Hydrocarbons and their Effects on Aquatic Organisms in Relation to Offshore Oil and Gas Exploration and Oil Well Blowout Scenarios in British Columbia, 1985

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HYDROCARBONS AND THEIR EFFECTS ON AQUATIC ORGANISMS IN RELATION TO OFFSHORE OIL AND GAS EXPLORATION AND OIL WELL BLOWOUT SCENARIOS IN BRITISH COLUMBIA, 1985

by

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PREFACE

This previously unpublished report was presented by the Department of Fisheries and Oceans (DFO), Pacific Region, to the Federal Secretariat and thence to the West Coast Offshore Oil and Gas Exploration Environmental Assessment Panel in 1985. This panel assessed the concern over the exploration for oil along the coast of British Columbia, and specifically a proposal by the proponents Chevron and Petro-Canada (Canada and British Columbia, 1986). As a consequence of the review there was a moratorium placed on such activities.

The information within this report is unchanged from the original submission and, as such it is an historical record. It provides technical information and deductions based on the available knowledge at the time of submission.

The report is based on two separate interventions by DFO at the technical sessions on "Oil and Gas Blow-Out Impacts" that were held during the hearings in 1985. The first intervention provided information of the effects of hydrocarbons on aquatic organisms and their habitat and the second summarized concerns about the impacts of oil well blowouts.

Since 1985, there has been an increase in scientific research on the effects of hydrocarbons on aquatic organisms and our knowledge has increased accordingly. Unfortunately, oil spillage continues to be a threat to the aquatic environment. For example, the grounding of the *Exxon Valdez in* 1989, and the subsequent discharge of 42 million liters of crude oil into Prince William Sound, Alaska, resulted in the loss of fishery resources and other wildlife. The significance of the effects remains a controversial topic between industry and government scientists. The debate reflects the problems associated with the timely and quantitative determination of effects in the field, and socio-economic values and concerns.

At present offshore oil and gas exploration along the coast of British Columbia is once again being debated, and this report is offered to indicate the level of concern for the well being of aquatic resources that was also expressed during the public review in 1985.

TABLE OF CONTENTS

ABSTRACT

Birtwell, I.K., and C.D. McAllister. 2002. Hydrocarbons and their effects on aquatic organisms in relation to offshore oil and gas exploration and oil well blowout scenarios in British Columbia, 1985. Can. Tech. Rep. Fish. Aquat. Sci. 2391: 52p.

This report comprises technical information that was presented at public hearings held in 1985 regarding the exploration for oil and gas along the coastline of British Columbia, Canada.

Attention was focussed upon economically important fish and their habitat, the concern for other components of aquatic ecosystems (such as invertebrates) and their inter-relationships, and the need to ensure the perpetuation of such resources for future use. The information presented in this report is supplemental to that provided in Initial Environmental Evaluations by Petro-Canada and Chevron who were the proponents of offshore oil and gas exploration.

The vulnerability of fishery resources (groundfish, herring, and salmonids) to spilled oil is revealed through the provision of information on the effects on different stages in the life history of these fishery resources. The effects of hydrocarbons on survival, growth, physiology, behavior, and disease resistance of these fish exemplify concern for their well being, and the habitats they utilize. Information is also provided on the effects of oil on invertebrates (zooplankton, crabs, shrimps and prawns, bivalves and benthic communities), and the implications to marine food webs (including the concern for marine mammals).

An improved understanding of natural ecosystems, relevant ecotoxicological studies, and an evaluation of spill countermeasures are topics requiring further research and understanding.

The level of concern for the biological resources at risk from oil spillage along the coastline of BC is emphasized, and illustrated through the use of scenarios of oil well blowouts. These scenarios used the West Coast Offshore Oil and Gas Exploration Environmental Assessment Panel's postulated 50-day spill and a release of 5000 barrels of oil a day. The vulnerability of juvenile salmon to spilled oil was used to simply illustrate the concern for fisheries and the associated economic impact.

In summary, it was deduced that spills are not improbable, that concentrations of spilled oil can be high, that even small oiled areas could contaminate large numbers of resource species such as young salmon thereby causing major losses, and that oil in water can kill or harm important species.

We conclude that there are grounds for serious concern over the risk to fish and fish habitat from the spillage of oil along the coast of British Columbia.

RÉSUMÉ

Birtwell, I.K., and C.D. McAllister. 2002. Hydrocarbons and their effects on aquatic organisms in relation to offshore oil and gas exploration and oil well blowout scenarios in British Columbia, 1985. Can. Tech. Rep. Fish. Aquat. Sci. 2391: 52p.

Ce rapport comporte des renseignements techniques présentés lors d'audiences publiques tenues en 1985 à l'égard de l'exploration pétrolière et gazière le long du littoral de la Colombie-Britannique, au Canada.

L'attention a été mise sur les espèces de poisson importantes au plan économique et leur habitat, les préoccupations au titre des autres composantes des écosystèmes aquatiques (dont les invertébrés) et les relations entre elles et le besoin d'assurer la pérennité de ces ressources aux fins d'utilisation future. Les renseignements içi présentés s'ajoutent à ceux fournis dans les évaluations environnementales initiales faites par Petro-Canada et Chevron, les promoteurs de l'exploration pétrolière et gazière en haute mer.

Les renseignements donnés sur les effets du pétrole sur les différents stades vitaux des ressources halieutiques (poisson de fond, hareng et salmonidés) mettent en lumière la vulnérabilité de ces dernières aux déversements d'hydrocarbures. Les effets des hydrocarbures sur la survie, la croissance, la physiologie, le comportement et la résistance aux maladies de ces poissons illustrent les préoccupations que soulèvent leur bien-être et les habitats qu'ils utilisent. Des renseignements sont aussi présentés sur les effets du pétrole sur les invertébrés (zooplancton, crabes, crevettes, bivalves et communautés benthiques) et ses répercussions sur les chaînes alimentaires du milieu marin (y compris les mammifères marins).

D'autres études, y compris des études écotoxicologiques pertinentes, et une évaluation de mesures de prévention des déversements d'hydrocarbures devraient être menées sur les écosystèmes naturels afin de mieux en comprendre les processus.

L'inquiétude au sujet des ressources biologiques menacées par les déversements de pétrole le long du littoral de la Colombie-Britannique est mise en lumière et illustrée par des scénarios d'éruption de puits de pétrole. Ces scénarios reposent sur le postulat d'un déversement de 5000 barils par jour pendant 50 jours utilisé par la Commission d'évaluation environnementale du projet d'exploration au large de la côte ouest. La vulnérabilité des saumons juvéniles au pétrole déversé n'a servi qu'à illustrer la préoccupation à l'égard des pêches et les incidences économiques connexes.

En résumé, les auteurs ont déduit qu'il n'est pas improbable que des déversements de pétrole se produisent, que les concentrations de pétrole déversé peuvent être élevées, que même une faible superficie souillée par le pétrole pourrait contaminer un grand nombre d'espèces halieutiques exploitées, comme les jeunes saumons, ce qui donnerait lieu à des pertes majeures, et que le pétrole présent dans l'eau peut tuer des espèces importantes ou leur nuire.

Les auteurs concluent qu'il est justifié de fortement s'inquiéter quant aux risques que posent les déversements de pétrole pour le poisson et son habitat le long du littoral de la Colombie-Britannique.

EFFECTS OF HYDROCARBONS ON FISH

In providing supplementary information (*to the Offshore Oil and Gas Exploration Environmental Assessment Panel*) in relation to the effects of hydrocarbons on marine and estuarine fish, particular reference has been made to certain review articles which provide pertinent information (for example, F.A.O. 1977a; Malins and Hodgins 1981; Malins 1982; McIntyre 1982; Sindermann 1982; Sprague et al. 1982).

Attention has been focussed upon economically important fish and their habitat. For convenience, these fish have been grouped as groundfish, herring and salmonids. However, we in no way wish to diminish concern for other components of aquatic ecosystems, nor the need to ensure the perpetuation of "renewable resources" for future use. Components of aquatic systems, at all levels of biological organization, may be susceptible to hydrocarbons. While we recognize the need to maintain stocks of currently valuable fishery resources and their supporting habitats, it is of fundamental importance that we attempt to understand the effects of hydrocarbon exposure, at both the individual and population level. If there is no effect on individuals (including effects on individuals of other populations that prey upon, compete with, or provide food for the population of interest) there will be no effect on the population (Wedemeyer et al. 1984).

Defining the effects on individuals is, in itself, a difficult task, although much research has been directed toward this goal. It is necessary to understand not only the effects of hydrocarbons on individuals and populations (stocks), but also biological processes within systems. It will only be possible to fully predict the effects of disruption to aquatic populations and systems when biological processes and their modification by natural and other factors are known. Thus, to understand the effects of hydrocarbons on fish stocks it is necessary to understand, for example, stock dynamics. F.A.O. (1977a) report that the use of existing fish statistics to demonstrate the deleterious, beneficial or null effects of oil is fraught with dangers due to the quality of the data and the potentially great numbers of unknown factors. The complexity of the task is also mentioned by Malins (1982) who states that it is generally not possible to predict the type or degree of impact of petroleum on organisms because little is known of the influence of natural and man-made environmental variables on its fate and effects. Exacerbating the problem is the question about the general relevance of experiments carried out in the laboratory to understanding effects in the field, and mixed reports concerning the mortality of fish stocks after oil spills. McIntyre (1982) comments upon the absence of long term adverse effects on fish stocks that can be attributable to oil, but is cautious to note that local impacts can be extremely damaging in the short term. Produce from specific localities can be tainted from exposure at the parts per billion (ppb) level, and remain unmarketable for long periods. Even a suspicion of tainting can be damaging to fisheries.

In the open ocean, below the surface film, concentrations of oil are very low (<1 $nL{\cdot}L^{-1}$). They are at levels where effects on populations would not be expected (McIntyre 1982). The effects of oil spills in open ocean environments have appeared to be transient and it is generally considered (though not confirmed) that mobile fish probably avoid contaminated areas. However, the paucity of information in the field may well be due to many causes. It may be partly due to the fact that impacted early developmental stages such as eggs and larvae do not survive long in marine environments (Malins 1982). There is an increasing awareness of the susceptibility of early developmental stages to oil, especially at the cellular and subcellular level, sometimes at concentrations substantially lower than those inducing morphological changes in juvenile marine organisms (Malins 1982).

McIntyre (1982) considers that fisheries on the continental shelves are at greater risk than those offshore, and that effects on shallow coastal intertidal areas may last for years. With proximity to land and population centres is the added complexity of other contaminants that may affect aquatic resources. Significant changes in commercial stocks do take place in inshore areas, although attempts are not usually made to link them with any single pollutant (McIntyre 1982). For example, there is no satisfactory explanation for the disappearance of oysters in the Firth of Forth; since drilling started in the Gulf of Mexico in the 1920's, major redistribution of the oyster fishery has occurred, and the valuable white shrimp has declined in relation to brown shrimp. Some investigators claim that these changes are attributable to man (F.A.O. 1977b).

The vulnerability of inshore areas to oil pollution is generally recognized, and it is essential that such areas are protected to ensure the health of aquatic organisms. The nearshore coastal environment of B.C. supports many diverse fishery stocks, which may or may not be discrete at certain times of the year. The vulnerability of organisms to oil pollution will tend to be related to seasonal changes in their distribution and abundance, and while an oil spill at one part of the year may have less impact than at another, it is important to recognize that the progressive degradation of habitats may lead to a problem of regional significance from what was originally of local and specific concern.

The relevance of some of these comments should be apparent in the following sections in which we have attempted to reveal some of the more recent information on the effects of oil on groundfish, herring and salmonids.

GROUNDFISH

This categorization of fish species is usually used to describe marine, commercial, non-salmonid fish species, with the exception of herring. The group encompasses pelagic and demersal species that utilize a variety of habitats ranging from deep-water areas e.g., halibut, to shallow estuarine intertidal banks, e.g., Starry flounder. The vulnerability of these fish to exposure to hydrocarbons will vary depending upon many factors, often specific to particular species. Certain species of fish lay demersal eggs (e.g., cod, and sandlance), others have pelagic eggs (e.g., English sole) or bathypelagic eggs (e.g., Petrale sole, Flathead sole, Dover sole, halibut) while different species produce live young (e.g., rockfishes). Even though eggs may be deposited at different depths, larval forms are present at the water surface, or in surface waters, at some time. Driven by ocean currents and the action of wind, larval fish come into shallow waters where they may reside for months to years, before moving to deeper areas (e.g., English sole, Starry flounder, halibut). The greatest abundance of eggs, larvae and young fish in surface waters occurs in summer (June to September).

Eggs and larvae

The susceptibility of these early developmental stages such as eggs, larvae and juvenile fish, to oil in surface waters, is high. (Hawkes and Stehr 1982, cited in Malins 1982) exposed surf smelt to 0.054 $mg \cdot L^{-1}$ or 0.113 $mg \cdot L^{-1}$ of the seawater-accommodated fraction of Cook Inlet crude oil for 4 $h \cdot d^{-1}$ beginning 6 h after fertilization. Hatching success was 40% lower than that of the controls and cellular aberrations were found in 27 d-old embryos.

After the wreck of the *Argo Merchant* off the East Coast of U.S.A., 1976, Longwell (1977, 1978) reported that 20% of cod eggs and 46% of pollock eggs were dead or moribund. Within the oil slick pollock embryos were grossly malformed in 18% of eggs. At the edge of the slick 9% were grossly abnormal, but at greater distances no abnormalities were found and no cod eggs were deformed. Eggs that were dead or moribund displayed a combination of cytological abnormality of the embryo cells or of the nuclear configurations, coupled with division arrest.

Oil concentrations up to 250 $nL \cdot L^{-1}$ were recorded in the upper waters in the immediate vicinity of the *Argo Merchant*. At oil concentrations of 50 $nL \cdot L^{-1}$ Tilseth et al. (1981) recorded a reduction in growth and change in buoyancy of cod eggs and larvae after a 14-d exposure. At 250 $nL \cdot L^{-1}$ malformations of head and jaws were recorded. Kühnhold (1972) considered that cod eggs were most susceptible to hydrocarbons just after fertilization. Despite these findings regarding the *Argo Merchant* incident, McIntyre (1982) concludes that the mortalities and other effects would probably not have a detectable effect on fish stocks in the offshore environment.

In a study on the effects of *Ekofisk* crude oil Johannessen (1976) showed that the water-soluble fraction reduced the hatching success of fertilized capelin eggs at concentrations of 10 to 25 $nL \cdot L^{-1}$.

After the *Torrey Canyon* accident Smith (1970) reported 50 to 90% of pilchard eggs dead, and juvenile fish scarce in plankton samples collected in the vicinity of the wreck (toxic dispersants were used to disperse oil in this incident and probably added to the effect of the oil).

Pollutants may combine with oil to affect fish in certain locations, and the findings of Longwell (1976) typify this for New York Bight. In this region one third of developing mackerel eggs were found to be abnormal, and at stations closest to a disposal site, eggs with the highest frequency of chromosomal and mitotic abnormalities were found.

These examples are provided to indicate that effects on early developmental stages can occur from exposure to hydrocarbons and although it has been concluded that these stages are extremely vulnerable, in the open ocean environment it has not been possible to conclusively demonstrate adverse effects on fish stocks *per se*. Nevertheless it is apparent that hydrocarbons can greatly reduce the individual's chances for survival (Rosenthall and Alderdice 1976) and accordingly population changes are of potential concern.

Juveniles and adults

The effects of hydrocarbons on adults of many species have been examined under laboratory and field conditions. Similar to the research that has been carried out on eggs and larvae much of the research on older fish concerns species that are found in the Atlantic Ocean, but a wider variety of topics has been examined.

Behaviour: Pearson et al. (1984) examined the effect of oiled sediment on the burrowing behaviour of the sandlance, a species which is highly significant in the food chain of many animals (e.g., coho salmon). It is abundant on the B.C. coast. This species avoids predation by burrowing in sand (Pearson et al. 1984). Oiled sand (>306 ppm Prudhoe Bay crude oil) resulted in a 20% reduction in the time spent buried. Furthermore severe anterior hemorrhaging was observed. This effect, followed by death, was recorded by Anderson (unpublished data, cited by Pearson et al. 1984) when sandlance were exposed to seawater with undispersed and chemically dispersed oil. Thus behavioural changes in burrowing may adversely affect the ability of this fish to avoid predators and exposure to contaminated sediment may result in other detrimental effects.

Fletcher et al. (1981) examined the effects of a 4-5 month exposure to Venezuelan crude oil in sediment (1 L per 45 kg) on the mortality, feeding and growth of winter flounders. The feeding rates of exposed fish were reduced in freshly oiled sediments, but weathered oil had little or no effect. McCain et al. (1978) also suggested that flatfish exposed to oiled sediment reduced food intake.

Weber et al. (1979) found that juvenile English sole did not avoid oil-contaminated sediment, accordingly they may be affected by the oil, however, if they avoid a contaminated area, they lose the use of that habitat. Kiceniuk and Khan (1983) consider that either way, there is an impact on the population until hydrocarbons return to a "no effect" level, which is, at this time, undetermined. Butler et al. (1982) also suggested that behavioral changes could affect survival. In this instance they examined the effects of #2 fuel oil and a dispersant on killifish. At two orders of magnitude below lethal levels, activity and depth preference changed suggesting that behaviour, essential for survival at both the individual and population levels (for example, feeding, anti-predator and reproductive behaviour), may be impaired with exposure to these pollutants in the wild.

Uptake of Hydrocarbons: Varanasi and Gmur (1981) examined the uptake of hydrocarbons (benzo-a-pyrene, naphthalene) in English sole. Benzo-a-pyrene and other polynuclear aromatic hydrocarbons remain relatively unconverted in sediments and therefore can be available for uptake by benthic organisms (Varanasi and Gmur 1981). English sole feeding on contaminated organisms, and in contact with oiled sediments could take in hydrocarbons. Benzo-a-pyrene was found to be metabolized to a greater extent than naphthalene. However the metabolites of benzo-a-pyrene are carcinogenic/mutagenic substances which bind to the cellular macromolecules in the liver (Varanasi and Gmur 1981). Spies et al. (1982) found that mixed-function oxidase activity in fish populations (flatfish) around Santa Barbara petroleum seeps were elevated, and considered this to be a functional adaptation to the chronic intake of petroleum. However, the ability of fish to metabolize hydrocarbons may vary among species. Malins (1982) reports an experiment in which flatfish were exposed to Prudhoe Bay crude oil concentrations in sediment for 3 to 4 weeks. There was no effect on Starry flounder, but in English sole histological, hematological and physiological changes were observed. The results are interesting, for Malins and Hodgins (1982) report that Starry flounder exposed for one week to the water soluble fraction of Prudhoe Bay crude oil accumulated 9000 times the concentration of C_4 and C_5 substituted benzenes (1 ppm) in muscle (Roubal et al. 1978). Malins and Hodgins (1982) give an example which shows that the elimination of hydrocarbons (at least parent compounds) can occur upon transfer to clean water. How quickly fish discharge petroleum hydrocarbons is considered to depend upon the species, tissue where the hydrocarbons are concentrated, and other factors (Malins and Hodgins 1982).

Disease: Contact with and/or uptake of hydrocarbons have been associated with fin erosion, fin ray deformation, ovarian histopathology, olfactory lesions, degeneration of ventricular myocardium, and cytogenetic anomalies. Some of the effects may well be associated with increased stress upon exposure (Sindermann 1982).

Supporting these statements Sindermann provides a number of examples from the literature: DiMichele and Taylor (1978) exposed killifish to 0.001 - 30 $mg \cdot L^{-1}$ naphthalene for up to 15 d, and recorded a number of effects. For example, at 0.02 $mg \cdot L^{-1}$ pathological changes (lesions, necrosis) of brain, liver and pancreas occurred. Generalized signs of chemical stress such as gill hyperplasia and hemorrhage were common, as were signs of metabolic stress. Gardner (1975) recorded olfactory lesions in Atlantic silversides exposed for 7 d to water soluble and insoluble fractions of crude oil, and Hawkes (1980) found degenerative changes in the olfactory epithelium of chemosensory cilia of larval sand sole after 8 d in a water soluble fraction of crude oil. McCain et al. (1978) record that English sole had severe liver pathology after a 4 month exposure to 0.2% Alaskan crude oil in clean sand. Payne et al. (1978) after a 6-month exposure of cunners to Venezuelan crude oil reported no histological changes, however there were significant changes in testis somatic index, lens diameter, and plasma chloride.

Six months after the *Amoco Cadiz* oil spill, 50% to 80% of mullet were found to have "penetrating ulcers" and occasional muscle lysis. No hemorrhaging or thrombosis, was recorded (Balouet and Blaudin-Laurencin 1980). Plaice, sole and dabs were frequently found with fin erosion for an 18-month period after this spill (Desauney 1979). Sindermann (1982) considers that the fin erosion syndrome in fish includes chemical stress probably acting on mucus and epithelia, and other factors.

Growth and survival: The work of Fletcher et al. (1981) on the effects of oiled sediment on the winter flounder provides additional information on the effects that hydrocarbons may have on the survival of fish. Winter flounder are obligatory residents of habitats (1 - 40 m depth) which could become contaminated with oil. In that they do not feed during winter Fletcher et al. (1981) suggest that their ability to grow and store enough energy reserves to survive the winter would be reduced upon exposure to oiled habitats: consequence of a reduction in feeding due to exposure to oil. They also found that oil, acting as a non-specific stressor could, in combination with high summer water temperatures (and effects of captivity), result in significant mortality. Whether this would happen under environmental conditions was not determined.

Reports on the direct kill of adult fish following an oil spill are relatively sparse. After the *Amoco Cadiz* spill there was an immediate kill of several tons of rock-living fish at the site of the wreck. Enhanced proportions of diseased fish were reported and one year class of flatfish was thought to have been reduced (McIntyre 1982).

At petroleum production platforms near the Louisiana outer continental shelf Stott et al. (1981) examined 11 species of fish for petroleum-induced lesions. Minimal morphological evidence of adverse effects by toxic petroleum elements on the ovary was found. The authors conclude that, like other reports, there are no deleterious effects on fauna at production platforms but they are cautious to indicate the need for further research around petroleum production platforms in relation to cytological changes in fish.

Summary and general comments

The results of recently reported information supplement previous work indicating the vulnerability of eggs, larvae and juvenile fish to oil. Many species of fish of current commercial importance have a phase in their life history that would be in shallow surface waters and thereby be highly vulnerable. In addition, there are many other organisms that are found in such waters that, although not commercially harvested, play an important role within the food chain, e.g. sandlance. Aside from effects on fish, effects on their food supply and their predators would be expected to affect survival, but the exact consequences are difficult to predict. However, it is expected that recovery of the shallow, nearshore areas along the B.C. coastline, especially in sheltered, low-energy areas, would be over many years.

It is apparent that fish (e.g. flatfish) do not always avoid oil-contaminated areas, and behavioural changes can occur and lead to decreased survival. Exposure to hydrocarbons usually results in uptake by fish. The rate of their metabolism and elimination is dependent upon many factors, but can occur rapidly. Metabolic products can cause a variety of adverse effects, in addition to general pathological effects due to exposure. Decreased food intake and growth reduction can also occur. Oil spills can have direct toxic effects on all stages in the life cycle of fish, but predicting the exact effects of oil spillage is extremely difficult.

There are many non-salmonid fish which are not addressed in this section, but which are also vulnerable to oil spillage. Numerous species of fish occupy nearshore areas and are part of nearshore habitats. They may provide food for, and/or compete for food with, currently harvested resource species. While the role of many species in nearshore habitats may be unknown, the preservation of the integrity of such areas is fundamental to the protection of the currently harvested resources.

HERRING

Pacific herring spawn in intertidal and shallow subtidal areas along the B.C. coast. The timing of spawning appears to be dependent upon area, and spawning in southern coastal waters often occurs before spawning in northern areas. Along the northern coastline of B.C. spawning generally occurs in March and April but can be as late as June or July. The vulnerability of these pelagic fish to spilled hydrocarbons will increase with their proximity to nearshore waters prior to, during and immediately after, spawning. Eggs deposited along the coastline will be highly vulnerable to oil spillage, and subsequently, the positively phototactic larvae which reside in surface waters, followed by juveniles which school and are captured in large numbers in shallow estuarine and nearshore marine areas, will also be susceptible.

Effects of oil

Oil has been shown to affect the survival, growth and development of herring. Much of the earlier work was carried out by Kühnhold and is reported in the reviews of Rosenthal and Alderdice (1976), F.A.O. (1977), Malins and Hodgins (1981) and Malins (1982). For example, Kühnhold (1972) examined the effect of crude oil on eggs and larvae of herring, and concluded that larvae do not seem able to avoid contaminated water, especially dispersions, as the chemoreceptors are probably blocked or destroyed quickly at the first contact with oil compounds. A similar result was also recorded in relation to another pollutant (BKME) (Birtwell 1977).

Lindén (1978), cited in Malins and Hodgins (1981), described the effects of two crude oils and a fuel oil on the development of Baltic herring. Alterations in embryonic activity and heart rate, premature or delayed hatching, malformed larvae, and decreased larval survival - albeit at relatively high total petroleum concentrations (3.1 to 11.9 $mg \cdot L^{-1}$) were recorded.

Smith and Cameron (1979) examined the effects of water-soluble fractions of Prudhoe Bay crude oil on Pacific herring embryos (48 - 144h, initial concentration <1 $mg \cdot L^{-1}$). Morphological changes occurred which included abnormalities of the mouth, failure of fins to differentiate from the body wall, and pectoral fin erosion. There was also evidence of abnormal neural development. Newly hatched larvae from control and experimental groups did not exhibit gross abnormalities, but abnormal cellular structure was observed in exposed fish (Cameron and Smith 1980).

McIntyre (1982) mentions that after the *Tsesis* spill in the Baltic, herring continued to migrate through the area, and that contamination was not detected in their tissues. However, there was apparently some reduction in spawning the following spring, but some investigators did not attribute this to the spill (Lindén et al. 1979). Contrasting with this view were the findings of Aneer and Nellbring (1982) who recorded a reduction in herring spawn in the oil spill area, and of those eggs that were taken to the laboratory for hatching, 54% from an unaffected area hatched, but only 25% of eggs taken from the area of the spill hatched. Ambiguity over the cause of reduced hatching is apparent and the authors consider that this may be a secondary effect of oil spillage which reduced the abundance of amphipods and isopods that are normally very abundant in the spawning zones. These organisms may play an important role as "health guards" for herring and other fish eggs deposited in algal belts by controlling fungus on fish eggs.

Adult female herring exposed to benzene, a principle aromatic component of crude oil, just prior to spawning, exhibited a reduced survival of ovarian eggs, and embryo and larval survival was reduced (Struhsaker 1977, cited in Malins and Hodgins 1981). However, Eldridge et al. (1977) found that the growth of post-yolk sac herring larvae increased (a phenomenon noted in other toxicological experiments) and that, in general, the metabolic processes of Pacific herring embryos and larvae were modified upon exposure to 0.1 and 1.0 $\mu L \cdot L^{-1}$ benzene. The exact significance of these findings is, however, difficult to ascertain in relation to the survival of individuals.

Summary and general comments

Petroleum hydrocarbons did not deter herring from migrating through an oil spill zone in the Baltic, however subsequent egg deposition and survival was considered to be impaired in the area of the spill. It is apparent that fractions of crude oil can be taken up by adult herring resulting in reduced egg and larval survival and viability. Hydrocarbons have also been shown to affect the development of herring and cause behavioural changes to the extent that larval herring may not avoid, or cannot avoid, oil in water.

Thus, it is deduced that while in the nearshore areas, herring adults, eggs, larvae and juveniles are highly susceptible to oil pollution. Their requirements for spawning and their behaviour as fry and larvae dictate a surface-water, near-shore habitat. In the vicinity of estuaries the imposition of chronic natural and pollution-induced stress must also be taken into account. Furthermore, the impact of oil on "preferred" spawning areas, and on herring food resources may be significant during their obligatory nearshore utilization phase.

Information on the effects on spawning adult herring confronted with an oiled shoreline are not available, nor is there any information on the effects of food loss due to oil, or on feeding. However, assuming that herring may not avoid contaminated areas, it is highly probable that large-scale mortalities of eggs, larvae and juvenile fish would occur.

The period of greatest vulnerability would be for about 7 months between February and August. A high level of concern is demanded for these fish, not only because of their value to fishermen but also because of their role in the food chain.

SALMONIDS

Large numbers of juvenile salmon migrate seaward each year. They may be found in nearshore estuarine and marine waters for protracted periods, which are seemingly species- and age-specific.

After hatching in freshwater (with the exception of some 'estuarine' spawning populations) juvenile salmon migrate directly, or after a period of residence, into brackish waters. The duration of residence in brackish waters differs among species. For example, wild underyearling chinook salmon tend to utilize estuarine areas for longer periods (months) compared to their hatchery reared counterparts (unpublished information) or pink salmon (Levy et al. 1979). During their estuarine residence and migration phase, juvenile salmon tend to be found in the upper water layers. They appear to have a surface water orientation (Birtwell 1977). Most frequently they occupy the less saline and shallow nearshore areas, and only move into slightly deeper and more saline waters as they become larger (typically > 80 mm).

Mixed populations of fish often occur together in the same areas. They feed actively on a variety of prey, often depending upon their availability. They will feed heavily on insects and crustaceans on the water surface, in the water column, in and on the substrate. Juvenile salmon are considered to be facultative, opportunistic predators.

In intertidal areas of estuaries they may be captured in extremely shallow (<25 cm) water depths as they move across intertidal flats with flooding tidewaters - a behavioural trait which could render them extremely vulnerable to oil spillage in this area, and other shallow nearshore habitats. Juvenile salmon dispersion in the marine environment does not appear to be widespread and large numbers of migrating salmon may be found concentrated along shorelines, in relatively shallow waters. It is generally accepted that juvenile salmon are highly susceptible to predation and environmental disturbances at the time they enter estuarine and marine waters. A time at which they must begin to adapt or tolerate seawater.

Depending upon prevailing water quality and quantity conditions, adult salmon returning to spawn, may be found at many locations and depths along the B.C. coastline. At times of low river-flows, adults will often hold off river mouths, in the estuaries, pending increased flows before moving upstream to spawning areas. At these times, high concentrations of fish are to be found, many close to, and breaking the water surface. Reduced water quality (for example, low levels of dissolved oxygen and/or other pollutants) in some fjord-type estuaries, may exert an additional effect on returning adults by forcing them to occupy shallow water (e.g. Port Alberni Harbour).

The vulnerability of salmonids to spilled oil would be greatest during periods of nearshore occupancy. Although populations using nearshore areas will vary throughout the year, it is possible to encounter juvenile salmon at most times. Early downstream migrant salmon have been captured in January in the Fraser River estuary and some species may utilize estuarine waters year round. Typically, juvenile salmon tend to decrease in numbers late to mid-summer in estuarine and nearshore coastal waters.

Oil toxicity

A number of research projects have been carried out on salmonids in recent years. In contrast to many of the earlier studies, in which lethal effects were investigated, recent work has tended to focus upon the sublethal effects and the following information reveals some of this work.

Rice (1983) reviewed some of the information on the effects of oil on salmonids and gives particular attention to pink salmon. He considers that the eggs of pink and coho salmon (in contrast to alevins and fry) are very tolerant of short-term exposures to oil.

Most research has, however, been carried out on older juvenile salmon (fry and smolts) and their susceptibility to oil. Moles et al. (1979) found that juvenile pink and sockeye salmon and Dolly Varden char were about twice as sensitive to Prudhoe bay crude oil in seawater as in freshwater. For pink salmon the 96h LC50 values (that is, the concentration required to kill 50% of test fish in 96 hours) were 3.73 $mg \cdot L^{-1}$ in seawater and 7.99 $mg \cdot L^{-1}$ in freshwater. In general, mortality occurred within the first 12 h of exposure to oil.

Moles and Rice (1983) carried out a longer-term experiment (40 d) on the effects of the water-soluble fraction of Cook Inlet crude oil on juvenile pink salmon. The 96-h LC50 and 40-d LC50 values for naphthalene and crude oil were 1.2 $mg \cdot L^{-1}$. Morrow (1973), when examining the effects of Prudhoe Bay oil on coho and sockeye salmon, found that at lower temperatures the toxic effect was greater. This finding is of significance in relation to the effects in colder waters wherein the persistence of toxic aromatic hydrocarbons would be increased (Rice 1983) compared to the same situation in warmer waters.

McKeown (1981) examined the toxicity of Alaska crude oil and a dispersant to coho salmon. The toxicity was greater in seawater. Long-term exposure to oil or oil plus dispersant at 5 $mg \cdot L^{-1}$ showed a slow accumulation, but the coho had the ability to cleanse themselves rapidly (dispersant caused a greater uptake of petroleum hydrocarbons). McKeown concludes that salmonid fishes are more resistant to oil pollution in salt water, and that if they do encounter such pollution, they can cleanse themselves quickly. This conclusion is in partial conflict with the opinion of Moles et al. (1979) regarding the sensitivity of salmonids in seawater (see above). However, the difference of opinion is most probably related to the age of the fish tested and different experimental procedures. The coho salmon used in McKeown's experiments had been acclimated to 15 ppt salt water for two months prior to testing, in contrast to the fish tested by Moles et al. (1979) which had been only given 3 d in 50% seawater prior to testing in full strength seawater. Moles et al. (1979) do state, however, that fish fully acclimated to seawater, after several weeks, may not be as sensitive to oil.

Rice (1983) comments that there is no evidence of bioaccumulation of hydrocarbons in the food chain, and that acclimation to sublethal exposures of naphthalene (1 to 14 d) resulted in a 30% to 40% increase in tolerance in pink salmon fry. However, concern must still remain over the metabolic products which may be derived from parent compounds and exert an effect on the exposed individual.

Growth

Moles and Rice (1983) report the results of 40-d studies on the effects of Cook Inlet crude oil (water soluble fraction <0.87 $mg \cdot L^{-1}$ total aromatic hydrocarbons) and naphthalene (<0.8 $mg \cdot L^{-1}$) on the growth, caloric content and fat content of pink salmon juveniles in seawater. Growth was reduced at the higher concentrations of toxicants, and the fish had a decreased caloric content, but fat content of the fish was not affected. The authors conclude that chronic marine oil pollution at a concentration as low as 0.4 $mg \cdot L^{-1}$ total aromatic hydrocarbons could reduce the growth of juvenile pink salmon. It is interesting to note that at 0.12 $mg \cdot L^{-1}$ naphthalene and 0.21 $mg \cdot L^{-1}$ crude oil (water soluble fraction) fish fed actively at the water surface, but they reduced feeding in the higher concentration tested (0.58 $mg \cdot L^{-1}$ crude oil). This implies that juvenile pink salmon will continue to feed in an oiled environment.

Young chinook salmon fed a mixture of aromatic hydrocarbons and 2,3-benzothiophene in food at 5 $mg \cdot kg^{-1}$ daily for 28 d suffered varying degrees of subcellular damage (Hawkes et al. 1980, cited by Malins 1982).

Affects on the growth of salmonids due to oil exposure could be detrimental to their survival. Rice (1983) comments that decreased growth of coho juveniles due to oil exposure could result in the need for an extra overwintering period, and increased mortalities. He considers that growth beyond a critical size is a primary survival mechanism for avoiding predation in some organisms such as juvenile salmonids. Rice considers that prolonged exposure to oil at 20% to 30% of the 96-h LC50 values (<l to 3 $mg \cdot L^{-1}$) will affect growth and will probably affect survival of the individual. In estuaries juvenile salmon must feed and grow rapidly to avoid excessive predation. More pink salmon die at this period than during the rest of their life cycle (Rice 1983).

Adaptation to salt water

Another aspect of salmon biology relating to survival in marine waters, is the ability of the fish to osmoregulate in salt water. Impairment of this function could affect survival.

Estuarine waters near population centres often contain contaminants, some of which may impair osmoregulation. Folmar et al. (1982) studied the effect of arochlor 1254 (a PCB) and No. 2 fuel oil on smoltification and seawater adaptation of coho salmon. Fish were injected with arochlor 1254 and then examined for a 6-week period during which their adaptation to seawater was studied. Mortalities occurred in all treatments, but in PCB-injected and fuel oil-exposed fish mortalities were greater. The authors concluded that tissue accumulation of PCB's, at concentrations that clearly could be derived through a contaminated diet or from water column exposure, delayed events preparatory to, and involved with, salt-water adaptation in coho salmon. The authors speculate that under natural conditions, additional mortalities may occur due to, for example, PCB- and/or fuel oil-induced behavioural and physiological alterations which could be reflected in an inability to escape predation or to capture prey.

Behavior

Folmar and Hodgins (1982) and Folmar et al. (1981) studied the effects of arochlor 1254 and No. 2 fuel oil, and Cook Inlet crude, oil (water-soluble fraction) respectively, on the predatory behaviour of coho salmon. Folmar and Hodgins (1982) investigated the predation of coho salmon on rainbow trout. Exposure to PCB and No. 2 fuel oil significantly impaired the capture of prey by the coho salmon predators. Similarly, Folmar et al. (1981) found that the water-soluble fraction of Cook Inlet crude oil ($343 \pm 93\ \mu g \cdot L^{-1}$) could significantly impair the capturing of prey by coho salmon, especially after a 10-d exposure. The authors consider that the cessation of feeding may have been associated with the metabolic products rather than the parent compound (a contrast with the findings of some other authors).

The topic of avoidance of oil by salmonids has received attention in recent years. Rice (1983) mentions that salmonids have the ability to detect and move away from oil polluted waters. A statement based primarily upon laboratory-derived data. However, as Rice points out, unmotivated salmonid behaviour in the laboratory may not reflect motivated salmonid behaviour in the wild. Salmon may be motivated to migrate through, and feed in, oil polluted areas, or, if the level of oil contamination is too great, they may move away or even succumb to the toxicant. There is some information that tends to reinforce these comments.

Morrow (1973) observed that juvenile coho salmon would swim in a surface film of oil and, similarly, so would chinook salmon (Bean et al. 1974). Juvenile coho did not avoid fresh Prudhoe Bay crude oil either on the water surface or dispersed in the water column (Maynard, 1980). In laboratory bioassays we have seen chum salmon take oil into their mouths from the surface of the test waters (unpublished information). There is also evidence from research with other pollutants that has shown a "non-avoidance" of potentially hazardous water quality conditions e.g. Sprague and Drury (1969) - rainbow trout and phenol; Birtwell and Harbo (1980) - juvenile salmon and pulpmill effluent in the field. Most recently Maynard and Weber (1981) reported their results on the avoidance of juvenile coho salmon exposed for 60 min to monocyclic aromatic hydrocarbons. In January and February coho did not avoid $2.8\ mg \cdot L^{-1}$, but 4 months later they did so. The 96h LC50 for the mixture was $3.6\ mg \cdot L^{-1}$ at 8°C. The conclusion was that whereas juvenile salmon would avoid individual components of the mixture, there was some question as to whether they would avoid toxic concentrations of these compounds found in the water-soluble fraction of crude oil.

Studies on the behaviour of adult salmon have been carried out by Weber et al. (1981) and Nagatani et al. (1983). Weber et al. investigated the behaviour of migrating adult salmon (99% coho, 1% pink, chum and chinook) ascending a fish ladder. A mixture of hydrocarbons was made to represent the water-soluble fraction of Prudhoe Bay crude oil. At $3.2\ mg \cdot L^{-1}$ 50% of the migrating adults avoided a ladder over which oil contaminated waters flowed. There was avoidance at $<1\ mg \cdot L^{-1}$ and about 40% avoidance at $1.5\ mg \cdot L^{-1}$. In the other study, Nagatani et al. (1983) exposed adult chinook salmon to either Prudhoe Bay crude oil ($0.18\ mg \cdot L^{-1}$), dispersed oil ($21\ mg \cdot L^{-1}$) or a dispersant, for 1 h. The fish were then tagged, and released 5 km downstream. Over a 13 d period fewer fish returned (72%) but 48% were recovered in 48 h. Afterwards, control groups tended to live longer than those fish which had experienced dispersed oil. No effects on the olfactory organs were seen upon histological analysis. Thus brief exposure of the adult salmon to hydrocarbons did not deter the majority of the test fish from migrating. It is of concern, however, that almost 30% of the fish did not return over the 13-d period, despite the short distance (5 km) they had to travel upstream.

Summary and general comments

It is apparent from the literature that spilled oil can have a detrimental effect on salmon at many stages in their life history. Although eggs were found to be more resistant than fry, the likelihood of oil contamination of eggs in the brackish water - marine environment, but for a few populations, is low. However, at the time of entry to seawater juvenile salmon were found to be sensitive to oil. The ability of the fish to osmoregulate in salt water was impaired and this is an essential process for survival in salt water. The additional complexity caused by natural factors and other pollutants may only serve to heighten the concern in estuarine areas near population centres.

Growth was found to be affected by exposure to oil, and a change in this aspect could be detrimental to survival (reduced avoidance of predators, competition for food increased, etc.).

Effects were also found on the behavior of salmon ranging from no avoidance of oil on the surface of test waters to an avoidance response by migrating adults. Behavioral changes could be extremely detrimental to juvenile salmon in particular. An apparent obligatory residence in shallow estuarine and nearshore coastal waters occurs. It is assumed that in the event of an oil spill, this behavioural trait will continue or perhaps avoidance may occur. While avoidance may be considered to be advantageous to the individual faced with an adverse situation, it is probably of short-term benefit. If avoidance results in a disruption of, for example, schooling behaviour, the premature occupation of a different depth or more saline waters, the long-term effect could be detrimental. Increased predation and osmoregulatory stress induced by higher salinity waters could affect survival. In addition, there is no guarantee that adequate food reserves or suitable habitat will be found in alternative areas to which the fish have moved.

Clearly, whether salmonids stay in an oiled environment, or avoid oil, the net effect would appear to be detrimental. The severity of the consequences of exposure will, however, depend upon many factors, and while juvenile salmon will be particularly vulnerable in the spring and early summer, adults will also be vulnerable during their return to freshwater spawning areas.

EFFECTS OF HYDROCARBONS ON INVERTEBRATES

Invertebrates are an important group in marine ecosystems which include all shellfish species (e.g. crabs, shrimp, clams), zooplankton and many benthic (bottom dwelling) species. Part of the life cycle of many invertebrate species is spent in the water column where they comprise a temporary plankton community (meroplankton). At the end of the pelagic phase, invertebrate larvae settle onto hard or soft bottom substrates where they grow from juvenile to adult form. At one or more stages of their life history most invertebrates are important as food items in the diets of other species, particularly fish. The relative importance of different

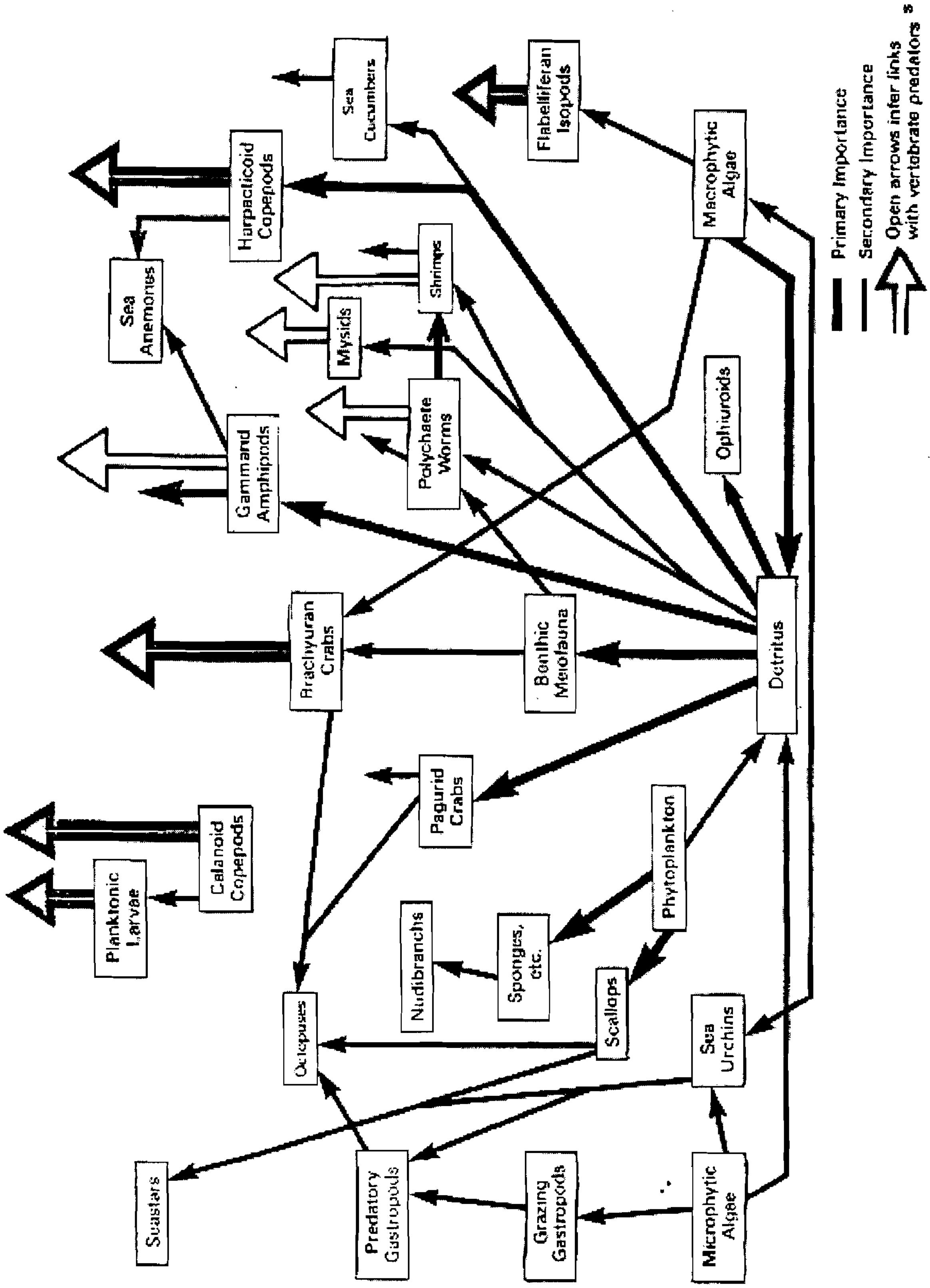

Figure 1 - Composite invertebrate food web for a shallow subtidal bedrock environment (from Petro-Canada IEE, 1982)

invertebrate species in a typical invertebrate food web are shown in Figure 1. Species shown which serve as food for other invertebrates and vertebrate predators such as juvenile and adult fish, include planktonic larvae, copepods, amphipods, shrimp, mysids and polychaete worms. Benthic invertebrates are important food items for many harvested shellfish species such as crabs and shrimp.

Figure 1 illustrates the complex network of interactions, which make up a marine ecosystem. At each level of the food web one or more species may be highly important to the diet of a particular resource species. In addition, the same species and others may be important in the diets of non-resource species that in turn may play key roles in maintaining a stable balance in the ecosystem.

In addressing the impacts of oil on the supporting food web of salmon, herring, groundfish and shellfish, we have discussed effects on 5 key invertebrate components: zooplankton, crabs, shrimp, bivalve molluscs and benthic communities. These components were considered to represent the most important food items for harvestable resources, especially for juvenile and adult fishes. During our review we also found that the most of the recent data on impacts from spilled oil was available for these groups. Although marine plants and algae are also part of the marine ecosystem, recent evidence suggests that these species do not suffer long term effects from spilled oil. In a study of the impacts of the *Amoco Cadiz* spill on an eelgrass (*Zostera marina* L.) community, Jacobs (1983) reported only localized effects on the plants lasting for a few weeks. Direct effects included plants with black 'burnt' leaves. However, this phenomenon was temporary and production of new leaf tissue was not interrupted. More serious impacts were observed on benthic invertebrates associated with the eelgrass community. One of the invertebrate groups affected (harpacticoid copecods) has been shown to be an important food item for juvenile salmon in British Columbia estuaries (e.g. Sibert, 1979).

The potential impacts of oil contamination from a spill on invertebrate resource species and their supporting food webs will depend to a large extent on the proportion of submerged oil present. Of particular interest is that fraction of oil, which is likely to contaminate bottom sediments. Sediment-associated oil from major spills has been shown to persist in the marine environment for many years, and can be re-released in potentially toxic concentrations (Seip, 1984; Vandermeulen et al. 1978). This situation is in contrast to spilled oil in surface waters which tends to dissipate or is readily removed through evaporation.

EFFECTS OF OIL SPILLS: AN UPDATED APPRAISAL

Zooplankton

Information on impacts of oil to zooplankton have been derived from three major sources: laboratory experiments, enclosed (experimental) ecosystems, and field monitoring of areas impacted by oil spills. Generally, a wide range of toxicity values have been reported for various crude oils in laboratory toxicity bioassays (see Table 1). Sublethal studies have indicated that hydrocarbons can damage development, and alter the behaviour and physiology of zooplankton species (Davenport, 1982) However, many laboratory experiments have used concentrations of oil which are considerably higher than those measured in the field.

In situ experiments using non-permeable or semi-permeable enclosures have been used to test the effects of low hydrocarbon concentrations on simulated marine ecosystems. Testing with relatively low concentrations (less than 40 $ng \cdot g^{-1}$) of hydrocarbons has stimulated growth in populations of microflagellates and small zooplankton species, while at higher concentrations (100 $ng \cdot g^{-1}$) copepod and other larger zooplankton populations have collapsed (Davenport, 1982).

The true test of the applicability of the experimentally derived data on oil effects is whether similar results are observed in the field after an accidental spill. After reviewing the results from a number of oil spill monitoring programs, Davenport (1982) concluded that no lasting damage to planktonic ecosystems caused by oil had been demonstrated. Biological monitoring had revealed trends of increased numbers of marine bacteria, temporary reductions in zooplankton densities, and increased phytoplankton production which was considered to be a response to the decrease in zooplankton predators.

Table 1 - Summary of median lethal concentrations of petroleum oils and zooplankton found in Canadian marine waters. All concentrations are in $mg \cdot L^{-1}$ oil measured in the water (from Wells, 1982).

Groups of Zooplankton	Type of Petroleum Oil ((No. of days) LC 50's)		
	Crude Oils	No. 2 Fuel Oils	No. 4 Fuel Oils
Ctenophores		(1 d) 0.59	
Molluscs			
Clams (embryos)	(2 d) 0.23 - 12		
(larvae)	(10 d) 0.05 – 2.1		
Crustacea			
Copecods (larvae and adults)	0.05 - 100		
(adults)		(4 d) 1-3	
Amphipods (larvae)	(2 d) 0.8	(2 d) 0.3	(2 d) ~6.2
Mysids (juveniles)			
Decapods			
shrimp (larvae and adults)	(4 d) 0.5 – 7.9		
lobster (larvae)	(4 d) 1.4		
	(30 d) 0.14		
crabs (larvae)	(4 d) <5		
Teleosts (eggs)	(4 d) 1-10		
		(4 d) 0.18 – 0.36	
(larvae)	(4 d) 3-12		

Detailed review of individual spills confirm these general conclusions. Studies on the *Tsesis* oil spill (Johansson et al. 1980) found effects on zooplankton communities were minor and short-lived, lasting less than 1 month. Reductions in zooplankton biomass (*Acartia* spp., *Eurytemora* sp., *Temora longicornis*) were measured in the immediate vicinity of the spill, but biomass levels had been reestablished within 5 days. No changes in the taxonomic composition or age structure of the copepod populations were found. Oil contamination of zooplankton was recorded up to 3 weeks after the spill. Peak hydrocarbon concentrations 5 km from the site of the *Tsesis* spill were 50-60 $ng \cdot g^{-1}$. Nearer the wreck, levels were in the order of 250 $ng \cdot g^{-1}$. Similar responses were described by Cabioch (1981) at the site of the *Amoco Cadiz* spill off the Brittany coast, one of the most extensively studied. High mortalities in zooplankton were observed up to 15 days after the spill. Elevated concentrations of aromatic hydrocarbons were recorded in copepods up to 100 km from the wreck (Mackie et al. 1978 cited in Davenport, 1982). Initially, a general decrease in biomass was measured but no differences in post-zooplankton biomass or composition could be detected between affected and offshore control areas after one month. Some inshore estuarine areas were affected for several months. Of interest were reports of continuing effects on some pelagic organisms up to one year later due to the periodic release of oil from contaminated sediments by winter storms.

Thus, no evidence has been gathered from previous spills to indicate any long-term impacts to the planktonic ecosystem. However, natural variability in planktonic ecosystems is high and may help to mask more subtle effects. One alternative approach is to assess the 'health' of the planktonic ecosystem through measurement of certain biochemical indices. Samain et al. (1980) determined concentrations and ratios of amylase and trypsin for whole zooplankton samples after the *Amoco Cadiz* spill. The authors found depressed amylase and trypsin concentrations from inshore zooplankton populations several months after the spill. Concentrations of amylase and trypsin give information about the physiological state of the organisms while ratios between the enzymes give data about the general tendency of zooplankton populations towards a herbivorous, omnivorous or carnivorous diet. This information can be used to assess changes in trophic relationships within the zooplankton food chain.

Crabs

A general overview of the toxicity of oil to crab larvae is provided by Wells (1982). In most studies, the 96-h LC50 for oil was between 2 - 5 $mg \cdot L^{-1}$. Early larval stages were shown to be more sensitive than later stages. Sublethal effects measured include slowed rates of development and growth inhibition (0.3 - 1.5 $mg \cdot L^{-1}$), delay in molting (0.6 $mg \cdot L^{-1}$), and reduced success in molting after pre-exposure to oil (1.1 - 1.9 $mg \cdot L^{-1}$) for 24 h (Wells, 1982). Larvae of *Cancer* sp. did not avoid swimming into surface slicks of crude oil when given the opportunity (Rice et al. 1976 cited in Wells, 1982). No studies were found on development of brachyuran larvae from oil-exposed eggs, or on the ability of megalops larvae to settle on oil-contaminated sediments.

Extrapolation of laboratory-derived toxicity data to the field is difficult, and cannot replace data gathered through properly conducted monitoring programs. Long-term studies on crab populations have been conducted at the sites of several major oil spills, and their results are summarized in Table 2. Krebs and Burns (1978) observed reduced density and difficulties in reproduction and recruitment in a crab population within an oil contaminated salt marsh environment. Recovery had begun but was not yet complete after 7 years. An intensive investigation on the effects of spilled oil on crab populations was conducted at the site of the *Amoco Cadiz* spill. Maurin (1981) reported no mortality in adults were observed immediately after the spill. A few individuals (5%) had elevated levels of hydrocarbons in the liver. Continued monitoring found few effects up to two months after the spill. However, subsequent analysis of catch statistics showed decreases in edible and spider crab catches over a one year period. In the subsequent year, catches increased but a smaller percentage of females was present, a fact which could affect recruitment for 4 - 5 years.

In a report on the ecological impacts of the *Amoco Cadiz* spill, Glemarec (1981) found that in a number of species (including crab populations) there was a succession or replacement of the pre-spill species present with different populations. With respect to crabs he says, "...the secondary series (species) allow proliferation of banal type species. The best illustration of this is the green crab (*Carcinus maenas*) whose spats are found in profusion, and which thus replaces nobler species such as the swimming crab (*Portunus puber*) or the edible crab (*Cancer pagurus*)". Although the exact mechanism related to oil, which causes the impacts, has not been identified, crab populations appear to be particularly sensitive to spilled oil. The impact is not short-term, but one of long duration affecting the recruitment capability of the population.

<u>Shrimps and prawns</u>

Studies with larvae and adult shrimp of *Pandalus* and *Eualus* spp. have shown both stages to be equally sensitive (Wells, 1982). Toxicity values range from 0.5 - 7.9 $mg \cdot L^{-1}$ (Table 1). Shrimp are also susceptible to narcosis prior to complete immobilization and death. Larvae of *Pandalus platyceros* were killed in 24 to 36 h after exposure to 0.008 - 0.012 $mg \cdot L^{-1}$ naphthalene (Sandborn and Malins, *1977)*. Wells (1982) reported that shrimp larvae were particularly sensitive to some oil/dispersant (*Corexit* 7664) mixtures (ILL 0.36 $mg \cdot L^{-1}$).

Compared to other crustacean species, relatively little work has been done on shrimps. We found no information on the impacts of spilled oil on commercial shrimp populations from field monitoring programs. The sensitivity of different life history stages of shrimp and implications of bioaccumulation by shrimp of petroleum hydrocarbons require further research.

<u>Bivalves</u> (clams, mussels, oysters)

A number of toxicity studies have been carried out on exposure of oil to eggs and larvae of bivalve molluscs, particularly clams, mussels and oysters (e.g. Byrne and Calder, 1977). The relative toxicity of oils in acute and chronic (10 day) bioassays is shown in Table 1.

Dispersed oil, crude oil and water soluble fractions have been shown to have strong effects on fertilization, but embryonic development and larval survival are generally affected only at nominal concentrations exceeding 10 $mg \cdot L^{-1}$ (Wells, 1982). Threshold concentrations for embryos and larvae have been derived for only a few Canadian species (Wells, 1982).

Maurin (1981) reported a 20% to 50% mortality in commercial oysters and mussels affected as an immediate result of the *Amoco Cadiz* spill. Contamination of tissues with hydrocarbons remained for up to 1 year after the spill. Histopathological lesions in tissue were also noted but their implications with respect to the population or its commercial value were not discussed. The conclusion reached was that the medium and long term damage were of greater concern than the immediate losses. No information was found on the effects of oil on the reproductive or recruitment capabilities of bivalve populations, and this appears to be an area that requires more study.

Benthic communities

Review of the more recently published literature shows that new information is available on long term impacts of spilled oil (e.g. Seip, 1984; Elmgren et al. 1984). Increasing evidence of long term impacts are being identified due to the continued study of major spills which occurred some years ago (e.g. *Tsesis* (1977), *Amoco Cadiz* (1978)). Results of new techniques for studying effects of spilled oil on benthic communities such as the use of experimental spills have also appeared (Englehardt et al. 1984; Clifton et al. 1984).

Some recent findings regarding long-term impacts of oil spills are given in Table 2. Changes in the diversity and numbers of benthic invertebrates are common impacts at many sites. Some animal populations which appear to be particularly sensitive to spilled oil include amphipod crustaceans which have disappeared entirely from areas impacted by oil, and have not returned even after 6 years (Elmgren et al. 1983). Amphipods are an important group in the waters of the Pacific Northwest as they are a preferred food item for juvenile salmonids in near shore environments. In addition to amphipods, recolonization of other populations of benthic invertebrates (e.g. polychaete worms, harpacticoid copepods) have been shown to be adversely affected by oil for long periods of time (Table 2).

The significant feature of the studies cited in Table 2 is that local impacts of spilled oil can affect biological populations and communities for many years. These results suggest that, in addition to short-term effects, spilled oil has impaired the ability of the organisms to recover to their natural (i.e. pre-spill) state. It should also be noted that, for many of the time periods cited in Table 2, the communities had not yet fully recovered, and the length of time given was a function of the length of the specific scientific study. The impacts observed are an integration of responses from a variety of toxic effects of oil on individual organisms. The toxic effects can result in death of the organism (lethal effect) or can impair its behaviour or biochemistry and therefore its ability to reproduce, move, feed, etc. (sublethal effect). An extensive database on the toxic effects of oil on individual organisms exists from the results of field and laboratory toxicity studies. These individual studies have been reviewed elsewhere (e.g. Percy, 1982; Malins, 1977).

Table 2 - Long Term Effects of Oil Spills on Marine Communities

Spill	Location	Time of Year	Effects Reported	Years Since Spill	References
Amoco Cadiz	Brittany	March	Elevated concentrations of oil in oysters	3	Seip, 1984
			Reduced yield in marsh vegetation	3	Gundlach et al. 1983
			Changes in species distribution	5	Vandermeulen et al. 1979
			Changes in biomass for different spp.		
			8% of oil deposited in subtidal sediments		
			Increased toxicity of artificially weathered (steam/air), stranded oil to marine algae		
			Re-release of oil from sediments during storms		
			Delayed effects on mortality, growth and recruitment of amphipods, flatfish, clams, meiofauna	3	Conan, 1982
			Complete destruction of amphipod sp. (*Aaipelisca*) population	3	Cabioch, 1981
			Replacement of long-lived species with species having short life cycles	3	Glemarec, 1981
			Reduced reproduction in female crabs	3	Maurin, 1981
			Displacement of dominant crab sp.		
Arrow	Chedabucto Bay	February	Retarded shell growth in clams	5	MacDonald and Thomas, 1982
Eleni	Norfolk Coast	May	Elevated hydrocarbon concentrations in mussel fish	1	Blackman and Law, 1980
Florida	West Falmouth	September	Reduced density, reproduction and recruitment of salt marsh crab population	7	Krebs and Burns, 1978

Table 2 Cont.

Spill	Location	Time of Year	Effects Reported	Years Since Spill	References
Tsesis	Baltic Sea	October	10% -15% of unrecovered oil incorporated into bottom sediments	6	Johansson et al. 1980
			Bioaccumulation of hydrocarbons in bivalves		Elmgren et al. 1981
			Severe ecological effects on soft bottom communities		Elmgren et al. 1983
			Reduced population amphipod sp. (*Pontoporeia*)		
			Species displacement		
Torrey Canyon	English Channel	March	Continued community perturbations during recovery process	10	Southward and Southward, 1978
Experimental	Willapa Bay	July	Invertebrate burrowing distributed oil into sub-surface sediments	2	Clifton et al. 1984
			Buried oil layers reduced infaunal burrowing		
MERL Experimental	Narragansett Bay	November	Highly significant declines in number of macrofauna and meiofauna individuals	6 mo.	Grassle et al. 1981
Experimental	Spitsbergen	July	No significant recolonization by microfauna (arthropods) at oiled sites	7	Sendstad, 1984
Diesel Oil	Spitsbergen	Not given	Disappearance of the amphipod *Gammarus setosus*	2	Gulliksen and Taasen, 1982
Motif	Wadden Sea	October	Altered species composition	7 mo.	Kuiper et al. 1984
			Mass mortality in cockles	3 mo.	
			Inhibition of reproduction	7 mo.	
			Changes in biomass	7 mo.	

IMPLICATIONS OF SPILLED OIL ON WEST COAST RESOURCE FOOD WEBS

From the recent studies summarized above, it appears clear that spilled oil can have long-term impacts on vulnerable components of marine food webs. The elimination of a year-class of a particular resource species by spilled oil and the prevention of new recruitment over several succeeding years could have serious implications for a local population. Examples of key fish food organisms which have been shown to be affected include, amphipods, polychaete worms, and meiofauna (e.g. harpacticoid copecods). These organisms play important roles in the diets of juvenile salmon and herring in coastal areas of the West Coast, and in the diets of groundfish, shrimp and crabs. The general relationship between these species and their predators is shown in Figure 1. Crustaceans (e.g. crabs, shrimp, amphipods) have been shown to be especially sensitive to oil and recovery from a spill may take many years. These organisms would be expected to be some of the most vulnerable to the effects of spilled oil on the West Coast.

However, an attempt to predict the consequences of impacts of spilled oil to one or more specific components of a resource food web is difficult for two main reasons. One constraint is related to biology. Marine food webs are inherently complex. Many major West Coast resource food webs encompass both benthic and pelagic ecosystems. The relationships in a typical West Coast food web shown in Figure 1 are essentially qualitative and are of limited use in predicting potential impacts from oil. Quantitative biological data on productivity, rates of recruitment, etc., must be developed before the existing information can be used for predictive purposes. In addition, food webs such as that in Figure 1 are generalized representations and more complete knowledge of species inter-relationships (e.g. predator/prey interactions) is required. Such information is essential in order to assess the ecological significance of experimentally derived data on oil toxicity. Furthermore, the toxicity of oil and oil/dispersant mixtures has been determined for only a few West Coast species of fish and invertebrates. Additional toxicity data for a wide range of harvestable and ecologically important West Coast species is required.

From studies in other parts of the world which have been subject to oil spills, recovery of marine communities has taken several years. It is generally recognized that recovery of marine communities takes much longer in colder environments than in warmer seas (Sprague et al. 1982; Waldichuk, 1980). Direct evidence of the long-term recovery period required by sensitive West Coast estuarine areas from man-made impacts has recently been demonstrated. McGreer et al. (1984) investigated the recovery of intertidal estuarine benthos from impacts of log boom storage and found that recovery had not begun 13 months after the source of the impact was removed. Thus, an oil spill on the West Coast could seriously disrupt natural food webs for a period of years. However, it is not possible to predict the consequences of such impacts on a specific resource due to our limited understanding of the workings of natural ecosystems.

A second major constraint is the ability to predict or anticipate key factors about an oil spill which would assist in predicting biological impacts. Such factors include the type, volume, timing of release (season), dispersal characteristics and duration of spilled oil, in addition to weather conditions at the time of the spill. It is, by the accidental nature of these incidents, impossible to have advanced knowledge of these factors in order to assess which sensitive habitats might be affected. That no two spills behave alike, even in similar marine environments, has become axiomatic among those studying the fate and effects of oil (Vandermeulen, 1982). However, it is generally recognized that spills occurring in spring or summer during breeding and early juvenile life stages of marine organisms have the most potential for impacting these populations. Therefore, a more complete knowledge about impacts under a variety of spill conditions is required. From information provided in the Chevron Canada Resources Ltd. IEE (1982) on one possible 'worst case' oil spill scenario, greater than 50% of the spilled oil is expected to sink into the water column, and possibly become adsorbed onto bottom sediments. If one accepts the assumptions in this model, the projected, potential area influenced by sub-surface spilled oil covers a wide area of the coast encompassing a number of sensitive habitats (see Figure 2).

CRITICAL SPECIES IN THE FOOD WEB OF MARINE MAMMALS

Petro-Canada Inc. (1983) show a generalized framework for the marine food web (Figures 5.21 and 5.22). Of special interest is herring, an important prey item in the food web that supports marine mammals. This species comprises part of the diet for northern fur seals, harbour seals, California sea lions, Steller sea lions, humpback whales, minke whales, Dall's porpoises, harbour porpoises and perhaps other toothed cetaceans which have not been studied extensively. Herring spawn, which is deposited in tidal areas, is vulnerable to contamination from oil and other materials.

The gray whale is unlike other cetaceans in that the species feed primarily on benthic and epibenthic organisms in shallow, nearshore waters. Principal prey species in British Columbia and elsewhere in the species range are amphipods and mysids (Murison et al. 1984; Oliver et al. 1984). These prey species could be eliminated should oil sink out of the water column and cover the bottom sediments. Gray whales would suffer directly by such a loss of food organisms, and might also ingest oil directly from the sediments. About 100-200 gray whales inhabit British Columbia waters.

INFORMATION/RESEARCH DEFICIENCIES

Our ability to predict impacts of spilled oil on marine food webs and recommend appropriate counter-measures can be improved with additional knowledge gained through properly designed studies. A number of recurring recommendations appeared in the literature on oil impacts reviewed and are summarized below. Of particular relevance is a recent document *entitled "Oil and Dispersants in Canadian Seas - Research Appraisal and Recommendations"*, (Sprague et al. 1982).

Improved understanding of natural ecosystems

Much of the inability to explain effects or predict impacts of oil spills is due to an incomplete understanding of the natural processes within marine ecosystems. Very little is known about effects of oil on marine bacteria, which are important in the breakdown of detrital

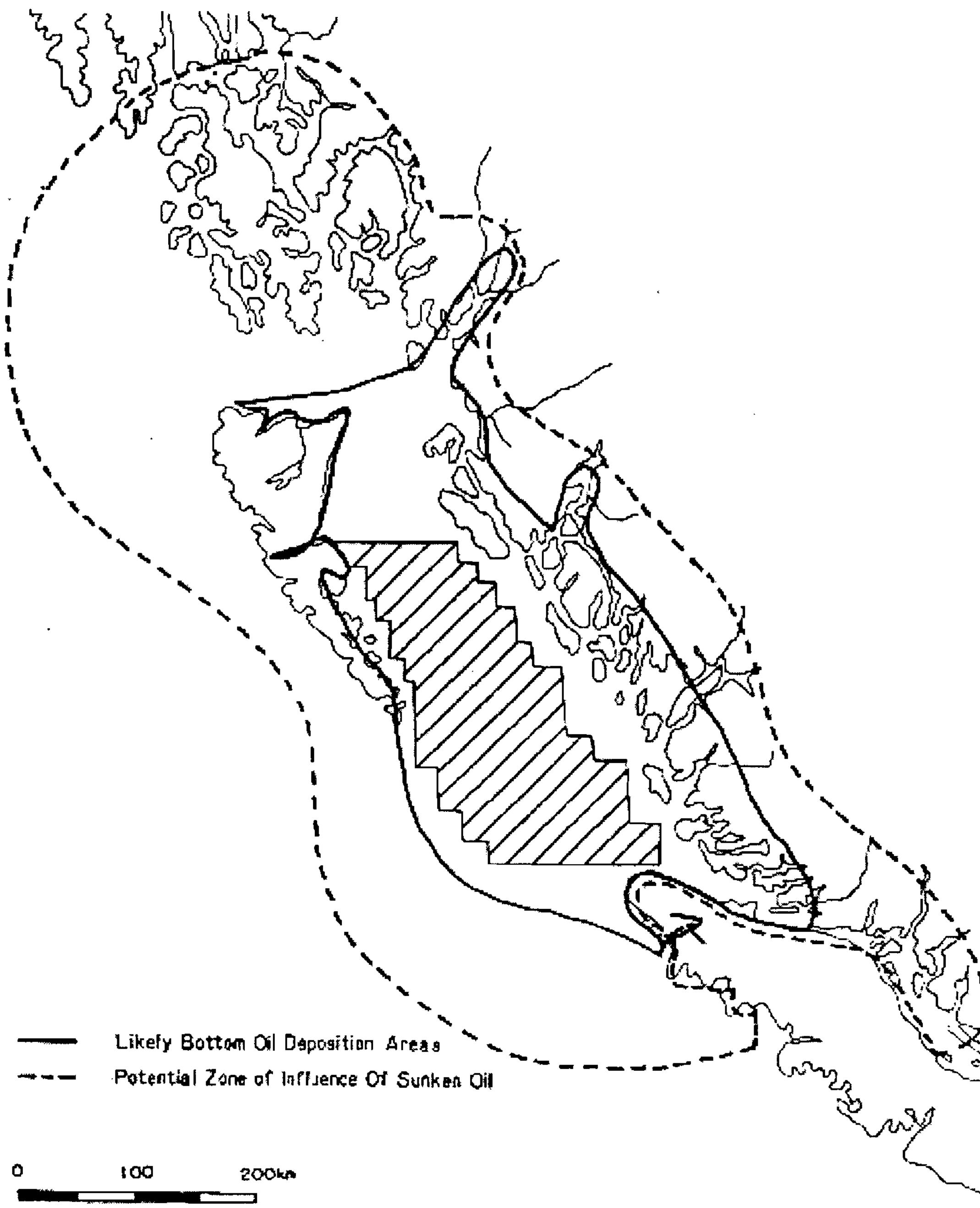

Figure 2 - Zone of potential subsurface influence of spilled oil from the Chevron lease area 60 days after initial release (adapted from Chevron IEE, 1982).

material - a basis for many marine benthic food webs. More knowledge of natural cycles and the factors influencing them are required. Although studies of whole ecosystems are desirable, it may be more practical to focus individual studies on support systems for a single resource species (e.g. crabs or prawns). Studies should be designed to gather quantitative data which can be used in predictive models.

Field-oriented ecotoxicological studies

A substantial amount of work has been carried out on the lethal and sublethal effects of oil, but most work has been the result of laboratory studies on single species. There is a need to expand toxicological testing from the laboratory to the field in order to assess the impacts on ecosystems of concern. Field-oriented, ecotoxicological studies are essential to evaluate the significance of toxic effects derived in laboratory studies to natural resource food webs. The use of experimental oil spills (1-15 m^3) is a promising area to address many of the unanswered questions on the consequences of spilled oil in the marine environment. Guidelines for conducting such studies in Canadian waters have been recommended (Sprague et al. 1982).

Sublethal effects studies

Laboratory studies should emphasize sublethal effects on marine organisms (e.g. effects on growth, reproduction, recruitment, behaviour) using concentrations and exposures similar to those found in the natural environment after a spill. There is a need to expand single species testing to multi-species or communities (i.e. studies using microcosms). Emphasis should be given to developing test responses that can be evaluated under field conditions. Results of laboratory studies should be amendable to verification by experimental or accidental spilled oil impact monitoring programs.

Effects of oil and dispersed oil mixtures on vulnerable biota and evaluation of countermeasures

Relative to the amount of information on the toxic effects of spilled oil, there is very little information on the fate and effects of oil/dispersant mixtures on marine species in West Coast (and other Canadian) waters. Vulnerable habitats include estuaries, salt marshes, fjords, and shallow subtidal coastal areas. In addition, the effectiveness and potential impacts of physical and chemical clean-up techniques should be assessed for biota in vulnerable habitats. Countermeasures for a range of habitats and circumstances are required so that appropriate information can be forwarded to an on-site spill coordinator at the time of a spill (Owens and Robilliard, 1981).

OIL WELL BLOW-OUT SCENARIOS AND RELATED CONCERNS

DFO, in its previous submissions to the West Coast Offshore Oil and Gas Exploration Environmental Assessment Panel, identified its concerns about oil spills, the basis for the concerns, and its resulting positions. Here, we summarize and clarify the basis for our spill concerns.

During the hearings, the Panel heard much about windstorms and high waves, as they pertain to drill rig safety, safety for personnel, expensive structures, and implications for well control and possible spills.

The concerns are shared by the Panel, the proponents, the regulators, various government agencies, and, apparently, most interveners and interest groups. They focus on, not average conditions, but on relatively low frequency, "maximum probable" events, with return periods of, say, 10 to 100 years. We are not aware of any objections to this type of consideration of events having potential implications for various types of safety. For example, with respect to weather, i.e. storm prediction, Chevron has stated unequivocally that if government cannot provide the required service, the proponent will. This is only one example of a concern for extremes rather than averages, from the many submitted.

Another example is in routine reporting of wave data. In addition to mean wave heights, significant wave heights (highest one third of the waves in the record) and maximum heights are treated in detail in submissions to the Panel. This type of approach seems to be accepted as objective, realistic and prudent, with respect to rig safety, and all that this implies.

DFO feels that a similar approach is required with regards to assessment of potential impacts of spills of oil on fisheries resources, even though present experience and data does not allow a formal method of doing so at present.

OIL SPILL PROBABILITY AND NUMBERS OF WELLS DRILLED

Given the uncertainties about geological structure and the occurrence of oil in the lease area, oil spill probabilities must also be uncertain. This uncertainty is in addition to that in existing estimates of spill probabilities. The "Additional Information Response" (to the Panels' Question 75), given by COGLA, February 1985, presents analyses suggesting that the probability of a significant oil spill from a single exploratory well is about 0.00014. Others, citing comments by C. Hatfield (Technical Expert to the Panel), believe that this estimate is too optimistic (Delkatla Wildlife Sanctuary Committee Presentation to the West Coast Panel, October 1, 1985).

DFO will not debate estimates of actual values of spill probability (per single well) to be expected. However, the focus, to date, on the probability of a spill from a single well may be a necessary but insufficient step in assessing potential risks. Regardless of the Panel's terms of reference, DFO must look beyond the initial two or three exploratory wells proposed by Chevron and recognize that if the early results are promising, many exploratory wells could be drilled. As the expected number of wells increases, spill probability will also increase. Further, the fact that more than one spill is possible must be taken into account in assessing risks and potential threats. While it is not possible to predict the expected number of exploratory wells, it could be substantial. The COGLA response to the Panel's Additional Information Question 75 indicates that 4,175 exploratory wells were drilled in the Norwegian offshore in the years 1976 to 1980. If this level of drilling is a possibility, clearly, the focus on single well risks is inappropriate.

It is possible to estimate the way in which the probability of one or more spills, P, changes with the expected number of wells drilled, given the probability, p, of a spill from a single well, assuming that the additional wells do not affect the value of p. It is similarly possible to estimate the expected number of wells yielding a specified chance of one or more spills given a value for p, on the same assumption (the assumption may be only partially tenable). It may be true that one well can have no effect on the probability of a spill from another well. However, increased exploration might imply evidence that estimates of the probability of finding hydrocarbons, and thus of spilling them, have increased. Conversely, drilling improves geological knowledge, possibly making problems more predictable and therefore preventable, barring the human factor, which is a significant element in accidents. However, it is assumed below that p is independent).

The number, N, of wells yielding the probability, P, of one or more spills given the probability, p, of a spill from one well is given by:

$$N = \frac{\log(1-P)}{\log(1-p)}$$

Results from the expression are shown in Table 3, in which the expected numbers of wells yielding 10, 25, and a 50% chance of one or more spills are given for a range of values for the probability of a spill from a single well. The results indicate that as p increases, the expected number of wells required to produce a given level of risk decreases markedly. Thus, a single uncertain value for p can imply a considerable range in the possible degree of threat.

Table 3. Number of wells yielding 10%, 25% and 50% chance of one or more spills, given various probabilities of a spill from one well.

Chance of one or more spills =		*10%*	*25%*	*50%*
Spill probability, one well =	.00010	1,054	2,877	6,931
	.00025	421	1,151	2,772
	.00050	211	575	1,386
	.00100	105	286	693
	.00250	42	115	277
	.00500	21	57	138

A re-arrangement of the above expression gives the probability of one or more spills for given values of the number of wells drilled, and of the probability of a spill from a single well:

$$P = 1-(1-p)^N,$$

where the symbols are as above. Results are given in Table 4 for different values of the expected numbers of wells drilled and of the probability of a spill from a single well. The table demonstrates that for a given level of p, the probability of one or more spills rises markedly with the expected number of wells. Thus, with a one in a thousand chance (p = 0.001) of a spill from one well the risk of one or more spills rises to over 60% if 1,000 wells are expected.

Table 4. Probability of one or more spills for different numbers of well, given probabilities of a spill from a single well.

Number of wells =	*1*	*10*	*100*	*500*	*1000*	*4000*
		Probability of one or more spills				
	.00010	.01000	.00995	.04877	.09517	.32969
	.00025	.00250	.02469	.11752	.22122	.63217
	.00050	.00499	.04878	.22125	.34355	.86473
	.00100	.00996	.09521	.39362	.63230	.98172
	.00250	.02472	.22144	.22144	.71394	.99996
	.00500	.04889	.39423	.91843	.99335	.99999

DFO recognizes the incremental aspect of expanded exploratory drilling. Thus in the above example, if 999 wells have been drilled without a spill the chance of a spill for the next well drilled would still be one in a thousand, not 0.623. Nonetheless, the above examples serve to illustrate our concern, that as the expected number of wells increases, the risk can rise to substantial levels, given the pace of exploration observed in other areas.

Further discussion of probabilities is warranted, in support of DFO concerns:

1. The probability of a major oil blowout from a single well may be quite low, although this seems uncertain. However, as illustrated above, the probability of one or more spills can become substantial with increases in the expected numbers of wells to be drilled.

2. *In the event of a major oil spill*, fisheries damage could range from minor to extremely serious, depending on the circumstances. Given the characteristics of the proposed exploration area and its fisheries resources, the probability of significant or worse damage seems unlikely to be low, for reasons given elsewhere by DFO. Speculatively, the probability of significant to severe impacts on fisheries resources might fall between 0.25 and 0.50, in the event of a major oil blowout.

3. The probability of significant or worse damage to fisheries is the product of the probability of a serious spill and the probability of damage to the resource in the event of such a spill, and is lower than either of the component values. If the probability of a serious spill for an expected 1,000 wells is say, 0.20 (see Table 4) and the probability of damage in the event of a spill is say, 0.25, the overall probability of significant or worse fisheries damage is 0.05. This estimate is a minimum, because more than one spill could occur. The full value could be estimated, but the example serves for purposes of illustration of our contention that single well spill probability estimates can be highly misleading.

Depending on the actual probabilities, and the expected number of exploratory wells, the fisheries damage probability could be either higher or lower than in the example given. However, even if lower, its value would have to be examined in the context of accepted attitudes and practices concerning risks in general.

Governments, industries, businesses, and the public at large accept the need for substantial efforts and expenditures for various forms of protection against threats having low probabilities in commonly accepted time scales. Serious flooding is infrequent, but dikes and other forms of expensive protection are widespread. Major earthquakes in particular areas, even in our high-risk zone, are rare, but they are taken into account in building codes at considerable expense. Most physical structures, including drill rigs, are built with engineering safety factors - using some multiple of probable extreme loads, again at substantial cost. Other examples could be given, including some from transportation, and the present preoccupation with return periods of major and infrequent storms in the lease area.

Public and private expenditures respecting prediction, prevention, mitigation, and compensation for the above and other low (over certain time scales) frequency events can be high. We recognize that the present exercise may also be an example, although as discussed above, probabilities may be higher than have been portrayed. We also recognize that plans and schemes for prediction, prevention, contingency planning and compensation exist and will be under further development. However, the proponents and the regulator appear to us to have taken positions, which if adopted, could weaken the basis for prevention, contingency planning, assessment of potential damage, and compensate on from a fisheries perspective. Petro-Canada and Chevron in their Initial Environmental Evaluations (IEE's) contend that the overall risk to fisheries would be low. COGLA/MEMPR, in the scenarios prepared at the request of the Panel, also conclude that risks to fisheries would be low, even in the event of major oil spills. Chevron, in its recent intervention, implies that there is virtually no basis for concern about risks to fisheries, again, even in the event of a major oil spill. The general grounds for these assessments are assertions about the low probability of serious oil spills, the reputedly low concentrations of dissolved oil associated with even serious oil spills, and, according to the Chevron intervention, the lack of harmful effects on salmon and herring even at concentrations of dissolved oil much higher than occur in association with major spills.

DFO does not accept the basis for virtual dismissal of concerns about fisheries impacts, for reasons given here and in other submissions (*to the Panel*). We feel that consideration of spill probabilities as well as other evidence supports strong efforts respecting fisheries resource assessment, risk reduction, contingency planning, and development of adequate compensation schemes.

CONCENTRATIONS OF SPILLED OIL IN SEAWATER

Many observations of oil in the sea associated with spills are low. However, even where the *average* concentration may be low, potentially harmful levels may be observed. In addition, as will be dealt with below, recent work suggests that concentrations causing harm are lower than sometimes reported. Views as to the toxic constituents conflict. Chevron, in its Prince Rupert submissions, stated that only the C_1 to C_{10} constituents are toxic. However, diesel (#2 fuel oils), widely accepted as being highly toxic, is composed mainly of C_{12} to C_{25} molecules, of which most are C_{15} - C_{16} (Pizzo et al. 1978). The gross composition of diesel averages about 30% alkanes, 45% naphthenes, and 25% aromatics. However, the latter, the most toxic may range up to 40%. While diesel is not the major concern here, the example emphasizes the inadequacy of considering only C_1 to C_{10} as toxic.

The variability in composition of crudes, is another difficulty in interpreting potential toxicity of observed concentration, to which must be added the variable effects of weathering, and innate analytical difficulties. Percentage volatiles (one rough index of toxicity) may range from about 15% to 60%. Within the volatile fraction of crudes reported by Pizzo et al. (1978), aromatics (the most toxic components) ranged from 1% to 16%, and naphthenes (the next most toxic) from 4% to 22% of the total volume of crude. Murban crude (Pizzo et al. 1978) is classed as predominantly parafinic, and would be expected to be of lower toxicity than naphthenic and aromatic crudes. The action of weathering and evaporation in reducing toxicity has often been referred to in submissions to the Panel, and as a basis for allaying concerns about oil which has been spilled for more than one or two days. However, substantial percentages of C_{14} and higher molecules can remain after 96 hours of weathering (Pizzo et al. 1978). As suggested above, toxicity is not limited to the lighter more easily vaporized fraction. Data on this point will be given below.

The Panel has been told (Chevron, Prince Rupert) that the *Ekofisk Bravo* blowout provides an example of a major spill for which oil in the water column was observed to be low. However, the *Bravo* well blew out into the air, to a substantial height. Audunson (1978) concluded that 35% - 40% of the crude was evaporated before or shortly after falling to the surface. The example is therefore not relevant to the type of oil blowout postulated by the Panel. Nonetheless, concentrations up to 200 $\mu g \cdot L^{-1}$ were observed; in the potentially toxic range.

Jernelöv and Lindén (1981) state that during the first part of the *Ixtoc* sub-surface blowout in the Gulf of Mexico, emulsified oil 1 to 4 cm thick formed a layer 0.7 to 5 km wide and about 60 km long, indicating that oil on the sea surface is not necessarily thin. The following observations on the *Ixtoc* spill are from Boehm and Fiest (1982). Concentrations near the blowout ranged up to 10,600 $\mu g \cdot L^{-1}$. Near the leading edge of the spill plume, 25 km away from the source, concentrations of oil droplets were 100 to 300 $\mu g \cdot L^{-1}$, and formed 70% to 80% of the oil in the water column. Chemical analysis indicated that this oil was not from surf ace oil driven down into the water column by mixing but was entrained while rising from the blowout The chemical and acoustic observations suggested that the subsurface plume of *largely unweathered* oil extended for about 20 km from the source before buoyancy and dilution caused the droplets to rise to the surface or become non-detectable. The chemically detected subsurface plume was limited to 25 to 40 km NE of the blowout, and appeared to be transported by subsurface currents rather than being driven by direct wind effects. The same authors suggest that the concentrations fell into the ranges observed by others. They cited results by McAuliffe et al. (1980) in which concentrations up to 950 $\mu g \cdot L^{-1}$ were observed under an untreated experimental surface oil spill, and up to 17,800 $\mu g \cdot L^{-1}$ under a treated experimental surface spill; *Ekofisk* observations with up to 300 $\mu g \cdot L^{-1}$; A*moco Cadiz* concentrations up to 350$\mu g \cdot L^{-1}$, and levels up to 450 $\mu g \cdot L^{-1}$ from the *Argo Merchant* spill. Moldan et al. (1985) found levels up to 700 $\mu g \cdot L^{-1}$ 30 days after a major tanker accident, with only small volumes of oil still leaking. Concentrations in the water column, after the *Mizushima* spill ranged up to 950 $\mu g \cdot L^{-1}$ (Nicol, 1976).

Thus, while the average concentration for oil spills may seem quite low, there is abundant evidence of high values. The composition and form of the oil observed is not always certain. Nonetheless, the upper ranges of concentration are cause for concern, whether dissolved or in the form of minute globules. Further, even when average concentration observed may be quite low, widely reported occurrences of dead or unhealthy organisms and altered communities gives compelling evidence showing that oil spills do have deleterious effects when looked for.

THE NEED FOR ADDITIONAL OIL SPILL SCENARIOS

Oil spill scenarios provided by Chevron in its IEE and by COGLA/MEMPR (in response to a request by the Panel) gave useful information on the potential distributions of oil spilled from postulated blowouts. However, neither series of scenarios treated potential impacts on fisheries adequately, as noted in earlier DFO submissions to the Panel. A basic tenet of the scenarios, that concentrations of oil in water resulting from spills are too low to have significant impacts on fisheries is unacceptable. The abundance, distribution, density, and rates of migration of resource species, salmon in particular, were also not adequately considered. Both of these objections were reported to the Panel by DFO, and were summarized in previous submissions.

Here we present two sketches, or mini-scenarios, which illustrate some of the characteristics which we feel must be incorporated in the development of future scenarios, if they are to be useful in future decision making. Better scenarios would assist in making decisions on where and when drilling should be permitted and under what terms and conditions, on the development of contingency plans, and in determining the approximate levels of compensation which would be required in the case of a major spill.

Sketch 1

In its guidelines for the development of scenarios by COGLA/MEMPR, the Panel postulated 50-day blowouts releasing 5000 barrels of oil per day. Ignoring evaporative losses (see below) this would yield 1,500 tonnes of oil two days old or less in the water at any one time during the 50 days of the spill. If this quantity of oil was spread over the sea surface in a thickness of 0.5 mm, an area of 3×10^6 m^2 would be contaminated. With thicknesses of 0.1 and 0.01 mm, the corresponding areas would be 15×10^6 and 150×10^6 m^2, respectively. These thicknesses of oil, if evenly mixed through a 10-m column of water, would yield concentrations of oil of 50, 10, and 1 $mg \cdot L^{-1}$ respectively. The model is obviously oversimplified, but is easily adjusted, and could provide a starting point for more detailed analyses.

Evaporation at the sea surface would reduce the toxic component of the crude. However, some potentially toxic components may exhibit little loss over 48 hours. Because the oil originates from a subsurface blowout, some of it will dissolve in the water column as it rises, or be entrained as globules, thus delaying or preventing evaporative losses of toxic components (see above). Some oil, on reaching the surface, will be mixed back into the water column significant areas around a sub-sea blowout. Published observations (elsewhere in this submission) support this contention.

So far this sketch suggests that concentrations of oil could be quite high in significant areas around major blowouts. Next we consider the numbers of young salmon that might be exposed to contamination in the above situation, assuming a 0.1 mm slick that has been mixed into a 10 m water column. For ease of calculation, a square area of contamination has been assumed. The results would be much the same for more realistic configurations. An area 3.9 km on a side would be affected, given the assumed conditions. With a migration rate of 16 km per day (Hartt, 1980) and a density of 0.01 young salmon m^{-2} (DFO, earlier submissions *to the Panel*), 31,200,000 young salmon would enter the contaminated area over the postulated 50 day period of the blowout. Each would be exposed for about 6 hours while traversing the spill, and would encounter concentrations of crude of 10 $mg \cdot L^{-1}$, assuming mixing to 10m depth.

If mortality due to direct lethal effects, delayed death due to sublethal influences and the effects of reduced or contaminated food averaged 50% of those entering the spill area, about 15.6×10^6 young salmon would die. If 20% of these fish had survived to catch and escapement, the losses of "adult" salmon would be about 3,120,000, a significant impact. This is roughly equivalent to the total returns of sockeye salmon to the Fraser River in a very good year, or all species to the Skeena River.

The numbers and assumptions in the above sketch are obviously arbitrary. However, it is intended as an illustration of a general approach to assessment of impacts, not a prediction. Nonetheless it may not be unreasonable. The conditions of the blowout were established by the Panel. The assumption of a relatively small area of high contamination around a blowout seems fair. The migration rate is taken from a widely accepted reference. The density of young salmon is midway between those observed in the coastal migration belt off southeast Alaska, and estimates for a coastal seaway cited by DFO in other submissions to the Panel. The major element introduced here is the estimate of the numbers of young salmon that would be exposed. Doing so indicates that, although only a very small fraction of the total study area was postulated to be seriously contaminated, a very significant impact could occur.

Sketch 2

The second sketch also derives from the Panel's postulated blowouts, this time for the Cape Caution scenario. Using data presented by COGLA/MEMPR in response to the Panel's scenario request it was shown that daily estimates of the two day termini of progressive vectors of wind-driven surface movements of oil largely fell within an envelope about 40 x 100 km in extent. Repeated oiling occurred along shorelines (COGLA/MEMPR) and in open water areas. Not all of the envelope would have been contaminated by fresh oil at any one time. However, a large portion of it would have been repeatedly oiled with fresh material. The COGLA/MEMPR treatment of spreading considered only wind-driven oil at the surface. If dissolved oil and entrained globules of subsurface oil were considered, the area contaminated at any one time would probably be more extensive.

Assuming the density of young salmon used in Sketch 1 above, about 40,000,000 young salmon would be present in the envelope at any one time. Assuming entry into the envelope along a 40-km front, and the above densities and migration rate, the area contaminated by two-day or younger oil would be entered by 320,000,000 young salmon during the life of the blowout. If 20% of these migrants died as a result of exposure to oil, or reduced and contaminated food, the loss would be 64,000,000 juvenile salmon. If 20% of these fish had survived to catch and escapement, the loss in returning adults would be 12,800,000. If 2/3 of them had been captured in the fishery at an average landed value of $5.00 each, the direct loss would be $42,000,000. Assuming that the lost escapements would have been sufficient for stock replacement, a similar, but decreasing loss in value of the catch would occur in successive cycle years, modified by the life history characteristics of the different species and stocks. A long-term loss of about $100,000,000 would not be an unrealistic estimate, in addition to the direct loss.

Due to the wider area considered, the number of young salmon exposed to hydrocarbons was greater in this sketch. Because of the larger area, concentrations (average, not maximum) would be lower, and the balance of mortality might be shifted from lethal effects to delayed mortality from sublethal and indirect impacts. However, even if the assumptions are considerably relaxed, major losses seem plausible.

Again, the above sketches are not put forward as predictions, but as illustrations of approaches to scenarios differing from those presented to date, and of the possible result of doing so on estimates of potential impacts on fisheries. In the sketches above only juvenile salmon were considered. Had other species and food webs been considered, the results would have been even more pessimistic. However, our chief conclusion is that the scenarios (*submitted by the proponents*) to date are inadequate, and that further efforts are essential if planning for risk reduction, contingencies and compensation is to be realistic.

THE SUSCEPTIBILITY AND EFFECT OF HYDROCARBONS ON FISHERY RESOURCES

Here we summarize, and emphasize, some of the concerns we have over the potential for oil to affect many biological components of our coastal waters. Most of these points are derived from information that has been submitted to the Panel at their request for additional information.

Particular attention will be given to currently important fish resources, such as salmon, herring and groundfish. However, in doing so we do not wish to diminish concern for other integral components of aquatic ecosystems, such as crabs, shrimps, clams, nor the need to ensure the perpetuation of healthy renewable resources for future use.

In assessing the potential for effects of oil on aquatic organisms, we must endeavor to understand the likelihood for organisms to encounter oil, aside from the physical, chemical and biological processes that affect spilled oil.

We have shown elsewhere that distributions of resource species are such that large numbers occur in the study area, and that relatively high concentrations of oil occur from spills. We thus conclude that serious exposure is possible. Here we treat the consequences of such exposure.

Information on the nature and effects of spilled oil is available for various locations around the world, but it is primarily from controlled laboratory studies that much of the cause and effect information has been derived. We cannot arbitrarily dismiss this large body of information, for it is primarily through such controlled experiments that specific effects can be identified, and, when coupled with ecological information, the relative susceptibility or resistance of important species may be identified, thus providing a basis for estimates of petroleum impacts on the environment.

Over the last decade, there has been a shift in the nature of research associated with understanding the effects of oil on organisms. Earlier work tended to focus upon lethal effects and often used high concentrations of oil. More recent studies have been oriented towards understanding the effects of sublethal concentrations, often over longer exposure periods. It is recognized that exposure to sublethal concentrations of hydrocarbons can jeopardize survival in a number of ways, examples of which will-be given later.

The vulnerability of organisms to oil will tend to be related to seasonal changes in their distribution and abundance. Accordingly, for a particular species, spilled oil may have less impact at one part of the year than another.

However, it is important to recognize that the mobility of organisms and transport of oil may lead to a problem of regional significance from what was originally of local and specific concern.

Features of the biology of some organisms may render some more susceptible to oil than others may be. For example, those species which migrate through or reside in shallow surface waters and along shorelines, or require food from these areas, for all or part of their life cycle, will be particularly susceptible, for they will likely be in close proximity to spilled oil. In the following comments, we emphasize such features.

Eggs and Larvae

Field and laboratory studies have demonstrated a wide range of lethal and sublethal effects of oil on eggs and other early developmental stages of fish.

Many species of groundfish produce eggs and/or larvae that are present at the water surface. Even though eggs may be deposited at different depths, larval forms are often present at the water surface at some time. Here they may be transported by currents and wind action to shallow habitats where they may rear, for months to years, before moving to deeper waters (e.g. English sole, Starry flounder, halibut). Herring deposit their eggs in the shallow subtidal and intertidal zones, and, after hatching (14 to 16 days), the larvae and juveniles live in shallow surface waters for months.

The presence of eggs and larvae in surface waters increases the susceptibility of these early developmental stages to oil.

Parts per billion (ppb) levels of fresh oil crude have been recorded to cause a variety of lethal and sublethal effects. Reductions in hatching success and in growth, changes in egg buoyancy, and abnormal development have been recorded at these low levels of oil.

Experience from oil spills has revealed similar effects. After the spillage of oil from the *Argo Merchant* on the East Coast of the U.S.A., many groundfish eggs were dead or moribund with cellular abnormalities, and some surviving larvae malformed.

These examples indicate the high vulnerability of early developmental stages of fish to oil. However, in the open ocean environment it has not been possible to conclusively demonstrate adverse effects on fish stocks *per se*. However, it is apparent that hydrocarbons can greatly reduce the individual's chances of survival and, accordingly, reductions in population size are of concern.

In an attempt to understand the effects of *weathered* crude oil on developmental stages of fish, researchers exposed embryos and larvae of chum salmon, English sole, sand sole and surf smelt to concentrations of oil at the ppb level. Concentrations of weathered crude oil of 100 to 500 ppb typically induced in all species either high embryo mortality or larval mortality, gross abnormalities and pathological changes. Exposure of smelt embryos to hydrocarbon concentrations less than 100 ppb resulted in cellular damage and severely reduced larval survival.

Thus it is deduced that not only fresh oil but also weathered oil at low concentrations has the capacity to directly or indirectly affect the survival of early developmental stages of fish.

Feeding and Growth

Survival of fish in the natural environment is considered to be related to many factors. In particular, the ability to feed and grow rapidly may enhance the survival of juvenile salmon in coastal waters. There is evidence that survival to adult is related to the size of juveniles, smaller juveniles having a lower survival. This pre-supposes that the fish are healthy.

Oil has the potential to affect feeding and growth of fish and a number of examples are to be found describing the effects of ppb levels and other sublethal concentrations.

Juvenile salmon will feed upon oil-contaminated prey. Experiments with juvenile pink salmon and prey containing low levels of oil have shown that feeding rate, growth rate and energy losses occurred. Exposure to the water soluble fraction of oil had an even greater effect on reducing fry feeding rates, a result noted by a number of researchers. One author suggested that juvenile salmon would probably continue to feed in an oiled environment as long as prey were present; that they would consume oiled prey (which would accumulate hydrocarbons to levels greater than those in the surrounding water) and furthermore, that organisms in contact with oiled sediments may provide a long-term source of contaminated prey. The size of pink fry fed oil-contaminated prey in prolonged exposures was reduced by more than one third; this could result in lower survival and hence lower returns of adults.

Juvenile salmon feed on a variety of prey and are considered to be opportunistic predators whose survival depends not only upon the ability to capture prey but also to escape predators. Experiments have shown that exposure to oil affects both the predator and the prey.

For example, the exposure of juvenile salmonids to ppb levels of crude oil (salt-water accommodated fraction) increased their consumption by coho predators, despite no apparent behavioural anomalies of the prey being evident to the researchers. Similarly, exposure of the predatory salmon to ppb levels of oil produced significant reductions in numbers of prey eaten. Furthermore, it was concluded that the breakdown products of hydrocarbons, and not parent compounds, were responsible for the change in feeding behaviour.

McAuliffe (Chevron, USA), while at the Prince Rupert hearings, mentioned the indirect effect of an experimental oil spill that resulted in small fish being preyed upon by barracuda. Thus providing evidence of the indirect, but lethal effects of oil spillage on prey organisms, and the ability of opportunistic predators to take advantage of the situation, despite the presence of oil.

The effect of spilled oil on growth of fish in relatively low-energy areas was documented in relation to the *Amoco Cadiz* incident. Estuarine flatfish and mullet had reduced growth, number of eggs produced, and recruitment up to 3 years after the spill. Many species of juvenile flatfish, salmon and other organisms use shallow water, often, low-energy environments, where oil persistence may be greater than in high-energy areas; thus the potential for exposure and associated effects is high.

While considering the effects of oil on feeding and growth, we have presumed that adequate food resources would be available. However, there can be no guarantee that the food resources of aquatic organisms would be immune from the effects of oil spillage. There is evidence from laboratory and field studies that reveal, for example, lethal effects or a reduction of crustaceans due to oil. These organisms are heavily preyed upon by, for example, juvenile salmon.

We conclude from the studies that have been carried out and experience in the field that, in general, spilled oil can have a detrimental effect upon the feeding and growth of fish.

Behavioral Considerations

Many observations on the behavior of fish in relation to oil appear to have been incidental to other aspects of experimentation, while a few studies have been specifically directed towards understanding fish behavior in relation to exposure to oil.

Certain obligatory behavioural traits will result in an increased susceptibility of fish to oil. It cannot be assumed that fish will avoid contaminated waters and both laboratory and field experiments have demonstrated that fish do not necessarily avoid harmful conditions in their environment. Motivated fish, competing for food, avoiding predators or migrating in the natural environment may react quite differently to less-stimulated and less-motivated fish held under laboratory conditions.

However, there are some behavioral traits, for example in salmon, which no doubt have evolved and assisted in the survival of the species which may jeopardize survival when faced with spilled oil.

We have shown that juvenile salmon occupy the uppermost part of the nearshore, coastal waters for protracted periods. Accordingly, they would be likely to encounter oil spilled into surface waters and along shorelines. The potential exists for exposure to result in sublethal effects, such as behavioral changes (aside from direct lethal effects) that could lead to increased predation (as mentioned earlier and, possibly similar to that observed by McAuliffe (Chevron USA) during an experimental spill). While juvenile salmon have been shown to have an age-related avoidance reaction to oil at various concentrations in laboratory experiments, other experiments have shown an attraction to oil slicks.

Juvenile salmon have been documented to be attracted to, and reside under, oil slicks; perhaps a response to increased cover and lower light intensities. Avoidance reactions can only be considered of short-term benefit for survival. They are a response to a detectable and recognizable stimulus, but many offsetting factors may reduce the benefit. A supply of food in a polluted environment could offset or otherwise affect the behavioral avoidance response.

Disorientation could result in greater exposure to higher concentrations of oil. For example, fish have been observed to nose oil films on the surf ace of water (a behavioral trait of many fish in response to stressors, for example, caused by low dissolved oxygen levels and, possibly, respiratory impairment).

Furthermore, certain laboratory and field studies have demonstrated that juvenile salmon will not continuously avoid contaminants that are lethal to them. There is also no assurance that avoidance will result in displacement to favourable habitats wherein food supplies, predators and other conditions are similar to their usually occupied habitats.

It is our opinion that the obligatory behavior of juvenile salmon to occupy shallow depths renders them particularly susceptible to oil (and other pollutants) in surface waters, and along shorelines.

With respect to the effect of oil on adult salmon behavior, information from combined field and laboratory experiments reveals some pertinent information. However, we have serious reservations about the experimental design and appropriateness of studies on the homing of adult salmon, which do not conclusively demonstrate that these fish will not be affected by exposure to oil.

Adult salmon, at times of low freshwater flows, hold at river mouths before upstream migration; others may spawn within estuarine reaches. Oil reaching these areas would have the potential to affect adult salmon, aside from food resources (prior to the cessation of feeding). Also, during a major oil blowout, adults might have to reside within or traverse extensive contaminated areas for many hours, or even days.

Adult salmon (mainly coho) were found to avoid hydrocarbons that were put into water running through a fish ladder. The avoidance was different for early and late run fish (possibly reflecting different levels of motivation to reach spawning grounds). The entire early run fish were depressed at nominal hydrocarbon concentrations of 2-3 ppm (700 ppb measured) while this concentration deterred 50% of later migrating fish.

Other experiments in which adult salmon that had returned to their home stream were exposed to oil for very short exposure periods and then released to make short (less than 9 km) migrations in fresh and salt water revealed mixed and disturbing results, which detract from their utility.

After a 1 hour exposure to oil, it has been concluded (McAuliffe, Chevron, USA) that there was little effect on homing success. However, in another similar study with longer exposure (8 to 22 hours; ppb levels), adult salmon returns were found to be directly proportional to hydrocarbon concentrations. Perhaps of most significance was the delay (2 days) for hydrocarbon-exposed fish to return. The low level of returning adults in all these experiments and the long time taken to return is of concern.

Adult salmon in freshwater can migrate at about 2 km per hour; hence, 3.5 hours would be the expected time required to cover the distance from release to capture point under, perhaps, optimal conditions. However, the salmon, took days, not hours, to return (for example, 8 days, control; 10 days, hydrocarbon-exposed fish).

If these results are representative of what may happen to migrating adults, we must assess the consequences of longer exposures, longer delays, and other effects, such as depletion of energy reserves, etc. Extrapolating, in a very simplistic way from a 2 day delay to travel a distance of less than 9 km after brief exposure to oil, to travelling greater than 10 times this distance after longer exposures, may result in a significant delay in the time to reach spawning, grounds - which could have consequences on spawning success.

Behavioral changes in response to oil have been reported for other fish and results have shown both avoidance and non-avoidance of oil.

From the available information, we consider that exposure to hydrocarbons has the potential to alter fish behavior and, furthermore, that behavioral traits may lead to enhanced exposure to spilled oil, rather than avoidance.

General Effects

Exposure to hydrocarbons has been shown to give rise to a number of other effects in fish. Contact with and/or uptake of hydrocarbons has been associated with disease.

After the large scale oil spill from the *Amoco Cadiz*, surviving flatfish and mullet exhibited a range of symptoms that could have been attributed to stress caused by oil contamination. Under laboratory conditions, exposure of juvenile and adult flatfish to crude oil impacted sediment did not demonstrably alter disease resistance. However, other studies have shown that-exposure to hydrocarbons can result in, for example, fin erosion, probably as an indirect effect due to increased stress. In other experiments, pathological changes occurred in the liver of flatfish exposed to oiled sediment.

The ability of fish to break down hydrocarbons has been demonstrated. Different species break down hydrocarbons at different rates, and various hydrocarbons may also be metabolized at different rates. The net effect is that fish may cleanse themselves of hydrocarbons depending upon a variety of factors. However, some hydrocarbons, present in small quantities, may be accumulated to concentrations much higher than those in their environment. Some breakdown products have also been reported to be carcinogenic/mutagenic.

Other effects that have been studied include a reduction in gonad maturation (in cod exposed to ppb levels of crude oil). Effects on number of eggs produced by plaice and mullet were recorded after the *Amoco Cadiz* spill, and complete degeneration of cells in the ovaries of eels.

Associated with exposure to oil is the potential for tainting. Examples are to be found of oil-spillage causing tainted fish (and other organisms). However, the duration of the taint is dependent upon many factors, including exposure and depuration (that is, self-cleansing) periods. It has been demonstrated that, after exposure, deputation will occur and reduce hydrocarbons. Accordingly, tainting will probably, in a clean environment, be diminished. Concern must be raised over the potential for other organisms (shellfish) which may depurate hydrocarbons slower than fish, and, by their presence along shorelines, the probability of repeated exposure from oil within sediments is increased.

Hopefully, these comments will have provided some indication of the need for concern over the effects of oil on fish. Many studies, both in the field and in the laboratory, have examined the effects of oil upon other components of the aquatic environment. By focusing upon fish, we have attempted to draw attention to species of current economic importance; however, they cannot be viewed in isolation.

Effects similar to those reported for fish at the lethal and sublethal level have also been documented for invertebrates in response to oil. Mortalities of shellfish have occurred when oil has reached shorelines; behavioral changes, such as reduced burrowing activities in clams (thereby increasing their vulnerability to predation) changes in the ability of crabs to detect prey, accumulation of hydrocarbons and tainting of flesh have been recorded, together with other sublethal effects.

Many invertebrates are consumed by fish, accordingly, effects upon prey items may give rise to reduced food availability for fish, and possibly contaminated food. The net effect could be decreased survival through reduced growth rates, greater susceptibility to predation, etc., as mentioned previously.

In this presentation, we have attempted to indicate that oil spilled into the coastal environment can have a variety of effects. Even at low, sublethal concentrations, effects upon organisms can jeopardize survival in this competitive environment.

Even the presence of an organism does not necessarily demonstrate the health of that environment. Subtle alteration to an organism's metabolism may jeopardize its survival.

Quite obviously, it is very difficult to predict when or where an oil spill may occur and the full consequences on the aquatic environment. Many research questions remain, but currently available information reveals the potential for damage to the aquatic environment from spilled oil. The severity of the damage will be, however, related to many factors, not the least of which is the biology of the organisms that could be exposed to oil.

Despite difficulties in experimental design, analytical inadequacies, and treatment of data, both field and laboratory evidence showing harmful effects of realistic concentrations of oil is overwhelming and incontrovertible.

CONCLUDING SUMMARY

1. The general approach to assessment of potential risks to fisheries, associated will oil spills, should follow the examples common in considering influence of the environment on rig safety. This would shift the focus toward most probable extreme conditions, rather than averages (e.g. average concentrations of spilled oil in water).

2. The focus or probability of an oil spill from single wells is inadequate. DFO must consider the implications of expansion of exploration beyond that presently proposed. Chevron has indicated that promising results in presently proposed activities could lead to more exploratory drilling. Our assessment indicates that for a given probability of a spill from one well, the probability of one or more spills can increase to substantial levels with realistically expected number of wells.

3. Concentrations of spilled oil in the water column are often observed to be low. However, high concentrations of oil are observed frequently enough to warrant serious concerns. Even when mean concentration may be observed to be low, dead or sub-lethally affected organisms demonstrate conclusively that spilled oil can have harmful effects.

4. Previously submitted data on numbers of young salmon per unit area and migration rates in crude oil spill scenarios demonstrated that very large numbers of fish could be exposed, even under relatively small slicks. Assumed mortality rates under the postulated conditions

lead to large losses of juveniles and consequent major reduction in returns of adult salmon. The results are not presented as predictions. They do demonstrate the need for much better impact scenarios as input to adequate planning for risk reduction, contingencies, impact assessment and potential levels of compensation.

5. Our re-examination of literature on the effects of oil on aquatic organisms confirms, beyond doubt, in our view, that spilled oil could have lethal and serious sublethal effects on our fisheries resources and their supporting ecosystems. Serious impacts on eggs, larvae, juveniles, and maturing fish are possible. Hatching, development, behavior, feeding, food assimilation, growth, and, as a result, survival, could be adversely affected.

In brief, spills are not improbable, concentrations of spilled oil can be high, even small oiled areas could contaminate large numbers of resource species such as young salmon causing major losses, and oil in water can kill or harm important species. We again conclude that there are grounds for serious concern.

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