bank Monitoring Program could not detect any uptake or accumulation of trace metals or hydrocarbons by the ocean quahog in the wild (Phillips *et al.* 1987).

The economically important snow crab and lobster species that are of interest to the fisheries in the Southern Gulf of St. Lawrence and Sydney Bight are more mobile than scallops and quahogs. As a result these mobile species might avoid areas that exhibit potential tainting problems, however little direct information exists for these species.

Summary of Operational Discharges

In summary, operational discharges during exploration drilling might cause biological effects over relatively short time periods and small distances from the discharge, but effects are site specific and depend on the development taking place. Smothering of benthic organisms by deposited mud and cuttings would not be anticipated outside about 0.5-km radius from the rig. The use of lower toxicity WBMs and SBMs, and well-contained SBMs, should minimise the direct mortality on organisms, as would the use of low toxicity oil for lubrication and a spotting fluid. The zone of impact around a rig varies with oceanographic conditions, at the particular location and time, and quantity of discharge. Impacts would diminish rapidly once drilling ceases. It is anticipated that the dispersed muds, cuttings and associated hydrocarbons would cause sublethal effects for some bottom dwelling organisms but this also needs to be verified by the application of existing tools and information. Because of the large degree of spatial and temporal variability in natural populations and the limitations of current sampling methods, it is expected that it would be very difficult to detect the net result of any impact at the population level. There is little evidence to suggest concern over possible tainting of either finfish or invertebrate resources, based on these WBM discharge scenarios. As with sublethal effects, potential impacts of tainting can be expected to be less with isolated exploratory wells than with a production field.

Potential Distant Impacts

Using a realistic scenario of exploration activities, one drilling rig operating at a time with 3-4 wells being completed over the exploration phase, it appears that impacts from routine seismic surveys and operational exploratory drilling activity is likely to have primarily localised impacts on the ecosystem components. The actual impacts will be dependent on the location, timing of the activities, and the properties of discharges.

The closed topographic characteristics of the Southern Gulf of St. Lawrence and the proximity of the potential activities to the shore in Sydney Bight (between 12 and 100 km) might give rise to some distant impacts outside of the areas under consideration. These distant impacts might include the transmission of some discharges to the shallow water and intertidal areas of Cape Breton.

In comparison to the operational discharges from exploratory drilling, there is a higher probability that contaminant hydrocarbons from a major oil spill or blowout would result in distant impacts based on physical/chemical characteristics and volume released over time. DFO has developed expertise to understand the fate, transport and effects of oil at sea and in coastal environments to support research programs related to the development of spill countermeasures (Lee and Stoffyn-Egli, 2001; Lee, 1999, Weise *et al.* 1999). In the event of an accidental spill, DFO will provide scientific expertise to the Regional Environmental Emergencies Team (REET) in our effort to minimise impacts on the fisheries and fisheries habitat. .

Depending on the timing, exploration activities may interfere with migration of finfish such as mackerel and herring through the area. Marine mammal migrations may also be altered. Mitigation measures would have to be considered to minimise any such impacts.

Potential Cumulative Impacts

Multiple Exploratory Wells

Based on the high cost of drilling exploratory wells, it is expected that there will be few wells drilled during exploratory activities.

The area has tidal currents that would tend to distribute discharges over an area larger than the footprint area in a matter of days. In a single well situation, this may be helpful in diluting the discharge, over a larger area and thus possibly reducing subsequent environmental impact. The critical issue would be whether threshold levels of discharge and toxins were reached at important areas with high densities of organisms. The linked modelling of currents, benthic boundary layer transport and studies on species potentially at risk, such as has been done on Georges Banks to determine the growth impacts in scallops, would be needed for evaluating future proposals for drilling sites.

Development and Production Phases

This review and assessment is limited to exploration activities. A review of production activities that are unknown at present and their potential impacts cannot be conducted. However it is important to note that many aspects of production activity have potential impacts on the marine ecosystem. While some of these activities are the same as for the exploration phase only greater in scale, others are unique to 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 volumes of routine discharges, such as sewage and biocides;
- fishing community loss of access for longer periods of time;
- release of produced water; and,
- gas flaring.

Of particular note for production and development would be an increased potential for chronic impacts that might result from exposure to lower concentrations of materials over a longer period of time. Environmental effects monitoring programs are required to adequately measure and quantify any potential chronic impacts (Gordon *et al.* 2000b)

EXCEPTIONAL EVENTS/CIRCUMSTANCES

In addition to the possible impacts from routine exploration activities, there are a number of events that have a very low probability of occurrence but pose a much greater risk to the ecosystem.

Oilspills

With any petroleum development there is always the chance of a major release of oil or gas into the environment at a rate faster than natural ecosystems can accommodate. In exploration there is usually no bulk storage or transfer of oil or gas, thus the risks and impacts of an oil spill are not significantly higher than that associated with marine shipping already occurring in the area.

Blowouts

In any drilling operation, there is a slight risk from a blowout where large quantities of oil or gas are released from well. A blowout occurs when it is not possible to control the flow of petroleum reserves from the well. This might occur anywhere in the water column from the sea floor up through the water column to the rig itself. Most blowouts do not lead to significant loss of hydrocarbons since often they seal naturally and cease flowing within a matter of hours or days. Regulations require that all feasible steps be taken to minimise the probability of a blowout. For example, blowout preventers, to stop or slow the flow of petroleum in unusual circumstances, are routinely installed on all wells at the seafloor. .

The history of oil exploration and development in the Gulf of Mexico over the past 50 years can be used as an example to estimate risk in the Southern Gulf of St. Lawrence and Sydney Bight, as regulations and operational guidelines are similar for both regions. From January 1979 through December 1998 there were 19,821 wells drilled in the Gulf of Mexico which resulted in 118 uncontrolled flows or blowouts indicating a 0.6% occurrence rate. The vast majority of these events were the diversion of shallow gas and in only one event was there a release of any liquid hydrocarbons (87 barrels of condensate). On-site monitoring programs reported no detectable environmental consequences. (W. Lang, US Minerals Management Service, personal communication).

Despite advances in technology and improved regulatory guidelines, there remains a slight chance that a blowout could occur. This may result in the release of a mixture of gas, gas condensate and/or oil. These three products behave differently in the water column and have different potential impacts.

The high volatility of the gas contributes to its evaporation into the atmosphere and the bulk of material dissipates rapidly through the action of the wind. This is also true for the lighter components within condensates and crude oils, which evaporate within the first hours and days after release. While the impact of these low-molecular weight constituents in the atmosphere, including effects due to long distance transport, are not well known, it is generally considered to be negligible due to the extent of dissipation.

Gas condensate is made up of chemicals associated with the gas that become liquid at standard temperature and pressure. Much of this material is highly soluble in water. Many of the hydrocarbons found in gas condensate are highly toxic. For example, condensate from the *Venture* well on the Scotian Shelf contains greater than 10% benzenes and naphthalenes, two of the most toxic groups of petroleum hydrocarbons. However, the high volatility of benzenes and naphthalenes would result in rapid evaporation from the sea surface, lowering the concentration in the water. Toxicity associated with the formation of a large water accommodated fraction of condensate from a blowout at the seafloor may cause local mortalities. While the overall level of impacts would be dependent on the duration, timing and location of the condensate release, it is expected to be short-lived following the stoppage of flow.

Observations made during the *Uniacke G-72* gas blowout are useful for evaluating a potential scenario for gas and condensate release in the Southern Gulf of St. Lawrence and Sydney Bight situation (Martec 1984). During the *Uniacke G-72* blowout condensate was lost from the platform above the sea surface. This blowout, which occurred at the end of February 1984, was relatively short-lived and dispersion of its condensate was assisted by several winter storms. It is estimated that 75% of the condensate was lost by evaporation during the first 24 hours after release. The remainder either formed a temporary surface slick or became entrained in the water column. The surface slick of this light condensate persisted for several days and was observed up to 10 km from the rig. Condensate dissolved in the water presumably persisted longer and travelled further because of decreased evaporation. Measured hydrocarbon concentrations, detected to depths of at least 21 m, were usually under 100 parts per billion (ppb) compared with background levels of about 1 ppb. Biological effects were not observed or evaluated.

In general, the environmental persistence of condensate spilled on the ocean surface appears to be relatively short, a matter of hours to days. However DFO research has shown that it may persist within the environment, if it becomes entrained within coastal sediments (Strain 1986). Under this environmental condition, the potential for detrimental biological effects becomes a concern due to prolonged exposure.

The environmental impacts of oil in the sea have been studied around the world for almost three decades. GESAMP (1993) recently published a major review, summarising the general understanding of the behaviour, fate and effects of oil released into the sea. The GESAMP report also includes case studies of blowouts and major oil spills under different environmental conditions. DFO scientists have played an important role in studying the fate of oil spills and their impacts.

Oil releases at sea may form a surface slick, be mixed into the water column and/or become incorporated into sediments. The relative amounts entering each pathway and subsequent behaviour will depend upon the type of event (i.e. platform blowout, seafloor blowout, sea surface oil spill, etc.), composition and physical-chemical characteristics of the oil, environmental conditions (wind, temperature, etc.) and oceanographic features.

It is expected that the bulk of any oil that may be released the Southern Gulf of St. Lawrence and Sydney Bight would initially concentrate at the sea surface to form a slick and be immediately subjected to evaporation, even in the case of a subsurface blowout. It has been estimated that evaporation removed 40-50% of the Bunker C oil spilled on Nantucket Shoals from the *Argo Merchant* in just 24 hours (Hoffman and Quinn 1979; Hoffman *et al.* 1979). Similarly about 23% of spilled *Hibernia* crude oil would evaporate in the first five or six hours after a hypothetical spill. Since the portion of oil lost by evaporation consists largely of the lighter fractions, composition of oil remaining in a surface slick after several days would be different from the original. Other processes that would play a major role in breaking up surface slicks following a spill include dispersion and dissolution into the water column. Photo-oxidation (near the surface) and biodegradation would become increasingly important after a few days. Under most conditions, surface slicks of unrefined oil should disappear after one to two weeks.

The presence of an oil slick on the surface will have the most serious biological impacts on birds, and marine mammals in the area. The federal Department of Environment has a role to play in providing data and information on the potential impacts of oil slicks on marine birds. Impacts of oil slicks on marine mammals are not well understood and are species specific, but of are concern with respect to development in the Southern Gulf of St. Lawrence and Sydney Bight areas since they are frequently used by marine mammals. Impacts of oiling in seals may be due to either external oiling or ingestion. In young seals, external oiling generally causes death because their coats are not developed enough to provide insulation in an oiled state. In adult seals the absorption or ingestion of oil may cause the mothers to not feed their young. Older seals appear to survive moderate levels of oiling despite some loss of waterproofing and buoyancy in their fur. The death of whales, dolphins and porpoises has not been linked to oil spill events. These animals are highly mobile, therefore exposure time is limited and they have been observed to avoid oil spills and contaminated waters.

The amount of spilled oil that enters the water by dispersion and dissolution varies considerably with composition and environmental conditions, but is generally on the order of 5-15%. Dissolution is considerably less than dispersion because of the low solubility of most oil components. Oil dispersed within the water may have a higher potential toxicity than surface slicks due to the reduced potential for evaporation of the lighter toxic components.

The depth to which oil penetrates depends upon wind, mixing, currents and water column structure. Entrainment in the water could also be greater if a blowout occurred beneath the sea surface or under storm conditions. In the shallow water areas of the Southern Gulf of St. Lawrence and Sydney Bight, such concentrations could extend uniformly all the way to the bottom. For example, oil spilled from the *Argo Merchant* was detected as deep as 20 m and probably penetrated deeper. Similar observations were made in Chedabucto Bay and along the eastern shore of Nova Scotia following the *Arrow* spill.

Once in the water column there are a number of ecosystem components potentially at risk.

Biological impacts on selected organisms and life stages in the water column have been demonstrated at oil concentrations that can occur under field conditions. Oil concentrations on the order of 100 ppb or less have been demonstrated to cause both lethal and sublethal effects on planktonic organisms. However, despite many studies, it is difficult to demonstrate that either major spills or chronic oil input might have any irreversible impacts on exposed marine planktonic communities. In most instances impacts at the ecosystem level may be low for several reasons. The volume of water contaminated with high oil concentrations is limited in both space and time due to rapid dispersion and weathering. Secondly, planktonic organisms generally have rapid rates of regeneration, on the order of days to months, and can therefore quickly compensate for any loss. Thirdly, replacement phyto-and zoo-plankton can be readily mixed in from surrounding waters.

Significant and variable natural mortatility among the early life stages of finfish and invertebrates makes it very difficult to indicate the impacts of oil-induced mortality on early life stages of these resources when exposed to contaminants. Existing juvenile and pre-recruit survey methods are characterised by large variability that makes it almost impossible to detect mortality resultant from oil exposure unless it is major and extends over a large area. An idea of the potential effects of oil-induced mortality on early life stages can be obtained using ecosystem computer models that evaluate quantitatively the impacts of different spill conditions. American modelling studies have demonstrated the types of impacts that various spill scenarios on Georges Bank could have on cod, haddock and herring stocks. Some scenarios predict cumulative losses in excess of 20% for both cod and herring (Reed *et al.* 1984; Spaulding *et al.* 1985).

The potential impact on fishery resources on the Southern Gulf of St. Lawrence and Sydney Bight will depend very much upon the timing and geographic location of a hydrocarbon release. Each species spawns during a limited time period and therefore would be more vulnerable at certain times of the year than others.

The effects of oil on adult fish in the field are difficult to study and therefore knowledge is incomplete. Nevertheless, fish do have the potential to avoid contaminated areas if the areas are small enough and they are able to detect them. Even though estimates of adult stocks are more precise than those of the young, mortalities as high as 25% could go undetected. While it is possible that long-term impacts are in fact minor, it is also possible that significant impacts on aquatic populations do occur but may not be detected with present methodology. High levels of variability in resource levels result from both natural and human factors. In addition stocks, such as some groundfish resources and some marine mammals, which are already under pressure, may be particularly sensitive to the impacts of low levels of oil.

Oil in the water column can result in the fouling of fishing gear or the closure of areas of the area due to suspected presence of oil. This loss of access to the area by the fishing industry could result in lower yields, depending on the duration and location of the blowout. There is also concern of market loss following spill events due to the public's perception of "contaminated" products.

The amount of oil reaching bottom sediments depends on numerous factors including the volume of the blowout, type of blowout (platform or seafloor), hydrocarbon composition, depth of water and degree of water column mixing. Transport mechanisms include: adherence to particles, incorporation into zooplankton faecal pellets, direct sedimentation of weathered oil particles and vertical mixing. The greatest amount of oil should reach the bottom in the shallow areas and possibly in intertidal areas with sufficient horizontal movement.

Concentrations of hydrocarbons in sediment in the range of 10 to 100 parts per million (ppm) could be expected from a blowout or spill. Due to the generally low energy environment, these concentrations could persist for a few months, as winter storms would be expected to play a role in dispersal and re-working of the sediments. Any mortality of benthic species induced by a single event would probably be limited in both extent and time. The same is expected of chronic sublethal effects, although the extent and duration of impacts could be greater. Widely distributed species should be subjected to little risk except in localised areas of high oil concentrations. However, species that utilise a limited portion of the area and have limited mobility, such as snow crab and herring that have eggs that adhere to the bottom for about 10 days before hatching, could be at higher risk if an oil release coincided with the location and timing of spawning. In the Southern Gulf of St. Lawrence and Sydney Bight species that have benthic eggs and/or larvae are of particular importance since they are potentially vulnerable to oil contaminated particulate material.

Oil in the water is transported under the influence of tides, surface currents and wind. While suspended in the water column, oil is transported horizontally by tidal currents, eddies, residual flow and other currents. During the winter months, oil slicks would be under the ice. In non-iced periods, if winds are light, trajectories should be influenced primarily by the residual current. Under storm conditions, surface water movement would be driven by the winds.

There is, however, some reason for concern about potential damage to the Southern Gulf of St. Lawrence and Sydney Bight inshore areas. There is a high probability that, if strong northerly winds occurred, such as may be associated with winter storms, some portion of the oil could move towards the coast of Cape Breton. Crude oil in a slick would evaporate and disperse during transit so the probability of fouling the shoreline is thought to be low. Oil that does reach the Cape Breton coast from a release site 12-100 km offshore, would be somewhat weathered and therefore less of an ecological threat than fresh oil.

It should be noted that trajectory calculations should be interpreted with caution. They are based upon long-term averages of oceanographic and meteorological conditions. Short-lived and unpredictable events, such as storms or hurricanes, can move slicks several hundred kilometres in unexpected directions relatively quickly. These same conditions, however, will accelerate the evaporation of oil and dispersion into the water column.

In the event of an accidental blowout or spill event, our first response is to minimise the transport of residual hydrocarbons to nearshore and coastal environments. While condensate spills at the sea surface are not expected to persist, in the case of crude oils, contingency plans should include measures for physical recovery of the bulk oil (booms, sorbents, skimmers). Each physical recovery method has limitations, depending on the amount of oil spilled, sea and weather conditions (including that of ice cover), and the geographical location of the spill (Fingas 2001). Treating the oil with chemical agents is another option for cleaning up oil spills on the sea surface. These include chemical dispersants that promote the formation of small droplets of oil that disperse throughout the water column. While chemical dispersants remove oil from the surface, minimising impacts on the bird populations, there remains debate over their overall effectiveness and toxicity (i.e. dispersed oil may be more toxic than the oil itself). Other chemical agents may include; emulsion breakers and inhibitors, recovery enhancers, solidifiers, and sinking agents.

Oil spills on shorelines are more difficult and time-consuming to clean up than spills in other locations, and clean up efforts on shorelines and nearshore habitats can cause more ecological and physical damage than if the oil is left to natural processes. Intertidal algae, an important food source for many intertidal fauna species, can be severely impacted by oil spills. Although readily killed by even a moderate oil spill, intertidal algae are usually the first biota to recover after a spill. Algae will re-establish on oil-coated rocks after the volatile components are removed by natural weathering processes. The effectiveness of natural attenuation (natural recovery) has been demonstrated at Black Duck Cove, a site impacted by the 1970 *Arrow* oil spill. While residual oil at elevated concentrations is evident within the sediments of the intertidal zone, habitat recovery was evident and biotests confirmed that the toxicity of the oil has been largely removed by biodegradative processes (Lee *et al*., 1998). Environmentally friendly, oil spill countermeasure strategies based on the acceleration of natural remedial processes such as biodegradation by nutrient enrichment and dispersion by oil-mineral fine aggregate formation have recently been developed (Lee *et al*., 1996, 1999).

In general, scientists have been unable to detect effects of offshore oil blowouts on the abundance or wholesomeness of fisheries resources, including the *Uniacke* blowout near Sable Island. However, this does not mean that effects do not occur. A gas or oil blowout could cause both lethal and sublethal biological impacts on individual organisms that would vary in severity according to hydrocarbon composition, type and blowout duration, location, time of year and environmental conditions.

UNCERTAINTIES

As with any complex assessment, there are uncertainties associated with various aspects of this review. In this case, uncertainties include the role of episodic perturbations on the physical regime, predator-prey relationships, limited information for some important species and the overall dynamics and resiliency of the ecosystem.

Studies on important species in the Southern Gulf of St. Lawrence and Sydney Bight, comparable to the work done for the scallop resource on Georges Bank, should be conducted. Until this is done, there will be uncertainties about the populations at risk, the pathway of impact and the processes involved.

The dispersion of drilling mud in the ocean is a complex phenomenon which is not fully understood and for which there are no 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.

There is uncertainty about the full range and nature of potential impacts from drilling waste discharges and/or accidental oil spill events on the ecosystem. Potential lethal and sub-lethal impacts of operational discharges or residual contaminant hydrocarbons on the marine resources, and the overall ecosystem structure and function, in the Southern Gulf of St. Lawrence and Sydney Bight Bank have not been thoroughly investigated.

There are great uncertainties about the possible impacts of seismics on adult invertebrate populations. Research is presently under way to address a number of these uncertainties.

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

Without a specific proposal it is not possible to provide details on the potential impacts, possible mitigation and hence the residual risks of exploration activity. This document has attempted to summarise in a general way the knowledge about potential impacts. Potential impacts can be mitigated through a combination of technological advances and scheduling of activities. The industry is continually advancing its strategies for mitigation. The risks associated with any residual impacts are a combination of known impacts and uncertainty about potential impacts. Scientific knowledge can contribute to the evaluation of that risk but the acceptability of the risk is a complex evaluation of potential costs versus potential benefits.

Because of the location of the 3 lease areas there are a number of knowledge gaps relevant to an environmental assessment of oil and gas exploration activity that are not covered by the generic assessment documents that have been prepared for the Scotian Shelf. For seismic surveys these include:

- the behaviour of seismics in shallow water,
- the impact of seismics on various life stages of benthic invertebrates, and
- the impact of seismic activity on fish migration.

For exploratory drilling these include:

- the behaviour of particulate wastes in shallow water, and
- the impact of noise on benthic invertebrates and on fish migration.

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