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Environmental Studies No. 52

Beaufort Environmental Monitoring Project 1986-1987 Final Report

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Beaufort Environmental Monitoring Project 1986-1987 Final Report

Northern Affairs Program

ESL Environmental Sciences Limited
Seakem Oceanography Limited

Published under the authority of the
Hon. Bill McKnight, P.C., M.P.,
Minister of Indian Affairs and
Northern Development,
Ottawa, 1987.

QS-8410-000-EF-A1
Catalogue No. R71-19/52-1988E
ISBN 0-662-15978-0

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This Report was prepared under contract for the Northern Oil and Gas Action Program (NOGAP), Northern Environment Directorate, Department of Indian and Northern Affairs. Additional funding was made available from Environment Canada. The views, conclusions and recommendations expressed herein are those of the authors and not necessarily those of the Department.

Indian and Northern Affairs Canada
Affaires indiennes et du Nord Canada

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PREFACE

The restricted objectives of the Beaufort Environmental Monitoring Project should be emphasized. The intent of the project is not to provide recommendations for a definitive research program which would address all the fundamental knowledge gaps that exist in the Beaufort region. The cost of acquiring these data would be very high and may still fail to address the issues that finally emerge as those of regulatory and public concern. The objective of BEMP is to identify and recommend those research and monitoring activities that are necessary for the responsible management of a phased development of Beaufort Sea hydrocarbons, through the administration of relevant legislation administered by INAC. The specific focus and objectives of BEMP should not detract from an overall recognition of our fundamental knowledge gaps in the Beaufort. Encouragement and support should be given to those agencies with responsibilities to conduct research programs which reflect their particular mandate in this region.

David P. Stone
Northern Environmental Protection Branch
Indian and Northern Affairs Canada

ACKNOWLEDGEMENTS

The Beaufort Environmental Monitoring Project relies on the cooperation and contributions of a large number of scientists and managers from government agencies, the oil industry, universities and consulting firms. We would like to acknowledge the contributions of all participants in the oil-based drilling mud and bowhead whale workshops held in March 1987; their conclusions and recommendations are presented in various sections of this report. The valuable information and discussion provided by Alex Aviugana and Fred Wolki of the Inuvialuit Game Council is appreciated. We would also like to acknowledge the enthusiastic support and contributions of Ed Pessah and John Ward of Dome Petroleum Limited, and Terry Antoniuk, Peter Devenis, Len Federko and Peter Kimmerly of Gulf Canada Corporation at the workshops, as well as the valuable input of Roger Green from the University of Western Ontario prior to and during the bowhead whale workshop.

Wayne Duval of ESL Environmental Sciences Limited was responsible for management of BEMP in 1986-1987 and organization of the two workshops held earlier this year. The assistance of the two workshop facilitators (Dave Bernard and Peter McNamee) from ESSA Environmental and Social Systems Analysts Limited is gratefully acknowledged. The recorders for the oil-based drilling mud workshop were Patricia Vonk and Wayne Duval of ESL, while John Ford and Wayne Duval assumed this role in the bowhead whale workshop. The following individuals were responsible for preparation of various sections of this report:

Summary and Introduction	Wayne Duval	ESL
Hypothesis No. 1	Wayne Duval	ESL
Hypothesis No. 20	David Thomas	Seakem Oceanography
Hypothesis No. 21	John Ford	ESL

Project Overviews:

Whale Studies	John Ford	ESL
Seals and Bear Studies	Lois Harwood	University of Alberta
Fish Studies	Patricia Vonk	ESL
Oil-based Mud Studies	David Thomas	Seakem Oceanography
Principals of Research and Monitoring Design	Roger Green	University of Western Ontario

ALAN BIRDSALL - AN APPRECIATION

As the Beaufort Environmental Assessment public hearings gathered momentum during 1982, it became increasingly obvious that a unique management regime would be required to create and maintain an appropriate environmental effects monitoring program for the Beaufort Sea. All those involved could easily agree on the magnitude of the task, but we vigorously disagreed on such fundamentals as what should be monitored, the valid indicators of unacceptable change, how change can be distinguished from noise, and so on.

In the midst of this predicament, Alan arrived with an unsolicited proposal which quickly evolved into the 'BEMP' now so familiar to us all. The first year was a harrowing experience. Hazards lurked around every corner. Furthermore, in their prognosis for the success of BEMP, the pessimists far outnumbered the optimists. The trump card was Alan. His innovative and unconventional management skill took us safely through a sea of difficulties. He thrived on problems. He would listen intently to a wide range of advice, and then announce with magisterial authority how things would be done. Frequently his pronouncement contained only a trace of our input! However, we quickly learned from the wisdom of hindsight that Alan's was the winning solution. The conclusion to the story lies in the success and acceptance which BEMP achieved through such a wide spectrum of government, industry, and northerners.

Alan bore his long illness with a characteristic blend of fortitude, optimism and realism. A few months after the inevitable end, his immediate family and a large group of friends gathered to share our memories. It was typical of Alan's personality that such a poignant occasion could be so happy and enjoyable. He was an outstanding friend, colleague and leader.

BEMP Steering Group

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SUMMARY

The Beaufort Environmental Monitoring Project (BEMP) was initiated in 1983 by Indian and Northern Affairs Canada and Environment Canada. Its purpose is to provide the technical basis for the design, operation and evaluation of a comprehensive and defensible environmental research and monitoring program to accompany phased hydrocarbon development in the Beaufort Sea. This document describes the results of two workshops held during the fourth year of the project and presents a review of recently initiated or completed research programs that are relevant to one or more BEMP impact hypotheses. In 1986-1987, a new impact hypothesis was formulated to address a change in the hydrocarbon development scenario that could involve westward transport of oil out of the Beaufort region during the open-water season.

The first of two workshops examined Hypothesis No. 20, which focuses on the effects of discharge of cuttings contaminated with oil-based drilling muds on fish, birds and marine mammals (**The discharge of drill cuttings contaminated with oil-based drilling muds during hydrocarbon exploration or production will reduce populations of fish, birds, and mammals or will decrease the harvest of these resources due to hydrocarbon accumulation in tissues**). It was concluded that discharge of oil-contaminated cuttings could affect the local abundance of these species in shallow nearshore areas due to loss of benthic habitat, but was not a significant concern in offshore areas because of the scale of possible industrial activities. Bioaccumulation and biomagnification of hydrocarbons adhering to the drill cuttings was considered highly unlikely and would not justify testing through a monitoring program. Workshop participants recommended five areas of future research and monitoring related to use of oil-based drilling muds in the Beaufort Sea. These were determination of the fate of discharged oil-contaminated cuttings, establishment of a hydrocarbon baseline data base, identification of critical nearshore habitats for fish, birds and mammals, evaluation of the potential for downhole generation of polycyclic aromatic hydrocarbons, and examination of the oxygen demand of oiled cuttings in this region.

The second workshop involved the evaluation of two hypotheses related to the effects of hydrocarbon development on the western Arctic population of bowhead whales. These hypotheses were examined by separate working groups. The first reviewed new information relevant to the original bowhead whale hypothesis (Hypothesis No. 1) and the second examined a new hypothesis related to westward transport of oil from the region.

The majority of the workshop participants examining Hypothesis No. 1 (**Ship traffic, seismic exploration and active offshore structures will cause a reduction in the western Arctic population of bowhead whales**) concluded that either it was possible but too difficult to detect, or it was not testable. Notwithstanding this conclusion, several participants believed that there was

a need to continue research on some critical links in the hypothesis. The discussion of research needs focused exclusively on examination of the distribution of adequate bowhead feeding habitats within and outside the industry zone, particularly determination of the rates of use of zooplankton patches inside and outside this zone. The need for pre-established "stopping rules" and benefit-cost analysis prior to initiation of this research were also supported by many of the participants. Another recommendation of the group was refinement of hydroacoustic techniques to allow distinction of physical and biological targets.

The second subgroup in the bowhead whale workshop concluded that the new hypothesis (**Tanker traffic and minor oil spills associated with the westward transport of Canadian Beaufort oil will cause reductions in the western Arctic population of bowhead whales and the harvest of this population by Alaskan Inupiat**) was valid, but most of its linkages were unlikely to occur at the level of shipping activity examined during the meeting (16 round trips between 1 August and 31 October each year). Further testing of the hypothesis was considered unjustified and no field research or monitoring programs were recommended. However, the group did suggest the need for re-analysis of existing data to determine the probability and possible significance of concerns reflected in three hypothesis links, and that efforts be taken to mitigate impacts of tanker traffic on the success of the fall bowhead hunt in Alaska.

RESUME

Le projet de surveillance environnementale de la mer de Beaufort (PSEB) a été entrepris en 1983 par le ministère des Affaires indiennes et du Nord canadien et par le ministère de l'Environnement. Ce projet doit permettre d'obtenir les données techniques de base nécessaires pour concevoir, exécuter et évaluer un programme de recherche et de surveillance environnementales qui soit à la fois complet et justifiable. Ce programme mis en oeuvre parallèlement à l'exploitation graduelle des hydrocarbures dans la mer de Beaufort termine sa quatrième année. Ce rapport fait état des activitiés de recherche entreprises durant cette année et renferme des recommandations quant aux études environnementales qui pourraient être entreprises à l'avenir.

INTRODUCTION

The Beaufort Environmental Monitoring Project (BEMP) was initiated in 1983 by Indian and Northern Affairs Canada and Environment Canada. The program is to provide the technical basis for the design, operation and evaluation of a comprehensive and defensible environmental research and monitoring program to accompany hydrocarbon development in the Beaufort Sea, relative to the regulatory responsibilities of the sponsoring departments. BEMP was considered necessary because of: (1) environmental concerns regarding this development; (2) general uncertainties associated with Environmental Impact Assessment (EIA); and (3) the need for a research and monitoring plan that is fully integrated with activities associated with phased development within the region.

The first two years of BEMP (1983-1984 and 1984-1985) involved relatively large workshops where participants discussed all impact hypotheses formulated during the initial year of the project (INAC and Environment Canada 1984, 1985). During the last two years, the project has focused primarily on hypotheses related to the effects of hydrocarbon development on bowhead whales and use of oil-based drilling muds in the Beaufort Sea. There are three reasons for the recent emphasis of the project in these areas. First, there are less significant concerns regarding potential effects of development that are reflected in the remaining BEMP impact hypotheses. This is because of the reduced level of industrial activity in the region during the last three years, combined with a development scenario that presently does not involve construction of shoreline structures that could adversely affect coastal migrations of anadromous fish. Second, there are still concerns regarding the effects of offshore industry facilities and activities on the western Arctic population of bowhead whales, as well as the possible environmental implications of the recent use of oil-based drilling mud formulations in Beaufort operations. Finally, these are the two areas where research activity has been greatest in the past few years and, therefore, it was considered important to review the results of these studies in the context of BEMP Hypotheses No. 1 and No. 20.

Despite the focus of BEMP on bowhead whales and oil-based drilling muds this year and in 1985-1986, ongoing and new research relevant to other hypotheses continues to be reviewed as part of the project. These reviews are presented in the form of Project Overviews in Appendix C of this report.

The workshop to evaluate Hypothesis No. 20 (Oil-Based Drilling Muds) was held on 4-5 March 1987 in Calgary, Alberta, and was attended by 15 specialists from government, industry and the private sector. This was the first opportunity to discuss a revised version of the oil-based drilling mud hypothesis from that evaluated during the second year of BEMP (INAC and

Environment Canada 1985). Hypothesis No. 20 was restructured last year to include Valued Ecosystem Components (VECs) other than Arctic cisco, broad whitefish and lake whitefish originally considered in 1985, but was not examined in a workshop (INAC and Environment Canada 1986). The hypothesis reviewed this year included fish, birds and marine mammals as its VECs.

The bowhead whale workshop was held on 10-11 March 1987 in Victoria, B.C. A total of 25 participants were invited to the workshop, including several Alaskan scientists. The original purpose of this workshop was to re-evaluate BEMP Hypothesis No. 1 in view of the results of several research programs completed or initiated since February 1986. However, a change in the potential development scenario for the region occurred a few weeks before the workshop, and could involve seasonal transportation of oil from the Beaufort in a westward direction off the coast of Alaska. In order for BEMP to be adaptive and iterative, it must be capable of responding to changes in the development scenario for the region. As a result, the management committee concluded that it would be important to formulate and evaluate a second impact hypothesis dealing with bowhead whales (Hypothesis No. 21) during the same workshop and invited an adequate number of participants to address both hypotheses.

The workshops were organized and conducted in the same manner as in previous years of BEMP. A facilitator directed the discussions of each group, while one or more rapporteurs maintained a record of the discussions. Following introductory comments on the overall organization and scope of a hypothesis, the results of studies that provide information relevant to each of its links were discussed. In many cases, the principal investigators in these research programs were among the invited workshop participants. The subgroup assigned to the new bowhead hypothesis was also responsible for formulation of its linkages. Each group was then asked to reach a conclusion regarding the validity of a hypothesis and to provide recommendations, where appropriate, on the need for further studies to either test the hypothesis or address key unknowns related to one of its links.

Following the 1987 BEMP workshops, draft report sections were prepared by the rapporteurs and distributed to all participants for review prior to completion of this report.

HYPOTHESIS NO. 1

SHIP TRAFFIC, SEISMIC EXPLORATION AND ACTIVE OFFSHORE STRUCTURES WILL CAUSE A REDUCTION IN THE WESTERN ARCTIC POPULATION OF BOWHEAD WHALES

PARTICIPANTS

Alex Aviugana	Wayne Duval
Dave Bernard	Dave Fissel
Michael Bradstreet	Roger Green
Paul Budgell	Rick Hurst
James Cubbage	Dave Mackas
Rolph Davis	Ed Pessah

INTRODUCTION

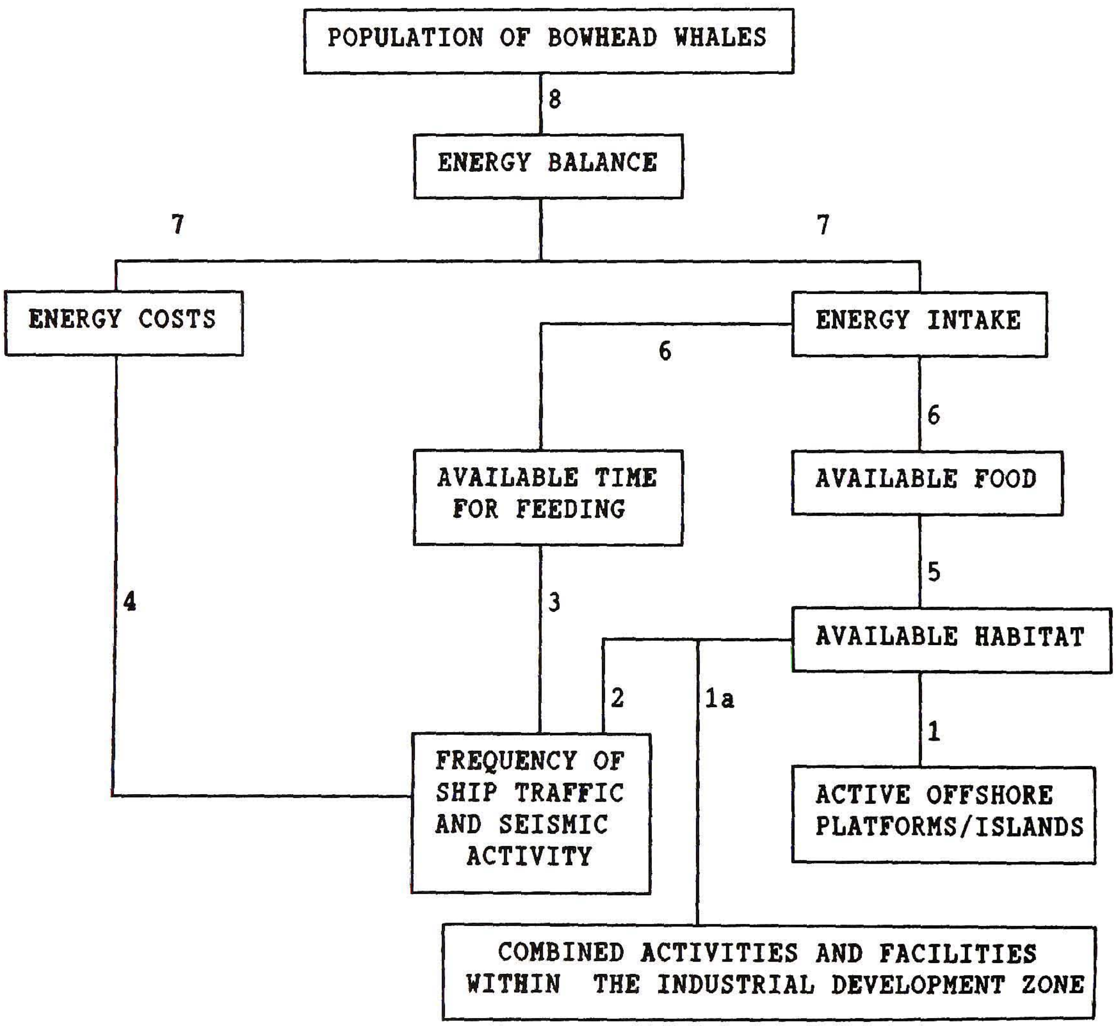
As in past years, several research programs that were considered relevant to one or more links in this hypothesis had been conducted since the last BEMP workshop. Project Overviews describing the objectives and overall design of these research programs and their relationship to Hypothesis No. 1 were distributed to participants prior to the 1987 workshop (Appendix C). The primary objective of the workshop was to review this new information as a means of evaluating the evidence for or against each hypothesis link. However, even greater emphasis this year was placed on: (1) evaluating the status of existing knowledge and key unknowns related to the effects of offshore hydrocarbon exploration on the western Arctic population of bowhead whales; (2) attempting to reach conclusions on the validity of the specific links and the entire hypothesis where possible; and (3) formulating recommendations for further research or monitoring that implicitly relate study outputs to management decisions. The majority of the invited technical specialists had participated in past BEMP workshops dealing with this hypothesis. A statistician (Roger Green) was included in the group this year to assist in evaluation of existing and possible future research design.

Prior to the workshop, Dr. Green reviewed the discussions of Hypothesis No. 1 presented in all previous BEMP reports, as well as several reports describing the design and results of past research programs directed at bowhead whales in the Beaufort Sea. A comparative evaluation of the basic principles of research design and the BEMP approach to evaluation of this hypothesis was presented at the outset of the workshop (Appendix B). During this presentation, it was suggested that it may be logistically impossible and cost-prohibitive to conduct the research necessary to apply standard statistical tests to the overall hypothesis, and that invalidation of one or more of its lower linkages may be the best overall strategy to address this issue. The latter could be accomplished through formal statistical tests or the "weight-of-evidence" approach discussed during the previous BEMP workshop (INAC and Environment Canada 1986).

FIGURE 1-1

POTENTIAL EFFECTS OF SHIP TRAFFIC, SEISMIC EXPLORATION AND ACTIVE OFFSHORE STRUCTURES ON BOWHEAD WHALES

Ship traffic, seismic exploration and active offshore structures will cause a reduction in the western Arctic population of bowhead whales.



Linkages

1a. The cumulative effect of all offshore industrial activities will be to create a large-scale zone of bowhead whale exclusion encompassing the entire industrial zone.

1. Each active offshore island or platform will exclude bowheads from a zone around the island/platform.

2. Ship traffic will exclude bowheads from a zone around the ship track.

3. Each passage of a ship will reduce the feeding time available to bowheads.

4. Each passage of a ship will increase the energy expenditure of whales due to avoidance behaviour.

5. The available aquatic habitat determines the level of available food.

6. The amount of available food and the time available for feeding determine the energy balance of a bowhead whale.

7. Energy intake and expenditures determine the energy balance of a bowhead whale.

8. The energy balance of a bowhead whale determines its survival and its ability to reproduce.

EVALUATION OF NEW INFORMATION RELEVANT TO HYPOTHESIS LINKAGES

Link 1a: **The cumulative effect of all industrial activities will be to create a large-scale zone of bowhead whale exclusion encompassing the entire industrial zone.**

This link pertaining to cumulative avoidance of the industrial zone by bowheads is the exclusion hypothesis. The systematic aerial surveys that have been conducted over the last seven years (Renaud and Davis 1981; Davis et al. 1982; Harwood and Ford 1983; Harwood and Borstad 1984; McLaren and Davis 1985; Duval (ed.) 1986; Ford et al. 1987) provide much of the evidence related to Link 1a. During both survey periods in 1986 (25 August-01 September and 07-14 September), bowheads were concentrated in three main areas: (1) along the Yukon coast between Kay and Shingle points and near Herschel Island, (2) in Mackenzie Bay about 40-60 km offshore of Shingle Point, and (3) along a band 40-100 km offshore of the Tuktoyaktuk Peninsula between McKinley Bay and

Cape Dalhousie. Substantial numbers of whales were also observed along the Yukon coast during a reconnaissance survey on 3 October. There was evidence that bowheads were actively feeding in each of these areas. Whales have been prevalent along the Yukon coast each year since 1983, and several authors have suggested that upwelling and relatively high densities of zooplankton may occur during some periods along this coast (Harwood and Borstad 1984; Bradstreet and Fissel 1986; Duval (ed.) 1986). The bowheads observed in Mackenzie Bay during 1986 were mainly associated with the interface between the Mackenzie River plume and colder, oceanic water. This area may also support locally high zooplankton densities during some periods. As in most years since 1981, bowheads were scarce in the industrial zone in 1986, despite substantially reduced activities of the petroleum industry compared to previous years.

The photogrammetric component of the 1986 surveys indicated that bowheads were segregated according to size within the study area. As in 1985, animals present along the Yukon coast were primarily subadults, whereas those off the Tuktoyaktuk Peninsula were mainly adults (Ford et al. 1987). Results of studies conducted in both years suggest that a significant proportion of the western Arctic bowhead population occurs outside the study area during late August and early September because adults are under-represented in samples from the southeast Beaufort Sea. Bowheads have occasionally been observed off the northern coast of Alaska during this period (Ljungblad et al. 1986), while adults are known to occur in Amundsen Gulf and adjacent waters (Davis et al. 1983, 1986a, 1986b).

The above research together with the results of concurrent studies of zooplankton abundance and distribution (Bradstreet et al. 1987) provide further evidence that the spatial distribution of at least some component of the bowhead population may be related to regional and local variations in food availability within the region. Whales were again congregated in areas either shown or believed to support relatively high densities of zooplankton, and were observed to be feeding at these locations. It was not possible to conclude on the basis of this research that bowheads have not continued to avoid the industry zone as a result of prior experience. However, it was evident that whales were not abundant in this zone despite substantially reduced activity of the industry in 1986 and were present in large numbers elsewhere (Ford et al. 1987).

Link 1: Each active offshore island or platform will exclude bowheads from a zone around the island/platform.

Several workshop participants indicated that there is a zone of undefined size around drilling rigs that bowheads tend to avoid. Two aspects of this displacement were discussed: (1) the simple physical presence of a structure which would contribute to some displacement through a small loss of habitat; and (2) observed avoidance of these structures, as well as the vessels and aircraft employed in support of drilling operations. There was general agreement among the group that bowheads do avoid some zone around rigs.

Two recent studies were discussed in relation to this hypothesis link. The first is a joint investigation by BBN Laboratories Inc. and LGL Limited for the U.S. Minerals Management Service (Miles et al., in prep.), and is designed to predict the range at which the behaviour of bowhead and gray whales is likely to be influenced by sounds produced at selected offshore drillsites in the Alaskan Beaufort Sea. The 1985 and 1986 field programs involved measurements at six offshore sites including natural ambient noise characteristics, acoustic signatures of industrial noise, sound speed profiles, and acoustic transmission loss characteristics. On the basis of the results of this research and existing data on the behaviour of bowhead and gray whales, the investigators will attempt to derive zones of potential noise detectability, zones of potential responsiveness, and zones of potential masking for both species. The results of this research are expected to be available in early 1988.

The second study was designed to document the reactions of migrating bowhead whales to an offshore drillsite. It was completed in the Corona Hammerhead area of the Alaskan Beaufort Sea by LGL Limited and Greeneridge Sciences Inc. (Report in preparation). The investigation involved use of aerial observations, photography and underwater acoustic monitoring to evaluate the reactions of bowheads as they approach an active drillsite.

Link 2: Ship traffic will exclude bowheads from a zone around the ship track.

No studies were initiated since the last BEMP workshop to directly examine this hypothesis link, although there were further observations of ship avoidance by bowheads during studies conducted in the Alaskan (J. Richardson, pers. comm.) and Canadian (M. Bradstreet, pers. comm.) portions of the Beaufort Sea. For example, the approach of the research vessel engaged in studies of zooplankton composition and abundance in bowhead feeding areas in the southeast Beaufort Sea caused avoidance responses by whales, although whales returned to the same area in the following days and some were the same individuals (Richardson et al. 1987).

Link 3: Each passage of a ship will reduce the feeding time available to bowheads.

No research relevant to this link in Hypothesis No. 1 was conducted in 1986.

<u>Link 4</u>: **Each passage of a ship will increase the energy expenditure of whales due to avoidance behaviour.**

No research specifically directed at examining the energetic cost of avoidance responses in whales has been conducted during the past few years.

<u>Link 5</u>: **The available aquatic habitat determines the level of available food.**

There was considerable discussion of recent research relevant to this hypothesis link in the 1987 workshop. Two major studies of zooplankton composition and abundance were conducted by LGL Limited in the Beaufort Sea during the summer of 1986 (Bradstreet <u>et al</u>. 1987; Richardson 1987), and these investigations were expected to provide important information on the characteristics of bowhead whale feeding habitats in the region.

Initial discussions by the group focused on the overlap between prime feeding habitats of bowheads and the locations of industry activities. It was suggested that there are likely to be a finite number of areas with adequate densities of zooplankton and that the location of some of these areas may vary among years. The degree of overlap between prime feeding habitats and sites of industry activity was considered a significant area of concern by several participants. Other participants emphasized that whale-ship interactions are common throughout the world and that temporary exclusion of bowheads from feeding areas should be viewed in this context.

Relatively high-density zooplankton patches may be associated with some oceanographic features in the Beaufort Sea. In 1986, coastal upwelling occurred east of Herschel Island, whereas frontal features were common near Shingle Point (Bradstreet <u>et al</u>. 1987). It was suggested that high zooplankton densities such as those observed off the Yukon coast can develop and disappear relatively quickly in response to regional wind events (M. Bradstreet, pers. comm.). However, the importance of these temporally-restricted zooplankton patches and the time required for bowheads to respond to their presence remain unknown. There is no information on how bowheads locate food.

<u>Canadian Food Availability Studies</u>

A brief review of the methods used during 1986 studies of zooplankton composition and abundance in the Canadian Beaufort Sea was presented by the principal investigator (Michael Bradstreet, LGL Limited). It was emphasized that because of the patchy distribution of zooplankton, conventional net tows are not the best technique for resolution of patch size and dynamics. Consequently, this study employed hydroacoustic methods in conjunction with net tows to allow calibration of the hydroacoustic data. It was reported that the correlation between hydroacoustic and abundance data was low in areas with strong physical gradients (e.g., temperature and salinity), and that interpretation is further complicated by the fact that the spatial distribution of zooplankton is correlated with these physical gradients. The hydroacoustic technique did show the presence of zooplankton patches along the survey transect lines, but they were difficult to resolve in waters less than 40 m deep. For this reason, emphasis in the workshop was placed on zooplankton data obtained from the conventional net tows.

This investigation indicated considerable variability in the abundance of zooplankton throughout those parts of the southeast Beaufort Sea surveyed. The highest zooplankton density was observed north of the Mackenzie Delta, while densities were moderately high off Cape Dalhousie. In comparison to these two areas, zooplankton abundance along the Yukon coast was relatively low. Few whales were observed off the Mackenzie Delta, but they were present in relatively large numbers off Cape Dalhousie.

The composition of zooplankton samples also differed throughout the study area. Copepods comprised about 80 percent of the zooplankton community sampled off the Yukon coast, whereas a more evenly-mixed community containing ctenophores and jellyfish was found off the Delta (Industry Zone). A high proportion of mysids was obtained in samples collected along the plume edge. The zooplankton community off Cape Dalhousie contained typical arctic copepod species and was dominated by jellyfish. The estuarine copepod, _Limnocalanus macrurus_, was predominant in samples collected near King Point and it was suggested that upwelling in this area may concentrate these organisms. It was also reported that the stomach of a bowhead harvested in Alaska in 1986 contained _Limnocalanus_. Euphausids were a minor component of the zooplankton community sampled in all parts of the study area.

There was a brief discussion of the size of bowhead whales observed in the clearly different feeding habitats off the Yukon coast and Cape Dalhousie (see also Link 1a). Primarily subadult animals were located along the Yukon coast, whereas larger adults were found off Cape Dalhousie. Some participants suggested that such age segregation of bowheads on their summer range could be either an innate behaviour or a learned response. In either case, different food preferences and feeding capability of smaller and larger animals could contribute to the observed age segregation. Others argued that learned avoidance responses by older individuals in the population could be responsible for the limited numbers of bowheads observed in the industry zone in recent years.

Availability of food to bowheads was discussed in relation to water mass distributions and their characteristics. It was stated that the greatest ability to correlate bowhead food availability and water mass characteristics exists along the Yukon coast because of the simultaneous presence of satellite imagery and oceanographic and zooplankton data. It was suggested that the role of the plume edge in concentrating zooplankton may depend on the distance of this front from the coast (J. Richardson, pers. comm.). The significance of the front as a concentrating mechanism likely decreases when it is located close to the coast. Similarly, zooplankton densities may be substantially lower during periods of strong northwesterly winds when there are fewer oceanographic phenomena that would concentrate planktonic organisms. Local winds moving seaward from the Brooks Range may also contribute to upwelling at certain locations and times and thereby lead to higher zooplankton densities.

Oceanographic phenomena that may lead to locally high densities of zooplankton off the Mackenzie Delta were considered more complex than those occurring along the Yukon coast. This was expected to be due in part to the variable wind regime, low relief of the Delta itself and shallow, gently-sloping seafloor bathymetry. Although studies cited in previous BEMP reports have provided evidence of high zooplankton densities near the edge of the Mackenzie River turbidity plume, the group concluded that it would be difficult to predict the locations of zooplankton patches elsewhere in this part of the Beaufort Sea.

Some workshop participants emphasized the need to examine zooplankton communities within Franklin Bay because it is outside the influence of the plume and bowheads in this area tend to be larger and appear to dive deeper than those found off the Delta or Yukon coast (W.R. Koski, LGL Limited, pers. comm.). Satellite imagery and adjacent wind data are available for this area, but there are no zooplankton data to allow analysis of possible biophysical relationships.

Discussions also focused on the importance of knowing the composition of the zooplankton community as well as the overall density and depth distribution of planktonic organisms. It was expected that the type and density of zooplankton may in some way influence the movements of bowheads in the region, because it is clear that animals are not randomly distributed and are unlikely to be randomly searching for food while on their summer range. The group discussed the potential that bowheads could be following or crossing zooplankton density gradients associated with oceanographic fronts, but it was eventually agreed that whales likely occur in many parts of the region where no fronts exist. It was also speculated that bowheads may be able to "predict" the locations of the best feeding areas given previous temporal and spatial trends in zooplankton distribution and abundance. For example, the presence of substantial numbers of immature bowheads off the Yukon coast each year since 1983 may be related to recurring oceanographic conditions that favour concentration of their prey.

Alaskan Food Availability Studies

The results of 1985 and 1986 bowhead food availability studies conducted in the Alaskan portion of the Beaufort Sea were briefly described by the principal investigator (John Richardson, LGL Limited). This research involved the sampling and hydroacoustic measurement of zooplankton along four transects to the 100 m isobath. Feeding bowheads were observed close to shore in 1986 and investigators were able to collect zooplankton samples in the vicinity of feeding whales. The densities of zooplankton in these areas were several times higher ($\sim 2\ g.m^{-2}$) than those measured in adjacent areas and were predominantly small copepods (Limnocalanus). Bowheads feeding in these nearshore waters were usually small, subadult individuals, as also documented in feeding areas along the Yukon coast.

The average biomass of zooplankton measured along the transects was similar in both years and decreased with increasing distance offshore. Zooplankton biomass was also comparable to that measured off the Yukon coast. During 1986, the highest zooplankton densities were recorded in areas where bowheads were feeding. In late September of both years, adult bowheads (including females with calves) were observed further offshore in waters 40-50 m deep. It was suggested that bowheads this distance from shore would be feeding on zooplankton species other than Limnocalanus.

Differences between the results of the 1985 and 1986 investigations and between the Alaskan and Yukon coasts were also discussed. In 1985, a predominant band of cold water was located along the shore. This was not observed in 1986, although comparable zooplankton densities were documented in both years. Marked horizontal temperature and salinity gradients were apparent in areas where bowheads were feeding, and the oceanographic phenomena responsible for these gradients may also create locally high densities of zooplankton (zooplankton patches) in nearshore areas. It is not known if such patches exist further offshore or the mechanisms that could lead to the formation of areas with high zooplankton densities away from the coast. High zooplankton densities are not found at the surface off Alaska. Consequently, there is also very little bowhead feeding at the surface and, because bowheads are not producing trails of mud from the seafloor when they surface, it is assumed that they are feeding at mid-water depths.

It can be concluded that, on a local scale, bowheads feed where their food is most abundant. Such zooplankton patches may be formed by relatively fine-scale oceanographic phenomena such as coastal or frontal upwelling. However, at present, broad-scale changes in the distribution of bowheads in the region can not be attributed exclusively to water mass changes. In the concluding discussion of the Alaskan and Canadian food availability studies, it was indicated that bowheads are not feeding all the time when they are present in the Beaufort Sea because whales have commonly been observed lying stationary at the surface or engaged in various social behaviours. The proportion of the time that bowheads feed is not known. It is also unknown if the amount of feeding time would increase as the energy intake per unit effort decreased, although it was suggested that there is probably a threshold zooplankton density below which it is not energetically beneficial for bowheads to feed due to the associated energy expenditure. Preliminary calculations suggest that this density is in the order of 1.0-2.0 $g.m^{-3}$, but this figure is expected to depend on the energy content of zooplankton and the season. The average zooplankton density in most of the Beaufort Sea shelf area is less than this approximate threshold (Thomson and Richardson 1987). Several participants indicated that the fundamental question was the fraction of adequate food habitats that are actually used by bowheads and their location with respect to the zone of industry activities in the region. In this discussion, reference was made to previous recommendations in BEMP workshops regarding the need to examine zooplankton patches that are used and those not used by bowheads, both within and outside the industry zone.

Isotope Studies

On the basis of evidence for other baleen whales, it has largely been presumed that little feeding of bowheads occurs during winter in the Bering Sea. As discussed in previous BEMP reports (INAC and Environment Canada 1984, 1985), the western Arctic population of bowhead whales is expected to obtain most of its annual energy requirements on its summer range in the eastern Beaufort Sea-Amundsen Gulf region and during their fall migration back to the Bering Sea. For example, bowheads harvested in spring have had little food in their stomachs and, until recently, there has been virtually no evidence of winter feeding.

The ratios of $^{13}C/^{12}C$ in zooplankton vary from the Bering Sea to the Beaufort Sea, with the proportion of C^{13} being less to the east. This carbon ratio trend is based on adequate data from Barrow to the Canadian Beaufort, but supporting data are very limited for zooplankton communities elsewhere along the Alaskan coast and within the Bering Sea. If bowheads are actively feeding, there will be a rapid turnover of carbon and, therefore, evidence for winter feeding could be obtained by determining the carbon ratio of tissues from whales harvested in spring and fall migration periods in Alaskan waters. In 1986, Schell et al. (1987) determined the carbon ratios in the muscle and baleen fibre of six whales harvested in spring and three whales harvested in fall. They have concluded through the use of kinetics functions that there is complete turnover of carbon in subadults in winter and that there is evidence of feeding during this period. During the workshop, it was suggested that more data are required to conclude that intensive winter feeding by bowheads does occur. Notwithstanding the lack of unequivocal evidence on the intensity of winter feeding, as well as information on the composition and abundance of zooplankton in the Bering Sea, it was considered likely that some zooplankton would be present in the winter months because of the 2-year life cycle of some species. It was also noted that, unlike the Beaufort Sea, the Bering Sea is considered predominantly a benthic-driven ecosystem (Jewett and Feder 1981). Therefore, bowheads may feed on benthic epifauna rather than zooplankton during the winter months.

Link 6: **The amount of available food and the time available for feeding determine the energy balance of a bowhead whale.**

As in past BEMP workshops addressing Hypothesis No. 1, this link was considered intuitive and based on fundamental bioenergetic principles. Therefore, it was not discussed further in the present meeting.

Link 7: **Energy intake and expenditures determine the energy balance of a bowhead whale.**

There is no new or old information to properly evaluate factors affecting the balance between energy intake and expenditures in the western Arctic population of bowhead whales. The primary concern of some participants was the influence of industry activities on the energy balance of individuals over their lifetime rather than in a single year. It was emphasized that there is virtually no information on the calving frequency, age of reproduction and longevity of bowheads.

Link 8: **The energy balance of a bowhead whale determines its survival and its ability to reproduce.**

This link is self-evident. There was no new information relevant to this link examined by the workshop subgroup. However, reference was made to earlier discussions where it was noted that adults are clearly under-represented in the samples of bowheads measured photogrammetrically during annual systematic surveys. Adults should theoretically comprise from 50-60% of the population (Ford et al. 1987), but this has not been observed in studies conducted to date. Even if a major portion of the adult component of the population is located within Amundsen Gulf and therefore outside the usual survey area, it was suggested that adults would still probably be under-represented in the population. A National Marine Fisheries Service study of the length distribution of bowheads as they pass Barrow, Alaska is expected to provide additional information on the age composition of this population.

EXPERIMENTAL DESIGN AND STATISTICAL CONSIDERATIONS

To provide a basis for discussions of major conclusions regarding Hypothesis No. 1 and possible future research and monitoring priorities, a general discussion of experimental design and statistical considerations was presented by Dr. Roger Green. This section summarizes the most important points made during the presentation with respect to the existing hypothesis and past research and monitoring efforts directed at bowhead whales in the region (see also Appendix B).

Hypothesis No. 1 focuses on a long-term time scale and it is only possible to make inferences to this time scale based on the results of shorter-term research programs and reviews of historical data such as whaling records. Most of the information on short time scales is circumstantial in nature and cannot be subjected to formal statistical tests, while the longer-term data are probably more important in terms of examining Hypothesis No. 1, but less reliable. It would be desirable to examine information available for each of three time scales: <u>long term</u> (e.g., whaling records); <u>decade scale</u> (e.g., annual systematic surveys); and <u>proximate scale</u> (e.g., feeding studies involving individuals in the population). However, it may be difficult to formulate linkages among the three time scales, particularly because the hypothesis itself deals with the long-term time scale.

Dr. Green emphasized the need to formulate null and alternate hypotheses and select a surrogate variable such as decreased abundance of bowheads prior to proceeding with the experimental design of future research (i.e., number of samples, seasonal effort, parameters to be tested, etc.). There are also three essential criteria that must be established prior to subsequent research design. The first is the acceptable Type I error level (α) or risk of concluding that there is an effect when one does not exist. The second criterion is the acceptable Type II error level (β) or risk of concluding erroneously that there is no effect. The final criterion is the magnitude of change in any variable (Δ_x) that will constitute a deleterious effect. It was emphasized that it is not possible to undertake a statistical test of a hypothesis without first establishing Δ_x. For example, a decrease in the abundance of a key algal indicator species by about one-third ($\Delta_x/x = 1/3$) may be considered evidence of a pollution problem. The magnitude of change, in given variables, that would be considered deleterious to the bowhead population has not been discussed in BEMP workshops to date and was not evaluated further by the present group.

In scientific research, investigators attempt to minimize Type I errors, usually setting $\alpha = 0.05$ (5%) as a conservative level of risk. In medicine, precisely the opposite is desired and so β may be set at 0.05 to minimize the risk of a Type II error (i.e., in medical diagnosis it is far better to inform a patient that he/she has a disease when this is not the case, than to tell a patient he/she is healthy when this is not true). For the purpose of BEMP Hypothesis No. 1, it may be desirable to simultaneously minimize the chance of Type I and II errors, whereas in "pure science", an investigator would avoid the Type I error and let the Type II error level fall where it may. Once α, ß and Δ_x have been established, the following expression can be used in experimental design:

Fractional change to be detected

"Noise"

$$\Delta_x/x = (Z_\alpha + Z_{1-ß})(CV)\sqrt{2/n}$$

n —Sampling Effort in Each Group

Standard Normal Deviation

In concluding this discussion, it was re-emphasized that any attempts to formalize the statistical evaluation of the bowhead hypothesis must consider the fact that there will still be a problem of different time scales and an obvious need to make inferences on the long-term time scale from information collected over proximate and annual time scales. Any extrapolation to the long-term time scale should also be made on a "worst case" basis rather than averages because events in single years have been known to cause major population changes. Despite the uncertainty that would be associated with selecting appropriate α, ß and Δ_x values, it will still be important to determine acceptable risk levels for Type I and II errors in any test of new (null and alternate) hypotheses relating the distribution of the bowhead population to either industry activity or natural differences in the availability and quality of their prey.

CONCLUSION RELATED TO HYPOTHESIS NO. 1

Following the discussion of experimental design considerations, each participant in the workshop was asked to express an opinion regarding five possible conclusions related to the existing bowhead hypothesis. These were:

1. It is extremely unlikely and does not justify further testing.
2. It is possible, but would be too difficult to detect.
3. More information is required before designing any further research.
4. It should be tested with a detailed research plan.
5. The hypothesis is not testable.

It was the majority view that either Conclusion #2 or #5 was true. During this round-table discussion, several important points were made by participants:

1. Several participants stated that the above conclusions should be applied to various links rather than the entire hypothesis. It was also suggested that there may be testable questions embodied within the hypothesis, even if the hypothesis as a whole may not be testable.

2. Concern was expressed that the risk of a Type II Error (ß) be minimized to the extent possible. Although both α and ß can be set low when there are no financial constraints on a project, it was believed that concentrating on a low ß would place the greatest emphasis on maintaining concern for the status of the bowhead population. However, the sampling effort must increase substantially as the risk of Type II error is decreased.

3. One participant suggested that it is unlikely that the bowhead population is presently limited by its food supply because numbers are well below historic levels.

4. As in the previous BEMP workshop, it was suggested that it may never be possible to "prove" or "disprove" this hypothesis, and that it may be necessary to rely on "weight of evidence". Similarly, other participants viewed the overall purpose of the hypothesis as a framework to focus research rather than a true testable hypothesis in a statistical sense.

5. There was discussion of the need for clear definition of "stopping rules", whereby predetermined goals in research directed at bowhead whales are set in relation to some combination of scientific and management objectives. Such "stopping rules" should also be established for other projects funded directly as a result of recommendations of BEMP workshop participants, including those relevant to other hypotheses.

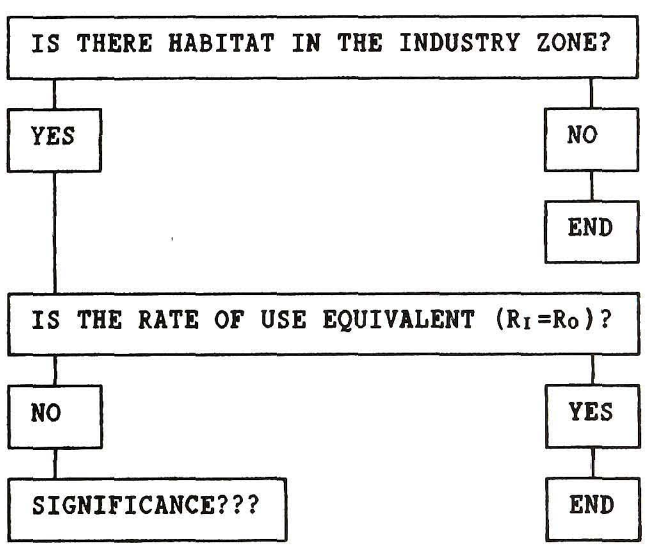
6. At present, the Inuvialuit are not significantly involved in review of research or management issues related to the bowhead whale population, although it is anticipated that greater involvement in these areas will occur in the future. As in the new bowhead whale hypothesis discussed later in this report (Hypothesis No. 21), potential concerns regarding interference with whale-watching activities (i.e., tourism potential) were identified during the discussions of Hypothesis No. 1.

7. Some participants believed that there was a need to continue research on various links in Hypothesis No. 1 despite the conclusion that the overall hypothesis was probably either untestable as formulated, or any changes that may be associated with industry operations would be too difficult to detect. The discussion of research needs focused exclusively on examination of the distribution of adequate bowhead feeding habitats within and outside the industry zone.

DISCUSSION

Workshop participants generally concluded that future research should focus on available food and habitat for bowhead whales in the Beaufort Sea, but should simultaneously consider the statistical factors discussed earlier (α, β, Δ_x) and have pre-established "stopping rules". The key question was considered to be **"Is the rate of utilization of zooplankton patches the same inside and outside the industrial development zone?"**

During the discussion of this question, it was necessary to assume that a given zooplankton patch has an equal probability of being used by bowheads independent of its location. Another important criterion was that zooplankton patches be of equivalent quality, which includes both the composition and density of planktonic organisms. Rate of use of these patches rather than availability of food per se was concluded to be fundamental to this question. The use of the following simple fault tree to focus on key questions was briefly discussed:



It was argued that the answer to the first question would have to be considered yes in at least some years (i.e., 1980 and 1981). This led to a discussion of the need to address: (1) natural variability in zooplankton densities and community composition both within and among years, and (2) properly define habitat in terms of some **volume threshold**. Such a volume threshold should be large enough to be detected by both whales and researchers. Synoptic coverage would be essential in this type of research, thereby favouring the use of hydroacoustic techniques over net tows to determine the spatial extent of areas where zooplankton densities exceed the pre-determined threshold. It was also suggested that synoptic coverage would have to include observations of bowheads, as well as the zooplankton patches that are being exploited by whales.

A 2 x 2 factorial design research strategy was discussed, whereby the rate of use of zooplankton patches inside and outside the industry zone is determined as a frequency for each of four conditions:

	PATCHES WITH WHALES	PATCHES WITHOUT WHALES
INSIDE INDUSTRY ZONE	**Frequency 1**	**Frequency 2**
OUTSIDE INDUSTRY ZONE	**Frequency 3**	**Frequency 4**

A third dimension for time could also be added to this table to address seasonal and/or annual variability in prey use patterns, and thereby allow application of a 3-way ANOVA or non-linear model contingency table analysis. In fact, it was suggested that it may be unsound to attempt such a test without an adequate time series.

Once Δ_x is established, it is then possible to determine the sampling effort (n) that would be necessary within and outside the industry zone during any given synoptic survey, assuming an equal number of patches in each area (total n would increase if it is unequal). This was attempted during the workshop using the following expression:

$$n = (Z_\alpha + Z_{1-\beta})^2 \frac{2p(1-p)}{\Delta_p^2}$$

where Z is the standard normal deviation, p is the proportion of patches used and Δ_p is the difference in the proportion of patches used. When $\alpha = 0.05$ (2-tailed) and $\beta = 0.5$ (1-tailed), the following table shows the critical relationship between n and Δ_p for $p = 0.5$ and $p = 0.2$, where p is the average proportion of patches used.

NUMBERS OF SAMPLES REQUIRED FOR EACH AREA

FOR $p = 0.5$

n	Δ_p
∞	0
134	.1
34	.2
15	.3
8	.4

FOR $p = 0.2$

n	Δ_p
∞	0
86	.1
22	.2
10	.3
6	.4

It was evident from this analysis that a relatively large sampling effort would be necessary to statistically test the null hypothesis that the availability and rate of use of zooplankton patches within the industry zone are not the same as outside this zone. Therefore, this led to further discussion of the need for a "stopping rule" and of existing abilities of researchers to find zooplankton patches where whales are not present. In earlier presentations, it was evident that net tows in areas where bowheads were feeding frequently showed high zooplankton densities. However, in a synoptic investigation of the type discussed here, the use of hydroacoustic techniques was considered the only practical means of locating zooplankton patches where whales are not simultaneously present. Further discussions focused on the existing technology for conduct of hydroacoustic research and the need for new equipment capable of discriminating biological targets from physical gradients within the water column, perhaps through the use of multiple scanning frequencies. The potential usefulness of sequential net sampling in conjunction with hydroacoustic measurements was also briefly discussed, although some participants expressed concerns that too much emphasis could be placed on resolution of small-scale patches rather than water mass correlations over a broader scale. It was eventually concluded that water mass correlations would be a co-requisite of research on the distribution of zooplankton patches.

Several other research design problems were raised during the discussion of any further investigations of bowhead food availability in the region. The first was definition of the control zone outside the region of industry activity. It was suggested that comparable water depths and distances from shore should be a pre-requisite for valid comparison of zooplankton densities within and outside the industry zone. It was recognized that seasonal variability in the location and extent of the Mackenzie River plume would complicate comparisons in many situations when much of the industry zone was within the influence of the turbidity plume. Another concern was proper definition of the industry zone, particularly because of inherent difficulties associated with comparison of waters off the Mackenzie Delta and Tuktoyaktuk Peninsula with those off the Yukon coast. There were also perceived problems related to the simultaneous collection of data on bowhead whales, particularly the appropriate time scale and methods. It was stated that aerial and ship surveys must occur concurrently and, in the case of systematic aerial surveys, the spacing of transects at 10-km intervals can miss significant whale concentration areas. For this reason, it was stated that research in support of food availability studies should not rely solely on systematic surveys of bowhead whales.

The need for continuation of the annual systematic surveys of bowheads during late August and early September was not discussed during the workshop, but was mentioned by participants during review of the draft report. These individuals suggested that there is still long-term scientific merit in conducting this research, despite the higher priority given to discussion of available food and habitat studies during the workshop.

RECOMMENDATIONS

There was NOT consensus among the group in relation to the need for further research related to Hypothesis No. 1 and the overall nature of such research. However, there was support from several participants in each of the following directions:

1. No further work related to BEMP Hypothesis No. 1 should be initiated without an associated "stopping rule" to ensure that the progress of such research is leading to resolution of the hypothesis, and its results are of practical use for management decisions of the sponsoring government agencies.

2. The group generally endorsed the value of research designed to determine the rate of use of zooplankton patches inside and outside the industry zone, although several participants emphasized the need for a benefit-cost analysis and time estimate for completion of this research.

3. Development of hydroacoustic measurement techniques that would allow distinction of biological targets from physical water column gradients was endorsed as an area of future need.

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HYPOTHESIS NO. 20

THE DISCHARGE OF DRILL CUTTINGS CONTAMINATED WITH OIL-BASED DRILLING MUDS DURING HYDROCARBON EXPLORATION OR PRODUCTION WILL REDUCE POPULATIONS OF FISH, BIRDS, OR MAMMALS OR WILL DECREASE THE HARVEST OF THESE RESOURCES DUE TO HYDROCARBON ACCUMULATION IN TISSUES.

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INTRODUCTION

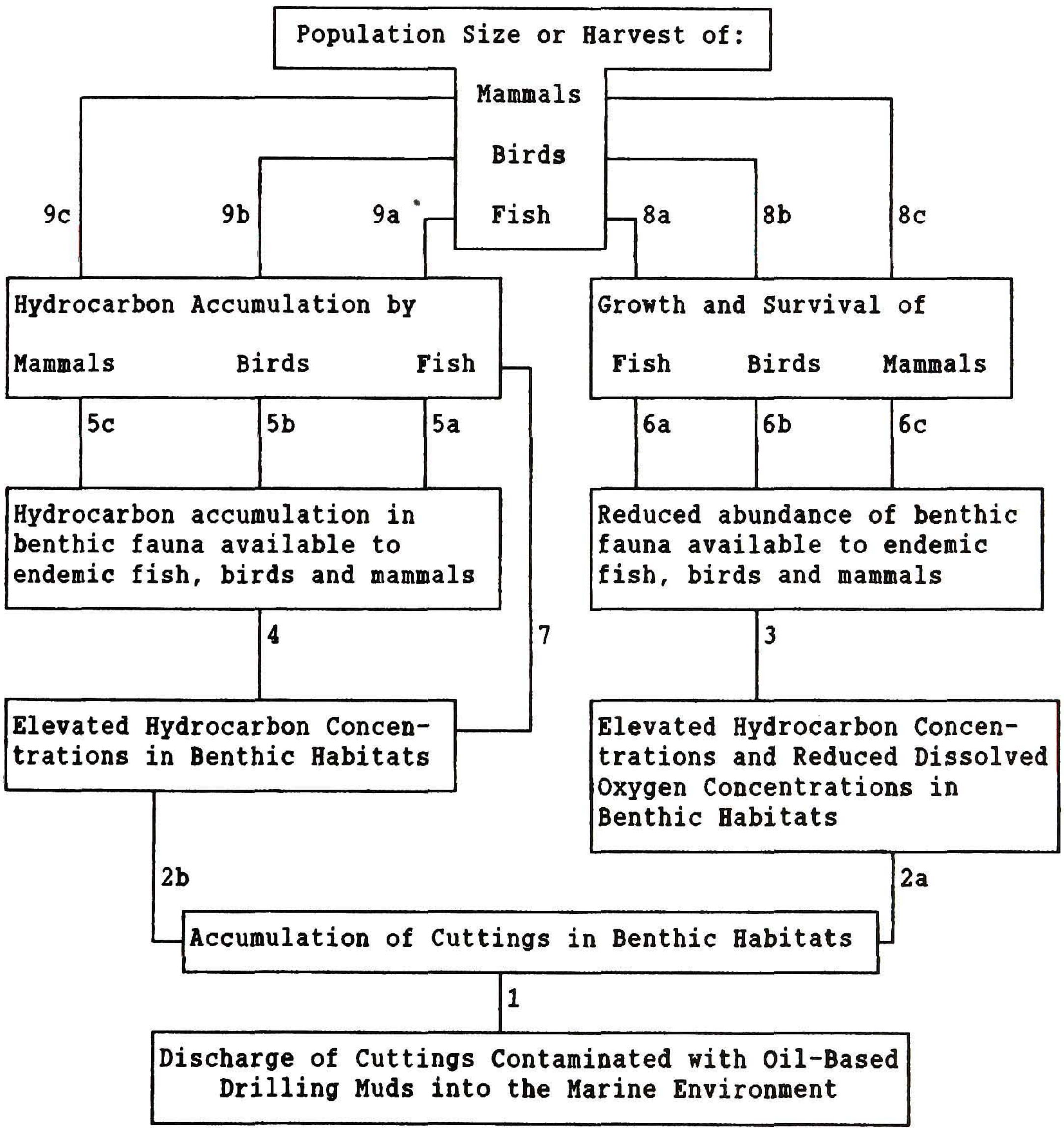
Since the last BEMP workshop on this hypothesis in 1985, the use of oil-based muds (OBM) and the disposal of cuttings contaminated with oil-based mud have become a reality in the Beaufort Sea. This fact combined with the need to evaluate the results of studies on subjects related to the use, disposal and possible environmental fate and effects of oil-based muds in the Beaufort Sea provided the focus for the current workshop held during March 1987 in Calgary.

The hypothesis presented to the working group is shown in Figure 20-1. The following sections summarize: (1) overviews of completed and on-going research that may be relevant to this hypothesis; (2) the probable validity of each of the hypothesis links; and (3) the overall conclusions and recommendations of the group for research and monitoring to address the hypothesis.

FIGURE 20-1

EFFECTS OF CUTTINGS CONTAMINATED WITH OIL-BASED DRILLING MUDS ON THE POPULATION OR HARVEST OF FISH, BIRDS AND MARINE MAMMALS

The discharge of drill cuttings contaminated with oil-based drilling muds during hydrocarbon exploration or production will reduce populations of fish, birds or mammals or will decrease the harvest of these resources due to hydrocarbon accumulation in tissues.



Linkages

1. Drill cuttings contaminated with oil-based drilling muds and discharged during exploration or development drilling will settle rapidly to the seafloor and resist subsequent widespread dispersion due to the cohesiveness of oil-based mud/cuttings mixtures.

2a. In areas of cuttings accumulation, elevated hydrocarbon concentrations will occur in benthic habitats.

2b. In areas of cuttings accumulation, elevated hydrocarbon concentrations and reduced dissolved oxygen concentrations will occur in benthic habitats during the slow degradation of oil-based muds adhering to drill cuttings.

3. The abundance of benthic fauna available to endemic fish, birds and mammals will be reduced in areas of mud/cuttings accumulation due to smothering, oxygen depletion and toxicity of petroleum hydrocarbons in drilling muds or the products resulting from their degradation.

4. Benthic fauna available to endemic fish, birds and mammals in habitats containing mud/cuttings mixtures will accumulate petroleum hydrocarbons.

5a. Decreased abundance of benthic fauna will affect the growth and survival of marine and anadromous fish.

5b. Decreased abundance of benthic fauna will affect the growth and survival of birds that feed on benthic prey organisms.

5c. Decreased abundance of benthic fauna will affect the growth and survival of marine mammals that feed on benthic prey organisms.

6a. Marine and anadromous fish will accumulate petroleum hydrocarbons from ingestion of contaminated prey.

6b. Birds will accumulate petroleum hydrocarbons from ingestion of contaminated prey.

6c. Marine mammals will accumulate petroleum hydrocarbons from ingestion of contaminated prey.

7. Marine and anadromous fish remaining in areas containing oil-contaminated cuttings will accumulate petroleum hydrocarbons directly.

8a. The size of marine and anadromous fish populations will be reduced due to local effects of reduced prey availability on growth and survival.

8b. The size of marine bird populations will be reduced due to local effects of reduced prey availability on growth and survival.

8c. The size of marine mammal populations will be reduced due to local effects of reduced prey availability on growth and survival.

9a. The population size or harvest of fish will be reduced due to the presence of petroleum hydrocarbons in fish tissues.

9b. The population size or harvest of birds will be reduced due to the presence of petroleum hydrocarbons in bird tissues.

9c. The population size or harvest of marine mammals will be reduced to the presence of petroleum hydrocarbons in marine mammals tissues.

General Aspects of Oil-based Muds, Cuttings and Cuttings Cleaning Procedures

Oil-based muds are drilling muds in which oil is the continuous phase. The main advantages of oil-based mud systems over water-based mud systems include: (1) improved hole stabilization particularly during the drilling of deviated wells; (2) increased protection of water-sensitive oil formations; (3) higher lubricity to ease release of the drill stem and prevent differential sticking; and (4) vast improvement of scaling and corrosion problems (Rogers 1974; Browson and Peden 1983; Lepine 1984). Diesel oil was originally favoured as the continuous phase of oil-based muds because it was readily available and inexpensive. In recent years, however, highly refined mineral oils such as naphthenic and paraffinic oils (the so-called low toxicity or alternative base oils) have replaced diesel because of their lower aromatic content and higher flash points.

Well cuttings become contaminated with drilling mud during the drilling process. Treatment of oiled cuttings by mechanical means including washing does not remove all the adhering drilling mud. Consequently, the discharge of drill cuttings will introduce some amount of petroleum hydrocarbons from the base oil to the marine environment. Based on information provided in Thomas et al. (1983), up to 25 percent (wt/wt) of the mud cuttings mixture may be petroleum hydrocarbons derived from oil-based drilling fluids for untreated diesel cuttings, 15 percent for treated diesel cuttings, and 5-10 percent for alternative base oil-based cuttings.

Summary of the Use of Oil-based Muds in the Beaufort Sea

Low toxicity oil-based drilling muds have been used to drill four wells in the Beaufort Sea (Johancsik and Grieve 1987a). The first, Nipterk L-19A, was drilled during the spring of 1985 using Esso DMO-75 as the base oil.

This well was a 55° directional well; oil-based mud was used because it offered a solution to directional drilling in a formation where severe hole problems and stuck pipe had been encountered earlier (Nipterk L-19). Use of the oil-based mud at Nipterk L-19A was very successful; in addition to eliminating hole problems, more than a doubling of the average penetration rate was achieved. Because the DMO-75 base oil contained an aromatic hydrocarbon content of 27%, ocean disposal of Nipterk drill cuttings was prohibited. Consequently, the cuttings were transported to shore and incinerated at Tuktoyaktuk. They had an overall oil retention of 23.7 g oil per 100 g drill solids. During late 1985, oil-based muds were used to drill wells at Adgo G-24 and Minuk I-53. The fourth well to employ oil-based muds was drilled in late 1986 at Kaubvik I-43.

Adgo G-24 was a 60° directional delineation well in the Adgo field. Vista ODC was used as the base oil. Although this base oil contained acceptably low concentrations of aromatic hydrocarbons for marine disposal, the cuttings were incinerated to avoid discharge to the shallow nearshore environment where ADGO G-24 was situated. The well was drilled successfully to a total depth of 3087 metres.

At Minuk I-53, a combination of VISTA ODC and DMO-75 up to a total aromatic content of 5% was used as the base oil to drill the portion of the well from 1000 to 3366 m total depth. Overall oil retention on the cuttings for the well was 13.6 g per 100 g dry solids. The cuttings were discharged to the ocean. At Kaubvik I-43, a mixture of VISTA ODC and EXXSOL D-60 was used for the interval between 984 m and 3323 m total depth. Oil retention on cuttings at this well was 14.95 g per 100 g dry solids. The cuttings were discharged overboard in ice-covered waters.

Regulatory Guidelines for the Use of Oil-based Drilling Fluids on Canada Lands

The use of oil-based drilling fluids on Canada Lands is governed by "Guidelines for the Use of Oil-based Fluids" (COGLA 1985) and administered by the Canada Oil and Gas Lands Administration. The critical environmental aspects of the Guidelines are:

1. Base Oil: The Guidelines suggest that the total hydrocarbon content of the base-oil should not exceed 5% and that the polycyclic aromatic hydrocarbon content should be as low as possible. Higher molecular weight polycyclic aromatic hydrocarbons (4-7 ring aromatics), in particular should not be present in the base oil. The base oil should be non-acutely toxic in a standard toxicity test using rainbow trout fingerlings, in which exposure is for 96 hours to the 100% water-soluble fraction of the base oil.

2. Oil Retention on Cuttings: Oil retention targets are 20 g oil per 100 g dry solids on a well average basis, with the maximum individual reading not to exceed 30 g oil per 100 g dry solids. Oil retention is measured by the standard retort test.

The Guidelines for approved oil-based mud formulations permit disposal of oil-contaminated drill cuttings directly to the ocean. Provision is made, however, to modify the guidelines to accommodate circumstances where there is known environmental sensitivity or concern (e.g., water depths < 20 m and critical biological habitats such as migration corridors, feeding areas, rearing areas, etc.).

Environmental Effects Associated with the Marine Disposal of Oil-based Mud Contaminated Drill Cuttings in the North Sea

Historically, most drilling in the North Sea has involved use of water-based muds. Diesel oil gradually replaced water as the base fluid and in 1981, 36% of the 212 wells drilled in the United Kingdom sector of the North Sea had at least one section or part of a section drilled with diesel-based muds (Addy et al. 1984). Over the years 1981-1983, the quantity of oil discharged from all offshore rigs and platforms operating in the North Sea in drill muds and cuttings increased from about 7500 tonnes to 17,500 tonnes. The UK sector accounted for 80-90% of the total discharges (14,000 to 15,750 tonnes). In 1983, Denmark discharged no diesel oil, while 24% of the Netherlands's, less than 50% of the UK's and 60% of Norway's discharged oil was diesel (Anon. 1985). By 1985, low aromatic content refined oils with a lower acute toxicity replaced diesel oil entirely in offshore drilling in the UK sector of the North Sea.

Numerous field studies have been conducted to determine the level of environmental disturbance resulting from North Sea drilling activities using diesel OBM and "low-tox" alternative oil-based mud (ABM). The results of these investigations have been discussed by Grahl-Nielson et al. (1980), Addy et al. (1983), Addy et al. (1984), Davies et al. (1984), Poley and Wilkinson (1983), and Hannam et al. (1987). The general conclusions of these studies are:

1. Cuttings contaminated with diesel OBM have a restricted environmental impact in time and areal extent. For bottom sediments, field observations indicate that three distinct zones of effect can be distinguished. Zone 1 extends from the production platform to approximately 500 m. Within this zone, the benthic community is impoverished, anaerobic conditions prevail in the surficial sediments and sediment hydrocarbon concentrations exceed 1000 times

local background. Zone 2 (200-2000 m) is a transition zone in terms of benthic diversity and community structure. Hydrocarbon concentrations are typically 10-700 times local background and aerobic conditions exist in the sediments. Zone 3 (800-4000 m) is characterized by hydrocarbon levels 1-10 times local background. No benthic community effects are evident within Zone 3.

2. The change to mineral oil-based muds appears to have had no influence on the nature of ecological effects described above in 1. The areal extent is the same and the main effects on the benthic environment are smothering of biota and organic enrichment.

In 1982, a joint research project was established to assess the environmental effects of oil-contaminated drill cuttings on the seabed fauna at Statfjord in the Norwegian Sector of the North Sea. A summary of the results of this research project relevant to BEMP Hypothesis 20 is presented in INAC and Environment Canada (1986).

The Development Scenario

Over the past decade, the scenario for the extent, pace and duration of offshore hydrocarbon development in the Beaufort Sea has changed greatly. With respect to the use and disposal of oil-based drilling muds and cuttings in the Beaufort Sea, the working group considered this hypothesis within the following probable, but not rigidly fixed, set of circumstances:

1. Oil-based muds would be used primarily in development and production drilling, and only rarely for routine exploratory drilling. Even for development and production drilling, oil-based muds would likely be used only in difficult (water-sensitive) formations, the deep portion of wells or the deviated portions of directional wells.

2. Between 5 and 20 wells would be drilled from a given platform or drilling unit.

3. Oiled cuttings would be discharged to the sea on a routine basis only if they conformed to COGLA guidelines. This would, theoretically, include the possibility of discharges to offshore and shallow nearshore areas.

4. Cuttings treatment facilities: On an existing drilling unit in the Beaufort Sea, cuttings would be treated with existing cuttings handling equipment which is capable of reducing the oil content of discharged cuttings to 10-30 percent by weight of dry cuttings (Figure 20-2: A. Hippman, Dome Petroleum, pers. comm.). As current regulations specify a maximum of 20 percent oil by weight of dry cuttings, no additional treatment steps would be taken unless this could not be achieved. A newly-designed drilling platform may incorporate additional cuttings processing systems to recover used (and expensive) base oil. Cuttings washing systems are capable of reducing cuttings oil content to 5-10 percent by weight of dry cuttings. High and low temperature thermal treatment systems reduce oil content to less than 5 percent by weight of dry cuttings and, in optimum situations, to less than one percent (Figure 20-2). Some systems recover base oil, whereas others are used exclusively to reduce the oil content of cuttings. If mechanical solids control equipment has reduced oil content to 10 percent or less, then thermal systems can be fed directly without the need to employ a cleaning system (A. Hippman, pers. comm.).

REVIEW OF LINKAGES

Link 1: Cuttings contaminated with oil-based drilling muds and discharged during delineation or development drilling will settle rapidly to the seafloor and resist subsequent dispersion due to the cohesiveness of mud-cuttings mixtures.

The use of oil-based drilling muds results in the production of drill cuttings coated with base oil. Only a portion of the oil adhering to the drill cuttings can be removed by a variety of solids control equipment and cuttings washing techniques (Thomas et al. 1983; Warnheim and Sjoblom 1986). Consequently, disposal of cuttings from oil-based mud systems will result in the introduction of base oil to the Beaufort Sea. Typically, North Sea cuttings have contained 6-17% base oil by weight. (Blackman et al. 1982). For those Beaufort Sea wells drilled with oil-based muds, base oil retention has been less than 20 g oil per 100 g dry cuttings for an environmentally acceptable base oil. Current regulations permit such drill cuttings to be discharged directly to the Beaufort Sea.

Evidence from operating oil platforms in the North Sea suggests that oiled cuttings will settle rapidly to the seafloor. The main factors influencing the time required for cuttings to reach the seabed are: (1) height

Discharge Of Oil-Contaminated Cuttings

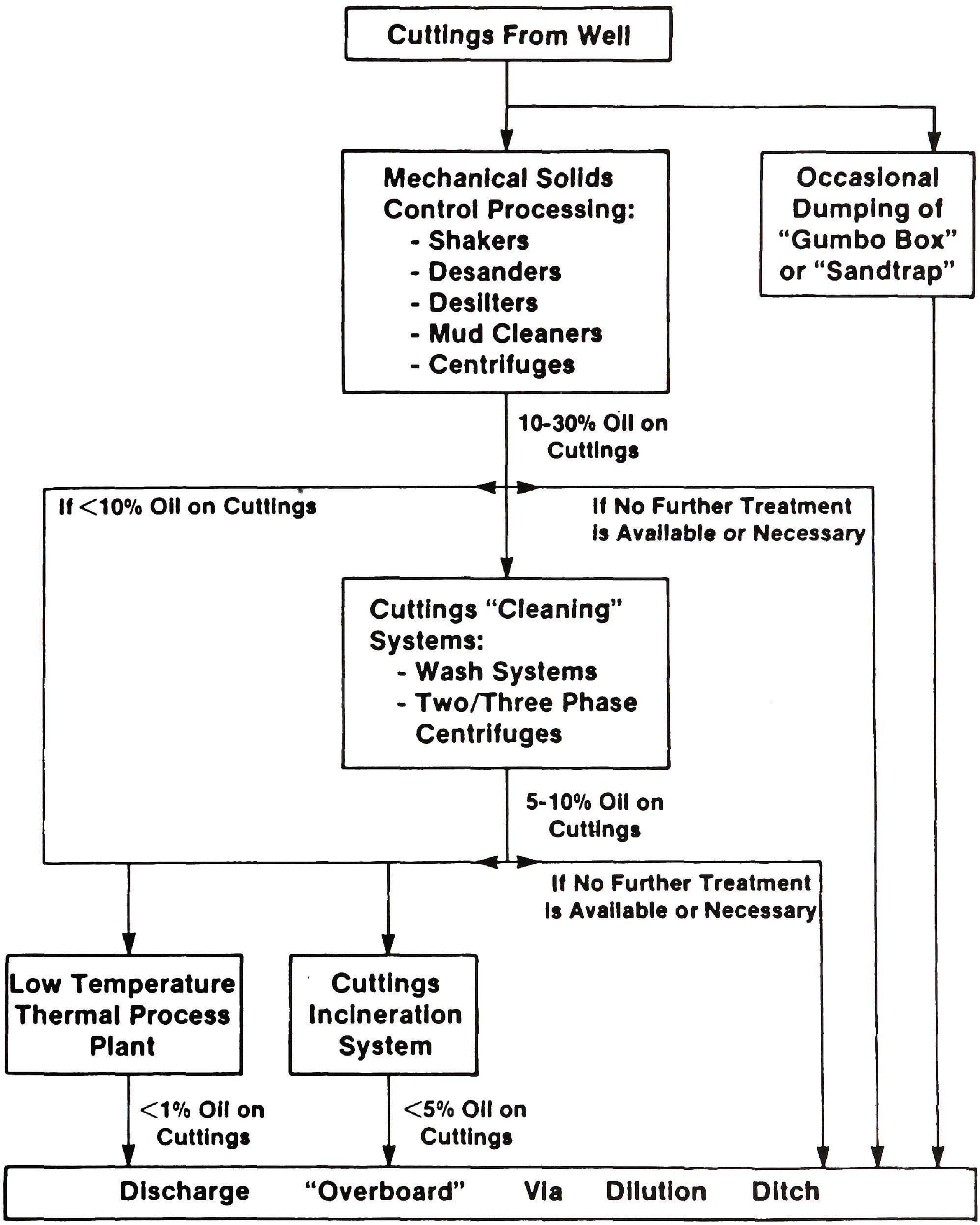


Figure 20.2 ... the treatment and discharge of oil-contaminated drill

of the discharge point above the seafloor; (2) density of the cuttings discharge; and (3) effective particle size distribution of the cuttings particles. Poley and Wilkinson (1983) indicate that for water depths of about 150 m, effective particle sizes in the range 0-2 mm and bulk densities of 1.7-2.5 g cm^{-3}, the time for the cuttings to reach the bottom will be less than 20 minutes in most cases. In the Beaufort Sea where most drilling locations are in water depths shallower than 35 m, it is likely that cuttings will settle rapidly to the seafloor (i.e., within minutes).

The initial areal extent of the cuttings accumulations on the seafloor will be determined primarily by the instantaneous value of the current velocity as the cuttings settle through the water column and are transported laterally. Grahl-Nielson et al. (1980) observed that at Statfjord (water depth 150 m) in the North Sea, virtually all cuttings were deposited within 30 m of the drilling platform when water currents were <10 cm s^{-1}. This observation was confirmed at the Brent Field (water depth 150 m) under similar current conditions. Poley and Wilkinson (1983) indicate that the areal extent of deposited cuttings (in 150 m of water) extends up to 1200 m when current velocities reach 30 cm s^{-1}. This areal extent is consistent with the general observation that most of the cuttings discharged from North Sea platforms are confined to within an area of 1000 m (Davies et al. 1984; Addy et al. 1984; UKOOA 1983). Increases in the quantity of cuttings discharged increased the thickness of the deposit, but not its areal extent. A recent ESRF study (Yunker and Drinnan 1986) on the distribution of low-toxicity oil-based mud discharged at two exploratory well sites near Sable Island Nova Scotia indicated that the zone of effect detected around the site occurring in a water depth of 70 m was similar in size to that suggested by North Sea experience. However, the zone of effect at the 16 m site was less than that predicted on the basis of the North Sea experience. An on-going study at the Minuk and Kaubvik well sites in the Beaufort Sea is attempting to estimate the zone of effect of oil-contaminated drill cuttings (see Project Overview No. 20-1). Because current velocities in the water column seldom exceed 30 cm s^{-1} in the areas of the Beaufort Sea where drilling occurs (Giovando and Herlinveaux 1981) and water depths are much less than 150 m, it is probable that the areal extent of cuttings piles will be less than those documented in the North Sea.

Once the cuttings reach the seafloor, their subsequent dispersal will be affected by bottom currents, ice scouring, storm events and natural sedimentation. The extent of dispersal will be linked directly to the amount of energy applied to the cuttings. Consequently, cuttings deposited in shallow areas (0-10 m) are most likely to be dispersed because the influence of storms, the incidence of ice scouring and the occurrence of strong bottom currents are generally greatest in the areas. High natural sedimentation rates (5 mm per year) and the cohesiveness of the oiled cuttings (Blackman and Law 1981) will tend to limit movement of cuttings on the seafloor. Experience with oiled cuttings in the North Sea suggests that cuttings deposits are so cohesive that they form a "pavement-like" material which prevents the transport of water and oxygen to the cuttings beneath this lid (Bakke et al. 1986). Yunker (1986) provides some data suggesting that "pavement" formation occurred during laboratory experiments conducted with cuttings contaminated with Vista ODC base oil from the Beaufort Sea Adgo G-24 well site.

The probable net effect of the physical processes influencing dispersion on a cuttings pile is not clear. For example, ice scouring may have little more than a furrowing effect on a cuttings pile and this would not likely result in significant dispersion or movement of cuttings, as might be expected if ice acted like a snowplow when it contacted cuttings piles. Storm waves definitely disturb bottom sediments in the coastal Beaufort Sea, but may cause burial of the cuttings with resuspended sediment as much as they promote their dispersal. In addition, active sedimentation in nearshore areas may cover cuttings to the extent that they are somewhat isolated from the influence of local currents and waves. On the basis of observations of the disintegration of abandoned artificial drilling islands in the Beaufort Sea (Harper and Penland 1982) where the cores of many islands have remained largely intact for several years, particularly once they have been reduced to subaqueous shoals, the action of natural dispersal mechanisms may be less effective in dispersing cuttings than might otherwise be expected in an area subject to harsh autumn storms and ice scouring.

On the basis of available information, the group agreed that cuttings contaminated with oil-based mud and discharged during drilling in the Beaufort Sea would settle rapidly to the seafloor and resist subsequent dispersal due to the cohesiveness of the mud-cutting mixture, although it was expected that some spreading of the cuttings (perhaps several hundred metres) would occur. It was concluded, therefore, that Link 1 is valid.

Link 2a: In areas of cuttings accumulation, elevated hydrocarbon concentrations will occur in benthic habitats.

The available evidence indicates that this link is valid. The level of hydrocarbon enrichment in benthic habitats to which cuttings have been introduced will depend largely on the quantity of cuttings discharged, the amount of oil adhering to those cuttings, and the effectiveness of natural dispersion mechanisms.

A simple calculation can provide considerable perspective relevant to this hypothesis link. A typical Beaufort Sea well is drilled to 3500 m (e.g., Amauligak I-65-A, Koakoak 0-22, Adgo G-24, Minuk I-53, Kilannak A-77 and Orvilruk 0-3 were drilled to total depths of 4520, 4900, 3087, 1940, 3000 and 4300 metres, respectively (COGLA 1987)). Assuming a typical casing program[1], the volume of cuttings produced will be approximately 400 m^3. It should be noted that this is a worst case estimate because water-based muds are generally used on the upper portions of wells, with oil-based muds being used to drill only the deeper portions and the deviated portions of directional wells. If these cuttings were discharged to the sea containing the maximum level of retained oil permitted by the COGLA guidelines, approximately 200 m^3 of base oil[2] would enter the marine environment for each 3500 m well drilled. In reality, the amount of oil discharged with cuttings will be less and would vary from well to well.

Several factors influence oil retention on cuttings.

(1) Cuttings Size: This is the single most important factor influencing oil retention. Oil retention increases exponentially as the particle size decreases. For cuttings finer than 500 m, the oil retention is greater than 20 g/100 g solids (Johancsik and Grieve 1987b). The significance of this relationship in the Beaufort Sea is that the oil retention on cuttings will likely be high at any location where large quantities of unconsolidated sandstone are present in the formation.

(2) Base Oil: Oil retention on cuttings will tend to increase as kinematic viscosity increases. However, this effect is smaller than the influence of cuttings size on oil retention.

(3) Mud Systems Density: In general, oil retention is less for a high density mud than for a low density mud.

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1 assuming 762 mm casing from 0-200 m, 508 mm casing from 200-600 m, 340 mm casing from 600-2000 m, 244 mm casing from 2000-3000 m and 178 mm casing from 3000-3500 m, the total volume of cuttings would be 360 m^3

2 assumes a cuttings specific gravity of 2.6. It is also noteworthy that small quantities of formation oil may occur occasionally with the base oil from as drilling with an OBM can extract some geological oil from the formation.

(4) Operation of Solids Control Equipment/Mud Formulations: The use of the screens on the shale shakers will tend to reduce oil retention by removing low gravity solids before they have an opportunity to disintegrate into finer solids (due to both mechanical agitation of the screens and the washing process) which then creates additional surface for the retention of oil. For effective solids control, it is desirable to use the finest shaker screens possible.

The pattern of enrichment of hydrocarbons in the sediments surrounding a drilling operation will be influenced by numerous factors as illustrated by considering the four cases below. It is stressed that the zones of effect or accumulation described in these cases and illustrated in Figure 20-3 are approximations only, although they are thought to be generally realistic given field observations in the North Sea and offshore Nova Scotia and environmental conditions known to exist in the Beaufort Sea.

CASE 1. High Use, Deep Water
10 wells drilled from a bottom-founded drilling unit in 30 m of water.

CASE 2. Low Use, Deep Water
1 well drilled from a bottom-founded drilling unit in 30 m of water.

CASE 3. High Use, Shallow Water
10 wells drilled from a bottom-founded drilling unit in 5 m of water.

CASE 4. Low Use, Shallow Water
1 well drilled from a bottom-founded drilling unit in 5 m of water.

Case 1: High Use, Deep Water

This case is intended to represent a production facility operating in a water depth of 30 m in the ice shear zone. The Amauligak field is located at about this water depth and in this ice regime. The example examines the possible fate of oiled cuttings produced by drilling ten 3500 m wells from a single location and discharging cuttings to the sea through a sealine at one location (Figure 20-3). As the average time required to drill a well would be about 45 days, completion of 10 wells would take about 1.5 years. Consequently, discharge of drilling waste would occur during both open water and winter conditions. While drilling is underway, it is assumed that discharge would be continuous. The entire drilling programme will produce 4000 m^3 cuttings containing about 2000 m^3 of retained base oil. Most of this material will make contact with the slope of the subsea berm within minutes.

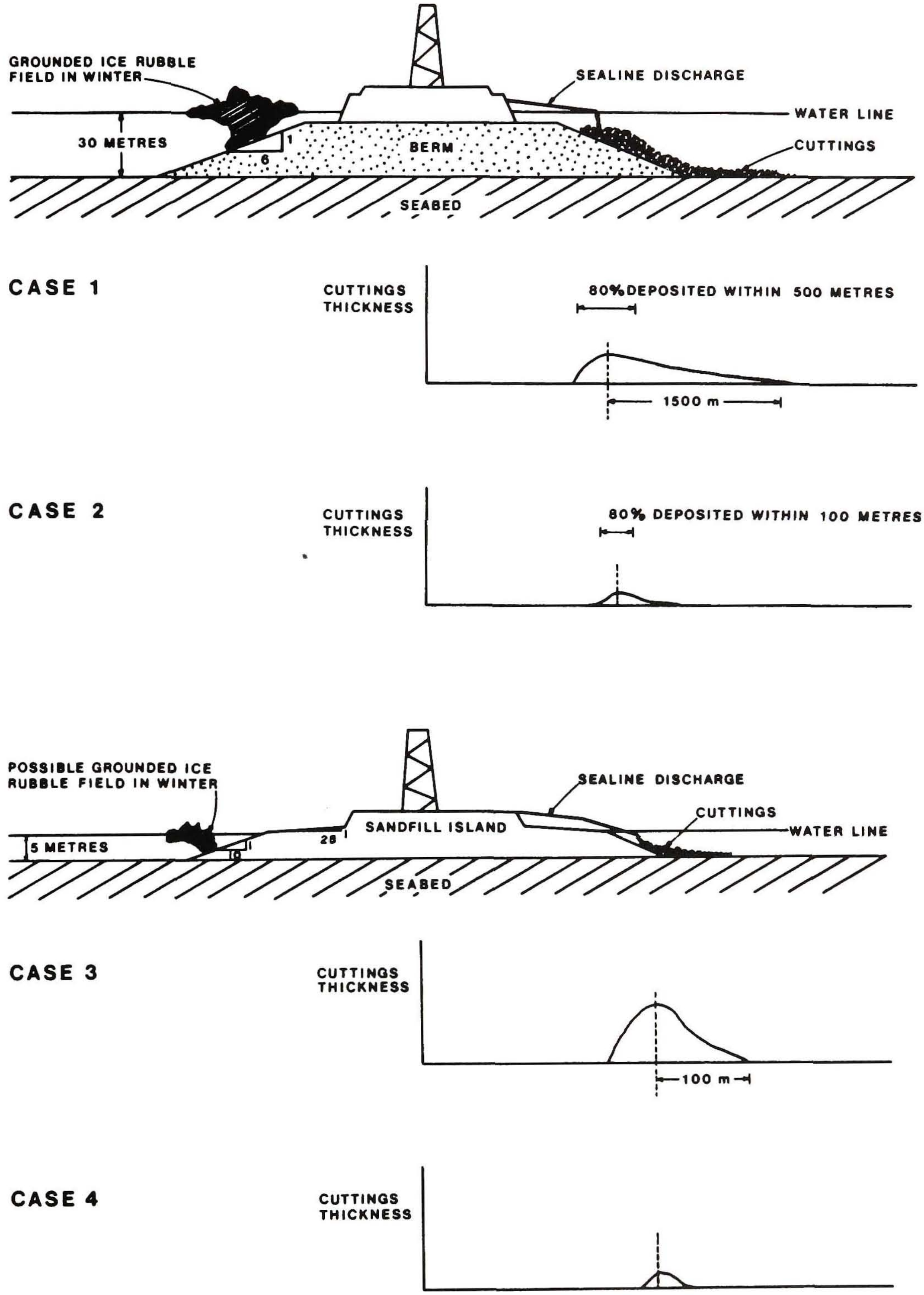

Figure 20-3 Schematic showing possible accumulation of drill cuttings under different drilling scenarios: Case 1. High use (10 wells), deep water (30 m); Case 2. Low use (1 well), deep water; Case 3. High use, shallow water (5 m); Case 4. Low use, shallow water.

Over time, the pile of cuttings will become thicker and extend a greater distance downslope. Some of the cuttings will be mixed with berm sediment during this process. Natural sedimentation together with the settling of sediment particles suspended during open water storm events will tend to mix uncontaminated sediment with the oiled cuttings. It is expected that most of the cuttings will accumulate within 500 m of the discharge area. Temporary confinement of cuttings within a limited area could occur if the discharge occurred into an area dammed up by an ice rubble field in winter, although dispersion and downslope movement would resume in spring following breakup. A gradient in the thickness of the cuttings pile is expected, with a maximum thickness of perhaps 1 m (Figure 20-3). In areas where the thickness of cuttings is several centimetres thick, the formation of a cuttings "pavement" will be likely and this area could conceivably cover an area 100 m in radius and account for 80-100% of the total cuttings discharged.

The concentration of hydrocarbons in sediments will not necessarily follow the distribution of cuttings. The highest sediment hydrocarbon concentrations will certainly be found in the areas of maximum cuttings accumulation near the discharge site. However, hydrocarbon concentrations may be elevated in sediments in areas where there are no cuttings present. This could occur because as the cuttings are discharged and settle through the water column, small amounts of oil dissolve and some oil droplets may separate from the cuttings. These hydrocarbons could then be scavenged by the naturally high suspended particulate load common to the southern Beaufort Sea during the open water season, and may be transported by currents to locations several kilometres or more away from the point of release to the marine environment. Overall, it is highly unlikely that significant enrichment of hydrocarbons would be evident beyond the distances (800-4000 m) at which such enrichment was measured around North Sea platforms, where total loading was higher and water depths 5 times greater. A more realistic estimate of the zone of significant hydrocarbon enrichment in the Beaufort Sea would be 500-1000 m.

Case 2: Low Use, Deep Water

This case is intended to represent the drilling of a delineation well in the ice shear zone. Total discharge of cuttings is 400 m^3 of which approximately 200 m^3 is retained base oil. Dispersion of oily cuttings will be highly dependent on environmental conditions at the time of discharge. In general, discharge of cuttings under ice during winter would represent a minimum dispersion case whereas discharge into open water during a high energy storm event would be a maximum potential dispersion situation. The general processes acting on the discharged cuttings would be similar to those described for Case 1. The major difference in Case 2 is simply the much smaller amount of cuttings discharged. It is likely that 80% or more of the cuttings would accumulate within 100 m of the release point discharge (Figure

20-3). Sediments enriched with hydrocarbons are not likely to occur beyond 500 m from the discharge site.

Case 3: High Use, Shallow Water

This case is intended to represent a production facility operating in shallow nearshore waters as might be the case in a field such as ADGO. The disposal of 4000 m^3 of cuttings over a period of 1.5 years in a maximum water depth of 5 m would result in a cuttings pile that was thicker and covered a smaller area than that predicted for the deep water case (Case 1). Most of the cuttings would probably accumulate within 100 m of the discharge (Figure 20-3) and form extensive areas of "pavement". Ice scouring would likely disturb the cuttings pile, but would not necessarily disperse or move it. Sedimentation rates of 4-5 mm per year could be expected in such shallow areas near the river delta. This accumulation of natural sediment together with sediment erosion or sloughing from the island slope and sediment settling following resuspension during storm events could be a very effective mechanism for burying cuttings and isolating them from the overlying water column. Enrichment of hydrocarbons in the sediments would probably be limited to several hundred metres around the discharge area. As in Case 1, enrichment in areas beyond these distances would be possible as the result of hydrocarbon transport out of the area on suspended particulates during the open water season.

Case 4: Low Use, Shallow Water

This case is intended to represent an exploration well in shallow nearshore waters. The fate of cuttings will be similar to that described in Case 3, except that the quantities involved are much smaller and the initial distribution of cuttings could be influenced greatly by the conditions existing in the receiving environment at the time the well is drilled (i.e., stable winter conditions or possible high energy open water conditions). Due to the shallow water, cuttings will reach the bottom very rapidly. Most of the cuttings will probably accumulate within tens of metres of the discharge site in winter and perhaps up to 100 m away in open water (Figure 20-3). Elevated hydrocarbon concentrations in sediments will likely be confined to approximately 100 m of the discharge location. Burial of the cuttings pile by sediments as described above in Case 3 would be more likely in Case 4 because of the much smaller volume of cuttings involved.

Link 2b: **In areas of cuttings accumulation, elevated hydrocarbon concentrations and reduced dissolved oxygen concentrations will occur in benthic habitats during the slow degradation of oil-based muds adhering to drill cuttings.**

It has already been established in Link 2a that elevated hydrocarbon concentrations will occur to varying degrees in areas of cuttings accumulation. The aerobic degradation of petroleum hydrocarbons by micro-organisms and the oxidative decomposition of organic compounds creates an oxygen demand (Riley and Chester 1971). If the rate of oxygen demand exceeds the rate at which the oxygen can be supplied, oxygen concentrations will decrease to the point that anaerobic conditions will develop. This will lead to a decline in redox potential and the proliferation of sulphate-reducing bacteria, the production of hydrogen sulphide gas, and a further decline in redox potential of the sediments.

There is ample evidence that this link is valid. Data obtained in studies of oiled cuttings on the seabed around North Sea production platforms clearly demonstrate the existence of anaerobic conditions in the sediments up to about 500 m from the drilling platforms (UKOOA 1983; Thomas et al. 1983; Addy et al. 1984; Davies et al. 1984). The reduced dissolved oxygen concentrations will be limited largely to the area within and beneath the zone of cuttings accumulation.

Link 3: **The abundance of benthic fauna will be reduced in areas of mud/cuttings accumulation due to smothering, oxygen depletion, and toxicity of petroleum hydrocarbons in drilling muds or the products resulting from their degradation.**

This link is valid. There are four general ways that the abundance (number of species or density (biomass)) of benthic fauna can be reduced in areas of oil-contaminated drill cuttings accumulation:

(1) smothering by physical burial;

(2) inhospitable anaerobic conditions;

(3) changes in substrate texture; and

(4) direct toxicity of the hydrocarbons (or their degradation products) in the drilling mud or direct toxicity of H_2S (anaerobic conditions).

Smothering by Physical Burial

Physical burial of benthic fauna is an inevitable consequence of discharging drill cuttings into marine environments. The areal extent of the zone of smothering depends on the volume of cuttings discharged and the mode of discharge (intermittent or continuous, one point source or many etc.). It is not expected that the zone of impact from smothering will exceed that reported from this cause around North Sea platforms (approximately 500 m) (Addy et al. 1984; Davis et al. 1984; UKOOA 1983) because of shallower water and, on average, the fewer number of wells likely to be drilled from a given platform in the Beaufort Sea.

Inhospitable Anaerobic Conditions

In general, the presence of anaerobic conditions resulting from the decomposition of organic enrichment in the immediate vicinity of discharge would reduce the diversity of fauna in benthic communities. However, the actual biomass of benthic fauna could increase over local background if large numbers of opportunistic species that can use petroleum as an energy source flourish. This phenomenon has been observed around North Sea production platforms such as Statfjord (Matheson et al. 1986).

Changes in Substrate Texture

The introduction of cuttings to the seabed will alter the local substrate texture. As indicated earlier, the greatest alteration will occur in the area of maximum cuttings accumulation directly beneath and in close proximity to the discharged site, where the local substrate is completely replaced by cuttings. Beyond this proximal zone, however, is an area where the local sediments are not totally covered by cuttings, but contain some cuttings or a thin veneer of fines that have settled from the discharge plume. The presence of small amounts of cuttings/fines may be sufficient to affect the distribution and numbers of benthic species.

Direct Toxicity of the Hydrocarbon (or their degradation products) in the Drilling Mud or Direct Toxicity of H_2S

Oil-based drilling muds have been shown to be toxic to many species of marine organisms. This toxicity can be related generally to the quantity of polycyclic aromatic hydrocarbons in the base oils and other mud additives. The inherent toxicity of many polycyclic aromatic hydrocarbons to marine life is well established (Anderson et al. 1974; Stegeman and Sabo 1976; American Petroleum Institute 1978; Sirota and Uthe 1981; Ahokas and Peltonen 1984; Zahn et al. 1984). Toxicity investigations conducted with oiled (Conoco Low PNA base oil) cuttings from the Shell PCI et al. Alma F-67 well on the Scotian Shelf indicate that, in short-term (96-h) static bioassays, the cuttings were not acutely toxic to three species of bivalve molluscs, Stage IV lobster larvae, sea urchins, threespine stickleback, Atlantic silverside or winter flounder (Hutcheson et al. 1984; Barchard and Doe 1984; Addison et al. 1984). In long-term (4-32 days) exposures, however, there was significant mortality in a surface feeding bivalve (*Macoma balthica*) and a deposit feeding polychaete (*Nepthys caeca*). Although the specific agent or agents present in the drill cuttings responsible for the mortality were not identified, it appears clear that the cuttings caused the death of invertebrates through some toxic mechanism.

Observations from the field are not so straightforward. Although a clear correlation has been demonstrated between benthic community disruption (including mortality) and hydrocarbon concentration in the sediments (Addy et al. 1983; Addy et al. 1984; Davies et al. 1984; Matheson et al. 1986), this correlation does not necessarily imply a toxic effect. It may simply reflect the effect of organic enrichment and the resulting anaerobic conditions. It is also possible that the effect may indeed be toxic in nature, but related to the presence of H_2S formed by the anaerobic action of sulphate-reducing bacteria rather than toxic hydrocarbons. Regardless of agent, if toxic effects occur, they will be limited to the small area of cuttings accumulation.

On the basis of the above information, it is expected that the overall effect of drill cuttings accumulation on the abundance of benthic fauna will be localized and insignificant on a regional scale. The reduction in abundance of fauna would be directly proportional to the area of habitat destroyed by placement of the cuttings. The workshop subgroup concluded that no serious consequences would result from discharge of oily cuttings, given that no critical habitats or populations of benthic species are known to exist in the Beaufort Sea and could be significantly affected by the scale of cuttings discharge likely to occur. The accumulation of discharged cuttings on the seabed would have more pronounced effects on benthic infauna than epifauna, although less mobile and sedentary epifauna could also be affected. The duration of the effect would vary from location to location depending upon effectiveness of local oceanographic processes in rehabilitating the affected area. For example, a high natural sedimentation rate would tend to bury the cuttings and provide a suitable surface for recolonization.

<u>Link 4</u>: **Benthic fauna and habitats containing mud/cuttings mixtures will accumulate petroleum hydrocarbons**

Benthic invertebrates have been shown to accumulate in their tissues the various classes of aliphatic, alicyclic and aromatic hydrocarbon compounds found in crude oil and refined petroleum products (Ehrhardt 1972; Scarratt and Zitko 1972; Farrington and Quinn 1973; Clark and Finley 1974; Fossato and Siviero 1974; Hunter <u>et</u> <u>al</u>. 1974; Mayo <u>et</u> <u>al</u>. 1974; Stegeman 1974; DiSalvo <u>et</u> <u>al</u>. 1975; Ehrhardt and Heinemann 1974; Neff and Anderson 1975; Gilfillan <u>et</u> <u>al</u>. 1977; Sirota and Uthe 1981; Widdows <u>et</u> <u>al</u>. 1982 Widdows <u>et</u> <u>al</u>. 1983). In fact, the bioaccumulation of contaminants (including hydrocarbons) by benthic invertebrates is the foundation of the U.S. National Mussel Watch Programme (Goldberg 1975; Goldberg <u>et</u> <u>al</u>. 1978; Philips and Segar 1986; Risebrough <u>et</u> <u>al</u>. 1983).

Specific examples of bioaccumulation of hydrocarbons by benthic invertebrate are given below.

(a) The marine worm, <u>Neanthes</u> <u>arenaceodentata</u> accumulated 30 ppm of aromatic hydrocarbons and 5 ppm aliphatic hydrocarbons when exposed to the water soluble fraction of No. 2 fuel oil for 4 hours (Rossi and Anderson 1976).

(b) Bivalves (<u>Ostrea</u> <u>lurida</u> and <u>Mytilus</u> <u>edulis</u>) accumulated paraffinic hydrocarbons following exposure to outboard motor fuel (Clark and Finley 1974).

(c) The clam <u>Rangia</u> <u>cuneata</u> accumulated benzo(a)pyrene from sea water during a 24-hour exposure (Neff and Anderson 1975).

(d) Uptake and depuration of petroleum hydrocarbons were measured in five species of bivalves (Boehm 1983), a sea urchin and a polychaete (Engelhardt and Norstrom 1982) at the Baffin Island Oil Spill site on Baffin Island following experimental spills of partially weathered Lago Medio crude and an oil/dispersant mixture in 1981. Petroleum hydrocarbons were detected in the tissues of all of the species within days of both spills. Initially, the oil was detected primarily in the gut of bivalves. Persistence of the hydrocarbons in the sediments resulted in a steady uptake by deposit feeders and tissue concentrations remained high. By the summer of 1982, the hydrocarbon concentrations in filter feeders were much lower than deposit feeders as the deposit feeders continued to remove significant quantities of oil from the sediment, whereas the filter feeders had depurated most of their body burden of hydrocarbons by this time.

(e) Blackman and Law (1981) studied the uptake of hydrocarbons from North Sea diesel-oiled cuttings by the bivalve detritivore Scrobicularia plana. They found maximum tissue concentrations of 6200 ppm and concluded that uptake must have occurred directly from the solid phase to produce such high body burdens.

Several factors have been shown to influence the bioaccumulation (the difference between uptake and depuration) of hydrocarbons by benthic invertebrates. These include:

1. The concentration and type of hydrocarbons in sediment and sea water

The degree of bioaccumulation in invertebrate tissues generally increases as the concentration of hydrocarbons in the sea water or sediment phase to which the animals are exposed also increases. For many compounds, bioaccumulation from solution (either overlying sea water or sediment interstitial water) can be directly related to the n-octanol/water partition coefficients (Geyer et al. 1982). Thus, paraffinic hydrocarbons and high molecular weight aromatics such as chrysene and pyrene tend to bioaccumulate more readily than low molecular weight compounds such as benzene and naphthalene.

2. The speciation of the hydrocarbons and presence of other complexing molecules

Studies of hydrocarbon uptake by several benthic invertebrates have indicated that the presence of particulates may increase or decrease bioaccumulation (Neff and Anderson 1981; McLeese and Burridge 1984). Ingestion of particulates may be an important pathway for bioaccumulation, particularly with hydrophobic compounds such as benzo(a)pyrene which bind strongly to particulates. The presence of dissolved organic matter such as humic substances has been shown to reduce the bioavailability of some types of hydrocarbons. For example, McCarthy (1983) demonstrated that the accumulation of benzo(a)pyrene by Daphnia magna was reduced by 97% in the presence of 20 mg humic acid L^{-1} water. Boehm and Quinn (1976) showed that the removal of dissolved organic matter from sea water caused a sevenfold increase in the uptake of hydrocarbon by the clam Mercenaria mercenaria, when exposed to No. 2 fuel oil.

3. The duration of exposure

The biological half-life of hydrocarbons accumulated by benthic invertebrates appears to be related to the length of time that organisms are exposed to hydrocarbons. Short-term acute exposures of hours or several days tend to lead to rapid depuration (Lee et al. 1972), whereas long-term chronic exposures (months) tend to result in retention of significant amounts of hydrocarbons by the organism for months (Widdows et al. 1982; Stegeman and Teal 1973). It is postulated by Stegeman and Teal (1973) that hydrocarbons can be stored in two distinctly different compartments within an animal: (1) the fraction stored in lipid deposits which cannot be eliminated readily; and (2) the fraction stored in various sites including organs which can be eliminated readily when the animals are no longer exposed to hydrocarbons.

4. The type of body tissue

There is some evidence for differential uptake of hydrocarbons among tissues within the same organism. Neff and Anderson (1975) showed that ^{14}C-labelled benzo(a)pyrene accumulated primarily in the viscera of the clam Rangia cuneata, with smaller accumulations occurring in the mantle, gills and adductor muscle. Lee et al. (1972) indicate that the hepatopancreas is a significant storage site for hydrocarbons in mussels. Boehm (1983) found that the more water-soluble aromatics (naphthalene, alkylated benzenes) were transported to the muscle tissues rapidly in Serripes groenlandicus, whereas the less water-soluble phenanthrenes and dibenzothiophenes were preferentially located in the gut.

5. Specific characteristics of the invertebrate species (feeding, habitats, metabolic processes)

Filter feeders acquire hydrocarbons primarily from the aqueous phase, whereas deposit feeders generally acquire their hydrocarbon burden from the sediment. Because concentrations of hydrocarbons in sediment are usually higher and more persistent than those found in the aqueous phase, deposit feeders often bioaccumulate hydrocarbons to a greater extent than filter feeders. The rate of feeding also may have an effect on the kinetics of bioaccumulation. Gilfillan and Vallas (1984) found that Serripes groenlandicus (a fast filter feeder) accumulated hydrocarbons more quickly and to a greater extent than did the slower feeding Mya truncata.

Invertebrates are generally incapable of, or extremely inefficient at, metabolizing hydrocarbons. Lee et al. (1976), however, demonstrated that the blue crab, Callinectes sapidus could metabolize benzo(a)pyrene, methylcholanthrene and fluorene to yield hydroxy derivatives.

6. Temperature

Fucik et al. (1977) report that the greatest uptake of naphthalene occurred in two clam species exposed to this aromatic hydrocarbon at 10°C and was lowest at 30°C. Fossato (1975) found that the amount of aliphatic hydrocarbons retained by the clam *Mytilus galloprovincialis* increased as the temperature of the sea water in the depuration environment decreased. These data suggest that environmental temperature can be an important factor in evaluating the extent of bioaccumulation of petroleum hydrocarbons by marine benthic invertebrates.

The above overview provides the following information relevant to this link of BEMP Hypothesis No. 20.

(1) benthic invertebrates can accumulate petroleum hydrocarbons;

(2) the rate and extent to which bioaccumulation occurs will depend strongly on the species exposed, the chemical composition of the base oil used in the drilling operation and the presence of other competing compounds in the sea water and sediments (including humic substances and dissolved organic matter);

(3) deposit feeding benthic organisms will tend to maintain high body burdens of hydrocarbons as long as they continue to be exposed to oil-contaminated cuttings or sediments whereas filter feeders will tend to be less affected;

(4) the use of the published literature to evaluate bioaccumulation potential by various invertebrate species may be limited due to the possible large influence of temperature on hydrocarbon uptake and depuration by marine benthic invertebrates.

Link 5a: Decreased abundance of benthic fauna will affect the growth and survival of marine and anadromous fish

A decreased abundance of benthic fauna could affect the growth and survival of marine and anadromous fish if availability of this food source were a critical determinant of the population size of these species. It is not expected, however, that the availability of benthic fauna as a food source will be affected to the extent that it could have a significant effect on the growth and survival of fish because:

(1) the area of benthic habitat affected by the disposal of cuttings will represent only a small portion of the total available habitat on the Beaufort Sea Shelf. For example, if the disposal of cuttings from a 10-well platform severely disrupted the benthic habitat within a 1000 m radius of the discharge point (worst case scenario), then approximately 0.005% of the shelf area would be affected. This area of habitat is considerably less than that already affected by island construction, dredging and natural ice scouring in the Beaufort Sea (EBA Engineering Consultants Ltd. et al. 1984, Harper and Penland 1982); and

(2) at the present time, there are no known areas of critical feeding habitat for fish in the Beaufort Sea. If such critical feeding habitats are identified in the future, then the potential would exist for decreased abundance of benthic fauna to have a significant effect on the growth and survival of fish. This would be possible if cuttings disposal disrupted a large portion of the available critical feeding habitat.

This link was judged to be valid, but the extent to which it occurred would be extremely small within the context of the current "several-location/10-wells-per-location" development scenario in shallow or offshore areas. Therefore, any significant effect would be highly unlikely.

Link 5b: Decreased abundance of benthic fauna will affect the growth and survival of birds that feed on benthic prey organisms.

This link was judged to be valid for the same reasons and to a similar extent as Link 5a. Any possible effect of drill cuttings on birds will be directly proportional to the scale of the discharge and would also be highly dependent on the location and water depth at discharge sites.

Link 5c: Decreased abundance of benthic fauna will affect the growth and survival of marine mammals that feed on benthic prey organism.

This link was also considered to be valid, but the extent to which it occurred would be extremely small given the current development scenarios for either shallow or offshore areas of the Beaufort Sea. Any significant effect would be highly unlikely. Any possible effect of drill cuttings on marine mammals will be directly proportional to the scale of the discharge.

Link 6a: Marine and anadromous fish will accumulate petroleum hydrocarbons from ingestion of contaminated prey.

The accumulation of hydrocarbons in the tissues of fish following consumption of contaminated prey is well documented (Hardy et al. 1974; Roubel et al. 1977; Anderson 1975; Whittle et al. 1977; Malins and Hodgins 1981). Although this link was considered possible, the extent to which hydrocarbons may accumulate in individual fish from ingestion of contaminated prey will depend on their feeding habits and the amount of contaminated benthic biomass available. The accumulation of hydrocarbons is the net result of four processes (1) uptake; (2) distribution among various tissues; (3) metabolic degradation; and (4) depuration. The uptake from contaminated prey depends on the rate of ingestion of the food, lipid content of the fish, hydrocarbon concentrations in the prey organisms and assimilation efficiencies of specific hydrocarbons present in the food. Generally, there must be continuous exposure to contaminated food for significant accumulation to occur, otherwise depuration during periods of feeding on uncontaminated food will allow gradual removal of accumulated hydrocarbons within fish tissues.

For the following reasons, the group concluded that only limited uptake of hydrocarbons would occur in marine and anadromous fish through ingestion of prey contaminated by oiled drill cuttings in the Beaufort Sea.

1. The area of the Beaufort Sea containing any contaminated prey will be small (several km^2). Consequently, the number of fish that may be exposed to contaminated benthic organisms will also be small. In addition, the duration of exposure would be relatively short and intermittent because fish would likely swim into and out of areas containing contaminated prey. The potential for exposure would also tend to be greater in nearshore areas than in offshore areas because greater numbers of fish occur within the shallow coastal areas of the Beaufort Sea.

2. The biomass of benthic fauna likely to be contaminated and, therefore, the total amount of hydrocarbons available to fish in their prey will be low. This can be illustrated by the following hypothetical example which would represent a worst case situation:

- there are five point-source discharges from platforms discharging oiled cuttings;

- cuttings piles have an exposed area of 2500 m^2 (50 m x 50 m);

- the cuttings piles are populated with benthic fauna at the maximum biomass observed in the 0-30 m zone of the Beaufort Sea (30 mg^{-2}, Wacasey 1975);

- the hydrocarbons from the cuttings are taken up by benthic fauna to 1000 ppm of body weight (this extent of accumulation is an upper limit of values reported by Clark and MacLeod (1977) for benthic organisms exposed to acute and chronic oil spills);

- 100% of the benthic invertebrates are available to fish per feeding cycle.

  Given the above conditions, the total benthic biomass on cuttings piles would be 250 kg. Given further that processes such as sedimentation and burial of cuttings do not reduce the availability of hydrocarbons to benthic fauna, the total amount of hydrocarbons associated with this 250 kg of biomass and available for consumption by fish would be 1 kg. Even at a retention efficiency of 10%, this amount of hydrocarbons could only cause a body burden of 100 ppm in 2000, 500-g fish.

3. In the case of drill cuttings accumulations in shallow nearshore waters, there would be only limited exposure of the VEC fish species (broad whitefish, lake whitefish and Arctic cisco) because these anadromous fishes spend only part of the year in nearshore waters. Furthermore, it is expected that these populations do not feed actively during this period (Bond 1982; Lawrence et al. 1984; Bond and Erickson 1985).

Habitat faithful groundfish such as starry flounder and Arctic flounder are the fish most likely to accumulate hydrocarbons from contaminated benthic prey. However, these species are not currently harvested in the southern Beaufort Sea.

Link 6b: **Birds will accumulate petroleum hydrocarbons from ingestion of contaminated prey.**

There is ample evidence that Link 6b is valid and birds will accumulate hydrocarbons if ingested with their food (Dieter 1976; Lawler et al. 1978a,b; McEwan and Whitehead 1980; Gorsline et al. 1981; Tarshis and Rattner 1982). The extent to which accumulation occurs, however, will depend on a large number of factors similar to those outlined above for Link 6a. Accumulation of hydrocarbons by birds from contaminated prey would be limited generally to nearshore areas of the Beaufort Sea where water depths are relatively shallow. The duration of the exposure would be short because birds would feed on benthic prey only during the open water season.

Although this link is generally valid, the argument of scale suggests that no significant accumulation of hydrocarbons would occur in birds as the result of ingestion of contaminated prey.

Link 6c: Marine mammals will accumulate petroleum hydrocarbons from ingestion of contaminated prey.

Marine mammals have been shown to accumulate hydrocarbons from contaminated prey (Kooyman et al. 1976; Engelhardt 1978). Although the link is valid, there are not expected to be significant effects associated with the possible consumption of contaminated prey by benthic feeding marine mammals (walrus, bearded seal) because of the very limited amount of contaminated benthic fauna that would be available to these animals (see Link 6a).

The group considered the possibility that marine mammals (bowhead whales, walrus, bearded seals, ringed seals) could be exposed to contaminated prey for relatively long periods if they were attracted to and remained around offshore structures. The mechanisms for possible biomagnification of hydrocarbons in each of these animals would be as follows:

- bowhead whales - direct ingestion of contaminated prey during bottom feeding. This is based on the observation of mud trails from the mouths of bowhead whales and sediment scours caused presumably by feeding bowheads (e.g., Ford et al. 1987).

- walrus - direct ingestion of contaminated prey during bottom feeding.

- bearded seals - direct ingestion of contaminated prey during bottom feeding.

- ringed seals - ingestion of Arctic cod which were contaminated by feeding on contaminated benthos.

The group concluded that the possibility of significant biomagnification of hydrocarbons in bowheads and walrus was rare because bowheads tend to avoid offshore facilities (see Hypothesis No. 1) and walrus are not normally resident in the Beaufort Sea. Consequently, prolonged exposure to contaminated prey would be highly unlikely. Biomagnification of hydrocarbons in ringed and bearded seals was considered possible given certain ice conditions. Ringed seals prefer a stable ice habitat as found in the landfast zone whereas bearded seals prefer a moving ice regime and the associated open water leads as found in the transition zone (Smith and

Stirling 1975; Burns and Frost 1979; Stirling et al. 1980). Thus, ringed seals attracted to stable ice around facilities in the landfast zone and bearded seals attracted to moving ice around structures in the shear zone would be most likely to experience conditions that could lead to prolonged exposures to oil-contaminated prey. The actual probability that significant biomagnification could occur in more than a small number of individuals was considered low given that: (1) seals would remain near structures only until the limited food was depleted; and (2) the chance of interaction of seals with structures would be low due to the small number of offshore facilities expected.

Link 7: **Marine and anadromous fish remaining in areas containing oil-contaminated cuttings will accumulate petroleum hydrocarbons directly.**

Direct leaching of oil from cuttings into sea water has been measured and appears to be very slow. Engelhardt et al. (1983) report initial rates of 0.1% of total oil per day, decreasing with time. Poley and Wilkinson (1983) indicate possible leaching rates of $2 g.m^{-3}.day^{-1}$.

There are four general pathways through which fish can accumulate hydrocarbons from oiled cuttings:

(1) absorption of hydrocarbons through the skin following direct contact between fish and oiled cuttings;

(2) absorption of dissolved hydrocarbons from seawater through the skin;

(3) absorption of dissolved hydrocarbons through the gills (respiration); and

(4) ingestion of food contaminated with hydrocarbons from the oiled cuttings.

Pathways (1) to (3) are relevant to Link 7. Connell (1974) indicates that pathway (3) is probably the most important of the three. Pathway (1) will be important with groundfish that inhabit areas near cuttings piles and, therefore, may come into direct contact with the oiled cuttings. As noted earlier, however, these fish are not harvested in the Beaufort region. Pathways (2) and (3) are those relevant to the direct uptake by pelagic fish of hydrocarbons associated with oiled cuttings. The extent of direct uptake would depend on the species exposed, the type and concentration of hydrocarbons present in the exposure time. The rate of uptake increases in direct proportion of increasing hydrocarbon concentrations in seawater (Spacie et al. 1983). The following conditions, therefore, would tend to favour direct uptake of hydrocarbons by pelagic fish:

(1) cuttings piles located in a low energy environment where dissolved hydrocarbon concentrations could remain relatively high;

(2) cuttings discharges in shallow areas where fish populations tend to be most abundant;

(3) when winter ice cover restricts water movement, thereby reducing transport of dissolved hydrocarbons away from disposal areas;

(4) any circumstances such as discharge of warm waters, disposal of organic-rich sewage or creation of artificial reefs, etc. that could encourage fish to remain close to cuttings piles for extended periods.

Although this link is valid, it is unlikely that direct uptake of hydrocarbons by fish will be significant because of the very limited areas expected to be affected by cuttings discharge in conjunction with the generally low probability of large numbers of fish occurring in areas of cuttings accumulation.

Link 8a: **The size of marine and anadromous fish populations will be reduced due to local effects of reduced prey availability on growth and survival**

Link 8b: **The size of marine bird populations will be reduced due to local effects of reduced prey availability on growth and survival.**

Link 8c: **The size of marine mammal population will be reduced to local effects of reduced prey availability on growth and survival.**

These links were judged to be invalid because the local losses of benthic organisms expected to result from the scale of drilling operations in the region would not have any significant effects at the population levels of these species.

Link 9a: **The population size or harvest of fish will be reduced due to the presence of petroleum hydrocarbons in fish tissues.**

Link 9b: **The population size or harvest of birds will be reduced due to the presence of petroleum hydrocarbons in bird tissues.**

Link 9c: **The population size or harvest of marine mammals will be reduced due to the presence of petroleum hydrocarbons in marine mammals tissues.**

The population size aspect of these links was judged to be invalid because the amount of hydrocarbons that could be introduced to the environment on oiled cuttings will be too small to cause mortality of the number of fish, birds or mammals necessary to influence the population size of these animals. As indicated in the discussion of Link 6a above, the amount of hydrocarbons available to fish could yield a body burden of 100 ppm in only two thousand 500-g fish. This number probably represents only a very small proportion of the fish population. For example, the catchable Arctic cisco population associated with the Colville River area of Alaska was estimated to be in excess of one million individuals (B. Bond, DFO, pers. comm.). As the number of catchable fish is usually much smaller than the number of non-catchable fish and because the Arctic cisco of the Colville River area are believed to be a small part of the Mackenzie River population, the total number of fish in the coastal Beaufort is in the order of millions if not tens of millions (B. Bond, pers. comm.).

As for Links 9b and 9c, the total amount and aerial extent of hydrocarbons released to the marine environment from routine oil-based mud usage is not likely to influence large numbers of larger, more mobile animals such as birds and mammals, although severe effects could occur with an individual animal or limited numbers of individuals on a limited scale.

The harvest aspect of these links was concluded to be valid, particularly for fish. The existence or mere perception that a taint might exist could reduce the desirability of fish, birds or mammals to human consumers. However, the group recognized that the potential for hydrocarbons to taint individual fish, birds or mammals was probably low due to the limited area affected by oil-contaminated cuttings and the low biomass of prey organisms that could accumulate petroleum hydrocarbons. The possibility of taint was recently examined in the groundfish dabs (_Limanda limanda_) captured close to the Beatrice oil platform in the North Sea, where cuttings contaminated by both diesel and low-toxicity base oils have been discharged (McGill _et al_. 1987). Although contamination from petrogenic hydrocarbons was apparent, none of the fish were found to have a definite taint. To date, there is also no evidence that the harvest of North Sea fishes has declined since the onset of offshore petroleum activities. A review of the factors influencing the acquisition of a taint and an evaluation of the concerns related to tainting of fish resources due to oil spills or hydrocarbon development activities is presented in Tidmarsh _et al_. (1985).

CONCLUSIONS

The structure of the hypothesis shown in Figure 20-1 can be divided into two branches. The right-hand branch encompassing Links 1, 2b, 3, 5 and 8 was viewed as one involving largely the aspects of habitat, where effects are related to habitat loss which in turn is generally related in a linear manner to the scale of activities. The left-hand branch encompassing Links 1, 2a, 4, 5, 7 and 9 is inherently more important in that it involves non-linear interactions such as bioaccumulation and biomagnification, which could lead to consequences beyond the scale or duration of habitat disruption.

The right-hand branch of the hypothesis was considered both valid and testable on a site-specific basis in shallow nearshore areas. In offshore areas where the available habitat is large relative to the scale of possible industrial activities, it was concluded that the hypothesis would fail at Link 5. Although the left-hand branch of the hypothesis was considered possible, it was considered highly unlikely and would not justify testing through a monitoring program.

RECOMMENDATIONS FOR RESEARCH AND MONITORING

Followings the discussion of information gaps during the workshop, research and monitoring requirements were identified in the five areas described below.

1. Fate of discharged oil contaminated cuttings

The group considered the adequacy of existing information for understanding the fate of cuttings in the coastal Beaufort Sea environment within the context of two distinct aspects of dispersal: (1) dispersion within the water column during descent of cuttings; and (2) redistribution of cuttings following initial contact with the seabed. It was concluded that existing dispersion models and field observations were generally adequate to understand the fate of cuttings discharged in offshore areas (loosely defined as areas where water depth exceeds 10 m) and for estimating the extent of seafloor affected. In nearshore (<5 m water depth) areas, however, there is no direct evidence for examining the validity of existing dispersion models and no direct observations or quantitative measurements of the influence of ice scour or storm events on cuttings piles. Nonetheless, the group accepted that the zone of influence associated with the discharge of cuttings in shallow water would certainly be no larger and probably much smaller than predicted by existing models, even when the influence of a large concentration of river-borne particulates capable of adsorbing and transporting oil particles was considered. An unknown factor in the post-depositional fate of cuttings is the extent that sedimentation will bury the cuttings, that scouring will disperse/mix/bury the cuttings, and that storm events will resuspend/bury the cuttings.

The following recommendations for research and monitoring were formulated by workshop participants:

(1) Information should be obtained to assess the actual (effective) size of oiled cuttings particles in the water column following discharge. Due to the viscosity of the base oil and presence of surfactants, it is likely that the particle size relevant to the dispersion model will be that of aggregates and not that of the smaller individual rock fragments.

(2) As all observations regarding cuttings dispersion have been based on single well discharges, direct measurements of the fate of discharged cuttings at a location where cuttings from a large number (perhaps 10) of wells are discharged should be undertaken as soon as there is a suitable opportunity.

(3) The group stressed the importance of obtaining data that would lead to a better understanding of the fate of drill cuttings in shallow nearshore areas. These areas are believed to be extremely important to the ecology of the Beaufort Sea. Based more on intuition than actual evidence, the group recommended that routine discharge of cuttings into nearshore shallow waters should be restricted until such time as there was sufficient information to identify and manage possible geographical or timing constraints to discharges. Consequently, it was suggested that following a complete review and analysis of the fate of oiled cuttings discharged at the Minuk and Kaubvik sites (reports should be available in late 1987), a monitoring program should be designed to determine the fate of cuttings in nearshore areas if and when cuttings are discharged to shallow water.

2. Establishment of a hydrocarbon baseline against which to judge effects of offshore development

A mass balance for hydrocarbons (particularly PAHs) should be completed for the Beaufort Sea. This will require data on background concentrations and identification and quantification of the various sources of hydrocarbons.

It was noted that two current NOGAP projects are underway that will make a mass balance possible within the next several years. These are: (1) a study of hydrocarbons in the MacKenzie River; and (2) a hydrocarbon baseline study of the southern Beaufort Sea.

3. Identification of critical habitats

A general conclusion of the group was that any environmental consequence associated with the marine disposal of oiled cuttings would be insignificant in a regional context. This conclusion was based on the assumption that no critical habitat for birds, fish or mammals existed on a scale that could be jeopardized by the expected scale of offshore exploration, development and production activities. The group expected that this assumption was probably valid for the offshore, but that due to the known or suspected intensive use of the nearshore by many VEC species for feeding, reproduction and migration, an attempt should be made to delineate existing, and identify additional potential, critical nearshore habitats.

4. Oxygen demand of oiled cuttings

The group concluded that the results of laboratory studies conducted to measure the oxygen demand of oiled cuttings would be exceedingly difficult to extrapolate to the Beaufort Sea due to the unknown relative importance of such factors as sedimentation, freeze-up, ice scouring and biological disturbance. Consequently, it was recommended that a field study be conducted to examine the physical and chemical aspects of oxygen oiled cuttings interactions. Ideally, the study should occur at an active disposal site after the discharge of cuttings from several wells.

5. Downhole generation of PAHs

It was suggested that temperatures and pressures commonly found downhole at metal-metal surfaces were conducive to the *in-situ* production of PAHs in the presence of petroleum compounds. No research or monitoring was recommended at the present time. However, an unsubstantiated rumour of an oil company currently preparing a report on this area of potential concern was discussed. To date the existence of such a report or study in progress can not be confirmed. An attempt should be made to determine whether research on this subject has been attempted by anyone. The issue should be considered again at the next evaluation of BEMP Hypothesis 20.

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HYPOTHESIS NO. 21

TANKER TRAFFIC AND MINOR OIL SPILLS ASSOCIATED WITH THE WESTWARD TRANSPORT OF CANADIAN BEAUFORT OIL WILL CAUSE REDUCTIONS IN THE WESTERN ARCTIC POPULATION OF BOWHEAD WHALES AND/OR THE HARVEST OF THIS POPULATION BY ALASKAN INUPIAT

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INTRODUCTION

This hypothesis and its linkages were formulated during the 1987 BEMP workshop to consider a development scenario which may include the seasonal transportation of oil from the Canadian Beaufort Sea in a westward direction off the coast of Alaska. In developing the hypothesis, the workshop subgroup simply used a seasonal production scenario proposed by Gulf Canada Corporation as a case study to focus discussion on the scale of activity that would be associated with this type of development. This scenario proposes that a small tanker (20,000-50,000 DWT) would be used to transfer oil, although other types of vessels may be used.

The approach of the subgroup in developing the hypothesis was similar to that followed during previous BEMP workshops. General concerns regarding the potential impacts of various activities were first discussed, and a number of specific indicators of these concerns were then identified. General issues raised by the subgroup were mostly related to possible disturbance of bowheads in response to the tanker traffic, although the potential impacts of minor oil spills that could occur during the transfer of oil were also discussed. Large-scale accidental oil spills are beyond the scope of BEMP, which is designed to address the effects of "normal activities" associated with hydrocarbon development. Therefore, catastrophic oil spills were not a subject of discussion in the workshop. Specific areas of concern identified by the subgroup included:

- size, age-sex structure and social structure of the bowhead population
- size of the harvest of bowheads by Alaskan Inupiat
- access to the harvest, or catch per unit effort (CPUE)
- access to bowheads for viewing from shore

The distribution of the bowhead population in space and time was then examined in relation to the distribution of activities that would be associated with a seasonal oil production and transportation scenario. In most years, a major portion of the bowhead population feeds in the southeastern Canadian Beaufort Sea during early August to early September. From mid September to mid October, most bowheads pass through Alaskan Beaufort waters in their fall migration to the Bering Sea. It was concluded that the tanker corridor may pass through areas used by bowheads during much of the projected season of operations (1 August - 31 October).

The workshop subgroup reviewed the Gulf proposal in detail to identify specific areas of concern and to formulate and assess the validity of linkages in the hypothesis. As emphasized earlier, the Gulf proposal was used as a model to develop the hypothesis, but discussions were not restricted to this proposal. The Gulf seasonal production scenario would involve use of a single ice-strengthened tanker to transport oil produced from the Amauligak Field in the Canadian Beaufort Sea to a location west of Point Barrow, where the oil would be transferred to a larger tanker for shipment to a Pacific Rim country. The production facility at Amauligak would consist of the Molikpaq, a mobile arctic caisson, positioned on a 16 m sand and gravel berm in 32 m of water. The Molikpaq is able to store about 30,000 m^3 of oil, which is approximately 6000 m^3 greater than the total capacity of a small shuttle tanker. Oil would be transferred from the Molikpaq to a shuttle tanker via a 16-inch (40 cm) suspended hose, capable of filling the ship in 8-12 hours. The transfer hose would be fitted with quick release, dry break connectors to minimize the risk of an oil spill should the tanker be forced to make an emergency departure from the site.

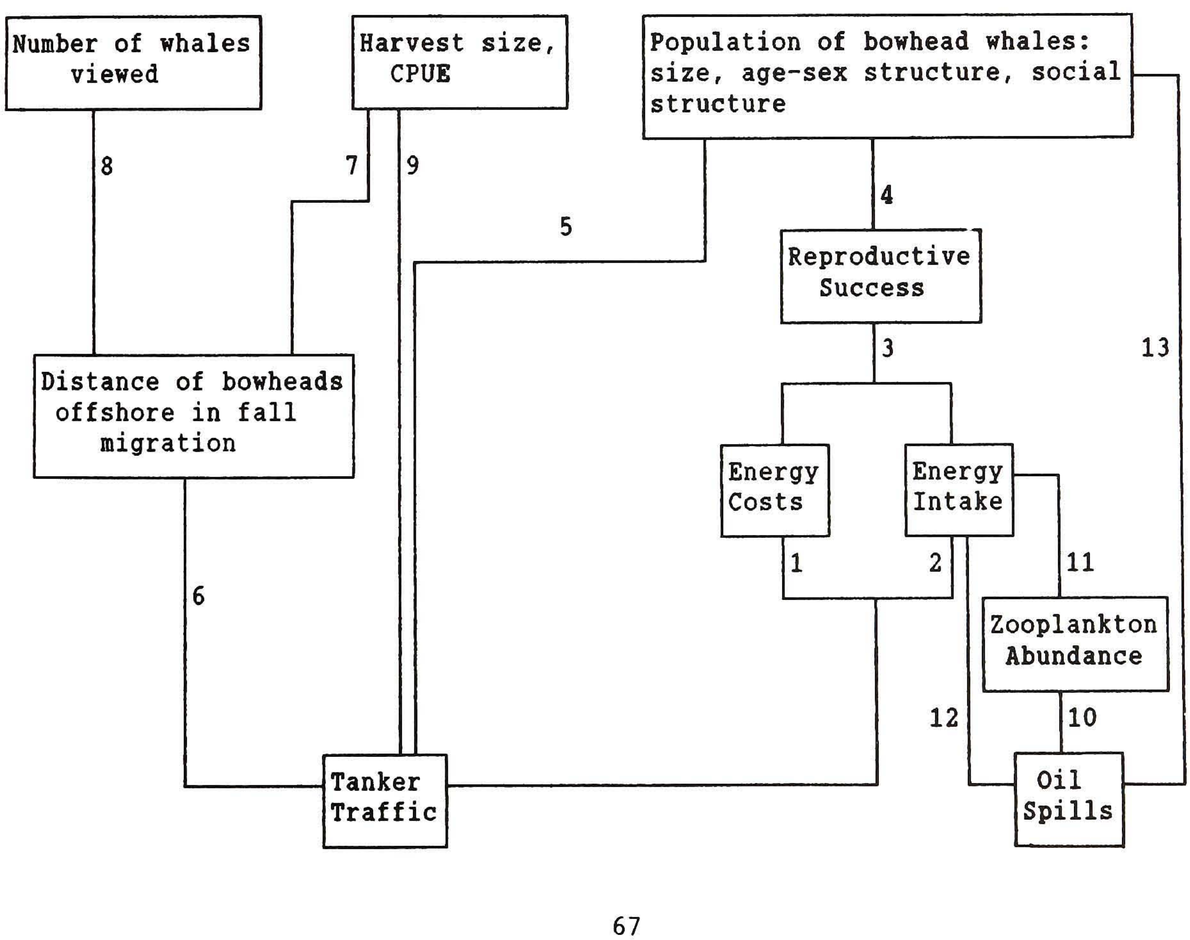
In this scenario, 16 round trips of the shuttle tanker would be completed during the period from 1 August to 31 October, with each round trip requiring about 7 days. Prior to departure of the shuttle tanker, the route would be overflown at an altitude of 30,000 ft (~9000 m) by an ice-reconnaissance aircraft equipped with an imaging radar system. The tanker would depart from the loading site only if < 5/10 ice cover was present in waters > 20 m deep along the entire route. Ice conditions would likely require that the ship approach within 10 km of the Alaskan coast near Barter Island and Point Barrow, especially during October.

Following discussion of the Gulf proposal, the subgroup considered the overall validity of the impact hypothesis by reviewing available evidence for each of its linkages. Potential effects of air traffic associated with a seasonal production scenario was raised initially as a possible concern, but later rejected as being significant. The only aircraft involved with the project would be a single ice-reconnaissance plane, which would fly at an altitude too high to have any influence on bowheads.

FIGURE 21-1

POTENTIAL EFFECTS OF WESTWARD TRANSPORT OF OIL BY TANKER ON BOWHEAD WHALES

Tanker traffic and minor oil spills associated with the westward transport of Canadian Beaufort oil will cause reductions in the western Arctic population of bowhead whales and/or the harvest of this population by Alaskan Inupiat.



Linkages

1. Tanker traffic will affect the energy balance of whales by increasing the amount of energy expended over the course of a year.

2. Tanker traffic will lead to a reduction in the energy intake of bowheads by reducing the time available for feeding.

3. The energy balance of a bowhead whale determines its survival and its ability to reproduce.

4. A decrease in reproductive success will lead to a reduction in population size.

5. Tanker traffic will affect the bowhead population through direct mortality, disruption of social behaviour, and separation of cows and calves.

6. Tanker traffic will cause a long-term offshore displacement of the fall migration of bowheads off Alaska.

7. Offshore displacement of the bowhead migration will cause a reduction in the harvest size and catch per unit effort (CPUE) in the fall hunt of bowheads by Alaskan Inupiat.

8. Offshore displacement of the bowhead migration will cause a reduction in the number of whales that can be viewed from shore.

9. Tanker traffic will be perceived by Alaskan Inupiat whalers to have a negative effect on the success of the fall hunt for bowheads.

10. Oil spills associated with tanker loading and unloading will reduce zooplankton abundance.

11. Reduced zooplankton abundance will decrease the energy intake of bowhead whales.

12. Oil spills will decrease the ability of bowhead whales to feed.

13. Oil spills related to tanker transport will directly reduce the size of the bowhead whale population.

REVIEW OF LINKAGES

Link 1: **Tanker traffic will affect the energy balance of whales by increasing the amount of energy expended over the course of a year.**

There is substantial evidence that a variety of marine vessels can cause avoidance responses by bowheads (Richardson et al. 1985a, 1985b). Such disturbance may cause whales to cease feeding and flee from ships, thereby potentially reducing food intake and causing a negative effect on the energy balance of individuals. The typical response of a whale to approach by a ship is to attempt initially to outrun the vessel, and then to veer off to one side as the ship closes. These responses usually occur at ranges of 1-4 km from the vessel, although reactions at greater distances have been documented. Disturbed bowheads may swim away from the ship for approximately 0.5 h, and during this period they may travel about 2-5 km.

To assess the overall significance of such disturbance responses, the subgroup estimated the energy expended by an individual whale fleeing from a ship. This calculation was based on the energy cost of motion for bowheads, which was estimated during the 1983-84 BEMP workshop (INAC and Environment Canada 1984) to be 0.08 kcal/kg/km for an adult. Assuming that an adult bowhead weighing 50,000 kg swims 5 km in response to the approach of a ship, approximately 20,000 kcal would be expended by the animal. Since the total energy requirement of an average adult bowhead is estimated at 1.6×10^6 kcal annually (Thomson 1987), each disturbance response would represent less than 0.02% of the animal's annual energy budget. If an individual was displaced by the tanker on each of the 32 trips assumed in the Gulf production scenario, this would result in a total cost of 0.40% of its annual energy budget.

The subgroup concluded that the energy expended per disturbance event was unlikely to be significant in the overall energy budget of a bowhead, and that there was only a remote possibility that any single individual would encounter the tanker on repeated occasions. It was thus concluded that Link 1 is unlikely, and further testing is unjustified.

Link 2: **Tanker traffic will lead to a reduction in the energy intake of bowheads by reducing the time available for feeding.**

The southeastern Beaufort Sea is known to be an important summer feeding area for bowhead whales (Würsig et al. 1985; Bradstreet and Fissel 1986; INAC and Environment Canada 1986; Richardson and Bradstreet 1987). A significant amount of feeding by some whales also takes place in Alaskan waters in late summer and autumn of some years (see Project Overview Nos. 1-3 and 1-8, Appendix C). Although the locations of congregations of feeding bowheads vary from year to year, a tanker would be expected to encounter some feeding whales sometime during its passages.

Given the documented disturbance responses of bowheads to moving vessels, it can be expected that there would be some disruption of feeding as a result of tanker passages. Factors that would determine the extent and significance of this disruption were expected to include:

- the size of the zone of disturbance surrounding the tanker;

- the number of feeding whales present within the zone of disturbance;

- the time required for individuals to recover from the disturbance and resume feeding; and

- the number of occasions each feeding whale encounters the tanker.

The size of the zone of disturbance would depend on the threshold of response of feeding bowheads to noise from the tanker, which in turn would depend on the source level of ship noise, sound propagation characteristics of the area, and ambient noise. There is no specific information on the reaction of bowheads to oil tankers, but it can be assumed that ranges of response will be similar to those documented for other marine vessels (i.e., at least 1-4 km).

The time that disturbed individuals may not feed is an important consideration with respect to the possible impact of disturbance on the energy intake of bowheads. The behaviour of whales disturbed by vessel traffic generally appears to return to normal within 1-2 h, although animals observed after this period have not always been feeding (Fraker et al. 1982; Richardson et al. 1985a, 1985b). During studies of bowheads off the coast of Alaska in 1986, Richardson et al. (1987b) documented displacement of whales from a feeding area in response to presence of the survey vessel. Through resightings of photographically-identified individuals, it was observed that at least some of the displaced whales had returned to the area by the next day and resumed feeding. However, whales only remained at this feeding location for five days, and it was not known if their ultimate departure was related to the disturbance or to other natural causes.

Given a development scenario similar to the Gulf proposal and if it is assumed that a bowhead loses 1 h of feeding time on each occasion that it encounters a tanker, a maximum of 32 h would be lost if the same individual was affected during each passage of the ship. This represents about 1.5% of the total time available for feeding during the 90-day period of tanker operations, if it is assumed that this species is able to feed at any time of day or night. The likelihood of any single bowhead encountering the ship on all of its passages along the transportation corridor is extremely remote due to the large size of the summer and fall range relative to the area of the corridor. However, there is evidence of considerable day-to-day tenacity to specific feeding locations (Davis et al. 1983, 1986a, 1986b; Richardson et al. 1987b), so certain individuals could be exposed repeatedly to underwater noise. It is not known whether whales would become habituated to this source of disturbance and, if so, whether the length of each interrupted feeding period would become progressively shorter. The subgroup concluded that Link 2 is possible, but its significance relative to the overall energy balance of bowhead whales cannot be assessed on the basis of available information.

Link 3: **The energy balance of a bowhead whale determines its survival and its ability to reproduce.**

Link 4: **A decrease in reproductive success will lead to a reduction in population size.**

For any animal, it is a fundamental principle that the balance of energy intake and expenditures directly affects its survival and reproductive potential, and that a decrease in the ability of individuals to reproduce will ultimately result in a decrease in population size. The western Arctic population of bowhead whales is believed to do most of its feeding in the Beaufort Sea during summer and early autumn (INAC 1987). Seasonal primary production, zooplankton abundance and the caloric content of zooplankton are all highest in summer. Like other baleen whales, bowheads are not expected to feed significantly during winter, although there is some evidence to the contrary (Schell et al. 1987). Nevertheless, because the abundance and caloric content of zooplankton are at their annual minimum in winter, it is very likely that most of the annual energy requirements of bowheads are obtained through feeding in the summer and early fall.

If a bowhead is disturbed while feeding, this could have a negative effect on the animal's overall energy budget unless it is able to compensate for the loss by extending feeding activities or feeding more intensively following disturbance. If an individual's annual energy requirements are not achieved during the feeding season, direct mortality or reduced reproductive ability could result. However, such effects are very unlikely given the low probability that the feeding of many bowheads would be interrupted significantly by the level of tanker activity associated with the type of seasonal production scenario examined during this workshop. Even if reproduction were inhibited through a negative or unfavourable energy balance in some individuals, it would be very difficult to detect or attribute resultant effects to any single factor. Some workshop participants believed that it may be worthwhile to determine the extent of feeding loss that could be tolerated by bowheads before mortality or reduced reproduction would result, and to estimate the number of disturbance episodes required to reach this level of feeding loss. There are very few data on the energetics of reproduction for large cetaceans, but information from other species can be extrapolated to formulate a predictive model (Thomson 1987). However, for the purposes of the present workshop, it was concluded that Links 3 and 4 were fundamentally valid, but would be too difficult to measure.

Link 5: **Tanker traffic will affect the bowhead population through direct mortality, disruption of social behaviour, and separation of cows and calves.**

This link addresses concerns that interactions of bowheads with tankers would result in a reduction in size of the western Arctic population through (1) direct mortality of individuals, (2) disruption of social activities such as mating, and (3), mortality of calves following separation of cow/calf pairs.

Direct mortality of bowheads could result from collisions or through entrapment in false leads created by the tanker or an attending icebreaker. There is evidence that bowheads may occasionally be struck by vessels (Nerini et al. 1984). Some participants noted that there are numerous records of collisions between ships and other large cetaceans. However, because the typical response of bowheads to the approach of a vessel is to flee, collisions with tankers or other vessels would likely be rare. The most probable situation where collisions could occur would be if whales were confined to an open lead in dense ice, but tankers would not operate in such ice conditions under the presently proposed development scenario. M. Nerini (pers. comm.) also observed that there are historical records of natural entrapments of bowheads leading to mortality near the coast of Siberia. Again, it was concluded that because tankers would not travel through areas of dense ice cover, the possibility of entrapment is remote.

Although socializing is not a common activity of bowheads during the summer and early fall, a variety of social interactions have been documented during this period (Würsig et al. 1985; Richardson et al. 1987b). Activities include aerial behaviours (breaching, flipper and tail slapping), playing with logs, and apparent (but rare) sexual interactions. The functions of such behaviours are unclear, but it seems unlikely that many are related to reproduction since mating is believed to occur during late winter and spring (Everitt and Krogman 1979; Davis et al. 1983; Nerini et al. 1984).

Studies conducted in the southeast Beaufort Sea by Richardson et al. (1985a, 1985b) have documented instances where social interactions of bowhead whales have been disrupted by the approach of vessels. Socializing whales typically cease interacting and scatter, and there is evidence that such groups may not reform within at least 2-3 h. Because it is unlikely that a single tanker would encounter and disrupt many socializing whales along its route, and because bowheads are not reproductively active during the period when seasonal oil production is proposed, it is unlikely that tanker traffic would have any significant impact on bowhead productivity through disruption of social behaviour.

Bowhead cows and calves typically remain in close proximity, but they occasionally become separated by distances of 100-200 m and, rarely, by distances of up to 2 km (Würsig et al. 1985; J. Richardson, pers. comm.). Cow-calf pairs apparently become reunited following periods of separation by exchanging contact calls (Würsig et al. 1985). If a tanker were to approach a cow and calf while they were 2 km apart, it is possible that the pair would become further separated as a result of avoidance responses. Their ability to maintain acoustic contact may also be decreased due to underwater noise from the ship and they may be unable to relocate each other following the disturbance. However, workshop participants concluded that this was unlikely because cows and calves would probably reunite before avoiding an oncoming ship. It was suggested that it may be worthwhile to examine hypothetical situations where a cow and calf would be unable to maintain vocal contact by modelling various ambient noise states, source levels of ship noise, and source levels of bowhead vocalization. With such a model, it should be possible to predict the range at which an approaching ship would become audible to the whales, the range at which behavioural responses are likely, and extent of the reduction in communication range at various distances from the ship.

In summary, the workshop subgroup concluded that the three components of Link 5 were unlikely to occur and, with the exception of the cow-calf separation question, further testing was not considered justified.

<u>Link 6</u>: **Tanker traffic will cause a long-term offshore displacement of the fall migration of bowheads off Alaska.**

<u>Link 7</u>: **Offshore displacement of the bowhead migration will cause a reduction in the harvest size and catch per unit effort (CPUE) of the fall hunt of bowheads by Alaskan Inupiat.**

The fall migration of bowhead whales out of the Beaufort Sea occurs off the north coast of Alaska between early September and late October, which is within the period of possible westward transport of oil by tanker (1 August - 31 October). The main migration corridor of bowheads varies among years in its distance offshore, but median water depths of the corridor are typically between 20 and 40 m (Moore and Ljungblad 1987). There was concern that tanker passages will cause a seaward displacement of migrating bowheads, and ultimately result in a reduction in the size or ease of the Alaskan Inupiat whale hunt in autumn (Link 7).

In 1964, a traditional fall bowhead hunt was resumed by Alaskan Inupiat living in the north slope villages of Kaktovik and Nuiqsut. The fall hunt typically begins around 1 September and continues until the quota is reached or until early-mid October. The annual catch at Kaktovik is usually 1-4 whales, and most are taken between 5 and 25 September. Whalers tend to hunt bowheads within 35 km of shore, where about 50% of migrating bowheads may be found. If this portion of the migrating bowheads were displaced further offshore, the CPUE and total size of the fall harvest could be affected.

There is little information to suggest that migrating bowheads which encounter a tanker off Alaska would be displaced offshore. Bowheads disturbed by vessels in shallow water tend to move into deeper water (Richardson et al. 1987b), but at the depths the tanker would operate (> 20 m), this directional tendency is unlikely to occur. It can be predicted that as a tanker approaches, bowheads would initially attempt to outrun the vessel and then turn 90° to either side, irrespective of the water depth.

In addition to the low probability of an overall offshore displacement, it would also be very difficult to detect if it did occur. Results of surveys conducted for the U.S. Minerals Management Service since 1979 indicate that there is considerable natural variability in the fall migration, although the factors responsible for differences in migration patterns are unknown (Ljungblad et al. 1986). As the sample sizes of whale sightings from these systematic surveys tend to be small, any subtle change in the migration corridor could not be demonstrated statistically without a great deal of survey effort. If a shift was detected, it would also be difficult to establish cause-effect relationships. Even if it were possible to demonstrate that natural factors were not causing an offshore displacement, it may be impossible to determine which of the many human activities along the Alaskan coast were responsible for any displacement of the bowhead migration corridor.

Like the bowhead migration itself, there is also annual variability in the harvest size and CPUE during the fall hunt. Because there is little quantitative information available on the CPUE in past years, any change in this level would have to be dramatic to be demonstrated. As with a shift in the location of the main migration corridor, a decrease in CPUE would be difficult to attribute to any one cause.

After considerable discussion, it was concluded that Link 7 is a valid consequence of Link 6, but Link 6 is unlikely to occur. However, workshop participants agreed that in view of the cultural importance of the fall bowhead harvest to Alaskan Inupiat, further research using existing data should be undertaken to assess the potential detectability of changes in bowhead migration routes resulting from a tanker corridor and other industrial developments. Specific data that could be included in such an analysis are whale sightings from surveys conducted during 1979-86, historical information on CPUE and location of the fall harvest, the distance offshore of recent and potential future ship traffic, and data on disturbance reactions of bowheads to vessels.

<u>Link 8</u>: **Offshore displacement of the bowhead migration will cause a reduction in the number of whales that can be viewed from shore.**

This link was formulated in response to concerns that ship traffic may interfere with future tourism related to whale watching from shore. Participants were unaware of any current organized whale-watching tours involving bowheads in the western Arctic, but expected that such an industry could develop in the future. The most likely locations for such activities would be Point Barrow during the spring migration, and the Yukon coast (including Herschel Island) during late summer. Part of the western Yukon coast has recently been designated as a Canadian national park, and tourism can be expected to increase in this area, although not necessarily to view whales from the shore. The spring migration of bowheads occurs before the summer seasonal transportation of oil could commence, and the Yukon coast is far from the proposed shipping route. The subgroup thus concluded that this link is unlikely and further testing is not justified.

<u>Link 9</u>: **Tanker traffic will be perceived by Alaskan Inupiat whalers to have a negative effect on the success of the fall hunt for bowheads.**

The perception among Inupiat whalers that offshore oil-industry activities have a negative effect on their ability to harvest whales has been an important issue on the north slope of Alaska for several years. It is a widely held belief among whalers that marine traffic, especially seismic operations, affects the behaviour and distribution of bowheads and may displace the animals from traditional hunting areas. In the past, incidents of perceived interference with the hunt caused by industry activities on the whaling grounds have resulted in complaints registered with the Alaska Eskimo Whaling Commission. Similar complaints can be anticipated should oil tankers pass through areas of active whaling along the coast of the North Slope during September and early October.

It is doubtful that tankers would occur in areas of bowhead hunting in most years. However, in years with heavy ice cover, vessels may be forced to travel closer to the coast, where an overlap with areas used for hunting is possible. In such cases, complaints of interference with the hunt would almost certainly result.

However, the group expected that potential conflicts could be largely mitigated through a cooperative arrangement between industry and the Inupiat whalers. Such a program was established in 1986 to minimize interference between vessel activities associated with oil exploration off the

Alaskan coast and the fall bowhead harvest (Anon. 1986). This program involved equipping whaling boats with satellite navigation systems and VHF radios, thereby allowing whalers to communicate their location to the crews of industry vessels. The captains of industry ships were therefore aware of the status of whaling in their area of operation and were able to modify their activities to avoid potential conflicts. A similar approach has been used successfully for a number of years in the Mackenzie River estuary to minimize interference of industry activities with the annual white whale harvest.

The workshop subgroup concluded that tanker passages in the vicinity of bowhead harvest areas would be certain to be perceived as having a negative effect on the hunt unless efforts are made to avoid potential conflicts by developing a program of open communication and cooperation between the whalers and industry.

Link 10: **Oil spills associated with tanker loading and unloading will reduce zooplankton abundance.**

Link 11: **Reduced zooplankton abundance will decrease the energy intake of bowhead whales.**

Link 12: **Oil spills will decrease the ability of bowhead whales to feed.**

Link 13: **Oil spills related to tanker transport will directly reduce the size of the bowhead whale population.**

There are four principal ways in which bowheads could be affected by an oil spill. These are (1) ingestion of oil, either directly or indirectly through consumption of contaminated prey; (2) loss of feeding efficiency through fouling of baleen; (3) displacement of individuals from important feeding areas; and (4) loss of available food through mortality of prey organisms (Richardson et al. 1983, 1987b; Duval et al. 1985).

Although large-scale, catastrophic oil spills are not examined in BEMP, the effects of minor spills associated with routine operations were discussed by this workshop subgroup. It is likely that minor spills would occur only at the locations of tanker loading and unloading. Because the tanker would unload outside the Beaufort region, only the risks of oil spills during the transfer of crude from the Molikpaq to the tanker were considered.

The workshop subgroup considered a minor spill scenario where a dry-break connector on the transfer hose failed, resulting in the release of about 6 m^3 of oil into the water. It was anticipated that this oil would spread to cover an area of 0.15 km in the first hour following the spill, and would naturally disperse within 48 h. Because of the small area that would be covered by oil and the low probability that feeding bowheads would be found in this area (Richardson et al. 1987a; Duval [ed.] 1986), it was concluded by the subgroup that Links 10-13 are unlikely and further testing is unjustified.

CONCLUSIONS

The workshop group concluded that Hypothesis No. 21 was valid, but most of its linkages were unlikely to occur at the level of shipping intensity given in the case study. Further testing was considered to be unjustified and no field research or monitoring programs related to the hypothesis were recommended relative to the case study. However, it was suggested that re-analysis of existing data should be undertaken to help determine the probability and significance of certain concerns in Links 5, 6 and 7, and that efforts be designed to mitigate the impacts identified in Link 9. These suggestions are as follows:

Link 5 - One of the potential impacts identified in this link was the possibility that calves would become permanently separated from cows as a result of disturbance caused by tankers. Although the group concluded that this was unlikely to occur, it was suggested that further study was advisable. This would involve a simulation analysis using existing data to determine the ranges at which cows and calves might be expected to detect and respond behaviourally to an approaching vessel, and the conditions under which vocal contact between cows and calves would be lost. Information to be considered in this model should include probable source levels of ship noise and bowhead calls, as well as sound propagation and ambient noise characteristics along the tanker corridor.

Links 6 and 7 - These links involve concerns that tanker traffic would cause an offshore displacement of the westward bowhead migration along the Alaskan coast, which would reduce the size or ease of the fall harvest of whales by Alaskan Inupiat. The group believed the links were valid but unlikely to occur. However, given the cultural importance of the fall bowhead hunt, it was suggested that further study be conducted to ensure that this is the case. Such a study would entail the development of a simulation model to assess the potential detectability of effects resulting from a tanker corridor. This model would utilize existing data on whale sightings obtained during 1979-86, historical information on CPUE and location of the fall harvest, the distance offshore of recent and proposed ship traffic, and the available data on reactions of bowheads to vessels.

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APPENDIX A

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APPENDIX B

THE FUNDAMENTAL PRINCIPALS OF RESEARCH AND MONITORING PROGRAM DESIGN IN RELATION TO THE BEMP PROCESS AND THE DESIGN OF SYSTEMATIC AERIAL SURVEYS FOR WHALES

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PRINCIPALS OF RESEARCH AND MONITORING DESIGN

1. Clearly formulate the question. Re-phrase as a null hypothesis and an alternative hypothesis.

2. There should be a control. If it is an observational study over space and time, try to have both a spatial and temporal control.

3. Have replicate samples within treatments, areas, etc.

4. There should be a balanced (equal) and random (or at least unbiased) allocation of samples with respect to factors of interest (but see Principal 8 below).

5. Do some preliminary sampling (a "pilot study") so that 6-9 can be done.

6. Evaluate the sampling method for consistency (lack of bias) over the entire universe that will be sampled.

7. Estimate necessary sample number (or adequacy of feasible sample number), and optimum sample unit size.

8. If there is large-scale spatial pattern, consider a stratified sampling design. To estimate spatial distribution allocate samples evenly over the area; to estimate abundance allocate samples proportional to estimated abundance.

9. Decide how to handle problems in the data: transform it? use nonparametric statistics? use simulation, randomization or jackknife? use sequential sampling? apply corrections for bias?

10. Stick with the results (i.e., let the hypotheses be falsifiable).

REVIEW OF PRINCIPALS IN RELATIONSHIP TO BEMP

1. Clearly formulate the question. Re-phrase as a null hypothesis and an alternate hypothesis.

The overall hypotheses is stated as: "Ship traffic, seismic exploration and active offshore structures will cause a reduction in the western Arctic population of bowhead whales." (p. xi, INAC and Environment Canada 1986).

The diagram on p. 14 and "linkages" on p. 15 provide the rationale for re-phrasing this as:

"...industrial development, primarily sources of high frequency underwater noise, will reduce or prevent bowhead whales from reaching areas of high zooplankton densities in the southeast Beaufort Sea, which they require for growth, survival, and reproduction" (p. 13, INAC and Environment Canada 1986).

Comments:

- One tests against Ho (null hypothesis), not Ha (alternate hypothesis). All the hypotheses are worded as the latter, not the former. The Ho might be the given wording with "will not" substituted for "will". It is not good scientific philosophy to test an Ha which implies proving an effect. Rather, one rejects "no effect". The burden of proof is carried by the person who seeks to reject Ho.
- Unfortunately, there is more than one plausible Ha if whales do not enter the industrially active regions. This is recognized in the BEMP reports (e.g., p. 22, INAC and Environment Canada 1986).
- What are the best response variables to use? What do we mean by "best"? This is one of the most important decisions in this study, and it is discussed extensively (e.g., p 18-21, INAC and Environment Canada 1986).

2. There should be a control. If it is an observational study over space and time, try to have both a spatial and a temporal control.

The need for a control is recognized (p. 17, INAC and Environment Canada 1986). This is a largely observational study over space and time, but there is really no temporal control ("before industry").

Comments:

- There is among-year (and within-year) variation in how much industrial area is used (p. 6, INAC and Environment Canada 1985), which could substitute for a real temporal control to some extent. The space-x-time interaction in occurrence of whales may be relatable to a space-x-time interaction of natural environmental pattern.

- An all observational study is intrinsically weak. There should also be experimental data (be it controlled or "natural" experiment), e.g., behaviour of whales in the presence of industrial noise versus in the absence of industrial noise.

3. **Have replicate samples within treatments, areas, etc.**

What are the samples in this study? Certainly they are allocated within "areas" (industrial versus elsewhere for example), and within years. But are they units of aerial survey effort (search time or area searched), or are they here because the primary objective is to assess distribution and determine its causes, not to estimate population abundance (p. 34, Harwood and Borstad 1985).

Comments:

- Perhaps we can model whale occurrences as a distribution in a natural environment multivariate space, categorized by major region and by year. A statistical test could be done of Ho: **"There is no difference between the distribution of whales in the multivariate environmental space, and the distribution of randomly allocated points in that same multivariate space with boundaries defined by the aerial surveys"**. Then a probability model could be constructed which would relate frequency of whale sightings to environmental variables.

- This might produce a "weight of evidence" that pattern in the natural environment (spatial, among-years, and interaction between them) is sufficient to explain whale distribution including industry vs. non-industry area differences (see discussion p. 19, INAC and Environment Canada 1986). Recall that the burden of proof is always on those wishing to reject Ho.

- It could also be a basis for weighting aerial survey effort in the future if the purpose is population abundance estimation (see 8 below).

4. **There should be a balanced (equal) and random (or at least unbiased) allocation of samples with respect to factors of interest (but see Principal 8 below).**

Random sampling is probably not feasible here, or even relevant if each sample is a "whale sighting". It will, however, be important to distribute search effort evenly over the region and to be consistent from year to year. This is recognized (e.g., p. 8, Harwood and Borstad 1985).

Comments:

- Bias is a major problem. This is recognized (e.g., p. 13-15, Harwood and Borstad 1985) but discussion about obtaining narrow enough confidence limits (p. 16 and 18, INAC and Environment Canada 1986) does not seem to recognize that confidence limits reflect precision only, and bias is likely to be as, if not more, important in this study.
- Corrections for known biases are discussed (p. 13, Harwood and Borstad 1985) but Lord knows what they are worth (p. 34-30, Harwood and Borstad 1985). In any case, there are corrections to abundance/density estimates and are likely to be of little help for reducing bias in data organized as "samples = whale sightings" and "responses = values of environmental variables".

5. **Do some preliminary sampling (a "pilot study") so that 6-9 can be done.**

In a sense, the first two years of the survey (1980 and 1981) represent a pilot study, or at least a learning experience. However, unlike a pilot study, this early data must serve two somewhat contradictory goals: (1) be a part of the final study results representing those years as well as they can, and (2) be the base for the learning experience which hopefully leads to "doing it right".

Comments:

- There is the constraint that the initial survey design (e.g., the stratification) can not be radically changed lest comparisons of results among years become impossible (p. 9, Harwood and Borstad 1985). This would not be the case where future strategy was based on a true pilot study.

- Previous work by others provides some "pilot study"-type information. Such previous work is cited extensively related to biases in sighting whales (p. 13, Harwood and Borstad 1985), sampling by aerial survey (p. 14, Harwood and Borstad 1985), tagging or otherwise following individual whales (p. 29-31, INAC and Environment Canada 1986), and so on. This is admirable, though also probably relatively easy given the amount of relevant published information.

6. **Evaluate the sampling method for consistency (lack of bias) over the entire universe that will be sampled.**

Sampling bias was discussed under Principal 4 above. Some underestimation biases mentioned in the reports are: whales below the surface (cows with calves especially), whales on the surface but missed, solitary whales missed more often than groups, transects not flown in particular time periods because of weather, and whale size underestimated because of angle of sight or body position. See p. 14-15 in Harwood and Borstad (1985) for a concise discussion of limitations of the survey method regarding bias. Overestimation bias (e.g., double-counting of whales) seems less likely to be a problem, but see the first comment below.

Comments:

- Use of sightings by industry personnel (p. 15-16, Harwood and Borstad 1985) and local hunters and trappers (p. 22-23 INAC and Environment Canada 1986) is discussed. This information may be useful for obtaining a more realistic total count of whale numbers, but inclusion of those sightings with aerial survey sightings would be likely to bias estimates of geographic and environmental distributions of whales. Obviously particular distances from shore, water depths and, most important of all, associations with human activity would be disproportionately represented in such "casual sightings". (See Principal 4 regarding the need to distribute search effort evenly over the region.)

- Since we are primarily interested in whale distribution and factors influencing it, underestimation of numbers is not a major concern <u>per se</u>. The major concern is that the frequency of whale sightings will not reflect the number of whales present because "sighting efficiency" may vary systematically as a function of factors such as water depth, weather, sea state, or age or sex or sociality of the whale. Thus, whale distribution and sighting efficiency would be confounded. Particular regions of the multivariate environmental space (see Principal 3) would be under-represented and the estimated probability distribution of whales in that space would be biased. It would be rather like estimating the distribution of a benthic species over a range of substrate types, using a grab which samples more efficiently in mud than in sand.

- If the art of bias-correction could be improved to the point where it was "condition-specific" (e.g., a particular correction applied to particular weather conditions, water depths, etc.) then the "unseen whales" estimated by the correction could be added on a location- and time-specific basis to the individuals seen, and environmental data could be associated with them. Thus, they could generate additional points in the multivariate environmental space, which would hopefully correct the bias to some extent.

7. **Estimate necessary sample number (or adequacy of feasible sample number), and optimum sample unit size.**

Obviously, as much aerial survey effort is being expended as costs will permit, but the adequacy of that feasible sample number might be estimated. However, this would have to be adequate for some specified purpose.

Comments:

- For abundance estimation, it could be "enough aerial survey effort to yield enough sightings to have seen X percent of the actual number of whales". Given an unknown actual number, the asymptote could be estimated for the curve "number of different whales seen versus cumulative aerial survey effort expended" (rather like using a species-area curve to estimate the number of species in a community). Of course one would have to be able to tell individual whales apart, just as one has to be able to tell species apart.

- For estimating a probability distribution of whales in a multivariate environmental space (see Principal 3), one could (1) take data from a given period of aerial surveys and estimate confidence contours, and then (2) use that estimated distribution to simulate whale sightings, varying the number and seeing how confidence contour "tightness" increases with increasing number of sightings.

- The power of the test described in the first comment under Principal 3 could be calculated directly, given distributions on the environmental variables and given numbers of sightings.

8. **If there is large-scale spatial pattern, consider a stratified sampling design. To estimate spatial distribution allocate samples evenly over the area; to estimate abundance allocate samples proportional to estimated abundance.**

In this study, large-scale spatial pattern is of several kinds, and the distinction among them should be kept clear. First, there is spatial pattern that does not correspond to the hypothesis but has the effect of increasing sampling error, thereby decreasing power in testing the hypothesis. Natural environment spatial variation is of this kind. Some of the factors involved (river discharge, Beaufort Sea currents, temperature and salinity profiles) vary spatially from time to time, so that an attempt to "stratify out" such spatial pattern will probably not succeed. An approach such as that described in Principal 3, which treats the natural environment variation as continuous variation, will probably do better. A second kind of large-scale spatial pattern is "zones" (p. 9, Harwood and Borstad 1985) which corresponds to geographic regions of interest for administrative reasons, or because the whales tend to be found there most easily. This is an arbitrary spatial pattern imposed for logistic convenience. Finally, there is spatial pattern which corresponds to the hypothesis. The "industry area" as opposed to "non-industry area" is in this category.

Comments:

- Zones and allocations of search effort within them must be consistent from year to year (previously discussed).
- Confounding of the first and third kind of spatial pattern is a likely problem. As previously discussed, the among-year variation in the natural environment spatial pattern may provide a basis for separating the effects of the two.
- As previously emphasized, we are interested here in estimating distribution rather than abundance. Therefore, we wish to allocate aerial survey effort evenly over the area.

9. **Decide how to handle problems in the data: transform it? use nonparametric tests? use simulation, randomization or jackknife? use sequential sampling? apply corrections for bias?**

This point is fairly self-evident, and has already been discussed to some extent. A simulation approach has been mentioned (see Principal 7), and application of corrections for bias have been discussed in several places above.

10. Stick with the results (i.e., let the hypotheses be falsifiable).

I see three concerns regarding "falsifiability of the results":

Comments:

- The first concern is that this project seems very open-ended. By when is a decision to be made? Based on what years of data? It seems that we are still re-phrasing old and formulating new hypotheses. If the project is to waffle on until everybody concerned is happy (or exhausted), then that may be the best political/administrative solution, but it isn't a good procedure for meaningful testing of falsifiable scientific hypotheses.
- The second concern is the apparent vagueness of some of the criteria. Formal statistical testing may not be appropriate, but the vagueness of statements like the 6th to 8th last lines on p. 14 in Harwood and Borstad (1985) leave open almost any conclusion from the data. Decision-making based on "weight of evidence" can be formalized.
- The third concern is the "test Ho not Ha" matter (see Principal 1). The "weight of evidence" may decide but one should test a null and the burden of proof, or evidence, is on the rejecter of the null. If this is understood and accepted, then the process of decision-making would be greatly clarified.

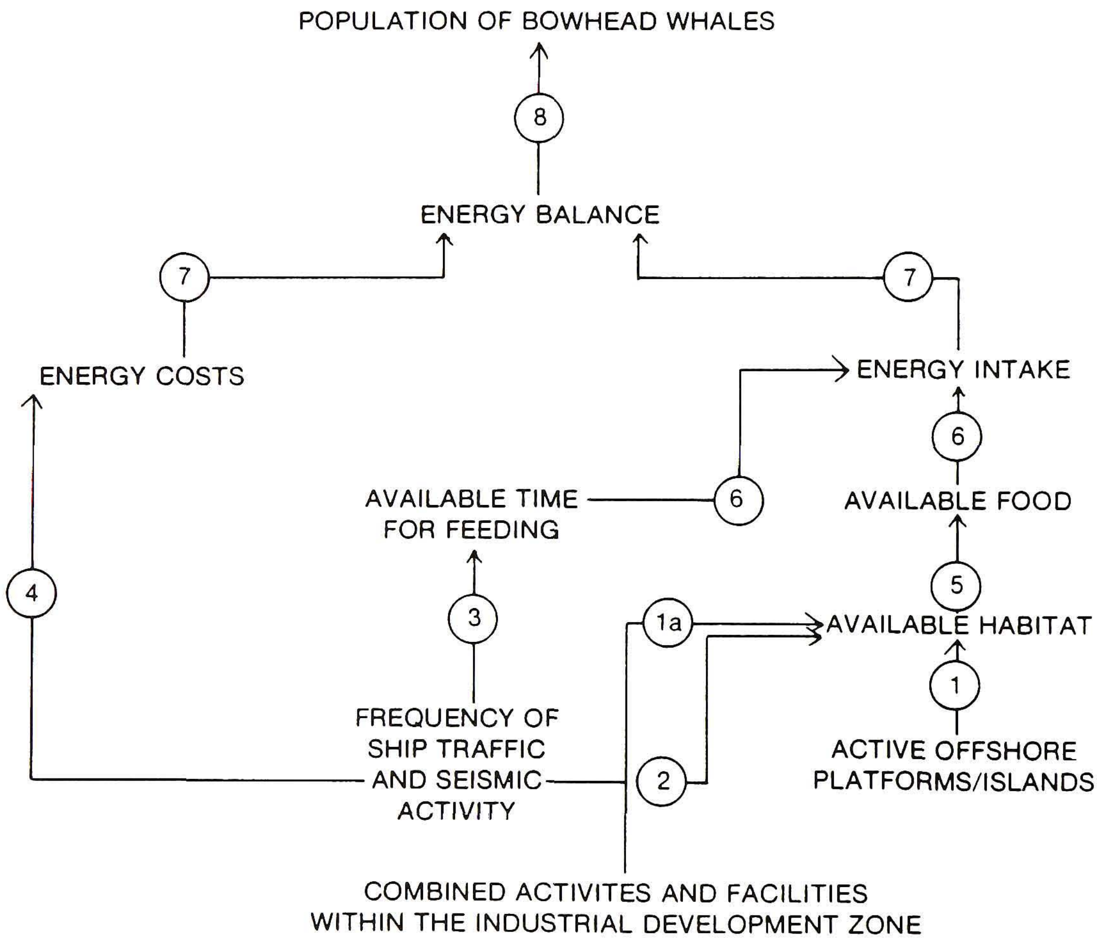
APPENDIX C

HYPOTHESES AND PROJECT OVERVIEWS

FIGURE 1-1

POTENTIAL EFFECTS OF SHIP TRAFFIC, SEISMIC EXPLORATION AND ACTIVE OFFSHORE STRUCTURES ON BOWHEAD WHALES

Ship traffic, seismic exploration and active offshore structures will cause a reduction in the western Arctic population of bowhead whales



Linkages

1a. The cumulative effect of all offshore industrial activities will be to create a large-scale zone of bowhead whale exclusion encompassing the entire industrial zone.*

1. Each active offshore island or platform will exclude bowheads from a zone around the island/platform.

2. Ship traffic will exclude bowheads from a zone around the ship track.

3. Each passage of a ship will reduce the feeding time available to bowheads.

4. Each passage of a ship will increase the energy expenditure of whales due to avoidance behaviour.

5. The available aquatic habitat determines the level of available food.

6. The amount of available food and the time available for feeding determine the energy intake.

7. Energy intake and expenditures determine the energy balance of a bowhead whale.

8. The energy balance of a bowhead whale determines its survival and its ability to reproduce.

* This hypothesis link was added to more clearly represent the emphasis on the cumulative impact of hydrocarbon development on bowhead whales.

BEMP PROJECT OVERVIEW NO. 1-1

TITLE: **1986 Bowhead Whale Monitoring Studies in the Southeast Beaufort Sea**

PRINCIPAL INVESTIGATORS: J. Ford, J. Cubbage and P. Norton

AFFILIATION: ESL Environmental Sciences Limited, Vancouver, B.C.; Cascadia Research Collective, P.N. Research Projects, Sidney, B.C.

FUNDING SOURCE: Environmental Studies Research Funds (ESRF); U.S. Minerals Management Service; Indian and Northern Affairs Canada (INAC)

EXPECTED COMPLETION DATE: Complete

RELEVANT BEMP HYPOTHESIS NO.: 1

BRIEF PROJECT DESCRIPTION

The 1986 bowhead whale monitoring program was the seventh consecutive year of systematic surveys of bowheads during late August to mid September in their summer range in the southeast Beaufort Sea. The purpose of the study was to determine the relative distribution, abundance and age segregation of bowheads in relation to oil industry activities in the region. Unlike previous years, the monitoring program in 1986 consisted of two separate studies. The first comprised systematic aerial surveys and aerial photogrammetric surveys during the late August period, and was funded by the Environmental Studies Research Funds. The second consisted of systematic aerial surveys over the same study area during September, and was funded jointly by the U.S. Minerals Management Service and Indian and Northern Affairs Canada. The two studies employed the same methodology and the results of both field surveys are discussed in the ESRF final report.

The study area for the systematic surveys extended from 141°W longitude (Yukon-Alaska border) to 127°W longitude (near Cape Bathurst), and from the 2 m isobath seaward. The northern boundary was 25 km beyond the 100 m isobath, except between 141°W and 138°W, where the boundary was 70°20'N latitude. The methods followed during the surveys were consistent with those used in previous years, and included a minimum of 10% survey coverage throughout the study area and observations of other marine mammals in the region. As in 1985, the late August survey program also included a photographic component which involved the use of a second survey aircraft and crew. The objectives of this study component were to obtain data on the age (size) distribution of bowheads in different parts of the study area, as well as photogrammetric information that would allow re-identification of individual whales.

The two systematic surveys of the study area were completed during the periods 25 August-01 September and 7-14 September. A reconnaissance survey along the Yukon coast was also completed on 03 October 1986. During both the August and September surveys, bowheads were concentrated in three main areas: (1) along the Yukon coast between Kay and Shingle points and near Herschel Island; (2) in Mackenzie Bay approximately 40-60 km offshore of Shingle Point; and (3) along a band 40-100 km offshore of the Tuktoyaktuk Peninsula between McKinley Bay and Cape Dalhousie (131°50'W - 129°30'W long.). Whales were also present in considerable numbers along the Yukon coast during the 03 October reconnaissance survey. There was evidence that whales were feeding in each of the three concentration areas. The Yukon coast has been identified in previous studies as an area of upwelling and potentially high zooplankton abundance. Whales have concentrated in this area each year since 1983. Whales observed in Mackenzie Bay were associated mainly with the interface between the Mackenzie River plume and colder, oceanic water. This area may also support locally high concentrations of zooplankton during some periods, and whales were also sighted here in 1984 and 1985. In 1986, the level of industry activity in the study area was far less than in the past few years. Bowheads were again scarce in the industry zone, as they have been in most years since 1981.

As in 1985, the photogrammetric component of the study utilized an onboard microcomputer interfaced to the aircraft navigation system and radar altimeter, as well as a camera leveling system to improve the precision and accuracy of whale measurements. Bowheads in the study area were again found to be segregated according to size. Animals present along the Yukon coast were predominantly subadults, while those off the Tuktoyaktuk Peninsula were mainly adults.

RELATIONSHIP AND RELEVANCE TO THE BEAUFORT ENVIRONMENTAL MONITORING PROJECT

Although systematic aerial surveys of bowhead whales in the Beaufort Sea have been conducted each year since 1980, the design of programs for the past three summers has been a direct result of recommendations made during BEMP workshops. The research is relevant to Hypothesis No. 1, which states that "ship traffic, seismic exploration and active offshore structures will cause a reduction in the western Arctic population of bowhead whales". The long-term database that is resulting from this (and other) bowhead research programs will contain some of the information necessary to distinguish potential effects of oil industry operations from within-season and yearly changes in distribution patterns associated with natural factors. The results of the 1986 systematic surveys, in conjunction with concurrent studies of food availability, provide further evidence that the spatial distribution of at least some component of the bowhead population may be a reflection of regional and local variations in zooplankton abundance. Whales were again congregated in areas believed to contain local concentrations of prey, and were observed to be feeding at these locations. The 1986 monitoring study was conducted concurrently with the bowhead food availability study (Project Overview No. 1-2), so information on abundance and distribution of whales can be compared with data on zooplankton density throughout much of the region.

BEMP PROJECT OVERVIEW NO. 1-2

TITLE: **Bowhead Whale Food Availability Study (1986-87)**

PRINCIPAL INVESTIGATOR: M. Bradstreet

AFFILIATION: LGL Limited, King City, Ontario

FUNDING SOURCE: INAC, NOGAP

EXPECTED COMPLETION DATE: Complete

RELEVANT BEMP HYPOTHESIS NO.: 1

BRIEF PROJECT DESCRIPTION

The primary objective of this study was to gain a better understanding of the importance of nearshore and adjacent marine waters between Cape Dalhousie and Herschel Island in the annual energy budget of the bowhead whale. It was designed to supplement the results of the 1985 study, "Food availability characteristics of the offshore Yukon coast to the bowhead whale" (discussed in INAC and Environment Canada 1986) by:

1. enlarging the sampling area to include the whole of the industrial zone and regions east of the industrial zone;

2. resampling the Yukon offshore area to allow inter-annual comparison of zooplankton densities; and

3. improving and expanding the use of hydroacoustic measurements to better estimate the total biomass and distribution of zooplankton available to bowhead whales in the southeast Beaufort Sea.

The study area in 1986 comprised the southern Beaufort Sea east of the Alaska-Yukon border including the Yukon offshore, the area approximately north of the Mackenzie Delta and the area off the western Tuktoyaktuk Peninsula. The seaward boundary extended to about the 100 m depth contour. Field work was conducted from the 68-m icebreaker class II supply vessel Arctic Ivik during the period from 27 August 27 to 08 September 1986. The following tasks were undertaken:

1. Sampling of zooplankton to determine its distribution, patchines and total biomass using various net tows, a 200 kHz narrow-beam echo sounder, and sampling of the epibenthos;

2. A physical oceanographic characterization of the study area including temperature, salinity and turbidity profiles, infrared satellite sea-surface imagery and meteorological measurements; and

3. Analysis of the zooplankton prey found to be available to the bowheads including determinations of calorimetry, lipid fractions and carbon isotope ratios.

A considerable amount of data was collected during the sampling program in 1986. Zooplankton, oceanographic and hydroacoustic data were collected at five stations along each of five transects in two areas: off the Yukon coast and off the Tuktoyaktuk Peninsula. In addition to the samples collected in this grid, samples were also obtained at the edge of the Mackenzie River plume, west of Pelly Island. Zooplankton samples were collected in close proximity to feeding whales off King Point; these samples contained the highest biomass of zooplankton of any in the study. In total, the following information was obtained during the field program: satellite images from five days, 206 net tows of zooplankton, 180 CTD profiles, 180 turbidity profiles, 59 epibenthic samples, 200 hours of continuous surface temperature data, 1171 km of hydroacoustic data and 580 vials of tissue for lipid, caloric and carbon isotope determinations.

There was a noticeable increase in the heterogeneity of zooplankton samples from 1985 to 1986. Preliminary analysis of the 1986 samples indicated that large calanoid copepods typical of cold, arctic waters and hydrozoans were generally much more common in 1986 than in 1985, when the estuarine, warm-water copepod Limnocalanus macrurus dominated the samples collected off the Yukon coast. These and other data are compared to concurrent information on bowhead abundance and distribution from the 1986 ESRF bowhead monitoring program (Project Overview No. 1-1).

RELATIONSHIP AND RELEVANCE TO THE BEAUFORT ENVIRONMENTAL MONITORING PROJECT

This project provides important information relevant to Hypothesis No. 1, particularly Links 5, 6, 7, and 8. These linkages relate to the apparent role of the southeast Beaufort Sea as an important feeding ground for bowheads during the months of August and September. Results of this study add to the "weight of evidence" regarding the validity of the two hypotheses that have been proposed to account for the interannual variability in distribution patterns of bowheads in the southeastern Beaufort Sea during 1980-86. These are that (1) whales may be avoiding the industrial zone as a behavioural response to industrial activity, and (2) they are responding to fluctuations in the distribution and abundance of food.

BEMP PROJECT OVERVIEW NO. 1-3

TITLE: **Importance of the Eastern Alaskan Beaufort Sea to Feeding Bowheads**

PRINCIPAL INVESTIGATOR: W. John Richardson

AFFILIATION: LGL Limited, King City, Ontario

FUNDING SOURCE: U.S. Minerals Management Service

EXPECTED COMPLETION DATE: 1987

RELEVANT BEMP HYPOTHESIS NO.: 1

BRIEF PROJECT DESCRIPTION

Most individuals of the western Arctic population of bowhead whales spend the period from May or June to September or October in the Beaufort Sea. During this period, they are believed to consume most of the food required for the entire year. Bowheads, like other baleen whales, are expected to consume little food in winter, although this is not presently substantiated with bowheads. Nevertheless, the Beaufort Sea is clearly of critical importance in the annual energy budget of the majority of the Western Arctic population of bowhead whales.

The general purpose of this two-year project was to quantify the proportion of the energy requirements of the Western Arctic bowhead whale stock that is provided by food resources located in the eastern Alaskan

Beaufort Sea from longitude 144°W east to the eastern edge of the zone whose jurisdiction is in dispute between the U.S.A. and Canada. The study area extended from the coast of northeastern Alaska north to latitude 71°30'N.

The main factors considered in meeting the objectives of the study were:

1. the numbers, activities and residence times of bowhead whales in the area;

2. prey identity, availability, distribution, patchiness and energy content, and oceanographic factors controlling these attributes of the prey of bowheads;

3. amount of prey (and energy) consumed by the various categories of bowheads that may feed in the study area (immature animals, adult males and females, etc.); and

4. total energy requirements of individual bowheads and of the population of bowheads.

The 1985 and 1986 field programs involved two main tasks: (1) studies of zooplankton and the physical and biological processes that affect zooplankton; and (2) studies of the utilization of the eastern Alaskan Beaufort Sea by bowhead whales. Each of these tasks included a variety of subtasks. In 1985 and 1986, studies of zooplankton and processes affecting their distribution and abundance included:

1. hydroacoustic surveys to determine zooplankton distribution and relative biomass in various areas and depths in the water column;

2. net sampling at selected stations and depths to determine actual numbers, biomass and species composition, and to provide zooplankton samples for size-frequency, calorimetry, and other analyses;

3. ship-based measurements of water temperature, salinity, and chlorophyll content;

4. aerial remote sensing of water temperature, chlorophyll and sediment content on a near-synoptic basis; and

5. digital processing of satellite imagery to acquire synoptic data on sea surface temperature and water colour on cloud-free days.

Studies of bowhead whales in 1985 and 1986 included:

1. aerial and vessel surveys of distribution, numbers, and movements of whales;

2. observations of feeding behaviour and other activities;

3. photogrammetric investigations to study population composition and recurrence of identifiable individuals in feeding areas; and

4. radio-tagging of individual bowheads (1986 only).

Favourable weather and ice conditions in 1986 resulted in a more successful field program than in 1985. Three weekly systematic aerial surveys of bowheads were conducted from 03-27 September, in addition to periodic reconnaissance flights for behavioural observation and photogrammetry. During the same period, zooplankton sampling and physical oceanographic measurements were completed in the vicinity of feeding bowheads and along four transect lines between the coast and 200 m depth contour. Five bowheads were successfully tagged with VHF-radio tags to allow tracking of individuals. The tags were deployed off the Yukon coast between Clarence Lagoon and Komakuk Beach, and three of the whales were re-located in the Alaskan study area up to four days later. One whale was detected on 01 October as it passed Point Barrow.

RELATIONSHIP AND RELEVANCE TO THE BEAUFORT ENVIRONMENTAL MONITORING PROJECT

This project is of considerable importance to Hypothesis No. 1, primarily through its relevance to Links 5 through 8. The study will provide information important to the assessment of the two hypotheses attempting to explain the low numbers of bowheads observed in the industrial zone since 1981. These hypotheses are that (1) bowheads have been excluded from the industrial zone due to disturbance, and (2) bowhead distribution is controlled by oceanographic factors that influence the distribution of their food. The present study is designed to determine whether bowheads feed preferentially in areas where density of plankton is high, and also to determine if such areas are identifiable by physical measures. If it is shown that bowheads do feed preferentially where plankton density is high, then this would lend support to the hypothesis that bowhead distribution is controlled by oceanographic factors affecting the availability of prey organisms. If easily-measured oceanic factors are highly correlated with food abundance, this would assist regulatory agencies in making defensible decisions about permitted industry activities in potential bowhead feeding areas.

BEMP PROJECT OVERVIEW NO. 1-4

TITLE: **Reproductive Parameters of the Bowhead Whale and the Status of the Western Arctic Bowhead Population**

PRINCIPAL INVESTIGATORS: R. Davis, P. McLaren and W. Koski

AFFILIATION: LGL Limited, King City, Ontario

FUNDING SOURCE: Sohio Alaska Petroleum Co. and other Alaskan industry sources; INAC and DFO

EXPECTED COMPLETION DATE: Complete

RELEVANT BEMP HYPOTHESIS NO.: 1

BRIEF PROJECT DESCRIPTION

The objectives of this study were:

1. estimation of gross annual recruitment rate (GARR), defined as the number of calves as a proportion of the population, for the western Arctic stock of bowheads;

2. estimation of the proportion of yearlings in the population;

3. assessment of geographic segregation of age classes on the summer range;

4. assessment of geographic segregation of animals of different reproductive status on the summer range; and

5. estimation of calving interval.

The study involved extensive systematic aerial surveys in both Amundsen Gulf and the Beaufort Sea. Bowheads were photographed whenever they were encountered, with the objective of photographing as large a proportion of the population as possible, particularly the adult portion of the population. Age classes were assessed through length measurements.

RELATIONSHIP AND RELEVANCE TO THE BEAUFORT ENVIRONMENTAL MONITORING PROJECT

This project is directly relevant to Hypothesis No. 1, "Ship traffic, seismic exploration and active offshore structures will cause a reduction in the western Arctic population of bowhead whales". Estimates of reproductive rate of this population have been attempted during studies designed for other purposes, and have been characterized by a wide degree of variability. This is the first investigation designed specifically to determine the reproductive rate.

The summer range of bowheads in the Beaufort Sea has varied from year to year, although the factors controlling distribution remain unknown. Few bowheads have been seen in the industrial zone since 1980 and it has been postulated that they have been excluded from an important feeding area due to disturbance from industry activities. Alternatively, the influence oceanographic factors on food resources may indirectly affect bowhead distribution. This study provides information on the reproductive status of the population and this will help determine the validity of these two hypotheses.

BEMP PROJECT OVERVIEW NO. 1-5

TITLE:	**The Relationship Between Bowhead Whale Distribution and the Oceanography of Northern Seas as Seen in Satellite Imagery**
PRINCIPAL INVESTIGATORS:	G.A. Borstad and M.R. MacNeill
AFFILIATION:	G.A Borstad Ltd.
FUNDING SOURCE:	Shell Western E and P Inc.
EXPECTED COMPLETION DATE:	Complete
RELEVANT BEMP HYPOTHESIS NO.:	1

BRIEF PROJECT DESCRIPTION

The main purpose of this study was to examine the distribution of bowhead whales in relation to oceanographic features of the Beaufort Sea interpreted through satellite imagery. Particular emphasis was placed on the Point Barrow area to identify possible oceanographic mechanisms that may attract bowheads to this region in some years. The study considers short-term oceanographic phenomena that may influence the location of bowhead feeding areas within a season, as well as large-scale factors that may affect the gross distribution of bowheads during the summer and the timing of fall migration.

RELATIONSHIP AND RELEVANCE TO THE BEAUFORT ENVIRONMENTAL MONITORING PROJECT

This project is relevant to Hypothesis No. 1 because it provides information on the oceanographic factors that may influence both small- and large-scale distribution patterns of bowhead whales in the Beaufort Sea. Positive correlations between whale distribution and oceanographic features likely to cause concentrations of zooplankton would add to the "weight of evidence" in favour of the hypothesis that the distribution of bowheads on their summer range is influenced by the distribution of their prey.

BEMP PROJECT OVERVIEW NO. 1-6

TITLE:	**Prediction of Drill Site-specific Interaction of Acoustic Stimuli and Endangered Whales**
PRINCIPAL INVESTIGATORS:	P.R. Miles, W.J. Richardson and R.A. Davis
AFFILIATION:	BBN Laboratories Inc., Cambridge, MA; LGL Limited, King City, Ontario
FUNDING SOURCE:	U.S. Minerals Management Service
EXPECTED COMPLETION DATE:	Early 1988
RELEVANT BEMP HYPOTHESIS NO.:	1 and 21

BRIEF PROJECT DESCRIPTION

The overall purpose of this study is to predict the range at which the behaviour of bowhead and gray whales is likely to be influenced by sounds produced at selected offshore drilling sites in the Alaskan Beaufort Sea. The specific objectives of the study are to:

1. measure the acoustic environment prior to the onset of industrial operations;

2. measure underwater sound propagation loss (transmission loss) in the area of existing and planned offshore industry sites;

3. monitor and record sounds associated with offshore drilling sites; and

4. synthesize results of the above with data and/or models of bowhead and gray whale responses to underwater sounds.

The 1985 and 1986 field programs were designed to obtain measurements at six selected offshore sites, including the natural ambient noise characteristics, acoustic signatures of noise associated with drillsite activities, sound speed profiles, and acoustic transmission loss characteristics to ranges of 20-30 km from each site. From these data and existing bowhead and gray whale behavioural data, the investigators will attempt to derive zones of potential noise detectability, zones of potential responsiveness, and zones of potential masking for both species.

RELATIONSHIP AND RELEVANCE TO THE BEAUFORT ENVIRONMENTAL MONITORING PROJECT

This project is of direct relevance to Hypothesis No. 1, which states that "Ship traffic, seismic exploration and active offshore structures will cause a reduction in the western Arctic population of bowhead whales", as well as the new hypothesis concerning the proposal to transport early Beaufort production to the west by shuttle tanker during the open-water season (Hypothesis No. 21). The study specifically addresses Link 1 of Hypothesis No. 1, which suggests that "each active offshore island or platform will exclude bowheads from a zone around the island-platform", as well as Links 2, 3 and 4. Although the acoustic data resulting from the study are restricted to sites in Alaska, they will be useful in predicting zones of influence of industry activity in the Canadian Beaufort where similar acoustic conditions may be expected.

BEMP PROJECT OVERVIEW NO. 1-7

TITLE: **Bowhead Whale Monitoring - Corona Hammerhead**

PRINCIPAL INVESTIGATORS: R.A. Davis and C.R. Greene

AFFILIATION: LGL Limited, King City, Ontario; Greeneridge Sciences Inc., Santa Barbara, CA

FUNDING SOURCE: Shell Western E and P Inc.

EXPECTED COMPLETION DATE: Early 1988

RELEVANT BEMP HYPOTHESIS NO.: 1

BRIEF PROJECT DESCRIPTION

The purpose of this study is to examine the behaviour of bowhead whales in relation to oil industry activities in the Corona Hammerhead area of the Alaskan Beaufort Sea. The study utilizes aerial observation and underwater acoustic monitoring to evaluate the reactions of bowheads as they approach an active drillsite.

RELATIONSHIP AND RELEVANCE TO THE BEAUFORT ENVIRONMENTAL MONITORING PROJECT

This project is of direct relevance to Hypothesis No. 1, mainly through Link 1, which states that "each active offshore island or platform will exclude bowheads from a zone around the island-platform". The study is designed to document the reactions of individual bowheads to an offshore drillsite. Components of the underwater noise spectrum that may result in disturbance responses will be identified and characterized, and the ranges at which whales may react to these noises will be determined.

BEMP PROJECT OVERVIEW NO. 1-8

TITLE: **1986 Bowhead Whale Aerial Survey and Acoustic Monitoring Study**

PRINCIPAL INVESTIGATOR: D. Ljungblad

AFFILIATION: Naval Oceans System Centre, San Diego, CA

FUNDING SOURCE: U.S. Minerals Management Service

EXPECTED COMPLETION DATE: August 1987

RELEVANT BEMP HYPOTHESIS NO.: 1

BRIEF PROJECT DESCRIPTION

The purpose of this study was to document the relative abundance, distribution and migration timing of bowhead whales in the Alaskan Beaufort Sea during the late summer and fall of 1986. A total of 287 h of systematic and reconnaissance aerial surveys was flown between 15 August and 15 October. An underwater listening station was established at Barter Island and monitored between 25 August and 11 October to acoustically determine the presence and abundance of bowheads. In total, there were 107 sightings of 158 bowheads. Daily sighting rates were highest in late September and early October, with a peak on 28 September. The highest daily call rate received at the Barter Island monitoring station coincided with the peak daily sighting rate. Overall distribution was similar to that observed in previous years. Although the timing of the 1986 migration was similar to past light-ice years, low sighting rates and a lack of feeding whales west of Barter Island were most similar to observations in past heavy-ice years.

RELATIONSHIP AND RELEVANCE TO THE BEAUFORT ENVIRONMENTAL MONITORING PROJECT

This study provides information on the occurrence and activities of bowheads in Alaskan waters that is relevant to Hypothesis No. 1. Data on the extent of feeding activity during the late summer in Alaska and the timing of fall migration will lead to a better understanding of the factors influencing the distribution of bowheads throughout the Beaufort Sea.

BEMP PROJECT OVERVIEW NO. 1-9

TITLE: **Feasibility of Tagging Bowhead Whales for Tracking by Satellite**

PRINCIPAL INVESTIGATOR: B. Mate

AFFILIATION: Marine Science Centre, Oregon State University

FUNDING SOURCE: U.S. Minerals Management Service

EXPECTED COMPLETION DATE: Unknown

RELEVANT BEMP HYPOTHESIS NO.: 1

BRIEF PROJECT DESCRIPTION

This study has been ongoing with various species of whales since 1979. Initially, conventional radio-tagging was tested successfully on gray whales. In 1983, a satellite transmitter was attached to a humpback whale and remained in place for 6 days while the whale travelled 1000 km. Subsequently, two gray whales were tagged in the winter of 1984 but the transmitters remained in place for only two days.

In the summer of 1986, there was an attempt to tag humpbacks off the U.S. east coast using an improved attachment system on the tag, and a deployment procedure involving use of a radio-controlled model helicopter. This attempt was unsuccessful because of bad weather and other events that resulted in loss of the model helicopter. There were further attempts to tag bowheads off the Yukon coast in August-September 1986, using the same tag but having it deployed from a small inflatable boat. One whale was approached close enough for tagging, but no tag was attached.

Tests of the new attachment system were conducted on a bowhead carcass at Kaktovik, Alaska. These trials demonstrated that firm attachment should be possible on a live animal using an improved tag.

RELATIONSHIP AND RELEVANCE TO THE BEAUFORT ENVIRONMENTAL MONITORING PROJECT

The ability to track individual bowheads for long periods of time would substantially increase existing information regarding whale movements in the Beaufort Sea (INAC and Environment Canada 1986). In particular, it may allow assessment of the response of individual bowheads to disturbance from industrial sources and their subsequent movement within or outside the zone of industry activity. These data would be very relevant to the evaluation of Hypothesis No. 1.

BEMP PROJECT OVERVIEW NO. 1-10

TITLE:	**Continuing Studies of the Eastern Arctic Bowhead Whale at Isabella Bay, Baffin Island**
PRINCIPAL INVESTIGATOR:	K. Finley
AFFILIATION:	LGL Limited, Sidney, B.C.
FUNDING SOURCE:	World Wildlife Fund, DFO, INAC, NOGAP
EXPECTED COMPLETION DATE:	1987
RELEVANT BEMP HYPOTHESIS NO.:	1

BRIEF PROJECT DESCRIPTION

The general objectives of continuing studies of the bowhead whale at Isabella Bay are to develop a better understanding of:

1. the biology and behaviour of the eastern Arctic bowhead whale as it relates to specific habitat use patterns;

2. the population dynamics and status of bowheads; and

3. the factors that may have a significant role in its potential for survival and recovery.

An important overall objective of the project is to develop a mutually credible, cross-cultural understanding of the natural history of the bowhead that will serve as a foundation for the development of a conservation strategy that has the sustained support and involvement of the indigenous people.

The 1986 field program was the third consecutive year of this study. Field work was conducted between 01 September and 20 October 1986. Shore-based observations were undertaken daily using binoculars and a theodolite from Cape Raper, Isabella Bay. Aerial photogrammetric surveys were conducted to measure and photo-identify individual whales in the study area.

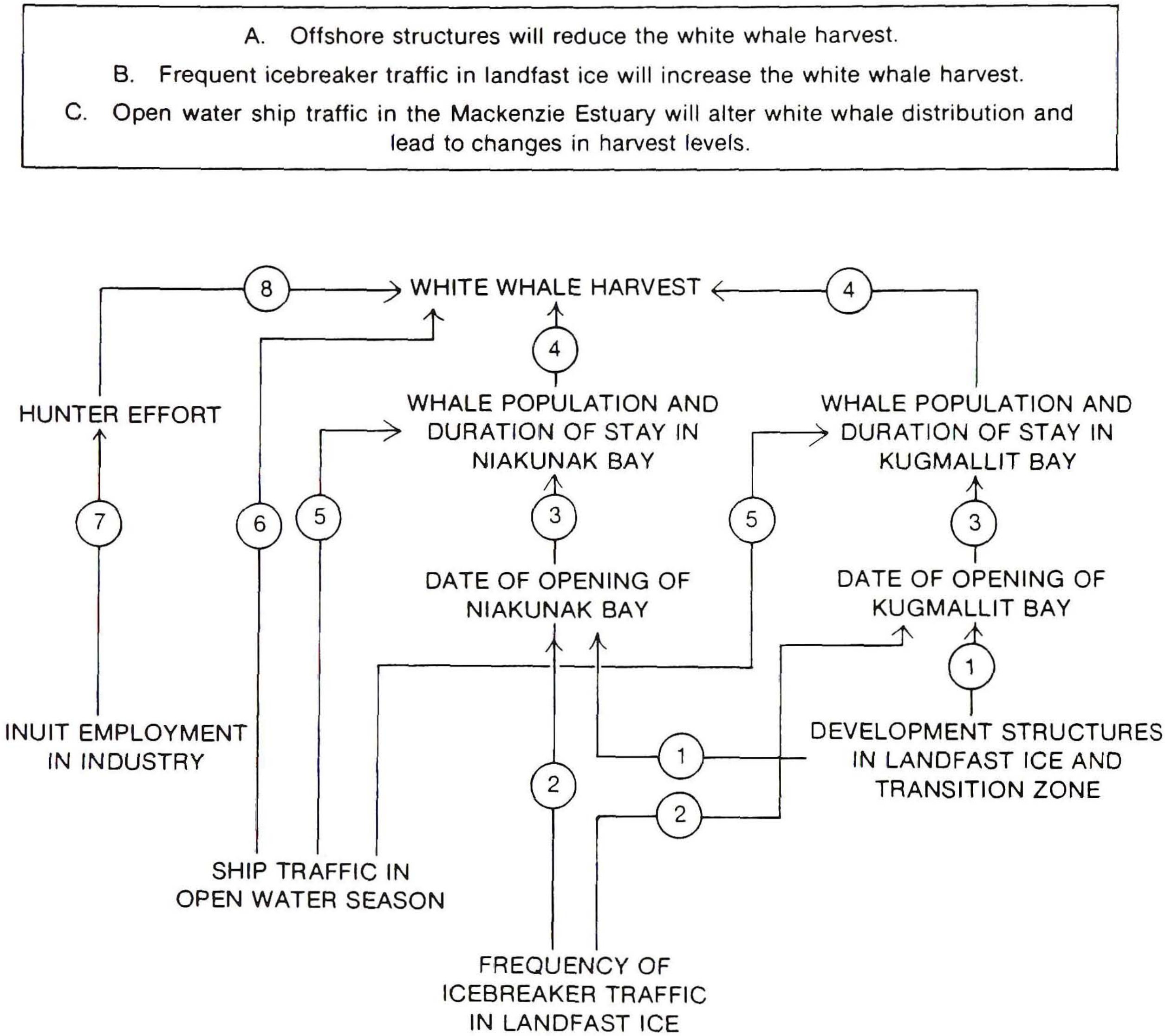
Zooplankton samples were obtained from net tows, and VHF radio tags were applied to whales using a crossbow from kayaks.

RELATIONSHIP AND RELEVANCE TO THE BEAUFORT ENVIRONMENTAL MONITORING PROJECT

This study provides information that is broadly relevant to many of the linkages in Hypothesis No. 1. Although it deals with a separate population of bowheads, the results will provide useful comparative information on feeding behaviour, diet, social interactions, and age (size) segregation of the population. All of this information will be of use in interpreting similar features of the natural history of bowhead whales in the Beaufort Sea.

FIGURE 2-1

THE EFFECTS OF VARIOUS FACILITIES AND ACTIVITIES ASSOCIATED WITH OFFSHORE HYDROCARBON DEVELOPMENT ON THE WHITE WHALE HARVEST

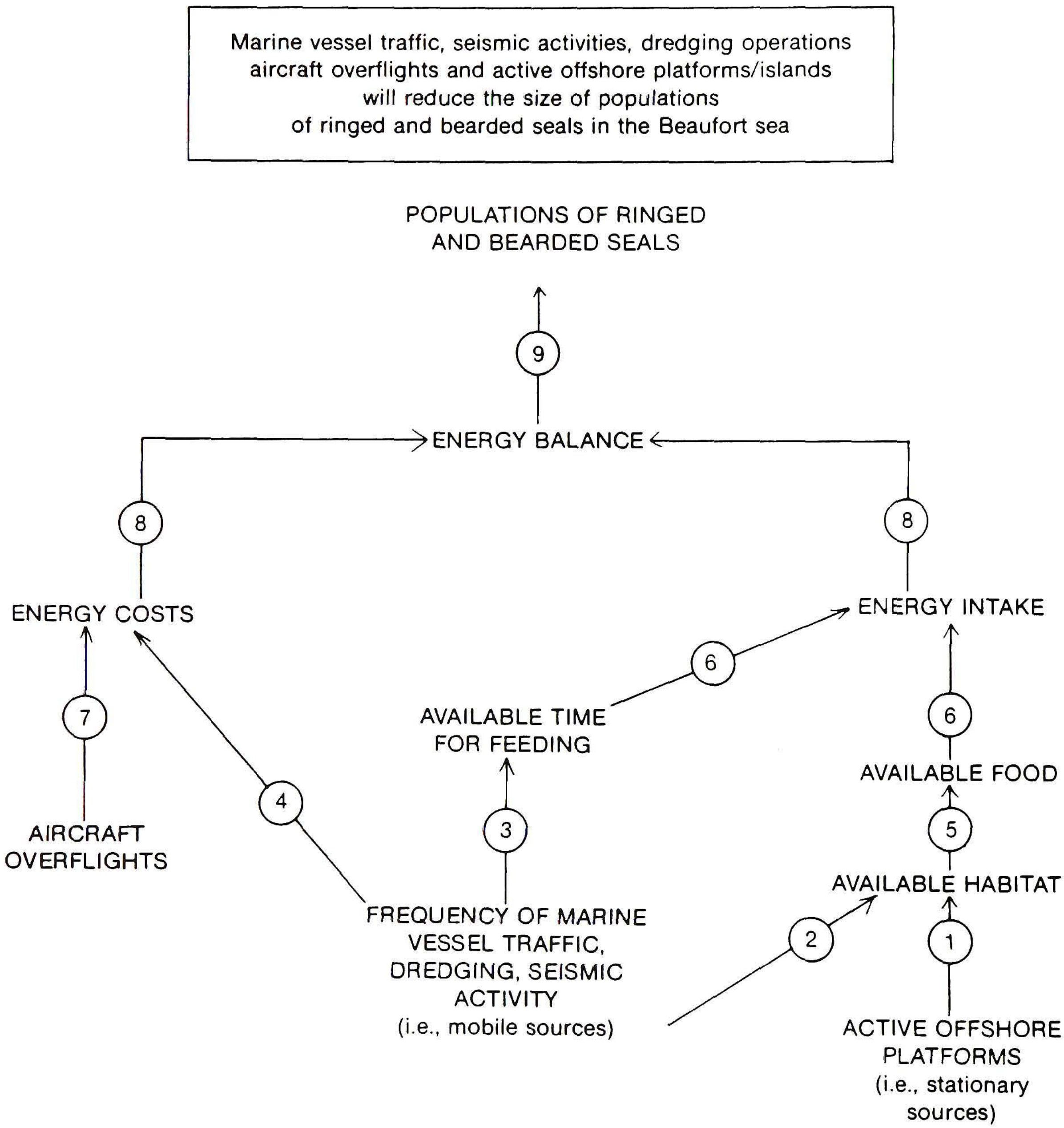


Linkages

1. Artificial islands off the Mackenzie Delta will delay the regional break-up of landfast ice.
2. Icebreaker traffic in the landfast ice in spring will advance the break-up of ice barriers across Kugmallit and Niakunak bays.
3. The timing of break-up of the landfast ice influences the timing of entry, and the numbers and the duration of residence of white whales in Niakunak and Kugmallit bays.
4. The numbers and the duration of residence of white whales in Kugmallit and Niakunak bays will influence the white whale harvest.
5. Ship passages through Niakunak and Kugmallit bays will disturb white whales, and this will reduce the number of animals that frequent the bays and/or the time that whales spend in the bays.
6. Ship traffic in Niakunak and Kugmallit bays will lead to changes in the distribution of whales in the bays, and these changes will lead to changes (probably reductions) in the harvest levels. In addition, ship traffic could directly interfere with hunting activities by frightening whales that are being hunted.
7. Increased Inuit employment by the oil industry and various supporting businesses will lead to changes in hunter effort.
8. Changes in hunter effort and experience will lead to changes in white whale harvest.

FIGURE 3-1

THE EFFECTS OF VARIOUS OFFSHORE ACTIVITIES AND FACILITIES ON POPULATIONS OF RINGED AND BEARDED SEALS IN THE BEAUFORT SEA



Linkages

1. Each active offshore platform will result in the exclusion of ringed and bearded seals from some habitat.
2. Marine traffic (ships, dredges, seismic vessels) will exclude ringed and bearded seals from available habitat.
3. Each passage of a ship or other marine vessel will reduce the feeding time available to ringed and bearded seals.
4. Each passage of a vessel will increase the energy expenditure of seals because of avoidance behaviour.
5. The available aquatic habitat can influence the level of available food.
6. The amount and quality of available food and the time available for feeding determine energy intake.
7. Noise from aircraft overflights will disturb hauled-out seals and lead to increased energy costs.
8. Energy intake and costs determine energy balance.
9. The energy balance of a seal determines its survival and its ability to reproduce. The energy balance of the individuals in a population influences the reproductive capacity and health of the population.

BEMP PROJECT OVERVIEW NO. 3-1

TITLE: **Beaufort Sea ringed seal monitoring study**

PRINCIPAL INVESTIGATOR: M.C.S. Kingsley

AFFILIATION: Dept. of Fisheries and Oceans, Freshwater Institute

FUNDING SOURCE: ESRF, DFO

EXPECTED COMPLETION DATE: Complete

RELEVANT BEMP HYPOTHESIS NO.: 3, 4, and 9

BRIEF PROJECT DESCRIPTION

The purpose of this study was to monitor the abundance and distribution of ringed seals relative to oil and gas industry activities in the Beaufort Sea to determine if these activities were having detectable effects on seals. The study occurred during spring from 1981 to 1984.

During the 1974-1979 Beaufort Sea Project, aerial surveys were conducted every June to count seals hauled out on the sea ice. Analysis of the data collected over the six years indicated large annual fluctuations in the density and estimated abundance of populations of visible seals. In 1981, when hydrocarbon exploration activities in the Beaufort Sea were intensified, a second series of ringed seal surveys with a more restricted but denser coverage was initiated off the Tuktoyaktuk Peninsula. The survey design incorporated north-south transects spaced every 15′ of longitude from 129°15′W to 136°30′W off the Mackenzie Delta and Tuktoyaktuk Peninsula. These transects were approximately 160 km long and were rounded to the nearest 20′ of latitude at their offshore ends.

A control area in Amundsen Gulf and Prince Albert Sound was included in the study design to allow comparison of any population changes in the Beaufort Sea with variation in an area which is both prime pupping habitat and unaffected by hydrocarbon exploration activities. The transects were spaced every 20′ of longitude from 114°40′W to 123°00′W and extended south to 70°30′N in Amundsen Gulf.

No association between low densities of seals and proximity to industrial activity was found during the four years of this program. In fact, it appeared that higher densities of seals occurred near active sites of industry activity in 1982 and 1983. This may be because exploration has been most concentrated in areas near the shear zone where high densities of seals tend to occur. This study was published as ESRF Report 025 (Kingsley 1986).

RELATIONSHIP AND RELEVANCE TO THE BEAUFORT ENVIRONMENTAL MONITORING PROJECT

Hypothesis No. 3 states that "Marine vessel traffic, seismic activities, dredging operations, aircraft overflights and active offshore platforms/islands will reduce the size of the Beaufort Sea populations of ringed and bearded seals". However, the hypothesis was considered unlikely given the anticipated hydrocarbon development scenario for the region, and as a result, no research or monitoring was recommended.

The seal monitoring study described here was initiated in 1981 (prior to BEMP), and is directly relevant to Link 1 which states that "Each active offshore platform will result in the exclusion of ringed and bearded seals from some habitat". The results of the seal surveys support the BEMP conclusion that the extent of exclusion would be inconsequential, and in most instances limited to the physical extent of the island/structure, and that the cumulative effects of all links in this hypothesis would probably be inconsequential.

BEMP PROJECT OVERVIEW NO. 3-2

TITLE:	**Changes in the population dynamics of ringed seals in the Amundsen Gulf**
PRINCIPAL INVESTIGATOR:	T.G. Smith
AFFILIATION:	Dept. of Fisheries and Oceans, Arctic Biological Station
FUNDING SOURCES:	DFO, Polar Continental Shelf Project
EXPECTED COMPLETION DATE:	1987
RELEVANT BEMP HYPOTHESIS NO.:	3, 4, 6 and 9

BRIEF PROJECT DESCRIPTION

This study involves the compilation and integration of extensive amounts of data collected by the Arctic Biological Station on the Amundsen Gulf ringed seal population during the period from 1971 to 1983. This long-term program has included investigation of various aspects of ringed seal population structure, recruitment, annual movements and physiological condition. Samples were collected in several areas within Amundsen Gulf including Minto Inlet, Prince Albert Sound, Prince of Wales Strait and Cape Parry, and also at other areas in the southeast Beaufort Sea.

Many aspects and components of this research have been presented elsewhere. The overall integration and interpretation of information resulting from this study, including resolution of seasonal and year-to-year changes, has required the uses of computerized techniques of data analysis and simulation. The author expects to provide the results of this research in a Canadian Bulletin of Fisheries and Aquatic Sciences in 1987. Topics covered include ringed seal distribution abundance, breeding habitat, reproduction, growth and body condition, feeding ecology, and demographic parameters.

RELATIONSHIP AND RELEVANCE TO THE BEAUFORT ENVIRONMENTAL MONITORING PROJECT

This study will provide information relevant to Link 9 of Hypothesis 3, through examination of effects of energy balance on ringed seal growth, survival and reproduction.

Smith's study is also relevant to Hypothesis 4 and 6, which relate to the effects of icebreaking in Amundsen Gulf on seal (and bear) populations. Examination of seasonal and annual variability in seal distributions and ice conditions will be particularly useful for analysis of Links 2 and 4 (Hypothesis 4) and Links 10 and 11 (Hypothesis 6).

There is concern that icebreaker traffic through Amundsen Gulf will affect ringed seal and polar bear populations, through alteration of ice type, coverage and location. Participants in the second BEMP workshop (INAC and Environment Canada 1985) concluded that, although such ship-induced destabilization of the Amundsen Gulf ice cover was not very probable, this area of concern deserved further consideration because of the potential serious nature of resultant impacts on seal and bear populations. Analysis of existing data was recommended to examine the effects of yearly changes in ice conditions on the distribution and abundance of marine mammal populations, and the data collected by Smith was identified as an important source of information for such an analysis. Examination of the 12 years of data will allow analysis of the relationship between variations in ice cover (most notably the extreme ice years of 1971, 1978 and 1981) and changes in ringed seal population parameters.

BEMP PROJECT OVERVIEW NO. 3-3

TITLE: **Environmental and ecological factors influencing ringed seal distribution in the southeast Beaufort during later summer and fall**

PRINCIPAL INVESTIGATOR: L. Harwood

AFFILIATION: Department of Zoology, University of Alberta, Edmonton, Alberta

FUNDING SOURCES: Department of Fisheries and Oceans, Department of Indian and Northern Affairs (DIAND), Minerals Management Services (MMS), Boreal Institute of Northern Studies (BINS), University of Alberta

EXPECTED COMPLETION DATE: 1988

RELEVANT BEMP HYPOTHESIS NO.: 3 and 9

BRIEF PROJECT DESCRIPTION

This project has involved examination of the relative abundance and distribution of ringed seals in the Beaufort Sea during the open water period for the years 1980-1986. Trends in seal distribution will be examined through comparison with oceanographic features depicted in satellite imagery or delineated through in situ sampling. In addition, a population estimate will be attempted as part of this study.

During the open water period, ringed seals occur in large (10's of 1000's), dense feeding aggregations, and these appear to persist through to freeze-up. The locations of groups varies among years, and this is believed to be related to variation in the distribution of seal prey items (e.g., zooplankton, Arctic cod).

RELATIONSHIP AND RELEVANCE TO THE BEAUFORT ENVIRONMENTAL MONITORING PROJECT

Seal distribution data collected from 1980-1986 can be used to evaluate Links 1 and 2 of Hypothesis 3, that is, have stationary and mobile industry activities excluded ringed sales from available habitat? However, since the project was not designed to determine a cause-effect relationships, quantification of subtle exclusions is not possible. Nonetheless, the surveys provide an extensive time series describing seal distribution in areas in the vicinity of and distant from industry activities, and this along with the oceanographic data, will be used to assess any evidence for large-scale exclusions of seals. Preliminary analyses to date suggest there have not been such effects, at least not to an extent detectable with methods employed in this investigation.

The study will also provide information relevant to Links 5 and 6 of Hypothesis 3, through an examination of the importance of fall feeding in the annual nutrition of ringed seals. If ringed seals are excluded from available and important feeding areas (e.g., if Links 1 and 2 are in fact valid and consequential), then information from this study could be used to evaluate the possible implications of such an exclusion. The seriousness of any exclusion would depend on it's location and timing.

The investigation also involves evaluation of the validity of use of aerial surveys to census ringed seals during the open water period, and will examine the advantages and disadvantages of employing the method for this purpose, and will present correction factors. Consequently, the methodological component of this study is also relevant to Links 1 and 2 of Hypothesis 3 which rely on monitoring seal distribution and relative abundance.

BEMP PROJECT OVERVIEW NO. 3-4

TITLE:	**Comparative aerial survey of ringed seals in Amundsen Gulf**
PRINCIPAL INVESTIGATOR:	M.S.C. Kingsley
AFFILIATION:	Department of Fisheries and Oceans Freshwater Institute
FUNDING SOURCE:	DFO
EXPECTED COMPLETION DATE:	Complete
RELEVANT BEMP HYPOTHESIS NO.:	3, 4, 6 and 9

BRIEF PROJECT DESCRIPTION

Twenty-six transect lines in Amundsen Gulf were surveyed simultaneously using both a visual count (two observers, Cessna 337, altitude 152 m) and a photographic census (9 x 9 format camera, turbocommander, altitude 1230 m) during June 1985. A formal comparison of the density of hauled-out ringed seals and seal holes obtained with each method will be conducted. The results of other photographic surveys for seals in Barrow Strait conducted during haul-out in 1984 and 1986 will also be described in reports from this investigation.

Data from the comparative survey will be used to calculate a correction factor to account for hauled-out seals missed by observers during visual surveys. While the visual technique is considerably more cost-effective than a photographic census, it is less accurate. This shortcoming can be alleviated, at least in part, through application of a correction factor derived specifically for each combination of survey conditions (timing, location, species, observers, etc.).

RELATIONSHIP AND RELEVANCE TO THE BEAUFORT ENVIRONMENTAL MONITORING PROJECT

The results of this methodological study are relevant to Hypothesis 3, 4 and 6, because each involves research designed to monitor the distribution and abundance of ringed seals. This investigation will permit more accurate and cost-effective seal census to be conducted in the future during the spring haul-out period.

BEMP PROJECT OVERVIEW NO. 3-5

TITLE:	**Density and distribution of ringed seals in Barrow Strait during late winter and spring**
PRINCIPAL INVESTIGATOR:	M.O. Hammill
AFFILIATION:	MacDonald College, McGill University, and Arctic Biological Station, Department of Fisheries and Oceans
FUNDING SOURCES:	DFO (NOGAP) and industry
EXPECTED COMPLETION DATE:	1988
RELEVANT BEMP HYPOTHESIS NO.:	3, 4 and 6

BRIEF PROJECT DESCRIPTION

This study was designed to quantify the effects of certain habitat features on the density and distribution of ringed seals in fast ice. To achieve this objective, it was necessary to develop a method that provided a reliable estimate of seal abundance.

Labrador retrievers, trained to located ringed seal structures (lairs), searched 12 different 4 km^2 plots between March and June 1984. In each plot, all seal structures located by the dogs were marked. By treating the marked structures as removals (Zippin, Biometrics 12:163-189, 1956) the population of structures in each plot was estimated.

Nine of the areas searched in 1984 were also searched in 1985 and 1986, and population estimates were obtained where the probability of detection of seal structures remained constant. Seal hole densities from all areas searched during the three years were also compared.

The removal method proved to be satisfactory in estimating the number of seal holes per unit area. Application of the model permits the quantification of year-to-year changes in density and distribution of ringed seals within their breeding habitat.

RELATIONSHIP AND RELEVANCE TO THE BEAUFORT ENVIRONMENTAL MONITORING PROJECT

The methodological component of this study is applicable to Links 1 and 2 of Hypothesis 3, which involve estimation of seal distribution and abundance. When available (1988), the analysis on ringed seal density and distribution during breeding will be directly relevant to evaluation of Link 2 of Hypothesis 4) and also Link 11 of Hypothesis 6.

BEMP PROJECT OVERVIEW NO. 3-6

TITLE: **Underwater vocalization of the bearded seal (*Erignathus barbatus*)**

PRINCIPAL INVESTIGATOR: H. Cleator

AFFILIATION: Department of Fisheries and Oceans
Freshwater Institute

EXPECTED COMPLETION DATE: Complete

FUNDING SOURCES: CWS, University of Alberta, Boreal Institute, DFO

RELEVANT BEMP HYPOTHESIS NO.: 3 and 5

BRIEF PROJECT DESCRIPTION

Underwater vocalizations of bearded seals were recorded during spring 1982 and 1983 at six sites in the Canadian Arctic. The repertoires of vocalizing seals varied among the six sites, suggesting that bearded seal may be relatively sedimentary and the geographically different vocal repertoires may be characteristic of discrete breeding stocks.

Vocalization surveys were conducted in Penny Strait, NWT during spring 1982-1984 to study the winter and spring distribution of bearded seals. While such surveys can be used to estimate relative abundance of seals for spatial and temporal comparisons, and to separate preferred seal habitats from unsuitable ones, it is not possible to use this technique to determine the absolute number of bearded seals at or near a site.

RELATIONSHIP AND RELEVANCE TO THE BEAUFORT ENVIRONMENTAL MONITORING PROJECT

This study is indirectly relevant to Links 1 and 2 of Hypothesis 3, which addresses the potential for stationary and mobile industry activities to exclude bearded seals from available habitat. The study discusses the advantages and disadvantages of vocalization surveys as a monitoring technique, which could in theory be used to monitor widespread and large-scale exclusions. However, the technique would not be adequate for measuring small-scale or subtle exclusions.

This study also has overall implications to Hypothesis No. 3. The data suggest that bearded seals may be relatively sedentary and have distinct breeding stocks. Consequently, if the hypothesis were valid for bearded seals and they were excluded from a certain area and the population reduced, recovery may be slow and survival low because adjacent populations could belong to distinct breeding populations.

This study also provides evidence relevant to Link 1 of Hypothesis 5, which states that "icebreaker traffic will interfere with male bearded seal vocalizations, and this will result in reduced mating success". While available data show that bearded seal calls are produced only during the breeding season and only by males, the potential for and implications of interference with these vocalizations are not known. However, the investigation will provide a comprehensive examination of bearded seal call frequency, repertoire, call slope and intensity and call duration for six geographically separate stocks. This information will be a useful starting point for the eventual evaluation of Link 1 of Hypothesis 5, and provides a permanent record of bearded seal vocalizations prior to potential onset of frequent icebreaker activity.

BEMP PROJECT OVERVIEW NO. 3-7

TITLE:	**Studies of ringed seals in the Alaskan Beaufort Sea during winter: Impacts of seismic exploration**
PRINCIPAL INVESTIGATORS:	T.T. Burns, B.P. Kelly, and K.J. Frost
AFFILIATION:	Alaska Department of Fish and Game Fairbanks, Alaska
FUNDING SOURCE:	Outer Continental Shelf Environmental Assessment Program (OCSEAP)
EXPECTED COMPLETION DATE:	Complete
RELEVANT BEMP HYPOTHESIS NO.:	3, 4 and 6

BRIEF PROJECT DESCRIPTION

The distribution and abundance of ringed seals off Alaska have been examined through aerial survey during haul-out (1970-1986), and through dog searches (on-ice) during pupping (1982-1984). Seal densities for various ice types and levels of ice deformation were calculated, and the relative abundance of seal structure types (e.g., holes, lairs) were compared among areas.

Of most relevance to the BEMP hypotheses is the experimental work which examined effects of seismic activity on ringed seals. In the nearshore Alaskan Beaufort Sea, ringed seal densities were on average 51% lower in areas of seismic activity than in undisturbed areas during the winters of 1975-77. During 1981 and 1982, however, studies indicated seismic activity had displaced seals from the immediate (150 m) area of activity, but that overall significant differences in density were not apparent between 'seismic' and 'control' areas. Nonetheless, interpretation of aerial and ground studies is complicated by factors such as the variability in seal haul-out patterns and in the natural incidence of alteration and refreezing of structures.

RELATIONSHIP AND RELEVANCE TO THE BEAUFORT ENVIRONMENTAL MONITORING PROJECT

This study is of relevance to both Hypothesis 3 and to Hypothesis 4, which states that "Increased frequency of icebreaker traffic through the landfast ice and through Amundsen Gulf will reduce ringed seal pup production and have subsequent effects on population levels". The study provides information regarding use of disturbed areas by seals and data on densities of seals in different types of ice. The latter information is useful for assessing the numbers of seals that might be affected by icebreakers in both the Beaufort Sea and Amundsen Gulf.

BEMP PROJECT OVERVIEW NO. 3-8

TITLE: **Dependence of ringed seals on subnivean lairs**

PRINCIPAL INVESTIGATOR: B.P. Kelly

AFFILIATION: University of Alaska, Fairbanks, Alaska

EXPECTED COMPLETION DATE: Complete (abstract published)

RELEVANT BEMP HYPOTHESIS NO.: 3, 4 and 6

BRIEF PROJECT DESCRIPTION

Ringed seals were shown to abandon subnivean breathing holes and lairs in the immediate vicinity of seismic lines (see Project No. 3-7). Assessment of the significance of such abandonment requires knowledge of (1) the nature and degree of the seal's dependence on breathing holes and lairs, and (2) the alternatives available to seals that have abandoned lairs and breathing holes. These were the objectives of the present telemetric study, which took place from early March - early June in 1982 to 1984, in the Beaufort Sea and Kotzebeu Sound. The temporal and spatial haul-out patterns of 13 radio-tagged seals were recorded.

Each seal maintained two to four lairs; some lairs were used by more than one seal. The greatest distance between seal holes used by an individual was 4.5 km. Until late May, air temperatures (recorded via transmitting thermistors) inside lairs were consistently higher than outside air temperatures. Air temperature inside a typical lair averaged 27.0°C warmer than outside windchills in March, 26.2°C warmer in April and 16.4°C warmer in May. Lairs were heated by sea water (-2° to -3°C) and body heat from seals. Haul-out by seals caused abrupt temperature increases (as much as +10.2°C) inside lairs. Periods of haul-out were highly variable in length and frequency until late March for pupping females and, generally, May for all other seals. In late March and early April, two females, apparently caring for newborn pups, hauled out at least once per day and for significantly longer periods than they did before or after nursing. Diel haul-out patterns tended to become pronounced with mid-day peaks in May.

RELATIONSHIP AND RELEVANCE TO THE BEAUFORT ENVIRONMENTAL MONITORING PROJECT

This study provides information on both (1) the dependence of ringed seals on subnivean lairs and (2) the alternatives that are available to seals that have abandoned lairs. The study also has the potential to provide correction factors to account for seals in the water during aerial counts of hauled-out seals in late spring. Such correction factors would be relevant to any research or monitoring program requiring knowledge of seal populations.

BEMP PROJECT OVERVIEW NO. 3-9

TITLE: **Distribution of abundance of ringed seals in relation to gravel island construction in the Alaskan Beaufort Sea**

PRINCIPAL INVESTIGATOR: S.R. Johnson

AFFILIATION: LGL Ecological Research Associates, Inc., Bryan, Texas

FUNDING SOURCE: Shell Oil Company

COMPLETION DATE: 1983

RELEVANT BEMP HYPOTHESIS NO.: 3 and 4

BRIEF PROJECT DESCRIPTION

The construction of Shell's Seal Island occurred between February and April 1982. This study involved censusing seal breathing holes and hauled out seals in a control area and an experimental area. The latter included Seal Island and its associated ice road. Aerial surveys were conducted at 100% coverage, and four times during early June 1982.

The authors could not determine conclusively if the construction at Seal Island and associated facilities had detrimental effects on the local seal population, and this is because no pre-construction data were available on 'natural' seal densities and distributions. However, the late winter densities of ringed seals (based on densities of seal holes) in the vicinity of Seal Island were higher than in the control area, suggesting that there was no significant loss of seals as a result of construction. The only effect of the construction activities appears to have been a very slight alteration of ringed seal distributions during late winter. On the basis of seal hole densities, it appears that ringed seals avoided the immediate area of Seal Island, because seal hole densities increased slightly with increasing distance from the island. Overall, however, the authors concluded that effects of Seal Island construction on ringed seals appeared to be insignificant.

RELATIONSHIP AND RELEVANCE TO THE BEAUFORT ENVIRONMENTAL MONITORING PROJECT

This study is directly relevant to Hypothesis 3, since the construction (Link 2) and presence of Seal Island (Link 1) could have excluded ringed seals from available habitat. The results of this study, like Project 3-1, support the BEMP conclusion that the extent of exclusion would be inconsequential, at least when considering the present development scenario (or as in this case, construction of one island).

BEMP PROJECT OVERVIEW NO. 3-10

TITLE:	**Potential impacts of man-made noise on ringed seal vocalizations and reactions**
PRINCIPAL INVESTIGATOR:	W.C. Cummings
AFFILIATION:	Oceanographic Consultants
FUNDING SOURCE:	Minerals Management Service
COMPLETION DATE:	1984
RELEVANT BEMP HYPOTHESIS NO.:	3

BRIEF PROJECT DESCRIPTION

The study was conducted in Kotzebue Sound, Alaska, during March-April 1984. A three-hydrophone array was used to record 245 hours of data. The source levels, vocalized frequencies (seasonally and diurnally), and call types were examined and reported for ringed seals. Recorded "industrial" noise was played to them, and there was either no change in seal vocal activity, or, increased vocal activity. The authors concluded that the study provided no evidence that petro-exploratory industrial noise reduced the occurrence of ringed seal vocalizations, but recommended that more research on sound propagation and attenuation be conducted.

RELATIONSHIP AND RELEVANCE TO THE BEAUFORT ENVIRONMENTAL MONITORING PROJECT

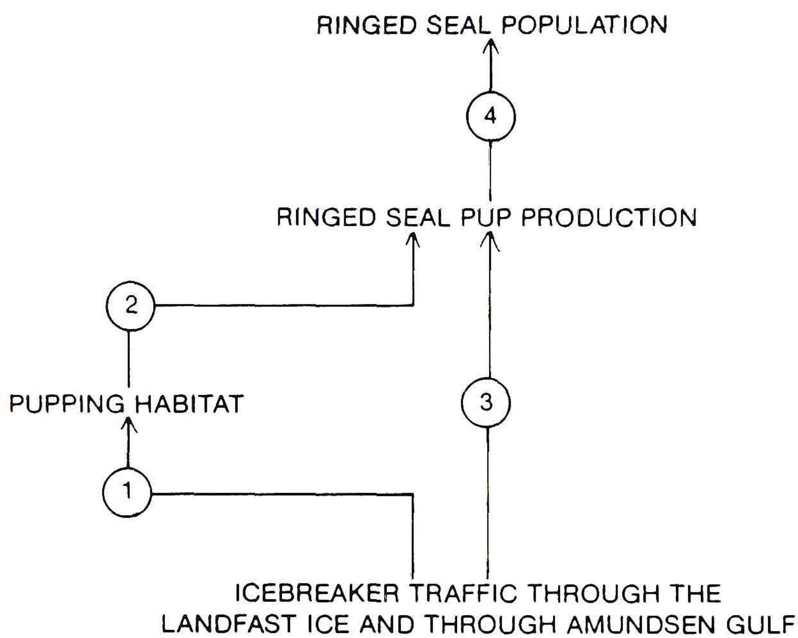
This study is relevant to Hypothesis 3, since it addresses Link 2 indirectly through examinations of the effects of industrial noise on seal vocal behaviour. The results of this study lend indirect support to the BEMP conclusion that the effects of industry activity, in aggregate given the present scenario, are probably inconsequential in terms of the seal population.

FIGURE 4-1

POTENTIAL EFFECTS OF INCREASED FREQUENCY OF ICEBREAKER TRAFFIC THROUGH THE LANDFAST ICE AND THROUGH AMUNSEN GULF ON RINGED SEAL PUP PRODUCTION AND POPULATION LEVELS

REVISED HYPOTHESIS NO. 4

Increased frequency of icebreaker traffic through the landfast ice and through Amundsen Gulf will reduce ringed seal pup production and population levels

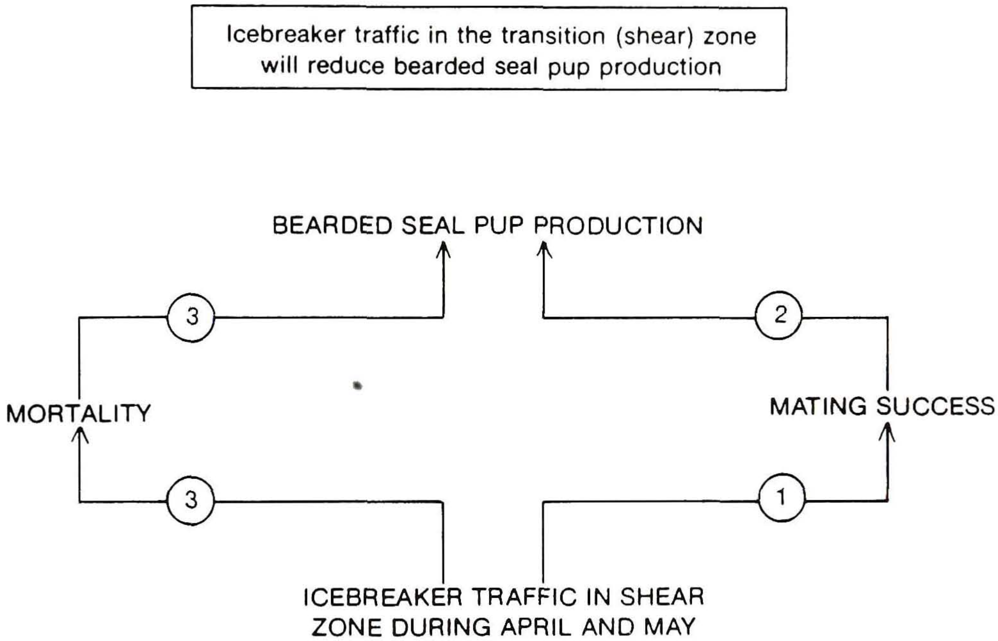


Linkages

1. Icebreaking vessels operating in the landfast ice and through Amundsen Gulf will decrease the amount of pupping habitat available to ringed seals.
2. Adequate pupping habitat is necessary for the production of ringed seal pups.
3. Icebreaker traffic in late March, April and May will kill ringed seal pups.
4. Reduced ringed seal pup production will result in lower population levels.

FIGURE 5-1

POTENTIAL EFFECTS OF ICEBREAKER TRAFFIC IN THE TRANSITION ZONE ON BEARDED SEAL PUP PRODUCTION

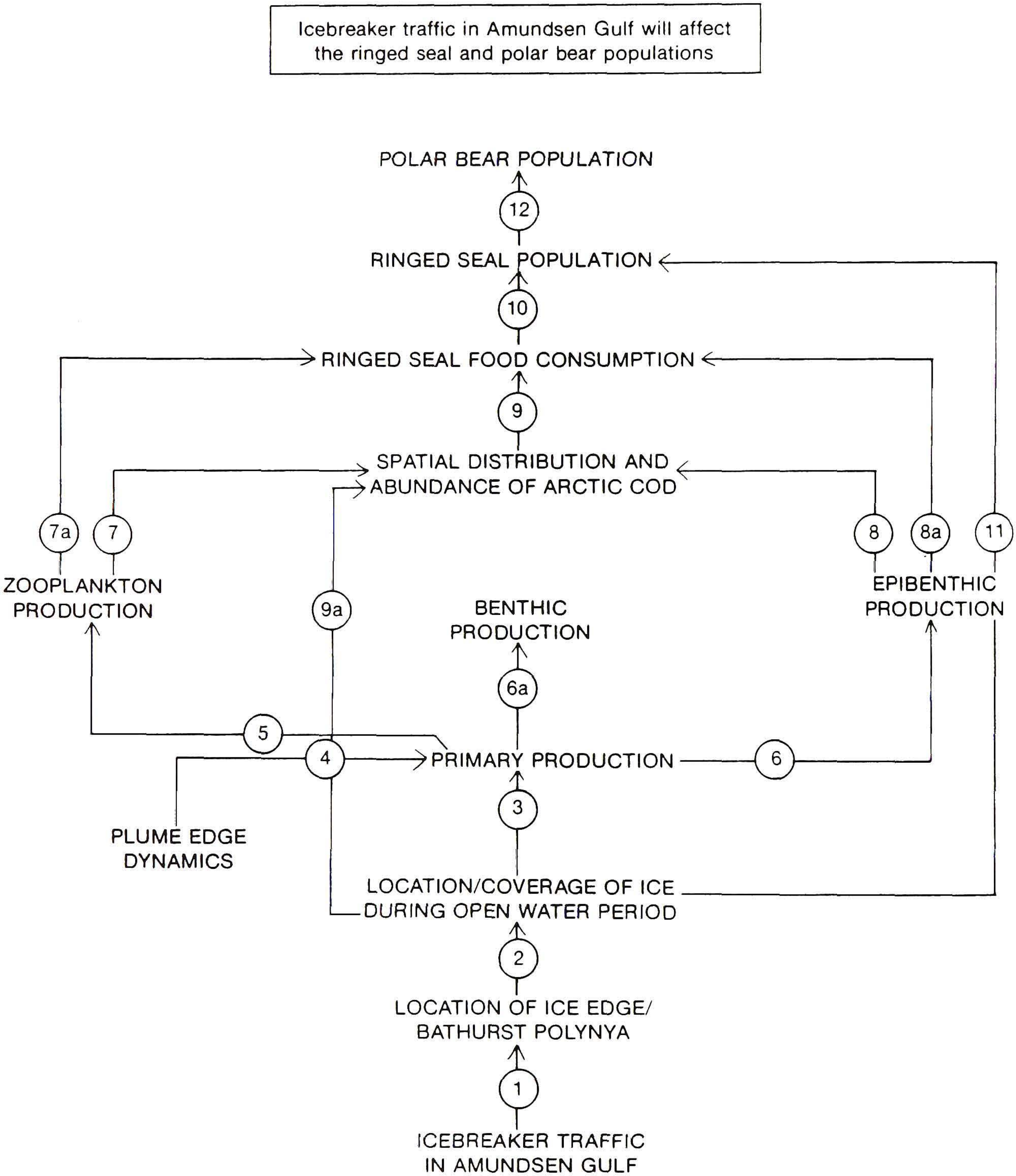


Linkages

1. Icebreaker traffic in the shear zone during April and May will interfere with vocalizations of male bearded seals, and this will result in reduced mating success.
2. Successful mating is necessary for production of bearded seal pups.
3. Icebreaker traffic in the shear zone during April and May will result in mortality of bearded seal pups.

FIGURE 6-1

POTENTIAL EFFECTS OF ICEBREAKER TRAFFIC IN AMUNDSEN GULF ON THE RINGED SEAL AND POLAR BEAR POPULATIONS



Linkages

1. Icebreaker traffic in Amundsen Gulf will move the stable ice edge to the east (and alter the Bathurst polynya) in winter and spring.
2. Movement of the stable ice edge may in turn change the total amount of open water in the region.
3. The coverage thickness and location of ice determine the level of primary productivity.
4. Primary production is enhanced (perhaps in patches) near the Mackenzie River plume edge.

5, 6 and 6a. The level of primary productivity determines the level of secondary productivity in zooplankton, epibenthos and benthos.

7, 8 and 9a. Distribution and production of zooplankton and epibenthos and the location of ice determine the production and distribution of arctic cod.

10. Quality and quantity of food determine ringed seal survival and mortality.
11. Location and type of ice are important in determining ringed seal distribution.
12. Numbers of polar bears are determined by numbers of ringed seals.

BEMP PROJECT OVERVIEW NO. 6-1

TITLE: **Mackenzie shelf fisheries habitat research**

PRINCIPAL INVESTIGATORS: M. Lawrence and L. de March

AFFILIATION: Fisheries and Oceans Canada, Freshwater Institute

FUNDING SOURCE: DFO, NOGAP

EXPECTED COMPLETION DATE: 1988

RELEVANT BEMP HYPOTHESIS NO.: 6, 19, and of general interest

BRIEF PROJECT DESCRIPTION

The planning for this study was discussed in 1985 BEMP Project Overview No. 30. During 1985, two other projects (1985 Project Overview No. 17, Fish feeding ecology; and Project Overview No. 23, The biological importance of Tuktoyaktuk Harbour to fish) became part of the overall fish habitat investigation.

The major objectives of this investigation are:

1. to identify, in both spatial and temporal terms, the areas of the Mackenzie shelf from Demarcation Pt. to Cape Bathurst that are of significance to estuarine and marine fish;

2. to characterize areas of important or critical marine habitats in terms of their physical-chemical environment, biotic community structure or production; and

3. to characterize the feeding habits of pelagic and demersal fish species of the Mackenzie Shelf in relation to habitat and season (open water vs. ice cover).

Data analysis for this project is ongoing.

In 1986, biological and oceanographic sampling was conducted at 71 locations on the MacKenzie Shelf over the period from May to September. Gillnets were used to sample fish under the ice, while bottom trawls were employed during the open-water period. Oceanographic sampling was conducted from Herschel Island to Cape Bathurst from July to September. Horizontal and oblique tows with 500 mesh gear were used to sample larval fish, zooplankton and neuston, while vertical tows with a 83 mesh net were conducted to determine the availability and abundance of larval fish food. Food resource partitioning among fish species in each area will be analyzed to determine the influence of location and season on the predator-prey overlap among fish species. Distribution and abundance data for major species are being compiled and mapped in relation to oceanographic parameters (depth, temperature, salinity, nutrients and chlorophyll). In addition, NOAA-6 satellite imagery is being assessed to determine the relationship of sea surface colour and thermal attributes to biomass of selected species.

RELATIONSHIP AND RELEVANCE TO THE BEAUFORT ENVIRONMENTAL MONITORING PROJECT

The results of this study will provide basic descriptive information on biological communities of the Mackenzie Shelf and will contribute to an increased understanding of energy flow in the Beaufort Sea and the trophic relationships among components of the system.

The study is relevant to Links 7, 8 and 9a of Hypothesis 6. These links suggest that a reduction in the abundance of zooplankton and epibenthos (prey of Arctic cod) will result in reduced numbers and size of cod, and that this in turn will reduce the population size of ringed seals.

This study may also provide insight into trophic relationships relevant to Hypothesis No. 19, "Dredging and deposition of spoil will reduce the bearded seal population". This could presumably occur indirectly as a result of dredging-related reductions in the benthic prey organisms of some fish species, which could then result in fewer and smaller fish being available for consumption by bearded seals. The present studies on the feeding habits of fish will lead to a better understanding of the plausibility of such a functional relationship.

BEMP PROJECT OVERVIEW NO. 6-2

TITLE: **Arctic Cod distribution, abundance and vulnerability to perturbation**

PRINCIPAL INVESTIGATOR: R. Crawford

AFFILIATION: Dept. of Fisheries and Oceans
Freshwater Institute

FUNDING SOURCE: DFO, NOGAP

RELEVANT BEMP HYPOTHESIS NO.: 6

BRIEF PROJECT DESCRIPTION

The overall objectives of this study are to: (1) determine the distribution and abundance of Arctic cod in various habitats and during various phases of its life cycle; and (2) delimit the spawning season of Arctic cod and identify major spawning locations. This study was initiated in 1984, with sampling effort focused in Resolute Bay. The 1986 sampling program continued to focus on Resolute Bay, but also involved hydroacoustic surveys at sites outside this area to obtain information on the abundance and distribution of Arctic cod and other fish species in the Beaufort Sea.

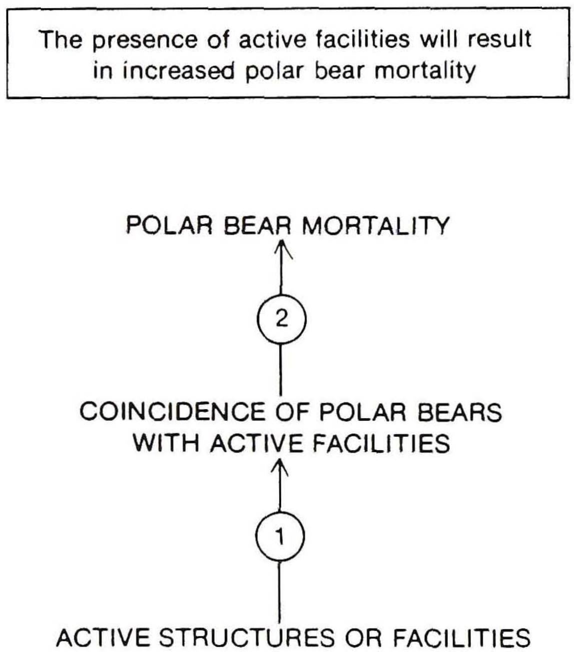
During the ice season, hydroacoustic surveys were conducted at sites in Resolute, Allen and Radstock bays, Barlow, Gascoyne and Griffin inlets, Resolute Passage, Wellington Channel, McDougall Sound, Queens Channel and the mouth of Admiralty Inlet. Results of these surveys indicated that fish were more abundant than in previous years and appeared to be most abundant near the landfast ice edge. During the open-water season, sampling was limited to within Resolute Bay. Arctic cod were collected using bottom trawls and gill nets and were observed using underwater video equipment. All fish collected will be aged and their stomach contents and sex will be determined.

RELATIONSHIP AND RELEVANCE TO THE BEAUFORT ENVIRONMENTAL MONITORING PROJECT

Research on Arctic cod and the role of this species in the diets of its predators is relevant to any impact hypothesis that involves wither direct or indirect linkages (through trophic relationships) between industrial development activities and key species of marine mammals or seabirds. This study is particularly relevant to Hypothesis No. 6 "Icebreaker traffic in Amundsen Gulf will affect the ringed seal and polar bear populations", because information may be obtained on spatial and temporal patterns in the abundance and distribution of Arctic cod, which in turn affect ringed seal food consumption (Link 9), seal population dynamics and therefore polar bear populations.

FIGURE 7-1

POTENTIAL EFFECTS OF ACTIVE FACILITIES ON POLAR BEARS



Linkages

1. Polar bears will encounter active structures or facilities.
2. Polar bears that approach offshore structures have to be controlled, and this will result in the need to destroy some bears.

BEMP PROJECT OVERVIEW NO. 7-1

TITLE:	**Bear detection and deterrent research/eduction**
PRINCIPAL INVESTIGATOR:	P.A. Gray
AFFILIATION:	Department of Renewable Resources Government of NWT, Yellowknife, NWT
FUNDING SOURCES:	Various gov. agencies (EMR, INAC, Manitoba Dept. National Resources, CWS, NOGAP) and industry (Mobil, B.P. Minerals, Gulf, Dome, Petro-Canada, Cominco, ESSO)
EXPECTED COMPLETION DATE:	Ongoing
RELEVANT BEMP HYPOTHESIS NO.:	7

BRIEF PROJECT DESCRIPTION

In the late 1970s, the NWT Wildlife Service (NWTWS) began research on methods to reduce bear-human conflicts and interactions, and in 1981, initiated a formal bear detection and deterrent program. To date, many detection and deterrent techniques have been identified and tested. Detection systems tested to date include a proximity detection unit, trip-wire fence system, microwave motion detection unit, dogs, bear monitors, and infra-red detection units, while bear deterrent methods tested include warning shots/cracker shells/airhorns, vehicles (snow, 3 wheel, helicopters) rubber bullets, flare cartridges, electric fences, and 12-gauge plastic/rubber slugs. Practicality, effectiveness, advantages and limitations of each method have been evaluated, and thus an appropriate system can be chosen for a specific site. Testing of the various systems and methods is ongoing.

One of the more promising deterrent techniques is the 12-gauge, pump-action shotgun, using a three-slug system (cracker shells, plastic slugs, lead slugs). Bears can be deterred using the cracker shells and plastic slugs, and if necessary, destroyed using the lead slug. This system provides personnel handling bear problems more options and should reduce the number of bears that must be destroyed. This system was recently described by Peter Clarkson, GNWT, Inuvik.

As bear detection and deterrent research is completed, it is important that this information be communicated to people living and working in regions inhabited by bears. In response to this need, three initiatives have been developed by the GNWT: (1) production of a "Safety in Bear Country" reference manual in 1985 and updated, (2) the "Safety in Bear Country" workshop program, and (3) operational plans for problem bear sites. An international conference on bear-people conflicts was recently held in Yellowknife, NWT (April 1987).

RELATIONSHIP AND RELEVANCE TO BEAUFORT ENVIRONMENTAL MONITORING PROJECT

Hypothesis No. 7 is valid and states that "The presence of active facilities will result in increased polar bear mortality". This hypothesis suggests that polar bears will be attracted to offshore structures (Link 1), and that the need to maintain worker safety could necessitate the destruction of some animals (Link 2). Research and communication on deterrent and detection systems will reduce the number of bear-human interactions and reduce mortality of bears that do become involved in these interactions.

BEMP PROJECT OVERVIEW NO. 7-2

TITLE:	**Status of polar bears in Alaska**
PRINCIPAL INVESTIGATOR:	S. Amstrup
AFFILIATION:	U.S. Fish and Wildlife Service, Anchorage, Alaska
FUNDING SOURCES:	U.S. Fish and Wildlife Service, Alaska Department of Fish and Game, and others
EXPECTED COMPLETION DATE:	Ongoing
RELEVANT BEMP HYPOTHESIS NO.:	6, 7, 9

BRIEF PROJECT DESCRIPTION

The U.S. Fish and Wildlife Service (USFWS) is presently responsible for the conservation and management of polar bears in Alaska. The principal objectives of their research program are to determine: (1) the size of Alaskan polar bear populations; (2) movements and distribution patterns; and (3) the location of maternity denning areas. Research on Alaskan bears has been ongoing since 1966, and has involved mark-recapture, and more recently (1983-1986) radio-telemetry studies with adult females.

Together with studies in the Canadian Beaufort, the Alaskan studies indicate that bears from Cape Bathurst to Point Barrow belong to the same breeding population, although subpopulations apparently exist.

The size of the Beaufort Sea population was estimated using four methods: two mark-recapture methods, and two methods based on sightings per hour of flight. Results using each method suggest that the population size is about 1800 bears. The population is believed to be stable.

In 1986, the emphasis of the project was shifted from tracking through radio-telemetry to tracking by satellite telemetry. The geographic position of 20 satellite-collared adult female polar bears is monitored every three days. In addition, the 1986 work included more emphasis on studying many aspects of bear predation on seals than in previous years. Less effort was directed at the mark-recapture program in 1986.

RELATIONSHIP AND RELEVANCE TO THE BEAUFORT ENVIRONMENTAL MONITORING PROJECT

This research provides information indirectly relevant to Hypothesis No. 6 and No. 7. The results of the Alaskan research are significant because they show that the Beaufort Sea polar bear population extends from Point Barrow to near Cape Bathurst. Therefore, any activity in Alaska that adversely affects this population could lead to reduced numbers of bears in the Canadian Beaufort (hence a potential for reduced harvest), and perhaps then to the perception that reduced harvest was due to offshore hydrocarbon development in the Canadian Beaufort. Although polar bear harvests are regulated in Canada, this is not the case in the U.S. There is presently a concern in Alaska that the unregulated subsistence harvest of polar bears is concentrating on female bears and cubs (which tend to use nearshore areas) to such an extent that it may begin to adversely affect the population if the harvest was to increase further.

BEMP PROJECT OVERVIEW NO. 7-3

TITLE:	**Assessment of the polar bear population in the eastern Beaufort Sea**
PRINCIPAL INVESTIGATOR:	I. Stirling
AFFILIATION:	Canadian Wildlife Service, Edmonton, Alberta
FUNDING SOURCE:	NOGAP, CWS, GNWTWS, Yukon Wildlife Branch, PCSP
EXPECTED COMPLETION DATE:	1988
RELEVANT BEMP HYPOTHESIS NO.:	6, 7, 8, and 9

BRIEF PROJECT DESCRIPTION

The objectives of this three-year study are to determine the size of the polar bear population in the eastern Beaufort Sea and Amundsen Gulf, the demographic and reproductive parameters of the population, and the distribution of subpopulations, and to compare these with results from studies conducted in the region from 1971-1979. A further objective is to evaluate effects of offshore hydrocarbon exploration activities on the polar bear population. It will be difficult to achieve this latter objective because of the compounding influence of recently increased quotas in Canada and unrestricted (and variably recorded) harvest practices in Alaska, and because no experimental procedure to evaluate cause and effect could be or was undertaken as part of the research. Effects will nonetheless be evaluated on the basis of judgments based on data collected, years of experience with polar bears, and other related information that can be obtained.

The study was initiated in spring 1985, and continued in spring 1986. A total of over 400 bears was handled in these years; each bear was tagged, measured and aged. Data analysis is in progress. The third and final year of the study will be 1987, and the results reported in 1988. The data base for the study will be expanded with mark and recapture data collected by the Yukon Wildlife Branch, GNWTWS, and USFWS, with radio-tracking data collected as part of Project 7-2, published information, incidental sightings by personnel on industry ships, and harvest data.

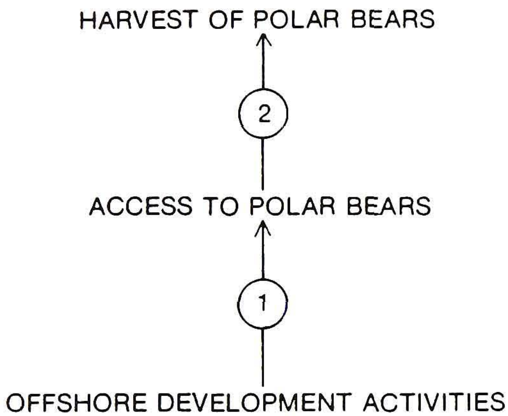
RELATIONSHIP AND RELEVANCE TO THE BEAUFORT ENVIRONMENTAL MONITORING PROJECT

This project will provide background information that is relevant to all hypotheses concerning polar bears (Hypothesis No. 6, 7, 8 and 9). Detection of changes in the size, demography, reproductive condition, body condition, and distribution of subpopulations in the polar bear population has clear relevance to Hypothesis No. 7. If the polar bear population were found to be changing, quotas would likely be adjusted and this could then affect harvest levels. Because bears will be directly examined during this work, information about oiled bears relevant to Hypothesis No. 9, "Chronic/episodic oil spills resulting from normal hydrocarbon development activities within and adjacent to the marine environment will result in localized mortality of polar bears", may also become available.

FIGURE 8-1

POTENTIAL EFFECTS OF OFFSHORE DEVELOPMENT ON POLAR BEAR HARVEST

Offshore development activities will reduce the harvest of polar bears

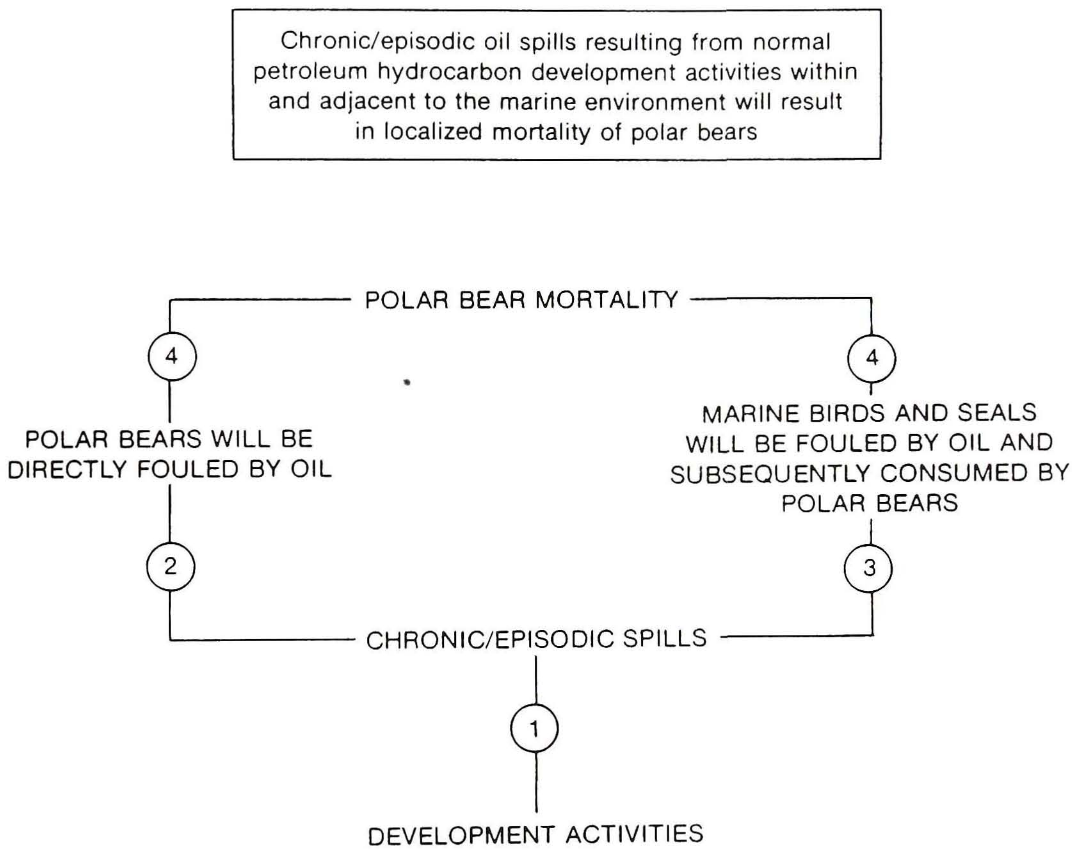


Linkages

1. Hunter access to polar bears will be reduced because offshore development will cause bears to move farther offshore and/or create physical barriers to Inuit travel on the ice.
2. Reduced access to polar bears will lead to reductions in the Inuit harvest of polar bears.

FIGURE 9-1

POTENTIAL EFFECTS OF CHRONIC/EPISODIC OIL SPILLS RESULTING FROM NORMAL PETROLEUM HYDROCARBON DEVELOPMENT ACTIVITIES WITHIN AND ADJACENT TO THE MARINE ENVIRONMENT ON POLAR BEARS



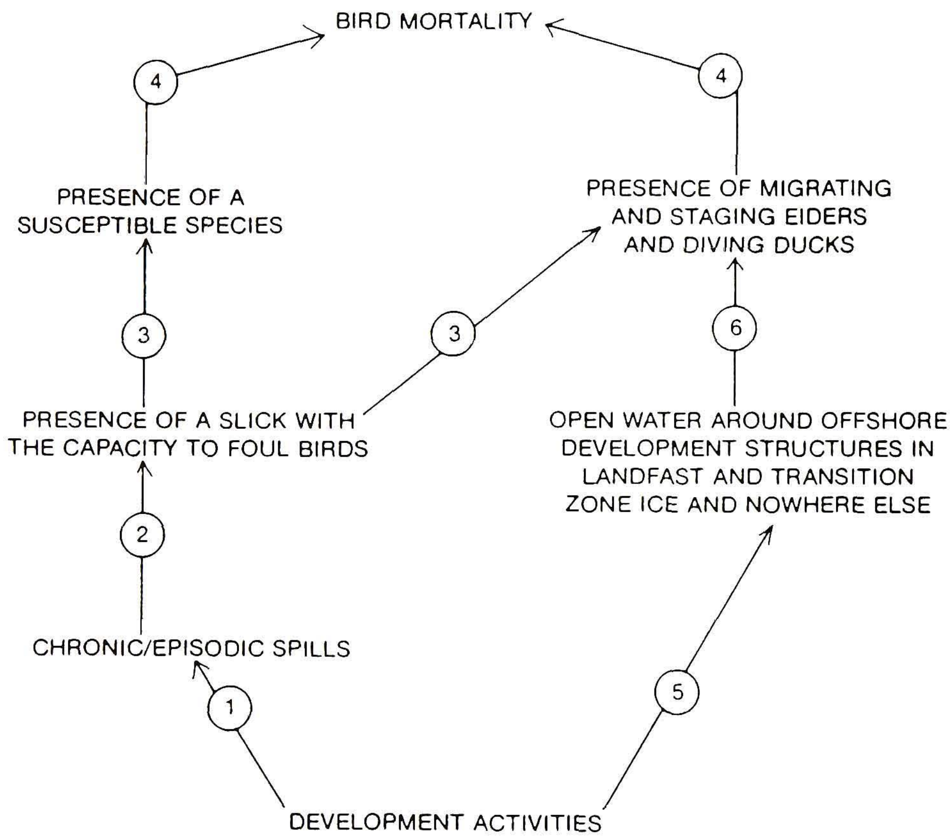
Linkages

1. Development activities will result in chronic/episodic spills.
2. Chronic spills will result in the direct fouling of polar bears.
3. Chronic spills will result in the direct fouling of marine birds and seals that are consumed by bears.
4. Mortality of bears will occur if oil is contacted or ingested.

FIGURE 10-1

POTENTIAL EFFECTS OF CHRONIC (EPISODIC) OIL SPILLS RESULTING FROM NORMAL PETROLEUM DEVELOPMENT ACTIVITIES ON BIRDS

Chronic (Episodic) oil spills resulting from normal petroleum hydrocarbon development activities within and adjacent to the marine environment will result in local mortality of certain species of birds

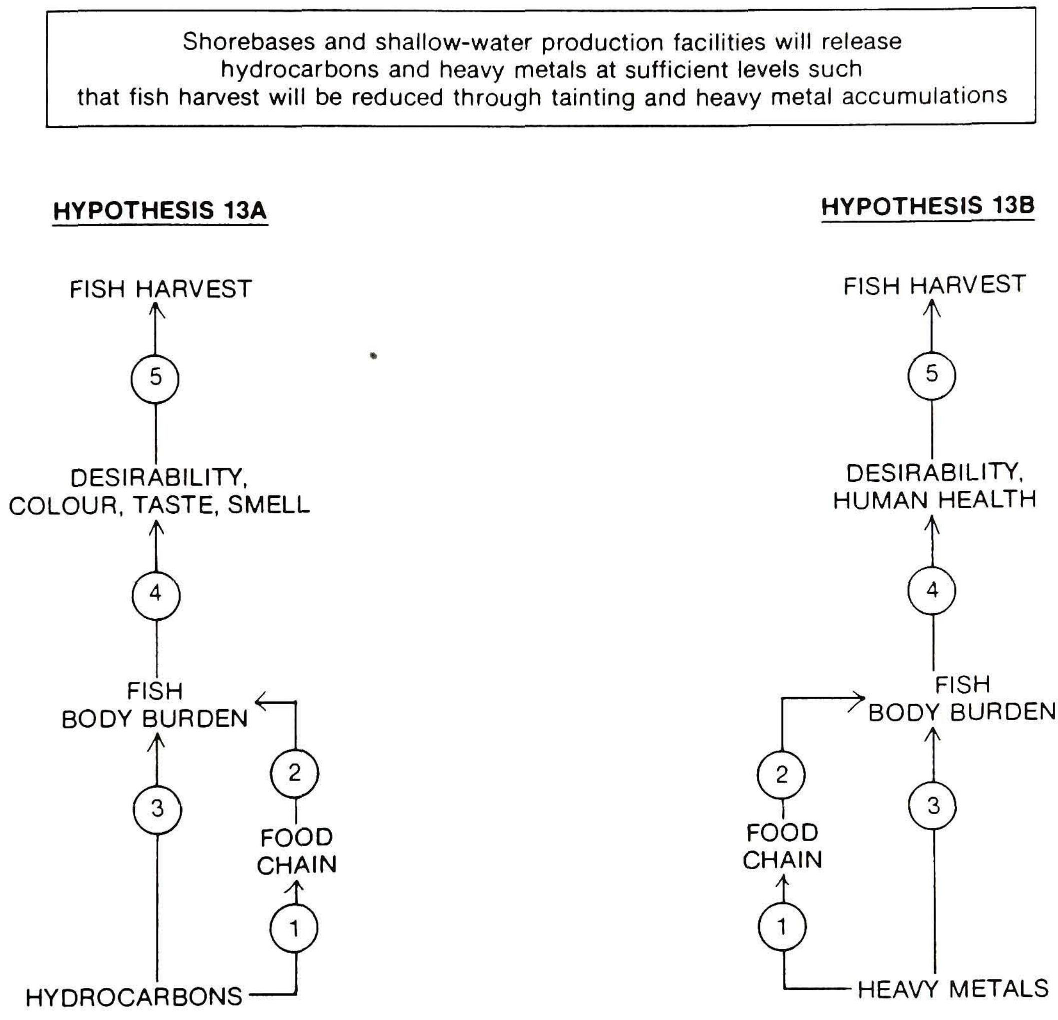


Linkages

1. Development activities will result in chronic (episodic) spills of petroleum hydrocarbons.
2. Where chronic (episodic) spills occur, slicks with the capacity to foul birds will be present under certain conditions.
3. Susceptible bird species will co-occur in space and time with the presence of a slick.
4. Mortality of birds will occur following slick contact.
5. Thermal discharges under or onto the ice from offshore production facilities will enhance melting and formation of open water around structures (Hypothesis No. 11, Link 3, 1983-84 BEMP report).
6. Eiders and other diving ducks are attracted to open water areas during migration and staging (Hypothesis No. 11, Link 4, 1983-84 BEMP report).

FIGURE 13-1

POTENTIAL EFFECTS OF RELEASE OF HYDROCARBONS AND HEAVY METALS ON FISH HARVEST



Linkages for Hypothesis 13A

1. and 3. Hydrocarbons in water and sediments will enter fish and prey organisms of harvested fish species.
2. Hydrocarbons can be passed through food chains.
4. Desirability of fish is decreased as a result of increases in body burden of hydrocarbons.
5. Decreased desirability will decrease fish harvest.

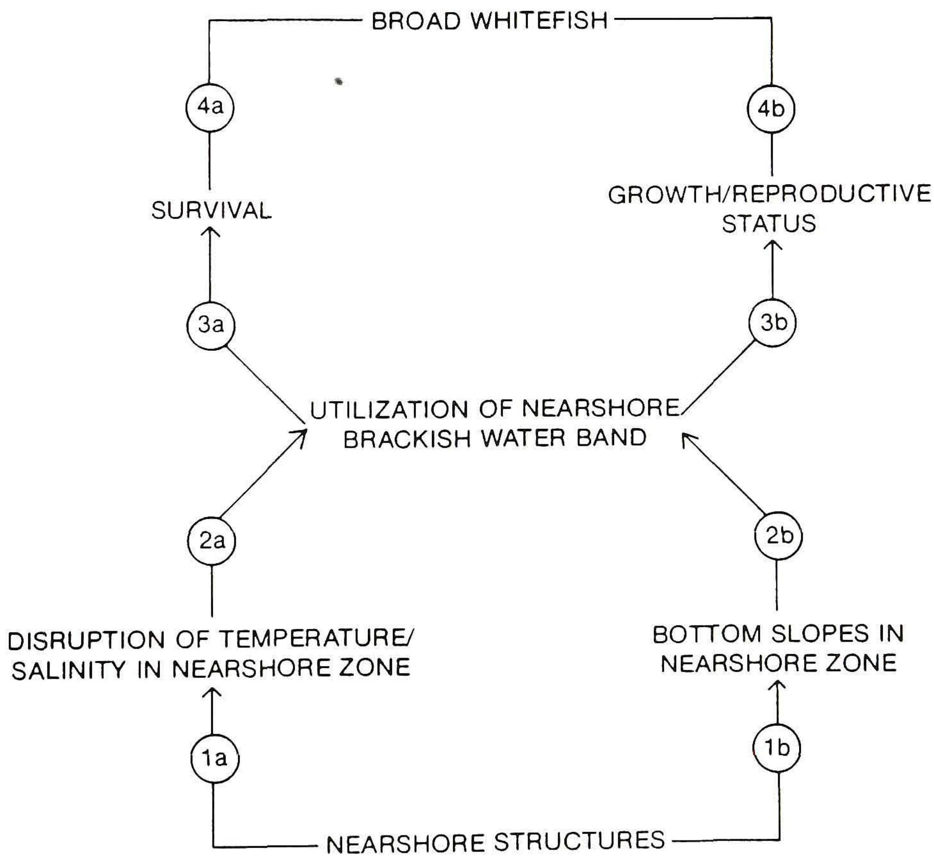
Linkages for Hypothesis 13B

1. and 3. Heavy metals from water and sediments will enter fish and prey organisms of harvested fish species.
2. Heavy metals can be passed through food chains.
4. Human health and desirability of fish can be affected by increases in heavy metal concentrations.
5. Decreased desirability will decrease fish harvest.

FIGURE 14-1

POTENTIAL EFFECTS OF NEARSHORE STRUCTURES ON THE ROAD WHITEFISH POPULATION

Nearshore structures will disrupt the nearshore band of warm brackish water and reduce the broad whitefish population



Linkages

1a. Shoreline modifications will change temperature and salinity characteristics of the brackish water band along the Tuktoyaktuk Peninsula.

1b. Nearshore structures will change the slope of the sea bottom within the brackish water band along the Tuktoyaktuk Peninsula.

2a. Disruption of the brackish water band will result in decreased utilization of the nearshore zone by broad whitefish.

2b. Changes in nearshore sea bottom slope will alter utilization of nearshore waters by broad whitefish.

3a. The reduced time spent in the nearshore brackish zone will cause an increase in mortality of broad whitefish.

3b. Disruption of nearshore habitat will cause a decrease in feeding time and consequently a reduction in growth and fecundity.

4a. Increase in mortality of broad whitefish would lead to a decrease in the number of spawners, and subsequent reduction in the number of harvestable fish.

4b. Reduction in fecunity and reduced viability of eggs and young would result in fewer available fish for the harvest.

BEMP PROJECT OVERVIEW NO. 14-1

TITLE: **Fish migration along the Tuktoyaktuk Peninsula**

PRINCIPAL INVESTIGATOR: K. Chang-Kue

AFFILIATION: Dept. of Fisheries and Oceans
Freshwater Institute

FUNDING SOURCE: DFO, NOGAP

EXPECTED COMPLETION DATE: 1987

RELEVANT BEMP HYPOTHESIS NO.: 14

BRIEF PROJECT DESCRIPTION

This study is investigating the movements of broad whitefish in Tuktoyaktuk Peninsula and MacKenzie estuary areas. Earlier studies have indicated that juvenile broad whitefish summer in drainages on the Tuktoyaktuk Peninsula and winter either in the same drainage or in shallow coastal bays. Tagged fish were recovered years later as spawning migrants in the MacKenzie estuary.

This study was designed to: (1) provide detailed information on the fall migration of broad whitefish; (2) identify major spawning grounds in Tuktoyaktuk Peninsula and MacKenzie Delta areas; and (3) identify overwintering habitats along the lower MacKenzie River and Delta.

In 1986, 25 broad whitefish in Kittigazit Creek were radio tagged to study the late summer and fall migration. The majority of these fish were immature (i.e., less than 8 years old). Late July tracking of these individuals indicated that they migrated downstream to the mouth of the creek within a week and made only very local movements within Kittigazit Inlet. By September, these fish still resided within the inlet, which supports the hypothesis that immature coregonids migrate downstream and move into major coastal bays and possibly the outer MacKenzie Delta channels (e.g., East Channel) to overwinter. In September, timer-activated tags were applied to 8 large whitefish at Horseshoe Bend to monitor the early spring activity of post-spawners. In addition, 6 whitefish were also tagged to monitor their movements until late November.

RELATIONSHIP AND RELEVANCE TO THE BEAUFORT ENVIRONMENTAL MONITORING PROJECT

This study is most relevant to Hypothesis 14, which states that "Nearshore structures will disrupt the nearshore band of warm brackish water along the Tuktoyaktuk Peninsula and reduce the broad whitefish population". The underlying assumption of this hypothesis is that broad whitefish use the warm brackish water found along the Tuktoyaktuk Peninsula as migratory route between spawning or overwintering areas in the MacKenzie River or Estuary and rearing areas in freshwater lakes on the peninsula. Interruption of this route, for example, by the diversion of coastal waters to offshore areas by long causeways, could have population-wide effects on the broad whitefish that inhabit the region through decreased survival (Link 4a) or decreased growth and reproductive potential (Link 4b). This study will address major data deficiencies regarding the seasonal use of nearshore waters by broad whitefish in the region.

BEMP PROJECT OVERVIEW NO. 14-2

TITLE:	**Whitefish stock description**
PRINCIPAL INVESTIGATOR:	J. Reist
AFFILIATION:	Dept. of Fisheries and Oceans Freshwater Institute
FUNDING SOURCE:	DFO, NOGAP
EXPECTED COMPLETION DATE:	1987
RELEVANT BEMP HYPOTHESIS NO.:	14, 16 and 17

BRIEF PROJECT DESCRIPTION

The purpose of this study is to determine the discreteness and number of broad whitefish stocks in the MacKenzie River drainage through morphometric, meristic and electrophoretic techniques. Samples of whitefish have been collected from the MacKenzie Delta and at several locations upstream. These specimens are being examined to determine the usefulness of specific characteristics as stock identifiers.

In 1986, approximately 1780 fish collected from the study area and from Alaska (for comparative purposes) during the 1985 field program were processed. This included taking 20 measurements, 9 meristic counts and 4 measurements of biological parameters, examination for scarring and external parasites and extraction of muscle, heart and liver tissue for biochemical analysis. Scale-aging of all broad and lake whitefish collected in 1983, 1984 and 1985 has been completed, and analysis of all other species is presently being conducted.

RELATIONSHIP AND RELEVANCE TO THE BEAUFORT ENVIRONMENTAL MONITORING PROJECT

This study is of relevance to all hypotheses concerning broad whitefish because it may provide data that will aid in assessment of the possible effects of hydrocarbon development on this species. If separate populations of broad whitefish exist in the region, they may be more susceptible to some development activities, particularly if such populations remain as relatively discrete units while in the Beaufort Sea.

BEMP PROJECT OVERVIEW NO. 14-3

TITLE:	**Salinity tolerance of whitefish**
PRINCIPAL INVESTIGATOR:	B. deMarch
AFFILIATION:	Dept. of Fisheries and Oceans Freshwater Institute
FUNDING SOURCE:	DFO, NOGAP
EXPECTED COMPLETION DATE:	1988
RELEVANT BEMP HYPOTHESIS NO.:	14

BRIEF PROJECT DESCRIPTION

The overall objectives of this study are to:

1. explain and predict juvenile and adult whitefish migration patterns in dispersal corridors in the nearshore Beaufort Sea in relation to salinity patterns; and

2. determine the effect of crude oil exposure on young broad whitefish acclimating to changes in salinity.

The first phase of the study involved conducting laboratory experiments on wild juvenile fish (broad whitefish, lake whitefish and least cisco) collected from Freshwater Creek, near Tuktoyaktuk, to determine the tolerance of these fish to a range of salinity levels and rates of salinity change. A manuscript of the 1985 study results has been published in the Fisheries and Oceans Technical Report Series.

In 1986, coregonid eggs were collected from spawning aggregations in the lower MacKenzie River. Once the brood stock has been established, the larval fish and fry will be stressed by exposure to crude oil and the effects of changing salinity on the fish will be documented. The study will quantify the physical and chemical habitat requirements and tolerances of young broad whitefish during their dispersal from the MacKenzie River to rearing and feeding areas in the freshwater systems along the Tuktoyaktuk Peninsula, and the effects that oil may have on this dispersal.

RELATIONSHIP AND RELEVANCE TO THE BEAUFORT ENVIRONMENTAL MONITORING PROJECT

This study is relevant to Hypothesis 14, which states that "Nearshore structures will disrupt the nearshore band of warm brackish water and reduce the broad whitefish population". The results of this study will not only contribute to the understanding of whitefish biology, but will also enable predictions to be made concerning the distribution of larval whitefish in the nearshore environment in relation to the salinity regime.

FIGURE 15-1

POTENTIAL EFFECTS OF NEARSHORE STRUCTURES ON THE ALASKAN POPULATION OF ARCTIC CISCO

Nearshore structures will disrupt the nearshore band of warmer brackish water and will reduce the Alaskan population of arctic cisco

ALASKAN POPULATION OF ARCTIC CISCO

↑ 3

YOUNG FISH (70-100mm) PREVENTED FROM MOVING ALONG THE YUKON COAST

↑ 2

DISRUPTION OF TEMPERATURE AND SALINITY IN NEARSHORE ZONE

↑ 1

NEARSHORE STRUCTURES

Linkages

1. Shoreline modification will change temperature and salinity patterns of the brackish water band along the Yukon Coast during summer.
2. Disruption of the brackish water band will result in decreased movement of young arctic cisco from the Mackenzie Delta to the Alaskan Beaufort Sea coast.
3. Decreased movement of arctic cisco will cause directly proportional decreases in the Alaskan population of arctic cisco.

BEMP PROJECT OVERVIEW NO. 15-1

TITLE: **Yukon North Slope fish habitat assessment**

PRINCIPAL INVESTIGATORS: M. Lawrence and W. Bond

AFFILIATION: Dept. of Fisheries and Oceans
Freshwater Institute

FUNDING SOURCE: DFO, NOGAP

EXPECTED COMPLETION DATE: 1988

RELEVANT BEMP HYPOTHESIS NO.: 15 and of general interest

BRIEF PROJECT DESCRIPTION

The primary objectives of this study are to:

1. obtain baseline biological descriptions of the marine and anadromous fishes utilizing nearshore habitats along the Yukon coast (species composition and distribution, age and growth, sex and maturity, food habitats);

2. describe the alongshore migratory patterns of anadromous fish during the open-water period;

3. identify specific areas that may be of importance to marine and anadromous fishes as feeding, spawning, nursery or overwintering habitat; and

4. characterize inshore habitats (to the 5 m isobath) in terms of temperature and salinity, and relate these variables to fish distribution and movement patterns.

Gillnets, trapnets and seines are being used to sample marine and anadromous fish populations between Kay Point and Calton Point. Sampling is being conducted during the open-water season, and the extent of anadromous fish movements are being evaluated through the use of conventional (Floy) tags.

The 1986 sampling program focused on the area enclosed by the 5 m isobath within Phillips Bay. Sampling was initiated on 23 June and was completed by 08 September. A single trap was set outside Niakolik Point and was operated on a daily basis. Three sites along the 5 m isobath were sampled on 23 occasions using variable-mesh gillnets, and six sites were sampled on a regular basis using small-mesh seines. Floy tags were applied to 2800 Arctic cisco. Water temperature and salinity were determined daily at each trapnet site and with each fish collection at seine and gillnet sites. Arctic cisco and Arctic flounder were the species most frequently captured.

RELATIONSHIP AND RELEVANCE TO THE BEAUFORT ENVIRONMENTAL MONITORING PROJECT

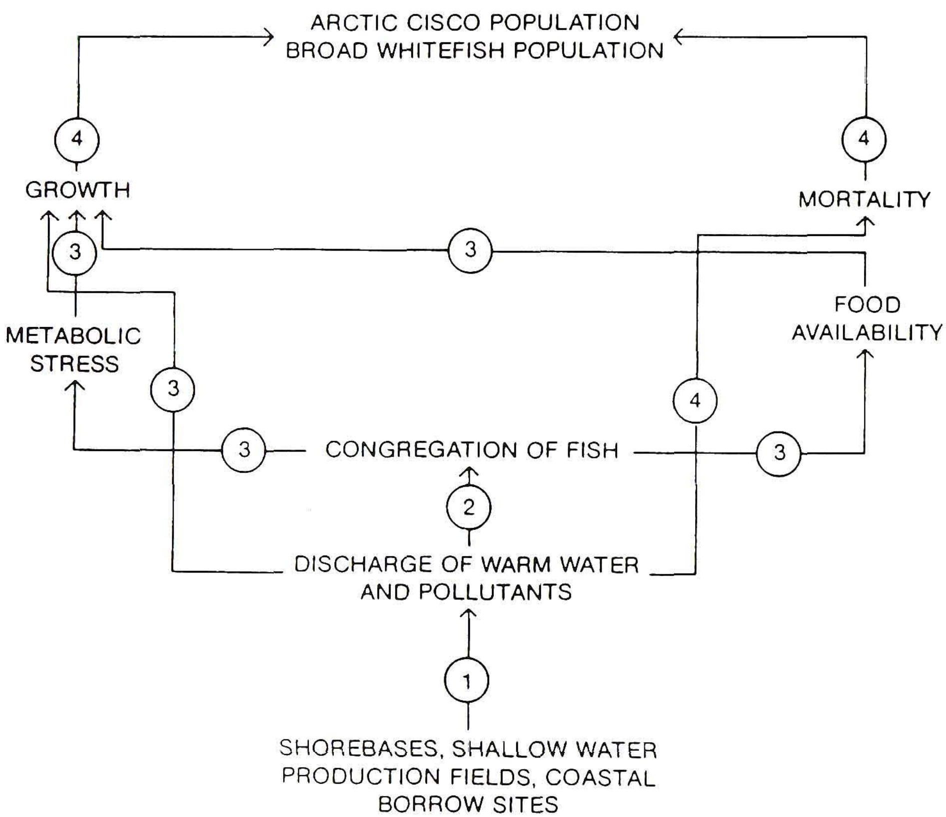
This study is particularly relevant to Hypothesis No. 15, which states that "Nearshore structures will disrupt nearshore band of warmer brackish water and will reduce the Alaskan populations of Arctic cisco". It will define use of the nearshore zone as a migration corridor for Arctic cisco and other fish species. The results of this 5-year program could verify or disprove the underlying assumption of Hypothesis No. 15. The assumption is that "Alaskan Arctic cisco" spawn in the Mackenzie River and then juveniles migrate along the Yukon coast to spend a number of years in Alaskan waters before mature or nearly mature fish return to the MacKenzie River to spawn.

In addition, this study is expected to provide basic descriptive information on other fish species that occur along the Yukon coast. These data will provide the basis for evaluation of the need for future monitoring programs related to hydrocarbon development activities in this part of the southeast Beaufort Sea.

FIGURE 16-1

POTENTIAL EFFECTS OF DISCHARGES FROM PRODUCTION FIELDS AND OTHER FACILITIES ON ARCTIC CISCO AND BROAD WHITEFISH POPULATIONS

The construction of shorebases and development of shallow-water production fields will result in a decrease in the populations of arctic cisco and broad whitefish

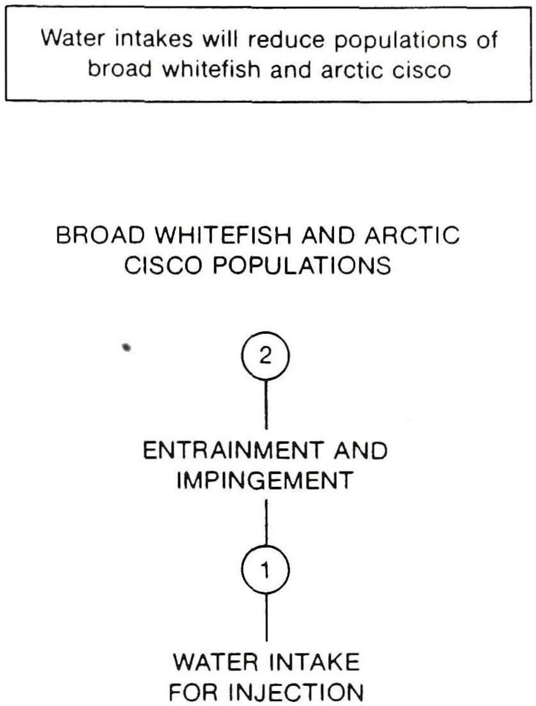


Linkages

1. Warm water effluents and production water will be discharged into the freshwater area of the outer Mackenzie Delta.
2. Fish will be attracted to thermal plumes.
3. Contaminants in produced water in areas where fish are congregated will result in increased stress, reduced food availability and decreased fish growth.
4. Direct mortality due to effluents and decreased growth will reduce arctic cisco and broad whitefish populations.

FIGURE 17-1

POTENTIAL EFFECTS OF WATER INTAKES ON BROAD WHITEFISH AND ARCTIC CISCO POPULATIONS

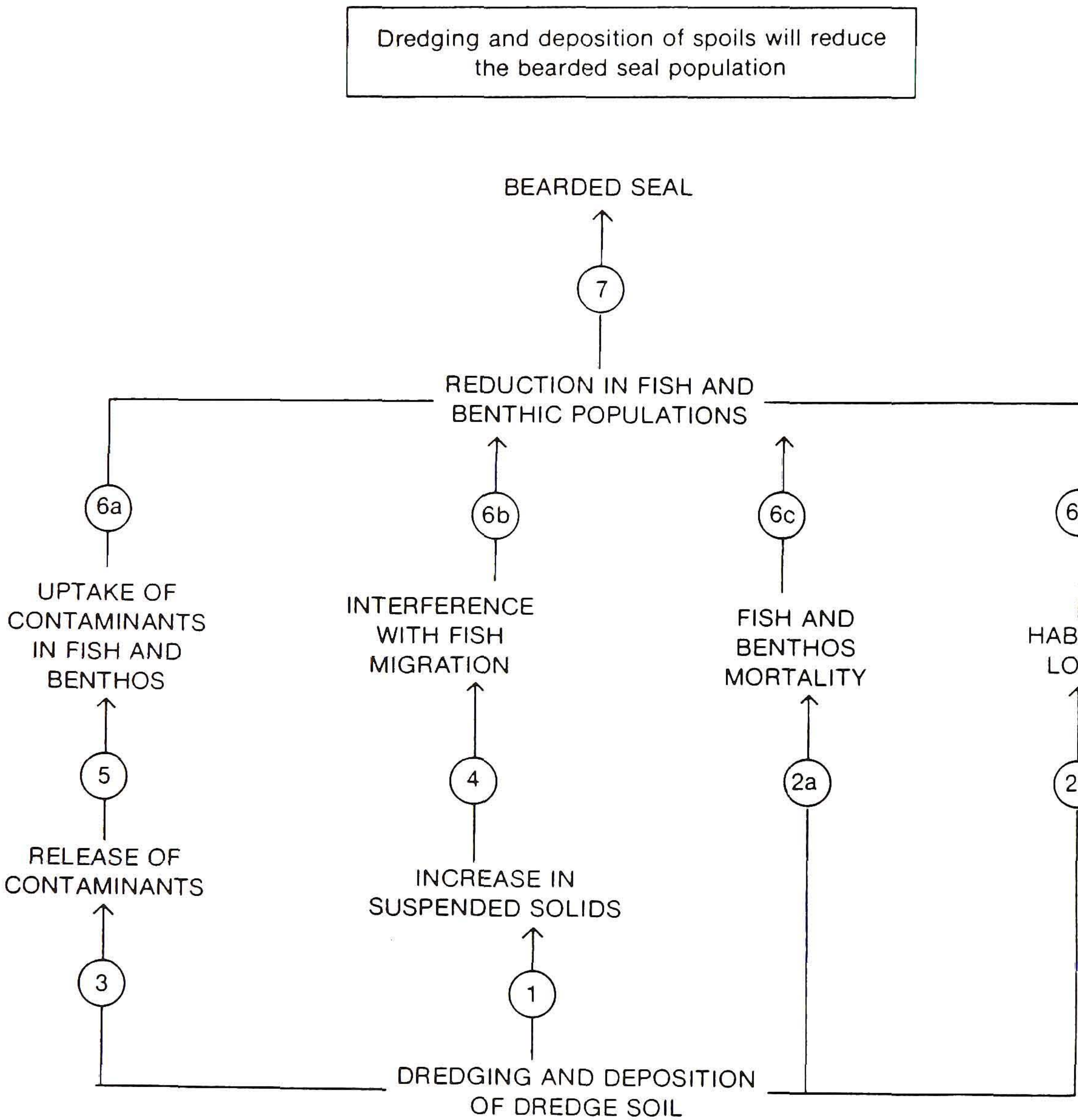


Linkages

1. The intake of water for reservoir injection will cause entrainment and impingement of juvenile broad whitefish and arctic cisco.
2. The mortality associated with entrainment and impingement will reduce broad whitefish and arctic cisco populations.

FIGURE 19-1

POTENTIAL EFFECTS OF DREDGING AND DEPOSITION OF SPOILS ON THE BEARDED SEAL POPULATION



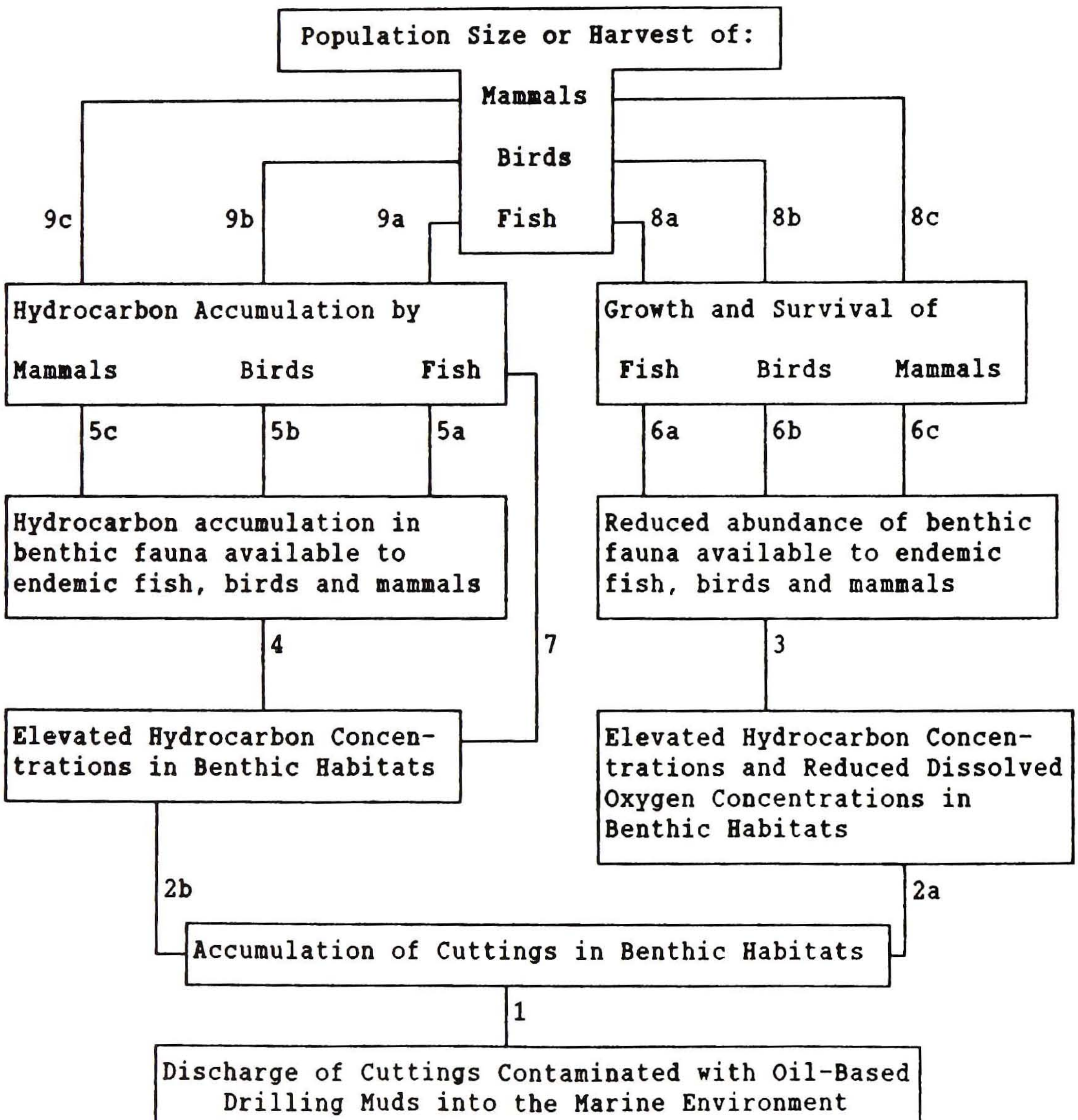
Linkages

1. Dredging and deposition of dredge spoils will increase concentrations of suspended solids in the water column.
2. Removal of seafloor material and its deposition in other areas will result in mortality of benthic invertebrates and fish and habitat loss.
3. Dredging will release contaminants from the sediments.
4. Increased suspended solids will interfere with fish migration.
5. Contaminants released during dredging will be taken up by fish and benthos.
6. Habitat loss, mortality, interference with migratory routes and uptake of contaminants will reduce fish and benthic invertebrate populations.
7. Reduced populations of prey (fish and benthos) will reduce the number of bearded seals.

FIGURE 20-1

EFFECTS OF CUTTINGS CONTAMINATED WITH OIL-BASED DRILLING MUDS ON THE POPULATION OR HARVEST OF FISH, BIRDS AND MARINE MAMMALS

The discharge of drill cuttings contaminated with oil-based drilling muds during hydrocarbon exploration or production will reduce populations of fish, birds or mammals or will decrease the harvest of these resources due to hydrocarbon accumulation in tissues.



Linkages

1. Drill cuttings contaminated with oil-based drilling muds and discharged during exploration or development drilling will settle rapidly to the seafloor and resist subsequent widespread dispersion due to the cohesiveness of oil-based mud/cuttings mixtures.

2a. In areas of cuttings accumulation, elevated hydrocarbon concentrations will occur in benthic habitats.

2b. In areas of cuttings accumulation, elevated hydrocarbon concentrations and reduced dissolved oxygen concentrations will occur in benthic habitats during the slow degradation of oil-based muds adhering to drill cuttings.

3. The abundance of benthic fauna available to endemic fish, birds and mammals will be reduced in areas of mud/cuttings accumulation due to smothering, oxygen depletion and toxicity of petroleum hydrocarbons in drilling muds or the products resulting from their degradation.

4. Benthic fauna available to endemic fish, birds and mammals in habitats containing mud/cuttings mixtures will accumulate petroleum hydrocarbons.

5a. Decreased abundance of benthic fauna will affect the growth and survival of marine and anadromous fish.

5b. Decreased abundance of benthic fauna will affect the growth and survival of birds that feed on benthic prey organisms.

5c. Decreased abundance of benthic fauna will affect the growth and survival of marine mammals that feed on benthic prey organisms.

6a. Marine and anadromous fish will accumulate petroleum hydrocarbons from ingestion of contaminated prey.

6b. Birds will accumulate petroleum hydrocarbons from ingestion of contaminated prey.

6c. Marine mammals will accumulate petroleum hydrocarbons from ingestion of contaminated prey.

7. Marine and anadromous fish remaining in areas containing oil-contaminated cuttings will accumulate petroleum hydrocarbons directly.

8a. The size of marine and anadromous fish populations will be reduced due to local effects of reduced prey availability on growth and survival.

BEMP PROJECT OVERVIEW NO. 20-1

TITLE:	**Oil-based drilling muds: off structure monitoring - Beaufort Sea. Minuk I-53 and Kaubvik I-43**
PRINCIPAL INVESTIGATORS:	P. Erickson, B. Fowler and D. Thomas
AFFILIATION:	Arctic Laboratories Limited
FUNDING SOURCE:	ESRF
EXPECTED COMPLETION DATE:	Late 1988
RELEVANT BEMP HYPOTHESIS NO.:	20

BRIEF PROJECT DESCRIPTION

The purpose of this study is to monitor the distribution of base oil hydrocarbon concentrations in the vicinity of the two well sites in the Beaufort Sea (Minuk I-53 and Kaubvik I-43), and to determine the areal extent of discharge cuttings at the sites. The sampling program involves a pre-drilling (background) and two post-drilling assessments of the areal distribution of base oil. In addition to routine collection of sediments around the drill sites, the sampling program includes collection of current, temperature and salinity data near both sites during cuttings discharge and deployment of sediment traps at both locations during cuttings discharge. This additional oceanographic information will be essential for the interpretation of the chemical results.

To date, only sampling around the Minuk site has been completed. Preliminary results indicate that Vista base oil could be detected during the first post drilling sampling conducted through the ice, but only to approximately 200 m of the sealine discharge. The rubble field that surrounded Minuk during the discharge period appears to have been an effective barrier to the seaward movement of cuttings contaminated with oil-based mud. On the second post drilling sampling survey conducted under open water conditions, concentrations of Vista base oil as much as 2000 times background could be detected up to 500 m from the sealine. A detailed analysis and interpretation of the chemical results is on-going.

RELATIONSHIP AND RELEVANCE TO THE BEAUFORT ENVIRONMENTAL MONITORING PROJECT

The results of this study will provide information regarding the fate of oiled cuttings in the Beaufort Sea. Information on the accumulation of the cuttings and their subsequent dispersal and redistribution in the benthic environment will be essential in assessing the possible effects of these discharges on populations of fish, birds and mammals in the region.

BEMP PROJECT OVERVIEW NO. 20-2

TITLE:	**Oil-based drilling mud toxicity**
PRINCIPAL INVESTIGATORS:	M. Hutcheson, P. Stewart and C. Hamilton
AFFILIATION:	Seakem Oceanography Ltd.
FUNDING SOURCE:	ESRF
EXPECTED COMPLETION DATE:	Fall 1987
RELEVANT BEMP HYPOTHESIS NO.:	20

BRIEF PROJECT DESCRIPTION

This study is designed to examine the chemical factors that contribute to the acute and chronic toxicity of oil-base drilling muds, particularly the type and quantity of aromatic hydrocarbons in the base oils. The specific objective of the study is to determine the acute and chronic toxicity of aqueous extracts of "low-tox" drilling fluid base oils, drilling muds prepared with these oils, and synthetic drill cuttings prepared from the formulated muds. The experimental program involves the laboratory exposure of four marine species to base oils and formulated drilling muds in both acute and chronic assays, and chronic exposure of benthic invertebrates to oiled cuttings in the field and laboratory.

To date, mud formulations containing five different base oils and varying concentrations of the primary emulsifier (all other constituents are constant among muds) have been successfully prepared for use in the experiment. All muds display the characteristics shown below.

Performance Specifications for Invert Emulsion Mud

mud weight	14 lb/gal
oil:water	90:10
plastic viscosity	35.9 sec L^{-1}
yield point	5.25 pascals
gel strength	6/7 dynes m^{-2}
electrical stability	900 v
API fluid loss (30 min)	5.8 cc
HPHT fluid loss (300/500)	23 cc

RELATIONSHIP AND RELEVANCE TO THE BEAUFORT ENVIRONMENTAL MONITORING PROJECT

The results of this study will aid in defining the inverse relationship between the proportion of aromatic hydrocarbons in base oils and the concentration of emulsifiers required to maintain satisfactory drilling performance characteristics. In so doing, the range of concentrations of aromatics in various usable mud formulations can be established, thereby allowing evaluation of the possible mobility of these components in the marine environment and subsequent bioaccumulation potential. The results of the research will also provide a better understanding of the inherent toxicity of the base oils and individual additives of oil-based muds, as well as the relationship between aromatic content and mud toxicity.

BEMP PROJECT OVERVIEW NO. 20-3

TITLE:	**Oil-based drilling muds: off structure monitoring West Venture C-62 and South Des Barres 0-76 Sable Island**
PRINCIPAL INVESTIGATORS:	M. Yunker and R.W. Drinnan
AFFILIATION:	Dobrocky Seatech Ltd.
FUNDING SOURCE:	ESRF
EXPECTED COMPLETION DATE:	Complete
RELEVANT BEMP HYPOTHESIS NO.:	20

BRIEF PROJECT DESCRIPTION

The purpose of this study was to determine the areal distribution and dispersal of drilling mud base oil following the discharge of contaminated cuttings from two drilling rigs near Sable Island. The two drill sites studied were characterized by substantially different physical and oceanographic regimes. The Mobile West Venture C-62 site was located in about 16 m of water along the south side of the eastern bar of Sable Island, where bottom sediments are well mixed by wind and wave action. The Shell South Des Barres O-76 site was located about 19 km north of the middle of Sable Island in approximately 70 m of water. During drilling of the latter well (summer and fall), the bottom sediments were not influenced to a significant degree by wave action. Because of the limited influence of the waves on the sediments at South Des Barres was an excellent location to fulfill a secondary purpose of this study, which was to examine the dispersal of oiled cuttings by currents. Although different commercial oil-based muds were used at each well (Technifluids "Biovert" System at West Venture C-62; Baroid "Environmul" at South Des Barres O-76), the same base oil (Conoco ODC) was used in both formulations.

Samples were collected at both sites along eight radial transect lines. At West Venture, sediment grab samples were taken at distances of about 200, 500 and 1000 m from the wellhead, whereas the distances at South Des Barres were 200, 800 and 1500 m along each transect line. Reference samples were collected approximately 3 km away from the wellhead in the expected "upcurrent" direction at both sites. A measure of total aliphatic hydrocarbons was used to trace the presence of base oil from the oiled cuttings.

At the West Venture site, hydrocarbon concentrations decreased to a level 10 times above background by ~200 m from the wellsite, with no apparent predominant direction of spread. The results of this study suggest that the oiled cuttings at West Venture were dispersed or buried, probably as the result of wave action in this relatively shallow (16 m) area. At South Des Barres, aliphatic hydrocarbon levels were 10 times background at distances ranging from about 200 to 1500 m from the wellhead. Hydrocarbon concentrations of more than four orders of magnitude above background were detected only within 200 m of the wellhead. These higher concentrations of aliphatics and the oceanographic regime at South Des Barres suggest that oil associated with cuttings may persist for a longer period in the deeper (70 m) water environment. Core samples taken at the West Venture site show that oil concentrations decreased with depth along the core, suggesting that some of the oil discharged with the cuttings may have migrated to the surface of the cuttings pile. The concentrations of Conoco oil in areas where cuttings had been discharged decreased by about two orders of magnitude after the drilling program was completed; sediment transport and dispersal processes in conjunction with "weeping" of the oil fraction were probably responsible for this decrease in hydrocarbon concentrations.

The report provides information on the weathering of Conoco oil and the post-depositional dispersal of cuttings and associated oil. There is some suggestion that there has been a significant contribution of PAH from the geological formation to the drilling cuttings discharged near Sable Island.

RELATIONSHIP AND RELEVANCE TO THE BEAUFORT ENVIRONMENTAL MONITORING PROJECT

This study provides a good basis for evaluation of Links 1 and 2 of the hypothesis, as well as the fate of cuttings contaminated with oil-based mud in two different depositional environments. Its results may also be compared with those of a companion ESRF study being conducted in the Beaufort Sea at the Minuk and Kaubvik well sites by Arctic Laboratories Limited. Both studies provide baseline information for possible future investigations into the persistence of discharged cuttings in the marine environment.

BEMP PROJECT OVERVIEW NO. 20-4

TITLE:	**Oxygen demand of oiled drill cuttings**
PRINCIPAL INVESTIGATORS:	M. Hutcheson and R. Odense
AFFILIATION:	Seakem Oceanography Ltd.
FUNDING SOURCE:	NOGAP
EXPECTED COMPLETION DATE:	Complete
RELEVANT BEMP HYPOTHESIS NO.:	20

BRIEF PROJECT DESCRIPTION

The purpose of this study was to determine the oxygen demand of oiled cuttings layered on the sea floor. The cuttings used for the investigation were from the Shell Alma F-67 well drilled on the Scotian Shelf in 1984. The total oil content of the cuttings was 8.4% and the base oil for the drilling fluid was Conoco mineral oil. Sub-objectives of the study were to: (1) evaluate the influence of underlying substrate type and cuttings thickness on the oxygen demand of the cuttings; (2) observe the change in redox potential of cuttings and sediments covered by seawater; and (3) compare the metal concentrations in pore water at the start and end of the 30-day flow-through experiments.

The main results of the research were as follows:

1. natural oxygen consumption rates ranged from 0-4 mL $O_2 m^{-2} h^{-1}$ (fine sediment) and 1-7 mL $O_2 m^{-2} h^{-1}$ (coarse sediment);

2. oiled cuttings layered over the natural sediments resulted in an increase in sediment oxygen consumption rate to as much as 18-fold above control rates. Consumption rates ranged from 0-19.2 mL O_2 $m^{-2} h^{-1}$;

3. fifteen to thirty days are required for differences among experimental treatments to become evident;

4. maximum increase in oxygen demand occurred with a 2.5 mm thick cuttings layer. The rate of oxygen demand tended to decrease slightly with thicker layers;

5. the oxygen demand of cuttings layered over natural sediments can be estimated by the following equations, which have been validated at about 1°C for cuttings thickness up to 15 mm over 30 days.

   For Fine Sediments

   $O_2 = -3.68 - 0.27 \text{ (day)} - 1.60 \log 10 \text{ (thickness} + 0.05)$

   For Coarse Sediments

   $O_2 = -2.25 - 0.28 \text{ (day)} - 2.26 \log 10 \text{ (thickness} + 0..05)$

6. the redox potential through the cuttings and underlying sediments remained positive in all treatments over the 30- day experiment, although some Eh profile changes were observed in the 2.5mm cuttings treatments;

7. concentrations of copper in pore water increased approximately 4-fold during the experiment under 15 mm of cuttings layered over fine sediments; zinc concentrations decreased by a similar magnitude, whereas mercury, cadmium and lead concentrations did not change.

RELATIONSHIP AND RELEVANCE TO THE BEAUFORT ENVIRONMENTAL MONITORING PROJECT

This study will provide the data required to evaluate Link 2 of Hypothesis No. 20, which suggests that the accumulation of cuttings in benthic habitats will lead to evaluated hydrocarbon concentrations and reduced oxygen concentrations. In addition, knowledge of the relationship between cuttings thickness and oxygen demand will be useful in assessing the potential impact of the accumulation of oiled cuttings in arctic benthic environments as a function of various disposal strategies and natural dispersal processes.

BEMP PROJECT OVERVIEW NO. 20-5

TITLE: **Investigations into the toxicity and bioaccumulation potential of oiled drill cuttings**

PRINCIPAL INVESTIGATORS: J.F. Payne and J. Kiceniuk

AFFILIATION: Dept. of Fisheries and Oceans, St. John's, Newfoundland

FUNDING SOURCE: NOGAP

EXPECTED COMPLETION DATE: On-going

RELEVANT BEMP HYPOTHESIS NO.: 20

BRIEF PROJECT DESCRIPTION

A series of experiments are being conducted to study the potential for oil-contaminated drill cuttings to induce MFO production in fish and to estimate the bioaccumulation potential of aromatic components of drilling fluids.

1. Used oil-contaminated drill cuttings from the ADGO, NIPTERK and MINUK wells in the Beaufort Sea are being evaluated for their potential to induce MFO synthesis in the detritus-feeding sticklebacks. Preliminary results indicate that all these contaminated cuttings are weak MFO inducers even though the PAH content of the muds varies widely.

2. The potential toxicity of drilling fluid base oils to bird eggs is also being examined. Results to date indicate that toxicity is extremely low compared with that of diesel oil and that toxicity increases with aromatic content of the oil.

3. Exposure of flounders to used oil-contaminated drill cuttings from the ADGO, NIPTERK and MINUK wells in the Beaufort Sea indicated a potential for bioaccumulation related to the PAH content of the cuttings.

4. The comparative biochemical toxicology of various fractions of crude oil (aliphatic, polar, aromatic) is being investigated to establish the toxicity of the aliphatic fraction, the "cut" used for the base oil in "low-toxicity" mud formulations.

RELATIONSHIP AND RELEVANCE TO THE BEAUFORT ENVIRONMENTAL MONITORING PROJECT

These studies will provide information about the potential mobility of drilling fluid components in the arctic marine food chain.

BEMP PROJECT OVERVIEW NO. 20-6

TITLE: **Long-term potential for leaching of oil-contaminated cuttings from the use of oil-based muds in the marine environment**

PRINCIPAL INVESTIGATORS: M.B. Yunker

AFFILIATION: Dobrocky Seatech Ltd.

FUNDING SOURCE: NOGAP

EXPECTED COMPLETION DATE: Complete

RELEVANT BEMP HYPOTHESIS NO.: 20

BRIEF PROJECT DESCRIPTION

This laboratory experiment was designed to determine the rate and duration of release of base oil from oil-contaminated arctic drill cuttings. The possible formation and characteristics of a consolidated oiled cuttings layer (the so-called "pavement" effect) that has been reported in numerous North Sea studies was also investigated.

Experimental conditions were chosen to approximate a shallow water (10-12 m) protected embayment (static or "no wave" tank) and a high energy location (wave generation tank). Uncleaned drill cuttings from the ADGO well in the Beaufort Sea containing approximately 11.4% CONOCO ODC base oil (<1% aromatic content) were allowed to settle in a uniform plane. The following measurements were taken in each of the static and wave generation tanks over the 49-day experiment.

1. concentration of base oil on surface cuttings eight times during the experiment and on subsurface cuttings on day 49;

2. concentration of oil in water (surface of tanks) 11 times during the experiment and in subsurface water on day 49; and

3. sediment penetrometer measurements seven times during the experiment.

The results of this research were somewhat inconsistent from a quantitative perspective, but did support several qualitative conclusions:

1. The oil content of cuttings in the surface and subsurface layers of each tank indicated that there was substantial upward migration of oil in the wave tank but virtually none in the static tank.

2. Gas chromatograms of the cuttings-associated oil for almost all sampling obtained from both tanks indicated little or no change in the base oil composition during the course of the experiment.

3. Oil concentrations on surface cuttings were generally greater in the wave tank than in the static tank indicating that waves encouraged the movement of oil upward through the cuttings pile to the surface.

4. Surprisingly, oil concentrations in surface water were generally lower in the wave tank than in the static tank, despite the obvious upward transport of substantial amounts of base oil. The reasons for this phenomenon are uncertain, but could be sampling and analytical artifacts.

5. Subsurface "pavement" formed in the wave tank below a relatively loose surface layer of watery cuttings.

RELATIONSHIP AND RELEVANCE TO THE BEAUFORT ENVIRONMENTAL MONITORING PROJECT

The results of this research suggest that wave energy may increase the rate of transport of oil from a cuttings pile to the water column.

BEMP PROJECT OVERVIEW NO. 20-7

TITLE:	**Development of a test protocol for assessing biodegradabilities of drilling fluid base oils**
PRINCIPAL INVESTIGATORS:	A. Gillam and S. Severin
AFFILIATION:	CBR International Corp.
FUNDING SOURCE:	Panel on Energy Research and Development
EXPECTED COMPLETION DATE:	1989 (Interim Report for Phase I - April, 1987)
RELEVANT BEMP HYPOTHESIS NO.:	20

BRIEF PROJECT DESCRIPTION

The objectives of this study, which is currently in its initial phase, are to: (1) review existing protocols for assessing the relative biodegradability of drilling fluid base oils and, if necessary, develop a new test protocol for regulatory applications; and (2) evaluate a range of drilling fluid base oils for their biodegradability and assess the influence of drilling fluid additives on the biodegradability of drilling fluid base oils. The existing River DieAway Test (RDA) and the Trickling Filter Test will both be adapted for marine application and used to evaluate the biodegradability of base oils in the initial stages of the study.

RELATIONSHIP AND RELEVANCE TO THE BEAUFORT ENVIRONMENTAL MONITORING PROJECT

The results of this study could be very useful in addressing a fundamental long-standing question regarding the effects of oil-contaminated cuttings in the marine environment --- are the observed effects on biota related to the inherent toxicity of the base oil or are they predominantly related to organic enrichment? The answer to this question will be important for evaluating the links in the hypothesis relating elevated hydrocarbon concentrations in the sediments to bioaccumulation potential and toxicity in benthic fauna, fish and birds.