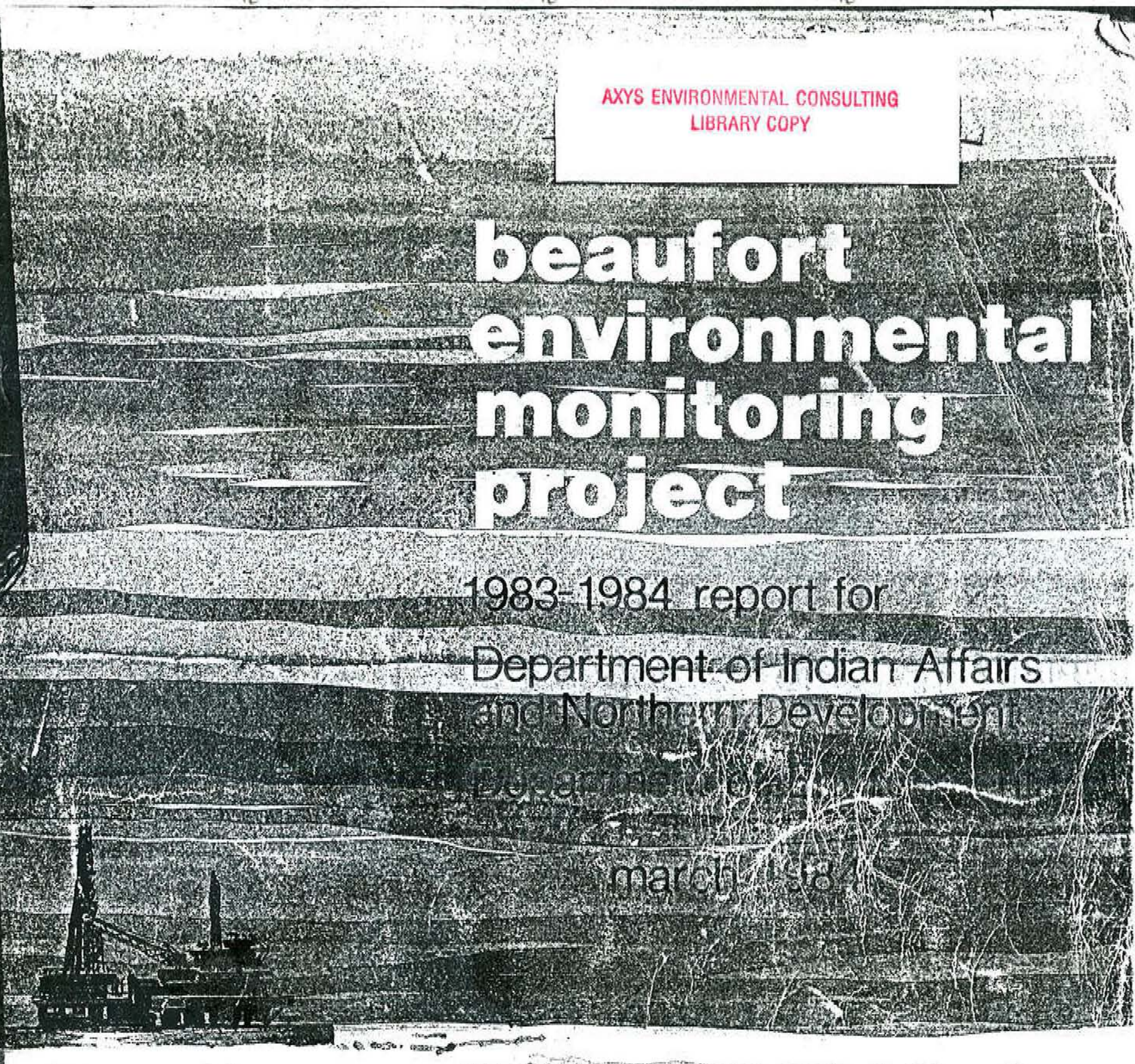

# beaufort environmental monitoring project

1983-1984 report for

Department of Indian Affairs and Northern Development

march 1984

LGL Limited environmental research associates
Environmental Research Associates
Sidney B.C.

ESL
Environmental Sciences Ltd.
Vancouver B.C.

ESSA
Environmental and Social
Systems Analysts Ltd. Vancouver B.C.

# BEAUFORT ENVIRONMENTAL MONITORING PROJECT

## 1983-1984 FINAL REPORT

Prepared by

LGL Limited
ESL Environmental Sciences Limited
ESSA Limited

For

NORTHERN ENVIRONMENT PROTECTION BRANCH
INDIAN AND NORTHERN AFFAIRS CANADA

Scientific Authority: David P. Stone

Funds for this study were provided by the Unsolicited Proposal Program of the Department of Supply and Services, Indian and Northern Affairs Canada, and Environment Canada.

BEAUFORT ENVIRONMENTAL MONITORING PROJECT

1983-1984 FINAL REPORT



Any comments concerning the content of this report should be directed to:

David P. Stone
Northern Environmental Protection Branch
Indian and Northern Affairs Canada
Les Terrasses de la Chaudiere
Ottawa, Ontario
K1A 0H4

# FORWARD

The three firms with primary responsibility for the conduct of this study were LGL Limited, ESL Environmental Sciences Limited and ESSA Limited. LGL was responsible for overall coordination of the project and biological aspects of the program; ESL was responsible for production of the study reports and physical aspects of the program; and ESSA coordinated the development of the simulation model and provided facilitators for the workshops. Each of these firms would like to acknowledge the important contributions made to this study by individuals from the following other firms:

Arctic Laboratories Limited
Arctic Sciences Limited
Woodward-Clyde Consultants Limited

## SUMMARY

### Introduction

There is considerable concern that hydrocarbon development activities in the Beaufort Sea may result in adverse environmental impacts. Because of these concerns and the recognized uncertainties associated with environmental impact assessment, there is a clear need for an environmental research and monitoring program that is fully integrated with future exploration and development plans. In response to this need, Indian and Northern Affairs Canada (INAC) and Environment Canada have initiated a program called the Beaufort Environmental Monitoring Project (BEMP).

The long-term objective of BEMP is to provide INAC and Environment Canada with the technical basis for design, operation and evaluation of a comprehensive and defensible environmental research and monitoring program to accompany phased hydrocarbon development in the Beaufort Sea. This report is the product of a series of steps aimed at meeting the immediate objective of providing INAC and Environment Canada with a research and monitoring plan that:

1) addresses those impacts that could be most significant if they occurred;

2) is based on the best current understanding of industrial development scenarios and ecological processes;

3) has the capability to respond to changing industrial development scenarios and new information regarding ecological processes in the region; and

4) represents the majority viewpoint of a broad range of disciplinary specialists with the necessary experience in research and environmental management in the Beaufort Sea.

During 1983-84, BEMP proceeded through an initial workshop, a series of technical meetings and a second workshop. Development of a simulation model was initiated in the first workshop (May 16-20, 1983). The model was later refined during several discipline-specific technical meetings. A series of impact hypotheses were generated through the process of refinement, and later evaluated at a second workshop held from November 28 to December 2, 1983. Participants at these workshops and technical meetings included experts from industry, government, universities and the consulting community.

## Definition of Monitoring

Monitoring was defined as the repetitive measurement of variables to detect changes directly or indirectly attributable to a specific development activity. The primary purpose of monitoring is to determine causal relationships between development activities and environmental effects. Understanding of the causes of these effects can then be used to plan appropriate mitigative responses. In the context of BEMP, monitoring is not surveillance or a part of the regulatory process used to ensure that industry meets the environmental terms and conditions of its operating permits. Monitoring is a scientific process, designed to test specific hypotheses linking sources of environmental impact (actions) to their expression in the biophysical environment.

Research is a test of a system process hypothesis, or baseline measurements. In BEMP, research will only be proposed if the existing level of understanding is inadequate to: (1) differentiate issues from non-issues; or (2) predict the direction of change.

## Valued Ecosystem Components

The Valued Ecosystem Component (VEC) concept described by Beanlands and Duinker (1983) was adopted in BEMP to aid in the definition of impact signficance. VECs were defined as resources or environmental features that are: (1) important to local human populations; or (2) have national or inter- national profiles; and (3) if altered from their existing status, will be important in evaluating the impacts of development and in focusing management or regulatory policy.

## Approach

Development of the research and monitoring plans described in this report was accomplished by proceeding through the following steps:

1) identification of Valued Ecosystem Components;
2) review of probable industrial development scenarios;
3) definition of the study area;
4) definition of the temporal horizon for monitoring;
5) identification of impact hypotheses that relate development activities to VECs;
6) preliminary screening of impact hypotheses for validity, relevance, and credibility;
7) evaluation of impact hypotheses; and
8) definition of research and monitoring programs necessary to test valid impact hypotheses.

Completion of these steps was accomplished through the use of the techniques and methods of Adaptive Environmental Assessment and Management (AEAM). This approach involves development of a simulation model describing relationships between development activities and the biophysical environment. The process forces workshop participants to think in inter-disciplinary, quantitative, dynamic terms about the possible interactions between the development and the environment.

The simulation model is composed of numerous linkages that connect the development activities to the VECs (see flowchart in back cover pocket). An impact hypothesis can be defined by tracing through a set of linkages from development activities to a VEC. Some hypotheses are straightforward and involve only one or two linkages, while others must encompass complex food web interactions. Each hypothesis was critically evaluated by a working group, and a monitoring/research strategy was proposed in those cases where the hypothesis was considered both valid and worth testing.

## Recommended Research and Monitoring

A summary of the recommended research and monitoring related to the 19 hypotheses that were evaluated in detail during the second BEMP workshop is provided below. At present, new research programs are recommended for five of these hypotheses, with all of these research needs relating to marine mammal populations in the Beaufort Sea. Most of these research programs are aimed at providing a better understanding of the factors affecting the distribution of whales and seals in this region. Support of existing research on polar bear detection and deterrents is also recommended. Other research activities are considered necessary if future industrial development scenarios include the construction of major solid-fill causeways along the Yukon coast and/or Tuktoyaktuk Peninsula.

The initiation of new monitoring programs is recommended in relation to four of the 19 hypotheses evaluated during the second workshop. These monitoring programs are directed at hypotheses dealing with the potential impacts of industry facilities and activities on bowhead whales and the white whale harvest, the effects of chronic oil releases on bird populations, and the potential uptake of hydrocarbons and tainting of fish within Tuktoyaktuk harbour. Continuation and revision of existing white whale and polar bear monitoring programs is also encouraged, while other monitoring would be dependent on the results of recommended research programs.

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|---|---|
| Hypothesis 1: | Ship traffic, seismic programs and active offshore platforms/artificial islands will cause a reduction in the western Arctic population of bowhead whales. |
| VEC: | Bowhead whale |
| Conclusion: | The hypothesis is valid and testable. |
| Research: | Summer/winter energy balance dynamics; distribution of food supply; acoustical behaviour monitoring methods. |
| Monitoring: | Annual distribution of bowheads and behavioural responses to industry activities/facilities; reproductive success; ambient noise monitoring. |

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Hypothesis 2:
(a) Offshore structures will reduce the white whale harvest;
(b) Frequent icebreaker traffic in the landfast ice will increase harvest;
(c) Open water ship traffic in the Mackenzie estuary will alter white whale distribution and lead to changes in harvest levels; and
(d) Inuit employment in the industry will change the white whale harvest.

VEC: White whale

Conclusion: The hypothesis is:
(a) Unlikely
(b) Unlikely
(c) Valid and testable
(d) Valid and testable

Research: Factors controlling distribution of white whales in Niakunak and Kugmallit bays.

Monitoring: Annual monitoring of regional landfast ice extent, distribution and breakup; continuation and revision of existing white whale monitoring program.

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Hypothesis 3: Marine vessel activities, seismic activities, dredging operations, aircraft overflights and active offshore platforms/ islands will reduce the size of ringed and bearded seal populations.

VEC: Ringed and bearded seals

Conclusion: The hypothesis is valid, but would either be hard to detect or not worth testing (see text).

Research: None

Monitoring: None

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| Hypothesis 4: | Increased frequency of icebreaker traffic (a) through landfast ice and (b) through Amundsen Gulf will reduce ringed seal pup production. |
| VEC: | Ringed seal |
| Conclusion: | The hypothesis is (a) unlikely and not worth testing and (b) valid and testable. |
| Research: | Further analysis of seal samples collected near Holman Island (1971-1982) in relation to Amundsen Gulf ice conditions; ice stability research. |
| Monitoring: | Dependent on research results: aerial photography of icebreaker traffic/ice regime in Amundsen Gulf; possible remote sensing of ringed seal birth lairs. |

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| Hypothesis 5: | Icebreaker traffic in the transition (shear) zone will reduce bearded seal pup production. |
| VEC: | Bearded seal |
| Conclusion: | The hypothesis is valid, but would be too hard to detect. |
| Research: | Bearded seal vocalization rates in control area and area exposed to icebreaker traffic (low priority). |
| Monitoring: | None |

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Hypothesis 6: Icebreaker traffic in Amundsen Gulf will affect the ringed seal and polar bear populations.

VEC: Ringed seal, polar bear

Conclusion: The hypothesis is unlikely.

Research: Data on ice cover and seal (prey) populations (1971-1983) should be examined for correlations between population parameters and annual ice conditions.

Monitoring: Not at present time; pending evaluation of research results.

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Hypothesis 7: The presence of active facilities will result in increased polar bear mortality.

VEC: Polar bear

Conclusion: The hypothesis is valid.

Research: None

Monitoring: Existing polar bear monitoring and deterrent programs should be supported and improved.

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Hypothesis 8: Offshore hydrocarbon development activities will reduce the harvest of polar bears.

VEC: Polar bear (harvest)

Conclusion: The hypothesis is unlikely.

Research: None

Monitoring: None

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| Hypothesis 9: | Chronic (episodic) oil spills resulting from normal petroleum hydrocarbon development activities will cause localized mortality of polar bears. |
| VEC: | Polar bear |
| Conclusion: | The hypothesis is valid. |
| Research: | Support of existing research on polar bear detection and deterrents. |
| Monitoring: | None |

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| | |
|---|---|
| Hypothesis 10: | Chronic (episodic) oil spills resulting from normal petroleum development activities will cause localized bird mortality. |
| VEC: | Birds |
| Conclusion: | The hypothesis is valid. |
| Research: | None. |
| Monitoring: | Regular observation of bird abundance, distribution and mortality at shorebases and offshore islands by trained on-site personnel. |

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Hypothesis 11: Oil slicks in open water areas around offshore structures during periods of ice cover will cause increased mortality of eiders and diving ducks.

VEC: Eiders and diving ducks

Conclusion: The hypothesis is valid, but not worth testing.

Research: None

Monitoring: None

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Hypothesis 12: Frequent low level aircraft flights over staging brant will cause increased overwinter mortality.

VEC: Brant

Conclusion: The hypothesis is invalid.

Research: None

Monitoring: None

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| | |
|---|---|
| Hypothesis 13: | Shorebases and shallow water production facilities will release (a) hydrocarbons and (b) heavy metals at sufficient levels such that fish harvest will be reduced through tainting and heavy metal accumulations. |
| VEC: | Fish (harvest) |
| Conclusion: | The hypothesis is (a) valid and testable and (b) unlikely. |
| Research: | None unless monitoring shows tainting, and then research would be required to identify source. |
| Monitoring: | Time-series measurements of hydrocarbons in fish from Tuktoyaktuk harbour; possible taste testing and caged fish programs. |

| | |
|---|---|
| Hypothesis 14: | Nearshore structures will disrupt the nearshore band of warm brackish water and reduce the broad whitefish population. |
| VEC: | Broad whitefish |
| Conclusion: | The hypothesis is valid and testable. |
| Research: | If a major nearshore structure is proposed: development of a numerical model of nearshore temperature variability; laboratory and modelling studies of fish growth and fecundity. |
| Monitoring: | If a major nearshore structure is proposed: measurements of temperature, salinity, currents and wind; possible tagging of broad whitefish. |

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Hypothesis 15: Nearshore structures will disrupt the nearshore band of warm brackish water and reduce the Alaskan population of Arctic cisco.

VEC: Arctic cisco

Conclusion: The hypothesis is valid and testable.

Research: If a major nearshore structure is proposed: research defining the migratory habitats of Mackenzie River stocks of Arctic cisco, and their contribution to the Alaskan stock; other research identified in relation to Hypothesis 14.

Monitoring: Same as Hypothesis 14.

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Hypothesis 16: The construction of shorebases and shallow production fields will result in a decrease in the population of Arctic cisco.

VEC: Arctic cisco

Conclusion: The hypothesis is unlikely and not worth testing.

Research: None

Monitoring: None

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Hypothesis 17: Water intakes will reduce populations of broad whitefish and Arctic cisco.

VEC: Broad whitefish, Arctic cisco

Conclusion: The hypothesis is unlikely and not worth testing.

Research: None

Monitoring: None

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|---|---|
| Hypothesis 18: | Air emissions associated with aircraft and marine traffic; and operation of drill rigs, offshore platforms and shore-bases will adversely affect air quality. |
| VEC: | Air quality |
| Conclusion: | The hypothesis is unlikely. |
| Research: | None |
| Monitoring: | None (see text) |

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| | |
|---|---|
| Hypothesis 19: | Dredging and deposition of spoils will reduce benthic invertebrate, fish and bearded seal populations. |
| VEC: | Bearded seal |
| Conclusion: | The hypothesis is valid and testable. |
| Research: | None |
| Monitoring: | Site-specific monitoring is recommended in areas of potential concern (see text). |

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ERRATA

TABLE OF CONTENTS

# 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 which finally emerge as those of regulatory and public concern. The objective of BEMP is to identify and implement those research and monitoring activities which are considered necessary for the responsible management of a phased development of Beaufort Sea hydrocarbons, through the administration of the 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

As indicated in the list of participants (Appendix II), this project represents the contributions of a large number of scientists and managers from government agencies, the oil industry, universities and consulting firms. The high level of cooperation and enthusiastic involvement among project participants were responsible for the collective judgements presented in this report. In particular, we would like to acknowledge the exceptional contributions of Ed Pessah (Dome Petroleum Limited) and Rick Hurst (INAC) at various stages in this project. We would also like to thank George Greene (independent consultant) for his assistance and efforts in the organization of the second workshop.

We sincerely appreciate the efforts of Lois Harwood (ESL) during the editorial review of this report, the word processing responsibilities assumed by Patricia Janvrin, Victoria Wagner and Shirley Green-Smith of ESL Environmental Sciences Limited, and the drafting completed by Brian Scruton of LGL Limited. The assistance of Pille Bunnell and Susanne Hansen of ESSA Limited in the cover design and flowchart preparation is also gratefully acknowedged. Doug Tait (independent commercial artist) was responsible for the cover artwork.

| | | |
|---|---|---|
| David Stone | (INAC) | Scientific Authority |
| Alan Birdsall | (LGL) | Project Coordinator |
| Wayne Duval | (ESL) | Report Coodinator/Editor |
| Aaron Sekarek | (LGL) | Biological Processes Coordinator |
| John McDonald | (ESL) | Physical Processes Coordinator |
| Bob Everett | (ESSA) | Simulation Model Coordinator |

# INTRODUCTION

There is considerable concern that adverse environmental impacts may occur in the Beaufort Sea as a result of hydrocarbon development activities. While there has been a large expenditure of time and money in the production and review of the Beaufort Sea - Mackenzie Delta Environmental Impact Statement (Dome Petroleum et al. 1982), many concerns persist because of the recognized difficulties and uncertainties associated with environmental impact assessment. In the Beaufort, these difficulties are compounded by the lack of experience with some of the innovative technologies proposed, and the limited experience of the petroleum industry in the offshore Arctic. Due to these remaining concerns and uncertainties, particularly in the context of Beaufort Sea hydrocarbon development, there is a clear need for an environmental research and monitoring program that is fully integrated with the exploration and development scenario. In response to this need, Indian and Northern Affairs Canada (INAC) and Environment Canada have initiated a program called the Beaufort Environmental Monitoring Project (BEMP).

## Long-Term Objective

The long-term objective of BEMP is to provide Indian and Northern Affairs Canada and Environment Canada with the technical basis for design, operation and evaluation of a comprehensive and defensible environmental research and monitoring program to accompany hydrocarbon development activities in the Beaufort Sea region.

To meet this objective adequately, the monitoring program must include the following features:

1) determination of the most significant environmental resources and features likely to be affected by development;

2) formulation and testing of impact hypotheses and predictions;

3) recommendation of mitigative measures and continual evaluation of their success; and

4) adaptability of future research and monitoring to reflect new information, identified data gaps, and changes in the development scenario.

Immediate Objective

This report is the product of a series of steps aimed at meeting the immediate objective of providing INAC and Environment Canada with a plan for initiating research and monitoring activities. Therefore, most of this report consists of descriptions of the elements of a defensible approach to research and monitoring. Prior to considering those elements, we have included a detailed description of the methods used throughout this program, since the nature of our recommendations have been heavily influenced by these methods.

To date, BEMP has proceeded through an initial workshop, a series of technical meetings and a second workshop. During the first workshop (May 16 to 20, 1983), development of a simulation model was initiated. The model was later refined during a series of technical meetings which followed the first workshop. A series of impact hypotheses was generated through the refinement process, and later evaluated at the second workshop held from November 28 to December 2, 1983. Since the focus of this project is monitoring, strategies employed for industrial developments elsewhere in the world, such as the use of "Biological Early Warning Systems", were also briefly discussed and evaluated at the second workshop. The advantages, disadvantages and principles behind these other approaches to environmental monitoring are summarized in Appendix I of this report. The names, affiliations and research interests of workshop participants are identified in Appendix II.

# METHODS

## Definitions

### Impact Hypotheses

Fundamental to the methods used in this project is the concept of an impact hypothesis. Simply stated, an impact hypothesis is a statement that links development activities with their potential environmental effects. Without a statement of relevant impact hypotheses to guide it, a monitoring program may become a directionless effort in data collection.

### Monitoring and Research

In BEMP, monitoring is defined as a test of an impact hypothesis designed to:

(a) measure environmental impacts; and
(b) analyze cause-effect relationships.

Research is a test of a system process hypothesis, or baseline measurements. In the context of BEMP, research will only be proposed if the existing level of understanding is inadequate to:

(a) differentiate issues from non-issues; or
(b) predict the direction of change.

Monitoring in this context is the repetitive measurement of variables to detect changes directly or indirectly attributable to a specific development activity. The primary purpose of monitoring is to determine causal relationships between development activities and environmental effects. Understanding the causes of these effects can then be used to plan appropriate mitigative responses. In the context of BEMP, monitoring is <u>not</u> surveillance or a part of the regulatory process used to ensure that industry meets the environmental terms and conditions of its operating permits. Monitoring is a scientific process, designed to test specific hypotheses linking actions (sources of environmental impact) to their expression in the biophysical environment.

Valued Ecosystem Component

Following the approach described by Beanlands and Duinker (1983), the Valued Ecosystem Component (VEC) concept was adopted in this project to aid in definition of impact significance. VECs were defined as resources or environmental features that:

a) are important to local human populations; or
b) have national or international profiles; and
c) if altered from their existing status, will be important in evaluating the impacts of development and in focusing management or regulatory policy.

Tasks

Development of the research and monitoring plans described in this report was accomplished by proceeding through the following steps:

1) identification of Valued Ecosystem Components;

2) identification of development activities;

3) identification of spatial extent and resolution of the model;

4) identification of temporal horizon and resolution of the model;

5) identification of impact hypotheses that relate development activities to VECs;

6) preliminary screening of impact hypotheses for validity, relevance, and credibility;

7) evaluation of impact hypotheses; and

8) definition of research and monitoring programs necessary to test valid impact hypotheses.

## Models and Workshops

Tasks 1 to 6 (described above) were facilitated by using the techniques and methods of Adaptive Environmental Assessment and Management (AEAM) (Holling 1978). This approach involves development of a simulation model of the relationships between development activities and the biophysical environment. The modelling process forces workshop participants to think in interdisciplinary, quantitative, dynamic terms about the interactions between the development and the environment. The simulation model is a set of linkages describing the interrelationships between the various components representing the biophysical processes of the Beaufort Sea and the proposed development activities. The elements of an impact hypothesis are defined by tracing through a series of linkages from a given set of development activities to an attribute or component of the environment for which there is public or scientific concern.

The modelling process was conducted in workshops and technical meetings. These workshops and technical meetings included experts from industry, government, universities and the consulting community (Appendix II), and were conducted by experienced facilitators/modellers. Table I-1 shows how the modelling, workshops, technical meetings and reporting relate to each of the eight fundamental tasks in the project.

TABLE I-1

TASKS AND ACTIVITIES IN MONITORING PLAN DESIGN

| TASK | MODELLING | MEETINGS | REPORTING/DOCUMENTATIO |
|---|---|---|---|
| Identification of VECs | Model building task | - scoping<br>- workshop 1 | - report documenting the VEC's prepared for presentation at workshop 1 |
| Identification of Development Activities | Model building task | - scoping<br>- workshop 1<br>- ongoing | - reports on each new development scenari( are prepared as scenario is revised |
| Identification of Spatial Extent and Resolution | Model building task | - scoping<br>- workshop 1<br>- technical meetings | - workshop 1 report model description |
| Identification of Temporal Horizon and Resolution | Model building task | - scoping<br>- workshop 1<br>- technical meetings | - workshop 1 report model description |
| Identification of Impact Hypotheses | Model structure is composed of linked impact hypotheses | - workshops<br>- technical meetings | - preliminary flow-charts and statements of impact hypotheses were prepared prior to workshop 2, based on the model building programming and analysis and discussions in technical meetings |
| Screening of Impact Hypotheses | Quantification of the links eliminates unrealistic or ill-specified hypotheses | - technical meetings | |
| Evaluation of Impact Hypotheses | | - workshop 2 | - final report |
| Definition of Research/ Monitoring | | - workshop 2 | - final report |

## Identification of VECs

A list of potential VECs, based on the perceived environmental concerns and issues related to Beaufort hydrocarbon development was prepared before the first workshop. Four sources of information were reviewed during preparation of this list:

1) Volume 4 (Biological and Physical Effects), Environmental Impact Statement for Hydrocarbon Development in the Beaufort Sea - Mackenzie Delta Region, 1982. Prepared by Dome Petroleum Limited, Esso Resources Canada Limited, and Gulf Canada Resources Inc.;

2) The Biological Effects of Hydrocarbon Exploration and Production Related Activities, Disturbances and Wastes on Marine Flora and Fauna of the Beaufort Sea Region. Beaufort Sea - Mackenzie Delta EIS Support Document Prepared by ESL Environmental Sciences Limited, 1982, for Dome Petroleum Limited, 450 pp.;

3) The Interim and Second (Final) Compendium of Written Submissions to the Beaufort Sea Assessment Panel on the Dome, Gulf and Esso Environmental Impact Statement, February, 1983.;

4) Individual submissions of the Technical Experts retained by the Beaufort Sea Environmental Assessment Panel (Greisman 1983, Mackay 1983, Parsons 1983).

The preliminary list of VECs was reviewed at the first workshop, and as a result of discussions at this time and during subsequent technical meetings, was revised to the list shown in Table I-2. The identification of VECs is a critical process because it (1) defines the quantities for which the simulation model must provide predictions through time, and (2) most importantly, limits the discussion of impact hypotheses and monitoring programs to those resources and supporting biophysical processes that are of greatest concern with respect to development in the region.

TABLE I-2

FINAL LIST OF VALUED ECOSYSTEM COMPONENTS
ADDRESSED AT THE SECOND WORKSHOP

- population, harvest, and available habitat for:

  - white whale
  - bowhead whale
  - ringed seal
  - bearded seal
  - polar bear
  - common eider
  - king eider
  - diving ducks (oldsquaw, scoters, scaups
  - thick-billed murre
  - brant
  - lake whitefish
  - broad whitefish
  - least cisco
  - Arctic cisco
  - Arctic char

- air quality

Identification of Development Activities

The development activity (action) is at the beginning of the causal chain defining an impact hypothesis related to a given VEC. In identifying the nature, extent and duration of development activities in the region, the project team worked closely with the proponents of hydrocarbon development to determine the range of activities contemplated. The activities were divided into four major groups:

1) exploration activities and drilling associated with discovery and delineation of oil resevoirs;

2) construction of islands and oil production facilities, and the drilling of production wells;

3) subsea pipelines and onshore gathering systems; and

4) transportation of produced hydrocarbons within the Beaufort Region by tankers.

The simulation model is designed to accept any number of different development scenarios and can be modified as required when the scenario changes. Scenarios for five different levels of development are currently included in the model, based on information provided by Dome Petroleum Limited and supplemented with specific estimates contained in the 1982 Beaufort Sea Planning Model (Dome Petroleum et al. 1982).

## Identification of Spatial Extent and Resolution of the Model

The current geographic scope of the project and, therefore, the spatial extent of the model was determined as follows. The Alaska-Yukon border was selected as a practical western limit to the study area. A line directly west from the northwestern tip of Banks Island was expected to encompass most possible positions of the polar pack ice edge and, therefore, delineate the northern limit of the study area. Amundsen Gulf, considered important in terms of the ice dynamics of the region as well as marine bird and mammal habitat, was selected as the eastern boundary. Since the focus of BEMP is marine, the landward extent of the study area was limited to 2 km inland within the Mackenzie Delta region, and the level of maximum storm surges elsewhere along the coast.

Within these spatial boundaries, the study area was further subdivided into 11 spatial units on the basis of ice conditions and the influence of the Mackenzie River turbidity plume (Figure I-1).

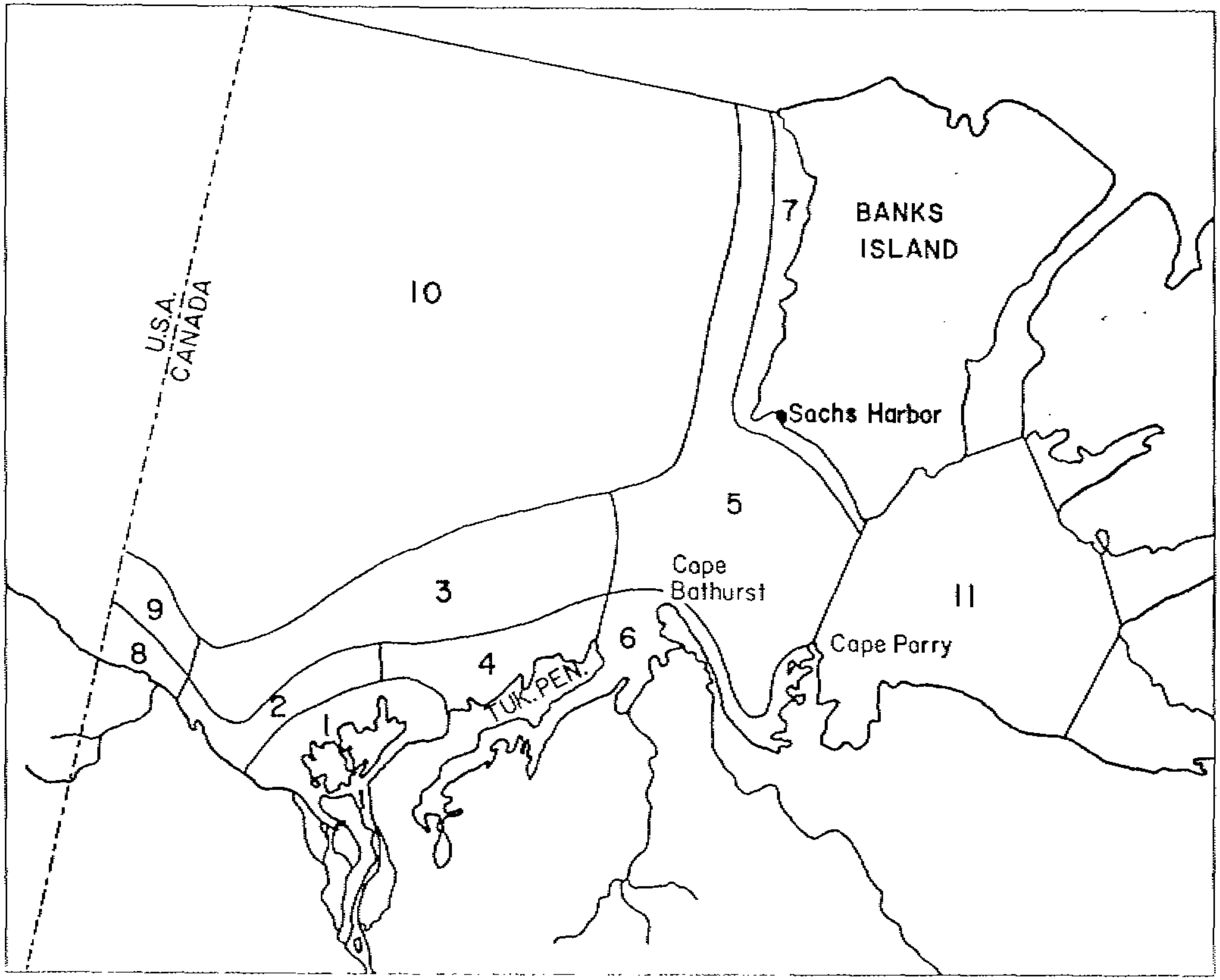


Figure I-1: Spatial units of the Beaufort Sea Region

Four ice zones were considered during the spatial bounding. The landfast ice zone was assumed to extend to approximately the 20 m isobath. The transition (shear) zone was basically defined as being located between the 20 and 100 m isobaths, although passing over much greater depths in the east (off Amundsen Gulf-Banks Island) and in the west (off Mackenzie Bay and the Yukon coastline). The polar pack was considered located seaward of the transition zone, while Amundsen Gulf was defined as a separate ice zone because of the expected importance of the recurring polynya in this region.

The location and spatial extent of the Mackenzie River plume was also taken into consideration during the definition of spatial subzones. Two different conditions were recognized:

1) a situation where sustained westerly winds cause the plume to be confined within the area bounded by the 20 m isobath; and

2) a situation where sustained easterly winds cause the plume to move offshore into the transition zone.

In addition, a zone shoreward of the 5 m isobath and adjacent to the Mackenzie River Delta was separately defined as an area of sustained and major plume influence. Within each of the 11 spatial units, water depths above and below the pycnocline were considered separately.

## Identification of Temporal Horizon and Resolution

The development of a dynamic simulation model required specification of the maximum time over which the effects of development would be examined (temporal horizon) and the time step (resolution) within that horizon. A time horizon of 30 years and a time step of 1 year were selected during the first workshop, although these specifications were further refined as the project proceeded. For example, to satisfy all disciplinary requirements, a weekly time step was eventually established for the period from April through October and a single week time step was established for the winter.

## Identification of Impact Hypotheses

The simulation model is composed of hundreds of linkages that connect the development activities to the VECs. An impact hypothesis can be defined by tracing through a set of linkages from development activities to a given VEC. Some hypotheses are straightforward and involve only one or two linkages, while others must encompass complex food web interactions. In either case, each linkage must be specifically defined for use in the simulation model. These linkages were initially defined during the first workshop and later refined at the technical meetings.

## Screening of Impact Hypotheses

Since the simulation model contains so many potential linkages and relationships, it was necessary to select a set of impact hypotheses from the large number of potential hypotheses for evaluation at the second workshop. The initial screening was conducted by the modellers. Preliminary flowcharts and impact hypothesis statements were developed on the basis of each individual's experiences in constructing the model and subsequent testing of the sensitivity of the VECs to critical assumptions used in development of the model. Unrealistic and ill-specified hypotheses were then corrected or deleted. In the technical meetings, this sub-set of potential impact hypotheses was further evaluated and eventually reduced to twenty-one hypotheses considered most important at that time. Another hypothesis was added to this list at the beginning of the workshop. Three of these hypotheses involving resource use could not be fully assessed by the present workshop participants, and are shown with their associated linkages in Appendix III.

A conceptual diagram of the hypotheses represented in the simulation model and the interrelationships among the linkages and VECs associated with these hypotheses is provided in the pocket on the back cover of this report.

The 19 hypotheses evaluated during the second workshop encompass a considerably larger number of perceived concerns associated with Beaufort hydrocarbon development by virtue of the multiple linkages involved in most of the hypotheses. One of the strengths of the Valued Ecosystem Component (VEC) approach is that it facilitates consideration of the cumulative indirect impacts of a number of environment-development interactions that may ultimately cause a change in a VEC. The range of environmental concerns that have been expressed in relation to Beaufort hydrocarbon production were reviewed during development of the simulation model, and most of these concerns are included as a linkage in one or more of the hypotheses presented in the following sections. Nevertheless, some of the potential concerns identified in the Beaufort Sea/Mackenzie Delta EIS, its support documents, and in the submissions of intervenors during the public review of the development proposal are not discussed in this report.

If an issue previously raised in conjunction with Beaufort development is not specifically addressed in this report, this is either because: (1) the concern was focused on environmental features or resources that are not within the geographic scope of this study; (2) the concern involves a component of the environment that is embodied within the structure of the simulation model, but would not be reflected in a change in a VEC; or (3) the workshop participants believed that on the basis of available scientific evidence, the issue was perceived rather than real. Examples of each of these categories of issues are provided below.

Examples of concerns that were not addressed because they lie outside the geographic scope of BEMP are: the potential attraction of polar bears and Arctic fox to solid waste disposal sites; disturbance of many species of birds that nest, stage and moult in coastal habitats adjacent to the Beaufort Sea but are not generally found in marine areas; and many strictly terrestrial issues that were raised in connection with the Yukon coast shorebase proposal.

The largest proportion of the environmental concerns that are not directly discussed in this report fall into the second category mentioned above, and generally include those issues that centered on environmental components other than VECs. However, several of the hypotheses examined during the second workshop involved linkages that included food web interrelationships and interactions with physical features such as the ice environment. For example, the effects of icebreaking and the physical presence of offshore structures on the stability and breakup of the landfast ice regime was considered in a hypothesis dealing with the range of development activities that could affect white whale harvest. Similarly, development-induced effects on Arctic cod and changes in epontic production were considered in relation to a hypothesis addressing the impacts of icebreaker traffic in Amundsen Gulf on ringed seal and polar bear populations.

The most significant of the issues that were considered perceived rather than real by workshop participants relate to the discharge of production wastes (water-base drilling muds, cuttings and produced water) in offshore waters. The effects of offshore production waste disposal have been the subject of numerous field monitoring and laboratory studies, and it is the general view that the impacts of offshore waste disposal are limited to a zone within a few hundred metres of discharge sites and are largely restricted to benthic habitats and resources (see Thomas et al. 1983 for review). Workshop participants recognized that some form of compliance monitoring may be initiated in relation to offshore production waste discharges, although an effects monitoring program of regional scope was not considered necessary given the localized nature of anticipated impacts. Other issues which have been voiced by various parties but were not considered real concerns from a regional perspective include: discharge of sewage; effects of underwater noise on fish; and changes in climate as a result of sea ice removal.

## Evaluation of Impact Hypotheses

The actual evaluation of the 19 impact hypotheses occurred during the second workshop. On the first day, each hypothesis was reviewed by the participants and, following this review, the necessary modifications, additions or deletions to the hypotheses were undertaken. For the next three days, each hypothesis was critically evaluated by a working group, and a monitoring/research strategy was proposed in those cases where the hypothesis was considered valid and worth testing. These working groups differed from the modelling subgroups (discipline specific), and were restructured daily to include a cross-section of expertise relevant to all aspects of the hypothesis under discussion.

The agenda for evaluation of each impact hypothesis included the following ve steps:

Step 1) Clarification of the Hypothesis:

This involved achievement of a consensus within the working group regarding the structure of the hypothesis and, if necessary, restatement of the hypothesis and/or its associated linkages.

Step 2) Documentation of the Existing Knowledge:

For all linkages constituting the hypothesis, the following information was documented:

a) evidence for and against;
b) uncertainties;
c) other information potentially useful; and
d) description of model projections (if appropriate).

Step 3) Conclusion:

This step required that the working group arrive at one of four possible conclusions. On the basis of discussions in step two (Documentation of Existing Knowledge), group participants concluded that a given impact hypothesis:

a) was extremely unlikely and not worth testing;
b) was possible, but too difficult to detect;
c) required more information before a monitoring plan could be designed (e.g., research); or
d) should be tested with a detailed monitoring plan.

Step 4) Monitoring and Research:

If the conclusion at step three was either (c) or (d), a discussion focussing on the linkages of the hypothesis was initiated. The discussion addressed the following questions in order to design a monitoring plan which would test the impact hypothesis:

a) What do we monitor ?
b) What do we want to know ?
c) What do we actually measure to accomplish (i) and (ii) ?
d) What information do we get from these measurements ?
e) How does this achieve what we want to know ?

Step 5) Documentation:

To adequately document the discussion and evaluation of each impact hypothesis, the "recorder" assigned to each working group delegated specific responsibilities to other group members, including the preparation of draft report sections. The recorder was responsible for ensuring that documentation of the discussion of a given hypothesis was completed and submitted at the end of the day.

In most instances, participants of each working group were given an opportunity to review the synthesized versions of the hypothesis documentation during the course of the workshop.

## Preliminary Design of the Research and Monitoring Plans

In most cases, the preliminary design of research and monitoring programs emerged out of the discussions which occurred during the evaluation of the impact hypotheses. Edited versions of the reports produced for each of the hypotheses evaluated during the second BEMP workshop are presented in the following sections of this report.

## Limitations in Scope

Limits in the scope of a project of this type are essential for efficiency. However, scope restrictions can be interpreted as shortcomings of a program unless specifically stated. This section identifies some of the subjects that were intentionally excluded from the present phase of the Beaufort Environmental Monitoring Project. Some of these subjects were considered outside the intended scope of the study, while others were worthy of consideration but could not be examined within the framework of the project due to time constraints or discipline expertise that was committed in advance to the workshops. In addition, specific assumptions regarding the Beaufort Sea hydrocarbon development scenario are also stated in this section.

1) This project was intentionally limited to consideration of the effects of hydrocarbon development activities on the environment, rather than the effects of the environment on industrial activities. It is recognized that various monitoring programs are ongoing and may be required in the future to examine the integrity of offshore facilities in relation to the ice environment and other aspects of industry operations in this region.

2) The hydrocarbon development scenario assumed throughout this project was the range and intensity of activities described in the Beaufort Sea/Mackenzie Delta EIS (Dome Petroleum et al. 1982). In particular, it was assumed that: (1) production facilities would not be located in waters less than 5 m deep; (2) if oil-base muds are used for exploratory or production drilling, oil-contaminated cuttings would not be discharged to the marine environment; (3) major dredging operations required for offshore island construction would not be conducted in inshore areas; (4) solid-fill causeways would not be required along the Yukon coast and Tuktoyaktuk Peninsula; and (5) all wastes associated with the development would be treated and discharged in accordance with the "best practicable technology" (Thomas et al. 1983).

3) Catastrophic oil spills and blowouts, while an important area of potential concern related to any hydrocarbon development, were not considered in this project because their infrequent and unpredictable occurrence makes these events an inappropriate target for routine monitoring. It was assumed that a scientific response to determine the short- and long-term effects of a major oil spill may be initiated in the event of this type of environmental emergency, but was outside the scope of this project.

4) The definition of the study area used throughout this project included that portion of the coastal zone to the level of maximum storm surges in areas outside the Mackenzie Delta, and to a point 2 km onshore within the Delta itself. However, the impacts of shoreline developments on the coastal zone per se were not considered during this project. It is recognized that such potential concerns may have to be addressed in future programs of this type.

5) As indicated earlier, a list of potential Valued Ecosystem Components was prepared prior to the first workshop. This list and other possible VECs were discussed amongst workshop participants, and a number of recommendations regarding VECs were not accepted by the group as a whole for various reasons. Among these were the following:

   a) Thick-billed murre: The colony at Cape Parry was originally identified as a VEC, but was not included in the modelling process or in the hypotheses considered in the second workshop, because potential concerns related to the impacts of hydrocarbon development on this colony were viewed as a very site-specific issue. Undoubtedly, protective measures should be instituted whenever development activities impinge on the Cape Parry area.

   b) Snow goose: The snow goose was selected as a VEC early in the project, but was excluded from further consideration prior to the second workshop because use of the marine environment by this species is extremely limited.

   c) Red-throated loon: The red-throated loon was recommended for inclusion as a VEC during a technical meeting held after the first workshop. However, since the full group of workshop participants did not have the opportunity to evaluate arguments for and against inclusion of this species, it was not added to the list of VECs.

d) Coastal zone, Bathurst polynya, landfast ice: The latter two environmental components were included on the list of potential VECs prepared in advance of the first workshop, while the inclusion of the coastal zone as a VEC was suggested by several of the participants during the first workshop. These environmental components were not included in the final list of VECs for the project because the full group of workshop participants did not have the opportunity to evaluate arguments for and against their inclusion.

6) The hypotheses considered in this report involve one or more linkages between development activities and a VEC. Where the hypothesis and its associated linkages were not only considered valid but also an area of potential concern related to Beaufort development, monitoring and/or research has generally been recommended. It is important to emphasize that this monitoring and/or research should include detailed measurements of the industrial activity, and not just focus on the VEC or the linkages between development and the VEC.

7) Three hypotheses involving native and non-native harvests of resources were considered during the second workshop. The focus of these hypotheses was the effect of changing harvest methods and patterns on VEC populations. However, the direction and magnitude of these changes could not be adequately addressed by the discipline specialists that attended the workshop. A logical framework for consideration of changing harvest was discussed during the workshop, but because judgements regarding the dynamics of the processes involved were not possible, only flowcharts for these hypotheses have been included in this report (Appendix III).

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# HYPOTHESIS NO. 1

## THE EFFECTS OF SHIP TRAFFIC, SEISMIC EXPLORATION AND ACTIVE OFFSHORE STRUCTURES ON THE WESTERN ARCTIC POPULATION OF BOWHEAD WHALES

Thomas, D.J., G.D. Greene, W.S. Duval, K.C. Milne and M.S. Hutcheson. 1983. Offshore oil and gas production waste characteristics, treatment methods, biological effects and their applications to Canadian regions. Unpub. Rep. Water Pollution Control Directorate, Env. Prot. Service. Env. Canada. Prep. by Arctic Laboratories Limited, ESL Environmental Sciences Limited and SKM Consulting Ltd. 334 p. + appendices.

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

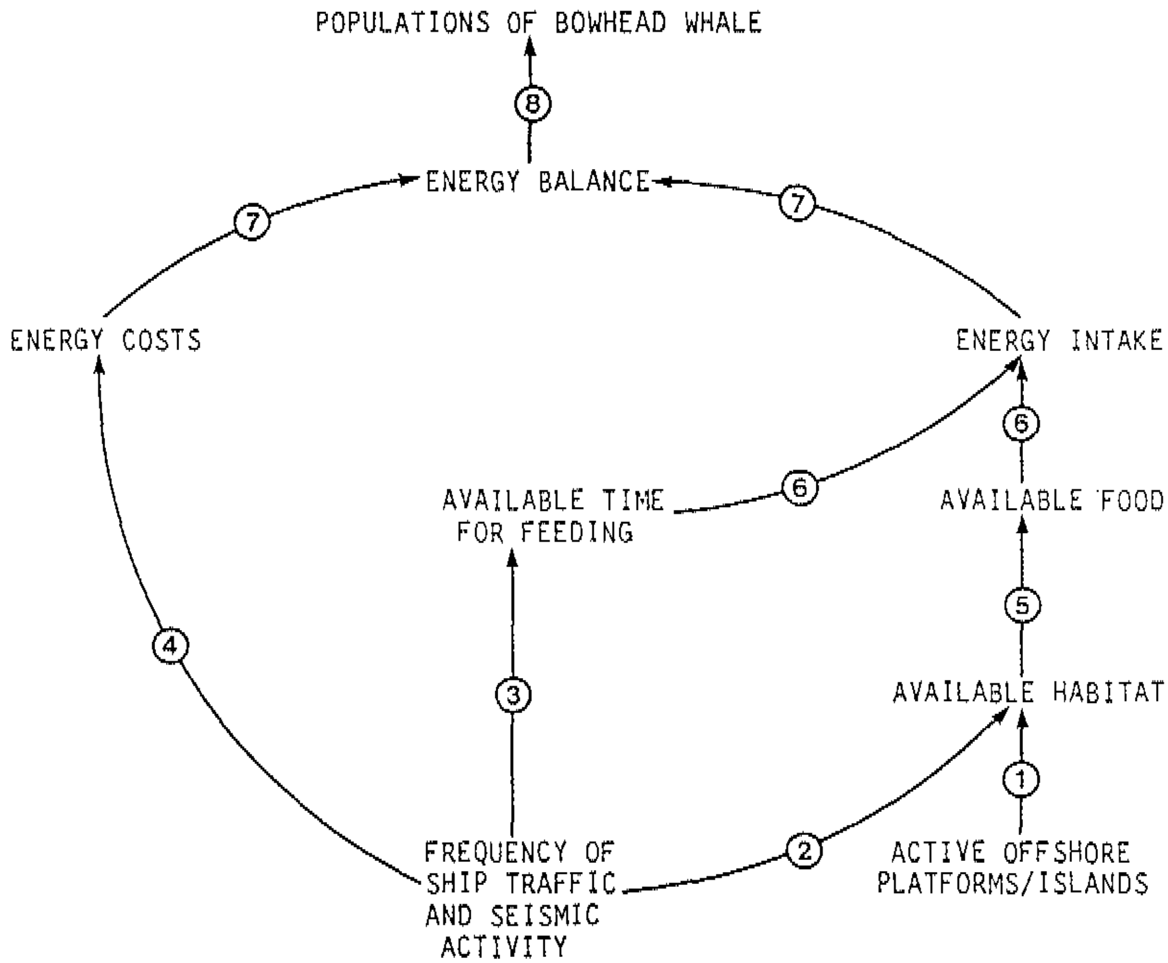


Figure 1-1 Potential effects of ship traffic, seismic exploration and active offshore structures on bowhead whales.

Linkages

1. Each active offshore island or platform will exclude bowheads from a zone around the island/platform. The size of this zone is unknown.

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.

## NAMES OF PARTICIPANTS

Rolph Davis
Max Dunbar
Dave Mackas
Peter McNamee
Ed Pessah
Don Schell
Aaron Sekerak
Denis Thomson
Doug Wolfe

## INTRODUCTION

The western Arctic bowhead whale population winters among the pack-ice of the Bering Sea, and summers in the Canadian Beaufort Sea and Amundsen Gulf. In May and early June, bowheads enter the Canadian Beaufort Sea through leads in the pack-ice which are far offshore and, therefore, well beyond areas where hydrocarbon development activities presently occur or are likely to occur in the future. However, the bowhead population occurs in areas that are in part coincident with and may be affected by offshore hydrocarbon activities from late June until mid September (Davis et al. 1982). The western Arctic population of bowheads was heavily exploited by commercial whalers from 1848 to 1915. The population has also been subjected to a subsistance hunt by Alaskan Inupiat since before the historic era. The pre-whaling population, estimated to be 14,000 to 20,000 bowheads, has been reduced to a present population of about 4000 animals (IWC in prep.). The population is considered "endangered" under U.S. legislation and by the Committee on the Status of Endangered Wildlife In Canada (COSEWIC).

It is well known that whales rely on underwater acoustic information for communication and perhaps orientation, although there is limited knowledge regarding the hearing capabilities of baleen whales (including bowheads). However, vocalizations are known to occur at very low frequencies (e.g., < 1 kHz), and most noise from offshore industry activities also consists primarily of low frequency components. Consequently, there is particular concern that bowheads could be affected by offshore development in the Beaufort Sea (see Richardson *et al.* 1983b for a review of these concerns and available information). The hypothesis examined during the workshop is that ship traffic, seismic activity and active offshore platforms and islands will cause a reduction in the western Arctic population of bowhead whales. The conceptual steps linking industry activities with hypothesized effects on the bowhead population are in Figure 1-1, and discussed in subsequent sections.

## LINKAGES

Link 1: Each active offshore island or platform will exclude bowheads from a zone around the island/platform. The size of this zone is unknown.

It has been reasonably well documented that marine mammals tend to respond more actively to moving sources of disturbance than to stationary sources (*cf.* Evans 1982; Fraker and Fraker 1982; Richardson *et al.* 1983a, 1983b). Fraker *et al.* (1982) demonstrated that bowheads were not actively avoiding the Issungnak artificial island off the Mackenzie Delta during periods of island repair and dredging in 1981. There are also several sightings of bowheads near stationary structures by industry personnel (Fraker and Fraker 1981). However, active drilling or production islands have associated ship and helicopter traffic, and these mobile noise sources might act in conjunction with on-island activities to produce a zone of at least partial exclusion around offshore islands and platforms (Richardson *et al.* 1983c, in press).

It was concluded that a zone of exclusion may exist around active offshore structures, but that the size of the zone is unquantified and would vary with a complex of factors. This exclusion might reduce the amount of habitat available to feeding bowheads.

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

The available data indicate that ship passages through or near bowhead aggregations cause avoidance reactions by the animals. However, bowheads have been observed to reoccupy single ship tracks within one or two hours (Fraker et al. 1982; Richardson et al. 1983b). There are no data regarding the potential long-term exclusion of bowheads from areas frequented by several ship passages or the sizes of zones of exclusion in areas with multiple ship passages. Similarly, it is not known if bowheads would habituate to repeated ship passages, thereby reducing the size of the zones of exclusion.

A potentially more serious loss of habitat and feeding opportunities could occur if some combination of industrial activities creates a large zone of total exclusion. This would occur if bowheads began to avoid the relatively large area of overall industrial activity rather than simply reacting to or avoiding specific activities within the industrial zone. During four years (1980-1983) of systematic aerial surveys for bowheads on their summer range, there has been an apparent decline in the use of the existing industrial zone in the Beaufort Sea by the bowhead population (Richardson et al. 1983d; McLaren and Davis, in prep.). However, it is not known if the distribution patterns observed to date are related to industrial activity or to oceanographic factors that determine bowhead food supplies.

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

The available data suggest that bowheads within 1 or 2 km of each side of a ship take evasive action as the vessel approaches. On average, affected individuals resume normal behaviour within one hour (Richardson et al. 1983a).

However, it is not known if bowheads are prevented from feeding during the 1-hour period of altered behaviour. The length of each interrupted feeding period may also become shorter with time if the whales habituate to the disturbance. Despite uncertainties associated with estimating the extent of lost feeding time, it was concluded that the loss could be significant to individual whales.

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

Ship passages may disturb whales to the extent that they stop feeding and flee from the ship. This would involve an energetic loss since feeding activities would be disrupted (link 6), and energy would be lost through the cost of idance. Tucker (1975) calculated the energy cost for motion of various species, although whales were not included in his analysis due to a lack of data. However, Sumich (1983) recently calculated the energetic cost of motion for a gray whale, and it is possible to estimate the cost of motion for a bowhead whale by plotting his data on Tucker's cost of motion figure. Using these data, a 50 tonne adult bowhead would be expected to expend 0.08 Kcal/kg/km, while a 23 tonne immature individual would expend 0.09 Kcal/kg/km. It is emphasized that these estimates are based on only a single data point. There are no other estimates that can be used for comparative purposes, or methods of assessing the reliability of the above calculations for bowheads. They are, however, the only available estimates for the energetic costs of motion by bowheads. It was concluded that this link is valid but its significance relative to the overall energy balance of bowhead whales cannot be assessed.

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

Studies conducted by Brodie (1981) and Griffiths and Buchanan (1982) have indicated that bowhead whales must feed in areas of dense zooplankton concentrations. The latter authors suggested that zooplankton biomass must be at least 7 $g/m^3$ for a bowhead to meet its energetic requirements. In other areas, the zooplankton biomass necessary to meet baleen whale energetic requirements has been located by using sophisticated acoustic techniques (Sameoto 1983). Although this type of study has not been conducted in the Beaufort, work in other areas indicates that the following phenomena may occur in the Canadian Beaufort Sea: (1) Oceanographic processes which are discontinuous in space and time give rise to a patchy distribution of phytoplankton in areas of high primary productivity, and (2) this results in a similar patchy distribution of areas containing a high zooplankton standing stock.

In the Canadian Beaufort Sea, high zooplankton standing stocks may result from high primary productivity within the Cape Bathurst Polynya and in areas of summer upwelling. The Cape Bathurst Polynya is open early in the season, and physical processes in this area may include the transport of nutrient-rich water to the surface (see Hypothesis No. 6). This could result in high primary and secondary productivity at a time of year when production is low throughout the remainder of the Beaufort Sea/Amundsen Gulf region.

In summer, upwelling events may determine areas with high diatom production and, therefore, result in aggregations of copepods and euphausiids. This phenomenon has been demonstrated in Alaskan waters where aggregations recur in the same general areas from year to year, but vary in specific location and extent (NOAA/OCSEAP Sale 67 synthesis report, in prep.). In the Alaskan Beaufort Sea, highest zooplankton standing stocks are found within the shelf break zone but not in the extreme nearshore zone (D. Schell, pers. comm.).

Evidence from other areas indicates that local aggregations of zooplankton may occur near fronts, upwelling plumes, bathymetric irregularities, the edge of river plumes, and other transient or quasi-stationary hydrographic features (Pingree et al. 1974; Mackas et al. 1980; Seliger et al. 1981).
Competition with the planktivorous Arctic cod for food may be another relatively important factor delineating bowhead whale feeding habitat. However, there is no information on these potential interactions or the scale of zooplankton patchiness in the Beaufort Sea. Consequently, it is not presently possible to delineate bowhead feeding habitat even in general terms.

It was concluded that if the amount of habitat is decreased, food availability could also be reduced. This relationship, however, is expected to be mediated by the range of factors affecting zooplankton concentration in the water column.

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

Determination of the energetic requirements of bowhead whales requires several assumptions regarding the biology and ecology of this species. In the simulation model, it was assumed that bowhead whales feed for 105 days in the Canadian Beaufort Sea and 60 days during the fall migration. Using data in Davis et al. (1983), it was estimated that the average length of an adult bowhead was 14.5 m, which corresponds to a body weight of 51.8 tonnes (Brodie 1981). Based on calculation methods provided in Brodie (1975, 1981), a whale this size would require 47,220 Kcal/d for basic metabolism and warming of air. However, the whales also migrate 6000 km, move while feeding and during other activities, and warm food (see Tucker 1975; Brodie 1981; Sumich 1983).

When these other factors are considered, the total annual energy requirement is estimated at $112 \times 10^6$ Kcal. Arctic zooplankton contain approximately 6.5 Kcal/g dry weight (Percy and Fife 1981), and dry weight is about 15 percent of the wet weight. Assuming that a bowhead whale feeds 165 days per year, on the average, it would then consume 870 kg/d (wet weight) during the summer and fall.

Although the stomachs of other baleen whales hold large quantities of food (>500 kg; Nemoto 1957; Lockyer 1981), the bowhead stomach is substantially smaller (about the size of a cow's stomach; T. Albert, pers. comm.). The maximum amount of food recovered from a bowhead stomach was about 40 kg (Lowry and Burns 1980), although the actual maximum capacity is unknown. If the above quantity is near the maximum capacity of the stomach, then an adult male or resting female would have to feed almost continuously throughout the day and process food at the rate of at least 36 kg/h. Consequently, the bowhead could be unlike other baleen whales in that it may be unable to take advantage of large concentrations of food and appears morphologically adapted to feed on small patches of high zooplankton concentrations. If the above is true, disruption of feeding could mean that an affected individual would be unable to recover lost feeding opportunities or energy expended in avoidance reactions.

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

This link is self-evident for any animal, and is presented here as a necessary precursor to the following link.

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

The energy balance of the individuals in the population strongly influences the reproductive capacity and health of the population.

Bowhead whales are believed to do most, if not all, of their feeding in the Arctic during the summer. However, there is only circumstantial evidence to support this hypothesis. For example, virtually all other species of baleen whales in both hemispheres that migrate to high latitudes for the summer do most of their feeding in these waters. Other indirect evidence in support of the hypothesis includes the fact that seasonal primary production and zooplankton stocks are highest in summer, and that the caloric content of zooplankton is also highest during summer. Zooplankton abundance and zooplankton caloric content are at their annual minimums in the Bering Sea during the winter period when bowheads are present. Bowheads harvested in the Alaskan Beaufort Sea in early fall (September) have food in their stomachs, whereas those taken in spring (May) have empty or nearly empty stomachs. Consequently, it is probable that the energy balance of bowheads is strongly positive during summer and highly negative during winter.

## CONCLUSIONS

The combination of (1) the high energy intake requirements, (2) spatial and temporal variations in usable prey concentrations, and (3) the apparent susceptibility of bowheads to some types of disturbance suggests that there is a potential for changes in energy balance which could lead to reductions in bowhead reproductive rates and population size. It was concluded that the present hypothesis was both valid and testable. The linkages concerning effects of industrial activities were expected to be possible, but since they have not been quantified in most cases, the implications of hydrocarbon development to the bowhead population are not known. Each link in the hypothesis is supported by circumstantial evidence. Direct and quantitative data are lacking in most instances.

The workshop subgroup concluded that the hypothesis should be tested with a monitoring program. It was also concluded that further research was required to examine the hypothesis and to support the proposed monitoring programs. The most important data gaps include the biology and energetics of bowheads, and factors controlling zooplankton distribution in the Beaufort Sea. The following sections discuss monitoring and research priorities, although there is considerable overlap between programs. For example, the monitoring programs will provide information on the biology of the bowhead whale, although the latter is included in the category of research.

## MONITORING

### 1. Behavioural Responses of Bowheads

A monitoring program is necessary to examine both the short and long-term responses of bowhead whales to existing levels of industrial activity in the Beaufort Sea. The program should have three inter-related components to address the specific objectives.

The first component should consist of systematic aerial surveys in the southern Beaufort Sea and Amundsen Gulf to document overall bowhead distribution. These surveys would complement past systematic surveys (1980-1983) by continuing to monitor overall distribution patterns, and ultimately allow assessment of year-to-year variation in bowhead distribution. Studies conducted to date indicate that the natural annual variability in distribution is large, but a longer time-series is necessary to document the full range and potential periodicity of distribution patterns. The relationship between bowhead distribution patterns and industry activities will be very important for assessment of the long-term effects of hydrocarbon development on bowheads. However, it should be emphasized that distribution patterns can only be interpreted after the factors controlling the distribution and abundance of zooplankton are determined. It is assumed that the variations in bowhead distribution observed during the four summers since 1980 are related to variations in food distribution and availability. Therefore, it is important to understand the physical oceanographic factors that control zooplankton distribution, abundance and patchiness in order to evaluate the possible effects of industry activities on bowhead distribution.

The second component of this recommended monitoring program involves quantification of the short-term behavioural responses of bowheads to industrial activities. Existing studies conducted on behalf of the U.S. Minerals Management Service (MMS) (see Richardson, ed. 1982, 1983) provide some information on these responses, but do not fully quantify responses in terms of the distances moved by affected whales and lost feeding time. These data are necessary to evaluate the basic links between industry activities and whale behaviour in the present hypothesis (Links 1, 2 and 3). Study methods should be similar (aerial) to those used in the MMS investigation, although an important refinement to this approach would be to include behavioural studies with individually marked animals whenever possible. Many bowheads can be individually recognized (Davis et al. 1983), and repeated observation of these individuals would provide information on the acclimation of bowheads to industry activities. It is important to document if individual bowheads habituate to disturbances, thereby reducing response times and distances.

The third component of this monitoring program should be a combination and expansion of the first two components and involve the use of aerial photographic techniques to identify and measure individual bowheads. There is some evidence that the various age and sex classes of bowheads are at least partially segregated in summer and, therefore, it is possible that only a proportion of the population would regularly occupy the portion of the Beaufort Sea where industry activities and facilities are located. If segregation occurs, a large proportion of the population may not be regularly exposed to industry activities. At the same time, however, it is possible that certain segments of the population, independent of age and sex, may traditionally occupy certain parts of the summer range. Consequently, the same individuals could occur in the industrial zone year after year. This particular population segment could learn to avoid the area or habituate more rapidly as a result of repeated exposures. Information concerning segregation and use of traditional areas could be collected during a wide-ranging aerial photography program conducted over a number of years. The information gained in such a program is necessary to evaluate the long-term responses of bowheads to industry activities. This type of program will also provide important information on the biology of the species (e.g., calving interval, size of individuals at first breeding, survival rates of sub-adults, etc.).

## 2. Reproductive Rates

The present hypothesis states that industry activities could lead to a reduction in the energy intake of bowheads. The consequences of such a reduction would most likely be manifested in lower reproductive rates, since females may fail to breed or to abort if they cannot obtain sufficient energy for maintenance. Monitoring the reproductive rate of the population therefore, would be the most direct manner of examining the potential impacts associated with this hypothesis.

In theory, it is a relatively simple procedure to measure the reproductive rate of a whale population using modified aerial transect and/or photographic methods. However, there are sampling bias problems that can significantly affect the accuracy of results. These problems relate to the lack of data on potential age and/or sex segregation of bowheads on the summering grounds, but could be examined in the previously described monitoring program. As information is collected, the problem should become less significant and reliable measures of annual reproduction should then be possible. It is therefore recommended that investigations of reproductive rate be conducted in conjunction with the previous monitoring program, since information on reproductive status would also be essential for determining patterns of age and sex segregation. Similarly, if segregation into traditional use areas occurs, it would then be important to examine and compare the reproductive rates of bowheads using the industrial zone with those of bowheads summering in other parts of the Beaufort Sea or Amundsen Gulf.

The aerial techniques used in this monitoring program component would also provide information on yearlings and perhaps two-year-olds that could be used to estimate calf survival rates. Data collected on animals that are identifiable from the air would also provide important biological information on the breeding interval and the stability of adult social and feeding groups.

3. Ambient Noise Monitoring

Monitoring of existing ambient noise levels in the industrial zone should be conducted over a one year period to allow calculation and subsequent assessment of the zones of influence of underwater noise, as well as temporal differences in noise levels resulting from different levels of industrial activity throughout the year. Ambient noise measurements should also be repeated in the future (e.g., after 10 years) to determine the magnitude of noise level increases with time. The results of this type of monitoring could then be used to estimate the potential effects of underwater industrial noise on inter-animal communications. If significant changes in bowhead population distribution and/or reproduction were detected during other monitoring programs, ambient noise measurements would be useful to examine cause-effect relationships.

## RESEARCH

As noted earlier, there is considerable overlap between recommended monitoring and research programs related to bowhead whales. The following four areas of research were identified during the workshop discussions.

### 1. Energy Balance

The present hypothesis depends on the validity of several assumptions and indirect measurements of bowhead energy intake. Important information regarding the energy balance of this species could be obtained by sampling the Alaskan bowhead harvest.

A fundamental data gap concerning bowhead energetic requirements is the extent to which feeding occurs during winter. A comparison of the physical condition of whales taken in spring and fall could provide some information on the relative amounts of food taken in winter. The types of information collected should include observations and measurements of blubber thickness, girth, fat deposits and liver condition.

Although the maximum capacity of a bowhead stomach is unknown, examination of fresh warm stomachs from harvested bowheads could be undertaken to determine maximum food handling capability. Similarly, observations on stomach musculature, histology, biochemistry and comparative anatomy could provide information on digestive processes in this species. Both of these types of data would be extremely useful in determining bowhead feeding regimes and in predicting potential impacts of disruption of the feeding regime.

Comparisons of isotopic carbon in liver, muscle, blubber and other tissues from bowheads landed during the spring and fall harvest could also be used to elucidate the question of winter feeding. The isotopic composition of bowhead prey organisms in the Bering and Beaufort seas would undoubtedly be different, and would be reflected in the isotopic composition of the bowhead tissue.

2. Distribution of Bowhead Food (Zooplankton Concentrations)

As noted earlier, the summer distribution of bowhead whales in the Beaufort Sea varies among years. During the four years for which systematic data are available, there has been a trend toward fewer animals occurring in the industrial zone. The reasons for this apparent down trend are unclear. Bowhead distribution is probably determined by the location of dense patches of zooplankton, which in turn are probably determined by predictable but variable meteorological and oceanographic factors. Thus, in years when zooplankton patches only occur outside the industrial zone, bowheads would not be expected to occur near industry facilities and activities, with the exception of a few transient animals. Therefore, it is important to understand the factors controlling the distribution of zooplankton patches in order to interpret bowhead distribution patterns in relation to food and industrial activities.

The following recommended research program has been designed to determine which factors control the distribution of zooplankton patches, and to provide a capability for predicting these distributions on the basis of simply measured surface and sub-surface conditions. A single program allowing accurate predictions using simple parameters (e.g., wind speed and direction, or temperature and salinity) will be a useful and cost-effective means for interpreting bowhead distribution patterns over the long-term, whereas a major ship-based program each year is unlikely to be financially justifiable.

(a) Feasibility Study

Since this particular research program would be a major undertaking, a feasibility study is recommended to provide direction for its design. The principal objective of the program would be to examine the relationships between bowhead whale distributions and large scale physical oceanographic features of the Canadian Beaufort Sea.

Griffiths and Buchanan (1982) reported that zooplankton standing stock was substantially greater in high salinity waters than in low salinity waters associated with the Mackenzie River plume. The position of the plume is in turn determined by prevailing wind patterns (MacNeill and Garrett 1975; Herlinveaux and de Lange Boom 1975). The hypothesis that should be tested in the feasibility study is that the location of the plume will determine large scale distribution of bowhead whales. Conceptual linkages of this hypothesis relate to the theories that (1) when the plume is driven inshore by winds, bowheads occur in zooplankton-rich saline shelf waters, and (2) when the plume encompasses the shallow shelf waters, bowheads are excluded since the area is characterized by low salinity water and low zooplankton standing stock.

The feasibility study should compare the results of bowhead distribution aerial surveys conducted during 1980-1983 with temperature and salinity profiles taken during the same periods at drillships and other platforms operating in the Beaufort Sea. It should also include examination of available data on winds, ice and flow rates of the Mackenzie River, as well as the results of Satellite imagery and remote-sensing productivity studies conducted in 1983 by Arctic Laboratories Ltd. (Borstad 1984).

Evaluation of the results of the feasibility study will provide essential information for the design of the main research program, and provide testable hypotheses directly related to the whale distribution data.

(b) Design Phase

It is probable that a formal design phase for the main research program will be necessary, although this design could be completed as a component of the feasibility study.

(c) Main Sampling Program

This program should examine the spatial and temporal distribution of bowhead prey species in relation to meteorological and oceanographic phenomena, with the aim of identifying simply-measured parameters that could be indicative of large scale zooplankton distribution patterns. These data would ultimately be used to interpret bowhead distribution data in relation to industrial activities, and to determine if these activities are excluding whales from prime feeding habitat. The three major objectives of this recommended research program are provided below.

Objectives

(i) To determine large scale patterns of zooplankton distribution, and their relationship to primary productivity and meteorological and oceanographic phenomena such as wind, temperature, salinity, upwelling events and the presence of polynyas,

(ii) To determine the effect of local aggregations of zooplankton on the location and intensity of bowhead feeding ground utilization, and

(iii) To identify dependable environmental correlates or predicators of the spatial and temporal distribution of zooplankton aggregations.

Approaches

The methodology for this study must stress integration of biological, physical and meteorological sampling. The success of the program will be dependent on the collection of a large number of data points from a large geographical area over a relatively long period of time. Therefore, the method of collecting the requisite amount of data at a reasonable cost should include use of automated electronic measuring devices with digital transfer of information to onboard computers. Emphasis on traditional sampling techniques and laboratory analyses should be limited.

Extensive spatial and temporal coverage of the area, including associated measurements of primary productivity, will be required to allow proper evaluation of large scale distributional features. Late winter/early spring measurements of productivity in the Cape Bathurst polynya would be especially important in this regard. The program should be conducted for three to five years to account for (1) the researcher learning curve, (2) persistence of features, (3) annual variability, and (4) opportunities to encounter all of the different hydrometeorological regimes occurring in the area.

The quantity of data required to adequately meet the objectives of the study would likely necessitate the use of high frequency acoustic techniques for the measurements of zooplankton distribution (spatial and vertical) and relative abundance. Through ground truthing, these data could then be used to provide quantitative estimates of zooplankton standing stock. All measurements must be accompanied by synoptic meteorological measurements and measurements of temperature, salinity and turbidity.

The program should be designed around a series of working hypotheses regarding primary production and zooplankton concentrating mechanisms, while stressing reasonable and workable logistics. The research program should also be progressive and adaptive to address changing research questions and hypotheses. An international effort may be appropriate given the special status of the bowhead whale in both Canada and the United States and the transboundary migrations of this bowhead population.

3. Bowhead Biology

Although the basic biology of the bowhead whale is poorly documented, the biological information necessary to complete the monitoring programs would be collected during the course of the studies outlined above. No other specific studies of bowhead biology are recommended at this time.

4. Passive Acoustics

The workshop group discussed some innovative approaches for passive monitoring of the acoustic behaviour of bowheads in the presence of industry activities. The feasibility of these techniques in the examination of important data gaps was not determined, although they are considered worthy of further conceptual design.

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# HYPOTHESIS NO. 2

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

A. Offshore structures will reduce the white whale harvest.

B. Frequent icebreaker traffic in landfast ice will increase the white whale harvest.

C. Open water ship traffic in the Mackenzie Estuary will alter white whale distribution and lead to changes in harvest levels.

D. Inuit employment in industry will change the white whale harvest.

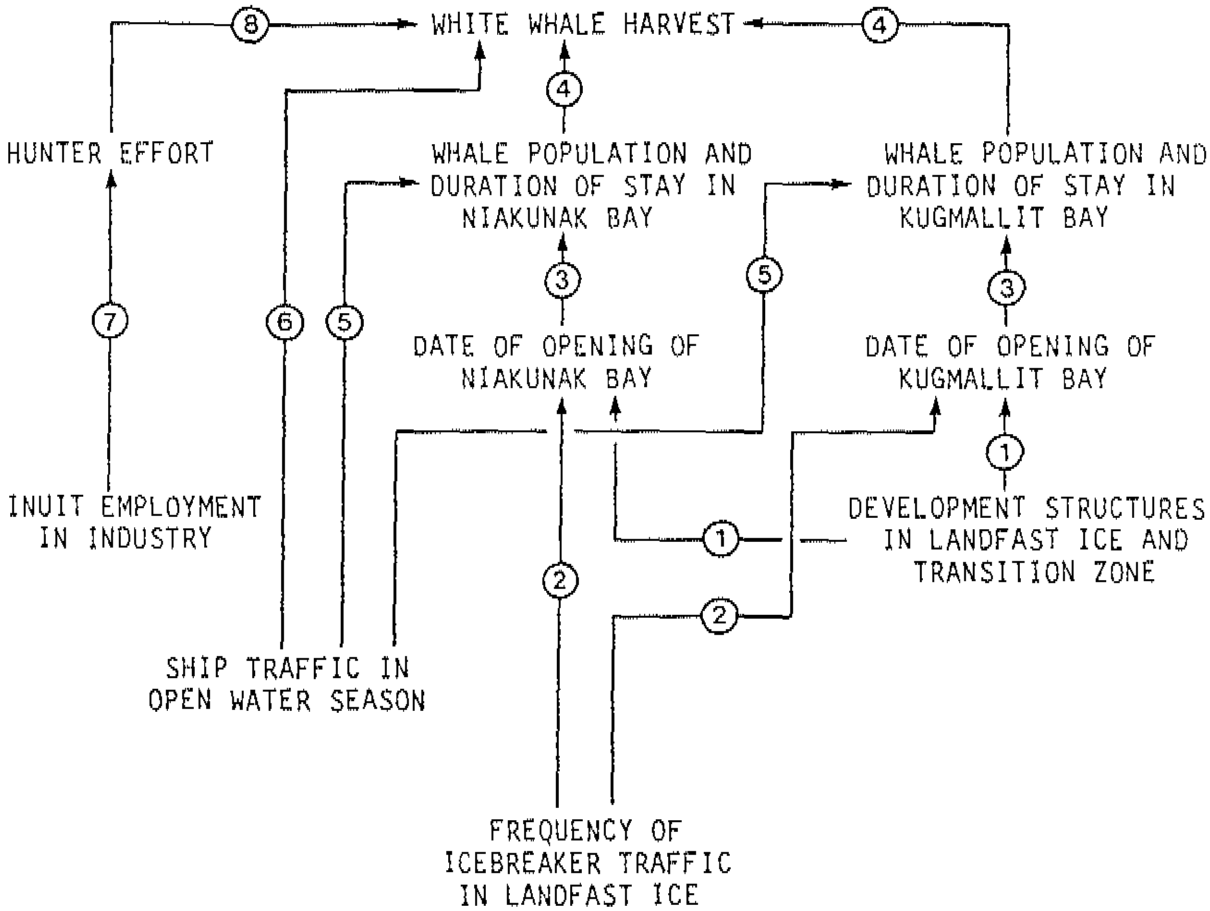


Figure 2-1 Potential effects of various facilities and activities associated with offshore hydrocarbon development on white whale harvest.

## Linkages

1. Artificial islands off the Mackenzie Delta will delay the regional break-up of the 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 determines the timing of entry, the numbers, and the duration of residence of white whales in Niakunak and Kugmallit bays.

4. The timing of entry, 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 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 will lead to changes in the white whale harvest.

## NAMES OF PARTICIPANTS

Ben Danielewicz
Rolph Davis
Max Dunbar
Joy Geiselman
Lois Harwood
Humfrey Melling
Tim Webb

## INTRODUCTION

The 'Mackenzie Estuary' stock of white whales winters in the Bering Sea, and migrates in the Canadian Beaufort Sea during May and June through leads far offshore in the pack-ice (Fraker 1979). The whales initially arrive offshore of Banks Island, move southward to Amundsen Gulf, and westward to the Mackenzie Estuary in late June. White whales enter the Estuary following break-up of the landfast ice, and spend about three weeks in this area. Davis and Evans (1982) suggest that since not all whales in this population utilize the Mackenzie Estuary, the stock would be more appropriately called the 'eastern Beaufort Sea population'.

It is not clear why all white whale populations occupy estuaries in summer. The most recent and probable explanation is that the whales moult while in these shallow areas (Finley 1982), although there may also be thermal advantages and social implications associated with the use of estuaries (Fraker et al. 1979). The maximum estimate of the number of white whales using the Mackenzie Estuary at one time, excluding young-of-the-year, is 7000 (Fraker and Fraker 1979; Norton Fraker 1983). Davis and Evans (1982) estimated that the entire population numbered at least 11,500 animals.

White whales are hunted by Inuit in areas of the Mackenzie Estuary where they concentrate during the month of July. Major hunting areas include Kugmallit Bay and Niakunak Bay on the east and west sides of the Estuary, respectively.

The annual landed catch has averaged 88.4 whales in Kugmallit Bay and 28.1 in Niakunak Bay during the 11 year period from 1972 to 1982. In addition, an average of 13.9 whales are landed annually by hunters stationed at Kendall Island in the central Delta (Norton Fraker 1983).

There is concern that activities associated with offshore hydrocarbon development will affect the white whale harvest through the potential for disturbances and changes in landfast ice break-up patterns. Either effect could result in altered use of the Estuary by whales. Four distinct hypotheses (Figure 2-1) have been formulated, and probable linkages defined. The hypotheses and associated linkages are discussed as a group below.

## LINKAGES

Link 1: Artificial islands off the Mackenzie Delta will delay the regional break-up of the landfast ice.

Artificial islands could delay break-up of the landfast ice in two ways. First, the islands could anchor the landfast ice, thereby delaying its drift away from the Estuary during break-up. Second, islands in the transition zone could increase the extent of the landfast ice, and this could result in a delay of break-up. The implications of delayed break-up include a potential for delayed arrival of white whales in the Estuary, and changes in whale use of this area. These effects could in turn alter the Inuit harvest of white whales.

The date of break-up in the Beaufort Sea has been recorded through Landsat imagery since 1973. Figure 2-2 illustrates the annual dates for both the fracture of the Kugmallit ice barrier and the complete clearing of the landfast ice. To date, there has been no evidence to suggest that artificial islands have affected either.

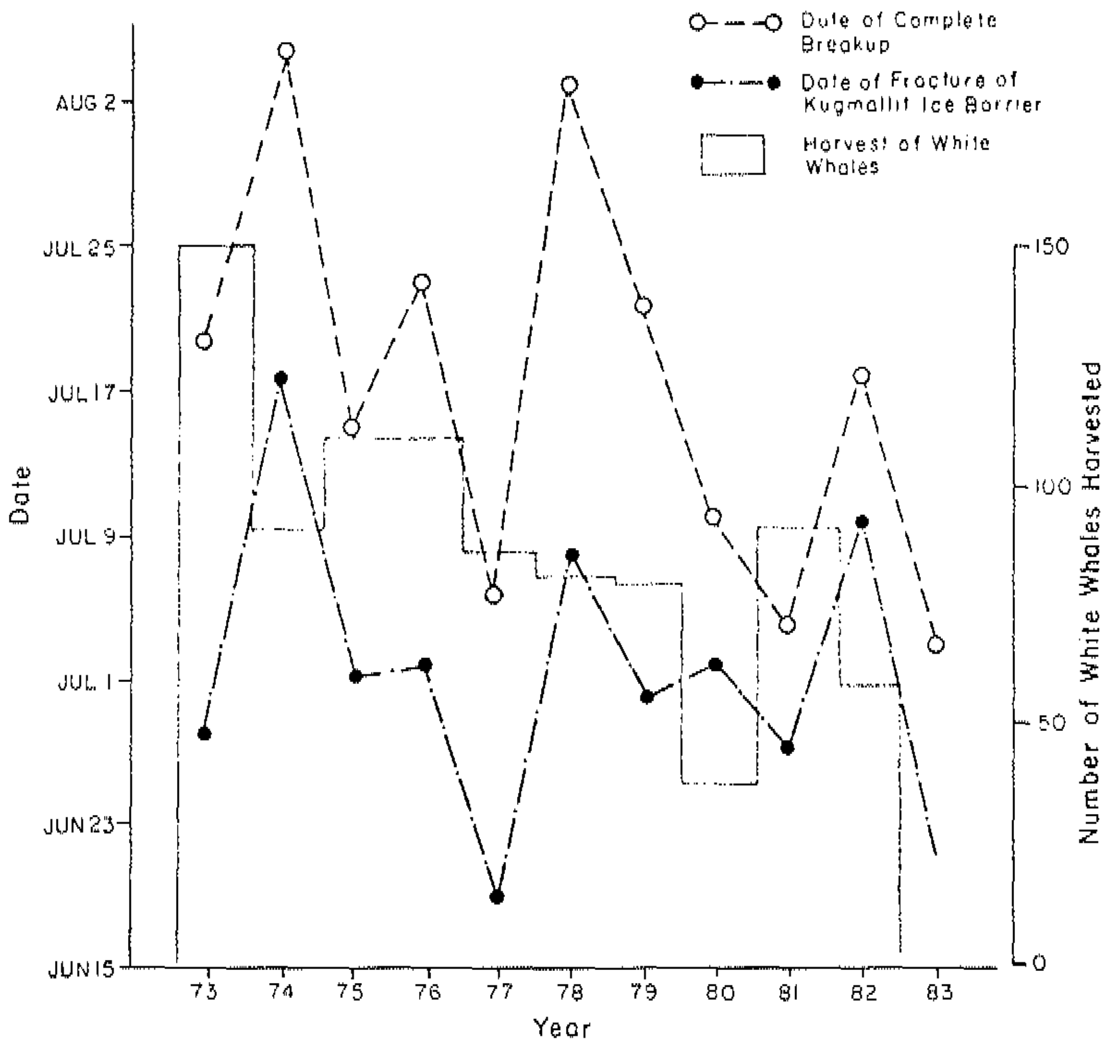


Figure 2-2 Dates of fracture of the Kugmalitt Bay ice barrier and the complete clearing of landfast ice in the MacKenzie Estuary as determined from LANDSAT imagery from 1973 to 1983. Points are connected for illustrative purposes only.

There is concern that artificial islands constructed seaward of the normal landfast ice edge (i.e., in the transition zone) could extend the landfast ice beyond its average limit. To date, only two islands have been constructed seaward of the fast ice edge. Uviluk was operated during the winter of 1982-83 and remained within the transition zone throughout that period. The island did not impede ice movements beyond its rubble field (radius of 100 to 200 m). Kogyuk, the second island to be constructed seaward of the landfast ice, was used for exploratory drilling during the winter of 1983-84. During this period, it remained in the mobile pack-ice. From 1973 to 1983, the Kogyuk site was located within the landfast ice zone in 2 of 11 years (1974, 1977).

The available data suggest that existing artificial islands have not had detectable effects on either the extent or break-up of the landfast ice. However, effects are difficult to detect given the high natural variability which characterizes the ice regime of the Beaufort Sea. Furthermore, it is not known whether the number of islands projected for construction in the future would have detectable effects on the landfast ice regime.

Link 2: Icebreaker traffic in the landfast ice in spring will advance the break-up of ice barriers across Kugmallit and Niakunak Bays.

During spring, break-up of the landfast ice proceeds simultaneously northward from the Mackenzie River and southward from the transition zone. The final remnant of ice to break forms an arch at approximately the 10 m isobath across Kugmallit and Niakunak Bays. On the average, these arches disintegrate 17 and 8 days following the beginning of break-up in Kugmallit and Niakunak bays, respectively. White whales do not have access to the bays until these arches break. Therefore, icebreaker traffic through these narrow ice remnants could result in whales having earlier access to these areas.

However, large icebreakers (i.e., > Class 2) cannot operate in either of these areas because depths are too shallow. No icebreaking activity is currently envisaged for the Kugmallit Bay area. However, if a Yukon shorebase is developed in the future, a limited amount of icebreaking activity would likely be required in Niakunak Bay during spring.

Link 3: The timing of break-up of the landfast ice determines the timing of entry, the numbers, and the duration of residence of white whales in Niakunak and Kugmallit bays.

Date of the first arrival of white whales in the Mackenzie Estuary is correlated with the date that the ice barrier across the bays is breached. On average, the first whales enter Niakunak Bay 2.8 days after the ice barrier is breached (n = 7 yrs.). In Kugmallit Bay, whales first enter an average of 1.2 days after the ice is breached (n = 8 yrs.). However, the arrival of large numbers of whales in the bays appears more dependent on time of year than on time of breakup. Large numbers of whales have arrived an average of 9.8 days after break-up in Niakunak Bay (n = 5 yrs.) and 8.3 days after break-up in Kugmallit Bay (n = 3 yrs.) (Fraker and Fraker 1982; Norton Fraker 1983).

Fraker and Fraker (1982) suggested that the relative numbers of whales occupying Niakunak and Kugmallit Bays is determined by the relative timing of break-up in these two areas. This suggestion was based on limited observations that the number of whales in Kugmallit Bay is lower in years when the ice there breaks later than in Niakunak Bay. More recently, however, Norton Fraker (1983) suggested that the relative numbers occupying each bay probably also relates to, and is influenced by, ice conditions along the spring migration route.

Although break-up dates in Niakunak and Kugmallit bays are highly variable (e.g., June 15 to July 11 during the period from 1973 to 1982; Fraker and Fraker 1982; Norton Fraker 1983), the length of time that the whales spend in the Estuary does not vary to the same degree. For example, relatively large numbers of individuals occur in the Estuary for about three weeks, regardless of the date of first arrival. Therefore, the available data suggest that the first arrival of whales in the Estuary is a function of break-up timing, while the number of whales reaching each bay and their length of stay is not.

The effects of industry-related break-up delays on whale use and distribution in the Mackenzie Estuary are unknown. In the Canadian High Arctic, severe ice conditions have prevented white whales from entering estuaries. In some instances, these whales have occupied alternate estuaries, or in extreme cases, do not enter estuaries at all (Finley 1976; Davis and Finley 1979; Koski and Davis 1979). It is possible that in extreme cases, delayed break-up of ice in the Mackenzie Estuary could also prevent whales from occupying this area. Since white whales probably occupy these areas for moulting (Finley 1982), there would presumably be no advantage to entering estuaries after the moult has been completed. However, there is no available information regarding the particular date after which the moult is complete, and therefore the time at which the whales may no longer enter the estuarine environment.

Link 4: The timing of entry, the numbers and the duration of residence of white whales in Kugmallit and Niakunak bays will influence the white whale harvest.

White whale harvest levels in Niakunak Bay have been relatively consistent (range: 20 to 35 whales) throughout the 11-year period from 1972 to 1982 (Norton Fraker 1983). The number of whales harvested is relatively low in comparison to the large number (over 6000 in some years) of whales that occupy this bay each July. As a result, these data cannot be used to evaluate the validity of the above linkage.

On the other hand, the harvest levels in Kugmallit Bay are relatively variable. Landings in this area have ranged from 37 to 150 whales (Norton Fraker 1983), while peak whale abundance in Kugmallit Bay has varied from about 120 to 2000 (n = 7 yrs.). The existing evidence suggests that when the abundance of white whales in Kugmallit Bay is very low (e.g., 120 animals in 1980), there is a corresponding reduction in the number of whales landed (Figure 2-3).

The clear relationship between the arrival dates of white whales in Kugmallit Bay and the number of whales harvested in a particular year is illustrated in Figure 2-4. In general, the number of animals harvested is lower in years when the whales arrive late in the bay. The link was therefore considered valid since both the number of whales present and the date of arrival appear correlated with harvest levels.

Link 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 whales spend in the bays.

Link 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.

It has been well documented in the Beaufort Sea and elsewhere that moving ships and barges can result in short-term changes in white whale distribution (Fraker 1977a, 1977b; Pippard and Malcolm 1978; Fraker and Fraker 1982; Finley et al. 1983; Norton Fraker 1983; F. Awbrey, W. Evans, pers. comms.). However, evidence from Alaska and Churchill, Manitoba suggests that white whales habituate to repeated ship disturbances in some instances (R. Davis, pers. comm.).

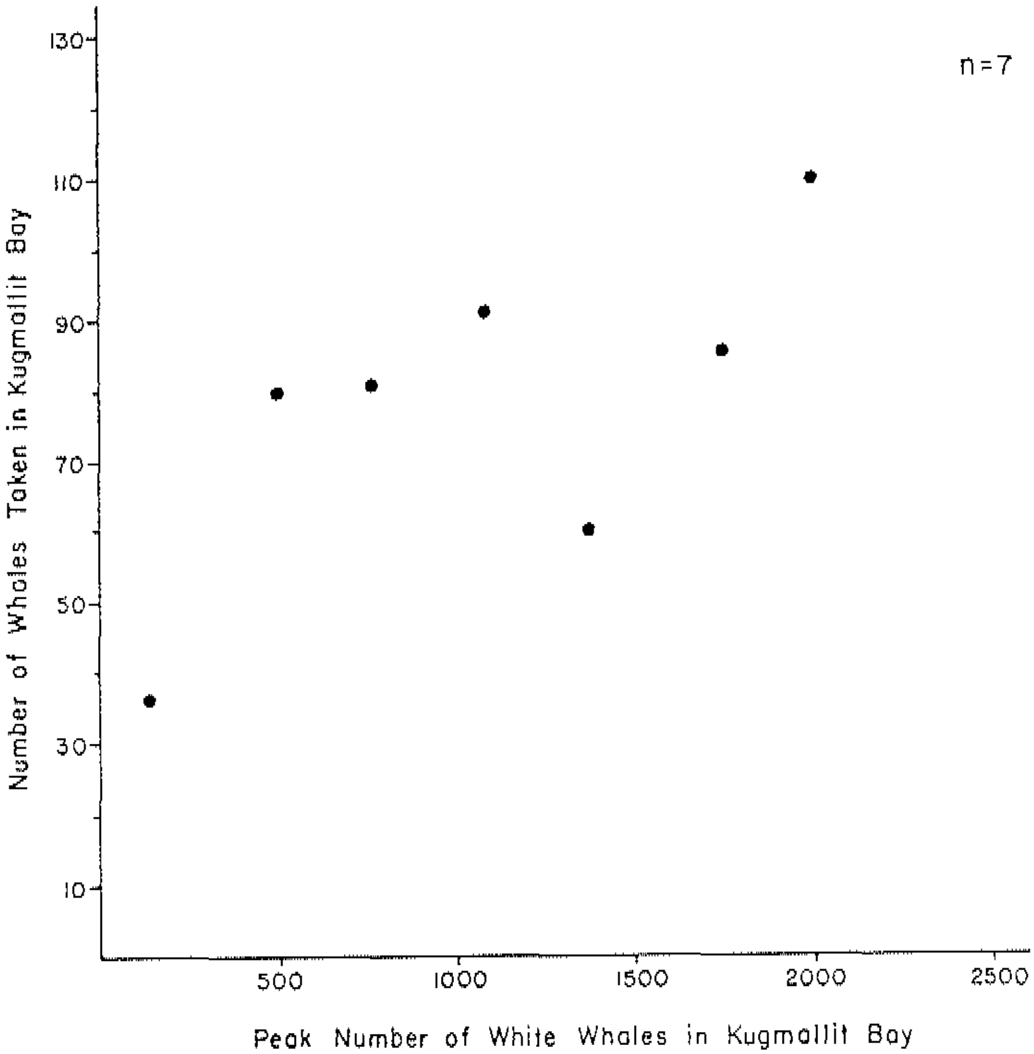


Figure 2-3 Relationship between numbers of whales in Kugmallit Bay and the annual harvest in the Bay.

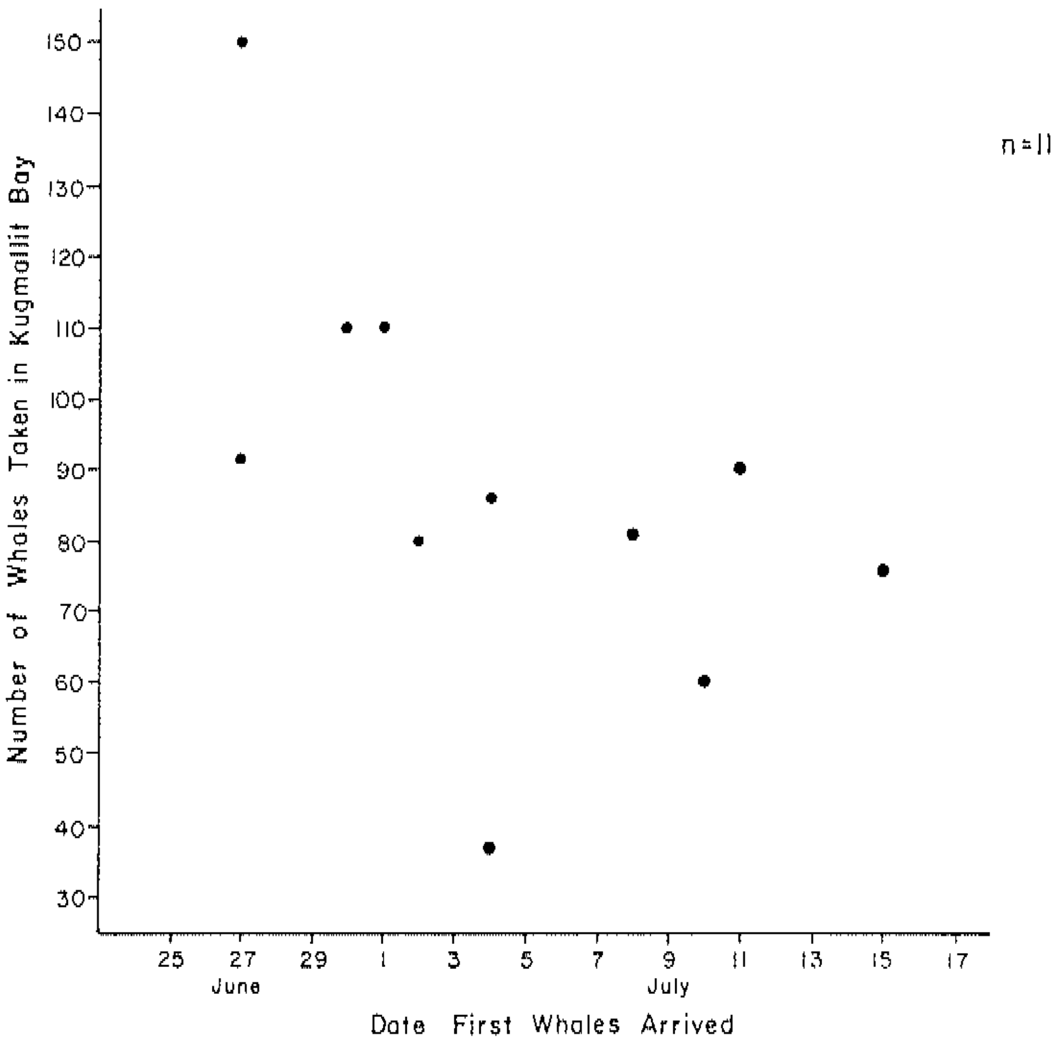


Figure 2-4 Relationship between date of first arrival of white whales in Kugmallit Bay and harvest levels in the bay (from Fraker and Fraker 1982; Norton Fraker 1983)

Marine vessel activities in Niakunak and Kugmallit bays may disturb white whales and cause short-term avoidance responses by some individuals. The potential for these activities to result in long-term changes in white whale abundance and distribution in the bays exists, although it is not known if and to what extent such changes would occur. Both short and long-term effects could lead to effects on white whale harvest levels through displacement of whales from traditional and/or accessible hunting areas.

In Kugmallit Bay, marine vessels follow channels along the southern and eastern shores. There is no evidence to suggest that the present level of ship traffic (i.e., 2 to 6 passages per day) is affecting white whale distribution in central and western portions of the bay (Norton Fraker 1983). There is also some evidence that white whales in the Estuary are generally habituated to disturbances associated with Inuit hunting activities, although hunting can lead to local changes in whale distribution (Fraker and Fraker 1982).

Link 7: Increased Inuit employment by the oil industry and various supporting businesses will lead to changes in hunter effort.

Inuit employment in the wage economy could reduce time available for hunting, and thereby reduce hunting effort. On the other hand, wage earners may have increased opportunities to purchase improved vehicles and equipment, and this could lead to improved hunting efficiency and increased catch-per-unit-effort (CPUE). At the same time, wage employment could reduce the experience and capabilities of the hunters, which in turn would reduce CPUE and increase the number of whales killed but lost. Although overall changes in hunter effort are likely to occur, the direction and implications of these changes cannot be predicted at present.

Link 8: Changes in hunter effort will lead to changes in the white whale harvest.

Although this link was considered valid, the direction of the potential changes in harvest levels are not known.

## CONCLUSIONS

A. It was concluded that delays in break-up could lead to a reduction in the white whale harvest. However, on the basis of projections in the present development scenario, substantial delays in break-up of barriers across Kugmallit and Niakunak bays have a low probability of occurrence. In addition, the timing of break-up is not the only factor determining the arrival time of white whales in the Estuary, although it is a good indicator in most years.

It is not known if industry-induced delays in break-up are possible, or would be of sufficient magnitude to result in a major reduction in the number of whales using the Mackenzie Estuary. However, within the range of natural variation observed between 1972 and 1982, there is a weak positive correlation between whale abundance and size of harvest, and a negative correlation between arrival date and size of harvest.

B. It was concluded that icebreaker traffic would not likely result in an early break-up of ice-bridges across Kugmallit and Niakunak bays. Icebreaking vessels will operate out of shorebases (e.g., McKinley Bay, Stokes Point, King Point) located outside of the Mackenzie Estuary, and therefore will not cross ice-bridges in either of these bays. This conclusion may require re-evaluation if barge traffic associated with future developments along the Yukon Coast traverse Niakunak Bay before disintegration of the ice-bridge.

C. The available evidence suggests that increases in ship and barge traffic in the Mackenzie Estuary could affect the white whale harvest. Whales may become less accessible to hunters if their distribution within the Estuary is affected by vessel activity, particularly in Niakunak Bay. Ship traffic may also physically interfere with the hunt. It is not known whether vessel traffic would affect the length of time that white whales spend in the bays, although there has been no apparent effect to date.

D. Increased Inuit employment in the wage economy is likely to change hunter effort and harvest levels, although the directions of these potential changes are unknown. Since these changes will largely be a matter of hunter preference, it is not recommended that they be monitored for their own sake at present. Nevertheless, it will be necessary to separate the effects of direct industry activities on harvest levels, from effects on harvest levels resulting from changes in hunter effort.

## RESEARCH

A study of the factors influencing white whale distribution within Niakunak and Kugmallit Bays should be conducted in order to provide the basis for separation of natural variability in white whale distribution from industry-related effects. Survey results collected during the past eight years should constitute the main data source, and should be evaluated with respect to the following:

- water temperature
- wind direction and lee shores
- turbidity
- flow rates of the Mackenzie River
- responses to existing hunting efforts.

Data have been collected for some of these factors, but have not been collectively analysed to date. Retrospective analyses of these data and existing information on whale distribution should be conducted. Any factors that appear to strongly influence whale distribution should be examined in future field studies. Water temperature, for example, could be examined remotely during whale surveys, and its effect on determining whale distribution then quantified. The parameters to be examined and the requirements of subsequent studies should be determined after the retrospective analyses.

## MONITORING

The group concluded that the existing white whale monitoring program should be continued and revised. Existing studies of white whale abundance and distribution in relation to industry activity in the Beaufort Sea constitute the longest time series of data for any Arctic marine mammal, and have allowed relatively confident evaluation of the status of Mackenzie white whale stock. The existing program is operational in the sense that it is designed to rapidly detect real or perceived problems associated with the white whale harvest, and to allow opportunities for mitigation. It is recommended that the program continue in the following manner.

### Component A

White whale harvest levels in the Mackenzie Estuary should continue to be monitored, and include information concerning the location and time of all kills. These data are currently being collected by the Department of Fisheries and Oceans.

This component of the monitoring program should also include the continuation of regular visits to the whaling camps. These visits provide information on hunter effort and harvest levels, as well as opportunities for identifying industry-hunter conflicts. Data concerning hunter effort patterns such as number of hunters, number and location of camps, and major equipment changes should also be collected during camp visits.

Component B

The abundance and distribution of whales in the Estuary should be monitored in conjunction with the direct monitoring of the harvest. This study component will allow for evaluation of potential industry-related effects on whale use patterns. A long time series of data is needed to encompass the range in natural variability. The basic approach should be to continue the aerial survey programs to document the following:

1) First arrival and peak abundance dates, and the relationship of these dates to timing of break-up. Surveys along the fast ice edge, at least as far east as Cape Dalhousie, should be conducted and supplemented with satellite imagery.

2) Systematic surveys of Niakunak and Kugmallit bays should be conducted following arrival of the whales in the Mackenzie Estuary. Two or three surveys of Niakunak Bay and 5-6 surveys of Kugmallit Bay would be required each year given the present level of industry activity in the area.

3) At the period of peak whale abundance, the outer Delta should also be surveyed to provide estimates of the total number of white whales using the entire Mackenzie Estuary. These estimates are necessary to examine long-term trends in the number of white whales using the Estuary.

Component C

If major industrial developments or increases in activity are expected, the monitoring program should be intensified. For example, if a shorebase is developed at King Point or Stokes Point, barge traffic could increase significantly in Niakunak Bay. A more intensive examination of whale distribution patterns should be undertaken one or two years before this type of development occurs.

Monitoring of behavioural responses of whales to any additional traffic or activities should be conducted after the increases in industrial activity. Any changes in whale distribution or abundance should be examined, and related to potential changes in harvest levels. The duration of the monitoring effort would be determined by the responses of whales, and the nature and extent of potential effects on harvest levels.

Component D

Monitoring for effects of offshore structures on ice break-up patterns should continue using remote sensing techniques. These studies should be carried out on an ongoing basis to determine if delays in break-up are occurring, and to separate natural variations from any industry-related effects.

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# HYPOTHESIS NO. 3

THE EFFECTS OF MARINE VESSEL TRAFFIC, SEISMIC ACTIVITIES, DREDGING OPERATIONS, AIRCRAFT OVERFLIGHTS AND ACTIVE OFFSHORE PLATFORMS/ISLANDS ON THE SIZE OF THE BEAUFORT SEA POPULATIONS OF RINGED SEALS AND BEARDED SEALS

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.

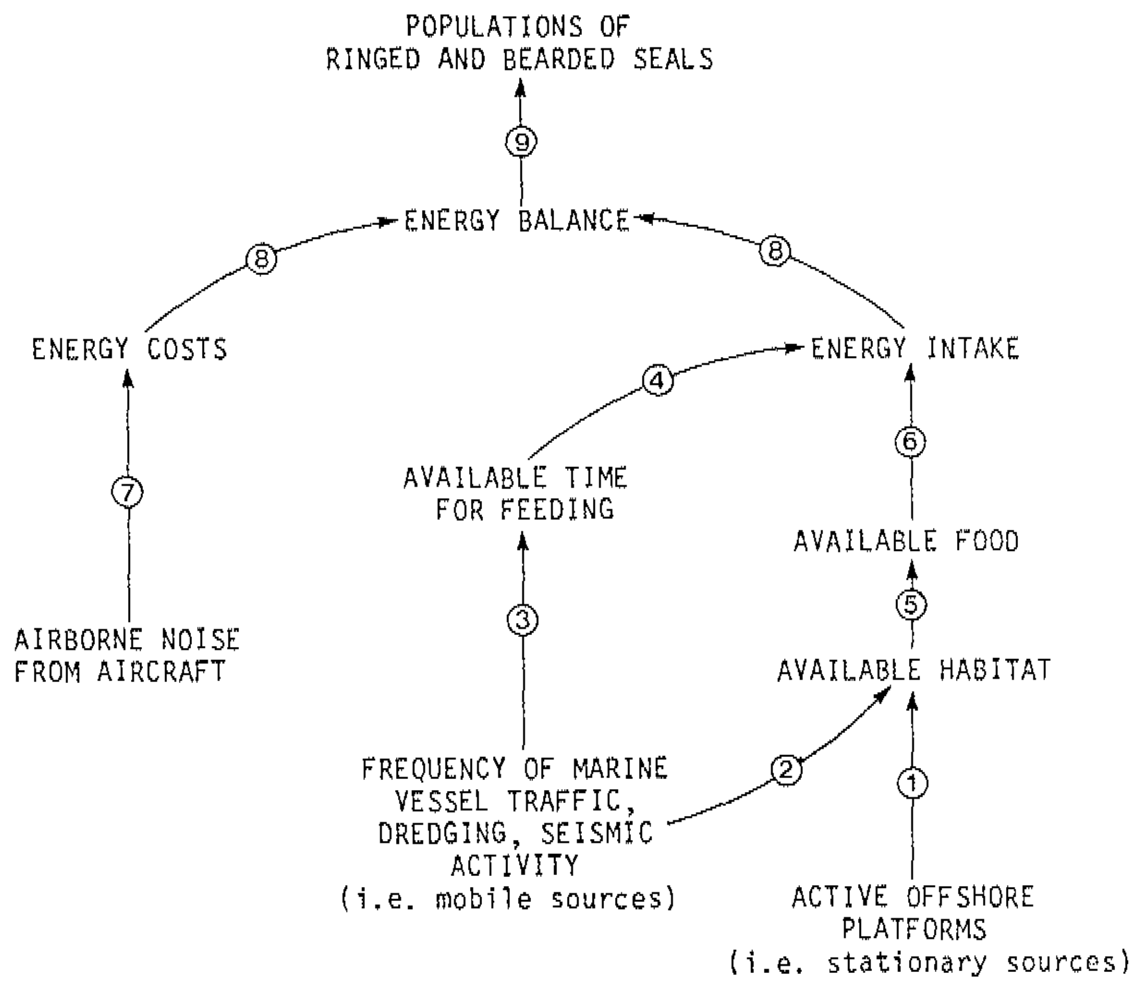


Figure 3-1 Potential effects of marine vessel traffic, seismic activities, dredging operations, aircraft overflights and active offshore platforms/islands on the size of the Beaufort Sea populations of ringed and bearded seals.

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, etc.) 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 determines the level of available food.

6. The amount 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 expenditures determine the 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.

## NAMES OF PARTICIPANTS

Rolph Davis
Bob Everitt
Joy Geiselman
Lois Harwood
Michael Kingsley
Brian Smiley
Denis Thomson

## INTRODUCTION

### Ringed Seal

The ringed seal is the most abundant and widespread species of marine mammal in the Canadian Arctic, and is harvested by residents of virtually all coastal arctic communities. Breeding adults occur primarily in landfast ice areas during winter, and pupping occurs during late March and early April in subnivean lairs on the ice (Smith and Stirling 1975). Within the Beaufort region, the bays of Amundsen Gulf support the highest densities of breeding seals (2.5 females/$km^2$). Ringed seal breeding densities in areas off the Mackenzie Delta and Tuktoyaktuk Peninsula (i.e., the development zone) are lower, probably within the range from 0.4 to 1.0 females/$km^2$ (Stirling *et al*. 1982). Subadults and non-breeding adults occur in leads and areas of thin ice in the transition zone during winter and spring (Stirling *et al*. 1975). The latter group is not expected to be territorial, and probably moves locally in response to food availability and ice conditions.

Large numbers of ringed seals haul out to moult during June, primarily on the landfast ice. In the Canadian Beaufort Sea and Amundsen Gulf, highest on-ice densities of hauled-out seals tend to occur along seaward portions of the fast-ice in Amundsen Gulf (2.6/$km^2$ in 1982; Kingsley and Lunn 1983). The densities of hauled-out ringed seals offshore of the Tuktoyaktuk Peninsula and Mackenzie Delta were 0.15/$km^2$ in 1981 and 0.42/$km^2$ in 1982 (Kingsley and Lunn 1983). Uncorrected estimates of the number of hauled-out ringed seals (an index of relative abundance) in the Canadian Beaufort and western Amundsen Gulf during haul-out have indicated that population levels fluctuate among years. During the period from 1974 through 1979, uncorrected estimates of the number of hauled-out ringed seals ranged from 23,000 (1977) to 61,000 (1978) (Stirling et al. 1982).

Bearded Seal

Bearded seals are also hunted by Inuit, but are not as abundant or important to the native harvest as ringed seals. During winter, bearded seals probably occur primarily in shallower (20 m to 50 m depth) areas of the transition zone or in nearshore pack-ice areas. Pups are born on moving pack-ice during late April and early May. Recorded uncorrected densities of hauled-out bearded seals offshore of the Mackenzie Delta and Tuktoyaktuk Peninsula were 2.1/100 $km^2$ of ice in June 1981 and 8.7/100 $km^2$ of ice in June 1982. Bearded seals tend to haul out near the fast-ice edge, or on small floes in the transition zone (Kingsley and Lunn 1983).

Natural fluctuations in the Beaufort Sea bearded seal population have also been demonstrated. In the period from 1974 to 1979, uncorrected estimates of the number of bearded seals hauled-out on the ice in the Canadian Beaufort Sea and western Amundsen Gulf have ranged from 1300 in 1977, to 3100 in 1978 (Stirling et al. 1982).

All of the various industry activities considered in this hypothesis could result in disturbance of ringed and bearded seals. The overall concern is that the cumulative effects of these activities could affect the energy balance of the seals by reducing the amount of time available for feeding and/or by increasing energetic costs through avoidance behaviour. A negative energy balance could then lead to reduced reproductive rates. Other concerns regarding the potential effects of offshore hydrocarbon development on seals are addressed in Hypotheses 4, 5 and 6.

## LINKAGES

Link 1: Each active offshore platform will result in the exclusion of ringed and bearded seals from some habitat.

Although no quantitative studies of the effects of offshore oil and gas exploration and production structures on seals have been conducted, there are numerous published and unpublished anecdotal accounts of seals in the vicinity of such facilities in the Beaufort Sea (e.g., Renaud and Davis 1981; Ward 1981; Harwood and Ford 1983; McLaren and Davis 1984). Industry personnel and ice observers stationed at offshore structures (and on vessels) in the Beaufort Sea frequently observe both ringed and bearded seals, with total numbers observed during the open water season ranging from a few hundred to over 1000. In addition, observers report that individual seals are often sighted near a given structure for extended periods (e.g., 24 hours). However, it is not known if these sightings represent all age and sex classes of seals or are more representative of one group such as subadults. It was agreed by the discussion group that although Link 1 is probably valid, the available evidence suggests that the extent of exclusion would be inconsequential and in most instances limited to the physical extent of the structure/island.

Link 2: Marine traffic (ships, dredges, seismic vessels, etc.) will exclude ringed and bearded seals from available habitat.

There are no empirical data which can be used to determine if seals are excluded from a zone around ship tracks, although theoretically such exclusions could occur. On the basis of many anecdotal observations of seals near offshore structures and vessels, the consensus of the discussion group was that exclusion of seals from available habitat would be localized and probably of short duration. Consequently, exclusion of seals from available habitat was not considered significant for the present levels of industry activity in the Beaufort.

A more serious concern is that the combination of all industry activities in the Beaufort during peak/high development periods may exclude seals from a much larger area. However, even a large scale exclusion was considered unlikely given (1) the present lack of small scale responses, and (2) the responses of other seal populations in industrialized areas (see Richardson et al. 1983).

An additional concern relates to the potential for exclusion of seals from habitats affected by icebreakers. In landfast ice areas, icebreaker traffic is expected to be restricted to relatively narrow corridors extending offshore from ports in McKinley Bay and along the Yukon coast. Consequently, assuming adherence to these corridors, the proportion of available landfast ice habitat that could be affected by icebreaking would be small (see Hypothesis No. 4). Icebreaking in the transition zone will have only temporary and localized effects on this dynamic habitat, and therefore permanent exclusion of seals from this area is unlikely.

Seismic exploration activity is of particular concern because of the intensity of noise which emanates from active seismic vessels, although it is not known how seals respond to this source of disturbance. However, seismic exploration in open water areas tends to be relatively short-term (a few weeks) in any particular area and does not occur in the same area every year. As a result, any habitat exclusion that did occur would be short-term and irregular. The consequences would likely be regionally insignificant, since food is probably not a limiting factor during summer and adjacent unaffected habitats could be used for feeding.

On-ice seismic programs which are conducted in winter could affect ringed seals, although the majority of this activity takes place on ice over waters < 3 m deep, and therefore too shallow to support overwintering ringed seals. Preliminary studies of the effects of on-ice seismic activity in Alaska on ringed seals suggest that habitat exclusion is extremely localized and unlikely to affect seal populations (Burns and Kelly 1982).

Overall, it was concluded that marine vessel traffic and seismic activity would exclude seals from little of the available habitat.

Link 3: Each passage of a ship or other marine vessel will reduce the feeding time available to ringed and bearded seals.

Although this link is undoubtedly valid since some seals will have to take action to avoid ships, the important consideration is whether or not their behaviour would be altered for periods long enough to affect energy intake. The anecdotal observations of seal behaviour near vessels and structures described earlier indicate that long-term interruptions to feeding do not occur, and energy intake is probably not affected.

Link 4: Each passage by a vessel will increase the energy expenditure of seals because of avoidance behaviour.

This link was also considered valid for both ringed and bearded seals, although again the important consideration is whether the increased costs would be sufficient to affect the overall energy balance of affected individuals. The general conclusion of the group was that since seals do not usually react markedly to industrial activities, the overall energetic costs of avoidance behaviour are likely to be small and probably inconsequential. An exception to this general conclusion might exist in localized areas during the late winter and spring of 'heavy' ice years.

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

The amount of food available to seals is, in general, a function of the amount of available habitat. As discussed in relation to previous linkages of this hypothesis, the amount of ringed seal habitat which would be excluded is small, and therefore signficiant reductions in energy intake are not likely to occur. Bearded seals feed primarily in benthic habitats, and their prey may be patchily distributed in suitable water depths. Consequently, the potential for exclusion of bearded seals from available habitat and therefore food would be greater than for ringed seals which feed in the water column.

Concerns relating to the potential effects of large scale dredging operations on benthic food resources available to bearded seals have been identified. However, natural scouring of the seafloor by ice is extensive in waters less than 50 m deep, and dredging associated with offshore development will affect a comparatively small proportion of the available habitat. For example, the spatial extent of seafloor removal due to dredging has been estimated to be no more than 6.3 $km^2$ annually. Consequently, dredging is not likely to significantly reduce the amount of food available to bearded seals.

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

This link is self-evident and valid. The previous discussions indicate that neither food availability through habitat exclusion nor available feeding time will be significantly affected by offshore development. Therefore, significant reductions in energy intake of seals are unlikely to occur.

Link 7: Noise from aircraft overflights will disturb hauled-out seals and lead to increased energy costs.

Hauled-out seals occasionally dive in response to overflights by low-flying aircraft. M. Kingsley (pers. comm.) estimated that 25 to 40 percent of hauled-out ringed seals dive when overflown by fixed-winged aircraft at altitudes of 90 to 150 m. The percentage of ringed seals in birth lairs that dive in response to overflights is not known, although the proportion is probably lower than for hauled-out seals since noise levels within lairs would be muted and no visual cues are associated with the noise.

The biological significance of repeated immersion during pupping or haul-out is not known. Seals are in an overall negative energy balance condition during the late spring, and there could be thermal consequences associated with repeated immersions during the moult. Seals repeatedly overflown could (1) vacate affected areas or (2) habituate to disturbances and not dive when an aircraft approaches, although the extent to which either of these responses would occur is unknown.

The reactions of individual seals to repeated overflights have not been directly studied. However, Finley (1976) indirectly examined the possibility that seals would vacate an area which was repeatedly overflown. A 17-km aerial survey transect over landfast ice in Resolute Passage was flown 31 times during the period from June 4 to July 8, 1975. There was no overall decline in the densities of ringed seals on the transect throughout the study period, and therefore, no evidence to suggest that ringed seals had vacated the area.

The discussion group suggested that the energetic costs to seals associated with diving in response to aircraft could be minimized by restricting overflights to a minimal number of well-defined flight corridors, and maintaining prescribed flight altitudes when weather permits. It was concluded that the energetic costs to affected individuals associated with diving in response to aircraft would be insignificant in a regional context.

<u>Link 8</u>: Energy intake and costs determine the energy balance.

This link is self-evident and valid, and a necessary precursor to Link 9.

<u>Link 9</u>: 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.

This link is valid and applies to both ringed and bearded seals. However, it was concluded that in the majority of cases, there would be no major changes to the energy balance of individual seals, and therefore populations. An exception to this may occur during the late spring of years with 'heavy' ice conditions when small changes in the natural energy balance may result in detectable effects.

## CONCLUSIONS

The group concluded that all links in the hypothesis were valid, and that the hypothesis itself was realistic. It was also concluded, however, that the cumulative effects of all links would probably be inconsequential. Most participants agreed that population effects were unlikely to occur, and the hypothesis was therefore not worth testing for either ringed seals or bearded seals. Some participants believed that effects on ringed seals were possible, but would be too hard to detect given the natural variability in Beaufort Sea ringed seal populations and the difficulty of establishing cause-effect relationships between population changes and industry activities.

## RESEARCH/MONITORING

No research or monitoring programs to address this hypothesis are recommended.

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## HYPOTHESIS NO. 4

## THE EFFECTS OF INCREASED FREQUENCY OF ICEBREAKER TRAFFIC THROUGH THE LANDFAST ICE AND THROUGH AMUNDSEN GULF ON RINGED SEAL PUP PRODUCTION

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

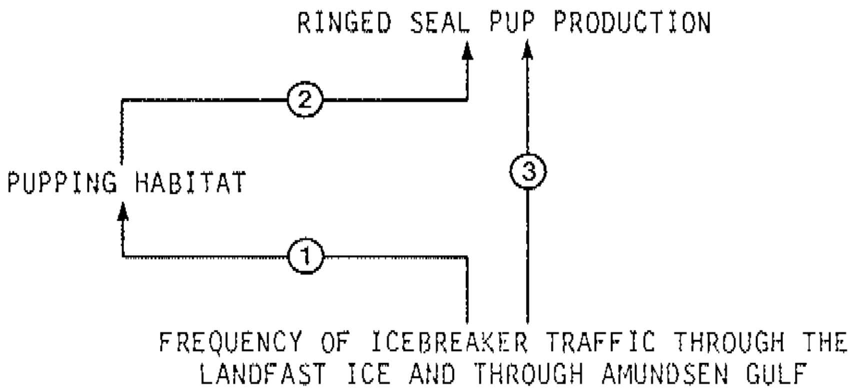


Figure 4-1 Potential effects of increased frequency of icebreaker traffic through the landfast ice and through Amundsen Gulf on ringed seal pup production.

## 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.

## NAMES OF PARTICIPANTS

Rick Hurst
Michael Kingsley
Peter McNamee
Arthur Mansfield
John Marko
Ed Pessah
Ian Stirling

## INTRODUCTION

The ringed seal is the most numerous and widely distributed marine mammal in the Canadian Arctic. It is an important element of Arctic marine ecosystems, both as a consumer and prey item. It is the primary prey of polar bears and therefore has a considerable influence on the abundance and distribution of the Beaufort Sea polar bear population. The ringed seal is also an important species in the harvests of Canadian Inuit.

Research in the Beaufort Sea has demonstrated that the location of ringed seal pupping habitat is strongly correlated with ice type (Stirling et al. 1975, 1977). Breeding seals occur in the highest densities on stable fast ice. In this habitat, females hollow birth lairs out of the snow, in the lee of pressure ridges and hummocks (McLaren 1958; Smith and Stirling 1975). In the Beaufort Sea region, stable ice areas important for ringed seal pupping occur along the west coast of Banks Island, in northern Amundsen Gulf, and in southern Prince of Wales Strait. Tankers moving between the Beaufort production zone and Parry Channel would pass through areas of high pup production in northern Amundsen Gulf and southern Prince of Wales Strait, while certain fast ice areas in the Beaufort Sea would also be traversed by icebreakers and ice-strengthened supply vessels.

There has been considerable concern regarding the potential effects of icebreaking activities on ringed seal populations. These concerns were identified during public hearings for both the Arctic Pilot Project (EARP, NEB) and the Beaufort Sea Development Project (EARP). To date, there have been no direct investigations of the effects of icebreaking on seals; only a few studies have addressed this area of potential concern and then only indirectly (Alliston 1980, 1981; Kingsley and Lunn 1983). Consequently, the lack of existing data precludes a confident assessment of the effects of icebreaking on ringed seals occupying affected fast ice areas.

Link 1: Icebreaking vessels operating in landfast ice and through Amundsen Gulf will decrease the amount of pupping habitat available to ringed seals.

Icebreaking activities could affect the amount of ringed seal pupping habitat in the following ways:

a) large scale destabilization of ice in Amundsen Gulf;

b) small scale alteration of the ice regime in a ship's path; and

c) exclusion of pupping adult females from ice in the vicinity of ship tracks due to underwater noise produced by vessels.

The following discussion addresses each of these three potential effects separately.

a) Destabilization of Ice in Amundsen Gulf

From November through to June or July, Amundsen Gulf is covered primarily by a first year ice pack. This pack includes small concentrations of multi-year ice which arise from late season influxes from the southeastern Beaufort Sea and Prince of Wales Strait. The Amundsen Gulf ice cover is usually characterized by distinct physical boundaries which correspond to transient, and sometimes long-lived, north-south trending leads. These leads generally extend between points on the coastlines of southern Banks Island and the mainland. They alternatively disappear and reappear at the same or different locations until, usually in January or later, a final seasonal edge is established separating the immobile or fast ice in the east from the relatively mobile ice to the west. Typical locations of these leads are indicated on Figure 4-2 (Smith and Rigby 1981). In most years, this boundary lead or division occurs at or to the west of a line from Cape Lambton at the southern tip of Banks Island to Cape Parry. Stable, consolidated ice conditions occur in the large proportion of Amundsen Gulf that lies to the east of this division. The stable ice corresponds to Type I ice habitat designated by Stirling et al. (1975) as prime ringed seal pupping habitat. Type I ice often occurs in the northern half of Amundsen Gulf, which is the area most likely to be traversed by icebreaking tankers. The ice to the west of the division is dynamic, and consists of temporally and spatially varying zones of thin and thick ice, detached floes and open water. This area is not likely to provide suitable habitat for successful ringed seal pupping.

Occasionally (see January 14, 1978 and February 18, 1979 on Figure 4-2), the situation described above is altered when the boundary lead extends into the extreme eastern portion of Amundsen Gulf. A more westward edge eventually formed in 1979 (Marko and Fraker 1981), but in the years 1971 (I. Stirling, pers. comm.), 1978 (Marko and Fraker 1981) and 1981 (AES 1981), the boundary lead was located in eastern Amundsen Gulf in early spring (Figure 4-3a,b). As a result, ice cover in the Gulf was unstable, and consisted of individual, mobile floes, leads, polynyas and generally prevalent stretches of open water and thin deteriorating ice.

The possibility that offshore fast ice areas may be susceptible to destabilization as a result of longitudinal passages by an icebreaking vessel has been considered by various authors (Marko 1978; Milne and Smiley 1978; Muller 1980; Martec 1982; Dickins 1983). In each study, conclusions were based on subjective evaluations of observed conditions, processes and operational

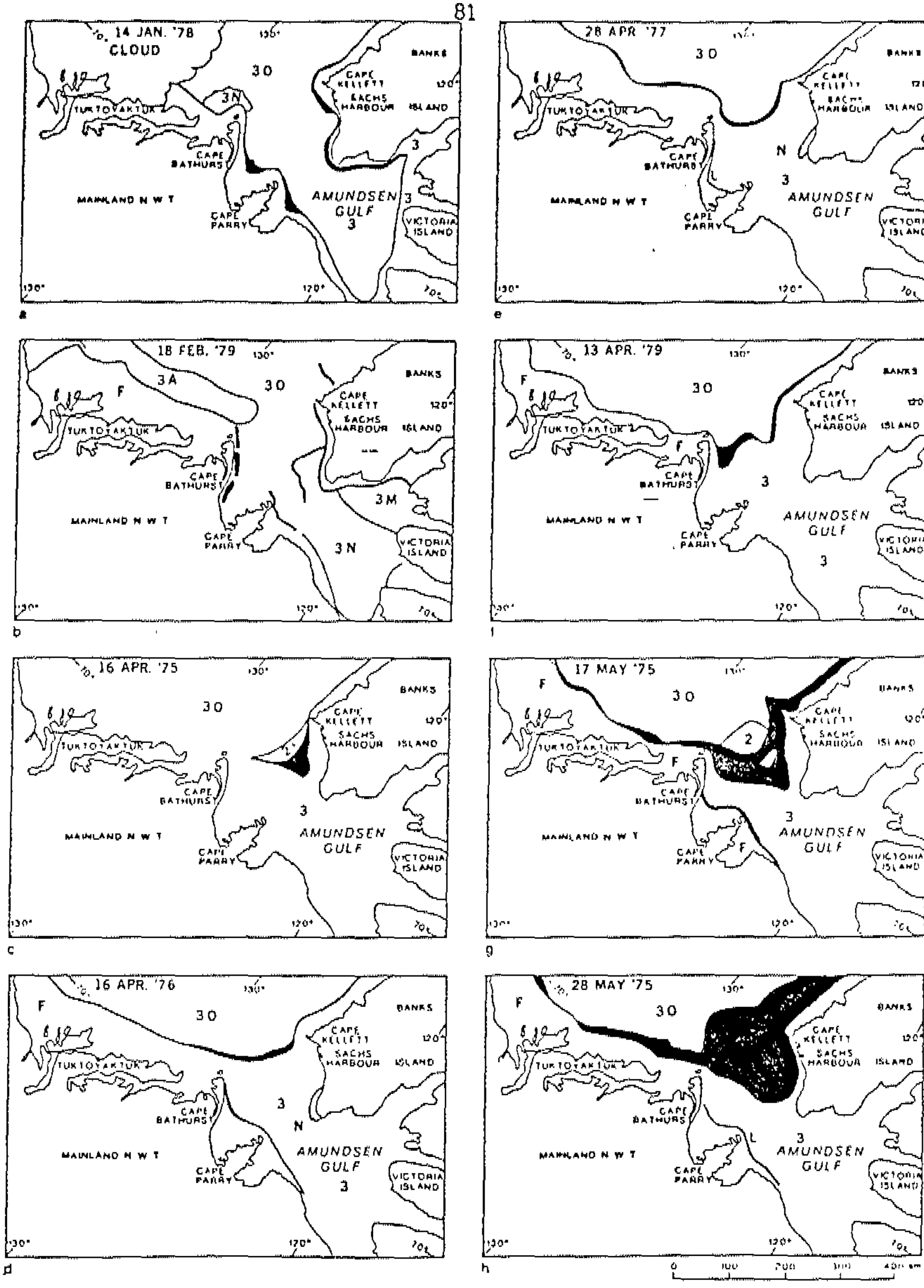


Figure 4-2: The Cape Bathurst polynya and adjoining lead systems showing the conditions during particular months and years (from Smith and Rigby 1981)

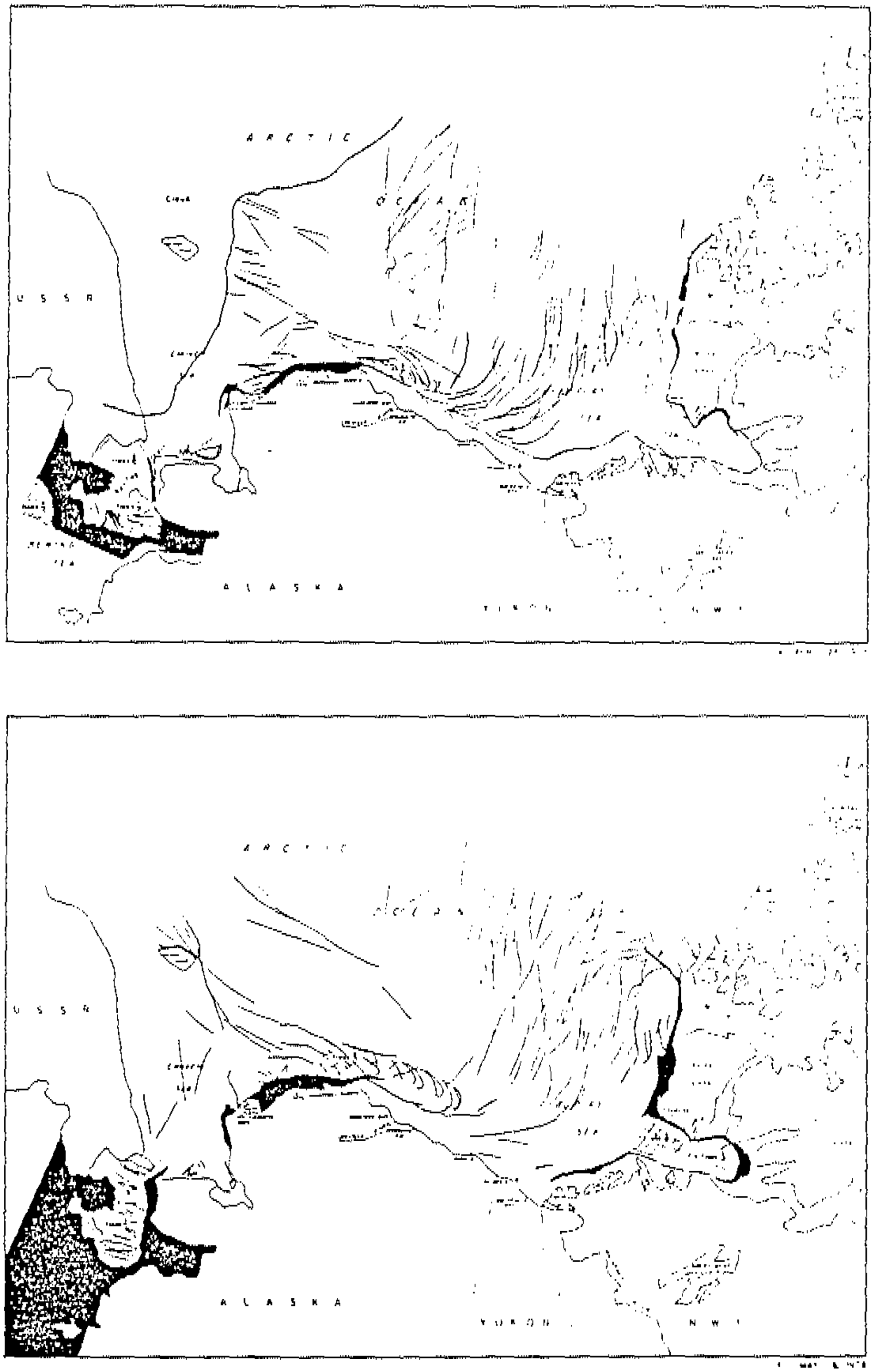


Figure 4-3: Distribution of ice and open water (or thin ice) in the western Arctic in spring, 1978 (from Marko and Fraker 1981).

marine experience. Studies were concentrated primarily in Amundsen Gulf and Lancaster Sound, since these are the locations of the two most prominent fast/mobile ice boundaries in the Canadian Arctic.

Theoretical treatments of the stability of these types of boundaries are provided in Sodhi (1977) and Pritchard et al. (1979). In the latter case, a rough derivation of plastic flow parameters was obtained from a comparison of observed southerly ice "breakouts" in Bering Strait to estimates of time dependent wind- and water-drag stresses acting on the ice cover. In this instance, internal ice forces were expected to be of lesser importance, but were suggested to be of possibly greater significance at other ice edge locations. Sodhi's treatment involved the application of models, originally derived from the movement of grain or sand through hoppers, to the macroscopic ice case. Although estimates of a cohesive strength parameter were obtained, neither this calculation or the Pritchard et al. (1979) treatment have been extended to include the presence of an externally-introduced structural flaw of the type that could be produced by an icebreaking vessel.

The behaviour of ice in Amundsen Gulf is very complex. Major features include: (1) repeated intra- and inter-annual shifts in ice edge position; (2) frequent development of complex lead structures; and (3) the unknown roles played by local ice rheology and external influences such as wind, air temperatures and current patterns. A finite probability exists that icebreaker traffic could significantly alter the extent of this ice cover in Amundsen Gulf. The alteration might be caused by (1) detachment and westward drift of ice floes adjacent to the original ice edge during icebreaker passages in the winter or spring, or (2) sufficient disruption of ice edge stabilization processes by regular icebreaker passage during early winter to allow significant westward movement of ice through the Gulf during the subsequent winter and spring months. The latter situation would lead to a major reduction in the amount of ringed seal pupping habitat.

The possibility that icebreaker traffic would destabilize landfast ice is considered remote. Icebreakers have been moving through the landfast ice between McKinley Bay and the shear zone of the Beaufort Sea since 1979. Typically, vessels have moved into the bay during freeze-up when the ice is 0.3 to 0.6 m thick, and out of the bay in mid June to early July when the thicker winter ice cover is deteriorating. However, mid winter passages have also occurred. In the winter of 1981-82, icebreakers made 26 round trips through the landfast ice opposite McKinley Bay during the months of November, December, March and June. Photographic aerial reconnaissance and satellite imagery during this period did not demonstrate any destabilization of the landfast ice regime.

At the end of May 1981, the icebreaker Kigoriak deliberately released a triangular section from the landfast ice by cutting a V-track at the ice edge. The wedge moved out to sea several days later during a period of strong southerly winds. The event, however, had no apparent effect on the natural ice regime. Large floes have calved naturally on June 14, 16 and 7 in 1979, 1981 and 1982, respectively.

b) Disruption of Pupping Habitat along Tracks of Icebreaking Ships

Icebreaking ships may cross areas of stable ice used for pupping by ringed seals. Ice in a vessel's track will undoubtedly be disrupted, but the important consideration is whether ice cover alterations are detrimental to seals. Alliston (1980) demonstrated that the numbers of seal breathing holes along winter icebreaker tracks off McKinley Bay was not different than the numbers recorded in adjacent unaffected areas, and that avoidance of habitat created in the tracks was not apparent. Since icebreaker tracks typically include broken and irregular ice, they may actually create pupping habitat by increasing the probabilities of the formation of snow drifts which could be used for birth lairs.

Even if it is assumed, as a worst case, that all icebreaker tracks are unusable by ringed seals, the overall amount of habitat affected would be small. At present, icebreaking corridors through the landfast ice extend only from McKinley Bay to the shear zone, although a further corridor through the fast-ice would be utilized in the future if a port is developed along the Yukon coast. In addition, existing and proposed corridors through landfast ice do not appear to include any areas of the Beaufort Sea that have been classified as primary ringed seal habitat (see Stirling et al. 1977, 1981).

Water depths in many of the areas affected are less than 10 m, and therefore unsuitable for ringed seals. From 1971 through 1979, thousands of kilometres of sea ice in the Beaufort were surveyed for polar bears (Stirling et al. 1975, 1982). During these studies, a reasonably accurate impression of the age and sex classes of seals taken by bears in different areas and habitat types was gained (Stirling and Archibald 1977, I. Stirling, pers. comm.). The observations suggest that landfast ice along the southern coast of the Beaufort Sea from Herschel Island to Cape Bathurst does not include primary ringed seal pupping habitat.

Rough estimates of the amount of pupping habitat potentially affected by icebreakers were calculated as follows. Shipping corridors through the fast ice from a Yukon port and McKinley Bay will be about 50 km in length. Approximately half the length of the fast-ice corridors would occur over ringed seal pupping habitat (e.g., in waters greater than 10 m deep). Assuming a corridor width of 2 km, approximately 100 $km^2$ of pupping habitat would be affected in zones 8, 2 and 4. These zones contain a total of 14,500 $km^2$, and therefore the affected area represents less than 1 percent of the combined zones.

As described earlier, however, fast ice habitats in the southern Beaufort Sea are comparatively unproductive with respect to ringed seals, while northern Amundsen Gulf and southern Prince of Wales Strait are more significant for pupping in this species. Icebreaking corridors in zones 5 and 11 are expected to be longer and somewhat wider than those described above, particularly during later stages of hydrocarbon development in the Beaufort region. Nevertheless, similar calculations of the amount of habitat affected in these areas also indicate that habitat loss would be minimal, with the exception of Prince of Wales Strait where habitat loss could approach 7 percent.

c) Effects of Underwater Noise

There have been no direct studies concerning the potential for ringed seals to avoid ice-covered areas that are characterized by industrial underwater noise. Therefore, it is not possible to predict whether pupping seals will avoid areas affected by noise. Through examination of breathing hole distribution during spring, Alliston (1980) found no evidence to suggest that seals avoided winter icebreaker tracks in areas offshore of McKinley Bay. Kingsley and Lunn (1983) examined the distribution of hauled-out seals in the Beaufort Sea during late June, and found no relationship to existing industrial activities. Although both of these studies were indirect and did not specifically examine pupping females, their results suggest that some age and sex classes of seals do not exhibit a widespread avoidance of underwater noise sources.

Link 2: Adequate pupping habitat is necessary for the production of ringed seal pups.

Preferred ringed seal pupping habitat can be characterized as stable, flat ice that is interspersed with pressure ridges that move little, if at all, following freeze-up. Ridges and hummocks that are drifted with snow are important for seal birth lairs, while snow depth between the pressure ridges is apparently not a critical factor. Stirling et al. (1975) termed the above as Type 1 ice, and report that prime ringed seal pupping habitat includes

Type 1 ice over water depths of at least 10 m. In the western Arctic, productive Type 1 habitat occurs in northwestern Amundsen Gulf, southern Prince of Wales Strait, and along the west coast of Banks Island. It is not known whether the amount of pupping habitat limits the production of pups by the seal population. The amount of pupping habitat is likely to be relatively constant on a year-to-year basis, with the exception of the larger variability associated with those years (i.e., 1971, 1978 and 1981) in which the fast ice zones of the northwestern Amundsen Gulf undergo winter break-up and destabilization (Marko and Fraker 1981; J. Marko, pers. comm.). The effect of this break-up on pup production or survival is not known.

Link 3 Icebreaker traffic in late March, April and May will kill ringed seal pups.

Although studies to examine ringed seal pups in lairs directly affected by icebreakers have not been conducted, there is concern that newborn and very young pups would be unable to avoid vessels and would subsequently die through crushing or exposure. The age when pups would be able to effectively avoid a vessel is unknown, although it would probably be no sooner than two or three weeks of age.

Densities of pupping ringed seals are low (< 1 or 2 $km^2$), and only small numbers of individuals would actually occur within a ship track during the few weeks when pups are vulnerable. Consequently, the proportion of pups at risk in any one year would be small; probably less than 1 percent of the total pups in the region. Loss of this proportion of pups would probably be inconsequential to the population, given the relatively high rates of natural mortality in the first year of life.

## CONCLUSIONS

Small scale alterations to the ice regime in a ship's path (Link 1b), and noise-related exclusion of pupping females from the vicinity of tracks (Link 1c) were both considered possible. However, the potential effects on ringed seal pup production were not expected to be regionally significant or worthy of further investigation. Similiarly, the regional impacts of direct pup mortality resulting from icebreaker traffic in April and May were expected to be insignificant at the population level.

On the other hand, large-scale destabilization of the Amundsen Gulf ice cover due to icebreaking activities (Link 1a) could be an area of significant concern, although present evidence for this link is largely circumstantial. It is recommended that further research regarding the potential for large-scale ice destabilization processes in Amundsen Gulf be undertaken to determine both the requirement for and suitable design of any monitoring programs.

## RESEARCH

Analysis of ringed seal samples collected by T.G. Smith (DFO) near Holman Island between 1971 and 1982 is planned for 1984. These analyses should indicate any significant variability in population parameters that may have occurred during that period (i.e., age-specific reproductive rates and mortality rates), and findings can be subsequently related to years of ice destabilization in Amundsen Gulf (i.e., 1971 and 1978).

If analysis of these data indicates that pup production is sensitive to variations in the ice regime, further ice stability research may be warranted. This research could include modification and direction of existing theories of ice strength and structure, and investigation of two-dimensional ice strain involving use of NOAA, Landsat and SLAR imagery. If these data indicate a requirement for higher resolution information, time series strain measurements in critical areas and deployment of sea bottom-mounted acoustic tracking arrays in conjunction with on-ice transponders could be considered. An examination of recent historical data may also be required. Emphasis during these studies should be placed on documenting: strain histories for comparisons with wind and possibly current measurement records; and the observed sequences of lead-forming and ice movement events.

## MONITORING

Uncertainties related to the potential for destabilization of the ice regime in Amundsen Gulf and potential impacts of this destabilization on ringed seal pup production are considered adequate justification for a monitoring program. Monitoring could include routine aerial photography of icebreaking activity in Amundsen Gulf, and analysis of the data collected (depending on the results of the previously described research) in conjunction with wind and large scale ice movement data. This monitoring program would provide further information on the probabilities and mechanisms of fast ice destabilization.

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# HYPOTHESIS NO. 5

## THE EFFECTS OF ICEBREAKER TRAFFIC IN THE TRANSITION (SHEAR) ZONE ON BEARDED SEAL PUP PRODUCTION

Icebreaker traffic in the transition (shear) zone will reduce bearded seal pup production

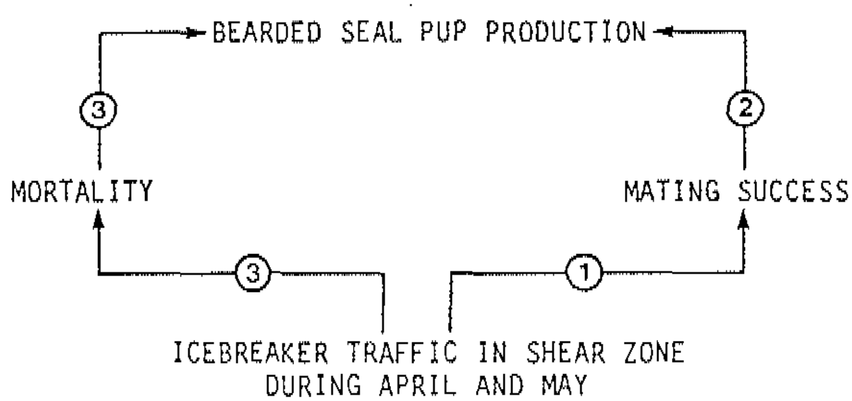


Figure 5-1: Potential effects of icebreaker traffic in the shear zone on bearded seal pup production

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 within the shear zone during April and May will result in mortality of bearded seal pups.

## NAMES OF PARTICIPANTS

Rick Hurst
Michael Kingsley
Peter McNamee
Arthur Mansfield
John Marko
Ed Pessah
Ian Stirling

## INTRODUCTION

Bearded seals are largely solitary animals which are usually widely dispersed and not known to occur in large aggregations in any habitat. They tend to avoid fast ice, but can be relatively common in certain types of pack ice and in the transition or shear zone (Burns and Frost 1979; Stirling et al. 1982). The size of the Bering Sea-Chukchi Sea population of bearded seals has been estimated at 300,000 to 450,000 (Braham et al. 1977). However, the Beaufort Sea provides much less favourable habitat than more westerly portions of the range of this population (Burns and Frost 1979). For example, aerial surveys of hauled out bearded seals in the Canadian Beaufort over a 6-year period have resulted in estimates of 2200 to 8300 individuals (Stirling et al. 1982). These estimates are not corrected for seals under the ice at the time of the surveys and therefore represent minimum numbers present in the area (Stirling et al. 1982; I. Stirling, pers. comm.). In general, past surveys indicate that there is approximately one bearded seal for every 20 ringed seals in the Canadian Beaufort.

Although not as important as the ringed seal to the native harvest, the bearded seal is used for domestic leather products. In addition, it is also preyed upon to some extent by polar bears (Stirling and Archibald 1977; Smith 1980). The bearded seal only represents a small proportion of the total seal kill by bears (i.e., on the order of one bearded seal for every 10 to 20 ringed seals -- Stirling and Archibald 1977; I. Stirling, pers. comm.), but may be important because of its large size and energetic value.

Bearded seals give birth to a single precocious pup on moving ice in late April or early May (Burns and Frost 1979). The preferred pupping habitat of this species is the shear zone, which is also the location of existing and proposed shipping corridors in the Beaufort Sea. Therefore, there is some concern that ship traffic will affect bearded seal production either directly, by crushing the pups, or indirectly, by reducing mating success and subsequent pup production (Figure 5-1).

## LINKAGES

Link 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.

Bearded seals (especially males) are highly vocal, particularly during the breeding season (Ray *et al*. 1969; Stirling *et al*. 1983). The calls are audible under some circumstances for more than 40 km, and may serve to attract female seals and exclude other males from underwater territories. During workshop discussions, it was suggested that disturbance could reduce vocalization rates and/or that ship noise could completely mask calls. Either of these reductions in communication could lead to reduced mating success and pregnancy rates. However, there has been little research on the behaviour of bearded seals, and there is essentially no evidence available to support or reject this link in the hypothesis.

Link 2: Successful mating is necessary for production of bearded seal pups.

This link is both self-evident and valid. Pup production is a function of the pregnancy rate which averages about 85 percent (Burns and Frost 1979; Smith 1981). However, there are almost no data on the extent of natural variability in pregnancy rates between years or between areas.

Link 3: Icebreaker traffic within the shear zone during April and May will result in mortality of bearded seal pups.

As indicated earlier, the shear zone is the preferred pupping habitat of bearded seals (Stirling *et al*. 1982), and will also be the preferred corridor for some shipping activity associated with hydrocarbon development in the Beaufort region. There is some limited anecdotal evidence of direct mortality of other species of seals due to icebreaking activities, although mortality of bearded seal pups or their mothers has not been documented to date. However, the workshop participants agreed that some degree of mortality would be expected within the region, particularly during the period of maximum vulnerability of seal pups, which is assumed to be 2 or 3 days after birth.

Pupping habitat available to bearded seals in the transition zone (spatial units 3 and 9) is approximately 34,000 $km^2$. It is reasonable to assume that the pupping females are relatively uniformly distributed throughout this habitat (Stirling *et al*. 1982). Pupping is also assumed to be fairly synchronous in the area, and as a result, the period when vulnerable pups are present on the ice is likely to be fairly short -- perhaps 2 to 3 weeks. Although it is not possible to predict how much icebreaker traffic would occur during this period, the combined width of the tracks from all passages is likely to be less than 1 km. To derive a very conservative estimate of the degree of mortality which could result from icebreaker traffic, it was assumed that all pups in a corridor 1 km wide and over a distance of 360 km would be killed. The latter number is the distance along the ice edge between Stokes Point and McKinley Bay. Therefore, only about one percent (360/34,000) of the available habitat would be affected by icebreaking activities, and only about one percent of the bearded seal pups would be at risk. Observed densities of bearded seals in this area range from 1 to 5 animals per 100 $km^2$ although not all of these seals are pupping females. However, individuals that are beneath the ice are not included in the above estimates. Thus, if the above assumptions are reasonable, it is considered likely that direct mortality of bearded seal pups due to icebreaking would amount to fewer than 20 individuals per year.

## CONCLUSIONS

At present, the level of understanding regarding bearded seal vocalizations and their importance in determination of mating success and pup production is inadequate either to accept or reject Link 1 in this hypothesis. More detailed information on bearded seal vocalizations and behaviour would be useful for prediction and interpretation of the potential effects of icebreaker traffic. However, given the limited understanding and difficulty in precisely measuring reproductive success, it is considered unlikely that industry-related effects on pup production would be detectable.

Although icebreaker traffic will probably result in direct mortality of some bearded seal pups (Link 3), such losses are expected to be insignificant to the population.

## RESEARCH

The hypothesis linkage that ship disturbance will lead to a reduction in bearded seal vocalization rates could be tested through a series of underwater recordings of seal calls. It would be necessary to establish a baseline for vocalization rates in both a control area and an area which would be exposed subsequently to icebreaker traffic. Use of a computerized array of hydrophones would be necessary to determine the location of individual seals and the numbers in each area. Recordings of bearded seal vocalization rates in both the control and disturbed area would be required before, during and after the disturbance period. A problem with this research program is that ship noise may mask seal calls, and thereby make it impossible to determine if vocalization rates change.

Even if the above experiments did demonstrate a reduction in vocalization rates, this does not necessarily mean that such effects would lead to reduced mating success and pup production. To evaluate this question samples of adult female bearded seals would have to be collected in a disturbed area and in an undisturbed control area. Relatively large samples would have to be collected to assure statistically reliable results. This type of research would involve the combined determination of the presence of a corpus luteum to indicate ovulation and the presence of a fertilized egg. The latter is difficult to determine because of the delayed implantation that occurs in seals.

It was also considered possible that the sampling program necessary to address the potential for reductions in pup production due to icebreaking would have a greater impact on the population than would this form of industrial disturbance. Therefore, the working group concluded that although a research program directed at bearded seal vocalizations could offer some relevant information, this research is not a high priority.

## MONITORING

A monitoring program to determine the impacts of icebreaker and tanker traffic in the transition zone on bearded seal pup production was not considered justifiable or practical.

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# HYPOTHESIS NO. 6

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

Icebreaker traffic in Amundsen Gulf will affect the ringed seal and polar bear populations.

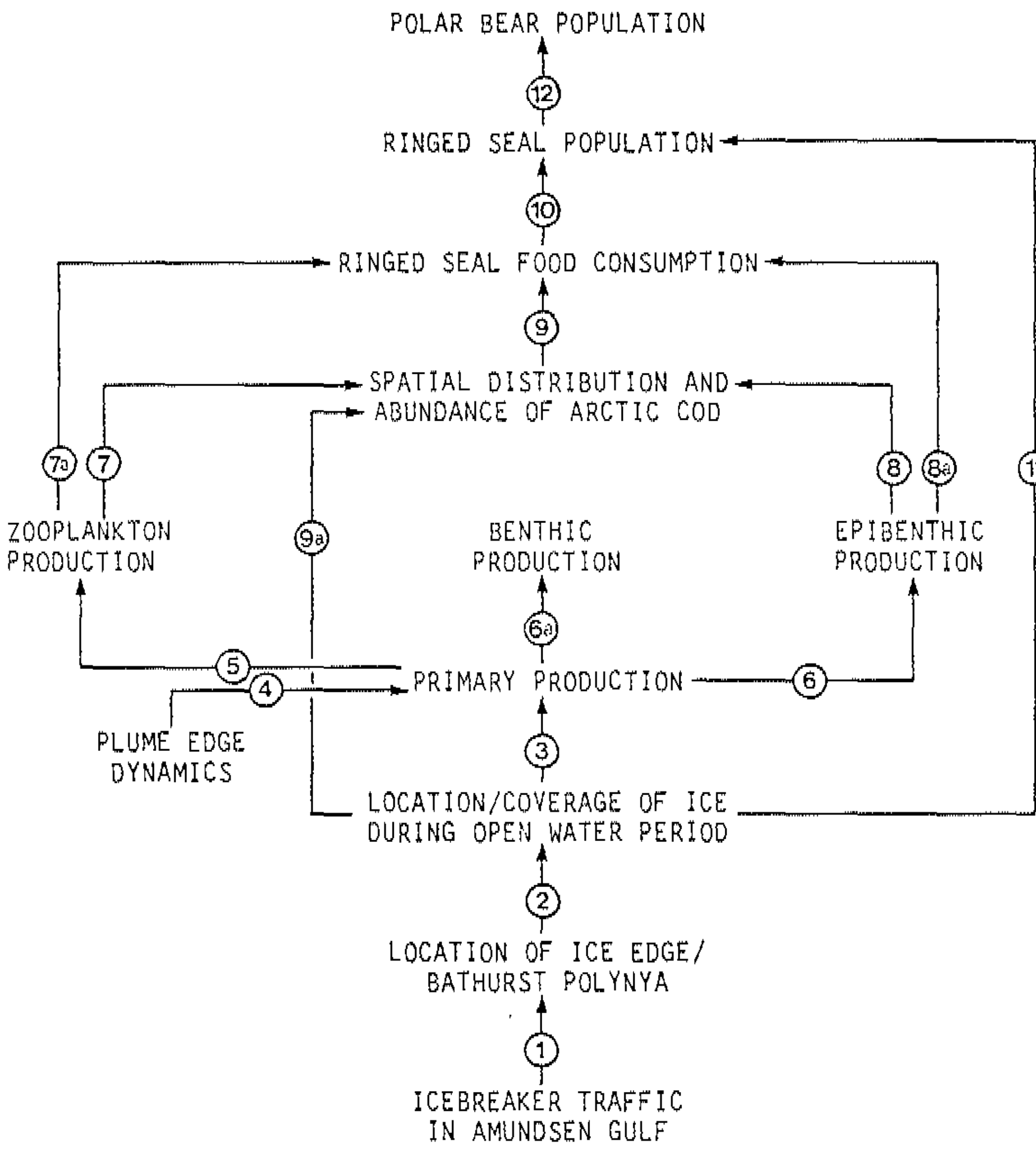


Figure 6-1: Potential effects of icebreaker traffic in Amundsen Gulf on the ringed seal and polar bear populations.

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 determines 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.

7a, 8a and 9. Spatial and temporal patterns in the abundance and distribution of Arctic Cod, epibenthos and zooplankton determine ringed seal food consumption.

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.

## NAMES OF PARTICIPANTS

| | | |
|---|---|---|
| Max Dunbar | John Marko | Ian Stirling |
| Dave Fissel | Dave Mackas | Don Schell |
| John Harper | Humfrey Melling | Ray Schweinsburg |
| Rick Hurst | Serge Metikosh | Aaron Sekerak |
| John McDonald | Langley Muir | Tim Webb |
| Peter McNamee | Ed Pessah | |

## INTRODUCTION

The hydrocarbon development scenario for the Beaufort Sea includes a transportation option for year-round tanker-icebreaker traffic from the production area through Amundsen Gulf and into Prince of Wales Strait (Dome Petroleum Limited et al. 1982, Vol. 2). During early production, two tankers would be operating, and this would result in four passages through Amundsen Gulf every month. In the later stages of the development, the number of tankers is expected to increase incrementally as the level of oil production gradually increases to approximately 1.2 million BOPD. The maximum number of icebreaker tankers in the current development scenario is twenty-four (Dome Petroleum Limited et al. 1982, Vol. 2), and therefore the number of icebreaker passes through Amundsen Gulf will increase to approximately 50 per month during peak production.

Hypothesis 6 states that icebreaker traffic in Amundsen Gulf will affect the polar bear population. As illustrated in Figure 6-1, the mechanisms for this area of potential impact are through 1) indirect food web-related effects and 2) direct alterations in ice type, coverage or location. The following material discusses the evidence for and against each of the linkages associated with this hypothesis, as well as various uncertainties identified during the discussions of workshop participants. This information is then used to form the basis of recommendations related to possible research/monitoring requirements and strategies.

## LINKAGES

Link 1: Icebreaker traffic in Amundsen Gulf will move the stable ice edge to the east (and alter the Bathurst polynya) in winter and spring.

Link 2: Movement of the stable ice edge may in turn change the total amount of open water in the region.

During the winter, distinct boundaries appear in the Amundsen Gulf ice cover that correspond to temporary, north-south oriented leads which connect specific points on southern Banks Island and northern N.W.T. coastlines. These boundaries alternatively disappear and re-appear at the same or different locations until January or later when, in most years, a final seasonal ice-edge is established that separates immobile or fast ice in the eastern Gulf from relatively mobile ice to the west (see Hypothesis No. 4, Link 1). Under appropriate wind conditions, the mobile ice moves away from the fast ice boundary, producing an area of open water which is commonly referred to as the Cape Bathurst Polynya. This polynya is by far the largest in the western Arctic; variability in the spatial extent of the Cape Bathurst Polynya during various years is shown in Figure 6-2.

Marko and Fraker (1981) analysed observations dating back to 1973, and suggested that the final seasonal fast ice boundary tends to occur along two basic curvilinear lines, roughly linking Cape Bathurst to Cape Kellett and/or to the southern tip of Banks Island. In two of the years of observation, 1978 and 1981, this boundary formed far to the east of its normal locations, precluding the existence of fast ice and the polynya in the western Gulf as shown in Figure 6-3. An opposite extreme in ice behaviour was observed in 1974 when consistent westerly and northwesterly winds caused the spring ice edge to form well to the west of the western entrance to Amundsen Gulf. This resulted in maintenance of a fast ice cover in all portions of the Gulf, and also prevented occurrence of the polynya in its normal spring location. Thus, there is great natural variability in location and extent of what is broadly known as the Bathurst Polynya.

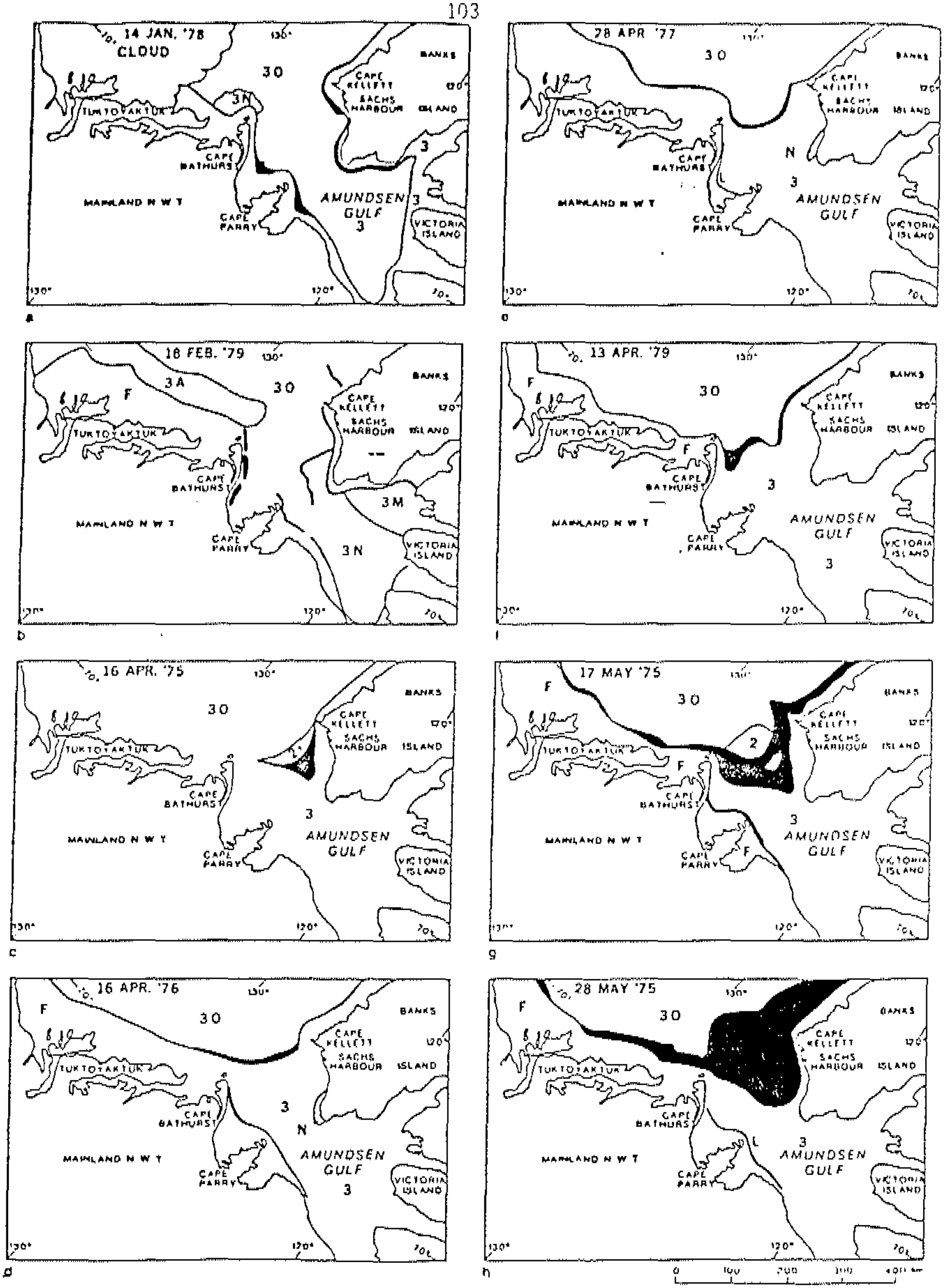


Figure 6-2: The Cape Bathurst polynya and adjoining lead systems showing the conditions during particular months and years (from Smith and Rigby 1981)

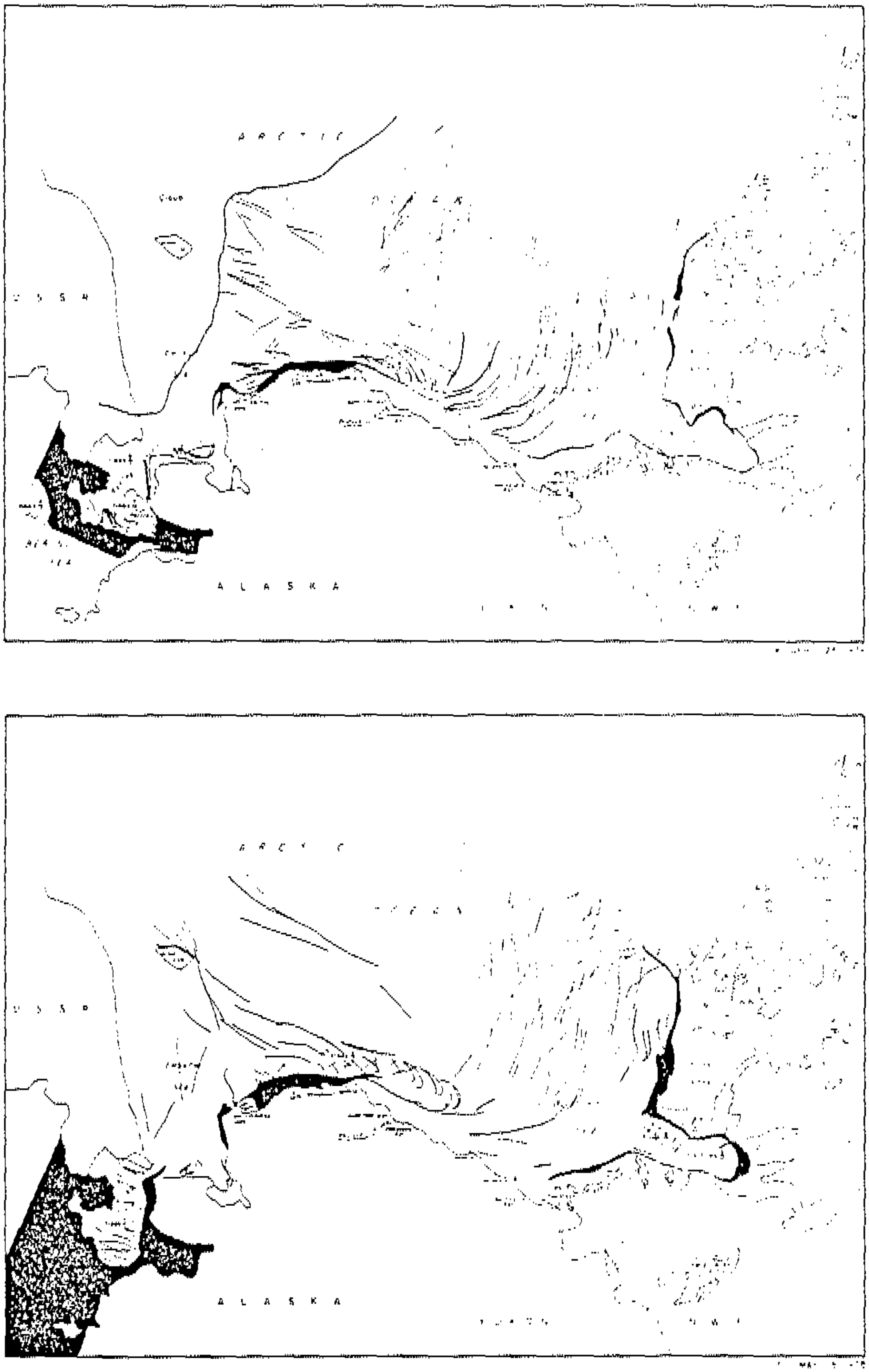


Figure 6-3: 1978 Spring ice and open water thin ice configurations in the western Arctic (Marko and Fraker 1981).

In the presence of an ice edge, the size of the polynya, in terms of the extent of open water and thin ice, is largely determined by the opening and closing effects of easterly and westerly wind fields (Marko and Fraker 1981). In most years, the predominance of easterly winds in spring produces a vast polynya area which is usually physically connected to similarly generated, but smaller, open-water bodies off the Tuktoyaktuk Peninsula and western Banks Island. The relatively high absorption of solar energy (low albedo) in open water areas leads to elevation of local water temperatures and enhances melting during the spring season. Wind-driven and other forms of upwelling, as described by Dunbar (1981) and Roed and O'Brien (1983), are believed to be active in the polynya, and increase the nutrient content of the upper water column. The latter phenomena are more fully discussed in subsequent material.

By late May or June, the combination of wind forcing and absorption of solar radiation by the sea ice and low albedo open water areas, begins to break up the adjacent fast ice. The clearing of this ice proceeds to the west, and commonly results in the formation of successively more easterly fast ice edges until the entire Amundsen Gulf pack is mobile and generally moving in a westerly direction toward the Beaufort Sea (Lemon et al. 1981). In this late spring and summer period, the Bathurst Polynya effectively ceases to exist as a recognizable entity.

More detailed information and a discussion of uncertainties related to Links 1 and 2 are presented for the following three phenomena in subsequent sections:

(a) The direct, local impact of icebreakers on the consolidated sea-ice.

(b) The physical processes involved in the stabilization of the consolidated ice edge across Amundsen Gulf.

(c) The possible role of vertical mixing that is driven through salt extruded during the formation of sea-ice, in the uptake of warmer, nutrient-rich deeper waters into the photic zone.

## Local Effects of Icebreaker Passage Through Floating Fast-Ice Fields

Icebreaker tracks are generally filled with brash ice following vessel passage (Dome Petroleum Limited et al. 1982, Vol. 4), and with time, the interstitial water between the blocks freezes. However, this refreezing process is slow due to the low thermal diffusivity of sea ice and, although the brash ice is thicker than surrounding unbroken ice, it remains weaker than the surrounding ice for periods of up to several weeks. This fact is reflected in the intention to reuse broken tracks for subsequent ship passages, rather than to break new tracks (Dome Petroleum, BEARP Hearings, Inuvik, Nov. 1983) and in work carried out by the United States Coast Guard (Greisman 1982). In contradiction to this, a workshop participant remarked that Canadian Coast Guard and Finnish icebreakers never reuse tracks because of greater resistance encountered therein. This apparent disparity may be explained by age of the track, although specific data are not readily available. As a working conclusion, it was assumed that the brash ice in a ship's track would be weaker in tension-compressions and shear than the surrounding ice for a period in excess of one day. If, after some weeks, the brash freezes to the degree that it is stronger than the surrounding ice, the overall strengthening of the regional ice field will be negligible because of the small area of track.

Class 3 icebreakers operating through the fast ice edge in Lancaster Sound during late spring have resulted in the release of small ($< 1$ km$^2$) ice floes (APP 1979; Dave Fissel, pers. comm.). Given the similar ice-edge situation in Amundsen Gulf, floes of at least comparable size might be released at the edge of the Bathurst Polynya during the transit of large icebreaking tankers. However, these floes would have an insignificant effect on the polynya since they are small in size compared to the polynya (tens of thousands km$^2$). Breakoff of these floes may be related to the existence of flaws in the ice sheet prior to vessel passage, or may be the consequence of cracks produced in the ice sheet by vessel passage. There is evidence for rapid and long-distance (hundreds of kilometres) propagation of cracks in sea ice subject to large local stresses (Milne 1972; Mukherji 1973; Marko and Thomson, 1977). These cracks release potential energy stored in thermally -and mechanically-induced tension-compressions. It should be noted that energy dissipated by tankers operating in ice is in the same order of magnitude as that dissipated by natural forces acting on large sea ice fields. For example, if an ice field the size of Amundsen Gulf (200 km x 400 km) is acted upon by a wind stress of 0.1 $N/m^2$ (10 m/s wind) causing drift at a speed of 0.1 m/s, the rate of energy dissipation is 800 MW. Icebreaking tankers could dissipate energy at a rate of about 100 MW (Dome Petroleum Limited et al. 1982, Vol 2). Therefore, although icebreaking tankers and their tracks are small in contrast to the size of Amundsen Gulf, their significance in terms of energy contribution is not. Note, however, that most of the energy lost by the icebreaker is likely dissipated over a relatively small portion of the total area of the Gulf (i.e., in the vicinity of the ship track), while the wind energy is applied to the entire surface area of unconsolidated ice. Furthermore, icebreaker energy dissipation would occur only for approximately 0.5 days/week during early production, while the wind forcing would be much more frequent.

## Large Scale Ice Edge Stabilization

Since the ice edge stabilization process(es) controls the location of the Bathurst Polynya, alterations to it and system equilibrium following icebreaker operations might change the position and characteristics (i.e. extent) of this important body of open water and thin-ice covered surfaces. Although there are at least two theoretical treatments of ice edge stability in straits (Sodhi 1977; Pritchard et al. 1979), there is not an adequate basis for (1) evaluation of the details of stabilization processes, or (2) assessment of modifications to these processes which may result from icebreaking tanker operations in ice fields.

Satellite imagery provides the major source of information concerning natural variation in the location of the ice fronts, and the spatial extent of the associated polynyas in the Beaufort Sea (see Marko and Fraker 1981). Some of the more significant features observed are:

1) The position of the pack ice west of Amundsen Gulf ultimately controls polynya formation; in years such as 1974, when the pack ice moved to the south and east (i.e., shoreward), the polynya did not develop;

2) The ice front may occur in different locations at various times during any given year, and large year to year variations have been recorded in its final (spring) stabilization position. In general, however, there appear to be about three "favoured" locations for ice front formation; and

3) The ice front may collapse or never become fully established. This situation apparently arises approximately one year in five, leading to a displacement of the polynya into the eastern end of Amundsen Gulf.

Although the above observations do not document the dynamics of ice-front formation or stabilization, they provide evidence for the marked spatial and temporal variability that characterizes ice-front formation. Two conflicting interpretations with respect to ice edge stabilization are suggested:

1) The processes involved in ice front formation are sufficiently delicate (as evidenced by sudden and drastic shifts in position and form) to allow disruption and specifically, destabilization during transit of an icebreaking vessel; or

2) The observed dramatic shifts in ice edge position and form are evidence for the causative influence of overwhelmingly large natural energy inputs associated with wind, water currents and internal ice forces applied to the entire surface area of the Gulf. The impacts of individual operating icebreakers are therefore considered inconsequential in comparison to these large scale natural high-energy events.

Unfortunately, existing data and understanding of large and intermediate scale ice behaviour are not adequate to allow a choice to be made between these alternative interpretations. Therefore, a definitive evaluation of the potential impact of icebreaking tanker traffic on ice edge stability in Amundsen Gulf is not possible at this time.

Stabilization of Sea-Ice Fields Over Deep Water - Physical Analogues

The physical factors contributing to the stability of sea-ice sheets in the absence of grounded pressure keels are not adequately understood. The observation that fast-ice edges over deep water are concave (Sodhi 1977) suggests that the masonry arch may be a somewhat analagous structure. The latter derives its stability from the conversion of imposed loads into compressive stresses on the individual components of the arch. Careful shaping of these components and of the "keystone" is necessary for proper stability under load. In the absence of empirical data, the arch model forms the basis of the following discussion.

In a sea-ice field that is many tens of kilometres across, individual floes are the analogues of masonry blocks. Stability can arise within certain random configurations of floes that compose the ice sheet, as these floes drift in response to winds and currents. The variability in the date of stabilization of ice cover in Amundsen Gulf (December to March; John Marko, pers. comm.) and the complete absence of stable ice in some years (e.g., 1971, 1978 and 1981), are likely indicative of the infrequent random occurrence of stable floe configurations. An analysis of the angle of internal friction across the Amundsen Gulf ice edge in 1973 by Sodhi (1977) lends some support to the present analogy.

In taking this analogy further, the stability of floating fast-ice fields can be attributed to the existence of an arch of individual ice floes. These floes are in a configuration which converts the imposed loads on the ice sheet (due to wind and current stresses) into compressive stresses on the floes. Presumably these compressive stresses do not exceed the compressive strength of the sea ice. In theory, the passage of an icebreaking vessel through this arch will subdivide one or more of the component floes, and therefore alter the geometry of the arch. In some instances, the 'new' geometry may not be stable and the arch could collapse into the adjacent open water (e.g., the Bathurst Polynya), thereby destabilizing the ice sheet behind the arch. Under prevailing easterly winds, the ice field from Amundsen Gulf would then gradually fill the Bathurst Polynya, and a new polynya would open in eastern Amundsen Gulf.

It should be noted that, according to the above model, destabilization will only occur if (1) the icebreaker penetrates the arch in one of the specific paths which crucially alters its geometry, and (2) if strong loads (e.g., easterly winds) are imposed on the arch before it can refreeze. The chances of destabilization would increase with both the number of ship transits and the number of vessel tracks.

Vertical Mixing In Polynyas

During the workshop, a hypothesis that changes may occur in the internal processes of a polynya, depending on its location, was discussed in relation to the biological importance of the Cape Bathurst Polynya. In particular, enhanced depths of vertical mixing in polynyas through penetrative convection would be potentially significant in terms of (a) nutrient uptake for enhanced primary productivity, and (b) potential thermal uptake of warmer Atlantic water from depths greater than 250 m. If this hypothesis of deeper vertical mixing in polynyas were correct, the thermal uptake effect would not be operative in those years (e.g., 1971, 1978, 1981) in which the ice edge stabilizes in eastern Amundsen Gulf, because water depths in this area do not exceed 200 m.

Large polynyas such as the Cape Bathurst Polynya are probably formed primarily by winds (Dunbar 1981). However, a study of the North Water (Muller et al. 1980) indicated that the formation of this polynya in Smith Sound is attributed to both wind and oceanographic effects. The results of this study suggest that there must be a source of heat input from depths greater than those investigated.

Russian scientists (Kupetskii 1959, 1962; Szekielda 1974) suggest that winds maintain open-water surfaces in large polynyas, and thereby make the ice-free (or comparatively ice-free) polynyas into 'ice factories'. The production of ice in polynyas is estimated to be four to five times greater than ice production in ice-covered areas. The constant freezing of the surface and downwind movement of new ice results in a constant supply of leached-out salt from the ice, and therefore a constant supply of dense saline water. The latter sinks and is replaced with water from the warmer, deep layers. Kupetskii (1962) estimated that sinking in the North Water occurs to depths of 2000 metres. A vertical exchange of this nature would result in the transport of nutrients and heat to the surface. This phenomenon has been suggested as a possible explanation for the known productivity of Lancaster Sound, which is expected to be located downstream from the "nutrient pump" in the North Water (M.J. Dunbar, pers. comm.).

Recent oceanographic studies of relevance to the present hypothesis have been conducted in two areas adjacent to the Cape Bathurst Polynya. Two of these studies were conducted in the Canadian Beaufort Sea during November, 1979 and March-April, 1981 (Melling, 1983; H. Melling, pers. comm.), while the third was conducted from the landfast ice in Amundsen Gulf during March, 1982 (Fissel et al. 1984). These investigations suggest that the degree of stratification of the water column within the Bathurst Polynya is approximately 30 to 60 percent of that observed in the North Water Polynya. Given normal rates of ice growth and heat exchanges through the surface, deep vertical convection is probably limited to depths shallower than 100 metres

(H. Melling, pers. comm.). Therefore, some other mechanisms must provide the additional increased salinization near the surface that would be required for vertical convection to the depths where the warmer Atlantic Water occurs.

An understanding of physical processes in the Cape Bathurst polynya is necessary for the adequate assessment of the present hypothesis. To date, oceanographic studies have not been conducted in either the North Water or Cape Bathurst polynyas. Therefore, the presence of vertical mixing processes which extend to sufficient depths to induce significant uptake of heat and nutrients remains unknown.

Total Open Water Area In Amundsen Gulf

During assessment of potential impacts of icebreaker traffic on the location of the ice edge in Amundsen Gulf, it is important to recognize that under many circumstances, the total amount of open water can remain relatively unchanged despite even drastic shifts in ice edge location.

The amount of open water or thin ice in the southeastern Beaufort Sea and Amundsen Gulf is governed by the winter and spring movements of both the Beaufort Sea pack ice and the ice fields of Amundsen Gulf. For example, if a generally eastward or northeastward movement of the Beaufort Sea pack occurs during early spring, a smaller than average area of open water occurs adjacent to western Banks Island and in those areas of Amundsen Gulf generally associated with the Bathurst Polynya. If destabilization occurs in the Amundsen Gulf pack under these circumstances (approximately 1 year in every 5), open water will appear around the eastern perimeter of Amundsen Gulf and will represent a significant proportion of available open water in both the southeastern Beaufort and Amundsen Gulf. In most years when stabilization occurs at a western location and there are simultaneous easterly or southeasterly movements of the Beaufort Sea pack, relatively small amounts of open water are present in both Amundsen Gulf and the southeastern Beaufort Sea through late June and July (Marko and Fraker 1981).

The largest amounts of open water in early spring (April and May) occur in years with a combination of easterly winds (which tend to move the Beaufort Sea ice pack to the west) and when stabilization of Amundsen Gulf pack ice is at a western location. Later in the year (during June and early July), the amount of open water is not usually significantly different during years of eastern (e.g., 1971) or western (e.g., 1973) stabilization but the locations of open water frequently are quite different. During years of western stabilization of Amundsen Gulf pack ice, open water tends to be the most prevalent in the southeastern Beaufort Sea, while during years of eastern or no stabilization, most of Amundsen Gulf is free of ice in June and July but a large amount of ice (formerly from Amundsen Gulf) occupies the southeastern Beaufort Sea off the southwest corner of Banks Island.

In summary, very large natural variations occur in the total amount of open water present in Amundsen Gulf during the spring period. Destabilization of the Amundsen Gulf ice pack is an important factor in determining the open water extent and location. However, the proximity of the polar pack ice edge would also appear to be a comparable factor in establishing the overall amount of open water. A more quantitative assignment of the relative importance of these two influences may be possible through analyses of near simultaneous satellite ice cover imagery and wind records.

Link 3: The coverage and location of ice determines the level of primary productivity.

Rates of primary production in the Canadian Beaufort Sea have only been measured at a limited number of locations during the open-water season. The majority of these studies were completed between 1973 and 1975, in conjunction with the Beaufort Sea Project and were summarized by Hsiao (1976). The following general account of primary production in the region is from Hsiao (1976), while more detailed reviews of existing data are provided in Dome Petroleum et al. (1982, Vol. 3A) and LGL and ESL (1982).

> "It is difficult to designate a single factor as being a limiting one in controlling the primary productivity taking place in the waters of the southern Beaufort Sea. Such a process is controlled by a combination of factors acting at different rates throughout the successive months of the year.
>
> "Light penetration is a prime factor in this area. During the summer months it may become limiting because of ice cover or from the heavy sediment content of the water added to the system by the Mackenzie River (Grainger, 1975). Nutrient availability is not likely a limiting factor in the inshore regions. Nutrients generally exist in high concentrations in this area, continually being replenished by the Mackenzie River outflow (Grainger, 1975). Mineralization in the shallow inshore waters might add to the available organic and inorganic nutrients. However, in the far offshore regions, the nutrient content of the euphotic zone, which is separated from the deeper nutrient rich waters by a thermocline during the summer, may very quickly become depleted and thus, limiting. The higher water temperatures of the inshore regions during the summer may determine to some extent the selection of phytoplankton species. Bursa (1963) stated that individual groups of the phytoplankton community might show seasonal succession in accordance with changes in temperature."

As in all aquatic systems, primary production in the Beaufort Sea is limited ultimately by light and nutrients, depending on location and season. Consequently, unusual nutrient or light conditions such as those encountered in polynyas, or during "heavy" or "light" ice years could have significant effects of primary production. Although studies have not been initiated to examine these potential differences in primary productivity, indirect evidence of possible sources of annual variability in production is available. For example, the ice in the Beaufort Sea was thicker, more extensive and persistent in 1974 than in 1975. Tummers (1980) studied the heat budgets of the southeastern Beaufort Sea during these years, and found that (1) the maximum surface sea temperature was 0.62 C° lower in 1974 than in 1975, and (2) the -1.5°C isotherm was at a maximum depth of 15 m in 1974 compared to 50 m in 1975. The reduced water temperature and probable shallower photic zone due to severe ice conditions and higher levels of turbidity due to ice damming in 1974 may not only have resulted in abnormally low primary production during this year, but also could have been reflected in higher trophic levels in the Beaufort Sea.

Productivity may be increased in polynyas early during the spring. The magnitude of such increases would likely depend on the surface area of the polynya, the simultaneous occurrence of light intensities suitable for phytoplankton growth and production and the residence time of water within the polynya. The factors supporting this hypothesis are:

1) the angle of incidence of light in late April would allow light penetration to depths of 30 to 40 m if open water is present;

2) primary production usually does not increase significantly until the water column becomes stable (typically June), but within larger polynyas, enhanced stratification earlier in the spring could result in relatively high production in late May.

It should also be emphasized that any differential enhanced production in polynyas during the spring would not be apparent after July because the ice cover would be rapidly clearing from all areas, thereby allowing increased rates of primary productivity throughout open water areas. Nevertheless, these differences in the timing or magnitude of primary production in polynyas could have disproportionately larger effects on higher trophic levels in the ecosystem.

Link 4: Primary production is enhanced (perhaps in patches) near the plume edge.

This linkage was originally included in the present hypothesis to account for dynamics occurring near the seaward edge of the Mackenzie River plume. However, its inclusion was subsequently considered inappropriate because the plume seldom reaches the Cape Bathurst Polynya. The only documented instance where the plume reached the polynya for brief periods was during the summer of 1974 when excessive nearshore pack ice contained the flow of Mackenzie River in a narrow coastal band along the Tuktoyaktuk Peninsula and as far as Amundsen Gulf. The workshop group suggested that this was a rare phenomenon, and therefore, not worthy of consideration in terms of enhanced primary production at a plume edge within Amundsen Gulf.

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

The main flow of energy in marine ecosystems such as the Beaufort Sea is through planktonic primary producers to zooplankton, epibenthos and benthos. The energetic relationships between these communities have not been studied in the Canadian Beaufort, but Campbell (1981) concluded that even in shallow nearshore locations of the Alaskan Beaufort with good (e.g., 5-10 m) light penetration, planktonic primary production was far more significant than benthic primary production, epontic primary production or heterotrophic production. It should be noted that altered production patterns may occur within the very turbid waters of the Mackenzie River plume. However, as indicated earlier, waters in Amundsen Gulf are unlikely to be influenced by the plume in the majority of years.

A major uncertainty that could be fundamental to the evaluation of food chain relationships associated with this hypothesis is the importance of timing of primary production and its apportionment to major secondary producers. For example, the timing of reproductive cycles of arctic herbivorous zooplankton (mainly copepods) are such that young are present in the water column at a time when maximum advantage can be derived from peak algal abundance (Grainger 1965). Sekerak et al. (1979), employing multivariate comparisons, found that this synchrony was a very prominent feature of the zooplankton community in Baffin Bay, while Grainger (1965) reported similar temporal relationships in the Beaufort Sea.

Another example of the probable importance of reproductive timing is that epontic (ice) algae appear to provide a source of early season production upon which some invertebrates can graze. Therefore, the most productive season of various epontic invertebrates likely begins earlier than that for either planktonic or benthic invertebrate populations. As a result, epontic productivity may be more important due to its timing than because of its magnitude (Alexander 1974; Alexander and Cooney 1979; Horner and Schrader 1982). On a seasonal basis, both benthic and epontic microalgae are probably less productive per unit area than are planktonic algae, but their location on a two-dimensional surface increases the probability of encounter by some types of grazers.

Changes in the timing of seasonal peaks in primary production could lead to increased benthic secondary production, and corresponding decreases in planktonic secondary production. For example, if herbivorous zooplankton were not abundant in the water column as a result of changes in seasonal peaks, much of the primary production may sink to the bottom (as dead algal cells) where it could then be utilized by benthic animals. This could have energetic implications, since with few exceptions, benthic organisms have not been found to be important food items for vertebrates in the Beaufort Sea, including those which are the primary focus of this hypothesis.

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

The relationships among Arctic cod, their food resources and physical environmental features have not been examined in the Canadian Beaufort Sea. The following is a summary of information available for other areas, primarily the Canadian Eastern Arctic and Alaska.

Biological Relationships

Evidence from other areas suggests that the diet of Arctic cod is largely zooplankton and epibenthos, including various epontic (ice-associated) invertebrates. For example, Bain and Sekerak (1978) reported that Arctic cod collected from small cracks in the ice near Resolute Bay, Cornwallis Island had consumed large quantities of an amphipod (*Onisimus litoralis*) which is known to be associated with the under-ice community in some areas and seasons. Later in the season, the diet of Arctic cod collected from predominantly open water areas was dominated by zooplankton (planktonic amphipods and copepods). In contrast, Bendock (1979) and Craig *et al.* (1982) reported that mysids (*Mysis litoralis* and *M. relicta*) were the most important prey organisms of Arctic cod in nearshore ice-free waters of the Beaufort Sea (Prudhoe Bay and Simpson Lagoon) in summer, while Lowry and Frost (1981) found that planktonic foods (copepods and amphipods) were the most important food items of Arctic cod in offshore waters in the Alaskan Beaufort Sea and the northeastern Chukchi Sea.

Available data suggest that Arctic cod are versatile in terms of their dietary requirements, and that their diet in the Canadian Beaufort is probably not substantially different from that observed in other regions. However, the factors controlling prey type selection, and the effects of unnatural changes in prey availability in the Canadian Beaufort Sea and other areas remain unknown. An overall decrease in zooplankton and epibenthic (including under-ice) production could presumably lead to decreased numbers and/or redistribution of Arctic cod.

It should be noted that food chain interrelationships are often complicated, and this can result in unpredictable effects when a change occurs within a given trophic level. For example, increased zooplankton production might be considered beneficial to Arctic cod. However, certain components of the zooplankton community (e.g., jelly fish, comb jellies and the amphipod Parathemisto libellula) are predatory, and are probably significant sources of mortality of Arctic cod eggs, larvae and juveniles. Therefore, while the predatory component of the zooplankton community may be a source of food for adult Arctic cod, it is simultaneously a major source of young cod mortality.

## Physical Relationships

The location and physical characteristics of ice may directly affect the distribution of Arctic cod. In Pond Inlet, Bradstreet (1982) reported that Arctic cod were notably more common in areas where the undersurface of the ice was rough and therefore, provided shelter. Few or no Arctic cod were observed by SCUBA divers in areas where the under ice surface was smooth. A considerable amount of other indirect evidence indicates that cod are sometimes associated with ice. Murdoch (1892, cited in Nelson 1975) reported that favoured fishing areas for Arctic cod in the Alaskan Beaufort were in the lee of large ice ridges where cod tended to concentrate. Visual shipboard observations also indicate that cod are sometimes relatively common in fields of pan ice. In 1978, Sekerak (pers. comm.) observed numerous small cod schools (i.e., 3-4 to 10-15 individuals) within a pan ice field in northeastern Lancaster Sound. During summer, Divoky (pers. comm.) reported that Arctic cod were relatively common in pan ice in various parts of the Beaufort and Chukchi seas, but were less common in the northern Bering Sea.

Distribution of Arctic Cod

A comprehensive sampling program for Arctic cod has not been conducted in or near the Cape Bathurst Polynya. Widespread sampling for planktonic young-of-the-year Arctic cod was completed on an intermittent basis from 1973 to 1975, and in 1977 (Hunter 1979). The results of this study indicated that young cod were widely distributed in surface waters of the Canadian Beaufort Sea, except in areas which were influenced by the Mackenzie River outflow. However, details regarding the ecology and life history of Arctic cod in the region remain unknown.

Links 7a, 8a and 9: Spatial and temporal patterns in the abundance and distribution of Arctic cod, epibenthos and zooplankton determine ringed seal food consumption.

The amount of food consumed (and energy required) by the population of ringed seals in the Beaufort Sea can be roughly estimated from metabolic studies conducted with captive seals. Parsons (1977) suggested that the average energetic requirements of captive ringed seals was approximately 600,000 kcal/seal/yr. The total population of seals in the Canadian Beaufort must consume several hundred thousand metric tonnes of prey annually to satisfy this average energy requirement.

Ringed seals feed on fish and crustaceans. The dominant prey organisms include gammarid and hyperiid amphipods, mysids, euphausiids and fish (principally Arctic cod). The diet of ringed seals is known to vary considerably with location and time of year (Vibe 1950, McLaren 1958, Lowry et al. 1978, Finley 1978). The most extensive analyses of ringed seal stomach contents have been completed in the Alaskan Arctic. In this region, there is considerable evidence that fish (predominantly Arctic cod) are the principal food item, particularly during the winter (Lowry et al. 1978). Similarly, Arctic cod were identified as the principal prey of ringed seals foraging over deep waters in the eastern Canadian Arctic (Bradstreet and Cross 1982) and Greenland (Vibe 1950). Pelagic crustaceans (Parathemisto, other hyperiid amphipods, euphausiids, etc.) were suggested to be the primary food of ringed seals during the summer months in the Alaskan Beaufort (Lowry et al. 1978). Although benthic decapods, epibenthic amphipods and mysids can occasionally form a significant part of the diet of seals in nearshore areas (Vibe 1950; McLaren 1958), pelagic zooplankton and fish are considered the most important prey items.

The relative importance of zooplankton and fish is difficult to assess, given the spatial and seasonal variability in the diet of ringed seals. Zooplankton may be critical as a food source at certain times of the year, even though they may be less important than Arctic cod in terms of total biomass consumed. For example, it is likely that zooplankton comprise a particularly large portion of the diet of ringed seal pups in the period immediately after weaning. This is apparently also the case for Weddell seals which occupy a similar niche in the Antarctic, and also applies to other ice-breeding phocids that are opportunistic feeders (e.g., harp seals).

Ringed seal stomach content samples have been collected from the Canadian Beaufort Sea, specifically by Dr. T.G. Smith (DFO), in conjunction with the Holman Island harvest. The study may be sufficiently comprehensive in terms of both sample size (hundreds or more) and duration (10 years) to eventually provide a substantial amount of valuable information regarding ringed seal diet. At present, however, there is virtually no published information on diet of ringed seals in the Canadian Beaufort.

Link 10: Quality and quantity of food determine ringed seal survival and mortality.

In the absence of a food surplus, reduced food availability will result in decreased prey consumption by ringed seals. If reduced food availability occurs to a significant extent in space and time, the physical condition of affected seals will deteriorate. This in turn would be reflected in reduced reproductive success and also in reduced survival, particularly in the case of subadults. In at least one documented instance, changes in ice conditions in the Beaufort Sea were correlated with decreased physical condition and reduced reproduction in ringed seals. As stated earlier in discussion of Link 3, ice conditions during the winter of 1973-74 were particularly severe, and persisted through the following summer. This appeared to result in reduced food production (or food availability) for ringed seals, since the population was in poor condition during the following year. There was a concomitant 50 percent decline in seal abundance between 1974 and 1975, and a 90 percent decline in reproductive rates over this same period (Smith and Stirling 1978; Stirling et al. 1977, 1981). Seal productivity, as measured by the proportion of young-of-the-year killed by Inuit hunters, did not return to 'normal' until 1977. Although the data for bearded seals were not as conclusive, Stirling et al. (1981) suggested that a similar decline and subsequent recovery of the Beaufort Sea population of this species occurred following severe ice conditions in 1973-74.

Link 11: Location and type of ice are important in determining ringed seal distribution.

Ringed seals are dependent on certain types of ice for haul-out, moulting, pupping, maintenance of breathing holes, and provision of habitat for prey species. Therefore, the type and distribution of ice are expected to be important factors affecting ringed seal distribution. Correlations between ice characteristics and pupping densities have been observed in the eastern Beaufort Sea (Stirling *et al*. 1981). However, several relationships between seals and the ice environment are not adequately documented and some relatively subtle differences in ice type and distribution may be of considerable importance to the regional population. For example, ringed seals may have difficulty maintaining breathing holes in heavily compacted ice, such as that which covered the Beaufort Sea extensively in 1974 (Ian Stirling pers. comm.). The observation that polar bears tracked in such areas rarely stop to dig out seal breathing holes lends support to the latter hypothesis. On the other hand, seal breathing holes in heavily compacted ice may actually be less accessible to polar bears so they do not attempt to reach the seals. There are, however, instances where bears have been observed digging out breathing holes in localized areas of rough ice or sites with deep snow, suggesting that they are able to detect seals, and attempt to reach individuals maintaining holes in extensive rough ice areas.

Link 12: Numbers of polar bears are determined by numbers of ringed seals.

Ringed seals, particularly pups, are the primary prey of polar bears in the Beaufort Sea. Consequently, when the ringed seal population in the region suddenly decreased by about 50 percent from 1974 to 1975, the reduced availability of prey was reflected in a decreased abundance of polar bears in 1975 and 1976. Reproduction and survival in the bear population did not appear to return to normal until 1977 to 1979, in conjunction with recovery of the ringed seal population (Stirling *et al*., unpublished data).

# CONCLUSION

Present knowledge does not allow a firm conclusion to be made regarding whether or not ringed seal and polar bear populations could be affected by icebreaker traffic in Amundsen Gulf through the mechanisms described in Hypothesis 6.

The hypothesis that icebreaker traffic through Amundsen Gulf will move the stable ice edge to the east was considered possible, but unlikely. However, this conclusion was reached on the basis of the very limited available information on the physical processes controlling ice edge stability in Amundsen Gulf. The impact of icebreaker traffic on the total amount of open water was expected to be less than the impact on location of the stable ice edge. The location of the consolidated ice edge in Amundsen Gulf is only one factor that determines the extent of open water; the position of the edge of the polar pack ice and wind conditions are other factors which may be of equal or greater importance.

The transmission of effects of ice breaking through the food chain to ringed seals and polar bears was also considered possible, but unlikely unless large physical changes occurred within Amundsen Gulf. With the possible exception of Link 4, all linkages associated with this hypothesis could be valid. However, it is expected that changes in the productivity and distribution of lower trophic levels due to ice-breaking would be small (i.e., much smaller than natural variations), and would likely be dampened before affecting higher trophic levels including ringed seals or polar bears. Ice-breaking could affect ringed seals by changing the ice so that the seals are excluded from the icebreaker tracks, but only small amounts of habitat are expected to be physically affected by ice-breaking operations.

# RESEARCH

Although the hypothesis was considered very improbable, effects could be highly significant because ice-breaking activities in Amundsen Gulf could cause changes in the abundance and productivity of regional populations of ringed seals and polar bears. For this reason, research is recommended to further examine the hypothesis.

More detailed examination of this hypothesis can be achieved through analysis of existing data on ice and seals in the Beaufort region. Ringed seal age structure data (1971-82) and stomach content samples collected by T.G. Smith (A.W. Mansfield, pers. comm.) should be analyzed for certain years to address the following two issues:

(1) Did the destabilization of the ice in 1971, 1978 and 1981 have a measureable influence on ringed seals by reducing survival of young-of-the-year, or productivity of young in subsequent years. If pup survival in the year of destabilization was reduced (or enhanced), the cohort should reflect this and be weak (or strong) through subsequent years.

(2) Similarly, if the effect of destabilization on ice thickness or amount of open water was correlated with production of ringed seal prey, then this should be reflected in changes in ovulation and pregnancy rates, and the strength of the cohort produced in the year following destabilization. These results should then be compared to years in which the ice was stable. Feeding habits of ringed seal pups, subadults and adults should also be examined for differences among years, particularly 1971, 1974-75, 1978 and 1981.

## MONITORING

Monitoring programs to test the hypothesis that icebreaker traffic in Amundsen Gulf will affect the ringed seal and polar bear populations are not recommended at the present time. The results of the above research will aid in determining if there is a need for monitoring programs.

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# HYPOTHESIS NO. 7

## THE EFFECTS OF ACTIVE FACILITIES ON POLAR BEARS

The presence of active facilities will result in increased polar bear mortality.

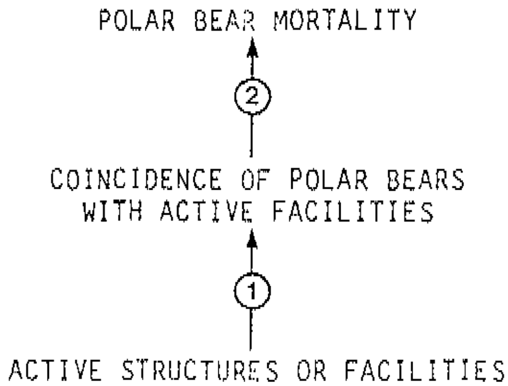


Figure 7-1: Potential effects of active facilities on polar bears.

Linkages

1. Active structures will attract polar bears.
2. Polar bears attracted to offshore structures have to be controlled, and this will result in the need to destroy some bears.

## NAMES OF PARTICIPANTS

Wayne Barchard
Wayne Duval
Jim McComiskey
Ray Schweinsburg
Brian Smiley
Nick Sonntag
Ian Stirling
Dave Thomas

## INTRODUCTION

Active industry facilities in the Beaufort Sea region are and will continue to be located both onshore (e.g., shorebases) and offshore (e.g., artificial islands), and there is concern that these sites of activity will result in the attraction of polar bears. However, the potential for attraction to onshore facilities is less than for those offshore because bears do not usually occupy nearshore fast-ice habitat in the southern Beaufort Sea during winter (Stirling et al. 1975, 1981). Therefore, the probability of attraction between freeze-up and break-up is low. During summer when the southern Beaufort Sea is ice-free, most polar bears remain on the offshore pack-ice, although a few individuals are occasionally stranded on land. While ashore, it is possible that bears will be attracted to onshore sites of human and industrial activity (I. Stirling, unpub. data). Experience in Hudson Bay suggests the greatest potential for attraction to onshore sites would likely occur during fall. For example, in western Hudson Bay, the entire polar bear population comes ashore during the summer when all of the ice in the bay melts. Although, few bears approach settled areas during summer, the numbers increase markedly during the autumn (Stirling et al. 1977). This probably occurs because the polar bears live on stored fat reserves during periods ashore, and become hungrier by fall. At this time, some individuals are willing to investigate possible supplemental food sources.

Existing offshore industrial sites and those proposed for future hydrocarbon development in the region will be located near the landfast ice edge and within the transition zone. These areas include habitat types preferred by polar bears in winter (Stirling *et al.* 1975). As a result, there will be increasing opportunities for polar bears to be attracted to offshore sites (c.f. onshore sites) as development proceeds.

## LINKAGES

Link 1: Active structures will attract polar bears.

It is widely accepted that some polar bears investigate occupied and unoccupied human facilities (Stirling *et al.* 1977, 1978). Presumably this occurs because polar bears are active predators and scavengers, and there is survival value in investigating all possible food sources. There is also evidence that bears which receive positive reinforcement (e.g., garbage) at a site of human activity return to, or remain at, that location (Stirling 1977; I. Stirling, unpubl. data).

Subadult males are most likely to investigate sites of human activity in the Beaufort Sea and elsewhere, although this behaviour has also been reported to a lesser extent with adult females accompanied by cubs (Stirling *et al.* 1977; Stenhouse 1982, 1983; I. Stirling, unpubl. data). Adult males have not been reported shot as problem bears around sites of human or industry activity in either the Beaufort Sea region or the Churchill, Manitoba area (R. Schweinsburg, I. Stirling; pers. comms.), suggesting that this age-sex class is not usually attracted to sites of human activity.

Many polar bears have already been reported at or near existing active offshore industrial sites in the Beaufort Sea. The increasing number of offshore facilities in prime bear habitat in the future may result in an increase in the number of instances when bears investigate these sites. Stenhouse and Latour (1983) conducted aerial surveys in the vicinity of active offshore structures and in distant control areas in the Beaufort Sea to investigate whether of polar bears are actively attracted to these sites. However, significant differences in habitat between experimental and control areas precluded any firm conclusions being drawn, and therefore the extent to which bears will travel to investigate offshore structures remains unknown. It seems likely that polar bears would only be attracted over relatively short distances, and that only a small proportion of the regional population would actually be involved in direct interactions with offshore structures.

The use of heated or produced water for ice management around offshore platforms may create areas of open water or thin ice. If seals were attracted to such areas, subsequent attraction of polar bears is also considered possible.

Link 2: Polar bears attracted to offshore structures have to be controlled, and this will result in the need to destroy some bears.

There have been several instances where it has been necessary to shoot polar bears for reasons of human safety at both offshore and onshore industrial sites in the Beaufort Sea and other arctic regions (Jonkel 1970; Schweinsburg and Stirling 1976; Stirling et al. 1977; Stenhouse 1983). In two instances in the Beaufort Sea, bears were shot after killing humans, while three such cases have occurred in the Churchill area (Ian Stirling, pers. comm.). In the past two years, two bears have been killed as nuisances at offshore sites in the Beaufort Sea. Additional animals may also have been shot by Inuit hunters at offshore industrial sites, but were not reported as "nuisance animals" because the bears were considered part of the legal quota. Thus, it is clear that bears can be dangerous to humans, and that some bears are destroyed because of this danger. However, it is not clear if all bears shot as nuisances actually posed a threat to human safety.

All bears involved in fatal human attacks have been subadult males in poor condition, suggesting that well-fed bears in good condition are less likely to be attracted to offshore sites of human activity than hungry bears in poor condition. Evidence from the Churchill area also indicates that male polar bears that visited the garbage dump as subadults avoided the area as adults (N. Lunn, Ian Stirling, pers.comms.). Therefore, it is probable that bears that are actively attracted to offshore sites would be more dangerous than bears that just happen to encounter these sites during their offshore movements. Thus, only a proportion of the total number of bears approaching a given offshore site are likely to pose a serious threat to humans.

Intensive research on methods for detecting and deterring polar bears is being conducted at Churchill, Manitoba (Stenhouse 1982, 1983). A deterrent technique involving the use of riot guns which fire rubber projectiles is particularly promising, and could be effective in reducing the numbers of bears that have to be killed by Inuit polar bear monitors at offshore industrial sites in the Beaufort.

## CONCLUSIONS

The link of this hypothesis that some polar bears will be attracted to active sites, particularly in the offshore areas, has already been accepted by both industry and government, and was substantiated by the present workshop discussion group. However, that bears which are attracted and become problems must be destroyed has not been unanimously accepted.

In response to the safety hazard associated with polar bear encounters, both monitoring and research programs have been designed and are presently in progress. Records of the number of bears observed near active sites (industry) and records of the number and location of bears killed in the Beaufort area (government) should continue to be maintained. The working group also recommended the continued support of research on methods of detecting and deterring polar bears.

## MONITORING

The existing polar bear monitoring and deterrent programs should be supported and improved. In addition, the workshop subgroup suggested that changes in data recording and the communication of information between government and industry should be implemented. Recommended changes include a more detailed, systematic recording of monitoring data, and improved training of polar bear monitors and supervisory staff at industry facilities. It was also suggested that monitoring and deterrent records should be summarized annually and reviewed once every 3 to 5 years to re-evaluate the present hypothesis.

The workshop group agreed that the following information should be recorded when polar bears are sighted at or near offshore facilities in the Beaufort Sea region:

- Location, date, age and sex (if known) of bears observed;

- Details of the incident

  - direction of approach of the bear
  - behaviour of the bear
  - time period that the animal remained in the area
  - how close it came to the site, personnel, and equipment on the ice, etc.
  - methods employed to deter the bear

  - rate and manner in which the bear responded
  - if a bear is killed, the reasons for this decision (e.g., bear threatening people or property).

- When a bear is killed, the following should be undertaken where possible:

  - collect lower jaw
  - record sex
  - measure the length and axillary girth (with the bear resting on its chest)
  - describe the condition in terms of the amount of fat on the carcass after skinning

- Maintain a weekly record (or daily, if change is occurring rapidly) of ice conditions within a few kilometres of the sites; the presence or absence of open leads, freshly refrozen leads, and proximity to the shear zone are of particular importance. Standard photography, aerial black and white photography and SLAR imagery would be of great value in interpretation of the frequency of polar bear sightings.

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# HYPOTHESIS NO. 8

## THE EFFECTS OF OFFSHORE DEVELOPMENT ACTIVITIES ON POLAR BEAR HARVEST

Offshore development activities will reduce the harvest of polar bears

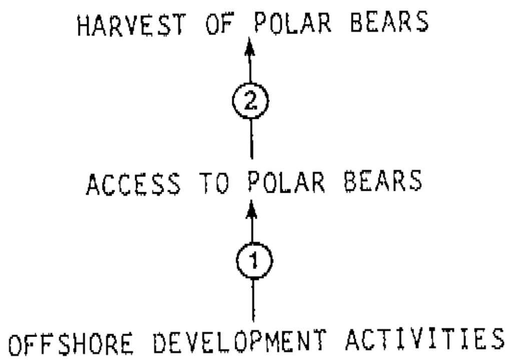


Figure 8-1 Potential effects of offshore development activities on polar bear harvest.

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

## NAMES OF PARTICIPANTS

| | |
|---|---|
| Wayne Barchard | Brian Smiley |
| Wayne Duval | Nick Sonntag |
| Jim McComiskey | Ian Stirling |
| Ray Schweinsburg | Dave Thomas |

## INTRODUCTION

Inuit hunters are concerned that Beaufort Sea hydrocarbon development activities will lead to a reduction in polar bear harvests. The hunters maintain that offshore industrial activities will (1) drive polar bears farther offshore (i.e., away from the landfast ice) and into areas that are inaccessible to hunters or (2) create barriers that prevent the Inuit from reaching hunting areas, thereby reducing the annual harvest.

## LINKAGES

Link 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.

### a) Potential for Effects on Polar Bear Distribution

Many observations have shown that bears are alarmed or frightened by the passage of ships and aircraft, and usually move away from the disturbance source (I. Stirling, pers. comm.). However, these reactions are usually of short duration, with affected individuals resuming their normal behaviour soon after the disturbance has passed. Some individuals also recover before the disturbance has passed and come to investigate it (I. Stirling pers. comm.).

The important question is whether repeated short-term disturbances would cause bears to abandon a large geographic area. There have been no studies which have directly examined this area of potential concern, although some indirect information exists and is discussed below.

The well documented problem of human/bear conflicts is clear evidence that many bears are not frightened by human activities (Latour 1983). Since 1973, fourteen polar bears have been killed following encounters with oil industry facilities and personnel in the Beaufort Sea (Stenhouse, 1983; J. Ward, pers. comm.). The frequency of nuisance bear encounters appears to be increasing in the Arctic. During the 5-year period from 1972 to 1976, 74 polar bears were destroyed as problem animals in the Northwest Territories, while in the 5-year period from 1977 to 1981, the total increased to 141 (Stenhouse 1983). These data suggest that there has not been a trend toward large scale avoidance of areas of human activity by bears.

Not all age and sex classes of bears react to human activity in the same way. For example, adult bears (particularly males) tend to avoid sites of human activity. This is thought to be related to the behavioural dominance of adult bears over younger, subadult animals, enabling them to feed in prime hunting areas with little competition from subordinates (R. Schweinsburg, I. Stirling, pers. comms.). As a result, adults have little need to investigate sites of human activity as potential sources of food. This is particularly noticeable in Churchill, Manitoba where adult males are not found around the town and its garbage dump site. Other age and sex classes of bears forage in these areas and become nuisance animals (I. Stirling, pers.comm.). Older males are also absent from the nuisance bear kill records in the Northwest Territories (NWT Wildl. Service, unpubl. data). It is therefore likely that adult males, and perhaps females, will not be attracted to sites of human activity in the Beaufort region unless the availability of natural food sources (i.e., seals) is greatly reduced.

There is some evidence to suggest that bears are more sensitive to disturbance in areas where they are being actively hunted (R. Schweinsburg, pers. comm.), but this behavioural response has not been well documented. In areas where bears are intensively hunted, their tracks tend to cross the floe edge at right angles, while in unhunted areas, tracks tend to follow the floe edge (R. Schweinsburg, pers. comm.). In addition, reports by NWT Wildlife Officers indicate that bears in heavily hunted areas tend to head for open water when they hear motors. It is these types of observations that have led to Inuit concerns that polar bears will avoid sources of disturbance. However, it is not clear whether such bears are reacting to the specific activities and potential danger associated with hunting, or whether they are reacting to disturbances in general.

b) Potential for Creation of Barriers to Inuit Hunter Travel

A second area of concern is that industry activity will result in changes in winter ice patterns in a manner that restricts or eliminates hunter access to polar bear harvest areas.

The presence of large numbers of artificial islands in the transition zone could extend the landfast ice zone and floe edge farther offshore, although the available evidence suggests that this is unlikely to occur (see Hypothesis No. 2). Nevertheless, even if the fast-ice were to extend a few kilometres farther offshore, hunters would not be prevented from reaching the floe edge. Trips to harvesting areas would, however, take proportionally longer.

There is also concern that ice rubble build-up near offshore structures and along icebreaker tracks would prevent hunters from reaching to polar bear harvesting areas. Although ice build-up will occur around structures in some circumstances, the area affected would be localized and is not expected to prevent hunters from reaching areas beyond the rubble fields.

Frequently used icebreaker tracks orientated parallel to the shore in the fast-ice zone could create rubble fields that are difficult (but not impossible) to cross by snowmobile. However, present development plans indicate that principal icebreaker routes through the fast-ice will be orientated at right angles to the coast from both McKinley Bay and the Yukon coast to the transition zone. Most traffic following routes parallel to the shore or the floe edge will occur within the transition zone. Consequently, it is unlikely that Inuit hunters would be prevented from reaching polar bear harvesting areas due to the presence of refrozen tracks created by icebreakers in the landfast ice zone.

Link 2: Reduced access to polar bears will lead to reductions in the Inuit harvest of polar bears.

This link is self-evident. In the short-term, harvest levels may be maintained through increased hunting effort in the secondary harvest areas located closer to shore. However, this practise would lead to increased mortality of females and dependent cubs, and therefore harvest could only be sustained at the same level for a short time.

## CONCLUSIONS

Although the logic behind this hypothesis was considered reasonable, a review of the available evidence suggested that Link 1 was probably not valid. However, because the data base for full evaluation of the hypothesis is incomplete, the following monitoring is recommended.

## MONITORING

The existing NWT Wildlife Service monitoring program which documents relevant information related to polar bears killed by hunters in the Beaufort Sea region is expected to be adequate to test this hypothesis. The workshop group recommended that these data be analysed in detail every 3 to 5 years to evaluate the hypothesis, and to determine if changes in the monitoring program are necessary. Information requirements in terms of the polar bear hunt are similar to those discussed earlier in relation to the evaluation of Hypothesis No. 7.

The above data on bear kills should also be supplemented with information on the development activities that occur in the region and data on ice conditions, and the amounts and locations of open water on a year-to-year basis. This information will be necessary for evaluation and interpretation of both the biological and hunter effort data.

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# HYPOTHESIS NO. 9

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

Chronic/episodic oil spills resulting from normal petroleum hydrocarbon development activities within and adjacent to the marine environment will result in localized mortality of polar bears.

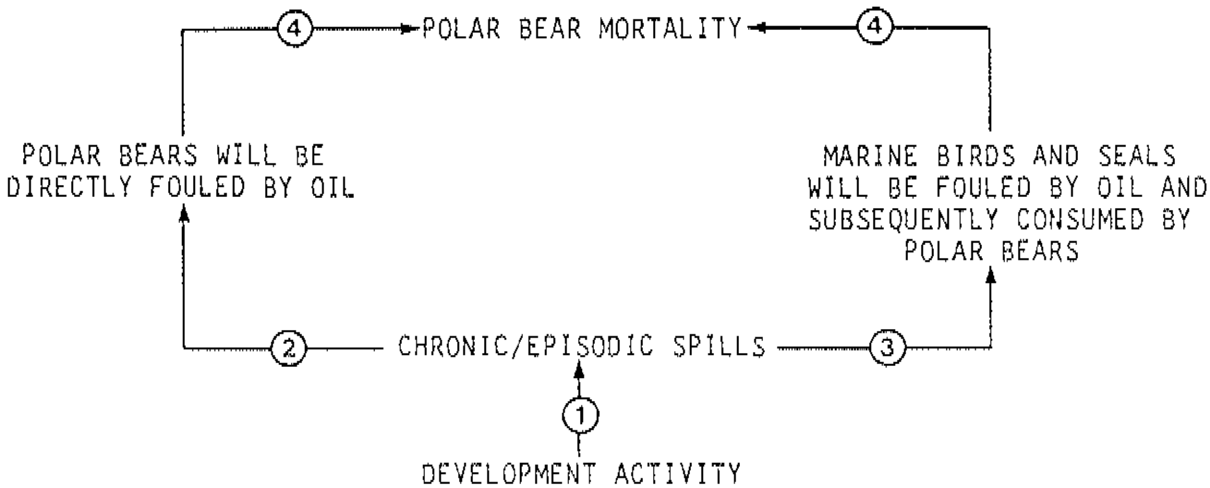


Figure 9-1 Potential effects of chronic/episodic oil spills resulting from normal petroleum hydrocarbon development activities within and adjacent to the marine environment on polar bears.

## Linkages

1. Development activities will result in chronic/episodic oil spills.
2. Episodic spills will result in the direct fouling of polar bears.
3. Episodic 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 and/or ingested.

## NAMES OF PARTICIPANTS

Rick Hurst
Ray Schweinsburg
Ian Stirling

## INTRODUCTION

Oil spills occur as a result of normal hydrocarbon development activities in the Beaufort Sea. At present, these spills are largely restricted to fuel (primarily diesel) used in various shorebased and offshore operations, but will likely include crude oil spills at offshore production facilities in the future. The location and frequency of chronic spills in the Beaufort region is discussed in greater detail in relation to Hypothesis No. 10.

Laboratory studies have demonstrated that oil fouling can cause polar bear mortality through the following mechanisms:

1. Reduction of the insulative capacity of fur, and subsequent metabolic alterations (Hurst and Oritsland 1982; Oritsland *et al*. 1982);

2. Toxicity resulting from oil ingestion during grooming (Engelhardt 1981; Oritsland *et al*. 1982).

There is some potential for bears to be affected by chronic spills in the Beaufort Sea, either through direct fouling following contact with surface slicks or indirectly through consumption of oil-contaminated prey.

## LINKAGES

Link 1: Development activities will result in chronic/episodic oil spills.

Information available from other offshore production areas and the oil spill case history literature in general both indicate that the vast majority of oil spills result from unavoidable human errors and equipment failures (Dome Petroleum et al. 1982). Data on the causes, frequency and sizes of spills associated with nearshore and offshore petroleum development activities are available from a number of sources (e.g., Dome Petroleum, unpublished data). This information can be used as a basis of extrapolation to provide estimates of spill probabilities, frequencies and volumes in the Beaufort development region. Although it is recognized that there has been a decrease in the occurrence of spills with (1) increased awareness, (2) more thorough training programs and (3) improved technology, the frequency and cumulative volume of chronic oil spills will likely increase with the level of hydrocarbon development in the Beaufort region. However, the overall relationship between probable spill frequency/volume and level of development in the region remains unknown.

Link 2: Episodic spills will result in the direct fouling of polar bears.

Polar bears may be directly fouled with oil by swimming in oil-contaminated waters, although this has never been observed in the wild. Nevertheless, the potential for direct contact with oil does exist, since polar bears have been observed swimming in all months, except during periods of darkness for which there are no records (R. Schweinsburg, pers. comm.), often at considerable distances from shore.

In the Beaufort Sea, bears occur near offshore facilities and artificial islands from October to June. In the future, many additional offshore structures could be constructed in or near habitat types where polar bears prefer to hunt (Stirling *et al.* 1975). In addition, some polar bears (particularly subadult males) are attracted to sources of human activity, including offshore industry structures (Stirling *et al.* 1977). Since these facilities are located in polar bear habitat and may attract bears, and are also potential sources of chronic oil spills, the potential for bears to contact oil near such sites is greater than elsewhere in the region (e.g., shorebases).

In summer, most bears occupy the polar pack ice which is located well north of the development zone. However, some bears are found in summer retreats along the coasts of Banks and Baillie Islands. If oil were to strand along these shorelines, polar bears could be fouled during their frequent movements between land and water areas.

There is no available information on the behaviour of free-ranging bears in the presence of an oil slick. Theories concerning their probable behaviour range from complete avoidance to attraction, but no experimental evidence or observations exist. The actual extent of oil contamination and the duration of contact would depend on a number of factors, including (1) whether or not a bear will actually swim through oil-covered waters; (2) the potential for repeated contact with surface slicks; (3) the type, thickness and viscosity of the oil; and (4) the amount of oil trapped in the fur.

Link 3: Episodic spills will result in the direct fouling of marine birds and seals that are consumed by bears.

Polar bears may contact oil either directly (Link 2) or indirectly through consumption of oiled prey (birds or seals). A discussion of the extent to which chronic oil spills may affect birds is presented in Hypothesis No. 11. The latter group concluded that some degree of bird mortality would result from chronic hydrocarbon spills, although the number of birds which will contact oil remains unknown.

Of undoubtedly greater importance for bears is the potential for ingestion of contaminated ringed seals which are the primary food source of polar bears (Stirling and McEwan 1975). For example, ringed seals have been observed completely covered with oil in Hudson Bay (Muller-Wille 1974). In addition, there have been several reported cases of exposure of seals to crude oil following spills in temperate waters (e.g., Davis and Anderson 1976; Duval et al. 1981).

The behavioural responses of ringed seals and bearded seals to spilled oil and the physiological impacts of oil contact (including mortality) in free-ranging individuals remain poorly documented (see reviews by Geraci and St. Aubin 1980; Richardson et al. 1983; Engelhardt, 1983). Investigations of oil spill incidents have generally not been conclusive in elucidating the physiological and toxic effects of oil contact by marine mammals. Marine mammal mortality has been associated with certain incidents such as the ARROW and the TORREY CANYON spills (Anonymous 1970; Spooner 1967). Similarly, grey seal and harbour seal deaths were reported following the KURDISTAN spill on the East Coast of Canada (Parsons et al. 1980). However, most available information regarding the effects of oil on ringed seals has resulted from a limited number of controlled laboratory studies (Geraci and Smith 1976a, 1976b; Engelhardt et al. 1977). These studies have demonstrated both the physiological pathways of hydrocarbon uptake and transient damage to the eyes, liver and kidney in this species. However, mortality of oiled ringed seals was only observed in some animals stressed by laboratory conditions.

During summer, scavenging polar bears could encounter oil-contaminated carcasses along the shoreline, while bears following leads used by birds (particularly eider ducks) and subadult seals during spring could also encounter oil-contaminated prey on or near ice edges.

Link 4: Mortality of bears will occur if oil is contacted and/or ingested.

Fouling

Fouling of polar bear fur through direct contact with oil can cause a significant reduction in the insulative capacity of the fur. Reductions to as little as 1/2 to 1/3 of pre-exposure insulation values have been demonstrated for oil-contaminated polar bear fur (Hurst and Oritsland 1982) and the fur of other amphibious mammals (Kooyman *et al.* 1977). These changes in insulative capacity could lead to a compensatory increase in metabolic rate and changes in skin and deep body temperature as demonstrated in polar bears (Oritsland *et al.* 1982; Hurst *et al.* 1982) and in sea otters (Costa and Kooyman 1983), and may ultimately result in mortality by hypothermia (Williams 1978; Costa and Kooyman 1983).

Ingestion

Bears can ingest oil either through grooming of fouled fur or ingestion of oiled prey. The existing experimental evidence suggests that the most serious concern with respect to effects of oil on bears is the chemical toxicity of ingested hydrocarbons (Oritsland *et al.* 1982; Engelhardt 1981). Grooming of oil from the fur following oil contact appears to be a certainty given the available experimental information (Oritsland *et al.* 1982; Hurst *et al.* 1982). Mortality of bears following oil ingestion certainly can occur, although the quantity of oil necessary to cause death is unknown.

The physiological and toxicological (lethal) effects of such oil ingestion were described for two polar bears experimentally exposed to oil (Engelhardt 1981; Oritsland *et al.* 1982). As a result of extensive grooming after exposure to crude oil, three polar bears ingested large quantities of oil, and this lead to peripheral hemolysis, erythropoietic dysfunction and renal abnormalities. Subsequent death of 2 of 3 of the oil-contaminated bears was thought to be largely due to renal failure.

The likelihood of consumption of oil-contaminated prey by bears has not been tested empirically. However, anecdotal information indicates that polar bears preferentially consume motor oil upon breaking into caches (N.W.T. Wildl. Serv. unpublished data), and generally consume oil and oil products regardless of source.

The present information suggests that polar bear mortality will result both from fouling of fur and ingestion of critical (but unknown) quantities of oil. Such potential industry-related mortality must be viewed in conjunction with hunting pressure through the existing quota system, and related to carrying capacity of the population. It is expected that, although the hypothesis is be valid, the number of bears affected by chronic oil spills would be small and probably not significant at the population level (unless the population is being hunted at maximum sustainable yield).

## CONCLUSION

The potential for polar bears to contact oil during hydrocarbon development activities in the Beaufort Sea does exist, although the number of animals that may be affected by chronic/episodic spills is unknown. Nevertheless, mortality of polar bears as a result of oil exposure or ingestion of contaminated prey would probably be limited.

## RESEARCH

The most significant information gaps at this time relate to the behavioural responses of polar bears to oil-covered waters and to oil-contaminated prey. Specific experiments addressing these concerns are possible and would involve relatively few logistical difficulties and a low probability of severe consequences to the study animals. However, studies of this nature would undoubtedly encounter extreme public and political opposition, and therefore may be untenable.

It is possible that some additional information could be obtained through *in vivo* experimentation (i.e., with polar bear pelts), and a program to determine hydrocarbon burdens in samples obtained from animals harvested by Inuit hunters. The maximum amount of opportunistic information should also be collected in any instance where polar bears contact oil in the Beaufort Sea or elsewhere in the Canadian Arctic. For example, observations could be taken concurrently with information on birds collected by oilspill response personnel (see Hypothesis No. 10). Alerting of all personnel to document sightings of oiled bears or of the response of free-ranging bears to oil, and the subsequent reporting of this information to regulatory agencies are also recommended.

## MONITORING

No specific polar bear/oil monitoring program is recommended.

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# HYPOTHESIS NO. 10

## THE 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.

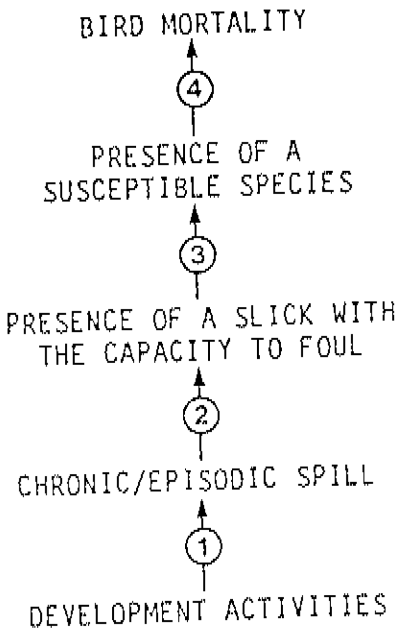


Figure 10-1 Potential effects of chronic (episodic) oil spills resulting from normal petroleum development activities on birds.

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.

## NAMES OF PARTICIPANTS

Tom Barry
Jim Bunch
Wayne Duval
Bob Everitt
Francois Guimont
Steve Johnson
Jim McComiskey
Ray Schweinsburg
Dave Thomas
Doug Wolfe

## INTRODUCTION

Oil spills occur as a result of normal hydrocarbon development activities in the Beaufort Sea. At present, these spills are largely restricted to fuel oils (No. 2 diesel) used for various shorebased and offshore operations (primarily marine vessels), but will likely include crude oil spills at offshore production facilities in the future. Information available through spill report files indicates that the volume of chronic (episodic) spills is inversely related to spill frequency, with the largest proportion of spills involving volumes of less than 1 barrel. At present, the greatest frequencies and largest volumes of oil spills are associated with existing shorebases in the Beaufort development region (Dome Petroleum, unpubl. data), although it is expected that the frequency of spills in offshore areas will increase incrementally as development proceeds.

Future sources of chronic oil spills could include shorebases (diesel, slops), offshore drilling and production facilities (diesel, crude, lubricants and other production wastes), and subsea facilities such as pipelines and gathering systems (crude). Tankers involved in transportation of crude oil as well as vessels (icebreakers, supply boats, dredges) associated with various support and construction activities may also result in occasional spills of crude oil or refined petroleum products.

It is generally agreed that birds are the resource which has been most visibly affected by oil spills (Brown 1982, ESL 1982). Information summarized by Duval et al. (1981) also indicates that the location and timing of spills (cf. volume of oil spilled) in relation to the distribution, abundance and seasonal habitat use of birds have been the primary factors affecting the severity of impacts of past spills. For example, widespread mortality of birds was reported following relatively small spills (<100 barrels) in marine temperate and subarctic environments, while impacts on birds have not been observed following many spills greater than 100,000 barrels (Duval et al. 1981). At the same time, the vulnerability of birds to oil spills varies substantially among species, and is highly dependent on life history and behavioural patterns (King and Sanger 1979). Nevertheless, due to the exceptional vulnerability of some species to even small quantities of oil in the marine environment, the effects of chronic oil spills on birds remains an area of potential concern related to hydrocarbon development in the Beaufort region.

## LINKAGES

Link 1: Development activities will result in chronic (episodic) spills of petroleum hydrocarbons.

Information available from other offshore production areas and the oil spill case history literature both indicate that the vast majority of oil spills result from unavoidable human errors and equipment failures (Dome Petroleum et al. 1982). Data on the causes, frequency and sizes of spills associated with nearshore and offshore petroleum development activities are available from a number of sources (e.g., Dome Petroleum, unpublished data). This information can be used as a basis of extrapolation to provide estimates of spill probabilities, frequencies and volumes in the Beaufort development region.

Although it is recognized that there has been a decrease in the occurrence of spills with (1) increased awareness, (2) more thorough training programs and (3) improved technology, the frequency and cumulative volume of chronic oil spills will likely increase with the level of hydrocarbon development in the Beaufort region. However, the overall relationship between probable spill frequency/volume and level of development in the region remains unknown.

Link 2: Where chronic (episodic) spills occur, slicks with the capacity to foul birds will be present under certain conditions.

Several models describing the physical and chemical weathering of oil, as well as the concurrent spreading and movement of slicks, have been developed in recent years. These models may have predictive value for evaluating the relative rates of oil weathering, but may not be useful for assessment of oil transport processes and rates with relatively small chronic spills. The most important spill features determining impacts of oil on birds would include slick thickness and detectability, although the slick thicknesses which may result in fouling of birds remain unknown. Two additional data deficiencies that were identified with respect to potential oil contamination of birds were (1) the probable fate and effects of oil which became encapsulated in ice throughout the winter months, and was subsequently released to melt pools or to the water column during spring break-up; and (2) the possible remobilization of oil that was stranded in intertidal and backshore habitats following chronic oil spills in nearshore areas.

Link 3: Susceptible bird species will co-occur in space and time with the presence of a slick.

In early spring, seabirds are attracted to sites that are or appear to be open water (T. Barry, pers. comm.). In addition, many species migrate along offshore leads and along shorelines which may be sites of oil accumulation following chronic spills in the Beaufort region. On the other hand, it was recognized that some species of birds may avoid oil slicks (King and Sanger 1979), while others may avoid areas of chronic oil contamination (e.g., offshore platforms) due to the physical presence of structures and human activities at these sites (Cornish and Allen 1983).

The major uncertainties identified in relation to Link No. 3 of this hypothesis were (1) the potential for attraction of birds (e.g., loons, gulls and diving ducks) to fish or invertebrates that are killed or narcotized, and are present at the surface following chronic spills, (2) the lack of data on the behaviour of several bird species at different times of the year, and (3) information on the location and extent of open water during the period of spring migration to the Beaufort region.

Link 4: Mortality of birds will occur following slick contact.

Many species of birds are highly susceptible (due to behaviour and life history) to oil spills, and have suffered mortality following contamination by petroleum hydrocarbons (Brown 1982; Duval *et al*. 1981). This mortality results principally from the physical effects of oil on thermoregulatory capacity and buoyancy, as well as the toxicity of petroleum hydrocarbons ingested during preening or feeding activities (Brown 1982). Relatively small spills can cause extensive bird mortality under some circumstances (Barrett 1979), such as when large concentrations of susceptible bird species occur within a restricted area. This situation does exist at some times of the year near proposed shorebase development sites in the Beaufort region.

Major data deficiencies associated with this linkage relate to (1) the documented difficulties in detection of bird mortality due to both emigration from the spill zone and sinkage of contaminated bird carcasses; (2) the lack of information regarding levels of contamination (i.e., slick thickness or spill volume) that will result in bird mortality; and (3) the limited data for assessment of the ecological significance of species-specific bird mortalities.

## CONCLUSION

It was concluded that there is sufficient information to accept the hypothesis that chronic/episodic oil spills will cause mortality of birds under some circumstances. The combinations of circumstances which may lead to bird mortality (i.e., volume of spill, oil type, time of year, type of habitat contaminated, slick thickness and movement, and the behaviour of contaminated birds) are not clear, but are expected to be highly variable. It is difficult to assess the significance of oil-induced mortality on seabird population levels. The early concern that the extensive seabird population of the North Sea area would decline after hydrocarbon development has been substantiated (Clark 1984). It was concluded that a monitoring program could be justified on the basis of the documented vulnerability of some species to relatively small spills, and the important bird habitats that occur along many portions of the Beaufort Sea coastline.

## MONITORING

Due to the episodic nature of chronic oil spills and high degree of uncertainty regarding the casual circumstances, nature and extent of potential impacts of these events on bird populations, an opportunistic approach is recommended for monitoring of the short-term and long-term effects of chronic spills in the Beaufort Sea. Monitoring should become an integral part of the existing oilspill response plans for the region, and could be conducted by personnel that are already experienced observers (e.g., Inuit) or are trained members of a response team such as the Beaufort Sea Oilspill Cleanup Cooperative. Following chronic spill incidents at shorebases and offshore facilities, one or more members of the response team would assume responsibility for documenting (1) the species and numbers of birds in the vicinity of the spill zone, (2) the number of birds (by species) that appear to have contacted surface slicks or oil stranded in shoreline habitats; and (3) the subsequent behaviour (e.g., flight away from the area) or mortality of affected individuals. It will be equally important to document fully those events where birds are present in an area, but remain unaffected, as well as other incidents where birds are not present at the time and location of a chronic spill. These data, when reported with other information regarding each incident (i.e., spill volume and type, extent of surface slick, time of year, percent of oil recovered, etc.), would provide a statistical basis for ongoing evaluation of the effects of chronic spills on bird populations of the Beaufort Sea.

It is emphasized that the overall success of this approach to monitoring would be dependent on the thoroughness of each observer's visual records and attention to detail. In addition, the success of the approach would also continue to depend on the rapid response to all oil spill incidents to avoid underestimates of bird contamination or mortality due to emigration and sinkage, particularly when the oilspill response team is centrally located (e.g., Tuktoyaktuk, McKinley Bay) and must be transported to the spill site. It is also recognized that under some circumstances (e.g., during explosion or fire hazard), priorities will be placed on human safety and rapid response rather than bird monitoring responsibilities. However, the opportunistic approach to monitoring of the effects of chronic spills on birds is expected to be effective in the majority of probable spill circumstances.

An additional recommendation with respect to this monitoring program is the documentation of oiled birds (species, numbers, location and time) in conjunction with all normal industrial operations in the region. The latter type of records would provide a measure of the cumulative impact of chronic/episodic oil releases on bird populations, and could be compared to observations taken by on-site oilspill response teams.

## RESEARCH

Accurate estimation of bird mortality, by extrapolation of bird mortality indices from the trained observer counts and on-site studies at spills, will require statistically reliable data that can only be obtained through an extensive laboratory and experimental oil spill research program. Predicted Beaufort hydrocarbon development levels do not justify this approach. Rather, the management philosophy should be to scrutinize closely the results of the monitoring program and to emphasize mitigative actions (i.e., actions to reduce the spill frequency and volume, and to enable rapid cleanup).

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# HYPOTHESIS NO. 11

## EFFECTS OF OIL IN OPEN WATER AREAS AROUND OFFSHORE STRUCTURES DURING PERIODS OF ICE COVER ON EIDERS AND DIVING DUCKS

Oil slicks in open water areas around offshore structures during normal periods of ice cover will cause increased mortality of eiders and diving ducks.

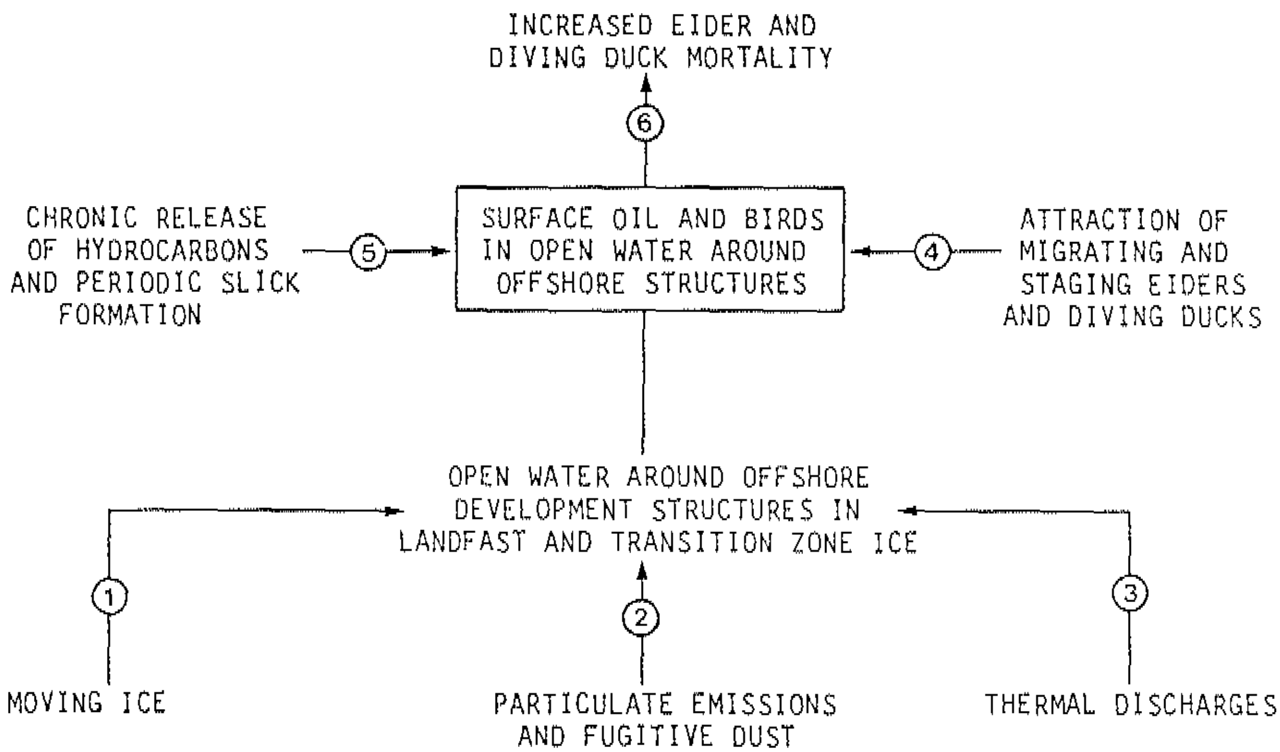


Figure 11-1: Potential effects of oil near offshore platforms on eiders and diving ducks (Mechanism A)

The various linkages in Mechanism A were evaluated by the workshop subgroup. During this discussion, evidence was presented that resulted in elimination of Link 2 (see below). Further discussion resulted in a general reorganization of the possible mechanism through which increased eider and diving duck mortality may occur. The revised linkages associated with the hypothesis (Mechanism B) are shown in Figure 11-2.

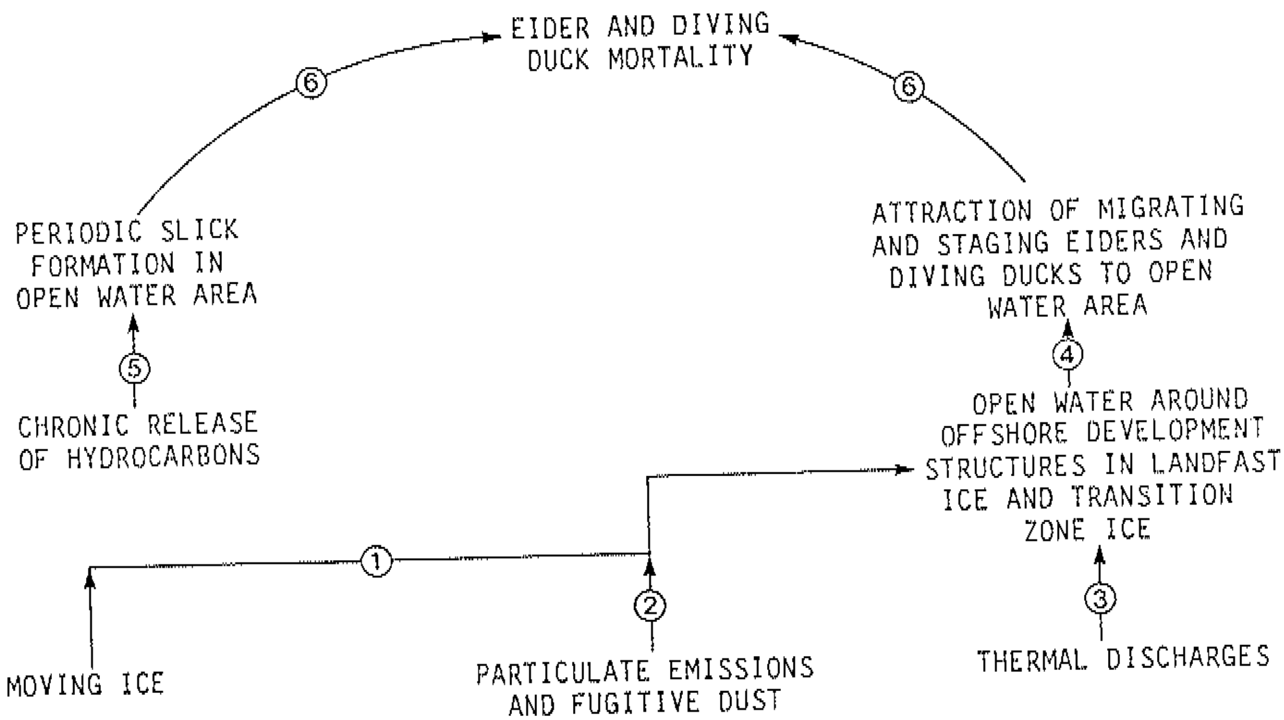


Figure 11-2: Potential effects of oil near offshore platforms on eiders and diving ducks (Mechanism B)

Linkages

1. Moving ice causes rubble fields and open water in the ice surrounding offshore structures.

2. Particulate emissions and fugitive dust will decrease the albedo (increase heat absorption) of the ice, leading to increased melting and earlier formation of open water areas around offshore structures.

3. Thermal discharges under or onto the ice from offshore production facilities will enhance melting and formation of open water around structures.

4. Eiders and diving ducks are attracted to open water areas during migration and staging.

5. Chronic releases of hydrocarbons from offshore structures will cause the periodic formation of oil slicks in open water areas.

6. Oiling of birds present in open waters around offshore structures will cause mortality.

## NAMES OF PARTICIPANTS

| | | |
|---|---|---|
| Tom Barry | Robert Everitt | John McDonald |
| Jim Bunch | Tarek Jandali | John Marko |
| Ben Danielewicz | Steve Johnson | Humfrey Melling |

## INTRODUCTION

Barry et al. (1981), Barry and Barry (1982), and Searing et al. (1975) have documented large concentrations of migrant eiders and other diving ducks during early spring migration (15 May to 15 June) in certain areas of open water along the edge of the shear zone in the southeast Beaufort Sea. Densities as high as 200 birds/$km^2$ were recorded in this area during spring 1974 (Searing et al. 1975). Similarly, data collected by Dome Petroleum (Dome Petroleum, unpubl. data) indicated as many as 40 birds/$km^2$ during spring in open water areas within several kilometres of an exploratory drilling structure located near the shear zone.

Chronic (episodic) accidental spills of petroleum hydrocarbons (diesel, crude) into the marine environment occur as a result of routine oil and gas exploration activities in the Beaufort Sea (Dome Petroleum, unpubl. data), and will likely occur with greater frequency as larger volumes of oil are handled during production.

It is also important to emphasize that even small oil spills in marine environments can result in extensive mortality of waterfowl and other species of marine-associated birds (Barrett 1979). A review of 100 world-wide oil spills completed by Duval et al. (1981) indicated that the circumstances surrounding spills (particularly location and season) and the types of habitats affected by oil in relation to the abundance and distribution of birds, were more important factors than spill volume in determining the impact of these events.

The major concern and basis for this hypothesis is that eiders and diving ducks, which have been assigned a very high Oil Vulnerability Index (OVI; King and Sanger 1979), may suffer extensive mortality if they contact an oil slick near an offshore production structure located near the shear zone. This concern is greatest during the spring migration period when birds may be concentrated in relatively high densities in available open water.

## LINKAGES

Link 1: Moving ice causes rubble fields and open water in the ice surrounding offshore structures.

Satellite imagery and observations by on-site industry personnel show that open water is created in the lee (downstream) of an artificial island or structure as ice moves past during the spring (Ben Danielewicz, pers. comm.). The satellite imagery also shows that moving ice in the transition zone creates other extensive areas of open water adjacent to but not caused by the presence of artificial islands or structures (John Marko, pers. comm.). Open water formation in the transition zone of the Beaufort Sea is a characteristic result of normal ice movement in the spring. However, if the ice is stationary, open water is not created in either the lee of artificial structures or in adjacent areas through this process. Therefore, the presence of open water in the transition zone during early spring is dependent on ice movement.

Link 2: Particulate emissions and fugitive dust will decrease the albedo (increase heat absorption) of the ice, leading to increased melting and earlier formation of open water areas around offshore structures.

This linkage was eliminated from the hypothesis because the small amount of particulate emissions and resulting fallout is not expected to significantly decrease albedo, and therefore should not contribute to the formation of open water around offshore structures (Tarek Jandali, pers. comm.). The total amount of particulate emissions during the year 2000, when proposed development activities would be at their peak (for the development scenario considered) have been estimated at about 12,000 tonnes/year (Dome Petroleum et al. 1982). The emission sources can be classified as two types: mobile (aircraft and marine vessels) and stationary (shorebases and platforms). The mobile sources (mostly marine vessels) would account for 83 percent of all particulate emissions, or approximately 10,000 tonnes/year. The remainder (2000 tonnes/year) would be emitted at shorebases, offshore platforms and drill rigs (Dome Petroleum et al. 1982).

Prior to the workshop, dispersion calculations were completed using a box model approach to estimate the order of magnitude in the level of dust fall loading which may be expected in the Beaufort region. The following assumptions were made during these calculations:

1) Because of the wide geographic separation of emission sources, Spatial Units 1, 2, 3 and 4 in the Beaufort Sea (see Introduction) were assumed to be affected by emissions. The approximate surface area of these combined zones was estimated at 60,000 $km^2$;

2) On an annual basis, the wind distribution and the location of mobile sources are such that the particulate fallout was expected to be uniform in these four spatial units.

On the basis of these two assumptions and the total expected particulate emissions identified earlier, an exceedingly low rate of dust fall ($20 g/m^2$/month) was estimated (Tarek Jandali, pers. comm.). In addition, the effect of particulate matter on the albedo would be very dependent on the period of application, and conditions such as snow drifting and occurrence of a thaw followed by freeze-up would limit or eliminate changes in albedo caused by dust fall (Williams 1967). Therefore, given the extremely low level of dusting expected from hydrocarbon development, in conjunction with the uncertainties associated with the actual effects of dusting on albedo, it was concluded that this link would not contribute to increased open water areas around offshore structures.

Link 3: Thermal discharges under or onto the ice from offshore production facilities will enhance melting and formation of open water around structures.

Depending on the precise set of conditions (e.g., ice thickness, current patterns) and the manner in which discharges are released from a production facility, either very little open water would be created or as much as 60,000 $m^2$ (0.06 $km^2$) of open water could occur in the vicinity of the outfall (Humfrey Melling, pers. comm.; Ben Danieliwicz, pers. comm.). Direct discharge of produced water and cooling water onto the surface of the ice near the structure would create the largest amount of open water. This area would be greatly reduced in situations where the water was mixed with dense, cold sea water and released at high speed into the water column (Humfrey Melling, pers. comm.). High speed discharges of much smaller quantities of water presently create open water areas of about 10 $m^2$ near existing facilities in the region (Ben Danieliwicz, pers. comm.).

Link 4: Eiders and diving ducks are attracted to open water areas during migration and staging.

Data collected by on-site petroleum industry personnel (Dome Petroleum, unpubl. data) indicate that densities of water birds during spring in areas around offshore artificial islands are not different from densities recorded in adjacent open-water areas (see also Barry et al. 1981; Barry and Barry

1982). It was therefore concluded that, under normal ice conditions, significant "attraction" of birds to artificially created open water around structures would be unlikely. However, during periods when the only available open water may be that present near a thermal dishcarge from an artificial production island (such as during a period when no ice movement is occurring and no open water is created), it is conceivable that some birds may be attracted to the structure. As indicated earlier, depending on the thermal discharge procedures, either a very small (10 $m^2$) or relatively large (60,000 $m^2$) area of open water may be created adjacent to an outfall. In such an extreme situation, the number of birds attracted to the area is expected to be proportional to the amount of available open water. However, this extreme situation where virtually no open water exists probably occurs once every 10 to 20 years (Barry 1968; Tom Barry, pers. comm.).

Link 5: Chronic releases of hydrocarbons from offshore structures will cause the periodic formation of oil slicks in open water areas.

Since the presence of an oil slick would be necessary to create a situation where bird mortality could occur, treated produced water discharges are not expected to affect birds. On the other hand, accidental episodic spills may cause occasional oil slicks near offshore production facilities. The existence of various mitigative procedures and oilspill contingency plans will reduce the risk of contamination of birds following these episodic events, and not all spills will result in a slick that is capable of fouling birds. In addition, the dynamic conditions associated with open water created by moving ice, would likely result in non-uniformities in the distribution of any oil slick and this would further reduce the risk to birds.

Link 6: Oiling of birds present in open waters around offshore structures will cause mortality.

Many species of birds are highly susceptible (due to behaviour and life history) to oil spills, and have suffered mortality following contamination by petroleum hydrocarbons (Brown 1982; Duval et al. 1981). This mortality results principally from the physical effects of oil on thermoregulatory ability and buoyancy, and the chemical toxicity of oil ingested during preening or feeding activities (Brown 1982). As indicated earlier, relatively small spills can result in extensive mortality of birds (Barrett 1979), and at the same time, significant numbers (thousands) of susceptible birds are known to occur in proposed offshore development areas in the Beaufort region (Dome Petroleum, unpubl. data).

Major data deficiencies related to this linkage are: (1) the documented difficulties in detection of bird mortality following oil spills due to emigration out of the area and sinkage of contaminated birds; (2) the lack of information regarding the levels of contamination (i.e., slick thickness or spill volume) that will result in bird mortality; and (3) the lack of information to allow assessment of the ecological significance of species-specific bird mortalities.

## CONCLUSION

The group concluded that it would be impractical to design a specific monitoring program to test this hypothesis during the expected life of the project (25 years).

Rationale

Two distinct scenarios were considered in relation to the concern that migrating eiders and diving ducks may be exposed to open water containing oil slicks in areas surrounding offshore structures.

Scenario A: A year when there is virtually no ice movement, and therefore no naturally-occurring open water during the period of bird migration; and

Scenario B: A year when there is ice movement and naturally-occurring open water.

Scenario A appears to have a recurrence interval of between 10 and 20 years. These years would be characterized by no ice movement and the lack of naturally-occurring open water and leads during the period of eider and diving duck migration period (mid-May to mid-June). Therefore, any open water around offshore structures would be caused by thermal discharges.

The annual frequency of chronic oil spills at each of these structures may be relatively high (from 5 to 15 per year, in all offshore areas based on historical records for exploration activities in the Beaufort Sea over the last 3 years; Dome Petroleum unpubl. data). However, most of these spills are unlikely to occur in the open water caused by a thermal discharge, and of those that do, not all may be of sufficient size to cause a slick that is capable of fouling birds. Nevertheless, there is a finite probability of the coincidence of an oil slick and migratory birds, assuming that offshore structures are within the migration path and that migrant eiders and diving ducks will land in open water areas adjacent to offshore platforms.

However, in view of the long recurrence interval (10 to 20 years) of Scenario A and the low joint probability of ducks and oil occurring at the same time and location during the short migration season, it is difficult to recommend a practical monitoring program that could document the impact of such a rare occurrence.

In Scenario B, open water around offshore structures may be caused by a combination of a thermal discharge and ice movement (i.e., open water wake in the lee of the island). However, when ice movement does occur, there would also be large areas of naturally-occurring open water relatively near these structures. There is also no evidence to suggest that migrating ducks would be attracted to offshore structures more than to other areas of open water. Bird observations by industry personnel and others at existing offshore structures in the Beaufort Sea indicate that densities of birds near artificial structures apparently are not different from densities in adjacent open water areas (Dome Petroleum, unpubl. data; Barry et al. 1981; Barry and Barry 1982; Searing et al. 1975). Therefore, an oil slick in artificially created open water during the period of eider and diving duck migration may affect only a very small number of birds. Consequently, the group concluded that a special monitoring program is not warranted.

Notwithstanding the above conclusions, the group indicated that it would be desirable for the operators to continue their existing bird observation programs as a routine operational procedure. These data should continue to be made available to Government agencies. This will ensure that as development proceeds and the number of offshore facilities increases, the basic assumptions and conclusions associated with this hypothesis may be re-evaluated.

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HYPOTHESIS NO. 12

THE EFFECTS OF LOW ALTITUDE AIRCRAFT FLIGHTS
ON STAGING BRANT

Frequent low altitude aircraft flights over staging brant will cause increased overwinter mortality.

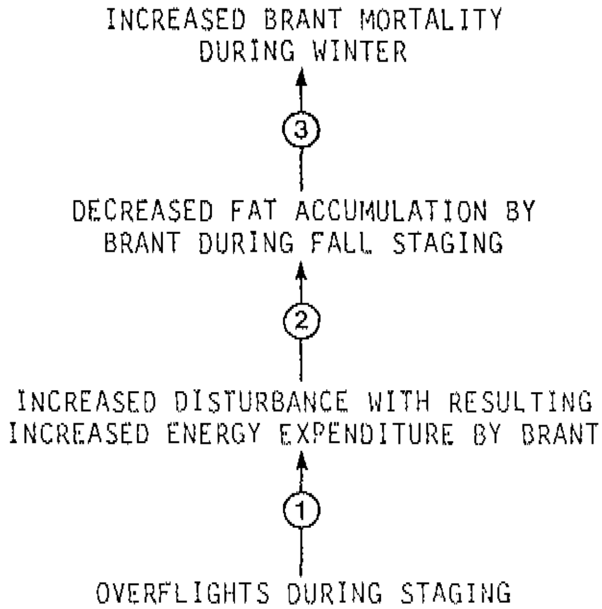


Figure 12-1 Potential effects of low altitude aircraft flights on staging brant

Linkages

1. Aircraft overflights during spring staging of brant will cause disturbances that are reflected in increased energy expenditure.

2. Increased energy expenditure will result in decreased fat accumulation.

3. Decreased fat accumulation will increase overwinter mortality of brant.

## LIST OF PARTICIPANTS

Tom Barry
Robert Everitt
Steve Johnson

## INTRODUCTION

The rationale for consideration of this hypothesis during the workshop was the assumption that staging brant may be affected by low-level aircraft overflights through mechanisms similar to those documented for snow geese (Patterson 1974; Davis and Wiseley 1974; Schweinsburg 1974). The various linkages associated with the hypothesis are shown in Figure 12-1.

## CONCLUSION

Although the workshop subgroup indicated that monitoring could be initiated in relation to this hypothesis, it was concluded that such a program would be impractical and would provide limited relevant information (Tom Barry, pers. comm.). The following rationale for not recommending a monitoring program was presented during discussion of the hypothesis. Although a large proportion of the total Canadian Beaufort Sea brant population can pass along the Beaufort coast in small flocks, and may stop to feed and stage in any one of a dozen different staging areas, they typically remain in these areas for no more than a day or two, depending on weather conditions. This is unlike the migration pattern of snow geese, where very large numbers of birds stage in a few relatively discrete areas for up to a month before migrating long distances (Koski 1977). Furthermore, unlike snow geese which appear to be very susceptible to disturbance by low flying aircraft (Gollop and Davis 1974; Schweinsburg 1974; Gavin 1980), brant are apparently only temporarily displaced as a result of aircraft overflights (Tom Barry, pers. comm.; Koski 1977). Consequently, possible disturbances caused by low-level aircraft flights across any one of these staging areas at any given time would probably have little or no measurable effect on the physiology (e.g., fat accumulation) of staging brant. The group also concluded that it would be virtually impossible to design a practical monitoring program capable of detecting a change in the overwinter brant mortality due to increased low level aircraft flights along the Canadian Beaufort coast during fall staging.

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# HYPOTHESIS NO. 13

## EFFECTS OF HYDROCARBONS AND HEAVY METALS ON FISH HARVEST

Shorebases and shallow water production facilities will release hydrocarbons and heavy metals at sufficient levels such that fish harvest will be reduced through tainting and heavy metal accumulations.

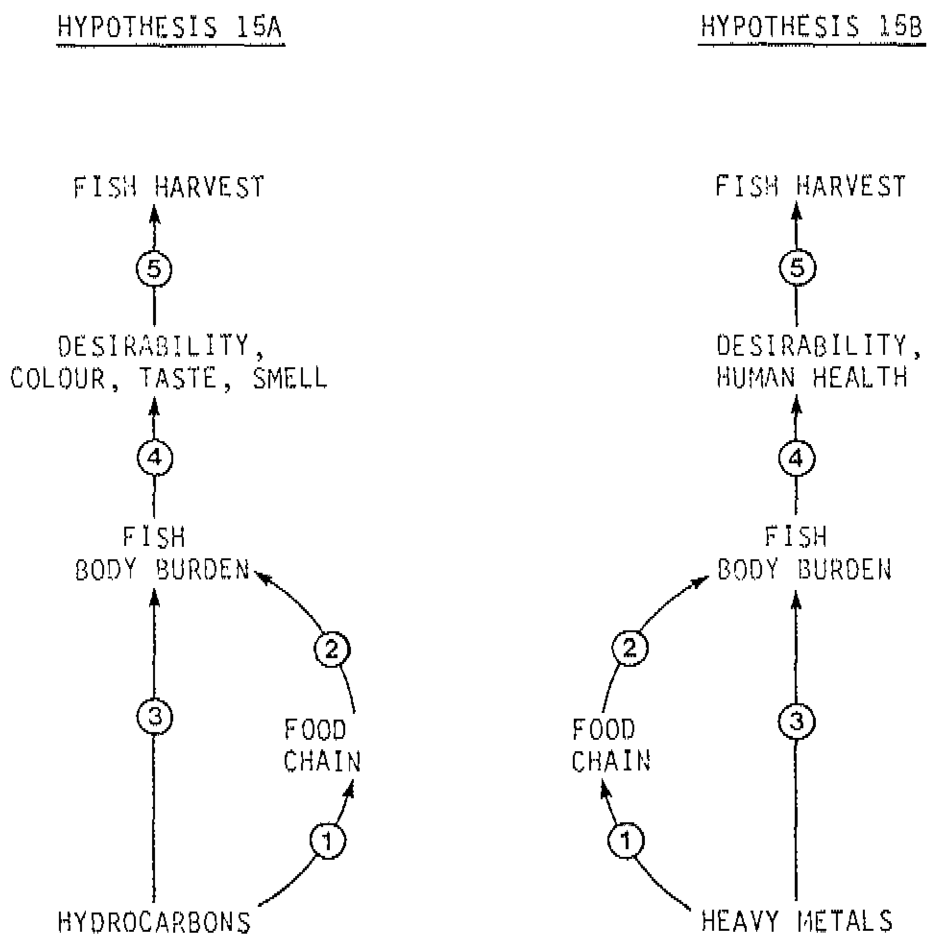


Figure 13-1: Potential effects of release of hydrocarbons and heavy metals on fish harvest

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 the body burden of hydrocarbons.

5. Decreased desirability will decrease fish harvest.

Linkages for Hypothesis 13B

1. and 3. Heavy metals in 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 can be affected by increases in heavy metal concentrations in fish.

5. Decreased desirability will decrease fish harvest.

## NAMES OF PARTICIPANTS

Wayne Barchard
Evan Birchard
Bill Bond
Ted Langtry
Serge Metikosh
Don Schell
Aaron Sekerak
Nicholas Sonntag
David Thomas
Denis Thomson

## INTRODUCTION

Several species of fish, particularly coregonids, are harvested by residents of Tuktoyaktuk and the more inland communities including Aklavik, Fort McPherson and Arctic Red River. However, the actual importance of the domestic harvest in various communities is difficult to estimate because detailed studies have not been conducted in the region. Corkum and McCart (1981) estimated that approximately 14,500 kg of fish were harvested in Tuktoyaktuk Harbour and the Mackenzie Delta area in 1978. Domestic fisheries continue to be important in the region, and a number of members of the working group suggested that there is a potential for future increases in the domestic fish harvest, as well as development of recreational and commercial fisheries. Due to the existing and possible expanding human use of fish in the future and experiences associated with tainting elsewhere in the world, the potential for hydrocarbon or heavy metal contamination and subsequent decrease in fish harvests is an area of potential concern within the Beaufort Sea. The following sections briefly summarize qualitative and quantitive evidence regarding the mechanisms of hydrocarbon and heavy metal uptake by fish, as well as the recommendations of the subgroup on monitoring strategies which may be required to address this question in the Beaufort region. Two closely related hypotheses were examined during the workshop (Figure 13-1), but are discussed separately in the remainder of this section because of clear differences in the degree of potential concern related to these contaminants.

## HYPOTHESIS 13A HYDROCARBONS

The release of hydrocarbons to the marine environment from oil production facilities throughout the world has been well documented (e.g., Cowell 1976; Dome Petroleum et al. 1982. Vol 6.). It has been estimated that from 0.1 to 0.3 percent of all oil produced is lost as a result of accidental chronic or episodic spills and intentional releases associated with normal operations. In the case of some types of chronic oil releases, fish are usually exposed to extremely low hydrocarbon concentrations beyond the immediate vicinity of discharge sites and this exposure is normally brief. For example, hydrocarbon concentrations in sea water resulting from produced water discharge are expected to be in the low ppm range only a few metres away from discharge points in offshore areas, and due to dilution in surrounding waters, quickly become indetectable within tens or several hundreds of metres away from point sources (Thomas et al. 1983). On the other hand, harbours and other sheltered shoreline locations where industrial activities are concentrated can be sites of more frequent hydrocarbon releases, and because dilution rates are generally lower, hydrocarbon concentrations can be higher than in offshore areas. In addition, such nearshore areas are more likely to support fish populations for lengthy periods, thereby increasing the duration of hydrocarbon exposure in comparison with the offshore situation.

## LINKAGES

Links 1 and 3: Hydrocarbons in water and sediments will enter fish and prey organisms of harvested species.

Fish and their food organisms can quickly absorb hydrocarbons through gill epithelia, mucosa and other soft body surfaces (Malins 1977; Teal 1977; Thomson et al. 1981; Dome Petroleum et al. 1982. Vol. 6). Storage or accumulation of petroleum hydrocarbons normally takes place in tissues with a high lipid content (Roubal et al. 1977; Whittle et al. 1977). For example, Neff et al. (1976) found approximately 600 ppm of total naphthalenes in killifish brain tissue after one hour exposure to fuel oil at concentrations of only 2 ppm total naphthalenes, while about 70 ppm of total naphthalenes were measured in muscle tissue. Various other authors have shown that rapid and differential accumulation of hydrocarbons occurs in different fish tissues following exposure to low concentrations of dissolved and dispersed oil in the water column (Varanasi and Malins 1977; Duval and Fink 1980; ESL 1982).

Invertebrates also accumulate hydrocarbons in their tissues (Varanasi and Malins 1977; Thomson et al. 1981; Duval et al. 1981). Bioaccumulation is especially common in invertebrates such as clams, polychaetes and mussels that pass large quantities of contaminated water through or over feeding or respiratory organs (Boehm et al. 1983). Arctic amphipods may survive exposure to high concentrations of oil (Cross and Martin 1983) and could retain a high body burden of oil for considerable periods.

Hydrocarbon depuration rates depend on a range of physiological and external factors such as competing metabolic demands, state of health of the organisms and water temperature but depuration is usually considerably slower than uptake. Some invertebrates are capable of depurating hydrocarbons from body tissues in only a few hours, especially if the exposure concentration is low and the duration of exposure is short (Duval et al. 1981). However, animals that have accumulated hydrocarbons over a long period through exposure to chronic oil pollution have a tendency to depurate hydrocarbons slowly (Boehm and Quinn 1977). Recent experience during the Baffin Island Oil Spill experiment (BIOS) has shown that benthic invertebrates can retain detectable quantities of oil for up to two years after exposure (Boehm 1983).

Link 2: Hydrocarbons are passed through food chains.

Although frequently postulated, uptake and accumulation of hydrocarbons due to ingestion of contaminated prey organisms has not been shown to be a dominant pathway in the tainting of aquatic animals. Hydrocarbons may be absorbed through the gut, although they appear to be quickly excreted and do not generally enter tissues (Teal 1977; Thomson et al. 1981).

Links 4 and 5: Decreased desirability as a result of hydrocarbon body burden will decrease fish harvest.

Concern regarding the tainting (usually reflected in an oily taste or, less commonly, odour) that results from petroleum hydrocarbon accumulation is frequently expressed by the public, and numerous cases of fish tainting following acute (oil spill) exposure to hydrocarbons have been described in the literature (Johnston 1976). A recent occurrence of fish tainting in Canada resulted from an oil spill into the Athabasca River near Fort McMurray. In this instance, tainting resulted in the closure of the Lake Athabasca commercial fishery (Alberta and Canada vs Suncor, Official Transcripts, Edmonton, Alta. 1982).

Most instances of tainting are directly associated with large oil spills, and only a few cases of tainting due to low level chronic releases of petroleum hydrocarbons have been documented. Nevertheless, tainting from chronic and episodic oil releases is considered a potential problem in confined bays and harbours with restricted circulation. Some recent information concerning tainting is available from a study conducted on samples of fish obtained from the harbour at Hay River, N.W.T. A taste testing panel concluded that fish from these waters had an oily flavour; however, the presence of hydrocarbons in fish tissue could not be confirmed during laboratory testing (S. Metikosh, pers.comm.). This may have been due to the subjective nature of taste testing procedures, inadequate controls, or the ability of taste panels to detect the presence of extremely small quantities of specific hydrocarbons and lack of correlation between tainting and standard chemical analyses. Whatever the reason, analytical determinations of hydrocarbon body burden do not always appear capable of detecting tainting.

The desire to harvest fish resources is usually reduced once tainting is detected. It is likely that the mere suspicion of tainting will also decrease the desirability of a particular resource.

## CONCLUSION

Evaluation of available data by the workshop group indicated that Link 2 in Hypothesis 13A (i.e., hydrocarbons are passed through food chains) was invalid or extremely weak, while other linkages were expected to be valid. It was concluded that tainting is unlikely to be a significant concern in any area except sheltered bays (such as Tuktoyaktuk Harbour) where: (1) subsistence fishing takes place; (2) substantial numbers of fish are present for a relatively long period; and (3) hydrocarbons are used and handled on a day-to-day basis at a number of sites.

## MONITORING

It is recommended that a time series measurement of hydrocarbon concentrations in fish flesh (e.g., Arctic cisco, broad whitefish, etc.) be initiated in Tuktoyaktuk Harbour. An inexpensive method for measurement of hydrocarbons should be used to minimize analytical costs and thereby allow analysis of an adequate sample size.

It is also recommended that if (1) time series measurements indicate significant increases in hydrocarbon concentrations within fish flesh; or (2) complaints of tainting occur, complementary programs should be considered to react to either or both of the above concerns. These could consist of a taste testing program and a study to identify the size of the area where tainting is occurring. The latter could involve placement of caged fish in experimental and control areas. Research would probably be necessary to establish the actual source of hydrocarbons that was causing the tainting. A "flow" diagram illustrating the recommended approach to the testing of this hypothesis is provided in Figure 13-2. As indicated in this diagram, monitoring/research activities other than the routine measurement of hydrocarbons in fish flesh would not commence unless: (1) increases in hydrocarbons were apparent in fish flesh; or (2) complaints of tainting occurred.

## HYPOTHESIS 13B HEAVY METALS

Extensive and varied research has been conducted during recent years in relation to the health hazard associated with heavy metal contamination, particularly in the case of mercury (Knauer and Martin 1972; Hardisty et al. 1974a, b; Bohn 1975; Renfro et al. 1975; Stenner and Nickless 1975; Carr et al. 1980; Liss et al. 1980; Neff 1982). It is generally believed that, with the exception of mercury and cadmium, heavy metals are not passed through food chains and, therefore, should not affect human health as indicated by the linkages shown in Figure 13-1. On the other hand, it is well known that mercury bioaccumulates, is passed through food chains and is a hazard to human health (National Research Council of Canada 1980).

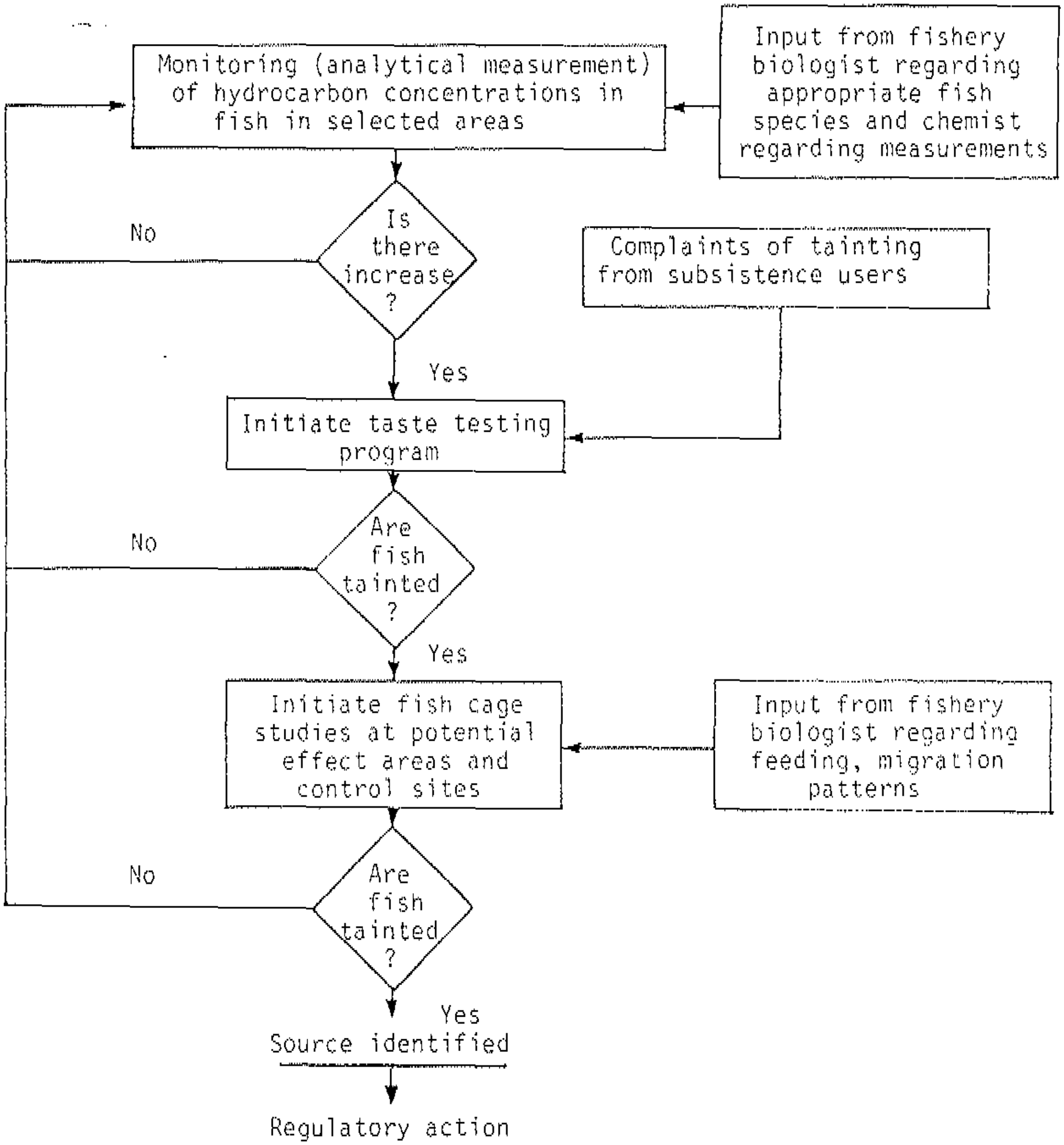


Figure 13-2 Suggested approach to monitoring for tainted fish in selected areas in the Beaufort Sea.

## CONCLUSION

Although the hypothesis was considered valid for mercury, no special monitoring programs were recommended. The workshop subgroup expected that the quantities of heavy metals which would be necessary to represent an area of environmental concern were unlikely to be associated with hydrocarbon development in the Beaufort Sea.

## RECOMMENDATIONS

It was suggested that potential problems associated with heavy metal contamination could be addressed through standardized compliance monitoring of waste streams, as well as screening of materials for heavy metal content before selection and use in the Beaufort Sea.

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HYPOTHESIS NO. 14

THE EFFECTS OF NEARSHORE STRUCTURES
ON BROAD WHITEFISH POPULATIONS

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

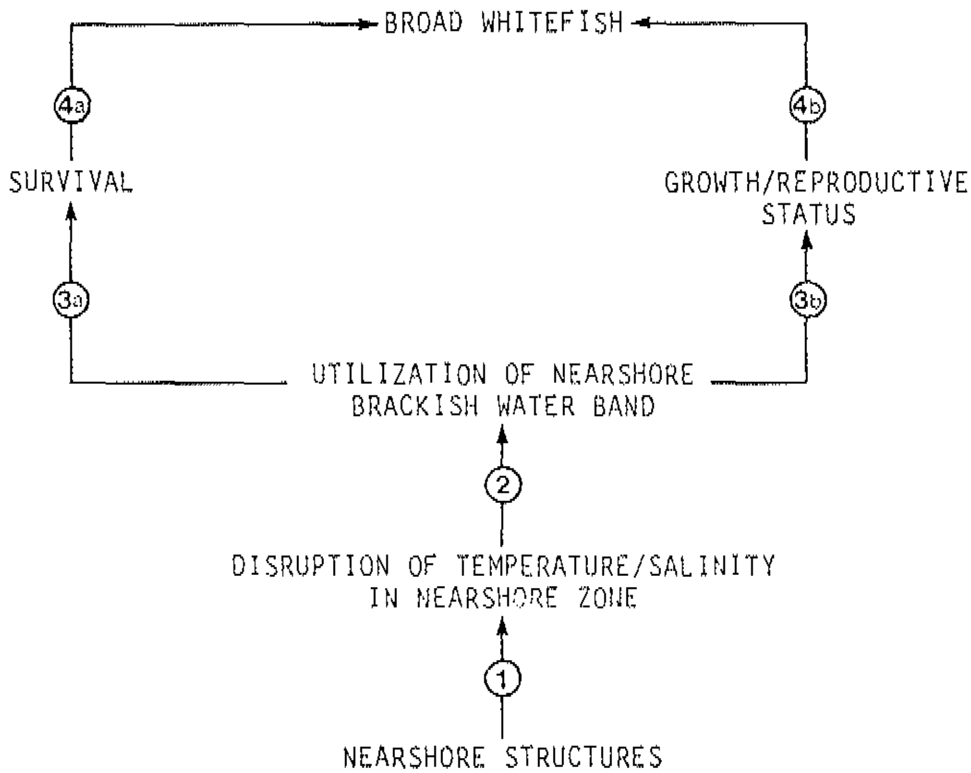


Figure 14-1 Potential effects of nearshore structures on the population of broad whitefish.

Linkages

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

2. Disruption of the brackish water band will result in decreased utilization of the nearshore zone 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 fecundity and reduced viability of eggs and young would result in fewer fish available for the harvest.

## NAMES OF PARTICIPANTS

David Fissel
Benny Gallaway
Bill Griffiths
John Harper
Phil Hill
Dave Marmorek
Langley Muir

## INTRODUCTION

The Mackenzie River populations of broad whitefish (Coregonus nasus) are an important resource to local residents, constituting a major component of the domestic (subsistence) harvest at Tuktoyaktuk, Aklavik and Arctic Red River (Bond 1982). Anticipated increases in the human population over the next two decades are likely to result in increased harvest levels for this species (see Hypothesis No. 13). As well, increased industrial activity in the nearshore waters of the Beaufort Sea may disturb the life cycle of broad whitefish by eliminating access to certain critical areas.

The Mackenzie River stocks of broad whitefish have a rather limited distributional range within the adjacent nearshore waters of the Beaufort Sea. Although classified as anadromous, the species is believed to be relatively sensitive to salinity and to prefer warm over cold water. Although there are no available experimental data on the temperature/salinity preferences and tolerances of this species, the results of field studies conducted in the Alaskan Beaufort have demonstrated significant positive correlations between abundance (catches) and temperature, and inverse relationships between abundance and salinity (e.g., Griffiths and Gallaway 1982; Critchlow 1983; Griffiths et al. 1983). Griffiths et al. (1983) suggested that movements of broad whitefish are in response to the intrusion of a cold-marine water front into warm, brackish nearshore water off the

Sagavanirktok River Delta in Alaska, and that temperature and salinity are probably the major factors controlling the distribution and movements of this species during their seasonal utilization of nearshore waters of the Beaufort Sea.

Important habitats in the Mackenzie Delta region include (1) over-wintering habitat in the main channels and nearshore areas immediately adjacent to the delta *per se*, (2) rearing habitat which consists of lake-stream systems on Tuktoyaktuk Peninsula and in the delta, and (3) migration and foraging habitat within a narrow band along the coast. Based on information from Bond (1982) and Bond and Erikson (1982) and W. Bond (pers. comm.), the expected seasonal use of these habitats is described below.

By October or November, broad whitefish have returned to their overwintering areas, either in lakes on the Tuktoyaktuk Peninsula or in and adjacent to the Mackenzie Delta. After freeze-up and throughout the winter, the fresh water flowing out of the Mackenzie River forms a wedge that moves to the east along the Tuktoyaktuk Peninsula. Available data suggest that broad whitefish move out of the Mackenzie Delta, possibly with the advancing freshwater wedge, so that by early spring (May-June), individuals are present at the mouths of the freshwater stream-lake systems on the Tuktoyaktuk Peninsula. These fish move up the rivers shortly after ice disappearance; the most intense period of migration usually occurs between 20 and 27 June. There is also a downstream movement of broad whitefish starting around 1 July. The fish moving downstream tend to be larger (many of 450 mm in length) than those moving upstream, and at least some are mature spawners. As the open-water season progresses, the freshwater wedge along the Tuktoyaktuk Peninsula is less well defined as surface mixing processes cause cooler marine waters to be close to shore. The broad whitefish that have remained in coastal waters and those that have entered these waters from the peninsula lakes likely move back into the Mackenzie Delta by September. Some small immature individuals appear to remain in the peninsula lakes from 1 to 4 years before returning to coastal waters.

Although knowledge is still incomplete and much of the above is speculation, available information suggests that an interruption or deflection of the nearshore movement of broad whitefish that prevents individuals from entering the freshwater lake system on the Tuktoyaktuk Peninsula could have population-wide effects (e.g., decreases in the number of broad whitefish). This could then be manifested in a reduction in the number of fish available to the subsistence fishery or to any commercial fisheries that may develop in future years.

Development activities in the nearshore zone of the Alaskan Beaufort have involved the construction of solid-fill causeways extending seaward and perpendicular to the coastline for several kilometres. As a direct consequence, longshore flow and temperature and salinity patterns in nearshore habitats have been changed (Chin et al. 1979; Woodward-Clyde Consultants, 1982). There is some concern that similar shoreline alterations in the southern Beaufort Sea might disrupt movement and migration patterns of broad whitefish, resulting in decreased utilization of important habitats and a resultant decrease in the well-being of the population. Since few broad whitefish appear to use nearshore marine waters west of the Mackenzie Delta, workshop discussions focused on areas to the east and on the Delta itself.

## LINKAGES

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

### Winter-Spring Oceanographic Conditions

A review of the limited available data shows that by late spring (April-May), a freshwater band extends to approximately the offshore limit of the landfast ice, which is approximately 30 km wide (Figure 14-2). The growth of the freshwater plume along the peninsula throughout the winter is likely governed by Coriolis and inertial forces. The plume maintains its integrity because of the very low kinetic energy available beneath the ice. However, it should be emphasized that only one set of direct current measurements obtained under the landfast ice is available for the region. Oceanographic Services Inc. (1970) provided one set of current measurements in April 1970 for a site approximately 15 km north of the entrance to Kugmallit Bay, where the maximum daily currents ranged from 5 to 18 cm/s. The under-ice currents are expected to be low for several reasons. The effects of wind mixing are eliminated by ice-cover and tidal mixing is very weak, typically limited to currents of 3 to 5 cm/s or less (Huggett et al. 1975; Henry and Foreman 1977). Due to the relatively low Mackenzie River outflow at this time, residual currents are also expected to be low. Assuming that the maximum pre-freshet river discharge rate of 5000 $m^3/s$ is completely confined to a cross-sectional area which is 5 m deep and 30 km wide, the surface layer flow would amount to only 3 cm/s.

To interfere with the plume spreading along the peninsula, nearshore structures would have to be on the order of the same width (i.e., approximately 30 km) as the presently observed plume which extends to the transition zone in April-May. It was considered unlikely that a structure shorter than this could impede the spreading of the plume along the Tuktoyaktuk Peninsula because the plume is driven primarily by its own inertial spreading. Given the low current velocities of the surface layer, changes in salinity resulting from flow separation or enhanced mixing [as discussed below] in the vicinity of the offshore end of the structure were also expected to be minimal.

On the basis of the above data, it was concluded that piers, causeways, or other structures along the shoreline of the Tuktoyaktuk Peninsula have very little or no likelihood of altering winter or spring dispersal patterns of broad whitefish, since any structure envisaged would not affect salinity patterns during that time of year.

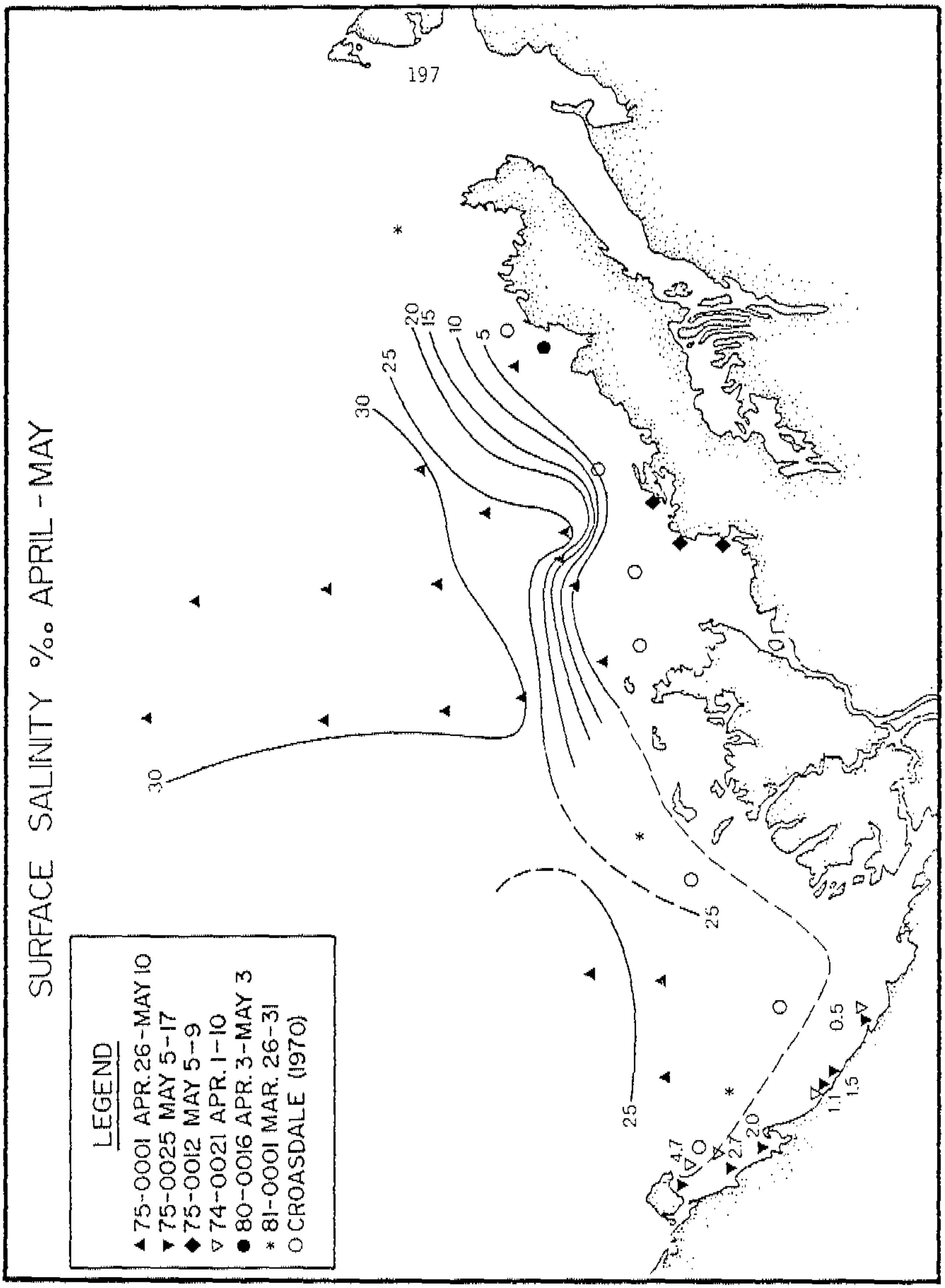


Figure 14-2 A compilation of all known surface salinity data available for months of March, April and May. Data set identification numbers and further detail on times and locations of measurements are provided in Cornford et al. (1982).

## Summer Oceanographic Conditions

Shoreline modifications (primarily causeways) can be expected to disrupt temperature/salinity characteristics in the nearshore zone during the open-water period due to the existence of a wind-driven current pattern, parallel to the coastline (coastal current) in the nearshore zone. This coastal current, in combination with the following oceanographic features, has the potential to disrupt T/S patterns:

1) a flow convergence producing stronger currents exists in the vicinity of the offshore end of the causeway;

2) a flow separation at the outer edge of the causeway producing a backwater zone between the causeway and the inshore edge of the strong flow on the downstream side of the causeway. This area would be expected to have length scales of the same order to an order of magnitude greater than the causeway; and

3) backwater areas created on the leeside of the causeway have a lifetime corresponding to the duration of the wind events (2 to 10 days).

Available data for examination of the existence of a wind-driven coastal current is limited to one site off the Tuktoyaktuk Peninsula (Fissel and Birch, 1984). These data indicate the presence of wind-driven currents parallel to the coastline having speeds of 2 to 3 percent of the wind, up to maximum speeds of 56 cm/s. Similar parallel coastal currents have been observed in the vicinity of the Prudhoe Bay causeway (Chin et al. 1979; Woodward-Clyde Consultants 1982).

Evidence in support of conditions 1 to 3 has been provided by studies conducted in the vicinity of the Prudhoe Bay causeway in Alaska. These studies have shown that causeways can cause local perturbations in the nearshore hydrography (Grider _et al_. 1978), which in turn may have an effect on fish migrations (Griffiths and Gallaway 1982; Critchlow 1983). A brief review of the physical system in the vicinity of the Prudhoe Bay causeway is provided below as background for evaluation of the potential for similar oceanographic mechanisms in proposed hydrocarbon development areas of the southern Beaufort Sea.

Figures 14-3a and 14-3b illustrate the general physical oceanographic conditions around the Prudhoe Bay causeway. Due to the shallow nature of this system, currents are primarily wind-driven. Easterly winds, which are slightly more common than west winds, cause westerly setting currents, whereas the stronger west winds drive easterly setting currents. Most current velocities are less than 50 cm/s in the lagoons, but may be stronger (less than cm/s) near promontories such as the Prudhoe Bay causeway.

The proximity of local rivers to the causeway strongly influences stratification. During easterly wind events, the plume from the Sagavanirktok (Sag) River is deflected to the west, creating a brackish surface layer (20 to 27 ppt) that is approximately 2 m deep. During westerly wind conditions, the "Sag" plume is absent in the causeway area (flow from the Kuparuk River is not large enough to create a distinct plume) and conditions at the causeway are typically well-mixed and marine (30 to 32 ppt salinity).

The circulation near the causeway under easterly winds is illustrated in Figure 14-3b. An anomalous "marine" water zone (salinity 30 to 32 ppt) typically occurs on the lee side of the causeway during these conditions (Chin _et al_. 1979). This "marine" water appears to be either (a) marine water trapped in the lee of the causeway from previous conditions or (b) marine water upwelled as a result of boundary layer separation and lateral entrainment of the marine water. As explained in more detail later, the presence of this "marine" water zone during easterly winds is less desirable

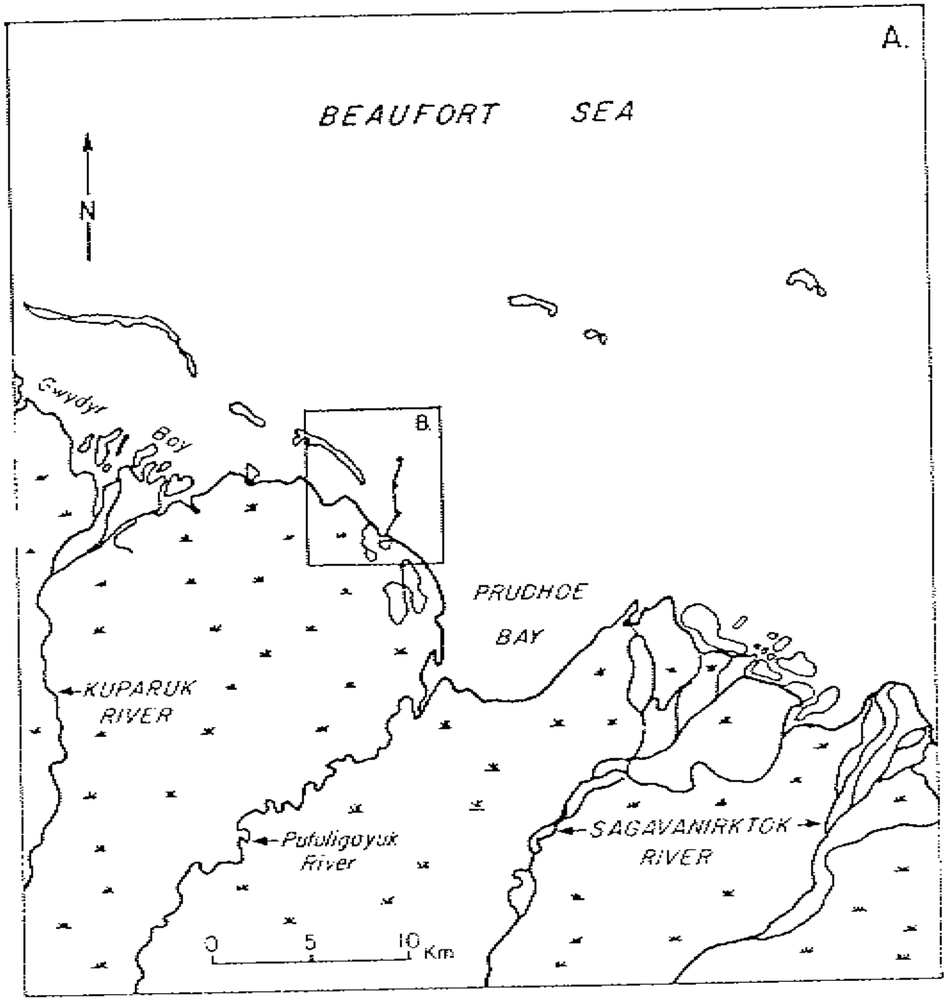


Figure 14-3a General location of Prudhoe Bay causeway.

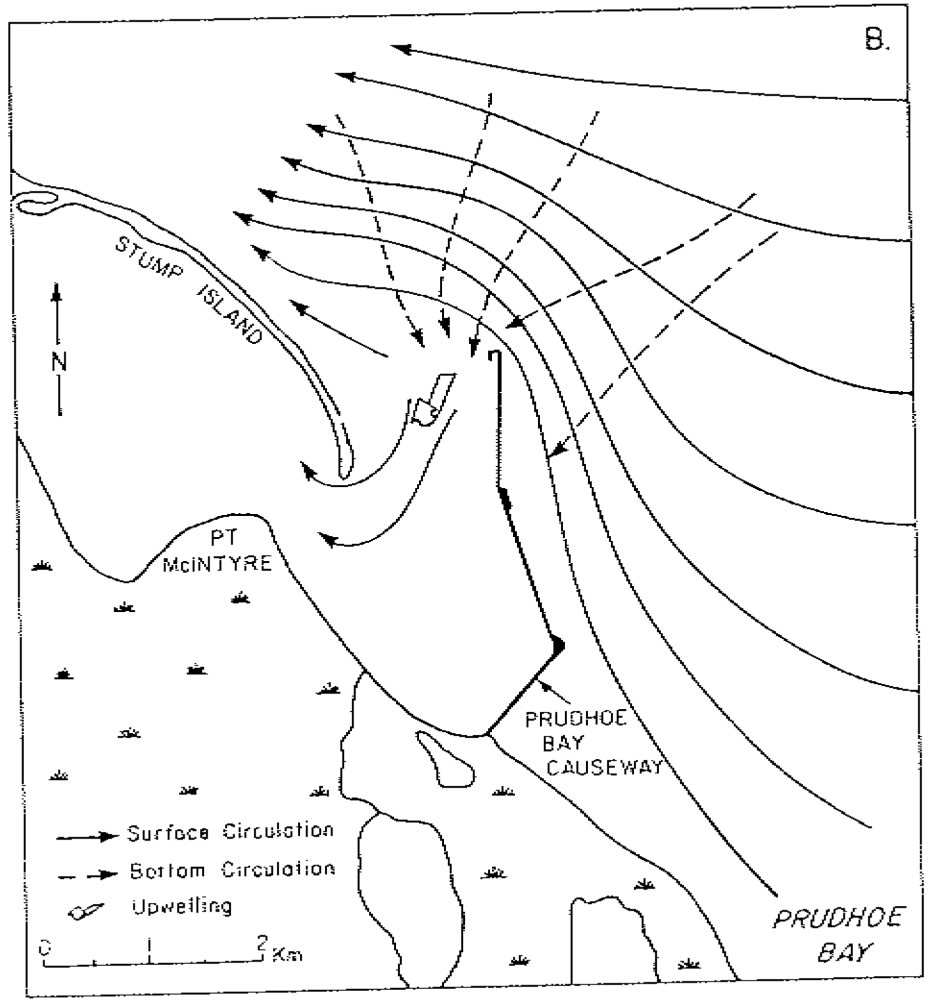


Figure 14-3b Idealized flow characteristics under sustained easterly wind conditions (after Chin et al. 1979).

in terms of fish preferences, and may cause a delay in fish migration. Under westerly wind conditions, the water column is mixed to the bottom and marine-like in all areas around the causeway (Chin et al. 1979; Woodward-Clyde Consultants 1982).

Numerical oceanographic modelling studies completed for the Sagavanirktok River delta (Downing et al. 1983) also suggest that shore-connected causeways can cause discontinuities in coastal temperature and salinity distributions, and that these distributions do affect fish migration patterns. The model was developed to test specific causeway configurations at a single location near the Sagavanirktok River mouth (Figure 14a), immediately east of Prudhoe Bay. The nearshore waters typically show strong vertical and horizontal gradients in temperature and salinity, although the two-dimensional model neglects the vertical density gradients for the sake of simplicity. The specific causeway location tested has distributory channels located within 1 km of the base, and this results in temperature/salinity patterns which are locally complex. The model was run for both easterly and westerly wind conditions. The results of this analysis indicated that salinity and temperature differences occurring across the causeway were typically in the range of 3 to 4 ppt and 1C°, with maximum across-causeway differences of up to 10 ppt (4 to 14 ppt) and 3C° (4.5 to 7.5C°) for a T-shaped causeway.

## Possible Alterations to Temperature/Salinity Characteristics due to a Causeway off the Tuktoyaktuk Peninsula

The occurrence of three specific physical conditions, separately or in combinations, are required in the presence of a causeway for it to cause significant temperature/salinity perturbations: (1) vertical stratification; (2) lateral gradients in temperature/salinity properties extending from the coast seaward to the end of the causeway; and (3) wind reversals. In the case of vertical stratification, the stronger currents at the end of the causeway could induce vertical mixing, which would then result in modification of temperature/salinity properties in the area downstream of the causeway. There is no evidence to support or refute possible vertical stratification in the nearshore zone along the Tuktoyaktuk Peninsula.

If lateral gradients in temperature/salinity extend from the coast seaward, lateral mixing would occur due to flow convergence around the end of the causeway, and this would result in downstream modification of temperature/ salinity properties. Under westerly winds, a pronounced lateral gradient has been observed at depths of 5 to 10 m or greater along the Tuktoyaktuk Peninsula (Cameron 1953; Herlinveaux and de Lange Boom 1975). Given the expected predominance of river water (i.e., warmer and less saline water than offshore) along the coastline, a lateral gradient should extend between the sites of the available observations offshore and the coastline. Under easterly wind conditions, measurements of lateral gradients are very limited. During fisheries studies conducted near Tuft Point in late August 1977, Jones and Den Beste (1977) measured salinities of 15 to 17 ppt a few hundred metres off the coast, compared to 20 to 21 ppt at locations 2 to 3 km from the coast. The existence of horizontal gradients under easterly winds is also suggested in a limited sample of enhanced satellite imagery (Harper and Penland, 1982; Marko and Oberski, 1982).

Upon reversal of wind patterns, one assumption is that the initially occurring temperature characteristics would be preserved in the backwater zone downstream of the causeway. There is no direct evidence that this would occur (requires the presence of a causeway) and the question might best be addressed by means of modelling (Research) as has been done in the case of the Alaskan causeway effects projections.

## Special Case Consideration of a Mackenzie Delta Causeway

An additional special case that might alter broad whitefish movements is a causeway off the Mackenzie Delta. Such a causeway may be constructed in support of a nearshore production field to provide all-weather access, since structures of this type are presently proposed for nearshore fields along the Alaskan Beaufort Sea coast.

The general conditions resulting in oceanographic alterations that were described previously would also apply to the Mackenzie Delta system (i.e., coastal currents exist, flow convergence and acceleration occurs near the offshore end of the causeway, and a horizontal temperature and salinity gradient is developed). Oceanographic conditions in the delta would be a similar case of the lateral gradient case described earlier due to the shallow water depths and lack of vertical stratification.

LANDSAT imagery (Harper and Penland, 1982) and isolated field measurements (McDonald and Martin 1976) suggest that horizontal temperature and salinity gradients are well-defined in the nearshore waters adjacent to the delta. Modelling studies conducted for a similar type delta-front in Alaska (Downing et al. 1983) show that causeway presence can cause marked across-causeway gradients in both temperature and salinity.

Although remote sensing and field measurements have documented the existence of well-defined horizontal gradients in the Mackenzie Delta area, no systematic study of the magnitude of currents, temperature/salinity distributions or driving forces (wind, density) has been completed to date. In addition, there is no available information on temporal variability in these processes.

Summary

Studies in the Alaskan Beaufort Sea have shown that natural temperature/ salinity regimes can be disrupted by man-made structures in nearshore waters. At the present time, there are insufficient data on natural conditions in waters off the Mackenzie Delta and to the east to accurately predict possible changes in the Canadian Beaufort due to causeways. However, the potential for change appears to be restricted to the open-water period.

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

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

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

Link 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.

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

Bond (1982) found that broad whitefish tend to remain inshore during the open-water season. For example, broad whitefish were never taken offshore in Kugmallit Bay and appeared to avoid even the deep waters within Tuktoyaktuk Harbour. Galbraith and Hunter (1975) reported the presence of broad whitefish in nearshore waters along the coast of the Tuktoyaktuk Peninsula, but did not capture any individuals in the deeper offshore waters. Broad whitefish appear to have a limited distribution in the nearshore waters adjacent to the Mackenzie Delta. A similar distribution pattern for this species has been found in the Sagavanirktok Delta area of the Alaskan Beaufort Sea (Griffiths et al. 1983). These authors found that the abundance of broad whitefish was significantly and positively correlated with temperature, and in 9 of 16 cases, was also significantly and inversely correlated with salinity. Griffiths et al. (1983) suggest that broad whitefish prefer habitats with warm brackish waters, all other factors being equal. At this time, it is not actually known if the observed and suspected distributional patterns of broad whitefish are indeed related to temperature and salinity. To date, the only pertinent study of a fish species found in the southern Beaufort Sea has been conducted with Arctic cisco (Fechhelm et al. 1983). The results of this modelling study indicated that Arctic cisco prefer warm brackish water over cold saline water, and the model outputs were used to mimic movement and habitat utilization patterns observed in concurrent field studies (Neill et al. 1983; Fechhelm and Gallaway 1983). Consequently, there is a possibility that the distribution patterns of broad whitefish could be altered in a manner that results in a loss of feeding time (Link 3b) during the brief open-water period, or increased mortality (Link 3a) due to salinity-induced stress. If either of these effects occurred, a reduction in the population of broad whitefish could result.

Although there is a potential that shorebased developments may affect the distribution patterns of broad whitefish, these structures may not, in fact, be barriers to fish. Craig and Griffiths (1981) and Griffiths and Gallaway (1982) showed that the ARCO causeway in Prudhoe Bay was not a barrier to migration of large (>250 mm) anadromous fishes, although the evidence regarding small (<250 mm) anadromous fishes was not conclusive.

## CONCLUSIONS

It was concluded that there are insufficient data to reject or accept the hypothesis that nearshore structures will disrupt the nearshore band of warm brackish water and reduce the broad whitefish population. However, at the present time, the development scenario for the region does not include structures that appear to have a reasonable potential to alter nearshore oceanographic conditions and, in turn, alter broad whitefish movements. Consequently, monitoring or research programs are not recommended at the present time. However, if future development plans change and include major structures connected to the shore, this area of potential concern and the need for research and monitoring should be re-examined.

## RECOMMENDED RESEARCH AND MONITORING PRIORITIES

No further research or monitoring is recommended at the present time, but if development plans change and the potential for interference with fish movements is increased, the following research and monitoring programs should be given future consideration.

### Research

1. Studies of winds oceanographic conditions, T/S profiles, current meter measurements along with concurrent wind data in nearshore waters within the general areas where structures may be built, or more site- specific observations if detailed project plans are available.

2. Studies on the population dynamics of broad whitefish to determine the potential population-wide significance of interference with their normal movement patterns.

3. Oceanographic research on the actual formation of a warm brackish water band adjacent to the coastline.

4. The preferential use of this habitat (if it exists) by broad whitefish.

Monitoring

If further research indicates that (1) there is a potential for disruption of broad whitefish movements, and (2) this disruption could reduce fish populations, a monitoring program including the following components should be initiated.

1. Detailed documentation of winds, currents, temperature, salinity, and other pertinent oceanographic conditions at the site of the proposed structure before and after construction.

2. Detailed studies on use of the nearshore waters by broad whitefish.

3. Laboratory studies of the growth and temperature/salinity preferences of broad whitefish to allow predictions concerning the direction and velocity of movements over small spatial/temporal scales.

4. Modelling to allow verification that the post-causeway fish distributions may or may not be solely explained by temperature/salinity conditions alone.

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# HYPOTHESIS NO. 15

## THE 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.

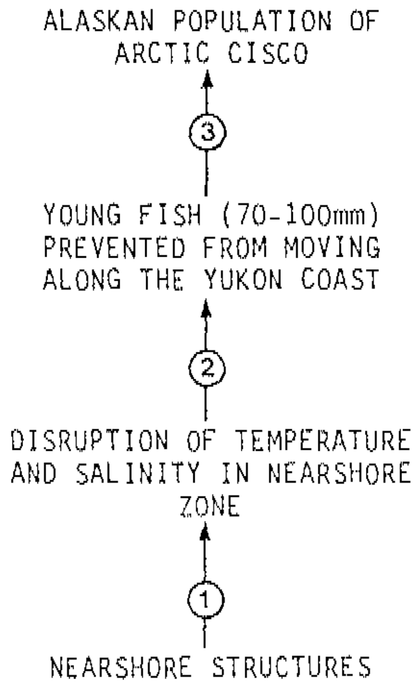


Figure 15-1 Potential effects of nearshore structures on the Alaskan population of Arctic cisco.

## 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.

## NAMES OF PARTICIPANTS

| | |
|---|---|
| Bill Bond | John Harper |
| David Fissel | Phil Hill |
| Benny Gallaway | Dave Marmorek |
| Bill Griffiths | Langley Muir |

## INTRODUCTION

The Arctic cisco (Coregonus autumnalis) is one of the most abundant and valued of the anadromous fishes occurring along both the Alaskan and Canadian arctic coastlines. In Alaska, Arctic cisco are presently harvested in seasonal subsistence fisheries at the villages of Nuiqsut (Colville Delta) and Kaktovik (Barter Island), as well as in a commercial fishery in the Colville Delta. The latter has been in continuous operation since 1967, and has involved a harvest of up to 71,000 Arctic cisco annually. In Canada, Arctic cisco also represent an important component of the subsistence fishery in the Mackenzie River and Delta regions (Hatfield et al. 1972), although there is presently no commercial fishery for Arctic cisco in this area.

The recruitment of the Arctic cisco in Alaska could be affected by nearshore developments that cause a disruption in the distribution of juvenile fish between the Mackenzie Delta and the Alaskan Beaufort Sea coast, since the Mackenzie River stock may be the source of the Alaskan population.

## BACKGROUND

This section briefly describes the general distribution and life history of Arctic cisco in the Beaufort region. This information is necessary to provide the background for discussion of the potential effects of the presence of a nearshore structure (particularly on the Yukon Coast) on the distribution and abundance of this species, and is largely taken from Gallaway et al. (1983) and Craig and Griffiths (1981).

Arctic cisco range from Point Barrow, Alaska, to Bathurst Inlet, Northwest Territories. Their distribution is apparently centred in the brackish waters around the Mackenzie (Canada) and Colville (Alaska) river deltas, which are habitats used for overwintering following summer feeding dispersals into the nearshore areas of the Beaufort Sea. Gallaway et al. (1983) suggest that the Mackenzie system may support the only spawning stock of Arctic cisco in the region, rather than there being two stocks - one associated with the Mackenzie River and the other with the Colville River (Figure 15-2). These authors postulate that spawning occurs in the Mackenzie River system in fall; young-of-the-year use the delta as nursery grounds during their first summer, and overwinter in this area. Some young-of-the-year may also be transported into the nearshore region during the spring freshet. At age 1, the small fish move into the nearshore environment during the summer to disperse and feed along the coast. Some unknown proportion of the population disperses to the west, and at some point are entrained by the net westward-flowing nearshore currents off the Alaskan North Slope coast. Near the approach of freeze-up, the Colville River and other rivers (e.g., Sagavanirktok River) provide brackish overwintering habitat in their lower delta areas adjacent to the sea. Arctic cisco that have been transported into Alaska use the Colville and other suitable river delta habitats on the Alaska North Slope until they attain sexual maturity and a size which enables individuals to contend with the longshore currents. At this time, Arctic cisco are expected to seek their natal stream in the Mackenzie River system to spawn. This postulated life history is generally consistent with the observed patterns of seasonal abundance and distribution of Arctic cisco found throughout the nearshore waters of the Beaufort Sea.

The hypothesis considered during the workshop centered around the construction of a solid-fill causeway or docking facility at some location along the Yukon Coast between the Mackenzie Delta and Herschel Island, and the possible effects of this type of development on the Alaskan stock of Arctic cisco. A flow chart showing the linkages for this hypothesis is presented in Figure 15-1.

## LINKAGES

Link 1: Shoreline modification will change temperature and salinity of the brackish water band along the Yukon Coast during summer.

As indicated earlier in discussions of broad whitefish along the Tuktoyaktuk Peninsula (Hypothesis No. 14), a nearshore structure could cause a disruption in the primarily wind-driven coastal currents. However, there is considerably more uncertainty regarding the nature of the nearshore currents off the Yukon coastline than along the Tuktoyaktuk Peninsula. This is the result of:

1) the lack of any direct current measurements; and
2) the possibility that the current patterns in this area may be more complex due to a combination of: (a) the proximity of the constricted passage between the coastline and Herschel Island; (b) the variable proximity of the Mackenzie River plume; and (c) the steep bathymetric gradients which exist to within 1 - 2 km of the coastline.

These influences could result in variations in the coastal currents which are not simply related to the local wind patterns.

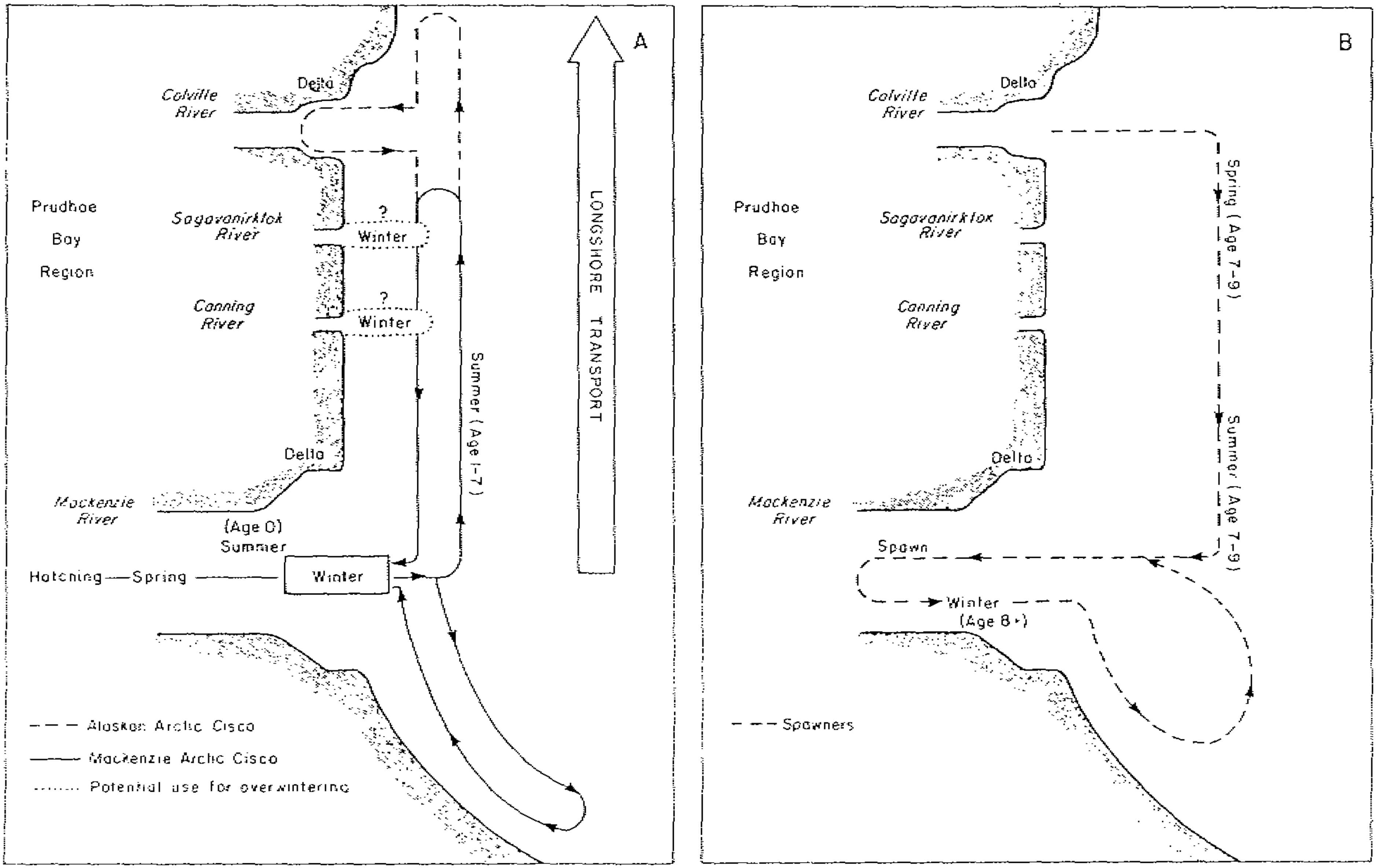


Figure 15-2 Conceptual model of Arctic cisco.

As indicated earlier (Hypothesis No. 14), the occurrence of three specific physical conditions (separately or in combination) are required before there is any temperature/salinity modification due to a nearshore structure. In the first case, vertical stratification is required to enable vertical mixing effect in the lee of the structure. Scattered sets of physical oceanographic data collected in the summers of 1960 (Grainger and Lovrity 1975) and 1975 (Kendel et al. 1975; Griffiths et al. 1977) indicate that vertical stratification is possible along the Yukon coastline, with warmer, less saline water overlaying a colder, more saline Arctic Ocean water to depths of 3 to 5 m. However, the existing summer T/S data are very limited (approximately ten sets of vertical profiles), and additional time series measurements are required to describe fully the temporal and spatial variations of vertical structuring in nearshore areas along the Yukon coastline.

In the second case, temperature and salinity properties of the water column can also be modified through mixing of lateral gradients near the end of the structure. However, there is virtually no direct information on the existence or amplitude of lateral gradients in T/S within the nearshore zone of the Yukon coastline. Based on satellite imagery (Harper and Penland 1982; Marko and Oberski 1982), and limited oceanographic data collected along the eastern end of the Yukon coastline (Fraker et al. 1979), large spatial gradients in temperature and salinity are known to occur at distances of a few kilometres to up to tens of kilometres along the coastline. The satellite imagery study of Marko and Oberski (1982) indicated that strong prolonged easterly winds deflect the Mackenzie River plume along the Yukon coastline, occasionally as far west as Kay Point. These authors observed thermal gradients over horizontal scales ranging from less than 5 km to approximately 10 - 15 km. During another period when the prevailing winds were easterly, enhanced Landsat imagery suggested that coastal upwelling resulted in a narrow band of cold saline water (Harper and Penland 1982). In this situation with easterly winds, upwelling was presumably evident because the Mackenzie plume had not yet reached the Yukon coastline. Thus, it appears that easterly winds during the summer can result in highly variable conditions off the Yukon coast. Under the influence of westerly winds, cooler more saline waters occur off the Yukon coast. This is in contrast to the situation off the Tuktoyaktuk Peninsula where the greater influence of the Mackenzie River plume results in warmer, more brackish characteristics. In addition, peak discharge from local Yukon rivers, may also result in lateral T/S gradients within the nearshore zone.

In the third case, T/S modification can also occur when wind patterns reverse, resulting in the maintenance of previous T/S properties in the backwater zone. As indicated in discussion of Hypothesis No. 14, questions related to modification of T/S properties in a backwater zone can only be addressed through modelling studies or after actual causeway construction.

Link 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.

The hypothesis that disruption of the temperature and salinity patterns of the nearshore brackish band could affect Arctic cisco distribution, and subsequently Arctic cisco harvest, is predicated on the assumption that this species utilizes and is typically found in a nearshore band of brackish water. Evidence for this assumption has been steadily increasing over the last few years. Numerous gillnet studies (this sampling method is biased towards the capture of large individuals) conducted from Point Barrow, Alaska to the Mackenzie Delta have shown that large Arctic cisco are typically most abundant within 1 km of the mainland shoreline. Studies conducted with fyke nets (which capture all sizes of fish) from the Prudhoe Bay region to near Demarcation Bay (Alaska - Yukon border) have demonstrated that all size groups of Arctic cisco tend to be most abundant adjacent to shore. In addition, laboratory studies have shown that small Arctic cisco have a temperature preference in the range from 10 to 15°C (Fechhelm et al. 1983), suggesting that they are most likely to be found in the warmest water available. Computer models using temperature, salinity and currents as the driving forces have generated catch-per-unit-efforts (CPUE) that are generally consistent with actual CPUE data from field studies (Fechhelm and Gallaway 1983). In view of all this evidence, it appears likely that Arctic cisco do utilize a nearshore band of warmer brackish water and, as a result, disruptions to this band could cause alterations in the local distribution of this species. However, it must also be emphasized that Arctic cisco can and do tolerate wide ranges in both temperature and salinity, and that under certain wind/current conditions the nearshore band of brackish water breaks down naturally. Causeway development along the Yukon coast may therefore alter the physical environment in a manner that occurs naturally at the present time. The pertinent question is whether the "population" would have the ability to continue normal dispersal patterns in the presence of such alterations, or if the changes would result in disruption of longshore fish movement.

Link 3: Decreased movement of Arctic cisco will cause directly proportional decreases in the Alaskan population of Arctic cisco.

Link 3 is based on an assumption that the Alaskan harvest of Arctic cisco is directly dependent on the number of small (age 1 and 2) Arctic cisco which migrate into Alaska from the Canadian Beaufort. The evidence in support of this hypothesis is described by Gallaway et al. (1983). From 1967 to 1981, the annual harvest of Arctic cisco by the Alaskan commercial fishery in the Colville River ranged from 9268 to 71,575. The fish taken ranged from 240 to 380 mm fork length and, although the harvest is conducted during and after the spawning season, few spawners or sexually mature fish are captured. Using the population dynamics model of Deriso (1980), Gallaway et al. (1983) were able to mimic the catch/effort trends of the fishery over the period of record. When simulating numbers of catchable-sized fish, the model was responsive to the actual trend if (1) a 5-year lag between appearance of small fish and their entry into the fishery was employed in the model; and (2) it was assumed that very few spawners were taken by the fishery. However, the major parameter contributing to the good correlation between simulated and actual harvests was a stock-recruitment relationship indicating a strong density dependence. It should be noted that the density dependence was unusually strong, and from a temporal standpoint, periods of low recruitment corresponded to "bad" ice years. It is therefore possible that the dynamics of the fishery correspond to irregular environmental events which either enhance or reduce the extent of movement of small Arctic cisco from the Canadian Beaufort into Alaskan waters.

The workshop subgroup considered any direct evidence that causeways would interrupt this dispersal process, and concluded that although delays may be possible, the question of completely interrupted movement of Arctic cisco could not be satisfactorily addressed on the basis of existing information. For example, a major recruitment of young Arctic cisco was observed in the area east of the Prudhoe Bay and the Prudhoe Bay causeway during 1981. A large proportion of these fish are known to have remained east of the causeway for a 3-year period, and to have used the Sagavanirktok River Delta region as both summer feeding and overwintering habitat. It is possible that these individuals were prevented from travelling westward into the region of the Colville River Delta by the causeway, although it is equally feasible that a certain portion of the Arctic cisco population always use the Sag Delta area. There are insufficient preconstruction data to test reliably either hypothesis, although trends in the Colville River commercial fishery over the next 2 to 3 years should allow evaluation of whether or not the Prudhoe Bay causeway has affected the distribution of Arctic cisco in Alaska.

## CONCLUSION

The group concluded that links in the hypothesis could not be proved or disproved on the basis of existing information, and that there was no strong evidence for rejection of the overall hypothesis. The rationale for these conclusions is summarized as follows.

Link 1: Although some aspects of the physical oceanographic regime are quite uncertain (e.g., currents), the group concluded that the potential for disruption of the nearshore temperature/salinity regime was probably greater along the Yukon Coast than along the Tuktoyaktuk peninsula.

Link 2: While Arctic cisco are known to be less sensitive to high salinities than broad whitefish, previous laboratory, field and modelling studies in Alaska have shown that causeways can significantly affect Arctic cisco distribution.

Link 3: Although it has not been conclusively demonstrated that Alaskan stocks of Arctic cisco originate from the Mackenzie Delta, existing evidence is consistent with this hypothesis. Therefore, if links 1 and 2 are valid, the Alaskan Arctic cisco populations could show significant declines as a result of nearshore T/S alterations.

## RESEARCH

The workshop group recommended that research should be conducted in view of the possibility that some form of shoreline alteration may be associated with the construction of a shorebase on the Yukon coast (e.g., current Stokes Point or King Point development scenarios; Dome Petroleum et al. 1982).

Research would be required to address several of the above uncertainties. Oceanographic research should include direct wind and current measurements in the nearshore zone along the Yukon coast over an extended period of time, beginning as early in the open-water season as possible. At two or three locations, current, temperature and salinity data should be obtained. At each location, current meters should be deployed in both the surface layer and near the bottom, anticipating a deeper arctic water subsurface layer. Research is also required to determine the spatial variability in temperature and salinity within the surface layer of the nearshore zone along the Yukon coast. This should consist of a small scale CTD survey under varying wind conditions in the vicinity of a proposed causeway site. Landsat imagery of the thermal band and data on the volumes of local river discharges should be collected simultaneously with the CTD surveys.

Biological research should be conducted simultaneously with the oceanographic investigations. Arctic cisco movements along the coast should be examined in relation to time, location, and the stage of development (e.g., age, maturity) of migrants, as well as possible controlling environmental stimuli (i.e., concurrent oceanographic program). In addition, the "population" or number of migrants should be estimated to allow evaluation of the overall significance of the movements.

## MONITORING

If the above research indicates a potential for disruption of movements of Arctic cisco and a causeway is eventually proposed, a monitoring program may then be necessary. The program would likely have to include the following components:

1) Detailed oceanographic measurements in the area before and after construction. This latter program should include daily measurements at various sites in the vicinity of the causeway. It would also be necessary to undertake synoptic measurements of daily river discharge during both the pre- and post- development monitoring programs due to the contribution of warm, fresh water from local rivers (e.g., Babbage River) to the Yukon coastal zone,

2) Detailed examinations of Arctic cisco movement (including tagging studies) in the area before and after construction.

3) Complementary modelling studies (e.g., Neill et al. 1983, Fechhelm and Gallaway 1983) to provide quantitative estimates of the effects of the causeway on movement and distributional patterns of Arctic cisco.

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# HYPOTHESIS NO. 16

## EFFECTS OF PRODUCTION FIELDS AND DISCHARGE OF POLLUTANTS ON ARCTIC CISCO AND BROAD WHITEFISH POPULATIONS

The construction of shorebases and shallow production fields will result in a decrease in the populations of Arctic cisco and broad whitefish.

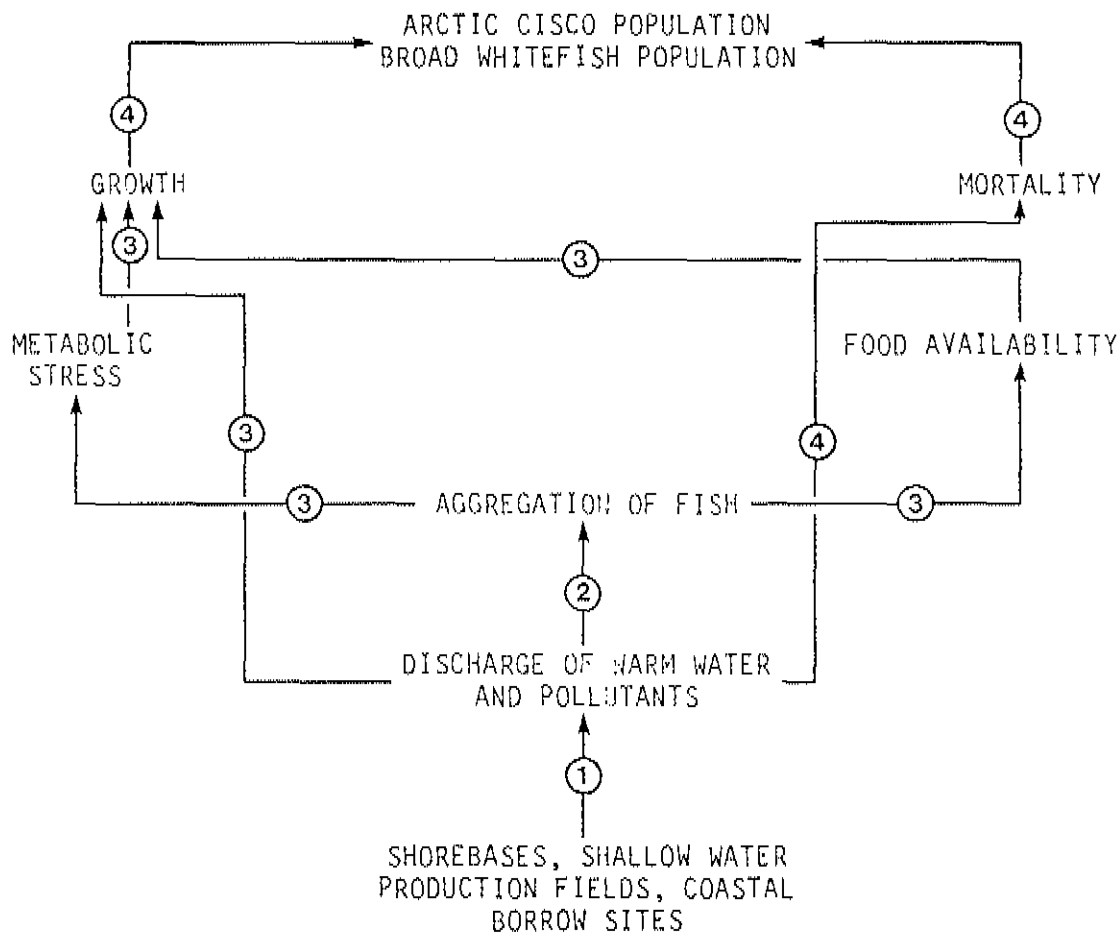


Figure 16-1. Potential effects of discharges from production fields and other facilities on Arctic cisco and broad whitefish populations.

Linkages

1. Warm water effluents and produced water will be discharged into marine waters during hydrocarbon production.

2. Fish will be attracted to thermal plumes.

3. Contaminants in produced water and aggregations of fish 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.

## NAMES OF PARTICIPANTS

Bill Bond
David Fissel
Benny Gallaway
Bill Griffiths
Phil Hill
Dave Marmorek
Langley Muir
David Thomas

## INTRODUCTION

Concerns regarding the potential effects of produced water discharges into shallow water coastal zones on broad whitefish and Arctic cisco populations were the primary reason for formulation of the hypothesis shown in Figure 16-1. Produced waters contain varying concentrations of petroleum hydrocarbons and trace metals, have elevated salinities and are often substantially warmer (estimated temperature of about 40°C) than ambient water temperatures (Thomas et al. 1983). Cooling water may also be discharged at offshore production facilities, and although total volumes may be comparable to quantities of produced water, cooling water would be characterized by a lower temperature (20°C) and near ambient salinity. As indicated in Figure 16-1, the thermal aspects of the waste discharges could result in aggregations of fish, thereby increasing their residence time in a zone where exposure to contaminants may lead to lethal and sublethal effects.

The hypothesis was considered by the workshop participants on the basis of a development scenario which does not involve production facilities sited in water depths less than 5 m.

# LINKAGES

Link 1: Warm water effluents and produced water will be discharged into marine waters during hydrocarbon production.

The first step in evaluation of this hypothesis was a review of the quantities of produced water which may be discharged from offshore and nearshore production facilities. It was assumed that a single production field at an offshore location (depths greater than 15 m) might consist of 20 wells having a combined produced water discharge of 16,000 $m^3$/d. In shallow water locations (depth between 5 and 15 m), the number of wells was assumed to be reduced by a factor of 5, with a commensurate reduction in discharge volume. These daily discharge rates were subsequently used to assess the potential magnitude of local changes in temperature and salinity, and elevated contaminant levels, that may be associated with production waste discharge.

Link 2: Fish will be attracted to thermal plumes.

Link 3: Contaminants in produced water and aggregations of fish will result in increased stress, reduced food availability and decreased fish growth.

During the ice-free season, the probability of thermal enhancement resulting from produced water discharge in shallow areas (at an assumed release rate of 3000 $m^3$/d) would be exceedingly remote due to very large dilution rates expected in these relatively high energy environments. Contaminant concentrations would also not be expected to reach levels that could be hazardous to biota, except perhaps in the immediate vicinity of a discharge site (approximately limited to within 200 m of the source [Thomas et al. 1983]). Contaminant concentrations could be higher during periods of ice cover, but available data suggest that anadromous fish are absent or scarce in waters greater than 5 m deep during winter.

Monitoring programs undertaken in other hydrocarbon production regions, particularly in the Gulf of Mexico (Rose and Ward 1981; Gallaway et al. 1981), indicate that effluent streams from production platforms in deeper waters are diluted very rapidly, and that resultant biological effects are minimal. For example, after a 4-year study in the Gulf of Mexico, Gallaway et al. (1981) concluded that:

1) The major effect of the Buccaneer Field was to provide a substrate that allowed development of a rich and diverse biofouling or artificial reef community;

2) The structures and reefs caused the aggregation of nektonic species preferring these habitats, as well as the subsequent attraction of various predators (particularly man);

3) Produced waters were toxic, although the direct effects on biota were restricted to organisms in habitats within a few metres of the outfall;

4) Indirect effects of chronic, low-level contaminant discharge were not shown to be significant;

5) Measurable uptake of contaminants appeared minimal and restricted to those species present in the biofouling food chain, and there was little evidence of bioaccumulation; and

6) The effects of the recreational fishery on fish were suggested to be an area of greater concern than the effects of the Buccaneer Field on either the fish or the recreational fishery.

## CONCLUSIONS

The workshop participants concluded that the impact hypothesis was extremely unlikely and not worth further consideration if wastes are discharged in waters greater than 5 m deep.

The most serious potential concerns related to the effects of produced water discharge on fish would be expected when a production platform is located in an area where temperature-sensitive species or life-history stages are present and a solid ice-cover simultaneously results in substantially reduced energy for mixing and dispersal. This situation could occur in shallow nearshore areas along the Tuktoyaktuk Peninsula prior to freshet (mid-May) but after the advance of the freshwater plume (e.g., Jan - Feb). Although hydrocarbon developments are not presently being considered in such areas, if a development satisfying the above criteria is proposed in the future, additional research to examine potential impacts and necessary mitigative measures would be warranted.

## MONITORING

Other than compliance monitoring to assure that regulatory guidelines are achieved in both shorebase and offshore waste streams, no monitoring was considered necessary if production wastes are discharged in waters greater than 5 m deep.

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# HYPOTHESIS NO. 17

## EFFECTS OF WATER INTAKE ON BROAD WHITEFISH AND ARCTIC CISCO POPULATIONS

Water intakes will reduce populations of broad whitefish and Arctic cisco.

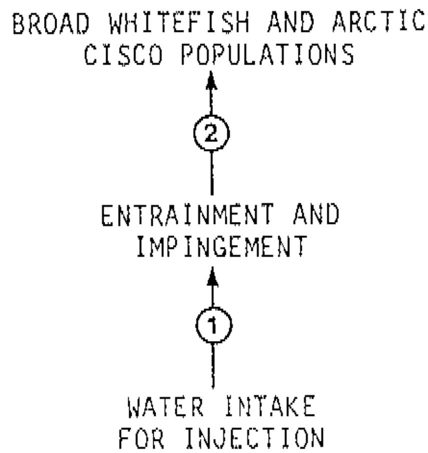


Figure 17-1 Potential effects of water intake on broad whitefish and Arctic cisco populations.

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.

## NAMES OF PARTICIPANTS

| | |
|---|---|
| Wayne Barchard | Phil Hill |
| Bill Bond | Dave Marmorek |
| Benny Gallaway | Langley Muir |
| Phil Hill | David Thomas |

## INTRODUCTION

Waterflooding is a secondary recovery process whereby filtered sea water is pumped into the reservoir to increase pressure for continued extraction of oil in the mid- to late stages of production. Several waterflood projects are planned in the Alaskan Beaufort. These include one for the Prudhoe Bay Field at the tip of the Prudhoe Bay causeway which will be operative in 1984, a second for the Kuparuk Field located at Oliktok Point which is also expected to be in operation within the near future (1984-86), and two others (Endicott Project and Lisburne Project) in the Prudhoe Bay area which are scheduled before 1990. Each of these intake structures will be located in the nearshore habitats that are most extensively utilized by anadromous fish (Griffiths et al. 1983; Griffiths and Gallaway 1982).

Available data for the Prudhoe Bay field and Endicott waterflood projects indicate that typical intake volumes may approximate 320,000 $m^3$/d or 3.5 $m^3$/sec (Woodward-Clyde Consultants 1982). At the intake structures, water velocities will be approximately 15 cm/s. The degree to which small anadromous fish may be entrained and impinged on intake screens under these conditions is presently unknown because such waterflood projects have not been initiated in the Arctic. However, entrainment and impingement losses associated with the cooling water intakes of nuclear and fossil fuel power plants can be high (Gallaway and Strawn 1974; Uziel 1980). Waterflooding has not yet been proposed in relation to hydrocarbon development in the Canadian Beaufort, but was considered during the present workshop due to potential widespread use in Alaska.

## LINKAGES

Link 1: The intake of water for reservoir injection will cause entrainment and impingement of juvenile broad whitefish and Arctic cisco.

Link 2: The mortality associated with entrainment and impingement will reduce broad whitefish and Arctic cisco populations.

The workshop subgroup suggested that these links were possible but not very probable in the Canadian Beaufort Sea. The following rationale was presented for this conclusion. ADGO is the only nearshore field that is currently under consideration for development (Dome Petroleum *et al*. 1982, Vol. 2). Therefore, most of the nearshore waters of the outer Mackenzie Delta and the nearshore zone (depths less than 3 m) utilized by broad whitefish and Arctic cisco are unlikely to be sites of water intake for potential waterflood projects. In the case of ADGO, the oil production rate has been estimated at approximately 110 $m^3$/d (Evan Birchard, pers. comm.). If it is assumed that injection water would be required after five years of operation, only about 200,000 $m^3$ of water would be necessary to replace the oil. This represents only about 60 percent of the *daily* requirements of some of the larger Alaskan (e.g., Endicott) nearshore projects (320,000 $m^3$/d). If ADGO is typical of the size of nearshore fields which could be found in the future in the Canadian Beaufort and the number of nearshore fields will be as limited as presently believed, it is extremely unlikely that significant mortality of anadromous fish would result from entrainment and impingement phenomena. Under worst case conditions, waterflood intake losses of small broad whitefish for the Alaskan Endicott waterflood project were estimated at about 5 percent of a small local stock, and it was stated that this stock would recover quickly upon cessation of the activity (U.S. Army Corp of Engineers and Environmental Research and Technology Inc. 1984).

## CONCLUSION

It was concluded that the hypothesis is extremely unlikely and not worth testing because: (1) the potential waterflood requirements of Canadian nearshore fields will be an extremely small fraction of those typical of the larger Alaskan nearshore fields (i.e., 100 $m^3$/d vs. 320,000 $m^3$/d); and (2) that, given worst case assumptions, losses of small anadromous fish associated with the Alaskan projects are expected to result in only small (if any) declines in the populations of these species.

## RECOMMENDATIONS

Studies on the effects of water intake structures associated with the Alaskan waterflood projects are due to commence in 1984. It is recommended that: (1) the results of monitoring studies being conducted under the auspices of the U.S. Environmental Protection Agency, Army Corps of Engineers and the National Marine Fisheries Service be reviewed as they become available; and (2) if these results indicate that there may be potential concerns related to water intakes in the Canadian Beaufort, then the present hypothesis should be re-evaluated.

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# HYPOTHESIS NO. 18

THE EFFECTS OF AIR EMISSIONS ASSOCIATED WITH THE OPERATION OF AIRCRAFT, MARINE VESSELS, DRILL RIGS, OFFSHORE PLATFORMS AND SHOREBASES ON AIR QUALITY

Air emissions resulting from the operation of aircraft, marine vessls, drill rigs, offshore platforms and shorebases will adversely affect air quality.

AIR QUALITY

↑

PRODUCTION ACTIVITIES

- Mobile Sources (Marine and aircraft)
- Drill Rigs
- Offshore Platforms
- Shorebases

Figure 18-1: Potential effects of air emissions resulting from the operation of marine vessels, drill rigs, offshore platforms and shorebases on air quality

## Linkage

1. Air emissions from a number of sources will adversely affect air quality.

## NAMES OF PARTICIPANTS

Wayne Barchard  
Francois Guimont  
Tarek Jandali  
Jim McComiskey

## INTRODUCTION

Operation of production platforms, shorebases, drill rigs, aircraft and marine vessels in the Beaufort Sea region, will result in a variety of emissions to the atmosphere. While a large portion of these discharges, such as nitrogen, carbon dioxide and water vapour are not considered harmful, a small portion are classified as pollutants and their ambient concentrations are regulated under the Ambient Air Quality Objectives established by Environment Canada (e.g., sulphur oxides and nitrogen oxides).

The following activities associated with exploration, production and transport of petroleum hydrocarbons will be the major sources of air emissions. These sources, and emission factors given for each, were used to estimate the quanitity of pollutants emitted to the atmosphere in the Beaufort Sea region. The objective of this evaluation was to verify or reject the above hypothesis. Unless otherwise stated, data cited regarding the amount and composition of air emissions in the Beaufort Sea were adapted from the Beaufort Sea - Mackenzie Delta EIS, Vol. 2 and 4 (1982).

1) Combustion of Solid Waste: Incineration of solid waste at shorebases, offshore platforms, and marine vessels will result in air emissions containing the following pollutants expressed in percent weight of combustible solid waste.

| | |
|---|---|
| Carbon Monoxide (CO) | - 1.49 percent |
| Nitrogen Oxides ($NO_x$) | - 0.22 percent |
| Sulphur Oxides ($SO_x$) | - 0.12 percent |
| Hydrocarbons (HC) | - 0.12 percent |
| Particulates (Part.) | - 0.62 percent |

2) Combustion of Diesel Fuel: The combustion of diesel fuel for internal combustion engines and power generators at shorebases, drill rigs, and by marine vessels will result in the emission of the following pollutants (expressed as percent weight of spent fuel):

| | |
|---|---|
| CO | - 0.92 percent |
| $NO_x$ | - 3.38 percent |
| $SO_x$ | - 0.69 percent |
| HC | - 4.92 percent |
| Part. | - 1.69 percent |

3) Combustion of Aviation Fuel: The following emission factors for combustion of aviation fuel are expressed as the weight of pollutant emitted for each landing and take-off cycle. This is standard practice, and includes all emissions occurring below 1000 m (3000 ft) that could significantly affect air quality at ground level. The two classifications of aircraft used here are (1) Jets (Boeing 737 or 767), and (2) STOL aircraft and helicopters.

EMISSIONS PER LANDING AND TAKE-OFF CYCLE (Kg)

| Pollutant | Jets | STOL/Helicopter |
|---|---|---|
| CO | 16.92 | 3.25 |
| $NO_x$ | 8.96 | 0.37 |
| $SO_x$ | 0.99 | 0.08 |
| HC | 4.06 | 2.30 |
| Part. | - | - |

4) Gas Flaring: Gas flaring at offshore platforms will result in emissions of $NO_x$ at the rate of 3.68 tonnes per million cubic metres of gas burned.

5) Fuel Tanks: The operation of storage fuel tanks at shorebases will result in fugitive emissions of hydrocarbons. These emissions are estimated to amount to 50 tonnes of hydrocarbons per year at each base.

6) Combustion of Separated Gas: Emissions of $NO_x$ resulting from the combustion of separated gas for power generation at offshore platforms is estimated to be 24 tonnes/day from all sources by the year 2000.

## LINKAGES

Link 1: Air emissions from a number of sources will adversely affect air quality.

The link between air emissions and air quality is direct. Therefore, in order to assess the significance of this hypothesis, the following information is presented:

1) quantitative estimates of total emissions for each pollutant;

2) identification of the spatial distribution of sources;

3) description of the dispersion calculations that were completed using a "box model" approach; and

4) comparison of estimated pollutant concentrations to regulatory guidelines.

## Total Emissions

Shorebases: Air emissions at shorebases will result from incineration of solid waste, combustion of diesel fuel, and release of fugitive hydrocarbons from fuel storage tanks.

a) Estimated quantities of solid waste incinerated when all facilities are developed and fully operational are tabulated below:

SOLID WASTE INCINERATION ESTIMATES FOR SHOREBASES

| Base | Solid Waste Incinerated (Kg/day) |
|---|---|
| Tuktoyaktuk | 4,200 |
| McKinley Bay | 3,600 |
| Stokes or King Point | 500 |
| Wise Bay | 75 |
| TOTAL | 8,375 |

b) The operation of diesel-fired plants are estimated to result in the release of 460 tonnes of atmospheric emissions per year per major shorebase. Since the data used in the present evaluation did not indicate what proportion of the emissions are comprised of pollutants, the total emissions were assumed to be pollutants.

c) Fugitive emissions from fuel storage tanks are estimated to be 50 tonnes of hydrocarbons per year per major shorebase.

In combination, these three sources will result in the following emissions:

SUMMARY OF EMISSIONS AT SHOREBASES
YEAR-ROUND OPERATION
(Kg/day)

| | Solid Waste | Diesel Plants | Fuel Tanks | Totals |
|---|---|---|---|---|
| CO | 125 | 404 | - | 529 |
| $NO_x$ | 18 | 1,460 | - | 1,478 |
| $SO_x$ | 10 | 304 | - | 314 |
| HC | 10 | 2,116 | 548 | 2,674 |
| Part. | 52 | 756 | - | 808 |

Offshore Platforms: Air emissions at offshore platforms will result from incineration of solid wastes, gas flaring, and operation of gas turbines.

a) Solid waste will be incinerated at each of the offshore facilities according to the following table:

SUMMARY OF SOLID WASTE INCINERATION AT OFFSHORE PLATFORMS

| Type of Offshore Platform | Solid Waste Incinerated Kg/day | Max. No. of Structures (yr. 2000) | Total Solid Waste Incinerated Kg/day |
|---|---|---|---|
| Exploration Island | 350 | 8 | 2,800 |
| Production Island | 700 | 32 | 22,400 |
| APLA (Processing and Loading) | 600 | 2 | 1,200 |
| TOTALS | | | 26,400 |

b) Gas flaring is estimated to be approximately 2.7 x $10^6 m^3$ (96 x $10^6$ $ft^3$) per day for all platforms.

c) Separated gas used to fire power generation turbines at oil production facilities is estimated to result in 24 tonnes/day of $NO_x$ emissions.

In combination, these three sources will result in the following emissions:

SUMMARY OF EMISSIONS AT OFFSHORE SHOREBASES
YEAR-ROUND OPERATION
(Kg/day)

| | Solid Waste | Diesel Plants | Fuel Tanks | Totals |
|---|---|---|---|---|
| CO | 394 | - | - | 394 |
| $NO_x$ | 58 | 10,000 | 24,000- | 34,058 |
| $SO_x$ | 32 | - | - | 32 |
| HC | 32 | - | - | 32 |
| Part. | 164 | - | - | 164 |

Drill Rigs: Air emissions from drill rigs result entirely from the use of diesel fuel in internal combustion engines. During the year 2000, the maximum number of wells drilled is estimated at 76, with drilling of each well requiring an average of 75 days. It is estimated that a total of 145 tonnes of emissions will be discharged per well per 75 day period (i.e., approximately 2 tonnes/well/day).

Dome Petroleum *et al.* (1982) does not state what proportion of these emissions are pollutants. Therefore, as a worst case approach, all emissions were treated as pollutants, resulting in the following quantities and composition:

SUMMARY OF EMISSIONS FROM DRILL RIGS
75-DAY DRILL PERIOD
(Kg/day)

| | Emissions/Drill Rig | Totals (76 Rigs) |
|---|---|---|
| CO | 160 | 12,160 |
| $NO_x$ | 580 | 44,080 |
| $SO_x$ | 120 | 9,120 |
| HC | 840 | 63,840 |
| Part. | 300 | 22,800 |

Mobile Sources: Marine vessels and aircraft are classified as mobile sources and result in emissions to the atmosphere due to combustion of fuel and incineration of solid waste (vessels).

a) Marine Vessels: Estimated quantities of solid waste incinerated and diesel fuel consumed for each of three vessel types were provided in Dome Petroleum et al. (1982) and are presented below:

MARINE VESSEL SOLID WASTE INCINERATION
AND DIESEL FUEL COMBUSTION ESTIMATES

| Vessel Type | Solid Waste Incinerated Kg/day | Diesel Fuel Combusted Kg/day |
|---|---|---|
| Class 10 Tankers | 200 | 797,810 |
| Logistics Traffic | 2,833 | 736,130 |
| "Stationary" Offshore Vessels | 10,665 | 68,130 |
| TOTALS | 13,698 | 1,602,070 |

b) Aircraft types and number of flights for the year 2000 were also taken from Dome Petroleum et al. (1982) and are presented below:

ANTICIPATED AIRCRAFT SUPPORT REQUIREMENTS
FOR BEAUFORT HYDROCARBON DEVELOPMENT
BY THE YEAR 2000

| Type | No. of Aircraft | Flights/day | Total Flight /day |
|---|---|---|---|
| Jets | 13 737's<br>or<br>5 767's | 1 | 13*<br>or<br>5 |
| STOL | 22 | 1.5 | 33 |
| Helicopters | 28 | 2.0 | 56 |

* Used in this analysis

In combination, these sources will result in the following emissions:

SUMMARY OF EMISSIONS FROM MOBILE SOURCES
YEAR-ROUND OPERATION
(Kg/day)

| | Marine Vessels Solid Waste and Fuel | Aircraft Jets and Heli/STOL | Totals |
|---|---|---|---|
| CO | 14,945 | 510 | 15,455 |
| $NO_x$ | 54,180 | 149 | 54,329 |
| $SO_x$ | 11,070 | 20 | 11,090 |
| HC | 78,838 | 258 | 79,096 |
| Part. | 27,160 | - | 27,160 |

<u>Summary of Emissions</u>: The estimated air emissions from the variety of sources described in previous sections have been combined to arrive at total emissions on a daily and annual basis; these are summarized in the following two tables, respectively.

SUMMARY OF OVERALL DAILY EMISSIONS
(Kg/day)

| | Shore-bases | Offshore Platforms | Drill Rigs | Mobile Sources | Totals |
|---|---|---|---|---|---|
| CO | 529 | 394 | 12,160 | 15,455 | 28,538 |
| $NO_x$ | 1,478 | 34,058 | 44,080 | 54,329 | 133,945 |
| $SO_x$ | 314 | 32 | 9,120 | 11,090 | 20,556 |
| HC | 2,674 | 32 | 63,840 | 79,096 | 145,642 |
| Part. | 808 | 164 | 22,800 | 27,160 | 50,932 |

SUMMARY OF OVERALL ANNUAL EMISSIONS
(Tonnes/Year)

| | Shore-bases | Offshore Platforms | Drill Rigs | Mobile Sources | Totals |
|---|---|---|---|---|---|
| CO | 193 | 144 | 912 | 5,641 | 6,890 |
| $NO_x$ | 540 | 12,431 | 3,306 | 19,830 | 36,107 |
| $SO_x$ | 115 | 12 | 684 | 4,048 | 4,859 |
| HC | 976 | 12 | 4,788 | 28,870 | 34,646 |
| Part. | 295 | 60 | 1,710 | 9,913 | 11,978 |

## Geographic Source Distribution

The location of production facilities and associated activities that contribute to air emissions are depicted in Figure 18-2 and are superimposed on the spatial units shown in the Introduction to this report. The figure identifies the following major source locations:

- Routes for icebreaking tankers
- Routes for marine logistics travel
- Offshore facilities
- Onshore facilities
- Aircraft flight paths.

Spatial units 1, 2, 3 and 4 are directly affected by these acitivites and the approximate combined area of these four zones is estimated at 60,000 $km^2$.

## Dispersion Calculations

Simple dispersion calculations were performed using a "box model" approach to estimate the order of magnitude of ambient ground level concentrations of the various pollutants. The following assumptions were made in the calculation of 24 hour average concentrations:

1) All pollutants are trapped below 300 metres above sea level. This corresponds to inversion heights that could occur in the area.

2) All pollutants emitted during a 24 hour period are spatially confined to spatial units 1, 2, 3 and 4, and are uniformly distributed within these zones. This assumption implies that additional pollutant input into this bounded space is counterbalanced by an equal amount of pollutant advection out of the space boundaries. The assumption of uniformity of distribution, while not entirely accurate (wind may

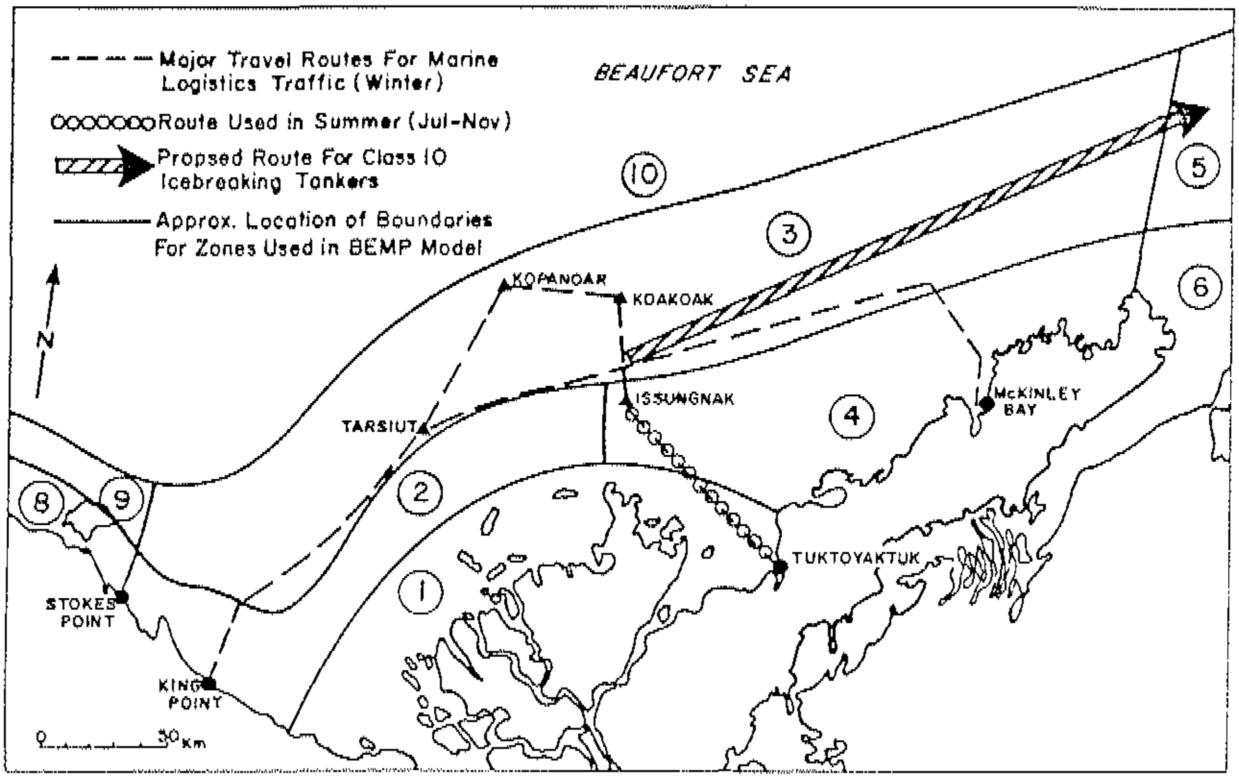


Figure 18-2a Approximate locations of marine vessel and tanker travel routes.

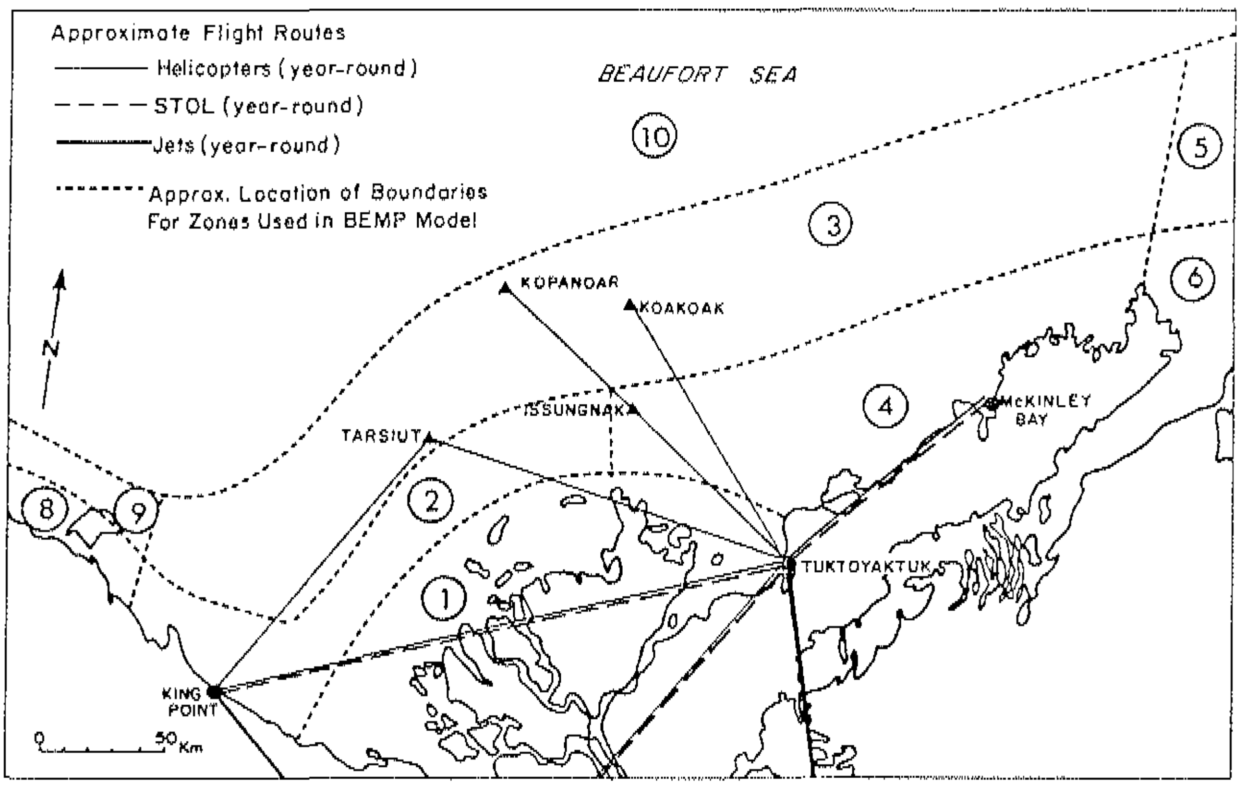


Figure 18-2b Approximate locations of aircraft flight routes.

prevail in a single direction for a day or days), is nevertheless reasonable in view of the fact that as much as 83 percent of annual emissions of some pollutants are from mobile sources that cover very large areas. Furthermore, the purpose of this analysis is to estimate the order of magnitude of concentrations rather than absolute values.

Results of dispersion calculations are summarized in the following table showing predicted concentrations of emissions as well as regulatory guideline concentrations established by Environment Canada.

PREDICTED CONCENTRATIONS OF VARIOUS POLLUTANTS
IN RELATION TO REGULATORY GUIDELINES

| | POLLUTANT | | | | | |
|---|---|---|---|---|---|---|
| ELEMENT | CO $\mu g/m^3$ | $NO_x$ $\mu g/m^3$ | $SO_x$ $\mu g/m^3$ | HC $\mu g/m^3$ | SUS.PART $\mu g/m^3$ | DUST FALL $g/cm^2/mo$ |
| Estimated 24 hour average | 2 | 8 | 1 | 8 | 3 | 0.002 |
| Regulatory Guideline | 6000 FED (8 hr) | 200 FED (24 hr) | 150 FED (24 hr) | NA Urban Areas O[1000's] | 120 FED (24 hr) | 0.525 FED Residential |
| Ratio (Factor of Safety) | 3000 | 25 | 150 | O[100's] | 40 | 250 |

These calculations indicate that, on a regional basis, air quality will not be significantly affected due to the very small contributions (less than background) resulting from the combined operation of aircraft, vessels, offshore platforms, sharebases and drill rigs. In order to place emissions from proposed Beaufort operations in perspective, it should be noted that gas processing facilities in southern lattitudes typically emit 50-900 tonnes/day of $SO_2$ and similar amounts of $NO_x$ from a single point source.

Ice Fog

Although Dome Petroleum et al. (1982) does not provide estimates of the quantity of water vapour emissions that could give rise to the formation of ice fog during cold spells, it is important to emphasize the following points.

- Ice fog will begin to form when ambient air temperatures are lower than -20°C, and will definitely form when temperatures are lower than -40°C.

- Formation of ice fog is caused by the emission of large quantities of water vapour from combustion processes. The formation is enhanced at the higher temperature limits in the presence of particulate matter in the atmosphere.

- Ice fog can accumulate locally (within 1 to 5 km) during prolonged periods of calm and cold temperatures, causing obstructed visibility, and thereby potentially affecting human activities.

- There are no mitigative measures available to reduce ice fog formation other than halting combustion and/or eliminating the source of emission.

## CONCLUSIONS

Based on the foregoing considerations, the group rejected the hypothesis that air quality will be adversely affected to an extent that would warrant the design and implementation of a regional monitoring program. This conclusion, however, should not preclude the possible need to implement air quality monitoring program(s) at major shorebases to monitor local effects as part of the required operational permits.

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# HYPOTHESIS NO. 19

## EFFECTS OF DREDGING ON
## BEARDED SEALS

Dredging and deposition of spoils will reduce the bearded seal population.

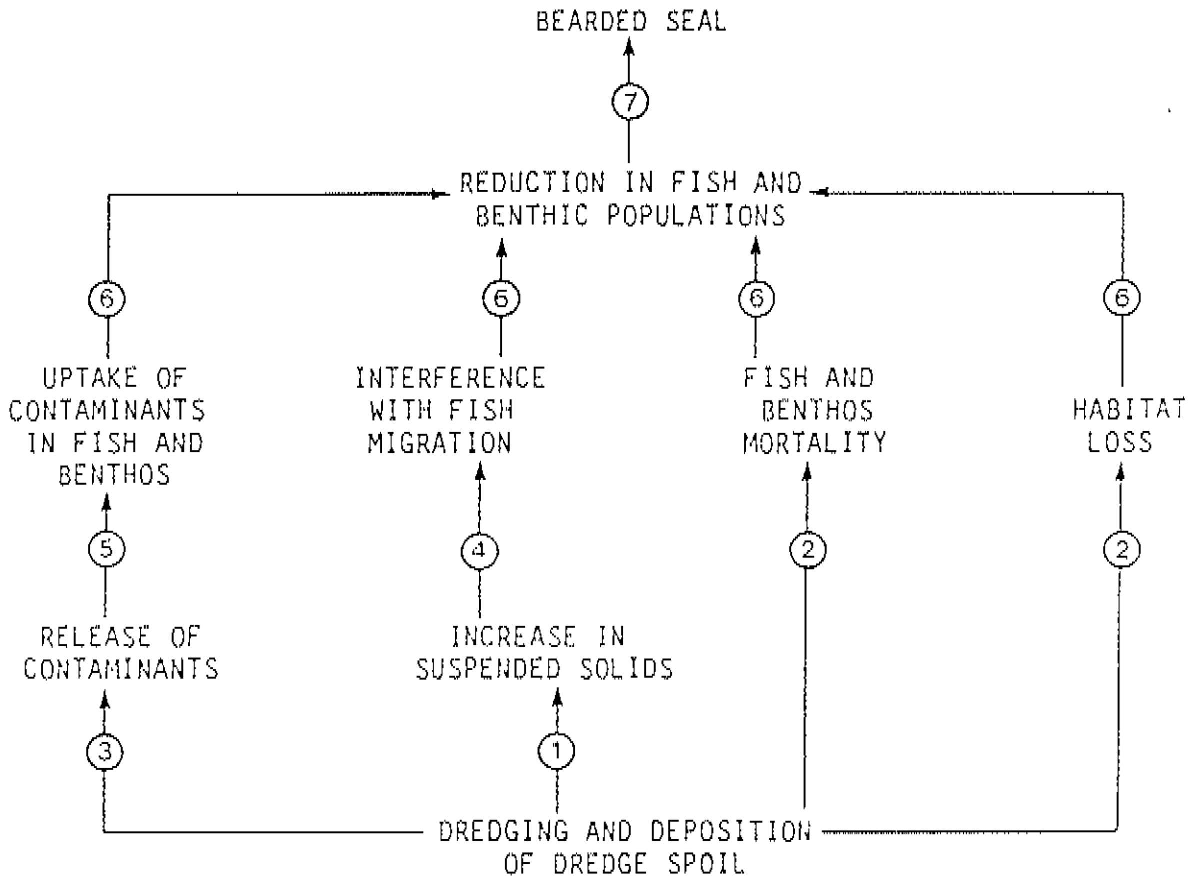


Figure 19-1: Potential effects of dredging and deposition of spoils on benthos, fish and bearded seals.

Linkages

1. Dredging and deposition of dredge spoil 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 number of bearded seals.

## NAMES OF PARTICIPANTS

Wayne Duval
Bob Everitt
Benny Gallaway
William Griffiths
John Harper
Ed Pessah
Aaron Sekerak
Dave Thomas

## INTRODUCTION

This hypothesis was not formally addressed in the workshop due to time constraints associated with each of the daily schedules and its treatment was therefore different from previous hypotheses. The subject of dredging was raised by several participants during the introductory sessions but although it was generally agreed that dredging may be an important area of concern in some parts of the Beaufort Sea, it could not be addressed within the framework of the present workshop. Consequently, a formalized hypothesis and written text was prepared to examine the issue. In order to ensure that the hypothesis received the same level of critical review, a group was formed (listed above) following the workshop, and comments and contributions solicited from each member during the preparation of this report.

This hypothesis and its associated linkages are shown in Figure 19-1. It states that dredging will cause a direct decrease in the abundance of benthic populations which may in turn decrease the available food for fish and marine mammals such as the bearded seal. In addition, increases in the concentrations of suspended solids within the water column due to dredging activities may act as a migration barrier to fish. Dredging may also release contaminants from the sediments, which could then accumulate within the food chain and affect important species. Since the hydrocarbon development scenarios presented at the workshop and described in the Beaufort Sea - Mackenzie Delta EIS (Dome Petroleum et al. 1982) involve substantial amounts of dredging, evidence for and against each of these linkages is briefly discussed in the following sections.

## LINKAGES

Link 1: Dredging and deposition of dredge spoil will increase concentrations of suspended solids in the water column.

There is little doubt that dredging activities increase the amount of suspended solids in the water column and, in some cases, concentrations of suspended materials can far exceed background (ambient) levels. For example, at the source of the spoil outfall, these concentrations may approach several thousand milligrams per litre. However, suspended solids levels are reduced rapidly with increasing distance from the point sources and typically reach ambient levels within a few kilometres of the dredging site. The dredge plumes that have been studied to date in the Beaufort Sea have generally been limited in duration and spatial extent (Thomas 1980; ESL 1982). In areas such as Tuktoyaktuk harbour, increases in suspended solids due to dredging operations are also often masked by turbidity levels naturally associated with the Mackenzie River plume (Erickson and Pett 1981; ESL 1982).

Link 2: Removal of seafloor material and its deposition in other areas will result in mortality of benthic invertebrates and fish and habitat loss.

The removal of the surface layer of the sea floor and its deposition in other areas will cause mortality of benthic organisms and to a lesser extent fish, and will also result in the removal or temporary disruption of existing habitat. Although studies conducted in the Beaufort Sea have shown that recolonization of newly exposed sand-silt substrate (cf. rock) begins almost immediately (Thomas *et al.* 1982; Heath *et al.* 1982; ESL 1982), complete recovery of the total benthic biomass lost due to habitat disruption may not occur for several years. In some cases, the construction of artificial islands in the marine environment will result in the creation of new habitats. However, it should be noted that the benthic organisms colonizing these new habitats and demersal organisms subsequently attracted to such sites would be in closer proximity to other development activities than may normally be the case.

The following worst case assumptions can be made to estimate the magnitude of substrate disturbances/habitat losses that may be associated with dredging activities in the Beaufort Sea: (1) no new habitat is created; (2) all habitat dredged is totally destroyed; (3) dredging occurs to an average depth of 1 m in the substrate; and (4) approximately 308 million cubic metres of dredged material will be required for the intermediate development scenario. Given these assumptions, dredging requirements to the year 2000 would result in the removal of about 300 $km^2$ of habitat. Since this is equivalent to approximately 0.1 percent of Spatial Units 1-11 or 0.7 percent of Spatial Units 2, 3, and 4, even this "worst case" loss would be a negligible amount in comparison to the total habitat available in the region.

It should be noted, however, that extrapolation of the total amount dredged to the total area of the region or various spatial units may not be defensible if relatively small areas contain large concentrations of important food organisms, fish or bearded seals.

Link 3: Dredging will release contaminants from the sediments.

Link 5: Contaminants released during dredging will be taken up by fish and benthos.

Link 6: Habitat loss, mortality, interference with migratory routes and uptake of contaminants will reduce fish and benthic invertebrate populations.

The term "contaminant" in dredged sediments is typically associated with the occurrence of heavy metals, although dredged materials in some parts of the world have also included various naturally-occurring and synthetic organic compounds. However, numerous dredging studies conducted in the Beaufort Sea and in other areas of Canada and the world suggest that heavy metals in natural sediments rarely accumulate to significant levels in the overlying biota (Herbich 1981; unpublished data, EPS, Halifax). This series of linkages in the hypothesis is therefore expected to be relatively remote.

Link 4: Increased suspended solids will interfere with fish migration.

It is considered unlikely that fish migration would be disrupted by the presence of high levels of suspended solids, although there are only limited experimental data on this source of impact in the Beaufort Sea or for fish species present in the region. Fish are known to use migratory pathways that naturally contain high ambient levels of suspended solids. Examples include fish migration corridors in the Mackenzie River and Delta, the Fraser River in British Columbia and the Mirimichi River in New Brunswick. In a recent study conducted near Barrow (Alaska), Sekerak and Craig (in prep.) found no evidence to suggest that dredging in the Meade River hindered movement of least cisco or lake whitefish.

Link 7: Reduced populations of prey organisms (fish and benthos) will reduce number of bearded seals.

Link 7 was thought to be valid even though the relationships among factors that ultimately limit bearded seal populations are poorly understood.

## CONCLUSIONS

Herbich (1981), in a paper that summarizes a comprehensive series of studies by the U.S. Corps of Engineers on the effects of unconfined disposal of dredged materials in open water, stated the following:

> "... the original fears of water quality degradation resulting from the re-suspension of the dredged material during dredging operations are for the most part unfounded.";
>
> "The greatest impact of dredged material disposal is the potential effect on benthic organisms."; and
>
> "Release of heavy metals and their uptake into organism tissue have been rare. Similarly, the accumulation of oil and grease residues by organisms has been minimal."

The workshop participants concurred with Herbich's (1981) basic conclusions, but noted that dredging programs in areas with: (1) very low water exchange rates; (2) high densities of important benthic or demersal biota; 3) large concentrations of fish; or (4) feeding areas of bearded seals should be considered special cases and evaluated on a site-specific basis in terms of the potential need for research or monitoring. Significant impacts could result if dredging operations were conducted in areas very close to the foreshore, or if dredging were to occur in confined areas that are important habitats of benthic or demersal resources (Pessah 1982).

## RECOMMENDATIONS

No general research or monitoring program is recommended. However, specific research and monitoring programs should be designed in situations where dredging has the potential to result in significant impacts. In these cases, care should be taken to ensure that the studies address the unique characteristics of the area to be dredged.

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# APPENDIX I

## THE APPLICATION OF BIOLOGICAL "EARLY WARNING SYSTEMS" TO THE DETECTION OF ENVIRONMENTAL CHANGE

### A BRIEF DISCUSSION

# INTRODUCTION

Since the primary focus of this project is monitoring and formulation of specific recommendations regarding monitoring priorities for Beaufort hydrocarbon development, several workshop participants raised questions on the differences between the objectives and approach used in the Beaufort Environmental Monitoring Program and the "Biological Early Warning System" monitoring strategies practised elsewhere in the world. Although the basic differences between the BEMP approach and various BEWS programs conducted elsewhere (e.g., "Mussel Watch") were discussed during the first day of the workshop, the participants agreed that an overview of the advantages and disadvantages of other monitoring strategies would be a useful supplement to the present report. A discussion group was therefore formed to conduct this brief review, and met on one afternoon during the session. The group comprised the following workshop participants:

Wayne Barchard
Jim Bunch
Wayne Duval
Ted Langtry
Don Schell
David Thomas

It is generally accepted that industrial development has placed stresses on the natural environment through the discharge of industrial wastes. Both the frequency and duration of adverse environmental effects have increased with intensified industrial development. This is particularly evident in the aquatic and atmospheric environments surrounding major industrial centres which receive discharges and emissions from a range of stationary and mobile sources. However, it is also known that the natural environment has a certain resiliency, and can withstand certain levels of waste discharge without suffering any significant deleterious biological effects. This property is commonly referred to as assimilative capacity. At the same time, physical or chemical changes in the marine environment as a result of industrial waste discharge are generally only considered an area of concern when they are reflected in biological change.

The fundamental questions during the design of monitoring programs to determine the potential ecological significance of industrial waste discharges must be focused on how industry-induced biological change can be detected, quantified, and interpreted, and when the assimilative capacity of an ecosystem is exceeded. Resultant monitoring strategies should therefore facilitate the detection of significant biological changes long before the consequences become extreme (e.g., mortality) or irreversible (e.g., mutagenic). This is the concept that forms the basis of a Biological Early Warning System (BEWS).

The need for early detection of biological change is exemplified by the classic example of the introduction of DDT into the environment. During the 1950's and 1960's, DDT was accumulating in the environment at concentrations below the contemporary limits of analytical detection. However, these concentrations were already above the threshold for serious biological effects, and almost resulted in the extinction of several species of raptors.

The advantage of BEWS as a monitoring approach is that once a trend in environmental quality alteration is judged to be serious or unacceptable, then a systematic stepwise mitigation plan can be initiated. Criteria which a satisfactory BEWS must meet in order to be useful include:

(1) the physiological and behavioural parameters in the organism selected for monitoring should be quantifiable;

(2) rapid and reliable detection of developing toxic conditions is essential (this usually involves chemical measurements);

(3) the monitoring protocol should not be inherently subject to "false alarms";

(4) the results must be interpretable; and

(5) the monitoring protocol should be relatively inexpensive and simple to apply.

During the past 20 to 30 years, environmental scientists have searched for a single all-purpose index of environmental health that can be used to monitor changes resulting from various forms of pollution. This research has focused on the four levels of biological complexity: the individual, population, community, and the ecosystem

Ecological (ecosystem) monitoring has been criticised because it is not only time-consuming to obtain the species lists and abundance data which are necessary for adequate resolution of cause-effect relationships, but also because the approach is relatively insensitive. The insensitivity is due to the fact that natural variations in ecosystems are often much greater than the perturbations caused by pollution, even in the case of very serious pollution. In a similar manner, monitoring methods based on the use of indicator species have not been entirely satisfactory because of difficulties associated with the selection of a suitable "indicator" species. An example is the polychaete worm Capitella capitata, which was considered an excellent indicator of organic pollution for many years. However, recent research has shown that in certain cases, the distribution of this species has been inversely related to pollution. Consequently, several investigators have reached erroneous conclusions because they did not consider some important facts regarding the life history of Capitella capitata. Finally, monitoring strategies directed at the population and community levels can also be criticized due to their expense and lack of specificity.

A criticism which is common to virtually all Biological Early Warning Systems used to date is that the most optimistic result is that a change in status of the biological system can be detected. It is extremely rare when an unambiguous statement can be made regarding the reason for the change.

The consensus of the workshop discussion group was that no single monitoring strategy appears to be sufficient to judge the hazards associated with the discharge of a certain waste on the environment and human health. Several methods might have to be considered and used to monitor a certain situation adequately.

The prevalent direction of research in the field of Biological Early Warning Systems is currently at the level of individual physiological and biochemical responses to pollutant stresses. In theory, a BEWS which is based on responses of individuals should be superior to measurements made on higher levels of biological association because physiological and biochemical changes should be detectable within any individual long before measurable effects can be documented at the population, community or ecosystem levels.

A brief overview of various Biological Early Warning Systems described in the current literature on this subject is provided in the following sections.

## THE MUSSEL WATCH

### Rationale

A large number of studies have shown that most organisms accumulate chemicals to levels which are proportional to the exposure dose. For example, vertebrates accumulate non-metabolizable chemicals such as Hg, Cd, Pb, PCBs and DDT, while invertebrates generally accumulate trace metals and possibly some organic compounds. The concept behind the Mussel Watch Program is that slow-moving or sedentary invertebrates can be used as "sentinels" and "integrators" of pollutants in the surrounding water. Mussels have been a popular choice for sentinel organisms because of their world-wide distribution, broad range of habitats, and tolerance to environmental stress. Limpets, barnacles, sea urchins, oysters and other bivalves have also been used as sentinel organisms in such programs.

## Advantages

The advantages of the Mussel Watch Program are that: (1) sampling is easy and inexpensive; (2) a large data base of results is available; and (3) the method has been applied on a global scale.

## Disadvantages

The accumulation of trace metals and organic compounds by mussels and other invertebrates varies with a number of factors such as season of collection, location within the intertidal zone, body mass, sex and degree of exposure to fresh water. These other variables must therefore be considered during the interpretation of monitoring results. In areas where mussels have to be imported, such as the Beaufort Sea, there is also the potential that the mussels may respond to contaminants that have no effects on endemic species, creating the potential for a "false alarm".

## References

Alexander and Young (1976)
Davies and Pirie (1980)
Goldberg (1975)
Goldberg *et al*. (1978)
Pentreath (1973)
Philips (1976)
Popham and D'Auria (1980)
Popham and D'Auria (1983)

# METAL BINDING PROTEINS (Metallothioneins)

## Rationale

Metallothioneins are low-molecular weight proteins that contain large numbers of sulphydryl groups. Research on mammals has shown that these proteins are involved in the intra-cellular binding of metals such as cadmium, copper, mercury and zinc. Metallothionein-like proteins (MLPs) have also been identified in many invertebrate groups, particularly in oysters and the mussel *Mytilus edulis*.

In the presence of cadmium, mercury or zinc, mussels will synthesize MLPs that bind the metals and thereby render them biologically inert. The concentrations of MLPs in tissues tend to be higher in animals collected from metal-rich habitats. Consequently, metallothionein induction can be used as an early warning indicator of a physiological/biochemical response to metal pollution.

## Advantages

Thioneins are easily isolated and quantified using standard biochemical procedures. This method is also likely a more sensitive technique for measurement of environmental stress than other approaches that involve determination of "whole animal" responses.

## Disadvantages

The method is largely a research technique rather than practical monitoring tool at the present time. Although isolation of thioneins is a relatively simple analytical technique, it is too expensive to be a cost-effective approach for a regional monitoring program. In addition, MLPs only appear to be induced in the presence of Cd, Cu, Hg and Zn, and therefore the approach has only limited applicability.

References

Noel-Lambert (1976)
Roesijadi *et al*. (1982)

## LYSOSOMAL LATENCY

### Rationale

Lysosomes are distinct membrane-bound organelles that primarily function in intracellular digestion. However, they are also important in more fundamental physiological functions including regulation of secretory processes, cellular defence mechanisms, and accumulation and sequestration of xenobiotics (particulary trace metals).

Chemical stresses on lysosomes cause alterations in the latency of lysosomal hydrolytic enzymes, which can subsequently lead to disturbances in the normal physiological functions of these organelles. Since the latency of lysosomes is quantifiable, and because many marine invertebrates possess highly developed lysosomal-vacuolar systems involved in intracellular digestion, lysosomal latency has been proposed as an index of pollution.

### Advantages

The technique involves measurement of a demonstrable physiological response to stress, thereby facilitating the documentation of a cause-effect relationship.

### Disadvantages

The major disadvantage of this technique is that it is relatively new, and therefore information on its performance and practicality is unavailable.

## References

Bayne *et al*. (1976)
Moore (1980)
Moore (1982)

## SCOPE FOR GROWTH

### Rationale

This bioenergetic monitoring approach uses an index called the "scope for growth", which is calculated as an available energy balance following losses associated with respiration and excretion processes. In theory, exposure of organisms to a pollutant increases the energy losses through either or both of these metabolic pathways, and thereby reduces the "scope for growth". Advocates of the approach suggest that a decline in this index is an early warning of a deteriorating environment due to pollutant stress.

### Advantages

The "scope for growth" index provides an integrated measure of physiological (*sensu latu*) effects within an individual or population exposed to a source of pollution.

### Disadvantages

This method requires extremely sophisticated analytical procedures and detailed measurements of variables such as particulate organic nitrogen and particulate energy content, and therefore is unlikely to be practical for most routine monitoring applications.

## References

Bayne *et al*. (1979)
Gray (1980)

# HISTOPATHOLOGY

## Rationale

This procedure is designed to identify pollution-induced tissue degeneration, inflammation or alteration in marine invertebrates. It has been suggested that an index of "histological well-being" provides an indication of marine invertebrate health in a region, and that the spatial distribution of pathological conditions in an area exposed to pollutant discharges may be a reliable indicator of environmental degradation.

## Advantages

Histopathological observations are relatively inexpensive and this allows the collection of large numbers of samples to provide statistically reliable results.

## Disadvantages

There are a number of apparent disadvantages to histopathological methods, and these disadvantages limit the suitability of the approach to monitoring applications. The primary problems with the approach are that (1) the definition of "normal" histological characteristics in tissues remain unknown for most organisms, and (2) cause-effect relationships demonstrated in the laboratory are difficult to detect in the natural environment because of the presence of interfering factors such as non-specific responses to disease.

## References

Gardener (1978)
Lord *et al*. (1981)
Malins (1982)

## MIXED FUNCTION OXIDASES (MFOs)

### Rationale

Mixed function oxidases consist of a complex of enzymes that are bound to the endoplastic reticulum, an interior membrane structure within cells. Available information suggests that these enzymes have an important role in the metabolism of hydrocarbons by vertebrates. The biochemical mechanism of hydrocarbon metabolism is very complicated, although it appears that during the metabolism of polynuclear aromatic hydrocarbons (PAH), reactive intermediates which are cytotoxic, mutagenic and carcinogenic tend to be formed. A physiological response of fish to oil exposure is the induction of aryl hydrocarbon hydroxylase (AHH) activity (Penrose 1978). As a result, measurement of AHH and other mixed function oxidase activities may be a useful approach to monitor the impact of natural hydrocarbon releases or industry-related discharges on environmental quality.

### Advantages

Measurement of MFO activity can provide quantitative data on the biological impact of petroleum hydrocarbons.

### Disadvantages

MFO activity is only strong in vertebrates, and is not a particularly useful measure of the response of invertebrates to hydrocarbon exposure. Since fish and other vertebrates are mobile, it is therefore difficult to link MFO activity measurements to the actual location of hydrocarbon exposure in an area.

References

Page and Fancey (1978)
Payne and May (1979)
Penrose (1978)

## CONCLUSIONS

The workshop discussion group concluded that the scientific basis for Biological Early Warning Systems (BEWS) is still evolving, and although it is currently the subject of intensive research, the applicability of many of these techniques is somewhat limited at the present time. It was also emphasized that the science of establishing cause-effect relationships is also in its infancy. The eventual development of satisfactory BEWS will occur once repeated successful quantitative measurements can be made, and the accurate prediction of biological effects can be demonstrated. Until that time, the prediction and assessment of biological effects resulting from industrial waste discharges should be based on well-documented case studies and the professional experience of scientists undertaking such investigations.

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# APPENDIX II

## PARTICIPANTS IN THE
## BEAUFORT ENVIRONMENTAL MONITORING PROJECT

# LIST OF PARTICIPANTS: FIRST BEMP WORKSHOP (May 16 - 20, 1983)

DENNIS ANDRIASHEK

Canadian Wildlife Service
5320 - 122nd Street
Edmonton, Alberta
T6H 3S5

ALAN BIRDSALL

LGL Limited
333 - 2453 Beacon Avenue
Sidney, B.C.
V8L 1W9

STEVE BLASCO

Geological Survey/EMR
Bedford Institute
Dartmouth, Nova Scotia

BILL BOND

Fisheries and Oceans Canada
114 Garry Street
Winnipeg, Manitoba
R3C 1G1

BILL BRACHEL

Environment Canada
Edmonton, Alberta

ROLPH DAVIS

LGL Limited
44 Eglinton Avenue West
Toronto, Ontario
M4R 1A1

MAX DUNBAR

IOM, McGill University
3620 University Street
Montreal, Quebec

WAYNE DUVAL

ESL Environmental Sciences Limited
34 - 1035 Richards Street
Vancouver, B.C.
V6B 3E4

ROBERT EVERITT

ESSA Ltd.
678 West Broadway
Vancouver, B.C.
V5Z 1G6

DAVID FISSELL

Arctic Sciences Ltd.
1986 Mills Road
Sidney, B.C.
V8L 3S1

STEPHAN FULLER

Cordillera Environmental Projects
Beaufort Panel Secretariat
2110 West 12th Avenue
Vancouver, B.C.

BENNY GALLAWAY

LGL Ecological Research Associates Inc.
1410 Cavitt Street
Bryan, TExas
U.S.A. 77801

WILLIAM GRIFFITHS

LGL Limited
333 - 2453 Beacon Avenue
Sidney, B.C.
V8L 1W9

FRANCOIS GUIMONT

Indian and Northern Affairs Canada - NAP
P.O. Box 1500
Yellowknife, N.W.T.

ALBERT HALLER

Indian and Northern Affairs Canada
Circumpolar Affairs
Les Terrasses de la Chaudiere
Ottawa, Ontario
K1A OH4

JOHN HARPER

Woodward-Clyde Consultants
100 Pringle Avenue
Walnut Creek, California
U.S.A. 94596

MICHAEL HAWKES

Yukon Government
P.O. Box 2703
Whitehorse, Yukon

RICK HURST

Indian and Northern Affairs Canada
Les Terrasses de la Chaudiere
Ottawa, Ontario
K1A OH4

TAREK JANDALI

ESL Environmental Sciences Limited
34 - 1035 Richards Street
Vancouver, B.C.
V6B 3E4

STEPHEN JOHNSON

LGL Limited
10110 - 124th Street
Edmonton, Alberta
T5N 1P6

BOB LANGFORD

B.C. Government
777 Broughton Street
Victoria, B.C.

TED LANGTRY

Indian and Northern Affairs Canada
Les Terrasses de la Chaudiere
Ottawa, Ontario
K1A OH4

JOHN McDONALD

ESL Environmental Sciences Limited
2035 Mills Road
Sidney, B.C.
V8L 3S1

PETER McNAMEE

ESSA Ltd.
678 West Broadway
Vancouver, B.C.
V5Z 1G6

JOHN MARKO

Arctic Sciences Ltd.
1986 Mills Road
Sidney, B.C.
V8L 3S1

DAVID MARMOREK

ESSA Ltd.
678 West Broadway
Vancouver, B.C.
V5Z 1G6

HUMFREY MELLING

Institute of Ocean Sciences
Fisheries and Oceans Canada
Box 6000
Sidney, B.C.
V8L 4B2

SERGE METIKOSH

Indian and Northern Affairs Canada
NWT Region
Box 1500
Yellowknife, N.W.T.

ROBERT MORRISON

Gulf Canada Resources Inc.
P.O. Box Box 130
Calgary, Alberta
T2P 2H7

LANGLEY R. MUIR

Canada Oil and Gas Lands Administration
355 River Road
Ottawa, Ontario

ED PESSAH

Dome Petroleum Limited
P.O. Box 200
Calgary, Alberta
T2P 2H8

DONALD SCHELL

University of Alaska
Institute of Water Resources
Fairbanks, Alaska
99701

RAY SCHWIENSBURG

N.W.T. Wildlife Service
Government N.W.T.
Yellowknife, N.W.T.

AARON D. SEKERAK

LGL Limited
333 - 2453 Beacon Avenue
Sidney, B.C.
V8L 1W9

BRIAN SMILEY

Institute of Ocean Sciences
Fisheries and Oceans Canada
Box 6000
Sidney, B.C.
V8L 4B2

NICHOLAS SONNTAG

ESSA Ltd.
678 West Broadway
Vancouver, B.C.
V5Z 1G6

DAVID STONE

Indian and Northern Affairs Canada
Les Terrasses de la Chaudiere
Ottawa, Ontario
K1A 0H4

DAVE THOMAS

Arctic Laboratories Limited
2045 Mills Road
Sidney, B.C.

DENIS THOMSON

LGL Limited
44 Eglinton Avenue West
Toronto, Ontario
M4R 1A1

TIM WEBB

ESSA Ltd.
678 West Broadway
Vancouver, B.C.
V5Z 1G6

JOHN D. WIEBE

Environment Canada
1812 - 1055 West Georgia Street
Vancouver, B.C.
V6E 3P1

BRIAN WILSON

Environmental Protection Service
Environment Canada
P.O. Box 370
Yellowknife, N.W.T.

LIST OF PARTICIPANTS: SECOND BEMP WORKSHOP (November 28 - December 2, 1983)

W. WAYNE BARCHARD

Marine Environmental Assessment Division
Marine Environment Branch
Environmental Protection Service
3rd Floor, Queensquare
Dartmouth, Nova Scotia

RESEARCH INTERESTS: Wildlife ecology; bioenergetics; population dynamics; ecological modelling; environmental impact assessment and monitoring.

THOMAS W. BARRY

Canadian Wildlife Service
1000 - 9942 - 108th Street
Edmonton, Alberta T5J 2K5

RESEARCH INTERESTS: Ornithology.

EVAN BIRCHARD

Esso Resources Canada Ltd.
237 4th Avenue S.W.
Calgary, Alberta
T2P OH6

RESEARCH INTERESTS: Marine ecology and environmental impact assessment.

ALAN BIRDSALL

LGL Limited
333 - 2453 Beacon Avenue
Sidney, B.C. V8L 1X7

RESEARCH INTERESTS: Impact assessment; data management and fishery management applied to Pacific salmon.

W.A. (BILL) BOND

Fisheries and Oceans Canada
501 University Crescent
Winnipeg, Manitoba R3T 2N6

RESEARCH INTERESTS: Fisheries biology; anadromous coregonids in Southern Beaufort Sea.

JIM BUNCH

Arctic Biological Station
Fisheries and Oceans Canada
555 Boul. St. Pierre
Ste Anne-de-Bellevue, Quebec H9X 3R4

RESEARCH INTERESTS: Interactions of algae and bacteria; fate and effects of petroleum.

BEN DANIELEWICZ

Dome Petroleum Limited
P.O. Box 200
Calgary, Alberta T2P 2H8

RESEARCH INTERESTS: Arctic physical oceanography; sea ice.

ROLPH A. DAVIS

LGL Limited
414 - 44 Eglinton Avenue West
Toronto, Ontario M4R 1A1

RESEARCH INTERESTS: Arctic marine mammals and birds; impact assessment.

MAXWELL J. DUNBAR

Institute of Oceanography
McGill University
3620 University Street
Montreal, Quebec H3Y 2X1

RESEARCH INTERESTS: High latitude biological oceanography.

WAYNE S. DUVAL

ESL Environmental Sciences Limited
34 - 1035 Richards Street
Vancouver, B.C. V6B 3E4

RESEARCH INTERESTS: Aquatic ecology and physiology; environmental impact assessment and monitoring

KARL K. ENGLISH

LGL Limited
333 - 2453 Beacon Avenue
Sidney, B.C. V8L 1X7

RESEARCH INTERESTS: Quantitative ecology; ecological modelling; fishery statistics.

ROBERT EVERITT

ESSA Ltd.
678 West Broadway
Vancouver, B.C.
V5Z 1G6

RESEARCH INTERESTS: Environmental monitoring; ecological modelling; resource policy analysis; environmental management data base design; fisheries management

DAVID FISSEL

Arctic Sciences Ltd.
1986 Mills Road, R.R. No. 2
Sidney, B.C. V8L 3S1

RESEARCH INTERESTS: Physical oceanography of the Canadian Arctic.

BENNY J. GALLAWAY

LGL Ecological Research Associates Inc.
1410 Cavitt Street
Bryan, Texas 77801

RESEARCH INTERESTS: Fish ecology; behavioural thermoregulation processes in Arctic anadromous fish.

JOY A. GEISELMAN

Environmental Studies Staff
U.S. Dept. of the Interior
Minerals Management Service
P.O. Box 10-1159
Anchorage, Alaska 99510

RESEARCH INTERESTS: Marine ecology; biological oceanography; fate and effects of oil in the marine environment; monitoring.

WILLIAM GRIFFITHS

LGL Limited
333 - 2453 Beacon Avenue
Sidney, B.C. V8L 1X7

RESEARCH INTERESTS: Aquatic biology; Arctic anadromous fish along the North Slope of Alaska.

FRANCOIS J. GUIMONT

Manager, Arctic Waters
Northern Affairs Program
Indian and Northern Affairs Canada
P.O. Box 1500
Yellowknife, N.W.T. X1A 2R3

RESEARCH INTERESTS: Hydrology; engineering related to environmental management and protection; environmental impact assessment and regulatory issues related to oil and gas exploration.

JOHN HARPER

Dobrocky Seatech Ltd.
9865 W. Saanich Road
Sidney, B.C. V8L 4M7

RESEARCH INTERESTS: Arctic coastal processes; sediment transport; coastal geomorphology.

LOIS HARWOOD

ESL Environmental Sciences Limited
2035 Mills Road, R.R. No. 2
Sidney, B.C.   V8L 3S1

RESEARCH INTERESTS: Marine mammals; environmental impact assessment.

PHILIP R. HILL

Atlantic Geoscience Centre
Bedford Institute of Oceanography
P.O. Box 1006
Dartmouth, Nova Scotia   B2Y 4A2

RESEARCH INTERESTS: Marine geology; sediment transport and seabed geology.

RICK HURST

Environmental Biologist
Offshore Environment Division
Indian and Northern Affairs Canada
Ottawa, Ontario
K1A OH4

RESEARCH INTERESTS: Impact assessment and monitoring for the offshore environment; marine mammals; energetics.

TAREK JANDALI

ESL Environmental Sciences Limited
34 - 1035 Richards Street
Vancouver, B.C.   V6B 3C4

RESEARCH INTERESTS: Meteorology; air quality; wind engineering.

STEPHEN R. JOHNSON

LGL Limited
202 - 10110 - 124th Street
Edmonton, Alberta   T5N 1P6

RESEARCH INTERESTS: Ornithology.

MICHAEL KINGSLEY

Fisheries and Oceans Canada
501 University Crescent
Winnipeg, Manitoba R3T 2N6

RESEARCH INTERESTS: Marine mammal population estimation and population dynamics; quantitative ecology.

E.K. (TED) LANGTRY

Offshore Environment Division
Indian and North Affairs Canada
Ottawa, Ontario KOA 2NO

RESEARCH INTERESTS: Aquatic biology; marine environmental impact assessment.

JIM McCOMISKEY

Frontier Development - Environmental Planning
Gulf Canada Resources Inc.
P.O. Box 130
Calgary, Alberta
T2P 2H7

RESEARCH INTERESTS: Environmental planning and assessment in frontier areas.

JOHN W. McDONALD

ESL Environmental Sciences Limited
2035 Mills Road
Sidney, B.C. V8L 3S1

RESEARCH INTERESTS: Physical oceanography.

PETER J. McNAMEE

ESSA Ltd.
678 West Broadway,
Vancouver, B.C. V5Z 1G6

RESEARCH INTERESTS: Research planning; ecological modelling; computing application to environmental problems; forest pest management systems design.

DAVE MACKAS
Institute of Ocean Sciences
Fisheries and Oceans Canada
Sidney, B.C. V8L 4B2

RESEARCH INTERESTS: Biological oceanography.

ARTHUR MANSFIELD

Arctic Biological Station
Fisheries and Oceans Canada
555 Boul. St. Pierre
Ste. Anne-de-Bellevue, Quebec H9X 3R4

RESEARCH INTERESTS: Marine mammals.

JOHN R. MARKO

Arctic Sciences Ltd.
1986 Mills Road
Sidney, B.C. V8L 4C1

RESEARCH INTERESTS: Ice dynamics; remote sensing; oil spill modelling.

DAVID R. MARMOREK

ESSA Ltd.
678 West Broadway
Vancouver, B.C. V5Z 1G6

RESEARCH INTERESTS: Aquatic ecology; ecological modelling; experimental design; acid precipitation.

HUMFREY MELLING

Institute of Ocean Sciences
Fisheries and Oceans Canada
Box 6000
Sidney, B.C. V8L 4B2

RESEARCH INTERESTS: Arctic physical oceanography; sea ice.

SERGE METIKOSH

Northern Affairs Program - NWT Region
Water Resources Division
Indian and Northern Affairs Canada
Box 1500
Yellowknife, NWT X1A 2R3

RESEARCH INTERESTS: Aquatic biology; assessment of biological effects of onshore and offshore developments in the NWT.

LANGLEY R. MUIR

Canada Oil and Gas Lands Administration
355 River Road
Ottawa, Ontario K1A 0E4

RESEARCH INTERESTS: Physical oceanography; monitoring and regulatory processes related to exploration and development.

ED PESSAH

Dome Petroleum Limited
P.O. Box 200
Calgary, Alberta T2P 2H8

RESEARCH INTERESTS: Marine ecology; toxicology; environmental planning and assessment.

DON SCHELL

University of Alaska
Institute of Water Resources
Fairbanks, Alaska 99701

RESEARCH INTERESTS: Arctic primary production.

RAY SCHWEINSBURG

N.W.T. Wildlife Service
Government N.W.T.
Yellowknife, N.W.T.

RESEARCH INTERESTS: Marine mammals; polar bears; monitoring and regulatory processes.

AARON D. SEKERAK

LGL Limited
333 - 2453 Beacon Avenue
Sidney, B.C.  V8L 1X7

RESEARCH INTERESTS: Fish ecology; trophic relationships and energy flow; importance of Arctic cod in Arctic ecosystems.

BRIAN SMILEY

Institute of Ocean Sciences
Fisheries and Oceans Canada
P.O. Box 6000
Sidney, B.C.  V8L 4B2

RESEARCH INTERESTS: Fish ecology; marine mammals; environmental impact assessment.

NICHOLAS SONNTAG

ESSA Ltd.
678 West Broadway
Vancouver, B.C.  V5Z 1G6

RESEARCH INTERESTS: Ecological modelling; strategic planning; communication; oceanic processes.

IAN STIRLING

Canadian Wildlife Service
5320 - 122nd Street
Edmonton, Alberta  T6H 3S5

RESEARCH INTERESTS: Polar marine ecology with particular reference to polar bears and seals; basic research management and environmental monitoring.

DAVID STONE

Offshore Environment Division
Indian and Northern Affairs Canada
Ottawa, Ontario
K1A 0H4

RESEARCH INTERESTS: Biological oceanography; environmental assessment and monitoring.

DAVID J. THOMAS

Arctic Laboratories Limited
2045 Mills Road
Sidney, B.C. V8L 3S1

RESEARCH INTERESTS: Chemical oceanography; marine geochemistry of the Mackenzie Delta area.

DENIS THOMSON

LGL Limited
414 - 44 Eglinton Avenue West
Toronto, Ontario M4R 1A1

RESEARCH INTERESTS: Benthic ecology; marine mammal feeding habitats and energetics; primary production processes.

TIMOTHY M. WEBB

ESSA Ltd.
678 West Broadway
Vancouver, B.C. V5Z 1G6

RESEARCH INTERESTS: Simulation modelling; experimental design; research planning; fisheries management; computer applications to resource and environmental problems.

DOUGLAS A. WOLFE

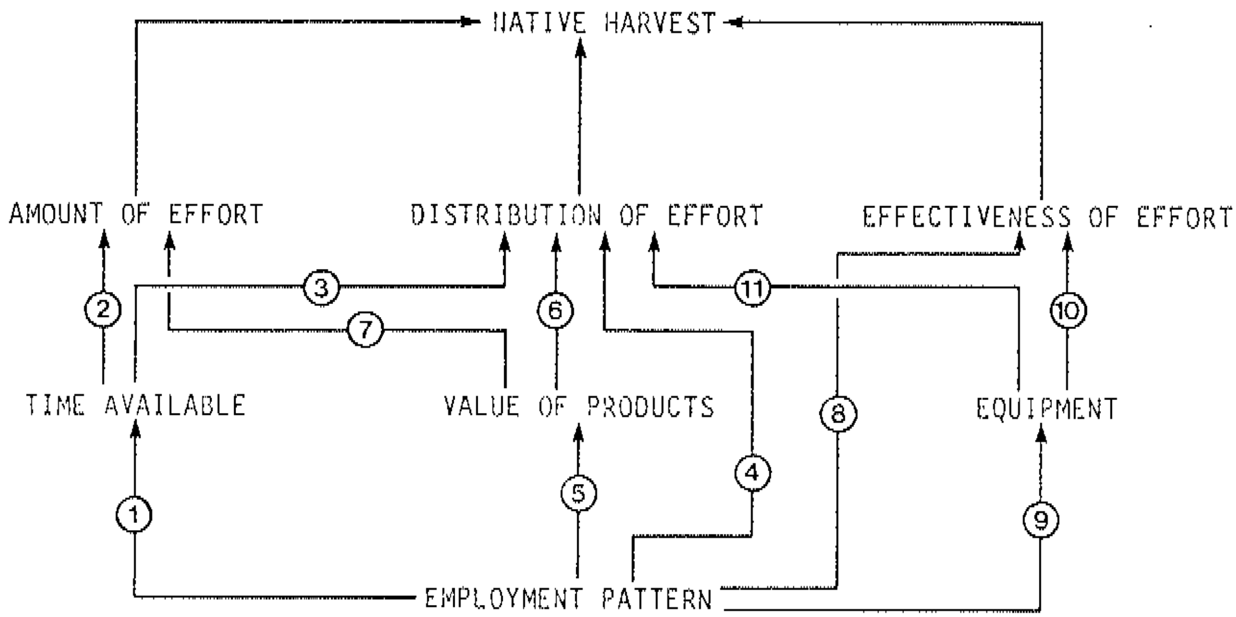
Ocean Assessment Division N/OM53
National Oceanic and Atmospheric Administration
Rockville, Maryland 20852

RESEARCH INTERESTS: Environmental impact assessment and monitoring.

# APPENDIX III

## HYPOTHESES AND ASSOCIATED LINKAGES
## NOT FULLY EXAMINED DURING
## THE SECOND WORKSHOP

Increased native employment in industry will change marine bird and mammal harvest levels.




Appendix Figure 1 Potential effects of increased native employment in industry on marine bird and mammal harvest.

# LINKAGES

## Linkages

1. The time available to natives for hunting will be affected by employment in a wage economy.

2. Total native hunting effort will be affected by limitations on time available for hunting.

3. Due to limitations in time available for hunting, hunting activities will be restricted to areas in the immediate vicinity of communities participating intensively in wage employment.

4. Wage employment will directly change the distribution of hunters and hunting effort.

5. Availability of wage employment will change hunting incentives.

6 and 7. Changed value of returns from hunting will change the total effort (time) and the distribution of effort.

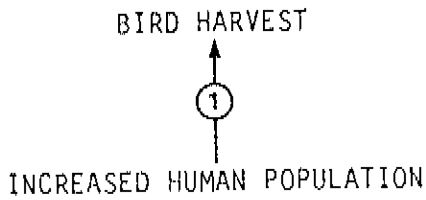
8. Wage employment will cause hunters to become less effective and skillful.

9. Wage employment will change the quality of equipment used by hunters.

10. Better equipment will increase hunter effectiveness.

11. The availability of better equipment will result in changes in the distribution of hunting effort.

A consequence of an increased human population in the Beaufort Sea region will be increases in recreational hunting of waterfowl.

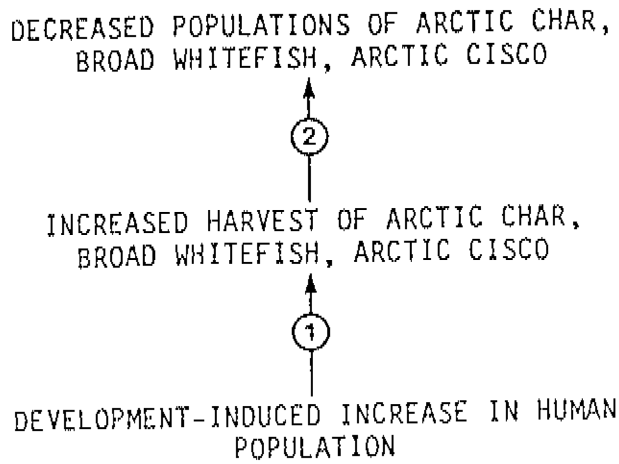



Appendix Figure 2 Potential effects of increased human population in the Beaufort Region on recreational hunting of waterfowl.

Linkage

1. Increased recreational hunting of waterfowl will result from an increased human population.

Human population increases will cause an increase in the harvest of anadromous fishes which will lead to reduced populations of these species.




Appendix Figure 3 Potential effects of human population increases on anadromous fish populations.

Linkages

1. Increases in the human population will increase the harvest of Arctic cisco, Arctic char and broad whitefish.

2. Increased harvest will lower Arctic cisco, Arctic char and broad whitefish populations.