Report of the Expert Panel on Science Issues Related to Oil and Gas Activities, Offshore British Columbia

An Expert Panel Report
prepared by
The Royal Society of Canada
at the request of
Natural Resources Canada

"studiis eodem diversis nitimur"
"different paths, one vision"

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February 2004

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This report provides a framework for public discussion on science issues related to potential oil and gas activities offshore of British Columbia (BC). There has been a series of moratoria on such activities for over 30 years and now the question is being asked, "should the moratoria --federal and provincial -- be lifted?" Decisions on this question will be taken by governments after debate involving public consultations. The purpose of this report is two-fold. Firstly, it is the response to a request made in mid-2003 by the Minister of Natural Resources Canada that an independent Expert Panel advise him regarding science issues around oil and gas development off the BC coast. Secondly, the report is intended to be one input to the public consultations that will be conducted later in 2004 by a separate review panel, appointed by the Minister.

The report is intended to be accessible to those people who have a stake in the future of the Queen Charlotte Basin, the area offshore BC to which this report is limited by the Minister's mandate. The majority of the stakeholders are not experts in the areas of science discussed. The report references much technical literature, but provides syntheses for the lay person, and is intended to be read alongside several other recent reports, which deal at greater length with particular issues.

The report must also be physically or electronically accessible to the stakeholders. It will be available on the internet, as are the complementary reports. Hard copies of the report will be available to local communities around the Queen Charlotte Basin, so that residents can participate fully in the public consultations that follow.

The Expert Panel has taken advice from a large number of people, and many organizations. All views presented to the Panel have been considered carefully, during the Panel's deliberations. The Panel has been guided by the precautionary principle in reaching its conclusion and recommendations. These provide a framework for ensuring that the appropriate knowledge is acquired and are intended to facilitate the consultations and decision making that will follow.

Jeremy Hall (Chair)
Richard F. Addison
John F. Dower
Ian J. Jordaan

10 February 2004

Prefatory Note

In May 2003, the Earth Sciences Branch of the Department of Natural Resources approached the Royal Society of Canada with a request to commission an Expert Panel to conduct a review of science issues arising from possible oil and gas activity, offshore British Columbia, and to identify science gaps that may need to be filled prior to, or following, any decision on lifting of the current moratorium on such activities. The Society agreed to do so, and the Committee on Expert Panels undertook the task of screening and selecting the individuals whose names now appear as the authors of this report for panel service.

The report entitled *Report of the Expert Panel on Science Issues Related to Oil and Gas Activities, Offshore British Columbia* represents a consensus of the views of all of the Panelists whose names appear on the title page. The Committee wishes to thank the Panel Members and Panel Chair, the Peer Reviewers, and the Panel staff for completing this very important report given the urgency that decision-makers placed upon delivery..

The Society has a formal and published set of procedures, adopted in October 1996, which sets out how Expert Panel processes are conducted, including the process of selecting Panelists. Interested persons may obtain a copy of those procedures from the Society. The Committee on Expert Panels will also respond to specific questions about its procedures and how they were implemented in any particular case.

The Terms of Reference for this Expert Panel are reproduced elsewhere in this report. As set out in our procedures, the terms are first proposed by the study sponsor, in this case Natural Resources Canada, and accepted provisionally by the Committee. After the Panel is appointed, the terms of reference are reviewed jointly by the Panelists and the sponsor; the Panelists must formally indicate their acceptance of a final Terms of Reference before their work can proceed. These are the terms reproduced in this report.

The Panel first submits a draft of its final report in confidence to the Committee, which arranges for another set of experts to do a peer review of the draft. The Peer Reviewer comments are sent to the Panel, and the Committee takes responsibility for ensuring that the Panelists have addressed satisfactorily the Peer Reviewer comments.

The Panel's report is released to the public without any prior review and comment by the study sponsor. This arm's-length relationship with the study sponsor is one of the most important aspects of the Society's Expert Panel process.

Inquiries about the Expert Panel process may be addressed to the Chair, Committee on Expert Panels, The Royal Society of Canada.

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Chair, Committee on Expert Panels

on behalf of the Committee Members for this Panel:

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EXECUTIVE SUMMARY

Background

The Government of British Columbia (BC) has asked the Government of Canada to consider lifting the federal moratorium on oil and gas activities offshore of British Columbia. In response, the Government of Canada is proceeding with a review to:

(a) identify science gaps related to possible oil and gas activity offshore BC;
(b) hear the views of the public regarding whether or not the federal moratorium should be lifted for selected areas; and
(c) consult with First Nations to ensure that issues of unique interest to First Nations are fully explored.

Part (a) of this three-stage process is this science review being conducted at the invitation of the Minister of Natural Resources Canada. Only the Queen Charlotte Basin (QCB) is under consideration by the Minister and the Expert Panel has therefore restricted its focus to the Dixon Entrance, Hecate Strait and Queen Charlotte Sound. The review included three open science workshops, in Vancouver and Prince Rupert, during which experts informed the Panel about the area, the nature of oil and gas activities and their impacts, followed by open discussion. The Panel also received and considered many written briefs before drawing its conclusions.

Responding to the terms of reference for the review

The key requirements spelled out in the terms of reference for the review are as follows:

(a) to identify science gaps which may need to be filled before a decision is made in respect to the moratorium;
(b) to provide a path forward on the science requirements which would precede, or be concurrent with, any exploration or development activity;
(c) to identify who should be responsible for filling the identified gaps;
(d) to evaluate risks associated with not filling an identified gap;
(e) to evaluate sensitive environments and previously recommended exclusion zones within the proposed review area; and
(f) to identify additional areas requiring special management measures in the event of a decision to lift the moratorium.

The Panel recognizes that oil and gas development takes place in discrete phases of activity separated by analysis and decision points. It has determined what science gaps need to be filled to ensure safe practice (safe for both human life and the environment) for each successive activity. These phases include exploration mapping (in the offshore, this is achieved mainly by seismic surveys which image the subsurface); exploration drilling, to test structures found for oil and gas; delineation drilling, to determine the extent of potentially commercial reservoirs of oil and gas; production; and decommissioning. It is likely to take about 15 years to move through the stages of activity prior to first production. There are periods of years before some activities occur and therefore adequate time to fill the science gaps for them.

Safe practice depends on knowledge, risk assessment and regulation. Because the three are closely linked, the requirement for science knowledge cannot be divorced from the needs for both risk assessment and regulation. We have described the need for quantitative risk assessment, and have made assumptions that the regulatory regime, put in place for oil and gas activity offshore British Columbia, would use current best practices from other areas of the world.

We have enumerated the science gaps that would need to be filled before each phase of activity commences. We have stated the consequences of not filling those gaps—potentially safety built into the design of facilities, which could lead to the activity being non-economic, or prohibition of activity until risks are better defined by acquisition of new knowledge. A third possibility—of activity being pursued and then being found harmful—is unlikley if the regulatory regime is sufficiently stringent.

We discuss the development of protected areas, and special restrictions that should be applied to oil and gas activities, as well as noting the need for other activities to be restricted around some oil and gas facilities.

The Panel completes its response to the terms of reference by making a series of recommendations and coming to conclusions with respect to moratoria. We note that the terms of reference refer to the moratorium (federal, presumably), but other moratoria cover this activity, including a provincial moratorium, and because most of those with whom we have consulted are aware of these, we use the plural herein.

In this summary, we outline our response to the terms of reference as described above, but first provide some background on the area of concern and the nature of oil and gas activities.

Physical setting of the Queen Charlotte Basin

The QCB is a semi-enclosed basin between mainland BC and the Queen Charlotte Islands. The basin is connected to the NE Pacific via Dixon Entrance (in the north) and Queen Charlotte Sound (in the south), and to the Strait of Georgia via Queen Charlotte Strait (in the southeast). Water depths in most of the basin are greater than 100 m, with maximum depths of more than 400 m. Several submarine canyons penetrate the basin.

Much of the seabed is covered by silty sediment, but there are rock outcrops, boulder beds, sands, and several unique sponge reefs. The rugged nature of the seabed poses several potential hazards to oil and gas activities: slope instability, moving sediment, shallow gas, and active faulting.

The QCB is an area of current earthquake activity. A fault movement would endanger the integrity of seabed structures cutting across the fault surface (e.g., a well bore), and could destabilize sediments. Earthquake waves (tsunamis) have been recorded in the QCB, but they are smaller than those of storm waves.

Tides and currents in the QCB are vigorous (1-5 knots). Drifter studies show evidence of eddies that retain water (and by extension, oil spills) in the basin. Wind and sea conditions in the QCB are among the most severe in Canada. Winter wind speeds average 35 km/h, with gusts of up to 200 km/h. Typical wave heights in the basin range from 1.5-2.5 m, but “monster waves” of more than 25 m may occur during extreme storms which can develop in less than 8 hours.

Ecological setting of the Queen Charlotte Basin

The QCB is a typical highly seasonal, mid-latitude, coastal marine ecosystem, like those elsewhere in British Columbia and in southern Alaska. Production is high in the spring, when plankton blooms fuel growth of higher trophic levels. Commercially valuable species include six species of salmon, a suite of demersal fish, and several invertebrate species. The QCB plays host to a number of ecologically sensitive species, including more than 20 species of whales and pinnipeds, sea otters, plus many species of colonial seabirds (including some for which much of the global population occurs in the QCB). The basin also contains a series of sponge reefs, unique in the world.

Except for commercially valuable species, the distributions of most marine species (and therefore the areas of critical habitat) in the QCB remain poorly known. Beach surveys have been conducted throughout the basin, but subtidal communities (especially deep water communities) have received little attention. To determine the best locations in which to establish representative marine protected areas (as well as site selection for monitoring sites), research must be undertaken to better describe the distribution of species in the QCB, with special attention paid to species sensitive to oil and gas activities. Collection of baseline and monitoring data should begin as soon as possible.

As of November 2003, sixteen marine species in the QCB were listed by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) as "endangered", "threatened" or "species of special concern". Under the Species at Risk Act (SARA), it is an offence to "…*kill, harm, harass, capture or take*…" an individual of any species listed as endangered or threatened. SARA also requires that Recovery Plans be developed for these species, including the identification and protection of critical habitat. Where such data do not exist (as is the case for most of the species at risk in the QCB) new studies must be undertaken to collect the necessary data. The Panel assumes that Recovery Plans will be implemented in a timely fashion, resulting in critical habitat being identified and protected. This will reinforce the requirements of regulation prior to commencement of oil and gas activities.

Oil and gas activities

Initial offshore exploration will involve seismic surveys conducted from ships. These surveys involve sophisticated echo sounding to create 2D images of sub-seafloor geological structure below the ship's tracks. The acoustic sources used can be harmful to nearby animals. 2D images provide a regional picture of geological structure and may lead to a phase of more intensive 3D imaging over favourable structures. Testing to find out if such structures contain oil or gas is then done by drilling. Rotary rigs, mounted on the seabed or free floating, would be used. Mud is circulated through the drill string to remove drilled out rock cuttings. Disposal of mud and rock cuttings is a contaminant issue. If discoveries prove commercial, production of oil and gas may be developed, using a more permanent operating platform. Transport of oil and gas from producing fields is either via pipeline or tanker. Discharge of large amounts of water produced from the reservoir with the oil, and oil spills from accidental leaks or blow-outs are additional contaminant issues. At termination of production, decommissioning involves plugging the well and cutting it off just below the seabed. Production platforms are then abandoned or removed.

The QCB has significant potential for oil and gas. Oil seeps occur on the Queen Charlotte Islands and gas seeps are known offshore, but despite pre-moratorium seismic exploration and eight wells drilled offshore, there has been no commercial discovery. It is thus difficult to estimate the oil and gas resource, but current estimates suggest there may be 6 fields of over 100 million barrels of oil, which together could produce 1.3 billion barrels, worth about C$50 billion. There may be 9 fields with more than 500 billion cubic feet of recoverable gas, totalling 9.8 trillion cubic feet, worth around C$60 billion. The hydrocarbon potential of the Basin is thus of similar order to the mature Cook Inlet oil and gas fields in Alaska, and to the currently developed or developing fields in the Jeanne d'Arc Basin offshore Newfoundland.

Environmental impacts and safety

Oil and gas activities can have negative impacts on marine and shoreline systems. Oil is unlikely to be produced from the QCB for at least 15 years and, as the technology will change during that interval, production processes and their impacts should be assessed closer to that time. The Panel has focussed on the activities occurring at the earlier stages of oil and gas development (i.e., seismic surveys and exploratory drilling). Oil and gas development in the QCB would lead to increased activity on shore, at service bases. Their impact will be merely incremental to other port activities.

Seismic surveys use air gun acoustic sources. These have localised lethal effects (i.e., within a few metres) on plankton, drifting eggs and larvae, but these will be small compared to natural mortality. Other physical effects on eggs are not of concern since it is unlikely they could be detected against background levels of mortality. Any fish or marine mammal within a couple of metres of an air gun detonation would be killed or suffer permanent hearing damage. Farther away, effects are more variable, but some marine mammals and fish change behaviour, with largely unassessed consequences for survival of individuals or populations, in the presence of air gun detonations. It is therefore prudent to prohibit seismic surveys at places during times when sensitive life-stages of commercially important or ecologically-significant species are known to be present (e.g., during juvenile or adult salmon migrations, or areas when herring are spawning). In such cases, basic patterns of distribution and habitat usage should be established before any seismic surveys are undertaken. The Species at Risk Act legislates that such studies be carried out for QCB species currently listed by COSEWIC as being endangered or threatened.

Exploratory and production drilling produce waste: cuttings, usually associated with residues of drilling fluids, and produced (i.e., formation) water. Discharges of cuttings leads to smothering of organisms on the seabed within the cuttings "plume"; if toxic residues from drilling muds are also present, these will exacerbate deleterious effects. Proponents should be required to address feasibility of "zero discharge" of cuttings (either by re-injection or transport to shore) as part of the permitting process for drilling. Some cuttings from water-based drilling muds (WBM) may have to be discharged at the initial seabed entry of exploratory drilling. The acute and sub-lethal toxicity of cuttings and mud should be dealt with during the permitting process, when their nature will be better defined. Produced water may present problems of sub-lethal effects, which should be assessed during the permitting of production operations.

The probability of major spills or blow-outs has been declining over the last two decades of oil extraction and transport. Such an event could still occur in the QCB. Spill trajectory models can be made, with assumptions about the nature of oil produced and the weather and sea-state conditions at the time. The impact of any spill would depend on the relative vulnerability of the local ecosystems, especially at the landfall. The QCB is largely an enclosed coastal basin, so any spill originating within it is likely to be caught up in the internal circulation eddies, until it reaches the shore, probably within a few days. Negative impacts can be expected on mammal, bird, fish and invertebrate populations. These effects may range from subtle sub-lethal effects to large-scale kills, depending on the size and timing of the spill, and the nature and biotic populations of the landfall. Negative economic impacts might include those on the fishing economy, both commercial and sport-fishing, due to loss of accessibility to fishing grounds and reduced marketability of fish, and impacts on tourism through loss of eco-tourism opportunities as a result of real or perceived environmental damage. Persistence of impacts due to slow degradation of spilled oils in gravel beaches or to slow recovery of affected species is a factor in risk assessment.

Assumptions

The identification of science gaps, itemised below, the consequences of not filling them, and the recommendations that follow are premised on the following principles and assumptions.

The precautionary principle. In engineering design and in risk assessments that are carried out as part of the development process, it is assumed that a precautionary approach would be used. The Panel's terms of reference interprets the precautionary principle so: "in the face of scientific uncertainty, it is preferable to err on the side of caution." The degree of caution to be applied would be determined on a case by case basis by quantitative risk assessment, in which the amplitude of the negative impact would be a function of both its immediate effect and its persistence. Our terms of reference also add, "the absence of full scientific certainty shall not be used as a reason to postpone decision-making."

Best practices. Best practices would be employed in all aspects of oil and gas development. These are continually improving and will be advanced further from the present state of the art by the time activities such as oil or gas production are likely to commence in the QCB.

Target safety levels. Oil and gas activities in the QCB must be safe for the people involved and for the wider environment. Safe practice must be regulated. We assume that assessments for the safety of oil and gas activities in the QCB would be carried out using the principles of risk analysis, guided by targets. The targets apply to consequences which entail a great risk to human life or a high potential for environmental damage, as in Canadian Standards Association S471, part of the Code for Offshore Structures. The targets for specific process causes are assumed at a level of 1 in 100,000 per year, and for all causes 1 in 10,000 per year. The ALARP ('as low as reasonably practicable') principle would be used to assist in judging specific processes within the range from 1 in 10,000 (10^{-4}) to 1 in 100,000 (10^{-5}) per year. In assessing safety with regard to human life and the environment, objective-based or goal-setting regulation would be preferable, with prescription where needed. To implement this, the requirements for regulators would be demanding and the expertise of regulator and staff critically important to the standards achieved.

Prime beneficiary pays. Any scientific knowledge required, that would benefit the community significantly by its relevance to issues beyond oil and gas activities alone, should be the responsibility of government. Scientific knowledge required only to benefit the assessment and development of specific oil and gas activities should be the responsibility of the developer. In cases where both benefits accrue, public-private partnership would be appropriate. In all cases, public access to the information collected and deliberations thereon is to be encouraged.

Regulation. It is assumed that a regulatory board would be set up at arm's length from government and industry to ensure safe and environmentally-responsible development, using current best practice.

Activity specific requirements. We assume that approvals for specific activities involved in oil and gas development would require specific conditions, as follows.

Seismic surveys. These would not be permitted in defined protected areas or close to sensitive areas at critical times for valued ecological and economic components (VEECs). Surveys would be carried out subject to common protocols practiced elsewhere (biological observers on survey ships, ramping up of air guns, termination of shooting on encountering VEECs in potentially harmful situations). In addition acoustic propagation modelling would be required for prior assessment of impact on sensitive areas and survey areas would be overflown by biological observers before commencement of surveys and at least once per day thereafter.

Drilling. Drilling would only be permitted after assessment of the impact of contaminants released into the ocean. The Panel notes that 'zero discharge' policies are being practised increasingly for disposal of drilling mud and cuttings in biologically sensitive areas, close to shore, with exceptions made for initial 'spudding' of drill holes in the seabed. We assume that regulation of discharges of mud and cuttings in the QCB would be at least as stringent as those in place for offshore oil and gas activities elsewhere in the world.

Production and transport. We assume that a zero discharge policy would apply with limited exceptions to initial 'spudding in' of drills into the seabed, incidental gas production, and produced water: reinjection, or disposal on land would be standard practice. For both permanent installations (platforms, pipelines) and mobile transporters (tankers), oil spill trajectory modelling would be required and a spill response plan (including all the associated infrastructure) would be put in place, with a requirement of no more than 24 hours delay between spill and on-site remedial action.

Decommissioning. We assume that all production infrastructure would be removed from the sea on cessation of production, and the well plugged, cut off a small distance below the seafloor, and abandoned.

Science gaps identified and consequences of not filling them

In considering the QCB and the oil and gas activities that might be pursued in it, the Panel suggests filling science gaps as follows.

Valued Ecological and Economic Components (VEECs). Species at risk, ecologically important species and harvested species constitute the VEECs of the QCB. These need to be defined as the foci for baseline and monitoring studies. Failure to determine these, could result in critical species not being studied, with risk of unassessed (and therefore unanticipated) impacts from oil and gas development.

High-resolution swath bathymetry is needed, especially for areas of the QCB with high hydrocarbon prospectivity. These data will allow areas of seafloor instability associated with gas seeps, steep slopes and rapid sediment transport to be identified. They are essential in characterizing benthic environments for selection of monitoring sites, and delineation of critical habitat. Without these data, there is potential for unstable foundations for seabed structures, and lack of understanding of the location of particular seabed habitats.

Measurements of currents, winds and waves should be accelerated. In particular, topographic modelling of winds is needed to allow for measurements at wind stations on variable topography on land to be reliably extrapolated to sea; bottom currents and trajectories in summer and winter flow at all depths is needed, for assessments of physical impact on structures; updated wind and wave hindcast models should be run for the same reason; variability of climate change on long time series for winds and currents should be established. These metocean data are needed for structural design, for oil spill trajectory modelling and for modelling dispersion of discharged mus and cuttings. Without these data, consequences of spills and releases would be inadequately resolved, and structures would be built to compensate for greater uncertainty in maximum and sustained loads, with consequences for economic viability of projects. Data collected should be focused on determination of impacts and loads for locations in areas of high hydrocarbon prospectivity.

Earthquake monitoring is needed to determine the temporal variability of stress release, and to establish how the stress release is partitioned among specific fault structures that may be close to oil and gas activities in the QCB. This should be done through installation of an enhanced network of seismographs in the QCB, including strong-motion seismographs, which give much improved data on events of >5.5 or so. The recurrence periods for such magnitudes are decadal or greater, so this is a long-term public-good need that might bring useful results within the time scale of oil and gas activities. All these data will be used to refine earthquake hazard estimates for the QCB, and to identify active faults. Without such data, structures may be designed to compensate, and there would be a greater probability of drilling through an active fault.

Acoustic propagation of seismic survey sources should be modelled for assessment of potential impacts on the behaviour of mammals (especially whales). Behavioural disturbance is itself uncertain because of the wide range of observed responses, but proposals for individual seismic surveys should be required to provide estimates of received sound levels at critical sites and times in the QCB. Without this, there might be behavioural disturbance during calving, migration through restricted channels, and similar events that might impair the viability of some of the smaller vulnerable whale populations.

The space-time distributions of fish that are VEECs is needed to define periods and areas when seismic surveys can be safely carried out, without endangering spawning, migration and populations. Of particular importance might be the inshore distribution of herring, and salmon migration routes.

The major confined spawning areas for critical fish species must be defined, together with the spawning times, so that seismic surveys can be excluded from those areas. While in general it appears that seismic sources kill fewer eggs and larvae than die because of harsh conditions or are preyed upon by other species, spawning areas for critical species should be avoided as a measure to assist in their recovery.

The space-time distributions of those mammals that are VEECs, together with their behaviour patterns should be determined so that critical concentrations at critical times can be avoided by seismic surveys. Recovery of vulnerable populations might be hampered by seismic surveying through nursery areas.

Observers on seismic vessels should log the occurrence and behaviour of diving birds close to active sources. It is unlikely that significant numbers of diving birds are harmed by seismic surveys, but there is little data on this: collecting some would be of value.

Baseline studies of benthic fauna and habitat, including seabed sediment hydrocarbon and other chemical distributions, benthic community structure, and other appropriate indices of environmental stress which have proved useful elsewhere, should be collected to provide a datum to allow the impacts of oil and gas activities to be assessed. Without such data, the attribution of cause of an unwanted event to a specific activity might not be possible.

Oil spill trajectory modelling should be carried out for a wide range of oil types, spill locations within the QCB, and weather and sea conditions. Seasonal variations in weather should be included. This will reveal general patterns for the dispersal of oil that will be of great value in setting up an optimal oil spill response system. Without such modelling, oil spill response will be less effective.

Defining the impact of oil spills on their landfalls should be derived from knowledge of shoreline types, from sources such as the BC Government Coastal Resource Inventory program and products derived from those data. Without this information, oil spill response might be less optimally designed.

Seasonal variations in species populations along shorelines is needed for assessment of the vulnerability of biota to an oil spill. Without these data, the priority assigned to, and nature of, oil spill response for different parts of an impacted coastline could not be made.

In meeting the requirements of the terms of reference regarding exclusion zones, the Panel suggests the following actions be pursued.

Marine Protected Areas in the QCB. There is a collective responsibility to identify the most suitable candidate areas and legislate their protection. This should be a high priority for the appropriate stakeholders. The Panel recommends that the natural resource potential—both of renewable and non-renewable resources—be considered as a factor in the choice of such areas. If this is not done, the uncertainties of when and how it might be done will mean continuing threats to species at risk and prove frustrating for those contributing to economic activity.

Critical species close to shore. For specific seismic surveys that are intended to approach close to the shoreline (within 1 km of the 20 m isobath), it should be required that the proponent establish the nature and distribution of biota (especially VEECs) within 1 km of the intended ship's track, in order to provide information for regulators to assess the safety of such surveys for those biota. This would allow for lifting of the suggested restriction made by the Panel (to exclude seismic within 1 km of the 20 m isobath) for areas that pass the test. Not allowing this might prevent discovery of potential prospects , near-shore that could be drilled from land.

Areas of critical habitat should be defined clearly by those stakeholders mandated to carry out the demands of the Species at Risk Act, so that seismic surveys can be excluded from them. Not to do so would further endanger the species for which those habitats are critical.

20 km coastal zone buffer for drilling Oil spill trajectory modelling for various possible scenarios has been proposed. The results should be used, with modelling carried out for specific oil and gas activities, to establish coastal zone buffers of such size that oil spill response would be activated before oil from a spill makes landfall. These buffers might be greater or smaller than 20 km, depending on location and specifics of plans for response. Until these analyses are available, the present 20 km buffer zone should be maintained.

The regional data needed cannot necessarily be collected quickly. In some instances, long time series are required to assess temporal variations of the natural system prior to commencement of oil and gas activities. Given the 15 years required to reach oil or gas production, and the knowledge that some parts of the natural systems are subject to decadal variability (the climate system especially), it is urgent to start measurement as soon as is practicable. This means that there should be overlap in time in the acquisition of science knowledge required for different oil and gas activities.

All the science gaps above need to be filled, but early priority should be given to the following baseline studies, which establish an observational datum now, before oil and gas activities start, and monitoring studies (in which long time series are needed).

Recommendations and conclusion

Based on the science gaps noted above and consideration of how to approach the science requirements in a coordinated way, where possible, the Panel offers the following recommendations and conclusions.

Recommendation 1: Advisory body

It is recommended that, at the earliest possible opportunity, an advisory body be formed of stakeholders from government (including those of First Nations), the oil and gas industry, other industries active or potentially active in the QCB, community leaders, environmental NGOs, and other relevant groups. *The Panel notes that such bodies in mature oil basins like Cook Inlet, Alaska, similar in many respects to the Queen Charlotte Basin, have been very effective in channelling concerns, organising monitoring programs, and in liaising with industry. The body would advise government, industry and regulators on matters and concerns related to oil and gas projects and requirements for safe practice.*

Recommendation 2: Baseline studies

The Panel recommends that collection of the following baseline data begin as soon as possible. These data are deemed necessary either to characterize baseline conditions (i.e., prior to any oil and gas development), or are considered vital to enabling the implementation of best practice at subsequent stages of development. Where appropriate, the value of these data in a context of change should be enhanced by incorporation of historical data, including traditional ecological knowledge.

- ***Characterization of the spatial and temporal distribution of ecologically important, sensitive and harvested species in the QCB:*** *The logical place to start would be with those species already listed by COSEWIC as endangered, threatened, or of special concern (in keeping with legislation under the Species at Risk Act), as well as species that are of ecological importance, but about which little is known (e.g., sand lance), and important harvested species.*
- ***Swath bathymetric mapping:*** *Necessary to identify areas of seafloor instability associated with gas seeps, steep slopes and rapid sediment transport. Also essential in characterizing benthic environments for selection of representative monitoring sites, delineation of critical habitat and the establishment of representative MPAs.*
- ***Measurement of near bottom currents:*** *These data are required to model environmental forces, sediment movement and the transport of water based drilling muds and cuttings during exploratory drilling.*
- ***Baseline studies of benthic fauna and habitat, including seabed sediment hydrocarbon and other chemical distributions, benthic community structure, and other appropriate indices of environmental stress which have proved useful elsewhere:*** *These data allow the impacts of oil and gas activities to be assessed.*
- ***Drifter studies of winter surface currents, and spill trajectory modelling:*** *These data are essential for extreme and operational modelling and for estimating oil spill trajectories.*
- ***Topographic modelling of winds:*** *These are needed so that site-specific estimates can be obtained of wind conditions at sea based on long-term observations of shore-based winds.*
- ***Strong motion seismograph measurements:*** *These data are needed to better characterize the ground motions associated with large earthquakes.*

- ***Reintroduce a network of seismographs around the basin:*** *These are needed to resolve better earthquake foci and determine the location and motion of active faults.*

Recommendation 3: Monitoring studies

The Panel recommends that chemical and biological monitoring studies (based on accepted best practices in other jurisdictions) should commence (or continue) as soon as possible at each of the following groups of sites:

- ***Potential and past drill sites:*** *Sites representative of locations where drilling has taken place in the past or is likely to take place in the future (to allow detection of changes caused by drilling activities).*
- ***Control (or reference) sites:*** *Chosen to be representative of locations where drilling is unlikely to occur (to allow detection of trends caused by natural factors or factors unrelated to oil and gas activities), and should include revisiting sites that have been sampled in the past to extend the time frame of analysis.*

Recommendation 4: Protected areas

The Panel recommends the following actions with respect to protected areas:

- ***In light of their unique nature, the sponge reefs in the QCB be officially designated as Marine Protected Areas (MPAs) as soon as possible.*** *These MPAs should be protected from all fishing and drilling activity, and be surrounded by an appropriate buffer zone. Because of the depth of water above the reefs, it is unlikely that there will be any impact on the sponges from the kinds of seismic survey described in this report.*
- ***Concerted action be taken by government (with assistance from other stakeholders) to determine the areas that should be protected in the QCB, the level of protection to be enforced, and to pass the enabling legislation.*** *In determining the areas to be protected, it would be appropriate to consider the potential for development of all the natural resources of the basin, renewable (fish, shellfish, etc.) and non-renewable (oil, gas, minerals).*

Recommendation 5: Other exclusion zones

The Panel recommends that

- ***The coastal exclusion zone for drilling be maintained at 20 km, until such time as more site-specific restrictions can be justified, for which improved knowledge of oil spill trajectories and shoreline vulnerability will be required; and***
- ***Seismic surveys should be prohibited from waters less than 20 m in depth, from any area within 1 km of the 20 m isobath, and from all areas deemed as critical habitat for species listed by COSEWIC as endangered, threatened or of special concern, and during periods when these species are most vulnerable (e.g., during migrations, spawning, etc).*** *As improved knowledge is acquired on the space-time distribution and activities of critical species in the QCB, and on the impacts of seismic survey on biota, the general restrictions should be replaced by more site- and time-specific restrictions.*

Conclusions regarding the moratoria on oil and gas activities

The moratoria were put in place because of concerns that oil and gas activities, including tanker traffic transiting through the area, would unduly endanger the environmental health of the region. The Panel has reviewed all the oil and gas activities that might ensue in the QCB, were development to proceed. It has also considered the effects of evolving practices by industry and of the increasingly stringent technical demands of regulation, in jurisdictions covering offshore U.S, the North Sea, and eastern Canada.

With implementation of the recommendations made above, and the assumptions on which they are based, all the safeguards will be in place, when they are needed, to ensure that assessments of risk of oil and gas activities to human life and the environment in the QCB are adequate. Such assessments would be undertaken by those most knowledgeable of the particular activities, of their impacts and of the consequences for those impacted. The assessments would involve public participation. Given all this, the significance of the moratoria to this discussion of science issues is reduced to their inhibiting the generation of relevant new knowledge. Our principal conclusions follow.

Conclusion 1

Provided an adequate regulatory regime is put in place, there are no science gaps that need to be filled before lifting the moratoria on oil and gas development.

It is extremely important to recognize that this does not mean that science gaps do not exist (we have outlined many). Nor should it be taken to mean that the Panel is recommending that development be allowed to begin immediately. What it does mean is that, if the moratoria were lifted, regulation would be in place to ensure that these critical science gaps would be filled before development of an oil and gas industry in the QCB. We also note that lifting the moratoria would enhance the opportunities for filling many of the science gaps, through shared-cost partnerships involving industry participation.

Conclusion 2

The present restriction on tanker traffic in transit along the West Coast of North America from entering the coastal zone should be maintained for the time being.

The current moratoria are intended to restrict tankers in transit along the West coast of North America from entering the coastal zone. Even with the improved record of spills in territorial waters off North America over the last 10 years, there is no imperative to relax this restriction. Detailed risk analysis in future may indicate sufficiently low risk of spillage that the restriction might then be relaxed.

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We are especially grateful to presenters (see Appendix II) for their contributions to the workshops and for their continuing advice during the preparation of this report; to participants in the workshops; and to those, in addition to presenters, who submitted briefs (listed in Appendix III). Reviewers of drafts of the report are thanked for their valuable advice.

CHAPTER 1

INTRODUCTION

1.1 Overview

The Government of British Columbia (BC) has asked the Government of Canada to consider lifting the federal moratorium on oil and gas activities offshore of BC. In response, the Government of Canada is proceeding with a review to:
(a) identify science gaps related to possible oil and gas activity offshore BC;
(b) hear the views of the public regarding whether or not the federal moratorium should be lifted for selected areas; and
(c) consult with First Nations to ensure that issues of unique interest to First Nations are fully explored.

Part (a) of this three-stage process is the science review reported herein. It is being conducted, at the invitation of the Minister of Natural Resources Canada (NRCan), at arm's length from government, by an Expert Panel appointed by the Royal Society of Canada. This report is the product of the science review and will feed into parts (b) and (c) of the federal decision-making process.

Only that area of the Hecate Strait and Queen Charlotte Sound (Figure 1.1) regarded as having high oil and gas resource potential is under current consideration by the Minister, and by the Expert Panel.

The Queen Charlotte region is one of great beauty, much admired and revered by the population in the area. It is part of the "jade coast" (Butler, 2003), so called because of the beautiful jade-green hue of the waters. It comprises an ecosystem rich in variety, with interlinked biological communities producing fish and wildlife appreciated and used for food and recreation by humans. Any offshore activities in the region must recognize the concerns felt by the people living in the area.

1.2 Historical background

Exploration for oil and gas below the seabed offshore BC began around 1958. Seismic surveys led to the drilling of a number of wells in the late 1960s, including eight in the seas of the Hecate Strait and Queen Charlotte Sound. The Government of BC imposed a moratorium on offshore exploration drilling during 1959-1966. In 1972 the Government of Canada imposed a moratorium on crude oil tanker traffic through Dixon Entrance, Hecate Strait and Queen Charlotte Sound (Figure 1.1) due to concerns over potential environmental impacts. The moratorium was subsequently extended to include all oil and gas activities. This was followed in 1981 by a similar prohibition by the Government of British Columbia. The Panel notes that the moratoria apply only to commercial activities: seabed geological exploration and regional seismic studies by academic and government researchers have continued (subject to formal permitting).

A review conducted jointly during 1984-1986 by the two governments, through the West Coast Offshore Exploration Environmental Assessment Panel, resulted in a report (WCOEEAP, 1986) containing 92 terms, conditions and recommendations to be applied to any resumption of offshore oil and gas activities. However, as a result of the Exxon Valdez oil spill in Prince William Sound, Alaska, both governments decided to continue the moratoria.

The Government of BC recently commissioned several studies to assess the potential impacts of offshore oil and gas activities. Two environmental reviews—one by AGRA Earth and Environmental Limited (AGRA1998), the other by Jacques Whitford Environment Limited (JWEL, 2001)—were followed by a science review (Strong et al., 2002) which concluded "There is no inherent or fundamental inadequacy of the science or technology, properly applied in an appropriate regulatory framework, to justify retention of the B.C. moratorium" although "there would be several important things that would need to be done before there could be any expectation of investor interest, public or private, in proposals for exploration and development work in the BC offshore."

The Government of BC provided copies of these studies to the Government of Canada and requested that the Government of Canada consider lifting the moratorium.

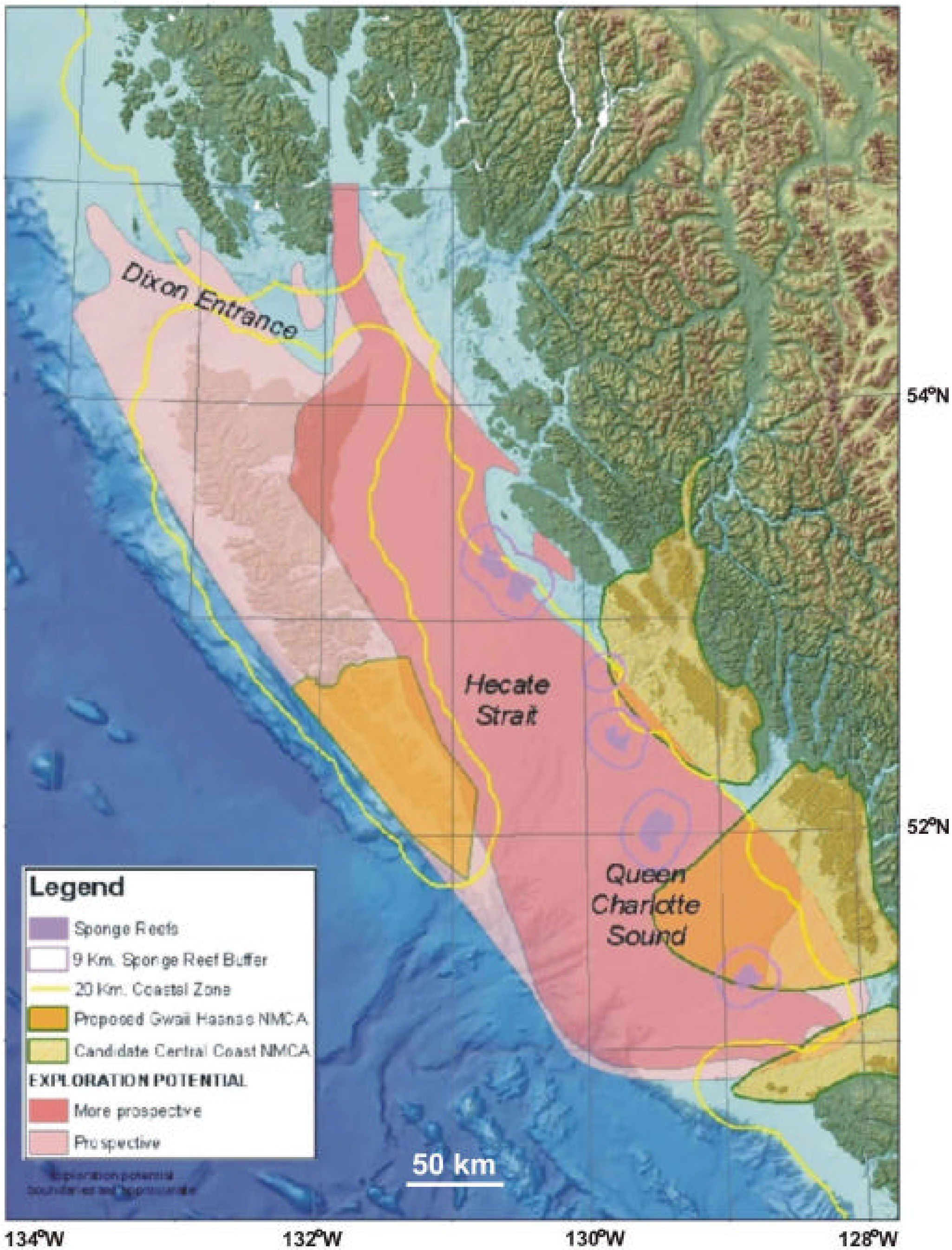


Figure 1.1. Area for consideration in this review, from terms of reference (see Appendix I)

1.3 Terms of reference

The complete terms of reference for the review are presented in Appendix I. The overall context is defined and the specific terms for the science component of the three-part review process are stated in paragraph 3.1 of Appendix I. The terms explain the Science Review Panel's responsibility "for conducting a series of science workshops, evaluating information presented therein, and preparing a summary report," that also draws on "previously conducted reviews in B.C. and relevant experiences from other Canadian and international jurisdictions." The report will be submitted to the Minister, the Public Review Panel and also to the general public before the Public Hearings and First Nations Consultations.

The science review panel was responsible for defining the scope of the workshops, inviting participants and facilitating the discussions. Qualified experts from governments, First Nations (to ensure that traditional knowledge is considered in the science review), industry, universities and advocacy groups, were invited to identify any science gaps which may need to be filled. The focus was not only on the identification of gaps which may need to be filled before a decision is made with regard to the moratorium, but also on the provision of a path forward on the science requirements which would precede, or be concurrent with, any exploration or development activity. The panel was also asked to identify who should be responsible for the filling identified gaps, whether it be government or industry. The risks associated with not filling a science gap were to be evaluated.

Sensitive environments identified by government departments, as well as previously recommended exclusion zones, were to be evaluated. The work should be guided by the precautionary principle and any additional areas requiring special management measures were to be identified in the event of a decision to lift the moratorium.

The Expert Panel has fulfilled these requirements and expects, as stated in the Terms of Reference, that "the report will focus the discussion of science related matters during Phase 2 of the review."

1.4 Precautionary principle

It has become accepted practice to use the 'precautionary principle' in assessment of the impacts of potential future activities. The precautionary approach defined in our terms of reference states "in the face of scientific uncertainty, it is preferable to err on the side of caution;" also "the absence of full scientific certainty shall not be used as a reason to postpone decision-making." This was used as guidance in conducting the present investigation. The spirit of the principle was expressed by Saunders (2000) as follows: "if one is embarking on something new, one should think very carefully about whether it is safe or not, and should not go ahead until reasonably convinced it is."

1.5 Review process

The Expert Panel (hereinafter referred to as "the Panel") broadened its consultations beyond the requirements of the terms of reference. In particular, the workshops were open to all interested parties. Two workshops were held in Vancouver, on 15-17 October 2003 and 28-30 October 2003. The first workshop dealt with the physical environment of the Queen Charlotte Basin (QCB), current industry practice and the generic impacts of such activities on biota. The second workshop dealt with the specific ecosystem of the QCB, its various components - the air-sea interface, the water column, the seabed interface and the coastal zone - and the impacts of potential oil and gas activities on them. A third workshop was held in Prince Rupert on 31 October 2003. The program followed during the workshops is appended (Appendix II). The workshops were attended by 70–100 people every day.

During the first workshop, the Panel asked industry experts to illustrate current industry practice in other operational areas where they face similar challenges to those presented by the QCB. The Panel made it clear that, wherever possible, the discussion of impacts should be subject to quantitative risk assessment. Any activity is subject to risk. Some risks are so improbable that they are usually disregarded, while others are more likely and actions are taken to avoid them, or to mitigate their effects. By quantifying risk, we can establish reasonable bases for decisions on activity and on priorities for refining estimations of risk. Simply listing all the risks an activity incurs offers no assistance to those making decisions and to those, such as the residents of the region of the QCB, whose advice is being sought by decision makers. The Panel intends to inform the public consultation processes that follow with some quantitative basis for weighing the potential rewards of oil and gas exploration against the challenges of operating in the QCB.

The first workshop also included some discussion of regulatory regimes. The Panel has to make assumptions about the regime that might be in place, so that it can make judgements about safety. This then allows the Panel to discriminate between those science gaps that should be filled before a decision is taken on the lifting of the moratorium from those science gaps that can adequately be filled later.

During both the first two workshops, the Panel asked presenters to inform us about new scientific studies and the future direction of ongoing scientific studies, so that the Panel would be aware of them in forming conclusions on science gaps.

The third workshop, in Prince Rupert, enabled us to hear the views of QCB residents about oil and gas activities. The Panel was also able to hear about residents' aspirations for future economic development involving the marine area, so that the Panel could evaluate the potential impacts of oil and gas activities on them.

Many topics were discussed during the workshops: each topic could have been the subject of its own workshop. The Panel requested presentations from key scientists with expertise in each of the specific topics and familiarity with the published literature and industry practice. All those interested, whether present at the workshops or unable to attend, were invited to submit written briefs by 14 November 2003. This modus operandi provided an opportunity for many to contribute material to the Panel for consideration in preparing this report. Some 90 presentations were made during the workshops; written briefs were received from virtually all the presenters; written briefs or reports were received from an additional 40 people, and the Panel accessed another 20 recent reports or communications not referenced in the text.

In assimilating the material presented and available in the literature, the Panel consulted with a number of scientists to assist with interpretations of data as we compiled our report.

1.6 Structure of report

Following this introduction, the report sets out the background to the hydrocarbon resource of the QCB to provide information on likely rewards from oil and gas activities. Then, the various phases of oil and gas activity are described that are typical of the discovery, evaluation, and production of hydrocarbons, including decommissioning. In order to provide a framework for decision making, there is a discussion of quantitative risk assessment, followed by a description of regulation and environmental assessment. Then, the physical and biological environments of the QCB are described and other uses of the marine area, current and potential, are explained. The impact of the physical environment on engineering design for safe operation and the environmental impacts of oil and gas activities on the QCB are then discussed, with summaries of the science gaps that should be filled. The status of protected areas is described and their relationship with oil and gas activities explained, together with a discussion of zones from which oil and gas activities should be excluded. After descriptions of the impact of oil and gas activities in an analogous basin (Cook Inlet in Alaska), we conclude the report with sections summarizing our recommendations for science gaps, and when and how they should be filled, leading to important baseline and monitoring studies, and recommendations regarding conservation areas.

Of particular value in the reading of this report, and strongly recommended for reference alongside it, are the reports listed at the end of the chapter.

1.7 The future

This report will be submitted to the Minister of Natural Resources Canada. It will then be made available to the public review panel and to the public. These public consultations are likely to commence within a couple of months of the publication of this report, allowing time for analysis of its content. Consequently, the public will have ample opportunity to discuss the content and recommendations of this report, over several months, before and during the public consultations. The federal government has also confirmed its intention to conduct separate consultations with First Nations.

The Expert Panel considers the following time line to be tight and realistic, provided land claims issues and ownership of offshore resources are settled within two years, and significant discoveries are made within a year of initial drilling. The timeline is adapted from a workshop suggestion by A. Hudec, but with additional time allowed for land claims settlements, which industry will likely require before any new exploration takes place in the Basin.

2004-2007	Establish regulatory regime; strategic environmental assessment; land claims issues settled
2007-2008	Environmental impact assessment for exploration (seismic surveys) and response
2008-2009	Initial 2D seismic surveys
2010-2011	3D seismic surveys on hydrocarbon prospects
2011-2012	Environmental impact assessment (drilling) and response
2012-2014	Exploration drilling
2013-2015	Delineation drilling
2014-2016	Environmental impact assessment (production) and response
2016-2019	Development planning; approvals; construction starts
2020	Production

Some might consider this time frame to be short, by comparison with developments elsewhere. In the Jeanne d'Arc Basin, offshore Newfoundland, two fields are producing and another is being developed now. The Hibernia field was discovered in 1979, and produced oil first in late 1997. The Terra Nova and White Rose fields were both discovered in 1984. Terra Nova produced oil for the first time in 2002; White Rose is expected to produce first oil in late 2005. In these cases, 18-20 years elapsed between discovery and first production. It took 11 years from the time of the Hibernia discovery to production. If it is assumed that the equivalent approval time for a field in the QCB were to be only three years, then the time from discovery to production could be reduced to eight years, especially if major production units (such as FPSOs - Floating, Production, Storage and Offloading vessels) can be adapted from the existing fleet.

It is important to note some issues with respect to the time frame suggested. Firstly, there are assumptions that the regulatory regime would be broadly similar to those on Canada's east coast (CNOPB, CNSOPB), thus requiring various environmental impact assessments and follow-up as pre-conditions to new phases of activity (we discuss this further in sections 3.8-3.11). Secondly, each step involves 'go, no-go' decisions, both by industry (mainly for economic considerations) and regulator (as required by CEAA and related legislation). There is no certainty that, once embarked on this path, oil will be produced from the Basin. Thirdly, and most importantly from the perspective of environmental protection, there are several years available for baseline environmental studies (at the decadal scale for some topics), for informed discussions about risk-reduction technologies, for assessment of species movements and for technological development before oil is produced. However, this should not be regarded as an excuse to postpone the acquisition of baseline data; experience elsewhere has shown the longer a time-series of baseline data is, the more valuable it becomes. Finally, we note that there will be less time available for such discussions with regard to initial exploration, so, as we discuss later, early efforts would be required to estimate impacts of, for example, seismic surveys.

In considering the review process to which the Panel is contributing, it is worth bearing the time frame in mind. There is adequate time to assess all known issues in depth and it is in everyone's interests to ensure this is so.

1.8 Recommended reports

The following reports complement this one and are strongly recommended for reading alongside it, since they provide valuable detail in particular respects.

The following four are directly about oil and gas activities offshore BC.

The "Strong Report" (Strong et al., 2002)
http://www.offshoreoilandgas.gov.bc.ca/reports/scientific-review-panel/

The "JWEL Report" (Jacques Whitford Environment Limited, 2001; hereinafter referred to as JWEL, 2001)
http://www.offshoreoilandgas.gov.bc.ca/reports/jwl-report/

The "AGRA Report" (AGRA Earth and Environmental Limited, 1998; hereinafter referred to as AGRA, 1998)
http://www.offshoreoilandgas.gov.bc.ca/reports/AGRA-Report/AGRA1998.doc/

The "1986 Assessment Report" (West Coast Offshore Exploration Environmental Assessment Panel, 1986; hereinafter referred to as WCOEEAP, 1986)
http://www.offshoreoilandgas.gov.bc.ca/reports/environmental-assessment/default.htm

Five reports regarding oil and gas activities and impacts on biota in the QCB are:

An overview of marine environmental research pertaining to west coast offshore oil and gas development (Bancroft et al., 2003).

Modelling oceanic fates of oil, drilling muds and produced water from the offshore oil and gas industry, with application to the Queen Charlotte Basin (Crawford et al., 2002).
http://www.dfo-mpo.gc.ca/csas/Csas/English/Research_Years/2002/2002_120e.htm

Physical oceanographic and geological setting of a possible offshore oil ad gas industry in the Queen Charlotte Basin (Cretney, Crawford, et al., 2002).
http://www.dfo-mpo.gc.ca/csas/Csas/English/Research_Years/2002/2002_004e.htm

Biogeochemical benchmarks for source identification of contaminants from an offshore oil and gas industry (Cretney et al., 2002).
http://www.dfo-mpo.gc.ca/csas/Csas/English/Research_Years/2002/2002_129_e.htm

Hexactinellid sponge reefs: areas of interest as Marine Protected Areas in the North and Central Coast areas (Jamieson and Chew, 2002).
http://www.dfo-mpo.gc.ca/csas/Csas/English/Research_Years/2002/2002_122e.htm

Readers will also find several reports written for the offshore petroleum boards of Newfoundland and Nova Scotia to be very valuable in offering reviews of various relevant issues. Again, these are readily available on the internet. They include:

Environmental assessment of seismic exploration on the Scotian shelf (Davis et al, 1998)
http://www.cnsopb.ns.ca/Environment/shelf.pdf

Environmental assessment of exploration drilling off Nova Scotia (LGL Ltd, S.L. Ross Environmental Resources Ltd. and Coastal Ocean Associates, 2000; hereinafter referred to as LGL et al., 2000)
http://www.cnsopb.ns.ca/Environment/drilling.pdf

Strategic environmental assessment, Laurentian Subbasin (Jacques Whitford Environment Ltd., 2003; hereinafter referred to as JWEL, 2003)
http://www.cnsopb.ns.ca/Environment/SEA2004.html

Orphan Basin strategic environmental assessment (LGL Ltd., 2003)
http://www.cnopb.nfnet.com/newsr/2003nr/sa767sea.pdf

Strategic environmental assessment of potential exploration rights issuance for Eastern Sable Island Bank, Western Banquereau Bank, the Gully Trough and the Eastern Scotian Shelf (Canada/Nova Scotia Offshore Petroleum Board, June 2003, hereinafter referred to as CNSOPB, 2003
http://www.cnsopb.ns.ca/Environment/GullySEAJune03.pdf

CHAPTER 2

OIL AND GAS RESOURCES AND ACTIVITIES

2.1 Overview

Decisions on the moratoria need to be informed by both the potential value of hydrocarbons in the Queen Charlotte Basin (QCB), and by the impact of oil and gas activities. This chapter provides background on the geology and hydrocarbon prospectivity of the basin. It then outlines the various activities associated with hydrocarbon exploration, production, transport, refining and decommissioning. Subsequent chapters discuss the impacts of those activities.

2.2 The geological context of the Queen Charlotte Basin

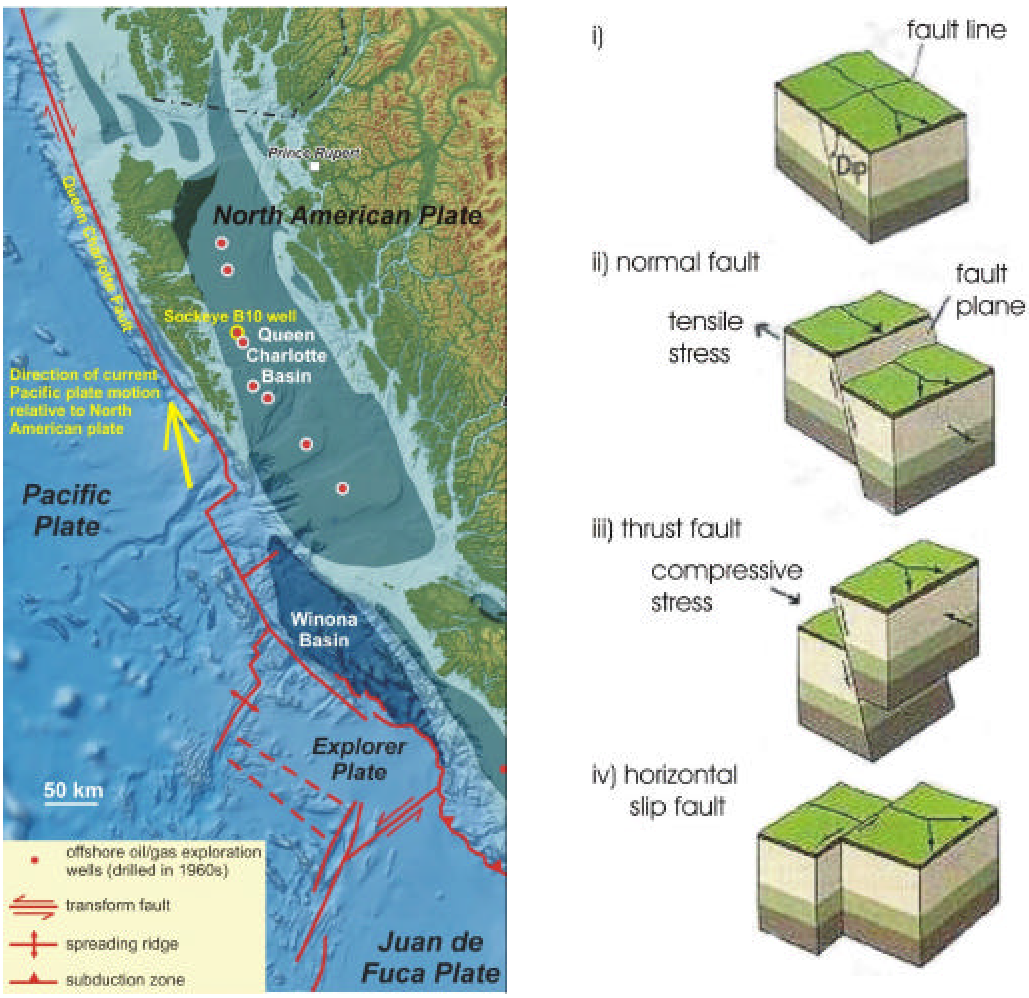
Knowledge of the geology of the QCB aids estimation of the basin's hydrocarbon prospectivity and also helps understanding the potential hazards to oil and gas activities from earthquakes and sediment movement on the seabed.

A detailed guide to the geological history of the QCB is provided by Woodsworth (1991), while the petroleum potential has been reviewed recently by Hannigan et al. (2001). The regional setting of the QCB, close to plate margins, is outlined in Hyndman and Hamilton (1993) and Rohr et al., (2000). Whiticar (in Strong et al., 2002) reviews the salient points of the hydrocarbon prospectivity of the area.

Earth's active geology is concentrated along the edges of a few large plates -- rigid shells that may be thousands of kilometres across but only around 200 km thick -- that move around the Earth's surface at a few centimetres per year, driven by slow convection currents in the mantle deep below. Most of the world's volcanoes and earthquakes occur along plate edges, as manifestations of continual plate motions. The QCB lies close to the edge of the continental North American plate where it collides with the oceanic Pacific plate (Figure 2.1a). The plate boundary lies at the foot of the continental slope a few tens of kilometres west of Vancouver Island and the Queen Charlotte Islands where the Pacific plate is forced down below the continental margin. The plate boundary is a fault dipping landward (Figure 2.1b, part (iii)), along which the North American plate overrides the downgoing Pacific plate. When the Pacific plate has descended deep enough—around 150 km—it starts to melt, causing the volcanism that built the Coast Mountain ranges of BC. The volcanic mountains are eroded as they build, the eroded sediment is transported to the ocean and is deposited in the QCB.

Until about 43 million years ago, this plate convergence and the related volcanism continued and the QCB filled with eroded sediments, including those of Cretaceous age with hydrocarbon potential (Figures 2.2, 2.3). Then the relative motion of the two plates changed from convergence to horizontal slip, like that which occurs along the San Andreas Fault. Standing on one side of the plate boundary fault and looking across it, the other side moves to the right (right-handed, or dextral, motion). Accompanying this horizontal motion, there was firstly minor separation (extension) until around 20 million years ago and then, since 5 million years ago, convergence (Hyndman and Hamilton, 1993; Rohr et al., 2000). The horizontal and extensional or compressional motions took place along different faults. In this locality, the Queen Charlotte Fault (Figure 2.1a), lying immediately west of the Queen Charlotte Islands, is a horizontal shear fault in the overriding North American plate. It is Canada's most dangerous fault in terms of past earthquake magnitudes (e.g., magnitude 8.1, in 1949).

Not all the relative plate motion occurred on the two faults. The soft upper edge of the North American plate in the QCB also deformed (Rohr et al., 2000). The episode of extension, accompanied by volcanic activity, affected the QCB with blocks of crust dropped down—rifted—to create new, deep basins that filled with sediment. These younger basins contain most of the hydrocarbon potential of the QCB. During subsequent convergence, folding and horizontal shear faulting affected the QCB. The overall result is a modern QCB with older (Cretaceous) basins, formed during plate convergence, and later (Miocene) rift basins, all cut by young (Pliocene to modern) horizontal shear faults and folds. These faults do not involve purely horizontal displacements (Figure 2.1b, part (iv)); there are relatively minor vertical displacements across them that change rapidly in size along them. Consequently, narrow sedimentary basins form between pairs of these faults, which trend approximately parallel to the plate margin and the main Queen Charlotte Fault. Examples of seismic cross-sections illustrating the basins and the geological structures that form in them are given in Figure 2.2.



(a) (b)

Figure 2.1. (a) Map of Queen Charlotte Basin showing plates, basin location, and offshore exploration wells. Yellow arrow shows oblique convergence of Pacific and N. American plates. This results in horizontal (right-handed) slip along Queen Charlotte Fault, and folding and thrust faulting in the Basin. Redrawn from P. Hannigan, J. Dietrich and K. Osadetz (2003, peronal communication, workshop presentation). (b) Cartoon showing kinds of fault movement (including those that occur along plate boundaries). Redrawn from Lithgow-Bertelloni (2004).

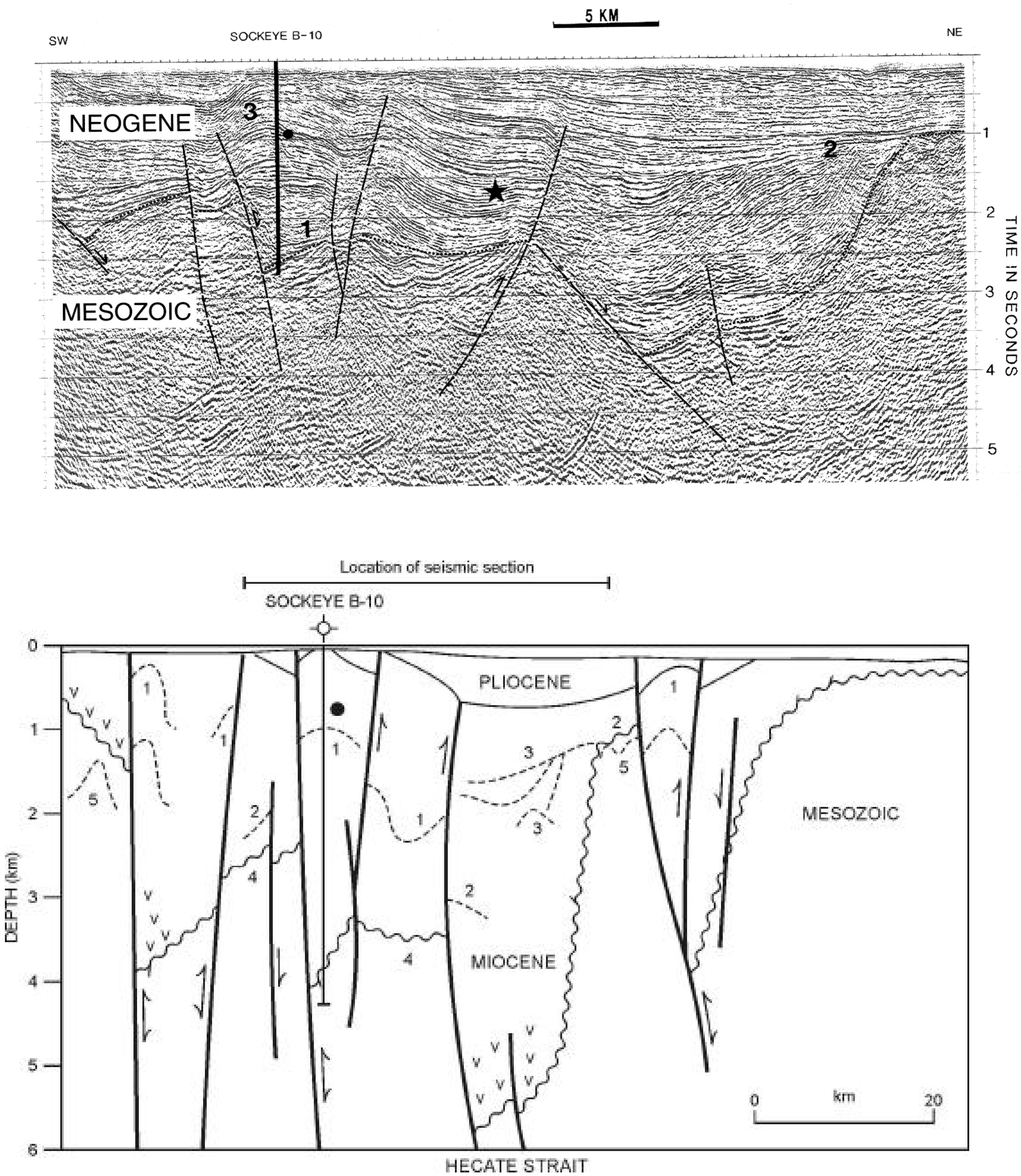


Figure 2.2. Interpreted seismic profile and line drawing from the Queen Charlotte Basin (adapted from Hannigan et al., 2001, Figures 6, 9). Seismic reflection profile shows rifted blocks of the basin with extensional faulting (1), a Tertiary unconformity (2) and late compressional faults and folds (3). An oil show was found in the Sockeye B-10 well at the position of the black, filled circle; the star locates interpreted direct hydrocarbon indicators. On the line drawing, the numbers indicate the variety of different oil and gas plays. Tertiary volcanic rocks shown by v symbol. Reproduced with the permission of the Minister of Public Works and Government Services Canada, 2004 and Courtesy of Natural Resources Canada, Geological Survey of Canada.

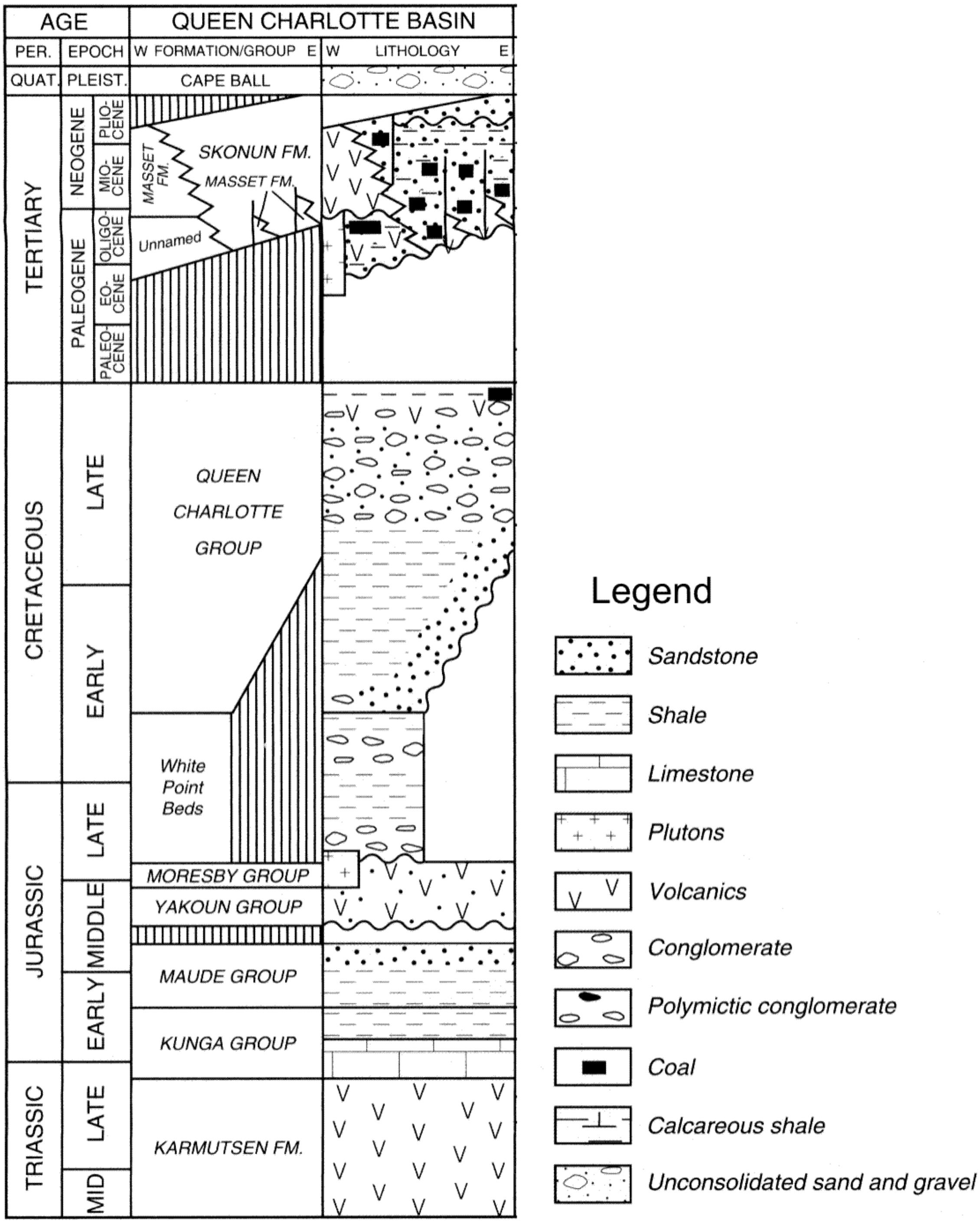


Figure 2.3. Seismic stratigraphy of the Queen Charlotte Basin (redrawn from Hannigan et al., 2001, Figure 8). Marine strata of Triassic-Jurassic age (Kunga and Maude Groups) and coals in late Cretaceous and Tertiary (Skonun) Formation are likely source rocks. Good reservoir rocks include Cretaceous and Tertiary sediments.Reproduced with the permission of the Minister of Public Works and Government Services Canada, 2004 and Courtesy of Natural Resources Canada, Geological Survey of Canada

2.3 Hydrocarbon resources of the Queen Charlotte Basin

There is a variety of oil seeps on the Queen Charlotte Islands (Hamilton and Cameron, 1989), and known gas seeps offshore (Barrie, 1988). This confirms that at least some of the factors necessary for hydrocarbon formation are present.

Four linked elements are required to provide an economic hydrocarbon reservoir in rocks below ground. Firstly, there must be a source rock that contains organic remains capable of being transformed into hydrocarbons. Secondly, the source rock must be buried deep enough, and for long enough that the organic remains become 'cooked' to produce oil or natural gas. Thirdly, as the hydrocarbons become squeezed out of the source rock by the weight of overlying rock, there must be a porous, permeable reservoir rock into which the hydrocarbons can flow, as they rise gravitationally through the water that occupies most pore space in rock. Fourthly, the hydrocarbons must be trapped below impermeable rock that prevents the hydrocarbons from escaping to the ground surface or seabed.

The oil and gas potential of the QCB has been modelled by Hannigan et al., (2001) based on existing well data, land outcrops, and a sparse grid of publicly available seismic reflection profiles (Rohr and Dietrich, 1992). Whiticar (in Strong et al., 2002; and 2003, personal communication, workshop presentation) has provided insightful interpretation of hydrocarbon generation from the source rocks in the QCB.

Particular combinations of geological structural, lithology and history that provide attractive probability of hydrocarbon deposits are described as 'plays.' The QCB has several 'plays.' Figure 2.2 shows a seismic profile and a geological cross section illustrating plays and the traps associated with them. Figure 2.3 shows a stratigraphic column of the QCB with various source and reservoir rocks identified. There are two important kinds of source rock: those that contain remains of land plants and those that include remains of marine animals (especially plankton). Plant remains cooked long enough in the deep Earth produce coal, in addition to large amounts of gas, particularly methane. Very little oil is generated from this source rock. Marine sedimentary source rock, rich in remains of plankton and algae, will first produce oil and a little gas as temperature rises at depth. At higher temperatures, more gas is produced until virtually all organic material is converted to gas with no residual oil. Source rock depths and temperatures vary from place to place because of geological structure and the local temperature history. Oil might be formed at one locality, while from the same rocks only a few tens of kilometres away, only gas might be produced. While the sedimentary, structural and thermal complexity of the QCB makes for a variety of possibilities for oil and gas production, predicting which play will operate where is difficult.

Source rocks are found in several geological formations in the QCB (Figure 2.3). The richest source rocks are limestones and shales of Triassic to Jurassic age that predate the plate tectonic processes defined above. These rocks have good potential for oil but their distribution across the QCB is patchy because of later uplift and erosion. There are some gas-prone source rocks in the late-Jurassic to Cretaceous sediments. Known coals in the Tertiary strata, strongly developed in the northern half of the basin, are indicative of fairly good gas potential. There is some minor marine oil-prone source rock of this age also.

The thermal history of source rocks determines if, and when, oil and gas were formed. It also helps establish if there were traps to catch the oil or gas when it was formed or whether the hydrocarbons broke surface and were dissipated. The maximum temperature to which rocks have been heated can be estimated by microscopic examination of the colour of organic material. In two adjacent wells in the QCB (Sockeye B-10 and E-66, about 12 km to the south, Figure 2.1), temperature estimates indicate that oil generation operates today at depths between 2.0 and 3.8 km (the oil 'window'). The Jurassic source rocks lie at quite different depths in the two wells, so that in one well they lie partly in the present-day oil window, while in the other they are deeper than the gas window and are described as 'over-mature.' In the latter case, those particular source rocks entered the oil window in the Jurassic (about 180 million years ago), whereas in the first well, they only entered the oil window in the Miocene (20 million years ago). In the intervening time, new geological structures formed that would be available to trap the younger generation of oil but not the older.

Potential oil and gas reservoirs occur in Cretaceous sandstones and in Miocene and Pliocene sandstones and conglomerates. The Miocene play involves traps caused by the folding that accompanies faulting during rifting, while the Pliocene play relies on folding associated with the horizontal shear faulting (Figure 2.2).

The principal conclusion from the analyses of Hannigan et al. (2001) and Whiticar (2003, personal communication, workshop presentation) is that the highest hydrocarbon prospectivity exists in a strip of ground running NW-SE, parallel to the plate margin and major faults in the area, from the SE coast of Graham Island down Hecate Strait to the middle of the Queen Charlotte Sound (Figure 1.1). The wells drilled by Shell in the 1960s occur along this 'fairway.' Rohr et al., (2000) noted that transpressional deformation increases northwards from the Queen Charlotte Sound to Hecate Strait region, so that the late compressional structures that might trap hydrocarbons would be better developed in the Hecate Strait. Further, the trends of maturity indicators from exposed rocks on Queen Charlotte Island (Vellutini and Bustin, 1991) suggest that southwest of the zone of highest petroleum potential (Figure 1.1), source rocks are likely to be overmature.

Despite direct indication of hydrocarbons in the QCB, the wells drilled so far, either on land or at sea, failed to make commercial discoveries. In the absence of hard data on oil or gas reservoirs, Hannigan et al., (2001) made a thorough statistical analysis of the likelihood of occurrences of oil and gas pools. This analysis assigns various probabilities to play conditions: presence of reservoir, source, and seal: timing of oil/gas migration, and preservation; volume of reservoir, oil/gas saturation, and production shrinkage. From this they have estimated that the total hydrocarbon resource of the QCB is 9.8 billion barrels of oil and 25.9 trillion cubic feet of gas. These are median estimates. There is a 50% probability that the hydrocarbon resource reaches this size. There is a 90% probability that the QCB contains in excess of 6.3 billion barrels of oil and 12 trillion cubic feet of gas. There is a 10% probability that the QCB hydrocarbon resource exceeds 19.4 billion barrels of oil and 48 trillion cubic feet of gas.

At the workshops, Hannigan indicated that the recoverable volumes might be around 25% of the resource for oil and about 75% for gas. From the median estimates, the largest single oil field in the QCB would have a recoverable volume of 440 million barrels; there would be 6 fields of over 100 million barrels, which together could produce 1.3 billion barrels. At US$30 per barrel, this would amount to an assessed value of about C$50 billion. From median estimates of the gas resource, the largest field would contain 2.5 trillion cubic feet of recoverable gas; there would be 9 fields with more than 500 billion cubic feet recoverable, totalling 9.8 trillion cubic feet. This would amount to an assessed value of around C$60 billion, at a price of US$5 per 1000 cubic feet.

To put these figures into a wider perspective, the median estimates of recoverable oil and gas from the QCB are broadly similar to—perhaps a little smaller than—estimates for the Jeanne d'Arc Basin, offshore Newfoundland, in which the Hibernia and Terra Nova fields are currently productive, and the White Rose field is being developed. The median estimate of oil for the QCB would satisfy total present Canadian demand (1.6 million bbl per day; http://www.capp.ca/default.asp?V_DOC_ID=603) for about 2.5 years; the median estimate for gas would satisfy current Canadian demand (7 billion cu. ft. per day; http://www.capp.ca/default.asp?V_DOC_ID=603) for about 4 years. By contrast, the total ultimate potential for production recovery of crude bitumen from Canada's oil sands is about 315 billion barrels (http://www.eub.gov.ab.ca/bbs/products/STs/st98-2003.pdf), over 200 times the volume of oil likely to recoverable from the QCB. The current producible reserves of oil sands projects operating today is 6.9 billion barrels (http://www.capp.ca/default.asp?V_DOC_ID=603), five times the likely recoverable from the QCB.

It is important to note that these estimates for the QCB are based on best efforts with modest data. After drilling over 20 wells in the QCB, no commercial discovery has yet been made. This is not cause for pessimism: the Hibernia oil discovery was the first offshore Newfoundland, and was found in the 36th exploration well in that basin.

2.4 The history of exploration in the Queen Charlotte Basin

The QCB was explored intermittently until 1972. The first well was drilled in 1913 on the west coast of Graham Island and more wells were drilled on the island between 1949 and 1984. Shell drilled eight offshore wells between 1965 and 1969 (see Figure 1.1 for locations). The offshore drilling was based on a substantial coverage of industry seismic profiling. Over 17,000 km of seismic was shot by Shell in the period 1963-1968 and, after the last offshore well was drilled, Chevron shot a further 2200 km of seismic profile. The latest moratorium on oil and gas activities was established in 1972. In the 1980s, the Geological Survey of Canada collected a regional grid of 1200 km of deep reflection seismic profiles (Rohr and Dietrich, 1992). The exploration licences issued are in abeyance. Their distribution is shown in Figure 2.4 and details of ownership can be found at http://webmap.em.gov.bc.ca/mapplace/minpot/offshore.cfm

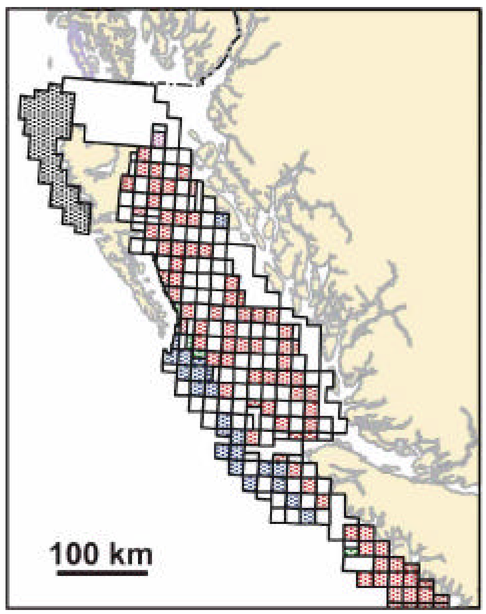


Figure 2.4. Map showing areas of exploration licences on hold through moratoria. Details of licence ownership can be obtained from the internet site from which this drawing was derived: http://webmap.em.gov.bc.ca/mapplace/minpot/offshore.cfm (courtesy BC Government).

2.5 Oil and gas activities: background

The practices of industry in exploring for, and producing, oil and gas offshore are described in a number of recent reports accessible on the internet (CNSOPB, 2003; Davis et al., 1998; JWEL, 2001 and 2003; LGL et al., 2000; LGL, 2003; Strong et al., 2002). These reports also deal with environmental impacts of the activities. In this section of the report, those activities that are likely to impact on the marine environment are summarised, as introduction to the impacts assessments described later.

2.6 Exploration activities

Exploration for hydrocarbons offshore starts with a compilation of existing geological information for the area concerned. This is the basis for designing geophysical surveys which are used to infer the structure of rocks buried below the seabed. Seismic reflection surveying is the primary tool used for this. The images produced by the seismic technique are analyzed to locate potential hydrocarbon traps. These prospects are then drilled with mobile rigs. On finding hydrocarbons, it may be necessary to drill additional wells to delineate the reservoir and test for its potential commercial development. Production usually requires different, semi-permanent infrastructure.

2.6.1 Seismic surveys

The land geology of British Columbia is mapped at regional scale and the prospective rocks of the Queen Charlotte Islands have been mapped in some detail (see Woodsworth, 1991, for a substantive overview). Geological structure cannot be extrapolated reliably offshore, so geophysical surveys are used at sea to image structure below the seabed. Regional variations in gravity and magnetic fields provide useful general indicators of where dense or strongly-magnetised rocks may be found, but direct imaging of buried geological layers that might be hydrocarbon traps is carried out by seismic survey (Figure 2.5a). This technique is described in CNSOPB (1998), with updates in LGL (2003, pp. 113-124). At sea, a sound source, towed just behind a moving ship, is fired just below the sea surface. The sound pulse, or 'shot', radiates like a wave through the water layer from the source and down into the solid earth below. Boundaries between different layers (the seabed for example) reflect small amounts of the incident wave and the weak echoes are picked up on a string of hydrophones towed in a thin flexible tube (streamer) at shallow depth behind the ship. The recordings are processed to produce images of subsurface geology on vertical profiles along the ship's track. This kind of survey is known as multi-channel seismic (mcs) reflection profiling.

The survey ship proceeds at a few knots, firing shots every 25 m or so. The reflections are detected on multiple hydrophones contained in the streamer, which may be several kilometres long. 100-200 km of profile can be completed each day.

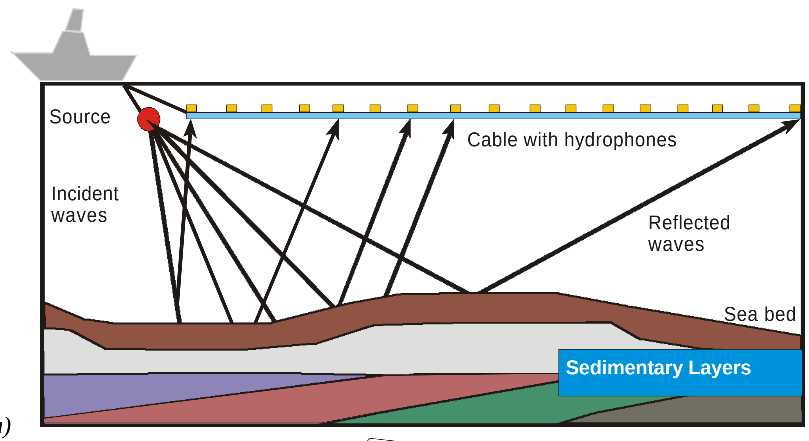
There are two kinds of mcs reflection surveys in common use. In reconnaissance surveys, a grid of survey lines is shot with lines a few kilometres apart. These are described as 2D profiles. In an area of 100 square kilometres, 8 km x 12.5 km for example, if profiles were to be shot four kilometres apart, with individual shots every 25 m, the total number of shots would be 1000, yielding 25 km of profile.

When hydrocarbon prospects are established and more detail is required to select drilling targets 3D seismic surveys are shot. The recording ship would tow several streamers, many tens of metres apart, covering a swath of seafloor up to 500 m wide (Figure 2.5b). By recording abutting swaths a complete coverage of the subsurface can be obtained. Using the same shot spacing as above, a complete 3D survey of the 100 square kilometres would involve 200 km of swath profile and 8000 shots.

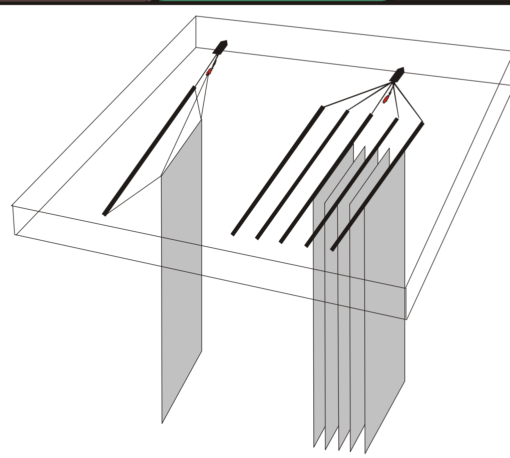
Only 2D seismic surveys have been completed in the QCB to date. These include 19,600 km of industry 2D profiling (Shell and Chevron, in 1960s and early 1970s), and 1200 km of profiles collected by the Geological Survey of Canada (in 1980s). 3700 km were shot with dynamite as source, 9300 km with a gas exploder source, and 7800 km with air guns. A total of 348 km of the lines were shot directly over the locations of the sponge reefs (see section 5.5), which were not known at the time.

There have been major advances in both acquisition and processing technologies in seismic imaging since the last industry acquisition in the QCB. If the moratorium were to be lifted and industry wishes to explore again, a regional grid of 2D seismic lines might be shot in a reappraisal of the QCB. Assuming a line spacing of four km over an area of 30,000 km^2 (approximately the area of the QCB that might be surveyed) a total length of 2D survey lines of about 7500 km would be shot. This survey could be completed in a period of about two months with allowances for 'down time.' A 3D survey of the same total area would take around a year but in early exploration such surveys are likely to be restricted to areas around only the brightest hydrocarbon prospects revealed by the initial 2D surveys. Such prospects might be adequately surveyed in 3D by covering only 10% of the basin, which could be surveyed in about two months. Discoveries might indicate the need for additional 3D seismic surveys and production might be accompanied by repeat surveys (so-called 4D or time-lapse seismic) which can be used to determine how the hydrocarbon reservoirs are being depleted by production.

The most significant impacts of seismic surveys on biota are caused by sound levels. Damage may include mortality, physiological damage, temporary hearing loss, and behavioural disturbance (see section 8.2). Air gun sources are used most often for marine seismic reflection profiling. These sources discharge compressed air into the water from a series of guns of different sizes (to provide the range of frequencies required). A typical source (Figure 2.6) would include three 15-m strings of around seven guns (total volume 5085 cu. in.), with the strings towed 8 m apart just behind the ship. This arrangement directs the sound downwards to penetrate the seabed, with a smaller amount being lost sideways. In the downward direction, at a range of many tens of metres, the wave from the source behaves like that from a point source with a strength of 6.5 MPa-metres (65 bar-metres, zero-to-peak level; 1 atmosphere of pressure = 1 bar = 10^5 Pa, i.e., 0.1 MPa) and a duration of about 20 ms. Close to the source array, the signal felt depends on the interference of the signals coming at different ranges in differing directions from the individual guns. Most guns give an acoustic signal of around 0.4 MPa-metres (4 bar-metres) but with different duration determined by gun size.



(a)



(b)

Figure 2.5 (a) Cartoon of 2D seismic profiling. A single source is towed in front of a single multi-channel hydrophone streamer. Reflections are recorded from a vertical cross-section along the track of the ship. Note that the length of seafloor 'illuminated' by each shot is half the length of the hydrophone cable (streamer). (b) Block diagram of two surveys across a marine area: a 2D seismic profile at the left produces an image of the subsurface in the shaded vertical area, as compared with a 3D seismic survey, to the right, in which several 2D profiles are recorded in one pass, to provide a 'swath' of subsurface reflection images. Note that the width of the swath of seafloor covered by the multiple streamer (3D array) configuration is half the width of sea across which the array of streamers is spread. (Figures redrawn fromD. Bogstie, WesternGeco, 2003, personal communication, workshop presentation).

Hydrophone streamers pose little threat to the marine environment. Plastic-tubed, liquid-filled streamers are built from individual sections of around 100 m length and they use oil for neutral buoyancy. Accidental puncture of such a section would result in a release of less than 0.4 cubic metres of oil. Currently, oil-filled streamers are being replaced by ones made with closed-cell plastic foam.

Because seismic surveys require the recording ship to travel at regular speed along straight line paths, towing a streamer of several kilometres length, other shipping is notified of the survey area and time. It is common practice for a liaison to be maintained with local fishing fleets, so that they avoid the immediate survey area during shooting. Compensation for significant loss of access to fishing areas is negotiated (see section 9.4).

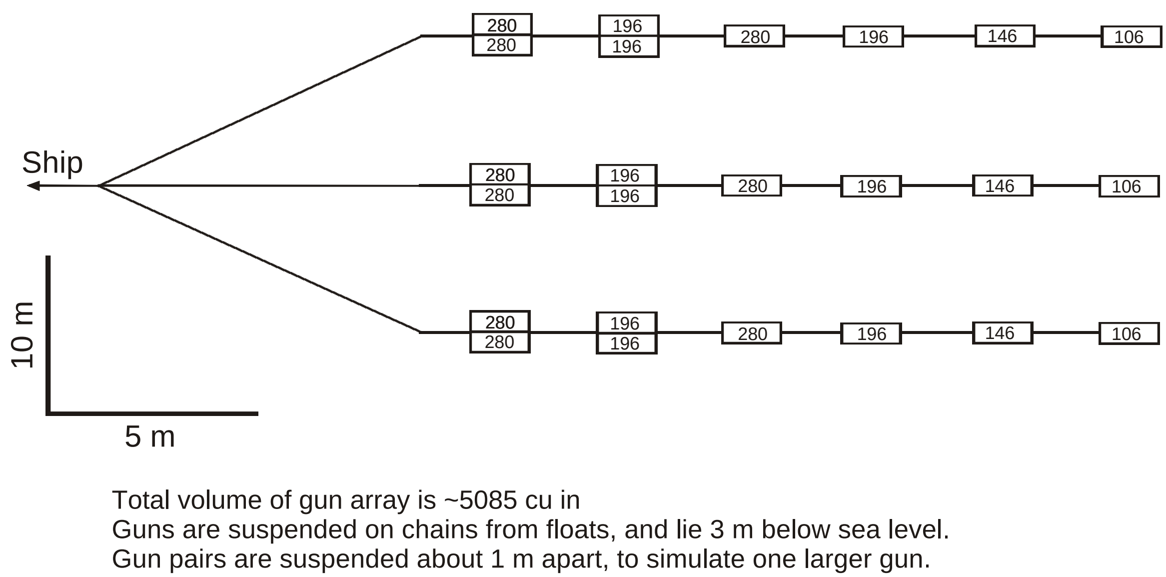


Figure 2.6. An air-gun seismic source array: plan view; air gun volumes in cubic inches. (Figure redrawn from D. Bogstie, WesternGeco, 2003, personal communication, workshop presentation.)

2.6.2 Exploration and delineation drilling

Seismic surveys reveal possible hydrocarbon traps but do not usually give direct indications of hydrocarbons. Drilling is the only sure way of testing geological structures for oil and gas. The methods used are summarised in LGL et al., 2000, pp. 11-22, and JWEL 2001, pp. 80-88. Mobile offshore drilling rigs are used for exploration. These are of various kinds. For the water depths of the QCB, the rigs used would probably be jack-up types (for shallow water), semisubmersibles for deeper water and drill ships for deep water (Figure 2.7; LGL et al., 2000).

Semisubmersible drilling rigs are very popular for drilling on continental shelves in water deeper than a few ten of metres. These rigs are supported by the buoyancy of large pontoons which are submerged (by admitting seawater) when operating but can be surfaced for transport and maintenance. The rigs are kept in fixed position by anchoring, and may be moved small distances by propeller thrusters. The wells drilled in the 1960s in the QCB by Shell used this kind of drill rig; it was built in Victoria (Figure 2.8). More modern versions have been built to withstand a range of severe metocean conditions (Figure 2.9).

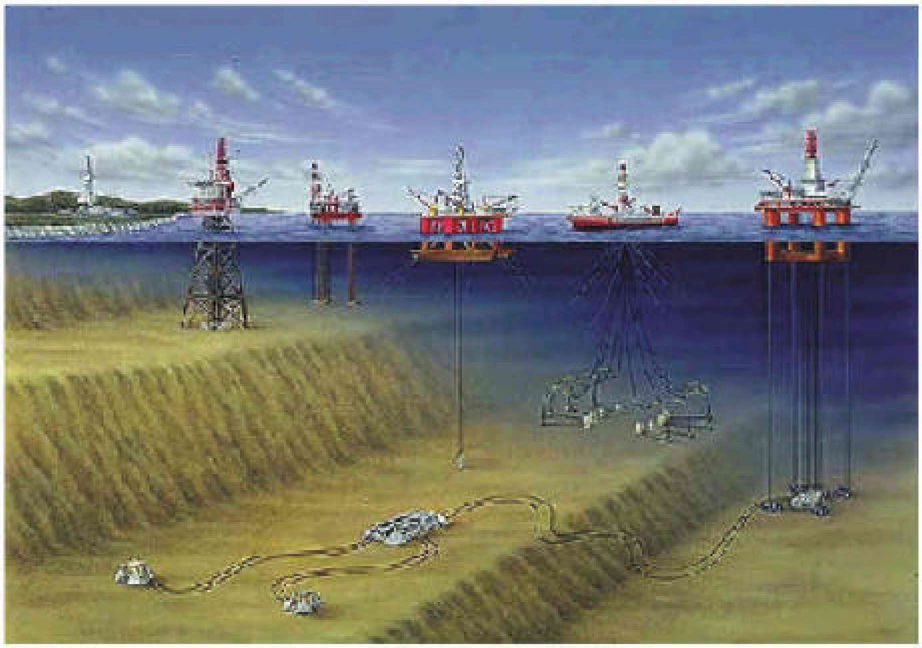


Figure 2.7. Different kinds of exploration and production rigs; from left to right: jacket, jack-up, semi-submersible, drill ship (or floating production, storage and offloading vehicle -- FPSO), tension-leg platform. Jack-up rigs are mounted on several long vertical legs, which can be racked down to the seabed to support the weight of the rig. The steel-girder-framed legs are then raised for transport of the floating rig to other sites. The geotechnical properties of the seabed must be known before such a rig is mobilized to a drill site, to ensure stability of the foundation. Figure from JWEL (2001).

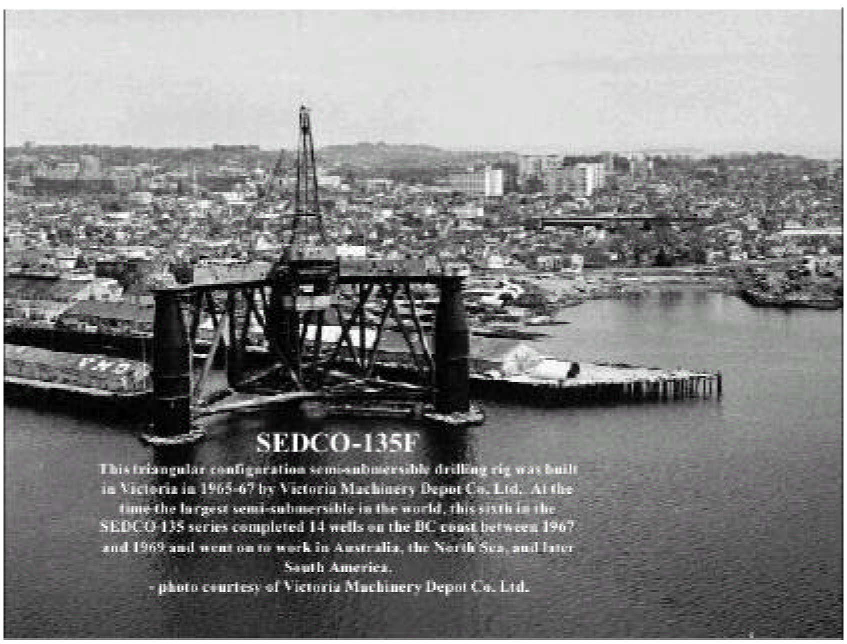


Figure 2.8. Exploration drilling rig, SEDCO-135F, built in Victoria, BC, and used to drill wells in the Queen Charlotte Basin in the 1970s.

Figure 2.9. Modern drilling rig, Eirik Raude, used for drilling in harsh marine environments, seen here operating offshore Atlantic Canada.

In deeper water, drill ships may be used. These are designed as normal ships but with a central drill derrick located above a moon-pool (a hole into the water in the centre of the ship) down through which the drilling operation takes place. The ship can be positioned by anchors in shallow water but is dynamically maintained on station in deeper water by propeller thrusters.

Prior to drilling, site surveys are undertaken to test the nature of the seabed and to make sure there are no signs of seabed gas emissions. These would indicate unstable seabed conditions, which would endanger the stability of jack-up rigs and be a potential cause of gas blow-outs during drilling.

Once on site, the rig is prepared for drilling, either by jacking up its legs, or by anchoring it over the site (possibly using dynamic positioning systems). Rotary drills are used, with wider diameter near the top of the hole, so that casing can be installed to prevent the hole collapsing. Drill bits are connected to the rig by hollow drill pipes. The bit is wider than the pipe so that fluid (drilling mud) can be circulated down the pipe to flush the rock cuttings from the drill bit and bring them back to the rig up the hole outside of the pipe. The cuttings are separated by screening and the mud recirculated. The drilling mud is based on either water or oil and contains a variety of chemicals for specific purposes. For example, barite gives the mud high density, which is useful as a safeguard against blow-outs caused by breaking into a permeable formation with very high water, oil or gas pressure. Water-based muds are usually used to initiate the well because, as the bit first enters the seabed, there is no way to contain the mud and cuttings. Once the first casing is set (usually after drilling about 200 m into the seafloor), a riser pipe is used to connect the drill rig to the casing and the drilling operation is then contained. Water-based muds are preferred by regulators but oil-based muds are used when particular problems arise. In current practice, the oil base is either a non-toxic synthetic oil or a low-toxicity mineral oil. Offshore eastern Canada, in cases where mud uses a synthetic oil base, cuttings may be discharged to the seabed locally, after washing so that no more than 6.9% by weight of the discharge is oil (Offshore water treatment guidelines, http://www.cnsopb.ns.ca/Environment/evironment.html). In some oilfields, all cuttings and mud must be disposed of onshore. Routine discharges, if permitted from a 5 km deep exploration well, would amount to about 1000 m^3 of cuttings and 5000 m^3 of water-based mud, including 3000 tonnes of solids of which about

75% would be barite, with bentonite and potassium chloride as the main minor components, and very minor amounts of caustic soda, lime, polymers (LGL et al., 2000, p. 18).

Drilling a well several kilometres deep may take a couple of months, including time taken to sample the rock (coring). The entire drill string (pipes and bit) may have to be pulled from the well occasionally to replace bits and to insert casing. During these procedures, tools are run down the well to measure physical properties of the rocks encountered. These so-called 'wireline logs' give continuous measurements of electrical conductivity, density, gamma-ray activity and seismic velocity. The logs are vital in correlating geological layers between wells via the grid of seismic profiles. Surface-to-well seismic measurements, using an air-gun array shooting from close to the rig with recordings down-hole, may be used to help the correlation of down-hole geology with seismic profiles.

High-density drilling muds usually prevent high-pressure formation fluids from blowing-out. But, as an additional precaution, blow-out preventers (BOP) are usually placed in the drill string close to the seabed. These valves will automatically shut off the drill string should pressure rise beyond an acceptable level. If hydrocarbons are found, the well may be tested for flow for a period of time to find out how large the reservoir is and how easily hydrocarbons flow. During this phase, gas is burnt in a flare; oil is separated from formation water, atomized and burnt in the flare; and excess formation water discharged to the sea after separation of oil. Very modest volumes of formation waters are produced in these tests compared with those released during production.

On abandonment of the well, the usual procedure followed depends on the desire for re-entry. If no re-entry in the future is contemplated, the well is sealed, the casing is usually cut off and removed just a few metres below the seabed and any seabed infrastructure is removed. For later re-entry, the well is plugged and the well-head capped.

The environmental issues posed by drilling are discharges of cuttings, mud, produced water, effluent from the rig, spills and blow-outs. The same issues are posed by the production phase but in differing proportions because the time spent drilling is then relatively small compared with that spent on production.

2.7 Production activities

Taking a hydrocarbon discovery to commercial production is a big step. Depending on the distribution of hydrocarbons in the discovered reservoir(s), a complex series of wells may need to be drilled: many initially, to tap different pools, several later, to tap other pools and to provide for injection of water into the pools to maintain reservoir pressure during secondary recovery. With current technologies capable of turning well bores from vertical to oblique, even horizontal, several pools can be accessed from one production site but the infrastructure at that site will be much greater than that required for exploration and delineation drilling. The production phase should be subject to independent assessments of rates, royalties, and environmental circumstances. The main production facility will be much larger and more complex than an exploration drill rig. This is because it will have to include facilities for separation of products (gas, condensate, oil, produced water) and their disposal through transport or discharge, with attendant requirements for storage in most cases, to buffer production and transport. For example, in deeper water, a small drill ship would be used for drilling the production wells but the production facility itself might be a larger floating production, storage and offloading (FPSO) ship.

2.7.1 Development drilling

Development drilling involves similar activities to exploration drilling but with less formation testing until the reservoirs are encountered. The similarities extend to drilling technology, use of muds, disposal of cuttings and dealing with prevention of blow-outs. Because the total distance drilled may be many times that of a single exploration well, the total local discharges (if approved) will be significantly larger. It is worthy of note that in recent approvals of production from wells within a few kilometres of shore, some regulators have insisted that there be zero discharge on site; cuttings and spent mud must be disposed of in an approved land site or reinjected.

2.7.2 Oil and gas production

Production involves pumping oil, flaring or reinjecting gas, separating products and dispatching products and waste. This phase will also include operations to enhance production as it wanes, including secondary recovery methods (e.g., injection of water or steam into reservoirs) and fracturing by hydraulics or explosives to enhance permeability around the well bore. Particularly prominent issues arise in this phase with respect to the discharge of produced formation water and to the storage and offloading of product. Formation waters are inevitably produced with hydrocarbons. These waters are brines, often more concentrated than seawater, and they will usually be contaminated with hydrocarbons and other substances including small amounts of heavy metals. The common methods of disposal of produced water during the production stage are discharge to the ocean, and reinjection into the hydrocarbon reservoir. Gas is also produced from oil wells (it may be dissolved in the oil at reservoir pressure but is released as pressure drops on the oil as it is pumped to the surface). Regulators on Canada's east coast expect industry to reinject co-produced gas, for conservation and later production. The hydrocarbon products are separated on the production facility and stored temporarily until they are transported from the platform facilities by tanker or pipelines. This necessitates the platform having some storage facility.

During production, the environmental concerns hinge around discharges—authorised and accidental—of hydrocarbon products and produced waters.

Production platforms in the QCB would probably be one of two types: either seabed-founded platforms or FPSOs. In both cases, there will be seabed well-heads connected with the platform facility but the engineering will differ in detail. FPSOs are being introduced by industry on Canada's east coast. They have versatility in being able to detach from the wells in adverse circumstances (e.g., to avoid the worst iceberg impacts) and ease of removal at decommissioning.

2.7.3 Offloading

At production sites where transport of crude oil is by tanker, it is necessary that the platform have a storage unit, which can be linked to the tanker by flexible hose. The storage and offloading unit may be separate from, but adjacent to, the production platform. Pipeline transport does not usually involve such storage.

2.8 Transport

Initial separation of produced oil, gas and water is carried out on the production platform. Traditional disposal of produced water is by release from the platform into the surrounding ocean with strict limits on allowable fractions of oil and metals. Concern about contaminant levels in enclosed basins is rising to the point where produced waters will either be removed for disposal elsewhere or reinjected into the ground. Natural gas may be a marketable product or, if a minor by-product in an oil field, it may be flared at the rig or reinjected to assist in secondary oil recovery. Marketable crude oil and natural gas will be transported away from the production facility, either by tankers or by pipeline, to shore-based processing facilities. There are possibilities of product leakage from either mode of transport and these will be addressed in section 8.4.

2.8.1 Pipelines

Pipeline technology has advanced considerably over the last few decades (Palmer and King, 2004). Pipelines are used on the seabed for transport of oil over short distances – a few kilometres to a few tens – and for transporting natural gas over larger distances sometimes over 100 km. Pipelines can be used locally for collection of product from adjacent well-heads, in which case they may have modest diameters (100 to 300 mm). Pipelines for export from a field are usually of larger diameter (300 to 1100 mm). Most pipes have a steel inner tube coated successively with an anti-corrosive sheath and concrete. Oil field pipelines have been laid and operated in water over 2000 m deep. Steel pipe may need to resist internal corrosion and the outer skin must be resistant to seabed erosion. Trenching of pipes may be required to avoid erosive effects of sediment transport from below the pipe, to avoid snagging fish trawls, or for protection from iceberg scour.

2.8.2 Tankers

Tankers are used for transport of crude oil from production platforms to shore-based collector storage facilities, either local to the producing basin or adjacent to a refinery. There is a variety of offloading arrangements, from surface single-point mooring systems, through submerged turret loading to single anchor loading (G. Westgarth, 2003, personal communication, workshop presentation). Critical technologies used in modern offloading systems that have improved spill records include highly specialized double-hull tankers, dynamic positioning (with three different positioning referencing systems), twin-engines, double bow and stern tunnel thrusters, a retractable azimuth thruster, improved fire protection, uninterruptable power supplies, an independently operating position monitoring system ('black box') and tanker discharge telemetry systems. Operations can continue in significant wave heights (> 5.5 m) and the spillage statistics have improved considerably (see section 8.4).

2.9 Service bases

All offshore oil developments rely on a local service base at a suitable harbour with good transport connections outside the region. The port would supply products and services to the exploration and production activities. Supply vessels ply between port and platforms, transporting personnel, drilling muds, drill pipe and the many other materials required on a regular basis. The port infrastructure must include ground for storage of drilling materials, facilities for preparing drilling muds and, possibly, means for disposal of platform discharges brought back to shore. The impacts on the marine environment would be typical of an industrial port.

2.10 Refining

Hydrocarbons produced from the QCB will be transported to refineries by pipeline or tanker. Tanker transport could involve direct shipment to refineries or might include trans-shipment using a local shore-based storage facility. The Cook Inlet in Alaska (see Chapter 10), is a mature oil and gas basin that has produced about the same amount of oil as is estimated for the QCB, and similar to the combined proven reserves of the Hibernia, Terra Nova and White Rose fields, offshore Newfoundland. Whereas Newfoundland oil is refined elsewhere, Cook Inlet oil is refined within the basin. This provides enhanced local employment opportunities, but it is likely that any production from the QCB could be refined through existing global refining capacity. The possibility that refining capacity might be established in the QCB is not considered further here, though this should be a focus of attention during ensuing public consultations.

2.11 Decommissioning

At the termination of production activities, facilities must be adequately decommissioned. For a FPSO, this is a straightforward process of detaching the FPSO from its seabed completions. The seabed infrastructure can be removed and the wells plugged and abandoned. In past practice, for permanent seabed-founded platforms, removal was not considered feasible. Platforms would be abandoned, with the wells plugged. Less massive platforms were toppled and sunk to reduce dangers to shipping. More massive structures (e.g., concrete-based platforms) were left standing. Current practice for oil fields, as with mining operations on land, is that production plans are only approved once an acceptable decommissioning plan is in place: removal of all infrastructure above the seabed would be expected. Bonds or some other form of guarantee have to be lodged so that, if a production company were to fail, the taxpayer would not be solely liable for the costs of decommissioning of the field. It can be anticipated that any production activity in the QCB would be as stringently regulated as any current practice and so should include plans to remove all production infrastructure above the seabed.

CHAPTER 3

DECISION-MAKING, REGULATION AND ENVIRONMENTAL ASSESSMENT

3.1 Overview

Human activities of the kind involved in the present report inevitably involve decisions under uncertainty. The structure of decision-making is illustrated in Figure 3.1 (see for example Raiffa and Schlaifer, 1961; Raiffa, 1968; Keeney and Raiffa, 1993). A decision is indicated by the rectangle, with the branches flowing from this showing the possible choices. For example, these could be the decisions to allow seismic testing, to limit this to certain areas, to limit this in space and time, or not to undertake such testing. Flowing from a decision, there are various chance aspects, or uncertain events, indicated by a circle in the figure. These are often termed "states of nature". In the example taken, the branches from the chance fork could be possible effects of seismic testing, on various species of fish and mammals. Associated with the chance fork are the probabilities of the various outcomes. At the end of each action-state pair (action followed by a state of nature) are the consequences of one's actions. For example, a certain strategy for seismic testing might have the potential to cause sublethal effects on a certain specified number of fish.

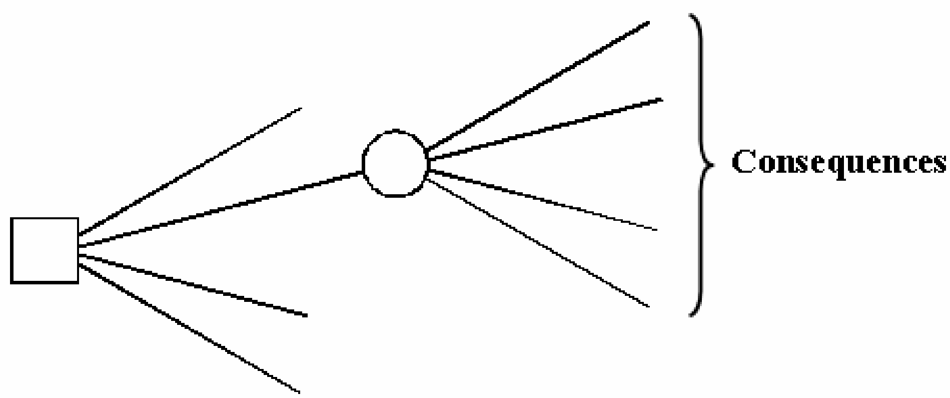


Figure 3.1. Structure of decision making. Decisions are indicated by squares (□) and chance events by circles (○)

The approach permits the analyst to structure any part of the problem under consideration, or the entire problem, to see clearly the possible consequences of an action and to focus on the key aspects in terms of probabilities and consequences. It is also possible to obtain a measure of the consequences on a common transformed scale. This is termed "utility," a measure of the desirability of the consequences. Often the scale from 0 (least desirable) to 1 (most desirable) is used. There is a rigorous theory to assist in making this transformation (Raiffa, 1968; Keeney and Raiffa, 1993); the approach also permits consideration of aversion to risk (see also section 3.4 below). Decisions can then be ranked in terms of expected utility. This will assist in ensuring that the main factors will be taken into account. Figure 3.2 shows the space that is under consideration (Jordaan, 2004). Risk analysis is concerned with events of low probability with undesirable consequences.

Strictly, the analysis is for a person's utility, although this can be extended for a group or organization. There are several interested parties in the development. No doubt, the benefits of oil and gas development flow to the oil companies, governments and to society; we shall point out these rewards but the focus of the report is on the risks to be considered by society—those consequences with negative (unwanted) implications.

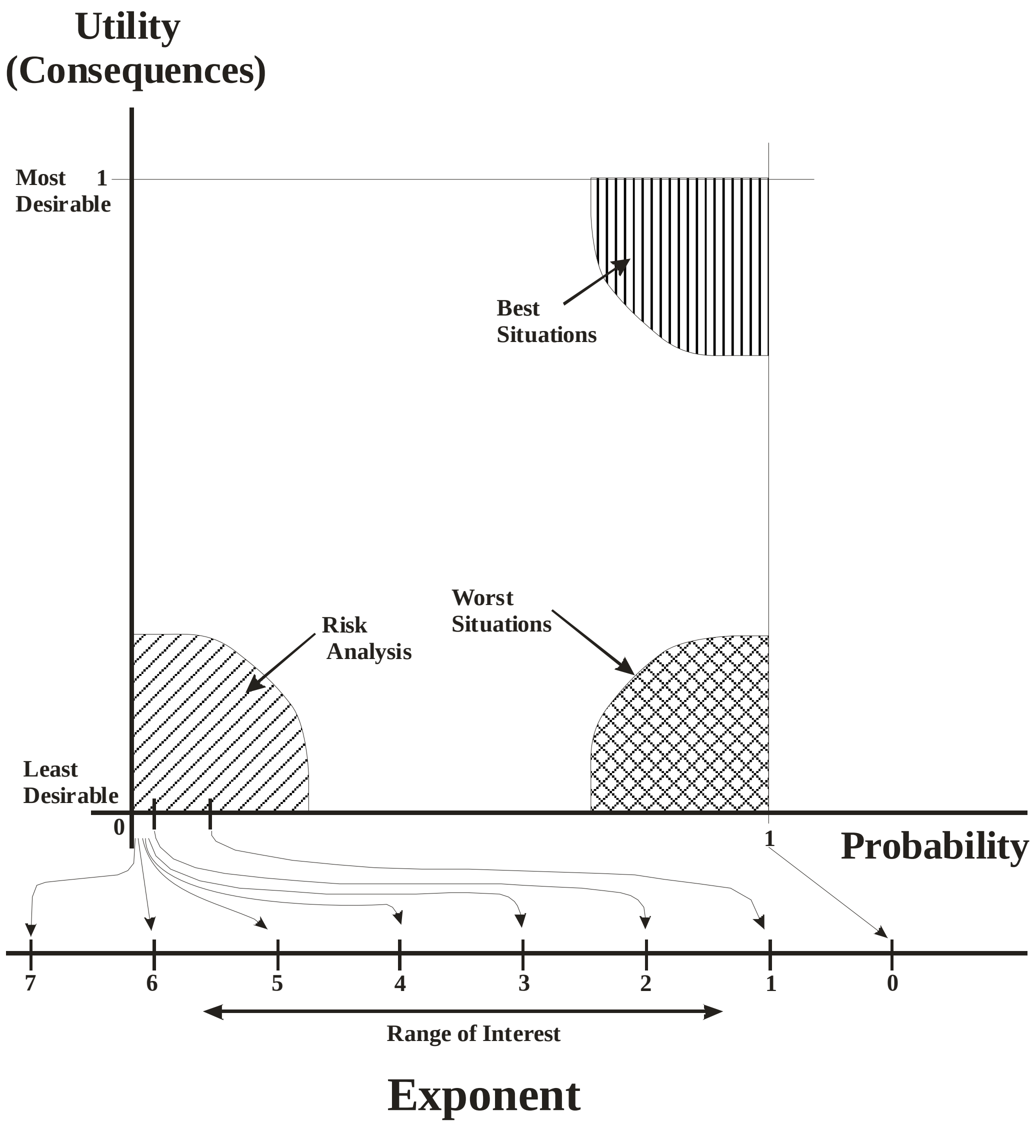


Figure 3.2. Area of interest in decision and risk analysis (schematic). See Section 3.3 for definition of exponent.

3.2 Rewards and risks

The consequence of a decision can be positive or negative. Investment in oil production results in a positive cash flow. Exploratory drilling might result in a dry well. The factors considered by oil companies include uncertainties related to the presence of hydrocarbons, to the adequacy of the reservoir, to the geometric integrity of the reservoir, and to the barriers that contain the hydrocarbons. This results in a probability distribution of the reserves which are compared to the commercial threshold. This will relate also to the price of oil; the potential cash flow is proportional to the price of oil. Based on the assumptions regarding the price of oil and gas of section 2.3, it has been estimated that the recoverable oil and gas reserves of the

Queen Charlotte Basin (QCB) may provide about C$ 110 billion over the life of the development (Hannigan et al., 2001).

There are inevitably risks associated with activities related to oil and gas activities but there are potential rewards as well. The decision to explore and develop is a reflection of the weighing of the rewards against the risks.

3.3 Risk assessment

Risks are related to the negative consequences, generally with low probability. Two aspects are important: chance, and unwanted consequences. We noted above that decision-making involves two aspects: probabilities (chance), and utilities (consequences); risks occur when the consequences are undesirable. Some analysts use “expected values”—the product of the probability and the consequences, added together for different outcomes. For example a situation with a 90% chance of a spill of 1,000 m^3 and 10% of 100,000 m^3 leads to an expected value of $(0.90 \times 1{,}000) + (0.10 \times 100{,}000) = 10{,}900$ m^3. This can be misleading since we might not consider a spill of size 10,900 m^3 to represent adequately the 10% chance of a much larger spill of 100,000 m^3. Risk aversion, as discussed in section 3.4 below, requires the use of nonlinear scales related to the attribute (spill volume in the present instance). It is preferable in general to consider the two factors (probability and consequences) first separately and then to consider them together.

Figure 3.2 shows a horizontal scale indicating various levels of risk, enumerating only one of the aspects of risk, the probability of occurrence. In this a “log” scale has been added, in which the probability is the exponent, as in the following. For example, a chance of one in a million of having an oil spill of a certain volume would have an exponent of 6.

1 in 10 = 10^{-1} = 1 in 10^{1}; exponent = 1
1 in 100 = 10^{-2} = 1 in 10^{2}; exponent = 2
1 in 1000 = 10^{-3} = 1 in 10^{3}; exponent = 3
1 in 10,000 = 10^{-4} = 1 in 10^{4}; exponent = 4
1 in 100,000 = 10^{-5} = 1 in 10^{5}; exponent = 5
1 in 1,000,000 = 10^{-6} = 1 in 10^{6}; exponent = 6

As we have noted, oil and gas activities inevitably have risks associated with them. Risk analysis is carried out either in a qualitative or quantitative manner; in the latter case the probabilities and consequences (Table 3.1) are estimated. In qualitative analysis, relative levels of probability and consequence are estimated. For example one might consider events that have never been observed in a certain time period, or that occur about once a year, and so on. Consequences might include slight effects or impacts, minor effects or limited impacts, major effects and impacts, and so on. It is preferable where possible to estimate probabilities and consequences. Table 3.1 summarizes and illustrates the main hazards faced in the offshore operations in the present study. Characterization in more detail is given in subsequent sections of the report.

3.4 Safety and risk aversion

Protection of human life, property, and the environment are fundamental objectives in engineering projects. This involves the reduction of risk to an acceptable level. The word "safety" conveys this overall objective. Generally, the first consideration in safety of offshore projects is that of human life. In the present endeavour, it became clear by the submissions and discussions at the workshops and after, that environmental concerns were paramount in the minds of the intervenors.

Risk aversion relates to the size of consequence (see for example, Keeney and Raiffa, 1993). We might be prepared to wager $10 for a 50% chance of a reward of $25 with 50% chance of losing the $10 but might not risk $1000 for a possible reward of $2500. The prospect of a 50% chance of losing $1000 might be

Table 3.1. Principal hazards in offshore industry

Time Period	Act or Event	Effects: Human Life or Injury	Severity	Effects: Environment	Severity
Operations: Transitory	Seismic Testing	Improbable	n.a.	Possible Damage to Fish Mammals Eggs Larvae Invertebrates	Generally Localized; Concerns for Mammals, Spawning Areas
	Drilling	Possible	Possibly Substantial	Possible: Oil Spills	Variable, Possibly Substantial
Operations: Continuous in Time	Drilling Cuttings	None	n.a.	Localized Toxic Effects on Bottom Fauna	Localized, Chronic
	Produced Water	None	n.a.	Localized Effects on Fish, Mammals	Localized, Chronic
	Structural Fatigue	Possible if Structural Failure	Possibly Substantial	Oil Spill Possible: Inshore Biota and Birds	Possibly Severe
Operations: Extremes at Points in Time Possibly Leading to Structural Failure	Wind	Possible if Structural Failure	Possible		
	Waves	Possible if Structural Failure	Possibly Substantial		
	Earthquakes	Possible if Structural Damage or Failure	Possibly Substantial		
	Tsunami	Possible if Structural Failure	Nearshore Effect	Possible	Nearshore Effect
Point in Time: Accidents	Fires, Explosions Dropped Objects	Possible	Possibly Substantial	Possible	Possibly Severe
	Oil Spills	Improbable	n.a.	Inshore Biota and Birds	

sufficient to deter us. In a similar way, larger and larger oil spills will have increasingly negative consequences—beyond the linear scale. A spill of 100, 000 m^3 might be considered to be more than 10 times worse than a spill of 10,000 m^3. There are formal means to analyze risk aversion (Raiffa, 1968; Keeney and Raiffa, 1993; Jordaan, 2004), involving the use of nonlinear transformations of the attribute under consideration. This reasoning is borne in mind, and is one of the factors considered in the assessments of this report.

3.5 Failure and safety levels; human factors

Functioning systems have generally a “demand” and a “capacity,” illustrated in Figure 3.3. The curves represent the relative likelihood of occurrence of various levels of demand and of capacity. For a system to be functioning well, it is necessary that the capacity is not exceeded by demand. If it is, “failure” of the system is deemed to have occurred.

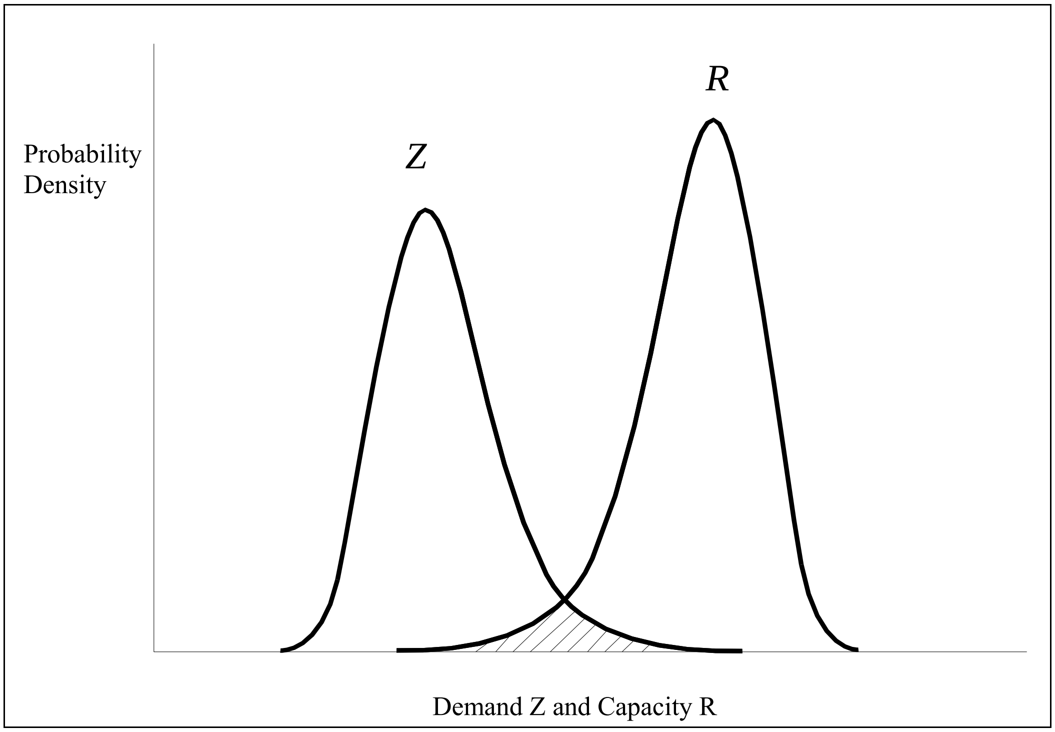


Figure 3.3. System demand and capacity. Overlap area indicates possible failure.

In an engineering system, for example, the demand could be wave loading on a fixed platform and the capacity could be the structural resistance. If probability distributions for load and resistance are developed, it is possible to determine the probability of failure based on a calculation related to the “overlap” area (diagonally-ruled area in Figure 3.3). At the same time, there are many “grey” areas related to this, for instance consideration of the reserve capacity of structures which can be difficult to enumerate. Also, the consequences of failure can be difficult to estimate; some yielding or local failure does not generally pose dangers but complete collapse could lead to considerable loss of life. The analysis of the complete failure process is difficult and complex and often a lower bound on the resistance is used that leads to an overestimate of the failure probability.

3.5.1 Human factors

Studies of actual failures in the offshore industry (Bea, 1998) and of engineering systems in general (Perrow, 1999) show that most accidents—60 to 80%—result not from the factors of the preceding paragraph but from human and organization factors. These might be designated “human error” or “operator error” but these terms tend to oversimplify the situation. Often the accidents result from human factors associated with the organization in terms of regulations and how they are implemented (see Perrow, 1999, in particular). The Piper Alpha accident (see Appendix V) is a case in point. Much has been learnt from such occurrences (see section 3.8 below). Regulations have subsequently been framed so as to avoid recurrence of the accident. Lessons have been learnt from other disasters such as the gas plant explosion at Longford in Australia. The conclusions from this accident (Hopkins, 2000) are that systematic identification of hazards is a vital factor in accident prevention, risk assessment related to organizational and technical changes is important, proper systems for reporting and communication must be in place, especially with regard to reporting "bad news" to management, and training is vital (Goobie, private communication; see also Hopkins, 2000).

3.5.2 Target safety levels

It is very useful to have guidelines for safety levels. Most work in this area has been developed for safety of human life and we shall take the approach suggested by the Canadian Standards Association (CSA, 1992) offshore standards, which made the association of the possibility of "great risk to life" and of "a high potential for environmental damage" as being approximately equivalent. They are both of importance in offshore engineering.

The usual starting point is the consideration of "basic risk" in life. This amounts to the risk of death that is impossible to avoid in living in our society. Since we are dealing with the single consequence, "death of an individual," the risk is taken as the probability in this case. Basic risk has been estimated at about one-third of the risk of all accidents (motor vehicle, falls, fires, homicide, ...). This estimate results in the value of approximately 1 in 10^4 = 1 in 10,000 = 10^{-4} per annum. This has also been estimated at the same level based on work from the Netherlands (see MIACC, 1995) using the "natural death" rate of 10 to 14 year olds. The figure also approximates the probability of death in a motor vehicle accident in Canada in a year.

Table 3.2 summarizes values presented by Wells (1996) based on work of the Health and Safety Executive (HSE) of the UK. Societal risk refers to that borne by a society living in a region where industrial activity causes risks to the society as a whole. We are dealing with workers in industrial activities. The value of 10^{-5} per year or one in 100,000 appears as a very reasonable target value for specific process causes. This is also supported by the work of MIACC (1995) who proposed risk levels for land use near hazards. The range proposed for individual risk was 10^{-4} to 10^{-6} per year depending on the land use. The HSE (2001) discussed risks in the context of a TOR (tolerability of risk) framework. It was pointed out that levels of risk have improved and that maximum levels of risk for workers are of the order of 1 in 10,000 whereas 1 in 1,000 had previously been used as the maximum.

Table 3.2. Risk values recommended by Wells (1996)

Target values of maximum risk not to be exceeded	
Employee individual risk	
All process causes	10^{-4} per year
Specific process causes	10^{-5} per year
Public individual risk	
All process causes	10^{-5} per year
Specific process causes	10^{-6} per year
Risk of major accidents (societal risk)	
Near miss from all process causes	10^{-4} per year
Accident from all process causes	10^{-5} per year
Catastrophic accident from all process causes	10^{-6} per year
Accident from specific process causes	10^{-6} per year
Catastrophic accident from specific process causes	10^{-7} per year

In all of these documents the concept of ALARP (as low as reasonably practicable) was stressed (see Figure 3.4). A range of 10^{-4} to 10^{-5} is suggested as the ALARP range for specific process causes, with the main target being 10^{-5}. The concept involves a tradeoff between risk and benefit for risks higher than 10^{-5} per annum.

Finally, it should be noted that the CSA offshore safety standard embodies a very similar risk target (see section 3.9 below).

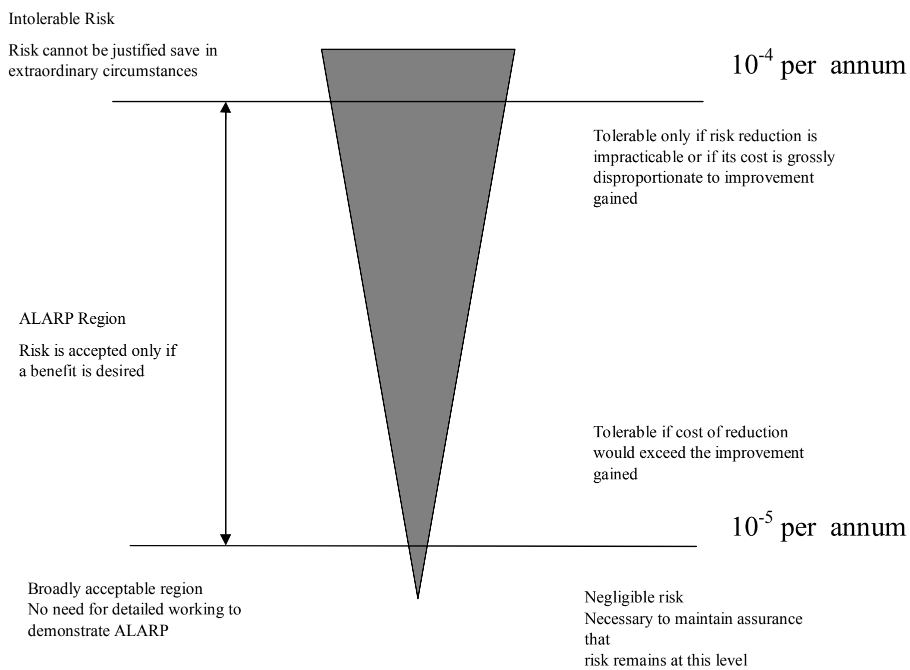


Figure 3.4 ALARP, as low as reasonably practicable, based on Wells (1996) and Melchers (1993) The upper line (intolerable risk) is set at 10^{-4} per annum and the lower one, defining the broadly acceptable region, is set at 10^{-5} per annum for the present application.

3.6 Precautionary principle

There are many definitions of the precautionary principle (or approach), yet the idea is quite simple. It embodies the idea of "better safe than sorry," or "erring on the side of caution" (the federal *Oceans Act*). The precautionary approach as defined in the terms of reference of the panel is as follows: "in the face of scientific uncertainty, it is preferable to err on the side of caution." It is also noted there that the absence of full scientific certainty shall not be used as a reason to postpone decision-making.

The essence of its intent is the assessment of risk. Saunders (2000) states the following. "In fact, the precautionary principle is very simple. All it actually amounts to is this: if one is embarking on something new, one should think very carefully about whether it is safe or not, and should not go ahead until reasonably convinced it is. It is just common sense." It is apparent that in the precautionary principle, aversion to risk is a key element. Saunders also states that "The precautionary principle does not deal with absolute certainty. On the contrary, it is specifically intended for circumstances in which there is no absolute certainty."

The principle is contained in numerous international laws and agreements. Appendix IV gives some background to the various statements of the principle. There is no single agreed definition. The approach advocated in the terms of reference has been used in the present study, and we emphasize particularly the importance of scientific uncertainty. Thus our approach is to assess all risks and associated uncertainties, and then to judge whether there are gaps in the science to be filled prior to offshore activities related to oil and gas.

It is to be noted that it is common in engineering practice in the absence of complete information regarding a parameter, to make an allowance for this in the design method resulting in increased conservatism. (In engineering "conservatism" is used to denote an extra allowance for strength, resulting in increased safety.) For example, data might indicate that the 100-year wave height is a certain value but a quantity might be added to this to compensate for uncertainties in the data base or in the modelling method. In the design of the Hibernia gravity based platform, an ice pressure of 6 MPa was used for global design against iceberg impacts. This was known to be conservative when the design was formulated and time has shown this to be definitely the case. It is now known that average pressures on large areas will generally be less than 1 MPa. These conservative lines of attack are fully consistent with the precautionary approach.

Furthermore, the approach to regulation, and in particular the Safety Case in objective-based regulation will, if wisely carried out, lead to detailed risk assessments before any activities are carried out. It is also axiomatic that the proponents of the development, industry in the present case, must make the case that the development is safe. O'Riordan and Cameron (1994) suggest that the principle is most likely to be applied where there are well regulated regimes with knowledgeably risk averse public opinion, where the regulation allows judgement as to what is tolerable, where the national culture cares for the defenceless, and where openness and accountability are features of the decision making process. The aspects regarding public awareness and attitudes are in place in the present instance and the remaining aspects point to the need for an appropriate regulatory regime.

We reiterate that the precautionary principle does not require absolute verification of safety. In any human activity there are risks and such a requirement would halt all technological development. The obligation is rather to demonstrate that a reasonable and acceptable level of risk has been attained (see Gray and Bewers, 1996, for a discussion). Many past discussions of the principle have centred on hypothesis testing. These discussions regarding scientific basis would preferably be phrased in a Bayesian context, in which the basis of hypothesis testing, and the many weaknesses of this procedure, can be exposed. The problem is much better analyzed as one of decision, with first the decision to experiment, followed by the result of the experiment, followed by the main decision, followed by the state of nature and the consequences measured by the utility. An example of the application of the decision-theory approach to an environmental question is shown in Figure 3.5. In an experiment aimed at determining the presence of mammals in a region before conducting seismic operations, a 5% exceedance probability in the test, corresponding to the 95% level used in hypothesis testing, would be arbitrary and insufficiently rigorous. A much more demanding requirement might be appropriate.

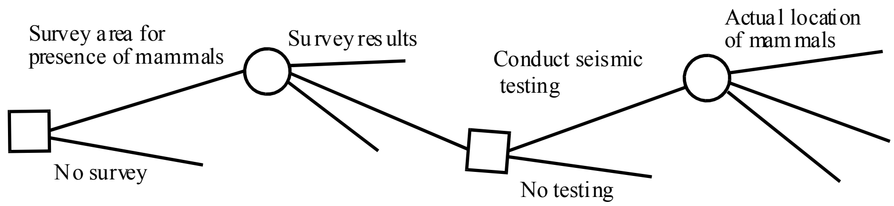


Figure 3.5. Decision analysis regarding hypothesis testing. Example in the context of environmental protection before seismic testing. Survey could consist of overflights. Utility (value) would appear at the branches at end of tree.

The present approach is summarized in two points: (a) assessment of all relevant impacts and associated uncertainties; and (b) assessment of whether the current state of scientific knowledge permits one to proceed to the next step, bearing in mind where appropriate that further assessments are to be made.

In the context of the second point, the regulatory regime is all-important (see Section 3.8 below, in which the Safety Case is discussed). Risks must be assessed and decisions made in such a way that the weight of the decision favours safety. Risk aversion dictates also that potential serious consequences should receive special attention. It is not sufficient to approve new technologies unless they can be shown to be unsafe. Rather, the "burden of proof" is on the innovator to show that the technology is safe. A word on this terminology: in dealing with risk issues, there is no deductive "proof;" it is rather a question of showing that the risks are managed to the level considered acceptable.

A final point should be made. The principle of "Polluter Pays" is often associated with the Precautionary Principle (see Saunders, 2000 for discussion, and O'Riordan and Cameron, 1994). This is also included in the US OPA 90 framework (see Section 3.10 below). It is assumed to be included along with the precautionary principle in the present study.

3.6.1 Record of offshore industry

Many statements of the precautionary principle are focussed on the application of new technologies, for example genetically modified foods. The present concern is not strictly new technology but rather application of known technology. Offshore oil and gas development has been carried out for many decades. Towards the end of the 19^{th} century wharfs were used in California for production. By the late 1940's several wells in the Gulf of Mexico had been drilled. By the present time over 4,000 facilities are in use in the Gulf of Mexico.

The record of the industry has been improving over these decades. It is important to assess recent trends and, indeed, to appreciate that the future promises further improvements. Several disasters have occurred and a selection of these will be reviewed below. Until about 1990, the safety record for human life in certain activities was about 10^{-3} per annum. This represents the record of workers on mobile offshore units in the time period 1980-90, during which several large accidents occurred. The Piper Alpha accident occurred in 1988.

Examination of the data since then indicates an improved trend. The record since 1990 for mobile offshore units is better than 10^{-4} per annum and indications are that it is continuing to improve. Some activities are more risky than others. Diving, some drilling operations and flying in helicopters are activities with higher risks.

The record regarding oil spills shows similar improvements. This is discussed in some detail in section 8.4. Historically, some very big spills have occurred but the recent record suggests that the situation is much improved. The size of a spill must be put into the context of time and the overall exposure.

The main point to be made here, in the context of the precautionary principle, is that offshore exploration and production are not new technologies and there is sufficient record for an assessment to be made of the safety of these operations.

3.7 Application of risk analysis to the environment

The overall approach is governed by the reasoning of the sections above. Particular problems could be modelled by idealizations suggested by this methodology. Application of decision and risk analysis methodology to conservation of the environment is under development (Harwood, 2000). For oil spills, there is a considerable amount of software and technology available (Garcia-Martinez and Brebbia 1998, for example). Figure 3.5 illustrates schematically how a strategy aimed at mitigation of impacts of seismic testing can be approached.

Probabilities and consequences of undesirable events must be analyzed. If large oil spills are to be considered, for example, these might be treated as accidents and the volume estimated at the annual exceedance probabilities of 10^{-4} and 10^{-5} (Figure 3.4). The impacts and mitigation of these spill volumes should then be modelled (see section 8.4). It is recognized that impacts can occur at different time scales, with some immediate (minutes to days) and some quite slow to emerge (years). This would be assessed in the modelling.

3.8 Regulation and safety

One of the main objectives of regulation is to achieve adequate levels of safety. The offshore industry is complex and Kallaur (2000), for example, emphasizes the range of issues. The US Minerals Management Service (MMS) rules currently reference all, or parts of, 85 different domestic standards on equipment or methods. Regulation also includes training and inspection. Training is highly important in light of the role of human factors in failures (section 3.5 above). MMS employs 60 inspectors to conduct more than 18,000 inspections related to facilities each year. The following brief discussion focusses on those issues considered important in the context of B.C offshore development.

Regulations are classified as being either prescriptive or objective-based. In the former, the specific means of achieving compliance with the regulation is mandated. One might specify "do not conduct seismic survey during the months of June and July." In the case of objective-based regulations, the goal to be achieved is specified and not the means to achieve it. In this case the objective might be "avoid damage to fish spawning in the area." Under this mandate, the regulatee has the possibility to adopt the most suitable means to achieve the objective.

Although a mixture of prescriptive and objective-based (or goal-setting) regulation is often used, the trend is towards stating objectives and permitting some flexibility in the method of achieving these. The use of quantitative risk assessment as a means of satisfying the objective-based regulations is becoming standard practice. This has long been the case in Norway. In the U.K., the Piper Alpha disaster and the consequent report by Cullen (1990) spurred the move towards the use of the "Safety Case" which is essentially an objective-based philosophy.

Sharp (2000) emphasizes that objective-based regulation "places clear responsibility on the organisations which create the risks; makes duty holders think for themselves; fosters a sense of ownership by duty holders of systems they develop themselves; provides flexibility which is more likely to lead to arrangements for controlling risk which are tailored to the particular circumstances; facilitates continuous improvement; is less likely to be overtaken by changes in technology."

3.8.1 Features of regulation in various jurisdictions

The management of safety is generally in the hands of national organizations such as the Minerals Management Service (MMS) for the outer continental shelf (OCS) of the United States, the Norwegian Petroleum Directorate (NPD) for the Norwegian offshore, the Health and Safety Executive (HSE) in the United Kingdom

Vinnem (1998) discusses Norwegian and other experience in the use of quantitative risk analysis. This had been used in the 1970's to confirm the appropriateness and robustness of the methodology and was required by the Norwegian Petroleum Directorate after 1981 for new installations in the conceptual design phase. The cutoff criterion of 10^{-4} per annum was introduced as the limit for accidents that need to be considered to define design basis accidents. This is consistent with the approach in CSA (1992).

After the Piper Alpha disaster and the Cullen report, the use of quantitative risk assessments became a part of the safety case analyses (see Sharp, 2000). Australian experience was originally based on prescription but after the Cullen report, and in particular the Longford disaster of 1998, there was a move towards objective-based regulation maintaining prescription where required (Butler, 2000). Strong and well resourced regulators are a necessity, with a role for national government in maintaining national consistency.

The MMS uses mainly prescriptive regulations (Kallaur, 2000). Typical of these are the regulations on well blowout preventers, or BOPs. These rules are prescriptive because they specify equipment, methods, and behavior. The requirement specifies the equipment application and the technical specifications. A BOP is required during all drilling operations. A number of specific technical features are required, such as annular and ram-type preventers and a range of valves and control devices. At the same time, there are objective-based rules within the MMS regulatory regime (Kallaur, 2000).

3.8.2 Canadian regulation

In Canada, the regulatory authority is in the hands of regional boards such as the Canada-Nova Scotia Offshore Petroleum Board (CNSOPB) and the Canada-Newfoundland Offshore Petroleum Board (CNOPB). The CNOPB regulations include both prescriptive and objective-based regulations but are mainly prescriptive.

It is important to note that the Newfoundland Offshore Regulations, SOR95-104, refer extensively to the Canadian Offshore Standards for structural design discussed in section 3.9. These standards contain explicit safety targets that are consistent with the value of 1 in 100,000 per year advocated in section 3.5.

3.9 Structural codes

Design of engineering installations is dealt with by various standards and codes of practice. In view of their importance, the situation with regard to codes of practice for the design of fixed and floating structures that are used in production is briefly reviewed. Such structural codes have been developed in several countries. For example, in the USA, the American Petroleum Institute (API) has developed Recommended Practices (RP). The classification societies (DnV, ABS, Lloyds,...) have rules for design and some of these are published. The Canadian Standards Association (CSA) has developed a standard based on a consensus of interest groups (such as operators, fabricators, consultants, and regulators) using load and resistance factors in design (LRFD). It has explicit safety targets

The CSA code was developed with the harsh environment of wind waves, ice and earthquake in mind. Explicit target safety levels were developed and a calibration was carried out to achieve these. The Canadian practice is contained in the Canadian Standards Association Code for the Design, Construction, and Installation of Fixed Offshore Structures. In particular the Standard CAN/CSA-S471-92, General Requirements, Design Criteria, the Environment and Loads part of the code sets the safety objectives for the code as a whole. An important aspect is the question of safety classes. These are defined in clause 4.5.2. The Standard defines two safety classes for the verification of the safety of the structure or any of its structural elements:

Safety Class 1 - failure would result in great risk to life or a high potential for environmental damage, for the loading condition under consideration; and

Safety Class 2 - failure would result in small risk to life and a low potential for environmental damage, for the loading condition under consideration.

The safety objectives are summarized in Table 3.3. The treatment of loads is tailored to meet these safety objectives. These are divided into rare and frequent, for example, earthquakes and wind loading respectively. Figure 3.3 illustrates the demand and capacity (load and resistance) and a calibration has been carried out to determine the factors in Table 3.4.

The S471 standard has recently been updated and a new edition will be issued. The safety provisions above have been maintained. It should be noted that the practice is to compensate for uncertainties by including conservatisms in estimates of load or resistance.

Table 3.3. Safety Classes and Reliability (CAN/CSA-S471-92, Table A1)

Safety Classes	**Consequences of Failure**	**Target Annual Reliability Level**
Safety Class 1	Great risk to life or high potential for environmental pollution or damage	10^{-5}
Safety Class 2	Small risk to life and low potential for environmental pollution or damage	10^{-3}
Serviceability	Impaired function	10^{-1}

Table 3.4. Annual Exceedence Probabilities for Specified Loads (CSA S471 Table A2)

	Safety Class 1		**Safety Class 2**	
	Annual Exceedence Probability, p_E	Load Factor	Annual Exceedence Probability, p_E	Load Factor
Specified loads, E_f, Based on frequent environmental processes	10^{-2}	1.35	10^{-2}	0.9
Specified loads, E_r based on rare environmental events	10^{-4} to 10^{-3}	1.0	10^{-2}	1.0
Specified accidental load, *A*	10^{-4} to 10^{-3}	1.0	N/A	N/A

3.10 Regulations for tankers

The International Maritime Organization (IMO) regulates international shipping. Its members have adopted a number of conventions, including the International Convention for the Prevention of Pollution from Ships, 1973, as amended by the Protocol of 1978 (MARPOL 73/78) and the International Convention on Safety of Life at Sea, 1974 (SOLAS 74). In 1992, the MARPOL Convention was amended to make it mandatory for tankers of 5,000 dwt and more to be fitted with double hulls, or an alternative design approved by IMO. After the sinking of the ERIKA off the coast of France in 1999, amendments were made to Regulation 13G of Annex I of MARPOL to speed up the elimination of single-hulled tankers by 2015. In 1995, Canada's *Oil Pollution Prevention Regulations* were amended to specify that any oil tanker undertaking voyages in waters under Canadian jurisdiction shall comply with standards for introduction of double-hulled construction.

In the US, the Oil Protection Act (OPA) of 1990 also specifies the modernization to double hulls, increased enforcement and the "polluter pays" principle. Canada has adopted the revised MARPOL requirements for the phase out of single hulled tankers on international voyages in waters under Canadian jurisdiction but will continue to apply OPA 90 (US) provisions for Canadian tankers on domestic voyages or trading to the US and for US tankers trading in waters under Canadian jurisdiction. The two regimes are not identical and there are different tonnage cut-offs. The OPA 90 and revised IMO schemes are very similar, so there will not be a significant difference in environmental protection.

3.11 Environmental impact statements

This description of current practice in offshore environmental assessment in Canada is based on experience of the east coast. The practice is first to carry out Strategic Environmental Assessments (SEA's) of any region in which oil and gas activities are being considered (LGL 2003, for example). These are not to be seen as replacing project-specific environmental assessments, which are complementary to the SEA's. They are concerned with regional-scale issues and assist in identifying issues in broad terms, for early consideration and planning and focussing of site-specific EA's. The SEAs include public consultation.

In Newfoundland, before obtaining a Work Authorization, there are several elements that need to be supplied, including an environmental assessment which has to be carried out. This applies to drilling programs, seismic surveys and development programs. These are specified under the Accord Act and under CEAA. It is noteworthy that the CNOPB is a Federal Authority under CEAA.

Seismic programs need a screening level assessment in which public consultation is recommended. Comprehensive studies with public consultation are required for the first wells drilled in an area not previously assessed in such a study. All aspects of the development plan, including safety, design and reservoir proposal are studied. Permitting of production developments is required under federal legislation, including assessment of proposals to limit habitat loss and ocean dumping. For permits for production operations, there are requirements for environmental effects monitoring.

For completing these requirements, there is much existing information from Fisheries and Oceans Canada, Environment Canada and National Energy Board programs such as the Program of Energy Research and Development (PERD) and the Environmental Studies Research Fund (ESRF). Baseline studies specific to production sites are needed, with modelling of oil spill trajectories and produced water, and any retained oil on drilling cuttings. Risk analyses for drilling waste management and oil spills are required. Monitoring of the environment is required with development using indicator species. The plans should be developed in consultation with the public, with a plan sufficiently robust to detect changes. Indeed, there is benefit in making Environmental Impact Statements more quantitative than has often been past practice (Gray and Jensen, 1993).

The White Rose project is a recent one in which the review process has been successfully completed for a facility faced with severe environmental conditions, including full CEAA process and public hearings (see link to environment under http://www.cnopb.nfnet.com/).

3.12 Assumptions for the Queen Charlotte Basin

For consideration of any possible oil and gas activities in the region, it is assumed that a competent regulatory regime is in place. This should be independent and at arm's length from government and industry. It is suggested that this be set up with guidance from those with substantial past experience.

There is also a good case for pooling national expertise in cases where safety issues, structural codes and probabilistic analyses are needed.

The preferable approach is based on the Safety Case (objective-based or goal-setting regulation) with prescription where needed, in other words, a judicious mixture of prescriptive and objective-based regulation. To implement this, the requirements for regulators are demanding. Sharp (2000) of the HSE states that "The expertise of regulator and duty holder staff is critically important to the standards of control actually achieved." Objective-based regulation places the responsibility for resolution of issues and development of solutions on the developer whose activity causes the risks.

It is further assumed that unambiguous safety targets are stated in the regulations. Targets for specific process causes are assumed at a level of 1 in 100,000 and for all causes 1 in 10,000 per annum. The ALARP principle should be used to assist in judging individual cases with a range from 1 in 10,000 (10^{-4}) to 1 in 100,000 (10^{-5}) per annum. These should reflect recent improvements (e.g., HSE, 2001). Values of the order of 1 in 1000 are no longer acceptable. It should be remembered in evaluating impacts that the amplitude of the impact should include a factor related to persistence.

The CSA offshore code reflects these safety objectives. This was issued in 1992 and has recently been updated (in press) with essentially the same objectives. The move at present is towards ISO standards. The current ISO drafts do not contain stated safety objectives so that the safety levels are at present not known. The present indications are that the draft of earthquake load levels are not equivalent to the CSA level. It assumed that the CSA levels of safety will be maintained for any offshore industry in British Columbia.

With regard to transportation of oil, it is considered that pipelines do not necessarily present a safer solution than tankers if the technology and operations for the latter correspond to modern developments using shuttle tankers (sections 2.8, 8.4). Accordingly, it is assumed in this report that any future transportation of hydrocarbons using tankers will be consistent with the new Marpol and OPA regulations, with double-hulled vessels, and further, with modern shuttle tanker technology and operations.

Implementation of regulations and design should be guided by the precautionary approach as stated in section 3.6 above. It is further assumed that environmental assessments, as in recent Newfoundland developments (CNOPB), be carried out, including a thorough SEA for the QCB. The present report and others that preceded it on BC offshore development outline the scope of the issues for such an SEA but do not substitute for it. An EA requires comprehensive documentation of potential impacts including modelling, for instance of acoustic propagation and oil spill dispersal and evaluation by critical species.

CHAPTER 4

PHYSICAL DESCRIPTION OF THE QUEEN CHARLOTTE BASIN

4.1 Climate, weather and waves

The marine climate, weather, and wave conditions in the Queen Charlotte Basin (QCB) have been recently reviewed by the Strong Report (2002), the JWEL Report (2001) and by Cretney et al., (2002). The main features of the system will thus be summarized only briefly in this section, and draw largely on data presented in the aforementioned reports as well as from workshop presentations presented to the Panel by D. Masson (Fisheries and Oceans Canada) and L. Neil (Environment Canada).

4.1.1 Overview of climate

The QCB experiences some of the most extreme wind and wave conditions in Canada. The climate is dominated by the Aleutian Low and the North Pacific High. The Aleutian Low, which dominates in fall and winter, produces winds that blow mainly from the south-southeast. Winds are strongest between November and March, when average wind speeds are usually in excess of 35 km/h (Table 4.1.), and gust speeds occasionally reach 200 km/h. During this period, intense storms sweep across the basin every 2-3 days. During spring and summer, when the system is dominated by the North Pacific High, winds over the QCB are less intense (usually less than 30km/h) and generally blow from the north-northeast.

Table 4.1. Winter wind conditions in the Queen Charlotte Basin. From data presented in Strong et al., (2002)

Month	November	December	January	February	March
Mean windspeed (km/h)	34	37	39	40	38
Maximum gust (km/h)	191	181	191	189	193

Although the QCB is a seasonal environment, the range of air temperatures experienced in the basin is relatively modest (Table 4.2). Across most of the basin, air temperatures vary by only 10-12°C throughout the year. One positive consequence of this is that freezing conditions, which are of considerable concern to oil and gas facilities in other jurisdictions, are not common in the QCB (usually fewer than 20 frost days per year). Annual rainfall in the area surrounding the basin is quite high but also quite variable, ranging from less than 1m to more than three metres per year, depending on the location.

Table 4.2. Weather averages for towns around the Queen Charlotte Basin. From http://www.climate.weatheroffice.ec.gc.ca

Location	Cape St. James	Sandspit	Prince Rupert	Port Hardy
Mean January temperature (°C)	4.9	3.2	1.3	3.3
Mean August temperature (°C)	14.2	15.0	13.5	14.1
Annual Rainfall (mm)	1563	1341	2469	1808
Days with winds >50 km/h	187	4.7	14.4	2.5
Days with temperature < 0°C	2.2	51	9.5	12

4.1.2 Winds and waves

Marine weather conditions off the coast of BC are monitored via an array of 16 weather buoys. In addition to weather data, the buoys also record wave height data. The locations and annual mean wave heights recorded for each buoy are shown in Figure 4.1. Annual mean wave heights in the QCB range from more than 2.5 m at the mouth of Queen Charlotte Sound, about 2m in the central portion of the Sound, to about 1.5 m in Dixon Entrance to the north.

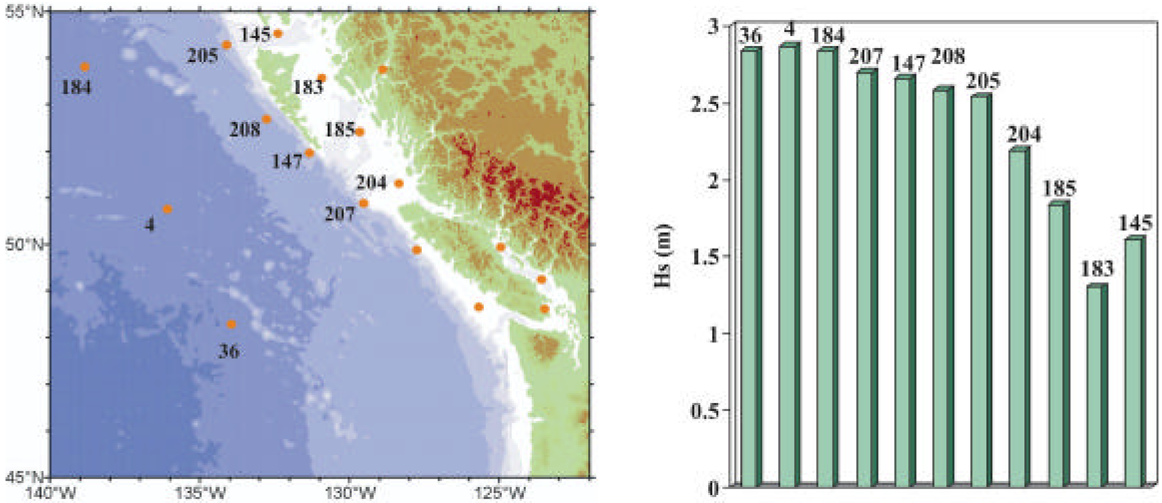


Figure 4.1. Left panel shows distribution of weather buoys along the BC coast. Right panel shows the annual mean significant wave height (m) for each buoy. (From D. Masson, 2003, personal communication, workshop presentation)

Hourly wind data are collected from a number of shore stations, with data available for the past 50-60 years. These data are further supplemented by lighthouse reports every 3 hours during daylight (Neil, 2003). In the 1986 WCOEEAP report, it was noted that a six-hour warning of extreme storms was the minimum required for an oil rig to safely cease operations and prepare to safely disconnect from its wellhead. At that time, the Atmospheric Environment Service (AES) of Environment Canada was unable to guarantee such forecasts and the WCOEEAP therefore recommended that exploratory drilling not be allowed to commence until such forecasts could be made. Although numerical modelling techniques and, consequently, the wind forecasts produced by the Canadian Meteorological Centre in Montreal (using data from weather buoys, shore based stations, and direct observations from ships of opportunity) have certainly improved in the intervening years (JWEL, 2001), the Panel was told that forecasters still cannot guarantee six hours warning for such extreme weather events (JWEL, 2001; Neil, 2003). Short-term forecasts will remain the responsibility of human forecasters in regional weather centres for some time to come.

4.1.3 Extreme waves and "weather bombs"

The strong winds and frequent storm events in the QCB also give rise to extreme sea state conditions, especially during the winter months. In addition, field studies near Cape St. James by Masson (1996) have demonstrated that interactions with the strong tidal currents of the QCB, such as those observed near Cape St. James, can also result in further amplification of wave height. A retrospective analysis (hindcast) of winds in the QCB covering the period of 1957- 1989 (MacLaren Plansearch, 1991, cited in Cretney et al., 2002) estimated a 100 year significant wave height (H_s) of about 13m (representing the average height of the highest 1/3 of the waves), and a highest wave height (H_{max}) of about 25m. Cretney et al. (2002) note, however, that these should be updated as they did not factor in the effects of shallow topography (which can amplify extreme waves) or the sort of wave-current interactions documented by Masson (1996).

Interestingly, there have been several instances in which weather buoys along the northern BC coast have recorded waves of up to 30m in height (Gower and Jones, 1994). These , if accurate, would be considerably higher than the predicted 100 year H_{max}. The authors note, however, that as these waves are measured from fixed accelerometers, it is possible that tilting of the weather buoy during severe storms could result in overestimates of wave height. Nonetheless, there is some direct evidence that "monster waves" do occur in the QCB region: in 1968 an oil rig anchored near Cape St. James encountered (and safely withstood) a wave estimated to be 29 m high (James, 1969).

Cretney et al. (2003) note that there are plans to add gimballed accelerometers and at least one directional wave sensor to the offshore weather buoys along the BC coast in the near future. This should help to improve our understanding of extreme waves in the QCB region. New techniques for detecting rogue waves from satellites equipped with synthetic aperture radar (SAR) are also being developed, and this will help to elucidate where and when (and under what conditions) such waves form (Dankert et al., 2003).

In addition to storm frequency and intensity, the speed with which extreme sea states can develop is of particular concern in the QCB. Figure 4.2 shows data from one such marine "weather bomb" event (recorded at weather buoy #207 in Figure 4.1) in which air pressure dropped by 60 millibars (from 1020 to 960) and H_s and H_{max} climbed to 14 m and 28 m respectively, in just 8 hours. Such rapid development of extreme sea states may have implications for oil and gas development.

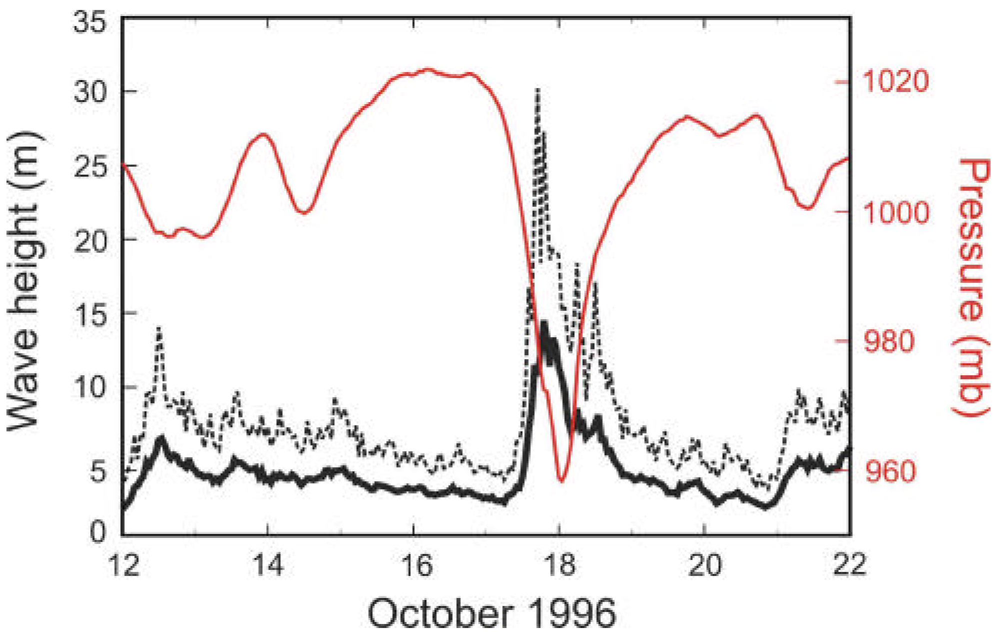


Figure 4.2. Data from weather buoy 207 showing rapid increase in wave height during a severe storm event. (From D. Masson, 2003, personal communication, DFO workshop presentation)

4.2 Bathymetry and physical oceanographic setting

The physical oceanographic setting of the QCB has been reviewed by Dodimead (1980), Tabata (1980) and Thomson (1981), based largely on data collected by the Pacific Oceanographic Group during the 1950s and 60s. Scientists from the Institute of Ocean Sciences (DFO) conducted a series of more detailed oceanographic studies between 1982-1995. The current state of knowledge of the region (based largely on results from these studies) has been recently reviewed by Cretney et al., (2002). Thomson (1981) describes the QCB as a coastal seaway consisting of three main oceanographic regions. In the north, the QCB is connected to the open subarctic Pacific via an east-west passage known as Dixon Entrance. In the south, Queen Charlotte Sound spans the region between Cape St. James (at the southern tip of Moresby Island) and the north end of Vancouver Island. The main body of the QCB, Hecate Strait, is bounded by the Queen Charlotte Islands to the west and the BC mainland to the east (Figure 4.3).

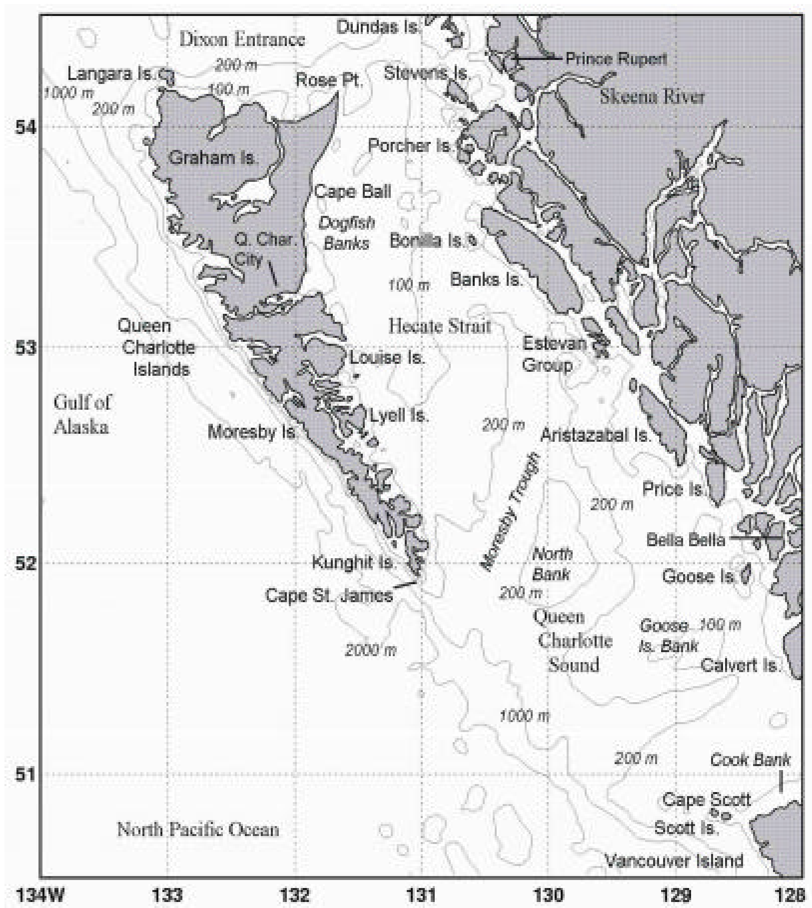


Figure 4.3. Bathymetric map of the Queen Charlotte Basin. (From W. Crawford, 2003, personal communication, workshop presentation)

4.2.1 Bathymetric features

Entering the QCB through Queen Charlotte Sound, the bottom depth begins to shoal from greater than 1000m to less than 400 m. Three submarine canyons extend into the sound. The largest of these, Moresby Trough, extends about 270 km northeastward toward Banks Island on the eastern side of Hecate Strait, shoaling from more than 400 m to about 100 m (Thomson, 1981). The other two canyons are shorter; one extends about 60 km east and shoals toward the Central coast while the other turns southeastward toward Queen Charlotte Strait. Hecate Strait is considerably shallower than Queen Charlotte Sound, with bottom depths averaging less than 100 m, and shoaling to less than 50m at the northern and eastern edges. In contrast Dixon Entrance is also quite deep with the main channel averaging more than 300 m. To the west, the channel splits into two branches around the shallow Learmonth Bank (<40 m), and then deepens to >400 m as the channels lead offshore.

4.2.2 Tides and tidal currents

The tide floods into the main portion of the QCB from two directions (Figure 4.4): northeastward through Queen Charlotte Sound and southward from Dixon Entrance (Thomson, 1981). Tides within the basin are generally classified as 'mixed semidiurnal,' meaning that there are usually two (unequal) high tides and two (unequal) low tides per day. The region also includes the highest tidal ranges in BC (Cretney et al., 2002).

Mean tidal ranges at the mouth of Queen Charlotte Sound and the western end of Dixon Entrance are generally around 3.0 - 3.5 m, with the tidal range increasing eastward. In the central portion of Hecate Strait the tidal range is more than 4.5 m, and tides in excess of 7.0 m occur near Prince Rupert and Queen Charlotte City (Thomson, 1981; Cretney, 2002).

QCB tidal currents are typically vigorous (Thomson, 1981) and have been simulated in several high-resolution tidal circulation models (*e.g*, Cummins and Oey, 1997; Foreman et al., 2000). In the central part of Hecate Strait, tidal currents average about 1 knot (0.5 m/s). In other areas (such as Rose Point in the north and Cape St. James in the south), tidal currents are much stronger, and can exceed 4-5 knots (2.0 - 2.5 m/s) (Cretney et al., 2002). Crawford et al. (1998) point out that this picture is further complicated in Dixon Entrance, where an internal tidal current with a magnitude of several knots (but often in a direction different than that of the surface tidal current) also exists. Elsewhere in the QCB, however, Thomson (1981) states that near-bottom tidal currents are usually only of order 15-25 cm/s.

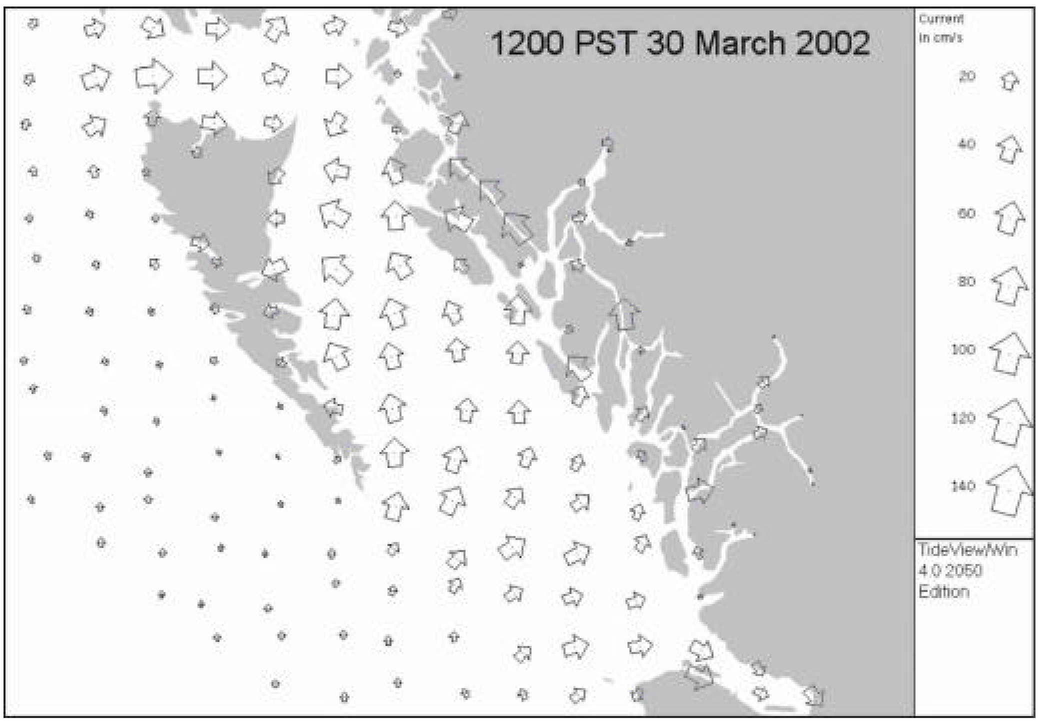


Figure 4.4 Tidal currents in the region of the Queen Charlotte Basin, based on Thomson (1981). Size of arrows is proportional to magnitude of current. (From W. Crawford, 2003, personal communication, workshop presentation)

4.2.3 Non-tidal currents

In addition to tidal forcing, circulation in the QCB is also affected by winds and river runoff. The influence of these two factors are generally out of phase, however, with river runoff (mainly form the Nass and Skeena Rivers in the northern portion of the basin) being most important in late spring through early summer (April - June) and wind forcing having its greatest influence during the fall and winter months (i.e. October to March).

Between 1982 and 1995, the near-surface circulation in the QCB was investigated using various types of drifters (usually either radio- or satellite-tracked) which were drogued to follow the movement of the upper 15m of the water column. Drifter studies were further supplemented by observations from satellites. The results of these studies have been summarized by Crawford et al., (1995, 1999) and Crawford (2001), who discuss several regions of particular interest. It should be noted that these studies were conducted in the spring and summer and that there is much less information available regarding the details of winter circulation patterns in the basin.

Drifters released in southern Hecate Strait and Queen Charlotte Sound during the summer generally followed only a few trajectories. Those exiting the QCB into the offshore did so via Cape St. James (occasionally achieving speeds of up to 5 knots). Those that remained in the basin either moved northeastward along Moresby Trough or they became entrained in a clockwise eddy in the southern portion of the QCB. Drifters released during the summer in northern Hecate Strait and Dixon Entrance were generally entrained into the counter-clockwise Rose Spit eddy (Bowman et al., 1992) where they became trapped for periods of days to weeks (Crawford et al., 1995). Summer outflow from the Skeena River also moves out of the QCB , through Chatham Sound, as a plume that extends westward along the northern side of Dixon Entrance although this occasionally turns south and also becomes entrained by the Rose Spit eddy (Cretney et al., 2002).

4.3 Tsunamis

Tsunamis are caused by sub-sea earthquakes or submarine landslides. The main risk from tsunamis is shore run-up, during which the wave shoals rapidly (up to 10's of metres in height) as it reaches land. In contrast, tsunami amplitudes at sea are generally quite small (of order 1 m). Tsunami threats to the QCB region come from both distant and local sources. The main distant sources are believed to be the Aleutian Islands, the Kamchatka Peninsula and Chile. Tsunamis from Alaska and Chile reached the region in 1960 and 1964, respectively, with amplitudes about 1 m in the vicinity of the QCB , measured in the nearshore, where amplitudes may be greater than in mid-channel because of run-up effects. Amplitudes were considerably higher along parts of the west coast of Vancouver Island.

Of perhaps greater concern is the possibility of a locally generated tsunami. Both the Cascadia subduction zone (to the south) and the Queen Charlotte Fault (along the west coast of the Queen Charlotte Islands) are believed to experience earthquakes of magnitude 8 or more every several hundred years. A moderate seismic event (magnitude 6.3) occurred on the Queen Charlotte Fault in 2001 and produced a small (but still measurable: 0.1 m) tsunami. Were a large earthquake to occur close to the QCB, the tsunami that would be produced could be severe, and with virtually no warning time. Most of the earthquakes along the Queen Charlotte Fault involve horizontal slip which would not produce a large tsunami effect.

Several models (summarized by Cretney et al., 2002) have been developed to predict the likely run-up conditions of tsunamis throughout the Cascadia region, while studies by Ng et al., (1990a,b) have specifically included the QCB. For most Cascadia zone tsunami scenarios the models predict run-up in the QCB of order 1m. The main shortcoming of these models is that they do not include realistic seafloor topography for the QCB, which is critical to accurate estimating tsunami behaviour (F. Stephenson, 2003, personal communication, workshop presentation). Elsewhere in this report the Panel has recommended that high resolution SEAMAP data be collected in the QCB (for various other purposes). We note here that these data would help improve estimates of tsunami run-up, in addition to helping pinpoint locations of possible underwater landslides (the other main source of tsunamis) in the QCB.

Tsunami alerts are issued by the Alaskan Tsunami Warning System and the International Tsunami Warning System. The Canadian Hydrographic Service (CHS) currently maintains three tsunami monitoring stations in BC: Langara Island (NW tip of the QCI), Winter Harbour (NW end of Vancouver Island) and Tofino. Although these stations are not currently part of the network of monitoring stations used by either of these tsunami warning networks, plans are apparently underway to tie them into the system in the near future (Cretney et al., 2002). The Panel assumes that should oil and gas development proceed in the QCB, the operators of such facilities will also be tied into the warning system through the CHS.

4.4 The seabed

The seabed of the QCB is covered by soft sediment, with bedrock exposed in a few places. The sediment is predominantly silty but there are marked local variations, including some boulder beds, as well as some biogenic reefs (e.g., the hexactinellid sponge reefs).

Glacial sediment (till), generally covered by post-glacial sediment, occupies much of the area, particularly in depressions in bedrock. The last major ice advance did not reach the QCB. The weight of ice depressed the land surface where it lay on the mountains to the east but a complementary peripheral bulge developed beyond it along the coast (Barrie and Conway, 2002). This resulted in the shallow banks of the QCB being exposed as land. These former lands within the QCB included lakes which were filled with lacustrine sediment and were bounded by shorelines with local deltas. Rapid subsidence of up to 150 m occurred when the ice melted about 10,000 years ago. Since then, subsidence has continued slowly in the QCB (Barrie and Conway, 2002). The resulting rise in sea level is responsible for coastal erosion today, as much as 1-3 m of shoreline retreat being observed locally per annum.

A series of unique siliceous (i.e., hexactinellid) sponge reefs was discovered on the seabed in the QCB during seismic surveys in 1986 (Figure 4.5). These reefs occur in 160-240 m water depth. They are situated along ancient iceberg furrows and are the only-known example of living hexactinellid sponge reefs in the world (Conway et al., 2001).

Regional features of the seabed are shown in Figure 4.6, and a detailed view of a small area of seabed is shown in Figure 4.7.

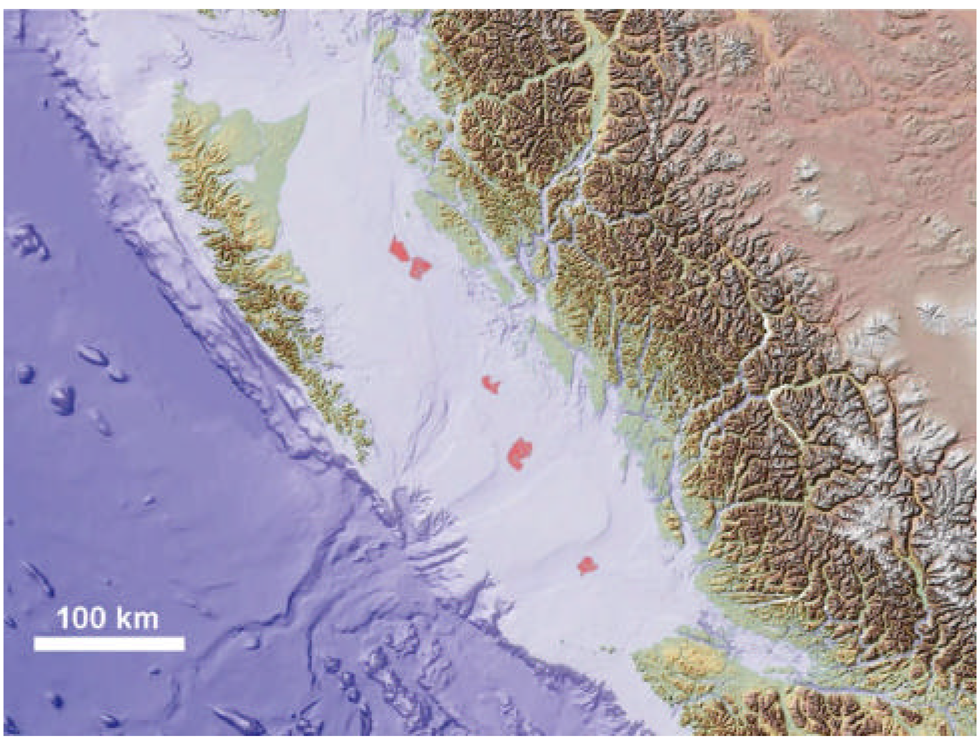


Figure 4.5. Shaded relief map of the Queen Charlotte Basin. Darker blue shows deep water Pacific Ocean basin; light blue shows continental shelf, with generally shallow water cut by a few deep troughs. Pink areas are locations of sponge reefs. (Figure provided by K. Conway, 2003, peronal commmunication, workshop presentation; location of sponge reefs is provided by Conway et al. 2001)

The unusually rugged nature of the seabed in the QCB poses a number of potential hazards to oil and gas activities. These include slope stability, moving sediment, shallow gas, and active faulting.

Figure 4.7 shows wrinkling of layers of sediment as they slip down slopes on the seabed. Downslope movement of sediment may be induced by earthquake ground motions or strong bottom currents during storm events and may be aided by high pore pressures within the sedimentary layering. Such movement has the potential to threaten the integrity of seabed infrastructure such as well heads, production platform legs and pipelines.

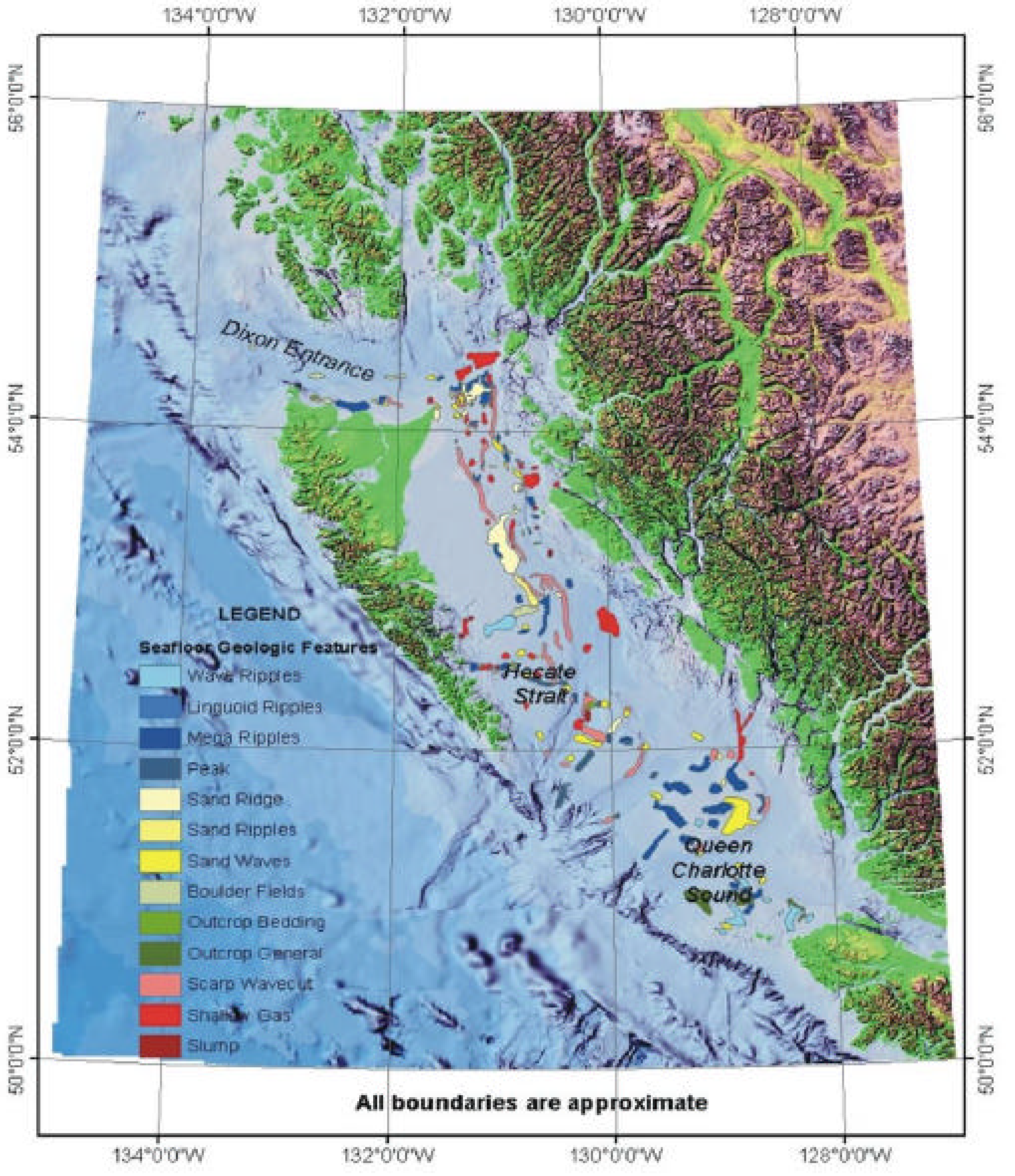


Figure 4.6. Major features of seabed sediments, Queen Charlotte Basin (From V. Barrie, 2003, personal. communication, workshop presentation; compiled from Barrie et al., 1990a,b,c,d,e).

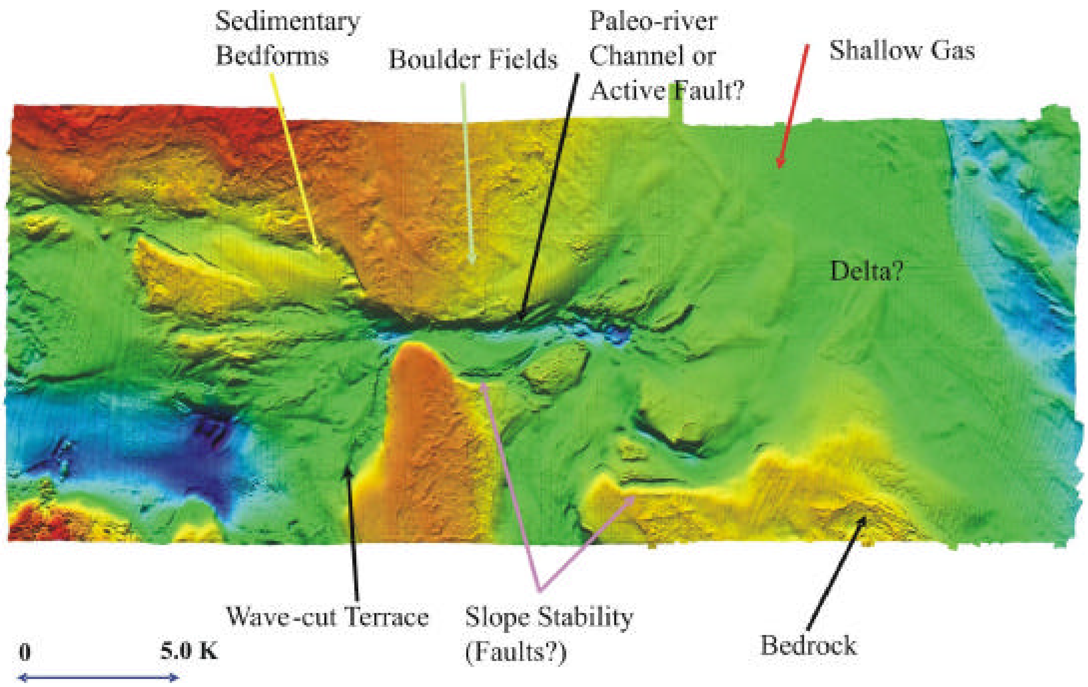


Figure 4.7. Swath bathymetry image of an area of the Queen Charlotte Basin (From V. Barrie, 2003, personal. communication, workshop presentation; preliminary interpretation of unpublished multibeam bathymetry data from Hecate Strait, Geological Survey of Canada, 2003).

The same problems could also arise from other mechanisms of seabed sediment transport, not just those associated with instability on steep slopes. There are considerable areas of the seabed in the QCB which appear to be formed by large scale ripples known as sand waves. These are migrating bedforms with amplitudes of around 1 metre, sufficient to undermine shallow-trenched pipelines and any other structures placed immediately on the seabed without burial.

Pock marks are a common feature of continental shelf floors, including the QCB (see Figure 4.7). They mark sites of eruption of gas from underlying sediments. The gas may be of shallow biogenic origin (e.g., methane) or from deeper thermogenic sources (e.g., usually a mixture of methane, ethane and propane). Gas will burst out of the sediment that contains it when its pore pressure exceeds that of the ambient stress field (in the case of unconsolidated sediment, this is essentially the load pressure of the sediment). The occurrence of pock marks in the QCB indicates that the local seabed is prone to such high pore pressures. This is of concern even in situations where the pore pressure is just below ambient, since the addition of a production structure on the seabed could cause an increase in pore pressure that would destabilize (liquefy) the sediment. An earthquake could also cause local pore pressure to fluctuate, so exceeding ambient.

The QCB is an area of current earthquake activity. Earthquakes occur along faults. To date, no faults imaged on high-resolution seismic profiling of the QCB show unequivocal evidence of currently-active faulting, but the grid of such profiles is sparse enough that active faults may exist. A fault movement would endanger the integrity of seabed structures cutting across the fault surface (e.g., a well bore) and could also cause a rise in pore pressures in sediments that could destabilize them.

Knowledge of seabed geology is obtained through high-resolution seismic profiling, using techniques similar to those employed in hydrocarbon exploration, except that sources are of higher frequency (to better resolve fine layering), and lower power, and often short single-channel hydrophone arrays are used as receivers. Deep-tow profilers are sometimes used to provide close-ups of the seabed in deeper water. Thus far, the seafloor geology of the QCB has only been mapped from a grid of profiles with spacings of 10-15 km (Barrie, 1988). Interpretation of the seismic profiles has been tied to seabed sampling on a 10 km grid. In some selected areas (e.g., around sponge reefs), swath bathymetric data has been obtained (Figure 4.7) to demonstrate the striking enhancement of knowledge from this 100% coverage of the seabed. This recently-developed technique can provide a wealth of information relating to seabed conditions, applicable to geotechnical characterizations needed for safe emplacement of seabed infrastructure and to mapping of habitats of critical benthic fauna. What is clear from the example illustrated is that many features of the seabed occur at length scales much shorter than the 10-15 km resolution of the seismic profiling grid, which therefore is susceptible to missing key features of the seafloor. Only one of the existing profiles crosses the illustrated area, showing that many features shown there might be missed, if swath data were not available.

4.5 Earthquakes

Earthquakes occur frequently in the region of the QCB (Figure 4.8; http://www.pgc.nrcan.gc.ca/seismo/recent/eqmaps.html; Bird, 1997; Rohr, in Strong et al., 2002, Appendix 8; JWEL, 2001, pp. 62-64). Most are located close to the Queen Charlotte Fault, a major horizontal-slip fault lying west of the Queen Charlotte Islands. Large earthquakes have been recorded from this fault: a magnitude 8.1 earthquake in 1949, and a magnitude 7.4 in 1974. Other earthquake foci lie along linear belts in the northern part of the QCB, close to known faults (e.g., the Rennel Sound Fault and the Sandspit Fault), the trends of which are almost parallel to the QCF. However it is also clear that many of the earthquakes in the northern QCB are not associated with known faults, but rather form a diffuse set, presumably reflecting motion along many minor faults. These earthquakes occur on land and within the northern Hecate Strait and can be quite strong: a magnitude 5.3 event was recorded in 1990. The mechanisms of the earthquakes within the QCB include both thrust (compressional) and strike-slip (horizontal shearing) fault displacements as is anticipated close to an obliquely convergent plate margin. These conclusions are based on analysis (Bird, 1997) of events recorded in 1982-1996 when additional seismic instruments were placed in the area. It is not clear whether a 14-year record can be used reliably to predict longer term distributions of events, for example, over the potential 20-50 years of production typical of many oil fields.

Anticipated levels of ground motion associated with earthquakes have been estimated in the latest earthquake hazard maps available from the Geological Survey of Canada (Adams and Halchuk, 2003). These are based on empirical relationships between ground motion and earthquake magnitudes established from intensive studies of seismicity in California. It is widely assumed that such relationships might reasonably hold elsewhere or, at least, lead to conservative estimates for other areas. Illustrations of ground motion (for 'firm' ground) show that the floor of the QCB is less susceptible to large motions than much of the Queen Charlotte Islands (Figure 4.9a), but that accelerations for an annual recurrence probability of $4x10^{-4}$ are still quite significant—on the order of 0.3 g. The regional variations illustrated are dominated by earthquakes on the Queen Charlotte Fault, though the effects of the very largest of these is not well constrained, nor is there certainty that the nature of earthquake activity is invariant with time as is assumed in such estimates. The possibility of large local ground motions close to active faults within the north Hecate Strait area also cannot be discounted and must be given special consideration in plans for drilling close to such faults. The Panel notes (from correspondence with oil company personnel) that oil production from wells drilled through active faults can be safeguarded from blow outs caused by shearing of the well bore by fail-safe valves below the intersection of the fault with the bore. It is also noted that planning of production would generally avoid such intersections if at all possible.

Oil is currently produced from earthquake-prone regions in many parts of the world, including the Los Angeles basin in California, which has similar active horizontal-slip faults to the QCB. Design criteria based on the CSA Offshore Standard (S471) would yield safe response to loads with annual exceedance probabilities in the range 10^{-3} to 10^{-4} (associated with so-called 1000 year and 10,000 year events, respectively). The uncertainties of extrapolating to the highest magnitude earthquakes from the instrumental record are not negligible; conservative estimates are used, but better instrumental determinations of stronger events would be valuable (most instrumental observations are good for magnitude 6 events or weaker). Strong motion instruments should be deployed to provide better information on the Queen Charlotte Fault, while seabed instrumentation within the northern Hecate Strait would yield valuable information on the local events.

It should be noted in this context that the estimates of recurrence of larger earthquakes are made from extrapolation of the frequency distribution of smaller earthquakes, given an expected limiting magnitude to which the distribution becomes asymptotic. This can lead to problems where the instrumental record insufficiently samples events of larger magnitude. An example from the Georgia Basin, a few hundred kilometres south of the QCB is given in Figure 4.10, which shows that there are a few large earthquakes in the record that lie above the extrapolation from smaller earthquakes.

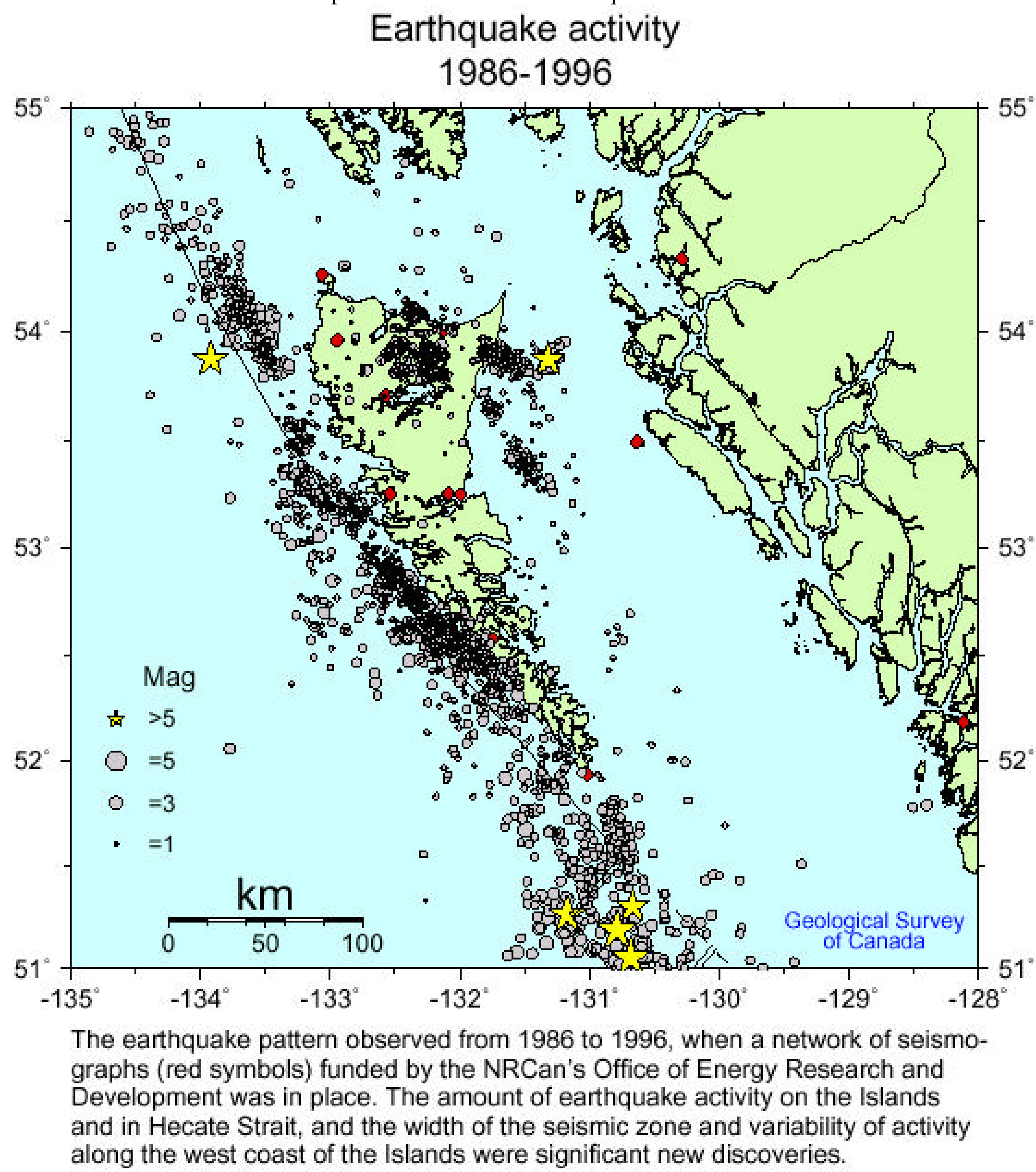


Figure 4.8. Epicentral locations for earthquakes recorded in Queen Charlotte Basin, during intensive data acquisition 1986-1996 (From Bird et al., 1997).

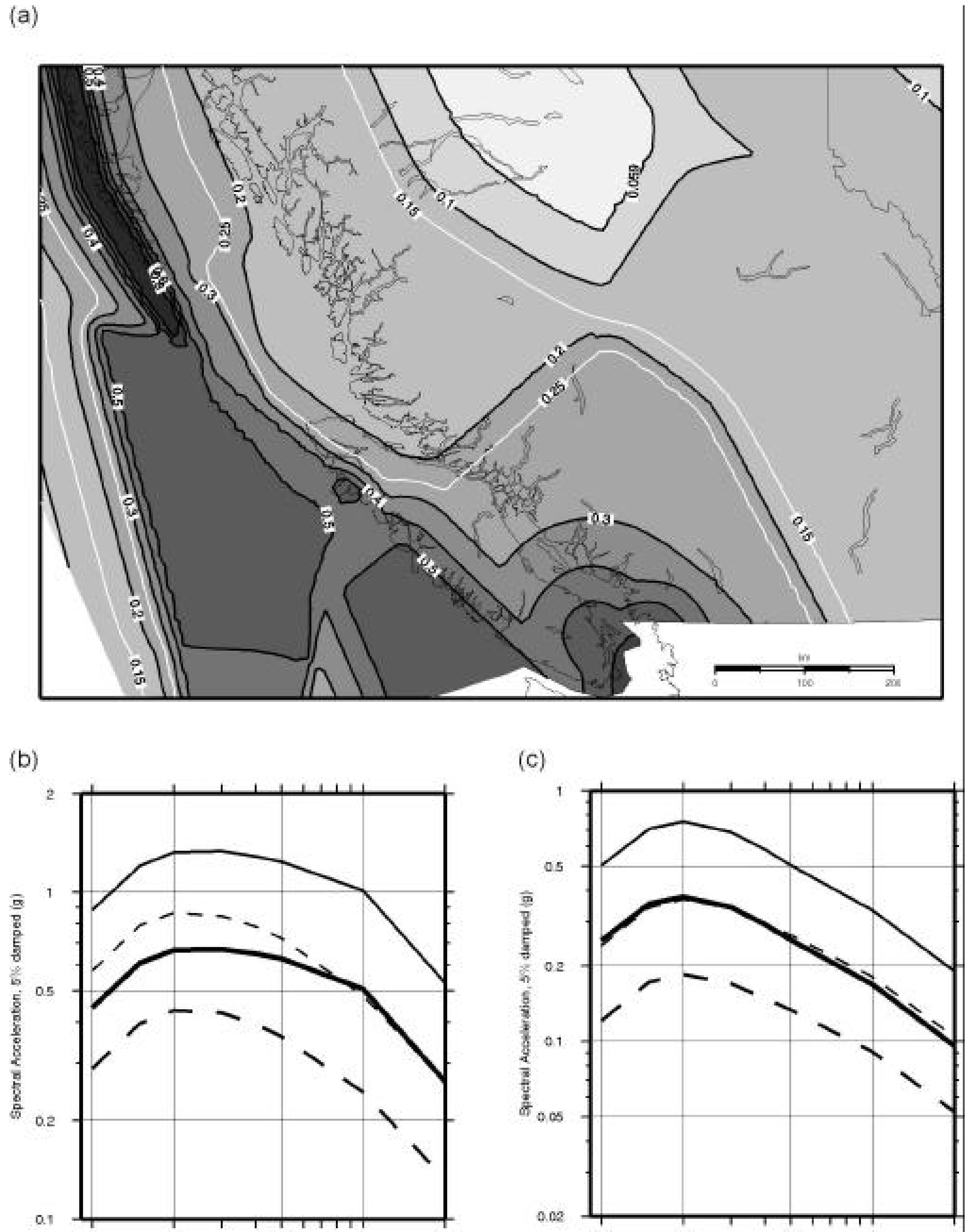


Figure 4.9. (a) Contour map for SW Canada of median estimates of peak horizontal ground acceleration for earthquake with 1 in 2500 annual recurrence probability. Values are proportion of g, (b) Robust uniform hazard spectra for Queen Charlotte City for events with 1 in 2500 and 1 in 500 annual recurrence probability (each with median and 84th percentile estimates), (c) Robust uniform hazard spectra for Prince Rupert for events with 1 in 2500 and 1 in 500 annual recurrence probability (each with median and 84th percentile estimates). Note lower expected accelerations than for (b). (Compiled from Adams and Halchuk (2003), Figures 22, 43, 44)

It may be necessary to allow for such divergence in estimating the ground motions for the threshold recurrence event. The magnitude-recurrence data for the Hecate Strait (Figure 4.11) show less anomalous behaviour at the high-magnitude end of the range, and the magnitudes are smaller than for the Georgia Basin at a given recurrence period. Uncertainties associated with the estimate of the expected limiting magnitude are larger for the lower exceedance probabilities (e.g., the 10,000 year event) than for the higher exceedance probabilities (e.g., the 1000 year event). From Figure 4.11, the expected magnitudes of the 1000 and 10,000 year events are around 6.5+/- 0.4, and 6.9+/-0.4, respectively.

All the above estimates of ground motion relate to that on 'firm' ground, a reference ground condition defined by Soil Class C (for the NBCC 2005 code; Finn and Wightman, 2003), which is represented by soils with a shear wave velocity of 360 to 750 ms^{-1} in the uppermost 30 m. Ground motion will be larger on softer ground, so that determining the geotechnical character of seabed sediments would be required for engineering design of seabed structures.

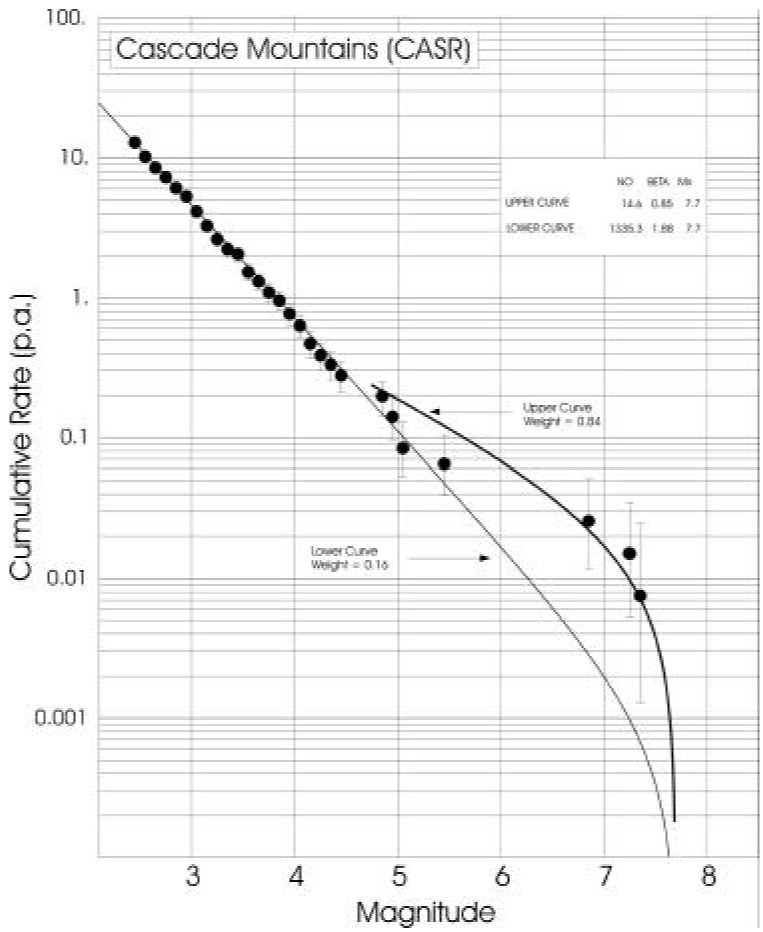


Figure 4.10. Magnitude recurrence data for shallow crustal earthquakes in the Strait of Georgia – Puget Sound region. Linear extrapolation from lower magnitude earthquakes would result in underestimate of the likelihood of larger earthquakes by as much as an order of magnitude. The upper curve is empirically chosen to allow for this exception. Both curves assume a maximum magnitude of 7.7 for the shallow crustal earthquakes considered for this analysis. From Adams and Halchuk (2003), Figure 5. Reproduced with the permission of the Minister of Public Works and Government Services Canada, 2004 and Courtesy of Natural Resources Canada, Geological Survey of Canada

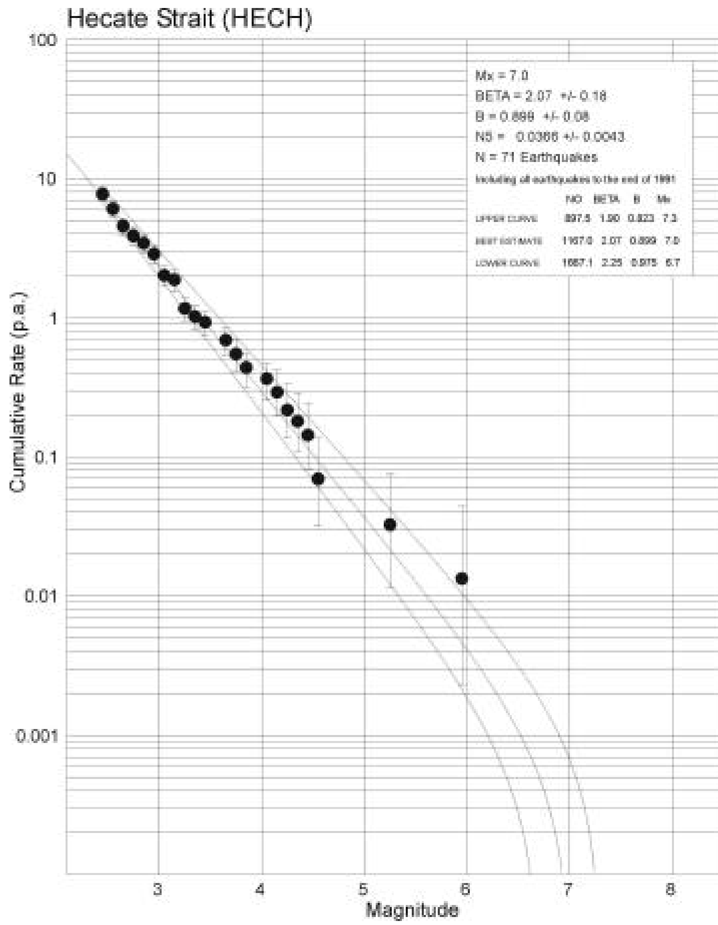


Figure 4.11. Magnitude-recurrence data for earthquakes in the Hecate Strait region, plotted by S. Halchuk as part of intended documentation for Canada's 4th Generation seismic hazard model (Adams and Halchuk, 2003)"

CHAPTER 5

MARINE ECOSYSTEMS OF THE QUEEN CHARLOTTE BASIN

5.1 Overview

The Queen Charlotte Basin (QCB) can be considered a semi-enclosed sea. At its northern end, the QCB connects to the offshore via Dixon Entrance, which runs east-west between the northern end of Graham Island and southernmost Alaska. The central portion of the basin, known as Hecate Strait, is relatively protected from the open NE Pacific by the Queen Charlotte Islands. In the south, the basin is more exposed, and is contiguous with the offshore NE Pacific via Queen Charlotte Sound, which extends between the southern tip of Moresby Island and the northern tip of Vancouver Island.

The marine fauna of the QCB has been recently reviewed in depth by the BC Offshore Oil and Gas Technology Update (JWEL, 2001). Although a complete inventory of species does not yet exist, the available data show the biological communities of the QCB to be typical of a highly seasonal, mid-latitude, coastal marine ecosystem. Although its greatest depths extend to about 400m (in the SW portion of the Queen Charlotte Sound), the QCB is still considered a continental shelf ecosystem. As such, the biological communities of the basin are quite similar to those seen in coastal waters elsewhere in BC and southern Alaska.

5.2 The plankton community

The phytoplankton community of the QCB is typical of a mid-latitude subarctic marine ecosystem. The basin is highly productive, due in part to the influx of dissolved nutrients from river runoff along the North Coast, particularly the Nass and the Skeena, as well as deeper oceanic water which enters the basin through Queen Charlotte Sound in the south. Like other mid-latitude marine ecosystems, production in the QCB is highly seasonal. Direct measurements of primary production are scarce, but sea-surface chlorophyll estimates from satellites show occasional strong phytoplankton blooms. The bulk of the annual primary production occurs during the spring bloom (April), during which the phytoplankton community is dominated by diatoms. In contrast, production later in the summer is typically dominated by various types of flagellates, as is the case elsewhere in coastal BC. A second smaller diatom bloom usually occurs in September.

In addition to the annual spring bloom, recent work by researchers from Parks Canada and DFO has revealed a localized region of highly productive waters in the basin. Analysis of 20 years of archival satellite data shows the region to be centred on Juan Perez Sound on the east coast of Moresby Island. During most summers, tongues of highly productive waters extend outward from Juan Perez Sound into the central part of the basin during July and August (Figure 5.1). However, it is not yet known how these features form, nor how important they might be to regional production processes.

The zooplankton of the QCB are representative of the coastal zooplankton community found throughout the Northeast Pacific. Zooplankton production in the basin is also highly seasonal. In general, zooplankton biomass is highest in early summer (May-June), following the spring phytoplankton bloom, with a secondary peak in the fall. In terms of both abundance and biomass, the community is dominated by calanoid copepods. Large copepods, which are most abundant in the late spring and early summer (and which are important prey for many juvenile fish) include representatives of the genera *Neocalanus*, *Eucalanus* and *Calanus*.

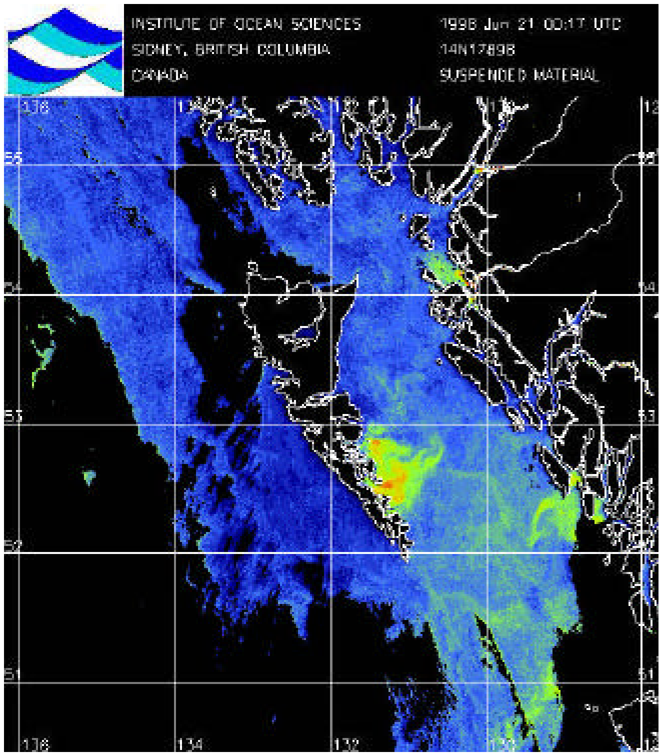


Figure 5.1. AVHRR satellite image of suspended material (most likely a phytoplankton bloom) near Juan Perez Sound, 21 June 1998. (From T. Tomascik, 2003, personal communication, workshop presentation)

The smaller copepods, which become more abundant later in the summer, include *Metridia*, *Pseudocalanus, Paracalanus* as well as members of the cyclopoid genus *Oithona*. Other important taxa include two species of euphausiid; *Thysanoessa spinifera* and *Euphausia pacifica*. Both are most common in September-October, however *T. spinifera* is by far the more abundant of the two. There is some indication that total zooplankton biomass in the basin has declined in recent years, having previously increased throughout the 1990's before collapsing during the El Nino of 1997. Since 1997, the biomass has been slowly rebuilding (Figure 5.2). The cause of this decline is not currently known. It seems likely, however, that it may be tied to El Nino effects, coupled with natural decadal scale shifts in zooplankton production recently documented in the Northeast Pacific (Rebstock, 2002, McGowan et al., 2003).

5.3 Fish communities

The fish fauna of the QCB is quite diverse, and includes distinctive nearshore, pelagic, and demersal communities. As in most other areas, however, our knowledge of these fish communities is confined primarily to those species which are fished commercially. With the exception of salmon and eulachon (both of which spawn in fresh water) and species such as herring (which lay their eggs on kelp and seagrass), virtually all of the fish in the QCB have pelagic eggs from which planktonic larvae hatch. Depending on the species, the larvae can then spend anywhere from days to weeks in the plankton, where they prey primarily on zooplankton. To date, with the exception of herring, there has been virtually no research on the larval ecology of fish in the QCB.

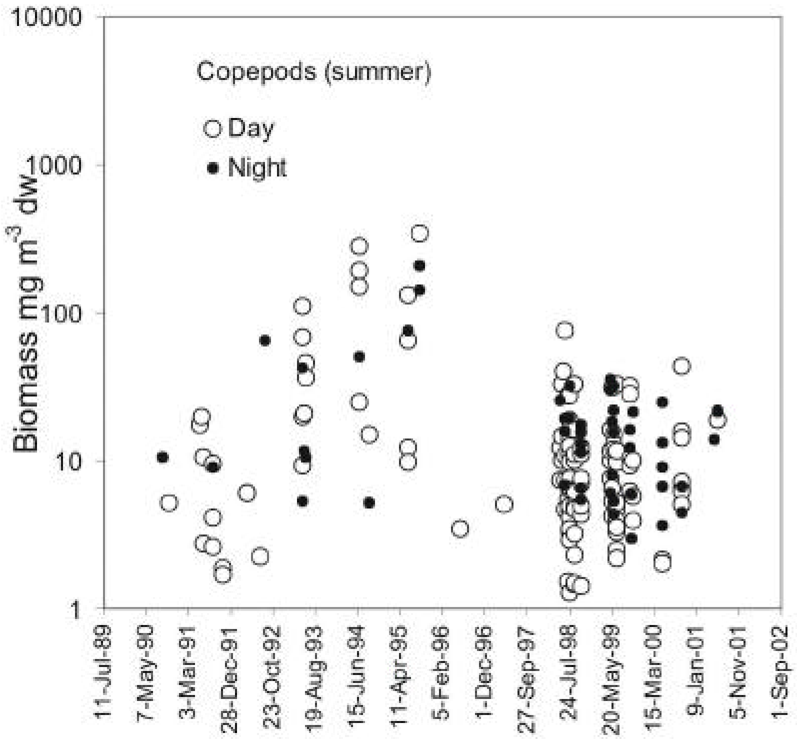


Figure 5.2. Decadal-scale trends in Queen Charlotte Basin zooplankton biomass. (From D. Ware, 2003, personal communication, workshop presentation)

5.3.1 Salmon

The QCB plays host to all six of the salmon species that occur in BC (sockeye, chinook, coho, pink, chum, and steelhead). Although there have been significant declines in many BC salmon stocks over the past decade, recent evidence suggests that these may represent natural cycles in salmon production as opposed to overfishing or habitat loss (e.g., McFarlane et al., 2000). At present, none of the salmon stocks that spawn in the rivers surrounding the QCB have been listed by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). However, three southern stocks (Interior Fraser coho and Cultus Lake & Saginaw Lake sockeye) have been listed as "endangered." The juveniles of these stocks migrate northward through the QCB during the spring as they head out to sea.

It has been estimated that there are at least 650 spawning rivers in the QCB, with the largest salmon runs occurring in the Nass River and the Skeena River, as well as the Bella Coola River, Smith Inlet and Rivers Inlet. Juvenile salmon (known as smolts) enter the marine waters of the basin beginning in the early spring. Depending on the species, the juveniles then spend anywhere from days to months in nearshore estuaries before moving into the basin proper as they begin migrating northward. In addition to those entering the QCB from its surrounding rivers, juvenile salmon from populations further south also pass though the basin on their northward migration. The QCB therefore represents a critical migratory highway for virtually all of the salmon populations from mainland BC, the east and west coasts of Vancouver Island, as well as Washington and Oregon. The exact position and timing of the migration routes are still poorly known. However, recent evidence suggests that most juvenile salmon (the exception being juvenile coho) stay very close to shore, and inhabit the upper 20m of the water column (David Welch, 2003, personal communication, workshop presentation). Adult salmon begin returning from the high seas to the QCB in the summer, with returns peaking in the fall. Depending on where they first strike the continental shelf, the adults either come south into the QCB via Dixon Entrance, or eastward via Queen Charlotte Sound. It is not yet clear what causes these interannual differences in return route, but it has been suggested that interactions between the Sitka Eddy (off SE Alaska) and the Alaska Current can influence where the fish first make landfall (Healy et al., 2000). Like the juveniles, adult salmon also appear to spend most of their time in the upper 20-30m of the water column.

Recent advances in acoustic tagging technology have made it possible to track even small juvenile (as well as adult) salmon. The Panel heard a brief overview of the Pacific Ocean Shelf Tracking (POST) program. POST (which is a sub-program of the *Census of Marine Life*) aims to establish a continental-scale tracking array to directly measure the movements, distribution and survival of fish in the ocean. A successful pilot study has already been carried out in Queen Charlotte Sound and Quatsino Sound on Vancouver Island. It is hoped that in the coming years this technology will provide better information on salmon migration routes in the basin, especially if the planned array were extended to cover Dixon Entrance and Queen Charlotte Sound. It may also help identify areas of particular importance to juvenile salmon (and which might therefore become candidate marine protected areas).

5.3.2 Groundfish

The QCB supports more than 50 species of groundfish, a large proportion of which are harvested commercially (Fargo and Tyler, 1991). Although bottom trawling takes place year round in the QCB (with around 50 vessels involved in the fishery), the highest level of activity occurs between May-Sept in Queen Charlotte Sound in the south, and in the deep trough running northeastward through Hecate Strait. In recent years the total annual trawl catch has ranged between 25,000-30,000 tonnes. The main species targeted by the fishery include Pacific hake, Pacific cod, walleye pollock, lingcod, soles, sablefish, spiny dogfish and numerous species of rockfish and sole.

Basic life history data and distributional data are available for most of the major groundfish in the QCB, although detailed species specific information on the location of spawning areas is still lacking. In contrast, life history data are still lacking for those groundfish species that do not contribute significantly to the fishery, as well as for the numerous species of rockfish inhabiting the QCB. Recent efforts by DFO have attempted to combine data on bottom-type with trawl catch data in order to better understand the distribution of groundfish habitat ranges within the QCB. Among the various groundfish encountered in the fishery, the only species currently deemed to be at risk is the Bocaccio rockfish, *Sebastes paucispinis*, which the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) currently lists as “threatened.” DFO has recently established a set of four rockfish protection areas in Queen Charlotte Strait.

5.3.3 Herring and other forage fish

Herring and sand lance constitute the two main species of forage fish within the QCB. The herring fishery represents one of the major commercial fisheries in BC and, consequently, there are good stock assessment data dating back to the 1930's. There are three main spawning areas (used by five herring stocks) in the QCB: the east coast of the Queen Charlotte Islands, a second along the north coast of the mainland and a third along the central coast. Herring eggs are sticky and are deposited on kelp and/or seagrass. The combined biomass of the QCB herring stocks is about 80-90,000 tonnes, although there is considerable interannual variability (+/- 30,000 tonnes) due to variability in recruitment (Figure 5.3 and Ware, 1997). In recent years herring biomass in the Queen Charlotte Island stock has been considerably lower than normal, exhibiting poor recruitment since the early 1990’s (Schweigert, 2002).

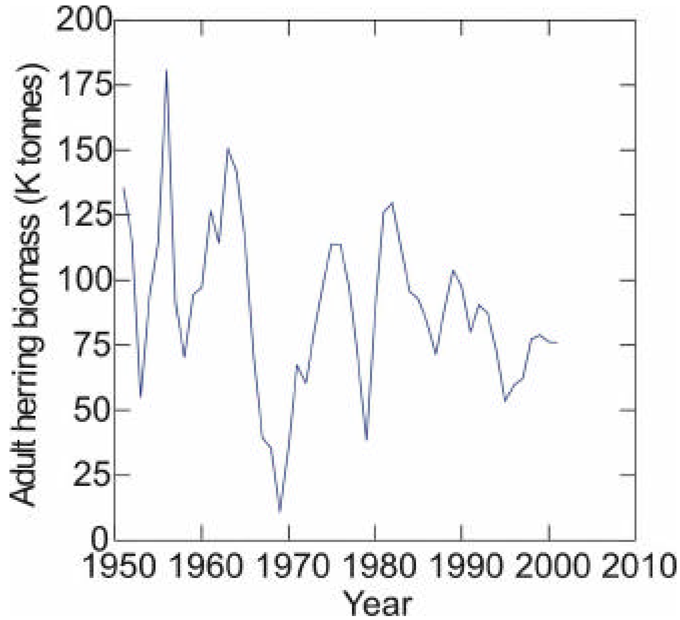


Figure 5.3. Time series of Queen Charlotte Basin herring biomass.
(From D. Ware, 2003, personal communication, workshop presentation)

The sand lance (*Ammodytes hexapterus*) is another small pelagic (2nd only to herring in abundance) known to be an important prey for many predators in the QCB. Very little is known about the ecology of this species, other than the fact that it spends much of the winter buried in the sand. To date, there has never been a targeted survey to estimate the biomass of sand lance in the QCB.

The third species of forage fish in the QCB is the eulachon (*Thaleichthys pacificus*), also known locally as the candle-fish. Unlike herring and sand-lance, eulachon are anadromous and spawn in the lower reaches of rivers and streams during late spring on the central and north coast (particularly the Nass, the Skeena and the Kitimat). Eulachon biomass has been in decline throughout BC since the mid-1990's. Although the reasons for this remain unclear there is concern within DFO for the long-term sustainability of the populations, to the extent that it has been suggested that Eulachon be considered for listing by COSEWIC (Hay and McCarter, 2000). As is the case for sand lance, data on eulachon ecology in the QCB are very limited.

5.4 Marine mammals

Thirty species of marine mammals have been documented from the QCB. The list includes twenty four species of cetaceans, of which eight occur commonly (the remaining 16 being recorded only rarely). Most of these species are not permanent residents of the QCB. Instead, they pass through the region on their annual migrations (northward in spring/summer, southward in the fall). Several of these cetaceans are currently listed by COSEWIC. The blue whale, the North Pacific right whale and the sei whale are "endangered," the humpback whale and northern resident orcas are "threatened" and the fin whale is a "species of special concern" (Table 5.1).

Very little is known about the ecology of these cetaceans within the QCB, and much of what is known comes from records collected during commercial whaling along the BC coast (which ended in the mid1960s). In 2002, DFO began a series of dedicated marine mammal research cruises in the QCB. Using intensive line-transect surveys, these cruises have begun to systematically collect data on the seasonal abundance and distribution, the population identity, species-specific feeding ecology and the locations of important feeding areas and other critical habitats. Despite this, it is not presently possible to accurately estimate the population sizes for most of these species, nor to describe their spatial and temporal distributions and habitat usage within the QCB.

In addition to cetaceans, five species of pinnipeds (Harbour seals, Steller sea lions, California sea lions, Elephant seals, Northern fur seals), as well as sea otters, also occur in the QCB. As with the cetaceans, however, only a few of these species are resident (e.g., harbour seals), while others pass through the QCB on their annual migrations.

Given their habit of "hauling out" onto shore, the population densities of the pinniped species are better known than those of the cetaceans. COSEWIC currently lists BC sea otter populations as "threatened." In November 2003, the status of the BC Steller sea lions was elevated from "Not at Risk" to "Species of Special Concern." The COSEWIC status report specifically mentions "the possibility of acute oil spills" as a particular threat to this population.

5.5 Invertebrates

With the exception of commercially valuable species such as Dungeness crab and geoducks, the benthic invertebrate fauna of the QCB has not been thoroughly censused. The range of benthic habitats available in the basin span intertidal to deep-water, nearshore to open ocean environments, and a range of exposures from sheltered inlets to high exposure rocky intertidal areas. Not surprisingly, the best censused benthic communities are those found in intertidal environments. Soft bottom intertidal communities (e.g., beaches and muddy intertidal areas) have been fairly well censused through numerous beach surveys to map the distribution of commercially valuable bivalves. In contrast, there have been only a few surveys (and usually of very limited regions) of the rocky intertidal regions of the QCB (Searing and English, 1983; Harper et al., 1994; Emmett et al., 1995; Lamb et al., 2000). The overall distribution of such regions can be determined from videotape collected during helicopter surveys by the BC Ministry of Sustainable Resources Management (as part of a larger effort to map the coastal resources BC). In the QCB these environments are usually dominated by sea mussel and goose barnacle communities which, elsewhere in BC, have been shown to support up to 140 species of invertebrates recorded per site (Jamieson et al., 2001).

The subtidal macrofauna in the region were last studied in the mid 1980's, when DFO researchers collected benthic samples from four areas in the northern part of Hecate Strait and a suite of fjords along the North Coast (Figure 5.4). During the study, benthic grad samples were collected three times between June 1985 and January 1986 (Burd and Brinkhurst, 1987). It was found that the composition of benthic communities varied as function of both water depth and habitat type (e.g., hard versus soft-bottom communities), but that, overall, the community composition showed little evidence of seasonality. Based on these admittedly limited data, it would appear that the composition of the benthic invertebrate fauna of the QCB is broadly similar to that found elsewhere in BC. In particular, community composition would appear to be quite similar to the relatively well censused community of La Perouse Bank, off the SW coast of Vancouver Island. In fact, it seems likely that there is significant connectivity between these two regions, as invertebrate larvae from the west coast of Vancouver Island are transported north toward Hecate Strait.

Unlike some deep fjords in other parts of coastal BC, there is no evidence of hypoxia or anoxic sediments in the main portion of the QCB. This is hardly surprising, since physical oceanographic research has characterized Hecate Strait as a well mixed and highly energetic environment (Thomson, 1981). This high-energy bottom environment also likely results in suspended material being present at all depths, and there is some suggestion that the subtidal benthic communities of the QCB are dominated by suspension-feeding organisms (B. Burd, 2003, personal communication, workshop presentation). There was also some suggestion (during sampling in the mid 1980's) that certain elements of the benthic macrofauna might be affected by periodic biomass fluctuations. At the time, it was proposed that this might have to do with benthic storm events or seasonal variation in predation. More recent evidence suggests a link to commercial trawling activity in the QCB (B. Burd, 2003, personal communication, workshop presentation).

The QCB also supports a series of unique deepwater sponge reefs. First reported in the early 1987 (having been previously known only from the fossil record), the four reefs are composed of the skeletons of various glass sponges (i.e., hexactinellids). It has since been shown that the reefs, which can be up to 15m in height and cover an area of about 700 km^2, are situated in bottom scours left by icebergs during the last Ice Age and may be at least 10,000 years old (Conway et al., 1991; Conway et al., 2001; Conway, 1999). It remains unclear why these reefs only occur in the QCB. Equally unknown is the role that the reefs play in the deep-water environments of the QCB, although underwater video surveys have recently shown that they harbour numerous species of fish and invertebrates. It has been estimated that perhaps 50% of the reef area has already been damaged by trawling (K. Conway, 2003, personal communication, workshop presentation). In recognition of this, DFO has implemented a temporary exclusion zone that bans commercial trawling activity in the area surrounding each reef. Long term plans for the protection of these unique environments are currently under consideration.

5.6 Seabirds

The marine avifauna of Haida Gwaii were recently reviewed by Parks Canada as part of their ongoing inventory of the Gwaii Haanas ecosystem (Harfenist et al., 2002). Drawing on a wide range of survey data collected throughout the region over the past several decades, they concluded that at least 1.5 million marine birds (representing 30 species) are believed to breed on Haida Gwaii. These include 13 species of seabirds, 8 species of nesting waterfowl, 7 species of shorebirds and 2 species of marine raptors. An additional 94 species (representing another 5-10 million individuals) are believed to utilize the QCB during annual migrations or for overwintering. The authors note, however, that for a variety of reasons (e.g., unequal survey efforts for different groups and areas, differences in survey protocols, the fact that many surveys were conducted on an opportunistic basis, weather-dependency of counts, etc.), these numbers should not be taken as population estimates *per se*. Seabird colonies around the QCB are located in Figure 5.5

Furthermore, with the exception of several well-censused colonial seabird species, the authors state that the available data are generally "inadequate as baseline data for monitoring population trends" (Harfenist et al., 2002).

Despite this, it is still possible to make some general statements about the marine avifauna of the QCB. Regarding the distribution of seabirds Harfenist et al. (2002) note that abundances increase throughout late

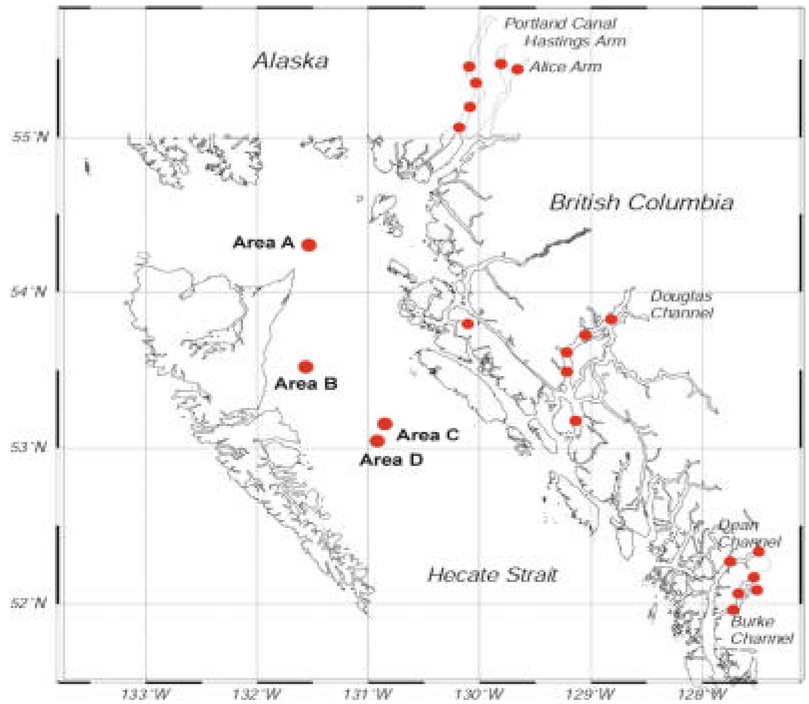


Figure 5.4. Locations of benthic samples collected in the Queen Charlotte Basin during the 1984-89. (From B. Burd, 2003, personal communication, workshop presentation)

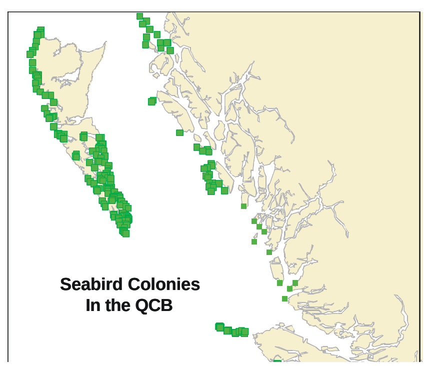


Figure 5.5. Location of seabird colonies in the Queen Charlotte Basin. (From D. Bertram, 2003, personal communication, workshop presentation)

winter before peaking in spring (when there are millions of birds in the area) and declining again as autumn approaches. The two species that dominate during spring, Sooty Shearwaters and Short-tailed Shearwaters, are southern hemisphere migrants that breed in Australia. Herring gulls, Thayer's gulls and Black-Legged Kittiwakes become dominant in the fall. Most of the seabirds in the QCB are colonial. They spend virtually all of their time at sea, often ranging more than 100km offshore, and feed primarily on zooplankton (e.g., euphausiids) and/or small fish such as juvenile herring, sand lance and salmon. Given the abundance and diversity of species utilizing the area, the QCB is believed to be one of the most important areas for marine birds on the west coast of North America (Harfenist et al., 2002), and includes populations of both national and international significance (Kaiser, 2002; D. Bertram, 2003, personal communication, workshop presentation). In part, this stems from the fact that coastal BC contains significant proportions of the global population of several seabird species. For instance, the region contains approximately 80% (-2.7 million) of the world's Cassin's Auklets, 50% (-700,000) of the Rhinoceros Auklets, 50% (-500,000) of the Ancient Murrelets and 20% (-66,000) of the Marbled Murrelets (Gaston and Jones 1998; Rodway 1991). The latter two species are listed by COSEWIC as being of "special concern" and "threatened," respectively (COSEWIC, 2003).

5.7 Valued ecological and economic components

Ecosystem health involves holistic analysis but in practical terms judgment has to be used in setting priorities for science studies. The choice of species for assessments of impacts of oil and gas activities should combine species at risk, along with representative species that are of either ecological or economic importance, from a wide variety of habitats. These would form the set of so-called Valued Ecological and Economic Components for the QCB. This set combines species of particular relevance to evaluating ecosystem health with others that have more direct commercial or cultural value. This is a pragmatic approach to prioritizing knowledge of impacts on biota, and one that is becoming more common in other jurisdictions (see LGL et al., 2000).

5.7.1 Species at risk in the Queen Charlotte Basin

Proclaimed in June 2003, the Species at Risk Act (SARA) is part of Canada's strategy to maintain its biodiversity and protect its wildlife. The Act makes it an offence to *"…kill, harm, harass, capture or take an individual of any species listed as extirpated, endangered or threatened…"* by COSEWIC. Further, the Act requires the responsible minister (Minister of Fisheries for aquatic species, Minister of the Environment for birds) to develop recovery strategies for those species listed as extirpated, endangered or threatened, and to develop management plans for species that COSEWIC lists as being of special concern. As part of any recovery strategy, SARA requires that the critical habitat of the species be identified, based on information provided by COSEWIC, or through new studies to identify such habitat in cases where insufficient data currently exist.

Table 5.1 summarizes those marine species that have been examined and listed by COSEWIC. The list includes 5 endangered species, 7 threatened species, 4 species of special concern and an additional 4 species that although currently not at risk, are under review by COSEWIC. Although many are not permanent residents of the QCB, the basin does represent part of their natural range at certain times of the year or during migrations. Based on the information received during the Workshops, the Panel notes that the spatiotemporal distributions and patterns of habitat usage of many of these species in the QCB is poorly known.

5.7.2 Ecologically important species

In many food webs there are certain species that play a particularly important role, either by virtue of being a key prey item for many other species, or perhaps as bio-engineers that affect the physical structure of the environment in important ways (e.g., by building structures that provide refuge for other species). In the QCB, herring, sand lance and juvenile salmon are examples of the former, while mussels (which form mussel beds), sea grasses and the hexactinellid sponges (that form sponge reefs) are examples of the latter.

5.7.3 Valued economic components

A wide variety of finfish and shellfish are harvested from wild populations in the Queen Charlotte Basin. Many of these species are subject to commercial harvesting, while others are gathered primarily as traditional subsistence for local peoples. Although a few of these species are currently listed by COSEWIC as threatened (e.g., Northern abalone, Bocaccio rockfish), the majority are not. In addition, the Panel heard from members of the aquaculture industry and from several First Nations representatives that an aquaculture industry (particularly for shellfish) is likely to develop in the QCB over the next decade.

The commercial and recreational fisheries (and their associated service industries) are at least as vital to the economic welfare of the QCB as any other industry, arguably more so now, with declining investment in mineral exploration, and the closure of paper mills. Consequently, in assessing the impacts of oil and gas development on the ecology of the QCB, it is important to assess effects not only on those species deemed to be at risk (e.g., by COSEWIC) or of particular ecological importance, but also on those valued economic components that provide significant amounts either of direct income or of subsistence.

Therefore, a proper assessment of the potential impact of oil and gas activities in the QCB requires knowledge of the populations, distributions and behaviours of (at least) the following economically or culturally important species:

Finfish: salmon, cod, sable fish, hake, pollock;
Groundfish: halibut, various species of sole, turbot, rockfish;
Pelagics: herring (esp. roe and spawn on kelp), eulachon; and
Shellfish/invertebrates: shrimp, crabs, prawns, octopus, abalone geoducks, sea urchins, sea cucumbers, mussels and clams.

5.8 Recommendation regarding science gaps

Species at risk, ecologically-important species and harvested species constitute the Valued Ecological and Economic Components of the QCB. These need to be clearly defined as the foci for baseline and monitoring studies. The species mentioned above should be included in the set of VEECs for the QCB. If such a set were not to be defined, critical species might not be studied, with risk of unassessed impacts from oil and gas development. Later sections of the report are focused on the needs of knowledge of VEECs for safe practice of particular activities.

As discussed elsewhere, benthic communities will be those most impacted by, and show sensitivity to, drilling and production activities. A full survey of the seabed—including side-scan and swath bathymetry, and sampling of seabed sediments and their fauna—in the area likely to be used for oil and gas exploration and production should be conducted as a baseline study.

Table 5.1: Queen Charlotte Basin marine species deemed to be at risk as of November 2003. Data from COSEWIC (2003)

GROUP	COMMON NAME	SPECIES
QCB Species Listed as "Endangered"		
Mammals	Blue Whale	*Balaenoptera musculus*
	North Pacific Right Whale	*Eubalaena japonica*
	Sei Whale	*Balaenoptera borealis*
Fish	Coho (Interior Fraser)	*Oncorhynchus kisutch*
	Sockeye (Cultus & Saginaw populations)	*Oncorhynchus nerka*
QCB Species Listed as "Threatened"		
Mammals	Sea Otter	*Enhydra lutris*
	Humpback Whale	*Megaptera novaeangliae*
	Orcas (Northern Residents)	*Orcinus orca*
	Orcas (Transients)	*Orcinus orca*
Fish	Bocaccio Rockfish	*Sebastes paucispinis*
Birds	Marbled Murrelet	*Brachyramphus marmoratus*
	Short-Tailed Albatross	*Phoebastria albatrus*
Invertebrate	Northern Abalone	*Haliotis kamtschatkana*
QCB Species Listed as "Species of Special Concern"		
Mammals	Fin Whale	*Balaenoptera physalus*
	Harbour Porpoise	*Phocoena phocoena*
	Steller Sea Lion	*Eumetopias jubatus*
Birds	Ancient Murrelet	*Synthliboramphus antiquus*
QCB Species Listed as "Not at Risk", But Currently Under Review		
Mammals	Grey Whale	*Eschrischtius robustus*
	Minke Whale	*Balaenoptera acutorostrata*
	Harbour Seal	*Phoca vitulina richardsi*
Fish	Eulachon	*Thaleichthys pacificus*

CHAPTER 6

OTHER USES OF THE QUEEN CHARLOTTE BASIN

Although the Queen Charlotte Basin (QCB) is remote and not densely populated, it is by no means an untouched or unexploited environment. The region, defined for statistical purposes as three BC Regional Districts—Central Coast, Kitimat-Stikine, and Skeena-Queen Charlotte—supports a population of about 66,000. About 30% of the population belongs to First Nations. Of the labour force of approx. 29,000, 17% are officially considered as being employed in the primary resource sector, i.e., fishing, forestry and mining; however, the large population at Kitimat, defined as being employed in manufacturing and processing, depends ultimately on the primary resource of hydro-electric power (BC Stats., 2003).

6.1 Existing resource industries: fishery, forestry, mining

At present, the two major renewable resource industries in the region are forestry and fisheries. The commercial fishing industry operating out of Prince Rupert is estimated to employ about 2400 workers using over 700 vessels and 11 processing plants. According to the Terrace Economic Development Authority (TEDA), estimated annual income from the fishery is around $150 million (TEDA, no date; Prince Rupert Community Profile, 2001). Employment in the forest sector is larger—TEDA estimates at least 2500. This is consistent with the fact that the Skeena Cellulose mill in Prince Rupert employs about 1100 (with about $90 million per annum in wages and benefits) and provides indirect employment for a further 3000 people, earning with $108 million per annum (TEDA, no date; Prince Rupert Community Profile, 2001). Forestry on the Queen Charlotte Islands probably adds about another 10% in economic value, since the allowable annual cut (AAC) of 361,000 m^3 (BC Timber Supply Review, 2000) represents around 10% of the AAC surveyed by TEDA. Although logging does not affect marine resources of the QCB directly, transportation and waste discharge (e.g., from Skeena Cellulose into Porpoise Harbour) certainly have some potential effects on regional marine environmental quality. Furthermore, logging practices inland may have degraded salmon habitat and hence reduced salmon production with consequences for marine salmon populations.

Mining and associated activities on the north coast are not very significant at present. Mining exploration expenditures in Northwest BC were about $5.6 million in 1999, compared to $110 million in 1990 (TEDA, no date). By 2002, only one mine was active (Huckleberry, at Smithers, which produces copper and molybdenum), employing about 200 staff with a total payroll of about $15 million (PWC, 2002, p. 11 and Appendix 17). Aluminium production in Kitimat, which uses locally generated hydro-electric power to process imported minerals employs over 1900 staff, with an annual payroll of about $145 million and local expenditures of about $45 million for goods and services (TEDA, no date). Shipments of minerals (probably mainly of coal from Tumbler Ridge in Northeast BC) through Prince Rupert, declined from 4.7 million tonnes in 1998 to 1.4 million tonnes in 2002 (PWC, 2002, Appendix 8).

6.2 Tourism

The current economic importance of tourism is difficult to assess, partly because of reporting methods which tend to aggregate information over a fairly wide area, and partly because the most recent data appear to originate from 1995-96. Total annual revenue in Northwest BC (which is a larger area than just the environs of the QCB) was $425 million; room revenues in Prince Rupert alone were about $7.5 million in 1995 and 1996. Recreational fishing is an important component of the tourist sector with almost 50 saltwater fishing charters and nine fishing camp (floating lodge) operations on the North Coast; about 2,000 non-resident fishing licences were issued annually between 1995 and 1998. It is anticipated that eco-tourism will be the fastest-growing “product area” in tourism in the region (BC Tourism, no date).

6.3 Aquaculture

Aquaculture may become a major factor in economic development in the region of the QCB. It is already a major industry at the northern end of Vancouver Island, where the focus has been on salmon. There is strong interest in development of aquaculture in the QCB, not only for salmon, but of other species, especially shellfish, which are a significant component of wild harvesting now. Aquaculture is concentrated in near-shore facilities, in relatively protected waters. Its presence would amplify the potential impacts of near shore contamination from oil spills.

6.4 Possible impacts, and need for further analyses

It is difficult to predict what impact oil and gas development in the QCB might have on these existing activities. There is no reason to expect any direct adverse effects on mining and forestry in the region, though the presence of drilling rigs in Hecate Strait might have a local, but probably temporary and insignificant, effect on some aspects of transportation of forestry and mining products and/or raw materials. The fishing industry might be more adversely affected. At the very least, there would be some loss of access of fishing vessels to exclusion zones around drilling rigs and around seismic survey vessels (see Chapter 2). A more significant effect might arise from the perception that the very presence of an oil and gas extraction industry might lead to contamination or tainting of fishery products from commercial, sport-fishing or planned aquaculture operations. It will be recalled that one of the effects of the *Braer* oil spill off the Shetlands in 1993 was to reduce the marketability of local farmed salmon, regardless of whether or not the fish were actually tainted (Goodlad, 1996).

The largest impact of oil and gas development in the region might be expected to be on the tourist economy. The major tourist attractions in the region involve some kind of outdoor activity (including sport fishing) or are based on regional cultural features such as historic sites and First Nations artefacts and associations (BC Tourism). Both of these may be adversely affected by oil and gas development: “wilderness” kayaking, or eco-tourism, is likely to lose some of its appeal if the visible oil and gas-related activities or installations, either on-shore or off-shore, detract from the (apparently) natural environment.

It is beyond the remit of this Panel to undertake socio-economic analyses of the impact of oil and gas development in the QCB, but we recommend that such analyses be carried out, extending from current work (e.g., Coasts Under Stress project, University of Victoria, J. Schofield, 2003, personal communication, workshop presentation; Northern Coastal Information and Research Program, University of Northern British Columbia, N. Dale, 2003, personal communication, workshop presentation).

CHAPTER 7

ENVIRONMENTAL ASPECTS FOR ENGINEERING DESIGN

In this Chapter, we describe the knowledge of the physical environment of the QCB required for engineering design of offshore structures, fixed, floating or on the seabed. The Chapter concludes with recommendations for filling gaps in that knowledge, and the consequences of not doing so.

7.1 Bathymetry

The bathymetry of the Queen Charlotte Basin (QCB) and the nature of the seabed have been described in Chapter 4. Generalities of the depth and nature of the seabed in the QCB are well known. The detailed information needed for design and location of seabed infrastructure is not available, except for very small areas which have been subjected to high-resolution studies, including swath bathymetry (see Figure 4.7). Founding of structures on the seabed requires knowledge of the local bathymetry, to identify steep slopes, moving sediment, and gas seeps. This also requires knowledge of the geotechnical properties of the seabed rocks or soft sediments. The optimal routing of pipelines requires designers to have knowledge of these factors for large areas of the basin.

The requirement for exploratory drilling and production is for site-specific studies to be undertaken as a precondition of permitting. Because some of the information required—detailed bathymetry, for example—can have other useful public value, it would be worthwhile acquiring swath bathymetry, controlled by seabed sampling, over at least those parts of the QCB of highest hydrocarbon potential. In choosing the areas to be covered by such a survey, it would be valuable to include known areas of higher resource potential, steep slopes, sediment movement, gas seeps, and sensitive zones, such as the localities of sponge reefs. It is also to be remembered that there is virtue in mapping large areas uniformly, and avoiding a patchwork coverage that can result in significant regional features being missed.

7.2 Wind, waves and current

7.2.1 Overview: objectives and uses of metocean data

In assessing the impact on oil and gas activities of meteorological and oceanographic ('metocean') factors, it is important to focus on the objectives for engineering design and operations. These are the following.

(a) Data to model the behaviour in time. We need to know the probability distribution of wind velocity, wave height and current velocity at points-in-time so that we can assess the response of a structure under operating conditions. An example of the use of such analyses is to assess possible failures due to fatigue. Possible downtime due to weather is another issue. Another important example is the need to model wind and currents for determining the trajectory of oil spills. Both probability distributions and where necessary correlations are needed.

(b) Data on extremes of winds, waves and current. These are used to complete the design for extreme forces resulting from these environmental factors, as outlined in section 3.9 on structural codes

.

(c) The data should be usable also for forecasts to assist in safe operations, and for tactical response to oil spills. It is to be noted that overflights can provide direct information in this regard.

7.2.2 Existing data

A detailed assessment of data is given in Chapter 4. The following summarizes the main points for the current analysis.

Winds and waves have been measured from 16 marine buoys since 1987 (Cretney et al., 2002). Shore stations have provided hourly wind data for past 50-60 years, while there are lighthouse reports every 3 hours during daylight (Neil, 2003).

Focused studies of the oceanography of the Queen Charlotte region, during 1977-1995 (Crawford, 2001, Crawford et al., 2002) were guided by the recommendations of West Coast Offshore Environmental Assessment Panel, 1986, which proposed exploratory drilling between June and October only.

With regard to current, two types of drifter (Loran-C and Argos) were used to determine surface and near-surface currents during the period 1990-95. Current meters were also installed at mooring sites in the waters surrounding the Queen Charlotte Islands for periods of 2 to 8 months at a time, from 1982 to 1995. Recordings were made on magnetic tape or computer storage devices. Most measurements of currents were accompanied by measurements of temperature and salinity.

Satellite imagery has been obtained since the late 1970's, with colour imagery obtained more recently. This work has allowed sea surface temperature measurements to be made, as well as measurements of sea surface heights since the late 1980's (Cretney et al., 2002). There is a record of 90 years of sea level variation at Prince Rupert, as well as other locations (Cretney et al., 2002).

7.2.3 Discussion

A substantial amount of analysis of wind and wave data has been carried out (see for example the list "Previous West Coast Studies" in Swail, 2003, p. 106). Good coverage of data in space and time is available. One concern is the generation of wind information at site-specific locations. The storms of interest will be associated with large scale low pressures and extratropical cyclones off the Pacific ocean (Vickery, personal communication). The long term records, of interest for extreme values, are land-based. The local topography will then be important in deriving wind speeds over open water. Either physical or numerical modelling can be used to fill this gap. Topographic models have been used to define wind speeds in other locations, for example in the Hong Kong area (Lythe et al., 1981; Ho and Mans, 2002).

Over time, efforts should be made to fill the "Pacific data void" for weather, though this is not seen as a gap that needs to be filled before offshore activities commence. The improved forecasts that would result might assist, for example, in implementing disconnect criteria related to sea state for a floating unit. Other operating environments including Newfoundland have to deal with explosive cyclogenesis (resulting in 'weather bombs'), which in any event is extremely difficult to forecast.

With regard to wave analysis, the most severe conditions occur in winter. A global wave hindcast study has been completed by Cox and Swail (2001), and for extremes off the west coast of Canada by MacLaren Plansearch (1992). This results in 100 year return period (10^{-2} annual exceedance) values of significant wave height and maximum wave height. The significant wave height is approximately the visually-observed wave height, and may be as little as half the maximum wave height. Current-wave interactions are important in the region and have been studied by Masson (1996). There are areas near the Queen Charlotte Islands where wave and current refraction are significant. Numerical refraction models can be used to calculate these effects. Other worthwhile recommendations include updating of the hindcasts, and associated extreme values, and the gathering of directional wave data.

Numerical simulations of ocean currents and surface particle drift have been created. These were evaluated against measurements using drifter motion and current meters, noted above. The simulations were based on the Princeton Ocean Model (POM) by Cummins of DFO and the study includes analysis of winds based on weather buoys, tides, buoyant flows, and bathymetry. Data and analysis for winter and near-bottom current conditions represent a knowledge gap with regard to oil and gas development. These are needed for determination of extreme values, and for analysis of trajectories of oil spills and of produced water and drilling cuttings.

7.3 Earthquakes

Seismicity of the QCB and environs is described in Chapter 4. The Queen Charlotte Fault which lies along the west coast of the Queen Charlotte Islands is part of a major tectonic plate boundary. Earthquakes are felt on a regular basis; a magnitude 8.1 event occurred in 1949, and a magnitude 6.3 event in 2001 (Cretney et al., 2002 contains a summary of recent work). The seismographic network, operated by the Geological Survey of Canada during the 1980s to mid 1990s (Bird, 1997), indicated considerable earthquake activity east of the QC Fault, in Graham Island and in Hecate Strait, and a band of activity on either side of the Fault was found.

Information on intensities from the 1949 earthquake is available, but this is sketchy (G. Atkinson, 2003, personal communication, workshop presentation). The Denali earthquake in Alaska (2002) of magnitude 7.9 provides an important analogue for ground motions. The current hazard maps (Adams and Halchuk, 2003; see Figure 4.9, Chapter 4) assume that ground motion in the QCB is related to seismicity in the same way as it is in California. This is likely to be a conservative assumption. Current GSC maps and the proposed 2005 NBCC maps are for spectral parameters at the 2% in 50 year probability level. This gives a design earthquake level such that the probability of this level being exceeded in 50 years is 0.02. This probability value is equivalent to 1/2500 per annum.

7.3.1 Discussion

In the hazard maps available at present there is uncertainty related to the rate of activity in time. This could be treated as parameter uncertainty and included in the analysis, resulting in conservative estimates of design conditions. To reduce uncertainty in the future, immediate deployment of a network of seismographs in QCB is recommended. The network should include strong-motion seismographs. These will enable the ground motions of earthquakes with magnitudes greater than 5.5 to be adequately determined. The recurrence periods for such magnitudes are decadal or greater, so this is a long-term public-good need that might bring useful results within the time scale of oil and gas activities. Geodetic quality GPS installations are also proposed. Collection of these data will assist in reducing uncertainty in future analyses and in situ specific regional studies.

The NBCC maps using a probability level of 2% in 50 years will establish a minimum baseline, but site specific regional studies for offshore regions of interest are needed. The CSA offshore standard S471 currently specifies a range of probability level for offshore structures from 1/1000 to 1/10,000 p.a., with the use of the lower probability level unless there are mitigating circumstances such as system ductility. ISO at present appears to endorse a less stringent approach to probability levels for design motions based on a simplified design approach with parameters mapped at 1/1000 (G. Atkinson, 2003, personal communication, workshop presentation). This may be an issue as codes are harmonized.

7.4 Tsunamis

7.5

The record of tsunamis offshore BC, and modelling of the effects, is described in Chapter 4. A tsunami is a series of waves of long wave length and period generated by a disturbance such as an earthquake, landslide, or sub-marine volcanic eruption. There was a substantial tsunami 300 years ago on the southern BC and Washington coasts. Tsunamis from the 1964 Alaska earthquake reached around 1 m at stations around the QCB (F. Stephenson, 2003, personal communication, workshop presentation). The amplitude increases as the water depth decreases, but this effect is lessened if they travel into wider water bodies.

Local earthquakes are likely tsunami sources. Modelling of tsunamis from a potential magnitude 9.1 earthquake on the Cascadia subduction zone indicates tsunami wave amplitudes of several metres along the southwestern coast of Vancouver Island, and effects could be amplified in inlets, depending on the bathymetry (Cretney et al., 2002; F. Stephenson, 2003, personal communication, workshop presentation). In the QCB, the most damaging local earthquakes, from the Queen Charlotte Fault zone, would be associated with horizontal slip, and these displacements on the seabed do not generate significant amplitudes of tsunami waves. The recordings of the 2001 earthquake on the Queen Charlotte Fault indicate displacements of only ~0.1 m.

In general, it can be concluded that tsunamis in the QCB will be negligible in amplitude compared to waves from storms. Consideration should be given to the 'run-up' effects of possible tsunamis in shallow waters especially in inlets. Modelling would be a design input in these cases. Tsunamis in the Cook Inlet area are caused by coastal landslides, themselves triggered by earthquakes or volcanoes, and this may be a consideration in some instances.

7.5 Recommendations regarding science gaps

In the foregoing, several knowledge gaps have been identified which should be filled to reduce uncertainties in estimating loads on structures. The specific needs are outlined in the sections below. In every case the consequence of not filling the gap would be that, in practicing the precautionary principle, structures would be designed with extra allowance for those larger uncertainties. This would result in most cases in projects being costlier than need be, with potential that some projects might then be uneconomic.

7.5.1 Bathymetry

For seabed structural design, pipeline locations, and tsunami modelling, high-resolution bathymetry is required. This can be obtained by swath bathymetry, tied to seabed sampling for geotechnical properties. The highest priority for data acquisition would be the area of highest hydrocarbon prospectivity in the QCB.

7.5.2 Metocean

With regard to metocean conditions, there are no specific needs prior to the commencement of oil and gas activities. In the event that oil and gas exploration and development is considered, it is recommended that a focus be developed amongst government scientists on the specific needs of the offshore industry. A plan should be developed based on engineering advice.

Seismic exploration could proceed without further scientific work on metocean aspects. It would be wise, if offshore development is contemplated, to commence or recommence measurements of currents, earthquakes, wind and wave as soon as possible. Drilling rigs are available with sufficient robustness that sufficient conservatism can be added to the requirements to permit operations without more information or study. Refinements to the analysis of wind, wave and current would at the same time assist in this choice.

Before production is commenced, the recommendations above should be carried out. These are topographic wind modelling (to enable estimates of offshore winds from land stations affected by relief); determination of bottom currents and trajectories in summer; winter flow at all depths, especially along eastern side of Hecate Strait; updated wind and wave hindcast models; and the use of satellite data. The impact of climate variability on regional oceanography is also of importance.

7.5.3 Earthquakes

The immediate deployment of a network of seismographs including strong-motion seismographs in the region is recommended. Geodetic quality GPS installations are also proposed.

CHAPTER 8

EVIRONMENTAL IMPACTS OF OIL AND GAS ACTIVITIES

8.1 Overview

There are two areas of principal concern regarding the impacts of oil and gas activities on the marine environment (Strong et al., 2002; see also Table 3.1 of this document). One is the effect of seismic surveys on the physical health and behaviour of biota. The other is the physical and, particularly, toxicological impact on biota of deliberate discharges of drilling waste (mud, cuttings) and produced water, and of accidental spills and blow-outs. These issues are assessed in this Chapter. Recommendations are made with respect to risk analysis. Full treatment is beyond the scope of this report and should be part of later impact assessments.

8.2 Seismic surveys

A detailed analysis of the environmental impacts of seismic surveys is available on the internet (Davis et al., 1998): it is applied to offshore Nova Scotia but has generic value. More recent analyses from reports for regulators on Canada's east coast are also readily available (LGL 2003; and references therein), and there is a variety of recent publications on different aspects of this topic (e.g., McAuley et al., 2000; 2003). There are two steps in estimating potential impacts of seismic surveys in the Queen Charlotte Basin (QCB). The first produces generic estimates of harm to different kinds of animals, while the second applies those generic estimates to our knowledge of the distribution of biota in the QCB in space and time.

8.2.1 Sound levels at various ranges from seismic sources

As described in section 2.6, individual air guns used in arrays for hydrocarbon exploration have peak sound levels of around 0.4 MPa-metres (recall that 1 atmosphere of pressure = 1 bar = 10^5 Pa, i.e., 0.1 MPa). This means that, at a range of x metres, the peak sound level will be a pressure of 0.4/x MPa, thus diminishing with distance. This inverse relationship applies at ranges less than the water depth in which the spreading of acoustic energy from a near-point source is subject to spherical divergence—the energy is spread out on an increasingly large spherical wavefront. At large distances sideways in the water layer, the decrease in amplitude tends to approximate cylindrical divergence because of the manner of propagation involving waves trapped in the water layer by its own internal properties (waveguide effects) and by strong reflections of energy back into the water layer from both the seabed and air-sea interface. Attenuation in cylindrical spreading is less rapid: in the above example the pressure-distance relationship would be $0.4/x^{0.5}$ MPa. This more-distant propagation also results in the received wavelet changing from a short (~ 20 milliseconds), sharp signal to a slowly decaying signal over hundreds of milliseconds at ranges of a few kilometres. The behavioural impacts of seismic surveys are witnessed at distances of up to several kilometres and more, for which cylindrical spreading would be appropriate. Mortality, on the other hand, is observed at ranges of about a metre, in which spherical spreading dominates.

The exact manner of propagation of seismic energy at ranges large compared with water depth can be modelled, provided there is reliable information on variations in water depth, acoustic velocity in the water layer (which depends on salinity and temperature), and elastic properties of the seabed. Such modelling has been of value in assessing the variability of propagation on the Scotian shelf (Davis et al., 1998), in order to estimate how impacts on biota might vary with range from seismic vessels. It should also be done for the QCB, for assessing impacts on animal behaviour in critical habitats at special times. Modelling may require improved knowledge of bathymetry, of the area and depth variations of temperature and salinity of the water layer (and their seasonal variations) and of the acoustic properties of the seabed. Model results should be verified with field observations.

In generic assessments of impacts of seismic surveys on biota, the use of the decibel scale is universal. The decibel scale for sound level provides magnitude relative to 1 μPa (1 μPa = 10^{-11} atmospheres or bars). The strength of a source in decibels is the signal level relative to 1 μPa at a range of 1 metre. So an air gun that has a strength of 0.4 MPa-metres, would produce a peak signal of 0.4 MPa at 1 metre, or 4 x 10^{11} μPa. The decibel scale measures ratios of two signal amplitudes (a and b) as 20 $\log_{10}$ (a/b). Each order of magnitude difference (x10) is 20 dB. An intensity of 10^{11} μPa would be 220 dB bigger than the reference level of 1 μPa. 4 x 10^{11} μPa would be another 12 dB higher - around 232 dB. Thus the air gun source would be described as having a strength of 232 dB relative to 1 μPa at 1 metre. Using spherical divergence, the signal strength at 10 m would be a factor 10 less than that at 1 m: this is 20 dB less, or 212 dB relative to 1 μPa. The same source would produce signal strengths at 100 m and 1 km of 192 dB and 172 dB respectively. In what follows, the Panel will assume that the dB signal level quoted uses the standard reference, that is, it is relative to 1 μPa.

An array of air guns of different sizes produces a mixture of signals of similar peak magnitude but different frequencies, so that the overall peak signal level going down into the sea-floor is greater than that from a single gun but by less than a factor of the number of guns. The 5085 cu. in. air gun array exemplified in the description of seismic activities (section 2.6) is made up of 21 guns, but the peak value is around 253 dB at 1 m, about 20 dB (only a factor of 10) greater than that of a single gun. Another key point is that the use of that source magnitude is good for estimating the received signal strength by spherical or cylindrical spreading at large distances, but breaks down in estimating signals at short range because of the differences in distance and direction from individual guns. Thus close to any one gun, e.g., at 1 m, the magnitudes of signals from other guns in the array, which might be from 3 to 15 m away, will be relatively small, and may not even be additive to the near-gun signal. This is an important consideration in estimating impacts.

The intended frequency range for seismic sources in oil exploration is around 5-100 Hz, but the energy radiated includes higher frequencies. Signal levels at 1 kHz tend to be 40 dB (a factor of 100) down on the 5-100 Hz level (Davis et al., 1998), but even at 2 kHz the air gun source may be above ambient noise levels at ranges of up to 2 km (Goold and Fish, 1998). Higher frequencies than this are radiated but at low levels from which they drop below ambient noise levels at much shorter ranges.

8.2.2 Impacts on marine biota: overview

From the variety of experiments and field studies in which the impacts of seismic shooting on biota have been observed, it is possible to make some generalizations about the level of received signals that may be responsible for physical damage. Table 8.1 summarises some of these data.

For a single gun with a source magnitude of 232 dB, a signal level of 230 dB would be received at 1.5 m. Organisms closer than 1.5 m to an air gun would likely be killed. Those closer than 4 m would suffer immediate significant internal injury, which might ultimately kill biota or, possibly prevent reproduction. Approach within 100 m might cause transient stunning of fish or mammals.

Behavioural responses are experienced at much smaller signal levels. For example, for fish of medium sensitivity, threshold levels of behavioural response vary widely in the range of 160-188 dB. A 172 dB level would be felt at about 1 km from a single gun.

While these estimates are for a subset of fish species, they are not grossly out of line with those for other species, and so they illustrate the general point that serious physical harm tends to be associated with ranges from air guns of a few metres (at ranges where spherical spreading applies), whereas behavioural effects may be felt at ranges of kilometres (where cylindrical spreading applies).

8.2.3 Impacts on fish

This summary is based on LGL (2003, pp. 124-131), Davis et al., (1998, pp. 89-100) and JWEL (2001 pp. 110-112) and references found therein. Fish approaching closer than 1.5 m to an air gun are likely to be killed by the blast. This applies particularly to the many species of fish that have gas-filled swim bladders. Most fish that die from the blast do so within 1-4 hours of exposure (JWEL 1998, quoting Yelverton, 1981). For our model array of 5000 cu. in., with 3 strings of 7 guns each, for each shot, fish would be killed that occupied a total volume around the guns of 300 m^3. Considering our model 20 km square survey area, it is then possible to estimate the mortality caused by typical 2D and 3D surveys. For 2D surveys, with 25 m shot spacing and 4 km line spacing, 4000 shots would be fired and the swept 'kill' volume would be 1.2 million m^3. This amounts to 0.03% of the top 10 m of the ocean in the survey area. For a 3D survey, with 500 m swaths, the number of shots and the swept kill volume would be multiplied by 8, so that the swept kill volume would be 0.24% of the top 10 m in the survey area. Applying the precautionary principle as an acknowledgement that the fish kill range of 1.5 m is based on a small subset of species, a greater assumed kill range of 3 m would result in these numbers increasing by a factor of 8. This is a swept kill volume that is still less than 2% of the top 10 m, even for a 3D survey. Given that fish are likely to avoid close approach to the guns, the expected mortality of fish caused by seismic surveys is very small.

Physical damage that might lead to loss of reproductive capacity would occur in larger volumes around individual guns, and the calculations become complicated by the overlap of damage volumes from adjacent guns. Assuming a damage range of 4 m, the swept damage volume for 2D and 3D surveys would be about 7500 m^3 per shot, or 0.8% of the top 10 m for a 2D survey and 6% of top 10 m for a 3D survey. Again avoidance behaviour makes it unlikely that visible physiological damage to fish will be significant. However, sub-lethal impacts such as hearing damage that might lead to long-term effects, are more difficult to predict. There is evidence that hearing loss may result from damage to sensory hair cells when an air gun is towed past caged fish at 5-15 m range (maximum received signal about 180 dB) (McCauley et al., 2003). For a full array, it can be expected that fish approaching within about 1 kilometre of the source might suffer such loss. Damage to sensory hair cells appears to occur over a long period of time after the blasting event, and there is no knowledge from these experiments on eventual long-term recovery.

Estimates of physical damage to fish need to take account of behavioural responses to operating air guns. A number of references cited in LGL (2003) suggest that avoidance reactions are quite variable. Schooling fish may not show avoidance unless they are in the direct path of the shooting ship. On close approach some species will move away, either sideways or downwards. There is also evidence of habituation to air gun shooting, or complete hearing loss (LGL, 2003). A general guideline concluded by LGL (2003, p. 125) is that a sound level of 160 dB is a reasonably conservative threshold level for behavioural response. This sound level might occur somewhere in the range of 3-12 km from the array (depending on sound propagation in the particular area).

Specific field and experimental studies also show that behavioural response is very variable. In the Barents Sea, trawl catches of cod and haddock declined by about half in the vicinity of seismic shooting and impacts were detectable up to 18 nm away (Engås et al., 1993) and five days after the end of the seismic programme, large fish had not returned to the area (Engås et al., 1993; Engås et al., 1996). Soldal and Lokkeborg (1993) found long-line catches of cod to be reduced within 5 nm from survey tracks; reductions of 55-80% were noted close to the tracks. Saithe catches (by trawling) were reduced by up to 33%, but shrimp catches from one trawl operation increased by 60% when the shooting started though there was no effect observed by a second trawler. (Sound intensity appears not to have been recorded in either of these surveys.) However, groundfish distribution is “patchy” over scales of a few kilometres, so these apparent effects of seismic surveys could in fact be attributable to natural variation in distribution. On the other hand, reef fish and invertebrates appeared to tolerate air-gun detonations at 195-210 dB (corresponding to ranges of 16-109m), though these were fired less frequently (once per minute) than during a “real” survey

(Wardle et al., 2001). Caged sand eel in the North Sea reacted slightly to seismic surveys (distance and intensity not specified) but did not flee to the sea bottom. No injuries or mortality were observed (Hassel et al., 2003). Simulations of killer whale and dolphin high amplitude sounds ("bangs") appeared to disrupt normal behaviour of anchovies (Marten et al., 2001).

Biochemical indices of stress (cortisol, lactate, and adenylate energy charge) in confined sea-bass were affected by air gun discharges, though values returned to the normal range within 72 h (Santulli et al., 1999). Farmed Atlantic salmon exposed to 10 detonations over 70 minutes of 2 MPa in pressure amplitude showed short term behavioural changes and had signs of injury to the ventral aorta and the coeliaco-mesentery artery. A trial uptake of catecholamines declined during the 48 h after exposure (Sverdrup et al., 1994).

Taking these data together suggests that air-gun discharges during seismic surveys can have at least transient effects on adult fish behaviour. Larger fish, with larger swim bladders that resonate at lower frequencies than those of smaller fish (JWEL, 2001) may show a more sensitive response. The possibility that fish may be damaged physically or may change their behaviour has led to restrictions on seismic surveys at sensitive times or locations (Patin, 1999).

This review suggests that permitting of seismic surveys should be assessed against adequate knowledge of temporal localizations of fish populations, especially for key species (an example would be paths and timings of migration of vulnerable salmon species). At this stage, we have only broad (i.e., poorly-resolved) information to identify all such sensitive areas or times in the QCB region to protect commercially important or ecologically significant fish species from possible harm as a result of seismic surveys. Many gaps remain in our knowledge of the distribution of other species.

8.2.4 Impacts on eggs and larvae

Estimates of impacts on eggs and larvae can be calculated on a similar basis to those on mortality and visible physical damage on older fish. Eggs and larvae will be killed at sound levels around 226-234 dB (0.6 - 3.0 m from an air gun), while visible damage to larvae occurs at 216 dB (about 5 m from an air gun) (Davis et al., 1998, p. 128, and references therein). In a survey off Norway, Saetre and Ona (1996, quoted in LGL 2003, p. 128) and Kenchington (2001, in JWEL 2003, p. 132) estimated that total larval mortality in the top 10 m during a 3D survey to be less than 5%. In other words, it seems to be generally accepted that severe physical damage and death will result if eggs and larvae are within a few m of an air gun discharge (Booman et al., 1996; Patin, 1999; JWEL 2001). Natural daily mortality rates among eggs and larvae is high—around 10% (Saetre and Ona 1996)—seismic impacts on populations may be undetectable in practice. Despite this, it would be prudent to avoid seismic shooting within any confined spawning areas for species the subject of conservation concerns.

8.2.5 Impacts on mammals

This topic has been reviewed extensively (Richardson et al., 1995) and more recent literature has been summarized in JWEL (2001). Marine mammals show varying responses to seismic surveys. Arctic ringed seals seem fairly tolerant of air gun firing, remaining within 150-250 m of the arrays (Harris et al., 2001) corresponding to a (received) intensity of about 190 dB. Dolphins, however, appear to be less tolerant, and tend to stay at least 1 km away, corresponding to a received intensity of <140 dB (Goold, 1996; Goold and Fish, 1998). They also appear able to detect air gun firing at a distance of 8 km. Bowhead whales seem even less tolerant: Ljungblad et al., (1985) observed total avoidance at a distance of over 7 km (received intensity 164 dB) . However, avoidance behaviour in bowheads and beluga in the Beaufort Sea tends to be variable, and long-term impacts limited – with bowheads returning in following years to areas surveyed by seismic (Richardson et al., 1986).

Beluga whales showed some temporary shifts in hearing threshold after exposure to water-guns at 226 dB, but dolphins showed no such change at 228 dB (J. Caldwell, 2003, personal communication, workshop statement). JWEL (2001) concluded that grey, bowhead and humpback whales would avoid seismic activities at received intensities of approximately 140–180 dB (see Richardson et al., 1995; and McCauley et al., 2000).

Much of the literature summarised above refers to species other than those found in the QCB region. However, most marine mammals use sound for some purpose (communication, echo-location or passive listening for potential predators: L. Barrett-Lennard, 2003, personal communication, workshop presentation). It seems reasonable to conclude that they will be disturbed to varying degrees by (received) intensities above about 160 dB as pulses, though thresholds for continuous exposures may be lower (R. Davis, 2003, personal communication, workshop presentation). At present there is no evidence of either temporary or permanent damage to hearing. Whether this temporary, and fairly short term, disturbance has any permanent effect on individual or population survival is not clear.

Most marine mammals appear to use sound. Some use it actively by making noises apparently for identification, to establish territoriality, or to detect obstacles or prey ("echolocation"). Some listen for potential prey. Baleen whales tend to produce lower frequency sounds (usually below about 2 kHz and rarely above 4 kHz) whose duration is of the order of seconds Toothed whales tend to produce slightly higher frequency sounds, in the 1-20 kHz range whose duration is of the order of seconds. Echolocation signals (by toothed whales) tend to be much shorter (<1 msec) and higher frequency (up to >100 kHz; Richardson et al., 1995). The question of whether seismic surveys could interfere with "communication" in marine mammals is unresolved. Continuous low frequency sound can potentially interfere with communication among baleen whales (JWEL, 2001), and has been associated with stranding events in toothed whales (Frantzis, 1998). Seismic sources are pulsed, not continuous, so their impact on communication may be much more modest. Since some fish species respond to whale noises (see Marten et al., 2001) the possibility exists that seismic surveys could interfere with predation by some marine mammals on fish; however, there seems to be no direct evidence that this actually happens.

In the absence of sufficient quantitative data describing the response of particular species of marine mammal to seismic surveys, many jurisdictions have adopted precautionary measures to mitigate potential effects. These include "ramping up" of air gun firing, limitations on firing when mammals are present within a pre-determined range (this requires that experienced marine mammal observers are aboard survey vessels) and avoidance of critical areas and times. On the Atlantic coast of Canada, an evolving code of practice is available and protocols have been developed in conjunction with DFO to minimise risk (R. Pitt, 2003, personal communication, workshop presentation). The UK has guidelines describing how seismic surveys should accommodate marine mammals at http://www.jncc.gov.uk/marine/seismic. The US National Marine Fisheries Service has set criteria for shutdown of seismic operations in the presence of marine mammals, following notices issued by the US Mineral Management Service (MMS, 2004).

These measures may be a practical approach to reducing exposure of marine mammals to air gun firing. However, they assume that enough knowledge exists about the distribution of marine mammals in survey areas for informed decisions to be made about critical habitats and periods. Such information about marine mammals in QCB is scarce (J. Ford and L. Nichol, 2003, personal communication, workshop presentation) and is based on (i) records from commercial whaling, usually pre-1960, (ii) opportunistic sighting of live or stranded animals (from sea or land), (iii) systematic surveys inshore in Gwaii Haanas in 1991 and 1993, and (iv) offshore systematic surveys (only since 2002). Furthermore, of the 24 species of marine mammals observed in the area, Blue, Sei and North Pacific Right whales are already listed by COSEWIC as "endangered"; humpbacks are listed as "threatened" and North Pacific Offshore Killer whales are of "special concern" (Table 5.1, Chapter 5).

8.2.6 Impacts on other species: shellfish, plankton, birds

Data on the impacts of seismic shooting on macroinvertebrates (scallop, sea urchins, mussels, periwinkles, crustaceans, shrimp, gastropods, squid) show that little mortality occurs below sound levels of 220 dB. Some show no mortality at 230 dB. For bottom-dwelling species, these data suggest no significant impact for seismic surveys provided the water depth is greater than about 20 m. Cautions should be added regarding key species not among those tested. However, Muraveyko et al. (1991; cited in Patin, 1999) concluded that an air gun operating at 14 MPa (~260 dB) had no effect on zooplankton beyond about 5-7 m. Boudreau et al. (2001) quote anecdotal evidence from a snow crab fisherman operating off Newfoundland that catches declined in the immediate vicinity of a seismic survey, but he found no decline at a distance of 50 nautical miles. A recent study (LGL and Oceans Ltd., 2003) showed no effects on health and behaviour of snow crab to received sound levels of 197-237 dB from an air gun array.

Deep diving birds (alcids) might be affected by air gun shooting, but very little work has been done on these species. Turnpenny and Nedwell (1994) found no apparent effect on diving birds observed from an operating seismic vessel, but no work has been done on hearing impacts. It would be prudent to maintain observation of diving birds during seismic surveys as they may not deliberately avoid a shooting ship. Many dive rapidly and might not have warning of adjacency to high sound levels (unlike fish).

8.2.7 Discussion of need for exclusion of air gun sources from particular areas

Sponge reefs

When the early industry seismic reflection profiles were shot, there was no knowledge of the existence of unique sponge reefs in the QCB. Indeed, they were discovered at the time of shooting of the GSC seismic reflection profiles in the 1980s. There is a current restriction on fishing over the sponge reefs to avoid physical damage from trawling. Since the reefs exist in around 200 m water depth, it is unlikely that seismic surveys will harm them: damage to shellfish, for instance, is restricted, in the species observed, to ranges of much less than 20 m. The sponges are filter feeders and are relatively primitive organisms with no known air or gas sacs which might be susceptible to damage at 200 m range. Comparison of the tracks of previous seismic profiling with the locations of the sponge reefs indicates that around 348 km were shot immediately over the reefs. It is not known if those surveys had any impact.

Shallow water; migration paths

The report of the West Coast Offshore Exploration Environmental Assessment Panel (WCOEEAP, 1986) recommended that seismic operations not occur within 10 km of the shore during grey whale migration and herring spawning periods (March, April, May, November and December). This is a requirement that is more sensitive to particular threats to biota but it can be moderated to take further research and other potentially-threatened species into account. The nearshore zone is valued for its distinct biota, of which the animals particularly threatened by seismic include shellfish, migrating salmon, and herring and their spawn. Given that there is no damage known to occur to either shellfish or spawn at ranges greater than a few metres, an exclusion zone of 1 kilometre from water depths shallower than 20 m is duly cautious. For consideration of fish, there should be exclusion of seismic from migration paths of salmon and from herring schools inshore. This requires more to be known about the paths and timing of migration of different salmon populations (especially along the mainland coast) and about the temporal and spatial distribution of herring. Seismic operations should be excluded from a zone including migration paths and a zone about 2-3 km wide around them during migration times.

Table 8.1. Summary of responses of marine biota to noise in seismic surveys.

Source Intensity (dB)	Range	“Received” intensity (dB)	Impact
> 225 approx.	1 – 10 m	140 atm approx.	Lethality to zooplankton, fish eggs and larvae; haemorrhage, paralysis, loss of vision in fish (Patin, 1999)
226	Not stated	Not stated	Temporary shift in hearing threshold in beluga; dolphin showed no such change at 228 dB (J. Caldwell, personal communication)
180 - 205	Variable	Not stated	Startle response in some fish spp. (McCauley, cited in JWEL 2001; Pearson et al., 1992; Booman et al., 1996); other spp. appear tolerant (Wardle et al., 2001; Hassel et al., 2003)
Not stated	< 250 m	190 approx.	Ringed seals tolerant.
Not stated	> 1 km	140	Dolphin avoidance (Goold, 1996; Goold and Fish, 1998); detection at 8 km range.
Not stated	7 – 25 km	115 - 164	Bowhead avoidance (Ljungblad et al., 1985; R. Davis, 2003, personal communication, workshop presentation); avoidance at lower levels is to continous sound from drilling activities
Not stated	Not stated	140 – 180	Avoidance by gray, humpback and bowhead whales (JWEL 2001)
Not stated	5 - 18 n.m.	Not stated	Reduction in commercial trawls of groundfish; no reduction in shrimp catches (Engås et al., 1993; 1996; Soldal and Lokkeborg 1993)
		80 approx.	Ambient noise

8.3 Impacts of drilling and production

The major environmental concerns arising from well drilling (either at the exploration or the production stages) have been the impacts of disposal of drilling wastes, particularly if oil based drilling fluids (“muds”) have been used. The discharge of “produced water” from production wells is a significant issue because of the volumes involved. Most production wells have a lifetime of several years during which other wastes may also be released near the rigs. These wastes include water and minor oil spills arising from marine transportation and so forth, and it is often difficult to conclusively attribute any impacts observed near drilling rigs to a specific cause.

8.3.1 Solid wastes

Drilling fluids (or "muds") are complex mixtures which function as lubricants and coolants, as a medium for removal of cuttings and to control hydrostatic pressure (Patin, 1999; Bernier, 2001). At present, most exploration drilling involves the use of "water-based muds" (WBM) in which the major components are salt water and barite. If directional drilling is required, especially at the production stage, "oil-based muds" (OBM) may be used, but since the discharge of diesel oil (on which older OBMs were based) raise issues of toxicity, these are being replaced by "synthetic-based muds" (SBM) which use synthetic hydrocarbon derivatives such as polyalphaolefins (PAO) or vegetable oil esters. Partly because modern OBM and SBM are relatively expensive, modern drilling (both at the exploration and production stage) requires procedures such as centrifuging to recover the hydrocarbon fluids from cuttings.

Several recent publications have reviewed the nature and impact of drilling wastes. GESAMP (1993) described the amounts of wastes, and their impacts, from offshore drilling operations up until the early 1990's. Olsgard and Gray (1995) have summarised the environmental impacts of oil and gas recovery operations in the North Sea based on studies carried out over the last 30-odd years. Patin (1999) has reviewed in detail the composition of drilling fluids, their toxicity and their environmental impact. Wills (2000) has summarised technological and legal aspects of drilling discharges, and concerns about environmental impacts. The following summary is based on these, and other related publications.

The amounts of waste produced during drilling operations are large. Patin (1999) quotes the following figures for discharges during exploration and production activities:

Discharges	**Amounts (tons)**
Single exploration well:	
Drilling mud:	150-400 (cumulative)
Cuttings (dry mass):	200 – 1000
Base oil on cuttings*:	30-120
Multiple well production site:	
Drilling mud	45,000 (based on 50 wells over 4-20y)
Cuttings	50,000 (" " ")
Produced water	1500/day (from a single platform)

(It should be emphasised that these numbers are very variable and are cited only to illustrate the scale of drilling operations. *Most exploration wells do not now use oil-based muds.)

The environmental impact of fluid and cuttings discharges arises from (i) the toxicity of drilling fluid components, (ii) smothering of benthic communities by large volumes of small particulate material from cuttings, and related to that, the residual BOD or COD from organic material associated with the discharges.

WBM have very small amounts of toxic components. These include biocides, corrosion inhibitors, and surfactants, which may account for only a small fraction of the total WBM composition but which contribute a significant fraction of total WBM toxicity (Patin, 1999). In the case of OBM, the diesel oil on which older OBM were based contributed significant toxicity due to its PAH content. Modern SBM contain very low levels of aromatic hydrocarbons (a few parts per billion) and appear to be more acceptable from a toxicity perspective. However, although components of OBM and WBM are demonstrably toxic in controlled bioassays, there appears to be no evidence for acute toxic effects (i.e., lethality) in the field.

Discharges of cuttings and their associated residual drilling fluids tend to be deposited fairly close to drilling operations. Cuttings themselves do not present any specific environmental problems; they are, after all, ground up natural rock. However, they inevitably contain residual drilling fluids, even after appropriate separation techniques have been applied to recover the fluids on the rigs. The extent of a cuttings "plume" depends on particle size of the cuttings and the local current regime, and can be traced by its barium content (from the barite used extensively in WBM), by its hydrocarbon content (from residual oil, in the case of OBM) or by sediment particle size distribution. The plume can usually be detected to beyond a 5 km radius from a drilling operation (Olsgard and Gray, 1995).

The main impact of cuttings is to smother existing benthic communities, though residual toxicity and/or BOD and COD due to residual organic material are additional concerns (Boudreau et al., 2001; Cranford and Gordon, 1991). Biological impacts of the cuttings plume are usually assessed by changes in species abundance and diversity in benthic communities and, using multivariate statistical methods, impacts have been inferred out to beyond a 5 km radius from some North Sea drilling rigs (Gray et al., 1990; Olsgard and Gray 1995), though this is based on multi-well production drilling in the pre-SBM era. Recent reports on the impacts of SBM suggest more limited distances (around 1 km) within which impacts can be observed (DNV, 1999). There is usually a trend in the severity of impact, with major reductions in both species abundance and diversity occurring close to a drilling rig (i.e., within a few hundred metres) and with community characteristics approaching those in non-impacted environments as distance from the rig increases (Daan and Mulder, 1996; Gray et al., 1990). Obviously, potentially confounding variables like sediment granulometry, depth, oxygen tension etc. must be controlled in such analyses, and this may be easier to achieve in the North Sea instances than in the QCB area, mainly because less detail is available about bathymetry and sediment types in the latter.

Several other sub-lethal impacts have been observed in field studies or inferred from laboratory or mesocosm work; these include behavioural changes in brittle stars (Newton and McKenzie, 1998), changes in feeding behaviour in invertebrates (Stromgren et al., 1993), and induction of cytochrome P-450 1A in fish (Leaver et al., 1987; Payne et al., 1987). Cytochrome P-450 1A is a detoxification enzyme in liver which is selectively induced on exposure of the fish to PAH. Most of these changes were attributed to the effects of aromatic hydrocarbons whose concentrations in modern SBM should be greatly reduced. Apart from their toxicity, residues of OBM and SBM on cuttings can be expected to create potential local BOD or COD problems. SBM other than ester-based products appear to be no more biodegradable than diesel-based OBM (Wills, 2000; SPE, 1998-2000).

The increasing evidence that cuttings (and associated drilling fluid residues) can have fairly widespread effects on benthic communities has led to many jurisdictions strictly limiting discharges of muds and cuttings contaminated by drilling fluids, at sea. Thus, in Europe, the Oslo-Paris Commission (OSPAR), which controlled disposal of wastes at sea, prohibits the use of diesel based OBM and recommends that cuttings should contain no more than 1% dry wt. OBM fluid; cuttings should be processed on shore, or re-injected to wells (OSPAR, 2000). Norway appears to interpret the OSPAR rules stringently, and in fact puts additional restrictions on discharges (Wills, 2000). In Australia, cuttings produced by the use of OBM containing >1% aromatic hydrocarbons may not be discharged at sea (Baker Hughes 2003). The USA prohibits all discharges within 3 miles of land, but may approve discharges outside that limit by licence (Wills 2000). In Atlantic Canada, the approach is to encourage co-operation between the offshore industry and the regulators, and to promote reinjection of cuttings, disposal on-shore or best-practice local treatment and discharge, depending on mud type (see Offshore Waste Treatment Guidelines, http://www.cnsopb.ns.ca/Environment/guidelines.html). In practice, re-injection is only possible after the well casing has been installed, so wastes from the initial phases of drilling are discharged to the sea.

8.3.2 Produced water

These are formation waters produced together with oil during petroleum extraction. Due to the volumes produced (which may range from 2,000 – 7,000 m^3/d; Patin, 1999) it is usually impractical to deal with them other than by discharge to the sea, though re-injection to the wells may also be possible (Wills, 2000). Produced water is usually treated on deck to reduce its oil content as many jurisdictions limit the concentration of oil in discharged produced water to some value below 50 mg/l (ppm) (Wills, 2000).

Produced water is inevitably highly variable in composition, and so chemical and toxicological analyses of it are not very representative; assessments of its environmental significance really have to be made on a case-by-case basis. With that caveat, produced water can be expected to contain hydrocarbons and mineral salts (from the formation being drilled) plus biocides, corrosion inhibitors and other components of injection water and deck wastes. The toxicity of produced water is therefore highly variable, but usually does not present any problems in a reasonably dynamic environment where rapid and large-scale dilution may be anticipated (Patin, 1999; GESAMP, 1993).

The main concern with produced waters lie with oil content, and the argument is made that even though discharge volumes are high, oil concentrations are low (usually below about 30 mg/l in the late 1990's) and the total amount of oil introduced to the North Sea via produced water represents probably only 3-5% of the total amount of oil introduced from all sources (Wills, 2000). However, western Europe is a highly developed and industrialised region, where there are large anthropogenic sources of hydrocarbons in the sea, and in a remote and sparsely populated area such as Queen Charlotte Sound or Hecate Strait, discharges of produced water to the sea may represent a much larger fraction of hydrocarbons introduced to the environment. Discharge of produced water continues at a steady rate as oil is produced, and tends to increase as production ages.

8.3.3 Monitoring

Monitoring is usually undertaken to meet one of two objectives: (a) to ensure compliance with regulations ("compliance monitoring") or (b) to establish temporal and/or spatial trends ("trend monitoring"). Compliance monitoring usually involves fairly frequent "end-of-pipe" sampling followed by analysis to ensure, e.g., that chemical concentrations in a discharge stream do not exceed a pre-determined value; trend monitoring usually addresses the consequences such discharges over larger scales of space and time. In one sense, therefore, the distinction between compliance and trend monitoring is artificial; nevertheless, in this discussion we focus mainly on the latter.

Taking the stages of oil and gas development in sequence, we find that seismic surveys are not very amenable to monitoring. The activity is not fixed in space, so spatial monitoring is irrelevant and the process is transient so monitoring of temporal trends is difficult,. The main difficulty, however, is that there is no clear "residue" of seismic activity or any well-defined response which would allow monitoring of its impact.

Drilling operations are easier to monitor, usually because they are (relatively) fixed in space and time. Various approaches have been taken to define the "footprint" of drilling rigs; these are based on monitoring chemical residues, principally hydrocarbons (arising from small spills, OBM, SBM, etc.) or barium (from barite) and occasionally other metals such as copper and zinc (Olsgard and Gray, 1995; Daan and Mulder, 1996). Such studies have usually been undertaken in retrospect, after a drilling rig has been in place for a matter of years or decades, but in principle such sampling and analysis could be carried out repetitively at appropriate intervals to monitor changes over time around rigs. It is to be noted here that offshore eastern Canada, environmental effects monitoring is now required for all production developments (see, for example, http://www.cnopb.nfnet.com/publicat/other/d97_02/english/toc-eng.html). In general, it appears that the "footprint" (as defined by chemical residues in the sediment) of a rig that has been in operation for a decade or so will extend for a radius of about the order of 1 km or so from the rig. The detailed shape and size of the footprint will depend on local current regimes (whose direction and velocity will control sedimentation of discharges) and on the amount and nature of the discharges.

The impact of chemical discharges from drilling rigs can also be assessed by measuring biological responses to them. Most measurements have focussed on changes in benthic community structure (Gray et al., 1990; Olsgard and Gray, 1995; Daan and Mulder, 1996). Provided obvious confounding factors such as depth, temperature, oxygen tension, etc., can be controlled, meio- or macro-faunal community structure may be correlated with sediment chemical residues and with rig activities in general. The change in community structure is probably a response to changes in particle size, organic matter content, or chemical residues, or to some combination of these (which may in turn affect the local redox environment). The effects of rig activities can often be seen to a radius of between 2 and 5 km, so the biological approach is as sensitive as measurements of chemicals in sediments, and potentially more informative as it addresses biological effects rather than just chemical distribution (cf. Addison, 1996). Another potential "effects monitoring" approach which has been suggested is to use induction of Cytochrome P-450 1A in fish liver; this indicates exposure of the fish to hydrocarbons (among other chemicals: Addison, 1996) and may indicate the presence of oil spills (e.g., Stagg et al., 1998) or of exposure to the diesel formerly used as a base oil in OBM (Payne et al., 1985). Since diesel-based OBM have effectively been replaced by SBM essentially free of low molecular weight polynuclear aromatic hydrocarbons (PAH), this approach would now be applicable principally to the detection of oil spills or discharges from rigs.

It is worth emphasising that most of the information about the distribution and impact of chemicals discharged from drilling rigs has emerged from studies of rigs that were operating in the North Sea in the 1970s. Regulations and operating procedures have evolved since then, and the environmental changes observed as a result of those activities would not necessarily be seen in operations in the QCB some time after 2010. Nevertheless, the approaches used to assess impacts of drilling rig activities in the North Sea would be applicable in the QCB, provided the appropriate pre-operational environmental conditions were established. This would require "baseline" definition of, for example, sediment hydrocarbon and other chemical distributions, of benthic community structure, including sampling of seabed sediments, and of the Cytochrome P-450 1A status of suitable indicator fish species. Such baseline studies, including full benthic surveys of sediments and fauna, have been very beneficial elsewhere (e.g., on the Norwegian shelf, Gray et al., 1999).

In assessing environmental change through monitoring studies, the time scales of biological response to change should be evaluated. As discussed in Appendix V for the Exxon Valdez spill, for example, it is to be noted that assessments made in 2002—13 years after the spill—showed recovery for many injured species, but several were in the process of recovery, and others have shown little or no recovery.

8.4 Oil releases into the sea

8.4.1 Note on units

1 m^3 = 6.29 barrels = 264 gallons (US)
1 barrel = 0.159 m^3 = 42 gallons (US)

The density of crude oil varies in the range of about 0.80 to 0.97 tonne per m^3, with light crudes at the lower end and heavy ones at the upper end. Conversion from m^3 to tonnes is achieved by multiplying by the density. Cubic metres and tonnes are therefore roughly equivalent, with the latter being typically 85-90% of the former.

8.4.2 Introduction

Crude oil is a complex mixture containing up to several thousand compounds (Cretney et al., 2002). Most of crude oil (usually >90%) is hydrocarbons (NRC, 2003), but compounds containing oxygen, sulphur, and nitrogen, and metals may sometimes represent 10% or more of the total. In general, lower molecular weight (MW) compounds are more volatile and also more water-soluble than higher MW compounds, and the persistence and toxicity of oil spilled or discharged in an accident will depend on the composition of the oil (among other factors discussed below) Toxicity is generally attributed to the polynuclear aromatic hydrocarbon (PAH) content of oils, and particularly to the lower MW and more water soluble PAH, which may represent 0.2-7% of total hydrocarbons (NRC, 2003).

8.4.3 Oil in the sea

Oil appears in the sea from a variety of sources. Table 8.2 summarizes the situation for North America (NRC, 2003). It is seen that natural seeps contribute a significant amount to the total. In fact seeps are the highest contributors of hydrocarbons and PAH into the sea. They tend to occur in oil-producing regions as would be expected. In the QCB, there are over 50 seeps of tar, oil and natural gas on the Queen Charlotte Islands (Hamilton and Cameron, 1989), and numerous gas seeps on the adjacent seabed (Barrie, 1988). The oil seeps at a slow rate and biota tend to acclimatize to the toxic content of the crude oil. In NRC (2003), there are estimates of the amount of PAH entering North American waters from the same sources listed in Table 8.2. In thousands of tonnes per year, natural seeps contribute 2.5, extraction 0.07, transportation 0.17, and consumption 2.2. The latter refers to consumption by humans, for instance car and boat owners, supplied to the sea in some cases by runoff, within which category paved areas contribute significantly.

Table 8.2. Petroleum release to the sea per year for various sources; North America 1990-99 best estimate (NRC 2003)

	Natural Seeps	**Extraction**	**Transportation**	**Consumption**	**Total**
Thousands of Tonnes	160	3.0	9.1	84	260
Percentage	62.5	1.2	3.5	32.8	100.0

The small value of only 1.2% in Table 8.2 is attributed to extraction of oil and gas. Produced water accounts for 90% of this total. It is released slowly at a rate depending on the reservoir, increasing as production ages. The remaining 10% of releases during extraction comprises atmospheric deposition and spills from platforms (0.16 tonnes). The latter constitutes only 0.06% of the total annual release to the sea. Transportation (pipelines and tankers) contributes about three times the amount from extraction. Human consumption provides the second largest contribution to oil in the sea (after seeps), with runoff and rivers depositing the largest amount in this category, followed by atmospheric deposition, and by recreational and other marine vessels.

The record regarding oil spills has been improving. Data from the US Coast Guard illustrating the trend are shown in Figure 8.1. This is for spills in U.S. waters.

8.5 Blowouts and oil spills

8.5.1 Introduction

In Chapter 3, risk analysis was introduced. In this sections, the activities under consideration are analyzed in terms of possible consequences and associated probabilities. With regard to probability, it is important to estimate the exposure correctly in risk analysis. How do accidents, say oil spills, occur in space and time?

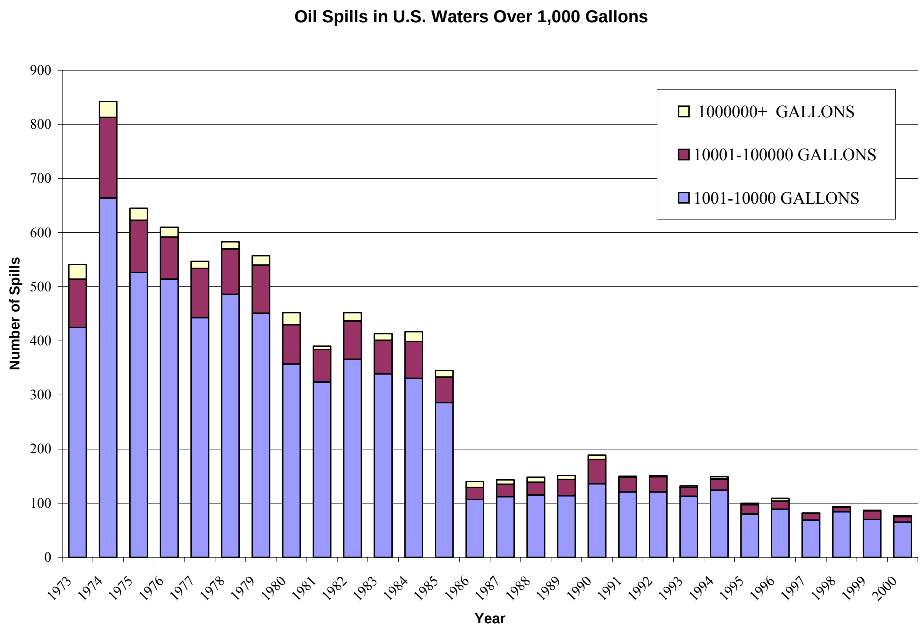


Figure 8.1. Trend showing declining rate for larger oil spills (U.S. Coast Guard data, Polluting Incident Compendium, http://www.uscg.mil/hq/gm/nmc/response/stats/Summary.htm)

We read every week or two of an accident involving aircraft. Many of these are associated with major airlines. Yet one assesses correctly that the risk on an individual flight is small since there are a very large number of flights per day. In a similar way, an oil spill at some location in the world is not on its own indicative of an unsafe situation but should be assessed in terms of the overall exposure, for example the number of offshore operations in the world.

Safety is a result of the care and expense devoted to carrying out technological operations. This is often related to the resources available to society. For example, Barnett and Wang (2000) analyzed the risk per flight for "advanced-world" airlines to be more than 20 times less than that for airlines of developing countries. With regard to oil releases, in the last decade about 150 m^3 were spilled annually from platforms in North America, according to data from the National Research Council (NRC, 2003). A 25% increase in spill rate was used in the NRC report to account for jurisdictions in which standards were not applied to the same level as in North American waters. An example of failure of technology, with regard to the Ixtoc I blowout (mentioned below and in Appendix V), is given in Husky (2000). In this it is stated that it "was caused by drilling procedures ... that are not practiced in US or Canadian waters and which are contrary to US and Canadian regulations and to the accepted practices within the international oil and gas industry." Environmental safety depends to a large degree on the jurisdiction and the associated management.

The other part of risk analysis is the question of consequences. These must be considered both for chronic leaks and for spills, which are much larger in rate of flow of the oil than the chronic leaks. We shall discuss the approximate spill volumes at specified exceedance probabilities per annum (Chapter 3), but there is considerable variability in the impacts on biota depending on factors such as weather conditions at the time of the spill.

Oil spills related to resource development result from various activities:

(a) drilling, completion and workover
(b) operations, leading to batch spills
(c) transportation by tankers, including the offloading process, and
(d) transportation by pipelines.

8.5.2 Risk during drilling and production operations

Background

The following is an overview of oil spill statistics. It is expected that full probabilistic analysis will be part of any environmental risk assessment. In NRC (2003) it is stated that "In the past decade, ... , improved production technology and safety training of personnel have reduced significantly both blowouts and daily operational spills." The values in the NRC (2003) report were compared to those in a previous 1985 NRC report. Table 2-3 in the 2003 report shows that in extraction, spills from platforms and pipelines reduced in volume by a factor of one-third. It should be noted that there has been a considerable increase in offshore production over the same time period. As a further example, in the Norwegian shelf of the North Sea, there have been only two oil leaks of the order of 1000 m^3 since 1980. On 19 May 2003, the Draugen leak of volume 750 m^3 was the third largest to occur on the Norwegian shelf. In 1992, a spill of 900 m^3 on the Statfjord field occurred. A valve on a hose to the loading buoy had accidentally been left in the open position. There are over 200 producing oil and gas fields in the North Sea and there were over 6500 exploration and development wells drilled on the North Sea shelves in the period 1980-1995.

Oil spills: probability of occurrence

In contrast to natural seeps and produced water, oil spills can occur at a high rate and occasionally in high volumes. Batch spills occur as a result of failures or errors in storage, loading, hoses or valves. They are smaller in volume than blowouts and are nearly instantaneous (generally minutes to hours). Table 8.3 summarizes data from Newfoundland. S.L. Ross (2002) notes that the rate has historically been found to decrease with time for new developments.

Blowouts are uncontrolled releases of oil from a well, persistent and of variable duration. The loading rate is high and may last for months. In the past, several large blowouts have occurred. In 1979 the Ixtoc I blowout in the Gulf of Mexico resulted in about 475,000 m^3 of oil being spilled over a period of almost 10 months. The largest in the North Sea occurred at Ekofisk Bravo during April 1977 when about 25,000 m^3 of crude oil leaked as a result of a blow-out lasting a week.

Table 8.3. Production platform spills, offshore Newfoundland 1997-2000
Note: Spills include crude oil and refined petroleum products (which include synthetic based oils with very low PAH content. Normalization in third column based on 40 wells drilled from 1997 – 2000. Data provided by C-NOPB

Spill Size (bbl)	Number of Spills	Spills per Well Drilled
0 – 1.0	22	0.55
1.1 – 9.9	8	0.20
10.0 – 49.9	1	2.5×10^{-2}
50.0 – 499.9	0	0
500.0 – 999.9	0	0
≥ 1000	0	0

Following the approach outlined in Chapter 3 and Section 8.3 above, for risk analysis it is important to develop estimates of the probability of occurrence of spills of various sizes. Two important factors have been identified above. First, there have been considerable improvements over time in the record of offshore developments. Second, sound regulation and high safety standards contribute significantly to improvements in the record. These factors must be accounted for in developing probabilistic estimates. Furthermore, there will be improvements in the future as well. These should be of benefit to safe production in the QCB, if it goes ahead, in 10-15 years.

In Husky (2000), estimates are made using historical data of the probability of large spills from blowouts during exploration and production. Table 8.4 summarizes the large spills greater than 10,000 bbl (1600 m^3), on a worldwide basis. It is noteworthy that, since 1988, the only blowout larger than 10,000 bbl was the Timbalier Bay production blowout in state waters of the US Gulf of Mexico (that is, not in the Outer Continental Shelf region, which is subject to US federal regulation).

We shall now summarize some estimates of historical frequencies based on Husky (2000) and LGL (2000, 2003), in turn based on work of SL Ross. The exposures used will be "per well drilled" for drilling operations and "per well-year" for production. Both are used for an estimate of annual risk; for wells drilled, it is assumed below that one is drilled per year. The resulting frequencies using the data of Table 8.4 is shown in Table 8.5. For the period up to 1988, there were 20,000 exploration wells drilled. There were 51,000 development wells up to 1988, and 200,000 well-years up to 1995. These values were used in Table 8.5.

Table 8.4. Large oil spills (>10,000 bbl = 1600 m^3) from well blowouts in the offshore (Husky 2000) excluding Norwuz (war-related) blowout

Location	Reported Spill Size in bbl	Year	Operation
Mexico—Ixtoc 1	3,000,000	1979	Exploration Well
Dubai	2,000,000	1973	Development Well
Mexico	247,000	1986	Workover
Nigeria	200,000	1980	Development Drilling
North Sea—Norway	158,000	1977	Workover
Iran	100,000	1980	Development Well
USA—Santa Barbara	77,000	1969	Production
Saudi Arabia	60,000	1980	Exploration Well
Mexico	56,000	1987	Exploration Well
USA S. Timbalier 26	53,000	1970	Not Known
USA Main Pass 41	30,000	1970	Production
USA Timbalier Bay-Greenhill	11,500	1992	Production
Trinidad	10,000	1973	Development Well

Table 8.5. Historical rates per well drilled—all jurisdictions (Husky 2000; LGL 2003)

	>10,000 bbl (= 1,600 m^3)	>150,000 bbl (= 24,000 m^3)
Exploratory Drillling (LGL 2000)	1.5×10^{-4} (3/20,000)	5×10^{-5} (1/20,000)
Production—Development (Husky2000)	7.8×10^{-5} (4/51,000)	3.9×10^{-5} (2/51,000)
Production—Production or Workover (Husky 2000)*	2.5×10^{-5} (5/200,000)	1.0×10^{-5} (2/200,000)

*Statistic is per well-year

The cutoff in time in the analysis above was rather arbitrary and could have been extended—the record since 1988 includes only one blowout larger than 10,000 bbl. In S.L. Ross (2002), the estimate of 20,000 exploration wells up to 1988 was amended to 35,000, reflecting the number of wells up to 2001, resulting in an estimate of frequency of 2.86×10^{-5} (1 in 35,000) for spills greater than 150,000 bbl.

Some comments on the methods of analysis should be made. The results will be very conservative, since the spills associated with the frequencies above are undoubtedly overestimates of future expectations. The reason for this statement is that the two factors noted above have not been implemented in these historical calculations. The spill rates have been calculated based only on historical information, with no adjustment for improvements over time. The data include some extreme cases where it is reasonable to deduce that best practice was not used. Adjustments in the estimates have not been made for the better practices that would apply in North American jurisdictions, as against the world as a whole. It should also be noted that the numbers of occurrences are rather small (up to 5). In this case a Bayesian approach is useful to assess the associated uncertainty (Devanney & Stewart, 1974; Smith et al., 1982).

With regard to the improvement of performance with improved technology, SL Ross (2002) makes a comparison between the US Gulf of Mexico and the North Sea: "Although the frequency of shallow gas blowouts is similar for both regions, the frequency of deep blowouts is almost five times higher in the U.S. Gulf of Mexico than in the North Sea." One possible reason stated in the report for this is that North Sea operators are required by law to include two barriers during exploration and development drilling, and this is not the case in the U.S. In Canada, regulations similar to those in the North Sea are applied, with two barriers being specified, so it was seen as reasonable to derive blowout frequencies for Canada on the basis of North Sea statistics.

Even on the basis of historical data without adjustment, it is important to note that large spills are comparatively rare. The annual frequency of spills being greater than 10,000 bbl (1590 m^3) and 150,000 bbl (24,000 m^3) respectively are approximately 10^{-4} (1 in 10,000) and 10^{-5} (1 in 100,000). This conclusion is reinforced by data for mobile offshore units analyzed by Jordaan (2001). Figure 8.2 shows the annual rates for various sizes of crude oil spill, for mobile offshore units. Data are from WOAD, (1996). (WOAD is DnV's Worldwide Offshore Accident Databank). For the years 1980-1995, and for volumes in the range 118-1177 m^3, the rate is slightly higher than 10^{-4} per annum. Mobile offshore rigs are mostly used for drilling and the rate "per unit-year" provides a ready gauge of risk for a particular well-defined activity. Taking into account the conservatism in the frequencies calculated above, the spill at the 10^{-4} per annum level is likely to be of the order of 1000 m^3 or less.

8.5.3 Risk of spills during transportation

Tankers

The improvement in tanker performance was noted in the NRC (2003) report where it was compared to that in the previous NRC (1985) report. Table 2-3 in the 2003 report shows that in transportation worldwide, spills reduced from 1.5 million tonnes per year to 420,000 tonnes per year for transportation in general and from 700,000 tonnes per year to 100,000 tonnes per year for tanker accidents. There was a considerable increase in offshore production over this period of time.

In section 3.10, we outlined the regulations regarding tankers, and in particular the OPA 90. An analysis of the tanker spills in US waters for the period 1886-1991 is compared to those in the period 1992-97 in Table 8.6 (from Cooper, 2003), essentially comparing the performance before and after OPA. The results are for accidents in U.S. harbours and coastal waters that resulted in "major" spills greater than 10,000 gallons (34 tonnes). There is a clear improvement as a result of the trend towards double-hulled tankers and other improvements in enforcement and management.

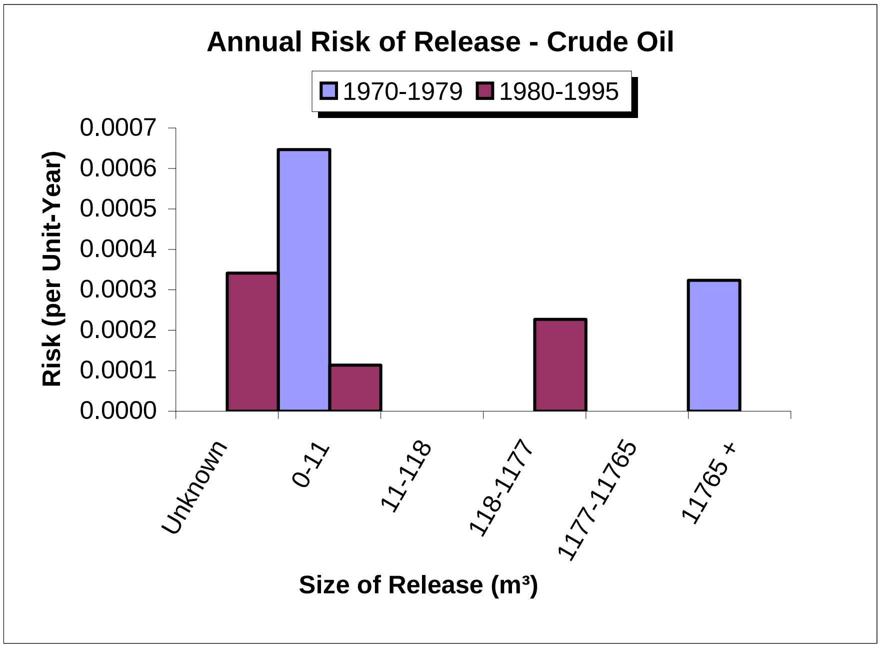


Figure 8.2. Crude oil release statistics; mobile offshore units (WOAD, 1996)

The use of shuttle tankers has also resulted in improved technology. Double-hulls including bunker tanks, redundant machinery and equipment, dynamic positioning to assist in offloading, specialized state-of-the-art software represent some of the recent developments. Navion, a company conducting shuttle tanker operations in the North Sea since 1977 reports (G. Westgarth, 2003, personal communication, workshop presentation) the following statistics.

(a) Number of shuttle tanker operations 13,000
(b) Oil loaded 10,000,000,000 bbls
(c) Major oil spills none
(d) Oil spills greater than 1 barrel 7

Major oil spills are greater than 30 m^3 in the offshore, 100 litres in port. The record is summarized as one oil spill greater than 1 bbl per 1,860 loadings.

Table 8.6. Tanker spills >34 tonnes in US harbours and coastal waters

	1986-91 (Pre-OPA)		1992-97 (Post-OPA)	
Spill Size (tonnes)	**Number**	**Average Spill Size (tonnes)**	**Number**	**Average Spill Size (tonnes)**
34-100	5	61	1	54
100-200	2	130	2	125
200-500	3	320	1	213
500-1000	4	862	1	564
1000-2000	3	1,365	0	0
2000-3400	2	2,168	0	0
> 3400	2	24,490	0	0
Totals	21	2,971	5	216

Pipelines

In North American waters, it has been estimated that 1900 tonnes of petroleum hydrocarbons are spilled into the sea per year (NRC, 2003). In the US OCS, there were 75 spills in the period 1990-99, with a discharge of 5700 tonnes in total (about 600 tonnes per year). Some large spills do occur. NRC (2003) has a discussion of the Lake Barre pipeline break, in which 940 tonnes were spilled. Accidents leading to loss of containment result from mechanical damage from causes such as ships' anchors. Ageing pipelines do present an increased risk due to corrosion.

8.6 Consequences: impacts of produced water, blow-outs and spills

8.6.1 Produced water

The environmental consequences of produced water are mitigated by the rapid dilution of the discharged waters. Patin (1999) points out that the long term effects have not been sufficiently studied. Platform spills are comparatively rare and of small volume with relatively minor consequences.

8.6.2 Blowouts and oil spills: overview

Assessments of the impacts of blowouts and oil spills compound several separate issues, as follows:
(a) the probability of release of oil (see section 8.5);
(b) the dispersion of the release from the point of issue;
(c) the locations of the ultimate fate of the release; and
(d) the impact on biota at the contaminated locations.

Having assessed (a) previously, we shall address (b), (c) and (d) in turn. In carrying forward the risk analyses described above, we note that the spill at the 10^{-4} per annum level in QCB is likely to be of the order of 1000 m^3 or less. During the ensuing discussion, we shall describe the biological impacts of much larger spills (e.g., *Exxon Valdez*, 1989) because their impacts have been more thoroughly studied—not because we believe that they are likely to occur, even once in 10,000 years, in the QCB.

8.6.3 Modelling of oil spill trajectories

The long-term fate of spilled oil is affected by several processes: evaporation, dispersion and emulsification (water-in-oil) being the most important. A light crude oil might lose up to 40% of its volume in the first day after the spill and 75% overall. On the other hand, a heavy oil spill in low temperatures might result in the rapid formation of emulsions and tar balls. These would have a much different impact as compared to a lighter oil spill in a warmer environment (where evaporation would be more prevalent). Until oil is discovered in the QCB, the only information on oil type is that being obtained from seeps (Cretney et al., 2002; F. McLaughlin, personal communication). Modelling for various oil viscosities is required until oil type is known. Water and climatic conditions will affect the mechanism of oil transport (chemical, photochemical, and biochemical reactions) and physical processes (such as emulsification) and dispersion.

Modelling of oil spill trajectories has been ongoing for some time (Mackay et al., 1980; Garcia-Martinez and Brebbia, 1998). There are now numerous models for the fate of oil spills (Patin, 1999) that can be used for assessing impacts and for risk analysis. The trajectory of the spill will depend on the currents and winds at the time of the spill, and this can also be modelled, together with the physical effects noted above. A good survey of various software available is given by Crawford et al. (2002). Analyses of evaporation, spreading, trajectory, amount impacting the shoreline and other factors have been applied to the Queen Charlotte area. Some results are shown in Figure 8.3 (M. Fingas, personal communication) for a spill of 1000 m^3 and these illustrate the ability to model fates and trajectories, using 'Oilmap' software. This is not intended to represent the solution to a particular problem but rather the tools that are available for risk analysis. The winds were taken as random in this case but the history of wind speed and direction can be built into the analysis. These tools can be used, as suggested, for risk analysis, and for assessing the behaviour of an actual spill to assist in contingency planning.

The modelling is particularly important in an area such as the Queen Charlotte basin, which is in certain regions almost surrounded by the shoreline. Oil spills will have a greater probability of reaching the shore with consequent increased environmental impact (Crawford et al., 2002). The oil can also penetrate certain beaches in the intertidal zone. Rocky shorelines should be contrasted with those soft substrate (mud, sand, gravel). There will be different biota along the different shorelines with areas such as estuaries posing special problems.

Volume is clearly an important quantity in the modelling of oil spills. As previously noted, a spill at the 10^{-4} level of annual exceedance is likely to be of the order of 1000 m^3. There is some uncertainty in the literature with regard to impacts as a result of the highly variable nature of these impacts. Different environmental conditions (wind, wave and current) for example can lead to entirely different fates for an oil spill. Some spills reach shore, others do not. Some regions are more sensitive than others. Figure 8.4 suggests an approach to the modelling for impacts on bird populations. A systematic approach coupled with simulation (e.g., Monte Carlo methods) should yield appropriate results. We considered above the volume of the spill as the main attribute. Consequences should be linked to the attributes under consideration.

8.6.4 Locations of ultimate fates of oil spills

Some of the biological impacts of oil spills—especially on seabirds—occur at sea when the slick is moving. Other impacts occur where the slick meets the shore line. Models such as that suggested in Figure 8.4 should assist in locating vulnerable shorelines. For the QCB, a variety of models must be run to allow for assessment of the responses for varying oil types, weather conditions, spill locations and spill sizes.

Modelling along these lines should be continued and make use of enhanced knowledge of seasonal variation of weather and currents as these become available. Valuable outputs from the models for the following stages of assessment are the length and location of shoreline that would be contaminated and the time lag between release and landfall. The landfall locations should be assessed for their physical characteristics (e.g., sand vs. boulder beach) to determine how oil will behave on the beach. The shorelines of the QCB are quite variable: while high-energy beaches with rocks, boulders and coarse gravels predominate, there are numerous embayments and estuaries, with sand and mud beaches. The physical characteristics of the shoreline in the QCB can now be assessed with the help of tools such as the BC Government Coastal Resource Inventory program and products derived from those data. It is unfortunate that public access to those data appears to be limited at this time.

Estimates of spill size, spill trajectory, and landfall can now be made using the tools of quantitative risk assessment. Uncertainties should be reducible in future with the aid of new data on weather and currents, and on oil types when these are discovered. Impacts on biota are more difficult to assess for the QCB.

8.6.5 Impacts on biota at the contaminated locations

In blowouts, the usual assumption is that emissions of gas do not pose a significant environmental risk (LGL, 2000; S.L. Ross, 2002), although possible explosions from them do constitute a risk to humans. Patin (1999) identifies several effects of gas on fish, although these might be expected to be localized during the blowout.

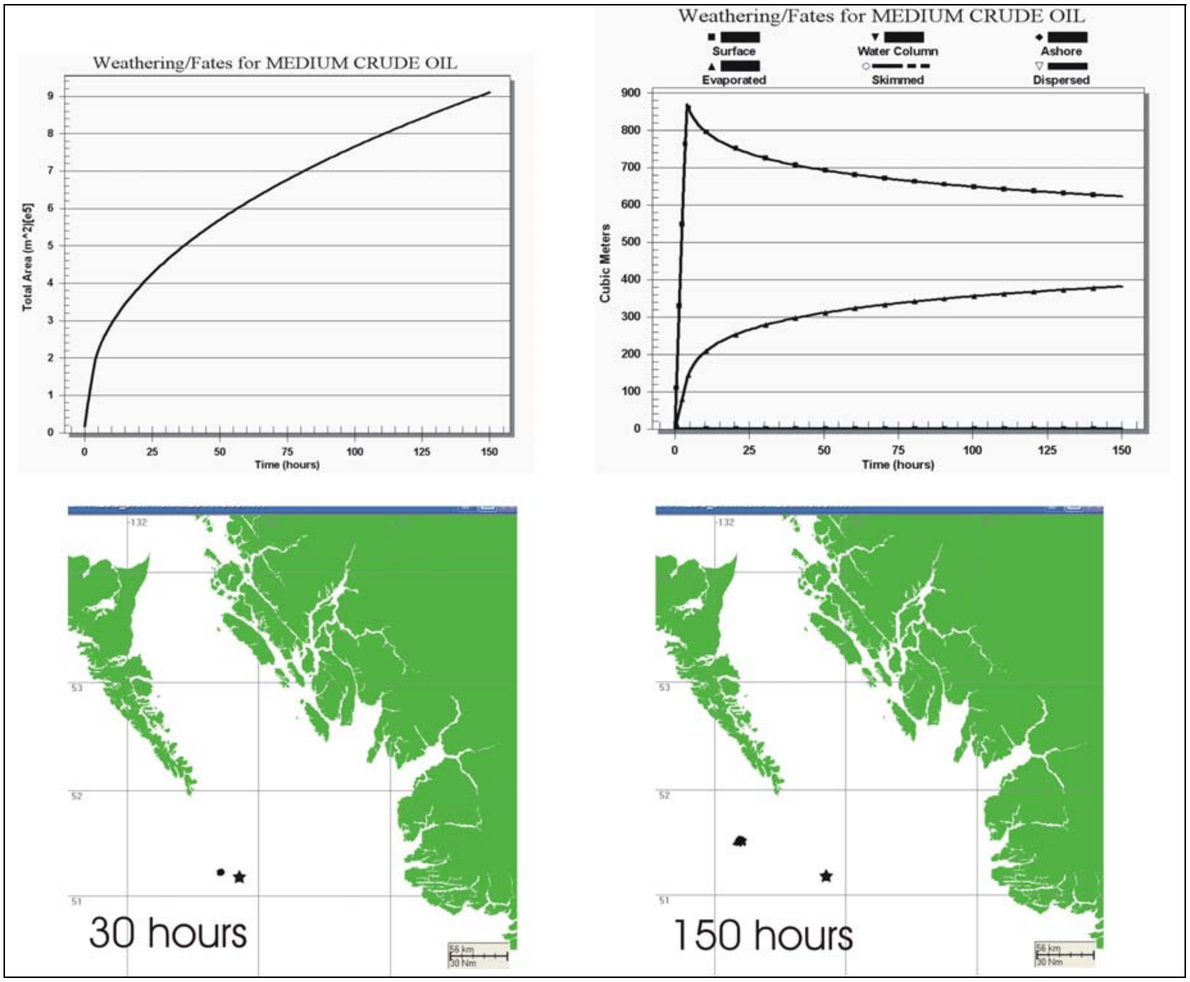


Figure 8.3 Spreading and fate of oil in 1000m^3 spill of medium crude oil in outer Queen Charlotte Sound. Maps show location of spill relative to release point (*) 30 and 150 hours after release. Time plots at top show 150 hours of fate of spill (release, evaporation, area). (M. Fingas, 2003, personal communication)

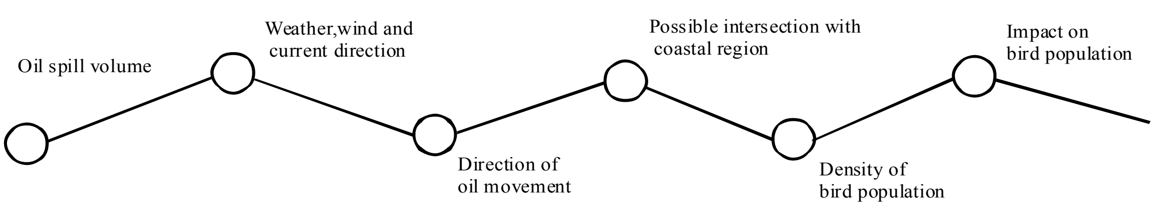


Figure 8.4. Schematic tree for modelling of spill impacts on bird population

and gas are involved in a blowout. The natural gas being compressible provides the driving force for an uncontrolled blowout. The velocity at the wellhead creates a turbulent zone resulting in the fragmentation

The behaviour of oil in the sea is well documented (Patin, 1999; NRC, 2003). Blowouts can occur on the surface or from the seabed. In the latter case, the oil rises to the surface through the water column. Both oil of the oil into droplets. If the blowout is on the seabed, water is entrained and buoyancy results in the formation of a plume. On the surface, the oil spreads into a slick and moves under the influence of wind and current. The oil moves approximately at the same velocity as the current with another component equal to about 3% of the wind velocity.

The biological impact of a spill or blow out will depend on several factors, including:

(a) the nature of the hydrocarbon spilled; this will govern the toxicity, distribution and persistence of the spill as lighter oils "weather" faster than heavy ones, and acute toxicity tends to increase with increasing lower molecular weight aromatic content;
(b) climate, weather and sea-state at the time of the spill and afterwards; these factors govern the distribution of the spill as wind direction and tidal or other currents move the spill, and higher energy or more dynamic systems hasten its weathering and redistribution throughout the water column;
(c) the physical nature of the "receiving" environment; this governs the persistence of the spill as exposed rocky shorelines allow faster weathering of spills than do sheltered sandy bays; and
(d) the sensitivity or vulnerability of biological systems.

The most important information gap in assessing the possible impact of an oil spill or blow-out is in biological data. Specifically, data describing the spatial and temporal (or seasonal) distribution of biota other than some commercially important species in the QCB are too generalised to be of real value here. Information describing the sensitivity of individuals, populations or communities to oil is available from other regions, but none from the QCB. Data on local distributions and sensitivities are needed to make the appropriate quantitative assessments of the consequences of a spill or blow-out.

We can make some general qualitative assessments of the probable behaviour and impact of a significant spill or blow-out. The following discussion assumes that something generally similar to a Prudhoe Bay crude oil (i.e., a medium to heavy crude, likely to persist over periods of days to weeks at a minimum) might be involved. We have chosen this as an example, since the *Exxon Valdez* Oil Spill (EVOS) in 1989 involved this oil, and the proximity of Prince William Sd. to NW BC and the similarities in topography and in biota between the two regions invite comparisons. For contrast, we have also considered the *Braer* spill, another spill in northern waters, off the Shetlands in 1993, but involving a lighter crude (Gullfaks). More details about the *Exxon Valdez* and *Braer* spills are summarised in Appendix V. These appendices also provide information about the spill of Bunker C oil from the barge *Nestucca* off Washington State in December 1989, some of which reached western Vancouver Island, and the most recent major oil spill, from the *Prestige* off western Spain in late 2002.

Immediately following a spill, dynamic processes of wind and wave action, and environmental weathering (mainly evaporation of more volatile components) tend to alter the physical nature of the oil. Depending on physical conditions, significant amounts of oil could remain on the surface (in calm conditions) or could be widely distributed throughout the water column as colloidal or particulate material. Given the generally dynamic wind and wave climate in the Hecate Strait region, it seems probable that an appreciable fraction of spilled and weathered oil would be dispersed in the water column, though some material would undoubtedly remain on the surface. As weathering proceeds, some particulate material tends to aggregate and/or increase in density, and so sediments out. Partly because of these processes and partly because of the hydrophobic nature of oil and its components, there is a general tendency for spilled oil to accumulate at interfaces, such as the sediment-water interface, the air-sea interface (i.e., the sea surface) and the land-water interface (shoreline). Thus, organisms that inhabit or use these interfaces may be most at risk, though this is not to say that biota occupying primarily the water column escape any impact of an oil spill.

It is possible to assess some of the more general impacts on biota. For organisms such as mammals or birds which occupy or visit the sea surface, a surface slick may present a serious threat, mainly because oiling may reduce the insulating properties of feathers or fur (though direct poisoning by ingestion of droplets may also occur). Estimating the biological impacts along the shoreline requires better information than appears to be available now for the QCB. Seasonal variations in species populations along vulnerable shorelines is required from further surveys, to augment the biophysical inventories already collected (which are based on single pass coastal video).

Some generalisations about the nature of spill impacts can be made from major spills in the past that have been well studied. One aspect that needs to be considered in assessment of risk is the time scales over which different components of the ecosystem recover. This has been well studied for the *Exxon Valdez* spill (see Appendix V), and shows that some species have not recovered in reviews conducted 13 years after the spill occurred (Peterson et al., 2003; and http://www.evostc.state.ak.us/facts/status.html).

8.6.6 Lessons from the *Exxon Valdez* and *Braer* spills

The following discussion assumes that something generally similar to a Prudhoe Bay crude oil (i.e., a medium to heavy crude, likely to persist over periods of days to weeks at a minimum) might be involved. We have chosen this as an example, since the *Exxon Valdez* Oil Spill (EVOS) in 1989 involved this oil, and the spill occurred in Prince William Sound, Alaska, which has similarities to the QCB in topography and in biota. For contrast, we have also considered the *Braer* spill, another spill in northern waters, off the Shetlands in 1993, but involving a lighter crude (Gullfaks). These were very large spills, beyond the range of the extreme events at specified probability levels given above.

During EVOS it was estimated that several thousand sea otters and several hundred harbour seals may have been killed by oiling (Laughlin et al., 1996). In contrast, during the *Braer* spill, only some sub-lethal impacts on grey seals were observed (Hall et al., 1996) and even these could not be attributed unequivocally to the effects of oil. The difference in scale of impact was probably partly due to the absence of a significant slick in the *Braer* spill. This reflects the very dynamic wind and wave action off the Shetlands at the time of the spill, in comparison to that in Prince William Sound immediately after EVOS. It is estimated that up to about 250,000 birds may have been killed by oiling during EVOS (though it is recognised that such estimates are only approximate, as they rely on extrapolation of much smaller numbers of carcasses actually recovered; Piatt and Ford, 1996). In contrast, only about 4,000 birds are believed to have died as a direct result of the *Braer* spill (Kingston, 1995), the difference in impact again probably being attributable to the absence of a large surface slick.

It is much more difficult to assess potential impacts on biota such as phytoplankton or zooplankton which may periodically occupy the surface layer, mainly because there is considerable natural “patchiness” in the distribution of these organisms.

Impacts of oil spills on sub-tidal and inter-tidal biota have also been recorded. Inter-tidal algae were reduced in number immediately following EVOS as were various mollusc species (van Tamelen and Stekoll, 1996; Hooten and Highsmith, 1996); abundance and biomass of barnacles and some oligochaetes, however, were enhanced. Sub-tidal macroalgae such as kelps seem not to have been significantly affected by EVOS (Dean et al., 1996a) but populations of epibenthic invertebrates showed changes which were generally correlated with the extent of oil distribution (Dean et al., 1996b). In the *Braer* spill, it was difficult to detect changes in benthic invertebrate community structure which could be clearly related to oiling (Kingston et al., 1995; Moore and Stevenson, 1997) and again, this may reflect the dispersal of the *Braer* oil in a highly energetic environment. This experience is in contrast to the situation following the *Amoco Cadiz* spill in the Bay of Biscay, in which clear trends in benthic community structure were seen immediately following the spill and during a recovery period of several years after the spill (Clarke, 1993). In both EVOS and the *Braer* spills, various impacts on pelagic fish (mainly occupying the water column) were observed. Various lethal and sub-lethal effects were observed in herring eggs and larvae exposed to EVOS in 1989 and it was estimated that larval production dropped by about 50% (Brown et al., 1996). This could not be related to a reduced return of adults in 1993, because of confounding factors other than oil exposure. Pink salmon exposed to EVOS showed reduced growth in early life stages in 1989 (but not

1990) (Geiger et al., 1996; Wertheimer and Celewycz, 1996; Willette, 1996) and this was probably not attributable to changes in prey availability (Wertheimer et al., 1996; Celewycz and Wertheimer, 1996). The reduced growth rate at early life stages probably led to a reduction of around 2% in survival to the adult stage (Willette 1996). There appears to have been no estimate of fish mortality following the *Braer* spill, but both pelagic and demersal fish showed signs of exposure to oil hydrocarbons as indicated by Cytochrome P-450 1A induction (George et al., 1995; Stagg et al., 1998). Similar indicators were observed in EVOS (Wiedmer et al., 1996; Collier et al., 1996).

From the foregoing, it is clear that any oil spill in the Hecate Strait/Queen Charlotte Sound region can be expected to have a range of biological effects, ranging from subtle biochemical changes to death, depending on species and exposure. However, the persistence and impact of an oil spill will depend on the general composition of the oil and the environmental conditions prevailing during a spill. Furthermore, given the scarcity of information about the numbers and distribution of potentially vulnerable species in the region (or even of their sensitivity to oil exposure) it is difficult to describe impacts more specifically. As a final point, however, we note that the *Braer* spill resulted in closure of a significant area to commercial fishing and aquaculture. This, and the perception that commercial species of fish and shellfish may have been exposed to oil, or may have been tainted by hydrocarbon uptake, had a large and direct economic impact (Goodlad, 1996).

8.6.7 Mitigation: oil spill response

There are various methods for mitigating the effects of oil spills: mechanical, chemical and biological means are all employed. The use of mechanical means—floating booms and skimmers—is preferred from an ecological point of view (Patin, 1999) and is preferred offshore eastern Canada, though chemical dispersants have been used in the North Sea. Typical rates of successful recovery in present activities in British Columbia are of the order of 15% of total oil spilled (C. Dougans, 2003, personal communication, workshop presentation). It is expected that special contingency plans will be developed for the Queen Charlotte area should oil and gas developments proceed. The effects of mitigation can be included in risk analysis (Reed and Ekrol, 1998).

8.6.8 Conclusion

The volumes of oil from produced water far exceed those of small batch spills, which produce relatively little pollution. Patin (1999) points out that the rapid dilution of the produced waters is usually used to support the conclusion that the environmental impacts are insignificant. He does point out that the long term effects have not been sufficiently studied. Two factors should also be considered for the QCB: the area is subject to much less industrial and human activity contributing to oil in the sea (compared to basins such as the North Sea) and, by contrast, there is likely to be a considerable contribution from seeps.

Large oil spills from blowouts and tanker accidents present an important risk, requiring a strong precautionary approach. Risk analyses for the QCB need to be thoroughly researched and structured (see Smith et al., 1982; US Marine Minerals Service site: http://www.mms.gov/eppd/sciences/osmp/index.htm). There is a need for modelling that addresses spill size and spill frequency in a realistic manner with modelling along the lines suggested in Figure 8.4. Estimates of events at specified exceedance probabilities (e.g. 10^{-4} and 10^{-5} per annum) should be carried out with realistic estimates of probability. Taking into account the conservatism in the frequencies calculated above, the spill at the 10^{-4} level of annual exceedance is of the order of 1000 m^3 or less. Conservative assumptions should be avoided when making probabilistic estimates: the conservatism embodied in the target safety levels should be the main factor in obtaining results that are in accordance with the precautionary principle. Any assumptions leading to additional conservatism, that have to be made, should be clearly stated. Modelling of oil spill trajectories with various assumptions about oil type, spill size and weather conditions can be done with available software. The physical characteristics of landfalls of spills in the QCB are already prepared in BC Government Coastal Resource Inventories. The weakest link in the series of estimates lies in the estimation of biological consequences, including the perseverance of impacts. While generalities of distributions of species over space and time for the QCB are known, details required for adequate assessment of biological vulnerability to oil spills represents a significant data gap. This needs to be filled before drilling and production proceed. It could be carried out as part of environmental assessments (Chapter 3) associated with specific activities, though the Panel suspects that it would serve the general public good to accelerate biological mapping soon.

Transport of oil by pipeline is considered to be safer from the point of view of possible environmental impact (Strong et al., 2002, p. 47) but this is not necessarily the case if consideration is given to modern shuttle tanker operation.

8.7 Recommendations regarding science gaps

In this section we extract from the earlier sections the knowledge needs required for assessment of practice of oil and gas activities which would be safe from an environmental viewpoint. We also discuss the consequences of not filling the science gaps identified.

Section 8.2.1 Modelling of ***acoustic propagation of seismic survey sources*** is needed for assessment of potential behavioural impacts on mammals (especially whales). Behavioural disturbance is itself uncertain because of the wide range of observed responses, but proposals for individual seismic surveys should be required to provide estimates of received sound levels at critical sites and times in the QCB. Without this, there might be behavioural disturbance during calving, migration through restricted channels, and similar events that might impair the viability of some of the smaller vulnerable whale populations.

Section 8.2.3. The ***space-time distributions of fish that are VEECs*** is needed to define periods and areas when seismic surveys can be safely carried out, without endangering spawning, migration and populations. Of particular importance might be the inshore distribution of herring, and salmon migration routes.

Section 8.2.4. The ***major confined spawning areas for critical fish species*** must be defined, together with the spawning times, so that seismic surveys can be excluded from those areas. While in general it appears that seismic sources kill fewer eggs and larvae than die because of harsh conditions or are preyed upon by other species, spawning areas for critical species should be avoided as a measure to assist in their recovery.

Section 8.2.5. The ***space-time distributions of those mammals that are VEECs***, together with their behaviour patterns should be determined so that critical concentrations at critical times can be avoided by seismic surveys. Recovery of vulnerable populations might be impacted by seismic surveying through nursery areas.

Section 8.2.6. ***Observers on seismic vessels should log the occurrence and behaviour of diving birds*** close to active sources. It is unlikely that significant numbers of diving birds are harmed by seismic surveys, but there is little data on this: collecting some would be of value.

Section 8.3.3. ***Baseline studies of seabed hydrocarbon and other chemical distributions, of benthic community structure, and Cytochrome P-450 1A status in indicator fish,*** should be collected to provide a datum to allow the impacts of oil and gas activities to be assessed. Without such data, the attribution of cause of an unwanted event to a specific activity might not be possible.

Section 8.6.3. ***Oil spill trajectory modelling*** should be carried out for a wide range of oil types, spill locations within the QCB, and weather and sea conditions. Seasonal variations in weather should be included. This will reveal general patterns for the dispersal of oil that will be of great value in setting up an optimal oil spill response system. Without such modelling, oil spill response will be less effective. These techniques are also fundamental in risk assessment.

Section 8.6.4. ***Defining the impact of oil spills on their landfalls*** should be derived from knowledge of shoreline types, from sources such as the BC Government Coastal Resource Inventory program and products derived from those data. Without this information, oil spill response might be less optimally designed.

Section 8.6.5. ***Seasonal variations in species populations along shorelines*** is needed for assessment of the vulnerability of biota to an oil spill. Without these data, the priority assigned to, and nature of, oil spill response for different parts of an impacted coastline could not be made.

CHAPTER 9

PROTECTED AREAS AND EXCLUSION ZONES

9.1 Marine Protected Areas: overview

Variously known as marine parks, marine conservation areas, marine sanctuaries (particularly when applied to marine birds), marine exclusion zones, marine ecological reserves or, most commonly, marine protected areas (MPAs) are essentially the marine counterpart to the better known terrestrial "park" model. Unlike terrestrial parks, however, most MPA's are—by their very nature—unseen by the public at large. The unifying feature of such areas is that general access, and the range of activities (e.g., ranging from public access, to commercial development and resource extraction) that can be undertaken within the boundaries are restricted to some degree. Hereafter, we will collectively refer to all of the above types of areas as MPAs.

Like terrestrial parks, MPAs vary both in terms of size and the degree of protection afforded the organisms and the environments within the MPA boundaries. Likewise, MPAs are established and administered by various government agencies (but most commonly under either federal or provincial jurisdiction), who may allow for varying degrees of activity within a given MPA.

In general, the objectives for establishing MPAs are numerous and diverse but remain broadly consistent with the objectives underlying the creation of most terrestrial parks. In some cases, MPAs are established to protect a particular species or a population that has been deemed to be "at risk." In other cases, MPAs are established to protect an entire ecosystem that is considered to be unique (e.g., the recent designation of the Endeavor Hot Vents as an MPA by the Department of Fisheries and Oceans). In still other cases, an area might be designated as an MPA to serve as a representative example of a particular type of widespread marine environment.

In large part, however, the specific management objectives for a given MPA often reflect the mandate of the administering agency. In Canada, for instance, the objectives of an MPA established by the Department of Fisheries and Oceans may be partly tied to ensuring the future stability of commercially valuable stocks (e.g., perhaps by protecting an important spawning ground), whereas MPAs established by Parks Canada might be more concerned with the fundamental goal of protecting marine biodiversity and a wide range of representative marine habitats.

Because of the varying management objectives underlying the creation of MPAs, the degree of protection offered can also vary. The least restrictive form of MPA is the long-used practice of seasonal fishing closures. During particular times of the year, particular types of fishing activity are prohibited in specified areas; during the remainder of the year, the area is accessible for commercial fishing activity. At the other extreme are so-called "no-take" MPAs, within which no resources of any kind (renewable or non-renewable) can be removed, and on top of which there may be additional restrictions on all other uses (e.g., shipping, aquaculture, shoreline development, public recreational use, etc.). In practice, however, most MPAs fall somewhere between these two extremes.

9.2 Existing MPAs in the Queen Charlotte Basin

Several MPAs and other exclusion zones already exist within the Queen Charlotte Basin (QCB, Figure 9.1). The most extensive of these, the QCB Coastal Exclusion Zone is based on a recommendation by the WCOEEAP (1986) and prohibits drilling activities within 20km of the coast in order to assure the "*protection of important marine life in the event of an offshore oil blowout.*" (WCOEEAP, 1986). The choice of 20 km was based partly on assumptions

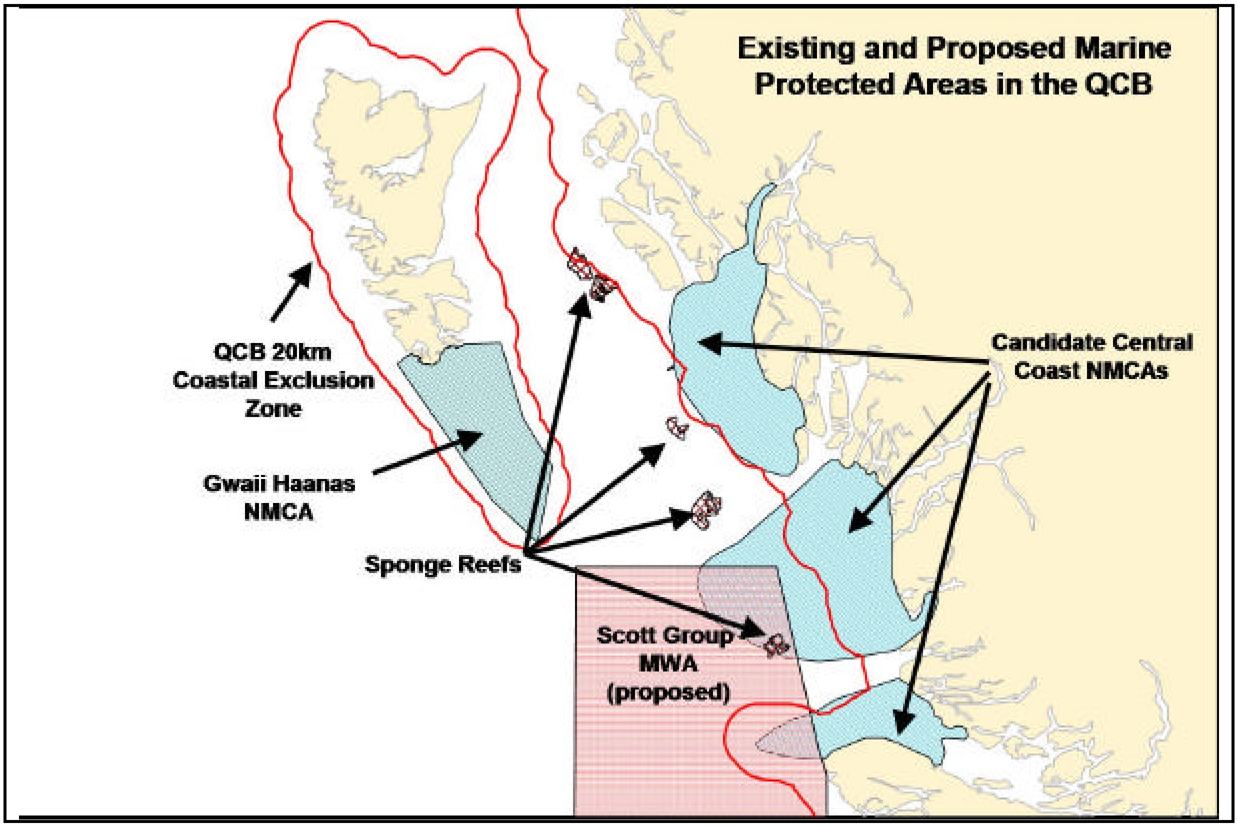


Figure 9.1. Existing and proposed marine protected areas in the Queen Charlotte Basin. (From online data provided by the BC Offshore Oil and Gas Team at http://www.offshoreoilandgas.gov.bc.ca/)

about the distance that an oil spill might be expected to drift in 1-2 days, thereby allowing time to initiate an emergency response before the spill contacted the shoreline. The WCOEEAP also recommended that seismic surveying be prohibited within 10km of shore during the grey whale migration and herring spawning period (March-May and November-December).

In 1993 Parks Canada established the Gwaii Haanas National Park Reserve, which covers the southern half of Moresby Island. Parks is also in the process of establishing a Gwaii Haanas National Marine Conservation Area (NMCA) covering some 3400 square kilometres and extending approximately 10 km offshore from the adjacent National Park Reserve (Fig 9.1). NMCA is the term used by Parks Canada to denote its network of relatively large marine protected areas that are currently being implemented on Canada's three coasts. NMCAs are established under the Canada National Marine Conservation Areas Act (2002). Although fishing and shipping activities are permitted within NMCA boundaries, oil and gas exploration and extraction are explicitly prohibited. It is envisioned that, once complete, this network of NMCAs will serve to protect a representative suite of Canadian marine environments and ecosystems.

The BC government also administers several provincial Ecological Reserves within the QCB that include marine components (Table 9.1). The province establishes such reserves to serve as areas:

(a) that are suitable for scientific research and educational purposes associated with studies in productivity and other aspects of the natural environment;
(b) that are representative examples of natural ecosystems in British Columbia;
(c) that serve as examples of ecosystems that have been modified by human beings and offer an

opportunity to study the recovery of the natural ecosystem from modification;

(d) where rare or endangered native plants and animals in their natural habitat may be preserved;

(e) that contain unique and rare examples of botanical, zoological or geological phenomena.

Table 9.1. Provincial ecological reserves within the Queen Charlotte Basin. (From online BC Parks data at http://wlapwww.gov.bc.ca/bcparks/conservation.htm)

Name/Location	Main Ecological Features	Size (ha)
Rose Spit Ecological Reserve, NE point of Graham Island	Sand spit, open dunes and shoreline meadows	170
Scott Islands (Sartine, Beresford and Triangle), North Vancouver Island	Seabird and sea lion colonies	106
Moore/McKenny/Whitmore Islands Ecological Reserve, eastern Hecate Strait	Seabird colonies	73
Dewdney and Glide Islands Ecological Reserve, eastern Hecate Strait	Variety of maritime bog, pond and scrub forest communities	3845
Lepas Bay Ecological Reserve, off NW corner of Graham Island	Seabird colonies, mainly petrels	4
Byers/Conroy/Harvey/Sinnett Islands Ecological Reserve, Hecate Strait,	Important seabird and marine mammal breeding areas	12,205
Duke of Edinburgh Ecological Reserve, NW of Port Hardy	Largest seabird nesting colony in Queen Charlotte Strait	660
Vladimir J. Krajina Ecological Reserve, W coast of Graham Island	Virgin marine shoreline, large seabird colonies	9834

The provincial ecological reserves within the QCB range in size from less than 10 ha to greater than 12,000 ha. All extractive activities are prohibited within the reserve boundaries.

Finally, although not yet formally designated as MPAs, the hexactinellid sponge reefs in the QCB (see Chapter 5.5) are each surrounded by trawler exclusion zones imposed by DFO.

9.3 Proposed MPAs in the Queen Charlotte Basin

In addition to the Gwaii Haanas NMCA, Parks Canada is currently examining three other areas within the QCB as candidate NMCAs. Chosen primarily on the basis of their representivity, the areas under consideration are centred on the eastern side of the basin (Figure 9.1) in the area commonly referred to as the BC Central Coast. Depending on which site is ultimately chosen for NMCA designation, parts of Queen Charlotte Sound and/or Hecate Strait would become inaccessible to future oil and gas activities.

The provincial ecological reserve in the Cape Scott Islands is currently limited to the islands themselves, plus a 1 km buffer zone that surrounds each of the islands. However, in recognition that the colonial seabirds inhabiting these islands can forage more than 100km offshore, Environment Canada (through the Canadian

Wildlife Service) has recently proposed a much larger marine reserve (Figure 9.1) that, if approved, would extend coverage to much of southern Queen Charlotte Sound.

The Panel was also informed that DFO is considering imposing several smaller MPAs within the QCB specifically designed to protect rockfish populations (A. Sinclair, 2003, personal communication, workshop presentation). It is not yet clear whether any non-fishing activities would be restricted in these areas.

Plans are also in the works to confer some sort of permanent protected status to the hexactinellid sponge reefs of the QCB (beyond that offered by the existing trawler exclusion zones imposed by DFO which, incidentally, are much smaller than those indicated in the terms of reference; see http://www-ops2.pac.dfo-mpo.gc.ca/xnet/content/MPLANS/plans03/Trawl03pl.PDF). Although it is not yet clear what form such an MPA would take, there have been attempts to have the five reefs designated as UNESCO World Heritage sites (S. Jessen, Canadian Parks and Wilderness Society, personal communication), based on the fact that the reefs are unique, quite ancient and are believed to be an important nursery ground for other species in the region.

9.4 Exclusion zones around oil and gas activities

Exclusion zones are usually established drill rigs, and production platforms, both to ensure the safety of the vessels and rigs as well as the safety of other vessel traffic in the area. On Canada's east coast, such exclusion zones generally extend 500m from any drill rigs and production platforms, or at least 50m beyond their associated anchors. With the exception of vessel traffic associated with the rigs (e.g., supply vessels, etc.), no other vessels or activities (commercial or otherwise) are allowed within the exclusion zones.

The duration of a given exclusion zone depends on the type of activities taking place within its boundaries. For instance, in the case of exploratory drilling, a given exclusion zone would likely only need to be in place for weeks to months (i.e., the time necessary to drill an exploratory well). In contrast, the exclusion zone surrounding a production facility would be in place throughout the entire working life of the facility (i.e., years to decades).

For seismic surveys, in many jurisdictions, liaison with fishing vessels and other ships in the vicinity is maintained. This avoids possible entanglement of the streamer array towed by the seismic vessel (e.g., 5-6 km long and perhaps 1 km wide) either with trawl gear or other ship's propellers. During the periods of survey, which may be a period of months, ongoing communications between the seismic vessel, the Coast Guard and the local fishing fleet are essential to ensure the safety of all.

Depending on where drilling and production take place, exclusion zones (even short-lived ones) can represent an economically significant loss of access to fishing grounds. This would presumably be dealt with by the regulatory regime through some form of compensation to fishers, as occurs in other jurisdictions.

9.5 Recommendations

Sponge Reefs

The Panel recommends that, in light of their unique nature, the sponge reefs in the QCB be designated as MPAs as soon as possible. These MPAs should be protected from all fishing and drilling activity, and be surrounded by an appropriate buffer zone. Because of the depth of water above the reefs, it is unlikely that there will be any significant impact on the sponges from the kinds of seismic survey described in this report. We note that the frequencies of sound of exploration seismic sources are around one thousand times smaller than those required for resonance—and hence likely damage—in the individual sponge structures.

Marine Protected Areas

The Panel recommends that concerted action be taken by government (with assistance from other stakeholders) to determine the areas that should be protected in the QCB, the level of protection to be enforced, and to pass the corresponding legislation. In determining the areas to be protected, it would be appropriate to consider the potential for development of all the natural resources of the basin, renewable (fish, shellfish, etc.) and non-renewable (oil, gas, minerals).

Coastal exclusion zone

The exclusion zone prohibiting drilling within 20km of the coast was established partly to allow sufficient time to mount an emergency response in the event of an oil spill (i.e., before the spill reached the coast). However, the Panel notes that under certain combinations of winds, tides and currents, an oil spill in the QCB might drift 20 km in less than a single day. Furthermore, it is recognized that some parts of the coast may be more sensitive to oil damage than others. Thus, the current level of protection afforded by the blanket 20 km exclusion zone is unclear. The Panel notes that, although models have since been developed to predict oil spill trajectories in the QCB during summer, comparable data do not yet exist to permit comparable predictions during winter months.

Based on this, the Panel concludes that the existing 20 km exclusion zone for drilling activities should be maintained for the time being. The Panel also recommends that, prior to initiating exploratory drilling, the necessary physical oceanographic data be collected to develop oil spill trajectory models for all seasons in the QCB, and that the existing inventory of shoreline data (collected by the BC government) be used to identify areas most at risk of damage from an oil spill. Together, these data should then be used to re-evaluate the utility of the existing 20 km exclusion zone. It may be that some areas of the coast require more protection, whereas drilling might be allowed closer to shore in less sensitive areas.

Exclusion zone for seismic surveys

The 10 km coastal exclusion zone recommended previously (WCOEAAP, 1986) for seasonal restriction of seismic surveys should be modified to exclusion of seismic surveys from waters shallower than 20 m and a zone within 1 km of the 20 m isobath. This would limit impacts on several harvested species (shellfish, herring) that populate the inshore areas and shallow waters. Less general—i.e., more site-specific restrictions—might be applied if there were adequate information on variation of critical species populations in space and time, and on the impacts of seismic surveys on critical species. Exceptions to the general exclsuion from shallow water might be permitted for those special seismic surveys that might be designed to cross the shore line to link marine and land profiles (so-called 'transition zone' surveys): individually, these would require detailed environmental assessment.

Seismic activities should be prohibited in all areas deemed as critical habitat for species listed by COSEWIC as endangered, threatened or of special concern and during periods when these species are most vulnerable (e.g., during migrations, spawning, etc).

As improved knowledge is acquired on the space-time distribution and activities of critical species in the QCB, and on the impacts of seismic survey on biota, these general restrictions should be replaced by more site- and time-specific restrictions.

CHAPTER 10

COOK INLET, ALASKA

10.1 Introduction

The interactions of the natural world are sufficiently complex that the impacts of a newly-introduced activity such as oil and gas production cannot always be estimated accurately. Comparisons with similar basins that have mature oil and gas development can offer valuable insights. The Cook Inlet Basin, in Alaska, has much in common with the Queen Charlotte Basin (QCB), and is worthy of closer analysis (Strong et al., 2002). The following summary is based on research by Pauline Honarvar.

Cook Inlet lies on the south central Alaskan Coast (Figure 10.1), and has been the centre of a thriving oil and gas industry for almost 50 years. Oil was first discovered in 1957 onshore at Swanson River (80 km SW of Anchorage) and in 1963 oil was discovered offshore in the centre of Cook Inlet (Wagner et al,. 1969).

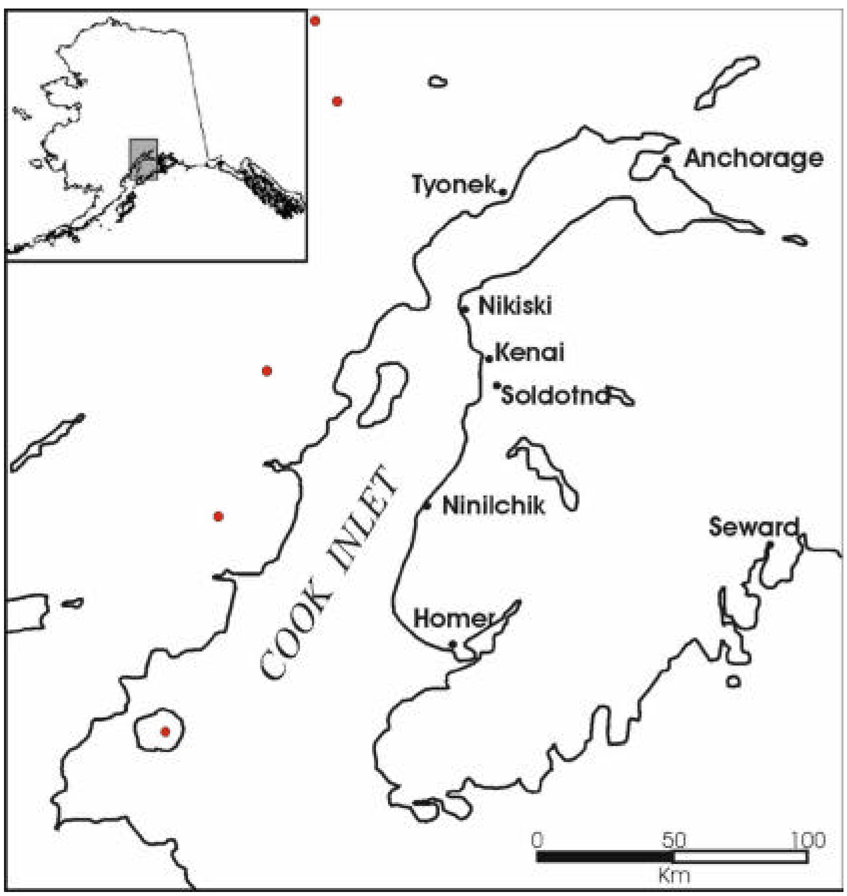


Figure 10.1. Map of Cook Inlet, Alaska. The red dots on the west side of Cook Inlet are the locations of active volcanoes.

Anchorage, located at the head of Cook Inlet, is Alaska's largest city (population of 260,000) and a major sea port. Other towns in Cook Inlet are Kenai (population of 6,900) and Nikiski (population of 4,300). Comparatively, Prince Rupert (as the largest city in the QCB area) is also a major seaport but only has a population of about 17,000 residents and the population of the Queen Charlotte Islands in total is about 6,000. The Cook Inlet area supports a much larger population base than does the QCB.

There are many similarities between Cook Inlet and the QCB. Oil and gas reserves of Cook Inlet are similar to the potential estimated by Hannigan et al., (see section 10.2 below). Both are enclosed waterways—Cook Inlet is a tidal estuary and the Hecate Strait is a partially sheltered shelf environment. Each has long-established commercial fisheries, a growing tourism industry, environmental concerns (protection of parks, sanctuaries, critical habitats), First Nations interests and the concerns of how to balance all these competing and coexisting enterprises.

Many issues of concern to BC residents and environmental groups have already been dealt with in the Cook Inlet area and these can be used as a template for monitoring oil and gas activities and their effects on the environment in the QCB. One of the major steps forward in the Cook Inlet area, especially after the Exxon Valdez oil spill, was to set up councils and 'keepers' to involve the public in the monitoring of the production and transportation of oil and gas. This includes actual monitoring projects as well as education and information dissemination.

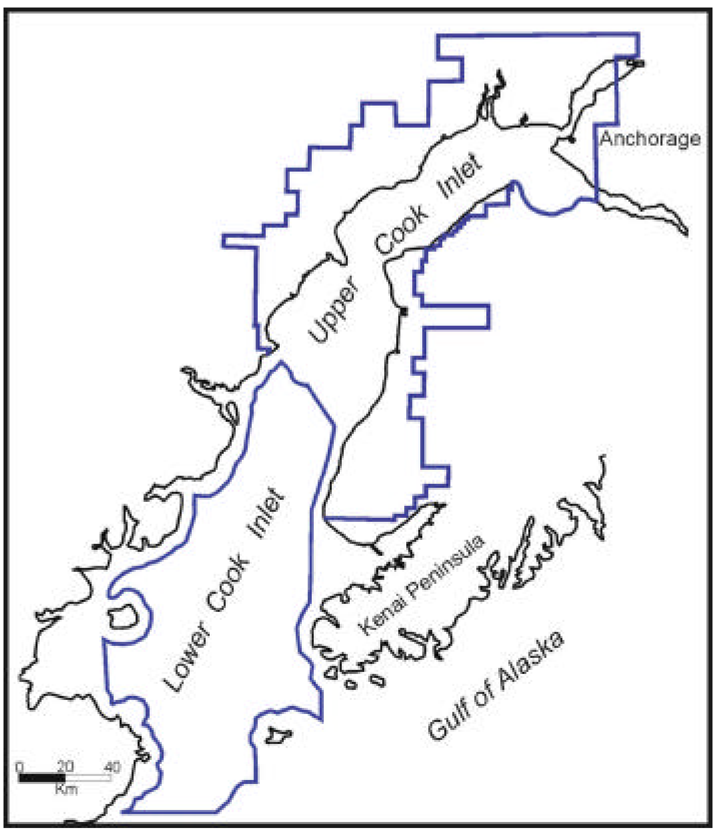


Figure 10.2. Outline map of the geological Cook Inlet Basin, based on area-wide oil and gas leasesale boundaries (from http://www.dog.dnr.state.ak.us/oil/products/publications/cookinlet/cookinlet.htm, J. Cowan, Alaska Department of Natural Resources, 2003, personal communication, workshop presentation)

10.2 Oil and gas production

The Cook Inlet basin is about 380 km long and about 80 km wide, as defined by the outline of the area wide oil and gas sales area (Fig. 10.2). Comparatively, the QCB is about 470 km in length (from the Alaska panhandle to the Scott Islands just north of Vancouver Island) and about 100 km in width. The high-potential oil areas in both basins are about the same in length—about 200 km—but the Cook Inlet area is somewhat wider.

Oil and gas were discovered on land in the Swanson River area of Cook Inlet in 1957, and in 1963 oil was discovered in the centre of Cook Inlet (Fig. 10.3; Wagner et al., 1969). There are presently seven producing oil fields on the Kenai Peninsula (>30,000 barrels per day, 'bpd') and 17 gas fields (>485 million cubic feet of gas per day, 'cfgpd'), according to Alaska's Oil and Gas Association (AOGA, 2000). There are 15 platforms tapping offshore fields. These are linked by pipeline to onshore storage tanks, from which oil is transferred by tanker to the refinery at Nikiski, which also has a fertilizer plant and a gas liquefaction plant. Peak oil production occurred in 1970 with 230,000 bpd; production is currently about 30,000 bpd (estimated to decline to 7,000 bpd by 2003; AOGA, 2000). The oil and gas industry employs more than 1500 workers, with hundreds more on contract, and contributes hundreds of millions of dollars annually to the local economy.

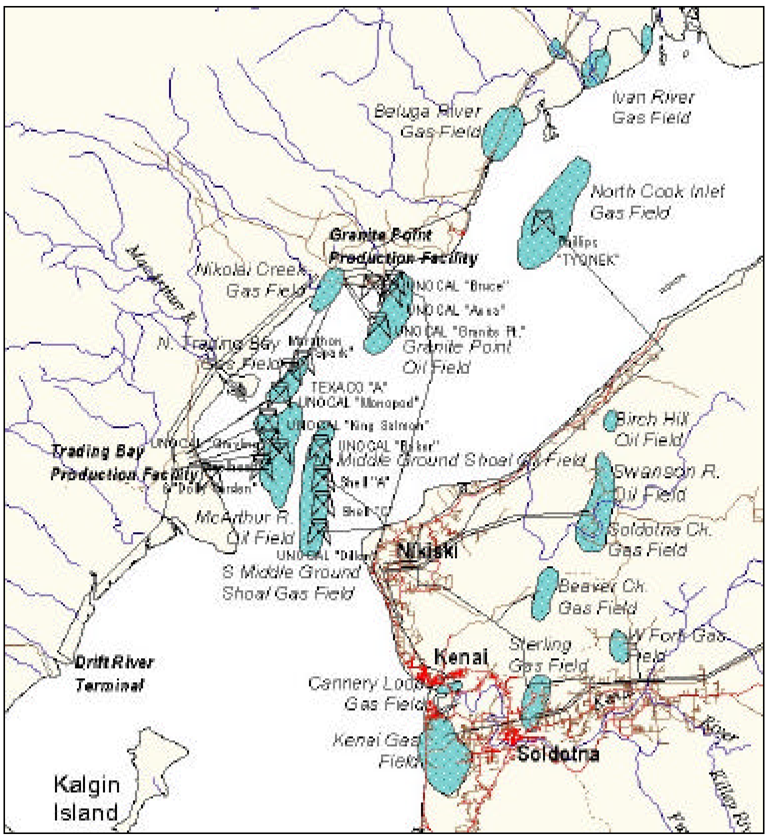


Figure 10.3. Map of Cook Inlet basin and oil facilities. Oil and gas fields are outlined in blue; pipelines are also indicated. An oil refinery is located at Nikiski. (From Cook Inlet Keeper, 2003).

The cumulative totals of production for Cook Inlet to 2000 are 1.2 billion barrels of crude oil and 5.6 trillion cubic feet of natural gas. It is estimated that 90% of recoverable reserves have been produced (AOGA, 2000). According to Hannigan et al., (2001), the QCB is expected to have 6 oil fields with over 100 million barrels recoverable, giving a total recoverable of 1.3 billion barrels. For the gas resource of the QCB, there would be 9 fields with more than 500 billion cubic feet, totalling 9.8 trillion cubic feet recoverable (Hannigan et al., 2001). The two basins are very similar in the size of the hydrocarbon resource.

The petroleum systems of the two basins are somewhat similar: both have Mesozoic source rocks and Tertiary reservoirs (see, e.g., Magoon, 1994, for Cook Inlet). Both also have compressional structures (folds and thrusts), though the Cook Inlet Basin lacks the extensional and horizontal shear episodes that characterize the later Tertiary history of the QCB.

10.3 Physical environment

Boyd and Shively (1999) summarize the physical environment of Cook Inlet. Offshore winds average 12-18 knots, but channelling in valleys can produce wind speeds in excess of 100 knots in inshore areas. Water depths in Cook Inlet are typically 20-40 m in the upper reaches where present oil production is focussed. A central channel descends to 75 m and deepens into the lower reaches to 150 m. There is a comparatively high tidal range in Cook Inlet, with the mean diurnal range of 9 m at Anchorage. The tidal range and inlet geometries are responsible for strong currents: maximum surface currents average about 3 knots. Bottom currents of 1.5 knots are strong enough to form migrating sand waves. Currents of up to 12 knots have been recorded locally. These currents transport large amounts of glacial sediment eroded from surrounding mountains, to be deposited in tidal flats or carried offshore to the Aleutian Trench. Cook Inlet contains ice from October through to April.

Like the QCB, Cook Inlet lies close to a plate margin. The subduction of the Pacific Ocean plate below the North American plate causes earthquakes and volcanoes. In the Cook Inlet region, there have been 99 earthquakes with magnitudes greater than 5.0 since 1899; four of these had magnitudes greater than 7.0. Some thrust faults in the oil field areas may be capable of generating earthquakes with magnitudes of 6.3-6.9. The earthquake risk is somewhat higher than that in the QCB. Active volcanoes lie on the western flank of Cook Inlet. The oil production facilities are out of range of ash flows from all but the largest eruptions, but flooding caused by ice and snow melting on upper slopes receiving volcanic ejecta is a recurrent problem. The impact of tsunamis generated outside of Cook Inlet Basin is low, but there is some potential danger from tsunamis produced by local volcanic debris avalanches reaching the shoreline. By comparison, the volcanic hazard in the QCB is relatively very small.

Strong currents affect sediments on the floor of Cook Inlet. Pipeline failures in the early history of Cook Inlet oil production have been attributed to erosion of sediment from below pipes. Preventive measures are now in place, including attachment of pipes to piles driven into the seafloor, anchoring of pipes in concrete, using heavy walled pipes, and regular side-scan sonar surveys to detect sediment motion. Coastal erosion is currently commonplace around Cook Inlet, as it is around the QCB, and set-back of facilities from coasts and river banks is required. Crossings of beaches subject to high erosion rates are allowed only with adequate reinforcement of infrastructure.

Shallow gas deposits pose risks to structures founded on the seafloor above them. Some blow-outs have been caused by them.

10.4 Seismic surveys

Since 1970, about 19,600 km of 2D seismic data, and 500 km^2 of 3D seismic data, have been acquired in Cook Inlet, and another 4000-5000 km may have been shot prior to 1970 (J. Cowan, Alaska Department of Natural Resources, personal communication, 2003). The total is rather similar to the total seismic profile length of about 21,000 km shot in the QCB. While we do not have information on sources used for the Cook Inlet seismic surveys, we can assume most of the pre-1970 data was shot with explosives, and most of the post-1970 data was shot with air guns.

10.5 Oil spills and blow-outs

Boyd and Shively (1999) quote oil spill statistics for Cook Inlet. During 1965-1980, 187 spills, with a total volume of about 7600 barrels, occurred. These were associated with production and transportation of crude oil. During this time there were 206 other spills (fishing vessels, product transportation vessels, others) with a total volume of 23,000 barrels. From 1987-1997, just over 5000 barrels were spilled in the Inlet, of which 96% was spilled in one event. Oil spills in Cook Inlet from exploration and production during 1984-1994 totalled 250 barrels; there has never been a major oil spill (>1000 barrels) in Cook Inlet associated with this phase of activity. There has never been an oil blow-out in Cook Inlet, but there have been three gas blow-outs.

Marine pipeline failures occurred in Cook Inlet during the 1960s and early 1970s. The failures were caused by sediment erosion, ice scour, corrosion, current-induced vibration, flange leaks and pipeline rubbing. There has been no reported seabed pipeline failure since 1976, though small leaks associated with marine pipelines continue. Very little oil has been spilled into the Inlet from shore facilities, with only a couple of incidents recorded in the 1990s. Two tanker oil spills have affected Cook Inlet. In 1987, oil—less than 3800 barrels—was spilled from the tanker Glacier Bay, en route to the Nikiski refinery. In 1989, the Exxon Valdez spilled 262,000 barrels in Prince William Sound, the major coastal inlet immediately east of Cook Inlet, and this affected fisheries in Cook Inlet.

Cook Inlet is the only estuary in the U.S. that receives discharge of drilling wastes; all other drilling and extraction activity in other U.S. estuaries operates under 'zero discharge' rules. Also, Cook Inlet platforms are exempt under a unique National Pollution Discharge Elimination System (NPDES) waiver. The 1996 estimates of the US Environmental Protection Agency (EPA) indicates that the oil and gas industry discharged more than 50 million barrels per year of oily water into Cook Inlet, which corresponds to more than 1700 barrels of crude oil per year. Dilution of this annual amount in the water volume of Cook Inlet yields a hydrocarbon content of 1 part in 2 billion. It is known that concentrations as low as 1 part in 1 billion of polyaromatic hydrocarbons (PAHs) can be toxic to fish embryos if exposure is chronic (Carls et al., 1999). While the average levels of concentrations of PAHs from discharged waters, once diluted in the total volume of Cook Inlet, are below the levels for toxic impacts on embryos, there may be local transient concentrations that are toxic.

The November 2003 Final Environmental Impact Statement for the Cook Inlet Planning Area (MMS 2003-056, Lois Epstein, Cook Inlet Keeper, personal communication) indicates that for new development drilling or production the new EPA requirements still allow for discharge of deck drainage and sanitary wastes but no longer allows for the discharge of produced water or drilling muds and cuttings.

10.6 Protected areas

The Cook Inlet area has four national parks, one national forest, one national estuarine reserve, two national wildlife refuges, four state parks and sanctuaries, and seven critical habitat areas (CIRCAC: *http://www.circac.org*). The total area protected is a significant fraction of land adjacent to the inlet and includes several inshore marine zones (Figure 10.4). Protection in Cook Inlet is more advanced than it is in the QCB, though actual protection and proposals of protection for the QCB may involve a higher proportion of the marine area.

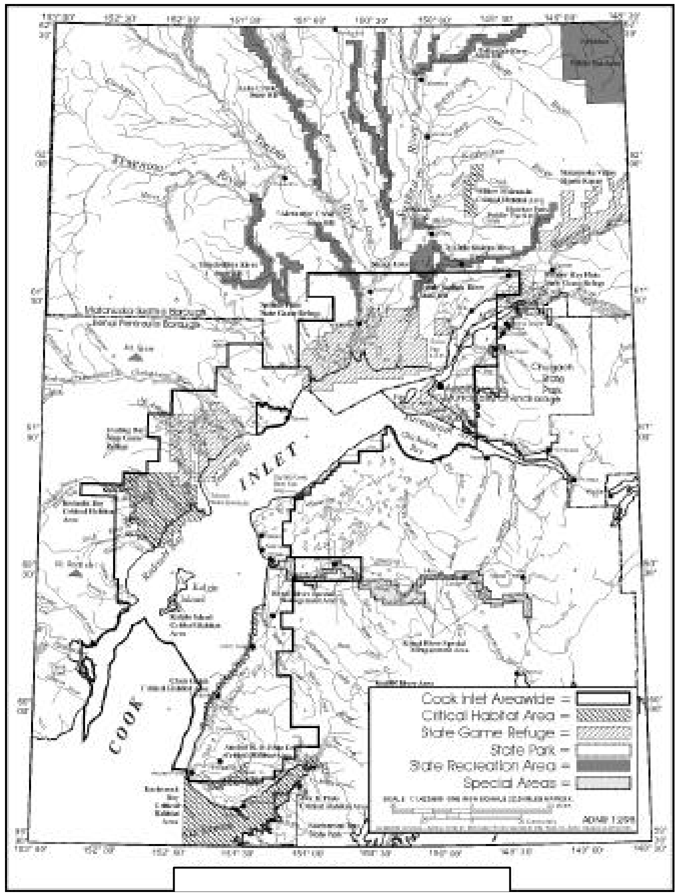


Figure 10.4. Map of protected areas in the upper Cook Inlet (from Boyd and Shively, 1999).

10.7 Impacts on biota

The lower Cook Inlet is particularly rich in biota (Wagner et al., 1969). The upper Cook Inlet area is an important migration pathway for fish, en route to spawning grounds. Harvested fish include salmon, halibut, flounder, sole, and sculpins. Harvested shellfish include crab, shrimp, clams, scallops, oysters and abalone.

The fisheries are important to the economies of both Alaska (http://www.cf.adfg.state.ak.us/geninfo/about/budget/03overvw.pdf) and British Columbia (http://www.agf.gov.bc.ca/fish_stats/pdf/BC_Fisheries_&_Aquaculture_Sector_2002.pdf). The commercial harvest in Alaska has an annual landed 'exvessel' value of around C$1.5 billion. Groundfish are responsible for over half this amount; salmon for about 20%.

In Cook Inlet, the salmon fishery is the most important and its landed value runs at about C$40 million per year, which exceeds by a modest amount the total landed value of the commercial salmon fishery in BC (excluding aquaculture, which accounts for $260 million). It is of interest to note here that revenues of the recreational (sport) salmon fishing industry in both Alaska and BC, for each of freshwater and saltwater, exceeds that of the commercial salmon fishery by an order of magnitude. Taking salmon harvest as an indicator of the health of the commercial fishery in Cook Inlet (see, e.g., annual statistics by species: http://www.cf.adfg.state.ak.us/region2/finfish/salmon/uci/ucihhar1960-2003.pdf), it is to be noted that annual totals climbed to highs in the late 1980s and have since dropped back to levels similar to those of the early 1960s. There are several reasons for variations in annual harvests in the fisheries, including management decisions on allowable catches, variations in prices, and stock levels. A successful salmon fishery continues to coexist alongside oil and gas development in Cook Inlet.

Among marine mammals, beluga whales in Cook Inlet (Huntington, 2000) are now listed as candidates for protection under the U.S. Endangered Species Act (http://www.fakr.noaa.gov/protectedresources/esaakspecies.pdf). The impact of oil spills on reducing prey, with consequent reduction of beluga population, is considered uncertain (http://www.fakr.noaa.gov/protectedresources/whales/beluga/eis2003/final.pdf).

10.8 Community involvement

A striking feature of oil and gas activity in Cook Inlet is the participation of various stakeholder groups in monitoring and advising the industry and its regulators. Much of this resulted from the Exxon Valdez oil spill in 1989, in neighbouring Prince William Sound. The resulting Oil Pollution Act of 1990 states that "only when local citizens are involved in the process will the trust develop that is necessary to change the present system from confrontation to consensus." Community involvement has been essential as a reaction to oil spills and other environmental problems caused by the oil and gas companies, even as recently as 1995 (see Cook Inlet Keeper below). The following notes on the various groups are offered as an example of how industry, government and community might interact in the QCB, were the moratoria to be lifted.

Exxon Valdez Oil Spill Trustee Council (EVOSTC: http://www.oilspill.state.ak.us)
The Exxon Valdez oil spill occurred in March of 1989 in Prince William Sound, just to the east of Cook Inlet. A total of 262,000 barrels of crude oil spread along 1,300 miles of the south Alaska coastline. The *Exxon Valdez* Oil Spill Trustee Council was formed to oversee restoration of the injured ecosystem through the use of the US$900 million civil settlement. It funds a couple of groups in Cook Inlet (CIRCAC, CIIMMS; see below).

Although it has been 14 years since the spill, oil still remains in the impacted area. Intertidal and shallow subtidal habitats are still contaminated, some species have not recovered, and the productivity of the ecosystem as measured by salmon and herring fisheries have not returned to pre-spill level (http://www.afsc.noaa.gov/abl/oilspill/oilspill.htm: the Auke Bay Laboratory is conducting research projects funded by the EVOSTC). During the first few years of remediation, there were quite different estimates of spill impact and biotic recovery by industry and independent observers (R. Greer, 2003, personal communication, workshop presentation).

Cook Inlet Regional Citizens Advisory Council (CIRCAC: http://www.circac.org)
Partially funded by the EVOSTC, CIRCAC was set up in 1991 as a result of the Oil Spill Act of 1990. The mission of the Council is to "represent the citizens of Cook Inlet in promoting environmentally safe marine transportation and oil facility operations in Cook Inlet." This is accomplished by 1) monitoring and researching impacts of operations, 2) advising on regulations, 3) reviewing industry permits, regulations, and contingency plans for facilities and tankers, and 4) recommending changes to existing practices. By law, major companies in the Cook Inlet oil industry are required to provide annual funding for CIRCAC.

Alaska's Cooperatively Implemented Information Management and Monitoring System (CIIMMS: info.dec.state.ak.us/ciimms)
Another project funded by the EVOSTC, through the Alaska Dept. of Environmental Conservation and the Alaska Dept. of Natural Resources, the CIIMMS project provides the public with web-based sources of information on Alaska's natural resources. This information consists of a wide variety of accessible maps and databases focused on southern Alaska, and contributed by numerous groups. It will be expanded into a state wide information system within the next few years.

Cook Inlet Keeper (CIK: http://www.inletkeeper.org/abtkeeper.htm)
The Cook Inlet Keeper was set up by environmental organizations in 1995 with 3 years of start-up funds provided by oil companies (Unocal, Shell-Western and Marathon). This was done as part settlement of over 4000 permit violations during the previous five years, caused by discharge of grey and produced water into Cook Inlet. The EPA found the allegations so serious that it joined the litigation. The CIK provides citizen education and monitors the environmental health of watersheds around the Inlet with a particular focus on water quality in streams, lakes and estuaries.

10.9 Conclusions

Cook Inlet has a thriving commercial fishery, a very lucrative sport fishery, and a growing tourism industry (a million people visit Anchorage each year), all of which have coexisted for over 40 years with oil and gas activity that currently provides employment to around 1500 people locally, and contributes hundreds of millions of dollars annually into the Alaskan economy (AOGA, 2000). Coordination of citizen's groups with stakeholders in industry and government is of value in monitoring industry performance, and its plans for future development. Public education and environmental monitoring, together with readily available information sources are key to this process. Impacts of oil development on the environment are being mitigated by improved methods and technologies.

An important lesson from the Cook Inlet history, is the value of an educated, informed citizenry. By coordination through multi-stakeholder groups, it undertakes monitoring of water quality and biota, to provide independent checks on industry performance and on general environmental quality, which is affected by many other processes both natural and anthropogenic. The acquisition of baseline data in assessing change is also underscored. The effectiveness of increasingly stringent regulation is also manifest in reducing spills and permitted releases of waste from offshore operations.

CHAPTER 11

CONCLUSIONS AND RECOMMENDATIONS

11.1 Context

The Panel has been asked in its terms of reference to consider three main questions:

(a) Do science gaps exist which need to be filled before a decision is made to lift the moratorium?
(b) If the moratorium were to be lifted, what science should be carried out concurrently with oil and gas exploration and development?
(c) Who should carry out this science?

In considering these questions, the Panel has taken into account several contextual factors:

(a) The original moratorium is over thirty years old, though it has been amended and updated over that time;
(b) Federal legislation relevant to environmental assessments has been enacted during the past decade, notably the Species at Risk Act, the Canadian Environmental Assessment Act, the National Marine Conservation Areas Act and the Oceans Act (to add to pre-existing legislation such as the Fisheries Act and the Canadian Environmental Protection Act);
(c) The moratorium has two quite separate intentions, first to prohibit oil and gas exploration activities in the BC offshore, and second, to prohibit transit tanker traffic in BC inshore waters.

As we discuss further below, the Panel's conclusions and recommendations have been reached after considering the implications of this legislation. In addition to this legislative context, the Panel has made some assumptions about the "operational" context in which oil and gas development might take place; these include the following.

11.1.1 Best practices

Best practices would be employed in all aspects of oil and gas development. These are continually improving and would be advanced from the present state of the art by the time activities such as oil or gas production are likely to commence.

11.1.2 The precautionary principle

In engineering design and in risk assessments that are carried out as part of the development process, it is assumed that a precautionary approach would be used, essentially a question of "erring on the side of caution." As defined in the terms of reference of the panel it is stated as follows: "in the face of scientific uncertainty, it is preferable to err on the side of caution." Furthermore, the associated principle of "polluter pays" is assumed to be implemented.

11.1.3 Prime beneficiary pays

Any scientific knowledge required, that would benefit the community significantly by its relevance to issues beyond oil and gas activities alone, should be the responsibility of government. Scientific knowledge required only to benefit the assessment and development of specific oil and gas activities should be the responsibility of the developer. In cases where both benefits accrue, public-private partnership would be appropriate. In all cases, public access to the information collected and deliberations thereon is to be encouraged.

11.1.4 Regulation

It is assumed that a regulatory board would be set up at arm's length from government and industry to ensure safe and environmentally-responsible development, using current best practice. The petroleum boards that regulate activity in offshore Atlantic Canada provide a starting model. At present, this would imply that the regulatory board would follow CEAA guidelines for environmental assessments and approvals, be responsible for regional strategic environmental assessments, and for project-specific assessment of environmental impacts and their mitigation.

Oil and gas activities in the QCB must be safe for the people involved and for the wider environment. Safe practice must be regulated. We assume that assessments for the safety of oil and gas activities in the QCB would be carried out using the principles of risk analysis, guided by targets. The targets apply to consequences which entail a great risk to human life or a high potential for environmental damage, as in Canadian Standards Association S471, part of the Code for Offshore Structures. The targets for specific process causes are assumed at a level of 1 in 100,000 per year, and for all causes 1 in 10,000 per year. The ALARP ('as low as reasonably practicable') principle would be used to assist in judging specific processes within the range from 1 in 10,000 (10^{-4}) to 1 in 100,000 (10^{-5}) per year. In assessing safety with regard to human life and the environment, objective-based or goal-setting regulation is preferable, with prescription where needed. To implement this, the requirements for regulators are demanding and the expertise of regulator and staff critically important to the standards achieved.

11.2 Looking forward over 20 years

In this chapter we draw together the conclusions from different parts of the report and consolidate them into a series of recommendations. It is worth remembering that the potential development of an oil and gas industry in the Queen Charlotte Basin (QCB) would occur over a considerable period of time. Recall the guiding timeline suggested in Chapter 1:

2004-2007	Establish regulatory regime; strategic environmental assessment; land claims issues settled
2007-2008	Environmental impact assessment for exploration (seismic surveys) and response
2008-2009	Initial 2D seismic surveys
2010-2011	3D seismic surveys on hydrocarbon prospects
2011-2012	Environmental impact assessment (drilling) and response
2012-2014	Exploration drilling
2013-2015	Delineation drilling
2014-2016	Environmental impact assessment (production) and response
2016-2019	Development planning; approvals; construction starts
2020	Production

This shows several discrete phases of activity: 2D seismic, 3D seismic, exploration drilling, delineation drilling, development drilling and production. After production, facilities would be decommissioned. For each phase, specific scientific knowledge is required for assessment of safe and environmentally-responsible practice. In this report, we set out those requirements, identify science gaps, suggest how they should be filled, and indicate what geographical areas should be excluded from development. The intent of this Chapter is to summarize those knowledge needs, and establish what the corresponding science gaps are and when they should be filled.

One particular aspect that should be examined at the earliest possible opportunity is community involvement. Oil and gas development is pursued by the private sector, subject to the approval of the public, formally through government-legislated process, informally through communication. The long term benefits of community involvement in both formal and informal approval is well-established in, for example, Cook Inlet (section 10.8) and the Shetland Isles (see, e.g., http://www.nora.fo/docs/Morgan_Goodlad.ppt; http://www.zetnet.co.uk/coms/kimo). All stakeholders should be kept informed of industry intentions and government-legislated permitting processes. Transparency in regulatory process is to be encouraged, and consequently all data collected for the regulatory assessment of oil and gas activities should be publicly accessible. There is a diversity of stakeholder groups, with equally diverse agendas, involved in oil and gas activities in the QCB: they should be brought together formally.

Recommendation 1: Advisory body

It is recommended that, at the earliest possible opportunity, an advisory body be formed of stakeholders from government (including those of First Nations), the oil and gas industry, other industries active or potentially active in the QCB, community leaders, environmental NGOs, and other relevant groups.

This advisory body would be responsible for a two-way process: informing the public and those they represent about industry plans and their impacts; and, after considering these, passing advice to government and the regulator, once that body is in place. It would also be encouraged to make independent suggestions, including any with respect to access to scientific and technical information, to government and the regulator on matters pertaining to safe and environmentally-responsible practice. The advisory group should have formal access to the regulatory authority.

11.3 Activity specific requirements

In order to define the science knowledge required before certain activities are approved, we have to make assumptions about the regulatory framework. We assume that approvals for specific activities involved in oil and gas development would require at least the following conditions.

11.3.1 Seismic surveys

These should not be permitted in defined protected areas or close to sensitive areas at critical times for valued environmental and economic components (VEECs). Acoustic modelling of sound intensities (verified by field measurement) from seismic shooting at sensitive areas should satisfy criteria to limit disturbance to marine animals, especially marine mammals, at critical times. Furthermore, initiation of shooting should require clearance from biological observers on the shooting vessel and on fixed-wing aircraft or helicopters flying over the shooting area. Flyovers should be repeated regularly, perhaps daily, during extended surveys. Air guns should be 'ramped up' at the beginning of shooting, and shooting terminated when marine mammals are observed close to the shooting ship, as practised elsewhere, e.g., offshore UK, http://www.jncc.gov.uk/marine/seismic.htm, and offshore US (MSS, 2004). Flocks of diving birds listed by COSEWIC should also be avoided.

11.3.2 Drilling

Drilling should only be permitted after assessment of the impact of contaminants released into the ocean. The Panel notes that 'zero discharge' policies are being practised increasingly for disposal of oil-based drilling mud and cuttings in biologically sensitive areas, close to shore, with exceptions made for initial 'spudding' of drill holes in the seabed. We assume that regulations for discharges of mud and cuttings in the QCB would be as stringent as those in place for offshore oil and gas activities elsewhere in the world. We acknowledge that alternative disposal of mud and cuttings on land should be subject to an environmental cost-benefit analysis relative to disposal at sea.

11.3.3 Production and transport

Zero harmful discharge policies should be applied to produced water. Under current Canadian east coast guidelines (see http://www.cnsopb.ns.ca/Environment/guidelines.html), operators are required to evaluate the feasibility of reinjection. If application is made to discharge produced water into the ocean at the production site, an environmental impact and mitigation analysis should be carried out so that an acceptable concentration limit of oil and metal discharge is not exceeded. Again the standard should be consistent with best practice in the world. Accidental oil spills associated with oil and gas production and transport can damage the environment over various periods of times. The fate, trajectories and impacts of oil spills from production platforms and from pipelines and tankers servicing them should be modelled and, from this, acceptable oil spill response plans developed, consistent with best practice. These analyses should be carried out using the techniques of risk assessment.

11.3.4 Decommissioning

All production infrastructure should be removed from the water column on cessation of production, and the well plugged, cut off a small distance below the seafloor, and abandoned.

11.4 Science knowledge required prior to oil and gas activities

In the preceding section, we outlined some of the requirements that should be met for safe practice of particular oil and gas activities. The activity specific requirements should be met by the developer. An example might be the modelling of acoustic propagation for assessment of marine animal disturbance at sensitive sites. Interpretation of those assessments by regulators requires them to have a sound knowledge of the regional characteristics of the basin. Acquisition of this regional science knowledge should be the responsibility of government. An example relevant to the acoustic modelling just mentioned would be knowledge of the space-time variability and behaviour of critical marine animals required to define specially sensitive times and places which would be targets for the modelling.

11.4.1 Filling science gaps; consequences of not filling gaps

The following science gaps have been identified in earlier chapters. Following our terms of reference, we list the gaps, reiterate why they should be filled, and explain the consequences of not filling them.

Section 5. Species at risk, ecologically important species and harvested species constitute the ***Valued Ecological and Economic Components*** of the QCB. These need to be defined as the foci for baseline and monitoring studies. Without deliberating on this, critical species might not receive adequate protection and be subject to risk of unassessed impacts from oil and gas development.

Section 7.1. ***High-resolution swath bathymetry*** is needed, especially for areas of the QCB with high hydrocarbon prospectivity. These data will allow areas of seafloor instability associated with gas seeps, steep slopes and rapid sediment transport to be identified. They are essential in characterizing benthic environments for selection of monitoring sites, and delineation of critical habitat. Without these data, there is potential for unstable foundations for seabed structures, and lack of understanding of the location of particular seabed habitats.

Section 7.2.3 ***Measurements of currents, winds and waves*** should be accelerated. In particular, topographic modelling of winds is needed to allow for measurements at wind stations on variable topography on land to be reliably extrapolated to sea; bottom currents and trajectories in summer and winter flows at all depths are needed, for assessments of physical impact on structures; updated wind and wave hindcast models should be run for the same reason; variability of climate change on long time series for winds and currents should be established. These metocean data are needed for structural design, for oil spill trajectory modelling and for modelling dispersion of discharged mus and cuttings. Without these data, consequences of spills and releases would be inadequately resolved, and structures would be built to compensate for greater uncertainty in maximum and sustained loads, with consequences for economic viability of projects. Data collected should be focused on determination of impacts of spills and releases of mud and cuttings, and loads for locations in areas of high hydrocarbon prospectivity.

Section 7.3.1. ***Earthquake monitoring*** is needed to determine the temporal variability of stress release, and to establish how the stress release is partitioned among specific fault structures that may be close to oil and gas activities in the QCB. This should be done through installation of an enhanced network of seismographs in the QCB, including strong-motion seismographs, which give much improved data on events of >5.5 or so. The recurrence periods for such magnitudes are decadal or greater, so this is a long-term need of general value that might bring useful results within the time scale of oil and gas activities. All these data will be used to refine earthquake hazard estimates for the QCB, and to identify active faults. Without such data, structures may be designed to compensate, and there would be a greater probability of drilling through an active fault.

Section 8.2.1 Modelling of ***acoustic propagation of seismic survey sources*** is needed for assessment of potential behavioural impacts on mammals (especially whales). Behavioural disturbance is itself uncertain because of the wide range of observed responses, but proposals for individual seismic surveys should be required to provide estimates of received sound levels at critical sites and times in the QCB. Without this, there might be behavioural disturbance during calving, migration through restricted channels, and similar events that might impair the viability of some of the smaller vulnerable whale populations.

Section 8.2.3. The ***space-time distributions of fish that are VEECs*** is needed to define periods and areas when seismic surveys can be safely carried out, without endangering spawning, migration and populations. Of particular importance might be the inshore distribution of herring, and salmon migration routes.

Section 8.2.4. The ***major confined spawning areas for critical fish species*** must be defined, together with the spawning times, so that seismic surveys can be excluded from those areas. While in general it appears that seismic sources kill fewer eggs and larvae than die because of harsh conditions or are preyed upon by other species, spawning areas for critical species should be avoided as a measure to assist in their recovery.

Section 8.2.5. The ***space-time distributions of those mammals that are VEECs***, together with their behaviour patterns should be determined so that critical concentrations at critical times can be avoided by seismic surveys. Recovery of vulnerable populations might be impacted by seismic surveying through nursery areas.

Section 8.2.6. ***Observers on seismic vessels should log the occurrence and behaviour of diving birds*** close to active sources. It is unlikely that significant numbers of diving birds are harmed by seismic surveys, but there is little data on this.

Section 8.3.3. ***Baseline studies of benthic fauna and habitat, including seabed sediment hydrocarbon and other chemical distributions, benthic community structure, and other appropriate indices of environmental stress which have proved useful elsewhere,*** should be collected to provide a datum to allow the impacts of oil and gas activities to be assessed. Without such data, the attribution of cause of an unwanted event to a specific activity might not be possible.

Section 8.6.3. ***Oil spill trajectory modelling*** should be carried out for a wide range of oil types, spill locations within the QCB, and weather and sea conditions. Seasonal variations in weather should be included. This will reveal general patterns for the dispersal of oil that will be of great value in setting up an optimal oil spill response system. Without such modelling, oil spill response will be less effective.

Section 8.6.4. ***Defining the impact of oil spills on their landfalls*** should be derived from knowledge of shoreline types, from sources such as the BC Government Coastal Resource Inventory program and products derived from those data. Without this information, oil spill response might be less optimally designed.

Section 8.6.5. ***Seasonal variations in species populations along shorelines*** is needed for assessment of the vulnerability of biota to an oil spill. Without these data, the priority assigned to, and nature of, oil spill response for different parts of an impacted coastline could not be made.

The regional data needed cannot necessarily be collected quickly. In some instances, long time series are required to assess temporal variations of the natural system prior to commencement of oil and gas activities. Given the 12 year timeline for oil and gas activities from seismic to production, and the knowledge that some parts of the natural systems are subject to decadal variability (the climate system especially), it is urgent to start measurement as soon as is practicable. This means that there should be overlap in time in the acquisition of science knowledge required for different oil and gas activities.

All the science gaps above need to be filled, but early priority should be given to the following baseline studies, which establish an observational datum now, before oil and gas activities start, and monitoring studies (in which long time series are needed).

11.4.2 Baseline studies

Recommendation 2: Baseline studies

The Panel recommends that collection of the following baseline data begin as soon as possible. These data are deemed necessary either to characterize baseline conditions (i.e., prior to any oil and gas development), or are considered vital to enabling the implementation of best practice at subsequent stages of development. Where appropriate, the value of these data in a context of change should be enhanced by incorporation of historical data, including traditional ecological knowledge.

- ***Characterization of the spatial and temporal distribution of ecologically important, sensitive and harvested species in the QCB:*** *The logical place to start would be with those species already listed by COSEWIC as endangered, threatened, or of special concern (in keeping with legislation under the Species at Risk Act), as well as species that are of ecological importance, but about which little is known (e.g., sand lance), and important harvested species.*
- ***Swath bathymetric mapping:*** *Necessary to identify areas of seafloor instability associated with gas seeps, steep slopes and rapid sediment transport. Also essential in characterizing benthic environments for selection of representative monitoring sites, delineation of critical habitat and the establishment of representative MPAs.*
- ***Measurement of near bottom currents:*** *These data are required to model environmental forces, sediment movement and the transport of water based drilling muds and cuttings during exploratory drilling.*
- ***Baseline studies of benthic fauna and habitat, including seabed sediment hydrocarbon and other chemical distributions, benthic community structure, and other appropriate indices of environmental stress which have proved useful elsewhere:*** *These data allow the impacts of oil and gas activities to be assessed.*
- ***Drifter studies of winter surface currents, and spill trajectory modelling:*** *These data are essential for extreme and operational modelling and for estimating oil spill trajectories.*
- ***Topographic modelling of winds:*** *These are needed so that site-specific estimates can be obtained of wind conditions at sea based on long-term observations of shore-based winds.*
- ***Strong motion seismographic measurements:*** *These data are needed to better characterize the ground motions associated with large earthquakes.*
- ***Reintroduce a network of seismographs around the basin:*** *These are needed to resolve better earthquake foci and determine the location and motion of active faults.*

11.4.3 Monitoring studies

It is essential to establish the ability to discriminate the impacts of oil and gas activities from other causes of change, both natural and anthropogenic, in a dynamic ecosystem. To do this well requires knowledge of how chemical, physical and biological conditions in the region change over time before oil and gas activities start. Measurements that indicate the trend of change with time constitute 'monitoring studies.' For the QCB, the objective is to record changes in marine systems associated with oil and gas activities over scales of distance of the order of 0.5 - 5 km and of time in the range 0.5 - 5 y. (in contrast to monitoring to ensure compliance with regulations, which applies to much smaller scales of distance and time).

Trend monitoring should be undertaken on the distribution in space and time of chemicals that would be associated with oil and gas activities and of known or expected biological responses to them. At a minimum, chemical measurements should focus on metal signatures of discharges, such as the distribution of barium from use of barite in water-based drilling muds, and on hydrocarbon distribution. Both kinds of measurements should be made in sediments. A minimum suite of biological measurements should include those of benthic community structure; other biological indicators such as fish hepatic mono-oxygenase induction should be undertaken as appropriate.

Monitoring sites should be selected to minimize the effect of confounding variables (such as depth, granulometry, total organic content, etc.) on chemical and biological indicators. Detailed bathymetry and descriptions of bottom structure and types should be collected for this purpose.

Recommendation 3: Monitoring studies

The Panel recommends that chemical and biological monitoring studies (based on accepted best practices in other jurisdictions) should commence (or continue) as soon as possible at each of the following groups of sites:

- ***Potential and past drill sites:*** *Sites representative of locations where drilling has taken place in the past or is likely to take place in the future (to allow detection of changes caused by drilling activities).*
- ***Control (or reference) sites:*** *Chosen to be representative of locations where drilling is unlikely to occur (to allow detection of trends caused by natural factors or factors unrelated to oil and gas activities, and should include revisiting sites that have been sampled in the past so as to extend the time frame of analysis.*

11.5 Protected areas and exclusion zones

11.5.1 Filling science gaps; consequences of not filling gaps

The following science gaps related to protected areas and exclusion zones have been identified in Chapter 9 (see section 9.5 for summary). For each, we discuss the consequences of not filling the gap.

Marine Protected Areas in the QCB. There is a collective responsibility to identify these and legislate them. This should be a high priority for the federal and provincial governments. The Panel recommends that the natural resource potential—both of renewable and non-renewable resources—be considered as a factor in the choice of such areas. If this is not done, the uncertainties of when and how it might be done will mean continuing threats to species at risk and prove frustrating for those contributing to economic activity.

Critical species close to shore. For specific seismic surveys that are intended to approach close to the shoreline (within 1 km of the 20 m isobath), it should be required that the proponent establish the nature and distribution of biota (especially VEECs) within 1 km of the intended ship's track, in order to provide information for regulators to assess the safety of such surveys for those biota. This would allow for lifting of the suggested restriction made by the Panel (to exclude seismic within 1 km of the 20 m isobath) for areas that pass the test. Not allowing this might prevent discovery of potential prospects , near-shore that could be drilled from land.

Areas of critical habitat should be defined clearly by those stakeholders mandated to carry out the demands of the Species at Risk Act, so that seismic surveys can be excluded from them. Not to do that would endanger the species for which those habitats are critical.

20 km coastal zone buffer for drilling. Oil spill trajectory modelling for various possible scenarios has been proposed above (section 11.4.1). The results should be used, with modelling carried out for specific oil and gas activities, to establish coastal zone buffers of such size that oil spill response would be activated before oil from a spill makes landfall. These buffers might be greater or smaller than 20 km, depending on location and specifics of plans for response. Until these analyses are available, the present 20 km buffer zone should be maintained.

11.5.2 Protected areas

The conclusions of Chapter 9 and discussion above support the following recommendations on protected areas and exclusion zones.

Recommendation 4: Protected areas

The Panel recommends the following actions:

- ***In light of their unique nature, the sponge reefs in the QCB be officially designated as Marine Protected Areas (MPAs) as soon as possible.*** *These MPAs should be protected from all fishing and drilling activity, and be surrounded by an appropriate buffer zone. Because of the depth of water above the reefs, it is unlikely that there will be any impact on the sponges from the kinds of seismic survey described in this report.*
- ***Concerted action be taken by government (with assistance from other stakeholders) to determine the areas that should be protected in the QCB, the level of protection to be enforced, and to pass the enabling legislation.*** *In determining the areas to be protected, it would be appropriate to consider the potential for development of all the natural resources of the basin, renewable (fish, shellfish, etc.) and non-renewable (oil, gas, minerals).*

11.5.3 Other zones from which oil and gas activities should be excluded

Recommendation 5: Other exclusion zones

The Panel recommends that

- ***The coastal exclusion zone for drilling be maintained at 20 km, until such time as more site-specific restrictions can be justified, for which improved knowledge of oil spill trajectories and shoreline vulnerability will be required; and***
- ***Seismic surveys should be prohibited from waters less than 20 m in depth, from any area within 1 km of the 20 m isobath, and from all areas deemed as critical habitat for species listed by COSEWIC as endangered, threatened or of special concern, during periods when these species are most vulnerable (e.g., during migrations, spawning, etc).*** *As improved knowledge is acquired on the space-time distribution and activities of critical species in the QCB, and on the impacts of seismic survey on biota, the general restrictions should be replaced by more site- and time-specific restrictions.*

11.5.4 Zones around oil and gas activities from which other activities should be excluded

Liaison with other users of the marine area is needed during oil and gas activities. A user group to liaise with industry should be established. Fishing should be excluded temporarily around exploration seismic survey ships and drilling rigs, and excluded around production platforms, until the platform is removed. It is assumed that programs will be offered to compensate other users for significant loss of access to the areas of oil and gas activities.

11.6 Implications for the moratoria

11.6.1 Discussion

The terms of reference require the Panel to identify *"any (science) gaps which may need to be filled before a decision is made in respect to the moratorium, but also provide a path forward on the science requirements which would precede, or be concurrent with, any exploration or development activity."* The Panel has approached this from the second perspective, by identifying new science knowledge needed to provide adequate assessment of the safety of each potential activity. This leads to consideration of the moratoria and the science implications of them.

The moratoria were put in place because of concerns that oil and gas activities, including tanker traffic transiting through the area, would unduly endanger the environmental health of the region. The Panel has reviewed all the oil and gas activities that might ensue in the QCB, were development to proceed. It has also considered the effects of evolving practices by industry and of the increasingly stringent technical demands of regulation, in jurisdictions covering offshore U.S, the North Sea, and eastern Canada.

With implementation of the recommendations made above, and the assumptions on which they are based, all the safeguards will be in place, when they are needed, to ensure that assessments of risk of oil and gas activities to human life and the environment in the QCB are adequate. Such assessments would be undertaken by those most knowledgeable of the particular activities, of their impacts and of the consequences for those impacted. The assessments would involve public participation. Given all this, the significance of the moratoria to this discussion of science issues is reduced to their inhibiting the generation of relevant new knowledge. Our principal conclusion follows.

11.6.2 Conclusions

Conclusion 1

Provided an adequate regulatory regime is put in place, there are no science gaps that need to be filled before lifting the moratoria on oil and gas development.

It is extremely important to recognize that this does not mean that science gaps do not exist (since we have outlined many throughout this report). Nor should it be taken to mean that the Panel is recommending that development be allowed to begin immediately. What it does mean is that, if the moratoria were lifted, regulation would be in place to ensure that these critical science gaps would be filled before development of an oil and gas industry in the QCB. We also note that lifting the moratoria would enhance the opportunities for filling many of the science gaps, through shared-cost partnerships involving industry participation.

The conclusion is premised on the assumptions above regarding the regulatory regime, the use of best practice in oil and gas activities and developments, and the mitigation of their impacts. We have recommended that baseline studies and monitoring studies of the QCB be commenced immediately. These, together, will help provide a rigorous framework for the permitting of safe and environmentally-sound activities. Furthermore, the Species at Risk Act (SARA) reinforces the need for urgent government action on filling science gaps related to many critical species in the QCB.

The current moratoria are also intended to restrict tankers in transit along the West coast of North America from entering the coastal zone. Even with the improved record of spills in territorial waters off North America over the last 10 years, there is no imperative to relax this restriction. Detailed risk analysis in future may indicate sufficiently low risk of spillage that the restriction might then be relaxed.

Conclusion 2

The present restriction on tanker traffic in transit along the West Coast of North America from entering the coastal zone should be maintained for the time being.

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APPENDIX I

TERMS OF REFERENCE

1 Background

1.1 Federal response

2 Geographic area for consideration

3 Public review phases

3.1 Phase 1

1. BACKGROUND

In 1972, the Government of Canada imposed a moratorium on crude oil tanker traffic through Dixon Entrance, Hecate Strait, and Queen Charlotte Sound due to concerns over the potential environmental impacts. The moratorium subsequently extended to include oil and gas activities. This was followed by a similar prohibition by the Government of British Columbia.

In September 1983, the Governments of Canada and British Columbia established the basis for a joint federal-provincial review of the potential environmental and socio-economic effects of oil and gas exploration offshore British Columbia. A five-member environmental assessment panel was appointed and held public information meetings and public hearings throughout northern coastal British Columbia. The Public Review Panel's report contained 92 terms, conditions, and recommendations to be applied to offshore oil and gas activities. However, as a result of the Exxon Valdez oil spill in 1989, the two governments decided to continue the moratoria.

The government of British Columbia recently commissioned several studies to assess the potential impacts of offshore oil and gas activities. This was followed by a Scientific Panel review, also commissioned by B.C., which concluded that *"There is no inherent or fundamental inadequacy of science or technology, properly applied in appropriate regulatory framework, to justify a blanket moratorium on such activities"*. The Panel also concluded that: "*There would be several important things that would need to be done before there could be any expectation of investor interest, public or private, in proposals for exploration or development work in the BC offshore."*

The government of British Columbia provided copies of the studies and the Scientific Panel review report to the Government of Canada and requested that the Government of Canada consider lifting the federal moratorium on oil and gas activities.

1.1 FEDERAL RESPONSE

On March 28, 2003 the Minister of Natural Resources Canada announced that the Government of Canada will proceed with a review to:

(a) identify science gaps related to possible oil and gas activity, offshore B.C. (Science Review);
(b) hear the views of the public regarding whether or not the federal moratorium should be lifted for selected areas (Public Hearings); and,
(c) consult with First Nations to ensure that issues of unique interest to First Nations are fully explored (First Nations Consultations).

All components of the review will take into account legal and regulatory safeguards that would be in place if the moratorium were lifted. Lifting the moratorium for specific areas would not result in activities until a regulatory regime is in place to assess proposed activities. A regulatory regime would respect the requirements of federal legislation and policy. Federal legislation which would apply to offshore oil and gas activities includes; the *Canada Petroleum Resources Act*, the *Canada Oil and Gas Operations Act*, the *Canadian Environmental Assessment Act*, the *Canadian Environmental Protection Act*, the *Canada Oceans Act, the Navigable Waters Protection Act*, the *Fisheries Act*, and the *Canada Labour Code.*

2. GEOGRAPHIC AREA FOR CONSIDERATION

The area recommended for review is that of highest estimated petroleum resource potential (see Figure 1 and 2 in Attachment 1).

Figure 1: Sedimentary basins - Canada's west coast region

Figure 1 shows sedimentary basins on the Pacific margin that are identified as prospective for oil and gas. Resource estimates for these basins are documented in the 2001 Geological Survey of Canada Bulletin 564, ‘Petroleum Resource Potential of Sedimentary Basins on the Pacific Margin of Canada’, by P.K. Hannigan, J.R. Dietrich, P.J. Lee, and K.G. Osadetz. They estimate that the Queen Charlotte region contains three to four times the gas resource potential of either the Tofino or Georgia regions and a significant oil resource potential that is not identified for either the latter two regions. Therefore, the review will focus on the Queen Charlotte region.

Figure 2: Resource potential and proposed exclusion zones

Within the Queen Charlotte region a qualitative evaluation of existing geoscience information permits a delineation of areas with greater prospectivity (see Figure 2). It should be emphasized that confirmation or otherwise of this delineation requires additional information.

It should also be noted that the Queen Charlotte region encompasses areas that expert departments have deemed to be particularly sensitive, as well as, recommended exclusion zones identified in the 1986 West Coast Offshore Exploration Environmental Assessment Panel Report. Some of the latter areas are identified in Figure 2 including:

1. A 20 km coastal exclusion zone which was recommended by the 1986 West Coast Offshore Exploration Environmental Assessment Panel to minimize potential impacts on marine life and sensitive near-shore environments from routine operations, or from an oil blow-out.

2. The proposed Gwaii Haanas National Marine Conservation Area (NMCA) in the southern most Queen Charlotte Islands (shown in deep yellow). Parks Canada recommends that this region be excluded from potential exploration and development activities on the basis of a first ministers’ MOU (1987), a detailed federal-provincial agreement (1988) and several subsequent federal, provincial and industry actions. The pale yellow areas on the east and south east side of Queen Charlotte Sound and Hecate Strait are regions identified by Parks Canada as potential candidate sites for a central coast NMCA because they are each natural and representative for the region and are deemed to meet the criteria of a ‘representative marine area’ as outlined in Parks Canada Guiding Principles and Operational Policies (1994).

3. The Department of Fisheries and Oceans designates the known sponge reef complexes (purple) and a ~9 km buffer zone surrounding them as 'no fishing zones'. The department has advised that the reefs are under consideration for designation as Marine Protected Areas.

Furthermore, both the Department of Fisheries and Oceans and Environment Canada are currently considering additional exclusion zones in this region based on their understanding of fish, mammal, and bird populations. It is anticipated that the science workshops will critically evaluate the impacts of oil and gas activities on ecosystems outside of the proposed review area.

3. PUBLIC REVIEW PHASES

The review will be divided into two phases. Phase 1 will include the Science Review as well as public information sessions. This will be followed by phase 2 of the review process, which will consist of Public Hearings and First Nations Consultations.

3.1 Phase 1

In consultation with his colleagues, the Minister of Natural Resources Canada shall appoint an independent Science Expert (Chair). This Science Expert will be responsible for conducting a series of science workshops, evaluating information presented therein and preparing a summary report on the findings. The evaluation will also draw upon previously conducted reviews in British Columbia and relevant experiences from other Canadian and international jurisdictions. The report will be made available to the Minister, the Public Review Panel and also to the general public in advance of the Public Hearings and First Nations Consultations. It is anticipated that the report will focus the discussion of science related matters during Phase 2 of the review. The Science Expert shall be supported by additional scientists with complementary expertise and knowledge (the Science Review Panel).

The independent Science Expert will be responsible for defining the scope of the science workshops, identifying workshop participants and facilitating workshop discussions. The science workshops will allow qualified experts drawn from governments, First Nations (to ensure that traditional knowledge is considered in the science review), industry, universities, advocacy groups, and alike to identify any science gaps which may need to be filled, <u>with a focus on the identification of any gaps which may need to be filled before a decision is made in respect to the moratorium</u>, but also provide a path forward on the science requirements which would precede, or be concurrent with, any exploration or development activity. They will also identify who should be responsible for the completion of identified gaps (i.e. government, industry, etc.) and carefully evaluate risks associated with not filling an identified gap.

Furthermore, the science workshops shall critically evaluate sensitive environments identified by expert departments as well as previously recommended exclusion zones within the proposed review area. Guided by the precautionary principle the science workshops may, as deemed necessary, identify additional areas requiring special management measures in the event of a decision to lift the moratorium. All such areas will be described in the summary report prepared by the Science Expert.

Notwithstanding the above, it is anticipated that the workshops will include issues such as:

1. Natural Hazards and their Potential Constraints on Exploration and Development, including:
    - Earthquakes
    - Seafloor and Sub-seafloor
    - Waves and Tsunamis
    - Weather
    - Wind factors

2. Potential Impacts of Exploration and Development on species habitat, on fish, birds and mammals, on marine protected areas and on marine ecosystems , including:
   - Seismic exploration
   - Exploration Drilling
   - Production

3. Impacts of Potentially Catastrophic Events on species habitat, on fish, birds and mammals, on marine protected areas and on marine ecosystems, including:
   - Blowouts
   - Oil Spills

SCIENCE WORKSHOPS: PRECAUTIONARY APPROACH

It is recognized that there are many definitions and interpretations of the precautionary approach and reasonable certainty. In order to avoid confusion, it is recommended that the participants agree to a common definition. For example, the precautionary approach as used in the federal *Oceans Act*, "in the face of scientific uncertainty, it is preferable to err on the side of caution".
Further, the absence of full scientific certainty shall not be used as a reason to postpone decision-making. The following four levels of scientific assertion are included for the consideration of the workshop participants.

- There is a complete series of precise and accurate observations, consistent with theory. The margins for error are narrow and enable the statement: ***We are certain that...***

- There is an incomplete series of observations (e.g., few observations from the particular ecosystem and species of interest), supplemented by a completed model / theoretical study. The margins for error-are fairly narrow and enable the statement: ***We are confident that....***

- There is an incomplete, series of observations supported by incomplete (e.g., calibrated but not validated) model / theoretical study. The margins for error are considerable. The statement can be: ***We predict that....***

- There is an incomplete series of observations and either no model exists or the models are not validated or calibrated. The margins for error are substantial, but not as large as for pure chance. The statement can be: ***It is our judgment that....***

Following the science workshops the Science Expert may, as deemed necessary, consult with workshop participants in the preparation of the summary report.

Attachment 1

Figure 1:Sedimentary basins - Canada's west coast region

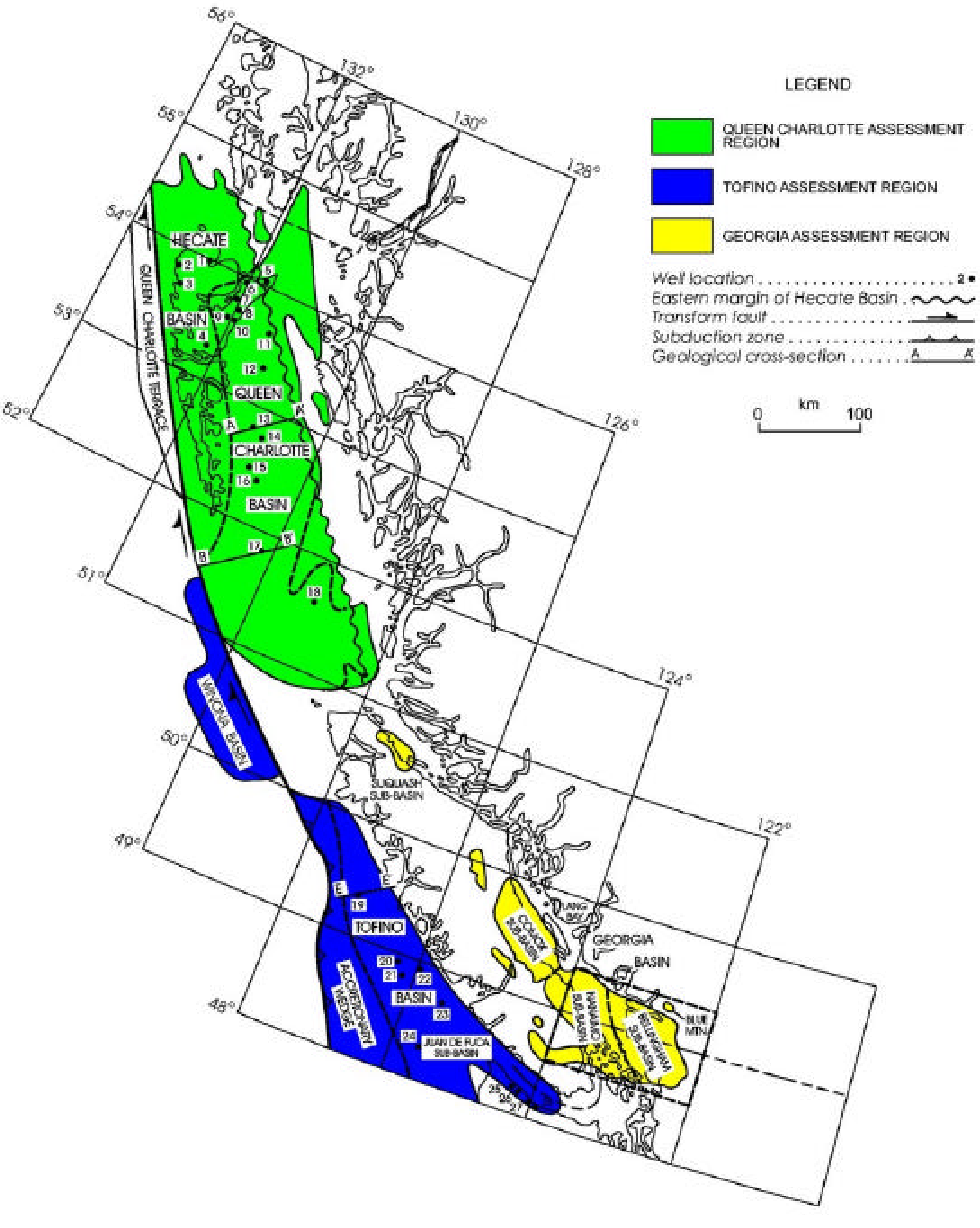
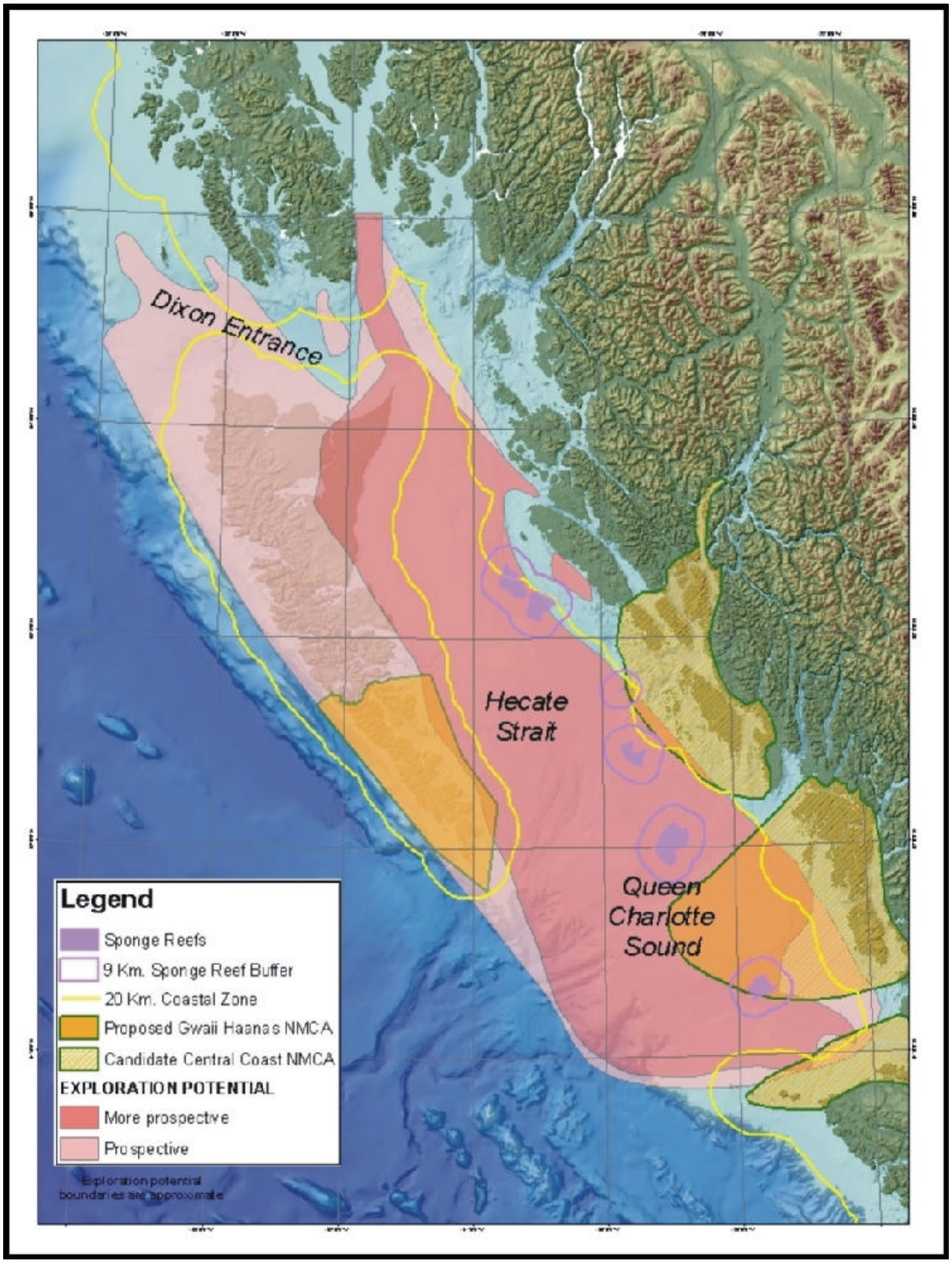


Figure 1. Regional setting and basin outlines of the west coast region of Canada. Assessment regions are shaded. Eastern edge of Hecate Basin modified from Haggart (1993).

Attachment 1

Figure 2: Proposed Exclusion Zones



APPENDIX II

WORKSHOP PROGRAMS

WORKSHOP I

Physical Aspects of Queen Charlotte Basin, and Risk Assessment of Hazards Related to Potential Oil and Gas Activities
Wednesday-Friday, October 15-17, 2003
Marriott Pinnacle Hotel, 1128 West Hastings Street, Vancouver

<u>Wednesday – October 15th, 2003</u>

Introductions

08:10 *Jeremy McNeil, Chair, Expert Panels Committee, Royal Society of Canada*
08:15 *Jeremy Hall, Chair*: Process and Ground Rules
08:25 *David Strong, University of Victoria*: A brief review of the Offshore Oil and Gas situation from the perspective of the 2001 British Columbia Scientific Review Panel

1. Geological background and hydrocarbon resources

08:40 Hydrocarbon resources of the Queen Charlotte region *(Peter K. Hannigan, J.R. Dietrich and K.G. Osadetz, Geological Survey of Canada)*
09:05 New hydrocarbon assessments for the Queen Charlotte Basin *(Michael Whiticar, University of Victoria)*
09:25 Frontier exploration and production: risks vs. rewards *(Marcel Hamonic, Shell Canada)*
09:55 Discussion

2. Risk management and assessment

10:30 Risk management for resource development *(Lorraine Goobie, Shell Canada)*
11:00 An overview of quantitative risk assessment methods *(Maher Nessim, CFER)*
11:30 Discussion

3. Oil and gas activities: general description of environment, operations, technology update, and identification of associated potential hazards

11:45 **Marine environment** *(Richard Addison, John Dower)*
Biota
Exclusion zones, marine protected areas
Rationale for zones adjacent to shore, sponge reefs

Physical environment

12:05 West coast wind, weather and climate issues *(Laurie Neil, MSC)*
12:25 Bathymetry *(Fred Stephenson, DFO)*
13:30 Oceanography and ocean currents *(Bill Crawford, DFO)*
14:00 Sea state *(Diane Masson, DFO)*
14:20 Tsunamis *(Fred Stephenson, DFO)*
14:40 An industry perspective on the metocean environment *(Cortis Cooper, ChevronTexaco)*
15:10 Discussion *(facilitated by Val Swail, MSC; contributions by Owen Hertzman, SFU, and John Marko, ASL Environmental Sciences)*
Earthquakes
15:50 Regional seismicity *(Garry Rogers, GSC)*
16:10 Seismic hazard and ground motion issues *(Gail Atkinson, Carleton University)*
16:40 Seabed character and dynamics *(Vaughn Barrie, GSC)*

17:00 Discussion

Thursday – October 16th, 2003

3. Oil and gas activities: general description of environment, operations, technology update, and identification of associated potential hazards
(continued from Wednesday)

Exploration

08:30 Exploration objectives and uncertainties *(Larry Stewart, ChevronTexaco)*
09:00 Geophysical surveys *(Kevin Williams, ChevronTexaco; Doug Bogstie and Eugene Gridnev, WesternGeco, Robert Pitt, Canning and Pitt Associates, Inc.)*
09:30 Exploration drilling *(DrewTaylor, ChevronTexaco)*
10:00 Discussion

Production

Fixed and floating production facilities
Development drilling
Production drilling
Seabed infrastructure, inc. subsea completion systems
10:40 *(Ralf Hirschfeld, Shell Canada;*
11:10 *John Bruce, Sandwell)*
11:40 Discussion

Distribution and transport

12:00 Pipelines *(Andrew Palmer, U. Cambridge)*
13:30 Oil transport solutions for the offshore industry *(Graham Westgarth, Teekay Shipping)*
14:00 Support facilities *(Norm Allyn, Westmar)*
14:30 **The East Coast experience** *(Don Sutherland, Husky Energy)*
15:00 Discussion

4. Design and risk mitigation of hazards, and physical and biological consequences: data, modelling, risk quantification, regulation *(Bill Maddock, Sandwell)*

15:40 **Design procedures**
Standards for offshore structures
Canadian standards
Limit states (failure; ultimate loads; time-dependent effects e.g. fatigue and corrosion; serviceability)
16:10 **Design for natural hazards**
Wind *(Barry Vickery, UWO)*
Waves, currents and tsunamis *(Michael Isaacson, UBC)*
Earthquakes
16:40 Discussion

Summary Discussion

17:00 **Ongoing and new science studies** (*S. Colvine, Natural Resources Canada; Laurie Neil, Environment Canada)*
Discussion

Friday – October 17th, 2003

4. Design and risk mitigation of hazards, and physical and biological consequences: data, modelling, risk quantification, regulation (continued from Thursday)

08:30 **Analysis and mitigation of impacts of oil and gas activities**
Acoustic impacts on biota
08:40 Seismic surveys *(Rolph Davis, LGL)*

09:00 Discussion
09:40 Drilling waste: mud, cuttings, produced water, flares *(Kelly Hawboldt, MUN)*
10:00 Drilling waste, oil spills: an operator's perspective *(Wishart Robson, Nexen)*

Oil spills, blow-outs
10:40 Statistics *(Ian Jordaan)*
10:50 Impacts *(Richard Greer, Golder Associates)*
11:10 Oil spill risk assessment and sensitivity analysis *(David Dickins, D.F. Dickins Associates)*
11:30 Oil spill response measures *(Norm Allyn, Westmar)*
11:40 Oil spills and the Queen Charlotte Basin *(Merv Fingas, Environment Canada)*
12:00 Discussion

Regulatory regimes

Assumptions about regime that might be set up for QCB, to guide panel re when science gaps should be filled
13:20 *(Kim Coady, C-NOPB;*
13:40 *Jan-Erik Hagen, Scando;*
14:00 *Al Hudec and Michelle Pockey, Davis & Co.)*
14:20 Discussion

5. Summary discussion

15:00 Protected areas and regional planning *(Roger Creasey, Shell Canada)*
15:30 Exclusion zones *(Jeff Ardron, Living Oceans Society; Michele Patterson, WWF)*
16:00 Discussion

16:30 **Gaps in knowledge** of the physical environment and generalities of impacts of oil and gas activities on biota. What gaps require filling before a decision is made on lifting moratoria, including baseline studies to provide foundations for demonstrating impacts of O&G activities? What further knowledge should be acquired after potential lifting of moratoria?

WORKSHOP II

Evaluating Potential Hazards and Biological Consequences of Oil and Gas Activities in the Queen Charlotte Basin
Tuesday-Thursday, October 28-30th, 2003
Marriott Pinnacle Hotel, 1128 West Hastings Street, Vancouver

Tuesday – October 28th
08:30 Introduction to Workshop II (*Jeremy Hall*)

1. Ecosystem integrity, with specific reference to the QCB
08:45 National Marine Conservation Areas in the QCB *(Tom Tomascik, Parks)*
09:15 Gwaii Haanas ecosystems *(Norm Sloan, Parks)*
10:00 Spatial data analysis & ecosystem modeling *(Jeff Ardron, Living Oceans Society)*
10:30 Questions and Discussion
2. The air-sea interface: birds and mammals
11:30 Marine mammals *(Linda Nichol,John Ford, DFO; Andrew Trites, UBC; Paul Spong, OrcaLab)*
2:00 Industrial noise *(Lance Barrett-Lennard, Vancouver Aquarium)*
2:30 Questions and Discussion
3:15 Seabirds and oiling *(Alan Burger, U. Vic.)*
3:45 Seabird habitats and trophic interactions: science gaps and ecosystem consequences of offshore oil and gas activities *(Doug Bertram, CWS)*
4:15 Seabirds and oil platforms *(Francis Wiese, U. Washington)*
4:45 Questions and Discussion

Wednesday – October 29th

3. The water column (wild fish, aquaculture, plankton, etc)
08:30 Pelagic fish and zooplankton *(Dan Ware)*
09:00 Groundfish *(Alan Sinclair, DFO)*
09:30 Questions and Discussion
10:15 Salmon *(Dave Welch, DFO)*
10:45 Aquaculture (*Bill Pennell, Malaspina*)
11:15 Questions and Discussion

11:45 **Summary discussion**
Ongoing and new science studies *(John Pringle, DFO)*

4. The sediment-water interface:

1:30 Benthic ecology *(Brenda Burd)*
2:00 Benthic invertebrates *(Glen Jamieson, DFO)*
2:30 Shellfish and other invertebrates *(Jim Boutillier, PBS)*
3:15 Questions and Discussion

Thursday – October 30th

5. The land-sea interface:
08:30 Nearshore biota *(Colin Levings, DFO)*
09:00 Oil spill response measures *(Craig Dougans, Burrard Clean Operations)*

6. Other Issues

09:30 Environmental impact assessment process *(Roger Creasey, Shell Canada)*
10:15 Exclusion zones *(Michele Patterson, WWF)*
10:45 Sponge reefs *(Kim Conway, NRCan)*
11:15 Understanding and minimizing impacts of discharges from offshore drilling and production operations *(Andrew Glickman, Chevron Texaco)*
11:45 Examples of environmental risk analysis of impacts of oil activities *(Isabel Johnson, Golder Associates)*
12:15 Questions and Discussion

7. Summary discussion

14:00 **Ongoing and new science studies**
Province of British Columbia Coastal Science and Information Initiatives
(D. Howes, Ministry of Sustainable Resource Management, BC Govt.)
UNBC NCIRP program: the LGL component *(Bob Bocking, LGL)*
Other
Environmental assessment *(Kathy Penney, JWL)*

15:15 **Gaps in knowledge**
What gaps require filling before a decision is made on lifting moratoria, including baseline studies to provide foundations for demonstrating impacts of O&G activities? What further knowledge should be acquired after a potential lifting of moratoria?

WORKSHOP III

Hearing from those in the region of the Queen Charlotte Basin
Friday, October 31st, 2003
Crest Hotel, Prince Rupert

08:30 **Welcome and introductions**

1. The review process, and progress of science workshops
(Jeremy Hall, Chair, Expert Panel)

2. Regional development

08:40 Economic and environmental issues around oil and gas development in the Queen Charlotte Basin *(David McGuigan, Pacific Coast Offshore Oil and Gas Association)*
09:00 Economic development around Prince Rupert: a perspective *(Robert Stromdahl, Prince Rupert Economic Development Corporation)*
09:20 Economic development around Prince Rupert: a perspective from the Port Authority (*Don Krusel, Prince Rupert Port Authority*)
09:40 POEA's Perspspective on the impacts of offshore oil and gas development in BC *(Terry Knight, Pacific Offshore Energy Association)*
09:55 Regional socio-economic impacts of offshore oil and gas development *(Al Hudec, Davis & Co.)*
10:15 Modelling the economic impacts of offshore energy development on the northern coast of BC *(John Schofield, University of Victoria)*
10:35 Discussion
11:20 Tsimshian Nation views of potential oil and gas activities *(Bob Hill/Teresa Ryan, Tsimshian Nation)*

3. Ongoing and new science studies

11:40 Northern Coastal Information and Research Program *(Norman Dale, UNBC)*

4. Resources of the Queen Charlotte Basin

12:10 Shellfish *(Bruce Watkinson, Tsimshian Stewardship Committee)*
12:30 Discussion
13:30 Aboriginal fisheries issues *(Susan Anderson-Behn, BC Aboriginal Fisheries Commission)*
13:50 Impact of oil and gas activities on biota in the Queen Charlotte Basin *(Margo Hearne and Peter Hamel, Delkatla Sanctuary Society)*
14:10 Other contributions (including *Jack Miller*) and discussion

4. Sensitive areas and exclusion zones

14:50 Sensitive areas *(Michele Patterson, WWF)*
15:10 Discussion

5. Other contributions and general discussion

6:20 Contributions from Clifford White, Harry Mose, Bill White, Odd Eidsvik, Larry Golden, Joy Thorkelson

APPENDIX III

AUTHORS OF BRIEFS AND OTHER RECENT CONTRIBUTIONS ACCESSED (excluding those referenced in the text, and excluding authors who made presentations listed in the workshop programs, Appendix II)

Contact		Affiliation
First Name	**Last Name**	
Taylor	Bachrach	Sierra Club of Canada
Chris	Barnes	UVic
Jacqueline	Booth	Jacqueline Booth and Associates
Ian	Bruce	David Suzuki Foundation
Kenneth	Brunn	Senior Lighthouse Keeper (retired)
Rolf	Bettner	Haida Gwaii Marin Resources Group Association
Chris	Campbell	Pacific Offshore Energy Group
Hadi	Dowlatabadi	Sustainable Development Research Initiative, UBC
Lois	Epstein	Cook Inlet Keeper
Dan	Esler	Centre for Wildlife Ecology, Simon Fraser U.
Ian	Frigaard	UBC Lab for Complex and Non-Newtonian Fluid Flows
Gerald	Graham	World Ocean Consulting
L.E.	Harding	Environment Canada
Craig	Harrison	Pacific Seabird Group
Stuart	Hertzog	resident: Sidney, BC
John	Hildebrand	Scripps Institution of Oceanography
John	Hunter	J Hunter & Associates Ltd.
Vicky	Husband	Sierra Club of Canada
Jessen	Sabine	Canadian Parks and Wilderness Society
Evert	Kenk	Cooperative Ocean Information Network: Pacific
Manfred	Krautter	University of Stuttgart
Otto	Langer	David Suzuki Foundation
Dan	Lawn	Living Oceans Society
Nora	Layard	Jacqueline Booth and Associates
Paul	Leblond	Can. Parks and Wilderness Soc.(CPAWS), BC Chapter
John	Lucas	Pacific Offshore Environment Association (POEA)
Valerie	MacDonald	Biologica Environmental Services
Alex	MacGillivray	School of Earth and Ocean Sciences, Uvic
Greg	Martin	Laskeek Bay Conservation Society
Robert	McCauley	Centre for Marine Science and Tech., Curtin University
Bill	MacDonald	Sierra Club of Canada
Terence	McGauley	McGauley Consultants Limited
Oonagh	O'Connor	Living Oceans Society
Rosemary	Ommer	Coasts Under Stress, UVic
Kevin	O'Neill	Radarsat International
Ben	Parfitt	Sierra Legal Defence Fund for Living Oceans
Arthur	Popper	Dept. of Biology, U. Maryland
Jeep	Rice	NOAA
Kristin	Rohr	Rohr Consulting

Mark	Shrimpton	Jacques Whitford Environment Ltd.
Gordon	Staples	Radarsat International
Kazi	Stastna	Sierra Club of Canada
David	Weller	National Marine Fisheries Service, NOAA
Lee	Williams	?
Rob	Williams	University of St. Andrews
Jonathan	Wills	Living Oceans Society
Sarah	Wren	Canadian Nature Federation

APPENDIX IV

BACKGROUND TO THE PRECAUTIONARY PRINCIPLE

O'Riordan and Cameron (1994) reviewed the history of the principle and suggest that its origins lie in the German socio-legal traditions developed in the 1930's by the democratic socialists. There are many definitions, for example the 1998 Wingspread Statement (see below). It is the basis of the Cartegena Biosafety Protocol agreed in Montreal in January 2000, as stated in Principle 15 of the Rio Declaration: "In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation."

Another, more detailed statement is the Wingspread statement of precautionary principle. An international group of scientists, government officials, lawyers, and labor and grass-roots environmental activists met January 23-25, 1998 at Wingspread in Racine, Wisconsin to define and discuss the precautionary principle. After meeting for two days, the group issued the following consensus statement:

Wingspread Statement on the Precautionary Principle (1998)

"The release and use of toxic substances, the exploitation of resources, and physical alterations of the environment have had substantial unintended consequences affecting human health and the environment. Some of these concerns are high rates of learning deficiencies, asthma, cancer, birth defects and species extinctions, along with global climate change, stratospheric ozone depletion and worldwide contamination with toxic substances and nuclear materials.

"We believe existing environmental regulations and other decisions, particularly those based on risk assessment, have failed to protect adequately human health and the environment—the larger system of which humans are but a part.

"We believe there is compelling evidence that damage to humans and the worldwide environment is of such magnitude and seriousness that new principles for conducting human activities are necessary.

"While we realize that human activities may involve hazards, people must proceed more carefully than has been the case in recent history. Corporations, government entities, organizations, communities, scientists and other individuals must adopt a precautionary approach to all human endeavors.

"Therefore, it is necessary to implement the Precautionary Principle: When an activity raises threats of harm to human health or the environment, precautionary measures should be taken even if some cause and effect relationships are not fully established scientifically. In this context the proponent of an activity, rather than the public, should bear the burden of proof.

"The process of applying the Precautionary Principle must be open, informed and democratic and must include potentially affected parties. It must also involve an examination of the full range of alternatives, including no action." [End of statement.]

APPENDIX V

NOTES ON SOME OFFSHORE ACCIDENTS

Introduction

The following notes have been compiled as background for the assessment contained in the report. The incidents listed below show some severe consequences to human life and to the environment. It is noteworthy that human factors are involved in all of them.

Ixtoc 1

This was the marine blowout resulting in the largest spill recorded, with a volume of 3 million bbl. It occurred in Campeche Sound, Gulf of Mexico, 1979-80. The accident was well summarized in WCOEEAP, (1986), which provides the basis for much of the following. The accident occurred while a semi-submersible unit was drilling an exploratory delineation well on June 5, 1979. It was only brought under final control on March 25, 1980.

The unit (SEDCO 135F) was drilling on June 3 at 3,657 m in 52 m of water with 244 mm production casing cemented at 3, 627 m. At 3615 m, the well had lost drilling mud. Drilling fluid circulation was then totally lost. It was decided to seal the well by withdrawing the drill pipe and inserting a plug. The drillstring was pulled. At the time when drill collars reached the level of the blowout preventers, mud flowed up the pipe and onto the platform. Preventers were closed around the collars, but flow increased inside the collars, which started to rise from the well. Shearing of the thick-walled collars by the preventers was not possible. The well caught fire and the crew was evacuated. The platform sank to the bottom. The blowout preventer stack remained intact on the seabed.

A large fire on the surface burned. By June 12 a slick 180 km long and 80 km wide had formed. By June 26, some success had been achieved in actuating preventer valves and a reduction in flow was accomplished Unfortunately, fluids immediately flowed around the wellhead on the ocean floor. This might have resulted because the string of cemented production casing ruptured.

Relief well drilling began, and other methods were attempted to kill the blowing well. A reduction in flow from 30,000 to 10,000 barrels per day resulted. Since fluid had begun to flow around the wellhead, the realistic method of control was a relief well. Two were drilled, and the second relief well was successful. The Ixtoc 1 well was at last brought under control on March 17, 1980, and plugged and abandoned on March 25. The duration of the incident was a total of 281 days.

The pipe rams in the blowout preventer will not shear drill collars and could not close off flow. Reliance on bag preventers and use of other fallback equipment were insufficient to provide a seal.

An analysis of the environmental impacts of the spill can be found in Jernelov and Linden (1981).

Ocean Ranger

On the morning of February 15, 1982, the semisubmersible drilling unit, the *Ocean Ranger*, was lost whilst drilling on the Grand Banks of Newfoundland. All 84 members of the crew lost their lives. The accident occurred during a severe storm. A wave broke a porthole in the ballast control room during the evening of February 14. A bow list developed probably as a result of malfunction of the ballast control system after the porthole had been damaged and sea water entered the ballast control room. Deadlights had been left open to assist in viewing the draft marks. These should have been closed in storm conditions. Intervention by the crew consisted of reactivation of the control panel allowing water to enter the port pontoon. Then, in an attempt to remedy the situation they actually increased the forward list since they failed to realize that one or more valves to the aft ballast tanks were open, and water was unintentionally pumped out of these aft tanks. There was a misunderstanding of the manual control system comprising rods, which were inserted in an attempt to close valves. This was a mistake. The result was the opening of up to 15 ballast tank valves, and an acceleration of the forward list.

The events surrounding the tragedy are summarized in the Royal Commission on the *Ocean Ranger* Marine Disaster (1984). Apart from the aspects regarding proper training of the crew, design weaknesses were identified, including the location and design of the ballast control room, the strength of the porthole, and the proper use of deadlights. Procedures and training in search and rescue are other issues that received attention.

Piper Alpha

Piper Alpha, an oil platform in the North Sea, caught fire and burned down on July 6, 1988. In the disaster, 167 people were killed, and the billion dollar platform was destroyed. The platform included a drilling derrick, a processing and refining area, and accommodation for persons working on the platform. It had two gas risers, and the gas was processed on the platform. The processed gas and other oil products were piped to shore. During a routine maintenance procedure, a backup pump for propane condensate had its pressure safety valve removed for checking. Since the maintenance workers did not have all the equipment needed, they were given permission to leave the pump out, and complete the work the next day.

During the same evening, the primary condensate pump failed. The personnel in the control room did not know of the maintenance of the backup pump, and decided to activate it. Gas escaped with considerable force from the hole left in the pump during maintenance. Ignition and explosion followed, blowing down a firewall. Large amounts of stored oil were ignited. The automatic deluge system had been turned off so as to protect divers in the water adjacent to the intake of the system.

The fire caused the gas risers to burst and the gas under pressure ignited causing an inferno of burning gas. At the peak, the flames were about a hundred metres in the air. The conditions for the crew became a nightmare, and only 62 were saved, many with severe burns. Lack of safety training was evident.

The subsequent enquiry was headed by Lord Cullen. His wide ranging report has had a significant effect on offshore safety and procedures. In particular, the use of goal-setting regulations, and procedures based on risk analysis were used in subsequent management of safety issues. Changes to the permit to work system were also implemented by industry.

Exxon Valdez

Details of the accident can be found on the *Exxon Valdez* Oil Spill Trustee Council website (http://www.evostc.state.ak.us/facts/details.html). The tanker Exxon Valdez transported North slope crude oil from the Alyeska Pipeline Terminal to Long Beach, California. She ran hard aground shortly after midnight on March 24, 1989. at Bligh Reef, rupturing eight of its 11 cargo tanks and spilling about 41,000 m^3 of crude oil into Prince William Sound. During the accident, no human lives were lost. Human factors relevant to the accident are discussed in the website noted above.

The major environmental consequences of the *Exxon Valdez* oil spill (summarized from Rice et al., 1996) are as follows:

1. Approx 2800 sea otters and approx. 300 harbour seals were killed; in addition, there was a possible loss of killer whales from Prince William Sd. following the spill (Laughlin et al., 1996) though this could not be specifically attributed to the spill.

2. It was estimated that approx. 250,000 seabirds were killed (though it is recognised that such estimates are only approximate, as they rely on extrapolation of much smaller numbers of carcasses actually recovered: Piatt and Ford, 1996).
3. Reduced growth was observed in early life stages of pink salmon in 1989 (but not 1990) (Geiger et al., 1996; Wertheimer and Celewycz, 1996; Willette, 1996) and this was probably not attributable to changes in prey availability (Wertheimer et al. 1996; Celewycz and Wertheimer, 1996). There was a probable reduction of about 2% in pink salmon returns in years following the spill (Willette, 1996).
4. Larval herring production probably dropped by 50% (Brown et al., 1996); it was not possible to relate this to later adult returns because of confounding factors.
5. Changes occurred in inter-tidal invertebrate communities; some invertebrate populations (algae and molluscs) were reduced while others, such as barnacles and some oligochaetes, which presumably were pollution-tolerant, were enhanced (van Tamelen and Stekoll, 1996; Hooten and Highsmith, 1996).
6. Subtidal macroalgae apparently were not affected (Dean et al., 1996a) but populations of epibenthic invertebrates showed changes which were generally correlated with the extent of oil distribution (Dean et al., 1996b)
7. Subsistence “fisheries”, particularly those based on invertebrates, were affected because of human health concerns (Bolger et al., 1996).

Damage to cultural and archaeological sites occurred as a result of increased access to the region during clean-up operations (Bittner, 1996).

Recent reports (Peterson et al., 2003; and http://www.evostc.state.ak.us/facts/status.html) show that response of the ecosystem can have various time scales, due to persistence of toxic subsurface oil and chronic exposure. At one end of the spectrum of responses, the common loon, three species of cormorant, the harbor seal, the harlequin duck, Pacific herring and pigeon guillemot have shown little or no clear improvement since spill injuries occurred; on the other hand, the bald eagle, black oystercatcher, common murre, pink and sockeye salmon and river otter have all met recovery objectives.

Nestucca

The following summary is based on Harding and Englar (1989). On December 23, 1989, about 875 m^3 of Bunker C oil were spilled off Gray’s harbour, Washington. The oil reached Vancouver Island on December 31. The spill affected about 150 km of coastline with light to moderate oiling along high tide lines; about 2 km were heavily oiled. Significant concentrations were found in areas containing important seabird, fish, shellfish and marine mammal habitats. About 3,500 seabirds were found dead in B.C. and 9,000 in Washington. Some seals, sea lions and river otters were found dead but deaths attributable to oil were not confirmed. Grey whales migrated through the area during March-April “without incident”. Crabs were contaminated at the entrance to Clayoquot Sound and fishing of these was closed until June 26. Other areas were closed to bivalve, gooseneck barnacle and mussel harvesting for several weeks, as a precautionary measure. Salmon habitats were in protected bays and not in the exposed outer coastline where most oiling occurred. The historical spawning locations in Barkley Sound (as documented) were altered but it was not certain if this was related to the oil. The commercial quotas were met and there was not any evidence of tainting of herring.

Prestige

On November 13, 2002, a tank in the ship burst in a storm whilst she was off Galicia in Spain. She was single-hulled, flying a Bahamas flag, and had been chartered by a Russian oil company based in Switzerland. On November 19, the ship broke into two. The Spanish government let the Prestige sink, and the wreck continued to leak oil. It was unlikely that the ship would have broken into two if it had been towed to calm waters, and the cargo transferred, as had been requested by the ship’s captain.

The leaking oil has polluted the sea bed and contaminated the Spanish coastline in a very notable ecological region. Simon Walmsley, senior policy officer for shipping for the World Wildlife Fund states that "The environmental devastation caused is at least on a par, if not worse,than the *Exxon Valdez*. The amount of oil spilled is more than the *Valdez* and the toxicity is higher, because of the higher temperatures." Questions have also been raised regarding the condition of the vessel at the time of the accident.

Short Biographies of Panel Member:

Richard F. Addison

Born and educated in Belfast, UK; B.Sc.(Hons.) in chemistry and Ph.D. in agricultural chemistry (animal nutrition). From late 1960's to 1992 worked as a research scientist in labs. of the Department of Fisheries and Oceans (and its predecessors) on issues relating to marine pollution in eastern Canada and the Arctic. As head of the Marine Environmental Quality division at Bedford Institute of Oceanography (Dartmouth, NS) co-ordinated DFO's responses to Environmental Impact Statements supporting proposals for offshore hydrocarbon developments in the Scotian Shelf/Sable Island area and in the eastern Arctic; co-ordinated DFO's scientific response of offshore emergencies including the Sable Island (Venture) gas blow-out (1984). From 1993-2001 was head, Ocean Chemistry division at Institute of Ocean Sciences, Sidney, BC. Since 2002 has been President of a successful environmental consulting company in BC.

Author of over 100 primary publications and another 60 invited reviews, book chapters and conference proceedings dealing with various aspects of pollutant distribution and environmental toxicology. Past Chairman or member of various inter-governmental working groups of the International Council for the Exploration of the Sea, the North Pacific Marine Science Organisation, and the Intergovernmental Oceanographic Commission which dealt with marine pollution. Fellow, Royal Society of Chemistry (UK) and Fellow, Chemical Institute of Canada; past Chairman, CIC Environment Division.

John F. Dower

Born and raised in St. John's Newfoundland, Dr. Dower received his BSc in Biology from Memorial University of Newfoundland and his PhD in Biology (biological oceanography) from the University of Victoria. He was a Research Associate at Queen's University (Kingston, ON) from 1996-1998, Assistant Professor at UBC (Earth and Ocean Sciences) from 1998-2000 and currently holds a joint appointment in the Biology Department and the School of Earth & Ocean Sciences at the University of Victoria. He has published on various aspects of marine ecology and biological oceanography and served on the DFO Advisory Team for the establishment of a Marine Protected Area at Bowie Seamount. He is a member of an international panel that conducted an ecosystem review of the Eastern Tropical Pacific (ETP) for the US National Marine Fisheries Service and of the City of Victoria's CRD Marine Monitoring Advisory Group. He participated in the GLOBEC Canada research program and is currently a co-PI on an NSERC Strategic Project examining the coupling of physical and biological processes in the Strait of Georgia.

Jeremy Hall, Chair

Dr. Hall is highly respected among the scientific community for his contributions to earth sciences research. He has chaired several important science committees, including the Canadian Geoscience Council and its Standing Committee for the International Continental Drilling Program, and has acted in a science advisory role to government for several years. Dr. Hall was a member, from 2000–2002, of the Minister's National Advisory Board for Earth Sciences, that reports to the Minister of Natural Resources.

Dr. Hall is a professor in the Department of Earth Sciences at Memorial University of Newfoundland. He holds a doctorate degree in seismic studies from the University of Glasgow and is a member of the Association of Professional Engineers and Geoscientists of Newfoundland.

Ian J Jordaan

Dr. Jordaan is presently University Research Professor, and for the period 1986 - 1996 was NSERC-MOBIL Industrial Research Professor of Ocean Engineering, at Memorial University of Newfoundland. He is also President, Ian Jordaan and Associates Inc., St John's. Previously he served as Professor, Department of Civil Engineering, at the University of Calgary, and worked for several years at Det norske Veritas (Canada) Ltd., ending as Vice-President (Research and Development) in 1986. He has been involved extensively in developing methodology for engineering design criteria, and in the use of probability theory, risk analysis and extremal analysis applied to engineering problems. He has also worked on problems in mechanics, including viscoelasticity, fracture and failure applied to various materials including ice. He was chair of the CSA Committee S. 471, General Requirements, Design Criteria, Environment and Loads, forming part of the Code for the design, Construction, and Installation of Fixed Offshore Structures, and continues to contribute to this effort by serving on several committees. He also served on a working group charged with reviewing the Proposals for the Revision of the Arctic Shipping Pollution Prevention Regulations. He has acted as a consultant in many studies, including the design loads for the Confederation Bridge, and studies for the Terra Nova design, the West Bonne Bay prospect, the Hebron development, and the White Rose development. He has published extensively in the areas of risk analysis, probabilistic design criteria and the mechanics of solids. He has received the Horst Leipholz Medal for contributions to mechanics, and the P.L. Pratley Award for the best paper on bridge engineering, both from the Canadian Society for Civil Engineering.

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