BEAUFORT REGIONAL ENVIRONMENTAL ASSESSMENT

March 2016

Key Findings: Research and Working Group Results

2011-2015

Canada

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EXECUTIVE SUMMARY

The Beaufort Regional Environmental Assessment (BREA), a geographically based research program, brought together key stakeholders to ensure that Inuvialuit and other decision-makers are better informed and prepared for offshore oil and gas development in the Beaufort Sea. This four-year, $21.8 million program was developed on strong, multi-stakeholder collaboration, and resulted in the development of targeted knowledge required for more efficient and effective regulatory, industry, and community-level decision-making in the Beaufort region.

The BREA supports a more efficient and effective environmental assessment regime through the development of regional information to address issues that are likely to recur in individual project-level environmental assessments. The information generated is useful to industry and communities; and provides regulators the evidence base for decision making on oil and gas development. Regulatory efficiency is gained by developing and making available to all stakeholders, through research conducted at the regional scale, baseline information that will lead to better prediction, monitoring, assessment and mitigation of project impacts. The incorporation of this information by project proponents and regulators into project-specific applications and reviews will accelerate review processes as well as increase the quality of environmental assessments. Designed as a partnership among Inuvialuit, industry, government, regulators, and researchers, a broad range of involvement was sought to incorporate the knowledge, expertise, and perspectives of all stakeholders affected by oil and gas development activity in the Beaufort Sea. The inclusive governance process engaged partners in the multiple committees as they deemed appropriate, ensuring the correct participants were engaged in relevant discussions. This initiative will not replace the need for project specific environmental assessments.

The Second Year Results Forum, February 2013, and the Final Results Forum, February 2015, were held in Inuvik, NT and were well-attended by representatives of all stakeholder groups. Inuvialuit communities and organizations, industry representatives, researchers, and federal and territorial government representatives discussed the research, the process and the results of the work undertaken under BREA. Community and stakeholder input at these meetings provide the basis for collaboration on resource development in the Beaufort.

Research Summary

A total of nine research areas and six cross-cutting issues of interest to all stakeholders were prioritized and refined through a multi-stakeholder Research Advisory Committee and community engagement sessions. Funded projects sought to provide regional information to facilitate oil and gas management in the Beaufort Sea.

Baseline fish information

- ✓ The results of these 3 research projects have provided a much better understanding of the offshore occurrence of Arctic cod and other fish during the summer period; added new integrated information regarding ecosystem roles, relative abundances, habitat associations and basic biology of offshore fish species; greatly increased baseline information on fish distributions; and examined mercury contents for biota in the Beaufort Sea, which will help to explain how mercury is bioaccumulated up the food web, with implications for top predator species such as anadromous fish, beluga, and seals.

Coastal and marine birds.

- ✓ These two research projects represent the most comprehensive and current compilation of data for coastal birds in the ISR, and the first regional review of coastal bird distribution since 1988. In addition, they address a key regional information gap by assembling and organizing existing datasets into a significantly more useful format for the assessment of the impacts of oil and gas activity on bird populations in the offshore Canadian Beaufort Sea.

Bird, fish, and marine mammal information

- ✓ This project assembled biological data for key species in the Beaufort Sea through the use of past and current studies, and traditional knowledge. The organization of biological data for several key species into vulnerability profile databases has improved the accessibility of this information for stakeholders and will inform partners with regards to the prioritization of areas and species for protection; site and seasonal planning for exploration and development; assessment of potential effects of oil and gas activities on the environment; and spill management planning and actions.

Ice Research: Sea ice types, Extreme Ice features

- ✓ Seven projects were commissioned to consider sea ice types and extreme features. Results include making the extensive Canadian Ice Service archive of sea ice observations and charts more readily available to the public and the development of information and analysis tools; an integrated sea ice project that resulted in measurements of multi-year sea ice to improve the understanding of the properties and behaviour of sea ice; establishing the impacts of earlier melt and degradation of multi-year ice in the Beaufort, and impacts on offshore development and transportation. Additionally, a guide was developed to help lower the risk of damage to overwintering vessels by improving the safety of overwintering practices.

Coupled ocean-ice-atmosphere modeling and forecasting

- ✓ This Integrated project is intended to enhance the METAREA operational coupled ocean-ice-atmosphere analysis and forecasting system and to improve the NEMO ocean model, to enable finer-scale applications in the Beaufort Sea. The project's three components result in an improved operational model of waves and sea ice for forecasting conditions in the Beaufort Sea.
- ✓ A related fourth project established a set of marine observatories in the southern and north-eastern Beaufort Sea that will provide data and measurements to the forecasting system.

Offshore geohazards and coastal processes.

- ✓ The first of these two projects generated an accessible GIS data inventory of coastal morphology and processes, surficial geology, nearshore bathymetry and sediments, permafrost and ground ice, processes of coastal change, and rates of erosion. This inventory reflects data digitized and observed from high-resolution satellite imagery, aerial photographs and other data archives to show changes in the Beaufort Sea coastal region over approximately 60 years. The second project expands knowledge of rates of coastal change in the Beaufort region, and improves understanding of the sensitivity and vulnerability of the coastline to climate change, particularly to storm events, coastal erosion, permafrost and morphologic change.

Web-based geospatial analysis tool.

- ✓ The application helps maximize the knowledge users can acquire from existing data by providing a location for the centralized storage of geospatial data for the ISR; tools with which to visualize and analyze the data; and, an important means for revealing and sharing new insights and understandings of the ISR.

Community priority projects.

- ✓ Polar Bears: By demonstrating that polar bears are not widely abundant in far offshore areas of the Canadian Beaufort Sea when the region is covered with ice, the survey provides preliminary direction to project applicants and regulatory reviewers in determining what to emphasize in future research, monitoring, and assessment as well as a number of practical and methodological suggestions for how best to conduct future aerial surveys of offshore polar bear populations, where and as necessary.
- ✓ Regional Coastal Monitoring: Baseline information collected during this project will assist in the evaluation of potential impacts of activities on the ecosystem, facilitating project-level environmental assessments by providing proponents with set indicators for cumulative impacts that can feed into government monitoring and community-based monitoring programs.

Going Forward in the Canadian Beaufort Sea

BREA partners agree that the momentum of this initiative must be maintained: to ensure continuing returns on research results; to ensure the Inuvialuit are as prepared as possible for oil and gas activity; and, to maintain the partnerships and engagement with government, industry, academia and local communities.

Areas identified for further work included:

- **Baseline ecological information**
- **Ice conditions and interactions with petroleum products**
- **Understanding offshore geohazards**
- **Spill prevention, preparedness and response**
- **Waste management**
- **Social, cultural and economic indicators**
- **Cumulative effects management**

On-going assessment and analyses of fishes, marine mammals, birds and the biologically necessary conditions in their environment continues to be critical for project-level environmental assessments. Baseline information requires a long-term commitment in order to understand the processes affecting valued ecological components. BREA work will lead to the basis for developing the appropriate measures to ensure valued components are monitored and cumulative effects are mitigated.

Regional Environmental Assessment

- Sound decision-making on Beaufort Sea resource development and management and conservation efforts requires a thorough understanding of baseline environmental (social and ecological) conditions, as well as an understanding of the changing environment and climate. Addressing knowledge gaps will further readiness for resource development in the Inuvialuit Settlement Region. A regional environmental assessment facilitates future project-specific environmental assessments by building on cumulative effects work, continues to engage all stakeholders in on-going efforts to simplify environmental assessments related to oil and gas development in the Beaufort Sea, and could provide a legislative requirement that ensures outcomes are considered in future environmental assessment processes. In addition, this option is an opportunity to move BREA results to active use through the development of management tools.
- The scope of a Regional Environmental Assessment should look at options for addressing the recommendations above; remain geographically scoped within areas of jurisdictional mandates i.e., the Beaufort Sea; focus on the regional level analysis of existing research data (fish, birds, polar bears, sea ice); and work on the cumulative effects of activity in the region.
- Consideration could also be given to expanding the scope of the regional study to include shipping or other reasonably foreseeable activities in the Beaufort Region.
- Finally, Inuvialuit and local stakeholders, industry, and federal and territorial governments have an interest in understanding and assessing the trade-offs of potential development scenarios. On-going dialogue and partnerships with all stakeholders are needed to ensure the right information and actions are being undertaken.

CHAPTER 1. INTRODUCTION

The Beaufort Regional Environmental Assessment, or BREA for short, involves bringing together key stakeholders to ensure that Inuvialuit and other decision-makers are better informed and prepared for offshore oil and gas development in the Beaufort Sea. Launched by the Government of Canada in August 2010, and led by the Department of Aboriginal Affairs and Northern Development Canada (AANDC), this four-year, $21.8 million program was built on strong, multi-stakeholder collaboration, and the need for targeted development of knowledge required for more efficient and effective regulatory, industry, and community-level decision-making in the Beaufort region.

Goals and Objectives

BREA arose from a consensus around the need for a more integrated approach to the development and sharing of information required for the management of oil and gas activity in the Beaufort Sea. The program consists of a set of 23 research projects designed to fill key information gaps, and a set of six working groups established to study and report on specific cross-cutting issues relevant to oil and gas exploration and development in the region. The working groups support the integration of research findings into regulatory, industry, and community activities.

BREA was undertaken with three key objectives in mind:

1. To ensure stakeholders are better prepared for future oil and gas exploration and development in the Beaufort Sea.
2. To generate knowledge in support of informed regulatory decisions on oil and gas activity.
3. To strengthen the partnership among Inuvialuit, industry, governments, regulators, and academia to prepare for oil and gas activity in the Beaufort Sea.

Alongside these overarching objectives, four goals were established:

1. To engage communities and advance their priorities for oil and gas preparedness.
2. To fill regional information and data gaps related to offshore oil and gas activities to support efficient and effective regulatory decisions.
3. To produce regional information and results that will simplify future project-level environmental assessments.
4. To support integrated management and planning in the Beaufort region.

Partnership

BREA is a unique partnership among Inuvialuit, industry, government, regulators, and researchers. A broad range of involvement was sought to incorporate the knowledge, expertise, and perspectives of all stakeholders affected by oil and gas development activity in the Beaufort Sea. For example, all six BREA working groups as well as the BREA Executive, Steering, and Research Advisory committees included full representation from among Government, Industry, and Inuvialuit partners. In addition, an Assistant

Deputy Minister-level committee was established to ensure alignment of the BREA program with the strategic direction and policies of the Government of Canada. The BREA governance structure is shown in Appendix 1.

BREA Program Areas

BREA Research Program

The BREA Research Program funded projects that seek to provide regional information to facilitate oil and gas management in the Beaufort Sea. Each project falls within one of nine areas of research priority:

1. *Baseline fish information.*
2. *Coastal and marine birds.*
3. *Bird, fish, and marine mammal information.*
4. *Worst-case environmental design limits for ice.*
5. *Sea ice types and extreme ice features.*
6. *Coupled ocean-ice-atmosphere modeling and forecasting.*
7. *Offshore geohazards and coastal processes.*
8. *Web-based geospatial analysis tool.*
9. *Community priorities.*

Each research priority area was selected based upon the deliberations of the BREA Research Advisory and Steering committees. For some areas a single research project was conducted, while for others several projects were conducted. Each of the individual research projects is summarized in Chapter 3 of this report.

BREA Working Groups

Six multi-stakeholder working groups were established with the goal of integrating across BREA research areas and ensuring development of information that meets the needs of resource managers for offshore oil and gas activity. The working groups are as follows:

1. Cumulative Effects Working Group
2. Climate Change Working Group
3. Social, Cultural, and Economic Indicators Working Group
4. Oil Spill Preparedness and Response Working Group
5. Waste Management Working Group
6. Information Management Working Group

The mandates and activities of the six working groups are described in Chapter 4 of this report.

Purpose and Structure of the Report

The purpose of this report is to highlight the progress and main findings made through BREA's research projects and working groups. The report is based on a review of BREA publications, as well as interviews with representatives from individual research projects and working groups. Interviewees' names, affiliations and roles within BREA are listed in Appendix 2.

The balance of this report is structured as follows. Chapter 2 provides key information on the forecast of oil and gas activity for the Beaufort Sea region. Chapters 3 and 4 provide descriptive summaries and key results from individual BREA research projects and working groups, respectively. Chapter 5 concludes the report, with a discussion of lessons learned from BREA, and a summary of key messages and possible future research directions.

Resources

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CHAPTER 2. OIL & GAS ACTIVITY FORECAST

The *Oil and Gas Exploration & Development Activity Forecast* was prepared by Lin Callow of LTLC Consulting in association with Salmo Consulting Inc. The purpose of the work is to provide a general description of potential oil and gas activities over the next 15 years (from 2013 to 2028) in the Beaufort Sea and to help provide a context for the work of BREA.

Since the report was prepared in 2013, market forces have changed the forecast again. The last months of the BREA, saw several companies delay their work in the Beaufort Sea indefinitely.

Oil & Gas History in the Beaufort Region

Oil and gas exploration began in the Mackenzie Delta/Beaufort Sea region in the late 1950s and early 1960s. In the early 1970s, activity increased and drilling began offshore with the discovery of both oil and gas. In 1984 the Inuvialuit Final Agreement (IFA) was signed, establishing the 906,430 km^2 Inuvialuit Settlement Region (ISR) which encompasses the Canadian Beaufort Sea

In total, there have been 142 wells drilled in the Canadian Arctic offshore. Most of that activity has been in the Beaufort Sea region with 92 wells drilled. All of the offshore wells in the Beaufort Sea have been drilled in water depth of less than 100m, and almost all of the offshore drilling took place in the 1970s and 1980s. The most significant offshore discovery during this time was the Amauligak oil and gas field. Since the 1980s, there has only been one other well, Paktoa C-60 drilled in 2005–2006 by Devon Energy. Over the history of exploration and drilling in the region, there have been minor spill incidents (such as well kicks and wellhead gas-water flows); however, despite the extreme conditions and the development and implementation of innovative drilling technologies in the Beaufort offshore, there has never been a major spill incident.

Despite billions of dollars invested in oil and gas exploration in the Beaufort Sea and the Canadian Arctic offshore, to date none of the discoveries have led to significant commercial production.

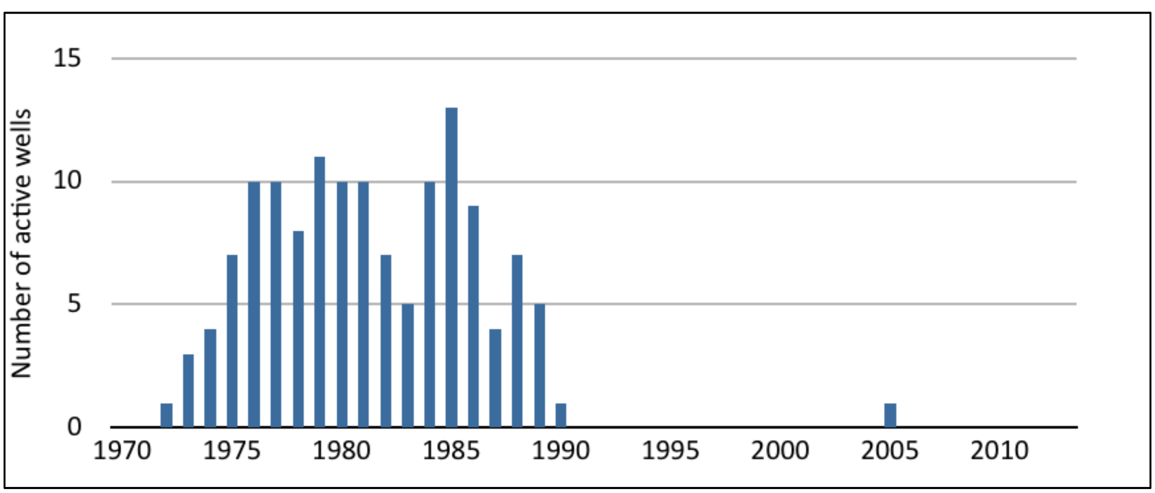

Figure 2.1. History of wells in the Beaufort Sea

Cycle of Offshore Oil & Gas Activity

Searching for oil and gas in the Beaufort Sea is challenging and expensive. The remoteness, long periods of darkness, and climatic conditions all add cost. Companies also need to navigate an involved multi-jurisdictional regulatory system. Climate change may now allow for more access, but it also may bring more challenging conditions (such as increased frequency and severity of storms). Future oil and gas development in the Beaufort will remain extremely costly and complex.

The time required to move from discovery through to production is estimated to be 10 to 14 years, including assessment, fieldwork, regulatory approvals, engineering design, and development.

Oil & Gas Research Potential

Table 2.1 lists the oil & gas resource potential for the Beaufort Sea and the Mackenzie Delta. The estimates are based on several studies. Likely there are more oil reserves in the Beaufort Sea than in the Mackenzie Delta, while natural gas reserves are estimated to be relatively evenly distributed between the Beaufort Sea and the Mackenzie Delta. Overall, the region is still in an early stage of exploration, so the potential of more and larger discoveries is likely. As Callow notes, "there is a strong indication that industry believes this area has the potential to hold large accumulations of hydrocarbons."

Table 2.1 Oil and Gas Resource Potential for Mackenzie Delta and Beaufort Sea

Resource	***Discovered Recoverable (Estimate)***	***Potential Marketable (Estimate)***
Oil	1.0 to 1.2 billion barrels 1.59 to 1.83 x 10^8 m^3	10.6 billion barrels 1.69 x 10^9 m^3
Gas	9 to 10.4 trillion cubic feet 2.55 to 2.95 x 10^{11} m^3	56.9 trillion cubic feet 1.61 x 10^{12} m^3

Oil & Gas Activity Forecast

Exploration licenses (ELs) represent an existing commitment to future activity. As of 2012, there were 16 active ELs, which in total represent over 25,000 km^2 of offshore leases and $1.9 billion of projected spending through to 2018. However, Callow indicates that under current market conditions most of this activity is unlikely to proceed on schedule.

The forecast uses a "plausible scenario model" based on assumptions reviewed with industry representatives. Following is a projection for activity in the Beaufort region through to 2028:

- Sporadic 2D seismic surveys through to 2028 (*e.g.*, 1 or 2 per year).
- One 3D seismic survey per EL area and a detailed well site seismic survey just before each well is drilled.
- The Mackenzie Gas Project is not currently viable; should market conditions improve, it may develop around 2023. This delay means that the potential for any discovered offshore gas tie-ins to the Mackenzie Gas Project will be delayed beyond 2028.
- Shallow shelf exploration wells are likely to start again, with one or two per year starting in 2016.
- Deep shelf and shelf slope exploration wells may begin in 2020, with two or three more by 2028.
- First commercial production in the Beaufort Sea may happen by 2025, with drilling and construction beginning in 2020.

As Callow notes in the forecast, there is a large margin of error with these projections, even over the short term. Environmental conditions, regulatory regime, and external market forces all affect the predictability of oil and gas activity.

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CHAPTER 3. RESEARCH PROJECTS

Introduction

The following sections provide descriptive summaries of each project undertaken as part of the BREA Research Program. The project summaries have been informed by the final reports and supplementary descriptions of the research projects, and, in most cases, interviews with key leads. A total of 23 summaries are provided, each situated within one of the following areas of research priority:

- *Baseline fish information.*
- *Coastal and marine birds.*
- *Bird, fish, and marine mammal information.*
- *Worst-case environmental design limits for ice.*
- *Sea ice types and extreme ice features.*
- *Coupled ocean-ice-atmosphere modeling and forecasting.*
- *Offshore geohazards and coastal processes.*
- *Web-based geospatial analysis tool.*
- *Community priorities.*

BASELINE FISH INFORMATION

Chapter 3.1. Hydroacoustic mapping of the offshore summer distribution of Arctic cod and other fish in the Canadian Beaufort Sea

Research Project Overview

This research project used state-of-the-art fisheries sonar and echo-sounder technologies (hydroacoustics) to map the distribution, abundance, and movements of pelagic fish in the offshore waters of the Canadian Beaufort Sea and Amundsen Gulf. Field work was conducted from research ships during the summers and autumns of 2011–2014. The focus of the research was to study the offshore occurrence of Arctic cod, a key species in the ecology of the offshore Beaufort, during the ice-free season. The hydroacoustic data collected by the acoustic equipment were supplemented with information from concurrent trawls done by ArcticNet and Fisheries and Oceans Canada (DFO). The results of this study complement recent research done on the winter distribution of Arctic cod in the Canadian Beaufort (Benoit et al. 2008; Benoit et al. 2010; Geoffroy et al. 2011).

This research project was conducted by ArcticNet, based at the Université Laval, in collaboration with DFO. It was one of two collaborative and concurrent BREA-funded studies investigating the offshore fish populations of the Canadian Beaufort Sea. The other research project — Fishes, habitats, and ecosystem linkages to oil and gas development in the Beaufort Sea — was led by DFO. Additional funding for the hydroacoustic project was provided by ArcticNet, the *Amundsen* Program, Kongsberg Maritime, BP Exploration Operating Company Limited, Imperial Oil Resources Ventures Limited, and Exxon Mobil.

Project Purpose and Goals

The composition (species, ages), distribution, and migration patterns of pelagic fish populations in the Canadian Beaufort Sea are poorly documented. That includes information on one of the ecologically key species, Arctic cod. The purpose of this project was to substantially improve our understanding of the pelagic fish populations of the Canadian Beaufort, with the ultimate goal of using this information to better inform decisions regarding offshore oil and gas activities. In particular, the project aimed to assess the relative importance of the active offshore lease blocks to overall Beaufort Sea summer fish populations, and to document the hitherto poorly known summer distribution of Arctic cod and other fish.

The main objectives of the project were:

(1) to document the summer distribution of fish, particularly Arctic cod, in the offshore Canadian Beaufort Sea in relation to bathymetry, water mass properties, currents, bottom type, predators, and prey availability;

(2) to confirm the species identity of fish echoes from the sonars using a Rectangular Midwater Trawl (RMT), trammel nets and commercial trawls;

(3) to assess interannual variability in the abundance and summer distribution of juvenile and adult Arctic cod; and

(4) to assess fish biomass in the exploration lease blocks in the summer relative to the regional background.

Fit Within BREA Program

Information regarding offshore fish populations was identified as a research priority for the BREA program. This project was one of two supported by BREA to address baseline data gaps on the composition, abundance, distribution, seasonality, and habitat use of offshore fish populations in the Canadian Beaufort Sea and Amundsen Gulf. The project contributed directly to BREA's key objective of building a stronger knowledge base to facilitate informed decision-making regarding oil and gas activity in the Canadian Beaufort Sea.

Methodology

This study was conducted in the Canadian Beaufort Sea and Amundsen Gulf, primarily during the months of August and September in 2011, 2012, 2013, and 2014, from the CCGS *Amundsen* and F/V *Frosti*. Several methods were employed to detect and identify fish in offshore waters. The primary method for this research project was the use of sophisticated "fish-finding" sonar technology: a fisheries sonar (Simrad SX90) and a multi-frequency echosounder (Simrad EK60). That technology was employed simultaneously with a variety of trawls, to collect some of the fish that were detected hydroacoustically by the sonars. Additional sonar data were collected regarding environmental conditions such as water depths and bottom types. Much of the trawl data were collected during the associated DFO project. Together, these multiple and concurrent data collection streams produced results that allowed not only the identification and mapping of fish, but also correlations with habitat conditions.

Schools of fish were detected hydroacoustically, and then samples of those fish were captured using trawls deployed at various depths. The collected fish were later identified to species, measured, and classified to age. Those data were correlated with the environmental data collected at the same time. The subsequent data analyses investigated a number of issues including (1) the ability of the acoustic data to identify and estimate fish biomass based on correlations between the acoustic echoes and the fish identified from the trawls; and (2) the correlation between the identity of the fish (e.g., species, age, size) and the habitats they were using, such as the depths at which they were swimming and whether they were over shallow shelf waters, the slope, or deeper waters beyond the slope.

Use of Traditional Knowledge

Traditional knowledge was not used during this study as little Traditional knowledge exists regarding pelagic fish populations and the far offshore of the Canadian Beaufort. Local knowledge is limited primarily to coastal fish occurrence. This study builds on that coastal information by extending our knowledge to the offshore.

Key Findings

The results of this study have confirmed that Arctic cod is the most abundant species of pelagic fish in the offshore Beaufort Sea. Previously, the prevailing assumption was that adult Arctic cod populate shallow coastal waters in summer. It was further documented that there is a clear spatial segregation of young-of-the-year Arctic cod from adults. Arctic cod less than 1 year old form a scattered layer in the top 100 m of the water column whereas larger fish (more than 1 year) form a distinct layer near the ocean bottom (200-400 m) over the slope as they do during the winter months; concentrations of larger fish are also found at 1000 m. Young-of-the-year cod were nearly uniformly distributed over the continental shelf and slope of the Beaufort Sea during the summer, and older cod were found over the entire slope. The study also determined that there is a direct relationship between the sonar signal target strength and the length of the fish; i.e., the signal strength increased with an increase in fish length.

Contribution to State of Knowledge

The results of this research have provided a much better understanding of the offshore occurrence of Arctic cod and other fish during the summer period, building on previous studies that had documented their winter distributions. In addition, the study provides baseline information on pelagic fish populations in and around the oil and gas lease blocks in the Beaufort Sea; in particular, it was discovered that Arctic cod distribution overlaps with these blocks.

Addressing Regional Information Gaps

Whereas coastal Beaufort fish populations had been studied previously, little attention had been given to offshore fish stocks. This project significantly updates and expands our understanding of pelagic fish populations: the species, numbers, and their distribution and movements with respect to environmental variables. This project also provided data specific to the offshore exploration lease blocks, and thus will be of value during future environmental assessments regarding activities in those areas.

Remaining Research Gaps

Ongoing analyses of the acoustic data collected through this project will

- Develop better estimates of fish biomass based on new target strength–fish length and weight–length relationships;
- Determine whether the biomass of Arctic cod now documented on the shelf slope is sufficient to account for the estimated energetic requirements of predators; and
- Further document the coastal distribution of Arctic cod and other fish.

Future ArcticNet scientific cruises will continue to collect acoustic and trawl data in the area annually, and will build on the results from the BREA-supported program to continue the monitoring of pelagic fish populations.

Regulatory Decision-Support

There are several findings from this research that will assist in the assessment of the potential effects of offshore oil and gas activities, and thus support associated regulatory decisions regarding future development. It is now known that important concentrations of pelagic fish are present in the oil and gas lease blocks throughout the year. Those fish stocks are the main food sources for belugas and seals, and thus are of importance to hunters in the Inuvialuit Settlement Region. The documentation that young-of-the-year Arctic cod occupy the top 100 m of the water column during the summer is relevant because that is the zone most susceptible to the effects of oil spills. It is also important to know that adult (>1 year old) Arctic cod occupy the deeper waters of the slope year-round and not only during the winter; the existing offshore exploration lease blocks are situated in those slope waters, which demonstrates that the species is at risk in the event of an oil spill at depth.

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Chapter 3.2. Fishes, Habitats, and Ecosystem Linkages to Oil and Gas Development in the Beaufort Sea

Research Project Overview

There are a number of pivotal species that occupy several distinct sub-ecosystems in the Canadian Beaufort Sea. Species' habitat associations, functional relationships, and key ecosystem processes are specific to each sub-ecosystem; hence, consequences of stressors and effects from oil and gas development will likely differ across the various ecosystems. Stressors affecting the middle trophic level, including fishes, result in cascading effects on the entire ecosystem, including components harvested for food by the Inuvialuit and Gwichi'in peoples. Information regarding fish communities and habitats in water deeper than ~150 m, the role of deepwater fishes in the ecosystem and their linkages to lower tropic levels, and linkages between shallow-water and offshore areas are currently poorly understood. This lack of data represents a distinct information gap that precludes effective planning and regulatory activities associated with industrial activities including oil and gas development. The distributions, habitat associations and ecological roles of offshore pelagic (water-column-dwelling) and benthic (bottom-dwelling) fishes in the regions have not been researched in detail due to environmental and operational constraints. Thus, the ecosystem roles, importance, relative abundance, habitat associations and basic biology of most offshore fish species remain largely unknown. In order to address these knowledge gaps, this project sought to obtain baseline information on deepwater fishes that inhabit the deeper waters of the outer shelf (~100-1000 m) in the Beaufort Sea. This project was led by Fisheries and Oceans Canada, in collaboration with researchers at the universities of Laval (hydroacoustics linkages), Manitoba (cod energetics, contaminants, and potential genetic linkages), Québec à Rimouski (benthic invertebrate linkages), and Waterloo (stable isotope analyses).

Project Purpose and Goals

The objectives of the project were to:

1) conduct trawling surveys of the outer continental shelf and slope (100-1000 m) in both pelagic and benthic habitats to establish a) fish occurrences and community diversity, b) habitat linkages, and c) ecological couplings (e.g., foodweb or trophic patterns) within and among these habitats in the offshore areas;

2) establish the functional relationships within and among deep-water slope, shelf and coastal benthic and pelagic sub-ecosystems in the Beaufort Sea (e.g., couplings associated with differential habitat use over the life histories of key fish species; diet, productivity and energetic linkages derived from stable isotope and fatty acids analyses of tissues; and baselines for key indicator contaminants);

3) summarize existing knowledge of fish occurrences and habitat associations geo-spatially, and integrate new findings with this knowledge to assess potential sensitivities of fishes, their habitats and ecosystem process to oil and gas developmental activities; and

4) link offshore research findings with those from shelf and coastal areas to establish baselines for ongoing monitoring of fishes, habitats and ecosystem integrity (e.g., community-based or compliance monitoring) as the basis for regulatory advice and decision making.

Fit Within BREA Program

This project is one of three that was carried out under BREA's "Baseline fish information" research priority. It is linked to the "Baselines and potential effects of mercury and hydrocarbons in Beaufort sediments and biota" project. The third project under the same research priority is "Active acoustic mapping of fish". The project also has linkages to other BREA projects including "Regional coastal monitoring program" and "Baselines, accumulation, cycling, and potential effects of hydrocarbons in Beaufort Sea sediments and biota".

By acquiring baseline information on the distributions, habitat associations and ecological roles of offshore fishes, the project contributes directly to BREA's key objective of building a stronger knowledge base to support informed decision-making regarding oil and gas activity in the Canadian Beaufort Sea.

The work primarily addresses BREA's goal of producing regional information and results that will inform project-level environmental assessments. However, it also addresses the other goals of filling regional information and data gaps to support efficient and effective regulatory decision-making, engaging communities and advancing their priorities for oil and gas preparedness, and supporting integrated management and planning in the Beaufort Sea.

Methodology

Regional-Scale Trawling Survey

To determine offshore fish occurrence, diversity, and community structure, a trawling survey that targeted both benthic and pelagic habitats was conducted during the open water seasons in 2012 and 2013 at shelf (20-200 m), upper slope (200-500 m), and deep-water (750-1000+ m) sites in the offshore Beaufort Sea. A total of 28 stations were sampled for fishes and their supporting habitat components along four main transects in 2012, with stations along each transect targeted at 40, 75, 200, 350, 500, 750, and 1000 m depths. An additional 27 gear deployments were conducted for adult and larval fishes, zooplankton and physical oceanographic properties to net-validate hydroacoustic work (i.e., sampling of concentrations of hydroacoustic targets detected in the water column) (Figure 3.2.1) and to characterize the water-column habitats. The study was designed to target areas through the highest concentration of lease blocks; and to maximize regional coverage over the central Beaufort Shelf and slope, and sites in the vicinity of the Yukon-Alaska border. Some repeat sampling was also conducted along transects originally sampled during the Northern Coastal Marine Studies Program (NCMS, 2003-2009).

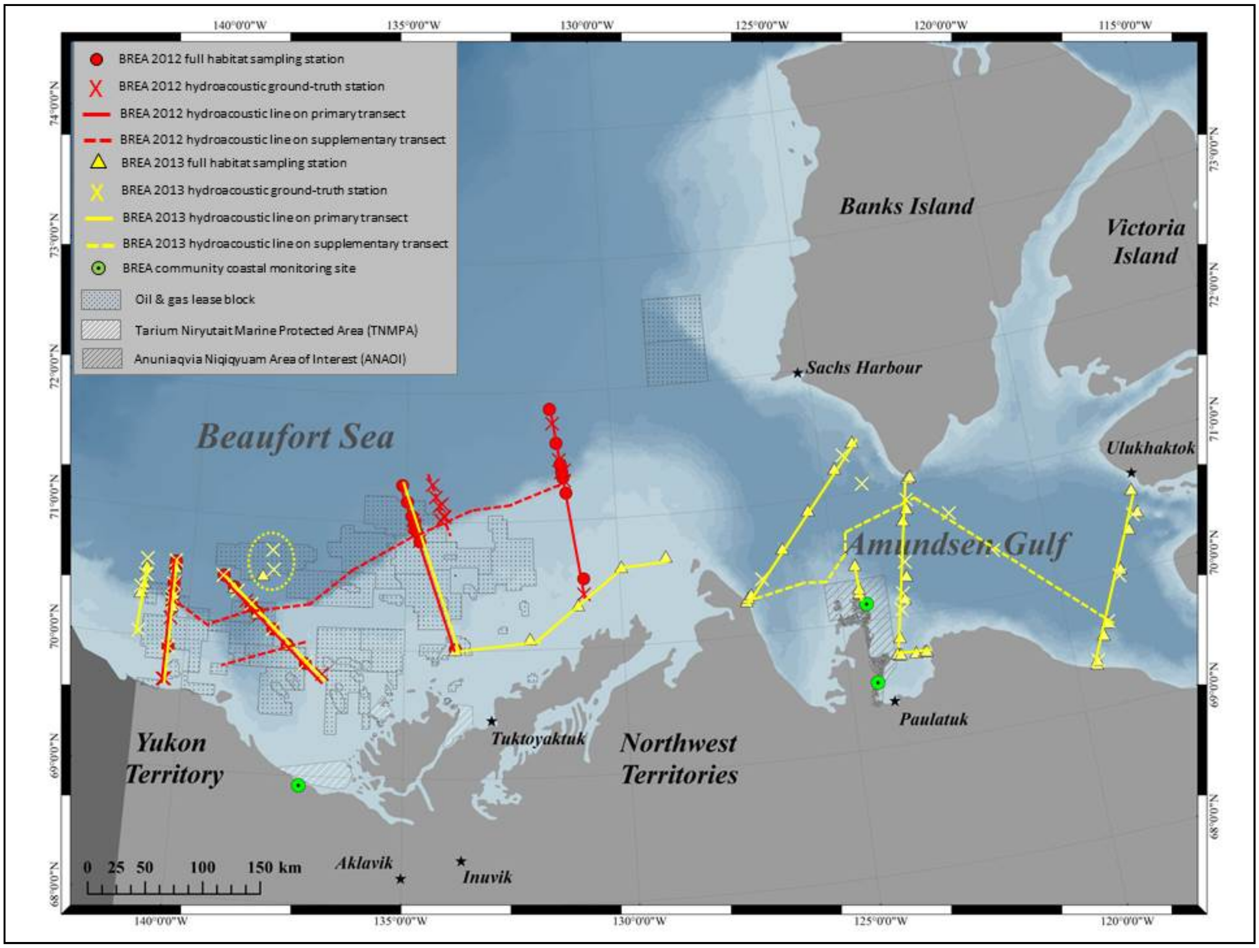

Figure 3.2.1. Stations sampled during the BREA Marine Fishes Project, including full habitat sampling for fishes, zooplankton, epifauna, infauna, sediments, marine primary productivity, and physical oceanography in 2012 and 2013 (red circles and yellow triangles, respectively) and supplementary work for fishes, zooplankton, and physical oceanography to ground-truth hydroacoustic samples in both years (red and yellow X's). Solid lines indicate hydroacoustic work along a primary transect for 2012 (red lines) and 2013 (yellow lines), and dashed lines indicate additional hydroacoustic work along transects of interest. Green circles denote linked community coastal monitoring sites supported in part through this project. The three westernmost transects are included in the Canada-US Transboundary Study; the deep-water pilot (1200-1500 m) sites are circled in a yellow dotted line.

The regional scope of the study was expanded in 2013 to focus on two general areas, divided by cruise legs. Activities during leg 1 focused on sampling new areas within Amundsen Gulf, including work offshore of the Cape Parry Migratory Bird Sanctuary and within the Anguniaqvia Niqiqyuam Area of Interest (ANAOI; Darnley Bay) relevant to the development of a marine protected area in this region. Work during leg 2 centered on the Yukon-Alaska border and was conducted in conjunction with the University of Alaska Fairbanks as part of the Canada-US Transboundary Study, aimed at developing comparative field and lab methods which can be applied at a broad regional scale. A total of 58 benthic habitat stations were sampled in 2013, and 18 mid-water trawl tows were conducted in association with hydroacoustics. Additionally, an at-sea pilot study was conducted to assess the capability of the vessel and gear to sample depths > 1000 m. Two stations were successfully fished at 1500 m depth, and a suite of full habitat parameters was sampled at 1200 m (Figure 3.2.1).

Hydroacoustic Survey
The study design included hydroacoustic surveys and net-validation along each transect to determine the distribution of pelagic biomass, in particular of Arctic Cod, a key species in the offshore food web. Supplementary hydroacoustic measurements across fish concentrations at 150-400 m depths also took place across Mackenzie Trough and along the shelf break in 2012. Similar work across Amundsen Gulf and along the Kugmallit transect was conducted in 2013 to determine consistency of the annual patterns of fish aggregations (Figure 3.2.1). The BREA Marine Fishes Project acquired the field hydroacoustic data; whereas much of the analysis was conducted through the linked project "Active acoustic mapping of fish" (Laval University).

Integrated Sampling of Relevant Habitat Components
In addition to benthic and mid-water trawling for fishes, activities also included bottom sampling for epibenthic invertebrates (organisms that live on top of the seafloor), sampling for sediments and infauna (organisms that live within the sediment), pelagic net sampling for zooplankton (key prey for marine fishes) and larval fishes, and sampling for relevant water mass characteristics (e.g., salinity, temperature and nutrients over depth). These samples were collected to determine critical habitat linkages (e.g., fish associations with particular habitats or water masses) and couplings, such as food web structure and energy flow within and among the offshore habitats, determined through follow-on laboratory analyses.

Over-arching Activities of the Offshore Program
For all biological samples acquired, first-order analyses included taxonomy and biomass of fishes and invertebrates (with invertebrate diversity conducted in collaboration with the Université du Québec à Rimouski). Second-order laboratory analyses included gut content and calorimetric analyses, as well as fatty acid and stable isotope analyses (the latter conducted through collaboration with the University of Waterloo). Archives of samples and tissues have also been developed for possible follow-on laboratory analyses (e.g., contaminant, genetic research; in collaboration with the University of Manitoba).

More generally, data obtained from the offshore sampling were coupled with those from nearshore sampling as part of a "Regional coastal monitoring program" conducted at multiple sites in the area (Figure 3.2.1) to address connections between these two marine ecosystems. Key components of the coastal program were supported through this BREA project; however, the majority of the program was developed through other means.

Multi-year sampling conducted by the offshore program and linkages to previous work (NCMS, 2003-2009) will enable an inter-annual comparison of fishes and habitats in key areas. A spatially referenced database of historical fish distributions was developed previously and incremented significantly through the BREA and subsequent marine fishes work (Figure 3.2.2). Additionally, new data generated from the current project will contribute spatially referenced data on fish distributions, abundances, and associated habitat-related parameters toward the BREA Toolkit developed under the project "Web-based geospatial analysis tool".

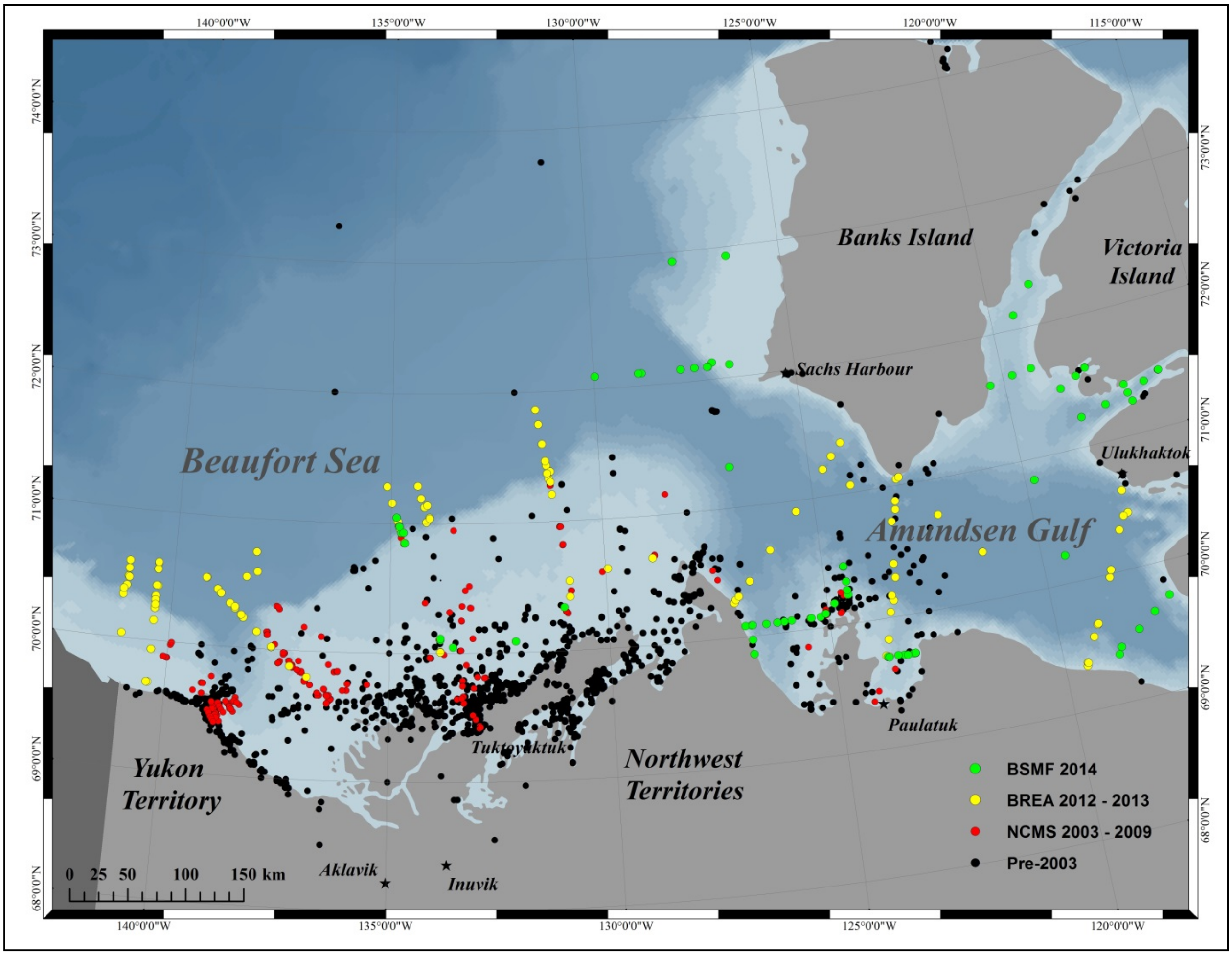

Figure 3.2.2. All point occurrence records for marine fishes based on an extensive literature review (Coad and Reist 2004; unpublished), including records prior to 2003 (black), records from the NCMS (2003-2009, red), and new stations from the BREA Marine Fishes Project (2012-2013, yellow), and follow-on Beaufort Sea Marine Fishes Project (2014, green).

Use of Traditional Knowledge

No traditional knowledge was acquired during this project, as this work mainly consisted of trawling surveys and associated analyses in the offshore area. However, as part of the "Regional coastal monitoring program" to which this BREA project is linked, community fishers from six Inuvialuit communities conducted onshore coastal sampling which allowed for direct community linkages to project activities, established coastal baselines, and allowed for linkages between onshore and offshore findings. In addition, Inuvialuit community members also assisted with work on the offshore trawling surveys. A research plan detailing the scope and initial analyses of the project formed the basis of a consultation workshop in Inuvik (December 2011) which sought to incorporate community input regarding the project. Preliminary results were also presented at the BREA workshop in Inuvik in

February 2013 and at annual meetings of the Inuvialuit Game Council (IGC) and Fisheries Joint Management Committee (FJMC).

Key Findings

New information was obtained from previously unstudied areas, particularly in deep-water (>200 m depth) habitats. Overall, 9,500 and 13,350 fishes from 11 and 13 taxonomic families were sampled in 2012 and 2013, respectively. In total, 39 marine fish species were captured directly by the BREA project in 2012, with an additional 10 species collected in 2013. These represent species previously known to occur in the area. A further 16 unidentified taxa, believed to be new records for the area, were captured; however, these require confirmation of species-level identifications (underway). Key findings for fish and relevant habitat components are summarized below. Of the 16 suspected new occurrences in the Canadian Beaufort Sea, some likely represent species previously present but unsampled, whereas others appear to be new to the region, new to Arctic Canada, and new to the Canadian fish fauna overall. Taxonomic verification of specimens by world experts is ongoing.

Distribution of Pelagic Fish Biomass

The hydroacoustic survey detected a wide-spread, offshore aggregation of fishes along the Beaufort Sea slope at stations from ~200-450 m depth in 2012, with a similar pattern in 2013 across the Beaufort Sea slope and throughout Amundsen Gulf. Net-validation of hydroacoustic methods with mid-water trawling documented relatively low diversity of fishes in these aggregations (6 species in total) with Arctic Cod numerically dominating pelagic catches and accounting for the majority (>80%) of total pelagic fish biomass across all samples from the area. Net-based sampling underestimated the pelagic biomass of Arctic Cod relative to the hydroacoustic data; thus, the combined approach of net-validating hydroacoustic work used during the current study is recommended for estimating Arctic Cod biomass in pelagic habitats in the future.

The age-at-depth distribution of Arctic Cod indicate that larval and juvenile fishes primarily occupy the upper water column (top 0-50 m), while older (1+ and 2+) age classes occupy deeper habitats. Diet analyses for pelagically occurring Arctic Cod suggest that food was not a primary driver for occupying pelagic habitats prior to descent toward bottom with increasing age. Rather, occupancy of intermediate depths may be a strategy to avoid seal predation in the upper water column and limit predation from other fishes such as larger Arctic Cod and Greenland Halibut near the bottom.

Benthic Fish Diversity and Habitat Associations

The family-level diversity of benthic fish families was comparable between the shelf, upper slope, and lower slope; however, species-level diversity and overall fish biomass was highest at upper-slope stations (i.e., 200-500m depth). Fish community structure analyses indicated the presence of four distinct assemblages corresponding to the nearshore shelf (18-75 m), offshore shelf (75-200 m), upper slope (200-500 m), and lower slope (500-1000 m) habitats. The nearshore and offshore shelf assemblages were primarily characterized by small-bodied, sparsely distributed bottom fishes such as Arctic Staghorn Sculpin (nearshore) and Twohorn Sculpin (offshore), whereas the deeper slope assemblages were characterized by a few larger-bodied species such as Greenland Halibut (upper and lower slope), and Arctic Skate (lower slope), as well as a suite of small-bodied fishes. Arctic Cod were ubiquitous across all habitats but were particularly abundant along the upper slope from 200-400 m depth across the entire upper Beaufort Sea slope, and also across the shelf break over deeper bottom depths farther offshore (i.e., also in pelagic habitats). A similar pattern of Arctic Cod biomass distribution was recorded 2013, suggesting that the 200-400 m water mass may be ecologically and biologically significant. This pattern, however, was not observed during follow-up work in 2014 conducted under the Beaufort Sea Marine Fishes Project, highlighting the need for a greater understanding of inter-annual variability in abundance and distribution of this key prey species.

Zooplankton/Ichthyoplankton

Zooplankton is a diverse group of organisms that include microscopic crustaceans, larval stages of some benthic (bottom-living) invertebrates, and gelatinous species such as jellyfish and ctenophores. They play an integral role in the marine food web by transforming energy from their phytoplankton food resources into highly energetic lipid reserves (~80% of body mass), and are the primary energy source for Bowhead Whales and pelagic fishes. During the BREA 2012 cruise, 104 zooplankton taxa were identified (92 at the species level). This represents a higher level of regional diversity than previously reported from more shallow sites (e.g., 79 species reported during the NCMS), likely due to the new (deeper) locations sampled during the BREA. Zooplankton rely heavily on photosynthetic primary production for energy (i.e., sympagic (ice-associated) primary producers or phytoplankton that require light to grow), and therefore the majority of all zooplankters were found in the upper 100 m of the water column. Numerous larval fishes were found to co-occur in this depth zone, utilizing the abundant zooplankton prey available. Taxonomic analyses of larvae fishes are pending, but preliminary results suggest that Arctic Cod and Stichaeidae (Pricklebacks) were the most abundant taxa.

Benthic Invertebrates

Benthic (bottom-living) invertebrates include the epifauna (animals living on top of the sediments, e.g., shrimps, crabs, sea stars) and infauna (animals living within the sediment, e.g., worms, bivalves), and are key components of the Arctic marine ecosystem. They represent a key prey base that directly support marine fishes, but also provide supporting ecosystem services related to coupling processes between the upper-water column and bottom habitats, and recycling nutrients and minerals. Benthic invertebrates are also relevant ecological indicators because they are relatively sessile, long-lived, are directly in contact with sediments, and different species and assemblages respond to specific environmental drivers. Benthic invertebrates are a diverse group of organisms, with at least 384 distinct epifauna taxa from 15 phyla, and 385 distinct infauna from 14 phyla sampled from 2012 and 2013. Samples and data will be used to report on benthic biodiversity, to determine regional species assemblages and key environmental drivers, to report on baseline levels of contaminants (mercury, hydrocarbons) and to determine the role of invertebrates in the offshore food web.

Coastal Fishes

Nearshore sampling generated new information on the ecology of numerous fish species, enabling analyses of the functional linkages between offshore marine and nearshore coastal habitats. Effort was particularly focused on collecting data for Capelin, which are abundant and co-occur with Arctic Cod in Darnley Bay. Dietary comparisons of these two forage fishes demonstrated a high degree of overlap in feeding preferences, suggesting potential competition between local populations. Information obtained from coastal sampling in Darnley Bay will also be used in the development and monitoring of the ANAOI, proposed as a new Marine Protected Area.

Contribution to State of Knowledge

Addressing Regional Information Gaps

Information, samples and data gathered during the offshore trawling surveys in 2012-2013 address key knowledge gaps regarding fish community structure, habitat utilization, and life history and trophic linkages within and among sub-ecosystems. Prior to the BREA Marine Fishes Project, linkages between shallow-water and offshore areas in Amundsen Gulf and deeper shelf, slope, and abyssal waters of the Beaufort Sea were poorly known. Thus, the project has added new integrated information regarding ecosystem roles, relative abundances, habitat associations, and basic biology of offshore fish species. Baseline information on fish distributions has also been greatly increased, with at least 13,282 new location records for marine fishes in the western Canadian Arctic added to the regional baseline since 2011 (Figure 3.2.2).

Stakeholder Preparation

By providing information on fish assemblages within the Beaufort Sea (both offshore and inshore), these data will assist in effective planning and regulatory activities associated with industrial activities related to oil and gas development. Specifically, the project provides information on the structure (e.g., diversity) and function (e.g., productivity and nutrient cycling) of all relevant components (e.g., fishes, invertebrates), processes (e.g., energy flow), and linkages (e.g., between nearshore and offshore communities) of the offshore marine environment in support of an ecosystem-based approach to management. In addition, it will serve as a baseline from which to monitor the potential effects of industrial development (e.g., habitat alteration, contaminants) and differentiate those from other stressors, such as climate change. The information can be used for assessing regional (Canada-US, Beaufort Sea – Amundsen Gulf) and local (e.g., Darnley Bay) ecosystem changes over time. Archival data will supplement new collections and provide longer-term context. Additionally, information from the project will aid in the identification of indicator organisms that could be used in establishing community-based and compliance monitoring programs.

Reporting

A summary report on the distribution and habitat associations of marine fishes of the Canadian Beaufort Sea and Amundsen Gulf is being developed. The report will serve as an information tool and will include distributional maps for each of the 52 fish species known from the area prior to the BREA marine fishes project, with summary information related to environmental preferences for key habitat features such as temperature, depth, salinity, and substrate composition. A follow-on supplement will update this with new species (once identities are confirmed). These reports will be useful tools for evaluating environmental impacts assessments of proposed work.

In addition, five primary publications are in progress for a Special Issue on Arctic Cod to be published in the journal Polar Biology. These works will include analyses of the spatial distribution of Arctic Cod in the near-bottom and water column habitats, co-occurrence and potential food competition between Arctic Cod and Capelin, analysis of Arctic Cod bio-indicators (fatty acids, stable isotopes), and a review of currently available information on Arctic Cod.

Further, a Special Issue on the BREA Marine Fishes Project is being developed and targeted for submission in early 2016. This publication will encompass analyses and information for key ecosystem components including physical oceanography, primary production, zooplankton, benthic invertebrates, and pelagic and benthic fishes. Papers will address the distribution of diversity, abundance and biomass, community composition and assemblage structure, association with supporting habitat features, and food web structure and function, as determined using bio-indicators (i.e., stable isotopes, fatty acids and contaminants).

Key information regarding the nature of the data and its spatial and temporal characteristics are summarized as meta-data and deposited with the Polar Data Catalogue in accordance with BREA guidelines. Key components of these data will also be published as formal Data Reports within the Fisheries and Oceans Canada report series.

Finally, all presentations, posters and other items delivered over the course of the project to indigenous peoples (e.g., FJMC and IGC meetings), scientific conferences, and BREA meetings will be assembled and archived with appropriate organizations (e.g., IGC, FJMC, DFO, AANDC).

Remaining Research Gaps

Continued baseline studies are required to increase our understanding of fish assemblages in the Beaufort Sea. As accessibility increases due to declining sea ice, comprehensive, multidisciplinary research surveys are required for more northerly and deeper areas to establish baselines critical to assessing fish and their habitat responses to Arctic change. Current project results show that, although significant information has been obtained for much of the area, many aspects represent unique or single samplings. Accordingly, substantive gaps remain in our spatial understanding and with respect to temporal variability in the overall system (both offshore and coastal) both seasonally and inter-annually.

Regulatory Decision-Support

The analyses and reporting of sensitivities of fishes and life history types/stages, critical habitats, and key ecosystem processes to oil and gas developmental activities will provide operational tools to the regulatory process, including project planning and evaluation. Understanding the potential effects of development, differentiating those from other stressors, such as climate change, and establishing baselines for ongoing monitoring of indicators relevant to valued components, process, habitats and ecosystem integrity facilitate both specific and regional-level assessments. The databases and mapping outputs from the project will also facilitate future assessment processes. Furthermore, the project will contribute to understanding the regional context through joint Canada/US sampling in the transboundary area of the Yukon-Alaska border.

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Chapter 3.3. Baselines and Potential Effects of Mercury and Hydrocarbons in Beaufort Sediments and Biota

Research Project Overview

An increasing interest in offshore oil and gas exploration and production, along with an increase in marine traffic and the transport of crude oil and its refined products, has amplified the probability of accidental oil spills in the Canadian Beaufort Sea. Increased hydrocarbon exposure may translate into adverse effects on marine organisms and greater health risk for indigenous people who harvest these animals. This project sought to establish the background levels and composition of hydrocarbons in both abiotic and biotic components of the Beaufort Sea prior to further oil and gas development, and develop our understanding of the factors controlling the transport, fate and biological effects of petroleum hydrocarbons spilled in the marine environment. The work also examined baseline measures of hydrocarbon metabolite formation and fish health parameters related to hydrocarbon exposure. In addition, the project aimed to obtain information on how mercury is cycled through the Beaufort Sea environment and the concentrations of mercury in biotic and abiotic components. This project was led by Gary Stern of the Department of Fisheries and Oceans.

Project Purpose and Goals

Oil and gas activities as well as shipping may lead to petroleum hydrocarbon pollution of the environment in the Canadian Beaufort Sea. However, hydrocarbons may also be present naturally, through oil seeps. The goals of the hydrocarbon component of the project were therefore to

1) Establish the background levels and composition of hydrocarbon compounds in sediment, zooplankton, benthic invertebrates, and fish of the Beaufort Sea outer shelf and slope regions prior to further oil and gas development.

2) Establish baseline measures of hydrocarbon metabolites in fish (*i.e.*, determine nature and levels affecting key fishes).

3) Measure indicators of fish health and link these to hydrocarbon exposure and internal metabolite concentrations so that the magnitude and extent of potential environmental perturbations can be assessed.

4) Generate maps and tables showing spatial distributions and concentrations of predominant and toxicologically significant hydrocarbon compounds in various components (*e.g.*, selected species of zooplankton, benthic invertebrates, fishes, and surface and suspended sediments).

5) Assess the geographical variability of current hydrocarbon levels in this region, and determine their natural variability over time prior to the industrial period.

6) Conduct chemical and physical oceanographic measurements in tandem with the collection of zooplankton and fishes so as try to determine how increasing water temperatures and primary productivity may affect hydrocarbon exposure.

7) Use hydrocarbon composition biomarkers derived from these data to establish their sources (natural seeps, terrestrial run-off, oil/gas combustion-related) in the marine ecosystem in this part of the Canadian Arctic, prior to any future oil and gas exploration in the region and prior to the likely expansion of shipping traffic through the Northwest Passage.

In association with the BREA project "Fishes, habitats and ecosystem linkages to oil and gas development in the Beaufort Sea", the goals of the mercury component of the project were to:

1) Establish the background levels and composition of mercury in both abiotic and biotic components of the Beaufort Sea outer shelf and slope regions prior to further oil and gas development.

2) Further our understanding of the study of environmental pathways of mercury, including its delivery, transport, and elimination from Arctic marine ecosystems.

3) Understand the potential effects of development and differentiate those effects from ones caused by other stressors (*e.g.*, climate change).

Fit Within BREA Program

This project is one of three that was carried out under BREA's Baseline Fish Information research priority. It is inextricably linked to the "Fishes, habitats and ecosystem linkages to oil and gas development in the Beaufort Sea" project, as it made use of the samples and ancillary data collected as part of the trawling surveys as well as coastal monitoring programs in the Beaufort Sea. The third project under the same research priority is "Active acoustic mapping of fish".

By acquiring data on the baseline levels and composition of hydrocarbons and mercury levels in invertebrates, fish, and sediments, the project contributes directly to BREA's key objective of building a stronger knowledge base to support informed decision-making regarding oil and gas activity in the Canadian Beaufort. The work primarily addresses BREA's goal of filling regional information and data gaps to support efficient and effective regulatory decision. However, it also addresses the other goals of engaging communities and advancing their priorities for oil and gas preparedness, producing regional information and results which inform project-level environmental assessments, and supporting integrated management and planning in the Beaufort.

Methodology

Biological and sediment samples were collected throughout several expeditions during the summer of 2012 and 2013 from various regions of the Beaufort Sea. Zooplankton and benthic invertebrate samples from previous expeditions were also made available. Physical and chemical oceanographic measurements were made concurrently along with the collection of all biotic and abiotic samples.

Surface sediment samples were analyzed for their hydrocarbon composition to examine the contribution from oil-based (petrogenic) vs. fire-based (pyrogenic) sources and the extent of terrestrial vs. marine input. In addition, surface sediment samples were analyzed for mercury to determine the source of the mercury to the sediments. Mercury concentrations were also examined in benthic invertebrates as well as zooplankton samples; data for fish are not yet available.

Concentrations of hydrocarbon metabolites were measured in the liver of arctic cod in order to examine the relationship between measured levels of metabolites and various health parameters in the fish; data for invertebrates are not yet available. Additionally, as vitamins E and A are critical to the normal development of fish embryos and they are known to be negatively impacted by exposure to hydrocarbons, these vitamins were also measured in the liver of cod samples.

Use of Traditional Knowledge

No traditional knowledge was acquired during this project, as this work consisted of measurements of baseline levels of hydrocarbon components in sediment and biological components. However, community workshops for consultation and community engagement did occur and were well received. A community workshop was held in Inuvik (December, 2012) to present and discuss the work.

Key Findings

Hydrocarbon metabolites were found in the liver of all 60 cod samples that were collected. The project found that as concentrations of a specific group of metabolites increased, the fish length and liver weight decreased. An increase in metabolite concentrations was associated with an enzyme that converts an inactive form of the thyroid hormone into its active form. Neither vitamin A nor vitamin E was detected in the liver, but the ester form of vitamin A was detected and found not to be associated with concentrations of metabolites.

Analysis of surface sediments showed that the Beaufort Sea is a highly petrogenic (fossil carbon-rich) as opposed to pyrogenic (combustion carbon-rich system) system, indicating that eroded coal outcrops, peat, and natural oil seeps are currently the main sources of hydrocarbons in the area, with forest fires and industrial and vehicular activity having less influence. This finding is different from most other river-dominated seas worldwide, including most other major Canadian sites. Furthermore, hydrocarbons in sediment samples showed distinct terrigenous (terrestrial plant based) contributions. These data show that plants present throughout the Mackenzie River watershed are influencing the inputs to marine sediments, with a much smaller influence from marine primary productivity. Ratios between two biomarkers show a terrigenous influence across all sites, although they are mostly on the boundary of a mixed marine algal/terrigenous input. This strong terrigenous signal is fairly unique among marine sediments worldwide.

Analysis of contaminants showed that concentrations of mercury and most metals in surface sediment samples increased with water depth/distance offshore, which may be related to higher organic matter input, perhaps due to a combination of greater aquatic (marine) primary productivity and lower (geological) sediment input. In general, higher mercury concentrations were observed going from west to east, and the highest concentrations were often found at sites where the water was 200-400 m deep, along the continental slope. This is possibly related to upwelling of nutrients from the mixed layer between different water masses.

The data also show that benthic invertebrates are likely accumulating mercury from the sediments. Mercury concentrations were on average much higher in the benthic invertebrates relative to the pelagic zooplankton, and there were clear, increasing trends between sedimentary mercury and benthic invertebrates for most species. Starfish were the exception, with concentrations decreasing with increasing sedimentary mercury concentrations. Analyses also showed that inner muscle tissue of benthic invertebrates was significantly more elevated in total mercury than the exoskeleton for a given sample/species, with the unusual exception of the shrimp samples. In addition, most species were found to have higher total mercury concentrations if they were sampled at deeper depths along the same transect. Concentrations of total mercury were similar among the same species and water depth, but in general, concentrations were highest in the more westerly transects. When compared to other studies, the data obtained on zooplankton during this project show that the western Beaufort and Chukchi Seas have by far the highest mercury concentrations across the Canadian, American, and Russian Arctic (Figure 3.3.1).

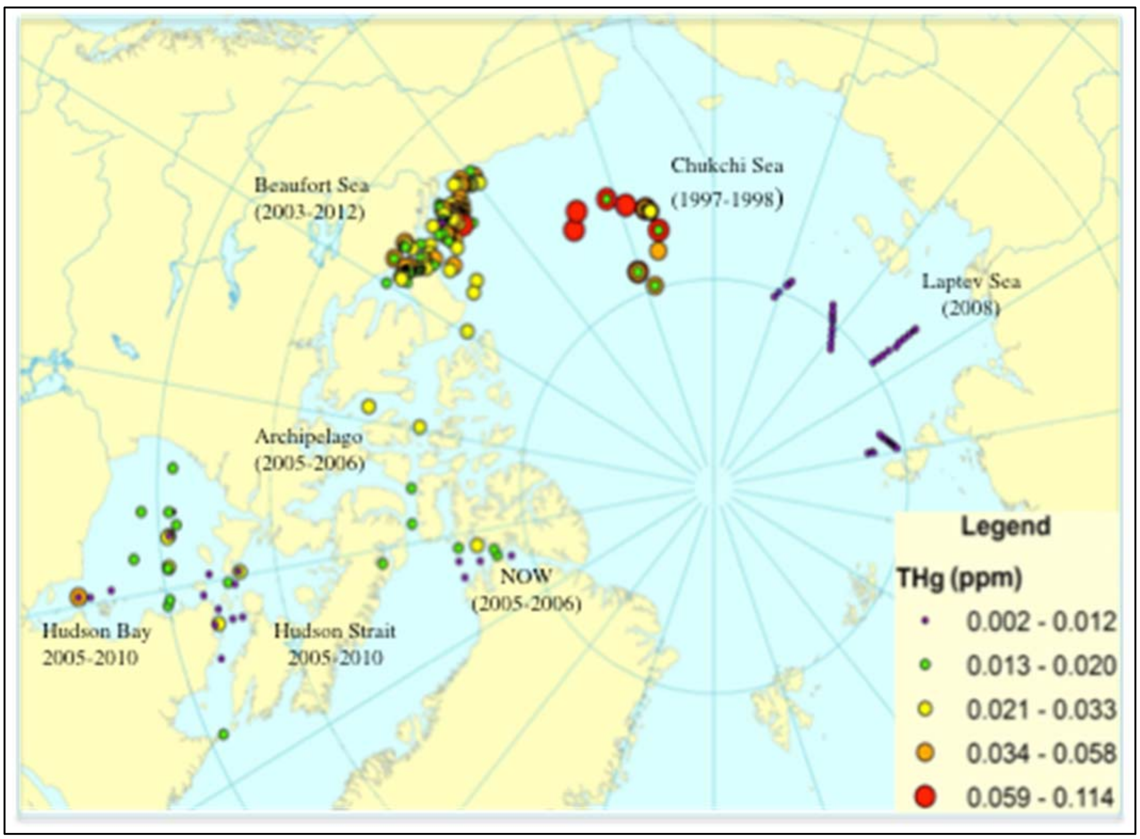

Figure 3.3.1. Pan Arctic total mercury concentrations (µg/g) in *Calanus sp*.

Contribution to State of Knowledge

Addressing Regional Information Gaps

This project has established background levels of hydrocarbons and hydrocarbon composition in sediments across all oil and gas lease areas in the Beaufort and across a significant gradient in water depth (0-1000 m), ranging from near the coast to the continental basin. In addition, relationships between hydrocarbon metabolites and various fish health parameters were examined during the course of the project. Information on baseline hydrocarbon and effects of hydrocarbons and their metabolites on fish in the Beaufort Sea were not well known before this project was undertaken.

Virtually no information is available on biomagnification and bioaccumulation of mercury in deep water and shelf adult fish. This project examined mercury contents for biota in the Beaufort Sea, and the information from this work will help to explain how mercury is bioaccumulated up the food web, with implications for top predator species such as anadromous fish, beluga, and seals.

Metadata on mercury and hydrocarbons in the Beaufort Sea have been added to the Polar Data Catalogue.

Stakeholder Preparation

The data obtained from this project will be useful in assessing the responsibility for and the impact of any future spill from shipping or drilling in the region, in addition to assessing the effectiveness of any clean-up strategies used by industry, the government or affected communities in the event of such a spill. This knowledge will benefit communities, as they will have information with which to pursue rectification from those responsible for any spills. The strong terrigenous signal in sediments can be used, in tandem with the hydrocarbon data, to determine sources of other oils, such as from spills, and to what extent biodegradation has occurred. Knowledge of what drives inter-annual and spatial variability in mercury concentrations in biota is useful to Beaufort communities to better assess how the ecosystem is changing over time and to determine if certain regions are more at risk than others of consuming species with high mercury concentrations. Temporal and spatial trends in biota mercury concentrations can lead to a better understanding of system variability, which can then be used for environmental assessments, including any potential impacts from oil and gas activity or shipping.

Remaining Research Gaps

Continued baseline studies are needed to increase our understanding of the effects of hydrocarbon metabolites on fish health, and work is needed to identify forms of vitamin A in fish. Although all samples for this project have been collected, benthic invertebrates still need to be processed for hydrocarbons and their metabolites, to determine the bioaccumulation of hydrocarbons in biota, in addition to the degree to which they are metabolizing these compounds. Fish samples still need to be analyzed for mercury and other contaminants. Sediment cores will be analyzed for temporal trends in carbon and contaminant cycles and changes in sedimentation rates and sources. The project may also examine the use of biomarkers to ascertain the exposure of marine organisms to local sources of hydrocarbons vs. new sources, as in the case of a spill.

Additional work will be undertaken as part of this project to analyze the hydrocarbon component and mercury data obtained during 2012-2013 with information that was collected by studies during previous years in order to examine spatial, seasonal, and annual variability in the data.

Regulatory Decision-Support

Understanding the fate of oil is essential for the conduct of environmental risk assessments, the development of oil spill countermeasures, and the monitoring of habitat recovery in the event of a spill. Information on baseline hydrocarbon components and metabolite levels prior to oil and gas development will directly support regulatory needs associated with project evaluation. It would not be possible to determine the effectiveness of an oil response strategy unless pre-spill information is available to which results can be compared. Baseline information on hydrocarbons and contaminants could also be used by regulators to develop water quality standards and guidelines.

Understanding the potential effects of development, differentiating those from other stressors, and establishing baselines for ongoing monitoring of indicators relevant to key ecosystem components, processes, habitats and ecosystem integrity are invaluable for the assessment process. Ongoing project research will also yield databases and mapping outputs that will be available to the public as well as regulators to facilitate assessments. Analyses of sensitivities of fish and invertebrate species will provide tools of long-standing utility to regulatory processes, and knowledge regarding mercury concentrations in biota will be useful to regulators in the development of possible mitigating actions.

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COASTAL AND MARINE BIRDS

Chapter 3.4. Coastal and Marine Bird Usage of the Beaufort Sea

Research Project Overview

The project Coastal and Marine Bird Usage of the Beaufort Sea compiled existing information regarding bird use of the coastal regions of the Canadian Beaufort Sea into a geo-referenced database and mapping system, ranked the importance of coastal areas based on their use by birds, and then identified baseline data gaps by coastal area, season, and species. The work was directed and co-authored by the Yellowknife office of the Canadian Wildlife Service (CWS), Environment Canada; Upun-LGL Limited, Inuvik, was the other co-author. This project complements another BREA -funded project, Birds of the Offshore Canadian Beaufort Sea (Harris and Smith 2013).

Project Purpose and Goals

The coastal regions of the Canadian Beaufort Sea support hundreds of thousands of migrating, nesting, and moulting birds. The entire western Canadian Arctic populations of some species migrate through the Beaufort Sea. As birds are the group of animals most at risk from oil spills, it is prudent to know in advance where the most critical areas are for birds. A report had been prepared previously — Key areas for birds in coastal regions of the Canadian Beaufort Sea (Alexander et al. 1988) — during the last period of active oil and gas exploration in the Canadian Beaufort, to address this issue. The purpose of this BREA project was to update and expand on that report by incorporating subsequent research, including a larger geographic area, and developing a geo-referenced database and mapping system that could be used as a tool to guide and assess oil and gas development. An additional goal was to identify data gaps regarding bird use of the Beaufort's coastlines by reviewing current information.

Fit Within BREA Program

The project falls directly under BREA's coastal, marine and sea birds research priority, and as noted above it is complementary to the Birds of the Offshore Beaufort Sea project. Furthermore, by assembling and organizing baseline data, this project contributes directly to BREA's primary goal of building a stronger knowledge base to facilitate informed decision-making regarding oil and gas activity in the Canadian Beaufort Sea. By facilitating access to baseline coastal bird occurrence data, it also contributes to other BREA projects, such as the Geospatial Analysis Tool project.

Methodology

There were six primary steps to this project: (1) data collection, (2) database design, (3) incorporation of the data into the database, (4) ranking the relative regional importance of coastal areas by species and season, (5) preparation of a written report with maps, and (6) preparing the online mapping tool.

The data were assembled from existing sources of bird survey data; no new field work was conducted. Much of the data came from field surveys conducted by the CWS since Alexander et al. (1988). Other sources of data were identified through a query of the Arctic Science and Technology Information System (ASTIS) database of the Arctic Institute of North America. Data sources included industry, academia, and other government agencies. Where possible, the original digital data were obtained.

The CWS created a GIS database structure, initially within which the Alexander et al. (1988) data were organized. Each additional new data set then was manipulated to fit that structure and to facilitate the subsequent ranking of coastal areas. Based on several factors including, for example, a species' density in an area and whether the area was a nesting colony, a level of importance (high, moderate, or low) was assigned for each species recorded there during each of three seasons (spring arrival and nesting, brood rearing and moulting, and fall migration). The level of importance for each species was relative to other coastal areas of the Canadian Beaufort. The overall ranks of use by all species were based on the underlying ranks for individual species. The two maps below show the rankings of importance for coastal areas along the Tuktoyaktuk Peninsula during the nesting season (early June to mid-July) for Greater White-fronted Goose, and for all species combined.

The geo-referenced database, and a GIS mapping system were used to make the data conform to an online mapping tool developed through another BREA-funded project, the Regional Synthesis of Coastal Geoscience for Management of Oil and Gas Activity.

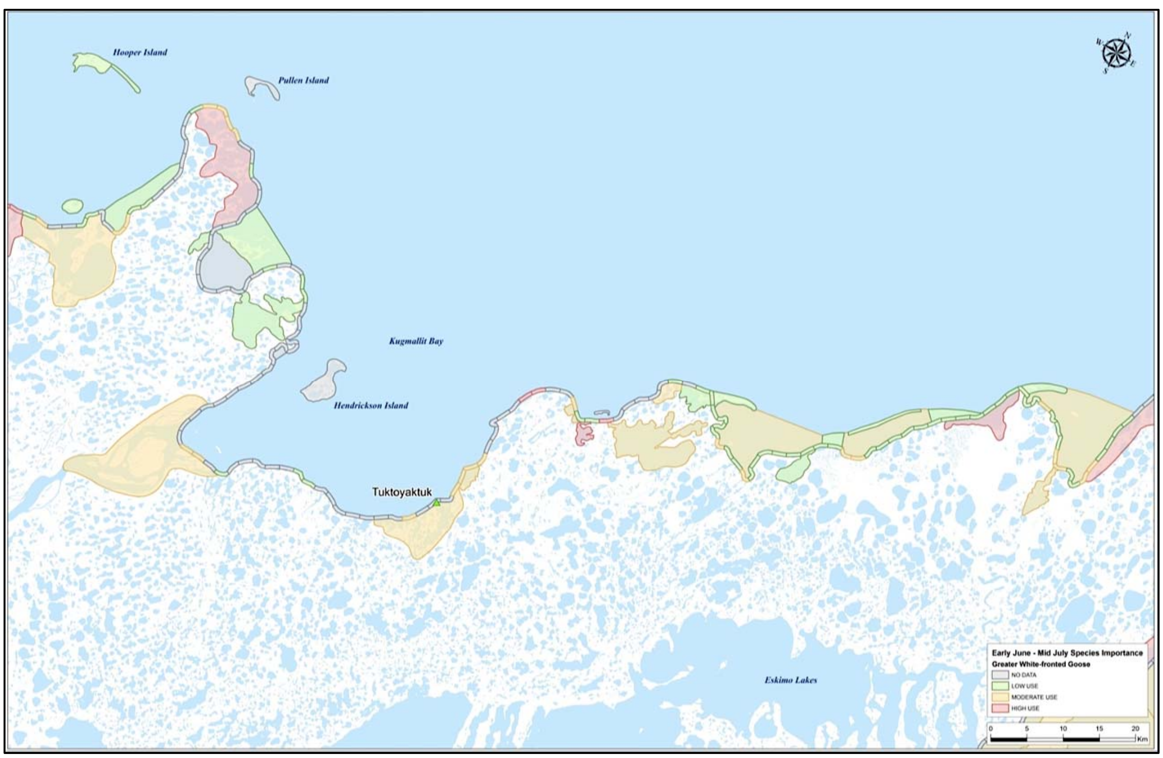

Figure 3.4.1 Greater White-fronted Goose – Early June to Mid-July Species Importance

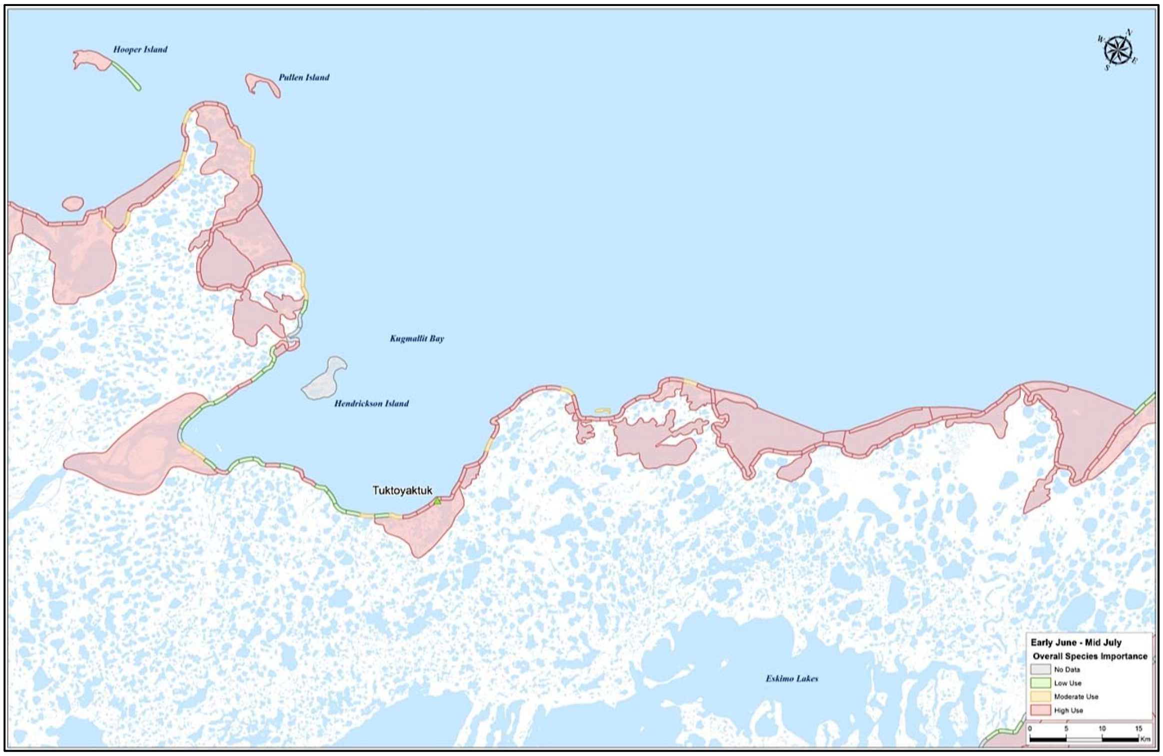

Figure 3.4.2 Overall Species Importance: Early June to Mid-July

Use of Traditional Knowledge

Traditional knowledge, as recorded in the Community Conservation Plans for the Inuvialuit Settlement Region (ISR), provided input especially in identifying those coastal areas of most importance to those waterfowl species harvested by the Inuvialuit.

Key Findings

The primary goals of this project were to identify, collect, and organize data rather than to conduct original research. Consequently, there were no key findings in the sense of new knowledge about the use of coastal regions of the Canadian Beaufort by water birds. Others may discover key findings in the data regarding the occurrence of birds. Nonetheless, the results of this project made important contributions to BREA's overall purpose (see below).

Contribution to State of Knowledge

Four primary products came out of this project:

1. A geo-referenced database on the species, numbers, distribution, and seasonality of birds along coastal regions of the Canadian Beaufort Sea,
2. A series of maps that present the data on use by birds of the Beaufort's coastlines with the GIS-based layers for the maps available for download,
3. A GIS-based mapping system that illustrates and makes accessible the relative regional importance to water birds of various sections of the coast, and

4. A report that summarizes the current state of baseline knowledge and provides a prioritized list of data gaps (Upun-LGL 2012).

A more detailed report that fully documents methods, results, and references is in progress. Converting the GIS-based mapping system to an online system is also in progress.

This is the most comprehensive and current compilation of data for coastal birds in the ISR, and the first regional review of coastal bird distribution since Alexander et al. (1988). Although not advancing the state of knowledge as such, the products of this project bring the existing regional information into a well-organized state, readily accessible to all stakeholders and interested parties including industry, regulators, researchers, and communities. This is the key contribution of this project to the goals of BREA.

Addressing Regional Information Gaps

This project significantly updates and expands on the earlier review, prepared by Alexander et al. (1988), which addressed similar concerns at that time. Banks, Prince Patrick, and Eglinton islands, and the mainland coast east of Cape Bathurst, are now included in the area of coverage. Also, the results of the many field surveys conducted in the 25+ years since Alexander et al. (1988) are now incorporated.

Remaining Research Gaps

A goal of this project was to use the compilation and review of existing data to identify remaining gaps in our knowledge, and thus guide future research. As expected, there are recent and comprehensive data for the Yukon coast, Mackenzie Delta, and Tuktoyaktuk Peninsula. Much less is known about areas east of Cape Bathurst (e.g, Franklin and Darnley bays), and Banks, Eglinton, and Prince Patrick islands. Seasonally, the best survey coverage is of the nesting period (June through mid-July). Comparatively few data, especially for the eastern mainland and offshore islands, are available from July through September (brood rearing and moulting, and fall migration).

Regulatory Decision-Support

Birds are highly vulnerable to both the direct and indirect effects of oil spills. As such, effective environmental assessments of oil and gas development projects require reliable and current information on the numbers, distribution, and activities of birds. The information compiled and organized into the database developed through this project helps to streamline and enhance this process. The data can be used for quantitative and qualitative impact assessments and spill analyses. Coastal areas of regional importance to water birds are now identified by season. That information can be used by all stakeholders both to prepare for and to minimize any adverse environmental consequences arising from oil and gas activity. For example, the database and maps could be used to avoid exploration activity in key bird areas and during key periods, or to prioritize such locations for initial response activities in the case of spills. Similarly, the data can be used to focus specific project-related baseline research on priority areas, species, and/or seasons. The gaps in our knowledge of bird use of particular coastlines, or specific seasons, are now known. Future survey efforts can focus on those gaps.

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Chapter 3.5. Birds of the Offshore Canadian Beaufort Sea

Research Project Overview

"Birds of the Offshore Canadian Beaufort Sea" was a project to identify, collect, and organize existing survey data on the distribution and abundance of birds in the offshore Canadian Beaufort Sea. The resulting database can be used to facilitate environmental assessments of offshore oil and gas activities. The project was conducted by Upun-LGL Limited.

Project Purpose and Goals

Birds are the group of animals most at risk from marine oil spills. The purpose of this project was to develop and provide a better tool to assess the potential impacts of oil and gas activities on offshore birds. Data on the occurrence of birds in the offshore Canadian Beaufort Sea had been collected during recent offshore seismic and research programs. However, those data were not centralized or organized in a common format. The goal of this project was to create a centralized, geo-referenced database to organize and store existing information, and to provide a platform for the collection of future data.

Fit Within BREA Program

The project falls under the *coastal and marine birds* research priority. By assembling and organizing baseline data, this project contributes directly to BREA's primary goal of building a stronger knowledgebase to support informed decision-making regarding oil and gas activity in the Canadian Beaufort Sea. With its focus on offshore bird occurrence data, this project may also provide information relevant to the "Web-Based Geospatial Analysis Tool" project.

Methodology

The main product of this project is a database of bird distribution and abundance in the offshore Canadian Beaufort Sea. The database was assembled from existing sources of bird survey data; no new field work was conducted. The sources of information were first identified through the personal knowledge of Upun-LGL staff, with additional leads provided by BREA staff. Data sources included private companies (industry), researchers (academia), and government agencies. Each data source was then contacted and requested to provide their data to the project. Submitted data were reviewed for accuracy and quality.

Concurrent with the collection of data was the design of the database structure. A design based primarily on a survey protocol used by the Canadian Wildlife Service in offshore Atlantic Canada was chosen. Each set of submitted records was then organized to fit that structure. The database consists of three main categories of information: cruise, watch, and sighting. Cruise data include general information about the overall survey program (*e.g.*, start and end dates, ship name and type); watch data include information regarding the brief period of continuous observation, such as time, location, observers, and weather conditions; and sighting data relate to any birds seen during a watch (*e.g.*, species, number, behaviour). Details of the data fields in each of these categories are available in the database user manual (Harris, 2013).

An atlas, consisting primarily of maps, was produced from the database (Harris and Smith, 2013). The atlas describes the methodology and general findings, with maps of survey effort and the distribution and abundance of key species and groups of birds. An example map from the atlas is shown in Figure 3.5.1, demonstrating where bird surveys were conducted and how much area was surveyed.

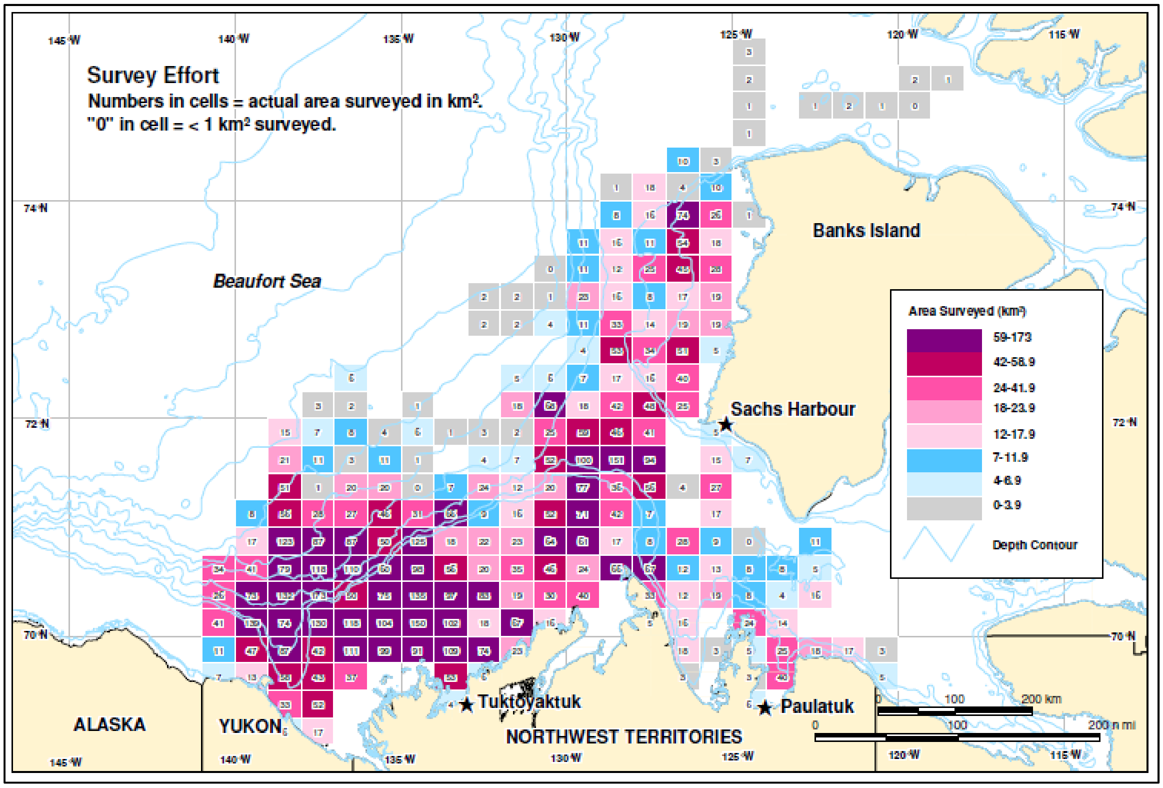

Figure 3.5.1. Extent of offshore bird survey efforts producing occurrence data included in the database

Use of Traditional Knowledge

Inuvialuit experience with the offshore Canadian Beaufort Sea, away from coastal areas, is limited. Consequently, Inuvialuit traditional knowledge did not play a significant role in this study.

Key Findings

The primary goals of this project were to identify, collect, and organize data rather than to analyze the data in much depth. Consequently, there were no key findings in the sense of new knowledge about the use of the offshore regions of the Canadian Beaufort Sea by birds. Nevertheless, the results of this project made important contributions to state of knowledge, and others may discover key findings in the data regarding the occurrence of birds.

The key findings of this project consist of the following recommendations regarding the improvement of the process of gathering information: (1) seek agreement on a standardized field survey protocol to ensure consistency of data collection and record-keeping; (2) strive for use of qualified observers who are experienced in surveying and the identification of local birds; and (3) continue bird surveys to address seasonal and geographical gaps in coverage.

Contribution to State of Knowledge

The project resulted in three products: a geo-referenced database, a database user manual, and an atlas report. All three products are publicly available through the Polar Data Catalogue, and are ready for use in the review of projects in the offshore Beaufort region. The atlas and database user manual are also available on the BREA website.

The completed database contains 9,606 records. To date, this is the most comprehensive compilation of data for offshore birds in the Beaufort region. Almost 80% of records are from moving watches, from which it is possible to calculate bird densities (number of birds per km^2). Although observations and survey effort are broadly distributed throughout the Canadian Beaufort Sea, most watches were conducted in the central Canadian Beaufort Sea off the Mackenzie River Delta and Yukon coast. Of the total of 3,780 sightings (birds are not seen during every watch), the majority were gulls, terns, and jaegers.

Addressing Regional Information Gaps

This project addresses a key regional information gap by assembling and organizing existing datasets into a significantly more useful format for the assessment of the impacts of oil and gas activity on bird populations in the offshore Canadian Beaufort Sea. Through the creation and design of the database, this project also identified insufficiencies within the present body of data and provides important suggestions for future survey work.

Remaining Research Gaps

Because this was not primarily a research project, any identification of research gaps is rudimentary. Nevertheless, a quick evaluation of the database reveals gaps in the geographic and seasonal coverage. Most survey effort occurred during the open-water season (primarily August and September) and away from the pack ice. That is a consequence of bird surveys being conducted for the most part during ship-based seismic surveys.

Coverage is thus poor for all other months of the year and in areas with pack ice, as well as in the Amundsen Gulf where little seismic exploration has taken place.

Regulatory Decision Support

Offshore birds are highly vulnerable to both the direct and indirect effects of oil spills. As such, environmental assessments of offshore oil and gas development projects can strongly benefit from reliable information on the occurrence of offshore bird species. The database developed through this project can serve as an important contributor to quantitative impact assessments and spill analyses. The establishment of a framework for assembling, organizing, and managing data on the occurrence of offshore birds will also facilitate the integration and use of future offshore bird study and survey results in environmental assessments of projects proposed for the Beaufort Sea.

With respect to the atlas, maps of population data aid in the identification of areas of importance for offshore bird populations, which can contribute to efforts by regulators and industry stakeholders to prepare for and minimize the potentially adverse environmental consequences associated with expanded oil and gas activity. Such benefits could potentially include avoiding exploration activity in key bird areas and during key periods, or prioritizing such spots for response activities in the case of spills. Mapping of areas used by offshore birds will in time be an invaluable tool; however, future surveys should employ a standardized protocol and trained observers.

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BIRD, FISH, AND MARINE MAMMAL INFORMATION

Chapter 3.6. Biological Data Needed for Net Environmental Benefit Analysis for Dispersants and In-Situ Burning in Spill Response

Research Project Overview

Vulnerability Profiles (VPs) were assembled that summarize biological data for a prioritized list of key species that occur in the Canadian Beaufort Sea. The VPs of various key species are needed to conduct Net Environmental Benefit Analyses to inform oil spill response planning in the Beaufort Sea. Net Environmental Benefit Analysis (NEBA) helps to identify the sensitivity of Valued Ecosystem Components (VECs) to spills, and highlights the advantages and disadvantages of various technologies that can be used to manage spills. When combined with data on the fate and movement of a spill and the sensitivity of a species to oil, the VPs are used to estimate quantitatively the impact of an oil spill on VECs. This project was undertaken by S.L. Ross Environmental Research Limited.

Project Purpose and Goals

The objectives of this project were to assemble a prioritized list of key species (VECs) that are vulnerable to the effects of oil spills; prepare spill VPs for each of the prioritized VECs for use in NEBA; fill information gaps for the prioritized VECs using traditional knowledge; identify remaining information gaps; summarize new information regarding hydrocarbon exposure effects and exposure-effect thresholds of oil spills on key species; and conduct an example NEBA for a hypothetical spill scenario to illustrate the use of VPs.

Fit Within BREA Program

This project assembled the biological data required for NEBAs, with a focus on the use of dispersants and in situ burning in the management of oil spills in the Beaufort Sea. Thus, the project falls directly under the Birds, Fish and Marine Mammal Information for Oil Response research priority. The distribution maps for a prioritized set of VECs that resulted from the project may also be relevant to the Geospatial Analysis Tool project. By assembling biological data that are pertinent to oil spill response management, the project contributes directly to BREA's key objective of building a stronger knowledge base to support informed decision-making regarding oil and gas activity in the Canadian Beaufort Sea.

Methodology

A prioritized list of VECs (*e.g.*, birds, marine mammals, fish, keystone components) most critical to protect during an oil spill was developed based on three criteria: importance to harvesters, role as keystone species in the Beaufort Sea food web, and status as protected species. For each of the VECs, biological data were then assembled, resulting in VPs identifying (a) the population(s) of each key species that occupies the Beaufort Sea; (b) the spatial distribution, aggregation areas, and harvest areas for each VEC; (c) changes in the vulnerability of the species caused by seasonal movements or the timing of the development of vulnerable life stages; and (d) habits that influence the potential for oil exposure.

To gather information for the VPs, the following resources were used: major studies from the past as well as ongoing work; traditional knowledge of community members; input from technical experts on key species; and published scientific literature. The VPs were then presented in a well-documented, easy-to-use format including natural resource maps, tables, and text. Each VP also identified key data gaps related to the VEC of interest.

Use of Traditional Knowledge

Three NEBA workshops were held in order to shape the project with input from key representatives of each Beaufort Sea community. In particular, the workshops aimed to gather traditional knowledge to help identify key VECs, obtain information on harvesting, and fill knowledge gaps for the VPs.

Key Findings

The primary goal of this project was to assemble available biological data for VPs for key species that occur in the Canadian Beaufort Sea. Thus, the key findings had more to do with improving the understanding of the vulnerability of VECs to impacts from spills and countermeasures than adding to it through new research. Key species for which VPs were developed include the Beluga Whale, Bowhead Whale, Ringed Seal, Polar Bear, Caribou, King Eider, Lesser Snow Goose, Black Brant, Long-tailed Duck, Broad Whitefish, Arctic Charr, Dolly Varden, Arctic Cod, and phytoplankton. Seasonal distribution maps for all these species are part of the VP databases.

The databases show that on a seasonal basis many arctic species' populations clump together in small areas, making such species more vulnerable to certain spills, and that some species appear to be more vulnerable than others to oil exposure, especially at certain times of the year and locations. The databases also illustrate that there are remaining knowledge gaps for many key species that should be addressed to improve spill risk assessment and response planning. Nonetheless, the findings from this project provide regional information on key species that will improve project-level spill risk assessments. When used as part of NEBAs, the VPs will strengthen the assessment process and therefore help support choices regarding oil spill response management.

Contribution to State of Knowledge

Addressing Regional Information Gaps

The project assembled biological data for key species in the Beaufort Sea through the use of past and current studies, and traditional knowledge. Information gathered at workshops with representatives from Beaufort communities was used to fill a number of regional information gaps. The project also identified remaining knowledge gaps for several key species.

Stakeholder Preparation

The organization of biological data for several key species into VP databases has improved the accessibility of this information for stakeholders. The data that have been assembled will inform partners in oil and gas activity with regards to the prioritization of areas and species for protection; site and seasonal planning for exploration and development; assessment of potential effects of oil and gas activities on the environment; and spill management planning and actions.

Remaining Research Gaps

This project showed that knowledge gaps of relevance to the VPs of key species remain, including: seasonal aggregation areas for Arctic Cod and phytoplankton productivity; marine harvesting areas for Broad Whitefish, Dolly Varden, and Arctic Charr; pre-molt migration distribution and migration behaviour of King Eider; and habitat use during staging and hunting areas for Lesser Snow Goose. Further studies can be undertaken to address the remaining knowledge gaps.

Regulatory Decision-Support

A major consideration in offshore petroleum development in the Beaufort Sea is the risk of environmental damage to VECs from oil spills, and the management thereof. The VP databases can help regulators and industry stakeholders plan for and minimize the potentially adverse environmental consequences associated with oil and gas activities. They can be used to help prioritize areas for protection or response activities in case of spills and assess risks to species more accurately. When used in NEBAs, the information can help in making incident-specific spill-management decisions, planning regional spill response strategies including the use of dispersants and in-situ burning (ISB), preparing dispersant use guidelines and regional dispersant use decision-trees, choose among spill countermeasures, and preparing project-specific environmental assessments where dispersants and ISB are proposed as primary spill response tools. VPs, in combination with oil spill models, can be employed to estimate quantitatively the effects of specific spill scenarios on key species in NEBAs.

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WORST-CASE ENVIRONMENTAL DESIGN LIMITS FOR ICE

Chapter 3.7. Overwintering in the Beaufort: Assessing Damage Potential to Vessels

Research Project Overview

"Overwintering in the Beaufort: Assessing Damage Potential to Vessels" was a research project to look at the risk of damage to vessels from ice, especially for barges that are storing fuel, left to winter in the Beaufort. The project was driven by long-standing community concerns about the consequences of a fuel barge if it were to be damaged by ice. The research was led by Anne Barker and Garry Timco of the Ocean, Coastal and River Engineering group at the National Research Council Canada (NRC).

Project Purpose and Goals

The project objectives were to assess likely ice loads for overwintering vessels as well as the potential for high ice loads, to provide recommendations for avoiding high ice loads, and to outline key considerations for overwintering.

Fit Within BREA Program

The project falls directly under the *worst-case environmental design limits for ice* research priority. With its focus on sea ice it may also provide some information relevant to the *sea ice types and extreme ice features* research priority. Additionally, given that the overwintering of barges was evidently a priority for local communities, this project may also have linkages to the *community priorities* research theme.

Methodology

The research included a historical review of the overwintering of vessels and barges in the Beaufort; a field study of ice conditions in McKinley Bay and Tuktoyaktuk Harbour; an analysis of potential ice loads in representative locations in the Beaufort Sea region; an overview of community consultations on this subject (held by Transport Canada) in Inuvik and Hay River; discussions with Transport Canada held in Winnipeg and Ottawa; and local discussions held by the researchers with members of the Inuvialuit Game Council, the Fisheries Joint Management Committee, and operators in Inuvik.

The research considered four typical locations for overwintering: sheltered bays, semi-sheltered bays, exposed offshore, and river environments. For each location, analyses and calculations of ice loads were conducted for freeze-up, winter, and break-up.

Use of Traditional Knowledge

Community concerns were identified through the review of results from community consultations held by Transport Canada, as well as the authors' own discussions with members of the Inuvialuit Game Council, Fisheries Joint Management Committee, and a local operator. Local community experience with overwintering was discussed at those meetings. The importance of the role of traditional knowledge in the selection of overwintering sites was particularly emphasized with respect to locations with dynamic ice conditions.

Key Findings

Historically, during the decades of the 1970s and 1980s when oil and gas exploration was active, overwintering of vessels in the Beaufort Sea and the Mackenzie Delta occurred regularly. This included oil and gas drilling vessels, other exploration structures, their support vessels, and fuel barges. From the historic record, the research team identified two instances when fuel barges had incurred damage from overwintering. The first example was from the Beaufort, in McKinley Bay in the 1980s. In this instance, the barge was damaged by ice. The decision was taken to offload fuel from the barge to prevent a potential spill; however, unfortunately there was a spill during the offloading procedure. The second example is from the year 2000, in Iqaluit. Ice formed under the hull of the barge, freezing it to the seabed. During spring break-up the ice melted unevenly and the barge tipped. Ice then punctured the hull, resulting in a spill.

The ice load analysis research comparing typical locations and times of year yielded the following considerations for the best overwintering conditions:

- A sheltered spot with a limited fetch area, to control pack ice driving forces.
- Sufficient water depth to have clearance under the vessel so that it does not freeze to the bottom or strike the seabed at low tide.
- Minimal dynamic ice movement in the spring, to avoid ice crushing forces or large floe impacts on a vessel and/or ice loads sufficient to break mooring lines.

It is important to bear in mind the value of traditional knowledge input for assessing ideal overwintering locations, for example when determining whether a potential location has had dynamic ice conditions in the past. In addition, any candidate river locations for overwintering require an intimate knowledge of the region and the local ice dynamics.

A methodology for assessing the suitability of overwintering locations is described in the project’s final report. The report also recommends that the ISR implement its own system for logging the locations and types of overwintering vessels, including barges.

Contribution to State of Knowledge

Addressing Regional Information Gaps

It is anticipated that oil and gas activity may increase in the Beaufort Sea, and in the absence of federal regulations (and a lack of clarity regarding where regulatory responsibility lies), the key findings from this project provide a guide for how to keep the risk of damage to overwintering vessels low. The project’s final report notes that in order to assess safety and risk, each overwintering vessel needs to be assessed individually, according to the type of vessel, its load, and the proposed location.

In the project report, the research team recommends a methodology for the evaluation of individual situations. This methodology calls for input from ice mechanics experts and naval architects, and should be led by operational experts. This team of experts would conduct ice load calculations relevant to freeze-up, winter, and in particular break-up, using the sample assessments presented in the overwintering report as a guide. Site selection should be followed up with appropriate, regular monitoring of ice conditions. If followed, this guide will improve the safety of overwintering practice.

Stakeholder Preparation

While it was beyond the scope of the project to create new regulations for offshore fuel storage during winters, the research does inform communities and decision-makers about the risks involved, best practices, and a potential monitoring method which may mitigate some of the risk. Thus it helps ensure that industry, governments, Inuvialuit, and other northern residents are better prepared for oil and gas activity offshore.

Remaining Research Gaps

The ice load performance of different vessel types in particular situations will always require case-specific assessment and study. A system for recording instances of overwintering vessels could generate knowledge in the first instance of the number, types, and locations of overwintering vessels.

Regulatory Decision Support

While community members agree that overwintering has a low likelihood of damage when best practices are followed, they remain concerned that there is still risk involved. From their perspective, the rules for offshore fuel storage should be at least as rigorous as the rules for onshore storage, especially since the risks of an accident are higher in the dynamic environment of sea ice.

Although proposing federal regulations goes beyond the scope of the “Overwintering in the Beaufort: Assessing Damage Potential to Vessels” research project, the team did note these ongoing community concerns. Since completion, the methodology proposed by this research project has been used in the development of federal guidelines for the overwintering of vessels in Canada’s North by Transport Canada. This is illustrative of the purpose of the BREA projects: using shared knowledge to inform and guide decisions.

The research team recommended that a system for monitoring overwintering barges be established. For each overwintering event, a record would be maintained of vessel type, location, cargo, and point of contact for the agency responsible for the vessel. The record would include information gathered according to the following monitoring schedule:

- Regular evaluations throughout the freeze-up period, to determine when the ice becomes landfast.
- Once landfast, monitoring of ice conditions: thickness, ice temperature, snow depth, signs of ice buckling, *etc*.
- Regular monitoring during the break-up period.

Based on discussions with Inuvialuit, the research team suggested that for the interim, records be maintained locally. “From discussions with the various stakeholders involved with overwintering, it is the authors’ opinion that it would be worthwhile for the ISR to implement record-keeping of overwintering fuel-storage vessels both within the settlement region, and for those relevant regions where a fuel spill could impact the ISR.”

As a follow-up, the authors further recommend that procedures and requirements for the overwintering of vessels, especially those used for fuel storage, be clarified by the Federal Government for both the Inuvialuit and Operators. “This should include the specific departmental names for permitting, regulating, *etc.* with specific contact information for emergency spill cleanup. This is directly related to the ongoing work […] being carried out by Transport Canada.”

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SEA ICE TYPES AND EXTREME ICE FEATURES

Chapter 3.8. CanICE: A Sea Ice Information Database and Web-Based Portal

Research Project Overview

CanICE is an on-line sea ice database that makes decades of sea ice charts and observations available to researchers and the public through a user-friendly website and search engine. The online search tool is being augmented with analysis tools that provide straight-forward access to information on sea ice extent, concentration, type, and characteristics such as movement and proximity to extreme ice hazards in the Beaufort Sea. Detailed information about sea ice is important for Northerners and anyone working in the Beaufort, as it exerts seasonal effects on weather and climate, marine ecosystems, safety of marine transportation, northern communities, and offshore resource development. This information is especially valuable as sea ice is becoming even more dynamic with climate change. This makes CanICE an important geo-database for potential oil and gas development in the Beaufort. The CanICE team includes the Canadian Ice Service at Environment Canada, the Canadian Cryospheric Information Network and Polar Data Catalogue at University of Waterloo, the Research Centre on Geomatics at Université Laval, and the Department of Geomatics Engineering at Ryerson University.

Project Purpose and Goals

The purpose of CanICE was to make the extensive Canadian Ice Service archive of sea ice observations and charts more readily available to the public and to develop information and analysis tools, rather than to carry out research on sea ice. The main objectives were to build a sea ice database; to integrate the contents of the new database into a publicly accessible web portal (in the Polar Data Catalogue); and to create online tools for analyzing and displaying the data and information.

Fit Within BREA Program

CanICE is part of the web-based geospatial analysis tool research priority. It complements the sea ice types and extreme ice features priority, as well as the offshore geo-hazards and coastal processes priority. The objective here is to ensure stakeholders (including the Inuvialuit and regulators) are better informed and to support safer development.

Methodology

To develop the database, the CanICE team digitized archived ice data from the Canadian Ice Service. These data include weekly sea ice charts derived from satellite imagery and professional analysis; ship and airplane observations; and information on ice ridging, ice floes, and icebergs over several decades. Analysis and visualization tools were then developed to allow users to display and analyze the data.

Use of Traditional Knowledge

User input was crucial to the successful development of the database and tools. The CanICE team presented their work at the BREA results forum in early 2013 and received feedback from Inuvialuit and other stakeholders regarding needs for Beaufort-related data and information products.

Key Findings

The CanICE team has digitized decades of archived ice data and has created a BREA sea ice database including over 200,000 of these historic scanned ice charts, storing them as images. The team has made a portion of the database images and information publicly accessible through the on-line Polar Data Catalogue web portal (https://www.polardata.ca/pdcsearch/) hosted at the University of Waterloo. After this conversion from paper to digital files and creation of the new Canadian Ice Service sea ice database in a modern form, all new Canadian Ice Service charts that are being created today are now compatible with and integrate seamlessly into the new database. At the same time, sea ice analysis tools have been developed by the teams at Laval and Ryerson to allow users to understand and assess sea ice conditions, especially potential sea ice hazards. Work is ongoing to integrate additional types of data and charts, including long-term climatological datasets, into the database and the website. Partners also continue development and enhancement of the online tools as web technologies evolve.

Contribution to State of Knowledge

A fully functional web-based CanICE database with analysis tools has been developed. Ice charts from the second half of the 20^{th} century have been scanned and made searchable (through metadata). Information on other ice indices, including sea ice extent, concentration, type, and other characteristics, has also been made available. The more recent digital charts allow for maps and/or tables to be created showing percent ice coverage, ice thickness, ice volume, ice stages, forms of ice, etc. This information can be used to characterize climate change processes thereby providing valuable input towards the assessment of oil and gas activities.

The developed tools enable the user to quickly and easily find information and study a variety of issues. The system allows users to isolate information to specific areas of interest based on several criteria: geographic location, ice concentration levels, ice stage levels, chart type, and time period. These ice visualization and search features are supportive of new interactive analysis and decision-making tools for the Beaufort. More sophisticated analytical tools are also under development (e.g., min/max, freeze thaw surfaces, undetermined ice thickness, etc.).

Understanding the full potential of the tools and how they should be further developed will be possible once the full range of users has had a chance to explore the potential of the online CanICE system. Possible areas of future development include animation of sea ice with the ability to illustrate change over time, and/or real-time maps and charts for the entire Beaufort. It would also be valuable to expand the digitization beyond the Beaufort to include the full Canadian Arctic.

Regulatory Decision-Support

"CanICE ensures that ice information most critical to evidence-based decision-making for Beaufort oil and gas activities is openly accessible in a timely manner and a format which addresses the needs of policy makers, regulatory bodies, Northern organizations, infrastructure developers and researchers/ modellers/forecasters, thereby streamlining data requirements for environmental assessment processes and improving timelines."

All stakeholders, including regulators will benefit from enhanced access to quality controlled, interoperable, multiple sources of ice information. Over time, it will also allow for a clearer understanding of the dynamic behaviour(s) of sea ice. In this way CanICE will be an important planning tool in the Beaufort for potential development, infrastructure, transportation, natural resources, habitat and integrated management.

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Chapter 3.9. Beaufort Sea Engineering Database

Research Project Overview

The "Beaufort Sea Engineering Database" (BSED) project focused on the development of an integrated database which houses historical ice and other environmental data. The database provides query, display, analytical, and export functions to support decision-making for oil and gas exploration, development, and regulation in the region. The project was driven by the need to enhance access to data required for the ice-related design, construction, maintenance, and assessment of engineered systems in the Beaufort. The NRC led development of the BSED, together with Joint Industry Project (JIP) members AANDC, British Petroleum, ConocoPhillips, Imperial Oil / Exxon Mobil, and Statoil. Currently, datasets included in the BSED stem from publically available sources as well as from the JIP members themselves. Additional sources may soon be included.

Project Purpose and Goals

The BSED strives to serve as a common source for ice and other environmental data, providing specialized analytical support for industry and regulators with interests in the management of ice and engineering-related dynamics and risks in the Beaufort. The BSED is primarily concerned with historical data on ice and environmental conditions necessary for assessing the severity of seasonal ice conditions in the Beaufort Sea. The database permits modelling of ice dynamics, and deriving probabilistic ice load values for use in engineering design and decision-making related to oil and gas facilities and operations. In addition to enabling data assembly and storage, the BSED also facilitates queries and visualizations, and analyses for determining design ice loads.

Fit Within BREA Program

The BSED project falls directly under the *sea ice types and extreme ice features* research priority and is linked with the "CanICE" project, which is also part of this research priority. Other BREA research priorities of relevance include: w*orst-case environmental design limits for ice, web-based geospatial analysis tool, and coupled ocean-ice-atmosphere modeling*.

Methodology

Development of the BSED was conducted in three phases. During the first phase, the database framework was developed, and nine demonstration datasets of different types and formats were incorporated. The second phase involved enhancing functionality and linking in other datasets of interest to JIP partners. The third phase involved implementing additional features and linking additional requested datasets. Figure 3.9.1 depicts the main elements of the database framework.

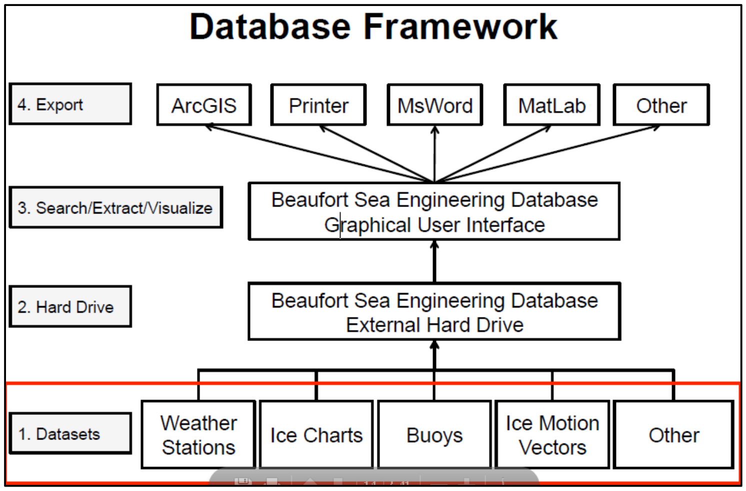

Figure 3.9.1. Main elements of the Beaufort Sea Engineering Database

Upon completion of the BSED, JIP members were trained in its operation and provided with a copy of the database and its user manual.

Use of Traditional Knowledge

To date, traditional knowledge and community consultation have not played a direct role in this project. There is, however, interest in developing components of the BSED suitable for housing traditional-knowledge-based data, as well as in working with communities to identify data types of greatest potential relevance for community conservation plans. Furthermore, traditional and local knowledge could play an important role in validating or augmenting site-specific information included in the BSED.

Key Findings

The BSED project resulted in two main products: (1) a geo-referenced database with datasets that will aid in assessing the severity of seasonal ice conditions, modelling of ice dynamics, and deriving probabilistic ice load values for use in engineering design and decision-making related to oil and gas facilities and operations; and (2) a database user manual. The BSED currently includes over 64 datasets and related metadata across ten main categories. Categories and example datasets are shown in Table 3.9.1.

Table 3.9.1. Ten main categories of data currently housed in the BSED

Category	Example Datasets
1.Bathymetry	*e.g.*, ArcticNet Base maps, Beaufort Shelf maps
2.Buoys	*e.g.*, International Arctic Buoy Program data
3.Hazardous ice	*e.g.*, Extreme ice feature data
4.Ice charts	*e.g.*, Canadian Ice Service charts
5.Ice motion	*e.g.*, Daily, weekly, monthly and yearly ice motion data
6.Ice properties	*e.g.*, Ice thickness and ice draft data
7.Met Ocean	*e.g.*, Tide, wave, and meteorological station data
8.Navigation	*e.g.*, Nautical charts, and shipping safety control zones
9.Stakeholders	*e.g.*, Frontier well sites, and oil and gas rights
10.Subsurface	*e.g.*, Geological map, soils map

Plans exist to expand the BSED through inclusion of further datasets, especially geotechnical data such as permafrost data and ice scour maps. Figure 3.9.2 provides a view of the current BSED user interface.

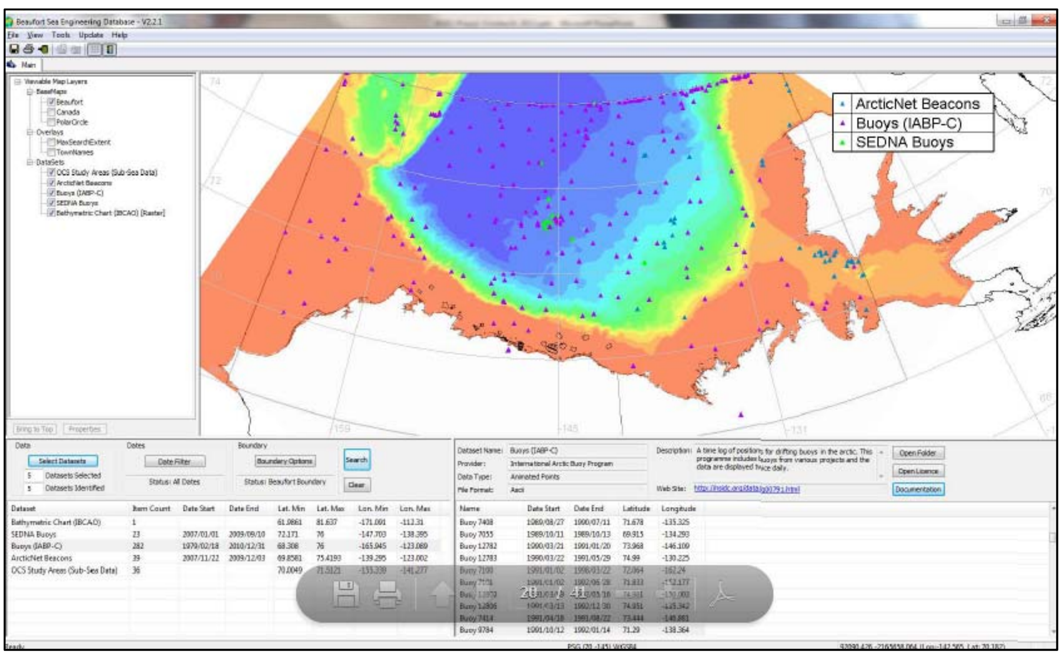

Figure 3.9.2. View of the BSED User Interface

Contribution to State of Knowledge

Issues of data availability have often posed a challenge to analyses required for ice-related design, construction, operation, and assessment of engineered systems in the Beaufort Sea. By assembling key data from across various agencies and private corporations, organizing them, and otherwise facilitating their use in analyses of sea ice and engineered systems, this project has helped address a key regional information gap.

Information housed and generated by the BSED can help inform engineering-related decisions ranging from infrastructure and transport route planning and design, to decisions on emergency evacuation systems for offshore platforms, and environmental response. The BSED should also be helpful for identifying remaining information gaps, and assisting in the prioritization of research to address these gaps.

The BSED advances community priorities by improving the knowledge base for engineering decisions and thereby supporting the mitigation of risks associated with oil and gas exploration and development.

Regulatory Decision Support

BSED data holdings, query and display functions, and analytical and export capabilities constitute progress towards simplifying project-level assessments as well as strengthening assessment processes. As a centralized data repository, BSED helps ensure oil and gas regulatory processes are able to draw upon the same source of high-quality information. This information can be applied by regulators in evaluating the potential environmental impacts of proposed oil and gas activity, and informing designs and conditions to mitigate risks.

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Chapter 3.10. Delineation of Extreme Ridges in High Resolution Satellite-Based Radar Imagery

Research Project Overview

The "Delineation of Extreme Ridges in High Resolution Satellite-Based Radar Imagery" research project was conducted by the Centre for Cold Ocean Resources Engineering (C-CORE), a multi-disciplinary remote sensing, ice, and geotechnical engineering organization. The work was led by Tony King, C-CORE's Director of Ice Engineering.

Ice ridges, which are visible as linear features, extend both above and below surrounding sea ice. The above-ice feature, the "sail", may be detected using remote sensing satellites, while the below-ice feature, the "keel", can be detected using sonar from the seabed. Ice ridges with deep keels, in excess of 20 m, can be a hazard for navigation and oil & gas infrastructure on or in the water. These extreme ice features can scour the seabed and therefore need to be considered even for buried pipes and caissons used for the protection of infrastructure on or beneath the seabed.

Project Purpose and Goals

The purpose of this research project was to correlate the observation of ridges using subsea sonar with remote sensing. Both observation methods have constraints and limitations. Using this analysis, the overall goal was to develop a way to routinely detect and monitor ice ridges using satellite radar.

Fit Within BREA Program

This project falls under the *sea ice types and extreme ice features* research priority. The work should be considered in relation to other research projects on *offshore geohazards and coastal processes* and *worst-case environmental design limits for ice*.

Methodology

Ice ridge keel measurements began in the Canadian Beaufort in the 1990s by the Institute of Ocean Sciences, a research branch of Fisheries and Oceans Canada. The Institute deploys sonar instruments at a handful of fixed locations and retrieves them a year later. Each sonar is anchored to the seabed and measures the underside of the ice as it drifts above the sonar buoy, using this measurement to calculate the depth of ice at that location. While the instruments are able to measure ice depth with great accuracy, they can only see a small footprint of ice at any one time. Furthermore, because ice depth sonar data is not available immediately, however useful the information is in understanding extreme ridges, it cannot be used in assessing approaching risks.

The upward looking sonar devices were deployed at only a handful of locations, at most three sites per year. Ice ridge depth data from 2003 to 2008 were analyzed and correlated to satellite data. Data for 2009 were affected by instrument malfunction, and data from 2010 on had not yet been processed when this BREA research project took place.

The research team then used historic satellite images to find these same ridges and confirm their movement over time. Optical satellite imagery, which is based on the visible portion of the spectrum, is limited to daylight and clear skies. Other limitations included the availability and resolution of historic satellite optical images, the dynamics of ice between satellite passes, and the visibility of the ridge itself (ridges which cast a shadow, against a uniform ice backdrop are more readily detected). The research team also looked at historic satellite Synthetic Aperture Radar (SAR) data. SAR does not require daylight and is not affected by cloud and/or weather conditions, thus there is potential for the observation of extreme ice risks year round.

Use of Traditional Knowledge

Local communities were not involved in this research; as such, traditional knowledge was not used.

Key Findings

Using the sonar ice ridge depth data from 2003 to 2008, extreme ice ridges (*i.e.*, ice ridges with keels > 20 m) were detected 117 times. From this discrete sample of sites over the five years, the largest keel depth detected was 32.4 m. Of the 117 extreme ice ridge sonar detections, 29 were identified and cross-correlated using optical satellite imagery. In terms of the historic satellite SAR data, the research team found that the ice ridges were not identifiable, and they could not correlate the 29 large ridges identified by subsea sonar and confirmed using optical satellite data.

The project team assessed a range of issues to characterize the strengths and weaknesses of optical satellite imagery in the detection and tracking of extreme ice ridges:

- Availability: tasking of available platforms.
- Cost: as a function of tasking, resolution, and effectiveness of current or near future platforms.
- Coverage: as a function of resolution orbit, altitude, and revisit times.
- Effectiveness: range of sensing options, image enhancement and analysis technologies for edge detection, and conditions that degrade effectiveness or create false positives.

Contribution to State of Knowledge

The "Delineation of Extreme Ridges in High Resolution Satellite-Based Radar Imagery" research project advanced the understanding of large ice ridge detection and monitoring using remote sensing techniques. However, with the datasets available, the research was not able to establish a methodology which would allow for the BREA partners to be better prepared in identifying or assessing the potential risk of extreme ice ridges. Further research is possible and recommended. The availability and resolution of satellite data, both optical and SAR, are improving, and there is also the possibility of tasking satellites during a specific test period to ensure coverage.

With or without additional research, the project team noted that there will be limits to the use of remote sensing:

- Ice ridge detection will likely continue to require optical satellite imagery, which means a dependence on daylight and clear skies.

- Ice conditions might also affect the ability to detect ridges: *e.g*., ice break-up, rubble ice, refreezing of leads, orientation of the ridge relative to the satellite track, and the angle of the sun.
- Satellite SAR may be able to track ridges once they have been identified through optical satellite imagery or any other method (*e.g.*, LiDAR, fieldwork, *etc.*).

Regulatory Decision Support

This research further demonstrates that extreme ice features such as ridges might pose significant risk to offshore oil and gas infrastructure and operations. Remote sensing may yet provide the ability to detect and assess the risk of approaching ice ridges. Currently, there is still more work required on the technique. Therefore, regulators, industry, and communities will for the time being have to plan for uncertainty regarding the risks of extreme ice ridges.

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Chapter 3.11. Quantifying Sea Ice Dynamics in the Beaufort Sea

Research Project Overview

All infrastructure in the Beaufort Sea region, including any potential oil and gas infrastructure, needs to take into account the dynamic nature of sea ice. In the Beaufort, sea ice tends to move in an anti-cyclonic gyre (in other words clockwise). At the same time, it is also well known that climate change is affecting sea ice in the Beaufort and across the Arctic. This research project quantifies sea ice velocities, and exchanges that have been happening in recent years and investigates the drivers of those changes. The research was led by Environment Canada in partnership with the University of Waterloo.

Project Purpose and Goals

How has sea ice velocity and ice area exchange, also known as sea ice flux, changed in the Beaufort Sea? "Investigating the root causes of these changes in ice motion and exchange reveal that despite few changes in the overall sea ice circulation pattern in the Beaufort Sea, changes in melt processes brought about by increases in surface temperatures and solar radiation absorption in addition to declines in sea ice concentration, age and thickness are instrumental in changing the Beaufort Sea from being known as a region for sea ice to thicken and mature to a region where sea ice has little chance of surviving summer melt" (Brady 2014).

Following were the three specific objectives of the research:

- Estimate sea ice velocity in the Beaufort Sea from 1997-2012 and compare the results with other methods.
- Estimate the sea ice area flux (exchange) within and between the Beaufort Sea and surrounding regions from 1997- 2012.
- Explore the drivers of variability in sea ice dynamics within the Beaufort Sea.

Fit Within BREA Program

The Quantifying Sea Ice Dynamics research project was one of several BREA projects that focused on sea ice. This research is key in helping to validate a coupled atmosphere-ice-ocean model being developed by Environment Canada to provide sea ice forecasting in the Beaufort. In addition, the ice motion results produced by this research can be used as validation for the coupled atmosphere-ice-ocean forecasting model being developed by Environment Canada and Fisheries and Oceans Canada.

This sea ice research has contributed to the BREA objectives of generating knowledge in support of being more informed and better prepared for potential oil and gas activity. While sea ice is generally declining across the Arctic including in the Beaufort, this research shows that it is becoming even more dynamic and therefore remains as a critical issue for any offshore development and regulatory regime. Thus the goal is to support efficient and effective regulatory decisions.

Methodology

The research calculated monthly sea ice motion estimates across the Beaufort by using sequential overlapping RADARSAT image pairs acquired through data access agreements with the Alaska Satellite Facility and Natural Resources Canada. Approximately 30,000 RADARSAT-1 and RADARSAT-2 images were used. The data series extended from 1997 to 2012 with a particular focus on July through October, the months when sea ice is more active, and also months of particular interest for offshore activity. The satellite image pairs were run through an image processing algorithm developed at Environment Canada to determine ice motion and rotation vectors. Those vectors were then gridded spatially to a 25 km grid and averaged monthly.

Sea ice motion results from this research were then compared against four other independent systems. The four systems were the International Arctic Buoy Programme, the Pan-Arctic Ice-Ocean Modeling and Assimilation System (both carried out by the Polar Science Centre), the Advanced Very High Resolution Radiometer Polar Pathfinder (out of the National Snow and Ice Data Centre), and Regional Ice Prediction System (RIPS) dataset produced by Environment Canada's Canadian Meteorological Centre.

The research then used a methodology of sea ice gates (see Figure 3.11.1). Sea ice gates are thresholds chosen to help distill large volumes of information into meaningful and representative measures of interest.

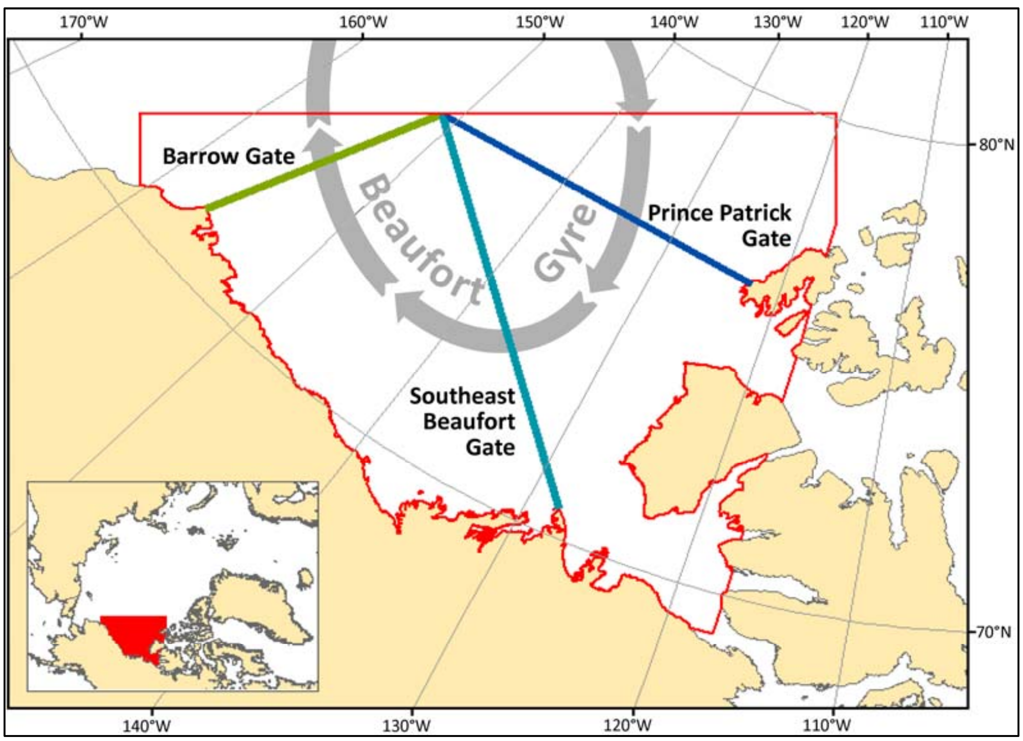

Figure 3.11.1 Sea Ice Gates

Knowing that the Beaufort has an anti-cyclonic (clockwise) gyre, three sea ice gates were chosen, two which help quantify the exchange of sea ice into and out of the Beaufort Sea (Barrow Gate in the West and Prince Patrick Gate in the North), as well as a gate which helps describe sea ice dynamics within the Beaufort (the Southeast Beaufort Gate).

Given that the primary input for this research was satellite imagery, the project did not utilize traditional knowledge.

Key Findings

Mean July to October sea ice motion over the 16-year 1997 to 2012 time series was estimated to be 4.8 km per day (±3.3 km per day). Speeds ranged from slowest in July, at 3.5 km/day, to 6.5 km/day in October. Over the 16-year time series the ice was also accelerating. A statistically-significant increase in speed of 0.07 km/day per month for July to October was observed. This represents an increase of approximately 6% per year in July-October ice drift speeds. When comparing the monthly gridded mean ice velocities to the other four independent systems the correlations ranged from 0.15 to 0.63, indicating weak to moderate agreement with the independent datasets. The results most favourably correlated with the Regional Ice Prediction System dataset. In general this research determined higher velocities against the four other systems, which may indicate that more work needs to be done to identify why these differences exist; still, it is clear from this research and the independent research that sea ice is accelerating in the Beaufort.

Sea ice flux, a measure of the total area of ice traversing the three gates, also showed interesting results. The Prince Patrick Gate is typically where sea ice enters the Beaufort via the gyre, while the Barrow Gate is normally where ice leaves the Beaufort to enter into the Chukchi Sea. The Southeast Beaufort Gate shows ice exchange (flux) within the Beaufort. Figure 3.11.2 shows the key results for the Beaufort Sea ice flux.

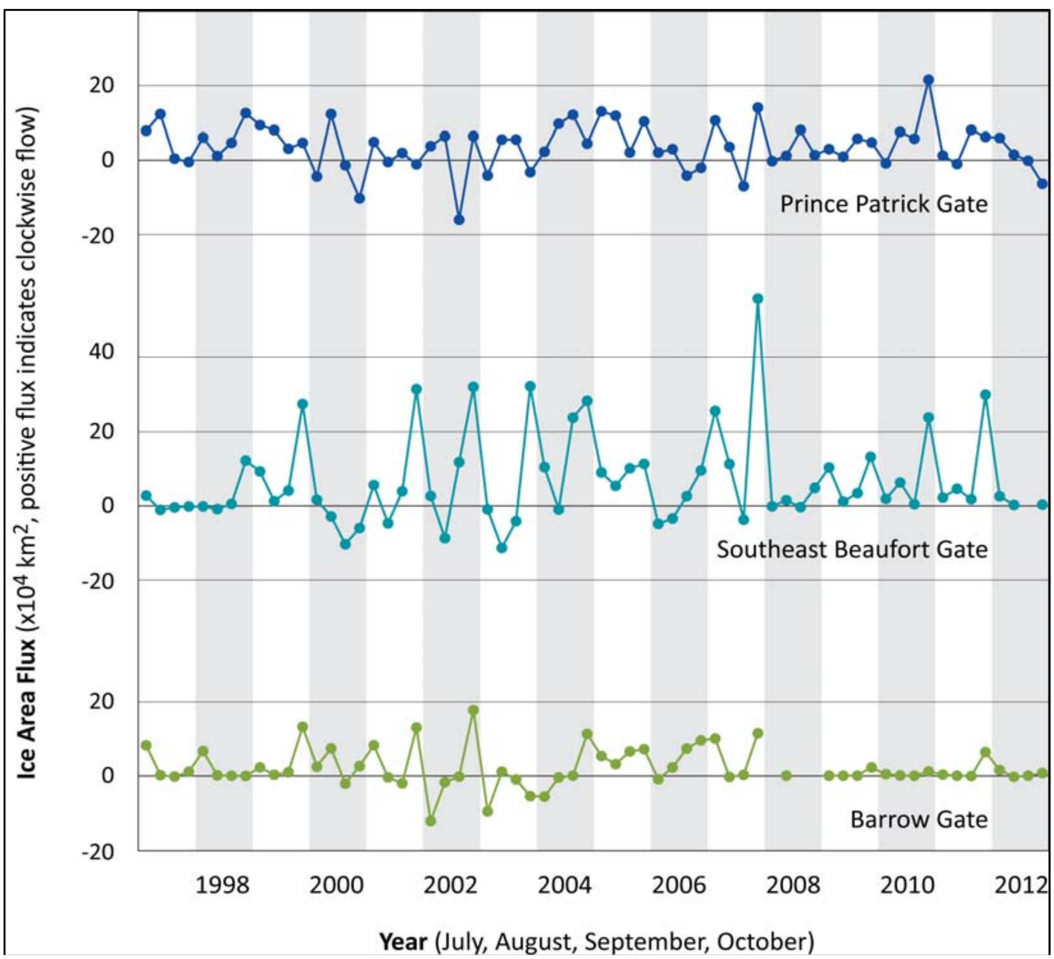

Figure 3.11.2 Beaufort Sea Ice Flux across Gates

Positive flux values indicate that sea ice is moving across the gate in the normal direction of the anti-cyclonic Beaufort Gyre (i.e. a positive flux indicates a clockwise direction). Historically, the Beaufort has been a place where sea ice thickens and matures. Another critical finding of this research is that this is now changing. Look at the Barrow Gate where ice typically leaves the Beaufort. In recent years (2008 to 2012) very little ice has been transiting out of the Beaufort via the Barrow gate.

As other research has shown, the context for this change in sea ice flux is a warming Arctic. Multiyear ice as observed in September in the Beaufort Sea has gone from approximately 206,000 km^2 in 1997 to less than 17,000 km^2 in 2012. The trend for mean September sea ice coverage in the Beaufort (all ice types) is that it is losing about 5,400 km^2 per year.

"Investigating the causal processes affecting changes in sea ice motion and area flux revealed that sea level pressure had a consistently significant albeit weak to moderate correlation with ice motion" (Brady 2014). Using correlation analysis, several other drivers were considered and rejected, including total ice area, open water area, multiyear ice area, first-year ice area and the Arctic Oscillation index. Results of this analysis further showed that changes in the sea ice area (flux) were not statistically related to either open water area or total absorbed solar radiation at the surface. Sea level pressure, on the other hand, was shown to be correlated with sea ice motion, likely due to the driving influence of sea level pressure on surface winds. The loss of multiyear ice may also lead to a "weakening the mechanical strength of the ice pack" (Brady 2014), which again might allow for faster drift speeds.

Contribution to State of Knowledge

In terms of sea ice life cycle, the Beaufort Sea was considered a favourable location for dynamic and thermodynamic thickening, in other words a "haven" for ice to grow. This very obvious decrease in ice area export via the Barrow Gate from 2008 to 2012 suggests that the sea ice is now melting before it can reach the Barrow Gate and thus cannot recirculate and mature.

This conclusion, as well as the increase in sea ice drift speeds in the Beaufort, should prompt more investigation. Future work would include more recent data (e.g. 2013 forward), explore the positive bias in speed estimates compared to other datasets, examine ice volume exchange between the Beaufort Sea and surrounding waters, and look at winter sea ice motion to consider potential relationship(s) between sea level pressure gradients at the exchange gates. It is important to understand the drivers of sea ice motion if we are to minimize the risks of sea ice hazards.

Regulatory Decision Support

Any oil and gas exploration and/or development in the Beaufort must necessarily consider the hazards and risks of an increasingly mobile sea ice cover. This research provides a baseline for sea ice motion in the region. This research shows that while some risks may be diminishing (e.g. the overall coverage of thick multiyear ice is decreasing), other risks are increasing, e.g. that ice is accelerating, and that it is even more dynamic than it has been in the past. Overall, this research indicates that the regulatory and industry decision support regimes will likely have a need for more frequent and consistent sea ice monitoring and forecasting.

“Understanding the effects of a changing Arctic climate system on the dynamic properties of sea ice is important for gaining insight into related systems including the surface energy balance, primary production, and wildlife habitat. A significant increase in variability and trends in sea ice motion in the Beaufort Sea will produce a heightened need for updated ice motion charts with shorter time periods between issuances to avoid hazards, and motivate improved ice motion forecasting” (Brady, 2014), in support of potential oil and gas activity and/or shipping.

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INTEGRATED SEA ICE PROJECTS

The following three projects, led by the National Research Council, York University and the University of Manitoba are part of an integrated sea ice project that will examine the characteristics of multi-year sea ice. The result will be measurements at the small, medium, and large scale that are brought together to improve our understanding of the properties and behaviour of sea ice in the Canadian Beaufort Sea.

Chapter 3.12. Characterizing Deformed Multi-Year Ice in the Beaufort Sea

Research Project Overview

Multi-year ice (MYI) often forms hummocks or ridges, which have corresponding ice keels underneath. It is important to gain an understanding of the thickness and strength of the ridges from crest to keel in order to engineer offshore structures that can safely withstand forces generated by ice ridges. “In the engineering community, hummocked multi-year ice is still considered to be the most hazardous type of sea ice in the Arctic and the least known, in terms of its thickness and strength” (Johnston, Jan 2014).

The Ice Strength and Thickness Research Project was carried out by the Ocean, Coastal and River Engineering group at the National Research Council. The research built on earlier National Research Council work funded by the Program of Energy Research and Development led by Natural Resources Canada. The BREA portion of the research took part over four years including two field seasons. During the second field season, setbacks occurred due to very dynamic sea ice conditions and a helicopter flight crew with limited experience. As a result, the season was prematurely terminated due to safety concerns. Overall, the project produced informative interim results and noted that a future field program would be required to investigate deep ice keels to more fully understand ice forces.

Collaborators and contributors to the research project included the Program of Energy Research and Development, Polar Continental Shelf Program, National Research Council’s Canadian Hydraulics Centre and Design and Fabrication Services, Industry, Sachs Harbour Hunters and Trappers Committee, Resolute Hunters and Trappers Committee, University of Manitoba, York University, Nunavut Research Institute, Aurora Research Institute, and the Canadian Ice Service.

Project Purpose and Goals

To date relatively few measurements have been made on ice ridge strength and virtually no ice strength measurements have been made on ice below 6m depth (Johnston, Mar 2014). The main purpose of this research project has been to measure strength of very thick multi-year ice at depths where we have little or no information. The ice thickness and strength measurements were analyzed against temperature and salinity. In particular the goal was to take measurements in the Beaufort and to compare and validate these results against ice ridge research in other parts of the Arctic and against other BREA projects considering ice ridges.

The goal of this ice thickness and strength research project is to use this information to guide design and regulatory considerations for the construction and operation of offshore infrastructure in the dynamic ice environment of the Beaufort. Specifically, the international standard for Arctic Offshore Structures (ISO 19906) could be improved by providing information about ice strength parameters for calculating the loads on offshore structures and ships, the influence of thickness, temperature and pressure of multi-year ice on structures.

Fit Within BREA Program

This project falls under the Sea Ice - Extreme Ice Features research priority. It complements other studies looking at extreme ice features such as the Delineation of Extreme Ridges in High Resolution Satellite-Based Radar Imagery and Understanding Extreme Ice Features in the Beaufort Sea.

Methodology

In order to calculate the force that sea ice can exert on a structure, it is necessary to measure, ice thickness, ice strength and floe size. This research project sought to measure thickness and strength. Multi-year ice with ice ridges was identified using charts from the Canadian Ice Service, satellite images and field reconnaissance. In the field the crew made transects cutting across ice ridges, measuring ice thickness along the transect. Ice thickness was measured directly via small diameter holes (less than 2") using both an auger and steam. Salinity and temperature were measured from ice cores. In order to measure the ice strength, the research team developed and fabricated a drill frame, which allowed cores to be extracted and a borehole indentor to measure ice strength deeper than had been previously measured. The borehole indentor was used in holes created from the coring device.

Several field sites were selected, within two Arctic regions. The first field season was in the Central Arctic near Resolute. It was chosen to test the equipment in a location where the logistics were more manageable and in a safer, more controlled environment (as the subsequent field season made very apparent). The second region was in the Beaufort, west of Sachs Harbour. The Sachs field season was set to run in the 2013 field season. Unfortunately, 2013 was the late winter / early spring when Beaufort Sea ice rapidly broke up moving westwards. In a matter of days flaw leads, from kilometers to tens of kilometers wide, had formed along the whole of the west coast of Banks Island prior to the research program commencement. These flaw leads continued to form throughout the summer and ultimately posed a safety hazard for the field crew operating by helicopter, especially due to fog forming along the flaw lead. The decision was made to discontinue the second field season with only initial data collected from the Beaufort. The program could have scaled-back the program (and collected ice thickness data only, with lesser equipment) but the program was shut down because of the limited experience of the helicopter crew.

Use of Traditional Knowledge

Traditional knowledge was not used directly in the technical process of the ice measurements; however, it was used to site the research work so as to avoid conflict with hunting activity.

Key Findings

This research project produced relevant information even though the Sachs Harbour portion of the project did not fulfill the intended objectives. Most critically, was that the project was able to contribute to the very limited body of knowledge on the characteristics of deep multi-year ice.

The borehole indentor and drill frame, the equipment designed and fabricated to measure ice strength at depth, were successful in the field. Early tests on level first year ice confirmed the accuracy of the borehole indentor. Work on multi-year ice showed that the instrument is able to deploy and measure the strength of ice ridges from crest to keel. Equally important was that the equipment configuration ensured that the corer and borehole indentor could be recovered from deep ice.

The main transect measured in the first field season (in the Central Arctic) showed that multi-year floes with ridges do have ice keels as previously understood. However, the greatest ice thickness was not directly under a ridge. The question this might raise is whether or not there can be ice keels in areas where there is no surface indication? This would be important to understand for the detection of hazards.

Temperature, salinity and ice strength profiles were measured at two separate boreholes during the first field season. Salinity had a high degree of variability and did not appear to have any relationship with the other variables. Ice temperature profiles (in spring) showed that the temperature in multi-year ice drops from the surface to its coldest in the first meters below the surface. Thereafter the temperature increases with depth, with its warmest temperatures at the base of the ice where it approaches the temperature of sea water.

Regarding ice strength, the research showed that there is a general correlation between ice strength and coldness, with colder ice being stronger, and thus there is a relationship between ice depth and ice strength. However, there was variability in the profiles, noting occasional layers of weakness in some of the profiles. As well, the deepest ice had more strength than a direct correlation with temperature might suggest. For example, in the profile shown below in Figure 3.12.1, ice at 1 m depth had a temperature of -14°C and a strength of approximately 25 MPa; ice at 10 m depth had a temperature of -3°C with a strength still around 20 MPa. There are many factors at play between ice temperature and ice strength. In spring, the highest strengths tend to occur towards the upper ice surface where the ice is coldest, while in summer, the highest strengths occur at the midpoint of the ice, again where the temperatures are coldest.

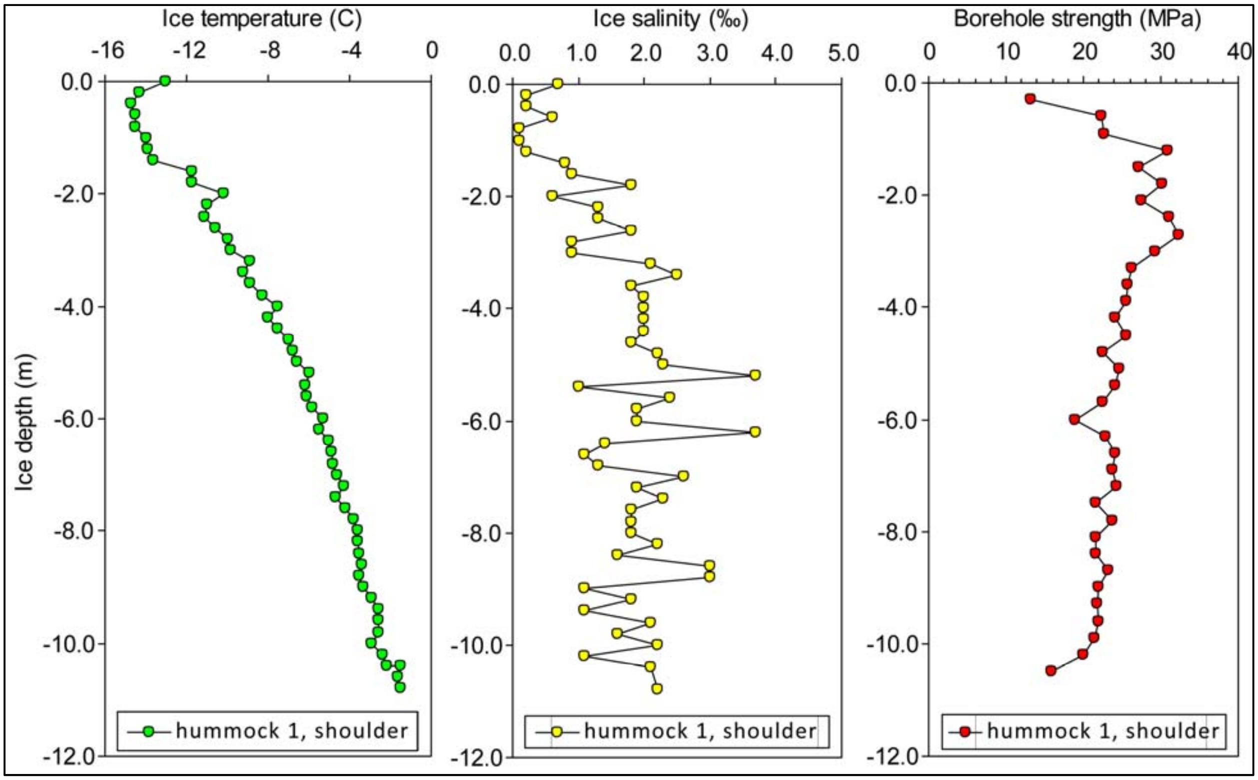

Figure 3.12.1 Ice Profiles

Figure 3.12.1 illustrates a typical vertical profile showing temperature, ice salinity and ice strength for a borehole made on a multi-year ice hummock. Measurements are referenced to the top surface of ice. The key finding here is that multi-year ice keels can be significantly stronger than first-year ice (for a given temperature), but that our level of scientific understanding is insufficient due to a lack of data. More ice strength measurements are required on deep multi-year ice. What is the effect of time of year? Or latitude? What about the effect of snow depth on the ice temperature? What about ice thickness? These are some of the factors that would be of interest in further studies.

This research also emphasized that the relationship between ice temperature and strength has a bearing on location and time of year. The important conclusion to draw here is that the ice strength (and therefore ice forces) varies and that more testing / data is required.

While safety concerns precluded the research from taking more ice strength measurements in the Beaufort, the field crew used its mobilization to gather what relevant information it could on multi-year floes with significant hummocking. The crew placed satellite beacons on two floes containing substantial ice ridges and tracked the movements of these floes for five months. The drift trajectories moved southward and into the Northern extent of the oil and gas lease area. This is evidence that ice ridges are a significant concern for oil and gas infrastructure in the Arctic. The team also documented ice features much more massive than ridges: hummock fields - not just isolated ridges.

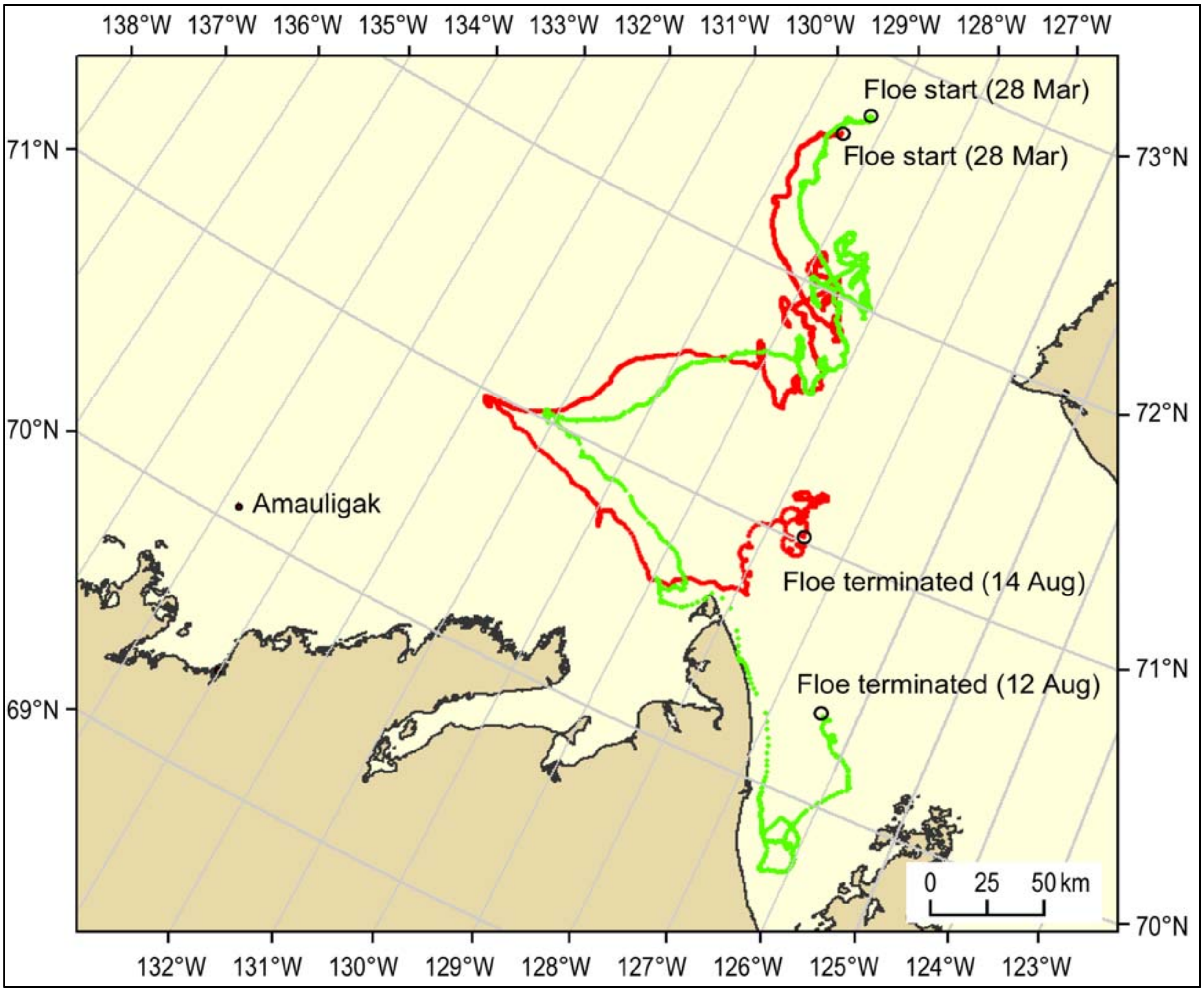

Figure 3.12.2 Floe trajectories of multi-year ice containing ice ridges (data courtesy of University of Manitoba)

"The drift trajectories of the two, hummocked multi-year ice floes on which drift trajectories are available for a period of five months clearly illustrate that some of the more significant floes encountered during the 2013 field study pose a very real hazard for structures in the southern Beaufort Sea, including the relatively near-shore Amauligak site" (Johnston, Jan 2014).

Contribution to State of Knowledge

In 1986 the Molikpaq platform in the Southern Beaufort was evacuated when an 8 to 12 m ice ridge was pushed towards it. "Our knowledge of multi-year ice has improved somewhat since then, but not enough to settle questions about […] the forces that multi-year ice in excess of 12m thick can exert on offshore structures. In the engineering community, hummocked multi-year ice is still considered to be the most hazardous type of sea ice in the Arctic and the least known, in terms of its thickness and strength" (Johnston, Jan 2014).

This ice strength and thickness research project added significantly to the number of field measurements of ice strength on multi-year ice, and provided the first ever measurements from 10 to 12 m ice depth. Clearly, more data is important, yet there are logistical challenges in collecting it. Questions remain about the range of ice forces in deep consolidated multiyear ice.

Regulatory Decision-Support

The primary purpose of this research is to provide better information on the forces that ice ridges can exert on offshore infrastructure, in order to ensure that the uncertainty is minimized for design standards for engineering offshore structures. The findings of the deep multi-year ice measurements help to inform these standards, yet uncertainty remains. The research also showed that time of year should be incorporated into these empirical ice strength parameter calculations.

Out of the ice strength measurements gathered here and in earlier studies (e.g. Johnston, Jul 2014), the research team has developed a rough empirical model for ice strength based on parameters such as ice thickness, ice temperature and time of year. This knowledge can be used to update the international standard for Arctic Offshore Structures (ISO 19906). Overall the research emphasized that multi-year ice ridges are a risk that needs to be managed for any offshore activity in the Arctic, and in particular the Beaufort.

There is another issue that assessors and regulators must consider, which this research project illustrated and clearly documented - the health and safety aspects of remote work and in particular measuring and/or monitoring ice hummocks/ridges and floes in the Beaufort. The logistical challenges provide useful insight when planning and regulating future research and monitoring programs that are proposed to assess, predict and mitigate risk to operations and infrastructure in the Beaufort. It also provides some insight into what these programs may be realistically able to achieve, and at what costs. Proponents must consider these factors in operational planning, and all stakeholders will be concerned as the factors will affect the success of operations in the Beaufort Sea.

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Chapter 3.13. Distribution and Thickness of Different Sea Ice Types and Extreme Ice Features in the Beaufort Sea

Research Project Overview

Severe ice conditions are a serious challenge to any operation in the Beaufort Sea. This research project carried out large-scale ice thickness surveys over the Southern Beaufort Sea in the springs of 2009, and 2011 through 2014. The airborne electromagnetic surveys covered off more than 3000 km of flight lines over the five-year observation period, quantifying ice thickness, ice distribution of first-year ice, multi-year ice and extreme ice features. The work was led by the Canada Research Chair for Arctic Sea Ice Geophysics at York University, in collaboration with researchers from Environment Canada, University of Alberta and the Alfred Wegener institute for Polar Research in Germany. The data analysis was supported through a university research award from Imperial Oil.

Project Purpose and Goals

The purpose of the project was to "obtain information on the large-scale spatial and inter-annual ice thickness distributions in the southern Beaufort Sea […] in preparation of safe and sustainable shipping and offshore operations."

Recognizing that the Beaufort Sea ice regime is dynamic and changing, this research sought to

- assess sea ice distribution and dynamics with a focus on thick ice and extreme ice features (e.g. ice islands).
- establish baseline sea ice data which can inform design criteria and regulations to ensure safety and environmental responsibility of any potential offshore oil and gas activity; and
- develop new methodologies for airborne sea ice observations.

Fit Within BREA Program

The Distribution and Thickness of Different Sea Ice Types and Extreme Ice Features research project was one of several BREA projects that focus on sea ice types and extreme ice features. As well, this research is key in helping to validate a coupled atmosphere-ice-ocean model being developed by Environment Canada to provide sea ice forecasting in the Beaufort.

Together the sea ice and modelling research will contribute to the BREA objective of generating knowledge in support of informed regulatory decisions on oil and gas activity. While sea ice is generally declining across the Arctic, it remains a critical issue for any offshore development and regulatory regime. This is especially true in the Beaufort where sea ice is very dynamic.

Methodology

The ice thickness surveys used a combination of a laser altimeter and an electromagnetic sensor, towed on a "bird" from a fixed wing DC-3 / Basler BT-67 airplane. The bird flew 80 m below the plane and typically 20 to 30 m above the sea ice. Using a fixed wing aircraft allowed the surveys to have a range of 1,500 km. This provides more flexibility and effectiveness than both helicopter and icebreaker surveys. The laser altimeter measured the distance to the top of snow/ice, and electromagnetic induction soundings measured the water ice depth. The difference of these two yields the ice plus snow thickness.

Overall, the surveys had an accuracy of ± 0.1 m over level ice. Where the profile of sea ice is not level, for example the keels of ice ridges, the sensor tended to underestimate the depths, and smoothed those ridges due to the wide footprint of the electromagnetic sounder. On the other hand, wide extreme ice features up to an overall thickness of 70 m (such as ice islands) can be measured using this system.

Surveys were completed in the spring of each year to represent the maximum, end of winter ice thickness, and to allow for the ice thickness data to be compared over time. Figure 3.13.1 shows the spatial coverage of the surveys. It is important to recognize that the results may be biased by the location and length of the flights, covering different regions and ice regimes every year. These differences were due to different weather and operational constraints during each survey and the limited time available to complete the surveys.

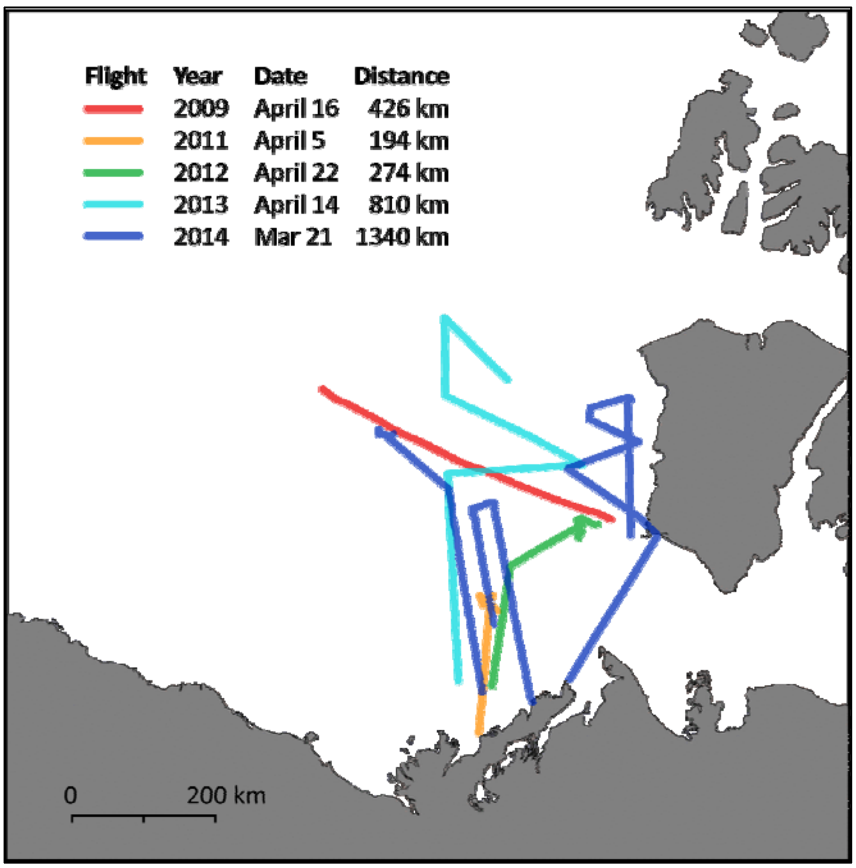

Figure 3.13.1 Ice thickness survey flight paths

Combined with GPS, cameras, and air-deployments of active satellite tracking buoys, this ice thickness measuring system aboard a long-range aircraft forms a sea ice observatory which could be used worldwide in support of climate observations, climate predictions, shipping, and oil and gas activities in ice-covered regions.

Use of Traditional Knowledge

There was no use of Traditional Knowledge in the design of this sea ice observation research, because its key study regions were in the offshore ice regimes where little hunting and fishing take place. However, as was pointed out at the BREA Results Forum, the technique could be applied in the near-shore environment if Inuvialuit Hunters Associations identified regions in which ice thickness surveys would be most useful. Open invitations to join the survey flights for wildlife observations or general experience were issued before the campaigns. As the aircraft operates at an altitude of only 100 m during the surveys, the flights are ideal for wildlife and ice observation.

Key Findings

The spring sea ice near coastal regions was dominated by first-year ice, 2.0 m thick. Figure 3.13.2 shows the frequency of different first-year ice thicknesses. The 2009 flight path was over multiyear ice further north only. Notice that even over this five year observation window the first-year ice appears to be thinning, with an additional modal thickness of 0.4 m appearing in 2014, representing large numbers of refrozen leads.

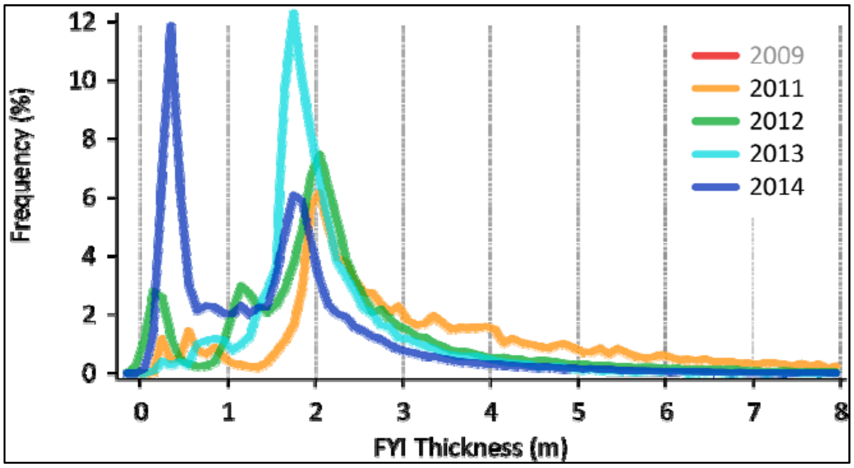

Figure 3.13.2 First-year Ice (FYI) Thickness Distribution

The multi-year ice thickness north of the first-year ice zone is illustrated in Figure 3.13.3 (note that the 2012 flight path was over first-year ice only). Like first-year ice, multiyear ice showed a model thickness around 2.0 - 2.2 m. In the early part of the five-year observation window, there was also a significant occurrence of 3.0 - 3.7 m thick multiyear ice. However, this thicker ice became much less common later in the five-year window, and in fact, thick multiyear ice is becoming much less common overall. In terms of thickness distribution, multiyear ice now looks a lot like first-year ice.

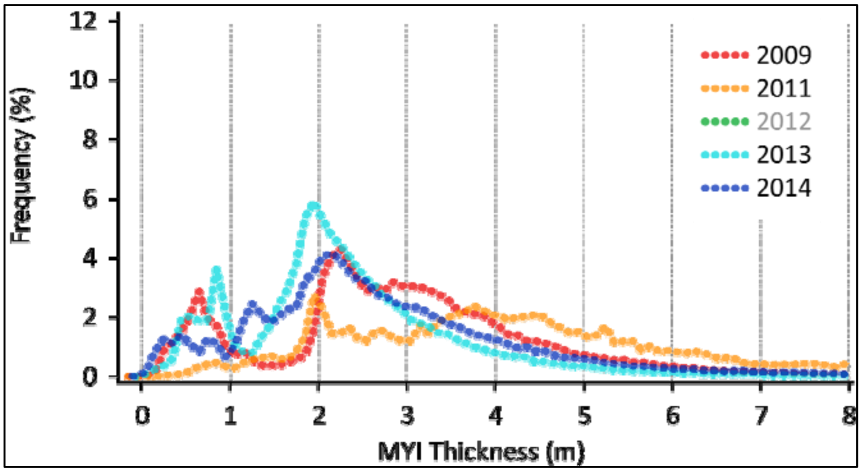

Figure 3.13.3 Multiyear Ice (MYI) Thickness Distribution

While both first-year and multiyear ice are reducing in thickness, they still have regions with thick and highly deformed ice. Often these areas occur in shear zones, for example along shore fast ice or coasts, or along the boundary between first- and multiyear ice regimes. As well, both first-year and multiyear ice also have extreme ice features.

Within this research, extreme ice features were defined as ice thicker than 6 m for at least 100 m of distance. Most of the ice that is greater than 6 m in thickness occurs along ice ridges, which are less than 100 m wide, and is thus not classified as an extreme ice feature in this research. Over the 3000 km of ice surveyed, over 200 extreme ice features were observed, across all years and ice types. Two ice islands between 20 and 30 m thick were observed during the five-year survey. It remains important that any sort of offshore activity consider and be prepared to withstand or to avoid extreme ice features.

Contribution to State of Knowledge

The Distribution and Thickness of Different Sea Ice Types and Extreme Ice Features research project has provided a significant baseline of ice data over several years, which complements other ice observations e.g. from satellites, and atmosphere-ice-ocean models for operational sea ice forecasting in the Beaufort Sea. This data is useful for Inuvialuit hunters, for oil and gas companies and for concerns of safety and environmental regulations. "Our recent results clearly show that ice conditions in the region are still serious, and can remain so well into the summer months." Much of the data has been made available for other researchers through the Polar Data Catalogue.

In addition to the insights into ice thickness distributions, trends and extreme ice islands, the research has also demonstrated and proved an observation system which has the potential to identify ice risks routinely and to better understand the dynamic nature of sea ice in the Beaufort. Building on the foundation of the sea ice thickness baseline data collected through BREA, this research will continue through the Marine Environmental Observation Prediction and Response Network (MEOPAR) in 2015 and 2016. Funds are being sought for a continuation of the research program into the future, together with researchers from Alaska and Germany.

Regulatory Decision-Support

This research does not make specific recommendations with respect to regulations. However, ice thickness is a design criterion for ice loads on offshore structures and ships, and thus the results are immediately applicable once dedicated infrastructure for the Beaufort Sea is being developed. In general, the project has provided a better understanding into the dynamic nature of sea ice including extreme sea ice in the Beaufort. This in turn should assist regulators and industry in decision making and in designing observation regimes in order to prepare for any offshore development. “Being prepared for any and all eventualities is one of the realities facing regulators and industry contemplating offshore oil and gas exploration and drilling.”

For example, for seasonal offshore activity, a comprehensive airborne survey in the spring would have the potential to identify the ice regime, including extreme ice features. Ice conditions could be monitored using satellites and GPS buoys with the possibility of utilizing additional airborne focused grid surveys as required. During the operating seasons, ice hazards can be identified by dedicated flights to targeted ice fields identified by satellite imagery upstream of the operating area.

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Chapter 3.14. RADARSAT Mapping of Extreme Ice Features in the Southern Beaufort Sea

Research Project Overview

This project, *Detection, Motion and RADARSAT Mapping of Extreme Ice Features in the Southern Beaufort Sea* is one of three studies comprising the BREA Integrated Sea Ice Project. It produced information for the Southern Beaufort Sea on thickness of remaining multi-year ice, physical processes contributing to multi-year ice decay, and the influence of atmospheric and ocean forces (winds and currents) on the movement of extreme ice features (EIFs) across a range of time scales and a range of pack ice concentrations. The project also tested satellite-based RADAR techniques for estimating wind speed in the marginal ice zone and for identifying and tracking EIFs, and it initiated a community-based monitoring program for measuring ice thickness near Sachs Harbour. While multi-year ice, ice islands, and compacted first-year ice can all constitute EIFs, this project focused specifically on multi-year ice and ice islands, the features of greatest concern to industrial and regulatory agencies in the region. Ice thickness and under-ice salinity and temperature profiles were also recorded on landfast ice in a community monitoring study based in Sachs Harbour. The University of Manitoba led this project, in close coordination with the leads of the two other studies making up the Integrated Sea Ice Project.

Project Purpose and Goals

In the Beaufort Sea, EIFs including floes of thick multiyear sea ice, ice islands calved from glaciers or ice shelves, and thick, ridged first-year ice represent hazards for shipping and offshore activities related to oil and gas exploration and development. The main goal of this project was to develop knowledge required to better monitor, model and predict the motion and physical characteristics of EIFs in areas of the southern Beaufort Sea where oil and gas exploration and development may occur. In particular, it focused on:

1. collecting new and integrating existing data to determine the thickness and thermo-dynamic characteristics of EIFs, and the influence of key ocean and atmospheric factors (currents and winds) on EIF motion;
2. developing approaches for identifying and tracking EIFs using satellite imagery; and,
3. piloting a community-based monitoring program (CBM) focused on the measurement of ice thickness near Sachs Harbour.

Fit within BREA Program

As noted, this project is one of three studies comprising the BREA Integrated Sea Ice Project. The other two studies address the thickness and strength of hummocky/deformed multi-year ice (see Section 3.12) and the large-scale spatial and thickness distributions of EIFs (see Section 3.13) in the southern Beaufort Sea. The three projects fall under BREA's "sea ice types and extreme ice features" research priority.

The current study and its Integrated Sea Ice Project counterparts contribute to a number of specific BREA goals and objectives. New information on and methods for assessing the motion and physical characteristics of EIFs will 1) better prepare stakeholders for future oil and gas exploration and development in the Beaufort Sea, 2) support informed regulatory decisions related to oil and gas activity, and 3) provide guidance for project-level environmental assessment.

Methods

The project studied EIFs situated in the eastern Beaufort Sea icepack, near Banks Island and "upstream" of oil and gas license areas further south and southwest. The ice in this subregion of the Beaufort is a mix of multi-year ice and ice islands embedded among younger first and second year ice floes, a complex icescape that results from ice in the Beaufort Gyre moving as a pack against and along the western and northern coast of the Canadian Arctic Archipelago. Field data were collected in the summer of 2011 (ship-based) and April-to-July 2012 (helicopter-based survey, drifting instrument packages and community monitoring) and winter 2013 (community monitoring only). Figure 3.14.1 shows the location of field work undertaken in 2011 and 2012.

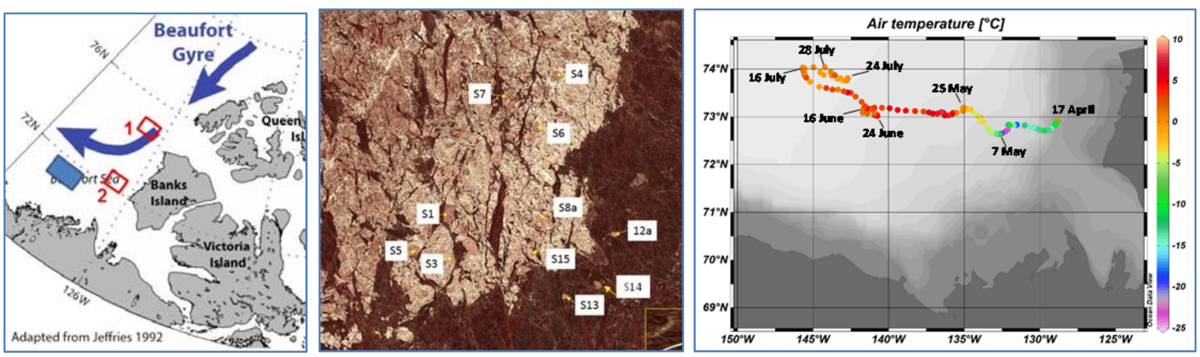

Figure 3.14.1. Location map showing (left) the field study regions in August 2011 (1) and April 2012 (2) in the context of the Beaufort Gyre (blue arrows) and oil and gas leases off the Mackenzie Shelf (blue rectangles); (middle) deployment locations of the primary site in 2012 (S1, with winds-currents-ice mass balance instruments) and ice beacons (other numbered locations) relative to the MYI pack (light tones in the RADARSAT image; dark indicates first year ice); and (right) track of the primary multi-instrumented drift site from 17 April through 28 July 2012 with air temperature indicated by coloured location symbols.

In August 2011, the icebreaker Amundsen was used to deploy fifteen drift ice beacons on multiyear floes northwest of Banks Island (Figure 3.14.1). Sea ice thickness was determined, and temperature and salinity profiles were measured at each site. Although this was not a BREA-funded expedition, analysis of data and publications resulting from these deployments was funded by BREA as described below.

In April 2012, eleven ice drift beacons were installed on multiyear ice floes, and one on an ice island, all about 80 km west of Banks Island (Figure 3.14.1). At one site (S1 on Figure 3.14.1), a suite of instruments was installed to record air temperature and surface wind velocity, under-ice ocean current profiles (to a depth of 60 m) and ice and near-under-ice temperature profiles, to support analyses of the relative contributions of different environmental forces on EIF motion and degradation at a range of time scales. All instrument were left to telemeter data to satellite as the ice drifted westward in the southern arm of the Beaufort Gyre. During the deployment, ice thickness was measured along a series of transects, by drilling and by electromagnetic induction using a sled mounted instrument. Under-ice profiles of salinity and water temperature were also measured.

RADARSAT-2 data were used to develop and test an improved algorithm for ice motion tracking and an algorithm for wind speed determination in the marginal ice zone. Komarov and Barber (2014) made advances in ice tracking by combining the strengths of two existing (co- and cross-phase correlation) methods for measuring spatial displacement of EIFs between sequential SAR images. Results were validated against historic ice beacon trajectory records. Also, development of wind-field information was carried out for the first time using RADARSAT-2 imagery in "horizontal polarization HH-HV Scan-SAR mode," the "beam mode" in most common use by the Canadian Ice Service. Experimentation with RADARSAT-2 imagery for the purpose of differentiating between first-year ice, multi-year ice, and ice islands (i.e., identifying EIFs) compared the effectiveness of different polarization modes across seasons and EIF types.

Sachs Harbour residents were trained in the use of a sled-mounted electromagnetic induction (SEMI) system for monitoring thickness of the landfast ice adjacent to the community. They recorded sub-ice salinity profiles by CTD, and made direct ice thickness measurement, to process and validate the SEMI data collected in a series of transects measured at weekly intervals from April to July 2012. Only 3 weekly surveys were carried out in 2013 because dangerous ice conditions developed in early May.

Key Findings

A first key finding of the project is that, in the Beaufort Sea, thermodynamics rather than dynamic processes are the main driver of ice melt (Candlish et al. 2014). In other words, while there are significant correlations between sea ice concentration and surface air temperature in the Beaufort, there are no significant correlations between sea ice concentration and wind speed or direction. Using data from the project and other sources Babb et al. (2015) show that the absorption of heat over open water in the marginal ice zone contributes significantly to the decay of multi-year ice floes; increasing solar heat input to the ocean since 1979 has driven an average increase of 4.3 cm per year in melt from the underside of multi-year floes in the region. Results by Barber et al. (2015) also showed that the amount of open water in the study region is controlled by ocean surface heat flux in the summer and fall and by dynamic processes due to the thinner ice cover. Results show that over the period 1978 to 2012, the amount of open water has increased linearly throughout the late fall, winter and early spring months (D, J, F, M, A, M, J) and increased exponentially in the summer and fall periods (J, A, S, O, N).

A second key finding is that changing climate conditions and ice distributions can lead to more frequent incursions of EIFs further south and west, even into the Chukchi Sea. This is explained in part by faster drift. The first ever beacon record of ice drift southward through the Bering Strait (as far as the Kamchatka Peninsula) was explained not by unusual weather conditions in 2012 but rather by low ice concentrations and therefore greater opportunity for EIF drift. Barber et al. (2014) use BREA and other data to demonstrate that in spite of a trend towards less multi-year ice in the Arctic, both multi-year ice and ice islands will continue to create hazardous conditions for marine oil and gas development in the southern Beaufort Sea well into the foreseeable future. They indicate that as long as the gyre continues to drive first and second year ice against the Archipelago coast, large, thick EIFs will continue to form and to be carried along the gyre into the southern Beaufort Sea. They also suggest that while, over time, fewer and smaller EIFs will be created, many will still be unmanageably thick and large, will drift at higher speeds, and may continue to be transported at least as far southward as the Bering Strait and as far westward as the Chukchi Basin (Barber et al. 2009, Barber et al. 2014).

A third key finding is the new models for wind speed assessments over open water in the marginal ice field, using synthetic aperture RADAR (Komarov et al., 2014). These models, now integrated into a quasi-operational system at the Meteorological Service of Canada, improve capacity to study and, ultimately better forecast the motion of EIFs in the margin ice zone.

A fourth key finding is the demonstrated accuracy of RADARSAT-2 sea ice tracking algorithms when compared with BREA ice beacon data (Komarov et al, 2014), and the usefulness of other imagery in distinguishing thin from thick snowpack.

Finally, the project demonstrated that success in identifying ice islands by RADARSAT-2 will vary from season to season. In winter and early in the melt season (until at least June in the southern Beaufort Sea) snowpack characteristics are similar enough on multi-year ice and ice islands that the two are not easily distinguished. During the melt season, differences in now sea ice surfaces melt relative to those of ice islands increase the detection capabilities of RADAR images. Water tends to stay on the surface of sea ice where on ice islands it can percolate down through cracks or run off. This increases the contrast of glacial ice from within the sea ice background.

Contribution to State of Knowledge

A major contribution to addressing regional information gaps relates to the prominence of the albedo feedback in sea ice degradation. In an earlier era characterized by perennial ice cover in the Beaufort Sea, seasonal melt was dominated by direct solar radiative heating (i.e., a weak effect on the surface of the ice). This project helped establish that increased ocean heating due to lowered sea ice concentrations during the summer season has been sufficient to melt on average 1.4 meters off the bottom of multi-year ice in the Arctic over the last 30 years. The project also showed that the increasing open water fraction has been linear through the cold season and nonlinear through the warm seasons, illustrating the strength of the ice-albedo feedback mechanisms on overall concentration.

The project also helped establish that in spite of earlier melt and degradation of multi-year ice in the Beaufort, EIFs are still carried westward at least as far the Chukchi Sea, and southward through the Bering Strait. The presence and in particular the speed at which these EIF's move create challenges for offshore development and transportation.

Stakeholder Preparation

The project contributed improved digital techniques for mapping the motion of the Arctic ice pack and for determining wind speeds in the marginal ice zone. It also contributed important information and improved modelling capacity for the prediction of EIF movement in the southern Beaufort Sea.

Remaining Research Gaps
Reliable identification of EIFs by remote sensing techniques remains a challenge particularly given poor RADARSAT discrimination of ice islands from multi-year ice, and between more and less hazardous multi-year ice floes, in the winter and early melt season.

Accurate forecasting of ice drift at the scale of days or tens of kilometers will require development of new techniques to monitor local wind and ocean current fields. These may include better surface wind determination from SAR, including direction as well as speed, and the use of higher frequency SAR such as is proposed by the European and Canadian Space Agencies. Higher resolution ocean current data may be obtainable from High Frequency Coastal RADAR installations, or may require arrays of cabled moorings collocated with drilling and extraction platforms.

Regulatory Decision-Support

Overall, this research has resulted in improved understanding and prediction of EIF conditions and movements in the southern Beaufort Sea. However, as stated above, there remain a number of important challenges both for identifying and providing finer-scale predictions of EIF movements.

The research provides regulators with important information for the development of "what-if" scenarios relating to the prevalence, movement and character of EIFs now and in the future, to help inform decisions on potential oil and gas activity.

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COUPLED OCEAN-ICE-ATMOSPHERE MODELING AND FORECASTING

The Integrated Environmental Modelling/Forecasting System for the Beaufort Sea

This comprehensive project was intended to improve the accuracy of weather forecasting at finer scales in the Beaufort Sea. This is important because oil and gas operations in the Beaufort Sea will be operating in areas that commonly experience extreme weather events, which pose safety risks to operations and navigation in the area.

The Integrated project was carried out through three smaller component projects, under the Coupled Ocean-Ice-Atmosphere modelling and forecasting research priority area. These projects are

- Enhancing the Canadian METAREA's operational coupled ocean-ice-atmosphere analysis and forecasting system for fine scale applications in the Beaufort Sea
- Forecasting ocean and ice conditions for the Beaufort Sea region from one to twelve months in advance
- Modelling Freshwater Flows to the Beaufort Sea.

Each of these separate projects contributes to the larger integrated modelling and forecasting system, and is described in greater detail in this chapter. However these BREA projects also use, interact with or contribute to other Canadian and international models or programs, as described below.

METAREA This is an international agreement that divides the world's oceans into regions, or METAREAs, for the purposes of coordinating the transmission of meteorological information to mariners travelling internationally. Nearby countries take responsibility for producing the marine weather forecasts for each region. Canada took over responsibility for two areas in the North and Arctic; one of these is METAREA XVII, which includes the Canadian Beaufort Sea. Canada's responsibility is led by Environment Canada. These are near-term forecasts of marine weather, rather than longer-term projections of general conditions in a region.

The work conducted under the Integrated Modelling/Forecasting System for the Beaufort Sea will help Environment Canada meet Canada's obligations to METAREA by producing better information for weather forecasting in the region.

NEMO The Nucleus for European Modelling of the Ocean is a state-of-the-art modelling framework, used in many countries for oceanographic research, operational oceanographic seasonal forecast, and climate studies (http://www.nemo-ocean.eu). NEMO is a computer model that is used mostly at larger scales, but the BREA research will configure the base model to model specific areas and conditions in the Beaufort Sea.

CONCEPTS The Canadian Operational Network of Coupled Environmental Prediction Systems is an operational Canadian-global, atmosphere-ocean-ice modelling system designed to produce weather forecasts. It is developed through the coordinated efforts of an ocean modelling group within three federal departments (Environment Canada, Fisheries and Oceans Canada, and National Defence) to develop ocean ice and atmosphere models over a large area. CONCEPTS uses NEMO within its modelling system and will improve the representation of conditions in the Beaufort Sea in the NEMO modelling framework.

CONCEPTS will contribute to the fulfillment of Canada's role as the issuing service for marine weather bulletins in the Arctic region under the international METAREA system.

The three components of the Integrated Environmental Modelling / Forecasting System for the Beaufort Sea

This large project is intended to enhance the METAREA operational coupled ocean-ice-atmosphere analysis and forecasting system and to improve the NEMO ocean model, to enable finer-scale applications in the Beaufort Sea. The project's three components will be integrated into an improved operational model of waves and sea ice for forecasting conditions in the Beaufort Sea.

The first component of the research program, "Forecasting Extreme Weather and Ocean Conditions in the Beaufort Sea," relates to the CONCEPTS modelling framework for short-term forecasting of ocean-wave-ice-atmosphere conditions in the Beaufort Sea.

The second component addressed the forecasting of ocean and ice conditions for the Beaufort Sea region for periods of one day up to 12 months in advance. It is titled "Seasonal Forecasting of Ocean and Ice Conditions in the Beaufort Sea."

The third project, "Modelling Freshwater Flows to the Beaufort Sea," will provide the operational hydraulic and hydrologic forecast system for boundary conditions of the Mackenzie Delta to the NEMO ocean model, to improve that model's accuracy in predicting offshore conditions in waves, ice and other factors.

A related fourth project in the overall research priority area established a set of three marine observatories in the southern and north-eastern Beaufort Sea that will provide data and measurements to the forecasting system.

Chapter 3.15. Forecasting Extreme Weather and Ocean Conditions in the Beaufort Sea

Research Project Overview

This research developed and implemented an ocean, wave, ice, and atmosphere model in order to better forecast upcoming ocean and weather in the Beaufort Sea. Conditions in the Beaufort can be challenging and at times extreme. Therefore, it is critical to understand and anticipate weather and ocean conditions to ensure any potential offshore operations are more prepared, efficient and safe.

This research was led by Fisheries and Oceans Canada, in collaboration with Environment Canada, McGill University, Université du Quebec à Rimouski, and National Defence. In particular, under Canada's commitment to participate in the Global Maritime Distress Safety System, the Beaufort falls under METAREA XVII. METAREAs are sea regions for the purpose of coordinating meteorological information to mariners, and METAREA XVII includes the Beaufort Sea across to the Bering Strait and up to the North Pole. Environment Canada has the responsibility to generate these enhanced weather forecasts.

This work overlaps with the Canadian Operational Network of Coupled Environmental Prediction Systems or CONCEPTS program, an agreement between Fisheries and Oceans, Environment Canada and National Defence. Whilst CONCEPTS is concerned with all of Canada, the BREA project allowed for focus on the southern Beaufort, dealing with some issues like sea ice. By coupling the atmospheric model with improved ocean, wave, and ice models this BREA project has led to a more refined and accurate forecast tool for the Canadian Arctic.

Project Purpose and Goals

The purpose of this project is to provide the best possible year-round estimate of ocean, ice and atmosphere conditions for any given location or transect. This information will be useful for a suite of applications: oil spill drift scenarios, search and rescue operations, potential design criteria, ecosystem assessment, ice management, transportation safety, etc. The usefulness of the forecasts extends across local residents, industry, science, and regulators.

Overall this fits with the BREA objectives to ensure stakeholders are better prepared for future oil and gas exploration and development in the Beaufort Sea, and to generate knowledge in support of environmental assessments and informed regulatory decisions on oil and gas activity.

Fit Within BREA Program

This project is one of three modelling projects which together augment forecasting in the Beaufort. These projects comprise BREA's Coupled Ocean-Ice-Atmosphere modelling and forecasting research priority area. Modeling of Freshwater Flows (see Chapter 3.17) considers the influence of the Mackenzie River, with the second largest drainage in North America, on the Beaufort. Seasonal Forecasting of Ocean and Ice Conditions (see Chapter 3.16) considers longer range forecasting of one to twelve months, while this Forecasting Extreme Weather and Ocean Conditions research project looked at short term, near real-time forecasting.

Together these models provide support for many other BREA research studies and working groups which can take advantage of estimated ocean-ice-atmosphere information such as temperature, salinity, winds, waves, sea surface state, marginal ice zones, and circulation. The data is produced as both predictive models and also historic data. The predictive model includes an analytical description of the current state of the ocean and sea ice at the beginning of the forecast period. The historic data (called a hindcast) is based on ocean and sea ice model runs constrained by actual atmospheric conditions for the hindcast period (typically 2003-2009). The output is valuable in the BREA context, providing a description of typical conditions and the frequency of extreme events. This information can be very useful for regulatory and planning purposes.

Methodology

The research methodology was divided into five tasks. The first was to utilize high resolution satellite swath data to analyze the oceans. New coastal altimetry and ocean tide data sets were added to this analysis. The second task was to improve ice forecasting, with more attention to ridges, leads, and ice deformation. These forecasts were compared to historic satellite and other ice experiment data. The third task was to improve the ocean forecast capability including refined ocean currents, water levels, temperature and freshwater content. These ocean forecasts were also run backwards in time to assess and refine the model performance. The fourth task was improved ice-wave coupling including the influence of sea ice in shallow coastal areas, floe behaviour and wind ice interface.

All of these tasks were integrated with the METAREA project. As part of the fifth task, protocols and routines were developed to assess and validate improvements these refinements brought to forecasting in the Beaufort Sea. The final aspect of the fifth task, which was not completed, was to disseminate the model forecasts more openly and widely. The dissemination work is ongoing. A public website is under development within CONCEPTS, which will include forecast information for the BREA region in a format more easily used by stakeholders. The Environment Canada public forecasts (marine, sea ice, and weather) already incorporate some of the improvements developed under BREA. Additionally the model can be used to provide tailored products – for example drift forecasts for search and rescue, or oil spill tracking.

Use of Traditional Knowledge

This research project did not utilize Traditional Knowledge. However, one of the project goals was to disseminate the information to local communities. The Inuvialuit have expressed strong interest in the research project products. Sea ice analysis and forecasts are both potentially useful for hunting, transportation and other recreational purposes. Through the BREA Results Forum, questions were posed as to how the model information could be made accessible for Inuvialuit. At the time of publication, the web-based public access tools for the forecast system were not yet available.

Key Findings

The key finding of this research project is the refined ocean-ice-atmosphere model, and the forecasts / hindcasts it yields. For example, the model ocean has resolved circulation to a 2 x 2 km mesh where it is possible to detect eddies in the circulation. Even though we are interested in the Beaufort, the model needs to be run for the entire Arctic and even North Atlantic. Testing against observed conditions has shown that the new model is both more accurate and more precise than previous forecasting models.

Especially important from the model is short term, near real-time forecasting. Development of a forecast model involves incremental improvements. The work within BREA has delivered many revisions to the model that together result in an improved hindcast and forecast (see Dupont et al., 2014). Areas of improvement include ice-wave interactions landfast ice, ice-atmosphere interaction, ocean physics and data assimilation. Figures 3.15.1 and 3.15.2 are examples of a graphic that the new model will be able to produce. Many groups will find these forecasts (and hindcasts) useful, including industry, regulators, Inuvialuit, etc.

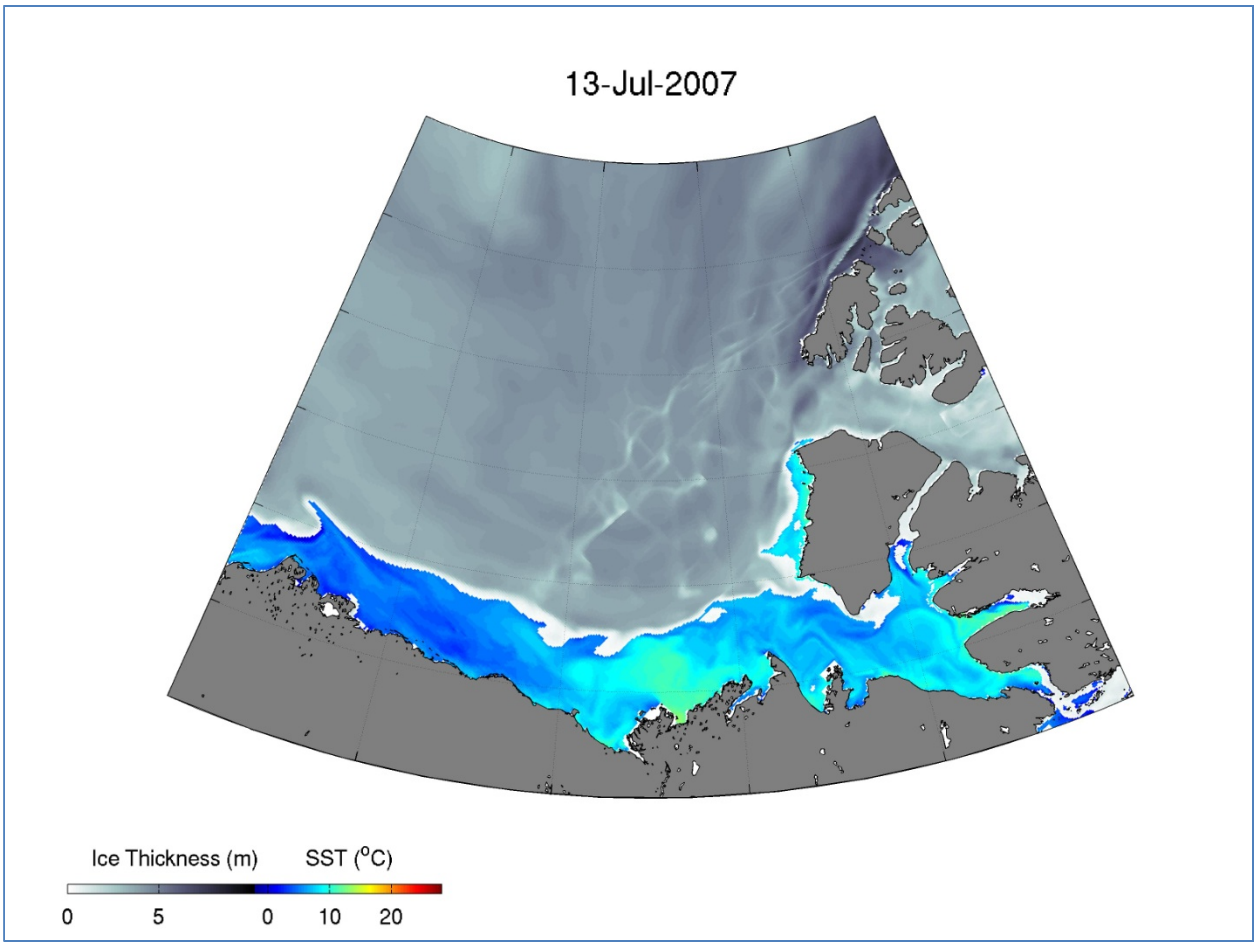

Figure 3.15.1. Sample sea surface map from hindcast, showing sea ice thickness and sea surface temperature.

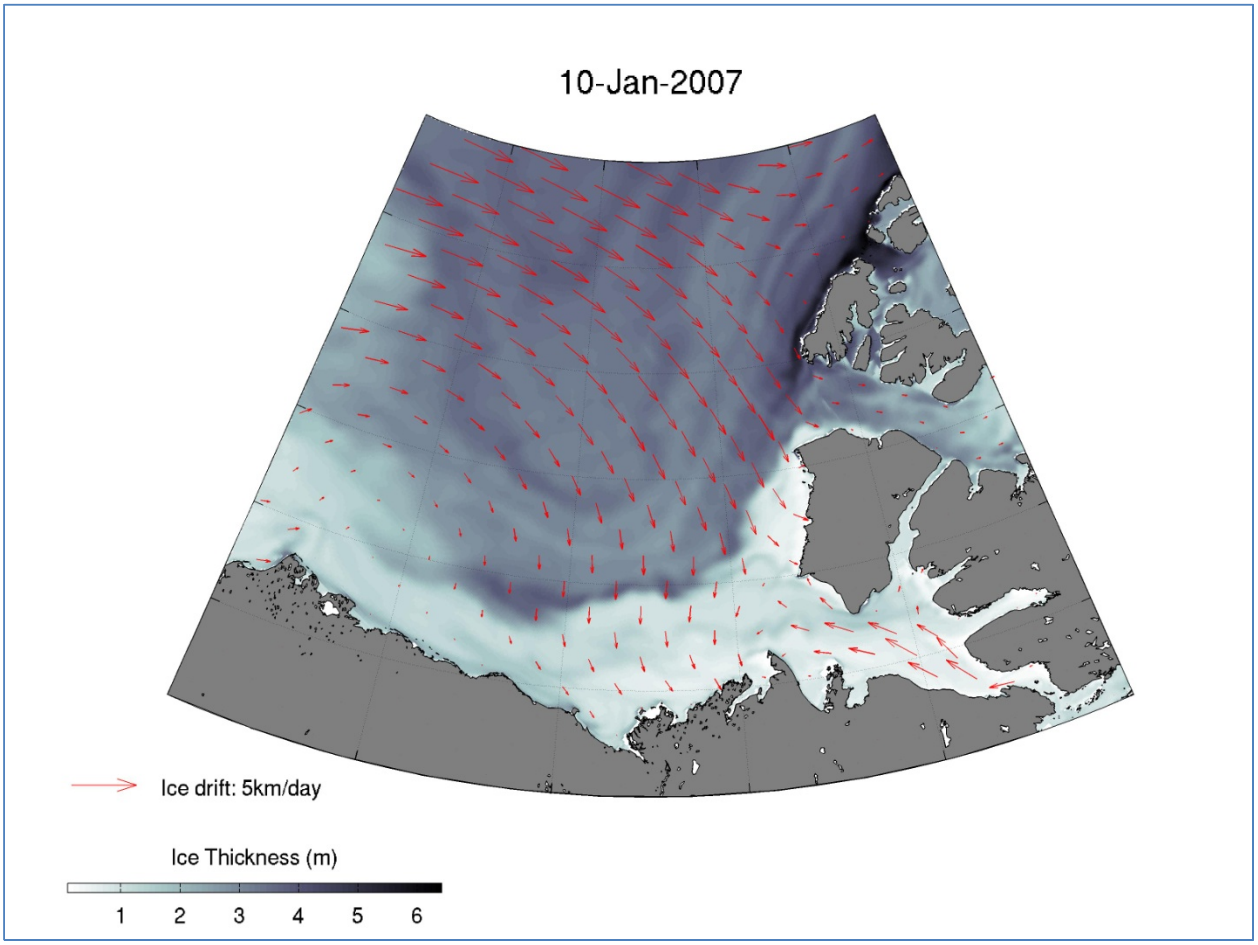

Figure 3.15.2. Sample sea surface map from hindcast, showing sea ice thickness and sea ice drift speed/direction.

Contribution to State of Knowledge

The Beaufort Sea is dynamic and changing. Overall the contribution of this research project has been to provide a better understanding of ice ocean and weather conditions that can be anticipated in the Beaufort. It can now also be used to look backwards in time to better understand the weather / climate processes that have been at work influencing the flora and fauna within the Beaufort. External to BREA, the main contribution of this research project has been to improve the METAREAs forecast and warning program. While the METAREAS focuses on marine areas, a coupled environmental prediction system improves the forecasts in all areas (including for example, improved weather forecasts over land).

Remaining Research Gaps

The original intention of the project was to ensure that this work was widely disseminated with the results being openly accessible. One of the challenges is with how to ensure such a large volume of information be made accessible. Providing the model forecast information to researchers will allow the integration of observation with prediction. This is a method for validating models more widely, and for providing the re-initialization of models over time so that they remain ground-truthed. It is also important to disseminate the forecasts to the Inuvialuit, to regulators and industry allowing for better integrated into local and regional planning and decision making.

Broadly, the work to disseminate the model and forecasts has not yet happened. However, this work is ongoing and there is a plan to produce a public website beyond the formal conclusion of the BREA research projects. Model development is also an ongoing process. Although the improvements identified in the original BREA proposal have been implemented, development continues. Additional observational data will allow further evaluation of the model hindcasts and forecasts, and subsequent improvements.

Regulatory Decision-Support

Overall, this research has yielded an improved understanding and prediction of ocean - wave - ice - atmosphere histories and futures. As stated above, the challenge that remains is to ensure that the model information is accessible for regulators, and more widely: Inuvialuit, industry and researchers. Currently descriptive forecasts are produced for mariners through METAREA. At this stage, what regulators need is the ability to see trends, assess risks and possibly to generate "what-if" scenarios to help inform decisions on potential oil and gas activity.

The hindcasts are a potentially useful asset for regulatory decision making. The public website under development as part of the CONCEPTS initiative is part of a wider dissemination strategy that will include a service desk function. This will allow the development of products for users including regulators – such as the hindcasts for specific regions and for specific applications.

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Chapter 3.16. Seasonal Forecasting of Ocean and Ice Conditions in the Beaufort Sea

Research Project Overview

Efficient and safe operations in the Beaufort Sea region require not only high-quality weather forecasts, but longer-term, seasonal predictions of ocean and sea ice conditions as well. Skillful seasonal predictions can help inform the planning of equipment transportation and installation, re-supply schedules, fuel requirements, and spill mitigation measures. This project focused on evaluating and improving the accuracy of predictions of ocean and sea ice conditions in the Beaufort Sea at the seasonal time scale, one-to-twelve months in advance. It contributed directly to improved ocean and ice prediction products for the Beaufort and other Arctic regions, to serve operational and regulatory needs now and in the future.

The project team was led by the Canadian Centre for Climate Modelling and Analysis (CCCma), with support from the Canadian Meteorological Centre (CMC) and the Canadian Ice Service (CIS). The project also linked with the North American Multi-Model Ensemble (NMME), a set of Canadian and US forecast models which has become the primary source of seasonal forecast information for North American interests.

Project Purpose and Goals

The main purpose of this project was to evaluate and help improve the performance of a high-resolution ocean and climate forecasting system – the Canadian Seasonal to Interannual Prediction System (CanSIPS) – for use in the prediction of ocean and sea ice conditions from one to twelve months in the future. The broader goal was to contribute directly to the development of improved ocean and sea ice prediction products that support offshore operations and help meet operational and regulatory decision-making needs in the Beaufort and other Arctic regions. The project also sought to make contributions to the ongoing expansion of the North American Multi-Model Ensemble forecast system.

Overall the project aligned with BREA's objectives to ensure stakeholders are better prepared for future oil and gas exploration and development in the Beaufort Sea, and to generate knowledge in support of environmental assessments and informed regulatory decisions on oil and gas activity.

Fit within BREA Program

This was one of three projects which together directly support the enhancement of weather, ocean and sea ice forecasting capacity for the Beaufort region. Modeling of Freshwater Flows considers the influence of the Mackenzie River, with the second largest drainage in North America, on the Beaufort. Forecasting Extreme Weather and Ocean Conditions considers short term, near real-time forecasting. The current project considers longer range forecasts of one-to-twelve months. These projects also comprise BREA's Coupled Ocean-Ice-Atmosphere modelling and forecasting research priority area.

Methodology

The project had three main methodological elements: i) assessing the seasonal forecast skill of CanSIPS in relation to a key set of sea ice parameters; ii) refining seasonal forecast skill through statistical downscaling; and, iii) assessing newly modelled wind speed changes in the Beaufort Sea.

i) Assessing seasonal forecast skill in relation to key sea ice parameters

Until fairly recently most seasonal climate and ocean forecasting systems used a ‘‘two tier’’ approach, relying on sea surface temperature information from an external source in order to establish “boundary conditions” for the atmospheric general circulation model producing the forecasts. Increasingly, however, long-range forecasting systems have adopted a ‘‘one tier’’ approach, using *coupled* ocean/ice-atmosphere models. CanSIPS is a coupled system, including two coupled ocean/ice-atmosphere models, CanCM3 and CanCM4 of the CCCma.

CanSIPS’ forecasting skill was assessed by testing the ability of the system to reproduce observed sea ice conditions through retrospective forecasts for the January 1979-December 2009 period, with lead times of 1-12 months. This process included three main steps, as follows.

“Initializing” CanSIPS (i.e., providing the ‘starting point’ for predictions): Initial model states for each seasonal forecast were established by running CanSIPS while maintaining key atmospheric variables, sea surface temperature, subsurface ocean temperatures, and sea ice concentrations at near observation-based values for each relevant time period. Observation-based values came from two interpolated datasets, the Hadley Centre Sea Ice and Sea Surface Temperature dataset and the National Snow and Ice Data Centre dataset. For the purpose of future operational forecasting, interpolated, observation-based values will be provided as near real-time products by CMC.

Retrospective forecasting: Once initialized for the beginning of each month of the January 1979 to December 2009 period (above), CanSIPS then produced forecasts with lead times of 1-12 months. Each forecast used an ensemble of 20 independent runs, 10 from each of the system’s CanCM3 and CanCM4 models.

Quantifying forecast skill: Forecast skill was quantified by using correlation analyses to compare ensemble mean forecasts with observation-based values for three main variables: sea ice extent, sea ice melt dates, and sea ice freeze dates.

ii) Refining seasonal forecast skill through statistical downscaling

Results of the above assessment of forecast skill helped guide the statistical downscaling of CanSIPS forecasts for the Beaufort region. Canonical Correlation Analysis techniques were applied to CanSIPS forecasts with lead times of 1-to-6 months, supported by a software system developed to assist with the effort.

iii) Assessing recently modelled changes in extreme wind speeds in the Beaufort

Extreme wind speeds have increased significantly over the 21st century in the Beaufort Sea. In light of this knowledge, and in order to support future refinements of CanCM3, CanCM4, and CanCIPS as whole, an ensemble of global circulation models (>10) from the recent IPCC 5thAssessment Report was assessed for its ability to replicate historical wind speed conditions in the Beaufort Sea.

Use of Traditional Knowledge

This research project did not use Traditional Knowledge because it focused on evaluation of a computer-based operational seasonal prediction system. However, one of the project goals was to disseminate the information to local communities, and key topic of discussion at the BREA results fora. At present, temperature and precipitation predictions are available through EC's WeatherOffice web site. Sea-ice products will be made available later on, following further refinement.

Key Findings

This project resulted in new knowledge of CanSIPS' forecasting skill, improvements to this skill, as well as a range of new datasets and software products.

CanSIPS' forecasting skill

For sea ice extent, CanSIPS' forecasting skill is highly influenced by the strong overall downward trend in annual sea ice cover, meaning forecasting accuracy for lead times greater than 2-3 months is largely attributable to this trend. As such, the modelled effects of other physical factors on sea ice extent in the Arctic, including the Beaufort, become much less reliable for lead times greater than 2-3 months. Therefore, on the whole CanSIPS currently exhibits limited skill forecasting inter-annual variability in sea ice extent.

However, CanCIPS' forecast skill is marginally better than simple 'persistence' forecasts, making it potentially useful as input to decision-making processes for activities or industries in which one or two month lead time decisions must be made (e.g. preparation or pre-positioning of ships or equipment).

Analysis of sea-ice melt date skill is an activity launched late in the project (made possible by newly-released satellite observations). This work will continue within EC/CCCma and may lead to a validated sea-ice melt date prediction product in the future.

Improvements to CanSIPS' skill

This work has provided insight especially into the influence of initial high-latitude environmental conditions on CanCIPS' seasonal forecast skill, resulting in new efforts to improve methods related to, for example, establishing initial snow depth and ice thickness values for the system.

Research involving combinations of forecast systems, like the NMME, reinforces early findings that the use of model ensembles tends to improve forecast skill. This approach is being actively pursued and will ultimately lead to more skillful and more consistent long-term forecasts for the Canadian and American portions of the Beaufort Sea. Further development and improvement of CanCIPS is integral to this effort and will help expand the suite of seasonal climate prediction products available via Environment Canada's Weather Office web site.

Future wind speeds in the Arctic

The work on longer-term projections of wind speed in the Arctic provided quantitative information on anticipated future changes in wind speed. Ensemble outputs project significant increases in both mean annual wind speeds as well as in extreme wind speeds. An inverse relationship was found between sea ice concentrations and wind speeds, suggesting that modelled increases in wind speeds may be caused mostly by the effect of sea ice retreat on the atmospheric layer closest to the earth, not by changes in atmospheric circulation or storminess.

Datasets and software products of the project

The following datasets and software products were developed or collated by the project:

- Software tools for generating hindcast data from CanCM3 and CanCM4 will be transferred to CMC for operational use.
- Data and metadata from previous CanCM3 and CanCM4 hindcasts and the World Climate Research Program's IceHFP project have been provided to the Polar Data Catalogue.
- Dataset of simulated daily maximum wind speeds, sea ice concentration, thickness, drift velocity, and six-hourly surface pressure from an array of climate model simulations from the IPPC 5th Assessment Report, for a grid of locations in the Beaufort Sea region have been provided to the Polar Data Centre.
- Web-accessible sea ice seasonal forecast products will be available through the Environment Canada Weather Office site and the NMME site.

Contribution to State of Knowledge

Addressing Regional Information Gaps

Though the forecasting of ocean and sea ice conditions in the Arctic has been the focus of significant effort since the early 1980s, forecasting skill has generally remained limited for periods longer than two months. Yet the need for longer-term forecasts – up to *twelve* months in advance – is arguably greater now than ever; increased industrial activity means more is at stake, and climate change is likely to result in more extreme wind, ocean and sea ice dynamics. Findings regarding the strengths and weaknesses of CanCIPS, as well as the main factors affecting its seasonal forecasting skill will help not only set the stage for further improvements to CanCIPS; they will also help inform present use of this and other forecasting systems for operational, planning and regulatory purposes in the Beaufort Sea.

Meanwhile, the longer-term wind speed projections have helped improve our understanding of factors effecting change in wind patterns and intensities, including the prominent influence of sea ice cover on the magnitude, timing and seasonality of these changes.

Stakeholder Preparation

The project helps prepare stakeholders in various ways. First, the evaluation and improvement of CanSIPS as a forecasting tool provides industry, regulators, and communities with an understanding of the status of ocean and sea ice forecasting skill for the region, as well as access to improved forecasts now and in the future. Second, the new projected wind information is of direct relevance to local communities and industry, especially insofar as it contributes to projections of future wave heights and coastal hazards; together with the winds themselves, these factors are critical considerations for the design of operational and maintenance regimes, emergency measures, and built infrastructure both on and off shore.

Remaining Research Gaps

As noted, CanCIPS' forecasting skill, especially for periods exceeding two months, will be the focus of continued work, including through collaborations with NAMM partners. Among other methods, statistical downscaling approaches will be further tested.

The range of forecast products that can be provided and research questions addressed through use of CanSIPS and the Integrated Environmental Modelling/Forecasting System for the Beaufort will always be limited by the amount and quality of available empirical data required to evaluate and initialize models. An important area of future research could therefore relate to the gathering of data of the types required by CanCIPS and the Integrated Environmental Modelling/Forecasting System. The Southern and Eastern Beaufort Sea Observatory System, the fourth project in BREA's Coupled Ocean-Ice-Atmosphere Modeling and Forecasting research priority area, could, among other initiatives, play an important role in this regard.

Regulatory Decision Support

Any oil and gas exploration and development in the Beaufort must necessarily consider the hazards and risks associated with ocean and sea ice conditions, recognizing that some of these conditions may become more extreme over time with the influence of climate change. Fundamental to all other risk mitigation measures is the provision of ocean and sea ice forecasts for time periods that correspond where possible with the planning requirements of offshore operations. In many cases, decisions about the provision, placement and use of equipment, or whether or not to undertake certain activities, must be taken many months in advance. The evaluation of CanCIPS' forecasting skill from one to twelve months in advance is a critical step towards providing more and better seasonal forecast products for offshore activities in the Beaufort. So too is work to refine model-driven forecasts with statistical downscaling techniques. This project has better positioned CanCIPS, together with its NAMM counterparts, for use by regulators in the Beaufort region.

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Chapter 3.17. Modelling of Freshwater Flows to the Beaufort Sea for Improved Offshore Prediction by the Metarea Ocean Forecast System

Research Project Overview

This project involved the development of a computer-based model to predict the volume, distribution, timing, and other characteristics of the outflow from the Mackenzie River into the marine waters of the Beaufort Sea. This is important because, although the discharge of large volumes of comparatively warm freshwater into the cold Beaufort Sea can influence weather and sea conditions, the relationship to weather and sea conditions is not well understood. The results of this project enable more accurate predictions of the Mackenzie River discharge into the Beaufort. As this is a critical component in forecasting weather and sea conditions in the area, the results also contribute to improved marine forecasts.

The Mackenzie River discharges large volumes of comparatively warm freshwater into the cold Beaufort Sea at the Mackenzie Delta. That plume of freshwater extends several hundred kilometers into the coastal zone, affecting currents, water density, water temperature, waves, and ice conditions in the nearshore Beaufort through myriads of complex interactions. The plume can also influence weather conditions. For example, it can intensify summer cyclones because of the energy the atmosphere picks up from the warmer freshwater. These storms can in turn generate waves and storm surges that can enter nearshore Mackenzie Delta waters, causing erosion and coastal inundation.

The volume and other characteristics (e.g., timing, water temperature, flow distribution) of the Mackenzie River discharge into the Beaufort are variable, influenced by high river flows during spring and summer, river ice on the channels of the delta, grounded coastal sea ice, and storm surge flooding. Similarly, the influence of the river discharge on sea and weather conditions is correspondingly variable. This study investigated existing data regarding these variables, and in particular the influence of the storage and subsequent release of large volumes of spring and summer floodwaters. The Mackenzie Delta greatly influences the amount and timing of water discharges into the Beaufort Sea from the Mackenzie River through the storage of large volumes of floodwaters. The floodwaters spill over the banks of the main delta channels into "off-channel storage areas" such as lakes and floodplains. The floodwaters are stored temporarily in these areas, then are gradually released back to the main channels as the floodwaters recede. The volumes are substantial, equivalent to many weeks of peak flow from the Mackenzie River basin. This hydraulic model of freshwater flows through the Mackenzie Delta will be linked with other models regarding ocean, wave, ice, and atmospheric (OWIA) conditions on the Beaufort. Together, these models will be used to forecast sea and weather conditions which are of vital importance to marine operations and navigation.

The Modelling of Freshwater Flows to the Beaufort Sea project was led by Environment Canada's National Hydrology Research Centre, at the University of Saskatchewan, in collaboration with researchers at Fisheries and Oceans Canada (DFO) in St. John's, and Dartmouth, and at Dalhousie University, and other researchers at the University of Alberta and Simon Fraser University.

Project Purpose and Goals

This project is one of three linked BREA-funded projects that make up the larger program, Integrated Environmental Modelling/Forecasting System for the Beaufort Sea, which is intended to improve the accuracy of weather forecasts in the Beaufort Sea. Sea and weather conditions in the Beaufort are influenced by the large volumes of freshwater discharged from the Mackenzie River into the Beaufort. The purpose of the Freshwater Flows project was thus to improve the ability to forecast weather and sea conditions through a better understanding of the interactions between the Mackenzie discharge and Beaufort Sea.

An objective of the Freshwater Flows project is to link with related work carried out by other agencies, and build on existing models. It links with the development, by Environment Canada (EC) and DFO, of CONCEPTS (Canadian Operational Network of Coupled Environmental Prediction Systems), which will improve the representation of conditions in the Beaufort Sea in the NEMO ocean modelling framework, to which this project contributes.

The specific objectives of the Freshwater Flows project are to:

- Develop and implement a hydraulic model of the MD that will estimate channel flows to the Beaufort Sea;
- Develop an off-channel water storage model of the MD to enable the hydraulic model to account for storage of water that modifies water flows from the Mackenzie River to the Beaufort Sea;
- Through the linkages with the NEMO ocean model, interactively model the river and ocean system;
- Evaluate the physical connection (transport-diffusion) 1-D and NEMO; and
- Provide boundary conditions and model codes as required to larger scale OIA models applied to the Beaufort Sea in related BREA proposals.

Fit Within BREA Program

As noted, this project is one of three components of the larger Integrated Environmental Modelling / Forecasting System for the Beaufort Sea, which is in turn part of BREA's Coupled Ocean-Ice-Atmosphere modelling and forecasting research priority area. The three projects will be integrated into an improved model of waves and sea ice that will enable greater accuracy in forecasting conditions in areas of the Beaufort Sea where oil and gas activities are taking place. The Modelling Freshwater Flows to the Beaufort Sea project will provide the operational hydraulic and hydrologic forecast system for boundary conditions of the Mackenzie Delta to the NEMO ocean model, to improve that model's accuracy in predicting offshore conditions in waves, ice and other factors.

Methodology

There were several components in the work of developing a hydraulic model of the MD. The first was an analysis of LiDAR data for the determination of the storage of water outside of the main river channels ("off-channel storage areas"), and its conversion into the format required by the models that will use the data. Validation was then done of lake/channel edge detection routines and elevation estimates, and of the entire combined LiDAR data set on both lakes and terrestrial areas.

The second step was to develop a model of the off-channel storage areas, using the LiDAR data and air photos to develop a relationship between water levels in the river channels and off-channel water storage, for use in the hydraulic model.

Third, an MD hydraulic model was developed to be provided to the NEMO ocean model. Boundary conditions were determined, using the River1D model developed by the University of Alberta to account for off-channel storage effects in the delta and river ice to represent flow distributions at the MD/BS interface for all seasons and scenarios. Successful calibration runs have been completed of low flow (open water and ice affected) conditions and testing is underway on the impacts of ice breakup and ocean backwater effects on flow distributions from the MD to the Beaufort Sea.

Fourth, the MD hydraulic model was run interactively with the NEMO model applied to the Beaufort Sea. The models were run iteratively and sequentially, so that MD flow redistributions could be used to update boundary conditions in the ocean model, and feedback from the ocean model could be used to refine downstream (backwater) boundary conditions in the delta model. This enables an accurate representation of flow distributions by the NEMO ocean model for both operational routine forecasts and extreme conditions.

Finally, the operational computer program for the MD hydraulic model has been provided to NEMO users for testing purposes.

Use of Traditional Knowledge

Researchers on this project collaborated with local communities, through the consultation processes followed by DFO and ArcticNet, participating in several information sessions in the Beaufort Region. In addition, the researchers have established a working relationship with the Tuktoyaktuk Hunters and Trappers Committee.

Key Findings

This project, and the larger project of which it is a part, are not primarily research projects. Instead, this study used existing data to create computer-based numerical models of the ocean and water flow systems that influence conditions in the Beaufort Sea. Therefore, the project was not making primary observations and measurements to generate new research findings.

Contribution to State of Knowledge

The work of developing a model of the interactions between the Mackenzie Delta and the Beaufort Sea has deepened researchers’ understanding of the relationships among these systems. For example, the work to complete this project has confirmed that off-channel storage is a significant component of total Mackenzie River flow. For the purposes of this project this recognition confirmed that off-channel storage must be included in hydraulic modelling of the delta to determine time dependent river flows to the Beaufort Sea, as needed by the ocean model. The linking of the ocean and Mackenzie Delta hydraulic models with the CONCEPTS OIA model provides greater information about the factors that generate conditions of concern on the Beaufort Sea and enables more accurate and longer-term forecasting of critical conditions.

Addressing regional information gaps

The development of a hydraulic model of the Mackenzie Delta was carried out to provide more accurate information for the NEMO ocean model, to improve the accuracy and level of detail of forecasts. For example, the NEMO model did not include time-dependent Mackenzie River runoff, so the modelled sea surface temperatures were too cold in the summer. Consequently, storm intensity, winds, minimum sea level pressures and storm surges at the Delta had been underestimated. Providing a more accurate representation of these processes required that other gaps be addressed on water flows and storage in the Delta. There was little information on the effect of the water storage in the delta on flows to the Beaufort Sea: discharges from the delta channels into the Beaufort Sea are not measured, and doing so is difficult because ocean tides make the relationship between water levels and discharge unstable. The analysis of LiDAR data was conducted in order to map the main channels and storage areas in the Delta, so the volume and timing of flows into the Beaufort Sea could be better understood.

Stakeholder preparation

This project contributes to the larger integrated modelling project, improving NEMO forecasting in the BREA priority areas by Environment Canada and DFO. The Beaufort Sea is dominated by high-impact and changeable environmental conditions, including highly variable sea ice cover that interacts with extreme weather events, ocean currents and waves, which create safety concerns for industries and transportation in the area. The forecasts will enable improved management decisions and emergency response, for example, by helping to build the capacity to simulate an oil spill trajectory in near real-time.

The Canadian Coast Guard will be able to use the publicly available information from this project in their Search and Rescue planning software, to monitor and forecast the drift of search objects.

Regulatory Decision Support

Improved accuracy in forecasting offshore environmental conditions will provide support for Environmental Assessments for projects planned for the area, as well as for regulatory decisions on projects. Data generated through these models can be used in the design of equipment and operational planning, to assist with oil spill modelling, the prediction of ocean ice conditions and movements, and the assessment of the effects of the environment on a project.

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Chapter 3.18. Southern and Northeastern Beaufort Sea Marine Observatories

Research Project Overview

The Southern and Northeastern Beaufort Sea Marine Observatories project was established in 2011 to collect data on some key conditions in the Beaufort Sea marine environment through the deployment of oceanographic instruments at three locations in the BREA study area. Ocean moorings were deployed in 2011, 2012 and 2014, and gathered year-round measurements from the entire BREA region, from Mackenzie trough to the north-eastern Beaufort Sea.

The project is led by the ArcticNet Network of Centres of Excellence of Canada, in collaboration with IMG-Golder, an Inuvialuit-owned environmental and engineering company based in Inuvik. There was also considerable support from the Canadian Coast Guard (CCG), through the operation and maintenance of the icebreakers CCGS Sir Wilfrid Laurier and CCGS Amundsen, and from the Institute of Ocean Sciences from the Department of Fisheries and Oceans. The project developed from an early collaboration in data collection in offshore exploration license areas between ArcticNet, IMG-Golder and Golder Associates, with support from industrial partners Imperial Oil, Exxon Mobil and BP, which continued through the BREA project.

Project purpose and goals

The major goal of the project was to collect multi-year and continuous data on ocean circulation, water properties, sea ice and biogeochemical fluxes at the local (exploration licenses) and regional (eastern Beaufort Sea) scales. This information will help decision-makers, regulators and stakeholders address issues related to oil and gas development in the Beaufort Sea.

Objectives of the research project in the south-eastern Beaufort Sea were:

- To quantify the seasonal and annual variability in oceanic circulation along and across the ocean shelves;
- To quantify the annual movement and thickness distribution of sea-ice, with particular focus on heavy, thick multi-year ice and glacial ice features;
- To quantify the seasonal and annual variability of vertical biogeochemical fluxes of organic and inorganic matter; and
- To maintain and extend existing time-series in exploration license blocks and to fill important data gaps in the southern and north-eastern Beaufort Sea.

Fit within BREA program

The project provides knowledge at both the local and regional scales, addressing gaps in information on inter-annual variability in oceanographic conditions in the BREA study area. The project also included strong community engagement.

The project is one of four projects under the BREA "Ocean-Ice-Atmosphere Modelling and Forecasting" research priority area. The data collected at the observatories will be critical in building the ocean-ice-atmosphere models to be produced by the other three projects developing an integrated Environmental Modelling/Forecasting System for the Beaufort Sea.

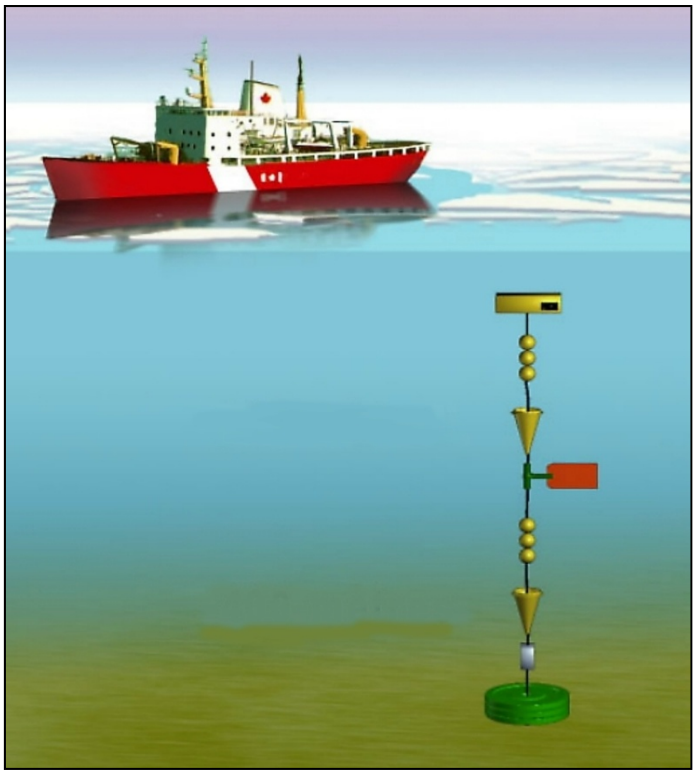

Figure 3.18.1. Schematic illustration of a mooring line supporting oceanographic instruments in ice covered waters

Methodology

The project was carried out through ship-based oceanographic sampling and the deployment of oceanographic moorings equipped with a suite of recording instruments in areas of the Beaufort Sea in which oil and gas exploration is expected to take place. Acoustic Doppler current profilers (ADCP), sediment traps, ice-profiling sonars, conductivity-temperature sensors, fluorometers and turbidity meters were positioned at various depths along submerged mooring lines anchored to the seabed. (Figure 3.18.1). The moorings were recovered and redeployed each fall in order to collect data on key ocean and sea ice properties continuously throughout the entire span of the BREA program. Observatories were established in three areas of the Beaufort Sea/Mackenzie Shelf: at the central shelf/slope in the Ajurak/Pokak exploration license areas, approximately 200 nautical miles northwest of Tuktoyaktuk; north of the Mackenzie trough at the western limit of the Canadian Beaufort Sea; and on the shelf and shelf-break off the western coast of Banks Island in the north-eastern region of the Beaufort Sea.

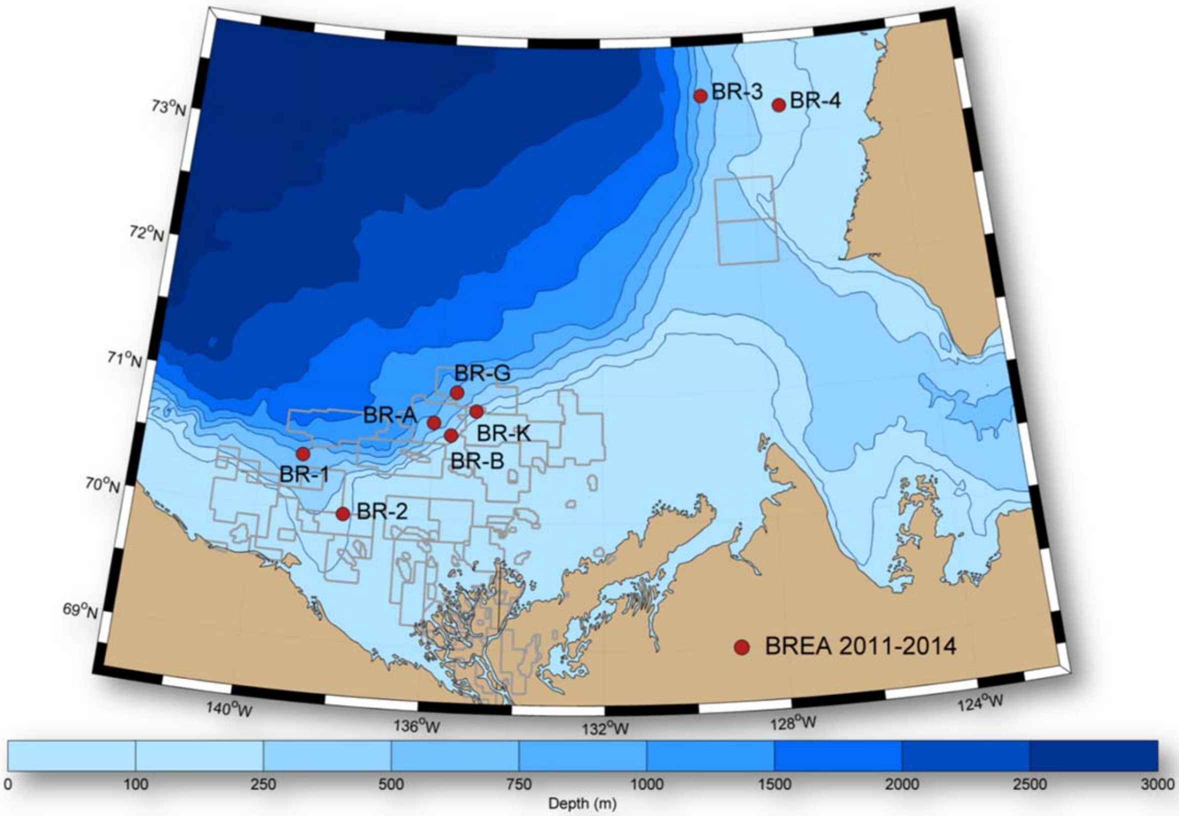

Figure 3.18.2: Map of Beaufort Sea showing mooring locations in the three marine observatories (From Forest, 2015).

The locations of moorings deployed in the three observatories during the BREA program are shown in Figure 3.18.2 above. In 2011, three moorings were deployed at the first observatory and one in the second, sea-ice conditions prevented the deployment of moorings off of Banks Island. In 2012 the moorings were retrieved and redeployed, and an additional mooring was deployed in the Mackenzie Trough observatory. These five moorings were successfully recovered in the fall of 2013 but could not be redeployed due to the unplanned curtailment of the ArcticNet expedition onboard the CCGS *Amundsen*.

All six moorings originally planned in the BREA proposal were deployed in 2014, with two moorings positioned in all 3 observatories. All moorings will be recovered by ArcticNet in the Fall of 2015. The observatories will be maintained at least until 2018 through the newly established integrated Beaufort Observatory (iBO) project funded by the Environmental Studies Research Fund (ESRF), ArcticNet, and Imperial Oil and involving partners from Golder Associates and the Department of Fisheries and Oceans, among others. This new project is a direct legacy of our BREA program.

Use of Traditional Knowledge

Community engagement and consultation is an integral part of this research project. IMG-Golder, one of the major partners in the project, is an Inuvialuit-owned company that has hired and trained many Marine Wildlife Observers (MWO) and other technical assistants from the Inuvialuit Settlement Region (ISR). Four MWOs were hired for sampling activities in the Beaufort Sea in 2012 and a number of Inuvialuit students and teachers were able to participate in onboard sampling and training activities, such as gathering baseline data on the occurrence of marine wildlife in the Beaufort Sea, and a resident of Ulukhaktok served as a skilled Moorings Assistant on the ship. The project was presented at an ArcticNet IRIS workshop in Inuvik in 2011 and at the Inuvik BREA Results Workshops in 2011 and 2015. Further results from the project will be presented at regional consultations and reporting conferences in the ISR as well as at national and international science conferences.

Key Findings

Results analyzed to date suggest that the data from the Beaufort Observatory are rich in value and quality and are relevant to the planning and management of oil and gas activities in the Beaufort Sea. The data indicate that there are strong spatial, seasonal and inter-annual variability of oceanographic processes. The moorings have allowed us to record numerous events relevant to industry and planning such as the impact of storms on ice motion and circulation, strong current surges > 0.5 m/s and sediment mobilization, frequency and intensity of upwelling-downwelling events along the shelf, mesoscale eddy activity within the shelf-break jet, as well as ice keels, thickness and motion of ice hazards provided through ice profiler data. The records show that energetic currents and complex temperature-salinity conditions develop in the water column at different times of the year and that slope and (outer) shelf environments are very different. There is evidence that there is tight coupling between atmospheric, sea ice, and ocean processes, including sediment transport and biogeochemical fluxes.

Contribution to state of knowledge

Addressing Regional Information Gaps

This research will improve baseline knowledge on the physical oceanography, biogeochemical fluxes, and sea ice conditions in the Beaufort Sea and will inform the regional synthesis of information gathered on the Beaufort offshore region. The unique dataset collected by the project will be used to validate regional circulation models and the trajectories of oil spills from the surface, or from the seabed, using plume dispersion or volume modelling on oil in the water column. The observatory off the west coast of Banks Island will gather data on an area of the north-eastern Beaufort Sea where year-round measurements have rarely been conducted.

ArcticNet has been collecting ship-based and mooring-based oceanographic data in the Beaufort Sea since 2002. Some of the observatories deployed as part of BREA have been deployed since 2009 through previous industry-academia collaborations, allowing year-round data collection over the course of 5 years and providing valuable information on the inter annual and seasonal variability of ocean conditions.

In addition to valuable ocean and sea-ice circulation data, the dataset collected by the project will shed light on shelf-basin exchange and processes that cause high productivity at the shelf break, and on the fate of sediment and particles that settle through the water column to the seafloor.

As with all ArcticNet research, all metadata of the information collected by this project will be made available to BREA stakeholders on the Polar Data Catalogue (www.polardata.ca), and reports and publications will be catalogued on the Arctic Science and Technology Information System (ASTIS) database.

Stakeholder Preparation

The data collected in this project will be essential for the estimation of inter-annual variability and physical conditions in and around the offshore exploration licence areas, collecting data that are directly relevant to those licence holders and other stakeholders with an interest in activities in those areas. For example, improved knowledge of the impact of storms and ice thickness and motion on ocean circulation and sediment mobilization will inform the design of structures used in oil and gas activities in the Beaufort Sea; improved forecasts of weather and marine conditions in the area, enabled by the calibration and validation of atmosphere-ice-ocean coupled models, will be valuable for all operations at sea. In addition, data on regional circulation models, including the frequency and intensity of upwelling-downwelling events and mesoscale eddy activity, will inform the determination of oil spill trajectories and will assist companies, governments and communities in planning the response to a potential oil spill in the region.

Remaining Research Gaps

Beaufort stakeholders are now active in designing, planning and assessing the infrastructure, methods and contingency measures needed for potential offshore oil and gas development. The cost, sustainability, acceptability and regulatory controls of offshore activities are strongly constrained by marine environmental conditions. An improved understanding of Beaufort Sea ice hazards and water column dynamics (ocean circulation along and across the shelf break, sub-surface eddies, vertical motion due to upwelling and downwelling) and the physical and geochemical properties of water masses, will be necessary to inform future development, at both local (drill site) and regional scales.

Regulatory Decision Support

The data collected by this project will be required for environmental assessments of exploration drilling projects in the Beaufort Sea, including information on ice thickness and particle fluxes, and validation of regional circulation models and oil spill trajectories. The year-round observations of marine conditions and of inter-annual variability in these conditions at the observatory locations will be essential for preparing project-level environmental assessments.

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OFFSHORE GEOHAZARDS AND COASTAL PROCESSES

Chapter 3.19. Regional Assessment of Deep Water Seabed Geohazards for Oil Spill Prevention in the Canadian Beaufort Sea

Research Project Overview

The project consolidated existing data and collected new information on deep water geohazards in the Beaufort Sea in order to prevent oil spills and other environmental induced challenges from those hazards during oil and gas exploration. Of particular interest is the protection of the integrity of the well bore and infrastructure such as the “drill string” and “riser platform”.

“Sea bed” and “sub-bottom” geohazards that are, or may be, found in the outer shelf and upper slope of the Canadian Beaufort Sea, and that have the potential to disturb foundation conditions include submarine landslides; mass transport deposits; low strength sediments; sea bed deformation and faults; mud volcanoes and diapirs; high sedimentation rates; shallow gas deposits and overpressure; ice scouring; eroded sediments; subsea permafrost; seismic events and methane hydrates/clathrates. The project was led by the Geological Survey of Canada (GSC), and included scientists from the GSC, universities, industry, and consulting firms.

Project Purpose and Goals

The objective of this project was to conduct sea-bed imaging and sub-bottom sediment profiling of the Beaufort Sea outer shelf and upper continental slope. The information gathered from these investigations will build upon data collected through other BREA studies and previous research campaigns to improve knowledge and understanding of the distribution and severity of seabed geohazards which could have an effect on deep water oil and gas exploration. This will inform industry and add to the knowledge base used by regulatory agencies and the Inuvialuit to assess BREA impact studies submitted by industry in preparation for deep water exploration drilling. Results are relevant to both engineering and environmental aspects of oil and gas activities, such as the stability of proposed exploration drilling structures and risk of oil spills due to wellbore instabilities caused by geohazards.

Fit Within BREA Program

This project assembled new and existing information on sea bed geohazards to improve knowledge and interpretation of sea floor conditions for use in project planning, engineering design, environmental assessment and regulatory decision-making, as well as during operations and emergency management by all responsible authorities and stakeholders. The resulting proactive planning will reduce risks of environmental damage from oil and gas operations and accidents in the Canadian Beaufort Sea.

Methodology

The project utilized the *CCGS Amundsen* research platform to conduct new sub-bottom seismic profiles and seabed multi-beam acoustic (multi-beam sonar imaging) surveys of the central Canadian Beaufort outer and upper slope and associated seabed mapping of the Northwest Passage acquired on route to the Beaufort Sea during cruises in 2011 and 2014. Piston and box cores were utilized to sample sediments in two areas of primary interest in order to appreciate sediment dynamics such as the frequency of submarine landslides. The samples are awaiting ageing. The study team also utilized data and results such as drill cores and seismic surveys from previous research and exploration programs in the area.

Use of Traditional Knowledge

Preliminary findings and discussion occurred with community members and stakeholders at the BREA Forum held in Inuvik in February of 2013 and 2015.

Key Findings

This project has contributed 600 square kilometres of new seabed multi-beam acoustic data (multi-beam sonar imagery) and 4500 kilometres of sub-bottom acoustic profiles in 2011 for the central Beaufort. The 2014 cruise increased the data coverage just west of the 2011 tracks within the "Chevron" lease and also in the area south west of Banks Island and in the western entry to the Amundsen Gulf. Twenty-eight box core samples and ten piston core samples were taken from the primary target areas in and around the "Chevron" lease and south east of Banks Island. Seventy-eight ^{14}C dates were calculated for sediments from existing cores. This new information has been added to existing data sets from previous studies including seismic and sediment cores.

Interpretation of data has improved the understanding and location of seabed geohazards to oil and gas operations in the Beaufort Sea. A key finding was that as one moves east to west there is a decrease in the occurrence and magnitude of submarine landslides, which the team attributed to the western region having older geology from the east, which is near the active plume of the Mackenzie River. Both multi beam sonar images and seismic profiles, running both east to west across the outer shelf and upper slope and north to south down the slope, provided insight into the size and depth of disturbance (magnitude) of submarine landslides. Dating of sediment samples, when complete, will provide insight into the frequency of these events.

Multi-beam sonar imaging indicated well defined relic ice scours at depths between 300 and 350 meters.

The digital geo-referenced data bases have been imported into the NRCan and Canadian Polar Data Catalogue.

Contribution to State of Knowledge

Addressing Regional Information Gaps

The project results have been added to the existing databases that deal with the subsurface and associated sediments of the Canadian Beaufort Sea.

Stakeholder Preparation

The databases will inform communities and oil and gas industry partners of identified sea bed hazards, and potential vulnerabilities are now better recognized because of improved understanding of the processes that may be active.

Remaining Research Gaps

This project is part of the continuing effort to both locate and understand sub-bottom and seabed geohazards in the Canadian Beaufort Sea, especially in those areas in which offshore oil and gas exploration and development may occur. The age and reoccurrence rates of hazards such as submarine landslides, information on areas at depths below 100 meters, information on offshore geohazards of the western portion of Canada's section of the Beaufort Sea, and surface to depth links that may affect sea bed dynamics were specific knowledge gaps identified by the team. This project adds to the information housed within the framework of the data bases held by NRCan and the Polar Data Catalogue. It will be used to help target further research of specific vulnerabilities that have been identified, including what appear to be low strength sediments and active fluid expulsion features.

Regulatory Decision Support

Preventing any release of contaminants into the marine or marine sub-surface environment is critical for ensuring the integrity of oil and gas exploratory drilling infrastructure, such as the drill string and the riser during off shore drilling operations, and the selection of stable sea floor sites. This investigation of the distribution and severity of seabed geohazards will add to the knowledge base for regulatory agencies and the Inuvialuit to assess Beaufort Sea environmental assessment impact studies submitted by industry in preparation for deep water exploration drilling. Results will support both engineering and environmental aspects. The new knowledge will also aid industry in determining alternative drilling systems that can be used to mitigate risks.

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Chapter 3.20. Regional Synthesis of Coastal Geoscience for Management of Beaufort Oil and Gas Activity

Research Project Overview

This project involved the synthesis of information for the Beaufort coastal zone, compiled from data from past studies and new data from field studies in selected locations, and focused on changes in coastal and seabed features and conditions due to climate change. The resulting spatial data inventory will be useful in assessments and ultimate development of ports, harbours, navigation aids, oil spill preparedness and other infrastructure required for oil and gas activity. The data will be accessible to communities and other partners, such as industry and regulators.

The project was carried out primarily by the Geological Survey of Canada (GSC) of Natural Resources Canada (NRCan), in partnership with the Inuvialuit Regional Corporation (IRC), Inuvialuit Land Administration (ILA) and Joint Secretariat, as well as the governments of the Yukon Territory and the Northwest Territories. Other partners included federal government departments (Parks Canada, Fisheries and Oceans (DFO), and Aboriginal Affairs and Northern Development (AANDC)) and research institutions (ArcticNet, Memorial University of Newfoundland, McGill University, University of Toronto, and Alfred Wegener Institute in Germany). The United States Geological Survey was also involved through the sharing of information.

Project Purpose and Goals

The project was initiated in order to address a lack of regional-scale data on coastal processes in the Beaufort region and lack of access to those data, particularly in regards to climate change impacts on coastal infrastructure on which oil and gas activity depends. In order to provide the regional information that will be required for assessments of proposed ports and other coastal infrastructure required for oil and gas activity, researchers compiled data from historical studies and gathered updated data on key locations. The project had three main objectives:

- To develop an inventory of existing data and research results, to ensure that legacy data are exploited and accessible for BREA purposes.
- To provide a regional synthesis and assessment of coastal knowledge in a georeferenced format as a basis for site selection, planning, environmental assessment, and regulation of coastal infrastructure such as ports.
- In consultation with Inuvialuit and other partners, to identify new data to strengthen the regional synthesis and begin to fill any critical gaps.

Fit Within BREA Program

This project is one of two that were carried out within BREA's Offshore Geohazards and Coastal Processes research priority area. It focused on coastal features and processes, while the other, Deep Water Seabed Geohazards, focused on offshore factors that are of concern to oil and gas activity. A primary means to disseminate geo-spatial data is through the Polar Data Catalogue (PDC), under arrangements made by BREA's Information Management Working Group.

Methodology

The research consisted of several components. One was a bibliography and data search to gather results of studies conducted in the Beaufort region from the late 1940s through to the present day; older data were converted into a georeferenced database in a geographic information system (GIS) so that it could be made accessible as decision support. The other component was a field program undertaken in 2012, 2013, and 2014 that made ground measurements at 47 sites along the Yukon coast, Richards Island, and Tuktoyaktuk Peninsula, which updated the coastal monitoring database and highlighted coastal change processes at those sites.

A Spatial Data Inventory was assembled that provides data on the coastal geology of the Beaufort coastal region at both regional and local scales, with a focus on existing or potential shore-based support sites and other coastal infrastructure for offshore oil and gas development. A data gap analysis was also undertaken to highlight the critical information still needed at the regional and local scale.

The research focused on the Canadian Beaufort Sea coastline and nearshore area extending from the Alaska border with Ivvavik National Park to Cape Dalhousie (Northern tip of Tuktoyaktuk Peninsula), as shown in Figure 3.20.1, below.

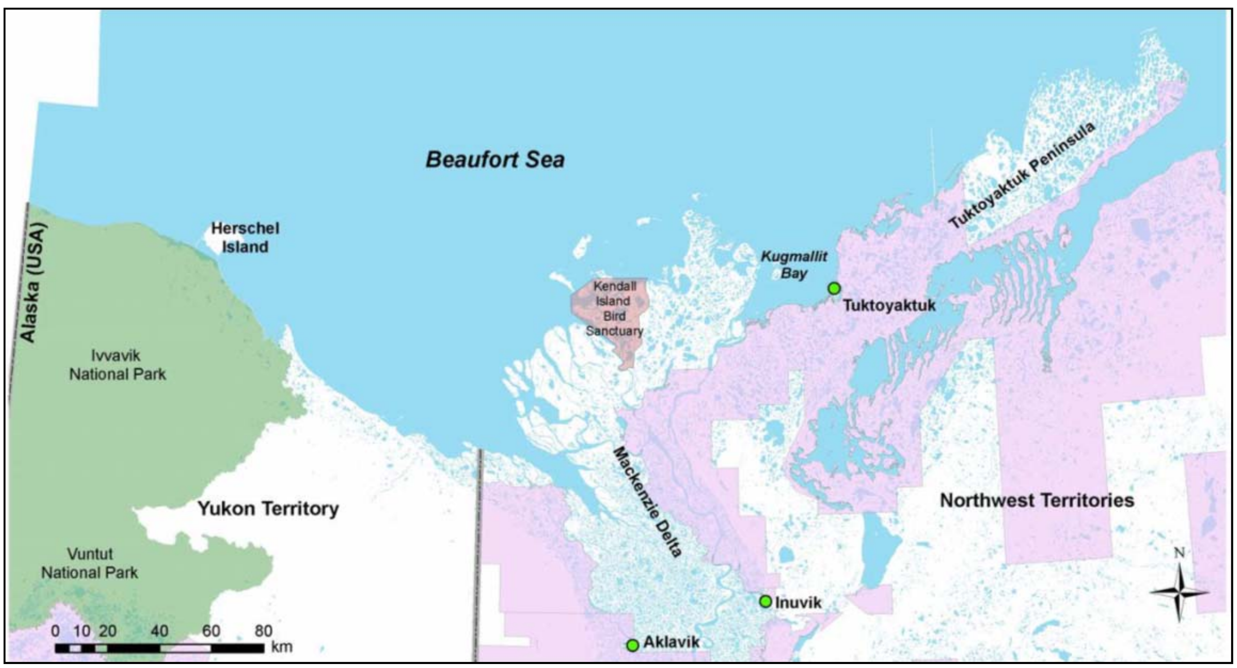

Figure 3.20.1. Study Area. From Regional Synthesis of Coastal Geoscience for the Beaufort Sea, NRCan. BREA Results Forum 2013 (pink area indicates Inuvialuit Settlement Region).

The Data Inventory included the following components, which have been delivered to the ILA and are accessible to the public through the PDC:

- Digital database of coastal monitoring sites, which provides an accurate representation of the coastline that identifies the land/water interface and is georeferenced to survey ground control points and high resolution satellite imagery. It contains coastlines digitized from 1947 and 2010 air photos and satellite images, allowing the comparison at the site and regional level of changes in the coastline from the early studies to the present day.
- Coastal Classification Database, separated into backshore, foreshore and nearshore, that identifies formation, material, ice content, type, and cliff height.
- Coastal Landform Topography and Nearshore Bathymetry from high resolution multibeam and LiDAR datasets, which help determine landscape and seabed morphology, and identify potential geohazards on the seabed (such as scours) and flooding limits on land through LiDAR modelling of storm surge flooding and spring freshet.
- Coastal Photo Database, containing thousands of spatially referenced coastal photos of the Beaufort coastline from the early 1970s to the present.
- Compilation of spring break-up newsletters from 2006 to 2014.

In addition, data pertaining to Surficial Geology layer (shape files) for the Beaufort Sea coastal region, synthesized at regional and local scales, are accessible through NRCan's downloadable digital database Geoscan. A bibliography of unpublished material, including internal reports, field notes, and works in progress, was also collected.

Figure 3.20.2 (below) shows a regional compilation of data as an example of the products created for the Data Inventory.

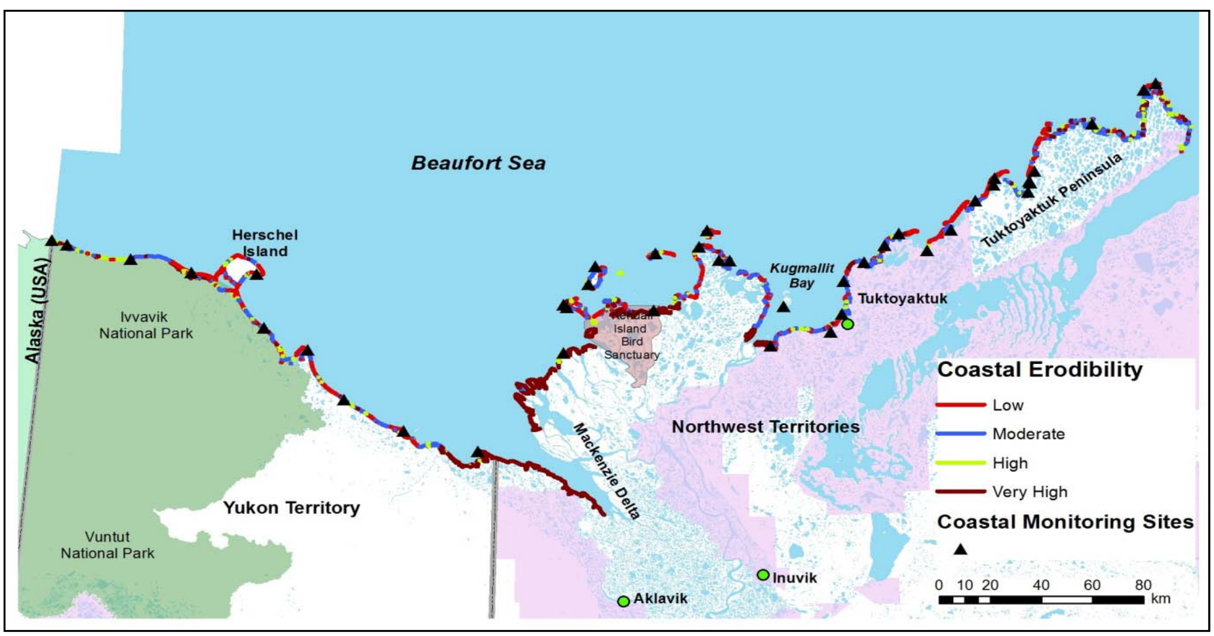

Figure 3.20.2. Regional Compilation of coastal erodibility data and coastal monitoring sites in the region

Use of Traditional Knowledge

Community engagement was extensive throughout the project. Preliminary consultations with the IRC, the ILA, the Inuvialuit Game Council, and the Joint Secretariat identified priorities for the research and confirmed the need for increased coastal geoscience knowledge to support the sustainable management of the Beaufort coastal zone. Community engagement included the identification of coastal changes of greatest concern, including harbor sedimentation and coastal erosion. Information produced by the project has also been shared with communities. For example, a set of brochures was made for distribution by the ILA on the coastal sensitivity and stability at several popular hunting sites (East Whitefish, Hendrickson Island, Kendall Island and Shingle Island), and the digital geospatial GIS data have been shared with the ILA to support its assessment of new coastal infrastructure requests.

Key Findings

The primary outcome of this research is an accessible GIS data inventory of coastal morphology and processes, surficial geology, nearshore bathymetry and sediments, permafrost and ground ice, processes of coastal change, and rates of erosion. This inventory reflects data digitized and observed from high-resolution satellite imagery, aerial photographs and other data archives to show changes in the Beaufort Sea coastal region over approximately 60 years.

The inventory expands knowledge of rates of coastal change in the Beaufort region, and improves understanding of the sensitivity and vulnerability of the coastline to climate change, particularly to storm events, coastal erosion, permafrost and morphologic change. This information will provide a regional framework enabling proponents, decision-makers, and communities to plan for project-specific environmental assessment requirements for the region. The main significance of this research is the utility of updated information on regional environmental conditions, including coastal change processes that create hazards or other concerns for existing or planned oil and gas infrastructure along the Beaufort coast. As such, it directly addresses BREA’s goal of producing regional information that simplifies project-level assessment: there are data at both regional and local scales, such as specific ports, required for assessments of infrastructure projects proposed for those locations.

The project engaged communities to advance their priorities for oil and gas preparedness. It was underlain by community consultations that identified community priorities for the work to be done, and responded to community priorities for information.

Contribution to State of Knowledge

Addressing Regional Information Gaps

This project has addressed gaps in information on coastal change processes in the Beaufort region by updating existing information on specific locations that had not been visited for 20 years. The project has also made the historic data more widely accessible by converting it to a digital georeferenced format that is compatible with more recent data formats, enabling comparisons of historic coastal processes with more recent changes that may be due to climate change.

In addition to gathering historic information and making it available in a digital format at a single web portal, as well as updating information on coastal change processes at specific key sites, the project has also identified several gaps in existing knowledge on coastal change on the Beaufort Sea coast.

Stakeholder Preparation

The information that has been gathered and made accessible will enable partners in oil and gas activity to understand the changes in the coast that are likely to develop over time at specific sites. This can help with planning and management of coastal infrastructure for oil and gas activities, including selecting a site that is suitable for the port or other infrastructure, and determining the type and level of maintenance that should be planned for at that location. The information will also strengthen assessment processes by providing access to these data for all participants in assessments, enabling the development of infrastructure plans and designs that integrate management of different methods and by several different partners, including proponents, governments, and communities.

Remaining Research Gaps

Knowledge is incomplete in several identified areas, and it is expected that additional gaps will be identified once the data compiled in the project are completely synthesized. With respect to basic coastal change processes, it is not known if the rate of coastal erosion has accelerated, or what the key influences are on seabed morphology. With respect to infrastructure, as assessments have not been conducted of all infrastructures along the coast, it is not known what critical infrastructure is at risk. Furthermore, there are no data for many potential sites at which harbours or ports could be located, so sufficient data may not be available for environmental assessments of infrastructure proposals at those sites. There are gaps in information on specific sites, such as the potential for sediment infill, acceleration of coastal erosion, and sediment budgets at the approaches to the Tuktoyaktuk harbour. Work to address some of these gaps will be carried out under external funding arrangements.

Regulatory Decision-Support

This research will contribute to assessments of the impacts of oil and gas development in the Beaufort Sea by providing access to up-to-date information on the conditions of coastal areas in the region, and at many specific sites at which new infrastructure may be proposed. These locational data are enhanced with improved information on the rates of coastal change and the vulnerability of those locations to a range of hazards that might impact the performance and safety of infrastructure at those sites.

Mitigation of impacts is facilitated and more robust when an assessment of impacts is based on accurate information of coastal changes and hazards at the regional and local levels. Project proponents can use and reference information from the databases to prepare environmental assessments and create disaster mitigation plans. Communities can access the database to independently assess the suitability of sites and infrastructure designs, in order to anticipate the impact of proposed projects on community infrastructure and activities, and contribute to project reviews.

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WEB-BASED GEOSPATIAL ANALYSIS TOOL

Chapter 3.21. Web-Based Geospatial Analysis Tool

Research Project Overview

The "Web-based Geospatial Analysis Tool" project focused on the development of an online software application for the ISR. The application is designed to store and display spatial information, and run analyses that industry, regulators, and other stakeholders require in order to better understand the complex relationships between environmental, socio-economic, and cultural values, and oil and gas exploration and development in the ISR. The application was developed by the Geomatics Lab at the National Wildlife Research Centre of Environment Canada, and is hosted on Carleton University servers.

Project Purpose and Goals

The main objective of the project was to build, test, and provide supporting documentation for a web-based geospatial analytical tool (geographic information system (GIS) software application) for stakeholders engaged in project environmental assessments, regulatory decision-making, and other resource management activities in the ISR. The application is intended to facilitate the "integration, visualization, and analysis of [data from] existing and BREA-associated research projects" so as to "aid BREA stakeholders in better understanding [among other things] the geographic distribution of areas […] sensitive for environmental and socio-economic reasons in the face of economic development" (Environment Canada, 2013).

Fit Within BREA Program

This project falls directly under the *web-based geospatial analysis tool* research priority. A main purpose of BREA is to facilitate an integrated ecological approach to oil and gas exploration and development through the preparation and sharing of information for future project-level environmental assessments, regulatory decision-making, and other resource management actions. The application developed by this project directly supports the preparation, storage, management, and sharing of such information. Furthermore, the geospatial visualizations and analyses it enables are designed to use data from BREA projects, as well as non-BREA sources of relevance for the ISR. BREA data may be drawn from any of the geo-referenced databases BREA projects have produced (*e.g.*, "Beaufort Sea Engineering Database", the "Birds of the Offshore Canadian Beaufort Sea" database), as well as from the various geo-referenced datasets or mapped information BREA's empirical research has generated. A key non-BREA source is the Polar Data Catalogue which is Canada's official polar data repository. Use of the application over time should help shed light on further key research gaps to address in support of the ecosystem-based management of oil and gas exploration and development in the ISR.

Methodology

Development of the application began with a survey of BREA Steering Committee and working group members, soliciting input on the functions and design features the application should include. Detailed input was received from four of the surveyed groups. Based on the results of the survey, the application was built and populated with pre-existing datasets as well as datasets from a small number of current BREA projects. It was then tested, and a user manual and demonstration PowerPoint were prepared to support its use.

The application has since been integrated into the website of the Geomatics Lab at the National Wildlife Research Centre, hosted on Carleton University servers. This location, outside Government of Canada "firewalls", ensures users are able to upload their own data files to the system, for use with the application.

The application was demonstrated at the 2012 North Slope Conference in Whitehorse, further refined, and then demonstrated again at the February 2013 BREA Results Workshop in Inuvik.

The application is currently available to users online (geomatics.nwrc.carleton.ca), requiring a secure password for access.

Use of Traditional Knowledge

Development of the application took into consideration the need to include mapped and other spatially-documented traditional knowledge, as well as spatially-documented information related to, for example, culturally valued areas. Traditional knowledge spatial data from community conservation plans were used to help test and demonstrate the application.

Considering sensitivities related to the sharing of traditional knowledge, it is important to note that password protection and a "single log-in" protocol are being used to prevent unwanted access to data and analyses that a particular user may wish to keep confidential.

Key Findings

This project resulted in the creation of a web-based geospatial analytical application, testing of the application, and development of user documentation in the form of a manual and a PowerPoint presentation. Various features of the application deserve particular mention and are addressed below.

(1) GIS software. The application provides online access to many of the same functions a full, desktop GIS would typically provide. This includes options for viewing, comparing, overlaying, and synthesizing spatial information, as well as the ability to measure (*e.g.*, spatial areas) and record results. In this respect, the application may help address a cost barrier which certain ISR stakeholders might otherwise face in pursuing GIS-related capabilities or analyses.

(2) Spatial data types. The application uses point, vector, and raster "mapped" spatial data. This could include land-use information such as park boundaries, traditional knowledge such as the location of nesting sites, the results of scientific studies, and local observations held or generated by researchers, governments, industry, communities, or other users.

(3) Data import and export functions. Datasets can be imported in standardized point, vector, or raster GIS file formats. While data files cannot be exported to other systems, users can import their own data, and store, manipulate, and analyze them. Users can also choose whether or not to make their data and analyses public or keep them confidential.

(4) Data sources. The application is designed to accommodate existing and future spatial information from numerous potential sources, including but not limited to BREA-supported studies.

(5) Metadata. The application accommodates metadata or accompanying descriptive information for all information layers.

(6) Complexity of use. While no GIS experience is necessary to view and explore the data layers currently available within the application, a certain amount of GIS knowledge is required to use some of its tools.

(7) Internet requirements. The online nature of the application could pose a barrier to users in locations with especially low internet bandwidth; however, because data storage and analysis take place on the central server where the application is hosted, the amount of bandwidth required is relatively low considering the functions and outputs to which the user has access. The application also relieves users from the expense and duplicate effort of establishing and maintaining their own GIS system.

(8) Security. Access to the system requires a secure password and a single log-in protocol. These security measures prevent access to other non-BREA applications on the website, help secure the application and the Base and Public Data folders, and prevent unwanted access to data and analyses that a particular user may wish to keep confidential.

(9) Coordination with other data repositories. Because the application is situated on a centralized server, coordination with other centralized data repositories, like the Polar Data Catalogue, is greatly facilitated.

Contribution to State of Knowledge

Addressing Regional Information Gaps

The application helps maximize the knowledge users can acquire from existing data by providing a location for the centralized storage of geospatial data for the ISR; tools with which to visualize and analyze the data; and, hence, an important means for revealing and sharing new insights and understandings of the ISR. As such, use of the application can help address known information gaps, while at the same time casting light on potential new information gaps to be considered. A key assumption in this regard is that the application will be well populated with data, and adequately maintained.

Stakeholder Preparation

As a public source of GIS-related analytical support and growing repository of ISR-specific spatial information, the application developed by this project holds significant promise to advance stakeholder preparation for oil and gas development in the Beaufort Sea. Key to its use and further growth as a management and awareness-raising tool will be the consistent addition and management of new data over time, and the ability on the part of the administrator to react to new or modified user needs. Finding the right champion for the application will be an important step towards increasing its profile, while its usefulness to stakeholders would be greatly enhanced through the provision of modest technical and training support.

Remaining Research Gaps

A range of actions have been identified that would help ensure the application achieves its promise. They are grouped into four categories below.

(1) Application. The existing application will require upgrades as host and internet system software evolve and as users identify new functionalities the application should provide.

(2) Data. The addition of further spatial data sets from BREA and non-BREA sources will be vital to ensuring the application meets its objectives. In some cases, data providers (*e.g.*, certain ISR communities with limited bandwidth) may require support in providing their data. Development of enhanced data sharing capacity could allow for exchanges with spatial datasets such as Arctic Portal CBMP and NOAA's ERMA, since these databases will also be used in environmental assessments. More generally, a protocol for the updating of data and links to other data sources would be advantageous.

(3) Metadata. The data layers currently contained in the application vary considerably in quality and focus. It has been suggested that a "metadata complier" would help ensure that the same background information is collected for each of the application's datasets, through the creation of standardized descriptive fields, as well as an option for the provision of additional dataset-specific information.

(4) Host, champion, and system operator. The Geomatics Lab of Environment Canada's National Wildlife Research Centre was contracted to write the application. Though they currently serve as unofficial Champion and System Operator, a longer-term plan for the hosting, maintenance, and profiling of the application must still be developed. A Champion could consider the following activities with respect to the application and its online presence: marketing; enhancements and upgrades; addition of datasets; monitoring and ensuring data accuracy; and user registration and support.

Regulatory Decision Support

The application this project developed has the potential to greatly enhance the quality of knowledge available to and produced by those with environmental assessment and regulatory roles in the ISR, by making GIS-based analytical capacity and otherwise broadly distributed spatial information centrally available. Its assimilative and analytical functions hold promise for helping users in the oil and gas industry better understand the values of other sectors and vice versa. It will also help identify conflicts, data gaps and solutions. The "Web-Based Geospatial Analysis Tool" is an application that can evolve in functionality and usefulness over time through technological improvement and the addition of datasets. It has the potential to becoming a valuable lasting legacy of the BREA program for all stakeholders in the ISR into the future.

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COMMUNITY PRIORITY RESEARCH AREAS

Chapter 3.22. Polar Bears in the Deep Offshore Regions of the Beaufort Sea: A Preliminary Study to Estimate Distribution and Density in Previously Under-Surveyed Areas

Research Project Overview

An aerial survey of polar bears in the far offshore of the Canadian Beaufort Sea was conducted in March 2012 in direct response to Inuvialuit community interest in the potential for polar bear use of offshore areas.

The research was led in partnership by the Joint Secretariat, Environment Canada, and AANDC. Trent L. McDonald of Western EcoSystems Technology Limited, Cheyenne, Wyoming designed the study, analyzed the data, and prepared the final report. Contributions to the project were also provided by the Government of Yukon, the Government of the Northwest Territories, the University of Alberta, and the Inuvialuit Game Council. Members of communities in the ISR, West Inc. Consultants, and Dennis Andriashek were involved in the survey.

Project Purpose and Goals

The research was a preliminary study to estimate the population density and distribution of polar bears in under-surveyed deep water areas of the Beaufort Sea, which overlap with oil and gas lease block locations. Broader goals of the survey were to build understanding of the potential impacts of oil and gas activities on polar bears in the area, and to contribute more generally to knowledge about polar bear habitat in the Beaufort.

Fit Within BREA Program

The survey was one of two projects established under the BREA *community priorities* research priority area. The other *community priorities* project focused on developing ecosystem indicators to support regional coastal monitoring in the ISR. Together, the two projects underscore the concern of the Inuvialuit for the health of the ecosystem and polar bear populations in the ISR.

The survey makes progress towards two BREA goals: producing regional information that will simplify project-level assessments; and engaging communities and advancing their priorities for oil and gas preparedness. In particular, it responds to concerns expressed by members of the Inuvialuit community that some polar bears may live year-round in the far offshore of the Canadian Beaufort Sea and may therefore be particularly vulnerable to oil and gas activity in the region.

Methodology

The survey was conducted with a fixed-wing aircraft, flying 24 randomly placed transects across the study area, with each flight surveying two transects. Half of the flights were flown from Sachs Harbour, and the other half from Inuvik. A total of 7,776 km were flown over the study area during the course of the survey (Snow, 2013), with flights ranging from four to five hours in duration. Four observers in the aircraft watched for polar bears on the ice, recorded data on sightings, and noted their positions using GPS.

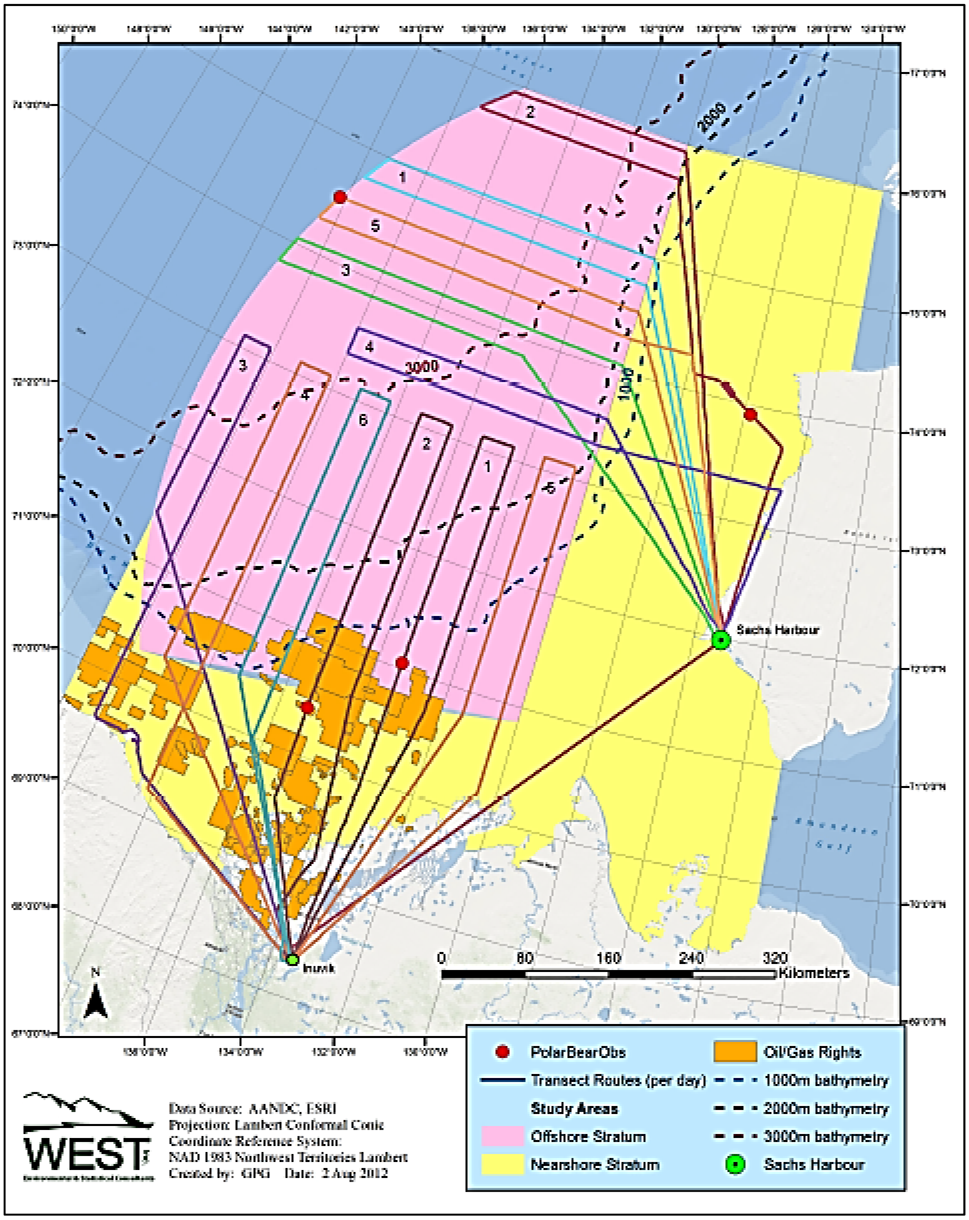

Figure 3.22.1. Map of study area for aerial polar bear survey (McDonald, 2012)

Key Findings

In total, the aerial survey detected four polar bears in two groups. Because more than two groups must be sighted to allow for development of a “sightability function”, and because sightability functions are required to develop estimates of bear population density based on individual sightings, the project team adapted a function from a previous study conducted under similar conditions (Evans et al 2003). Adaptation and use of the earlier-developed sightability function resulted in an estimated population density of 0.061 bears per 100 km^2, or 124 bears in the region for the second half of March 2012. This estimate is an order of magnitude lower than the 0.87 bears per 100 km^2 reported for nearshore areas of the eastern Chukchi Sea and the western Beaufort (Evans et al. 2003), as well as markedly lower than any previously reported population densities anywhere within the polar bear's known range (Taylor and Lee, 1995; Amstrup at al., 2000; Aars et al., 2009).

Contribution to State of Knowledge

Addressing Regional Information Gaps

Past sightings of polar bears near flow edges in the study region have been made from ships during ice-free periods of the year. These sightings have prompted interest and concern among the Inuvialuit community regarding the possibility of bears residing permanently in far offshore areas and, therefore, in relatively close proximity to ongoing or planned oil and gas activity. This study should help address these concerns. As the first aerial polar bear survey in the region during the ice-fast time of year, its findings support those of past studies conducted for similar regions and times of year, albeit with different techniques. Namely, offshore areas of the Beaufort Sea do not likely support resident populations of polar bears (Amstrup, 2000; Durner et. al. 2009).

Stakeholder Preparation

By demonstrating that polar bears are not widely abundant in far offshore areas of the Canadian Beaufort Sea when the region is covered with ice, the survey provides preliminary direction to project applicants and regulatory reviewers in determining what to emphasize in future research, monitoring, and assessment. The study also provides a number of practical and methodological suggestions for how best to conduct future aerial surveys of offshore polar bear populations, where and as necessary.

Remaining Research Gaps

Because the aerial survey appears to confirm past studies' assertions that polar bears rarely occur in far offshore areas during periods of ice cover, the population density and distribution of polar bears in the Beaufort offshore may be more accurately and efficiently assessed through further GPS collaring and related studies.

Regulatory Decision Support

Given the scarcity of polar bear sightings made during this study, and the extent to which these results corroborate the findings of other efforts to examine polar bear distribution and abundance in the Beaufort Sea and analogous regions, regulators may choose to consider recommending or requiring alternative modes of data collection relating to the movement, habitat use, and resource selection of polar bears in offshore areas of the Beaufort where oil and gas activity are ongoing or proposed.

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Chapter 3.23. Regional Coastal Monitoring in the Inuvialuit Settlement Region: Ecosystem Indicators

Research Project Overview

In order to have effective ecosystem-based management and the ability to provide sound advice for regulatory needs, an understanding of baseline ecosystem structure, function and health is needed. To characterize the ecosystem and how it responds to stressors, the natural variability of key indicators needs to be monitored over the long term. Thus, in preparation for cumulative impact monitoring, the development of a framework for coastal monitoring in the Inuvialuit Settlement Region (ISR) was needed.

This project supported the development of a regional baseline monitoring program that used biomarkers to improve our understanding of the structure and function of the Beaufort Sea coastal food web. The biomarkers were stable isotopes and fatty acids, which are chemical compounds that can be traced through an ecosystem and thus provide information on the structure of the food web and links among the different species occupying various trophic levels (e.g., plankton to fish to seals and whales). The development of a baseline improves our understanding of how food web indicators can reflect current and potential future effects of environmental stressors and responses to stressors, both locally (e.g., oil and gas activity) and regionally (e.g., climate change/ice loss). Additionally, the use of food web biomarkers allows for better documentation and understanding of connections between the offshore and coastal ecosystems that are essential in providing the foundation for effects monitoring.

The BREA-funded portion of the project focused on the analytical component of a regional community-based monitoring program. This program has built on partnerships with Fisheries and Oceans Canada (DFO); DFO has developed several community-based monitoring programs in the ISR. In particular, it built on previously successful monitoring programs (e.g., belugas at Hendrickson Island) and incorporated new sites at harvest locales throughout the ISR. This project was led by the Inuvialuit Game Council (IGC) and the Fisheries Joint Management Committee (FJMC), in partnership with DFO and the six Hunters and Trappers Committees (HTCs) in the ISR.

Project Purpose and Goals

The goal of the program was to develop a robust and unified regional approach to coastal ecosystem monitoring that could be continued into the future for cumulative effects and ecosystem process monitoring. The program recognized the existing monitoring programs in the ISR, and attempted to expand to all ISR communities and synergize efforts with the BREA offshore fish research program conducted concurrently by DFO. The overarching goal was to characterize the Beaufort Sea ecosystem and better inform managers/decision makers on ecosystem responses to changes or stressors such as climate change or development related activities.

The key objective of the program was to improve our understanding of ecosystem links between coastal and offshore food webs. Also essential was to develop a coastal monitoring program that focused on the aquatic/marine ecosystem, largely centered around i) coastal fish, ii) beluga and iii) their supporting ecosystem (habitat), at harvest sites for each of six ISR communities. This approach was taken to 1) meet community needs/wants by collecting data on species of priority to them and most relevant to subsistence harvesting activities; and 2) provide baseline information on numerous species within the ISR that will contribute to both cumulative impacts monitoring activities as well as the early detection of possible future impacts associated with oil and gas activity in the Beaufort.

Fit Within BREA Program

By conducting a coastal monitoring program and examining biomarkers, the project contributes directly to BREA's key objective of building a stronger knowledge base to support informed decision-making regarding oil and gas activity in the Canadian Beaufort. The work primarily addresses BREA's goal of producing regional information that informs project-level environmental assessments. However, it also addresses the other goals of filling regional information and data gaps to support efficient and effective regulatory decisions, engaging communities and advancing their priorities for oil and gas preparedness, and supporting integrated management and planning in the Beaufort. This project is linked to the "Fishes, Habitat and Ecosystem Linkages" project.

Methodology

Samples and supporting habitat data were collected to monitor key indicators that can set a baseline for future monitoring efforts. The coastal monitoring occurred during the open water season, typically in July, but timing varied among sites. The primary species monitored and sampled depended on the harvest site, but the species were those that were commonly harvested at each community and thus easily monitored and highly valued. Samples were collected and shipped out for analysis. Laboratory analysis of key ecosystem indicators included stable isotopes of carbon, nitrogen, and sulfur (University of Waterloo, Ontario; DFO in Winnipeg); fatty acids (DFO; Freshwater Institute, Winnipeg); and key morphometrics (length and condition indices). Stable isotopes and fatty acid data were evaluated in relation to age/sex data, and habitat and environmental variables. These data were then used to establish links within the food web between coastal and offshore ecosystems.

The community coastal program obtained samples and information on i) coastal fish, ii) beluga, and iii) the supporting ecosystem (habitat) at harvest sites for each of six ISR communities (Table 3.23.1). Although the particular species of fish that were monitored differed among sites, methods were standardized by employing common biomarker indicators (i.e., stable isotopes, fatty acids) that define trophic interactions. The HTC in each community partnered in the design of the local study; thus, the key species and ecosystem components that were monitored reflect the interests of each community.

Table 3.23.1. Community-based Coastal Site Design.

Ecosystem Type	Harvest Site	Community	Primary VEC	Secondary VEC
Estuarine	Shingle Point	Aklavik	Fish	Beluga
Estuarine	Kendal Island	Inuvik	Beluga	Fish
Estuarine	Hendrickson Island	Tuktoyaktuk	Beluga	Fish
Marine	Darnley Bay	Paulatuk	Beluga	Fish
Marine	near town	Sachs Harbour	Fish	Beluga
Marine	near town	Ulukhaktok	Fish	Beluga

Use of Traditional Knowledge

The project funding from BREA supported the analysis of the samples. Community consultation and Traditional Knowledge did not contribute to this aspect of the study; however, TK was integral to the design of the field program in each community. Communities and HTCs provided guidance on the development of the beluga and fish monitoring programs. In response to community requests, joint programs were developed with Tuktoyaktuk, Paulatuk, and Inuvik to collect local knowledge of beluga habitat and health. Based on early findings from those beluga programs, similar initiatives to collect local knowledge regarding fish are being developed at Shingle Point and Darnley Bay.

Key Findings

This project is still in the early phases of data analyses and research is ongoing, so key findings are not available yet. Some preliminary information is provided here. Fish and beluga were collected each year from 2011 to 2014. In 2012 and 2014, fish and beluga samples were received from all six ISR communities, and five communities provided samples in 2013. In 2012 and 2013, 951 and 500 fishes, respectively, from coastal sites were processed for full morphometrics and analyzed for stable isotopes and fatty acids. In addition, in 2012 and 2013, 57 and 59 beluga samples, respectively, were analyzed for stable isotopes and fatty acids. All data for fishes and whales were entered into an access database. Ongoing analyses will characterize the fish food web, describe the beluga diet, and investigate links between the beluga diet and coastal and offshore fish populations. Analyses of variation of diet biomarkers among beluga will describe differences related to gender, size, and age as well as among tissues.

Contribution to State of Knowledge

Addressing Regional Information Gaps

While coastal monitoring has occurred sporadically and locally throughout the ISR, this was the first attempt to unify coastal monitoring for several communities and to coordinate this effort with offshore trawling surveys to examine the connections between coastal, shelf, and deep water ecosystems. The newly acquired information will serve as a baseline, and improve our understanding of links between coastal and offshore food webs that were previously unstudied in the region.

Stakeholder Preparation

Regional environmental assessments require knowledge on ecosystem processes, variability and sensitivities/vulnerabilities to stressors. Baseline information collected during this project will assist in the evaluation of potential impacts of activities on the ecosystem. This work will facilitate project-level environmental assessments by providing proponents with set indicators for cumulative impacts that can feed into government monitoring and community-based monitoring programs.

The sample monitoring/collection aspect of the program was directed toward building capacity in each community to establish and maintain long-term coastal monitoring of key species and other ecosystem components in relation to oil and gas activities and climate change.

Remaining Research Gaps

Long-term monitoring is required to document changes in the ecosystem that are related to natural variability and stressors, such as climate change and potential impacts from industry.

Regulatory Decision-Support

To have effective ecosystem-based management and the ability to provide sound advice for regulatory needs, a baseline understanding of ecosystem structure, function, and health is needed. Thus, in preparation for cumulative impact monitoring, the development of a strategic framework and protocol for coastal monitoring was required. The baseline data that were collected will inform decision making, and will be available to set guidelines on thresholds for regional assessments.

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CHAPTER 4. WORKING GROUPS

Introduction

BREA established six working groups to address cross-cutting issues of interest to all stakeholders. The syntheses were based on reviews of working group reports and informed by interviews with working group leads and/or members. The six working groups are introduced below and then described more fully in the sub-chapters.

The Cumulative Effects Working Group, led by AANDC, is mandated with developing a regional framework to facilitate stakeholder support of and participation in cumulative effect assessments (AANDC, 2014). Prioritizing regional concerns based on identified “valued components”, the development of a cumulative effects management framework seeks to complement the baseline understanding established through the BREA research program.

The Climate Change Working Group, led by Environment Canada, was formed to support environmental assessment and regulatory decision-making as it relates to climate change aspects of relevance to oil and gas activities in the Beaufort Sea (AANDC, 2014). A key function of this group was to identify and recommend action to fill climate change data gaps in this region. To date, results from this working group include an assessment report prepared by Environment Canada and AANDC (2013) on the potential impacts of climate change on oil and gas activity in the Beaufort Sea. In addition, this group commissioned the report by Callow (2012) forecasting oil and gas exploration and development activity in the Beaufort Sea.

The Social, Cultural, and Economic Indicators Working Group, led by the Inuvialuit Regional Corporation, seeks to examine the impacts of Beaufort Sea resource development from social, cultural, and economic perspectives (AANDC, 2014). This is viewed as a necessary part of any framework designed to mitigate and/or prepare for resource development pressures. This group will work to establish social, cultural, and economic baselines for the ISR, which will help to identify potential and actual impacts of oil and gas activity in the region and allow for monitoring of long-term effects.

The Oil Spill Preparedness and Response Working Group, led by the National Energy Board (NEB) and AANDC, is mandated to identify pathways for improving government, Inuvialuit, and industry response capabilities related to significant spills associated with oil and gas activities in the Beaufort Sea (AANDC, 2014). Activities include engaging Inuvialuit and other stakeholders to understand their concerns, resolving knowledge gaps to help develop a response plan, coordinating with other research projects in the area, and assisting in the development of memoranda of understanding for environmental response. Results to date include a sponsored workshop on the use of dispersants in the Beaufort Sea, a report identifying Inuvialuit oil spill response capacity, and a report on the respective roles of various organizations and groups given a Tier-3 oil spill (BREA Oil Spill Preparedness and Response Working Group, 2011; 2013A; 2013B).

The Waste Management Working Group, led by Environment Canada and the Government of the Northwest Territories, was formed with the goal of facilitating development of a Regional Waste Management Strategy for the ISR (AANDC, 2014). By expediting environmental assessment, regulatory review, and decision-making processes, this multi-dimensional strategy should be of value to regulators, industry, review boards, and other stakeholders. It could also serve as a model for the development of similar strategies in other regions of the Northwest Territories.

The Information Management Working Group, led by AANDC, developed a coordinated information management system that will make BREA information, as well as existing and historical sources of information about the Beaufort, more available and accessible. The system makes use of two existing northern information management nodes. The BREA Information Policy requires and supports entry of BREA research project and working group results into two nodes: the Polar Data Catalogue and the Hydrocarbon Impacts Database of the Arctic Institute of North America's Arctic Science and Technology Information System (ASTIS).

Chapter 4.1. Waste Management Working Group

Working Group Overview

As oil and gas activity in the ISR increases and moves from exploration to development, the amount of industrial waste generated in the region will also increase. Currently, the ISR does not necessarily have the capacity to accommodate increased quantities or new types of industrially-generated waste. The Waste Management Working Group was formed in order to begin addressing this gap, by laying the early groundwork for an eventual Regional Waste Management Strategy (RWMS) for the ISR. Based upon a desktop survey of current waste management practices in the ISR, the Northwest Territories, and a select set of similar remote, northern jurisdictions, the Working Group produced a report that provides: a conceptual framework for an RWMS in the ISR; a proposed process for development of an RWMS in the ISR; elements of an implementation plan for the proposed development process; and insights regarding the potential scope of an RWMS in the ISR, as well as key clients and stakeholders.

This Summary of the Working Group's efforts is based primarily on two documents: the Summary of Results presented at the February 2013 BREA Results Forum in Inuvik (Environment Canada, 2013), and the Working Group final report entitled *Scoping, Framework and Process for the Development of a Regional Waste Management Strategy in the Inuvialuit Settlement Region* (AMEC, 2014).

Group Objectives

The Waste Management Working Group was established primarily to work towards two core BREA objectives (Environment Canada, 2013):

- To assist in moving towards a more holistic, regional approach for the identification and resolution of waste management issues related to oil and gas activities in the Beaufort Sea region.
- To support efficient and effective environmental assessment and regulatory decision-making as related to relevant aspects of waste management.

The Waste Management Working Group itself adopted three additional objectives:

- To produce a conceptual framework for an RWMS for the ISR.
- To develop a draft process for the development of a functional RWMS.
- To provide background and contextual information from international, national, and in particular regional experiences, which could help inform delivery of an RWMS.

Fit Within BREA Program

The objectives of the Waste Management Working Group are most directly related to two of BREA's four goals: to produce regional information that simplifies project-level assessments, and to strengthen assessment processes and integrated management. An RWMS, if implemented, would simplify and strengthen project-level assessments and integrated management by informing the waste management component of the Environmental Protection Plan required of proponents under project environmental assessments, and by proactively addressing potentially contentious issues outside of the environmental assessment and regulatory processes.

The Working Group's efforts also relate to BREA's third goal: to engage communities and advance their priorities for oil and gas preparedness. With respect to engagement, while the Working Group did not directly interact with local ISR communities (as most of the work was a desktop exercise), significant community engagement and consultation would be required as part of any future process to develop an RWMS in the ISR. For example, the Working Group final report (AMEC, 2014) suggests that the development of an RWMS in the ISR include: an oversight committee with representatives from, among other groups, Inuvialuit organizations and Inuvialuit communities; and an extensive community and broader stakeholder consultation process. With respect to advancing priorities for oil and gas preparedness, the Working Group consolidated knowledge and developed new materials without which an RWMS development process could not take place.

An RWMS in the ISR would greatly strengthen regional and community preparedness for oil and gas exploration and development activities in the Beaufort Sea. In the past, waste generated by industrial activity in the ISR has at times placed pressure on community landfill facilities in the region. Depending on future levels of oil and gas activity in the ISR, this will not remain a sustainable approach.

Key Findings

The main achievements of the Waste Management Working Group were the survey of background and reference information on various aspects of waste management in the ISR and other relevant regions, and the development of a conceptual framework and related guidance for development of an RWMS in the ISR. These achievements are captured in the Working Group final report (AMEC, 2014). Surveyed Canadian jurisdictions were the ISR, the Northwest Territories, Newfoundland, and Alberta. Jurisdictions outside of Canada were also surveyed, namely the Alaska North Slope and Norway.

The framework and related guidance consist of several components, which are set out as elements that could be investigated in more detail and ultimately implemented in future steps towards development of an RWMS in the ISR. These components are as follows:

(1) Draft Table of Contents for an RWMS in the ISR. The draft Table of Contents outlines factors which an RWMS should address, including a description of the region and of oil and gas activity in the region, current practices and challenges of oil and gas waste management, lessons learned from the other jurisdictions as well as from previous experience with oil and gas activity in the ISR, and the evaluation and selection of implementation scenarios (based upon estimated levels of future oil and gas activity in the ISR and hence different potential amounts and types of wastes, and distributions of sources).

(2) Proposed Process for Development of an RWMS in the ISR. The proposed development process begins with a scoping phase (which is already largely complete by virtue of the Working Group's efforts and its final report). It then continues with a review of challenges, and the evaluation and selection of implementation options (including any required technical studies). Finally, it concludes with the key steps of planning for implementation — including infrastructure siting and design, permitting and Environmental Impact Assessment, construction, and the development of operational specifications.

(3) Governance Structure. The Framework suggests a governing oversight body be formed and tasked with producing the terms of reference for development of an RWMS in the ISR, as well as with overseeing its development. Suggestions are provided for the representational mix of the committee (membership), and for its role in ensuring effective technical work, consultation, and communication.

(4) Consultation and Communication Plan. Significant emphasis is placed on the development and implementation of a consultation and communications plan. This includes the determination of groups to be consulted, development of a consultation process design, support for stakeholder participation, and management of records and access to information.

(5) Guidance on Scope. Clarity is provided regarding the eventual scope of an RWMS in the ISR. The following aspects of waste management are currently considered "in scope": waste generated by oil and gas sector and affiliated activities (*e.g.*, camp waste); liquid, solid, and sludge waste; onshore and offshore wastes; and municipal wastes. Other aspects of waste management are currently considered "out of scope": wastes generated by industrial or commercial sectors other than oil and gas; wastes discharged to the atmosphere (*i.e.*, air emissions); and wastes from large spills. Currently, and further to the RWMS inclusions and exclusions just noted, it is suggested that an RWMS in the ISR would apply exclusively to regionally-generated wastes, as opposed to accommodating wastes from outside the ISR.

Contribution to State of Knowledge

The Working Group's efforts have contributed in two distinct ways to the state of knowledge regarding the management of oil and gas activities in the ISR. The first is through its review of both the regulatory context for oil and gas exploration and development in Canada and the "industry waste management practices utilized by oil and gas exploration and development activities in remote, isolated, and extreme environments." With characteristics comparable to conditions in the ISR (AMEC, 2014; p. 26), the Working Group has provided a sense of what may be possible in the ISR with respect to the proactive management of oil and gas related wastes. The second distinct manner is by providing a framework and related guidance for the development of an RWMS in the ISR. With this, the Working Group advances thinking about what could be required in order to carry out such a process.

Regulatory Decision Support

Development of an RWMS in the ISR would, if implemented, contribute to the efficiency and effectiveness of environmental assessment and regulatory processes, the preparation of regulatory information by industry, and the mitigation of environmental impacts of waste disposal at the local and regional level.

Regulatory institutions at the federal, territorial, and regional levels require that proponents of oil and gas exploration and production projects submit plans for the management of the wastes generated by these activities. Environmental assessments of proposed offshore oil and gas exploration and production activities are required at the federal level (under the *Canadian Environmental Assessment Act* (CEAA 2012)) and at the regional level (under the Inuvialuit Final Agreement (IFA)). The NEB authorizes oil and gas activities under CEAA 2012 and administers the regulations under the *Canada Oil and Gas Operations Act* (COGOA). Under the IFA, proposals for the development of oil and gas projects in the ISR are subject to an environmental screening by the Environmental Impact Screening Committee. All such environmental assessment requirements generally include the submission of an Environmental Protection Plan, which must include a plan for the management of waste. The development of an RWMS could streamline the preparation of these plans by creating a central and systematic approach to waste management that meets current standards, and would facilitate the approval of the plans and provide further assurance that they are adequate to protect the environment.

Administrative and practical guidance on the management of waste disposal, provided by authorities at all levels, would be directly supported by an RWMS based on best available technology and a comprehensive and inclusive approach to its development. The federal NEB oversees a set of guidelines "to aid operators in the management of waste material discharged to the natural environment from offshore drilling and production installations" (AMEC, 2014; p. 6). The Government of the Northwest Territories is responsible for managing community solid waste, which it does through its *Guidelines for the Planning, Design, Operations and Maintenance of Modified Solid Waste Sites in the Northwest Territories*.

The development of an RWMS would relate directly to the territorial management of waste disposal sites, as much of the waste generated by past and current industrial activity in the region has been disposed of in municipal or community facilities. This means of waste disposal will not be feasible to manage the volume of wastes generated by oil and gas exploration and production activities that may occur in the ISR in the future. Therefore, the development of an RWMS will not only support the regulatory and administrative responsibilities of territorial and regional authorities, but will also mitigate the environmental impacts of waste disposal by adopting optimal waste management methods and infrastructure.

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Chapter 4.2. Climate Change Working Group

Working Group Overview

The Beaufort region is currently affected by climate change, and these changes are projected to continue in the future. The BREA Climate Change Working Group was made up of Inuvialuit, industry, and government representatives of both territorial and federal departments. The Working Group investigated how climate change would positively and/or negatively affect potential oil and gas exploration and development in the Beaufort Sea. The Working Group gathered, reviewed, and summarized the science and traditional knowledge of climate change relevant to offshore activities.

Group Objectives

The purpose of the Climate Change Working Group was twofold:

- To identify and recommend actions to fill information and data gaps related to climate change of relevance to offshore oil and gas activities in the Beaufort Sea.
- To support efficient and effective environmental assessment and regulatory decision-making, particularly as related to relevant aspects of climate change and adaptation.

Fit Within BREA Program

The Working Group made a series of recommendations to the BREA Research Advisory Committee and Steering Committee, identifying requirements for monitoring, modelling, and critical research, and noting the importance of these issues to offshore oil and gas. This work responds to the BREA objectives of producing regional information on climate conditions in the Beaufort Sea region, which will strengthen assessment processes and facilitate integrated management. The Working Group engaged communities in a local workshop at which preliminary results were discussed, and local and traditional knowledge were incorporated into the Working Group's final report.

Key Findings

The science and traditional knowledge are clear: the Beaufort is being affected by climate change and more change is projected in the future. The Beaufort is already a dynamic environment; climate change is making it more so. As a result, climate change is a priority that needs to be better integrated into decision-making.

Table 4.2.1. Key Findings of Climate Change Impacts on Oil and Gas in the Beaufort

Key Positive Effects	Key Negative Effects
• Longer operating seasons for seismic and drilling activities due to reduced ice cover and thickness • Earlier mobilization and later demobilization of vessels both to and from the Beaufort Sea, as well as from overwintering anchorages and offshore areas • Reduced icebreaking requirements	• Increased threats to drilling and production platforms due to increased ice velocities and the increased presence of glacial ice features • Larger wave heights may cause delays in ship support activities and seismic operations • Increased sea surface temperatures which may increase degradation of permafrost in coastal areas, with implications for coastal oil and gas infrastructure • Reduced use of ice roads and ice spray islands in nearshore areas • Increased coastal areas affected by storm surge potentially affecting infrastructure

The Working Group also concluded that, due to the variability of the projected climate, "oil and gas companies will need to plan and prepare for extreme events in all phases." Furthermore, if the lifespan of a project is long, it will be necessary to prepare for the range of changes which are projected to occur over the life of the project.

Contribution to State of Knowledge

The Climate Change Working Group brought together a suite of scientific research as well as local and traditional knowledge. Through this they were able to identify which climate and ice variables were of critical importance. These included wave height, wind speeds, sea temperature/heat content, sea level, coastal erosion rates, sea ice (distribution, type, concentration, and thickness), presence of glacial ice, predictability of weather and storms, increased frequency and severity of storms, and later freeze-up of ice and earlier break-up. The climate change science and traditional knowledge were complementary and showed strong agreement, adding strength to the findings of the Working Group.

While the Working Group contributed to synthesizing the overall body of knowledge on climate change in the region, it also identified knowledge gaps and made a series of recommendations for further research, traditional knowledge, monitoring, and modelling. The following is a subset of the priority recommendations:

- Continue interaction and knowledge exchange between Inuvialuit and Western scientists and keep the research active and current.

- Integrate Western science and traditional knowledge programs through community-based monitoring.
- Coordinate long-term monitoring and community consultation (*e.g.*, through Traditional Knowledge Coordinator).
- Develop atmospheric regional climate model.
- Research ice hazards: ice deformation, marine glacial ice, and landfast ice.
- Improve knowledge of ecosystem functions.
- Model contaminant transport pathways in sediment, water, atmosphere, and biota.
- Model inshore and wave surge for coastal erosion.
- Introduce climate change guidelines into environmental assessments.
- Investigate climate adaptation options.
- Integrate this work with other ongoing projects (*e.g.*, ArcticNet's Integrated Regional Impact Study in the Western Arctic).

Regulatory Decision Support

The Working Group presented its entire climate change synthesis with a focus on relevance to the "environmental assessment and regulatory processes for Beaufort Sea oil and gas exploration and development activities." This was one of the central objectives that the group set and achieved.

The Working Group noted that climate change effects on projects are not addressed consistently, if at all, in the various stages of the current assessment and regulatory regimes. For example, the NEB (the primary regulator in the Arctic) does not refer to climate change in the filing requirements for offshore drilling in the Canadian Arctic. The regulator does, however, require that environmental effects be addressed.

One of the key recommendations of the Working Group is to encourage the creation of climate change guidelines (*i.e.*, best practices pertaining to potential climate change effects on oil and gas activities) for inclusion in environmental assessments. In this way, climate change can be mainstreamed into existing assessment processes. The Working Group final report is a good reference for decision-makers in considering climate change.

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Chapter 4.3. Social, Cultural and Economic Indicators Working Group

Working Group Overview

The Social, Cultural and Economic Indicators Working Group was established to identify the impacts of oil and gas development on communities in the Inuvialuit Settlement Region (ISR), by gathering and assessing baseline data and developing indicators of key social, cultural and economic conditions. This will support the achievement of benefits, and mitigate negative impacts, of oil and gas projects in the Beaufort Sea. The work of this group builds on the ISR Indicators Project, which began with a review of the goals of the Inuvialuit Final Agreement and was expanded through the Beaufort Sea Strategic Regional Plan of Action (BSStRPA), as well as the Beaufort Sea Integrated Ocean Management Plan (IOMP) to prepare Inuvialuit, governments, and industry for oil and gas development in the Beaufort Sea.

The Working Group was to oversee the implementation of the social, cultural and economic base line data component of BREA, in collaboration with the partners carrying out the IRC's Indicator Project, which will develop a set of measurable indicators for monitoring socio-economic conditions in the ISR, with an emphasis on tracing the impacts of resource development. This work is led by the IRC in partnership with ReSDA (Resource and Sustainable Development in the Arctic), and the Arctic Council's Arctic Social Indicators Working Group (ACSIWG). The development of indicators required the collection and assessment of baseline data on social, cultural and economic conditions in the ISR: a formal working relationship between the IRC and the NWT Bureau of Statistics was established to collect statistical and departmental administrative data from which to develop indicators.

The Social, Cultural and Economic Indicators (SCE) Working Group was led by the Inuvialuit Regional Corporation (IRC). Several components of the work have been conducted in partnership with, or with the assistance of, other organizations, such as the ReSDA (Resource and Sustainable Development in the Arctic), and Lakehead University.

Purpose of the working group

The purpose of the SCE Working Group was to develop base line data and indicators to identify the impacts of oil and gas development in the Beaufort Sea on communities in the ISR, in order to support benefits of development and mitigate negative impacts. Specific objectives for the working group were to:

- Develop baseline data and indicators of social, cultural and economic conditions in the ISR to assist in identifying potential and actual impacts of offshore oil and gas activities;
- Produce baseline data to enable monitoring and measuring of long-term effects of oil and gas development, in order to develop and implement measures to mitigate negative impacts and reinforce positive impacts of development;
- Carry out further data mining by collecting and organizing administrative data to fill indicator gaps with data;

- Assess data collected to identify impacts and associated vulnerabilities that may result from resource development and to identify appropriate mitigation measures;
- Undertake further research to inform social, cultural and economic assessments and identify any additional efforts required from industry and government to mitigate negative impacts of development.

Fit Within BREA Program

The Working Group activities strongly align with BREA's goals of engaging communities and advancing their priorities for oil and gas preparedness, as well as producing socio-economic information to simplify project-level assessments. The work of the working group contributes to the Indicators Project and several research partnerships developed by the Inuvialuit Regional Corporation (IRC), and as such responds directly to community needs. IRC staff present data that has been collected to communities to assist with their decision-making on oil and gas activities and program development planning.

The Working Group's mandate is integrated with the Cumulative Effects Working Group, and will use a framework developed by that group for monitoring.

Key Findings

The SCE Working Group completed projects related to all of its stated objectives, all of which are relevant to ISR communities' ability to assess and manage the impacts of oil and gas activity in the Beaufort Sea.

With respect to the development of indicators, a study by ReSDA provided recommendations on key indicators, based on the Arctic Social Indicators developed by the ACSIWG, which could be used by industry and by government regulators. The Arctic Social Indicators were examined as a potential means of measuring impacts; however, the indicators were too broad to identify impacts and were created primarily to measure overall human development in the Arctic. Another major report by the SCE Working Group, *Measuring the Effects of Major Projects in the Inuvialuit Settlement Region*, reviewed the methodology that should be used to develop and assess indicators for social, cultural and economic impacts of oil and gas development activities in the Beaufort Sea. A main finding was that the methodology used in a previous assessment was not suitable, and that a new methodology and sets of indicators were needed that captured both the direct impacts of oil and gas activities, and the more complex secondary and tertiary effects that result from community responses to those activities. A set of suggested indicators was validated through application to a previous development cycle that was experienced in the ISR.

Progress was made on each of the objectives related to the collection, organization and assessment of base line data. First, existing and new data were gathered by the NWT Bureau of Statistics and from education administration data, and all updated data were imported to the IRC's Inuvialuit Indicators project website (www.inuvialuitindicators.com). Second, maintenance of data on education administration was transferred to the Beaufort Delta Education Council, making these data more accessible, and improving the assessment of students in ISR region schools. Third, an Environmental

Scan was completed that serves as the basis for an assessment of gaps in data on the impacts of resource development needed for monitoring indicators.

Finally, additional research was initiated on several topics of interest to stakeholders. The IRC completed household surveys to gather the perspective of Inuvialuit in the communities and more detailed data on their social, cultural, and economic conditions. These surveys resulted in reports on Addictions and Mental Health (2010), Social Housing and Income Support (2011), and the "Economics of an Inuvialuit Household," which was completed in the community of Paulatuk in 2012, and will be extended to the other five Inuvialuit communities. This identifies household income and expenses, and will help define the value of the traditional economy, such as harvesting and country foods. There will be follow-ups to this work, and the results will be available to the public. Finally, an Education Research Project was completed by the ISR in partnership with Lakehead University, which will inform the development of measures to improve the employment and economic opportunities from resource development.

Contribution to State of Knowledge

The gathering of data on social, cultural and economic conditions of ISR communities from a range of diverse sources will be important in measuring the impacts of resource development, and hence the identification of measures to support beneficial impacts and to mitigate adverse impacts. The collection and analysis of baseline data already provides an improved understanding of the trends in a set of social domains in the ISR, and a comparison of these trends with those in other northern regions. The holding of these data in ISR databases enables regional and community offices and individuals to interpret the data and evaluate the effectiveness of response measures.

Further work will be needed on several of the tasks carried out by the SCE Working Group; the ISR has a strong interest in continuing monitoring of social, cultural and economic conditions in the region and will be making ongoing contributions to many of these monitoring projects. First, the indicators must be formalized, as the methodological framework that was developed (in *Measuring the Effects of Major Projects in the Inuvialuit Settlement Region*) left room for the identification of indicators for the complex indirect effects of resource development, which interact with broader social, economic and cultural contexts. Additional factors that could be measured and used as indicators that are relevant to social and cultural conditions in the ISR have been suggested, and could be incorporated into subsequent data collection exercises. In addition, work will continue on the collection and analysis of base line data, and on the development of a system for monitoring the indicators. Finally, recommendations will need to be developed on measures to mitigate negative impacts of oil and gas activity.

Regulatory Decision Support

The indicators and baseline data will enable the determination of impacts of oil and gas development to be used in project-specific environmental assessments required by regulatory agencies, and for ongoing monitoring of impacts and cumulative effects. In particular, the indicator methodology set out by the Working Group will guide regulators in the social, cultural and economic factors that industry should describe in environmental impact studies and monitor throughout projects, ensuring that the indicators reflect the most appropriate factors.

The collection of appropriate baseline data and monitoring of indicators of the impacts of development will facilitate an evaluation of the impacts on ISR communities and the determination of the most appropriate measures to support the effects desired by communities, and mitigate adverse or negative impacts.

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Chapter 4.4. Oils Spills Preparedness and Response Working Group

Working Group Overview

The Oil Spill Preparedness and Response Working Group was formed to identify ways to improve the ability of government, the Inuvialuit and industry to respond to a significant spill related to oil and gas activities in the Beaufort Sea by

- Engaging Inuvialuit and stakeholders and understanding their concerns.
- Resolving knowledge gaps in order to assist development of a coordinated and tiered response plan, including the consideration of oil spill countermeasures.
- Identifying research studies, as well as workshop and training opportunities to educate and clarify government, Inuvialuit, and industry roles.

The Oil Spills Preparedness and Response Working Group was concerned with preparing for the development of spill response plans and capacity, with a particular focus on the involvement of the Inuvialuit in spill response. The Working Group conducted its work through a review of the use of chemical dispersants to respond to a spill; a study on the different roles that organizations could play within a coordinated response system structure; and the development of training modules needed to provide Inuvialuit organizations and communities with the capabilities to carry out the response roles that they have identified.

The Group was co-chaired by AANDC and the National Energy Board (NEB), the federal regulator of oil and gas activities in the Arctic offshore. Other members represented the Inuvialuit Game Council, Inuvialuit Joint Secretariat, the Canadian Coast Guard, Environment Canada, Fisheries and Oceans Canada, Transport Canada, the Government of the Northwest Territories Department of Environment and Natural Resources, Yukon Government, and the Canadian Association of Petroleum Producers. Several of the products of the Working Group were contracted to consultants; these include the Dispersant Use Workshop (conducted by SL Ross Environmental Research Limited), the Study on Inuvialuit Community Spill Response Training in the Beaufort Region (carried out by Kavik-Stantec), and the training manuals (prepared by Counterspil Research Inc., supported by Owens Coastal Consultants Limited).

Group Objectives

Offshore drilling companies are responsible for anticipating, preventing, mitigating, and managing incidents and oil spills associated with their activities, and must demonstrate to the NEB, the regulator, that they have adequate contingency plans and emergency response procedures to mitigate a spill. However, a large spill could exceed the ability of the company to manage the effects, necessitating the assistance of the governments and other agencies. Inuvialuit communities and the public have been concerned that an oil spill in the Beaufort Sea could have significant impacts on health and the environment, as well as on wildlife harvesting activities, and have asked for assurance that government oversight is in place to ensure appropriate oil spill prevention, preparedness and response. Adequate preparedness and response capability requires clarity on the roles and responsibilities of the Federal and

Territorial Governments and other agencies. In addition, in order for Inuvialuit organizations and communities to be involved in preparedness and response activities, the roles that they could play in response to a spill need to be identified and supported through education and training.

The subject matter addressed by this Working Group most directly meets the BREA goal of engaging communities and advancing their priorities for oil and gas preparedness. It also addresses the goal of strengthening assessment processes and integrated management by ensuring that company plans and capacity for preventing and managing oils spills are adequate and integrated with the plans, roles and capabilities of other organizations.

Fit Within BREA Program

The Working Group undertook studies that were in addition to several BREA research projects. The most directly related is the research project on Biological Data to Assess Net Environmental Benefits and Costs of Dispersants, which falls under the research priority area of Bird, Fish and Marine Mammal Information for Oil Spill Response.

Other research projects could produce information that would be of use in several aspects of oil spill preparedness and response, including impact assessment and monitoring. These include research on the Beaufort region coastal environment and resources that could be affected by an oil spill, such as Coastal, Marine and Offshore Bird usage of the Beaufort Sea; Offshore Fish Populations, Habitat and Ecosystems, Baselines and Potential effects of Mercury and Hydrocarbons in Beaufort Sediments and Biota; and Regional Coastal Monitoring in the Inuvialuit Settlement Region: Ecosystem Indicators.

Other research that is relevant to the work of this Working Group focuses on factors that could contribute to an oil spill, such as Deep Water Seabed Geohazards; Overwintering of Barges in the Beaufort Sea; and several projects under the Sea Ice and Extreme Ice Features research priority.

Key Findings

The Working Group completed several studies, workshops and reports in clarifying roles and responsibilities and developing a curriculum for training needed to prepare Inuvialuit for fulfilling their roles.

A workshop on “dispersant use in the Canadian Beaufort Sea” was held in July, 2011. This workshop was intended to inform regional stakeholders about chemical dispersants and the implications of their inclusion in the ‘toolbox’ of spill countermeasures that are available to responders in the Beaufort Sea, as well as to identify paths for planning the use of including dispersants as a potential measure along with containment and recovery, in-situ-burning, and shoreline cleanup. The workshop heard that Inuvialuit are concerned about the use of chemical dispersants and want assurance that further research will provide greater understanding of the potential impacts on wildlife and ecosystems in the Beaufort Sea, and that companies will have properly trained personnel dealing with spills.

The Working Group conducted a survey of the response roles that several relevant organizations expected they could fill in the response to a Tier 3 oil spill. A Tier 3 spill is defined as one that is severe enough to exceed the on-site response capabilities of the operator or that becomes regional in extent, and may require contributions from governments and organizations. It was recognized that some of the functions described by Inuvialuit respondents could be applicable to a wider range of situations.

This survey was sent to four types of organizations: Inuvialuit and community organizations and one non-government organization based in Inuvik; Federal departments and agencies (including the NEB); and Territorial governments and departments. Response rates averaged 47%, and varied within group types from 19% for Inuvialuit and community organizations to 100% for the NEB. It asked respondent organizations about their mandates and authorities for offshore oil response; policies or agreements on responding to offshore spills; their anticipated role in response to a Tier 3 spill, including the kinds of roles they could fill in an Incident Command Structure (ICS); and the types of incidents about which they would expect to be informed. The report provides a first look at how organizations view their roles and presents a simplified Incident Command System Structure, illustrating the type of structure that would likely be developed to coordinate roles for the response to a Tier 3 spill. The results of the survey can serve as the basis for the development of an ICS in preparation of future drilling programs in the Beaufort Sea.

A training needs workshop was held in 2012 to help determine the specific training that would be needed to enable Inuvialuit communities and organizations to prepare for an oil spill response. The workshop followed a set of consultations with Inuvialuit community organizations and residents, as well as the NEB, other regulators, and oil and gas companies, that asked about the capacity in the community to respond to a spill, the response roles residents would be interested in when oil and gas activity develops, and the type of training that would be most appropriate to enable residents to carry out those functions. Inuvialuit expressed a desire to be involved in all aspects of spill preparedness and response, including advisory roles, spill response activities, and monitoring, in addition to support roles such as camp cooks and transportation support. The study made fourteen recommendations, ten of which could be initiated within a few years. The recommendations pertain to training needs, funding, youth education, knowledge sharing, and the establishment of a spill response entity such as a cooperatively owned or Inuvialuit-owned company.

Finally, based on the training needs identified in the workshop and revised by the Working Group, a training program was prepared. A curriculum was developed in a set of ten modules, covering spill causes, response measures, regulations and planning, health and safety, and transportation and logistics activities. The Working Group is reviewing, and will report on, the status of the remaining training needs recommendations before April 2015. Currently, six of the fourteen recommendations are being wholly or partly addressed; and four recommendations are not targeted to be initiated until the 2018 to 2021 time frame.

Contribution to State of Knowledge

The consultations and studies of the Oil Spills Preparedness and Response Working Group have tried to improve the knowledge of Inuvialuit communities regarding oil spills, and particularly the use of chemical dispersants. All partners should have greater clarity on their own and others' responsibilities and capabilities in preparing for and responding to a spill. Implementation of the training recommendations could result in a greater level of knowledge and capacity among Inuvialuit.

The Working Group has noted that several other issues remain to be considered. These include the management of spill response waste; the preparation and dissemination of information on in-situ burning; a description of response best practices and guidelines; a follow-up on Inuvialuit training needs and spill response mandates and roles; and alternatives to chemical dispersants. In addition, the longer-term recommendations have yet to be implemented; these include conducting the training course that was developed.

While much of the planning of organizational roles, as well as the formation and structure of a spill response entity and training curriculum, can be initiated immediately, it is recognized that other recommendations may not need to begin until drilling activities are authorized (likely within the next decade). The functions developed by the Working Group will be essential at that time, in order to ensure that the resources are in place to support oil spill preparedness and response plans required by regulators, and to respond should a significant spill occur.

Regulatory Decision-Support

The Working Group's products will contribute to regulatory preparation by identifying partner organizations that can work with companies in the event of an oil spill. Inuvialuit preparedness may be enhanced by their greater knowledge about oil spills and response systems. Future training, using the curriculum prepared by Counterspil Research Inc. for the Working Group, should further advance the ability of communities to prepare for a spill and be aware of their roles, and the responsibilities of other partners, in planning and response activities.

An effective response system, which clearly identifies in advance the responsibilities and capabilities of all partners, would help to mitigate the risks of damage and negative impacts caused by a large (Tier 3) spill. The ability of Inuvialuit communities to protect their wildlife harvesting and other resources should be improved as a result of their knowledge and oil spill response training. Other related research projects would also help to build knowledge and capacity in preparing for oil spills.

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Chapter 4.5. Cumulative Effects Working Group

Working Group Overview

A cumulative effects assessment is an existing required component of regulatory applications and Environmental and Social Impact Assessments. Project proponents are guided in their assessment of cumulative effects in the ISR by the *Canadian Environmental Assessment Act, 2012* and Regulations, and by the Environmental Impact Screening Committee and Review Board Guidelines. However, resource managers have indicated that the current methods employed by proponents to assess cumulative effects fall short of expectations.

The Cumulative Effects Working Group was formed to begin addressing this methodological gap through the development of a pilot cumulative effects framework initiative meant to complement the establishment of a baseline understanding of environmental conditions in the offshore Beaufort through the BREA Science Program.

This summary of the Working Group's efforts is based primarily on notes from meetings, in-person and teleconferences, as well as the *Beaufort Regional Environmental Assessment Cumulative Effects Framework* (AMEC, 2015).

Group Objectives

The Cumulative Effects Working Group was established to develop a pilot for a regionally-based cumulative effects framework that identifies linkages and sensitivities between stressors and valued components, and establishes a methodology for measuring changes in valued components relative to baseline conditions. The pilot study should help provide greater consistency in project assessments and provide a better means for regulators to appropriately consider cumulative effects.

The framework is intended to start simply and be implemented, tested, and refined through decision-making over time. The development of a regional framework outside of a project-specific application facilitates the participation of all stakeholders (governments, Inuvialuit, and industry) and supports the process for the identification of valued components and stressors to be included in cumulative effects assessment in subsequent project assessments.

Fit Within BREA Program

The objectives of the Cumulative Effects Working Group are most directly related to two of BREA's four goals: to produce regional information that simplifies project-level assessments; and to strengthen assessment processes and integrated management.

Considerable amounts of environmental data have been collected in the Beaufort Delta region in the past. Some coordination and integration of these activities has occurred, but there is no comprehensive framework in place to ensure environmental data collected by various parties contributes efficiently and effectively to the existing knowledge base; to inform the assessment and management of cumulative effects; and to promote environmental, socio-cultural and economic sustainability in the midst of regional industrial development.

Key Findings

As the Beaufort Sea is a relatively undeveloped region in Canada, the area is well-suited for establishing baseline information to properly inform cumulative effects assessment. At the same time, cumulative effects assessment plans have been contemplated for the region and there already exists partial knowledge of ecosystem function and interactions between valued components and stressors in the Beaufort Sea. There is potential to improve regulatory efficiency by developing a model for considering cumulative effects on a regional scale that clearly indicates the entities that are responsible for collecting information that could feed into the model.

The main output of the Cumulative Effects Working Group is the *Beaufort Regional Environmental Assessment Cumulative Effects Framework* (AMEC 2015). This report to the Working Group offers a structure for considering cumulative effects at a regional level with respect to four pilot valued components – beluga and arctic cod/arctic char, formal education, employment and cultural vitality. While researching the report, the consultants noted that several administrative factors exist that will affect the implementation of a cumulative effects framework. These include:

(1) Significant Information Sources. While much of the information needed to understand the cumulative effects on the pilot valued components exists, it is distributed across many governmental, community, and academic organizations. The various formats of the information further complicate its use for analysis.

(2) Routine monitoring activities. Regular, continuous and timely analysis of available data is necessary to ensure proper decision-making and resource management planning with respect to new project development.

(3) Academic Research. There are numerous sources of academic research results, including departmental reports (governments), academic journals, and industry reports (e.g. environmental assessments and regular monitoring reports).

(4) Government and Stakeholder Commitment. As no single agency has overall responsibility for the implementation of cumulative effects management in the Beaufort Region, it would be necessary to formalize commitments for continued development and implementation of the framework.

Contribution to State of Knowledge

The pilot framework for cumulative effects is built on upon a network of identified information sources for four valued components. Figure 4.5.1 illustrates the diversity of this network.

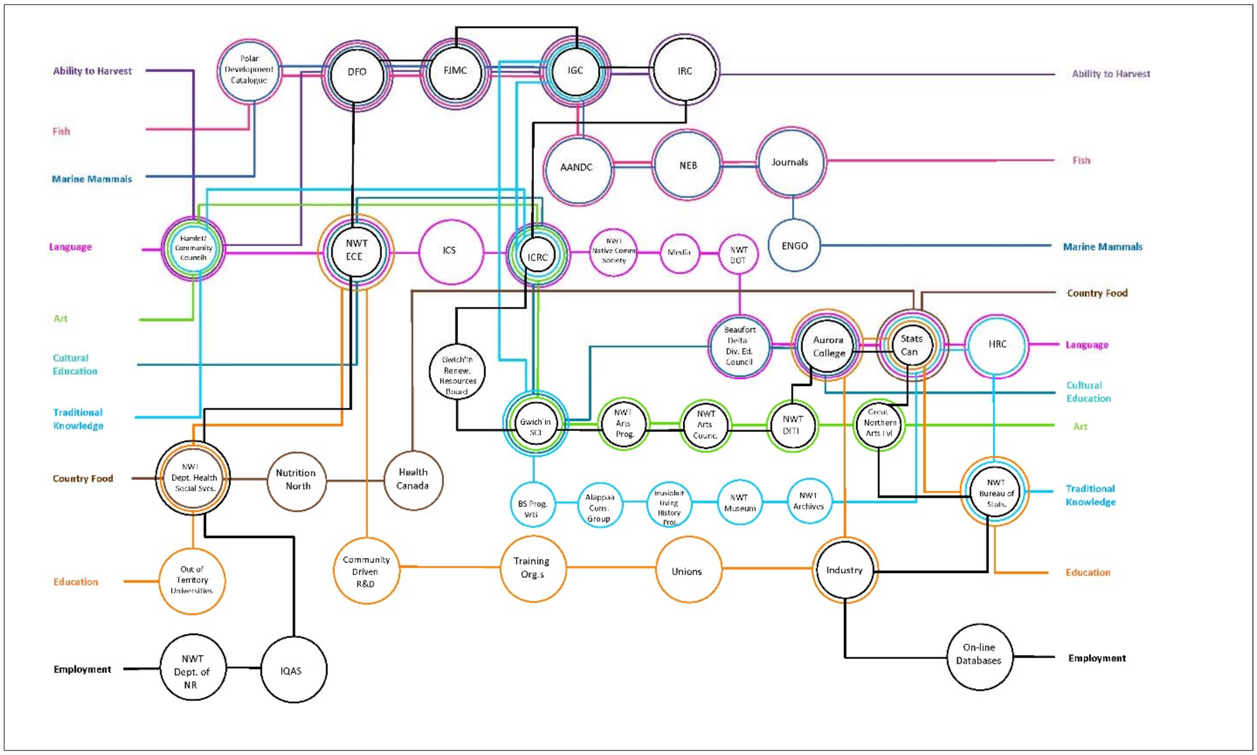

Figure 4.5.1. Cumulative Effects Framework – Information network (p. 167, BREA CEF, 2015)

Decision-making with respect to the management of cumulative effects on any given VC rests with the relevant regulatory agencies. Organizations identified in the network above could provide the information necessary to making the appropriate informed decisions as per the flow chart in Figure 4.5.2.

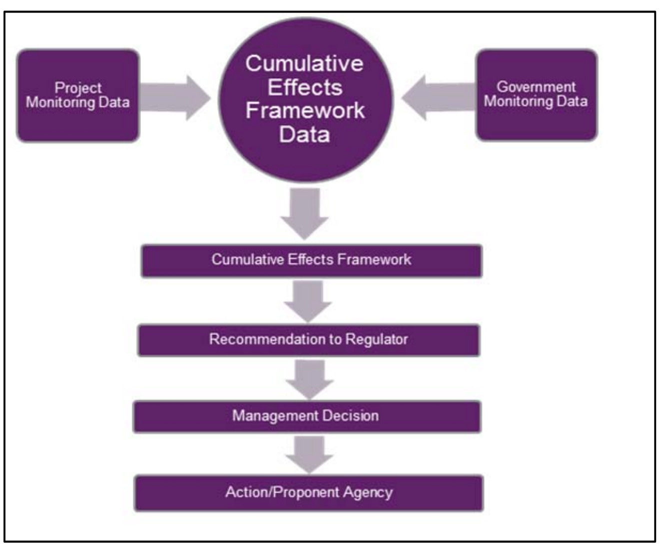

Figure 4.5.2. CE Decision-making Flow Chart (p.170, BREA CEF, 2015)

Regulatory Decision-Support

Applying a consistent methodology for considering cumulative effects will likely result in regulatory efficiencies by creating alignment on information and process requirements, and reducing public and regulatory concerns in public hearings and panel reviews. It may also help clarify when mitigation and/or monitoring of indicators are required, i.e. when cumulative effects are deemed to be significant for a specific valued component.

Finally, the *BREA Cumulative Effects Framework* (AMEC, 2015) sets out a number of recommendations to the Working Group. These recommendations include the continuation of the Cumulative Effects Working Group beyond the end of the BREA (and what the Working Group should look like). The consultants also recommend enhanced communications between organizations having a role in data acquisition/management as well as decision-making; greater data-sharing among stakeholders; and the expansion of the pilot CE framework to include more valued components and to set decision points with respect to management of the valued components.

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Chapter 4.6. Information Management Working Group

Working Group Overview

The Information Management Working Group was formed to make BREA data and information available to the public, regulators, industry, and academics through an existing set of websites and databases. The Working Group was chaired by AANDC, with contributions from managers of the Polar Data Catalogue (PDC) and the Arctic Science and Technology Information System (ASTIS).

Group Objectives

The purpose of the Working Group was to ensure that all data, metadata and information related to each BREA research and working group project are accessible to the public and stakeholders, while recognizing and conforming to requirements that private and sensitive information be maintained appropriately confidential. The main objectives of the Working Group were:

- To establish the BREA Data and Information Management Policy (DIMP) in order to set a framework and define expectations for the preparation, provision, maintenance, and use of BREA research and working group project data and information.
- To facilitate integration of BREA-related data and information into the BREA website, the PDC, and the Hydrocarbon Impacts (HI) Database of ASTIS, in accordance with the terms of the DIMP.
- To contribute to efforts to promote to stakeholders the accessibility of BREA data and information through the BREA website, PDC, and the HI Database.

Fit within BREA Program

The contributions of the Information Management Working Group were essential for the success of BREA as a whole. In order to meet such fundamental objectives as “[ensuring] stakeholders are better prepared for future oil and gas exploration and development in the Beaufort” and “[filling] regional information and data gaps,” BREA requires effective and reliable mechanisms for sharing and managing research and working group project data and information. The Information Management Working Group oversaw the development and implementation of these mechanisms.

Key Findings

The most remarkable overall outcome of this project was the choice made by the Working Group to utilize ASTIS (HI Database) and the PDC — two well-established databases previously developed to fulfill key mandates with respect to the tracking of polar information products in Canada — for the storage and profiling of BREA-related data and information. Instead of developing a new data and information management system for BREA (notwithstanding the BREA-specific website itself), the Working Group opted to contribute to two existing databases. In turn, BREA-interested users will benefit from access to the large holdings of other (non-BREA) Beaufort Region data and information housed within ASTIS and the PDC.

More particular outcomes of the Information Management Working Group project include the BREA Data and Information Management Policy (DIMP, 2012); coordinated use, development, or tailoring of the BREA Website, PDC and HI Database to accommodate BREA project data and information; and population of the BREA Website, PDC, and HI Database with BREA research and working group project data and information. The balance of this section addresses each of these outcomes in further detail.

Data and Information Management Policy.

By way of the DIMP, the Working Group established

- The BREA Data and Information Framework;
- Responsibilities for the provision, maintenance, and archiving of BREA research and working group project data and information;
- Requirements for the protection and citation of BREA research and working group project data and information.

The Data and Information Framework defines three classes of BREA projects and specifies the provision of information, data, and metadata at both the project and product levels (Figure 4.6.1, below). Each class of project is defined according to the character of its product. Of the three product types, "data products" are defined as including databases and geo-referenced data files; "information products" as including reports, journal articles and conference presentations; and "decision support tools" as including geo-referenced databases or information that use tools to collate and/or display data and information.

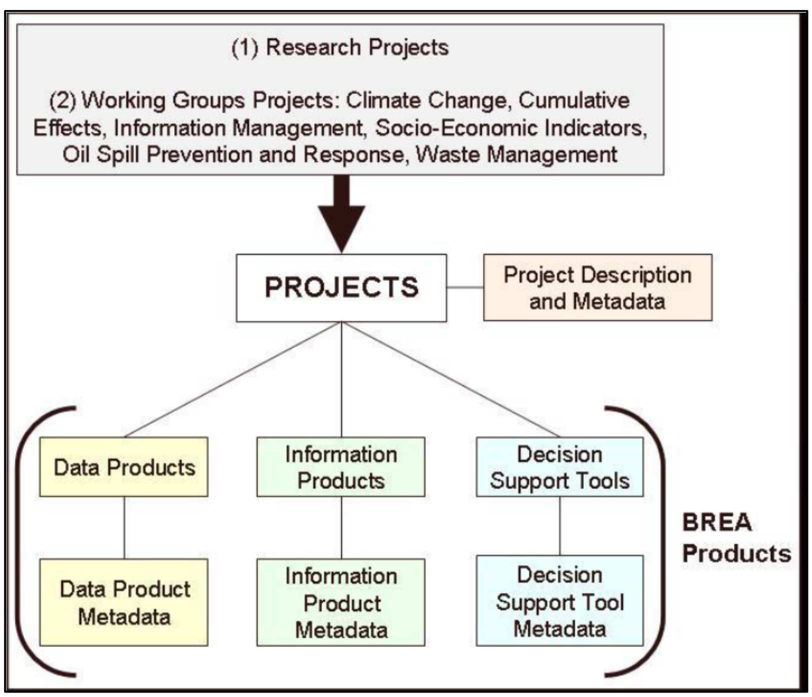

Figure 4.6.1. BREA Data and Information Framework (p. 3, DIMP, 2012)

Responsibilities for the provision, maintenance, and archiving of BREA project data and information are divided among various parties:

- *Principal Investigators* are responsible for providing all data, metadata and information from research and working group projects funded by or otherwise benefitting from BREA. Information products (or their links) should be provided for posting to the BREA website, as should plain language summaries of every BREA project, regardless of category; decision support tools should also be linked to the BREA website, from the originator's site; and all other data, metadata, and information should be uploaded to the Polar Data Catalogue.
- *AANDC* is responsible for linking through the BREA website to all BREA-related Polar Data Catalogue data and information, as well as for ensuring all BREA reports and publications are indexed on the Hydrocarbon Impacts Database.
- *Administrators* of the Polar Data Catalogue and the Hydrocarbon Impacts Database are responsible for maintaining these repositories to enable storage of BREA-related data and information.
- Finally, the DIMP requires *users* of BREA data and information to formally acknowledge data originators, contributors, and sources (*e.g.*, in the form of a formal citation).

BREA website. The BREA website (www.beaufortrea.ca) has been developed as an information portal with links to the data, metadata and reports produced by BREA research and working group projects. As noted, certain information products (such as plain language project summaries) are included on, rather than linked to, the BREA website, in order to facilitate access by stakeholders and the general public. When the work of the BREA program is complete, the website will be transferred to the Joint Secretariat to ensure long-term accessibility.

Polar Data Catalogue. The PDC was initiated in 2007 through the collaborative efforts of ArcticNet, the Canadian Cryospheric Information Network (CCIN), the Department of Fisheries and Oceans Canada, and Noetix Research Inc. of Ottawa, Ontario to "facilitate the exchange of information about the Canadian Arctic among researchers and other user groups, including northern communities and international programs." The PDC is an online searchable database of metadata and data files that describes catalogues and provides access to the diverse data sets generated by polar researchers. As such, the PDC is used by a range of parties and programs, including the Government of Canada Program for the International Polar Year 2007-2008 and the Northern Contaminants Program (https://www.polardata.ca/pdcinput/public/aboutus.ccin). As noted, BREA information stored on the PDC includes project metadata, data products and data product metadata. As with the PDC collection in general, BREA data are submitted by researchers as they complete quality control of their data files. The ideal situation is quick preparation and upload of new files. This happens occasionally, but more often there is a delay between data collection and upload to the PDC. OGC (Open Geospatial Consortium) compliance and the incorporation of GeoServer provide internationally-standardized Web Map and Web Feature services which ensure the PDC supports effective sharing of BREA metadata with other interested online data portals and clients. BREA geospatial data can be displayed using a map-based viewer, developed for use with shape files which have been natively uploaded to the PDC or converted from contributed tabular datasets. Finally, a low band-width search application called PDCLite facilitates access by northern users in locations with limited Internet speed.

Hydrocarbon Impacts Database. The HI Database (www.aina.ucalgary.ca/hi) was initiated in 2001 when AANDC funded its creation as a "subset database" within ASTIS, at the Arctic Institute of North America. The HI Database is a searchable database and website that describes publications and research projects about the environmental impacts, socio-economic effects and regulation of hydrocarbon exploration, development and transportation in northern Canada (Progress Report 2013-14). BREA data stored within the HI Database include metadata and abstracts — indexed according to detailed subject and geographic indexing terms — along with hyperlinks to publications available online. Within ASTIS, but outside the HI Database proper, an "Inuvialuit Traditional Knowledge" section will be added to the Research Program drop-down menu (index) for the Inuvialuit Settlement Region subset database, making more than 700 Inuvialuit traditional knowledge documents, including BREA-related data and information, more accessible.

Contribution to State of Knowledge

The BREA program supported research on a wide range of topics under nine research priority areas including ecology and wildlife, ice conditions and hazards, and community priorities, targeted to fill gaps in information on the Beaufort Sea region, many aspects and areas of which have not been fully researched. The data management and sharing services instituted by the Information Management Working Group complete the BREA Program by putting in place the mechanisms and systems that make the information produced under the program fully accessible to partners in oil and gas exploration, Inuvialuit communities, researchers, and the public through user-friendly online interfaces.

Importantly, Inuvialuit were engaged by the Working Group (or their delegates) to provide input to and learn about the BREA website, PDC, and HI Database (Paull, 2013). Access to these sites and databases will help Beaufort region residents learn of research activities undertaken in the area, and provide information on the people or companies to contact to learn more.

Further relevant data and information will be generated by a variety of ongoing BREA research and working group projects, all of which will be used to update the BREA Website and BREA records in the PDC and HI Database. So too will relevant information and metadata from non-BREA sources dealing with the Inuvialuit Settlement Regional. Ongoing infrastructure support will be required, and modifications and improvements may be made as a result.

Historically, one of the most important services both ASTIS (HI Database) and the PDC have provided is long-term archiving and data security.

Regulatory Decision-Support

The organization and accessibility of BREA Program data and information, together with all other assessment-relevant Inuvialuit Settlement Region information housed by the PDC, HI Database, and BREA website, will help support application of the fullest and best available knowledge in assessing the impacts of resource development in Canada's Beaufort Sea region.

Similarly, the upkeep and use of these databases is a strong step towards the "full disclosure" to stakeholders of information related to assessments, as well as to other regulatory functions such as oversight of permits and licences, monitoring and follow-up and other resource management functions. This will help build stakeholder and public trust in regulators and in regulatory decisions. Since environmental assessment in the ISR is a *public* process (on the co-management arrangements of the Inuvialuit Final Agreement), concerted efforts to fully and effectively disclose assessment-relevant information is essential for upholding the institutional arrangements upon which hinge the regulation and management of natural resources in the Canadian Beaufort.

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CHAPTER 5.0. FINAL SUMMARY AND RECOMMENDATIONS

Chapter 5.1. Key Findings

BREA was designed to build on the foundations of initiatives that came before it. The Beaufort Sea Strategic Regional Plan of Action (BSStRPA), completed in 2008, identified twenty-three issues, thirty-two recommendations, and fifty specific actions to plan and prepare for potential benefits and adverse impacts from oil and gas development. In August 2010, the Government of Canada announced the Beaufort Regional Environmental Assessment based on the recommendations made in the Plan of Action, recognizing that this new funding would only address the top priority gaps.

Over the past four years, the 23 research projects added to the body of knowledge as identified by the Beaufort Sea Strategic Regional Plan of Action. As elaborated above, a total of nine areas were prioritized and refined through a multi-stakeholder Research Advisory Committee and community consultation and engagement sessions.

Some of the recommendations under BSStRPA are specific to individual stakeholders and as such were not suitable for addressing under BREA. Others are being addresses outside of this initiative through regulatory improvements and other activities. Of the 32 recommendations, BREA contributed to 22 by either directly contributing to the need (e.g. Regional Waste Management Strategy) or by developing information that will be used to address the recommendation (e.g. 'Overwintering in the Beaufort: Assessing Damage Potential to Vessels' is being referenced in the development of new standards with respect to offshore fuel storage).

Both the Second Year Results Forum, February 2013, and the Final Results Forum, February 2015, were held in Inuvik, NT and were well-attended by representatives of all stakeholder groups. Inuvialuit communities and organizations, industry representatives, researchers and federal and territorial government representatives discussed the research, the process, and the results of the work undertaken under BREA. Meeting notes, which can be found online at www.BeaufortREA.ca, summarize the discussions and provide the basis for recommendations below.

BREA contributed to the generation of much information and to the analysis of many issues. The summaries in Chapters 3 and 4 show the many successes and positive impacts of the work. There remain elements where further research is required.

- BREA was not able to fully address cumulative effects to the extent first described in the work plan. This will be important for project specific environmental assessments.
- The Framework for a Waste Management Strategy did not develop into a full blown strategy as was expected at the onset of the BREA.
- The integration of traditional knowledge was extremely successful with some projects (e.g. Regional Coastal Monitoring in the ISR), but despite efforts, was not consistently integrated across all projects.

Chapter 5.2. Communicating Results

An important result of BREA has been the partnerships. BREA brought together many organizations and individuals, with different perspectives and responsibilities, and collaboratively developed plans to achieve its objectives. This was achieved by:

- Ensuring clearly defined shared governance with strong central leadership, and participation of all stakeholders in program components;
- Ongoing stakeholder engagement (governments, regulators, Inuvialuit, industry and academia) to identify priorities and shape objectives and work plan;
- Building on past investment and current initiatives (government, Inuvialuit, industry, academia) to ensure we advance issues beyond saying 'we need to know more';
- Securing dedicated resources for BREA implementation to build synergies with other programs (BREA research leveraged on average, $2.20 for every dollar invested).

Regular communication of results and publically accessible information builds trust and ensures use of BREA products in management decisions. BREA's integrated approach for assessment of key gaps prior to development is considered a best practice to efficiently address knowledge gaps and cumulative effect considerations with an area-based rather than project-based approach. BREA's governance structure, while large, provided the opportunity for all stakeholders to be involved where they felt appropriate throughout the process.

A program review was conducted by consultants from Donna Cona Inc., in November 2014. This review was conducted in order to determine whether the BREA initiative was successful in achieving its goals, and whether the governance model was one that could be recommended for use in any future similar multi-stakeholder collaborations.

Results of this review show that efforts during the planning stages resulted in significant progress in identifying areas of research priority, allowing for significant advances in filling regional information and data gaps, and overall scientific understanding of the Beaufort Sea through the BREA research program.

BREA results and outcomes are expected to help better prepare governments, Inuvialuit, regulators, and oil and gas proponents for oil and gas exploration in the Beaufort Sea. They are also expected to contribute to better informed and more effective regulatory decisions.

Chapter 5.3. The Way Forward

Current Context in the Beaufort

The *Oil and Gas Exploration & Development Activity Forecast,* prepared by Lin Callow of LTLC Consulting in association with Salmo Consulting Inc. and discussed in Chapter 2, provided a general description of potential oil and gas activities from 2013 to 2028 in the Beaufort Sea and provided a context for the work of BREA. However, as the economic conditions must be correct in order for development in the Beaufort Sea to occur, market forces in 2014 and 2015 may result in further delays to development. The timely addition of knowledge with respect to the Beaufort Sea and BREA's outcomes will serve future project assessments.

BREA results are valuable and results were, and continue to be, referenced in the development of standards, by proponents in project descriptions and by regulators. BREA partners agree that the momentum of this initiative must be maintained to ensure continuing returns on research results; to ensure the stakeholders are as prepared as possible for oil and gas activity; and to maintain the partnerships and level of engagement from all stakeholders.

At the BREA Final Results Forum in Inuvik, NT, February 24-26, 2015, stakeholders expressed broad interest in smoothing the way for investment in the future. Specifically, stakeholders expressed interest in further research and coordinated efforts on areas such as fish and fish habitat, offshore geohazards, oil interactions in ice, waste management, cumulative effects management, and social, cultural and economic indicators in order to address remaining knowledge gaps.

The Environmental Studies Research Fund (ESRF), the Canadian High Arctic Research Station (CHARS) and the Program for Energy Research and Development (PERD) are examples of sources of funding to continue research in this area. Fisheries and Oceans Canada, the Inuvialuit Regional Corporation and Inuvialuit Game Council co-chair the Beaufort Sea Partnership, which developed the Integrated Oceans Management Plan and is a forum through which priority issues may be addressed.

In August of 2015, the Inuvialuit Joint Secretariat hosted the pilot session of the Oil Spills training course developed through the working group. This session included the participation of representatives from each of the six Inuvialuit communities in addition to the co-management boards.

RECOMMENDATIONS

Following earlier individual and coordinated research and assessment initiatives, the Beaufort Sea Strategic Regional Plan of Action took a community-based approach to the identification of regional needs with respect to planning for future offshore oil and gas development, and the actions needed to address them. This plan and its recommendations formed the basis in selecting the nine priority research areas and six key issues addressed under BREA.

The development of targeted knowledge under BREA supports a more efficient and effective environmental assessment regime providing regional information that addresses issues that are likely to recur in individual project-level environmental assessments. Regulatory efficiency is gained by developing and making available to all stakeholders, through research conducted at the regional scale, baseline information that will lead to better prediction, monitoring, assessment and mitigation of project impacts. The incorporation of this information by project proponents and regulators into project-specific applications and reviews will accelerate review processes as well as increase the quality of environmental assessments. Stakeholders at both BREA Results Forums combined with the research and working group summaries in Chapters 3 and 4 have contributed to the review of results, key findings, and delineation of remaining gaps.

Below are the key areas recommended for further research and for further action. As communities, industry, regulators and governments move forward in their need to be prepared for oil and gas development, it is necessary to take into account the timing of each action and the need to ensure work is complementary to other initiatives.

Baseline ecological information

- While BREA and its predecessors have made great strides in understanding the Beaufort Sea environment, on-going assessment and analyses of fishes, marine mammals, birds, and the biologically necessary conditions in their environment continues to be critical to preparations for project level environmental assessments. Baseline information requires a long-term commitment in order to understand the processes affecting valued ecological components.

Ice conditions and interactions with petroleum products

- Ice research played a key role in BREA, with seven research projects undertaken in order to better understand ice, its features and characteristics, and better understand its movement patterns in the Beaufort Sea. It is a very important research area with significant implications for local people, transportation, operations, and marine traffic. As with the ecological components mentioned above, longer-term baselines will improve the ability to predict and quantify the movement of ice, affecting oil and gas operations in many ways.
- In addition, a clear understanding of how the different types of ice interact with petroleum products in the differing conditions found in the Beaufort Sea is of critical importance in the context of spill response planning.

Regional Geohazards

- Given the direct relationship between offshore geohazards and spill prevention, it is important to further regional geoscience research. As part of the continuing effort to both locate and understand sub-bottom and seabed geohazards in the Canadian Beaufort Sea, especially in those areas in which offshore oil and gas exploration and development may occur, results so far will help target further research of specific vulnerabilities that have been identified.

Spill prevention, preparedness and response

- While the responsibility for development falls to industry and their research partners, all stakeholders have the same need for understanding the effectiveness of each option in differing conditions. As the NEB considers alternate approaches to meeting the intended outcome of its Same Season Relief Well Policy, new technologies and techniques are being developed for all facets of spill prevention, preparedness and response.
- Given risks associated with proximity and impact, community representatives have often expressed the need to be trained in identifying, understanding, responding to and staying safe in the event of any spill, large or small. The curriculum delivered through the Oil Spill Preparedness and Response working group was a start: having the proper equipment accessible and being trained on how and when to use it is essential. As all types of activity and traffic in the Arctic Ocean increases, so do the risks of having a spill.

Waste management

- The working group prepared the framework for the development of a Regional Waste Management Strategy. Initiating the early development of strategy and implementing it will contribute to its effectiveness by ensuring proper planning decisions and permissions are achieved prior to oil gas development.

Social, cultural and economic indicators

- In order to accurately measure and monitor the community level impacts, both positive and negative, of oil and gas development in the ISR, the working group highlights several recommended next steps. First, the indicators must be formalized. In addition, work must continue on the collection and analysis of baseline data, and on the development of a system for monitoring the indicators. Finally, there is a need to develop recommendations on measures to mitigate negative impacts of oil and gas activity.

Cumulative effects management

- The BREA Cumulative Effects working group advanced the initial phases of a framework for the management of cumulative effects. While this type of work has been undertaken in the past, there are few successful models to follow. Work remains with respect to finalizing a set of key valued components, which must be agreed to by relevant stakeholders in government, industry and aboriginal organizations. Moving forward, it is necessary to ensure fair determination of responsibility for mitigating and addressing cumulative effects, ensuring monitoring and management activities relies heavily on long-term analysis of baseline data and addressing issues that are not captured under mandatory project-specific environmental assessments.

Regional Environmental Assessment

A regional approach to environmental assessment, seen as a best practice for areas with multi-project resource development, should be considered for the Beaufort Sea. Such a study would facilitate more timely reviews in the case of specific projects and advance responsible oil and gas development. It would maintain the momentum, while addressing issues that are beyond a single project's impacts in the ISR. A regional environmental assessment facilitates future project-specific environmental assessments by building on cumulative effects work, continues to engage all stakeholders in on-going efforts to simplify environmental assessments related to oil and gas development in the North, and could provide a legislative requirement that ensures outcomes are considered in future EA processes. In addition, this option is an opportunity to move BREA results to active use through the development of management tools.

The scope of a Regional Study could include:

- The recommendations above;
- Focus on the regional level analysis of existing research data (fish, birds, bears, sea ice);
- Further work on the cumulative effects of development in the region;

Consideration could also be given to:

- Expanding the scope of the regional study to include shipping or other reasonably foreseeable activities in the Beaufort Region;
- Remaining geographically scoped within areas of jurisdictional mandates i.e., the Inuvialuit Settlement Region.

Finally, Aboriginal and local stakeholders, industry, and federal and territorial governments have an interest in understanding and assessing the trade-offs of potential development scenarios. On-going dialogue and partnerships with all stakeholders are needed to ensure the right information and actions are being undertaken.

Chapter 5.4. Accessing BREA Results

Results of the work undertaken with the support of the Beaufort Regional Environmental Assessment can be publicly accessed through the following sources.

BREA Web site:

www.BeaufortREA.ca

Polar Data Catalogue:

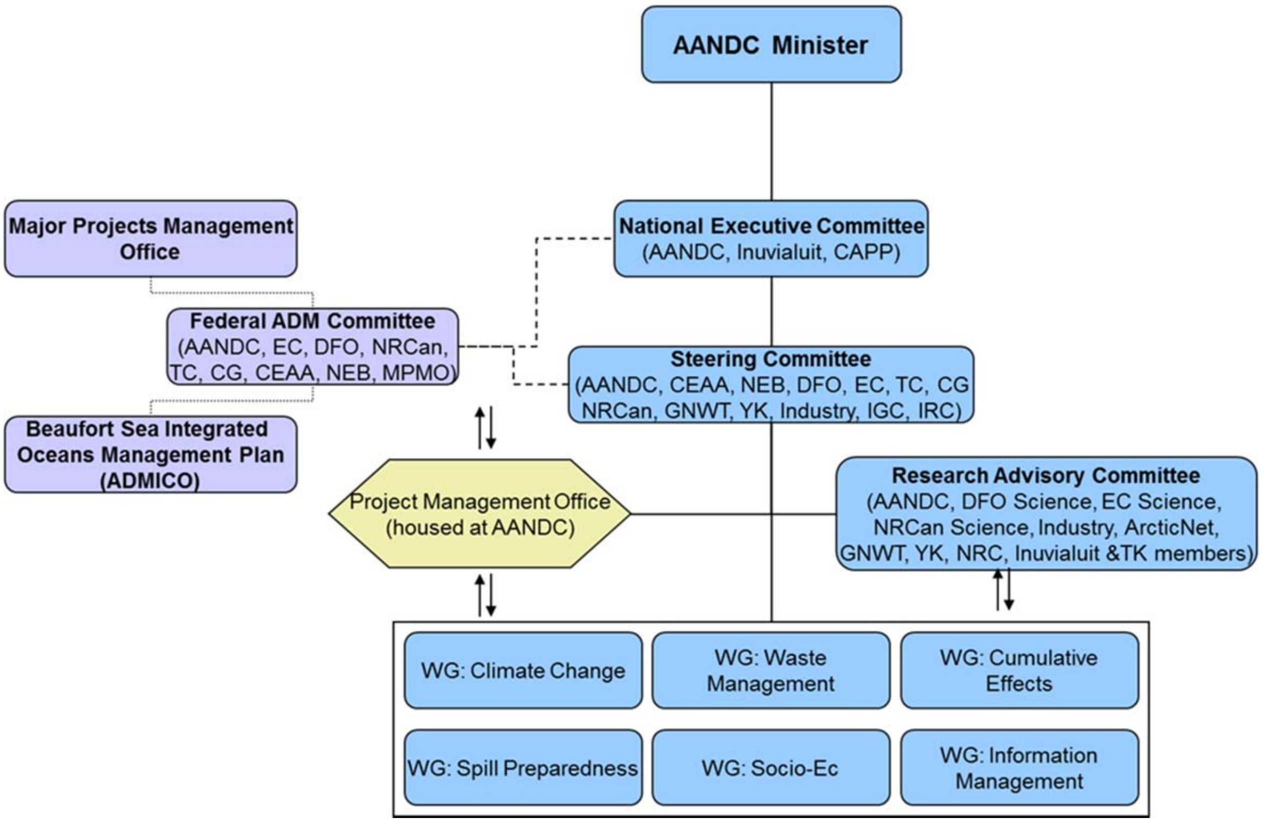
www.polardata.ca

Arctic Science and Technology Information System (ASTIS):

www.arctic.ucalgary.ca/astis-search

APPENDIX 1. BREA GOVERNANCE STRUCTURE

BREA is governed by a participatory governance structure that includes federal and territorial governments, industry, Inuvialuit, and academic organizations.



BREA Governance Structure. [Abbreviations: AANDC – Aboriginal Affairs and Northern Development Canada, CAPP – Canadian Association of Petroleum Producers, CEAA – Canadian Environmental Assessment Agency, CG – Coast Guard (Canada), DFO – Fisheries and Oceans Canada, EC – Environment Canada, GNWT – Government of Northwest Territories, IGC – Inuvialuit Game Council, IRC – Inuvialuit Regional Corporation, MPMO – Major Projects Management Office, NRC – National Research Council, NEB – National Energy Board, NRCan – Natural Resources Canada, PC – Parks Canada, TC – Transport Canada, TK – Traditional Knowledge, YK – Government of Yukon]

APPENDIX 2. BREA BACKGROUND

The Beaufort Sea has in the past been the site of significant oil and gas exploration activity, dating back to the 1950s (BSStRPA, 2008). This continued for almost 40 years, with approximately 53 discoveries of hydrocarbon resources in the Beaufort Sea and Mackenzie Delta occurring between 1970 and 1989 (BSStRPA, 2008). In all, recent estimates indicate the presence of approximately 1.01 billion barrels of recoverable petroleum, and 9 trillion cubic feet of marketable natural gas in the area (NEB, 1998).

However, the collapse of gas market prices and changes in federal subsidies for frontier drilling made such Northern exploration uneconomical, leading to a temporary cessation of oil and gas exploration activity in the early 1990s (BSStRPA, 2008). Inactivity persisted until the Mackenzie Gas Project renewed interest in the area.

Though officially launched in 2010, with a four-year investment totaling 21.8 million dollars, BREA is based on recommendations from the earlier Beaufort Sea Strategic Regional Plan of Action (BSStRPA) that a coordinated and integrated approach should be taken to address the challenges of renewed oil and gas exploration activity in the region. The BSStRPA arose from a 2004 letter written by the Inuvialuit Game Council (IGC) to the Minister of Environment, expressing concerns that current environmental assessment procedures focused too much on individual projects, with insufficient attention to the cumulative social and cultural consequences. In response, a workshop was held in March, 2005 to address the concerns raised and launch the process to develop a plan of action (IEG, 2005). In 2008, this plan was released, identifying 32 recommendations grouped into three overarching themes:

1. Improve regulatory efficiency and effectiveness;
2. Optimize benefits and mitigate environmental, social, and cultural impacts; and
3. Plan for uncertainty.

BREA builds on past and current research efforts. Many of the research priorities echo those identified in a review by the National Energy Board (NEB 2011) on Arctic safety and offshore drilling requirements. Meanwhile, linkages have been made with various Government of Canada initiatives, providing benefit to both parties. These include:

- The Beaufort Sea Integrated Oceans Management Plan;
- The Program on Energy Research and Development (PERD);
- The Polar Continental Shelf Program;
- The Cumulative Impacts Monitoring Program; and
- The Environmental Studies Research Fund.

Similar linkages have been made with industry and international parties and other research initiatives, such as those organized under the framework of ArcticNet and the International Polar Year (IPY), further improving both support for BREA and the impact of BREA's results.