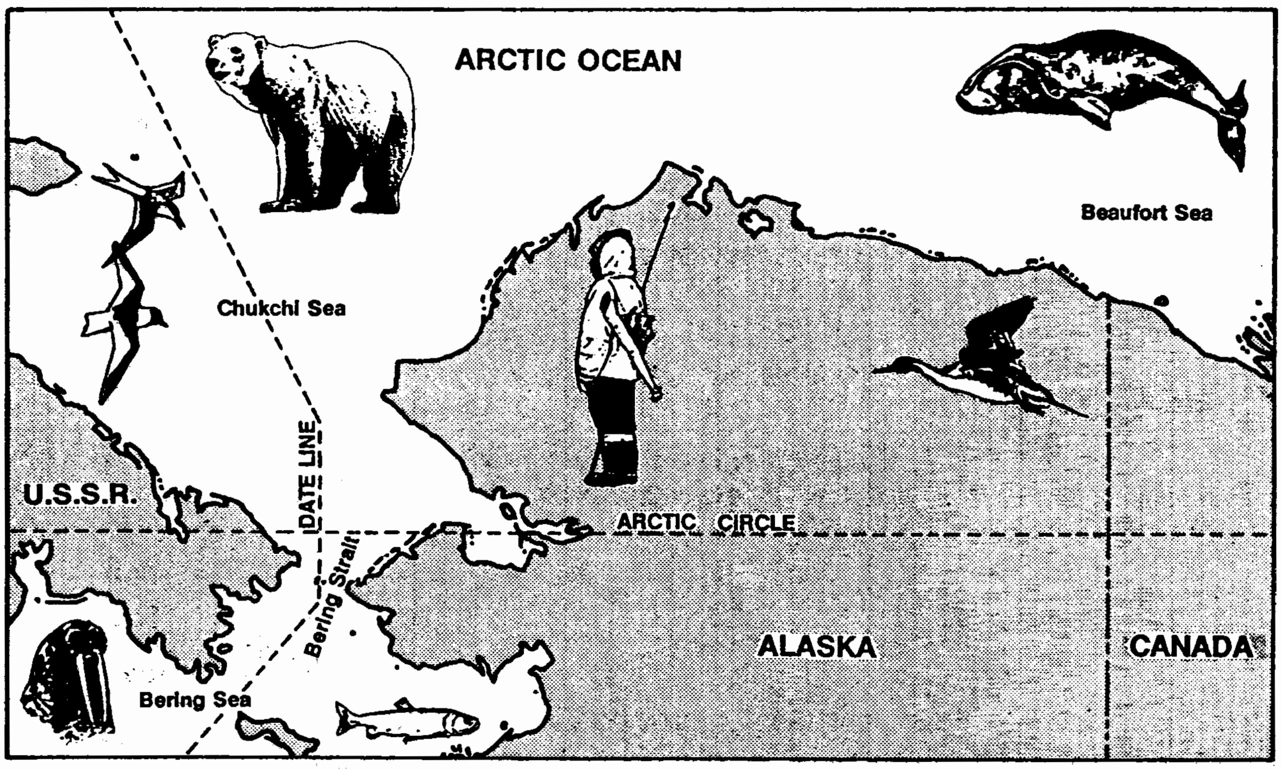
OCS Study
MMS 88-0040

ALASKA OCS REGION

Arctic Information Transfer Meeting

Conference Proceedings



MMS U.S. Department of the Interior
Minerals Management Service
Alaska OCS Region

June 1988

OCS Study MMS 88-0040

ALASKA OCS REGION
1987
ARCTIC INFORMATION TRANSFER MEETING

Conference Proceedings

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MINERALS MANAGEMENT SERVICE
ARCTIC INFORMATION TRANSFER MEETING

INTRODUCTION

Since 1975, the Minerals Management Service (MMS) Alaska Outer Continental Shelf Region Environmental Studies Program has funded over 100 million dollars of research to study the Arctic environment. The purpose of these studies is to provide federal resource managers and policymakers with the best information available on the Arctic for decision-making purposes, and to improve our understanding of the potential impacts of oil and gas development on this ecologically sensitive region.

Information Transfer Meetings (ITMs) are MMS-mandated and are designed to be used as a tool to share MMS Environmental Studies Program results with other MMS program personnel, and also the scientific community, other federal, state, and local government agencies, and the general public. ITMs generally focus on information resulting from past and present ongoing research, in particular lease sale planning areas.

The Alaska Region Environmental Studies Program has funded two ITMs to date. The first ITM was held in Anchorage, Alaska in May 1985 and focused on results of studies conducted in the Bering Sea region. The conference proceedings (OCS Study 85-0084) are available through the Alaska OCS office. The second and most recent ITM is the subject of these proceedings. Held at the Anchorage Hilton between 17-20 November 1987, the ITM focused on studies and research conducted in the Arctic region - the Beaufort and Chukchi Seas.

In conjunction with the ITM, the National Oceanic and Atmospheric Administration (NOAA), Outer Continental Shelf Environmental Assessment Program (OCSEAP) held an Information Update meeting on 18 November. OCSEAP, formed in 1974 as a result of an interagency agreement between NOAA and the Bureau of Land Management (BLM), provides MMS with marine environmental information in support of the need to make sound management decisions regarding the development of oil and gas resources in Alaska.

The scientific presentations at the 1987 ITM included a total of 35 speakers. General topics included: physical and chemical oceanography, endangered species, biological sciences, socioeconomics, and information management. A total of 161 people attended the meeting. Registered attendees are listed in Appendix III. A special MMS fisheries study planning session was also held on the last day of the meeting. Recommendations from that meeting's discussion are included in these proceedings.

Summaries of each speaker's presentation and the discussion following groups of two or three speakers are presented in order of the conference agenda with only slight modifications. The meeting agenda is given in Appendix I. Speaker bibliographies are included in Appendix II.

Because many speakers and participants used acronyms to abbreviate agencies, studies, and scientific jargon during the talks and the discussion periods, a list of the acronyms used and their definition is provided in Appendix IV. Metric to English unit conversions for the reader's convenience are given in Appendix V.

SUMMARY OF MMS OIL AND GAS ACTIVITIES

SUMMARY OF OIL AND GAS ACTIVITIES IN THE U.S. BEAUFORT SEA

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SUMMARY OF OPERATIONS

Six wells were completed in the Beaufort Sea Outer Continental Shelf (OCS) in 1986 and one in 1987. The first well in 1986 was drilled and tested by Amoco from Sandpiper Gravel Island into Lease OCS-Y 0371. Spudded in February 1986 and completed in July 1986, the well was drilled to confirm Shell's discovery well which was spudded in 1985 and completed in January 1986. The discovery well tested at flow rates of up to 2,500 barrels of oil per day (BOPD) and 18.5 million cubic feet (MCF) of natural gas per day. Results of the second well have not been released. Both wells are temporarily plugged and abandoned.

The third well was drilled by Amoco into the Mars Prospect located on Lease OCS-Y 0302 in Harrison Bay. This well was the first exploratory well drilled from a man-made spray ice island in the Alaskan Beaufort Sea. The island was constructed during the 1985-1986 winter season in 25 ft of water. High capacity pumps sprayed water into the air. Water drops froze and fell to the ice surface, creating an ice mass which sank and grounded on the sea floor. Spraying continued until the ice island reached an elevation of 25 ft above sea level. The island was extensively instrumented to monitor for settlement, lateral movement, and temperature fluctuations. Drilling began in March 1985, and drilling, testing, abandonment, and site clearance were completed in late April. The island underwent gradual melting and wave erosion at the edges and eventually broke up sometime in July.

Two wells were completed using Canmar's *Explorer II* drillship between July and October 1986. The first well was drilled by Shell Western Exploration and Production Inc. (SWEPI) at the Corona Prospect on Lease OCS-Y 0871 located in the eastern Sale 87 area in 116 ft of water. The well was spudded in July and completed in mid-September. Upon completion of the Corona well in late September, Union Oil Company of California took over as operator of the *Explorer II* and spudded a second well at the Hammerhead Prospect on Lease OCS-Y 0849 in 100 ft of water. The Hammerhead well was completed in mid-October.

Due to the short open-water operating season, SWEPI and Union both requested and received a one-time exception to Sale 87, Lease Stipulation No. 4, which prohibits exploratory drilling during the fall bowhead whale migration. These exceptions were granted in conjunction with the companies conducting a bowhead whale behavioral study to determine the reaction of whales to drilling noise. Although SWEPI completed drilling operations on September 10, 1986, prior to commencement of the fall migration, the study was conducted during the drilling of both wells. The study consisted of aerial monitoring and behavioral observations of whales. There were limited whale sightings in the vicinity of drilling operations. A final report by LGL, ecological research associates, Inc., the study contractor, is expected to be submitted in the near future.

Amoco also received approval to drill its Erik and Belcher Prospects in the eastern Beaufort Sea during the 1986 open-water season under an exception to Sale 87, Lease Stipulation No. 4, but did not conduct any operations.

Shell and Union participated in the 1986 Oil/Whalers Working Group through which industry and native whalers established a communications and coordination program to avoid interference with the subsistence whale hunt while conducting drilling operations.

The Canmar SSDC was used for the first time in the Alaskan Beaufort Sea in the fall/winter of 1985 when Tenneco drilled its Phoenix Prospect located on Lease OCS-Y 0338 in Harrison Bay in 61 ft of water. The well was spudded in September and abandoned in December. The SSDC was joined with a purpose-built steel mat, which increased its operating depth from 30 to 80 ft.

In 1987, Shell drilled a third well from its existing Tern gravel island in Foggy Island Bay on Lease OCS-Y 0197. The well was spudded in February and completed in May. Two other wells were drilled from Tern Island in 1982 and 1983, which were temporarily abandoned.

Tenneco spudded a well at its Aurora location on Lease OCS-Y 0943 on November 2, 1987. The well is located approximately 3 miles offshore of the Arctic Coastal Plain and 128 miles east of Prudhoe Bay and is currently being drilled. Tenneco is using the SSDC/MAT to drill this well which was moved onto location on September 13, 1987. Tenneco participated in the 1987 Oil/Whalers Working Group to avoid interference with subsistence whaling activities while moving the SSDC/MAT onto location.

Amoco was granted a one-time exception to Sale 87, Stipulation No. 4, to drill its Thorgisl and Belcher Prospects during the 1987 drilling season in the eastern Beaufort Sea. Amoco has given no indication that either well will be drilled this year.

ARTIFICIAL GRAVEL ISLAND ABANDONMENT

Two of the four gravel islands in the Beaufort Sea OCS have been permanently abandoned. Exxon abandoned its Beechey Point gravel island located on Lease OCS-Y 0191 in 1983. The island is still above water but shows some signs of erosion. A two-year post abandonment monitoring study indicated that the gradual erosion of the island has not significantly affected the environment, including the boulder patch community which is located around the island.

Standard Alaska completed final reclamation and abandonment of its Mukluk gravel island west of Prudhoe Bay in October 1987. Constructed in 1983, the island is located in 49 ft of water, and it is the deepest water man-made gravel island in the U.S. Beaufort. Abandonment included removal of the wellhead and casing from the well to below the mudline and removal and disposal of gravel bags and filter cloth material. In areas where gravel bags and filter cloth were exposed, they were removed to a depth of 25 ft below sea level. In areas where the gravel bags and filter cloth were covered with gravel, they were removed to a depth of 15 ft below sea level. All material below 25 ft was left in place. An aerial monitoring program will be conducted by Standard for the next five years to document the condition of the island.

The two other man-made islands on the OCS, Sandpiper and Tern, are being maintained and have temporarily abandoned wells on them. Sandpiper is located on Lease OCS-Y 0370 in 49 ft of water. Tern is on Lease OCS-Y 0196 in 22 ft of water. These two islands, and Shell's Seal Island, which is located on state-submerged lands and from which two wells were drilled into federal leases, have experienced various degrees of erosion and deterioration during this summer's open-water season. Damage is not considered severe enough to threaten the temporarily abandoned wells, and repairs and maintenance will be conducted next year after breakup.

FUTURE ACTIVITY

We anticipate exploratory drilling in 1988 to continue on existing Beaufort Sea leases. The level of future activity in 1988 and beyond will depend in part on new leases issued as a result of the Beaufort Sea Sale 97 which is scheduled for sometime after March 1988, and the Chukchi Sea Sale 109 scheduled for May 1988. Exploratory drilling in these sale areas will likely continue to use the existing available drilling units which are available, including Canmar's ice-reinforced drillships, Beaudrill's Conical Drilling Unit, the Kulluk, with associated ice breakers and ice class support vessels, the SSDC/MAT, and CIDS.

Additional exploratory delineation of the existing Seal Island discovery in the Sale BF lease area may be initiated prior to lease expiration in 1991. Other Sale BF leases may also be explored prior to the 1991 expiration date.

There are currently 14 active exploration plans approved for existing Beaufort Sea leases and exploratory drilling activities can be conducted under any of these plans.

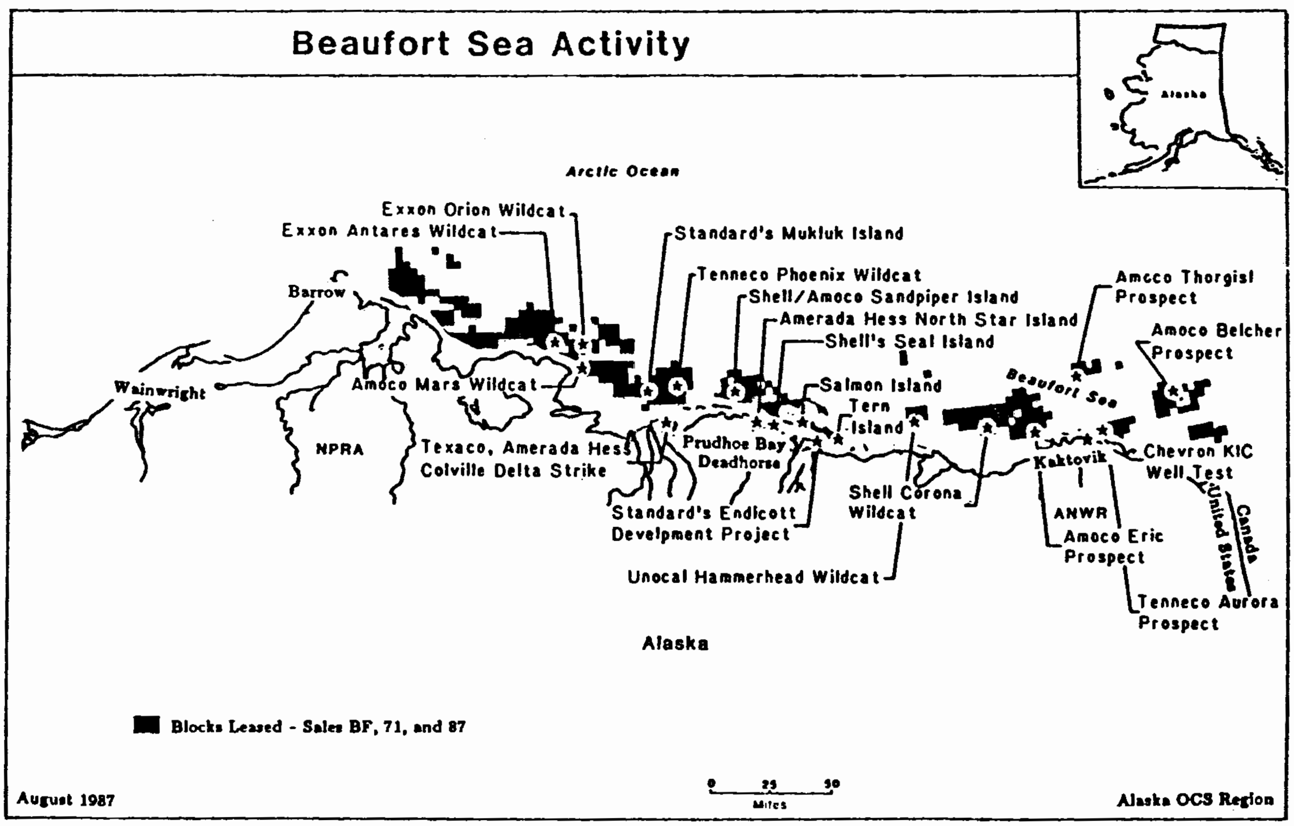

Figure 1. Beaufort Sea Activity.

PHYSICAL SCIENCES SESSION

Speakers

M. J. Hameedi

W. Stringer

R. Pritchard

K. Aagaard

M. Spaulding

M. Reed

D. Padron

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THE ARCTIC OCEAN

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The Arctic Ocean is the smallest and shallowest of the four oceans. It has the most extensive continental shelf, occupying 53% of the seafloor and extending as far as 1300 km from the coast (in the Barents Sea). In comparison, only 10% of the seafloor of the Atlantic Ocean and only 4% of the Pacific Ocean seafloor is classified as continental shelf.

A cursory look at the map of the Arctic Ocean will reveal that the ocean is nearly land-locked, with only a few very restricted openings to the Atlantic and Pacific Oceans: a sort of cold mediterranean sea or polar mediterranean. The Bering Strait is about 90 km wide and 50 m deep; Nares Strait, located between Ellesmere Island and Greenland, is only 15 km wide and 250 m deep. The mean northward flow of low salinity water through the Bering Strait is estimated at 0.6-0.8 Sv (million cubic meters per second), but the flow is quite variable and often reverses. The major opening is the Fram Strait, between Greenland and Spitsbergen, which is 2,000 m deep and 250 km wide. It is through this strait that water from the Atlantic Ocean flows into the Arctic Basin at an average rate of nearly 7 Sv. This water, warmer and more saline than the surface water outflowing from the Arctic, sinks to mid-depths and functions as a heat reservoir in the otherwise very cold surroundings. An apparently large volume of higher salinity brine, formed over the Arctic continental shelf during freeze-up, also exits via the Fram Strait into the North Atlantic Ocean. This water can be traced by its characteristic salinity and dissolved oxygen content.

Characteristically, the Arctic Ocean has a surface layer of cold and relatively freshwater, which extends down to tens of meters. The low salinity of the surface layer is maintained principally by a heavy influx of freshwater from the rivers bordering the ocean, despite the constant export of freshwater (and ice) to the Atlantic Ocean. The total annual river runoff into the Arctic Ocean is estimated at 3,500 km^3, with the Ob (385 km^3), Yenisey (562 km^3), Lena (574 km^3), and Mackenzie (340 km^3) Rivers being the major contributors.

Another main, and much more obvious feature of the Arctic Ocean, is the presence of the permanent sea ice cover whose expanse is nearly 10 million km^2. The ice cover has a tremendous influence on the regional climate and ocean circulation: the high albedo (0.6) of sea ice reflects most of the incident solar radiation; the ice cover suppresses evaporation and impedes the formation of low-to-medium clouds; and strong density stratification in the water column retards nutrient replenishment, and as a consequence, primary productivity in the subjacent waters during the summer. Sea ice can play havoc with marine transportation and installations, and it can impede clean-up operations after an oil spill.

The Arctic Ocean is biologically poor. The paucity of fauna and flora of the Arctic is well-known. For example, among the nearly 23,000 species of fish in the world, only 25 to 30 fish species are known from the Arctic waters. Similarly, only 40 among the 1,500 copepod species in the world, and only 2 among 30 or so species of chaetognaths are known from the Arctic. A number of typically North Atlantic and North Pacific species drift into the Arctic Ocean with the inflowing water. Such species, for example, the copepod *Neocalanus cristatus*, a North Pacific (and northern Bering) species found in the Chukchi and Beaufort Seas, are not considered arctic species.

Not only is the species richness in the Arctic Ocean low, the annual primary production (and as a consequence, biological production at all other levels) is low as well. According to recent estimates, annual primary production over the shelf is equivalent to 27 gC/m^2 and declines over the slope to 9 gC/m^2. These values represent a 16-fold increase over previous estimates, but, relative to most other oceans, including the oligotrophic ones, they are still quite low. The factors contributing to this low production are several; however, the rapid uptake of nutrients from the surface waters during a short burst of primary productivity and extremely retarded replenishment of nutrients from the deeper waters due to the strongly stratified water column are clearly the most important. Nutrients, particularly nitrate-N, are virtually undetectable in the surface layers during the open water period (August-September); a nearly permanent nutrient maximum layer is found 120-140 m deep. Intense algal blooms and high plankton biomass are known to occur throughout the shelf region, notably due to "upwelling" near the ice edge and along small stretches of the coastline, but they are spatially and temporally limited.

Why are the species diversity and biological production so low? Let us examine a few factors, starting with lower temperature.

Lowered temperature is one of the most obvious features of the polar oceans. Its manifestation on biological production and species diversity is probably very minimal. In fact, Margalef has argued that, based on the concept of entropy and assuming all other things being equal, lowered temperature would favor higher specific diversity in the polar marine ecosystem. According to Margalef, any ratio of predator/prey - either in terms of biomass or production - is expected to be higher at low temperature, and if this ratio can be extrapolated to the ecosystem level, one could pack more species, and more biomass, with the same amount of primary production. In other words, more trophic pathways could be supported in a cold environment, making for a higher diversity. But we know that other things are not equal. A closer examination of data reveals that **fluctuation** of temperature and **seasonality** of events are much more important determinants of biological activity in the Arctic than is the water temperature.

In general, organisms in the polar seas have a higher metabolic rate than would be deduced from the relationship between temperature and metabolism for temperate species, i.e. the "Q_{10} rule" is not followed. This is because temperature at high latitudes is not only low, it is fluctuating. A fluctuating temperature is biologically equivalent to a constant temperature higher than the mean of the fluctuating temperature.

Polar phytoplankton do not grow faster than temperate species at low temperatures. The observed doubling time for arctic species (about 0.5-0.8 doublings/day at 0°C) is similar to the value one can derive from the relationship between temperature and maximum algal growth for temperate species (0.7-0.9 doublings per day). The optimal growth of a number of phytoplankton species (only a few have been investigated) occurs at 9-10°C, remarkably similar to the temperate species. It appears that the polar species do not have particular adaptive strategies for lower ambient temperatures.

Although temperature *per se* may not be very important in terms of the Arctic biota, there are several adaptations that the Arctic fauna and flora have evolved to benefit from what is available and to survive in a highly fluctuating environment. A few such adaptations are noted below.

Shade-adapted Phytoplankton: The Arctic phytoplankton is shade-adapted and is known to actively photosynthesize at 1% (or even lower) of the incident solar radiation. It has relatively low C:Chl ratio, but under nutrient limited conditions the ratio increases dramatically.

Long Life Cycles: The marked seasonality and paucity of biological production is also reflected in long life cycles of the secondary producers. Some Arctic copepods have life spans of two and even three years. A number of small copepods, which can have as many as five generations per year in temperate waters, have only one generation per year in the Arctic. This apparent one-year minimum in pelagic life cycles could have evolved in response to the need for delaying spawning until the next phytoplankton bloom to assure sufficient food supply for the brood.

Large Body Size: The individual body size of Arctic animals is large; this is particularly obvious in zooplankton. There are several probable reasons for this. Large and better-nourished offsprings usually have a greater chance of survival in a varying and hostile environment. Adult populations of such species could be maintained through biological competition (k-strategy) rather than be characterized by marked fluctuations in response to the physical environment (r-strategy). Let us recall that there is a positive correlation between body size and fecundity, particularly in the case of cold-blooded animals. A comparison of two species of Pacific salmon provides an example: the average number of eggs laid by king salmon *Oncorhynchus tshawytscha* is 5,000 and that by pink salmon *Oncorhynchus gorbuscha* 2,000. King salmon, on the average, are five times (10 kg) larger than pink salmon (2 kg). Thus, the larger the body size, and larger the progeny, the greater there is the chance of survival through a relatively long life span.

Resting Spores: Another obvious adaptation for survival through the highly cyclic environment is the formation of resting spores, which are quite common among the centric diatoms in the Arctic (resting responses to unfavorable environmental conditions with latter germination under favorable conditions). It is of interest to note that the resting spores in the diatom *Thalassiosira nordenskioeldii* are formed mainly at temperatures between 0-5°C and not at all at 15°C. The viability of the resting spores is also temperature-dependent: in the case of *T. nordenskioeldii*, spores remain viable for up to 570 days at 0°C and only for a week at 20°C.

Migrations: The well-known seasonal migration of a number of species in the Arctic is cued to the availability of food and suitable habitat for survival.

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ARCTIC REMOTE SENSING

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Remote sensing techniques are customarily employed to sample datasets for a variety of reasons, including a need for simultaneous wide area coverage, a requirement for data acquisition at hostile or not easily accessible locations, and a desire for data samples at remote locations at relatively high rates. The sampling of environmental conditions in the Arctic is a particularly good example of the utility of this approach to acquiring data simply because remotely sensed information is often the only record of events and their sequence.

The best known remotely sensed datasets are in image format. These first became available in the form of meteorological satellite imagery in the late 1960s, but the data quality from this source was considered rather poor for surface environmental studies until the early 1970s. Starting in 1972, LANDSAT imagery became available in four sampled wavelengths, including two bands in the near infrared which made vegetation-related studies possible. These images provided data at 80-meter resolution which yielded a wide variety of arctic information, including a number of datasets of considerable interest to the Outer Continental Shelf Environmental Assessment Program (OCSEAP). Examples are: drift patterns of sediment suspended in the ocean, the boundary of the fast ice and its change over time, the movement of drifting ice (see Figure 1), the timing and patterns of ice formation and removal (see Figure 2), and the location of massive ice ridge systems. About this same time the quality for the meteorological satellites' thermal infrared sensors improved to the point that studies of oceanographic temperature related phenomena could be undertaken. These images yielded information concerning temperature distributions in the Alaskan offshore environment, including the alongshore drift of warm water from the Alaskan Bering Sea coast through the Bering Strait into the Chukchi Sea. In addition, the thermal infrared images have yielded sea ice information during the dark winter months when visible band imagery was not useful. In particular, these images have yielded the presence and size of polynyas in the Bering and Chukchi Seas. Recently, LANDSAT added a 7-channel, high resolution "Thematic Mapper." These two datasets - the U.S. meteorological satellite data currently acquired by NOAA-7 with the 5-channel Advanced Very High Resolution Radiometer (AVHRR), and the LANDSAT series data currently acquired by LANDSAT 5 with both a 4-channel MSS and a 7-channel Thematic Mapper - represent the major source of arctic remotely sensed image format data. At present, this dataset is very nearly fifteen years in length and is a valuable source of statistical data describing a variety of environmental conditions.

However, these are not the only datasets available: The U.S. Air Force conducts the Defense Meteorological Satellite Program (DMSP) which has operated a series of meteorological satellites since 1973. These data are available in two spectral samples: a very broad spectral band spanning the entire visible and photographic infrared wavelength regions, and a thermal infrared band situated in a wavelength region that corresponds to cloud and sea ice temperature. The U.S. Navy has operated a number of sea surface altimeter satellites currently represented by GEOSAT that samples sea surface height at Alaska's latitude on a 75 km grid. In 1977, NASA launched SEASAT, with an L-band Synthetic Aperture Radar (SAR) and an altimeter. Unfortunately, the satellite only operated for a few months in 1977. However, even this short operating period created a dataset which is still being analyzed.

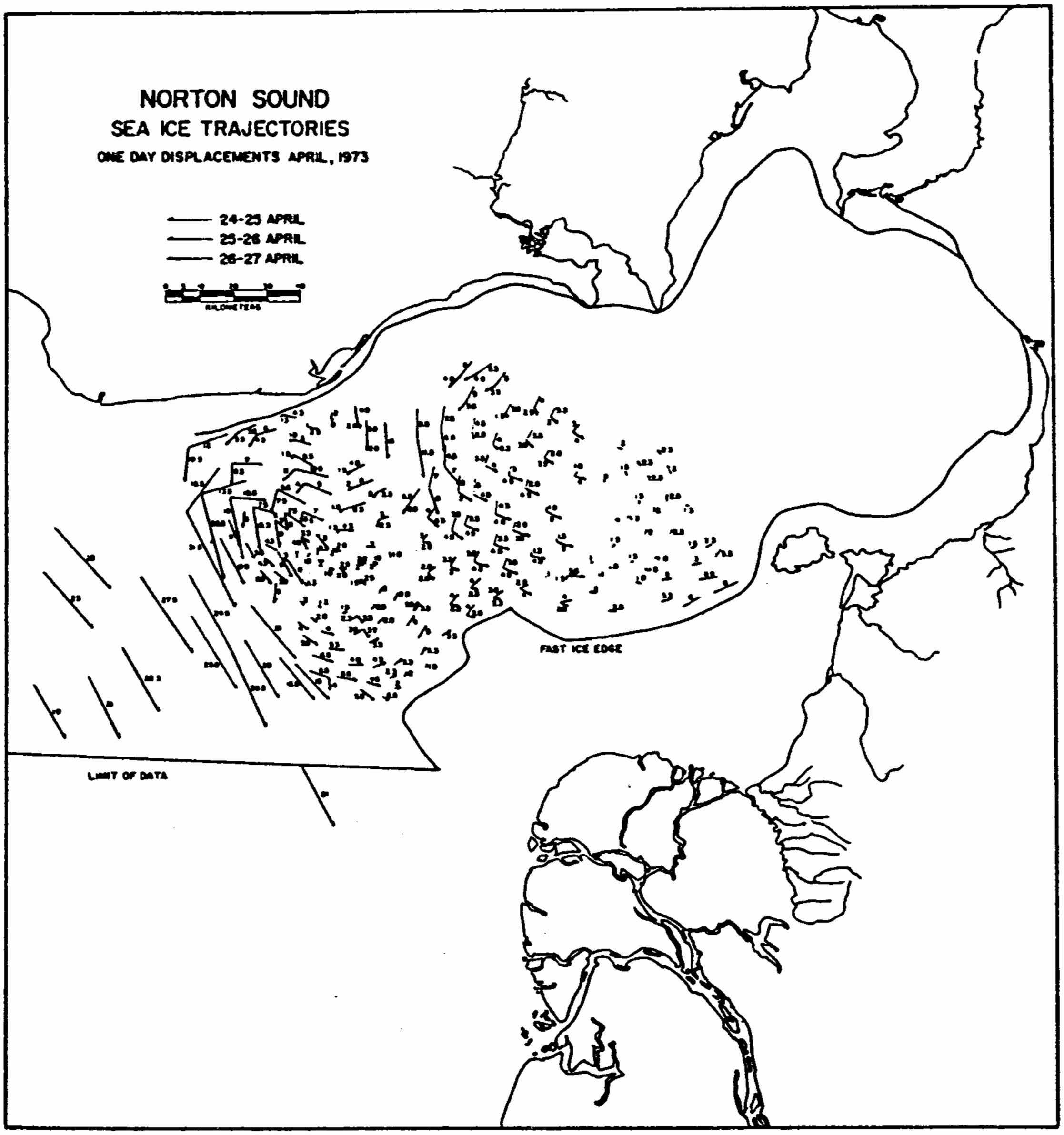

Figure 1. Shown here are Norton Sound ice displacements observed between April 24 and 27, 1973. During this period the ice appears to be participating in two counterclockwise (looking down) gyres. At the same time, the ice in the adjacent Bering Sea is streaming past the entrance to Norton Sound on a nearly due south heading at speeds ranging up to 27 km/day. One piece of Norton Sound ice, which has entered this stream from the top of the western gyre, has a displacement of 31 km in one day.

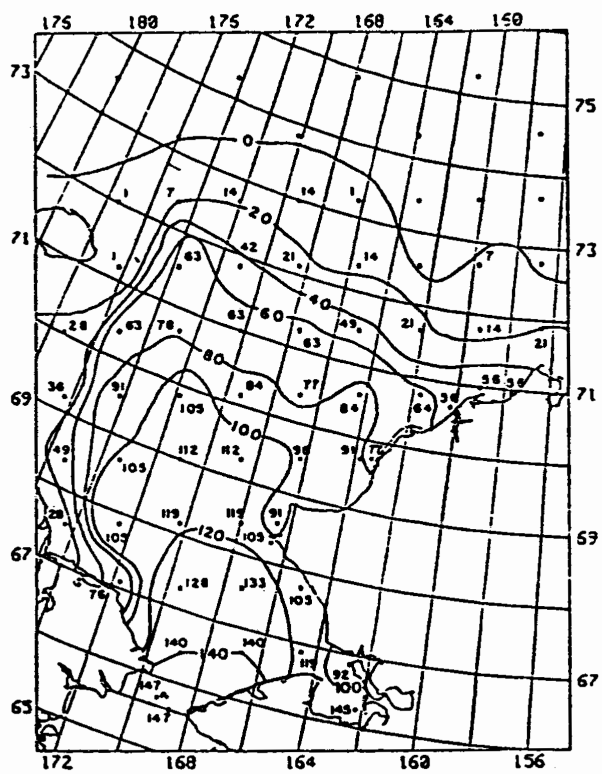

Figure 2. Median length in days of the longest period of continuous ice-free water determined for 67 stations in the Chukchi Sea.

A few years ago, NOAA placed a 5-channel passive microwave radiometer onboard a Nimbus satellite as part of an experimental attempt to provide sea ice data that was not cloud dependent. These images are available, but the resolution is on the order of tens of kilometers and, therefore, the data are generally only used to determine gross features of the Arctic and Antarctic ice packs. Nevertheless, these data have been utilized in statistical studies of the ice edge location during cloudy periods when no other data were available.

The SEASAT data showed that a great deal of ocean and ice information could be obtained continuously by radar eliminating interference from clouds or the need for illumination, and thus created a worldwide interest in image data from this source. Currently three organizations - the European Space Agency, the Japanese Space Agency, and the Canadian Center for Remote Sensing - are all planning to launch satellites carrying imaging C-band SAR starting in 1990. In preparation for this, the National Aeronautics and Space Administration had funded a project to install a receiving station for these datasets at the Geophysical Institute of the University of Alaska Fairbanks. SAR data when received is actually a hologram, being mathematically convoluted in both azimuth and range. As a result, a rather large computer is required to perform the deconvolution operations before an image can be seen. This operation, as well as archiving, cataloging, and distribution, will be performed at the Alaska SAR Facility. The first images should be available early in 1990.

A variety of studies are envisioned to be based on these data - some of which should be of interest to OCSEAP. These include studies of ice floe movement and polynya formation - both of which have met limited success in the past as a result of cloud and fog cover. In addition, it will be possible to more adequately monitor Beaufort Sea alongshore flow during summer as indicated by ice drift. These flow patterns have offered tantalizing glimpses of gyres and other interesting ice edge phenomena in the data available to date. Another area where information will be greatly enhanced is the availability of ice presence data in general. In particular, our information in the eastern Beaufort Sea should be enhanced. This is important because ice is present close to shore here all summer, but since cloudiness is greater here than anywhere else along the Beaufort Sea, behavioral and statistical data regarding this ice has been the most difficult to obtain. We also anticipate to at last gain insight into the formation of fast ice during fall and early winter, including the formation of the massive shear and pressure ridges which anchor the fast ice. Finally, we know from SEASAT imagery that through SAR imagery, it will finally be possible to monitor the presence and motion of ice islands and other large ice features such as multi-year floes.

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Question (Nauman): What is the resolution of satellites now available and what is the smallest lead you can measure?

Response (Stringer): First of all, I should point out that the resolution and the ability to detect objects are really two different items. Resolution is the ability to determine that there are two objects in your field of view about one, which is the term that comes from the use of telescopes by astronomers. Usually the measure of resolution is a pretty good idea of what you can detect, but clearly something could be smaller than your resolution and be detectable. For instance, an extremely bright light bulb would be detectable with a system that had large picture elements if the light bulb was bright enough. It would just appear on your screen to be as big as the entire picture element. So, there are a couple of questions. The resolution element on LANDSAT, on MSS (multi-spectral scanner) is 80 m. The resolution element of the Advanced Very High Resolution Radiometer (AVHRR) is something like a kilometer. Maybe it's less now because that's been changing. There is a military satellite (DMSP) with a resolution element somewhere between LANDSAT and the AVHRR. I'm not exactly sure what it is, but some of their sensors, I think, are on the order of 0.5 km. The SPOT satellite has a panchromatic sensor which has a 10 m resolution element. The thematic mapper of LANDSAT has resolution elements on the order of 20 m. I think the SEASAT had resolution elements on the order of 30 to 40 m. I also think the resolution elements on this new series of satellites are on the order of 20 m, but strangely enough, the actual resolution is around 30 m, which means they are oversampling the data. So, that gives you an idea of the size of resolution elements. However, if you are detecting leads, you will note that a lead on a lot of imagery will be essentially black, for instance, in the near infrared (IR). The near IR is almost totally absorbed by water. Therefore, in the near IR, a lead will look black, whereas the surrounding ice (especially if it is snow-colored) will look white. Under a condition like this, the lead, which is considerably smaller in width than a resolution element, will still change the gray level of that resolution element. Therefore, leads smaller than a resolution element are detectable. In fact, there have been some studies performed that show that sometimes on a LANDSAT you can have a lead as small as about 20 m wide that is detectable on the resolution element. However, when you look at the image, it would appear like it was 80 m wide. There is an ambiguity between a 80 m wide lead that is partly frozen or a 20 m lead that is totally open. I would say with the present satellites, it is possible to detect leads on the LANDSAT that are about 10 or 20 m wide. On SPOT, I suspect that you are actually able to detect leads that are about 5 m wide and it remains to be seen what will be true on SAR. I suspect it will also be able to detect leads that are considerable less wide than a picture element.

Question (Eppshine): Are there plans to have drifting buoys in the Arctic?

Response (Stringer): There have been and there will be buoys in the Arctic. Their positions are tracked by these position measuring satellites. Bob Pritchard is going to talk about measurements made with drifting buoys. The nice thing about the buoys is that they can also radio back temperature and pressure. So, they not only give you information about ice trajectories, but also information that allows you to look at the weather systems that are associated with the drifting buoys.

SEA ICE MOTION

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INTRODUCTION

The broad continental shelves of the Beaufort and Chukchi Seas are one of the remaining undeveloped areas that show potential for oil and gas production. The presence of sea ice for up to ten months of the year requires specially designed drilling rigs, limits the drilling seasons, and dictates the methods that can be used to explore for petroleum and produce it when discovered. The motion of the ice cover and its thickness and extent are essential parameters in the engineering designs needed for both exploration and production. Therefore, knowledge about sea ice motions is of practical interest, in addition to our interest generated by scientific curiosity.

Since the OCSEA Program must provide input for the Environmental Impact Statement describing the effects of Arctic offshore petroleum exploration and production, the fate and behavior of oil spilled during any of these operations must be known. Studies have shown that oil spilled on or under the ice cover will be contained by the rough top and bottom surfaces, and it will move with the ice. Therefore, if we are to know where oil might be transported after a spill, we must know the motion of the sea ice cover. We are interested primarily in the large scale motion of the ice over time periods of months to years. When the ice motion is different at two locations, the deformation between the ice floes changes the ice conditions. On scales of tens of kilometers, deformations occur as leads form, and the ice floes raft and ridge. These processes must be understood in order to describe the large scale behavior of the sea ice cover.

Sea ice motions have been measured directly by placing camps or buoys on an ice floe, and observing the change in position using the NOAA satellites. These ARGOS buoys periodically transmit a known high frequency signal that is received by a satellite. The frequency of this signal appears to change because of the satellite motion, and this change allows the buoy position to be estimated. The ARGOS buoys have been deployed throughout the Arctic Basin since the mid-1970s, and, along with camps, have provided roughly 120 station-years of ice motion data. These observations have been used directly to estimate the average ice motions at each location and the range of motions from one season or year to the next. Buoy position estimates are accurate to within 0.3 km, and daily-average velocity estimates are accurate to within about 1 km/day.

Sea ice motions have also been estimated by mathematical models of the behavior of the sea ice cover. These models use winds or barometric pressure fields as input and provide estimates of the sea ice motions as output. Barometric pressure fields were available as early as the 1950s, and provided a longer term database than the buoy measurements. However, the

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mathematical models and their input data are less accurate than the buoys. Sea ice dynamics models can estimate motions to within about 3 km/day.

The forces acting on the ice cover include air stress, water stress, a Coriolis force, sea surface tilt, and internal stress divergence from the inter-floe forces. These forces accelerate the ice and change its kinetic energy. The inertial force is negligible when averaged over a day. If the neighborhood of an ice floe has more than about 15% of its area exposed to open water, then the inter-floe forces are negligible, and each floe can drift freely without interacting with its neighbors. The winds and currents can therefore diverge or converge the area without breaking the ice floes. If the ice is more compact, then inter-floe forces require that rafting and ridging accompany any convergence or shear of the area. The forces vary in each floe, but if we average the inter-floe forces over a neighborhood of tens of kilometers, then the internal stress that causes these deformations varies slowly over hundreds of kilometers. Therefore, as the ice pushes against a coast, the effect of the coast can be noticed in the ice behavior at distances of a thousand kilometers. These effects have been described by ice dynamics models. The general ideas are reasonably well-understood. Mathematical models have been developed to describe the ice behavior, and a few computer simulations have been made to verify that the models are accurate. These simulated motions are compared to data from drifting buoys.

Each of the above approaches has advantages and disadvantages. The buoys measure motions of individual ice floes accurately, but only a short history of observations exists and few buoys are nearshore. Ice dynamics models provide an understanding of the physics and a longer history, but are less accurate. In light of these limitations, the OCSEA Program has pursued both avenues of research: buoys have been deployed to gain more direct observations, and models have been developed and used to improve understanding of the physics and to make use of historical barometric pressure field data.

MOTIONS

Arctic Basin

The long term general circulation of sea ice in the Arctic Basin includes a clockwise gyral motion in the Beaufort Sea and a transpolar drift stream from the eastern Siberian shelf across the North Pole and southward in the East Greenland drift stream. The long term temporal average ice displacement is 1-2 km/day, and the rms daily motion is 7 km.

A comparison between daily-averaged winds and ice velocities shows that the ice speed may be estimated to be 0.8% of the geostrophic wind speed, and turned 8° to the right of the isobars. This regression explains over 70% of the velocity variance for ice that is at least 400 km from shore.

Beaufort Sea

The Beaufort Gyre carries ice westward across the north slope of Alaska at an average speed of roughly 3-5 km/day. During a storm with 12 m/s (25 kn) winds, the ice pack some 400 km from shore can move about 25 km/day. Landward of the barrier islands, the ice becomes motionless by about December of each year, although there have been incidents when the ice has been pushed on the order of a hundred meters onto the shore in fall and spring. The ice is often motionless seaward of the barrier islands, but can move with the pack ice under the right wind and ice conditions. Between the mobile pack ice and the landfast ice, the ice is heavily deformed by the shear and compression as the polar pack moves unsteadily westward. In 1975-1976, the AIDJEX project had 4 camps and 20 buoys drifting in the Beaufort Sea. Nearer to shore, the OCSEA Program deployed roughly 10 more buoys. Since 1979, the First Global GARP Experiment (FGGE) program has deployed nearly half of its buoys in the Beaufort Sea, although few have been closer than 200 km to shore. Roughly 50 station-years of ice motion data are available for this region.

Ice dynamics models have simulated the ice behavior accurately here. The ice motion is driven by winds, currents, and internal stress transmitted from the polar ice pack around the nearshore Beaufort Sea. During summer, the ice stress is negligible because the thin ice melts and creates open water. When there is little open water or young ice, either in winter or in summer after convergence eliminates the open water, the ice responds to wind and current stresses averaged over hundreds of kilometers. The winds provide the largest external force to move the ice in the Beaufort Sea. The geostrophic current is typically less than 0.30 m/s (0.6 kn). The Beaufort undercurrent is larger but typically has no surface manifestation to affect the ice motion. Although there are local wind features, such as mountain barrier effects near Barter Island and sea breeze effects, these become less important in winter because their extent is less than 100 km.

Chukchi Sea

The dynamics of the Chukchi Sea ice behavior are complicated because the region is influenced by many processes. To the north, the Chukchi Sea merges into the Beaufort Sea with its multi-year ice cover. To the south, in the Hope Basin region, the ice is confined by the land. Near the Bering Strait, it is affected by the current, that has a northward average, but is punctuated by strong reversals that exert large drag forces on the ice. Since 1976, there have been at least six field projects, each of which deployed 4-6 buoys on the ice. The ice behavior was generally similar from year-to-year, and here we describe the ice behavior during one such project.

From December 1981 through June 1982, the average drift of the Chukchi Sea ice cover was toward the northwest, moving approximately 650 km. Ice from the Hope Basin moved north-northwestward about 500 km. Within about 200 km of the Alaskan northwest coast, the ice tended to move back-and-forth alongshore in episodes lasting approximately 10 days. The daily ice motion was typically 5-10 km, which accumulated to about 200 km per month, but because the ice moved back-and-forth, the net seasonal displacement was about 100 km or less. The tidal and inertial oscillations were small. The alongshore component of motion was similar everywhere along the coast, suggesting that the dominant force was applied by currents driven by the large-scale atmospheric pressure systems. The current explained from 44 to 93% of the ice velocity variance, while the wind explained from 2 to 77%. The current is a more important factor in moving the ice in the nearshore Chukchi Sea.

In the absence of ice stress divergence, a free drift model should provide a good approximation to the force balance. In the southern Chukchi Sea near Hope Basin, the free drift model explained 88% of the variance of the ice motion, but farther north along the Alaskan coast it explained only a negligible amount. Therefore, the ice stress divergence was important in the northeastern Chukchi Sea during this time period. The Chukchi Sea ice north of Cape Lisburne is about 1 m thick by early January and grows to about 2 m by March. This ice becomes heavily rubbled by the deformations that accompany the frequent ice motion in this region so that the ice stress can become large and dominate the force balance equation.

Bering Strait

We have just discussed the sea ice behavior during 1981-1982, when sea ice in the northeastern Bering Sea was transported northward into the Chukchi Sea. Several buoys drifting on this ice oscillated over 300 km back-and-forth through the Bering Strait up to three times. In the previous year, a similar northward transport, without the oscillations near the Bering Strait, was also observed. During still other years, satellite imagery has shown, and modeling studies have confirmed that northeasterly winds and southward currents have transported Chukchi Sea ice into the Bering Sea. At some times during southward currents, a structural arch has formed across the Bering Strait, with the ice stresses resisting the drag force from the large southward currents. Studies using mathematical models have shown that these arches can be broken down if the currents and winds are large enough.

Ice dynamics models have shown that the currents exert the dominant force on the ice during the times when the structural arch breaks down. The set up/set down of the sea level to the north and south of the Bering Strait causes these currents, which create drag forces on the ice that are larger than the local drag force from the winds. During arching conditions, the internal ice stress field is similar to that found in the soil above a tunnel or in a stone wall over a doorway. At the same time, the central and western Chukchi Sea ice is prevented from moving southward by the northern Siberian coast. This support is similar to a column acting as a buttress for the arch.

SUMMARY

Since the mid-1970s, we have learned much about the ice motions in the Beaufort and Chukchi Seas. The average motions and the range of variability from year-to-year have been estimated from well over a hundred station-years of observations. In general, the ice motions follow the patterns suggested by earlier investigators. There have not been too many surprises as we have quantified this behavior. Mathematical models have been developed, and these can describe the observed behavior accurately. The models provide understanding about the forces that cause the observed ice motions, and allow us to estimate ice motions during times when ice motion data are not available. Together the data and models provide the information needed to describe ice behavior that might be expected during the exploration and production phases of petroleum development in the Beaufort and Chukchi Seas.

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ARCTIC CIRCULATION AND PHYSICAL OCEANOGRAPHY

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THE LARGE-SCALE PERSPECTIVE

The Arctic Ocean is a markedly mediterranean sea, and this combined with the high latitude leads to a unique climatology and circulation. Of particular importance are the processes and conditions native to the periphery of this largest of the world's mediterranean seas, for an understanding is now emerging that the Arctic Ocean is to a large degree forced at its lateral boundaries, and that much of the organized transport appears to be trapped along these boundaries. It is within this perspective that we need to understand the regional oceanography of northwestern and northern Alaska, for the events which occur there have consequences for regions far removed. Conversely, these shelves are themselves affected by events originating in distant places.

Four major issues are involved: ocean ventilation, boundary currents, eddy generation, and advective exchanges with the seas to the south.

Ocean Ventilation. Beneath a shallow mixed layer, the Arctic Ocean is very strongly stratified. This effectively isolates most of the Arctic Ocean from the overlying atmosphere, with enormous consequences for the climatology of the atmosphere, ice, and ocean. A second remarkable feature of the Arctic Ocean is the very saline water which fills the deep basins and flows south into the Greenland and Norwegian Seas, ultimately to exert their influence on the deep North Atlantic. A variety of physical and geochemical work during the past few years has shown that both of these basin-scale features have their origin over the shelf seas bordering the Arctic Ocean. These shelf seas are therefore ventilating both the intermediate and deep ocean, transferring surface properties into the subsurface interior. The physical process ultimately responsible for this circulation is brine rejection during sea ice formation. Under appropriate circumstances, dense waters of enhanced salinity can be formed during freezing, and these waters may flow off the shelf as sinking gravitational plumes, subsequently spreading into the interior of the ocean. Work on the Alaskan shelves during the past decade has been instrumental in developing our present understanding of this phenomenon.

Boundary currents. Recent flow measurements at several sites in the Arctic Ocean show strong, but narrow boundary currents directed counterclockwise along the perimeter of the two major basins (the Canadian and Eurasian). These currents are found subsurface over the upper slope and outer shelf, with both the shallow surface layer and the ice cover generally moving in the opposite direction. In the Beaufort Sea, where we first discovered this boundary current, we have called it the Beaufort Undercurrent. This flow is the dominant feature of the circulation seaward of about the 50m isobath. Note that it runs counter to the prevailing westward motion of the ice (Figure 1). The flow is in effect a large scale conveyor belt which carries water and materials eastward, but with considerable low-frequency variability, including frequent reversals. In contrast, the interior circulation in much of the Arctic Ocean appears to be very weak, so

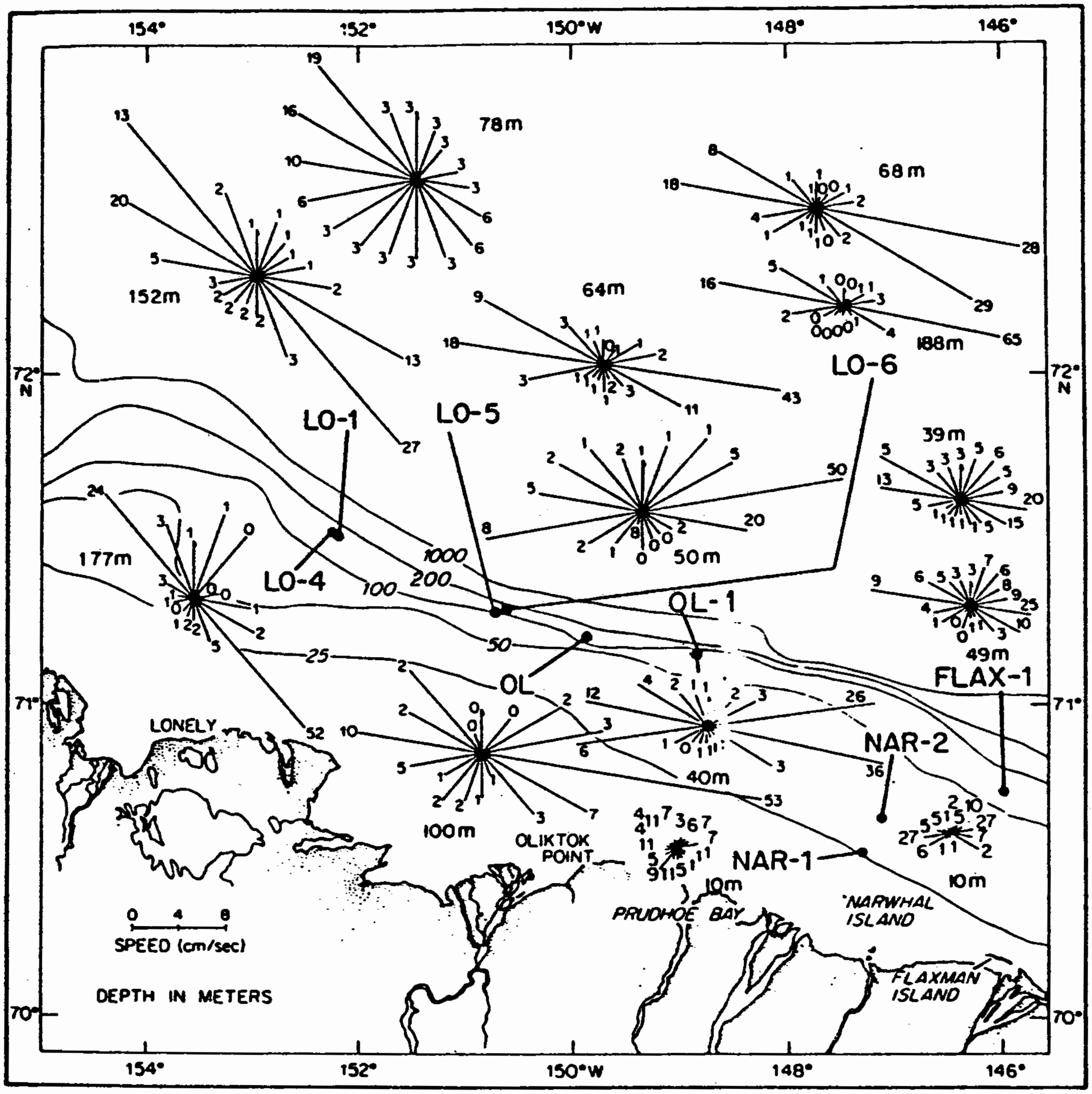

Figure 1. Current roses from 1976-80. Depth of measurement shown adjacent to each rose. Heavy dots show mooring locations. Adapted from Aagaard (1984).

that these subsurface boundary currents may well prove to be the principal large-scale organized advective features of the Arctic Ocean.

Eddy generation. Essentially the entire concentration of kinetic energy within at least the Canadian Basin of the Arctic Ocean is in the field of time-dependent motion. In turn, below the mixed layer the single largest identifiable contribution to the time-dependent motion is from the mososcale eddy field. These small vortices have a characteristic diameter of about 20 km and the maximum speed is typically near 25 cm s^{-1}, although flow more than twice that has been measured. Large numbers of these eddies have now been found throughout the Canadian Basin, the majority embedded in the main pycnocline (i.e. as subsurface spinning lenses between about 50-350m), although a number of deeper ones have also been observed. The eddies are likely very long-lived (of order a year or more), and they quite likely constitute a significant transport and mixing mechanism within the Arctic Ocean. The anomalous hydrographic properties of the pycnocline eddies, together with dynamical constraints on their generation, suggest that they are generated in the northern Chukchi Sea, a prime suspect being the mouth of Barrow Canyon (Figure 2).

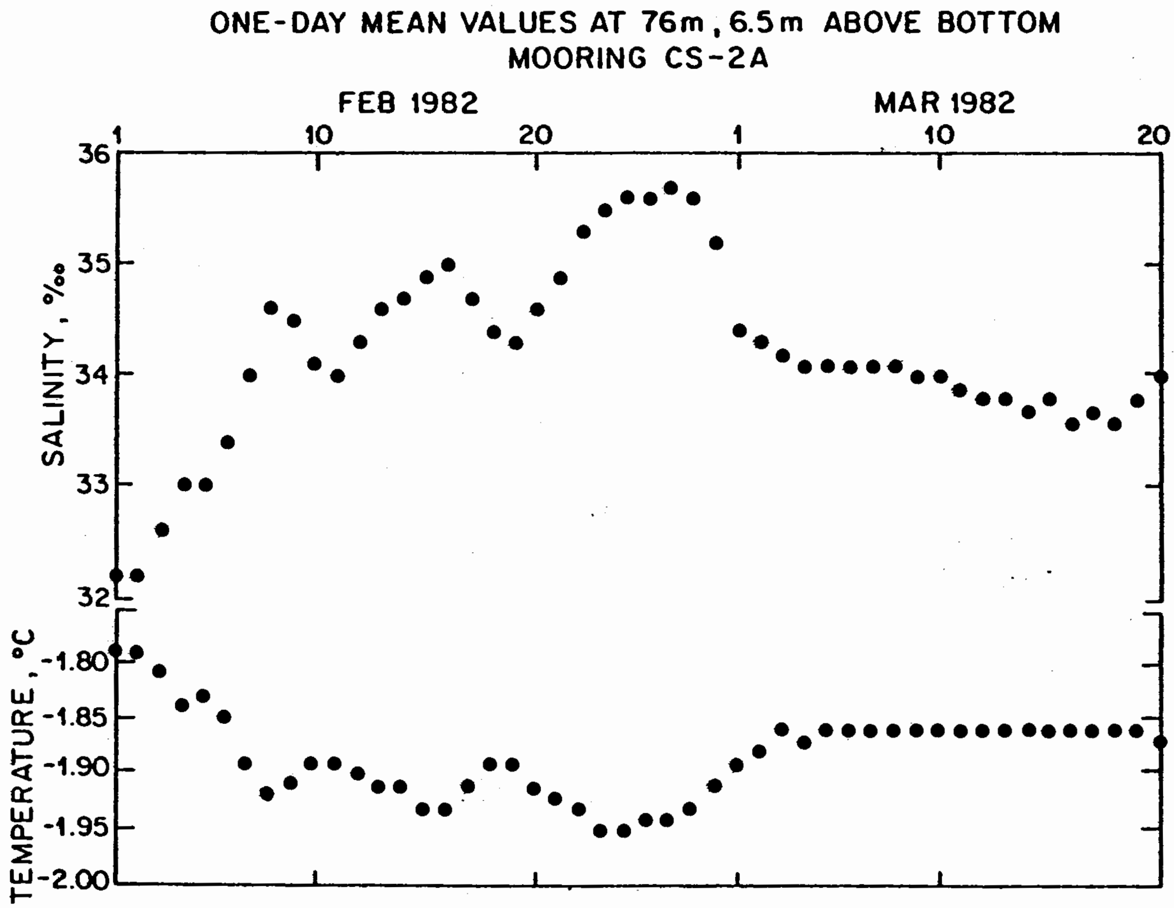

Figure 2. Daily mean salinity and temperature 6.5 m above bottom in Barrow Canyon during later winter 1982. The farfield ambient salinity is near 32.5. The record represents surges of brine draining northeastward into the Arctic Ocean. From Aagaard, Swift and Carmack (1985).

Advective Exchanges. While the largest exchanges between the Arctic Ocean and the seas to the south are through the various passages connecting to the Atlantic, the inflow from the Pacific through the Bering Strait plays a crucial role in maintaining the density structure of at least the upper Arctic Ocean (Figure 3). As pointed out earlier, this has enormous climatic consequences for the Arctic. On the regional scale, the effect of this inflow is also unequivocal. The water from the south, which in summer is anomalously warm, causes the Chukchi to become ice-free much earlier in the year than would otherwise occur, and it likewise extends the ice-free season later into the fall. However, the importance of the Bering Strait flow is not limited to the physical environmental, but is equally directed at the biological regime. The nutrient-rich waters carry Pacific planktonic life forms into the Arctic; they define a migratory pathway between the Arctic and the Pacific for a variety of animals; and they redistribute the extraordinarily high organic production of the northern Bering shelf.

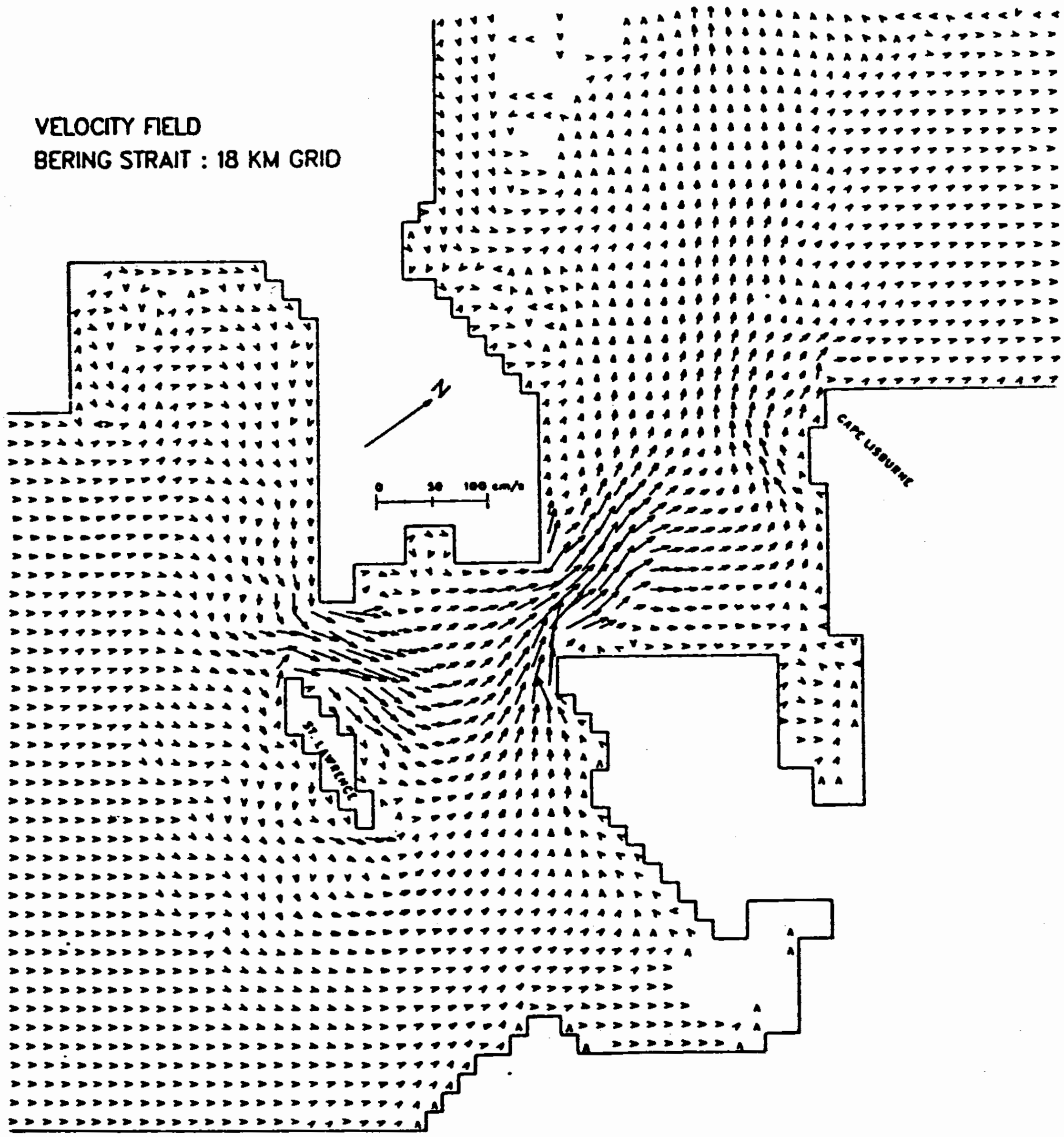

Figure 3. Shelf circulation in the Bering and Chukchi Seas according to the barotropic model of Overland and Roach (1987). The wind stress is zero.

THE REGIONAL CIRCULATION

Within this large-scale perspective, I will provide a brief synopsis of the regional circulation off northwestern and northern Alaska.

Bering Strait. In the mean, the surface of the Pacific Ocean stands about 0.5m higher than that of the Arctic Ocean. This difference in sea level is capable of driving a northward flow of about 1 Sv (10^6 m^3 s^{-1}) through the Bering Strait. As the water moves northward across the Bering shelf, vorticity constraints likely concentrate the flow on the western side, so that a majority of the water passing through the Bering Strait has come through the Anadyr Strait, west of St. Lawrence Island (Figure 3). This basic flow pattern is substantially modified by the variable and largely meridional wind field acting on the ocean within a rather complex coastal geometry. The net effect is to alter the sea surface topography such that northerly flow is reduced during northerly winds and increased during southerly winds; under strong northerly winds, the flow will actually reverse toward the south. Northerly winds dominate during winter, resulting in a reduced long-term mean flow through the Bering Strait of perhaps 0.8 Sv or less. There is a pronounced annual transport cycle, with summer values about twice those occurring in winter. In addition, there are large interannual transport variations associated with corresponding variations in the wind field.

Chukchi Sea. Within the Chukchi Sea, the generally northward flow is markedly steered by the bathymetry. This results in a divergence at the latitude of Point Hope, with the more saline western fraction of the flow (the Bering Sea water) following the Hope Sea Valley northwestward and probably entering the Arctic Ocean over Herald Canyon. The less saline eastern fraction (the Alaskan coastal water) continues northeastward parallel with the coast, entering the Beaufort Sea north of Point Barrow. The western branch is probably the larger of the two. Both wind and baroclinic effects modify this basic scheme. As in the northern Bering Sea, the flow can reverse under strong northerly winds, and at least one-half the total current variance in the eastern Chukchi Sea is predictable from the geostrophic wind field. In addition, strong baroclinic jets are common, in which the speed can exceed 100 cm s^{-1}. The strongest jets occur in summer at the pronounced temperature and salinity fronts which frequently occur near the coast. Weaker jets are found intermittently in winter, when saline water is formed near the coast during the accelerated freezing and brine rejection which accompanies coastal polynya formation.

Beaufort Sea. Within the Beaufort Sea, the inner shelf and nearshore regions appear to be primarily wind-driven, with local baroclinic effects largely those due to high summer runoff. Seaward of about the 50m isobath, the circulation is dominated by the Beaufort Undercurrent which in the mean runs counter to the generally westward ice drift. Maximum speeds near 75 cm s^{-1} have been recorded, but the long-term means are normally in the 5-10 cm s^{-1} range. The flow is highly variable on a time scale of days and longer, including frequent current reversals, and much of this variability appears to be forced by the longshore wind component. In contrast to the situation in the Bering Strait, however, there is no obvious seasonal cycle. The Beaufort Undercurrent carries with it much of the water which has come northward across the Chukchi Sea, and in the summer and fall this results in a great expanse of warm water extending eastward across the Beaufort Sea. This Pacific influence is also obvious in the high subsurface nutrient levels and in the wide-spread occurrence of plankton of Bering Sea origin. A final matter is that there are frequent upwelling events on the outer shelf, representing vertical

excursions of 100 m or more, but their dynamics and significance are at this point not well understood.

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QUESTIONS AND DISCUSSION: *Physical Sciences Session*

Question (Paluszkiewicz): Was the upwelling in November wind-driven or was that related to variability with the undercurrent?

Response (Aagaard): It was related to the undercurrent. This is not the classic coastal upwelling. I'll show you a picture on Thursday from the records that we just pulled back this year with a new kind of instrumentation. If you look at the phase propagation from those along the shelf, you get something like a meter per second velocity which would be about what you would expect from an internal long wave. We finally have a dataset that is synoptic, from a point where we can start dealing with energy and phase propagation. I think we will find that it is tied in with quasi-geostrophic motion along the boundary.

Question (Paluszkiewicz): Along the same lines, have you tied the variations in the undercurrent to variations in the pressure head or to variations in the baroclinic field?

Response (Aagaard): There again, I think we are now accumulating a wind set that will enable us to do that. I suspect we will find that we can take care of a lot of the variance with even a rather crude approximation of the geostrophic wind field. This is true not only on the shelves. For example, we did this a few years ago in the Chukchi. We found that nearly half the variance can be accounted for rather simply. I suspect that as we start dissembling the Beaufort Undercurrent, we will find that the variability is in fact wind-driven. It may not be a simple thing to understand dynamically, because, for example, just looking at some preliminary records with the naked eye, it looks like you have higher modal structure both vertically and horizontally. I think this is increasing the experience; that you need to incorporate a lot of modes when you are dealing with shelf waves. You need to incorporate a lot of modes before you begin to understand the dynamics of it. There are several modes vertically as well, I think.

Question (Paluszkiewicz): Have you started the shelf wave calculations?

Response (Aagaard): No, we're just processing data at this point, but I'll finish a few slides in time to show you on Thursday. I think it might interest you.

Question (Schell): I was interested in long term transport through the Bering Strait. You implied that there has been a decrease since the 1950s. What is the transport over the last 10 years in relative terms? Has it been declining or fairly steady right up until 1986?

Response (Aagaard): I can't give you a very good answer on the last two years of the timespan. My feeling is that they would probably continue this trend that we started seeing in the early 1980s, which was toward conditions more reminiscent of the 1950s and 1960s, and that we are on an increasing curve again.

Question (Schell): Since about when?

Response (Aagaard): Basically from about 1970 with the exception of these two years (pointing to graphic). You've got lower than mean values overwhelmingly, but I think we are on an ascending curve right now. So, the change occurred in the late 1970s/early 1980s.

Question (Crane): What are the engineering units on the pressure ridges? What is the scale of the pressure fields on those ridges?

Response (Pritchard): I'm sorry I don't understand. You mean what stress and what forces can they exert?

Question (Crane): What is the magnitude?

Response (Pritchard): For an individual ridge, I don't know. The only numbers this scale modeling can address are stresses averaged over tens of kilometers. That's not directly translatable into an engineering stress level. Some of that knowledge is available and maybe someone else in the audience would like to answer the question.

Question (Crane): Where is the distribution of those eddies and if there are multi-year life, what is the distribution on that advection of those eddies, if they are principal features?

Response (Aagaard): The vast majority of the eddies that have been seen are in fact sitting in the major density structure, sitting in the pycnocline. And those are the ones which we would expect to be coming from the shelves (and the Alaskan shelves in particular) for the Canadian Basin. However, there are other eddies that have been found that extend much deeper which are associated with other water masses. For example, with the Atlantic layer, and they are probably coming from the other side of the Arctic Ocean. As to how they transport, it may be a little too simple to think of them simply as passively being moved around by this very weak mean circulation which has scale speeds of probably less than a centimeter per second. Vortices like that are capable of self advection. There is also recent evidence that in fact they are capturing each other. So, the answer is I don't think we know anything useful today about how we draw a trajectory of such eddies. However, the Basin is full of them - something like a third to a half, maybe at any given time, the area would have a coherent vortex like this.

Question (Hachmeister): Is there any agreed-upon theory yet for the generation mechanism for those eddies? You were mentioning that they were generated along the coast (and you are pointing in particular, it looked like toward Barrow), maybe implying they were coming out of Barrow Canyon. Is that generally felt to be a source of the generation and what is the mechanism? Is there a theory on that?

Response (Aagaard): Barrow Canyon is one place that has been identified as probably being a major source. I think that the dynamics of the generation is something that one would have a long debate on if you got into one room with people who have ideas about it. There is, for example, a suggestion made a long time ago that they are driven by essentially a product of baroclinic instability. I think that has come into some disrepute. There is also a current notion that in fact they acquire their relative vorticity from side friction. There is a lot of skepticism with respect to that suggestion. But there are several different thoughts today that do have one thing in common. They essentially represent a separation so that anytime we have a flow being put near a perturbance, the flow would separate at that point regardless of how it acquired its initial relative vorticity. I think that is a very, very likely factor in the dynamics over Barrow Canyon. This way we have a strong flow, some inherent vorticity coming up past Point Barrow and it separates right at the bathymetric diversion point.

Question (Hachmeister): Does that imply that the central part of the coastline probably doesn't enter into it? Let's say, away from Barrow Canyon.

Response (Aagaard): Well, yes it would. There are other ways of getting this. For example, collapse features. I suspect that very nice slide shown by Dr. Hameedi of the northern Chukchi Coast, if you look how complicated the bathymetry was over on Chukchi Rise, which is just where you have a large input coming across the central Chukchi through Hope Sea Valley. I suspect that is a place where you could probably generate these things. But what points to the Chukchi and Alaskan Shelf as a source are the basic water properties. And there was a suggestion very, very early, for example, that before the significance of those anomalies was fully appreciated, these could be locally generated in the Arctic Ocean through a baroclinic instability, and I think that is probably impossible, the dynamics simply doesn't permit that. They are coming from the edges. In all these things we are saying that the edges control what happens in the interior.

Question (Nauman): When you talked about the result of the ice pressures or the ice movement, can you say anything about forecasting of ice motion from an operational standpoint? I'm referring more to when you are forecasting. Can you forecast with any degree of certainty? How much lead time (six hours, twelve hours, a week)? What will that result be on operations?

Response (Pritchard): Yes, I think that the models that I talked about have a very powerful capability for forecasting for up to the order of a week. I believe winds can be forecast with confidence with some degree of skill out to that time interval, and the models can then predict the behavior. The one thing ignored is that we are able to predict the currents. Depending on the region that you are in, if your currents also have to be predicted, then you have a coupled ice-ocean model. This is a far more complicated situation if that has to be done to the same level of complexity. But I think we have a lot of skill in forecasting out to about a week.

Response (Aagaard): I think the limitation of forecasting is meteorological. Certainly true of the ocean. The Beaufort is a difficult place to get a good wind field.

Question (from the floor): Is a week a long enough lead time? Are we saying that a week's lead would be enough time? (Inaudible)

Response (Aagaard): I would agree with it to the extent that I think the ice modeling will do a very nice job if you put the right wind on it. But I think the problem is we can't do a good job on the wind in that time scale.

Response (Pritchard): Knut, I'm not sure I would agree completely on that. We have, in developing some forecasting models, tried to evaluate how well the NODS winds perform over a week long period. We do this by comparing the week-long forecast against analyses at that later validation time. Although I don't have skill numbers, there is a fair amount of skill in making those predictions.

Response (Aagaard): Well it's scale-dependent to some extent, right? For example, as you get down to the smaller scales, forecasting becomes very difficult. A very good example is what is happening in the eastern U.S. Beaufort where there are some peculiarities of the atmospheric circulations associated with the proximity of the mountain range to the coast. There, USGS has for a long time suggested that there is in fact a coastal current divergence somewhere near

Barter Island, probably just a little bit west of it. Summer flow is to the west toward Barrow in the western part of the region. Movement is eastward in the eastern part of the region. That is probably a wind-driven kind of phenomenon. I don't see a lot of hope in doing a good job forecasting that on a week's time scale. Do you think that's pessimistic, Bob?

Response (Pritchard): I think you can only say that we and at least some others have included some barrier effect, mountain barrier effect in the forecast and at least it's realistic. Certainly everything you've said about how much tougher it gets on a smaller scale, I agree with. I must confess that my thinking in answering your question really was relative to heavier ice conditions rather than open water conditions. The heavier the ice conditions are, basically the response is to winds which are averaged over larger distances. Local effects then become less and less important. So, in the winter time the forecasting is easier. In the summer, when you try to forecast the drift of an individual flow, it gets much more difficult. Local features are then controlling factors.

Question (Nauman): It seems like in the last few years we've had operations there, in looking at the weather records, it appeared that we had storms that occurred without any warning or very little warning. Yet the storms lasted less than or up to 24 hrs. In each case, there were some consequences, although not serious. They might be if you had a longer duration blow. What prompted me to ask this question was: If you could forecast a long duration blow then you would be able to predict or plan for that event.

No Response

OCEAN CIRCULATION AND OIL SPILL TRAJECTORY MODELING FOR ALASKAN COASTAL WATERS

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Applied Science Associates, Inc. (ASA) is currently under contract with NOAA/OCSEAP to:

- Provide the National Oceanic Atmospheric Administration (NOAA) and Minerals Management Service (MMS) with hypothetical stochastic oil spill trajectories for specified launch points in Alaskan coastal waters as input to oil spill risk analysis for proposed lease sales.

- Compute dynamic oil mass balances for selected spills.

- Provide high resolution hydrodynamic modeling for selected areas in support of other study efforts.

- Document the development and application of the models by preparation of publications, reports, and a model user's manual.

With the significant decrease in leasing activity over the past several years, ASA, in response to guidance from NOAA and MMS, has focused on a series of model verification studies. A brief summary of selected studies is presented below.

Numerical Simulation of Wind-Driven Flow and Ice Transport through the Bering Strait.

The ASA two-dimensional, vertically averaged hydrodynamic model was applied to predict the wind-forced circulation in the Bering and Chukchi Seas. A simulation of the steady state flows induced by a 10^{-6} sea surface slope between the North Pacific and Arctic Oceans gives a northward transport of 1.97 Sv (Sv=10^6 m^3 s^{-1}), with 67% and 33% of the flow passing through the Anadyr and Shpanberg Straits, respectively. The transport and velocities in the straits scale linearly with the imposed slope. A wind field derived from the Fleet Numerical Oceanographic Center (FNOC) model and validated with available observations was used as input to perform simulations for February 1982. Comparison of model predictions to current and sea elevations observations (Figure 1) in the Shpanberg and Bering Straits and Chukchi Sea are generally in good agreement (R=0.78). A sensitivity study investigating the influence of open boundary-condition specification, model grid size, bottom friction coefficient and wind-forcing representation showed that the wind is the most important parameter. The model, however, normally under-predicts the wind-driven response. Correlation of model-predicted transports with mean current speed and wind speed are in reasonable agreement with the data and have correlations of 0.75 or higher. The transport wind speed correlation is approximately a factor of two higher than earlier estimates, but varies substantially, depending on the simulation period. Simulations show that the latitudinal and longitudinal momentum balances are essentially geostrophic and the area between St. Lawrence Island to Cape Lisburne responds essentially as a unit to wind-forcing at periods of 2.5 days and longer.

A free drift ice model, using the wind-driven hydrodynamic predictions described above, was employed to predict the trajectory of five ice drift buoys deployed by NOAA/PMEL during February 1982. Model predictions generally show the correct sense of travel and reproduce the observed reversal of movement through the Bering Strait. The predicted speeds are generally lower than those observed, however. The modeled trajectories invariably become trapped in the nearshore region and do not represent the long term behavior well. Poor trajectory predictions of several drifters is potentially caused by the lack of adequate spatial and temporal resolution and accuracy in the wind field and the assumption that the ice is in free drift.

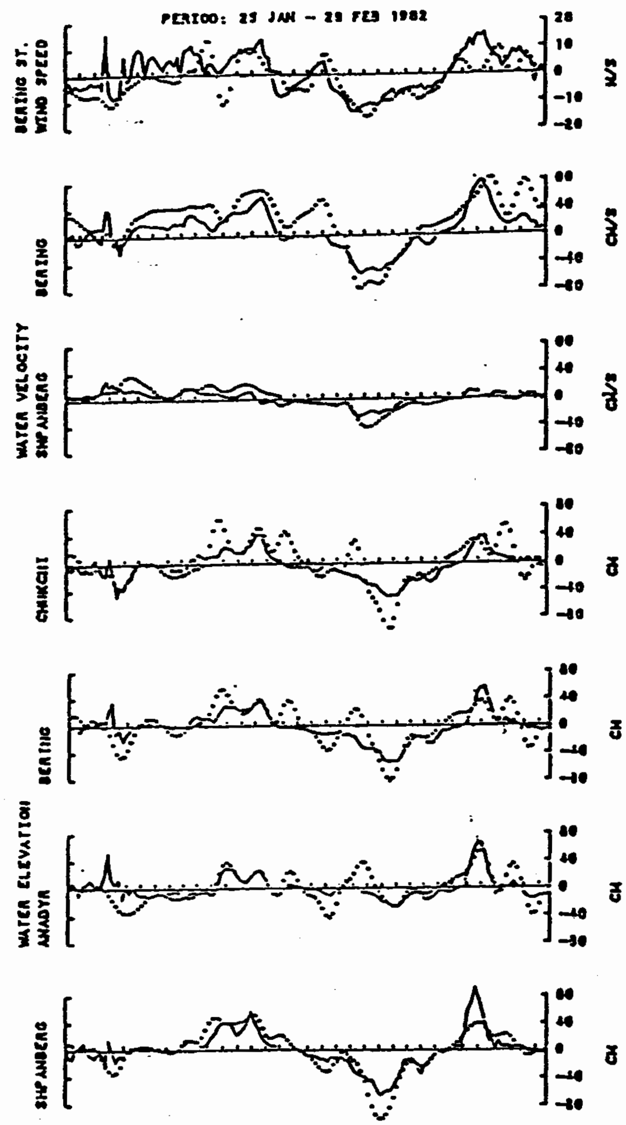

Figure 1. Comparison of model predictions (solid lines) to observations (dots) for winds, currents (Shpanberg and Bering Straits) and sea elevation (Chukchi, Bering, Anadyr and Shpanberg). Model predictions use the fine-grid simulation. Data is derived from Aagaard *et al.* (1985), except for the wind, which is taken from Tin City, Alaska. The horizontal axis is time in days.

Numerical Simulation of the Tides in the Bering and Chukchi Seas

The ASA two-dimensional vertically averaged hydrodynamic model in spherical coordinates with 0.2° latitude and 0.313° longitude resolution was employed to predict the semi-diurnal (M_2, N_2) and diurnal (K_1, O_1, and P_1) tides in the Bering and Chukchi Seas. Boundary conditions for the model were derived from Schwiderski's global ocean tidal model. Model predictions for the amplitude and phase of the sea elevation and major/minor axis speed and direction of currents were compared with observations collected by researchers from NOAA/PMEL and earlier modeling investigations. The model predicts a complex tidal pattern for the study area with the semi-diurnal and diurnal components having seven and four amphidromic systems, respectively. Several of the systems are virtual, with their centers located very near or on land. The predicted number and location of these systems is generally in agreement with previous modeling studies. Figure 2 shows the model predicted co-amplitude and phase lines for the M_2 tide. Model predicted tidal amplitudes for both the semi-diurnal and diurnal tides are typically within 2-4 cm of observed, while the phase differences are 15-30°. The model estimated tidal currents are within 3-7 cm/s and the orientation of the major axis is within 10-35° of observed values. The largest predicted

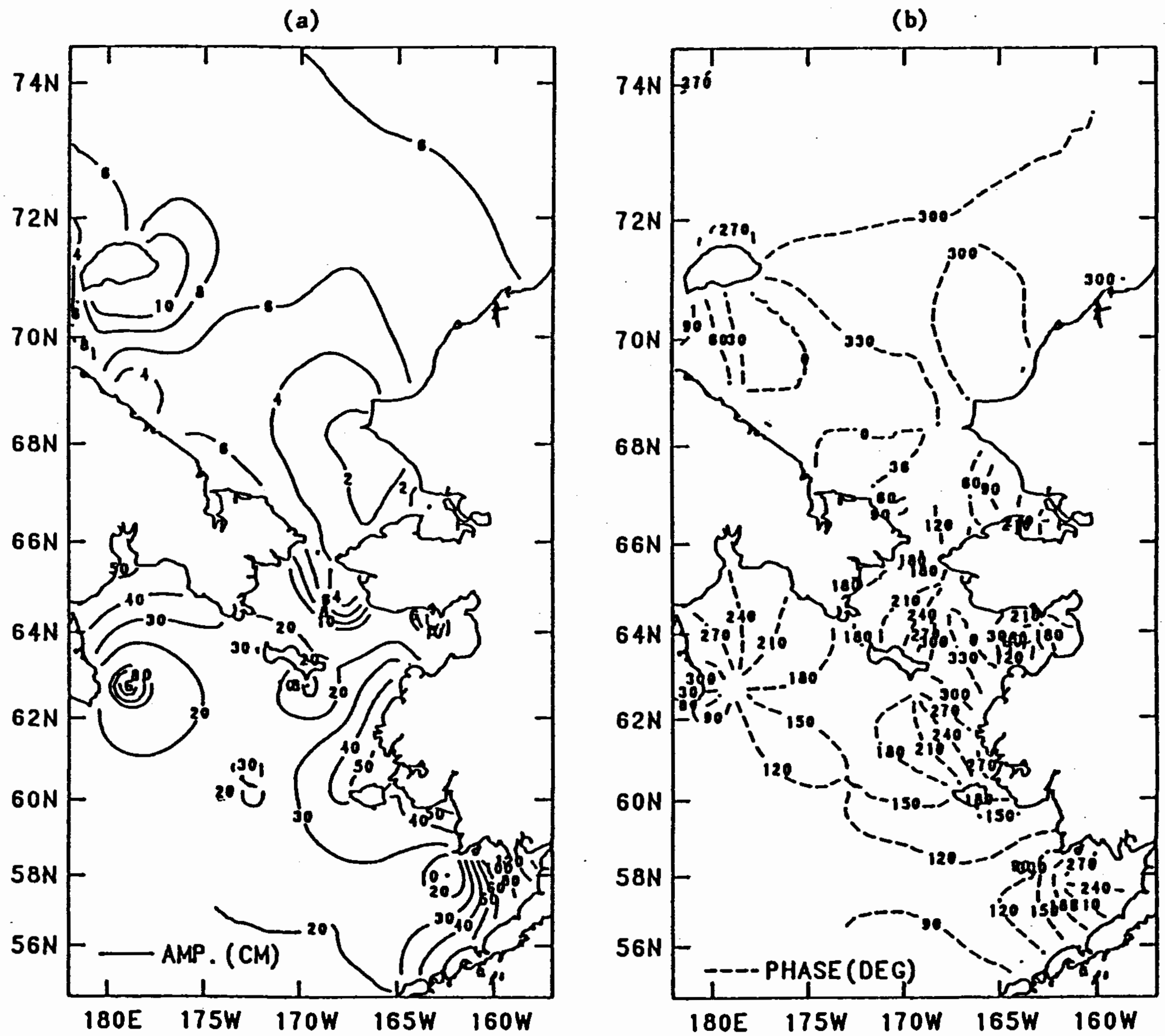

Figure 2. Hydrodynamic model predicted cotidal map for the M_2 tides. Solid lines (a) are co-amplitude lines (cm) and dashed lines (b) are co-phase lines referenced to Greenwich (degrees).

errors are in areas with extremely strong spatial variations of the tide (near amphidromic points) that occur in the vicinity of the passages: Bering, Anadyr and Shpanberg Straits. The predictions are equivalent to or better than those from any existing published model of the area.

Two studies are presently in progress. In the first, the ASA hydrodynamic model is being used to predict the wind-driven flows in the Beaufort Sea and to compare model predictions to observations. Data collected by NOAA/PMEL will be used to verify the predictive performance of the model and to gain an improved understanding of the circulation dynamics of the region. The model predictions are being made on a 15-25 km resolution grid for two 30-day periods: October 1986 and February 1987. These were selected by NOAA/MMS personnel as being two periods of particular interest. Wind-forcing will generally be derived from the FNOC's weather model. FNOC predictions will be compared to field observations to assess the performance of the wind model. The ice fields will be initialized using the NOAA Joint Ice Center satellite-derived data and other available observations. Model-predicted currents and sea surface elevations will be compared to available field observations.

The second study in progress is the preparation of a comprehensive user's manual for the model system.

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THE MMS COASTAL ZONE OIL SPILL MODEL

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Oil spill trajectory and fate models typically follow a surface slick until it contacts a coastline, at which time the simulation ceases. The model described here is designed to simulate oil spill fates both before and after a coastal contact.

This Coastal Zone Oil Spill (COZOIL) model has been designed to include explicit representations of as many of the known active processes as possible. The mass balance pathways are delineated in Figure 1. Multiple discrete batches of oil, or spillets, are used to represent the surface slick. Spillets are circular while offshore but become elliptical upon contact with the shoreline. The amount of onshore-offshore foreshortening is governed by a balance between wind stress and gravity spreading forces, and results in alongshore spreading of the spillet. Evaporated hydrocarbons are given no spatial representation, but are simply accumulated from all sources during the simulation. Entrained oil offshore is represented by discrete particles which are advected by the local currents. Inside the surf zone, entrained oil takes on a continuous representation, discretized by alongshore grid cell. Transport in the surf zone is governed by a classical radiation stress formulation. Incorporation of water into surface oil (emulsification) is simulated offshore. De-emulsification (de-watering) is allowed to occur for oil which is on the foreshore or backshore.

Oil coming ashore may be deposited on the foreshore or the backshore, or carried into coastal lagoons, ponds, or fjords. Oil on the foreshore penetrates into the underlying sediments at a rate dependent on sediment grain size and oil viscosity. Oil may also be carried into the beach groundwater system by wave overwash. Reflotation of surface oil occurs during rising tides.

The model is inherently deterministic with respect to results of any single simulation. Stochastic oil distribution estimates are produced by combining the results of multiple simulations, each of which is driven by a separate weather scenario.

The COZOIL model can be conceptually divided into a set of initialization processes, followed by computational and output routines (Figure 2). During initialization the spill scenario is established, including specification of oil type, spill size and duration, simulation duration and study area topography and geology.

The initialization program leads the user through a series of queries. An option between verbose (i.e. complete) and abbreviated output is open to the user at program startup. The option selected affects only the amount and detail of output produced by the model, with no affect on the actual computations performed. The most complex portion of the initialization process is the establishment of the geophysical environment within which the simulation will take place. To allow for input errors and facile alteration of the simulation environment, an iterative loop has been built into this section of the program. Thus, the user can alter the originally specified set of coastal reach parameters, whether they were obtained interactively or from an external file.

The second important part of the model initialization process centers on the specification of the environmental data used to drive the simulation. First, the user must either direct the model to access an existing wind dataset, or input a new time series. The model then requests the name of an existing tidal current dataset, or sufficient data to create one. A wind-driven current dataset is then created by the model from the wind record, if the user does not specify an existing dataset. Finally, the model either computes waves from the wind record, or accesses a wave time series from an external file.

Model output is controlled by the program itself; the user controls only the time interval between outputs to the screen and to data storage files. Outputs at the end of each user-specified time interval include boiling point cut information by surface spillet and coastal reach, an overall mass balance, and line plots showing the location of surface spillets and the alongshore distribution of hydrocarbons. COZOIL also tells the user when the new environmental data is being read into the model, and shows the results of ensuing wave height and angle computations. If the user elects the abbreviated output option, much of this secondary information is suppressed.

Figure 3 shows the conceptualization of the beach groundwater system incorporated into the model. Figure 4 shows the modeled penetration rate for diesel fuel into various substrates. Data for Alaskan borrow pit sand is also shown. Figures 5-8 show results of a model run with a sand beach. Figures 5 and 6 show overall mass balances for the near term (first 6 days) and the long term (90 days), respectively. Figures 7 and 8 show for the same timeframes the distribution of oil on, in, and in front of the beach.

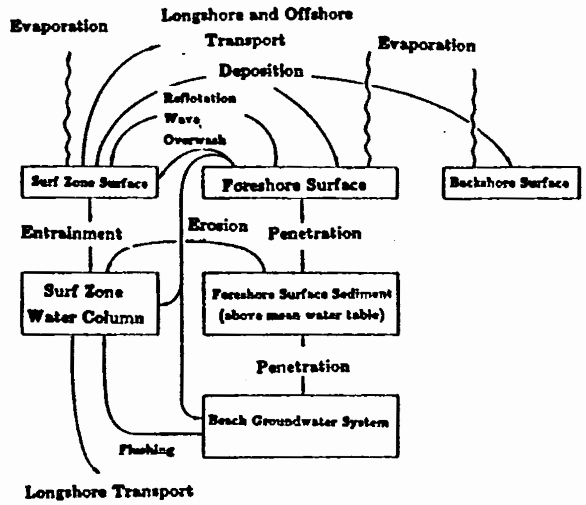

Figure 1. COZOIL mass transfer pathways in the coastal zone.

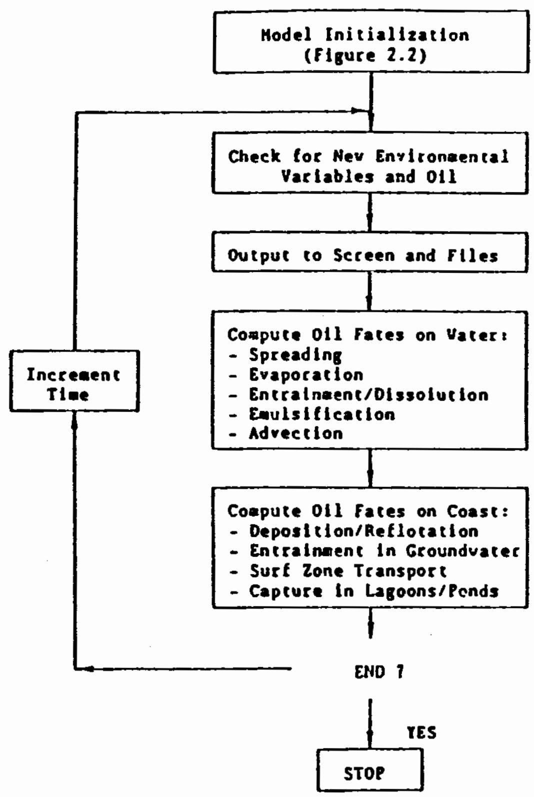

Figure 2. COZOIL model system schematic.

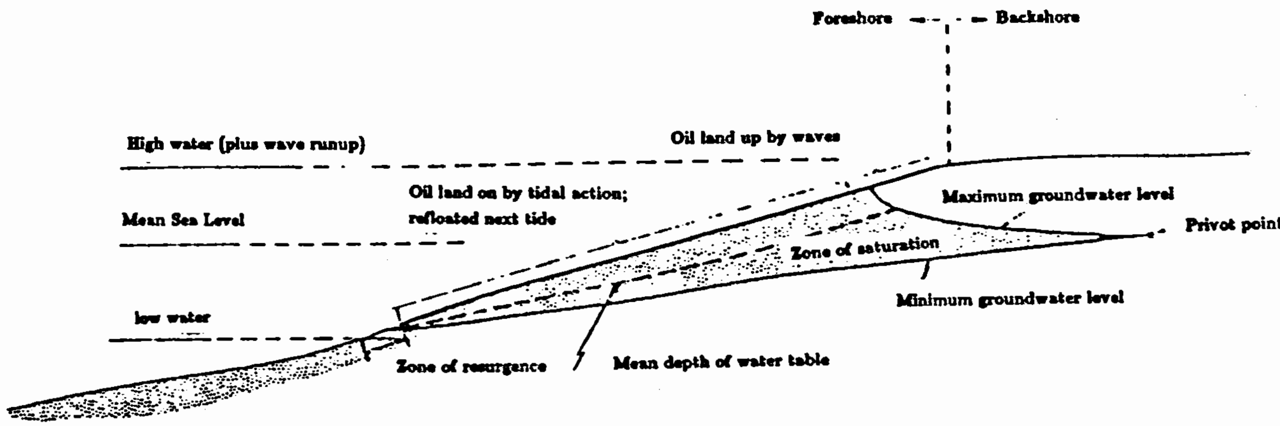

Figure 3. Schematic of beach groundwater system.

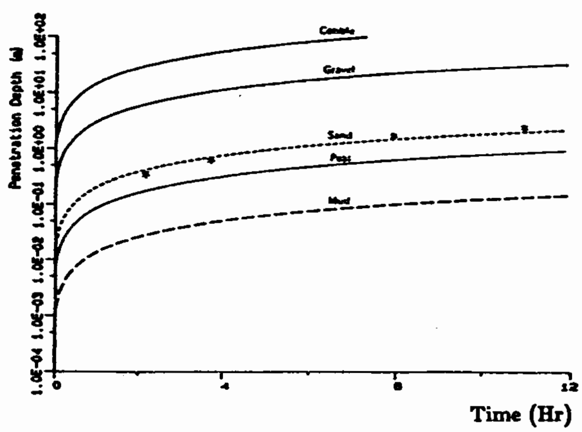

Figure 4. Penetration of diesel fuel into various substrate as a function of time. Asterisks show data reported by Holoboff and Foster (1987)

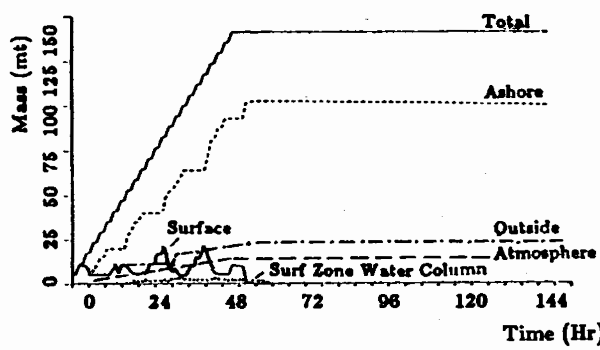

Figure 5. Overall mass balance for oil coming ashore on a sandy beach (first 6 days).

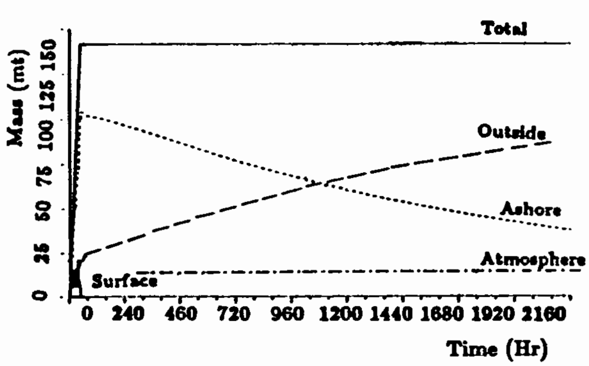

Figure 6. Overall mass balance for oil coming ashore on a sandy beach (first 90 days).

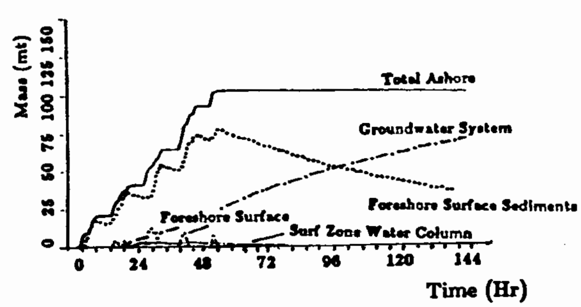

Figure 7. Distribution of mass associated with the shoreline (first 6 days).

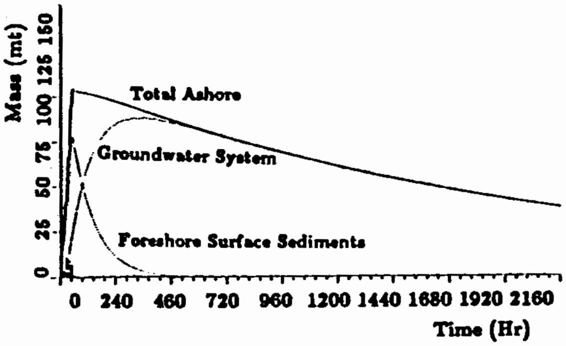

Figure 8. Distribution of mass associated with the shoreline (first 90 days).

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QUESTIONS AND DISCUSSION: *Physical Sciences Session*

Question (Schaeffer): This question deals with the oil spill model discussed by Mark Reed. I wonder if there is some way to use the model to consider the advantages of various counter measures such as mechanical removal of the oil or chemical dispersion?

Response (Spaulding): The answer to that is certainly, yes. You can easily extend these models, since you know what the model essentially predicts for the fate and distribution of oil. All you need to add to that is some information about what kinds of equipment you have, how long it takes to get there, what their effective removal rates are for mechanical equipment and for the chemicals. All you need to do is talk about the dispersant effectiveness and the amount of oil that you can hit with that dispersant. We have had experience with making those kinds of calculations and looking at impacts on the ecosystem and the fisheries.

Question (Coon): I was surprised when I looked at the ice trajectories that you didn't model the ice moving as far as the buoys moved, even though you had a free drift ice model so you weren't eating up any energy in the ice. I would have thought to see larger excursions of the model than the measured values. Can you comment on that?

Response (Spaulding): When we did the comparison of the observed currents to the predicted currents, the correlation coefficients were generally quite high, about 0.78 was the typical value. But you can see that the model under-predicts the currents in general so the correlation analysis just says that they are correlated and how correlated they are. But it says nothing about the magnitudes. So the model essentially under-predicts the currents. It's not as energetic as the currents; therefore, you would guess that you're not going to get as energetic a motion. Changing the wind field doesn't change that, so my assumption is that it's because you do some really strong spatial averaging with the kinds of wind fields that we have available.

Question (Coon): But, so none of it has to do with the ice model and how it's doing any of the interactions with the ocean?

Response (Spaulding): It certainly can't sort that business out. My first guess would be that we're under-predicting the currents. So that's the first thing I would look at. The next question is to whether indeed the free drift is representative of what goes on. We took that as an assumption based on the analysis that was done on the drifter data originally. In hindsight that may not be an appropriate assumption.

Question (Coon): It is interesting because as much motion as you were having, it would seem like at that period free drift might be alright, but lots of the other periods during the winter in that area, when you didn't see hardly any ice motion but obviously there were lots of currents, is probably when it would be more suspect. Those would be my thoughts anyway.

Question (Cowles): Looking at the shape of the penetration curve, comparing the sand and cobble and mud and so forth, it struck me that the degree to which they were parallel, particularly for the cobble, was being parallel to the sand. Can you explain the rationale? I would think that one would continue off in a different direction than the other; where it's steeper all the way out to the right of your graph. It seemed to me that the cobble would maintain a greater slope, intuitively.

Response (Reed): You mean because of less frictional, lower frictional losses in the substance? Yes, perhaps that equation doesn't behave that way. It may be something lacking in the equation itself. I don't have observations measurements for a variety of different sediments to test it against. I only found that one instance, at least so far, that one very nice set of measurements for Alaskan borrow pit sands.

The simple theory there is, of course, a del ^2P is equal to some value which is a classic pressure kind of thing and flows. The pressure differential drives the flows through the system and it's only two independent parameters that you have in there. One independent parameter is the viscosity of the material you are trying to drive through; the other one is some information about what that looks like, what those passages are. If you make the assumption that the passages only change in terms of the size but not in terms of the pattern, and secondly, the system is linearly dependent on the other thing, you'd only get a family of curves that look exactly the same. When you just change the viscosity or you change the effective porosity, you would get that same family, unless there is some non-linear behavior. However, the theory doesn't predict any. There is nothing in there to change the velocity of the function of depth, which is what you would need to get the slope changing. So, the velocity essentially, is a constant velocity.

Question (Paluszkiewicz): My question refers to Dr. Spaulding's model on the ice trajectories and would carry through to the oil spill trajectories. Do you use the Fleet Numerical Oceanographic Center (FNOC) winds adjusted to buoys, did you say?

Response (Spaulding): That is correct.

Question (Paluszkiewicz): And I was wondering if you could elaborate on just what that procedure involved and how you dealt with the parts of the FNOC grid that had no buoys to be adjusted?

Response (Spaulding): There is a series of offshore buoys around Alaska. What we did was look at a comparison of FNOC winds to the observed buoy winds for the time periods we were interested in. Actually, we looked at them for much longer time periods. We adjusted them so that they are mean values, and made one adjustment constant for everywhere (it turned out that it was about a 0.8), so it was about a 20% reduction. We didn't make any change in the angle at all and just set that wind everywhere and let that alone. So that's the adjustment process.

Question (Paluszkiewicz): So it's a mean over time and space?

Response (Spaulding): It's a mean over time and space and those spatial points are determined by buoys throughout that area.

Question (Paluszkiewicz): The FNOC winds are 2.5 degrees by 2.5 degrees. Are you concerned by the lack of spatial resolution in your trajectory modeling?

Response (Spaulding): Oh, yes. The spatial resolution question is fairly important as we've shown here in terms of these simple simulations that compare predictions to observations for a limited time period. If you just said that you wanted to predict the flow through the Bering Strait correctly, it doesn't make any difference whether you have any spatial information on the wind field or not. It turns out that if you want to predict currents at some locations away from the

Bering Strait, then the spatial variation of the wind field becomes important. We've used the FNOC data because it's the most consistent data; the best set we've seen that's consistent with the observations. We've made checks over about six or seven different stations and have found it's quite good. In terms of the resolution, I think that it's inadequate specifically for some of these tight, fast moving storms. I don't think that it has the resolution for that, but I don't think there is any other game in town except a limited, fine mesh model for the area which hasn't been fully developed.

Question: So, the Weather Service hasn't done the LFM winds for the Bering Sea yet?

Response (Spaulding): No.

BEAUFORT SEA TECHNOLOGY UPDATE

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INTRODUCTION

Petroleum exploration activities are taking place in increasing water depths in the Beaufort Sea. In 1985, the Minerals Management Service (MMS) commissioned Han-Padron Associates of New York to conduct a study entitled "Beaufort Sea Petroleum Technology Assessment." The study evaluates the present state of petroleum technology suitable for Diapir Field Planning Area water depths ranging from 65 to 300 ft, and analyzes the unit costs, construction schedules, and manpower requirements associated with offshore petroleum development. In 1987, MMS commissioned Han-Padron Associates to expand and update the cost data developed in the 1985 report. The 1985 report is publicly available but the 1987 report is confidential.

EXPLORATION TECHNOLOGY ASSESSMENT

A considerable amount of exploration drilling has been carried out in the Alaskan Beaufort Sea, but most wells have been drilled in water depths less than 65 ft. Numerous exploration platform concepts have appeared in the literature and they have been developed to differing degrees of refinement ranging from conceptual proposal to full detail design, model testing and, in a few instances, prototype construction. Since there are so many different concepts, the following classifications were established for the studies:

- Artificial Islands
- Bottom Founded
- Floating

A summary of the status of the various exploration platform concepts is presented in Tables 1, 2 and 3.

In order to estimate exploration platform costs, and ultimately exploration and delineation well drilling costs, generalized platform concepts were developed for each of the three basic categories. Preliminary designs for these generalized concepts were developed and used as the basis for preparing cost estimates which were prepared as a function of water depth. Based on the generalized platform costs and the costs of the other various aspects of petroleum development, the cost to drill an exploration or delineation well for each of the three categories of platforms was developed.

Figure 1 illustrates qualitatively the lowest per well drilling cost versus water depth, assuming that the source of borrow material for artificial island fill is located adjacent to the exploration site. Figure 2 is similar but it is based on the assumption that the borrow source is located approximately 6 mi from the site. Figure 1 reveals that when the borrow source is located at the exploration site, the Sacrificial Beach Island (SBI) is the most cost-effective platform concept in water depths less than approximately 70 ft; the Caisson Retained Island

(CRI) is the most cost-effective concept in water depths between 70 ft and 105 ft; and in water depths greater than 105 ft, the Conical Drilling Structure (CDS) is the most cost-effective system.

When the borrow source is located approximately 6 mi from the exploration site, the costs of the CRI and SBI are significantly increased and the CDS is the most cost-effective system for water depths greater than 70 ft.

The floating system is not cost-effective in any water depth within the study area for the extended drilling program considered.

PRODUCTION TECHNOLOGY ASSESSMENT

Numerous Beaufort Sea production platform concepts have been proposed, but the number is considerably less than that proposed for exploration platforms. The development of these concepts, particularly for deep water, is less advanced than for exploration platform concepts.

A number of the concepts proposed for production platforms are similar to those proposed or utilized for exploration platforms. However, the design criteria for a production platform, which must stay on location for 20 years or so, are considerably more severe.

Table 1. Artificial Island Exploration Platforms.

Concept Name	Maximum Water Depth(ft)	Present Status
Gravel Island	65	Operational
Sacrificial Beach Island	65	Operational
Sandbag-retained Island	23	Operational
Sandtube-retained Island	10	Proposed
Necklace Island	60	Proposed
Tarsuit Caisson Island	70	Operational
Caisson Retained Island	85	Operational
Ice Island	40	Operational
Stacked Steel Caisson System	65	Proposed
Cellular Island	100	Proposed

Table 2. Bottom Founded Exploration Platforms.

Concept Name	Maximum Water Depth(ft)	Present Status
Arctic Cone Exploration Structure	110	Proposed
Mobile Arctic Caisson	130	Operational
Arctic Mobile Drilling Structure	60	Proposed
Mobile Gravity Platform	135	Proposed
Monopod Jack-up Drilling Rig	90	Detail Design
Mobile Arctic Drilling Structure	40	Proposed
Sohio Arctic Mobile Structure	60	Detail Design
Concrete Island Drilling System	55	Operational
BWA Caisson System	60	Detail Design
Single Steel Drilling Caisson	100	Proposed
Mobile Arctic Island	120	Proposed
Sonat Hybrid Arctic Drilling Structure	65	Proposed
Portable Arctic Drilling Structure	75	Proposed
Conical Monopod	75	Proposed
Arctic Drilling Structure with Detachable Caisson Mat	200	Proposed
BWA Arctic Steel Pyramid	120	Proposed
Mobile Arctic Gravity Platform	165	Proposed
Bottom-mounted Ice-cutting Platform	180	Detail Design
Zee Star Arctic Mobile Drilling Rig	130	Proposed
Arctic Composite Platform	65	Proposed

Table 3. Floating Exploration Platforms.

Concept Name	Present Status
Conical Drilling Unit (Kulluk)	Operational
Egg-shaped Ice-resistant Barge	Proposed
Swivel Drillship	Proposed
Ice-cutting Semi-submersible Drilling Vessel (ICSDV)	Detail Design
Arctic Drill Hull	Proposed
Ice-class Semi-submersible (Ice Maiden)	Proposed
Ice-resistant Semi-submersible Drilling Unit	Proposed
Arctic Drilling Barge	Proposed
Round Drillship	Proposed
Conventional Drillship	Operational
Conventional Semi-submersible	Operational

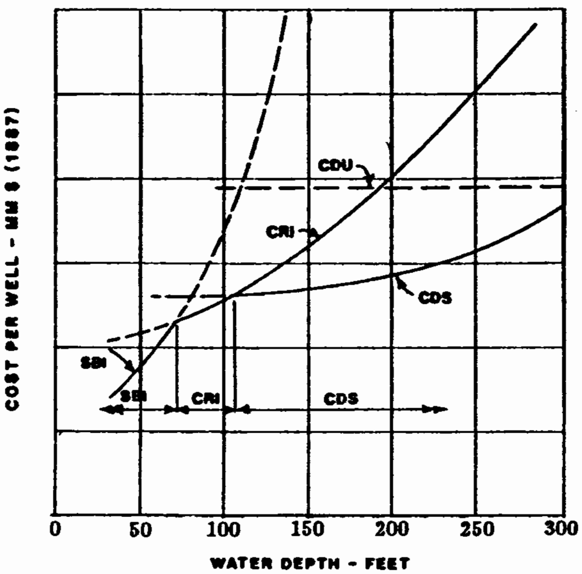

Figure 1. Per well cost versus water depth - borrow source at site.

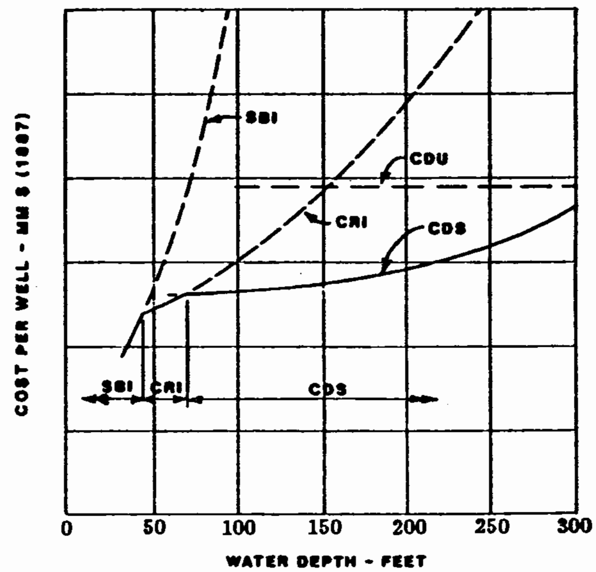

Figure 2. Per well cost versus water depth - borrow source 6 mi from site.

Note: Figures have unlabeled Y axis because data is proprietary.

In order to estimate production platform costs, generalized platform concepts were developed for artificial islands and bottom founded systems. Preliminary designs were prepared and used as the basis for preparing cost estimates. For artificial islands, only the CRI concept was considered. A SBI was not considered because of the permanent nature of the platform and the extensive annual maintenance that would be required. Although the recently developed Endicott Field utilized gravel islands, a gravel island was not considered because of the probable unavailability of a source of gravel borrow within an economical distance from a deepwater site. The prefabricated bottom founded production platform concept, referred to as a Conical Production Structure (CPS), is similar to the CDS.

Figure 3 illustrates qualitatively the minimum platform capital cost versus water depth for production rates of 100, 200 and 300 millions of barrels per day (MBPD) and assuming that the source of borrow material for the CRI is located adjacent to the platform site. Figure 4 is similar, but it is based on the assumption that the borrow source is located 6 mi from the CRI site. The figures reveal that for higher production rates and deeper water the CPS is more cost-effective and conversely, for lower production rates and shallower water depths, the CRI is more cost-effective.

TRANSPORTATION TECHNOLOGY ASSESSMENT

The primary alternative for transporting crude oil from the Diapir Field to the "Lower 48" is to install a marine pipeline to shore and land pipeline connecting to the existing Trans-Alaska Pipeline System (TAPS). TAPS has a rated capacity of 2.0 MBPD and present throughput is considerably lower. In addition, the capacity of TAPS can be increased, if necessary, by adding pump stations, using flow improvers, and looping critical pipeline sections.

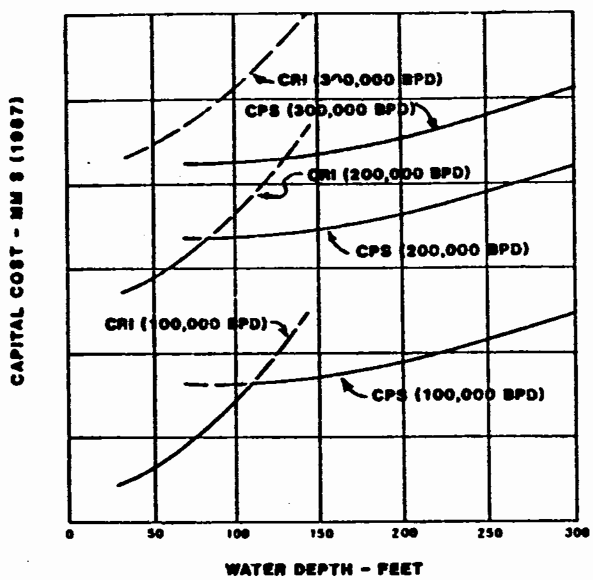

Figure 3. Production platform capital cost versus water depth - borrow source at site.

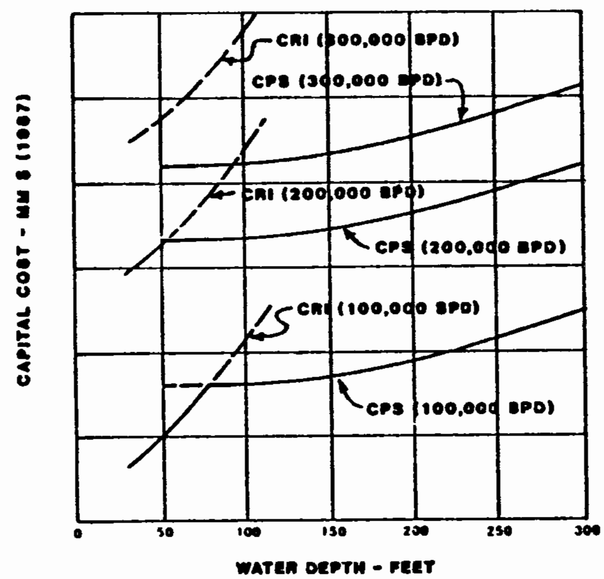

Figure 4. Production platform capital cost versus water depth - borrow source 6 mi from site.

As a sensitivity case analysis, it was assumed that TAPS will be unavailable for crude oil produced from the study area. In this case, a number of alternative transportation systems were considered, including:

- A marine pipeline to shore and a land pipeline to and paralleling TAPS.
- A marine pipeline to shore and a new north-south pipeline.
- An offshore loading/storage system and icebreaker tankers.
- A marine pipeline to a nearshore terminal for loading icebreaker tankers.

Marine Pipelines

For the past decade and a half, the petroleum industry has been actively engaged in research and development of the technology for the design and construction of subsea oil pipelines in the Arctic. Critical environmental factors include ice and weather conditions, their effect on construction equipment and the effective length of construction season, the nature of the seabed soil, seabed ice gouging and, in the permafrost zones, the prevention of permafrost degradation. Preliminary designs and cost estimates for marine pipelines were prepared for production rates of 100, 200 and 300 MBPD. Figure 5 illustrates the required pipe diameter as a function of pipeline length for the three production rates considered. Figure 6 illustrates the required installed horsepower (including 50% spare capacity). These figures are valid only for

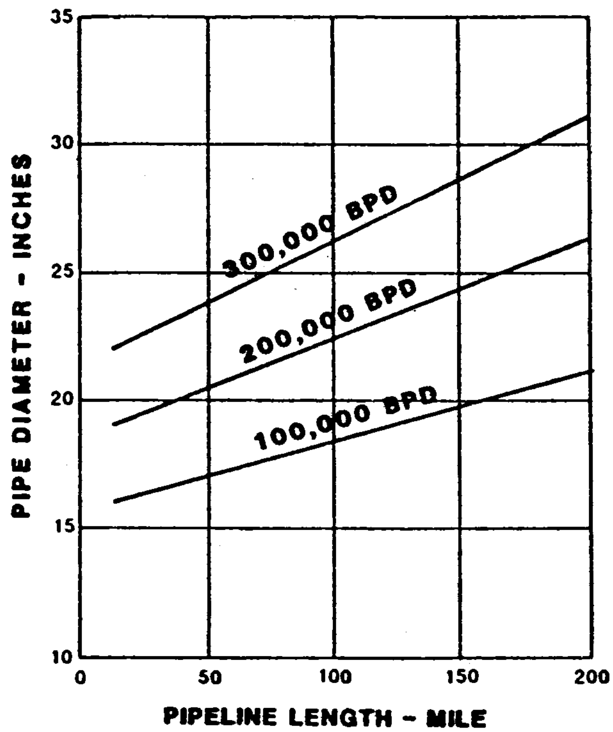

Figure 5. Marine pipeline pipe diameter versus pipeline length for various production rates.

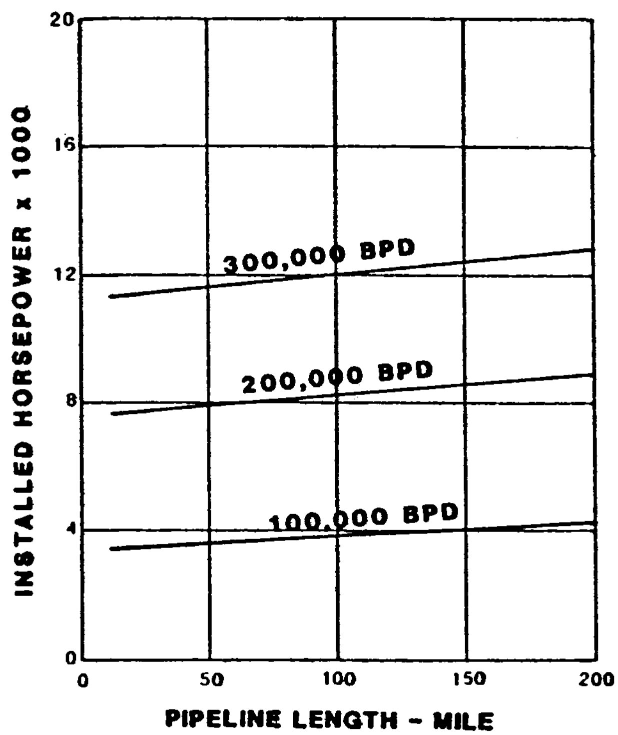

Figure 6. Marine pipeline installed horsepower versus pipeline length for various production rates.

crude oil with properties similar to Prudhoe Bay crude and are very sensitive to the actual properties. Also, they are only approximate because the pipe diameter and installed pumping horsepower are interdependent for a given pipeline length and production rate.

Land Pipelines

TAPS was placed into operation in August 1977 and since that time several other onshore pipelines in the Alaskan and Canadian Arctic have been constructed. Therefore, considerable technical and cost data are available. However, Arctic land pipeline costs are extremely sensitive to regulatory requirements and the economic state of the pipeline construction industry at the time the construction contract is awarded.

Offshore Loading Terminal

The selection of the optimum offshore loading terminal for a particular scenario depends on many factors. A number of offshore loading terminal concepts have been proposed. However, for purposes of the study, none were considered cost-effective. Based on the defined criteria and the fact that the optimum production platform for most of the study area is considered to be a large, bottom founded structure, it was determined that the use of the production platform as the offshore loading terminal is the most cost-effective alternative. The production platform would be modified to increase its width at the waterline and to provide adequate crude oil storage capacity. A seawater displacement system would be utilized to balance internal and external pressures and to maintain sufficient structure negative buoyancy when the crude oil is withdrawn from storage.

The use of the production platform as the offshore loading terminal provides the following benefits over the use of an independent structure:

- Significantly lower capital cost
- Lower operating costs
- Lower manpower requirements
- Consolidation of operations at a single location

However, the concept does have several areas of concern requiring further study, particularly:

- Difficulty of arranging a loading system that will permit the moored tanker to weathervane

- Ability to provide sufficient fendering to prevent a catastrophic collision

- Capacity and behavior of mooring hawsers

- Ability to adequately clear ice rubble.

THE BEAUFORT SEA MONITORING PROGRAM: ANALYSIS OF TRACE METALS AND HYDROCARBONS FROM OUTER CONTINENTAL SHELF (OCS) ACTIVITIES

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INTRODUCTION

The Department of Interior, Minerals Management Service (MMS) is charged with administering oil and gas exploration and development activities on the Outer Continental Shelf (OCS). In this capacity, MMS is also responsible for monitoring potential environmental effects resulting from such activities. A scientific appraisal of the feasibility of conducting a monitoring program in the U.S. Beaufort Sea and the framework for such a design were subjects of a joint MMS-NOAA workshop held in 1983. The proceedings of this workshop recommended implementation of the initial phase of the Beaufort Sea Monitoring Program (BSMP). This three-year study was initiated to develop a monitoring program to determine whether changes in key toxic and source-diagnostic trace metal and hydrocarbon concentrations were detectable in the Beaufort Sea environment.

The objectives of this study were to establish and implement a monitoring program to: 1) detect and quantify changes in trace metals and hydrocarbons in the Beaufort Sea sediments and sentinel organisms that might result from discharges of OCS oil and gas exploration and development activities; adversely affect or suggest adverse effects on man or his environment; and influence federal OCS regulatory management decisions, and 2) identify potential causes of any such changes. A set of null hypotheses was designed to aid in evaluation of the environmental impacts of Beaufort Sea OCS oil and gas-related development activities.

METHODS

Field Sampling Program

During the first year of the study in 1984, a series of stations was established in the nearshore (<25 m) area between Cape Halkett and Barter Island (Figure 1). To meet the objectives of the program, the station selection rationale incorporated the following considerations:

- Location of stations within Lease Sale No. 71.
- Use of a combined area-wide and activity-specific strategy.
- Incorporation of a gradient approach along with both the area-wide and activity-specific approaches.
- Reoccupation of a limited number of baseline stations.

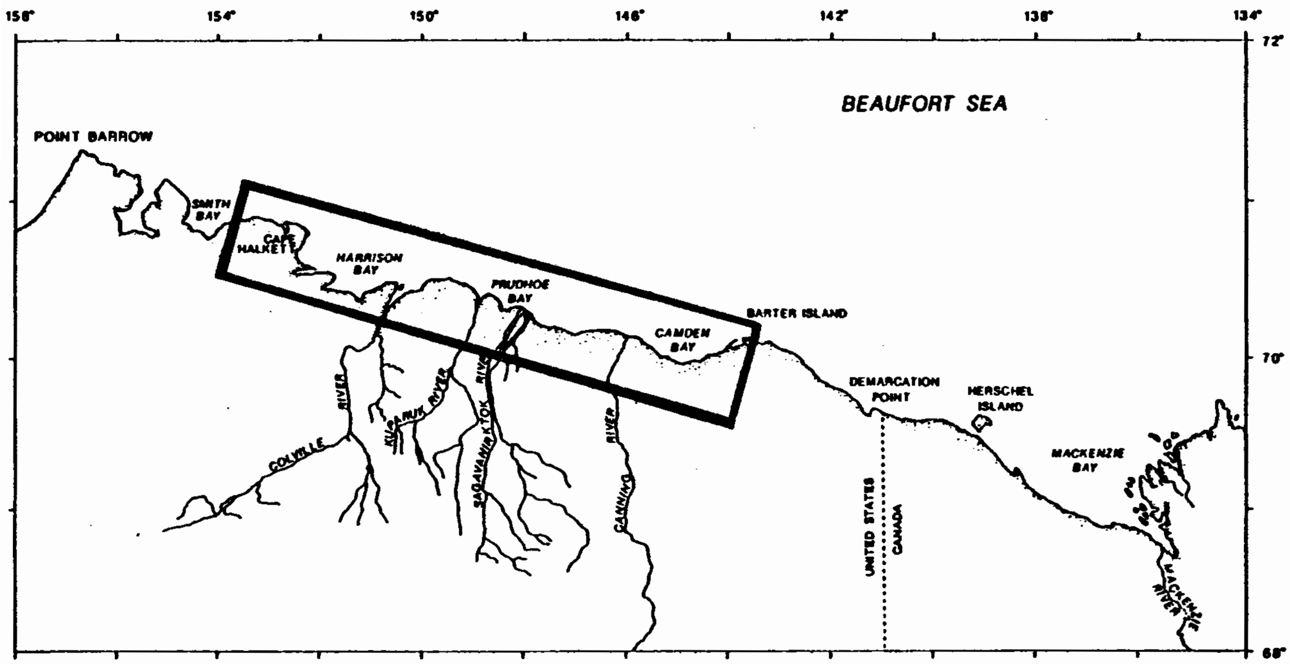

Figure 1. Beaufort Sea monitoring program study area.

After the first sampling year, some minor changes to the basic sampling design were made, and 10 river and shoreline peat stations were added. All stations sampled during the three-year study are shown in Figure 2.

The field program was comprised of three annual sample collections carried out during the summer open-water season. Stations were oversampled and eight replicate surface (0-2 cm) sediment samples were collected at each station. Infaunal bivalves and amphipods were obtained at selected stations throughout the study area. Samples of shoreline peat and river sediment were obtained during Year2 and Year3 to examine the influence of these source materials on the composition of the Beaufort Sea sediments.

Laboratory Analysis

The trace metal and hydrocarbon parameters for which analyses were conducted were selected because of their importance as indicators of oil and gas development activities and/or their toxicity. Replicate sediment samples and animal tissues were analyzed for barium, chromium, vanadium, lead, copper, cadmium, and zinc (Ba, Cr, V, Pb, Cu, Cd, and Zn) by X-ray fluorescence, atomic absorption and inductively-coupled plasma emission spectrophotometric techniques. Saturated and polynuclear aromatic hydrocarbons (PAHs) were analyzed by flame ionization gas chromatography (GC-FID) and gas chromatography-mass spectrometry (GC/MS), respectively. Sediment grain size and total organic carbon (TOC) analyses were paired with trace metal and hydrocarbon analyses to aid in interpretation of the geochemical dataset.

Annual and three-year mean concentrations of trace metal and hydrocarbon parameters were determined and confidence intervals for each parameter were established. Statistical

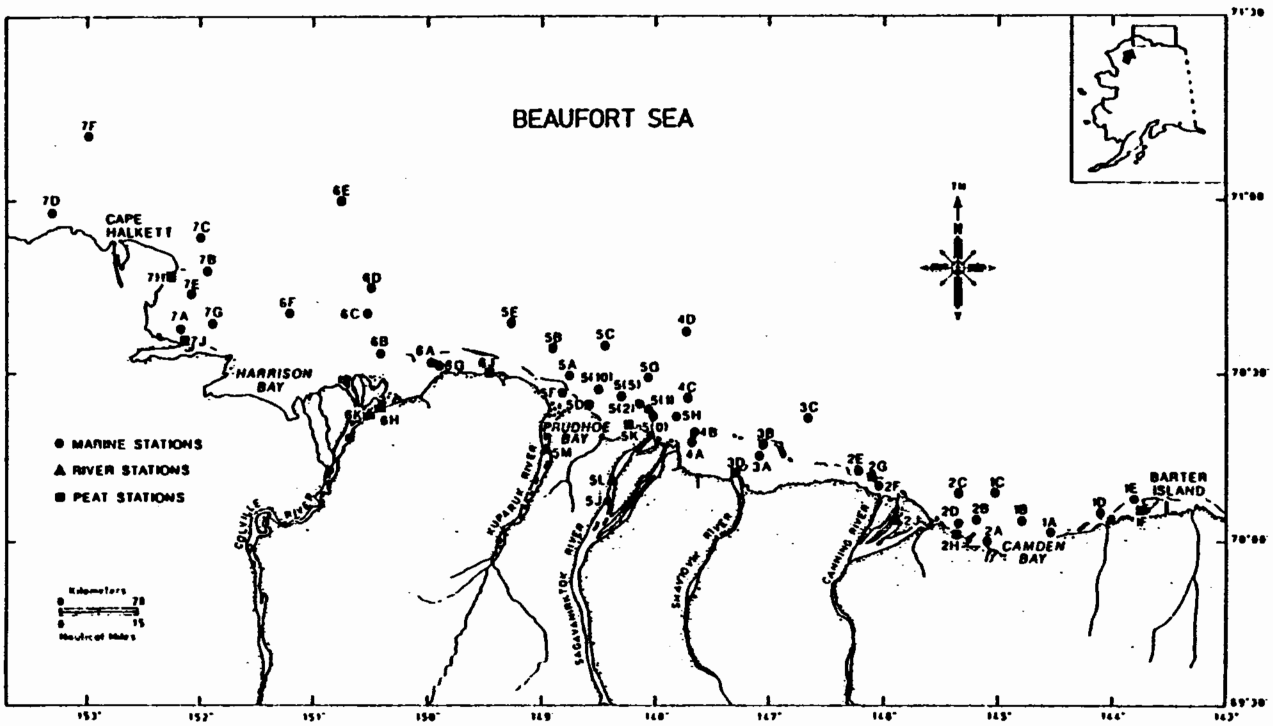

Figure 2. The Beaufort Sea monitoring program study area and station locations.

analyses (two-way mixed-model ANOVA) were performed to characterize the temporal variability of trace metal and hydrocarbon concentrations, and to make station-to-station comparisons.

RESULTS

Sediment Trace Metals

The three-year dataset for trace metals in Beaufort Sea sediments reveals a wide range of concentrations. The mean metal concentrations reported in this study are within the range of values reported by others for arctic coastal sediments. Mean barium concentrations in bulk sediments range from 120 to 700 µg/g (dry weight). Lead and copper levels are in the range of 5 to 30 µg/g, while chromium, vanadium, and zinc occur between 20 and 140 µg/g. Levels of trace metals are generally higher in the fine-grained and TOC-enriched sediments. Annual variations in the concentrations of metals at a station were generally small, unless accompanied by a significant change in sediments grain size. Regionally, levels of all metals were generally more elevated in sediments from the western study area (Harrison Bay region) than in other regions. The enrichment observed in the Harrison Bay area is due to the influence of the Colville River, the largest single source of sediment to the U.S. Beaufort Sea. Analysis of potential source materials (shoreline peat and river sediments) indicated that peat does not appear to be significant in enhancing the concentrations of trace metals in the Beaufort Sea sediments. Major rivers appear to be more important sources of both trace metal and sediment inputs to the Beaufort Sea.

Sediment Saturated and Aromatic Hydrocarbons

In comparison to other OCS regions, the saturated and aromatic hydrocarbon concentrations of the Beaufort Sea sediments are somewhat elevated. Three-year mean total saturated hydrocarbons ranged between 2 and 50 $\mu g/g$ (dry weight), while mean total 2- to 5-ring PAHs varied from 0.1 to 2.0 $\mu g/g$. As observed with the sediment trace metals, hydrocarbon concentrations are similarly correlated to sediment grain size and proximity to major river discharges. Highest concentrations of saturates and PAHs were associated with the Harrison Bay sediments. The composition of the Beaufort Sea hydrocarbons, which are largely fossil-derived, also differs from most other shelf sediments. Evidence of petrogenic inputs was detected in sediments from the major rivers as well as from the Beaufort Sea. Examination of key diagnostic ratios (e.g., LALK/TALK; N/P; P/D), and the saturated and aromatic hydrocarbon compositions of source materials (shoreline peat and river sediments) and offshore sediments indicated that river sediments are enriched in both fossil hydrocarbons and peat, and that the composition of river sediments is similar to the offshore sediments. Petrogenic inputs detected in the Beaufort Sea sediments may be related to oil seeps and coal outcrops occurring upstream of rivers that discharge into the Beaufort Sea.

Trace Metals and Hydrocarbons in Animal Tissues

Several species of infaunal bivalves and amphipods, representing broad coverage of the study area and a range of feeding mechanisms, were analyzed for trace metals and hydrocarbons. Overall, the concentrations of both metals and hydrocarbons were very low. Differences in the tissue concentrations were noted among different species and feeding types. Annual variability of trace metals in bivalves collected at the same stations was low. In contrast to the elevated levels of PAHs in the sediments, concentrations in the animal tissues were detectable but very low, indicating that sediment-bound PAHs are not readily bioavailable. There does not appear to be a correlation between animal body burdens and sediment concentrations of either trace metals or hydrocarbons.

SUMMARY OF PROGRAM AND RECOMMENDATIONS

The three-year Beaufort Sea Monitoring Program was successful in accomplishing a broad range of goals defined at the initiation of the study. The required technical goals were completed successfully and the framework for future monitoring programs in the Beaufort Sea has been established. The BSMP has resulted in a comprehensive three-year dataset that defines the baseline chemical and geochemical characteristics of the nearshore Beaufort Sea.

Specific recommendations for monitoring that have resulted from this program include:

- Reoccupation of the specific 39 stations is not critical. Instead, a key component of the sampling design should consider geographic regions delineated by similar geochemical characteristics.

- The sampling design strategy should combine an activity-specific/gradient approach strategy (individual station data evaluation) with a strategy of area-wide/random station placement in BSMP-characterized regions (regional data evaluation).

- Extend the area-wide pre-activity sampling and analysis to the east of the present study area (e.g. Barter Island to Canadian border).

- Maintain a low-level regional sampling and analysis plan at areas defined as "high risk" with respect to the likely intensity of future oil and gas development operations.

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QUESTIONS AND DISCUSSION: *Physical Sciences Session*

Question (Robertson): I interpreted your slide on metals as meaning that the concentration of metals in the marine sediments was more similar to the concentration in the peat than they were to the river sediments. Yet, I understood your conclusion to be the opposite; that the marine sediments looked like they were more related to the river sediments. Did I misunderstand something there?

Response (Steinhauer): No. I glossed over that quite a bit, mainly because I'm not a metals person and I didn't anticipate questions like this. We only had data from one year and it's kind of difficult to formulate really hard and fast conclusions; but I'm sure that there is a combination of both elements at work that the peat erodes into the river, and the river contributes the sediments to the Beaufort Sea. So, I think it was less clear with the trace metals but a little more clear with the hydrocarbons.

Question (McCrea): Concerning the offshore loading scenario, I was wondering how much downtime you allowed with the shipping?

Response (Padron): That's a good question. We didn't go into it in great detail so I can't tell you a number. My guess would be in the order of 10 to 20%, but we didn't study it to the detail that would justify my giving you a number or implying that the number is better than that, it's not.

Question (McCrea): Follow-up, how much storage did you estimate would be needed in those production platforms that would in fact also be your loading platform?

Response (Padron): If I remember correctly, it was about 10 days of production. So, it was a function which production rate we were using.

Question (McCrea): What would the production rate be?

Response (Padron): About ten days worth of production.

Question (Prentki): On the storage of the oil on the offshore loading platforms, would that be below the water surface or on the top of the platform?

Response (Padron): That would be below the water surface. It would be a seawater displacement system.

Question (Snyder): The charts that discuss the different production rates starting at 100,000 to 300,000 barrels a day, did you consider smaller rates of daily production or can those charts be used to estimate smaller production rates?

Response (Padron): No, we did not consider smaller rates on the assumption that we were looking at fairly deep water and it was our assumption that a production rate less than 100,000 barrels per day wouldn't be justified. In fact, it's quite questionable whether 100,000 barrels would be justified. The charts are not directly applicable for estimating smaller production rates. In fact, you'll notice that we presented the curves as separate curves for different production rates rather than presenting the data as a function of production rate because it is a stepped effect. At 100,000 barrels per day, you would be using one drilling rig; at 200,000, you would be using two drilling rigs; at 300,000 barrels per day, you would be using two drilling rigs **plus** satellite wells. It's not a smooth function, so, it's not really applicable to jump down to say, 50,000 barrels per day. You would have to take another look at it.

COASTAL GEOMORPHOLOGY OF ARCTIC ALASKA

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The coastal geomorphology of arctic Alaska is a total manifestation of a number of long-term (global tectonics) and short-term geological processes superimposed by cataclysmic effects of storm waves. The Arctic coastline is generally backed by wide low-lying coastal plains which reflects a morphology typically associated with trailing-edge Atlantic type (passive) continental margin. This margin is formed at divergent plate boundaries and is characterized by relative tectonic inactivity and large sediment accumulation. The general configuration of the coastline conforms to the "alignment" patterns of the adjacent hinterland rock formations. There are exceptional local areas on the Chukchi Sea coast, such as at Pt. Lisburne, where rocky promontories (some with precipitous faces) occur because of the abutting of the western Brooks Range foothill against the coast.

Considering the regional erosional/depositional regime (e.g. land erosion, wave erosion, river deposition and marine deposition), four genetic coastal types have been proposed to classify the shoreline of northern arctic Alaska. The coast can be alternatively classified based on four categories of coastal relief within a scale of low (2 m) to very high (8 m) relief. About 74% of the Arctic coast has a relief of 5 m or less; the average relief is approximately 4 m.

The coastal plain is characterized by numerous prograding (constructive) arcuate deltas. The morphology and associated landforms of these deltas primarily reflect deltation under relatively higher wave than tidal energy and an annual sediment input rate that is slightly above the rate of sediment removal by wave/tidal/ice action. The deltation processes in the Alaskan Arctic are marked by the unique phenomenon of sediment-charged fluvial overflow on sea ice at spring breakup. A consequence of this is the bypassing of sediment deposition at the delta platform. There are several microrelief features unique to the arctic beaches (e.g. ice-push ridges, sea-ice sand and gravel cones, "kaimoo" ridges, sea-ice kettles) and coastal plain (e.g. ice-wedge polygon, pingos, thaw lakes). The formation of these features is attributed to cryogenic processes. The poor development or near absence of modern sand dunes in most coastal regions of the Alaskan Arctic is presumably due to the combined effect of restricted transport of sand by onshore winds from the snowbound coastal beaches and the lack of shrubs in the backshore to trap sands.

The coastal plain is dotted with innumerable shallow (1-3 m) lakes. These lakes have evolved from the enlargement of ponds resulting from the thaw of permafrost ground along ice-wedge polygons. Most of the lakes are oriented northwest, presumably due to the action of northeasterly winds.

Chains of barrier islands and spits have evolved along both the Chukchi and Beaufort Seas' microtidal coasts, but there are wide differences in the morphology and size of the barriers in the two regions. Their extensive development in both regions is due to the presence of low tidal energy, sustained terrigenous sediment input and strong littoral currents. It appears that the major morphologic features of the Alaskan Arctic barriers do not conform to the model of barriers generally ascribed to microtidal areas. The arctic barriers are transgressive depositional sequence, some of which (e.g. Cross Islands) have a landward migration rate of about 6 to 11 m/yr. There are a few tundra blanketed islands (e.g. Pingok, Bodfish) off the Beaufort coast which are essentially Pleistocene relict coastal highlands. The lagoons adjacent to these islands have evolved as a result of progressive coalescence of coastal lakes and subsequent submergence of the enlarged lakes by post-glacial rise in sea level during Holocene.

The net year littoral sediment drift along the Beaufort Sea coast is westward and along the Chukchi Sea it is northeastward. The potential transport rate past any point is generally in the order of about 10^4 m^3 (which is essentially confined to the ice-free three months). However, episodic storm waves can have a catastrophic effect, as suggested by the possible movement of 1.5×10^3 m^3/day of beach -- a volume equivalent to sediment normally transported in 20 years. Consequently, occasional storms can bring about dramatic and large-scale change in the extent and morphology of the arctic barriers.

The erosion rate of the Alaskan Arctic coast is 2-5 m/yr, which is among the highest on earth. This high rate, which is primarily due to thermoerosion of permafrost infested coast (with up to 70 to 90% of intercalated ice), commonly results in the formation of 2-10 m coastal scarps.

In conclusion, the effect of cryogenic and "normal" wave/current processes on the geomorphology of the Arctic shoreline is quite apparent. However, the influence of intensified wave action during episodic storms can far outweigh the "normal" wave and ice-related activities.

ARCTIC BOUNDARY ISSUES

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The boundary between state and federal offshore submerged lands in the Alaskan Arctic is ambulatory. This means that as the shoreline accretes or erodes the offshore leasing line, projected from the moving baseline, also moves. Where disputed state and federal versions of the boundary exist, both move with shoreline changes. To assist the State of Alaska and Federal leasing offices in keeping track of the elusive coastline, the State Department of Natural Resources (DNR) and the Minerals Management Service (MMS) have joined with the National Ocean Service (NOS) to form the Boundary Working Group (BWG).

The BWG has continued a survey program, begun by the DNR in 1980, to update the NOS charts of the Beaufort and Chukchi Seas. These coastal charts were based on United States Coast and Geodetic Survey (C&GS) hydrographic surveys from 1948 to 1952. Since the legal definition of the coastal baseline requires both vertical and horizontal data, the survey program has involved tide measurements as well as geodetic and photogrammetric surveys. Some active areas have been surveyed two or three times since 1980 and some fairly stable areas have not been resurveyed since the original C&GS surveys.

The BWG work has further documented observations which have been made by many previous observers in the Alaskan Arctic. The most significant changes from 1950 to the present are as follows:

- Offshore islands in the Beaufort Sea are migrating rapidly southward and are generally being reduced in size. Retreat rates of up to 20 meters per year have been noted. The Plover Islands east of Barrow are among the most active.

- Breaks and reconnections are common occurrences in offshore islands and bars. Lateral movement of sediments greatly exceeds shoreward movement.

- The frozen mainland coast of the Beaufort Sea is also eroding rapidly. Erosion rates exceeding 10 meters per year are common from Cape Simpson to Cape Halkett.

- River deltas, for the most part, are not advancing in the Beaufort Sea and are in fact retreating in some areas. The Colville Delta is accreting in the east but is eroding rapidly in the west.

- The greatest amounts of coastal retreat are associated with fall storms when west winds have created high meteorological tides and when the coast has extensive ice-free ocean areas offshore.

- Erosion rates along the Beaufort Sea coast appear to be much higher than along the Chukchi coast, but BWG surveys have not been completed in the Chukchi Sea.

Data from all BWG survey work are available from the DNR and MMS and are being used to update NOS charts and tide publications. United States Geological Survey papers now in preparation are also using these survey data.

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QUESTIONS AND DISCUSSION: *Physical Sciences Session*

Question (Schell): The coastline appears to be retreating in the order of a meter and a half per year if you project that back, for say, 500 years or something like that. That implies that it has traveled a kilometer or two inland, and if the coastal gradient around there is like a meter in every 500 meters inland, one would expect to find really high bluffs on the north slope. By now, it would have chopped it all back. So, the obvious answer is either the sea level is coming up that fast or the coastline going down that fast. Which is it?

Response (Naidu): On the basis of that estimate, one would expect coastal bluffs of something like 30 or 40 ft with scarps, and we don't see that. That more or less; it's just that the coastal plain is subsiding, because of the melting of the permafrost. Because the sea level is not going up as much as possible.

Question (Schell): If the coastal plain was up, how do those relic boulders get there? If the coastal plain was that much higher 2,000 years ago, then how did those relic boulders get there? They couldn't have rafted there?

Response (Naidu): Relic boulders were intercollected with the coastal deposits, the coastal plain deposits. They were eroded, and they are like deposits.

Question (Schell): So, you don't think those big boulders in the patch were relics or transported from Greenland or something like that?

Response (Naidu): They could have been transported or they could be "on the-spot-like" deposits. Once the coastal shoreline or coastal plains eroded, those boulders were left in place. The fine particles were winnowed out.

ENDANGERED SPECIES SESSION

Speakers

W. J. Richardson

D. Schell

P. Fishman

B. Mate

S. Moore

BOWHEAD WHALE FEEDING

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This paper summarizes our present knowledge about the locations and seasons of feeding by the western Arctic population of bowhead whales, their types of food, feeding modes, and the patchy distributions of prey and feeding. Our present understanding of the importance of feeding in Alaskan Arctic waters is summarized in the context of the annual energy requirements of the population.

Feeding has been observed most commonly in the Canadian Beaufort Sea in late summer and in the Alaskan Beaufort in early autumn. However, some feeding occurs at other places and seasons. Most bowheads harvested during spring migration around western Alaska have empty stomachs, but some spring feeding has been documented. Feeding is also suspected off northeast Siberia in autumn. No serious attempts to look for feeding have been made in early summer or in winter. Some other species of baleen whales feed opportunistically in winter and it is possible that bowhead feeding occurs during more of the year than formerly thought.

Bowheads feed mainly on small crustacean zooplankton, especially copepods and euphausiids. Zooplankton is filtered from large volumes of water by the baleen. From 1980 to 1986, the Minerals Management Service (MMS) funded direct observations of bowhead behavior in the Beaufort Sea during summer and autumn. During 1985-1986, food availability was also studied during coordinated zooplankton and bowhead studies funded by MMS and the Canadian Department of Indian and Northern Affairs.

During this work, three feeding modes were identified:

- Surface feeding, sometimes in coordinated echelon formation.
- Near-bottom feeding, recognizable when bowheads bring mud to the surface.
- Water-column feeding, the most common feeding mode.

The amount of zooplankton in the water at locations where bowheads have been observed feeding far exceeds the average zooplankton biomass for the Beaufort Sea as a whole. Systematic echo sounder surveys have confirmed that zooplankton is concentrated both horizontally and vertically. Peak biomass occurs in "patches" a few meters thick and up to a few kilometers in horizontal extent. Bowheads concentrate their feeding in these dense patches of zooplankton, where biomass averages about 2 g/m^3 about 10 times the average biomass over the continental shelf of the Beaufort Sea as a whole. At any one time, only a fraction of the area of the Beaufort Sea contains a sufficient concentration of prey to allow efficient feeding, and even there efficient feeding is possible at only a narrow range of depths.

The distribution of feeding bowheads during late summer is uneven and highly variable within and between years. One factor hypothesized to affect the distribution of feeding is the variable location of the plume of warm, turbid, freshened water from the Mackenzie River. With easterly winds this plume often extends west into Alaska; with westerly winds it is restricted to more easterly areas. Zooplankton biomass is low in the plume waters and higher in marine waters. Feeding bowheads often concentrate outside the edge of the plume where cold marine waters with patches of densely concentrated zooplankton are present.

Zooplankton has not been sampled at enough bowhead feeding sites to determine how closely the large scale variations in bowhead distribution are tied to variable food abundance. However, zooplankton biomass in the Beaufort is strongly related to water mass characteristics; water mass locations are highly variable, and feeding bowheads concentrate at sites where their prey is concentrated.

Some feeding areas are used mainly by sub-adult bowheads (especially nearshore areas), whereas others are important to female bowheads with calves. Lactating females have higher energy needs than do other bowheads, and are believed to be under considerable energy stress. The food that they consume provides the energy needed to form the milk on which the calves depend. Thus, areas used for feeding by lactating female bowheads may be especially important to the population.

The western edge of the main summer feeding range is near the Alaska-Yukon border. Before the start of pronounced westward migration, the western-most feeding bowheads are just east of the border in some years, and just west of the border into Alaskan waters in other years. After migration begins, many (if not all) bowheads continue to feed intermittently as they travel west through the Alaskan Beaufort. Zooplankton availability in the eastern part of the Alaskan Beaufort at that time is similar to that in the Canadian Beaufort. However, the average bowhead spends no more than a few days in the eastern Alaskan Beaufort Sea. Based on estimated residence times, feeding rates and energy requirements, it seems clear that the western Arctic bowhead population as a whole acquires only a small percentage of its annual energy needs in the eastern Alaskan Beaufort. The few individual whales that feed there for considerably longer than average, perhaps for 10 days in some years, may acquire enough of their individual annual food requirements in the eastern Alaskan Beaufort to make that area a significant feeding area for those individuals.

Some feeding continues as bowheads travel farther west. Naval Ocean Systems Center surveyors have found that feeding becomes less frequent and less consistent in the western Beaufort than in the eastern Alaskan Beaufort. However, considerable feeding has been documented as far west as Point Barrow in some years.

The lack of direct evidence about the amount of feeding in the Chukchi and Bering Seas complicates any interpretation of the significance of bowhead feeding in the Beaufort Sea. A companion paper by D. M. Schell in these proceedings addresses this question using carbon isotope ratios in whales and their prey as a natural tracer of energy sources.

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APPLICATIONS OF STABLE ISOTOPE RATIO TECHNIQUES TO THE NATURAL HISTORY OF MARINE MAMMALS

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Natural history investigations of the large baleen whales present formidable problems due to the difficulties in observing the animals in their natural environments. Recent reports (Schell *et al.* 1987, 1988) show that bowhead whales (*Balaena mysticetus*) have marked annual oscillations in stable carbon and nitrogen isotope abundances along the length of the baleen plates in the mouth. These oscillations result from the seasonal movements of the animals from wintering grounds in the Bering Sea to the summering areas of the Canadian Beaufort Sea. Zooplankton along the migrational path have differing isotopic abundances of carbon and nitrogen which are reflected in the composition of the keratin in the continuously growing baleen plates (Schell *et al.* 1987; Saupe *et al.*, in prep). Since up to 20 years feeding record may be present in the plates of a large bowhead whale, considerable insight may be gained on the natural history of the whales and their habitat usage. We report in this paper and in a subsequent paper (Saupe *et al.*, this volume) on the isotopic abundances in zooplankton prey which produce the large variations in *B. mysticetus*, and a revised growth rate for *B. mysticetus*, based upon isotopic determination of ages. We also present preliminary data indicating applicability to other species of marine mammals.

Figure 1 shows the carbon and nitrogen isotope ratios along the baleen plate of a large *B. mysticetus* taken by Inupiat hunters near Point Barrow, Alaska. Subsamples of baleen were cut from the plate at 2.5 cm intervals along its length and combusted with CuO at 900° C in evacuated quartz tubes. The carbon dioxide and nitrogen produced were analyzed for stable isotope abundances on a VG SIRA-9 mass spectrometer.

We presented evidence for annual periodicity for the peaks as follows:

- Observed geographical patterns of carbon isotope abundances in zooplankton along the migratory path of the whales would be expected to produce an annual oscillation. Isotope abundances in consumers reflect diet (with small deviations from internal isotope fractionation) (Saupe *et al.*, this volume; Schell *et al.* 1988).

- The isotope abundances in newly formed baleen correspond to the regional zooplankton isotope abundances. The three *B. mysticetus* analyzed which were killed in the fall in the eastern Beaufort Sea showed ^{13}C-depleted baleen being formed, whereas 13 analyzed which were killed during the spring northward migration show ^{13}C-enrichment in the newest-formed baleen.

- Appearance of bomb-produced radiocarbon occurs at the appropriate temporal location in baleen of whales that lived during the early 1960s. The maximum input of radiocarbon from U.S. and Soviet testing of nuclear weapons occurred in 1961-63. The radiocarbon spread rapidly through the atmosphere and into the euphotic zone of the ocean. Baleen plates from two animals tested showed sharp increases in ^{14}C from atmospheric nuclear weapons testing, corresponding to the years 1963-65, if the peaks are assumed annual, confirming annual periodicity (Schell *et al.* 1988).

Analyses of inter-peak distances indicates that baleen grows faster in young whales than in subadult and adult animals (Table 1). During the first year, baleen plates grow in excess of 45 cm but the growth rate slows to 35 to 45 cm in the second year, 27.5 to 35 cm in the third year, and is typically between 16 and 20 cm/yr in adults (>12 m length) (Examples: Figures 157-158 in Schell *et al.* 1987). Based on the interannual distances in isotope ratio peaks along the plates, it is possible to estimate wear from the distal ends in young animals and to construct an age-body length curve. The results of our analyses on baleen plates of 13 subadult animals are shown plotted against body length in Figure 2. Between years one and four, little growth in body length is evident. A regression line on ages over four shows an increase in body length of 0.37 m/yr. Previous estimates based on length frequencies of native harvested bowheads concluded that *B. mysticetus* attained a length of 8 to 9 m during the first year of life and averaged 10.6 m during their second summer. Our data show that although the whales grow very rapidly from approximately 4.5 m at birth to 8 to 9 m at year one, there is an abrupt slowing of growth rate thereafter, presumably following weaning. Weaning is believed to occur after the first 8 to 12 months of life. Approximately 8 to 10 more years are required to attain 10.5 m in body length. Southern right whales (*Eubalaena glacialis australis*), which are morphologically similar to the bowhead and have a similar feeding strategy, have been observed to grow much faster. Right whales attain a length of 10.5 m in their second year of life and reach 13 m by four years (Whitehead and Payne 1981). Sexual maturity for female southern right whales is estimated to occur at a length of about 14.5 m, which is reached by age six. Growth curves for southern right whales show no evidence of a pause in growth as found in bowheads. Our data imply (Figure 3) that bowhead whales may take 17 to 19 years to reach the assumed breeding size of about 13-14 m in length.

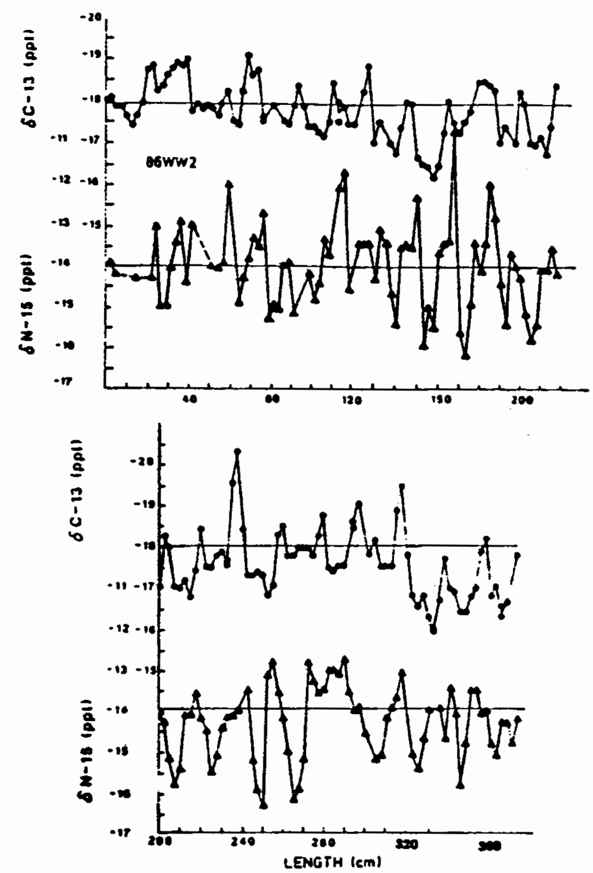

Figure 1. Carbon and nitrogen isotope ratios along a baleen plate from a 17.7 m bowhead whale taken at Wainwright, Alaska, in spring 1986. Most recently formed baleen is at 0 cm.

The isotope ratios in the baleen, and especially in the muscle and visceral fat of animals killed in the spring compared to those killed in the fall, show that the greatest abundance of points along the traces from *B. mysticetus* correspond to isotopic abundances typical of prey

Whale[1] (sex - season taken)		Body Length (m)	Baleen Length (m)	Baleen Growth[2] Increments (cm/yr)				"Estimated A (years)
				>45	35-45	27.5-35	<27.5	
86B2	(F-S)	8.7	0.65	(1)				1
87WW3	(F-S)	8.2	0.60	(1)				1
87H4	(F-S)	7.8	0.65	(1)				1
87B7	(M-F)	8.5	0.78	(1)				1.5
86B5	(F-S)	8.1	0.95	(1)	(1)			2
86KK1	(F-F)	7.6	1.45	(2)	(1)			3.5
86B1	(M-S)	8.2	1.35	(1)	(1)	(1)	(1)	4
86B4	(M-S)	8.9	1.50	*	(1)	(1)	(4)	7
86B3	(F-S)	8.9	1.70	*	(1)	(1)	(4)	7
86KK3	(M-F)	10.4	1.85	*	(1)	(1)	(4)	7.5
66B	(M-S)	9.7	1.75	*	(1)	(1)	(6)	9
86B7	(M-S)	10.7	1.90	*	*	(1)	(8)	11
86B6	(F-S)	12.3	2.40	*	*	*	(12)	>15
86WW1	(M-S)	15.9	3.15	*	*	*	(17)	>20
86KK2	(F-F)	17.1	3.80	*	*	*	(20)	>23
86WW2	(F-S)	17.7	3.75	*	*	*	(20)	>23

[1] Indicates year, location and sequential number of kill.
B = Barrow; H = Point Hope; WW = Wainwright; KK = Kaktovik.

[2] Asterisks indicate missing increments lost through erosion from the tip.

Table 1. Bowhead whale (*B. mysticetus*) growth rate data from isotopically analyzed baleen plates. "Estimated age" represents actual age of the animal assuming birth occurred in spring. Values in parentheses are the number of annual growth increments in the given length range progressing from the tip of the plate toward the jaw.

species in the western and southern areas of the migratory range (Schell *et al.*, in prep). The average ^{13}C isotopic abundance in tissues from subadult spring-killed *B. mysticetus* was significantly enriched (p = 0.01, two-tailed "t" test) by 2.1 ppt for visceral fat and 1.6 ppt for muscle relative to fall-killed subadult animals. This implies that a major fraction of the total carbon of the animal was derived from the western and southern parts of their annual range. Although at this time it is impossible to accurately estimate the relative amounts of food that the whales obtain from the Beaufort versus Chukchi versus Bering Seas, these data contrast with previous feeding scenarios which suggested that bowheads feed in the summer in the eastern Beaufort Sea and relied almost entirely on stored reserves for the winter (Lowry and Frost 1984).

The pronounced isotopic markers in whale baleen led us to seek similar isotopic variation in keratinous tissue from other marine mammals in the western Arctic ecosystem. Figure 3 shows the carbon isotope ratios in the claws of three polar bears -- an animal killed off Prudhoe Bay in the central Beaufort Sea, an animal taken near St. Lawrence Island in the northern Bering Sea, and an animal killed at Point Lay. Based on the isotopic records in the three animals, the Prudhoe bear had spent the entire time represented by the growth of the claw in the eastern Beaufort Sea, whereas the Bering bear was a resident of the western region. The bear killed at Point Lay, however, shows a transition in isotope ratios which suggest that it had migrated from the western Arctic east into the eastern Beaufort Sea and then only recently had returned to the Chukchi Sea. We have since analyzed toe nails from two ringed seals (*Phoca hispida*) (not shown) and find that the carbon isotope ratios in this important prey of polar bears closely match the anticipated values for each region. This indicates that isotope abundances can be effective tracers of carbon flow within ecosystem food webs.

The above data indicate that stable isotope abundances in keratinous tissues of marine mammals may provide useful information on demography and habitat importance, both of which are important in regulating harvest of rare species such as *B. mysticetus*. The long-term isotopic records may also prove useful in understanding the mesoscale environmental changes in the oceanic environments of these animals.

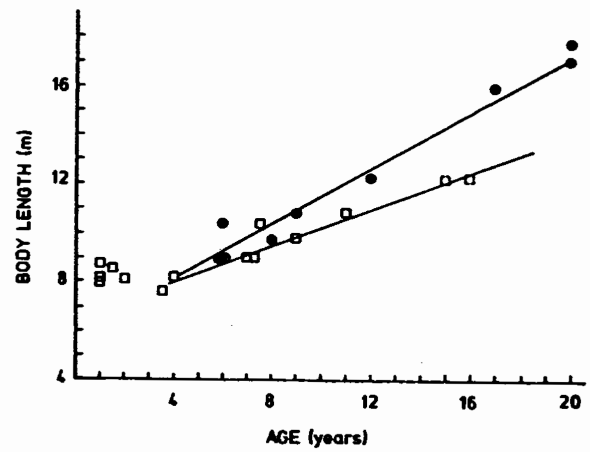

Figure 2. Body length and age as determined by del ¹³C oscillations in bowhead whale baleen. Uncorrected isotopic ages (circles) represent actual measured counts of annual cycles. the subadults are also shown with ages corrected for wear from the distal end of the baleen plates (squares) (from Table 1). For whales less than four years old, corrected and uncorrected ages are the same. Dotted values for whale 86B6 reflect uncertainly as to the loss of three or four years of baleen growth. Corrected ages for the largest whales cannot be determined because of baleen wear.

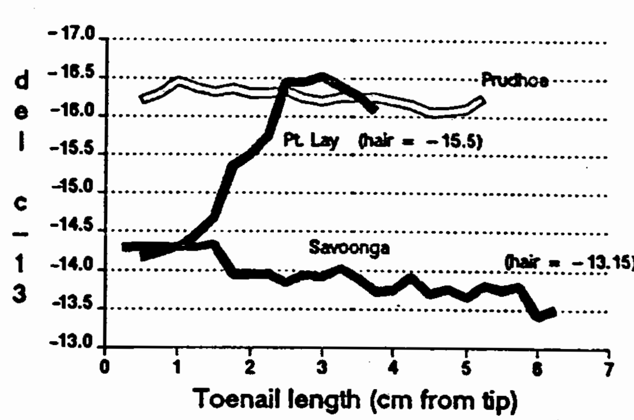

Figure 3. Carbon isotope ratios (/oo) in claws from three polar bears taken in the areas shown. Also shown is the carbon isotope ratios for hair from two of the animals.

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QUESTIONS AND DISCUSSION: *Endangered Species Session*

Question (Mate): Don (Schell) that's really neat stuff. I am wondering though, it seems as an alternative possibility, you're looking at something as simple as summer wood -- winter wood in a tree analogy, where there are fast growth rates and slow growth rates during a year. Similarly, such growth rate changes might change the dilution factor of what is going out into the baleen. Could you address that?

Response (Schell): First of all, the growth rates of the baleen plates are pretty well nailed down now. We've collected animals from over a sufficient length of time and compared the gaps between a long length to show that it isn't that the baleen grows fast or slow. There are changes in rates as you saw in that B3 whale that was up there. The optimum feeding is apparently in the fall but the actual change in growth rate is slower. Almost certainly, the animals do feed better at certain times of the year. Again, from baleen growth rates, it appears that optimum feeding occurs somewhere between September and December. And that could well be. To turn over the carbon in the body, however, the muscle tissue is a different story. When you look at a two part-per-thousand shift over the course of fall to spring in muscle tissue and visceral fat, which is the more energetically mobile tissue, in order to replace that entire amount of carbon implies that the whale is not just eating a little bit of food which is showing up in the baleen and making the oscillation. It implies that it is turning over the entire amount of carbon in the animal. If you do an estimate of the energetics required for a 12 m whale, they have got to have 7 tons of carbon to carry them through the winter. It's hard to believe that if they have an 8 ton blubber blanket that they are going to use 7/8 of it to coast on, when there is no physical discernable difference between spring whale and fall whale as far as condition index goes.

Question (Mate): As a follow-up to that, I guess my concern is that in some tissues, the route of assimilation is really different. For instance, you might find a pesticide coming first into muscle in high concentrations then showing up in lipids with a delayed reaction. But an excretion route might take the route of say, pulling from the lipid base rather than muscle base, so it would have a time lag. I don't know what the circumstance is in the carbon base where it comes from for baleen, but I'm just wondering that it would be very hard to have a control, of course, on growth rates of baleen. You might have growth rates that seem to indicate optimization in October to December, but it might be a delayed route. Or, these ratios might be different because the input that is being laid down is not the resource that's being drawn upon for the excretion route. For example, things like mercury, where we get differences in nail growth, hair growth, according to conditioning and feeding habits. It's an excretion route, so people who have looked at that kind of thing have seen variations according to nutritional demand, and I was just wondering whether there is any analogy at all possible with baleen whales?

Response (Schell): It could be. There is good isotopic evidence now on relative turnover rates, and we are looking at this. These experiments have been done with lab animals. We are actually right now in the middle of trying to do this type of thing with caribou. But within muscle tissue of laboratory animals, it has been shown to have a turnover time of about 30 days. Collagen is about like 90 days. Liver tissue (glycogen in the liver, that is the major pool where the energy is stored and moved out on demand) is typically in the order of 10 days. One of the things we need to do is to get a good suite of tissue samples taken from harvested animals over the course of the season. For example, get them from Gamble, Point Hope, Barrow, and from Katovik, in which case we've got almost the entire seasonal cycle. Then, we could get at a lot of the questions that you're pointing out there. The only thing I wanted to point out was that in order to turn over the fat and the muscle carbon to the extent that we see, apparently with these animals, (and remember that was a very small sample) implies they're getting a major amount of their energy during other times of the year at places where the isotopic content is typical of southern and western distribution. This afternoon I'll show you some data with polar bears.

Question (Newbury): I just wanted to point out that John Richardson showed a slide that supports the point that Don Schell was making. In your report Don, you talked about the similarity in the growth rates of the baleen in the front of the jaw and the back of the jaw. I think it was about the 10th slide that John Richardson showed that comes across very well (slide put on). You can see the bands all along the jaw. Here you can see those bands going from the front (the shortest baleen) to the back. To me that says that whether you test a piece of baleen, a short piece of baleen towards the front of the jaw or a long one toward the back, you're going to get the same sort of growth rate.

Response (Schell): That's true, and what we've actually done is matched plates and run the isotopic composition along the two plates from opposite sides of the mouth. They are identical. In other words, by using those little ridges as alignment aids, we have run them to verify that indeed you don't get discrimination from one side of the mouth to the other. Tomorrow, in Susan Saupe's paper on zooplankton distributions, there will be a lot of the background information regarding what causes these shifts and why you see various isotopic shifts even though you may not see it within one taxon of zooplankton.

Question (Fishman): John (Richardson), your information says that the major or the primary feeding is during the summer in the eastern Beaufort. Don, you're saying that the optimum feeding is in the fall and early winter on the westward migration. Would you care to comment on that? How do we resolve that?

Response (Richardson): Well, I said that we have information that suggests there is intensive feeding in the summer and the early autumn, and that there is at least incidental feeding at a couple of other times a year. However, we have no detailed, direct observations at some of the critical times and places. So, I'm not sure that the results purported in the two papers are necessarily at odds with one another. Clearly, there is still a major question as to what proportion of the annual energy requirements are met in the various parts of the range.

Question (Naidu): Don (Schell), you showed very nicely substantiated growth rates of whale's baleen plates using the C^{14} signal. What about animals which were born after 1963? Do you have any independent evidence, any other natural radionucleotides such as Pb_{210} or so you'd like to consider?

Response (Schell): Well, certainly not with C^{14}. Fortunately there has been only one major excursion of 550 megatons in the atmosphere and let's hope that was the only one. There have been questions, for example: Could the Chernobyl give a signal that could be picked up? No, it couldn't. It turns out that C^{14} is optimum for this particular type of one point analysis, just by virtue of the fact that carbon isn't a common element in sea water, whereas the little bit of cesium or other radionucleotides from Chernobyl would have been diluted out. Whether that's true in the North Atlantic where there may have been a higher input, I'm not sure. But as far as I was concerned, as soon as I had demonstrated to my own satisfaction that those were indeed annual oscillations, I was willing to let it go at that.

Questions and Discussion: *Endangered Species Session*

Question (Holland): Don, with regard to the zooplankton, you said they were theoretically enriched in the Bering Sea and depleted in the Beaufort Sea. Are we certain of the depletion in the Bering, how good a database do you have on the plankton?

Response (Schell): Really good, you will see that tomorrow. Susan Saupe will be talking on stable isotope distributions in zooplankton across the range of the bowhead whale.

Question (Holland): John, you were saying that some of the whales that are taken in the Chukchi area apparently have some food in their stomachs. Is there any indication where that's being assimilated, where they are feeding?

Response (Richardson): All the evidence suggests that food in a whale's stomach turns over and disappears very rapidly. So, on the scale we are looking at, the food is acquired at the place where the whale is killed. Is that what you're asking?

Question (Holland): Yes. I was wondering how long assimilation takes and if anybody has looked at that?

Response (Richardson): Whales that are chased for a long time, a few hours while they are being hunted, generally have empty stomachs. Evidence of that sort suggests that it turns over pretty fast. Another avenue of argument is that based on what our energetic calculations say whales must acquire per day in order to come close to meeting their annual energy requirements versus the size of the stomach, they've got to be turning over the content of the stomach in a matter of hours in order to be able to eat enough.

OIL AND EUPHAUSIIDS: LABORATORY RESULTS, ECOLOGICAL NOTES, AND OIL SPILL IMPLICATIONS

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OBJECTIVES

The environmental assessment of oil and gas development impacts in arctic marine waters must include indirect as well as direct impacts to marine organisms. The bowhead whale (*Balaena mysticetus*), which has special biological and social significance, has received a great deal of scientific attention in recent years. The Minerals Management Service (MMS) funded recent research concerning the effects of spilled oil on krill (euphausiids), a major food item of bowheads.

This presentation briefly summarizes the results of laboratory tests in which euphausiids (*Thysanoessa raschi*) were exposed to various concentrations of the water-soluble fraction (WSF) of Prudhoe Bay crude oil. These results are then synthesized with information from a variety of sources to estimate the impacts of a hypothetical oil spill to euphausiid populations in the Alaskan Beaufort Sea.

STUDY RESULTS

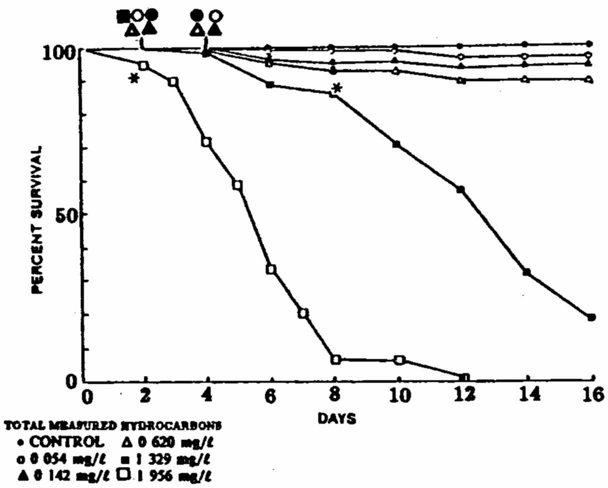
Laboratory results showed that WSF concentrations producing euphausiid mortalities were relatively high, compared to published results for other crustacean species. Larval animals were less sensitive to oil WSF than juveniles or adults; gravid females were the most sensitive of the groups tested (Figures 1-4). The higher concentrations of oil WSF also resulted in longer periods between molts for adult euphausiids.

The effects of hypothesized oil spills on euphausiid populations in the Beaufort Sea are difficult to estimate due to a scarcity of ecological information for this species. Distribution and abundance data are virtually non-existent; life cycle information for the Alaskan Beaufort is also unknown. For these reasons, indirect information concerning euphausiid ecology was used to estimate parameters for the oil spill scenario exercise.

The synthesis of euphausiid and oil laboratory results, literature on the behavior of spilled oil in marine waters, and estimates of euphausiid ecology in the Beaufort Sea resulted in the conclusion that the effects of a hypothetical oil spill would be negligible regarding euphausiid populations.

CONTRIBUTIONS TO BASIC KNOWLEDGE

The laboratory tests discussed in this report provide important information regarding the effects of oil WSF on arctic euphausiids. These tests may be the only such work accomplished with *T. raschi*, and demonstrate that this species is easily maintained and used for toxicity testing.



*Significance difference from control group 15% level.

Figure 1. Adult euphausiid survival at test levels of oil WSF.

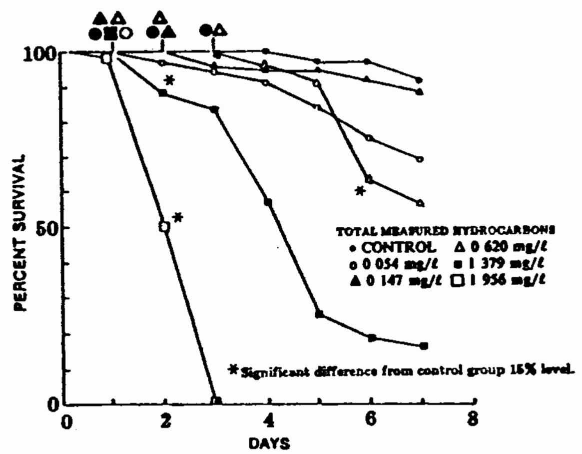


Figure 2. Gravid female euphausiid survival at test levels of oil WSF.

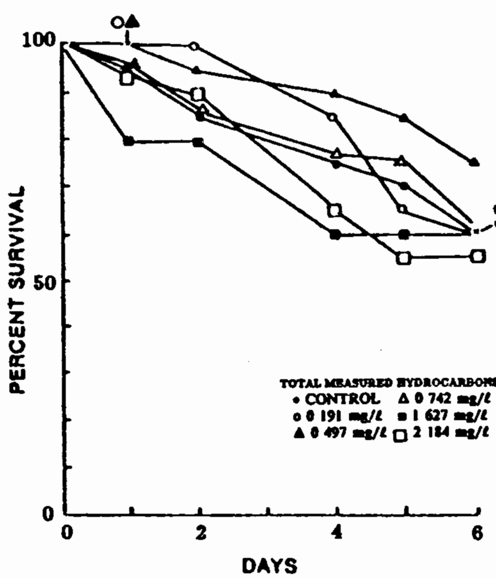
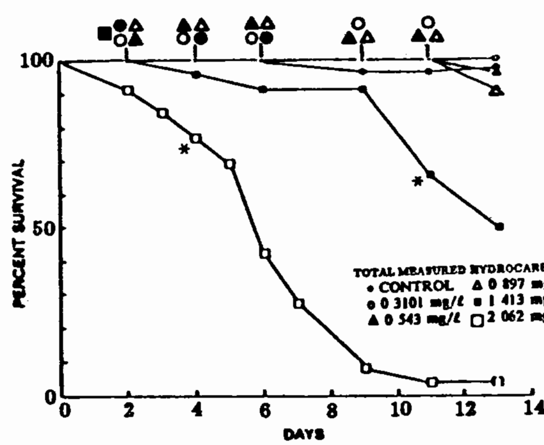


Figure 3. Larval euphausiid survival at test levels of oil WSF.



*Significance difference from control group 15% level.

Figure 4. Juvenile euphausiid survival at test levels of oil WSF.

The oil toxicity literature indicates that pelagic organisms are more sensitive to oil than either benthic or intertidal organisms. This is attributed to pelagic organisms being adapted to a relatively more uniform environment. This generalization is not clearly demonstrated by a comparison of our test results with those for benthic and intertidal animals; although it must be stressed that comparisons between toxicity studies of this nature are generally not valid.

Larval crustaceans have generally been described as somewhat more sensitive to oil than adults; our test results show the opposite for *T. raschi*.

A synthesis of available literature and unpublished accounts indicates that: 1) euphausiids are more important in western Beaufort food chains than in the eastern Beaufort; 2) arctic cod (*Boreogadus saida*) and bowhead whales (*Balaena mysticetus*) are major consumers of euphausiids in the western Beaufort; ringed seals (*Pusa hispida*) and sea birds are minor consumers of these organisms; 3) euphausiids comprise a major portion of the bowhead whale annual diet; 4) the Point Barrow-Plover Island area supports major seasonal concentrations of euphausiids, and thus provides an important feeding area for birds and mammals; and 5) the Bering Sea intrusion could be an important variable in euphausiid population dynamics, supplying favorable environmental conditions as well as imported euphausiids.

CONTRIBUTIONS TO ISSUES OF OIL AND THE ENVIRONMENT

The maximum measured and predicted oil WSF concentrations in arctic marine waters during a spill event are lower than concentrations that produce lethal or sub-lethal effects on euphausiids in the laboratory. The highest concentrations, in fact, seem limited to the top few meters of the water column, and decay curves are fairly short. Any effects of spilled oil on zooplankton populations are likely to be short lived due to the patchiness of zooplankton density, the production level of these animals, and the importation of animals from other areas.

Given the conclusions drawn above, the effect of oil spills on the food supply of bowhead whales is probably negligible.

This paper does point to the need for additional information:

- Additional toxicity studies are needed to confirm or change the conclusions drawn from this single set of experiments;
- More information is needed on the physical and chemical behavior of spilled oil in arctic marine waters;
- Studies are needed to test the behavior of euphausiids, and other key marine species, in the presence of oil.

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TRACKING WHALES BY SATELLITE

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Little is still known of the normal movements, behaviors and dive patterns of free-ranging whales because they are difficult to identify as individuals and observe over long periods of time. The habits of individual whales are important because collectively they describe what their population does. Satellite-monitored radio tags can now track virtually any number of whales simultaneously anywhere in the world and send data which can interpret the animal's health and habits.

The feasibility of satellite tracking began in 1979 when Minerals Management Service (MMS) funded a whale tracking study using conventional, very high frequency (VHF) radio tags. A radio tagged gray whale moved at least 6,680 km from Mexico to Unimak Pass, Alaska in 94 days (Figure 1), at an average speed of 85 to 127 km/day (3.5 to 5.3 km/hr). Only the nearshore migratory habits of this species allowed the low-powered (short range) transmitter to be monitored from shore without involving expensive ships and aircraft. In offshore studies, widely dispersed animals must be tracked individually because of the short reception range. The new "barnacle" attachment was so successful that consideration of longer duration studies and larger tags needed for satellite tracking began. So, in 1980, VHF tags were again used to determine dive durations and pattern data from 11,080 gray whale dives to estimate whether whales surfaced frequently enough during the 15-minute duration of a satellite pass overhead to make satellite tracking feasible. The VHF study was typical of conventional telemetry work, requiring 10 people to work three months to tag, track and log data from whales.

ARGOS is the only satellite system presently available which can provide locations for whales equipped with specialized transmitters. Prior to 1983, these transmitters were too large and power consumptive for whales, but, in cooperation with Telonics, an experimental transmitter was developed which now provides satellite-monitored data from free-ranging whales and other marine mammals. Extremely accurate locations (90% within 1 km) are achieved by using very stable ultra-high frequency (UHF) transmitters. Positions are calculated from Doppler shift data (the change in frequency heard by the satellite receiver resulting from its speed as it passes the transmitter). ARGOS receivers are carried on two polar-orbiting NOAA weather satellites, which jointly pass over all portions of the earth from 7 (tropical) to 24 (polar) times daily. Transmitters send a two-watt signal which the satellite can receive up to 2,500 km away. To conserve battery power, a saltwater switch was developed to initiate transmissions only when the transmitter surfaces and during pre-programmed times when satellites are overhead.

The first successful tracking of a whale by satellite occurred in 1983 when a humpback whale (*Megaptera novaeangliae*) off Newfoundland, Canada was tracked 700 km during six days (Figure 2). The whale's location was calculated 10 times and showed an average movement of 5.9 km/hour (similar to the migrant gray whale speed) to an area offshore where the cold Gulf Stream and the warm Labrador currents converged. This area, like an upwelling, was characterized by high productivity and was often used by humpback whales feeding on concentrations of spawning capelin. This was the first documentation of a nearshore animal

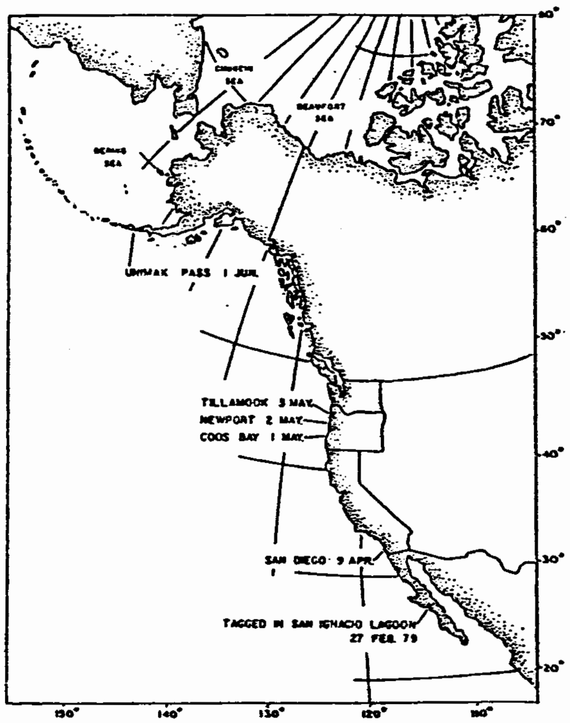

Figure 1. Locations and dates of signal receptions from a radio tag attached to an adult gray whale (100W) during the northward migration of 1979.

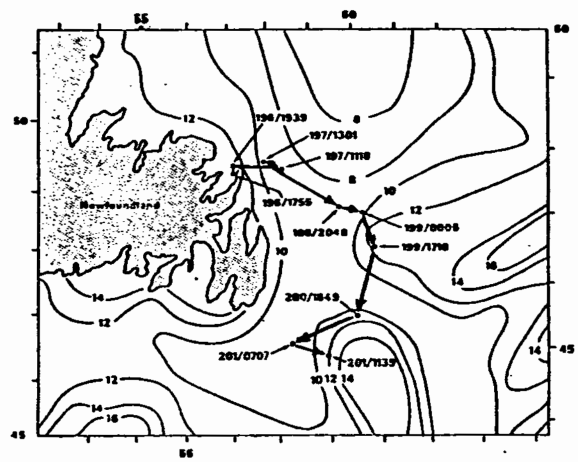

Figure 2. Ten locations of a satellite-monitored humpback whale tagged off Newfoundland in 1983. Isotherms (light lines) show temperatures of the sea surface in centigrade averaged over the six day experiment. The dark line traces the whales movement of at least 700 km to a convergence area offshore where other humpback whales were observed feeding.

moving directly offshore to another whale feeding area. How do whales know where to find food (memory, sensing favorable oceanographic factors, or listening to other whales vocalize) and navigate to it (dead reckoning, magnetic headings, or celestial cues)? This prototype transmitter had a short operational life as most of its energy was used to keep the oscillator circuit warmed up, whether it was transmitting or not.

In January 1984, a female gray whale (*Eschrichtius robustus*), with a modified Telonics transmitter, collected depth information every 15 seconds and reported information about dive duration, temperature and depth profile with each transmission. The experiment lasted for only a few days, probably as a result of breeding activity. The tagged whale spent 45 minutes of the first hour after tagging in vigorous mating behavior with two males. The tag did not appear to inhibit the whale's behavior.

Although not funded by MMS, the next significant development in satellite tracking marine mammals was built upon the progress of the MMS studies. A 1985 collaboration between the U.S. Fish and Wildlife Service and Oregon State University resulted in tracking a free-ranging manatee in Florida for 100 days. A similar 1986 experiment tracked a female manatee with a calf for 300 days, after which the transmitter was replaced and tracking continued for an additional 10 months. The tagged manatee was a female with a calf at the time of tagging. The calf went

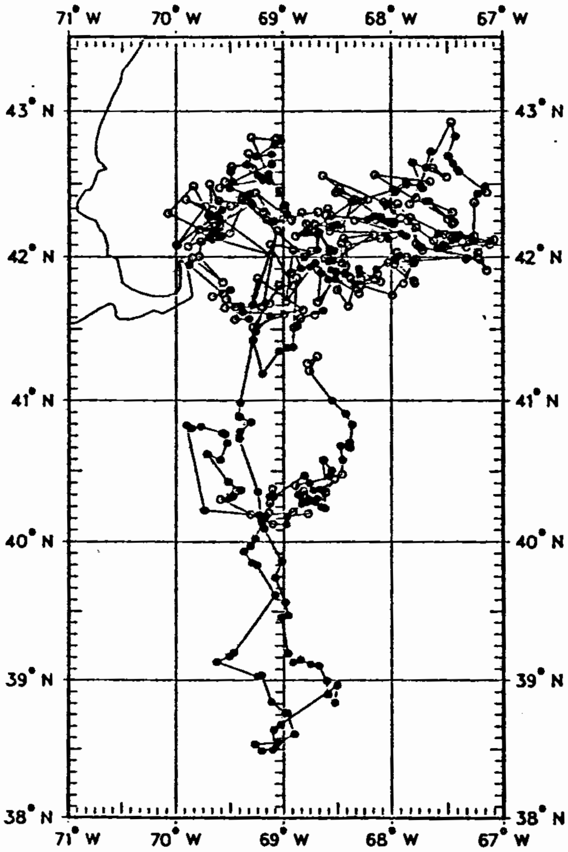

Figure 3. The 95-day track of a satellite-monitored pilot whale in the North Atlantic. A distance of 7,588 km was travelled between 479 locations (Mate, unpubl. data).

through normal development and was weaned. This was the first study by any means to demonstrate the daily movements and natural foraging range of a free-ranging marine mammal over such an extended period.

The first long term satellite-monitored study of a free-ranging whale took place during 1987 in the North Atlantic. An immature pilot whale (*Globicephala macrorhychus*), stranded in December 1986, was rehabilitated by the New England Aquarium and released on 29 June 1987 carrying a Telonics transmitter. The whale was tracked by satellite for 95 days and covered a distance of at least 7,588 km between 479 satellite-determined locations (Figure 3). The average daily movement (80 km/day) and a maximum movement of 234 km in 24 hours suggest how wide ranging small cetaceans can be. Every dive was counted (mean = 2,020) and its duration measured. The average dive lasted 40 seconds. The number of dives in a 12-hour period varied from 636 to 1,433, reflecting changes in the animal's activity patterns and metabolic rate. Swimming speeds averaged 3.3 km/hr for the entire 95-day period. Average speeds in excess of 16 km/hr were maintained for periods >3 hrs.

Important correlations of the animal's movements and dive patterns were made with sea surface temperature measurements, which varied from 14 to 30°C. The whale encountered temperatures down to 6°C during deep dives, which occurred primarily before sunrise and secondarily just before sunset. Deep dives coincided with the nocturnal rise in the water column of the deep scattering layer and of the pilot whale's favorite prey, squid. Few deep dives were recorded during daylight hours. If daytime feeding occurred, it was a completely different strategy. This was the first direct documentation of the importance of night feeding to this species. The highest swimming speeds were also observed at night and just before sunset, suggesting that this whale either traveled fast in pursuit of prey or moved quickly to search for other prey patches. Surface resting activity lasted up to 15 minutes and was most common during the first three hours after sunrise. Surface resting occurred on a 4- to 7-day cycle. These data represent the first long-term data on surface resting patterns for a free-ranging cetacean.

The feasibility of tracking marine mammals has now been proven and these examples show its utility over relatively long periods. A February 1987 Marine Mammal Commission workshop (sponsored by MMS) summarized whale radio telemetry studies and recommended satellite-monitored radio tags as the most promising tool for the long-term study of pelagic whale movements. The most challenging problems will be attachment and deployment techniques. Once successfully deployed, satellite tags will be a cost effective means of gathering whale data. Tags cost about $4,000 (approximately the same as a single day of vessel charter) and are monitored for $12.00 per day. Although behavioral observations will still be necessary, they will be relatively inexpensive. Satellite-determined locations can guide observers to tagged whales on good weather days so they can spend their time actually observing whale behavior rather than searching for whales.

The successful monitoring of a single whale by satellite for even a few days can provide insights into the species' diving behavior, movements, diurnal rhythms, and energetics. While the daily dive patterns and energetics of whales are of interest, it is the longer term movements within foraging area, breeding grounds and along migrating routes that are also important to assess potential impacts of offshore development. For instance, satellite-monitored tags could be used on bowhead whales to gather information on:

- The foraging range (and site tenacity) of individual whales during their Beaufort Sea occupancy.
- The importance of certain areas for feeding, staging and migration.
- What diurnal and geographic differences in dive habits reflect differences in behavior.
- The speed of movements between feeding areas and during migration.
- The relationship of whale distributions to environmental factors such as sea surface temperatures, bathymetry and ice coverage.
- The amount of time whales spend at the surface, which affects how often they are sighted during aerial surveys and affects the interpretation of aerial survey data (Moore, these proceedings; Richardson, these proceedings).

It may also be possible to conduct experiments with tagged whales along their migration route to determine if whales avoid specific sounds. If tags remained operational for longer periods or whales are tagged in other regions, it will be possible to identify the complete fall migration route through the Beaufort, Chukchi and Bering Seas and learn something about the wintering grounds of the bowhead. Isotopic studies (Schell, these proceedings) suggest that these areas may be important to extend the seasonal and geographic feeding range of the bowhead whale. In the future, satellite-monitored radio tags are likely to provide much of the oceanographic data which describes why certain habitats are preferred by endangered whales.

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QUESTIONS AND DISCUSSION: *Endangered Species Session*

Question (Barnes): In the test that was done on the simulated oil spill, what was the areal extent of the spill and what was the spill volume. Secondly, would you expect any different results in the Katovik or the Camden Bay area?

Response (Fishman): This work was done a couple of years ago, so I will have to dig to get the answers to the first part. I really haven't looked at the risk assessment modeling that has been done in the Katovik area. So, a lot of it is going to depend on the oceanographic features and the type of spill that you are looking at. Is it a sea floor blowout, a surface spill -- what's it going to be? We used three different spill scenarios. The first one was a 200,000 barrel spill, a kind of an instantaneous spill with a duration of 96 hours. The other one we used was 2,000 barrels per day continuous spill over a five-day period. The third was the same as the first one. So basically those two -- an instantaneous large spill, and then a small spill that was a continuous leak over a period of days.

Question (Barnes:) The reason I asked the question was that obviously the conditions, at least at certain times of the year, can be fairly significant between Barrow and Katovik. Also, there hasn't been any oil and gas exploration offshore in Barrow, but there has been in Katovik. The drillship is also a little bit different.

Response (Fishman): It is kind of a guessing game because you have to try and estimate somehow what's really happening in the water column. To my knowledge, there has been very little data collected (of the distribution of that water soluble fraction in the water column) during actual oil spills. So, that would be some important information to plug into this kind of modeling.

Question (Richardson): Have you considered the situation of whales feeding in shallow waters, for example, along the Beaufort Coast in both Alaska and Canada where they feed fairly frequently? Their food is obviously closer to the surface since all the water is closer to the surface.

Response (Fishman): Yes, we did consider that, I must admit we were on a very limited program. We tried to select what we considered our worst case. The shallow water example is something we thought about quite a bit, because there is a lot of evidence that whales feed in very shallow water. It's not clear what euphausiids are doing in the shallow water. It's not even clear what they are doing in the deeper water. A lot of the information we have on euphausiid ecology is from the north Atlantic and some of the fjords in Norway. So, the kinds of things we are seeing there are probably not very applicable to the situations in the Beaufort.

Question (Richardson): So, do we conclude that your conclusion that there are minimal effects in terms of affecting the prey of whales would apply to the shallow waters or do we conclude that we don't know whether it would apply to the shallow waters?

Response (Fishman): My best guess is that it would apply to the shallow waters in the sense of looking that it is fairly medium to long term effect. In shallow waters, the impact would probably be greater within a short time period. But if you are looking at the overall impact on the food resource, the movement of animals into an area, and the patchiness of the animals and the prey animals, it is going to give you a more favorable circumstance or situation if you allow that kind of wording. In regards to the duration of the impact, looking at the long term effect, etc., yes, -- the shallow water is going to be impacted to a greater extent.

Comment (Mate): I'll take advantage of a few moments here to make a couple of remarks. One is that satellite tracking can be extremely cost effective. Monitoring for our pilot whale study amounted to less than $200/day amortized over the cost of the original tag, the cost of application, the data recovery, and analysis to date. In the Arctic, safety and costs are very big features. One of the nice features of this kind of a system (satellite tracking) is that you can monitor virtually any number of animals you like. I might also add that those of you who are interested in oceanographic data or other things (i.e. movement of ice) do obtain that type of data just as easily. In fact, probably easier than for whales. I think, however, even though you can do this without onsite observers, there is still going to be a need periodically for biologists to go out. There is no substitute for going out and looking and seeing what's happening. The nice thing about this is you can sample that effort; make it coincide with good weather, and not spend your time searching for whales. You can go back to the same animals time and time again, and get some times series behavior from individuals. The last thing is that we need to be realistic about what kind of expectations we might look at for bowhead whales. At the present time, information on just two days of movements would be a substantial increase in our knowledge about what individuals do. I think periods though on the order of three months during the open water season (and I use that term loosely) would be exceptionally successful. If we could keep something attached for a period of two to three months, we would learn an awful lot about bowhead whales. I think the challenges that remain are in the attachment and deployment process. The problems should not be minimized; they are still substantial, and I'll say that in terms of what we are doing with conventional techniques. While they have been very successful, I think we are going to add some resolution by continuing those techniques, but we've got the bulk of what they have to offer us.

Question (Cowles): Certainly the information that could be obtained from tagging looks like it's going to be quite extensive. Another question in a lot of peoples' minds is what is the significance of the application of the tag to the animal, in terms of behavioral effects on the animal or physiological effects, and some kind of injury? Can you address that in terms of how you see tagging in the context of harassment or injury of whales?

Response (Mate): Yes, that is a good question and thank you (return to slides). I made the point that you don't go 4,700 miles for an 11 ft long animal without putting some fuel in your tank. I think that it is important to realize that with the pilot whale we basically bolted this tag to the animal's dorsal fin with a saddle pack. (slide showing tag on fin). Six delrin rods made of surgical quality plastic were put through the animal. The volume of what is holding this tag on to this much smaller animal is approximately 15 times the volume of what we propose to put on the large whales. Now, the advantage, of course, is that it is a hands-on attachment technique, which makes it quite a bit easier to do. But, the effect of the equipment on the animal appears to be minimal. The tag is about the size of 2.5 packages of cigarettes, a large coffee cup sort-of-size. The duration of dives, the pattern of dives, the number of dives in a 12-hour period and the speed of movement were the same the last two weeks of the 95-day experiment as they were during the first two weeks. So, the health to the animal is clearly an issue that has been addressed by this experiment for that species in that water and it has to be done for every animal, and certainly relative to bowhead whales, pilot whales are dirt common. They aren't threatened or endangered, and I recognize and respect that difference (slides presented showing bowhead whale skin and the tag applied to bowhead blubber at Katovik). The environmental conditions in the Arctic are quite a bit different, even your working circumstances. We've looked at some exotic ways of getting these tags out to the animals, including a small radio-controlled helicopter. I still think this method had marvelous potential but it required a really skilled operator. In summary, then, the health of the animal is an issue, but the things that go into the whale are much smaller in scale and size than things that occur naturally, in terms of cracks in the animals skin, parasites, and other animals. I think experiments might best be done on less endangered or more accessible animals to demonstrate the technology. One of the considerations is to do it on right whales in the north Atlantic, which are very closely related to bowheads.

AERIAL SURVEYS OF ENDANGERED WHALES

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Aerial surveys for endangered whales have been conducted over the Bering, Chukchi and Alaskan Beaufort Seas under the auspices of the Minerals Management Service (MMS), U.S. Department of the Interior since 1979. The bowhead whale (*Balaena mysticetus*) has been the principal species studied. Historically, bowheads had a nearly circumpolar distribution north of 60°N, but exploitation in the late 19th and early 20th centuries seriously reduced the number of whales in each of five geographically separate stocks. The largest population, the western Arctic stock, migrates around western and northern Alaska each year between wintering areas in the Bering Sea and summer feeding grounds in the Canadian Beaufort Sea. The spring migration generally occurs along open-water lead systems that annually develop relatively nearshore in the Chukchi Sea, but offshore and well north of oil exploration activities in the Alaskan Beaufort Sea. During the fall migration, however, bowheads commonly occur nearshore within or near oil lease areas in the Alaskan Beaufort Sea. Therefore, although the MMS curtailed aerial surveys of the spring migration in 1984, they have continued to monitor the fall migration in relation to ongoing oil exploration activities.

Bowheads are commonly seen in the eastern Alaskan Beaufort Sea from August through October. In August, and through the first half of September, bowhead swimming direction is usually not significantly clustered, but by the latter half of September and throughout October most whales are swimming in a westerly direction (Figure 1). Concern that noise from oil and gas development activities influences the fall bowhead migration has been addressed in two ways:

- Through direct observation of bowhead whale behavior when they are near such activities.
- An analysis of the distribution of bowheads during September and October.

The behavioral response of bowheads to industrial noise has generally been "mild" at distances of 10 km or more. The analysis of the bowhead migratory route, as described by median depth at random bowhead sightings, resulted in a relatively consistent migratory route being described along the 20 to 28 m isobath, with only one year (1983, 145 m) being significantly different from any other (Figure 2, Table 1). Ice cover in the Beaufort Sea remained heavy throughout the fall in 1983 and may have influenced the distribution of migrating bowheads, although there is no direct evidence of this. The shift offshore to deeper water in 1983 was roughly 45 km; greater than that expected if caused by noise.

Feeding bowheads have been seen each year during the migration. The percentage of feeding whales was higher in years of light or no ice cover than in years of heavy ice (Table 1). Ice cover can limit primary and therefore secondary productivity by deflecting and diffusing light. Between 1979-84, feeding bowheads were seen along the migration route in significantly shallower water and lighter ice cover than non-feeding whales. Thus, prey abundance and availability of feeding opportunities likely influence the distribution and duration of the bowhead migration each fall. When bowheads reach the Chukchi Sea, at least some whales take up southwesterly heading, swimming in a direction that would take them roughly over Herald Shoal enroute to their wintering grounds.

Acoustic monitoring to detect migrating bowhead whales was conducted from Barter Island in 1986 to supplement data derived from aerial surveys. Over 7,100 calls were recorded during 590 hours of monitoring effort (Figure 3a,b). The peaks in number of calls and calling rate (no. calls/hr) generally correspond with peaks in sighting rates, supporting the idea that acoustic monitoring is a reasonable way of extending data gathering through darkness and bad weather when surveys cannot be conducted.

The distribution, relative abundance, and behavior of gray whales (*Eschrichtius robustus*) has also been studied. Principal areas surveyed have been the summer feeding grounds in the northern Bering Sea and the eastern Chukchi Sea. Gray whales have been seen in the northern Bering Sea from May through November, and in the northeastern Chukchi Sea from July through October. Most whales seen are feeding, as evidenced by large plumes of sediment that they bring to the surface. Cow/calf pairs have been disproportionately seen along the coastal Chukchi Sea, compared to the northern Bering Sea; most calves were seen in July.

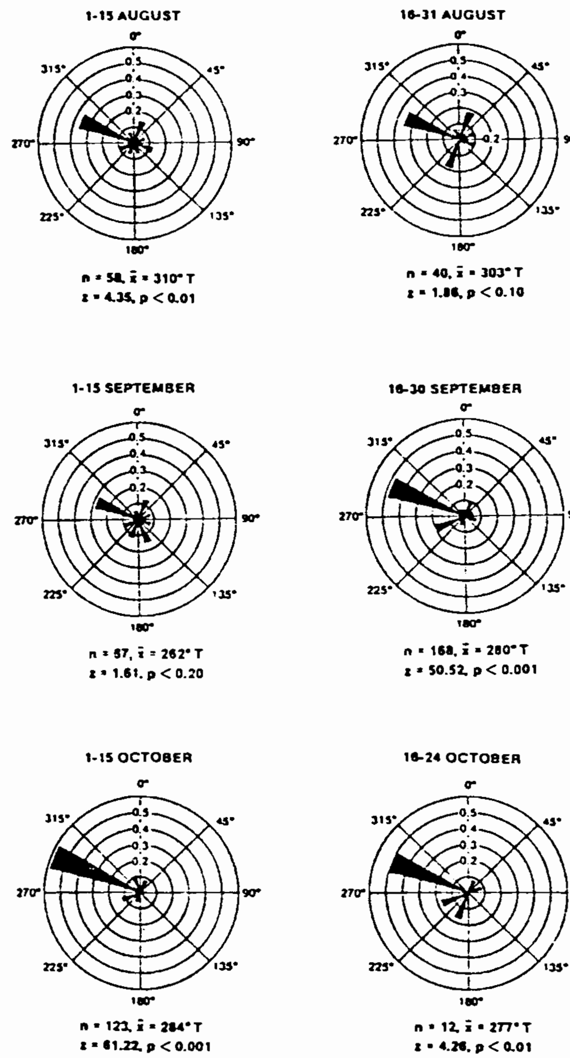

Figure 1. Bowhead swimming direction in the Alaskan Beaufort Sea, 1982-1986.

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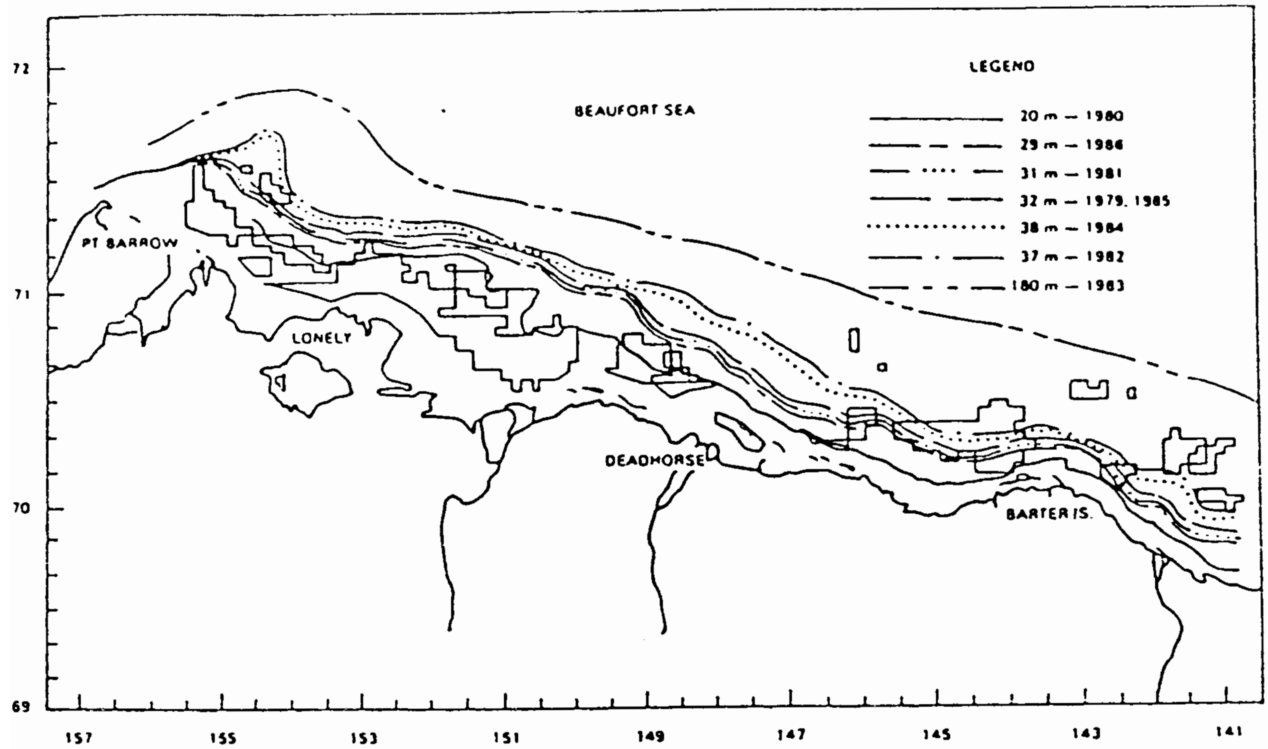

Figure 2. Annual median water depth contours depicting the bowhead migration route across the entire Alaska Beaufort Sea, September-October 1979-1986. Outlined areas depict OCS oil and gas lease areas within the Beaufort Sea Planning Area of the Alaskan Beaufort Sea.

Table 1. Summary of annual bowhead migration period, peak WPUE and date, number (percentage) of feeding bowheads, 5-day SPUE peak and SPUE peak period, average September-October ice cover, and median depth at bowhead sightings in the Alaskan Beaufort Sea, 1979-1986.

	1979	1980	1981	1982	1983	1984	1985	1986
Migration Period Length (Days)	20 Aug- 25 Oct (66)	4 Sep- 9 Oct (35)	7 Sep- 20 Oct (43)	2 Sep- 17 Oct (45)	3 Sep- 17 Oct (44)	7 Sep- 20 Oct (44)	22 Sep- 20 Oct (29)	7 Sep- 17 Oct (41)
WPUE: Peak	7.33	1.25	15.75	23.60	1.86	10.73	5.23	6.01
Date	14 Oct	18 Sep	28 Sep	16 Sep	24 Sep	26 Sep	6 Oct	28 Sep
Feeding Bowheads	50(25)	5(11)	41(14)	108(22)	14(8)	148(39)	35(25)	40(26)
5-day SPUE: Peak	2.69	0.61	6.70	2.53	1.35	1.60	0.97	1.25
Period	26-30 Sept	11-15 Sept	26-30 Sept	21-25 Sept	16-20 Sept	6-10 Oct	11-15 Oct	26-30 Sept
Average Sep/Oct Ice Cover	≤10%	≥60%	≤10%	0%	≥60%	≤10%	≥40%	≤5%
Median Depth	29 m	20 m	29 m	38 m	145 m	28 m	29 m	25 m

Ljungblad, D. K., S. E. Moore, and J. T. Clarke. 1986. Assessment of bowhead whale (*Balaena mysticetus*) feeding patterns in the Alaskan Beaufort and Northeastern Chukchi Seas via aerial surveys, Fall 1979-84. Rep. Int. Whal. Commn. 36:265-272.

Moore, S. E., D. K. Ljungblad, and D. R. Van Schoik. 1986. Annual patterns of gray whale (*Eschrichtius robustus*) distribution, abundance and behavior in the northern Bering and Eastern Chukchi Seas, July 1980-83. Rep. Int. Whal. Commn. Spec. Iss. 8:231-242.

Moore, S. E., J. T. Clarke, and D. K. Ljungblad. 1986. A comparison of gray whale (*Eschrichtius robustus*) and bowhead whale (*Balaena mysticetus*) distribution, abundance, habitat preference and behavior in the Northeastern Chukchi Sea, 1982-84. Rep. Int. Whal. Commn. 36:273-279.

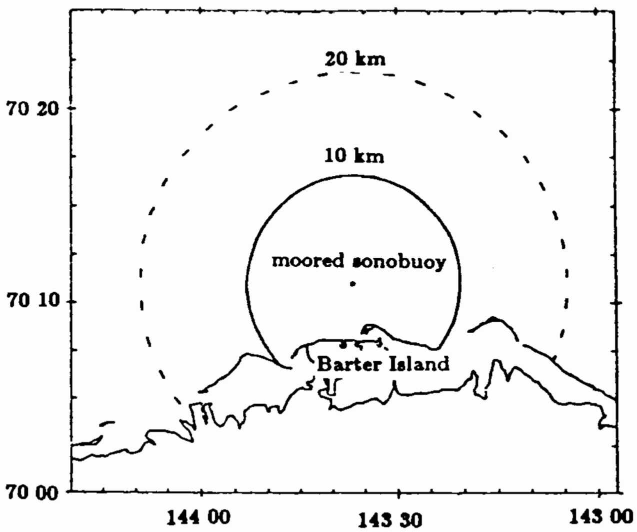

Figure 3a. Acoustic monitoring study area depicting shore station, location of moored sonobuoy, and 10 km and 20 km proposed radial limits of hydrophone reception.

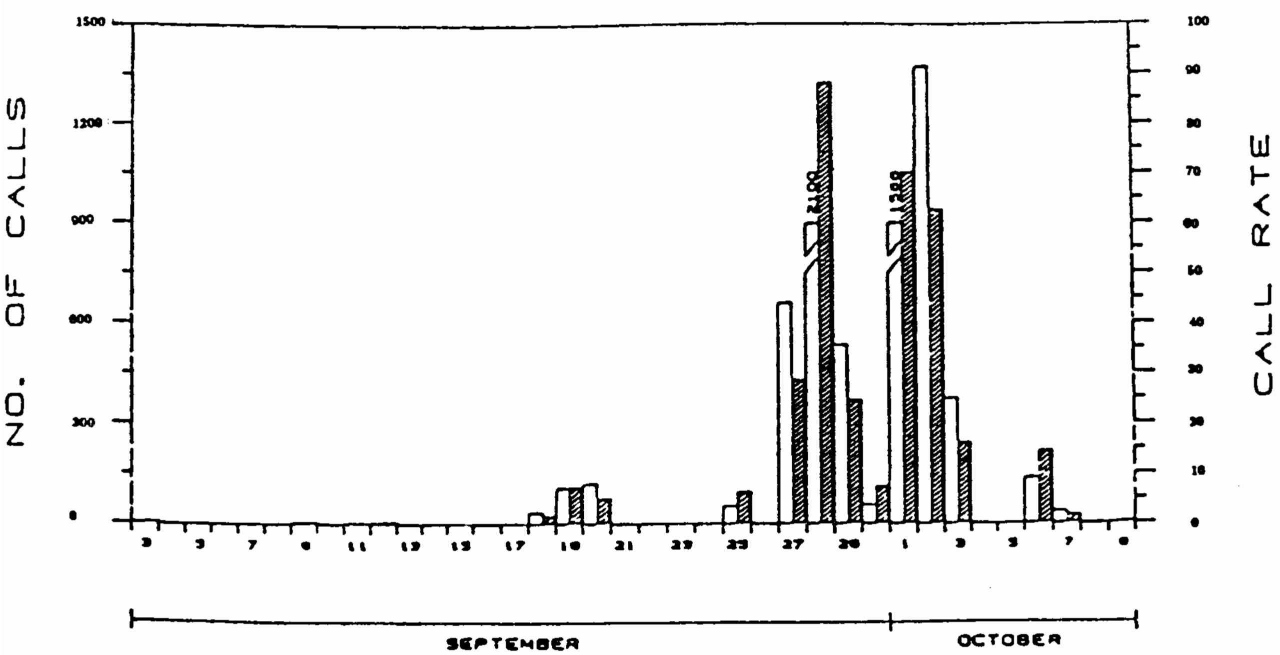

Figure 3b. Histogram depicting number of bowheads calls and call rate (calls/hr) at the Barter Island acoustic station.

Question (Brower): Were whales only affected by noise at a distance of 7-8 km, or were there other instances where they were affected at distances of 35 km, 10 km, or 2 km?

Response (Moore): That was basically the result of Don Ljungblad's work, four experiments were involved, and statistically, the statistical change in behavior and blow rate, surface time and so on, was at the 7.5 to 8 km range. That's how I understand it.

Question (Brower): So the blasts were intentional at those distances?

Response (Moore): Yes, they were bringing the active boats in.

Question (Brower): Do you have any document in relation to what you said about the fall migration going out to the Wrangell Island?

Response (Moore): Out to Wrangell Island? No, we haven't seen a diagram of that.

Question (Brower): That leads me to my next question, why do you say that whales go out to Wrangell Island during the fall migration?

Response (Moore): I don't say it as much as you'll find it in other documents. I believe Howard Brahm in 1984 mentioned whales going over to Wrangell Island and then down the coast. I think that is a 1984 NOAA publication. In fact, what I was trying to say is we have not seen that situation. We have seen animals that are coming around and heading in a southwesterly direction, but we have a small database.

Question (Brower): I haven't read what Ljungblad has done (is there any notation as to what happens to the whale at 8 km)? Do they go back to the normal migration after they pass it; do they go and stay back there until the blasting is all over; or do they resume their normal migration?

Response (Moore): Well, let me clarify the way the experiments were done. The objectives were to look at animals prior to the approach of an active geophysical vessel, then to remain with that group as long as possible. Within the 30 to 60 min timeframe after the experiment, the whales returned to the behavior that they were evidencing prior to the experiment. But, because we couldn't track the animals, we couldn't tell exactly what the animals did after that. Basically, our time was up in terms of fuel and logistical consideration.

Question (Montague): You indicated that your data have shown primarily a south, southwest migration west of Barrow. I think maybe you should point out that there's really only one year where there was a lot of evidence of that occurring, and that despite intensive effort in the past few years, hardly any bowheads were seen at all west of Barrow. Can you comment on that?

Response (Moore): We didn't see very many whales in 1986 or in 1987. However, in 1982 and 1983 as well we saw whales that were headed in a southwesterly direction. So, between 1982 and 1987 that's what the data show, but most of the sightings were made in 1982 and 1983.

Question (Mate): The search areas that you typically run go out to 72° N. Don't whales, and in some years the ice, go out beyond that? Have there been any special efforts made when the ice was far out to go out and take a look along ice edge areas and, if so, what do you find?

Response (Moore): We tried to do that this year because as Jerome Montague pointed out, we haven't seen very many bowheads, particularly in the Barrow area. This year and last year, the ice was out beyond 72° N, so we extended our lines and flew on out to 73° N. We did encounter ice there. We saw only one whale in those searches of the ice. We dropped some sonobuoys and tried to listen for whales out there. We didn't hear anything but we did find the ice and some bears.

Question (Emerson): Regarding those mean depth distribution sightings and the precision of Mann-Whitney tests, are you factoring in the weather windows that are sometimes quite variable for your observations?

Response (Moore): In terms of timeframes?

Response (Moore): No, I'm just looking at September and October. I've also run an ANOVA test on this same data because Doug Chapman with the University of Washington wasn't pleased at all with the Mann-Whitney procedure. The result was the same, A3 being different. But, I was just comparing random bowhead sightings during the September and October timeframe. I was not looking at weather or anything like that.

Question (Emerson): But even during that short period, you would still have quite a variance between years as to where you could see the whales offshore. The weather window that you can actually spot them -- does that vary from year to year?

Response (Moore): The weather certainly varies from year to year, but during September and October, survey periods have been consistent. I haven't looked at the variance of effort from year to year, but we have surveyed during that entire time period in both years. Effort will be down in any year due to weather. I'm not sure I'm catching your question or the impact.

Question (Emerson): In other words, in some years you're not going to be able to get to the same place even in your random sampling observations just because of the weather. That would have to affect the precision of where these mean distributions are.

Response (Moore): From 1982 to 1986, we surveyed through all blocks 1-12 during that time period. From 1979 to 1981, we did do closer-to-shore type of surveys.

Question (Mate): We did some work at Oregon State using some acoustics as an active way of scaring seals away from fish hatcheries and fishing gear problems. In the past, people have tried using biologically significant sounds like killer whales. We went for a totally different approach of trying not only to frighten them, but maybe even hurt them if they came in real close. So, it was within the animal's control to come or go. But, we were trying to discourage them from coming into certain areas. We weren't successful in causing pain. We are convinced of that because we did have animals that eventually habituated to those noises. They came in. It was a small part of the population. I suppose it could be argued they were deaf, too, but the thread here is that we saw a trend toward habituating to sounds that were even novel, very, very loud, and eurythmic. We tried to mix it up to keep the animal off guard.

Are you aware of any seismic vessel movement experiments where vessels in range of whales continued to run, to see what happens to a whale, and if habituation is possible? Or have there been any sightings of whales closer than you suggest to boats that were active that might suggest periods when whales are in control during periods of noise? I think the Doppler Shift has something to do with it. We noticed that sounds which sound like they are moving are far more effective than if they are stationary sources.

Response (Moore): There is some evidence of habituation by bowheads, I believe, but I'm not the best person to speak of that. Maybe John Richardson. To answer your questions, Bruce, there is suggestion of habituation to noise with bowheads as in most animals but John would be better to answer the direct question on the seismic vessels.

Response (Richardson): No one has information from individual bowheads that had been approached repeatedly or exposed over a prolonged period of time to seismic sounds. Obviously, a radio tagging approach would be the most obvious way to get at that. What is available is information of two or three types. Bowheads have been observed in Canadian summer feeding grounds where a seismic vessel was present. Whales remained in the area for a fairly long period of time. Groups of bowheads have been observed remaining in an area where a seismic vessel is working back and forth day after day with whales. We don't know if it's the same individual whales, but there are feeding whales there over a period of days and even a couple of weeks. Another related kind of observation is that we do see whales coming back. We do see whales in areas where there has been a lot of seismic exploration in the previous year. We see whales back there the following year at the same time. Again, we don't know if it was the same individual whales that have come back to an area when that area was heavily ensonified from seismic operations the previous year. This level of evidence is pretty weak for long term questions.

Question (Brower): On the aerial photogrammetry -- have you noticed any differentiation to size elements of whales in the white markings on the chin or by the tail?

Response (Moore): We haven't done photogrammetry, sizing or identification of individuals. LGL ecological research associates has done that type of work.

Question (Carroll): What was the sample size and how many whale sightings per year did you use to produce the whale tracks during your offshore distribution study?

Response (Moore): The median depth tracks?

Question (Carroll): Yes.

Response (Moore): That was dependent upon how many bowheads we saw in random transects during the year. I would have to go look at my table again to tell you that, but again, we just used the September-October timeframe. The 1983 data year is represented by an individual track and that track is represented by however many animals we saw on random transects that year.

Question (Carroll): Will there be a final report?

Response (Moore): I should have mentioned that the annual report for this study is in the back of the room and all that information is summarized there. I brought some of our International

Whaling Commission reports which summarizes our feeding bowhead and our gray whale information and I have put them on the side table.

SOCIOECONOMIC SESSION

Speaker

R. Worl

SOCIOCULTURAL AND SOCIOECONOMIC CHANGES IN BARROW

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I was happy to see that the revised agenda removed my paper from the endangered species session. I do not think that the Inupiat are endangered but, looking around the room, I fear that anthropologists might be.

In late 1986, my colleague Chuck Smythe and I finished a year-long study entitled "Barrow - A Decade of Modernization". Reflecting on that title, I realize I have been in Barrow that entire decade. I arrived in 1975, just before the oil boom, and continued my studies throughout the boom period. To my mind, 1985-86 marked the beginning of the "post-boom" - the downturn in the economy. Here, I want to paint a broad overview of the socioeconomic and sociocultural changes that have occurred on the North Slope throughout the decade.

The most evident changes in Barrow are physical ones - the modern houses, the roads and buses, the large facilities. Yet these only hint at the effects on the social and cultural system. As an example, I will note changes resulting from one modern facility, the water delivery system. Prior to the 1970s, people got water from ice or from ponds. Many continue to supply their own drinking water because they don't like the chlorinated variety. Yet, in the mid-70s people were happy to see the water delivery system instituted. I was happy; I did not wish to relive my youth - packing water, heating it, and packing more. But this one system brought a host of unintended changes to the social and cultural system. First, an income was necessary to buy water - it was not delivered for free. Thus, you needed a job. Also, the men - usually fathers and sons - hauled the water. This activity entailed social interaction between father and son and between old and young. During these outings, considerable information about the environment was transferred from one generation to the next. Moreover, it involved good physical activity. After the introduction of the water utility, this activity disappeared along with the cultural things associated with it. While jobs were needed, "leisure time" (unrelated to subsistence activities) was also created.

Modern housing also had its unintended consequences. Many new houses were built; the North Slope Borough (NSB) became the largest Barrow landlord constructing over 300 houses. Multi-family houses first appeared. Eben Hobson's dream to modernize Barrow included putting his people in modern houses. But, in fact, the new houses went primarily to non-Inupiat. The NSB provided houses for their employees and the people who qualified for such housing tended to be non-Inupiat. The Inupiat people did get new housing, but most often they got the low income variety. With the appearance of new housing, nuclear families became physically separated from their extended ones; new housing also brought de facto segregation because non-Inupiat employees lived in one type of housing while the Inupiat lived in the low income type.

The new roads brought "urban sprawl" to Barrow - people began to move out to Browerville. With the roads came cars and buses. In the winter, the cars were left running to keep them warm; this caused a pollution problem. Cars and buses also brought dust that made the air-drying fish and meat difficult. People often had to camp out of town to dry their harvests.

The boom period - primarily from 1975 to 1985 - brought increased employment as well as opportunities to develop private business. The NSB became the largest employer. In 1984, they accounted for 71% of all Barrow jobs, either directly or through contracted services, including the Capital Improvement Program (CIP). The CIP alone accounted for 34% of all Barrow employment. During this period, the Inupiat people were employed by the Borough, not by the oil companies. In part, this was by design; Mayor Hobson wanted jobs for his people and implemented a local hire clause that insured local jobs would go to the Inupiat. Eben Hobson also kept the unions out through an agreement with them - all to guarantee jobs for his people.

During this period, Inupiat women entered the work force in significant numbers. Again, the new NSB-funded economy provided this new opportunity. During the boom, woman tended to hold lower paying, administrative positions. It is significant that after the boom these became the permanent jobs and Inupiat women, rather than the men, tended to remain employed.

Employment opportunities encouraged the in-migration of non-natives. In 1970, the Inupiat population constituted 91% of Barrow's entire population; by 1985, it had dropped to 60%. For the ages between 30 and 50, non-natives outnumbered natives, due to the large number of non-native males who came to Barrow for work. By 1985, non-natives held 59% of the jobs while natives held 41%. At the beginning of the "post boom," Barrow had 38% unemployment; 80% of it was Inupiat, mostly males.

A private sector emerged in Barrow with the boom. During this period, 20 businesses swelled to around 200. Originally, I thought this signified Inupiat moving into the private sector, but, in fact, such was not the case. The Inupiat controlled corporations established under the Alaska Native Claims Settlement Act (ANCSA) - the Arctic Slope Regional Corporation (ASRC), Ukpeagvik Inupiat Corporation (UIC), and their subsidiaries. However, 80% of private sector companies were owned by non-Inupiat people.

The number of non-native families increased. Prior to the boom, the small number of such families was usually associated with the school and hospital and resided in segregated compounds. With the increased availability of houses and jobs, non-native families resided throughout Barrow. Their ethnic composition changed as well. Prior to the boom, non-natives were primarily white. The boom brought ethnic diversification; a relatively large Filipino community emerged (5% of Barrow's total) and other ethnic groups, including Koreans, Hispanics, and Yugoslavs also in-migrated. By 1885, social interaction was beginning to occur and also some mixed marriages.

Significant changes in Barrow's social organization were occurring. The '75 to '85 period witnessed a tremendous growth of formal institutions - particularly ones associated with the NSB, ASRC, and UIC, as well as voluntary organizations. The Inupiat people demonstrated a remarkable institutional adaptability and were very successful at controlling and utilizing new institutions to advance their political and economic interests. For example, the ASRC become very sophisticated, not only in terms of its North Slope economic activities, but also in terms of its political contacts with other native organizations. As demonstrated in the 1991 debate, they were influential in Washington, D.C. Through the Alaska Federation of Natives (AFN), they established native alliances with other regional corporations; they also encouraged other regional native corporations to invest on the North Slope.

Women played a significant role in institutional development and, by moving into these institutions, they redefined the "women's role." Also, there was institutional conflict as indicated by the range of legal suits occurring among ASRC, UIC, AFN, the Barrow City Council, and the NSB. This was a period which the Inupiat people were trying to realign themselves in the institutions that they had been instrumental in developing.

We see that the large scale physical changes in Barrow hinted at social changes - many that were unintended. Yet, in complex patterns, those social changes also underlined cultural persistence. The most important fact, perhaps, that our 1986 study reaffirmed was the persistence of the extended family. Even though people were moving into nuclear family dwellings, those extended families continued to exist as a core of interlocking households. These interlocking households were tied by economic activities, primarily subsistence ones. A range of other cultural elements, such as adoptions and naming conventions, helped cement extended family relationships. Again, neither social change nor persistence were absolute, each interlocked with the other. For example, while as in the past, adoptions continued to link households together and traditional adoptions remained numerous, during the '75 to '85 period, formal and legal adoptions became popular. While this shift reflected the continuity of social forms, it also indicated a disintegration of some extended families and a generally increasing dependence on formal institutions.

In fact, institutions began to assume many functions previously held by families. For example, sharing with elders decreased, although it remained significant. The NSB, through its senior citizen program, assumed responsibilities for caring for the elderly. Thus, the senior citizen lunch program lessened the pressure on extended families to share with their elders. But I want to emphasize again the mix of change and persistence - although changes in sharing patterns occurred, sharing continued and it continued to tie extended families together.

The growth of formal institutions encouraged the emergence of Inupiat female headed households. In 1985, we found that one third of all the native households were headed by women - often single women raising children. We suspected this was happening but we were still surprised by the magnitude.

The boom period brings rapid change but, perhaps because such periods must inevitably end in a bust, the Inupiat people continue to rely on a core of traditional activities and sentiments. In the boom period, subsistence remained important; the bowhead whale and inland hunting complex were the core activities. Economically, subsistence was probably not as central as it is now. The 1985 downturn of the economy clearly marked a re-intensification of these activities. In the late 1970s or the early 1980s, a study indicated that 20% of the diet was subsistence foods. This is a significant amount; 20% hungry is still pretty hungry. But in 1985, we see a re-intensification of subsistence.

Changes in Barrow have been significant and they have been rapid; politics has been transformed as has the economy. Yet, beneath this change, and in spite of it, we find a persistence of traditional kinds of activities such as subsistence as well as a social organization based on extended families.

QUESTIONS AND DISCUSSION: Socioeconomic Session

Question (Kenney): Was a change in the population ratios of natives and non-natives due more to native families moving to other communities or just an increase in non-natives?

Response (Worl): Definitely, many non-native people migrated to Barrow. However, Inupiat families also out-migrated, primarily Atqasuk and Nuiqsut families.

Question (Newbury): At one time, the rate of change occurring was fairly disruptive in that it brought elevated rates of alcoholism and violence. Have those rates decreased? Is there evidence that the rate of change is not as disruptive as it once was?

Response (Worl): Surprisingly, while there was rapid change on the North Slope, we must not make the assumption that rapid change equates with disruption. We can take suicide as one indicator or social disruption. If you contrast the North Slope with the Northwest Region (we now call it the Nana Region), we find that suicide in the Northwestern Region was much higher. The social disruption was greater there even though change was not more rapid. I think the resiliency and adaptability of the North Slope Inupiat was remarkable.

Question (Armstrong): From your long experience in Barrow, where do you think the town is headed?

Response (Worl): I think that a non-Inupiat population will remain, but at reduced numbers. At this point, this group includes people who have the private businesses and the access to employment, and they also own houses. I feel confident that the Inupiat will continue. They have had boom periods before and they have always successfully returned to their traditional livelihoods during the bust cycles that follow. I do believe that, unlike in previous boom-bust cycles, many institutional changes will remain in place.

Question (Armstrong): With the increase in marriages between the Inupiat and whites, what is happening in those relationships? Are those families taking on more Inupiat types of traditions? Some that I have witnessed have sent their kids off to college; they are not real traditional. I am wondering what this is going to do to the flavor of the community over time?

Response (Worl); Mixed marriages were beginning to increase and the results were mixed as well. Many non-Inupiat people married into the community and were assimilated toward Inupiat society. At the same time, the reverse also occurred: Inupiat married to non-Inupiat became less involved in their culture.

Question (Naidu): The bottom line of any socioeconomic or sociocultural change is: Are the people happier now?

Response (Worl): Oh, I don't know, I didn't measure that.

Question (Naidu): I would also like to know if the crime rate has gone up or down?

Response (Worl): Although I have not collected these statistics, I would have to say that it has increased.

Question (Naidu): What do you think would be the role of the community college in a community like Barrow?

Response (Worl): That's a very interesting question, because at one point, there was an Inupiat college. I think it depends on the college itself - how it adapts itself to the community. A Harvard University in Barrow probably won't work. However, if you look at some rural colleges, the one in Bethel, for example, they can be very successful. For some reason the rural college was not successful in Barrow.

BIOLOGICAL SCIENCES SESSION

Speakers

D. Schell

R. Bailey

K. Frost

P. Becker

C. P. McRoy

ARCTIC MARINE ECOSYSTEMS OF THE CHUKCHI AND BEAUFORT SEAS

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The arctic marine ecosystems along the Alaskan coast are characterized by the extreme influence of advected primary production, which is transported northward through the Bering Strait, and the importance of localized upwelling in the eastern Beaufort Sea. Over the past few years, the results of the Minerals Management Service (MMS)-sponsored bowhead whale feeding projects and the National Science Foundation (NSF)-funded Inner Shelf Transfer and Recycling program (ISHTAR) have provided considerable insight into the factors controlling the productivity and ecosystem processes involved in this region. A comprehensive summary is beyond the scope of this synopsis, but several highlights can be described.

Beaufort Sea

The Arctic Ocean is the most oligotrophic of the world oceans, and the central basin is characterized by very low annual primary production. The seasonal melting of ice, coupled with the inputs of freshwater from Soviet rivers, serves to create and maintain an exceedingly stable surface layer of water that very effectively prevents nutrient supply from deep water. It has been estimated that the annual carbon fixation of Ice Island T3, then near 86° north latitude in the central Arctic Ocean, was about 1 g C/m^2 or only about 2% of the current estimated production in the central gyres of the Atlantic and Pacific Oceans, which have been described as "biological deserts." More recent estimates by Canadian researchers have increased the annual productivity estimates for the central Arctic Basin almost tenfold, but it retains its distinction as the least productive of the world oceans.

In contrast, the coastal Alaskan Beaufort Sea is much more productive in response to several environmental conditions that serve to stimulate and support primary producers. Thinner ice and higher concentrations of nutrients allow development of a layer of ice algae on the underside of the ice each spring. Although this algal layer does not represent a large fraction of the total annual primary productivity, its timing and density serve to provide a supply of food to juvenile crustaceans at a time of the year when water column productivity is very low. Phytoplankton populations are supplied with advected nutrients and the earlier melting of ice allows increased light penetration and better wind mixing of nutrient-rich deep water into the euphotic zone. The western Beaufort Sea receives Bering Sea water carried northward by coastal currents and with it large populations of plankton. This advection of nutrients, plants, and zooplankton results in a marked increase in predator animals in the vicinity of Point Barrow. Large numbers of Ross' gulls (*Rhodostethia rosea*), kittiwakes (*Rissa tridactyla*), and shorebirds take advantage of fall concentrations of zooplankton in this area. Marine mammals, particularly ringed seals (*Pusa hispida*) and bowhead whales (*Balaena mysticetus*), are also often seen feeding in this area.

The Bering Sea water spreads eastward from Point Barrow along the coast and its effects are soon diluted out. The central Alaskan Beaufort Sea is thus the more depauperate of biota, since further eastward the prevailing winds drive localized upwelling and support a second rich area of biological production near the Canadian border. Here, during the short open water season, coastal upwelling causes increased phytoplankton growth, which in turn supports high densities of copepods. This area is used actively by feeding subadult bowhead whales, and their repeated presence in the coastal waters may indicate that this region is important feeding habitat. Although most of the whales feed further east than the Alaskan border, the extension of this highly productive region into Alaskan waters may serve to supply westward migrating whales a supplemental food resource during fall migration. The zooplankton productivity is also important as food for arctic cod (*Boreogadus saida*), which in turn are very important prey for beiukha whales (*Delphinapterus leucas*) and ringed seals (*Pusa hispida*).

The relative abundances of zooplankton taxa reflect the differing sources of primary production and the hydrodynamics of the system. The eastern Alaskan Beaufort Sea is characterized by high densities of small neritic copepods in the coastal waters and by an abundance of large arctic pelagic calanoid copepods offshore. Further west, the relative abundances of taxa changes sharply, and near Point Barrow euphausiids dominate the biomass of hard-bodied plankton. Copepods are far less abundant. Predators such as chaetognaths and jellyfish are abundant throughout the coastal waters.

During early fall, large aggregations of euphausiids occur near Point Barrow and these are consumed by surface-feeding birds as well as by marine mammals and fishes. Inmigrations of Ross' gulls and other birds take advantage of this seasonal food resource. Lack of suitable nesting habitat may account for the paucity of diving birds along the Beaufort coast. Loons (*Gavia* spp.) and oldsquaws (*Clangula hyemalis*), which nest on the tundra and feed and stage in nearshore waters, are common, but murres (*Uria* spp.) and other alcids are relatively rare. Only near Point Barrow, where artificial nesting habitats have been introduced, have guillemots (*Cephhus* spp.) become common.

The nearshore zone of the Beaufort Sea is yet another biome that responds much more dramatically to seasonal extremes. In summer, the inputs of relatively warm freshwater and the shallow waters allow warming to greater than 10°C. The higher temperatures and low salinity along the coastline makes this area excellent habitat for the populations of anadromous fishes which use the streams and rivers of the North Slope as overwintering habitat. Least cisco (*Coregonus sardinella*), arctic cisco (*C. artedii*), broad whitefish (*C. nasus*), smelt (*Osmeridae* spp.), arctic char (*Salvelinus alpinus*), and humpback whitefish (*Coregonus pidschian*) all feed on the abundant mysids and amphipods that comprise most of the epibenthic invertebrate fauna of the estuarine region.

Winter freezing of the nearly 2 m thick ice cover effectively removes the availability of the nearshore habitat to fauna. Under-ice salinities rise to hypersaline concentrations of over 60 parts per thousand (ppt) in many lagoons and bays and sediment stirred up by fall storms freezes into the ice column. Sediment-laden ice is optically opaque and the lack of light penetration removes this habitat from both ice algal and phytoplankton production until melt occurs in the following summer. Only species that can tolerate extremes in salinity and temperature are common in this habitat.

A striking exception to the marine food webs that are supported by phytoplankton is the localized kelp bed found in Stefansson Sound north of Prudhoe Bay. This kelp bed with its associated herbivores and high densities of biomass is unique along the Alaskan Beaufort coast. The kelp, *Laminaria solidungula*, is superbly adapted to the harsh under-ice environment of the nearshore zone. This alga has the ability to fix and store carbon as complex polysaccharides during the open water months of late July through September. During winter, in complete darkness, the alga draws upon the stored reserves and seasonally abundant nutrients to complete its annual growth. The food webs of the kelp bed support animal species found nowhere else in such abundance as in the Beaufort Sea.

Chukchi Sea

The least known of the waters around Alaska is the Chukchi Sea. The lack of commercially important fishes, presence of ice cover for much of the year, and the political restraints that prevent sampling in the Soviet sector, all have long discouraged investigative research. This shallow sea is characterized by seasonal ice in the southern part and perennial pack ice of varying extent in the region bounding the Arctic Ocean. Typically, offshore winds open large polynyas along the Alaskan coast each spring and these offer a migratory passageway for bowheads and belukha whales moving northward to summering grounds in the Beaufort. As the ice retreats northward, the Pacific walrus (*Odobenus rosmarus*) herds follow and feed on the abundant benthos. Gray whales (*Eschrichtius robustus*) arrive from southern wintering areas and consume much of their annual food supply in the beds of ampeliscid amphipods.

The extremely high densities of animal life in the southern Chukchi Sea are supported by a northward flow of phytoplankton that rivals in productivity any other marine site on earth. Nutrient-rich Anadyr Current water flows northward across the Bering Sea shelf and once confined to the euphotic zone by the shallow bottom near the Bering Strait, undergoes prodigious phytoplankton blooms. This productivity is accompanied by zooplankton which grow in biomass as the water moves northward. Large numbers of euphausiids and pelagic copepods are carried along and are preyed upon by the returning stocks of bowhead whales in the fall. Much of the excess primary production sinks to the bottom and supports the benthic community on which the gray whales, seals, and walrus feed. Polar bears (*Ursus maritimus*), as top of the food chains, are more common in the Chukchi than in the less productive Beaufort Sea.

In contrast to waters farther south, however, much of the Chukchi Sea provides poor habitat for salmonids and other commercially important fishes. Other species of ciscoes and whitefishes common along the Beaufort coast are much less abundant in the coastal lagoons of the Chukchi. Arctic cod and marine forage fishes such as capelin (*Mallotus villosus*) and smelts are sufficiently abundant, however, to support large numbers of belukhas when spawning aggregations occur in summer. The lower mean water temperatures and lack of large rivers for overwintering habitat for anadromous fishes result in a shift of consumer abundance from fishes to marine mammals and diving birds.

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ARCTIC FISHES: DISTRIBUTION, ABUNDANCE AND USES

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Fish fauna of the Alaskan Beaufort and Chukchi Seas are one of the least understood faunal assemblies in the world. Investigations in the area have centered on specific proposed developments, with the majority of information collected in connection with oil and gas development in the Prudhoe Bay area and the Arctic gas pipeline studies. The majority of information collected has been summarized by Peter Craig in his paper on "Fish Use of Coastal Waters of Alaskan Beaufort Sea: A Review." In the paper, Craig lists a total of 64 fish species in the Beaufort Sea. Of the total, 43 are marine, 3 are freshwater and 165 anadromous species are reported.

This discussion will focus on those species which are of primary importance in either commercial or subsistence fisheries or have some special appeal to the residents of the area. I have chosen to concentrate on the arctic cisco (*Coregonus artedii*), least cisco (*C. sardinella*) Bering cisco (*C. laurettae*), humpback whitefish (*C. pidschian*), broad whitefish (*C. nasus*), pink salmon (*Oncorhynchus gorbuscha*), chum salmon (*O. keta*), arctic char (*Salvelinus alpinus*), rainbow smelt (*Osmerus mordax*), arctic grayling (*Thymallus arcticus*) and Pacific herring (*Clupea pallasii*). In the presentation, I will summarize the polar distribution of these species to demonstrate that we are not the only part of the world in which these species occur and demonstrate that they are of major importance to other arctic countries. I will show the distribution along the northern Alaska coast that is of primary importance when considering potential oil and gas development. It is important to note that a number of the species are seasonally and geographically important for different reasons; for example, the arctic char is taken in some areas of the Beaufort and Chukchi coast as a subsistence fish at all times of the year, while in other portions, it is used mainly for a sport fishery during the short summer season.

Fishes of the Arctic Ocean are used in numerous subsistence fisheries. Those fisheries harvest about 210,000 lbs. of fish annually which, according to Peter Craig's report, approximately equals the villages' annual harvest of bowhead whales. The fisheries tend to concentrate on anadromous species like whitefish, char and salmon, although the arctic grayling is also taken. In addition to the subsistence fisheries in the Chukchi Sea, a commercial harvest of approximately 300,000 chum salmon occurs each year, mainly in the Kotzebue Sound area. In the Colville River Delta, the Helmrick family annually harvests about 60,000 whitefish, primarily arctic cisco. Combined with the sport fishery for arctic char at Kaktovik and Oliktok Point, the majority of Beaufort Sea fishes are not utilized. There are a number of species that are utilized as a minor or insignificant incidental catch.

Oil and gas development may potentially place some arctic fish stocks at risk. Unless we understand fully the distribution and abundance of arctic fishes and the ecological requirements of those fishes, it is impossible to predict what effect development may have. It is imperative that we are able to fully assess the distribution, abundance and uses of these species to insure that all stocks are conserved.

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Question (Barnes): Randy Bailey, how did you estimate the 200,000 lbs of estimated subsistence of fishes? Was that an actual survey at the villages including the Helmricks? How did you do that?

Response (Bailey): That information comes directly out of Peter Craig's recently released subsistence report. It's not my data, it's Peter's information.

EFFECTS OF INDUSTRIAL ACTIVITIES ON RINGED SEALS IN ALASKA, AS INDICATED BY AERIAL SURVEYS

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Ringed seals (*Phoca hispida*) are the most abundant marine mammals found in seasonally ice-covered waters of northern Alaska. These seals are an important subsistence species for coastal residents of northern Alaska and are a major ecological component of the arctic and subarctic marine fauna. Ringed seals normally spend winter and spring on and under extensive unbroken shorefast ice. The fast ice also provides a convenient platform on which various aspects of petroleum development can be conducted. Areas most suitable for industrial activity may also support relatively high densities of ringed seals.

In June 1970, Burns and Harbo conducted the first extensive aerial surveys of ringed seals in fast ice areas of the Chukchi and Beaufort Seas. Since seismic exploratory activities were ongoing in the study area, they attempted to determine whether the surveys could detect any effect of seismic activities on seal distribution. Based on their data, the authors concluded that seismic operations such as were being conducted had not appreciably displaced ringed seals.

Extensive aerial surveys were again conducted in June of 1975, 1976 and 1977, principally to investigate annual fluctuations in ringed seal abundance along the Beaufort Sea coast. Specific tests of the effects of on-ice human activities were not included in the survey design. However, since there was considerable on-ice seismic activity in the study area, permitting agencies requested that these data be used to compare seal densities in areas with and without extensive seismic survey activity. Data for the three years combined suggested a 50% (range 22 to 88%) lower density of seals in "seismic areas" than in adjacent "controls." Beginning in 1979, a cutoff date of 20 March was imposed on seismic operations in water deeper than three fathoms in order to avoid disturbance of ringed seals during the primary pupping period. However, the cutoff restricted the duration of the industry's operations and eliminated the optimum working period in terms of daylight, weather, and ice conditions. Therefore, in 1981, further studies were undertaken to clarify and quantify the possible impacts of on-ice seismic exploration on ringed seals. Intensive aerial surveys were one component of that program.

In 1981 and 1982, aerial surveys were conducted in the Beaufort Sea with emphasis on areas of intense seismic activity. Comparisons were made of the density of seals along seismic lines and on control lines midway between the seismic lines. Comparisons were also made between two sets of seismic and adjacent control blocks. While the results were sometimes equivocal or even contradictory, these studies, in aggregate, indicated that on-ice seismic activity, of the type and intensity conducted at that time, did not result in large-scale displacement of ringed seals in the central Beaufort Sea. However, because ringed seals are abundant and ecologically important and because they live and have their pups in areas where industrial activities commonly occur, there was a clear need to further develop techniques for assessing their abundance and to determine what factors influence their distribution. The Minerals Management Service and the NOAA/OCSEAP funded a study from 1985-1987 to monitor the ringed seal population off Alaska and to continue investigating the possible effects of industrial activities on ringed seals.

Data were obtained around three artificial islands (Seal, Northstar and Sandpiper) in the central Beaufort Sea for each of three years. Interpretation of the data regarding density around individual islands was complicated and the utility of such data limited by several factors:

- Sample sizes were small, particularly within 2 nautical miles (nm) of the islands.

Table 1. The density of ringed seals at holes in relation to distance from any of three artificial islands in the Beaufort Sea, June 1985-1987.

		Distance from any island (nm)				
Survey	nm^2	0-2	2-4	4-6	6-8	8-10
85-1	103	0.7	2.5	1.0	1.8	1.2
85-2	67	1.5	3.2	2.0	1.9	1.4
86-1	34	6.5	3.9	6.6	2.0	3.7
86-2	75	5.1	6.3	5.4	11.4	6.4
87-1	45	4.7	6.7	2.4	4.1	4.0
87-2	50	7.1	8.1	9.5	5.8	5.4

- The islands were close enough together for interactive effects to occur.

- Not all islands were in similar operational status either within or between years.

To address the first two of these problems we determined the minimum distance of a sighting from any of the three islands (Table 1). In 5 of the 6 comparisons, the density of seals at holes was 12 to 72% lower within 2 nm of any island than it was 2-4 nm away. Inspection of the raw data indicated that for the single exception the higher density at 0-2 nm was probably an artifact of the way position was assigned to the survey interval. Although the density of seals was lower near the islands in both 1985 when all islands were active and 1987 when none were active, the magnitude of the difference was much greater during activity (50 to 70%) than in its absence (12 to 30%).

A block comparison of industrial and adjacent control areas was also done for all three years. In 1985, industrial activity, including seismic lines, ice roads, and islands, was widespread, resulting in an industrial block approximately 60 nm across. In 1986, the only obvious activities were the artificial islands and associated ice roads, resulting in an industrial block which was only 16 nm across (Figure 1). During 1987 surveys, there was no obvious offshore industrial activity; however, data were analyzed according to the 1986 industrial and control blocks for comparative purposes.

In both 1985 and 1986, the density of total seals was significantly higher in the industrial block than in the control blocks (Figure 2). In 1987, in the absence of any offshore industrial activity, density in the "industrial" block was also higher than either control, suggesting that some characteristics other than the presence or absence of activity were responsible for the difference.

Aerial surveys of ringed seals in 1985-1987 were the most extensive and systematic conducted in Alaska, and the first for which between-year statistical comparisons were possible. Data from those years demonstrated substantial year-to-year variability in ringed seal densities (Table 2). Between 1985 and 1986, observed density of total seals hauled out on the Chukchi Sea fast ice increased 60% from 2.9 to 4.7 seals/nm^2. Increases in individual sectors ranged from 30 to 90%. In the Beaufort Sea, the overall increase was 12%, from 3.0 to 3.3 seals/nm^2, with the

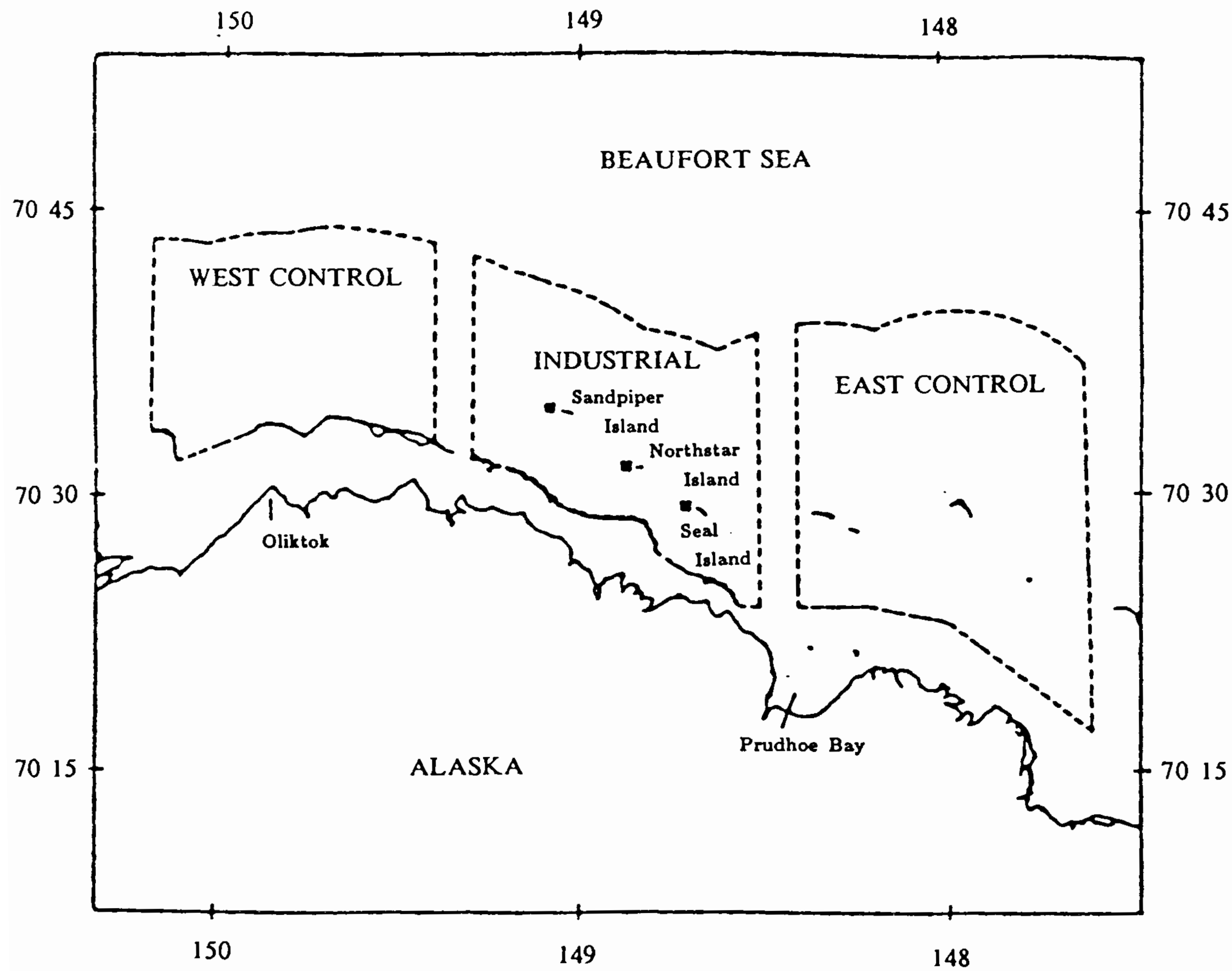

Figure 1. Map showing locations of artificial islands in sector B3 of the Beaufort Sea and 1986 industrial and control blocks.

western-most sector near Barrow decreasing 7%, and the central sectors increasing 20 to 30%. The causes for such inter-annual variation are unknown. While relationships between seal abundance and physical parameters such as ice deformation and extent of fast ice do exist and may explain small scale differences in the distribution and abundance of seals, they cannot account for the large observed inter-annual differences. We have no measure of biological parameters such as prey availability, which may be a major factor in determining overall ringed seal distribution and abundance in a given year.

Historical data also indicate substantial year-to-year variability in the occupancy of nearshore areas by ringed seals. The density of ringed seals on the fast ice of the Beaufort Sea, as a whole, has dropped from a high of 3.3 seals/nm^2 in 1975, to a low of 1.1 seals/nm^2 in

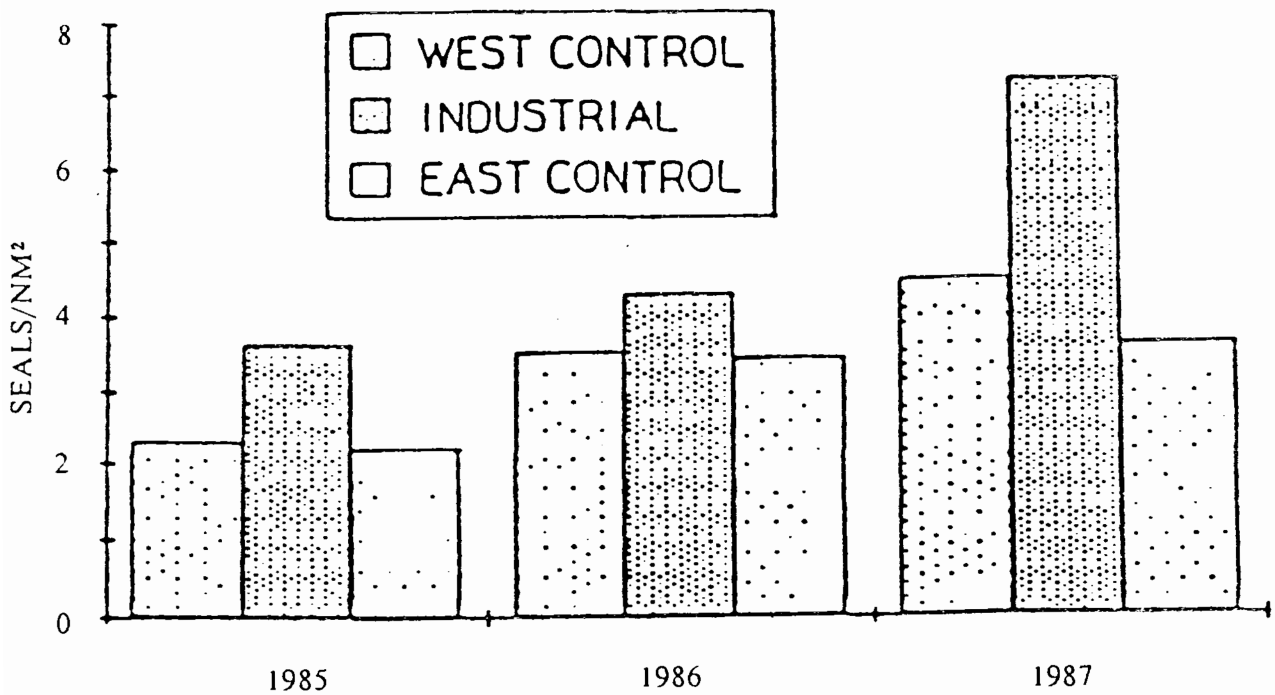

Figure 2. Density of ringed seals (total seals/nm²) in industrial and control blocks in the central Beaufort Sea, June 1985-1987.

Table 2. Comparison of ringed seal densities (total seals/nm²) on the shorefast ice of the Chukchi and Beaufort Seas based on surveys conducted in 1985-1987. Data from the Chukchi Sea in 1987 are not yet analyzed.

Sector	Density 1985	1986	1987
C1	3.08	5.77	
C2	2.89	4.30	
C4	3.57	5.20	
C5	2.04	2.73	
C6	1.85	3.25	
B1	2.22	2.07	2.95*
B2	2.74	3.63	4.61*
B3	3.33	3.99	5.79*
B4	2.01	-	-

*Preliminary data.

1977, and subsequently steadily increased to 3.3 seals/nm² by 1986. The density in any particular year ranged from 50% below to 40% above the mean density for eight years of surveys since 1970. In the Canadian Beaufort Sea near Tuktoyaktuk, ringed seal densities have fluctuated from 55% above to 70% below the long-term mean in a far less regular manner than the Alaskan Beaufort Sea.

Such annual and long-term variability demonstrate the need for regular and relatively extensive coverage of areas in which smaller-scale comparisons are being made. For example, the density of ringed seals in the central Beaufort Sea decreased in the mid- to late-1970s and subsequently increased in the mid-1980s (Figure 3). This could be attributed to changes in industrial activity, which intensified in the late 1970s and early 1980s, then gradually decreased. However, the western Beaufort Sea, which

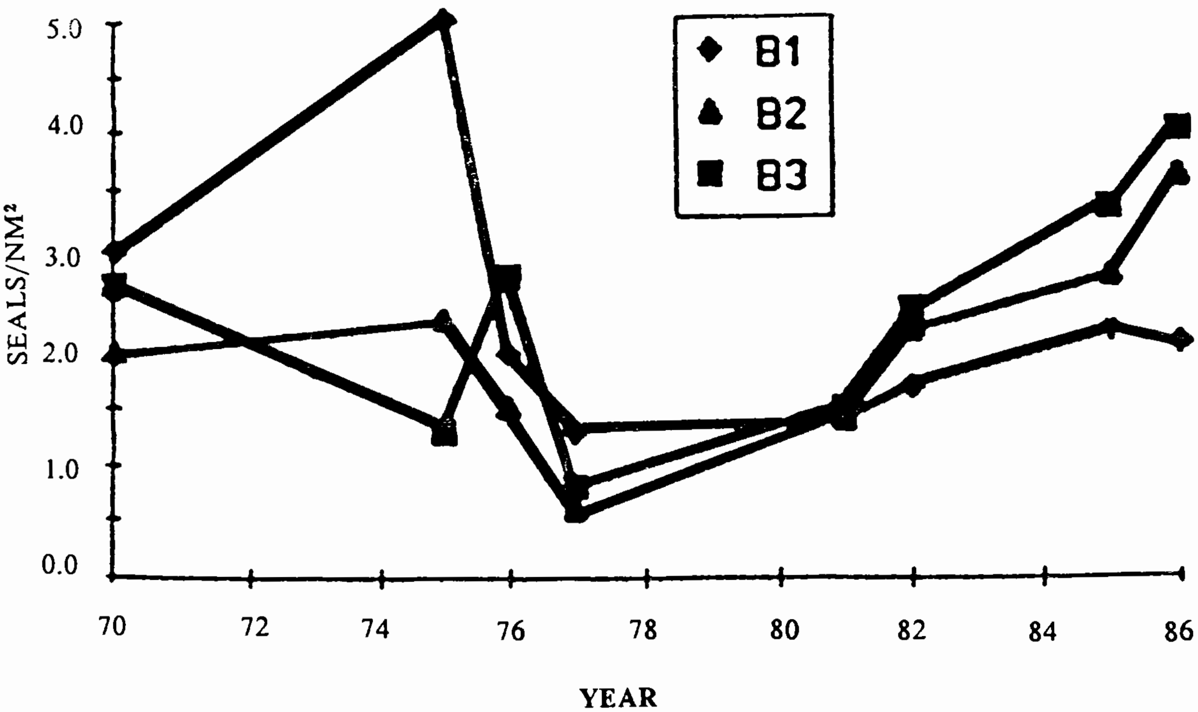

Figure 3. Density of ringed seals in three sectors of the Beaufort Sea based on aerial surveys conducted in 1970-1986.

experienced little or no seismic or other industry activity, showed the same fluctuations in density during this time period. Furthermore, the major decline in density, which occurred in the study area between 1975 and 1977, also occurred in the Canadian Beaufort Sea.

In aggregate, analyses of historical and recent aerial survey data emphasize the importance of matching research technique to the question at hand. Our data indicate that in 1985-86 there were no apparent broad-scale effects of industrial activity on the density of ringed seals as measured by aerial surveys. The data do not discount local effects which would be more appropriately detected by other techniques, nor do they discount the possibility that regional effects could occur at different levels of industrial activity. Most aerial surveys conducted during peak years of industrial activity in the central Beaufort Sea did not have sampling effort or design suitable for statistical analyses of differences between relatively small areas. By conducting on-ice studies, Burns and Kelly found that although aerial surveys showed no significant difference in densities along seismic and control lines, the rate of alteration or refreezing of lairs and breathing holes within 150 m of seismic lines was approximately double the rate at distances greater than 150 m. Kelly and others have also reported results of on-ice studies which indicated ringed seals do respond to disturbance.

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MARINE MAMMALS OF KOTZEBUE SOUND

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Kotzebue Sound and the adjacent waters of the southeastern Chukchi Sea are included in the Hope Basin OCS lease sale (Sale #133). This area is inhabited by a variety of marine mammals, including three species of seals; walruses; polar bears; harbor porpoises; and five species of whales. All of these species are highly mobile and move freely into and out of the region. Only ringed seals (*Phoca hispida*) are abundant in the area during winter and early spring. Belukha whales (*Delphinapterus leucas*) are usually common during summer, and spotted seals (*Phoca largha*) appear in large numbers in summer and fall. The remaining species are generally short-term visitors or occur in very low numbers.

Ringed seals in Alaska have been the subject of aerial surveys since 1970. Prior to 1985, surveys were conducted in different areas in different years, resulting in excellent coverage of some areas and very poor coverage in others. In 1985-1987, systematic surveys were flown off the coast from southern Kotzebue Sound north and east to Barter Island. Results indicate substantial annual variation in density and distribution. In both 1985 and 1986, the highest densities of basking seals in the Chukchi Sea were observed in Kotzebue Sound and on the shorefast ice between Cape Lisburne and Point Lay. The lowest Chukchi Sea densities were between Point Lay and Barrow. In the Beaufort Sea in all three years, densities were highest in the central region between Oliktok and Flaxman Island and lowest near Barrow.

Between 1985 and 1986, the observed densities of ringed seals in all sectors of the Chukchi Sea and all except the sector near Barrow in the Beaufort Sea increased by 20%-87%. The increase was greatest in the Chukchi Sea, particularly in Kotzebue Sound and west of Point Barrow. The actual number of seals hauled out on the fast ice was also estimated by multiplying density times the area of fast ice. These calculations indicated that the total number of seals on the Beaufort Sea fast ice was not significantly different between 1985 and 1986, in large part because the observed increase in density was offset by a decrease in area of fast ice. In contrast, in the Chukchi Sea in 1986, the total number of observed seals, as well as the density, increased by about 1.5 times. The estimated number of seals observed on the shorefast ice in 1986 was 21,000-29,000 in the Beaufort Sea and 24,000-30,000 in the Chukchi Sea, for a combined total of 45,000-59,000 (Table 1).

Belukhas whales occur in two "waves" in northern Alaska. The first wave consists of belukhas migrating through the spring lead systems mostly in April and May, enroute to the Mackenzie estuary region. The second wave, thought to be a separate management stock, arrives in Kotzebue Sound in mid-June. These whales remain in the Sound for three or four weeks and are then thought to move north to the Kasegaluk Lagoon area in early July, where they remain until sometime in August. Based on the chronology of sightings, belukhas in these two areas are thought to belong to the same group, but this hypothesis has not been verified.

Belukhas are hunted by coastal residents of several villages along the Chukchi Sea coast, and have been an important component of local diets for centuries. The major hunts on "summer whales" occur in Kotzebue Sound, off Kasegaluk Lagoon near Point Lay, and near Wainwright.

Table 1. Estimated numbers of ringed seals hauled out on fast ice of the Beaufort and Chukchi Seas during May-June 1985 and 1986.

	1985		1986	
Sector	Fast Ice Area-nm^2	Estimated Number of Hauled-out Seals	Fast Ice Area nm^2	Estimated Number of Hauled-out Seals
B1	1,255	2,100-3,400	1,300	2,300-3,100
B2	2,415	4,900-8,400	2,175	7,000-8,800
B3	2,565	6,600-10,500	2,625	9,500-11,400
B4	1,510	2,600-3,500	435	2,700-5,500
Beaufort Total	7,745	18,600-24,700	6,535	20,800-29,000
C1	2,590	6,500-9,500	2,515	12,600-16,500
C2	370	600-1,500	650	1,800-3,800
C4	845	2,300-3,700	990	4,400-5,900
C5	610	800-1,700	905	1,800-3,200
C6	475	600-1,100	740	1,100-3,700
Chukchi Total	4,890	12,500-15,900	5,800	24,200-30,100
Grand Total	12,635	31,100-40,600	12,335	45,000-59,100

Until 1984, the Kotzebue Sound hunts, particularly the one in Eschscholtz Bay, were the largest and most predictable in northern Alaska. Since 1984, very few belukhas have been seen in Kotzebue Sound, and the harvest has been very low or nonexistent.

In summer 1987, as part of a study of the marine mammals of Kotzebue Sound, aerial surveys were flown off Kotzebue Sound and north along the coast to Point Lay in an effort to determine whether belukhas were indeed absent or present only in very small numbers, or whether they had moved to less accessible parts of the Sound where they were less likely to be disturbed. Extensive interviews were conducted with local residents in conjunction with the surveys in order to provide additional observation and/or direct the surveys.

Belukhas were seen in Eschscholtz Bay during late June surveys. A single group of approximately 50 whales was sighted on several different days (Figure 1). No belukhas were seen elsewhere in Kotzebue Sound on our surveys, although local residents reported a few sightings near Kotzebue and Cape Krusenstern. During early July, no belukhas were sighted in Kotzebue Sound or Eschscholtz Bay. Approximately 725 belukhas were seen west of Point Lay on 8 July (Figure 2).

Based on 1987 field work, it is apparent that belukhas are still greatly reduced in number in Kotzebue Sound. In the early 1980s, estimates of 500-1,000 whales were common, and hunters in both the Kotzebue area and Eschscholtz Bay were regularly successful. Since then, sightings have been irregular and hunting success extremely poor. At Point Lay, hunters continue to be successful, and substantial numbers of whales sighted. It is still unknown what, if any, relationship there is between Kotzebue Sound belukhas and Kasegaluk Lagoon belukhas. It is important to continue studies of distribution, abundance, and stock identity in order to minimize the possibility that at some future date such declines or changes in distribution are inappropriately attributed to oil and gas activities.

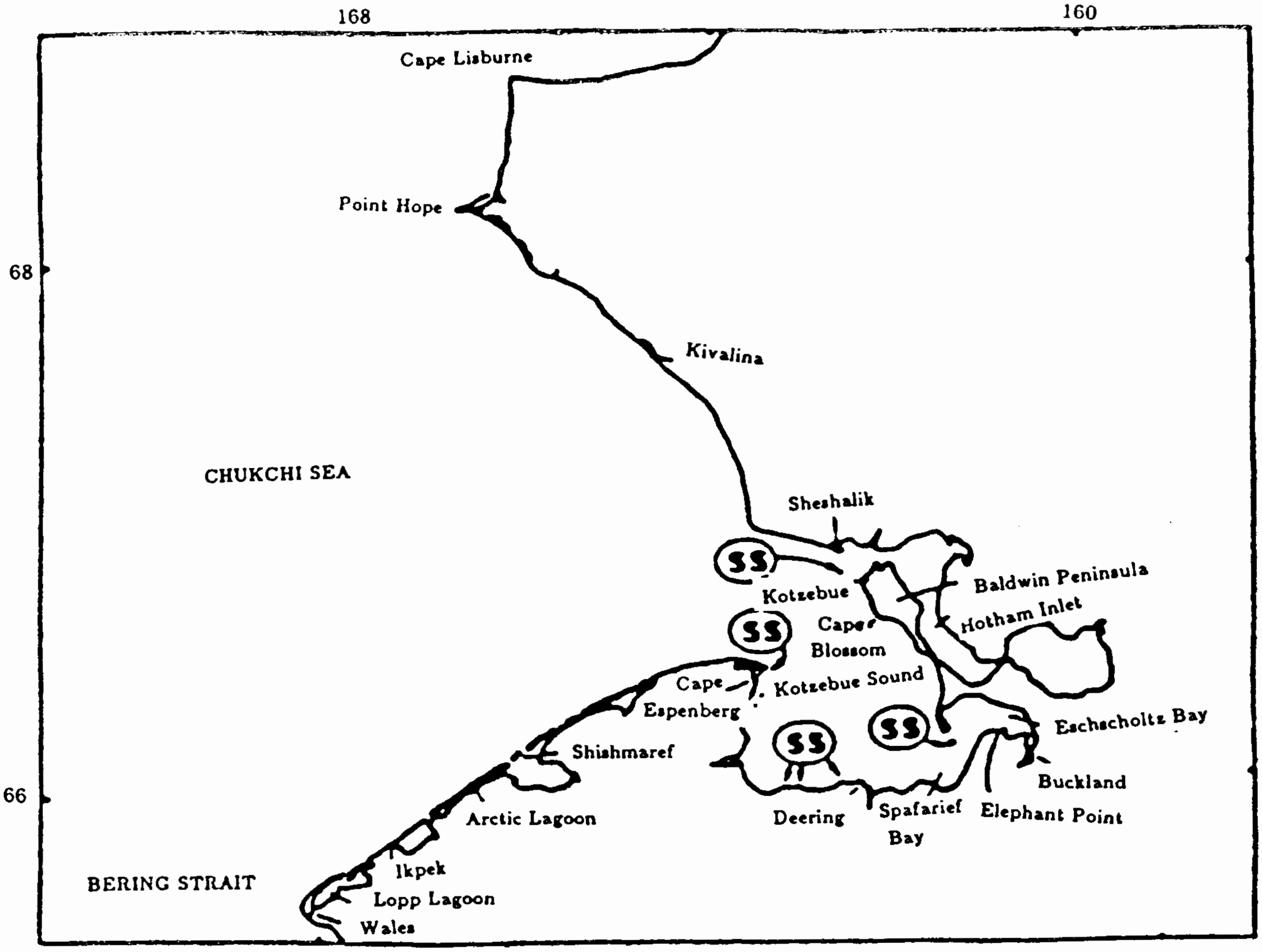

Figure 1. Belukha whale sighting in Eschscholtz Bay, June 1987.

The third major marine mammal species in the Kotzebue Sound region is the spotted seal. Spotted seals are most abundant in late summer and autumn. Field work was conducted in September 1986 and August 1987 to identify haul-out areas and to obtain, as possible, stomach contents for use in delineating trophic dependencies of these seals. Field work was augmented by interviews with coastal residents. The major haulout in Kotzebue Sound is located on the offshore sand bars near Cape Espenberg. Approximately 450 spotted seals were observed there in September 1986. As many as 1,000 were seen there in the 1970s. Other haulouts include offshore rocks near Clifford Point, Rex Point, and Cape Deceit in southern Kotzebue Sound; the rocks between Puffin and Chamisso islands in the eastern sound; and the bars seaward of Kotzebue and in and near the mouth of the Noatak River (Figure 3).

Hunters identified crangonid shrimp as the most common food of spotted seals in southern Kotzebue Sound. Crangonid shrimps also make up about 10% of the diet of belukhas taken in Eschscholtz Bay. Based on data from otter trawls, these shrimps are extremely abundant in southern Kotzebue Sound.

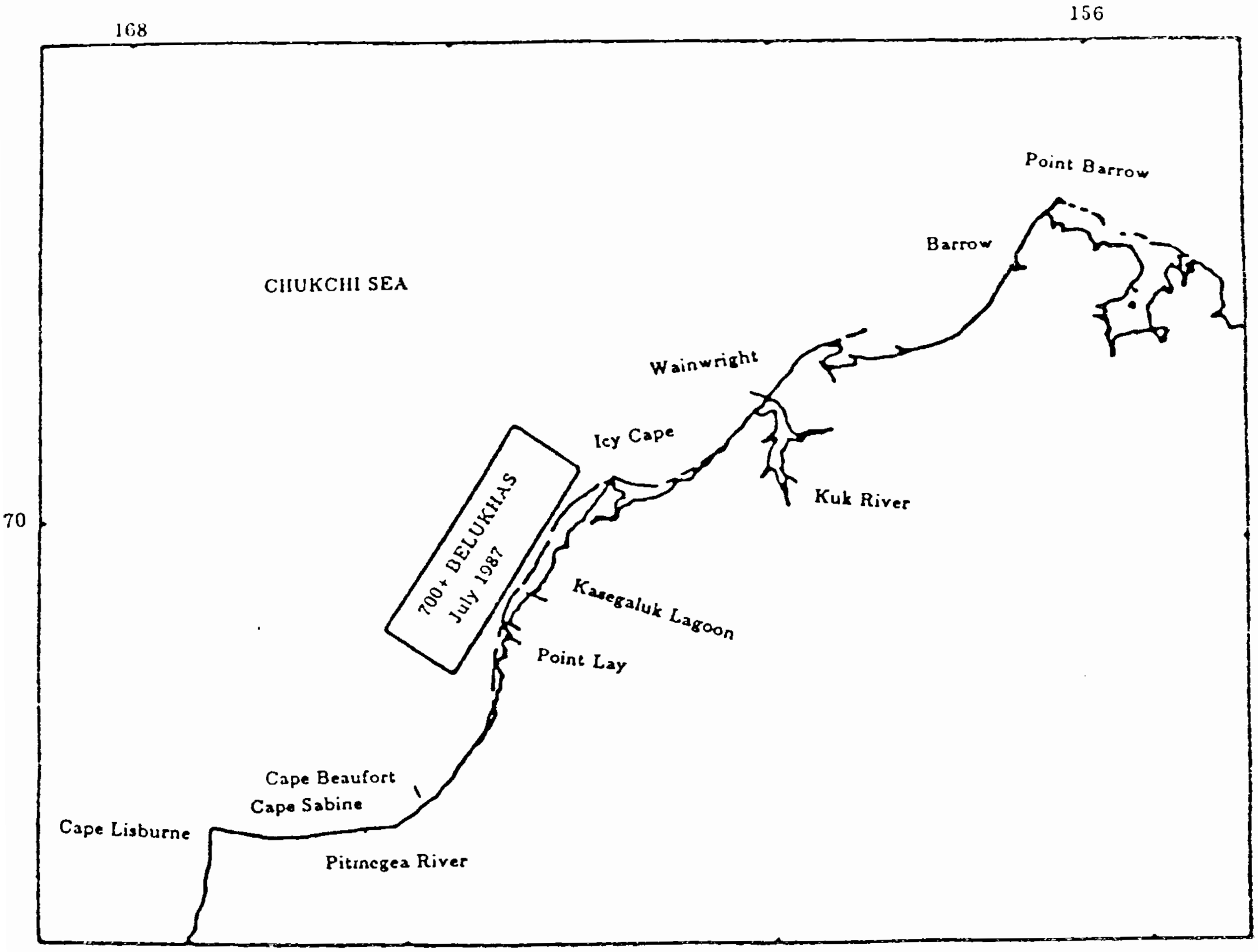

Figure 2. Belukha whale sighting near Point Lay, July 1987.

Marine mammals are important in the diets and subsistence economies of the residents of the Hope Basin region. They are top-level consumers, and may interact or compete with humans for fisheries resources. It is appropriate that they be included in ecosystem studies of this area.

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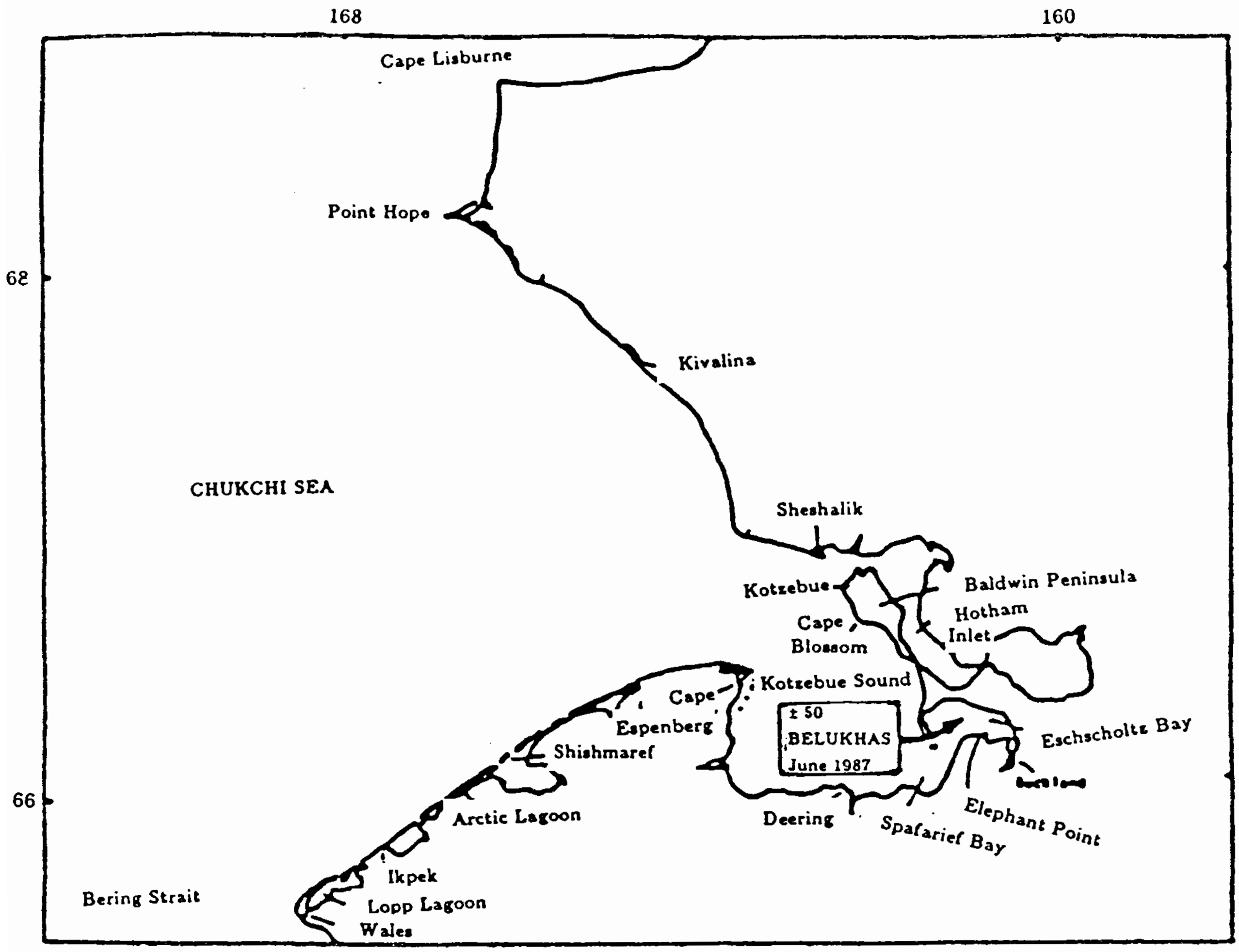

Figure 3. Locations of spotted seal haulouts in Kotzebue Sound.

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ACQUISITION AND CURATION OF ALASKAN MARINE MAMMAL TISSUES

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The concept of archiving biological and environmental samples for retrospective analysis is recognized as a major component of systematic environmental monitoring. The long-term storage of carefully selected, representative samples in an environmental specimen bank is an important complement to the real-time monitoring of the environment. The retrospective analysis of archived samples allows the comparison of present and past analytical techniques and values, thus providing continued credibility of past analytical values, and allowing flexibility in environmental monitoring programs.

Marine mammals are considered top predators in the marine environment. Chemical analysis of their tissues can be particularly useful in determining whether bioaccumulation of contaminants (and potential biological effects) associated with human industrial activities, including offshore petroleum and mineral extraction, is occurring in marine food chains. The collection of marine mammal tissues over a period of several years will provide an archive of samples that can be used to determine baseline contaminant levels against which future contaminant measures can be compared.

The Alaskan Marine Mammal Tissue Archival Project was initiated in 1987 with funding from Minerals Management Service's Outer Continental Shelf (OCS) Studies Program. The project is being conducted by the Alaska Office, Ocean Assessments Division, NOAA, and the National Bureau of Standards. The goal is to archive a representative collection of Alaskan marine mammal tissues for future contaminant analyses and documentation of long-term trends in environmental quality.

The marine mammals of principal interest include: polar bears (*Ursus maritimus*), bowhead (*Balaena mysticetus*) and belukha whales (*Delphinapterus leucas*), Dall's porpoise (*Phocoenoides dalli*), walrus (*Odobenus rosmarus*), Steller sea lions (*Eumetopias jubatus*), northern fur seals (*Callorhinus ursinus*), bearded seals (*Erignathus barbatus*), ringed seals (*Pusa hispida*), spotted seals (*Phoca largha*), harbor seals (*Phoca vitulina*), and sea otters (*Enhydra lutris*). These animals represent a range of sizes, habitat use, and subsistence values.

- Geographic range of the species.
- Geographic range of a single population (whether local or migratory).
- Mode of potential contamination through the food chain (bottom or pelagic feeder).
- Whether it is a subsistence species.
- Availability of baseline biological information.

- Ease of collecting fresh samples where source is predictable and protocol can be followed.

- Whether agency programs exist that can provide collections.

- Availability of species specific contaminant information.

The project has three objectives for the first two years:

Collect Alaskan marine mammal tissues that are suitable for determining levels of organic and inorganic contaminants.

Collections of tissues for archival are being limited to freshly killed animals taken by researchers or taken in subsistence hunts. When a sample archived by this project is analyzed, the researcher must have confidence that the sample was collected as prescribed in acceptable protocols. No dead and stranded animals nor old specimens archived from past programs will normally be accepted by this project. As an additional task, however, the project is surveying and cataloging existing tissue collections held by other individuals and organizations and evaluating their suitability for future contaminant analysis by this project.

Transport, catalog, and curate the tissues in a condition suitable for long-term storage and eventual contaminant analyses.

After collection, samples are packaged, transported, cataloged, and archived according to protocols consistent with those employed by the National Biomonitoring Specimen Bank, National Bureau of Standards, Gaithersburg, Maryland. This facility, designed for long-term storage, is the result of 10 years development by NBS and EPA, and several years of comparative studies with specimen archiving programs of West Germany, Japan, Sweden, and Canada.

Storage is under liquid nitrogen vapor at -150°C, which is the best condition available for minimizing sample degradation. Samples will be selected by OCSEAP/MMS for future contaminant analysis. Emphasis will be on those contaminants associated with offshore mineral extraction. Requests by other researchers and agencies for archived samples will be considered on a case-by-case basis.

Determine the most appropriate collection protocols for long-term specimen banking of marine mammal tissues.

Field collection protocols were tested in July 1987 during the subsistence harvest of the northern fur seals on St. Paul Island. These collections were obtained through cooperation and coordination with the National Marine Fisheries Service, TDX Corporation, and the local people of St. Paul Island. The protocols were evaluated as to their practicality and suitability for obtaining uncontaminated samples of four tissue types (liver, kidney, blubber and muscle) and were revised as warranted.

Protocol evaluation will continue throughout the life of the project as more species are sampled. Selected tissue samples may also be analyzed to determine the suitability of each tissue with respect to levels of inorganic and organic contaminants.

Opportunities for cooperative efforts and exchange of information with the Canadian Wildlife Service and the Canadian Department of Fisheries and Oceans are being pursued and, where feasible, such efforts will be incorporated within the project.

Although the emphasis is on the collection of tissues for analysis of contaminants that may be associated with the petroleum industry, it is also recognized that the development of an archive of marine mammal tissues collected and stored using carefully controlled procedures provides a resource that may be useful in a variety of ways. Such an archive developed over several years provides a resource of materials for future investigators addressing questions concerning the transport of elements and compounds (contaminants and non-contaminants) throughout the polar ecosystem, regardless of source. It is hoped that this resource will gain wide support from the many agencies involved in marine mammal research and management, environmental assessment and management, as well as organizations and individuals with interests in the polar ecosystem, as a whole. Future studies in cooperation with the primary funding agency (Minerals Management Service) may be considered.

Additional information on project objectives and management, justification for the species, tissues, and contaminants of interest, and specific instructions for collecting, handling, and storing samples are provided in the report, "Alaskan Marine Mammal Tissue Archival Project: A Project Description Including Collection Protocols, November 1987." At this time, the protocols have been employed only in the collection of northern fur seal tissues; therefore, the details in this report are somewhat biased toward this species. As these procedures are applied to the sampling of other marine mammals, the protocols will probably be modified. Therefore, this document represents the first in a series of reports providing the most recent protocols used by the project. Specific comments which can be used to improve the project are welcome. Questions and comments should be directed to:

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QUESTIONS AND DISCUSSION: *Biological Sciences Session*

Question (Hameedi): This is not quite a question, but unlike most coastal inhabitants around north and northwestern Alaska, the people of Kotzebue had a historical dependence both on the land and the marine resources for their food and other subsistence purposes. If there are no belukha whales to harvest, for example, (you have indicated there are very few that have come in in the last few years), what does the State of Alaska do in terms of allowing them to hunt more land animals? Or, what happens when they don't get sufficient amount of food items from the sea, they go to the state and the state says they can have more caribou or more moose or more whatever else is hunted. Is that a problem?

Response (Frost): It has been in the past. It's not right now because the western arctic caribou herd is very high. There was a real low, maybe a zero or very, very, low harvest of belukhas in the late 1970s. There was indeed a problem with the people indicating to the state that they really did need more caribou when caribou were much lower in numbers at that time. There was a lot of controversy at that time in trying to get the harvest limit on caribou raised so the people could compensate for the lack of belukhas. But it is a give and take kind of situation. As long as you end up with abundant caribou or as long as fish are abundant when belukhas are low, you shift your diet but you aren't in major trouble. But, if you end up with belukhas low and caribou low as happened in the 1970s, then you have a much larger problem. Right now caribou numbers are high and other resources are fairly abundant so people can shift diets. It's probably worth mentioning that as Rosita Worl told you earlier, in Barrow, she saw a lot of people falling back on more traditional ways now that money is tighter and jobs are fewer and farther between. That's a generalization that I believe can be extended to other parts of the state and not just Barrow. I just recently returned from visiting a number of the villages in northwest Alaska and the Kotzebue Region where money is tight and jobs are short. People need that marine mammal meat or caribou meat or whatever it is now much more than some of them did three or four years ago when they had higher paying jobs.

Question (Naidu): For Paul Becker, maybe a bizarre question, but I hope you'll take it seriously. That is, the most important element in the whole ecosystem I guess is man. That is what we should be concerned about. Are any tissue samples of human beings collected and archived?

Response (Becker): Not that I know of from Alaska. The tissue samples that have been taken for human beings were part of the development project for the specimen bank. It involved collection of liver samples from autopsies in three cities -- Seattle, Chicago, and Boston. That again is something that was funded by EPA and was done for that area. What you brought up is quite interesting. Once you talk about obtaining human tissue samples, I personally feel uncomfortable about it. But the point is, that a major concern is for humans as a top predator within the Arctic ecosystem where these contaminants may be found.

Question (Naidu): The reason I asked you this question is this, I cannot recollect the article I read some time ago that there was some very significant differences in the mercury content of natives living in the Siberian area and that in the Alaskan area. That was attributed to the polar bears and seals that the communities from the two different areas were thriving on.

Response (Becker): I'm not really familiar with that particular thing that you are talking about and would like to find out more about it.

Response (Frost): Sathy (Naidu), it's true that concentrations have been a lot higher. In fact, one of the trade magazines I read pointed out that this sort of irony happens in eastern Canada right now. Some of the Eskimo hunters are acting in advertisements for Omega 3 fatty acids. At the same time, they are advertising for those they're not able to eat; they have been told not to eat a lot of the marine mammal tissue because it's so high in mercury. So on the one hand, the resource is good for them healthwise, but on the other hand, it's contaminated to the point that government is actually recommending that they consume very low levels.

Question (Naidu): What are the sources of mercury?

Response (Frost): I think Alaska has much lower levels of mercury than eastern Canada. It's my impression that those elevated levels haven't been detected in the Beaufort.

Response (Becker): The Canadians have quite an extensive database for contaminants, both organochlorines and metals, for their area of the Arctic. From the eastern to the western side of the Arctic, it appears that they do have very high levels. There are some additional situations with high levels of cadmium in walrus which many of you may be familiar with, which resulted in a program of analysis of tissues from the St. Lawrence Island area because of the high cadmium levels. Historically, high levels of mercury are known within the fur seal tissues from St. Paul Island. So, as far as marine mammals are concerned, there is historical data for some species - some with elevated levels. But, it appears that for most of these, Canadians have quite a bit of data indicating very high levels there. However, it may be because their database is much better than what we have.

Question (Naidu): Were they (clams) purged before the analysis?

Response (Becker): No. Are you talking about food samples that are taken?

Question (Naidu): Tissue samples of clams, bivalves.

Response (Becker): The clams that have been collected and archived in the program are part of the National Mussel Watch Program. I'm not sure how many samples of these mussels are from Alaska, if any at all.

Comment (Mate): I did a post-doctorate study looking at heavy metal metabolism in marine mammals that dates back 15 years, so I may not be up to speed, but at least in one regard marine mammals are taking in mercury in a form of methylmercury in fish that's really toxic to most humans and most other mammals. However, they have developed a means of de-methylating that and rendering it innocuous to the mammals' system. That's something they've had to cope with for eons, because most mercury and cadmium occurs naturally. A lot of it comes from geo-thermal activities. The value in this I see is in the man-made contaminant area where they don't have any preadapted biological system to take care of those things. But, the thing that concerns me is that because these animals move great distances, they aren't like clams or mussels that are sessile and represent necessarily the area they were collected in. They navigate through large bodies of water along their whole migratory route. Therefore, interpretation is a real problem, and it's related to age-sex class categories, among other things. Unless there is a general trend upward where you can say that generally, the whole environment looks like it's getting more of this particular kind of thing. It's going to be very difficult to interpret some of this stuff. I'm glad to see it being put away; I'm not being critical of that.

Response (Becker): I understand that. And for certain species, for example, the candidate species for our study (if one looks at it from the standpoint that they want to select an indicator species that is localized, non-migratory, maybe something like the harbor seal) would be something to look at over a period of years. You do run into problems with interpretation with migrating species as you said. I might also point out that these tissues that are archived may have other uses besides just being contaminants. In other words, if there is a question as far as transport of various types of trace elements through the polar system, perhaps a system of tissues that are placed in long term storage could be of interest to researchers who are involved in this particular question. So as I see it, this is being sponsored by MMS right now for future analysis of contaminants related to oil and gas. But, as I see it, setting up (this is what I'm looking at) a network of systems to obtain samples is of benefit to a lot of people for a lot of different reasons besides just oil and gas-related purposes.

Question (Mate): Kathy (Frost), when you looked at the changes in density relative to the islands, you indicated that it's a small sample size. Is it an unequivocal conclusion at this point to you that these things are tightly bound or correlated or is it? I know you'd like a greater sample size, but how do you feel about that; how strong are you on it?

Response (Frost): My only unequivocal feeling is that aerial surveys are not the right survey tool to address that fine scale of a thing, Bruce. Although aerial surveys are very good at looking at broad regional trends, they are not the proper tool for looking at something like differences that may be in the order of hundreds of meters down on the ground and I guess the indications are that although there are equivocal data that suggest reduced numbers of seals right around those islands, what actually is causing those lower densities may be something as simple as water depth. Distance from the island also correlates with depth just as well as it does with a lot of other things. If you look at the density of seals with distance from land, density is lowest close to land and higher farther offshore. So, there are a lot of really complicating items that in order to understand would require you to work on the ground together with dogs. You would have to do it in a systematic kind of way with an overall view (a survey picture) to look at a broad sweep but also with dogs down on the ground so you are actually mapping the location of breathing holes and/or lairs in an exact manner. There are logistical problems in trying to fly an aircraft at 120 miles per hour over a point source and keep track of navigational errors and rounding errors. The smallest increment that we could deal with is plus or minus two miles. You're rounding up or you're rounding down, depending on whether you're coming from onshore to offshore, or from offshore to onshore towards the island. You introduce all sorts of error into the system. So, it's pretty hard to be very much more precise with this technique.

Question (Mate): As a follow-up to that then, can you use a dog technique without adversely impacting the distribution of seals yourself? In other words, does your measuring technique disturb the seals and chase them out of the area?

Response (Frost): The measuring technique over the long term will. If you work in a area really extensively day after day, you'll affect the alteration rate, at least, of lairs, and less so breathing holes. In a small area, say around an island or point source disturbance, you can work a reasonable size area in one or two days. I think that you can basically eliminate the effect of the animal. Refreezing depends on the air temperature. It can occur very quickly or relatively slowly, but if you are doing a one-time-in survey sort of approach as opposed to working the same area day after day or week after week for a long term sort of study, I think that you can design it so the dogs don't affect your data.

ISHTAR: INNER SHELF TRANSFER AND RECYCLING IN THE BERING AND CHUKCHI SEAS

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ISHTAR is a multi-disciplinary, multi-university ecosystem study designed to test the hypothesis that inter-annual changes of atmospheric forcing on water transport through the Bering Strait result in a twofold to fourfold difference in:

- The flux of nutrients from the shelf break of the northwestern Bering Sea.
- The primary production north of St. Lawrence Island.
- In the burial of carbon in Chukchi Sea sediments.
- In the amount of energy passed up the food web.
- In the chemical properties of the Arctic Ocean water transported south across the Greenland-Scotland ridge systems.

ISHTAR began in 1983 with a single 10-day cruise supported by a small grant from the National Science Foundation (NSF). This cruise was essentially a pilot operation to gather some additional data to test our early hypothesis concerning organic matter cycles on the Bering/Chukchi shelf. The results of this cruise, in combination with historical data available for the region, were used to prepare the ISHTAR I proposal. ISHTAR I received NSF support beginning in October 1984. The first full field season was in 1985 and the last cruise ended in early October 1987. The results of the full field season have been analyzed and are available as progress reports.

The results of the pilot study in 1983, although only from a single short cruise, significantly changed our early hypothesis (Sambrotto *et al.* 1984). Based on historical data and that from the Processes and Resources of the Bering Sea (PROBES) project in the southeastern Bering Sea, we proposed that the inner shelf (i.e. that inside the front associated with the 50 m isobath) in the north Bering and Chukchi Seas would be driven by land derived nutrients, primarily from the Yukon River. We knew from work in the southeastern Bering Sea that primary production after the spring bloom was nutrient (nitrogen) limited and expected that the Yukon, as a major pristine river with a nitrate content of about 10 μM, would be a driving force to sustain production through the summer. The cruise results did not confirm this. The Yukon plume is confined to the coast and outside of the immediate vicinity of the Yukon Delta. We could find no enrichment effect from the river on the shelf. We did find the three water masses described by Coachman and his colleagues (Coachman *et al.* 1975), and even with very limited data, determined that the interaction of the three determined the organic matter cycles in space and time.

From east to west, the shelf water masses are the Alaska Coastal Water (ACW), the Bering Shelf Water (BSW), and the Anadyr Water (AW). The latter two are physically similar but both are distinct from the relatively warm, low salinity ACW, and it is the front between the ACW and the BSW that is most well defined. The coastal water which contains the accumulated land runoff from the Yukon and other rivers of the Alaska coast apparently has but a single primary production event in early summer after the sea ice breaks up. For the remainder of the ice free season the coastal water has a low phytoplankton biomass (chlorophyll *a*) and productivity. This is a dramatic contrast to the adjacent BSW. This water mass has its origins far south of St. Lawrence Island in the region of the continental slope. The water flows north across the shelf where a branch flows west to become Anadyr Water, reaching the surface in the vicinity of the St. Lawrence Island. This is cold, nutrient laden water and as it progresses across this shallow shelf, it supports very high phytoplankton biomass and production. The situation is somewhat analogous to an upwelling system where nutrients enter in the south near St. Lawrence Island and growth continues downstream throughout the lighted portion (most) of the water column. We estimated the annual production for this system to be about 300 g C m^{-2} yr^{-1}, nearly twice that of the southeastern Bering shelf and higher than any other arctic area (Subba Rao and Platt 1984). At the time, no distinction was made between the Bering shelf and Anadyr Water but data from the most recent field season suggest that this may have been premature (Figure 1). There is, in fact, an apparent enigma in the Anadyr system in that although nutrients are high, production is very low. Such a conclusion awaits further analysis of the data from 1985. We now have a view of three adjacent water masses with distinct productivity regimes. We have identified areas of high organic matter deposition and subsequent nutrient regeneration and we have some correlation with the role of these regimes to higher trophic level species. More detail is included in each component proposal.

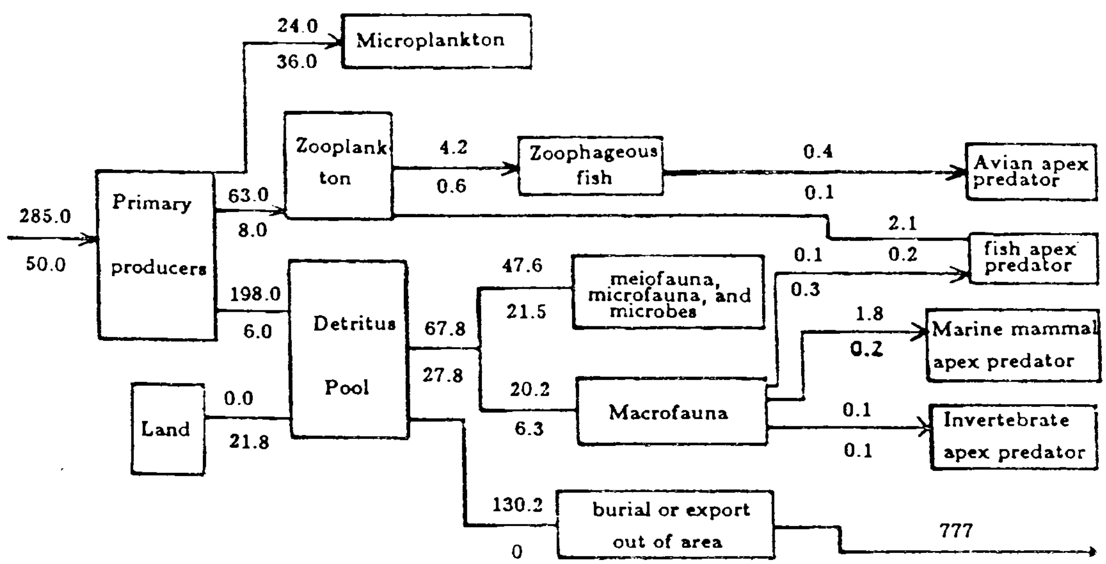

Figure 1. Revised annual carbon flow (g C m^{-2} yr^{-1}) in the Bering Shelf/Anadyr water (upper value) and Alaska Coastal water (lower value) in the northern Bering and Chukchi Seas.

The other Institute of Marine Science (IMS)-directed project related to ISHTAR was a study of processes and resources of the Bering Sea shelf (PROBES). This project focused on studies of the ecosystem of the middle and outer shelf domains of the southeastern Bering Sea.

The results of the project are extensive and much of the information is summarized in a special issue of Continental Shelf Research (Vol. 5, Nos. 1, 2, 1986). A major finding of that study was the understanding of the interaction of oceanographic with ecosystem processes leading to predominantly benthic or pelagic food webs on a predictable basis. The PROBES work, by design, largely ignored the inner shelf but the hypotheses in ISHTAR were a natural outgrowth of that project.

ISHTAR consists of the following individual research components:

Component A: Physical Oceanography.

L. K. Coachman of the University of Washington and J. J. Nihoul of the University of Liege have deployed current meters, are making hydrographic measurements, and are constructing circulation submodels to describe the role of advection and turbulent mixing in the introduction of nutrients into the euphotic zone, their redistribution in plankton, and their deposition as detritus on the continental shelf and slope.

Component B: Moored Biological Instruments and Simulation Analysis.

J. J. Walsh of the University of South Florida has constructed and deployed fluorometers and transmissometers at the same sites of the current meter installations. The resulting biological and physical time series will allow specification of the inter-annual variability in factors controlling production in the Bering and Chukchi Seas. These time series also will provide validation data for the ecosystem simulation models. J. J. Walsh, in collaboration with the other ISHTAR investigators, will construct simulation models as a means of focusing the research of this multidisciplinary effort. Each field season Eulerian models will be used to compute time series of chlorophyll, measured at the current meter/fluorometer arrays. Lagrangian models also will be used to simulate the spatial distributions of nitrate, ammonium, dissolved organic carbon, phytoplankton, carbon and nitrogen, total particulate matter, and sediment organic residues. Using the data provided by the other ISHTAR components, the submodels of each state equation will be revised each year as part of a continuing effort in the synthesis of data through construction, evaluation, and revision of hypotheses.

Component C: Carbon Processes.

C. P. McRoy of the University of Alaska, T. E. Whitledge of the University of Texas, and T. H. Blackburn and T. Fenchel of the University of Aarhus are measuring photosynthesis, and mineralization and deposition of organic matter in this shelf ecosystem. Through determination of the amount of nitrogen and phosphorous sedimented from the water column and the amounts returned to the water column from the sediments, an independent assessment is being made of the validity of estimates of C14 primary production, ^{3}H thymidine secondary production, and filtration rates of ciliates and microflagellates. At the end of each field season these measurements and data on the amounts of particulate organic carbon in the water column and sediments will be used to test and update the ecosystem model.

Component D: Nitrogen Processes.

J. J. Goering of the University of Alaska and P. L. Parker of the University of Texas are measuring the uptake, recycling and sedimentation of nitrogen compounds. Using isotope ratio methods for both nitrogen and carbon, measurements are being made of the amount of terrestrial detrital input to this shelf ecosystem, phytoplankton uptake of nitrogen, and nitrogen recycling by microbiota in the water column and sediments. At the end of each field season these measurements and data on the amounts of particulate nitrogen compounds in the water column and sediments will be used to test and update the ecosystem model.

Component E: ISHTAR Management.

An executive council of Drs. McRoy, Walsh, Goering, and Coachman will ensure effective transfer of information and data between the four scientific components. A management office at the University of Alaska will arrange logistics (staging for cruises, travel), data storage and distribution, scheduling of workshops, and preparation of annual progress reports. This office is also the communications link with other national and international studies, agencies, and interested persons.

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QUESTIONS AND DISCUSSION: *Biological Sciences Session*

Question (Newbury): I wanted to point out when the gray whales leave in the fall, as Don pointed out, bowhead whales come into the area to feed. They come down to the western Chukchi which is fairly rich. They come down through the Anadyr Strait area but they don't seem to stay in the Anadyr Strait water. I think they overwinter southwest of St. Lawrence Island on the shelf. Alan Springer mentioned earlier in this meeting that the relatively light surface water, relatively fresh, warm surface water keeps that Bering current off the shelf as it comes up along the shelf. It keeps the current offshore until it gets right up by the Anadyr Strait. During winter, when the bowheads are in that area, that surface water isn't going to be as light -- it's going to be colder, more saline. My question is, what are the chances of the current that's moving north along the shelf break coming up onto the shelf more frequently, making that area richer and being a source of the food that Don Schell is picking up in the bowhead feeding?

Response (McRoy): It has to do with the physics of transport. By and large transport declines in the Bering Strait in the winter, and as I understand it's a more across-the-board decline in the transport of the various water masses rather than a differential. If that's the case, rather than having an enhanced sort of condition in winter, it might be balanced by lower transport in general, part of which is this Anadyr flow. How the stratification in the distribution vertically in the water column of this core of water is influenced in the winter compared to the summer, I don't know.

Question (Newbury): I meant way south of the Strait, south of St. Lawrence. The whales could stay in Anadyr Strait water but they don't, they stay over on the shelf. There must be a reason for that.

Response (McRoy): Maybe we should ask Knut Aagaard instead of talking about his data. As I understand it, the Anadyr Strait water is on the far western side of the Bering shelf and you don't run into it. There's still that middle and outer shelf pattern that starts in the southeastern Bering Sea which extends west probably to St. Matthew Island at some point. And that's cold water; down around -1°C. Even in summertime it can be that cold in the middle shelf down around St. Lawrence.

Comment (Schell): I think the question is moot. In winter, the water is so deep mixed that you're not getting any production. Most of the copepods and most of the oceanic species are deep overwintering so they migrate to depth at the edge. You wouldn't expect to find any biological results during the winter even if you had increase transport of nutrient rich water.

Response (McRoy): But this water that's coming out of Anadyr and heading west could in fact be, because in winter it's a little warmer and because it originates down in deep water. It's not the same temperature as the really shallow shelf water. It could be responsible for that St. Lawrence polynya. It essentially flows this way and turns north. If it slows down it's going to tend to go more east as well.

Question (Newbury): Your satellite color bands show a branch of water south of St. Lawrence Island -- maybe that's more prominent in the winter?

Response (McRoy): It could well be, I agree. But this water, if it's just coming up here is not necessarily high production, it's Anadyr water. It's when it starts to mix with these other waters. In fact, you see there's even another one, essentially a Siberian coastal water here. It needs that stratification to allow those nutrients to be utilized by phytoplankton.

Question (Springer): How far south do bowheads winter?

Response (Newbury): My impression is that they winter southwest of St. Lawrence. Also, we do know they move around and are associated with polynyas.

Question (Newbury): Maybe the evidence of winter feeding that Don Schell is picking up is really food that they are getting on the way to their wintering grounds; they feed as they come down through the western Chukchi, the Bering Strait and through the Anadyr Strait water rather than getting that much food on their wintering grounds.

Response (McRoy): Understand that this water is a transport mechanism for essentially oceanic species of zooplankton that are occurring at the slope, the shelf break, and which are being transported across the shelf. If you didn't have the Bering Straits -- a good historical question for you -- if you didn't have that connection between the Atlantic and the Pacific you're not going to have that flow through there all the time. So, it suggests considerable variation of the ecology of the food webs across the shelf with geological time. If you stop that, what do the bowheads do when the Bering Straits are closed?

Outer Continental Shelf Environmental Assessment Program

Arctic Information Update

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U.S. Department of the Interior
Minerals Management Service
Alaska OCS Region
OCS Study, MMS 88-040

ARCTIC INFORMATION UPDATE SESSION

Speakers

W. Stringer

C. Pease

K. Aagaard

W. Johnson

R. Cooney

S. Saupe

A. S. Naidu

H. Feder

R. Everett

A. Springer

P. Pope

L. Hachmeister

D. Glass

A STUDY OF POSSIBLE METEOROLOGICAL INFLUENCES ON POLYNYA SIZE

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A polynya is rigorously defined as an irregularly shaped opening enclosed by ice which may contain brash ice or uniform ice of markedly thinner ice than the surrounding ice. Polynyi are frequently described in the literature as non-linear open water areas surrounded by sea ice without mention of whether an attempt was made to clearly differentiate the open water from thin ice or if such a distinction was possible. Polynyi are considered by many to be important for the understanding of climatic, oceanographic, and biological phenomena in the Arctic, and since the NOAA series of satellites have collected visible and infrared band imagery containing polynyi for well over a decade, it appeared feasible to use this imagery to document the dates of appearance and disappearance of polynyi for the Bering and Chukchi Seas, as well as to quantitatively determine polynya areas and relate these areas to climatological data. In order to utilize the existing imagery, a computer program was devised to allow rectified polynya areas to be mapped and their areas determined from digitized satellite images which record data in space oblique projection.

Nineteen polynyi were originally identified for the study; a twentieth, the Anadyr Gulf Polynya, was added later (Figure 1). Of the twenty polynyi, six were defined as the "North Coast Polynyi" because they form off the north-facing coasts of St. Matthew, St. Lawrence, and Nuniwak Islands, and off the Yukon Delta, Seward Peninsula, and Chukotsk Peninsula. They occur less frequently than polynyi adjacent to coasts facing south. They appear to arise from a reversal of winds from the north or northeast, the predominant wind direction in winter over that part of the Bering and Chukchi Seas north of St. Matthew Island.

The original intention was to digitize polynya areal extent from as many years as possible. The images were processed from January through June on a daily basis. Tables were prepared which display these measurements. In those cases where an area could not be measured, each polynya site was designated as frozen, obscured by cloud cover, not available, or fused with the main body of open water.

The daily polynya areal extent tables enabled the calculation of total open water area contributed by polynyi to the Bering and Chukchi Seas on a monthly basis for the six years investigated. All polynyi south of the Bering Strait were summed for the Bering Sea total; all polynyi north of the Bering Strait were summed for the Chukchi Sea total. The sums were compiled daily for each month for all six years and the maximum sum for each month in each year selected. The maximum area observed for each month out of the six years was then chosen as the model monthly polynya open water area. Percentage total open water contributed by polynyi was calculated using these monthly areas and the total areas for the Bering and Chukchi Seas. These percentages are compatible with the wintertime 5 to 10% open water contributed by leads in the Bering Sea which have been reported.

Summary statistics were calculated for all twenty polynyi for all six years. Monthly average, median, maximum and minimum polynya areal extent are recorded in square kilometers. Standard deviation and standard error are given as well. Time series plots of daily polynya areal extent were made for all twenty polynya for all six years. These plots allow visual evaluation of daily areal variation as well as the frequency of observation of each polynya over a month.

The daily polynya areal extent tables, the total open water table for the Bering and Chukchi Seas, the summary statistics, and the time series plots constitute the most complete record of open water area contributed by polynyi to the Bering and Chukchi Seas available to this date.

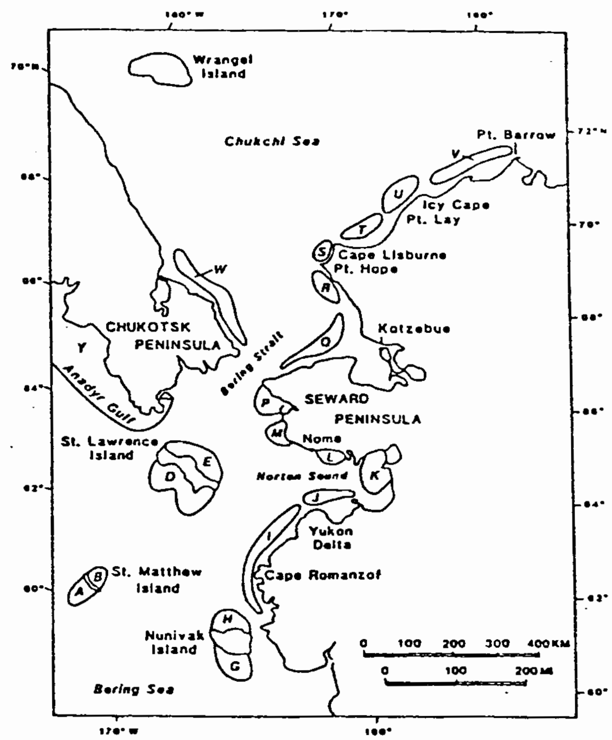

Figure 1. Map showing approximate location of persistent polynyi in the Bering Sea/Chukchi Sea study area.

These data give quantitative documentation for an exceptional polynya formation event easily visible on the Advanced Very High Resolution Radiometer (AVHRR) imagery of February 1975. On February 8, 1975, a huge polynya extended from the site of the Seward Peninsula Polynya South, north to Pt. Lay (Figure 2). This polynya is conspicuous within the daily polynya areal extent tables. Comparison of the summary statistics of the Seward Peninsula Polynya South for February 1975 and 1977 confirm large polynya formation. The maximum percentage of open water in the Chukchi Sea for February 1975 is comparable to open water extent normally common in April.

Attempts were made to correlate monthly climatic data available at four synoptic weather stations in the Bering and Chukchi Seas, with monthly median polynya areal extent for the polynyi near them.

Linear correlations were found between average monthly temperature at Barrow and the Chukchi Polynya and at Nome and the Norton Sound Polynya. These correlations were statistically significant, but small. They implied that polynya areal extent increases as the temperature increases.

Linear correlations were found between wind related variables and polynya areal extent. These correlations were also statistically significant, but small. For St. Paul and St. Lawrence Island Polynya, and for Nome and the Norton Sound Polynya, the correlations implied that polynya area extent decreased with increasing wind velocity. For Kotzebue and the Kotzebue Sound Polynya, the reverse was observed.

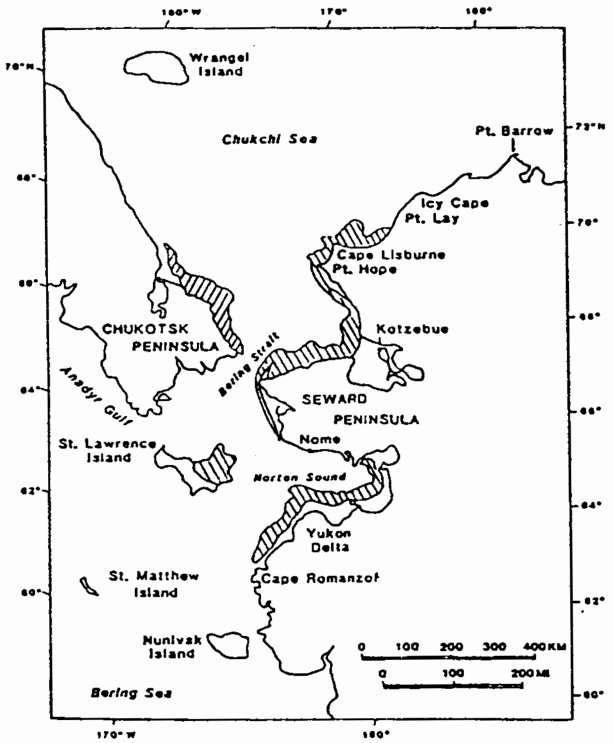

Figure 2. Polynya formation on February 8, 1975.

Neither the temperature-based nor the wind-based correlations were so large or universal that they can unambiguously explain how and why polynyi form. Furthermore, no correlations were found which suggested an explanation of the unusual polynya observed in 1975.

One, therefore, concludes that temperature and wind velocity do have an effect on polynya areal extent; however, clarification of these effects is complicated by other factors. These factors may include the following:

- Intermittent influence of temperature and/or wind velocity on polynya areal extent.
- Inappropriate selection of sites to obtain temperature and wind velocity due to the scarcity of synoptic weather stations in the Bering and Chukchi region.
- Inability at this time to determine the best climatic data derived variable to correlate with polynya areal extent.
- Influences, such as current movement or sea surface temperature, which are associated with the oceans and for which there is no adequate database.
- Concurrent action of oceanographic influences with the atmospheric ones centered upon in this study.

An improvement in the attempt to correlate climatic variable with polynya areal extent is suggested by a qualitative explanation offered for the appearance of very large polynyi and North Coast Polynyi in 1975. These atypical polynyi were associated with the formation of a high barometric pressure center within the Alaskan landmass, north of Alaska, or over MacKenzie Bay. This situation is uncommon in the months preceding May. Perhaps pressure differences between synoptic weather stations should be studied. The suggestion here is that atmospheric forcing may be related to major ocean current event and that polynyi are related to current drag forces more than any other factor.

Additional improvements in the attempt to explain polynyi formation would undoubtedly also arise from additional measurements of sea surface temperature and current movement near polynya sites during the time of their formation.

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BEAUFORT/CHUKCHI ICE MOTION AND METEOROLOGY UPDATE

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INTRODUCTION

In August 1986, the Pacific Marine Environmental Laboratory began a two-year study of the circulation of the coastal Beaufort and Chukchi Seas. In support of this goal, we made observations of meteorological parameters and sea ice drift so we could understand the context of the oceanographic measurements.

Three meteorological towers were deployed on land along the northern coast of Alaska during August and September 1986 to supplement the sparse network of National Weather Service (NWS) stations. The NWS maintains primary weather stations at Nome, Kotzebue, and Barrow. There are also secondary weather observation stations at Cape Lisburne and Barter Island, maintained by DEWLINE personnel. Our stations were placed at Icy Cape southwest of Barrow, at Lonely between Barrow and Prudhoe Bay, and at Resolution Island in Prudhoe Bay.

Three sets of satellite-tracked drifting stations or buoys were deployed on the pack ice during the observation period. A typical deployment consisted of a meteorological station with an anemometer, a current meter, air and water temperature sensors, and a barometer, embedded in an array of two or three smaller buoys, each with a thermister and barometer. These deployments were made by helicopter in October 1986 from the ice breaker *Polar Star*, in March 1987 directly from Barrow and Prudhoe Bay, and in November 1987 from Prudhoe Bay.

The following preliminary discussion is focused on the weather with a few general statements about the ice conditions and movements, because the weather was quite unusual during the entire study period and because the ice motion data is only partially analyzed to date.

AUTUMN 1986 AND WINTER 1987

The air temperatures over the coastal Beaufort and Chukchi Seas did not cool off until the third week in November 1986, nearly a month later than the climatological average (Figure 1). The September/October cruise of the Coast Guard icebreaker *Polar Star* encountered the least ice in the coastal Beaufort Sea in thirty years. Low pressure centers passed through the area with frequencies and intensities typical of mid-latitude early autumn, and one storm immediately before the cruise caused extensive storm-surge damage in the Barrow area, including road damage, beach erosion, and destruction of archeological sites.

Pressure and temperature records for the several meteorological stations across the north slope were very highly correlated with only a slight lag between Icy Cape and Resolution Island in Prudhoe Bay; showing that the systems which propagate up the Chukchi coast and across the southern Beaufort were moving rapidly and were probably part of a larger scale shift in the hemispheric weather pattern. The early winter was relatively mild with temperatures generally

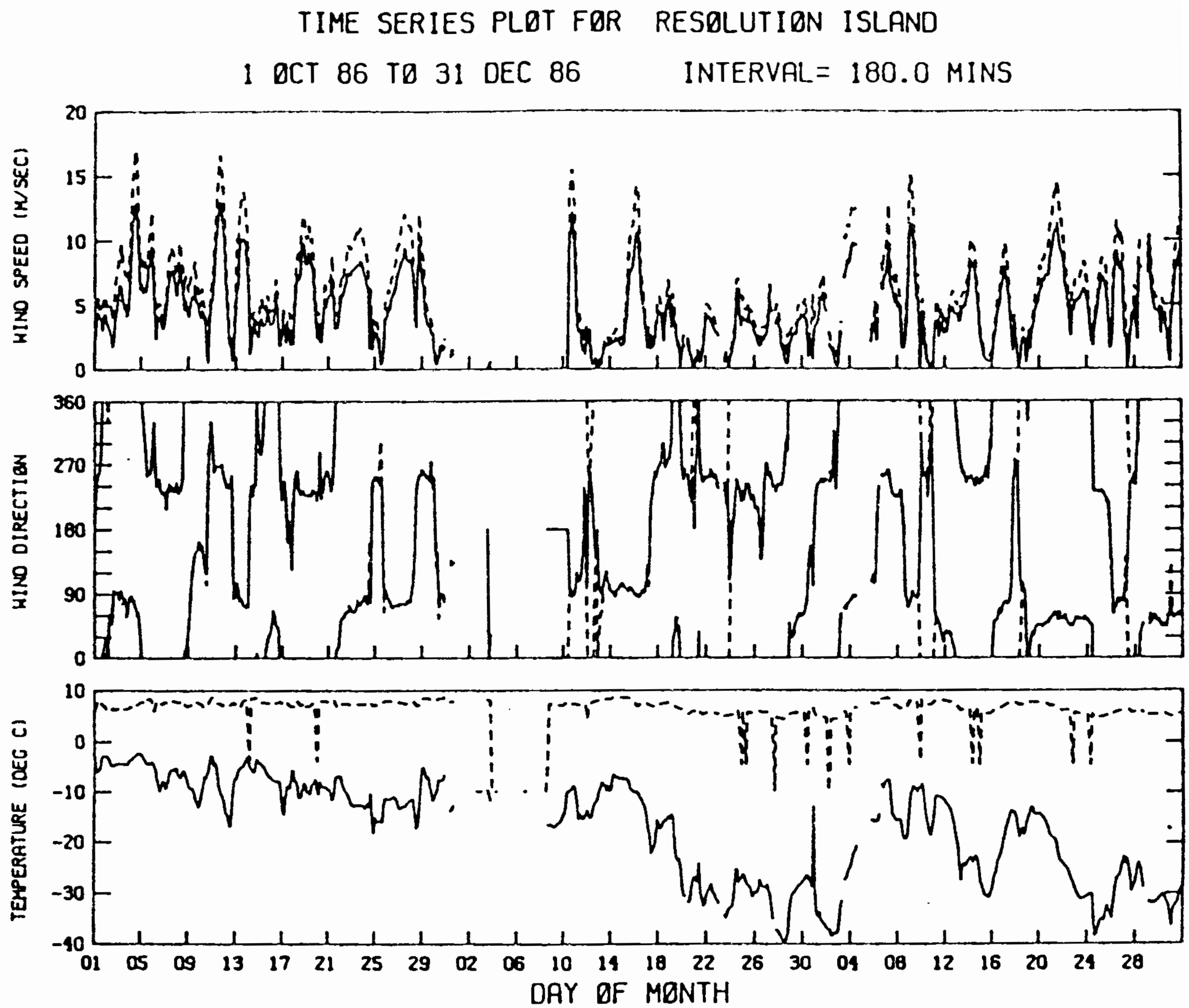

Figure 1. Plot of wind speed (m/s), direction (true angle), air temperature (solid line in C), and internal temperature (dashed line in C) for October through December 1986 for Resolution Island in Prudhoe Bay, Alaska. The one week gap in the record in early November was caused by the crash of the satellite downlink computer in Maryland. Note the frequent passage of low pressure centers at intervals of three to five days during this period.

between -40 and -10°C. There was one week in mid-February 1987 with surface air temperatures below -40°C. Most such intense cold periods occurred when a high pressure was centered over the area and wind speeds were concomitantly low.

SPRING AND SUMMER 1987

During late winter and spring, the wind set up persisted from the east, the climatologically average direction. By about the spring equinox, the solar radiation that penetrated through relatively clear skies induced a strong diurnal variation in the air temperature, and the temperatures across the slope increased from -30°C at the end of the first week in April to

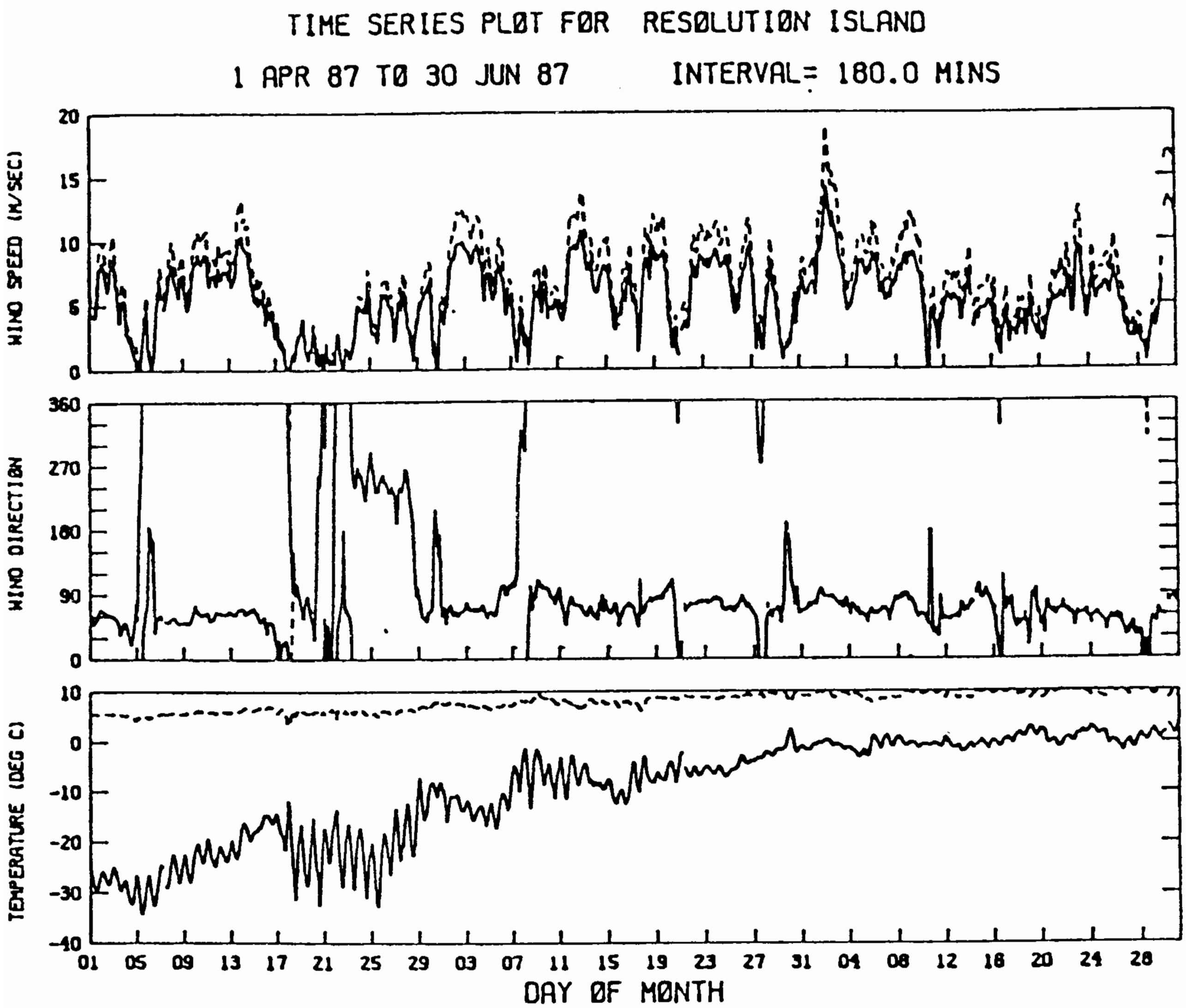

Figure 2. Similar plot for April through June 1987 for Resolution Island. Note the storm diurnal fluctuations in the air temperature during the relatively clear period of warming in the spring and the transition to low diurnal variations and stable temperatures during the onset of Arctic stratus in late spring. Also note the incredible persistence of easterly winds during the spring months.

around 0°C by the end of May 1987 (Figure 2). At this time, the temperature stabilized and the diurnal variations were diminished by the onset of persistent arctic stratus clouds. From about the summer solstice until just prior to the autumn equinox, the air temperatures were steadily between 0 and 10°C. In mid-August, low pressure centers started to punch through to the north slope from the Bering Sea, as observed from the August/September cruise of the NOAA ship *Surveyor*.

AUTUMN 1987

This autumn's meterological pattern is closely following the pattern set during 1986 with extreme minimum summer ice extent; the Beaufort coast open until the first week in November, and the frequent passage of low pressure systems through the area. An interesting consequence of the large amount of open water in autumn is the production of "lake-effect" snow over the north slope.

SUMMARY

The Alaskan Arctic maritime climate during the mid-1980s is characterized by:

- Warm coastal currents, frequent penetration of storms into the Arctic in summer and autumn.
- Minimum summer ice extents that have never been recorded.
- Late freeze-up of the Beaufort coast.
- Delayed freeze-up of the Chukchi and northern Bering Seas.
- Rapid westward drift of ice across the coastal Beaufort in winter.
- Northward mean drift of ice through the Bering Strait into the Chukchi Sea.

These correlations are in strong contrast with conditions during the mid-70s when summer ice rarely cleared Barrow and winter maximums were some of the worst ever recorded. It is not yet clear whether this warming is part of a decadal-scale variation or part of a larger global warming trend.

The conveyor-belt process, in which pack ice is blown into warm water, melts, and thereby cools the water so that ice can advance further, is at work in the autumn coastal Beaufort and Chukchi Seas. This was shown by the repeated melting out at the ice edge of buoys placed inside the pack near or just after **minimum** ice extent (Figure 3). Calculations have not yet been made to show the relative magnitude of the contribution of this mechanism versus radiative cooling of the ocean in preconditioning the water for fall freeze-up.

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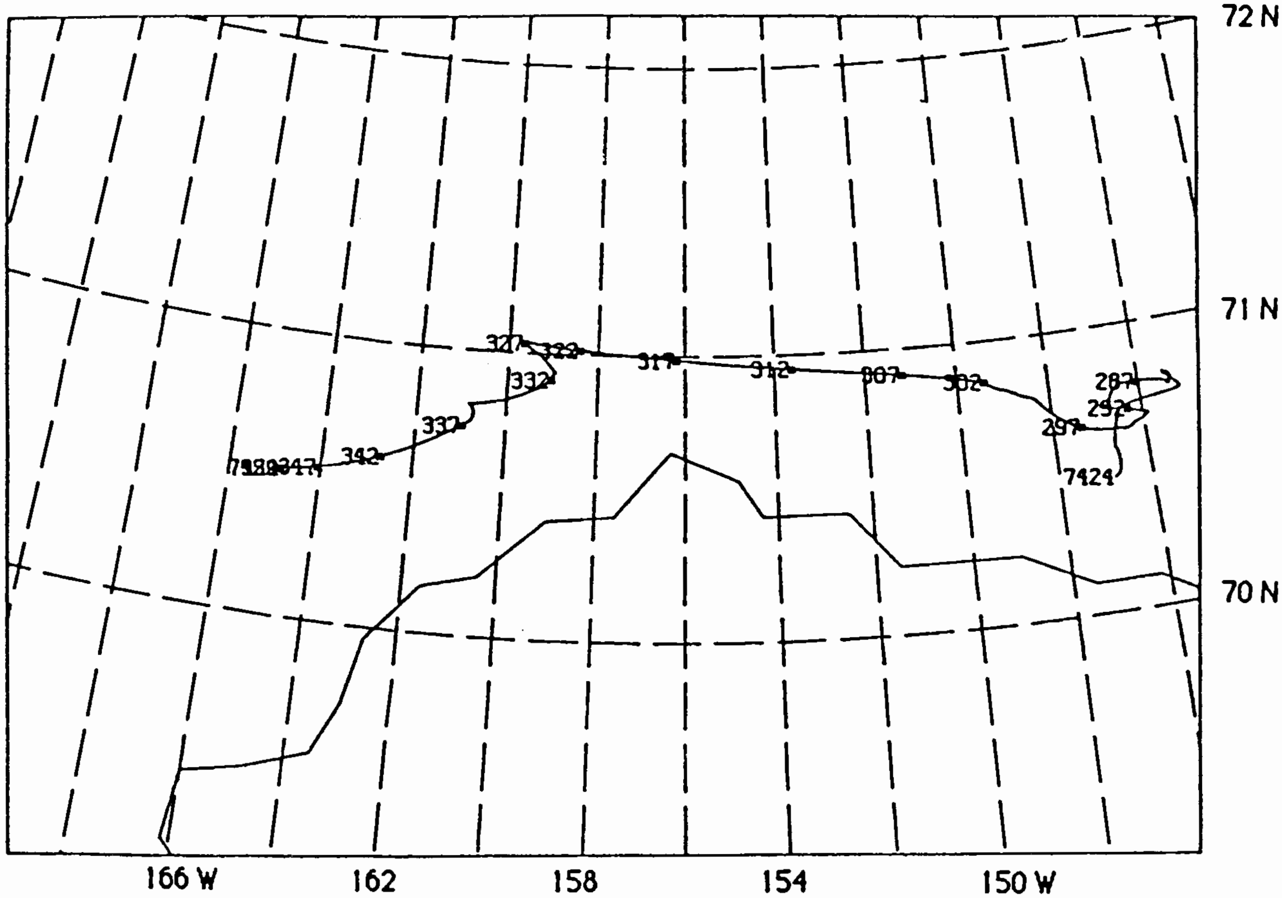

Figure 3. Drift track of an ARGOS sea ice buoy westward across the Beaufort and into the Chukchi during the autumn of 1986. Time ticks are labeled every fifth day in Julian Days. The station was deployed on 9 October 1986 and melted out along the advancing Chukchi ice edge in December.

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CIRCULATION: BEAUFORT SEA UPDATE

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THE FIELD WORK

In October 1986, NOAA/PMEL began an 18-month field study in the Beaufort Sea, with supporting measurements in the Chukchi and northern Bering Seas. The goal was to acquire detailed information about the variability of the flow over the shelf, and of its atmospheric and oceanic forcing, and to do so over a sufficiently long period that understanding of the regional circulation and its low-frequency variability would be significantly improved in both a dynamic and a statistical sense.

The initial measurements included six hydrographic sections across the shelf and slope, distributed from 156-141°W (Figure 1). In addition to current, temperature, and depth profiles (CTD), these sections also included sampling for dissolved oxygen and nutrients. Five arrays of moored instruments deployed in October were retrieved the following March and April, and two more in September. During the March/April 1987 field season, three complete hydrographic sections were re-run, together with portions of a fourth, and seven new moored arrays were deployed. An eighth mooring was put out in August. These will all be retrieved in 1988.

HYDROGRAPHIC SECTIONS

Preliminary examination of selected fall hydrographic sections shows most of the northern Alaskan shelf being inundated by the warm Chukchi Sea influx, with maximum temperatures of 3-4°C. The warm water also extended out over the slope in a subsurface layer.

The upper 50 m of the ocean were nearly devoid of nitrate, both over the shelf and over the slope, and regardless of the stratification of the upper ocean. On the other hand, ammonia concentrations were quite large and tended to be associated with the warm water from the Chukchi. While both phosphate and silicate were reduced in the upper ocean, they were far from depleted. However, the largest values of these latter nutrients occurred off the shelf, and then at depths well below 100 m. These concentrations correspond to the universal nutrient maximum within the Arctic Ocean pycnocline.

MOORED MEASUREMENTS

Preliminary examination of three of the fall-winter moorings suggests long-term mean eastward motion in the undercurrent close to 10 cm s^{-1}, with peak low-passed speeds about five times this. Near and seaward of the shelf break the mean velocity profile probably goes through zero somewhat above 100 m, presumably reversing to mean westward motion in the upper part of the water column. (Note, however, that this does not mean that the instantaneous motion in the upper ocean can not be directed eastward.) By 1000 m depth, the mean longshore motion is again near zero.

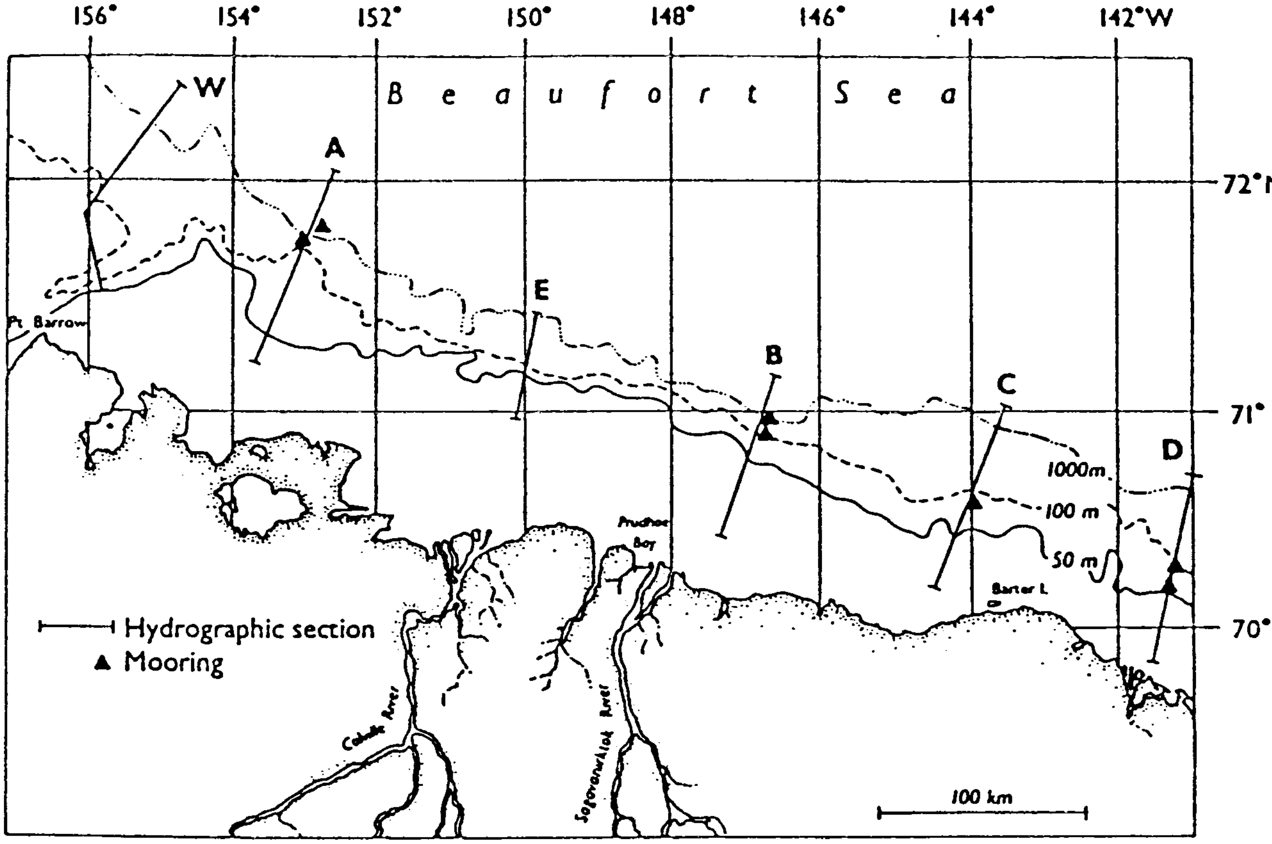

Figure 1. Location of hydrographic sections from October 1986 and of moorings deployed in October 1986 and recovered in 1987.

The velocity records show large variability on time scales of 5-10 days, with frequent reversals. Much of the variability appears to be coherent both vertically and also horizontally across the shelf break. However, differences between the records from adjacent instruments point to the existence of higher horizontal and vertical wave modes as well as the fundamental.

The SEACATS provide a new measurement capability. The temperature and salinity records, representing conditions about 1.5 m above bottom, show fluctuations, with time scales similar to those of the velocity records (Figure 2). The characteristic peak-to-peak amplitudes are about 1.0-1.5°C and 1-2 psu. Such variations suggest vertical excursions (upwelling and downwelling) of order 100 m from mean isopleth levels. These events may therefore represent significant exchanges between the shelf and the deep ocean, with consequences for both the physical and biological regimes.

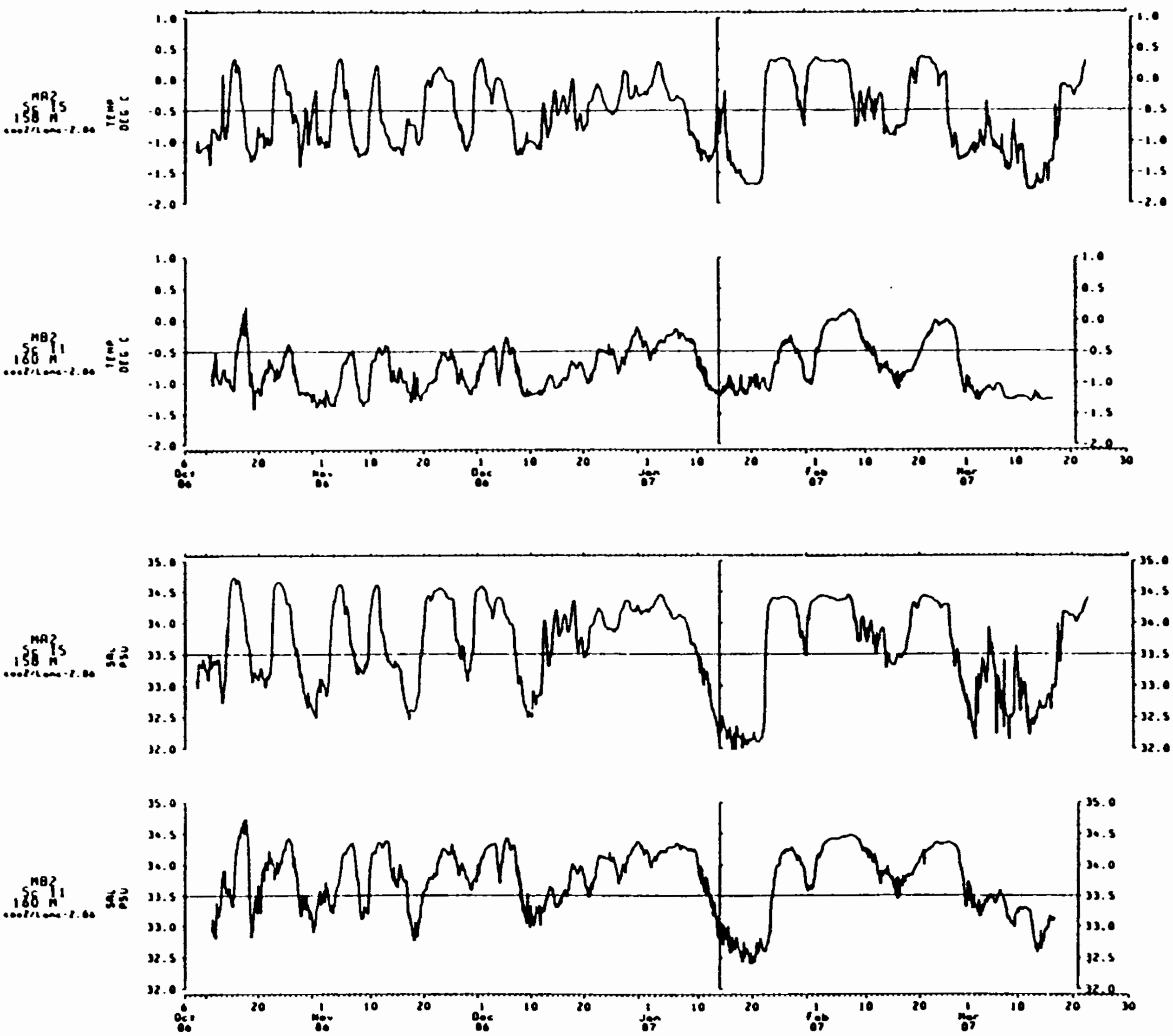

Figure 2. Temperature and salinity observed 1.5 m above bottom on the outer shelf near 153°W (MA2) and near 147°W (MB2). Note the large low frequency upwelling events.

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Question (Hachmeister): Could you explain why there were two relative eastward motions for one of the current meters?

Response (Aagaard): The question concerns this bimodality in direction is a rather curious thing in the eastward motion. I believe that was right. It was the intermediate current meter at roughly 150 meters depth on the slope and it was kind of curious. I don't have any ideas about it at this point.

Question (Hachmeister): I just wondered what the depth was relative to the depth of the shelf break.

Response (Aagaard): It's roughly at the shelf break.

Question (Crane): For Carol Pease and Knut Aagaard, one of Carol's slides shows the current profiler as one of the instruments to be used. How will you analyze that data and how will you calibrate it to traditional moored current meters. What is your assessment of its application in the Arctic?

Response (Pease): The doppler profilers? They didn't work. We deployed those in September and they came up blank because the recording mechanisms did not work. We've supposedly repaired them. They're serial number one and two.

Question (Crane): These are bottom-mounted?

Response (Pease): Yes, they are bottom-mounted, upward looking profilers. They had a high density recording mechanism which failed on both of them and they were re-deployed. Knut put one of them out again last spring, and I put another one out from the *Surveyor*, so we'll see in April if they worked at all before we decide.

Question (Crane): What's your promise of their potential application then?

Response (Pease): Well a couple of different things, one, my own selfish viewpoint is that for once we might be able to get ice measurements and ice velocity out of them, if they do work. Secondly, I don't know how many bins we have them set up for but, hopefully, individual bins can be calibrated to current meters at the bin level. However, it's not clear yet until we see some statistics out of these things of what we are really going to end up with.

Response (Aagaard): We attempted to solve this almost intractable problem in getting time series in relatively shallow water. A rule of thumb has always been that we don't like to put instrumentation higher than about 40 m from the sea surface, because the odds of losing it are very great, due to ice. Up to about 40 m, we do pretty well. So, in other words, somewhere around the 50 m isobath is normally where the cutoff is. The only way that one can be put shallower is to go into fast ice and suspend it from that. That still leaves some very large holes. So, the idea was to try and get some information out of an area in which we simply don't have any measurements. Secondly, of course, we get something close to a profile at the depths at which these were deployed. You get measurements roughly every 2 to 5 m. Another feature, in the hard ping mode (which is when you use it in an inverted sense on a ship) is that it gives you bottom tracking. It is our hope, that in fact we can get ice drift out of that. It was a doubly sophisticated installation in this case, because it additionally had a complete Seabird CTD on it, but that was not the real problem. The problem came in data recording. Everybody else had that problem too. The problem is with a particular 60 megabyte recorder which has some hardware problems. These were compounded by some software problems in this case. It's the sort of thing we need to be working toward, but we are going to have some growing pains.

Question (Newbury): Which of the polynyi along the northeast Chukchi coast or along the east side of the Chukchi Sea, in terms of area and persistence, are very important? The one south of Pt. Hope? Or, are the others quite persistent, quite large also?

Response (Stringer): We have the numbers now, but off the cuff I couldn't tell you. One thing I wanted to leave the meeting with was an idea of what sorts, what sorting of information would be useful to people. That's the kind of thing we're going to have to take out of these numbers. And, in fact, I wouldn't want to make or hazard a guess because it wouldn't be based on looking at the numbers. It would just be based on what my memory is. The sort of thing that frightens me the most is making generalizations not based on real numbers. But I can get those numbers for you.

Comment (Newbury): I think that has oceanographic implications. There are polynyi on the southwest side. I think that possibly has biological implications late in the fall, during November and December.

Response (Stringer): In fact, another thing that we want to do is look at the correlation among the polynyi or sets of polynyi, because some of them are very likely anti-correlated too, north facing polynyi or south facing polynyi.

Comment (Aagaard): I could perhaps add something to that: I think it is the south facing coasts that from a physical standpoint are important ones. For example, the Gulf of Anadyr probably puts out a fair amount of brine. One of the issues that we should start looking at is: To what extent those kinds of structures are preserved as they move northward? Can you, in fact, import brine through the Bering Strait or do the shears effectively destroy them?

Question (Stringer): One thing that I'm interested in is if we have an event with lots of south facing polynyi opening up, I would really like to know which way the currents are going at that time.

Response (Aagaard): The brine events themselves are capable of driving a relatively weak thermohaline flow. The strength of that flow is kept low because the vertical extent of the layers is not very great. So, you can't get a terribly large pressure gradient from it. The kinds of pressure gradients that we have seen in these layers suggest that something on the order of 5 cm/sec is appropriate. We did a paper a few years ago on the induced circulation south of St. Lawrence in connection with the brine events. And you certainly will see the deeper coastal current reverse when you get that flow. It is straight-forward, baroclinic effect. Because these layers are so shallow, there are strong frictional effects and these tend to make them bleed out in a bottom Ekman layer, or something like that, into the interior. You don't have that isolation from frictional effects that you get in the summertime, which, of course, are much thicker and where you get much higher baroclinic speeds.

CURRENT RESPONSE TO WIND IN THE CHUKCHI SEA
A REGIONAL COASTAL UPWELLING EVENT

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INTRODUCTION

The circulation in the northeast Chukchi Sea near the Alaskan coast is dominated by wind forcing and time variable inflow through the Bering Strait. In addition, seasonal ice production and melting greatly modifies water mass properties. The prevailing interpretation of the flow between Cape Lisburne and Point Barrow is that the flow is generally northeastward, with the center of the transport approximately 50 km offshore. Near the coast, the flow may also be northeastward, although there are indications of recirculation systems "behind" the major capes which interrupt this flow. Farther offshore, the northeastward flow produces "bays" in the marginal ice zone, due to the melting action of the warm water in the flow. Wind stress forcing from the east and northeast also can produce reversals of this prevailing flow toward the southwest. Time series current measurements in this region have supported this interpretation, although they have revealed large reversals in the alongshore flow in response to the wind. These reversals account for a significant amount of the variance in current meter measurements.

The water mass which is flowing northeastward along the coast is usually a mixture of Bering Sea water and Chukchi resident water. This water is thought to be found at deeper depths after passing about 71°N, and is then overlain by water derived, in part, from the Beaufort Sea.

DATA

A cruise was conducted on the NOAA ship *Oceanographer* in August and September 1986 in the Chukchi Sea. Cooperation with the scientists on the previous cruise allowed us to deploy four current meter moorings. These moorings were instrumented with sediment traps and Aanderaa RCM4 current meters. Since the moorings were to be in place less than a month, the current meters were deployed primarily to obtain estimates of the current velocities that the sediment traps were experiencing during their sampling. Very little in the way of significant statistics was expected from the current records with durations between five and eight days. However, as is often the case, these short time series sampled an interesting and significant wind forcing event. Current, temperature and depth (CTD) profiles were acquired after deployment of the moorings and after their recovery. The R/V *Oceanographer* has an Acoustic Doppler Current Profiling (ADCP) system which was operated during the cruise. To determine the source of the variations in the currents, the winds from the National Weather Service (NWS) station at Barrow were obtained from the Local Climatic Summary.

RESULTS

A time series plot of sticks proportional to the wind and current strength and direction (Figure 1) demonstrates a relationship between the wind and currents. The currents at the three moorings near the Alaskan coast indicate a reversal of the normal northeastward flow to

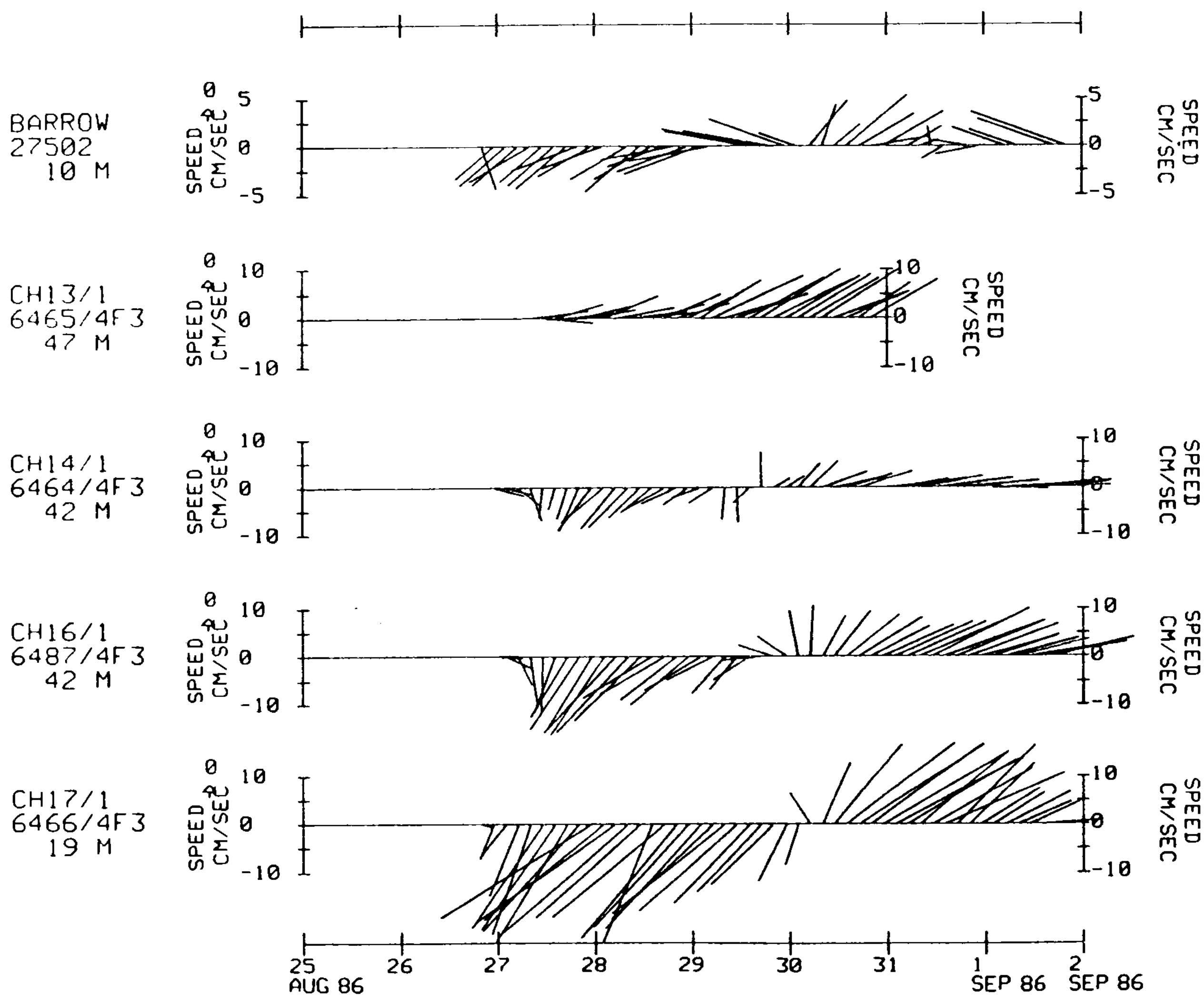

Figure 1. Vectors of wind at Barrow and ocean currents at four current meter moorings in the Chukchi Sea.

southwestward. This reversal was produced by wind, which had begun to blow from the east/northeast at up to 30 miles per hour. The nearshore mooring (CH17) had the largest amplitude variation of currents and the largest temperature variation. The amplitude of the reversal decreased offshore, from CH17 to CH14. The station further from the coast, CH13, was near the ice-edge and on the other side of Barrow Canyon and a sub-sea bank. The flow at CH13 was consistently toward the east, and is only poorly related to the wind.

Cross correlation analysis was performed to obtain time lag estimates for the maximum correlation between the wind at the NWS station at Barrow and the currents measured at the moorings. The highest correlation was observed at CH17 with a value of 0.88 at 6 hours lag. The correlation decreased with distance offshore and the time lag of the highest correlation increased.

The temperature time series from the current meters supports the idea that the wind was producing upwelling (Figure 2). The temperature at CH17 decreased from warmer than 6°C before the wind reversal to less than 0° on August 30. The two current meters at CH16 and CH14 showed very slight decreases, but they were already measuring less than 0°C. The timing of the temperature response produced the minimum temperature coincident with the reversal of the current from the anomalous southwestward flow to northeastward. From the CTD cross section, the 0° isotherm occurred at about 30m depth subsequent to the event, at the time when the moorings were recovered. Thus, the upwelling resulted in lifting this isotherm at least 10m to the 19m depth of the CH17 current meter.

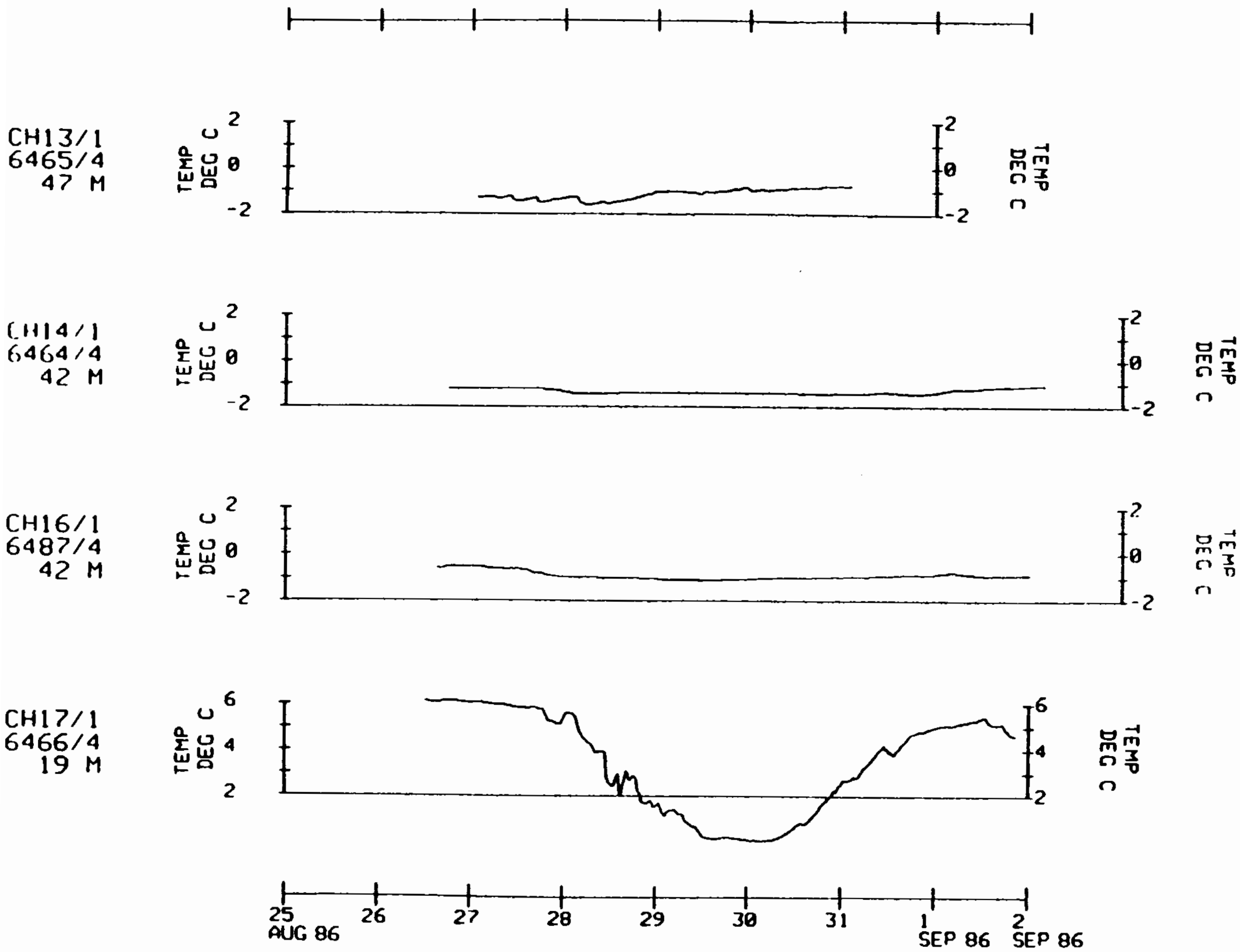

Figure 2. Time series of temperature at the four current meters.

The ADCP currents from the ship-mounted system give an idea of the horizontal extent of the current response (Figure 3). The ADCP data was acquired from a point near Barrow on the cruise continuously at two minute intervals. These data were smoothed with a 61 point triangular

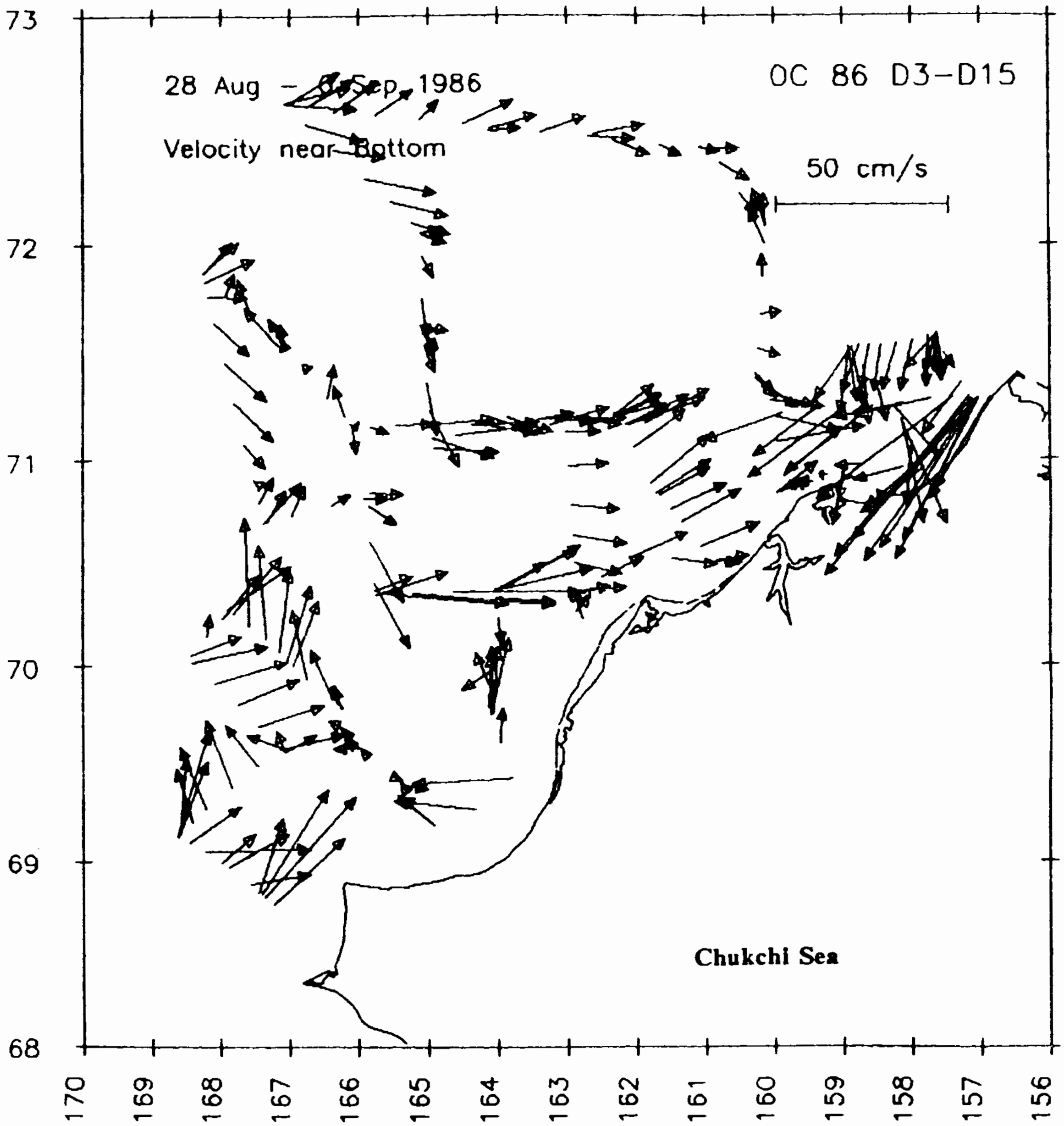

Figure 3. Instantaneous velocity vectors measured by the ADCP on the *Oceanographer*. The vectors near Barrow show the current reversal associated with upwelling.

filter and then subsampled at one hour intervals. The smoothed data show strong southwestward flow near Barrow at the same time and at roughly the same distance offshore as CH17. Subsequently, as the ship proceeded offshore, the current velocities must be interpreted with both the wind event time history and the spatial current distribution.

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ARCTIC PLANKTON COMMUNITIES

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Biological studies of the Arctic Ocean date back to the early 1900s when the Soviet Union began actively studying those seas and the deep ocean bordering its extensive northern coastline. Much of that work was directed toward understanding specific aspects of the biology of those cold northern waters. More recently, U.S. and Canadian scientists have initiated studies of their own arctic marine ecosystems. A number of these investigations have examined and described processes known to promote or constrain the synthesis and transfer of organic matter in marine systems elsewhere. I take this opportunity to very briefly review some of what is generally known about plankton communities in the Arctic, and particularly to point to some relatively new findings suggesting the importance of the intruding subarctic pelagic community that enters the Arctic Basin via the Bering Strait.

Observations undertaken at Duft Station Alpha in 1957 and 1958 confirmed what had long been suspected about the annual production cycle in permanently ice-covered regions; namely, that primary productivity is limited by light to only a tiny fraction of each year (Figure 1). This means that both the magnitude and duration of the water column plankton "bloom" is greatly compressed in time around mid- to late summer when the snow albedo is at its annual minimum and melt water on the ice, coupled with open leads, allow sufficient penetration of solar energy to simulate phytoplankton growth. It is now generally accepted that between 1 and 5 g C are fixed annually per square meter of sea surface in the high Arctic, making this the least productive region of the world ocean.

This small amount of annual production is distributed among members of a markedly impoverished zooplankton community characterized by low diversity, low biomass and slow growth. One of the major large calanoids, *Calanus hyperboreus*, requires two years rather than one to complete its life cycle, presumably because of food limited growth during the narrow "production window" each year. Similar congeneric or closely related subarctic species (*Calanus finmarchicus, Neocalanus plumchrus*) complete their respective life cycles in a single year.

As is the case over other continental margins, the production cycle in most arctic shelf and coastal environments is somewhat more productive than the deep-ocean system. The most recent estimates from arctic waters indicate that up to 30 g C m^{-2} can be fixed by primary producers in shelf and coastal environments, with perhaps as much as 50% of this production contributed by an under-ice algal community. This amount is roughly the same as that produced in the large oligotrophic subtropical gyres located at roughly 30° north and south latitude in the Atlantic and Pacific Oceans.

Studies of zooplankton communities in the Alaskan and Canadian Beaufort Seas document mixtures of oceanic and neritic species occurring over the relatively narrow shelf, presumably in response to large and mesoscale mixing phenomena. Three "type" communities have been proposed, based on apparent association with watermass characteristics:

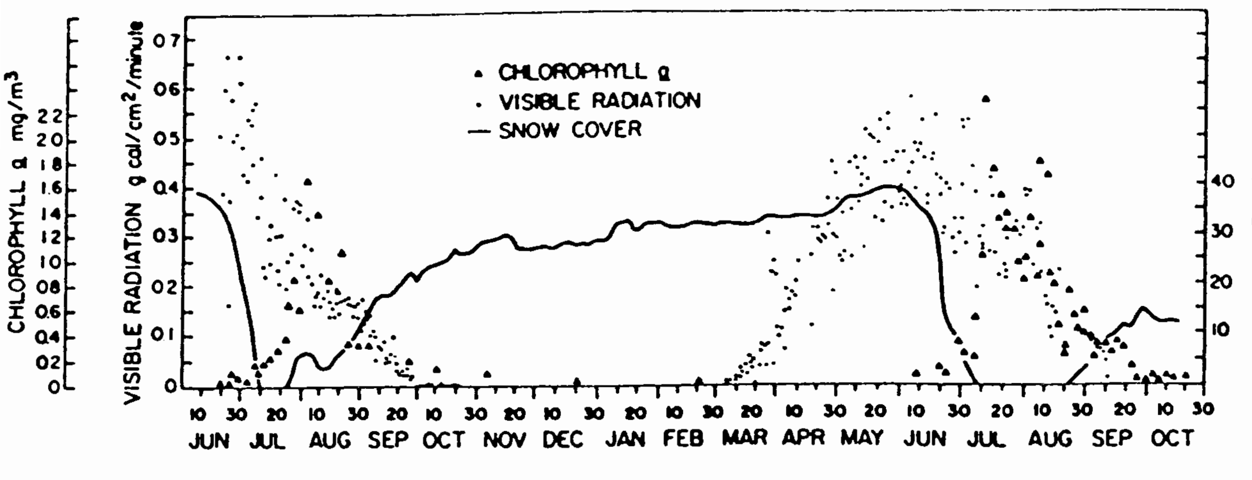

Figure 1. The relationship between snow depth, solar radiation and chlorophyll measured at Duft Station Alpha, 1957 and 1958 (Nemoto and Harrison 1981).

- A generally euryhaline and eurythermal assemblage found in the inshore and upper waters of the shelf (0 to 100 m).
- A deep, cold water group (below 1°C).
- A distinctly brackish water community generally restricted to the shallow coastal environment or to low salinity water (<25 ppt) (Figure 2).

Typical copepod indicators include *Calanus hyperboreus*, *C. glacialis*, *Pseudocalanus minutus* and *Oithona similis* representing the first group, while *Gaidius tenuispinus*, *Heterorhabdus norvegius*, and *Chriridius obtusifrons* are the deep water forms. *Limnocalanus macrurus*, *Acartia clausi* and *Eurytemora herdmani* typically indicate brackish inshore conditions.

A forth assemblage, found in the western Beaufort region, is introduced with the northward flow of Bering Sea water through the Bering Strait. These subarctic zooplankters, represented by the copepods *Neocalanus cristatus*, *N. plumchrus*, *Calanus marshallae*, *Eucalanus bungii*, and *Metridia lucens*, are often found as far east as the Alaska-Yukon border. There is no evidence that these invading species are able to reproduce under arctic conditions. However, in at least some localities,

ARCTIC ZOOPLANKTON*

Group I Shelf and Open Ocean: Upper 100 m

Calanus hyperboreus
Calanus glacialis
Pseudocalanus minutus
Metridia longa
Oithona similis

Group II Nearshore and Coastal Brackish

Limnocalanus macrurus
Acartia clausi
Eurytemora herdmani

Group III Offshore Deep Water

Gaidius tenuispinus
Heterorhabdus norvegicus
Schaphocalanus magnus
Chiridius obtusifrons

Figure 2. Indicator groups of Arctic zooplankton by hydrographic province (Grainger 1965).

notably the Chirikov Basin and southern Chukchi Sea, the presence of these "oceanics" and their transport northward is reflected by the presence of some of the largest colonies of seabirds and mammals found anywhere in the Arctic. Also, the unusually high production of organic matter associated with upwelled deep water flowing northward into the Chukchi Sea, 2-4 g C m^{-2} d^{-1}, rivals the richest marine regions in the world ocean (Figures 3, 4, 5, 6, and 7).

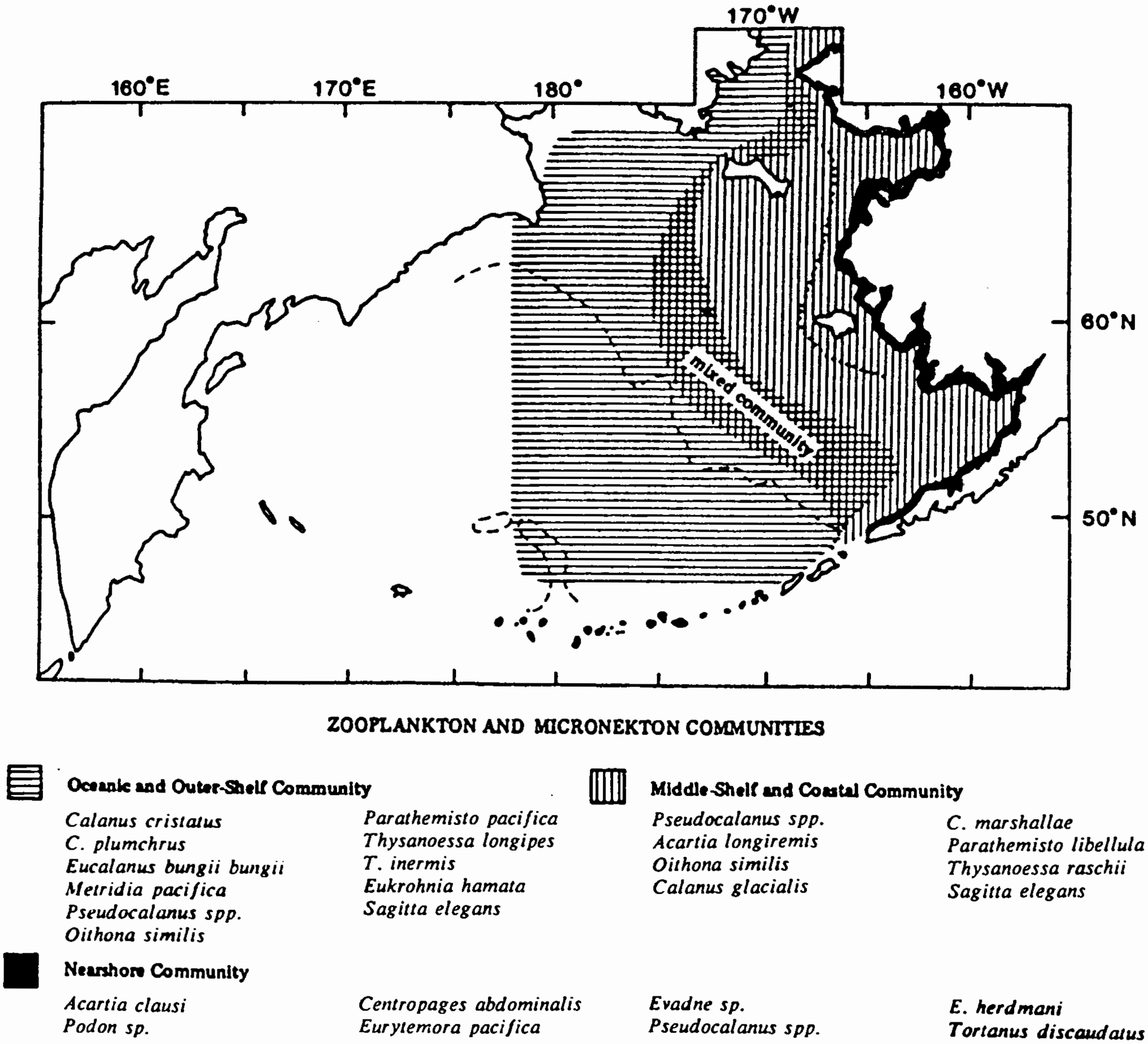

Figure 3. The distribution of zooplankton communities in the eastern Bering Sea (Cooney 1981).

The broad-scale ecological ramifications of this "enrichment" of the Chukchi and western Beaufort Seas, associated with oceanographic processes (transport and production) occurring in

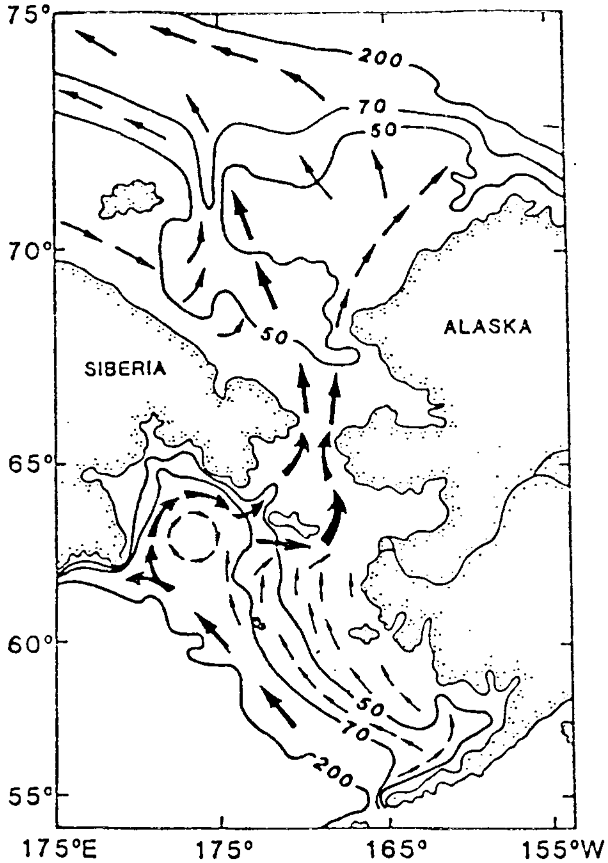

Figure 4. Generalized northward flow through Bering Strait.

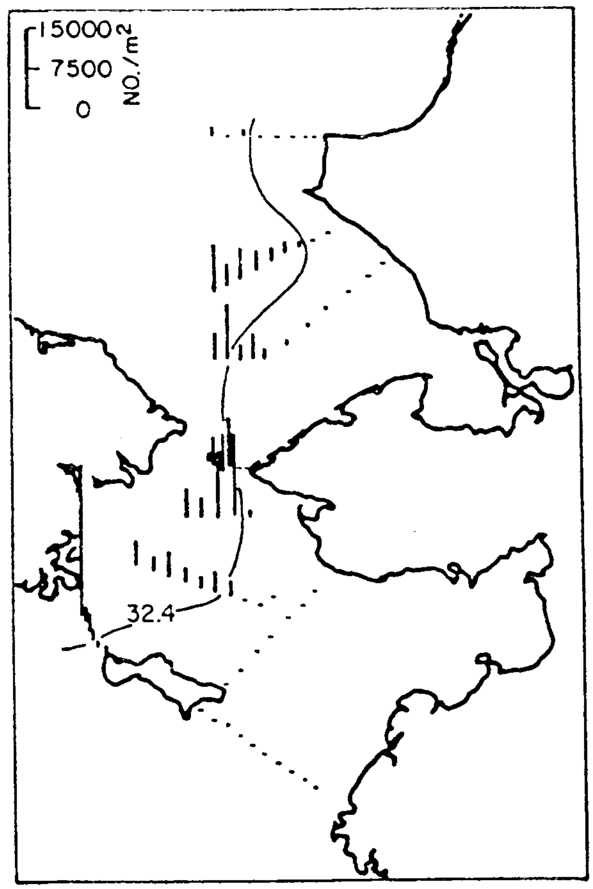

Figure 5. Distribution of oceanic copepods in the northern Bering and southern Chukchi Seas (Springer 1988).

the Chirikov Basin/Bering Strait region, is presently the subject of continuing and planned future research sponsored by the National Science Foundation (NSF) and the National Oceanic and Atmospheric Administration (NOAA). Most of the invading subarctic zooplankters are large-bodied organisms that contain significant amounts of lipids and wax used for overwintering and reproduction. If preliminary estimates of the amount of organic matter transported northward as zooplankton moved by currents through the Bering Strait are correct, approximately 20 million metric tons of weight or 1.4 million metric tons of carbon can be carried northward during the period June-September of each year. By way of comparison, this amount is approximately one-tenth of what is generally considered to be the sustained annual fisheries catch for the entire world.

Of perhaps even greater importance than the actual amounts of material entering from the subarctic Pacific each year would be the indication of how variable the transport process is. It seems likely that inter-annual variations in the amount of organic matter reaching consumers in

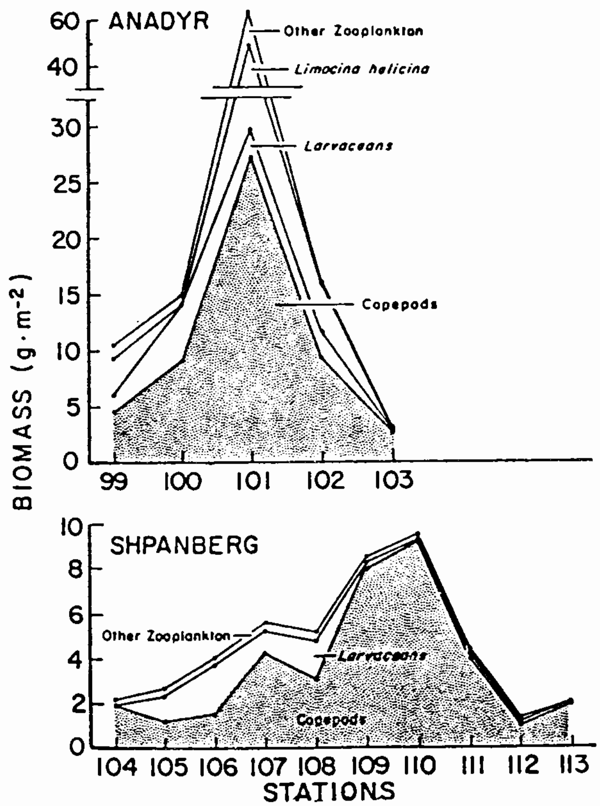

Figure 6. The standing stock and composition of zooplankton sampled in the Anadyr and Shpanberg Straits in the southern Chirikov Basin (Springer 1988).

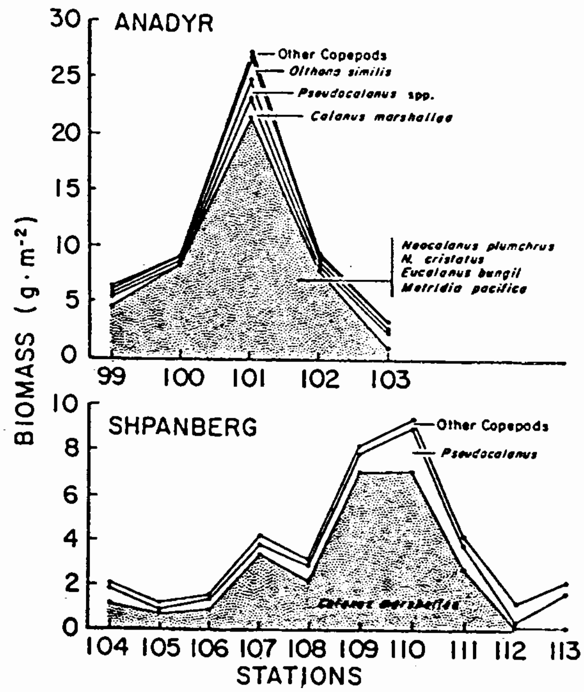

Figure 7. Composition of copepod communities sampled in Anadyr and Shpanberg Straits, southern Chirikov Basin (Springer 1988).

the Chukchi and western Beaufort Seas via the Bering Strait depend both on the natural variation in Bering Sea "source" stocks of plankton and year-to-year changes in the timing and amount of water moving northward. The Japanese suggest the former may be cyclic by a factor of about two over periods of three or four years, while the latter is almost certainly related to short, medium, and long-period variations in atmospheric forcing. The mediating influence of ice-cover, its extent and duration, is also a factor to be considered in addressing questions of inter-annual variability.

The coastal lagoon/sound environments of the Arctic represent the interface regions between the wetland and riverine systems and the true coastal marine habitats. Kotzebue Sound and Harrison Bay in coastal Alaska represent examples of quite large shallow embayments influenced greatly by discharge from relatively substantial rivers. Here, the summer zooplankton community is characterized by a very predictable "brackish water" assemblage of both freshwater and marine origin. Surprisingly, on occasion, some members of these brackish populations become important components of food webs supporting more typical oceanic species. The most recent studies of bowhead whale feeding in the eastern Beaufort Sea implicate the medium-sized brackish water copepod, *Limnocalanus macrurus*, as an important food item. As might be more reasonably expected, the brackish, inshore shallow-water plankton community is also utilized by migrating anadromous fishes as they enter and leave freshwater each year. It is also generally believed that these shallow systems are basically benthic in structure and function, with little organic matter harvested by zooplankton in the shallow water column. This contention is presently being investigated by a large multi-disciplinary study of Kotzebue Sound under NOAA sponsorship.

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Question (Newbury): I appreciated Ted Cooney's comment. It was about the ecological significance of the movement of Bering water organisms into the southern Chukchi. Going back to the discussion we had yesterday regarding Don Schell's isotope analysis of bowhead tissue and the relative importance of feeding outside of the Beaufort Sea, I'd like to propose that we discuss what kind of information will help us pin that question down more - more isotope information, more cruise information, Bruce Mate's satellite tagging-type information, analysis of historical data. It's kind of an open question and I think an important one. I'd like to see some more discussion about it, particularly now when there are investigators here who can comment on some of the ideas that have come out.

Comment (Cowles): That's an interesting idea. It would be more instructive if that type of discussion could occur at this point. If there is anything more specific to bring to bear on it, I'd be interested in it.

Comment (Schell): It's funny how fast this progressed. At the Bowhead Whale Conference last year, (some of you may recall who were there), we put up our initial isotopic findings. At that time based upon stable isotope ratios of the whale, we concluded that for young whales, approximately two-thirds of the food was being derived from the southern and western parts of their range. For the adult whales, it looked like most of the food was derived from the western and southern part of their range. At the time, that was almost heretical. The previous assumption had been that these animals went into the eastern Beaufort where they fed for the summer and then coasted for the winter on their reserves that were accumulated during the summer. I think between Alan Springer's work on transport of copepods and on the zooplankton information that is coming out of ISHTAR, especially the biomass data, it's important to realize that between the Bering Strait and what we call the edge of the Arctic Ocean, the Chukchi Sea production drops by at least a factor of 10. The area around Wrangell Island down to the north Bering Sea has probably some of the most highly productive waters in the world and the whales are taking full use of that biomass. It's interesting to note that the bifurcation of the currents that was pointed out on one of those bowheads going north matches very closely; some of those whales head southwest, some head to Wrangell and come down, they're probably doing the same thing, they are both taking advantage of it. So, it really probably makes no difference whether they come southwest or whether they go over to Wrangell and come down. What they are doing is reaping the harvest of sulfites that has accumulated in the full summer's production, that has been transported north into the Chukchi Sea. It's just been fascinating watching the pictures of this jigsaw puzzle emerge over the course of the last year; it's just starting to fall into place now.

I think it will be really interesting over the next couple of years when the results of the NOAA program and ISHTAR begin to tie down the actual quantification. There is a lack of information on the Soviet sector. We need some kind of international cooperation. It's significant that Gorbachev in his Murmansk speech this fall said as one of the major topics he would like to see international cooperation to preserve the Arctic, conduct an integrated study of the Arctic, and Arctic coastal communities. And this would be an ideal situation. International cooperation is needed to identify some of these variables that are critical environmental questions for both the U.S. and USSR.

Question (Mate): Is there much production that takes place early in the spring, and is the sweep of zooplankton past the polynya areas early enough to have potential as a feeding component for bowhead whales?

Response (Cooney): Let me take a guess at that. These large copepods, *Neocalanus* and *Eucalanus bungii*, probably represent the biggest packets of food other than euphausiids in that region. They come to the surface of the bordering ocean as early as February and March. That means that they begin their drift across that broad shelf toward that target area around St. Lawrence Island at about that time. When they arrive and what the transit times are - I guess we'd have to ask Knut Aagaard and others who have made that calculation - but certainly, it would appear that early in the spring they are in the surface waters and beginning to move northward. It's not unreasonable to expect that forage stocks of these large copepods would be present in that region quite early in the year.

Question (Hameedi): Ted, we have heard quite a bit about the transport of these large copepods into the Chukchi Sea. Have you determined whether most of the organisms are copepodite V adults or younger forms. Because, if they are only the large forms, then of course the habitat for them in the Chukchi Sea is entirely not suitable to carry out their living. Because the adults do not feed, and they are mostly females, they are just being packaged and transported to the Chukchi Sea where they are consumed in shallow water. Have you ever looked at the samples which may have had some copepodite stages, which may have migrated during the early part of summer or late part of spring?

Response (Cooney): I guess the answer specifically to that is, no. I don't have that information. Alan Springer probably does and would be the person to ask. It is likely that at least in the early to late summer regime one would expect that most of the one-year old living copepods would be in probably stage five, trying to migrate away from the surface to overwintering depths. These copepods overwinter at depths below 200 m if they can find that kind of water. Of course in the Chukchi Sea, they are out of luck. So, there is certainly some question about what happens to that biomass. We know that the birds go after a lot of it. We suspect that it enters food webs in the Chukchi when these animals move from the surface to depth, and they get as deep as they can. What happens when they get as far as the edge of the shelf in the Arctic Ocean? As far as I know, no one knows.

Comment (Hameedi): This, of course, has very interesting implications relative to their being there and merely represents what I mentioned during the first day of this meeting. They are fugitive species which come in from the Bering Sea and are available to be consumed. This essentially represents exported material, a kind of a subsidy into the southern Chukchi Sea from the Bering Sea.

Response (Cooney): I am sure that if the sea level was such that the Bering land bridge was present rather than the Bering Strait, production in that area would be vastly different than what it is now. The leak of that water through upwelling processes or water that is brought to the surface makes that region one of the most productive areas in the world's ocean.

Question (Fishman): I am trying to piece this information together. Can you give us a general idea of what the transport time is for this subarctic water that is moving up? I'm particularly interested in that part of the water mass that is moving across northeasterly towards Barrow. What kind of times are we talking about?

Response (Cooney): The mean speeds are probably about 25 cm/second or 25 km/day roughly. The distance you are talking about is 700 km or so.

Question (Fishman): Another thought, and this gets back to what Don Schell was saying. Essentially, I'm picturing a kind of a conveyor belt that's moving material from the subarctic up into the Chukchi and over to the east. If this material is being dumped into the eastern Chukchi and western Beaufort, knowing that whales, birds and other animals are feeding on this material in the Chukchi and Beaufort Seas, is that going to show up in the isotopic records? What is it going to look like? The question is, where are the whales feeding and are they feeding on plankton that is down south, up north, and east? The other question I have is related to these upwelling events. Is there an interaction between upwelling events and the subarctic water that's moving past? That's somehow going to interact and affect zooplankton in the water mass that's moving from the subarctic. Is there any kind of connection you see there?

Response (Cooney): I think that the lighter, warm, and fresher water is going to move offshore, so that you will find that the colder, salty water is right next to the coast. That would presumably take the plankton with it, slightly farther offshore than you might find.

Question/Comment (Aagaard): We've repeatedly heard a statement that we need to get west of this political dateline that runs up through the central Chukchi. There are some very large scale problems that directly relate to the things we are talking about. For example, global carbon fluxes. One of the important issues here is what happens to the carbon transport? Is the central Chukchi, in fact, a sink for that or is it exported into the Arctic Ocean? But getting west of the line is something which we can devotedly wish for. It is something that some of us can work a little bit towards but the process will be stocastic, I suspect. But there is something we can do that we should do; that we need to do. That is, to move into the northern Chukchi. We need to go farther west than we have in the northern Chukchi; we need to move west from the Barrow vicinity. If we do our work right there, I think we can get a good handle on some of the issues that we think we can only do by going west of the line. In fact, some of the answers may be answered as we move westward in the northern Chukchi. For example, I noticed that one picture that was shown here this morning shows the bifurcation about where Hope Sea Valley breaks off.

Question (Kenney): Weren't the Canadians doing quite a bit of work this summer in their sector and could you say something about that?

Response (Aagaard): There have been several Canadian efforts. One of them was related to ice circulation and ice forecasting issues. They actually extended their measurements slightly to make them overlap with ours. There is another program in the Canadian Beaufort where they are specifically looking at more hydrographic and chemical kinds of problems. Specifically, the Canadians are looking at primary production and the natural occurrence of hydrocarbons and their sources. This is a program that is run out of IOS. This year was their first full year and there is some uncertainty as to what will happen next year. That program is run out of the Department of Indian and Northern Affairs, but the work is actually being done by the Department of Fisheries and Oceans. Studies have been conducted as far as the US-Canadian boundary and they have a lot of information on the Mackenzie plume. Its large estuarine circulation pulls, I suspect, a lot of material onto shore. There are some physical issues that are being explored both from modeling and from measurements.

Comment (Cooney): There have been a lot of surprises in the ISHTAR Project. And that's the interesting thing about this project, we just stand by for surprises. About the time you think you've got it figured out on an 8 1/2" x 11" piece of paper, somebody else comes up and says that's not likely to be the case. So don't fall in love with your 8 1/2" x 11" depictions on a piece of paper, they are likely to change.

Comment (Newbury): I felt that I was making a mistake yesterday when I was talking about the area southwest of St. Lawrence Island. Don Schell had mentioned that bowhead feeding occurred in the southwest part of their range. I focused in on the Bering Sea. Actually, I think it's more likely bowheads feed in the Chukchi on zooplankton with a Bering Sea label. It's really fall feeding, not winter feeding. Also, Knut's question about how to get west of the line - I think Peter McRoy mentioned yesterday that it is difficult to run cruises over there. I'd like to hear about the possibility of getting satellite information from Carol Pease and Bill Stringer. Perhaps the disadvantage is that it's only the surface expression. Is it possible to put a buoy in the water? Satellites aren't limited by the boundary line. I think another possible way to get information is to seek international cooperation with some group like the International Whaling Commission. Perhaps we can get permission to obtain cruise information from that area. Lastly, I want to touch on a point that Bruce Mate brought up. I think Don Schell's information is really interesting and I believe it in a way. However, we somehow need independent confirmation of it before we ought to grab it and run with it.

Question (Holland): You mentioned that there is a lot of zooplankton which moves up into the Chukchi and that it can form in February and March on the southern, or the northern Bering. Is there any information with regard to the way or the quantity of zooplankton that moves through at a given time? Is it a high density, low density, or consistent mass? What manner does it move through, quantitatively speaking, spatially?

Response (Cooney): I guess the answer to that involves some understanding of short term variability, north/south flow through the Bering Strait and variability in the zooplankton source populations in the northern Bering Sea. There's not a great deal known about variability in zooplankton source populations in the northern Bering Sea. In the 1970s, the Japanese, at least in the records, saw about a two-year periodicity with a factor of about 2 changes in oceanic stocks of zooplankton that would essentially represent the source organisms. I think that if Knut Aagaard is willing to talk about the seasonal and maybe shorter period fluctuations of flow, you would see that there is quite a bit of noise about 0.8 Sverdrups of flow northward through the Straits. I guess the answer to your question is we are really not sure what those numbers would be.

Question (Holland): I suspected that was the case. I was just thinking in terms of whale feeding again and the densities that are required for that type of activity.

ISOTOPE STUDIES OF ARCTIC ZOOPLANKTON

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The Alaskan Beaufort Sea is characterized by a geographic gradient in stable carbon isotope abundances in zooplankton (Figure 1). The relative abundances of the stable isotopes of carbon are conservative in food webs and the distinctive isotope ratios can be used as tracers. Within a food web, there is a small enrichment of the heavier isotope as carbon is passed up the trophic levels. These slight enrichments are also very useful in determining the position of an organism in the trophic scale. Organisms from the eastern areas are depleted in ^{13}C relative to similar zooplankton taxa in the western sectors. These zooplankton are important prey for the bowhead whale, *Balaena mysticetus*, and their isotopic signals are retained in tissues of the whales (see Schell and Saupe, these proceedings). The relationships between geographic gradients in del ^{13}C, zooplankton biomass and trophic structure aid in understanding prey-consumer interactions.

Stable Isotope Studies

Extensive zooplankton sampling was conducted along the Alaskan and Canadian Beaufort Seas during late summer and early fall of 1985-86 for both biomass and isotopic determinations. Zooplankton from the northern Bering and southern Chukchi Seas were collected in the summer and fall of 1987. Zooplankton for isotope analysis were dried, ground with CuO, combusted in evacuated quartz tubes, and the CO_2 cryogenically cleaned for analysis on a mass spectrometer. The ^{13}C content of Beaufort zooplankton increased from east to west (Figure 2; see also Table 1). Euphausiids and copepods collected in September and October 1986 are depleted in the ^{13}C in the eastern Alaska and western Canadian Beaufort Seas relative to those further west by a 3 ppt difference. Bering Sea zooplankton, in turn, are enriched in ^{13}C relative to all Beaufort Sea samples, continuing the trend towards increased ^{13}C in the southern and western areas of bowhead range.

There is an apparent trophic enrichment between euphausiids and copepods of 1 ppt in del ^{13}C at all transects sampled in the Bering and Beaufort Seas. Enrichments in ^{13}C, relative to copepods of other predatory or omnivorous zooplankton organisms such as chaetognaths, mysids, and amphipods are also evident indicating higher trophic status (not shown).

Composition of Zooplankton Biomass

Taxonomic determinations on zooplankton collected in October 1986 on the USCGS icebreaker *Polar Star* showed that near Point Barrow the euphausiid contribution to the total biomass was much greater than near the Canadian border. Copepods offshore of Barrow contributed less than 2% of the biomass. At transects in the central Alaskan Beaufort Sea,

Table 1. Carbon isotope ratios of euphausiids and copepods in 1985-86 along the migratory route of *B. mysticetus*.

	Copepods			Euphausiids	
	Mean	S.D.	n	Mean	S.D.
Northwest Bering	-20.7	1.0	17	-19.3	0.7
West Alaska Beaufort	-22.8	0.9	5	-21.7	0.8
Central Alaska Beaufort	-24.6	0.6	4	-23.5	0.4
East Alaska Beaufort, 1985	-25.8	0.8	7	-21.6	2.8
East Alaska Beaufort, 1986	-26.2	1.3	34	-24.7	1.3
West Canada Beaufort, 1985	-26.7	0.7	6	-24.0	0.2
West Canada Beaufort, 1986	-25.1	1.0	6	-23.3	0.1

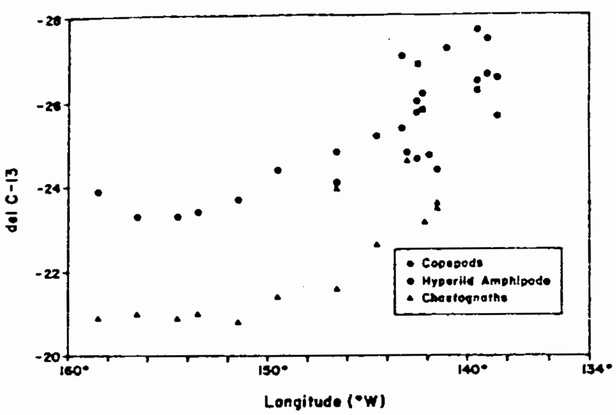

Figure 1. Carbon isotope ratios for copepods, chaetognaths, and hyperiid amphipods from the Alaskan and Canadian Beaufort Sea. Data west of 142 from Dunton (1985). Other data are from this study.

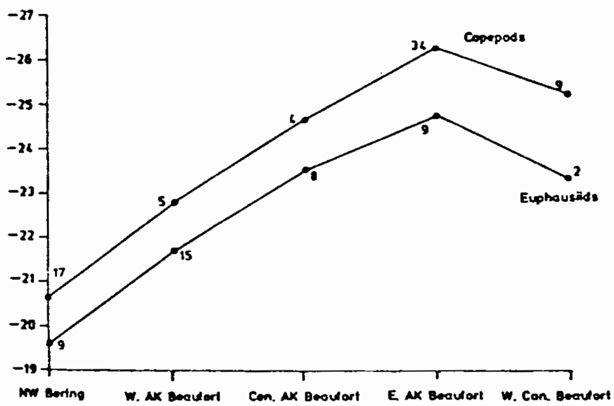

Figure 2. Mean carbon isotope ratios in copepod and euphausiid samples. All Beaufort number are from late summer/ early fall 1986. Bering numbers are from late spring 1987. The total number of samples averaged for each point is listed next to the symbol.

euphausiids were still a major fraction of total but the copepod fraction of the biomass had increased. Near Canada, euphausiids were minor contributors to the total biomass and copepod importance had increased dramatically. The changing importance of these zooplankton to the total biomass of major prey species is shown in Figure 3a. For comparison we also show the biomass estimates of the same zooplankton groups from the western Canadian Beaufort Sea (Figure 3b). As in the eastern Alaskan Beaufort Sea, copepods dominate the biomass. The similarity between zooplankton compositions in 1985 and 1986 in eastern Alaska Beaufort Sea samples implies persistence in these patterns.

Weighted Isotope Trends

The marked changes in taxa and isotope abundances of these prey organisms can be combined to show the greater geographical gradient in total prey ^{13}C that would be consumed

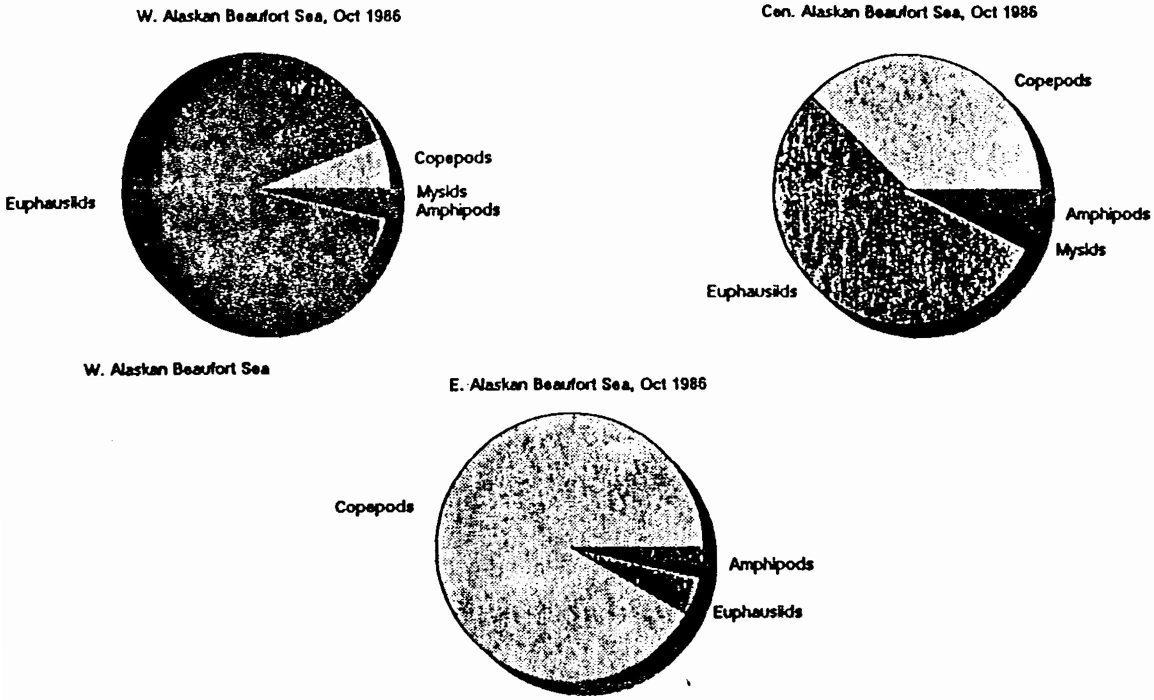

Figure 3a. Proportional biomass of major bowhead prey organisms across the Alaskan Beaufort Sea.

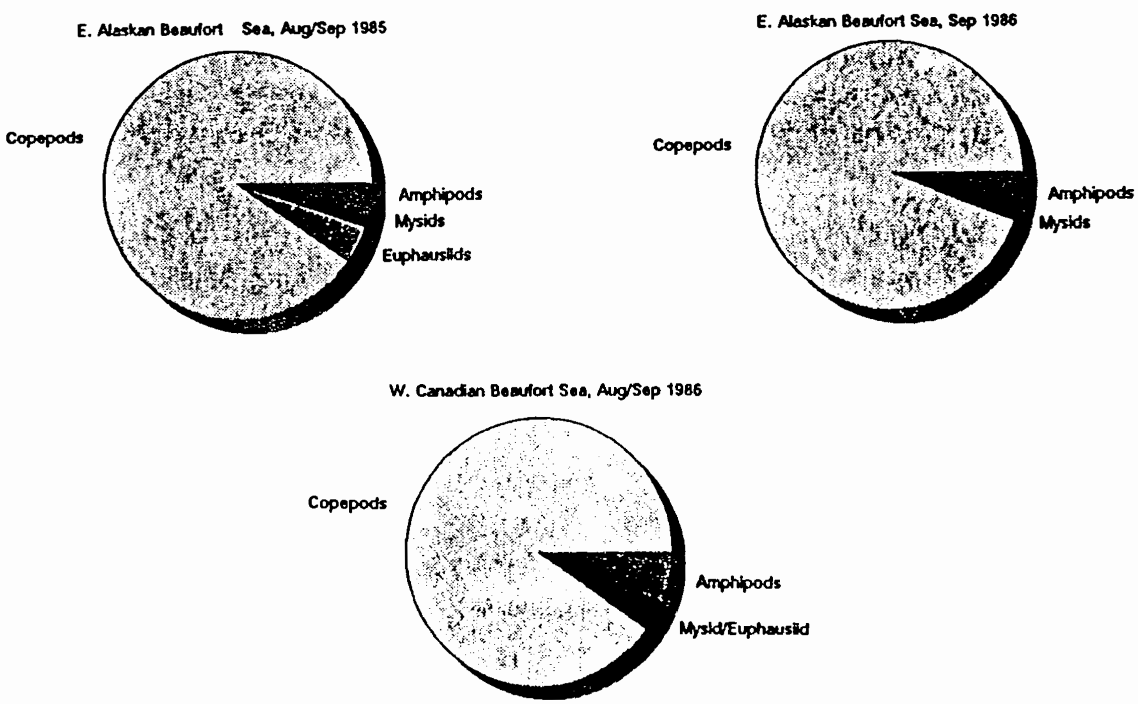

Figure 3b. Proportional biomass of major bowhead prey organisms from the eastern Alaskan Beaufort Sea and the western Canadian Beaufort Sea.

by a feeding bowhead whale. Weighted del ^{13}C values were calculated for the different regions of the Beaufort Sea based on the relative abundances of copepods, euphausiids, mysids, and amphipods. Although soft-bodied organisms such as chaetognaths and jellyfishes contributed to the total wet-weight biomass, their numbers were not included in the calculations as they are mostly water by weight and contribute little to the total food carbon. Across the Alaskan Beaufort Sea there is greater than a 4 ppt difference in weighted del ^{13}C as shown in Figure 4. This pronounced geographic gradient in prey ^{13}C content results in a large isotopic change in bowhead whale tissues as they feed through these areas. The shape of this weighted del ^{13}C curve will change with changing biomass fractions of the prey species. The isotope ratios of zooplankton along the migratory route of ***B. mysticetus*** closely match the isotopic ratio oscillations found in the keratinous tissues of their baleen plates which allows estimates of the importance of each of these areas to feeding bowhead whales.

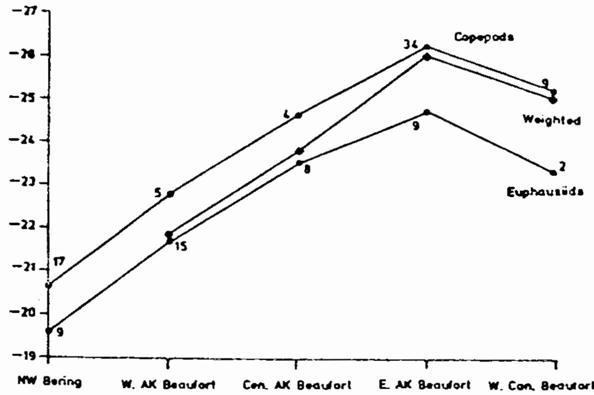

Figure 4. Weighted average ratio in the food available to bowhead whales migrating through the Alaskan Beaufort Sea and mean del ^{13}C ratios of copepods and euphausiids.

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CONTINENTAL SHELF SEDIMENTS, ARCTIC ALASKA

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The continental shelf of the Chukchi Sea differs from the 'normative shelf' in being relatively wide, having seasonal sea ice cover and a somewhat more sheltered regime than the open ocean. By comparison to the Chukchi, the Beaufort Sea shelf is narrower and has much longer yearly ice cover.

Several maps are available to depict the spatial distribution patterns of grain sizes of surficial sediments of the Alaskan arctic continental shelves. The basis of the sediment textural nomenclature in a recent map (Naidu 1987) (Figure 1) was a triangular diagram (Figure 2) devised by Folk (1954, 1968). The map devised by Naidu was generated by collating data from 2,314 granulometric analyses and depicts the variations of sediment classes and sorting values.

The latter sediment map illustrates that all sediment types, except the sand class, occur in the Alaskan arctic shelves. However, there is considerable spatial variation in sediment types. In fact, the patchy nature of sediment distribution is considered quite typical for the arctic shelves. The entire continental shelf region is non-graded, inasmuch as there is no progressive decrease in overall particle size from the coast to the shelf edge (Figure 3). In the Beaufort and Chukchi Seas, the sediments are generally poorly to extremely poorly sorted. The inner shelf of the Beaufort Sea has sand mud or muddy sand, whereas the middle shelf is dominated by gravelly mud or sandy mud and the outer shelf by mud. By comparison, the inner shelf of the Chukchi Sea, the Bering Strait and vicinity, and the shoals are carpeted by relatively coarser material (e.g. muddy gravel, gravelly muddy sand or sand). Acoustic records in the vicinity of Pt. Barrow, northeast Chukchi Sea, provide evidence of the presence at the shelf surface of highly dipping rock outcrops. The rest of the Chukchi Sea is predominantly constituted of gravelly mud, sandy mud, and mud.

Factor analysis of granulometric data has been conducted to explain the evolution of the distributional pattern of sediments. The intricate mosaic of surficial sediment types across the Alaskan arctic continental shelves is primarily related to the unique environmental setting (relatively wide shelf, ice cover and occasional storm surges), current regime, and complex Pleistocene transgressive-regressive history. The general sediment patchiness is presumably a result of intense but haphazard reworking of the sea bottom by ice gouging and erratic transport and deposition of mud by ice. The boulder beds in the Beaufort Sea shelf are most likely relict ice-rafted dropstones and reflect areas of little deposition at the present time. The sheltered Kotzebue Sound is a trap for terrigenous mud. Clay minerals distribution patterns have proved useful in the elucidation of the sources of clays derived from major rivers, their dispersal pathways, and depositional sites by regional currents. The presence of sand and gravelly-sand along stretches of inshore and the Bering Strait reflects deposition under local intensified current action. The permafrost intercalated shorelines are retreating at rates of 2-5 m/yr from thermo-erosion. These rates are among the highest on earth and pertain only to the summer months. The eroded shores are reworked by waves, resulting in the deposition of lag

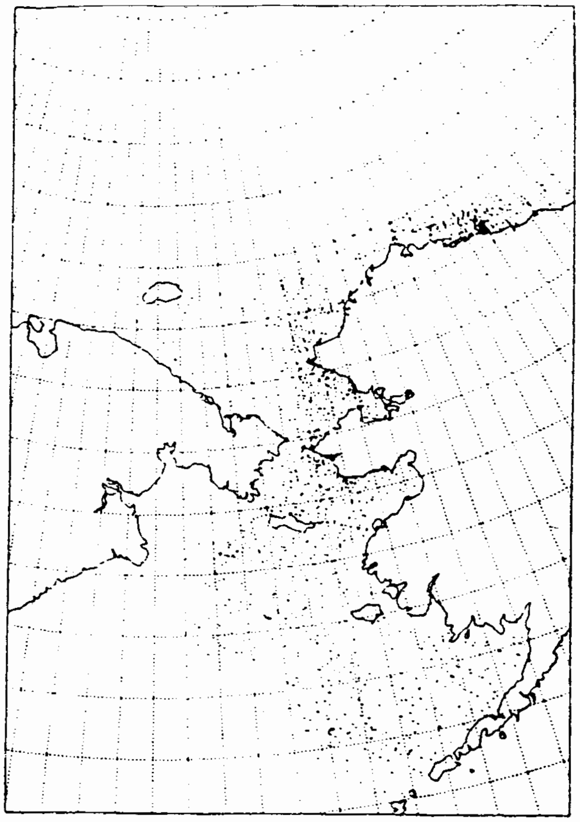

Figure 1. Location of sediment samples from the subarctic and arctic continental shelf.

gravel deposits on shore. The fate of the winnowed sand and mud has remained an enigma, as most of them are presumed not deposited in the shelf adjacent to the shore. A hypothesis that the fines are advected to the Canada Basin is not substantiated by heavy mineral and chemical studies.

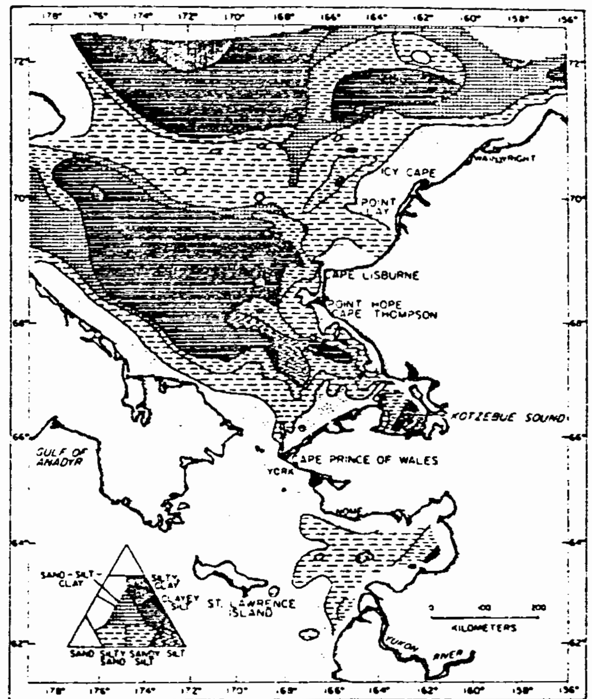

Figure 3. Granulometric composition of Chukchi Sea continental shelf sediments (after McManus *et al.*, 1969).

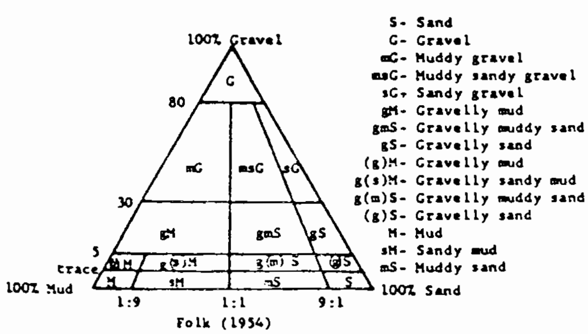

Figure 2. Classification of sediments according to Folk (1954).

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CHUKCHI SEA BENTHOS

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Although studies of the benthos north of the Bering Strait span nearly 30 years, few of these investigations were quantitatively oriented. The most comprehensive studies were conducted by S. W. Stoker, who examined the distributional, biomass, trophic and productivity aspects of the bottom fauna (primarily infauna) of the eastern Chukchi Sea between 1970 and 1974. His data and insightful conclusions serve as a framework for understanding the benthic system of these waters. Subsequent to Stoker's investigations, infaunal and epifaunal studies were initiated by Feder for the National Oceanic and Atmospheric Administration/Outer Continental Shelf Environmental Assessment Program (NOAA/OCSEAP) from the Bering Strait to Point Hope and extending into Kotzebue Sound. The infaunal studies temporarily expanded Stoker's earlier quantitative work, while the epifaunal (trawl) investigation represents the only quantitative assessment of this segment of the benthos. More recently, J. M. Grebmeier, working with the benthic component of an National Science Foundation (NSF) project (ISHTAR), studied how various environmental parameters influence benthic structure and biomass on either side of frontal system between two water masses (the Bering Shelf/Anadyr Water and the Alaska Coastal Water). Although her work was primarily conducted in the northeastern Bering Sea, she occupied stations in the southeastern Chukchi Sea as far north as Cape Lisburne.

Two years ago a NOAA-sponsored investigation was initiated by the Institute of Marine Science to further examine the benthic system of the Chukchi Sea east of the International Dateline from the Bering Strait to the waters north of Point Barrow (72° north latitude). The investigation was initially divided spatially into two substudies. The first examined the area north of Point Hope and the second examined the region extending from the Bering Strait to Point Hope and into Kotzebue Sound (Figure 1). Although the two substudies are currently pursued somewhat independently of each other, ultimately, all data will be integrated in order to examine the benthic system of the entire study area. It is the initial data from these two investigations that will be treated here.

Most of the analyses to date have been accomplished with data collected from north of Point Hope. The data analyzed consisted of taxon abundance and biomass of organisms collected with a Van Veen benthic grab. The dominant organisms in both regions are polychaetous annelids, bivalve mollusks, and crustaceans (primarily amphipods but occasionally barnacles). A hierarchical cluster analysis of the abundance data (an analysis that examines similarity between stations occupied interns of abundance of taxa in common) from the region north of Point Hope delineated four station groups and four stations that did not join any group (Figure 2). The results of a principal coordinate analysis (a procedure that is useful for interpretation of cluster analyses) using the same data showed the same station groups (Figure 3). The fauna of the groups and stations along the coast consist of taxa living in and on sandy-gravel substrata, with amphipods, barnacles, and sand dollars dominating according to coastal location (Figure 2). Suspension-feeding organisms are most common on sandy-gravel bottoms (Figure 4). Station Group I taxa are living in a mixed sandy-gravel-muddy bottom, while the two northerly groups (Groups III and IV) consist of taxa primarily associated with a muddy bottom. Deposit-feeding taxa dominate the fauna of Station Groups I, III, and IV) (Figure 5).

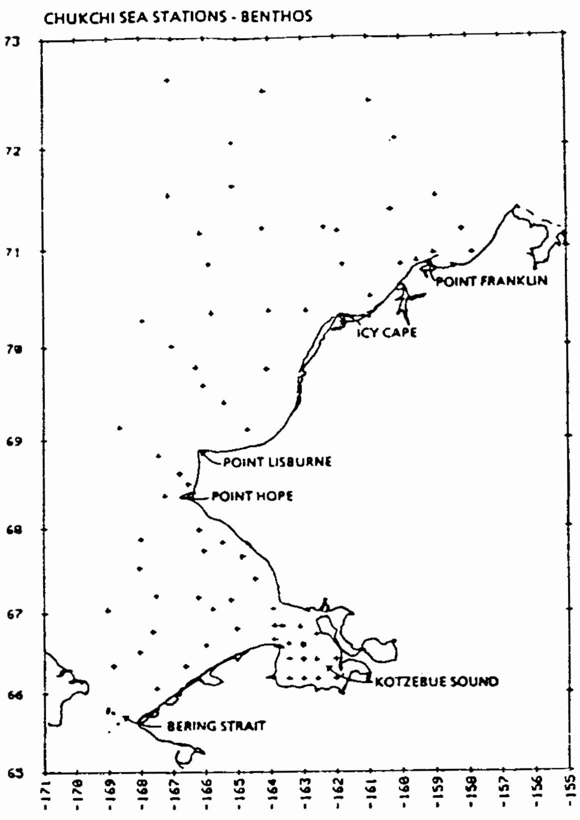

Figure 1. Benthic stations occupied in the Chukchi Sea from Bering Strait to Point Barrow in October 1986.

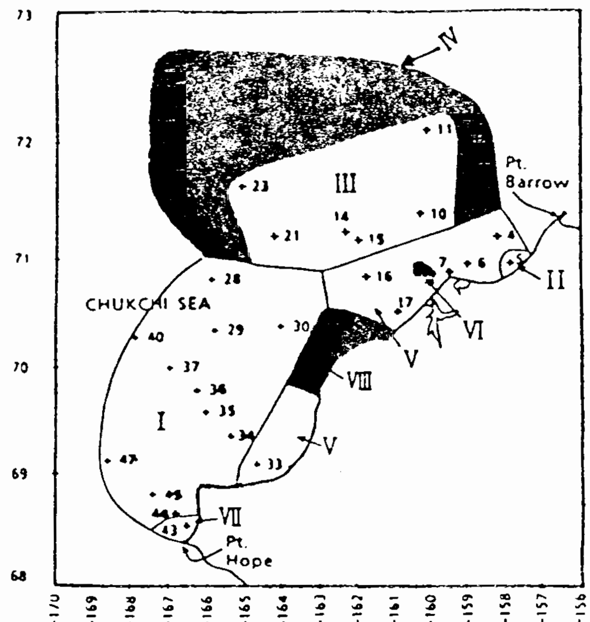

Figure 2. Distribution of macrofaunal groups based on a hierarchical cluster analysis.

The fauna north of Point Hope to Point Barrow varies in abundance and biomass (gC/m^2) by region. Highest abundance values occur primarily close to the coast north of Icy Cape (Figure 6) with organisms dominated by barnacles and tube-dwelling ampeliscid amphipods. High biomass values are particularly obvious at coastal and offshore stations at and north of 71° north latitude (Figure 7). Ampeliscid amphipods, a major food resource of gray whales, represent a dominant component of the fauna at coastal stations just north of Icy Cape extending north of Point Franklin (Figure 8). The latter region has been identified as an area where these whales tend to congregate.

Grebmeier, in her work on the benthos in the northeastern Bering and southeastern Chukchi Sea, demonstrated that benthic biomass (gC/m^2) was significantly higher to the west of an oceanic front between the Bering/Anadyr and the Alaska Coastal Water (Figure 9). The Bering/Anadyr Water has been demonstrated to be highly productive, and she suggests that the high primary production of this water produces a persistent and carbon rich food supply to the benthos. This frontal system (delineated by bottom salinity varying from 32.4-32.7 0/00) has not been identified within the northern Chukchi Sea, although the northward flow of the mixed

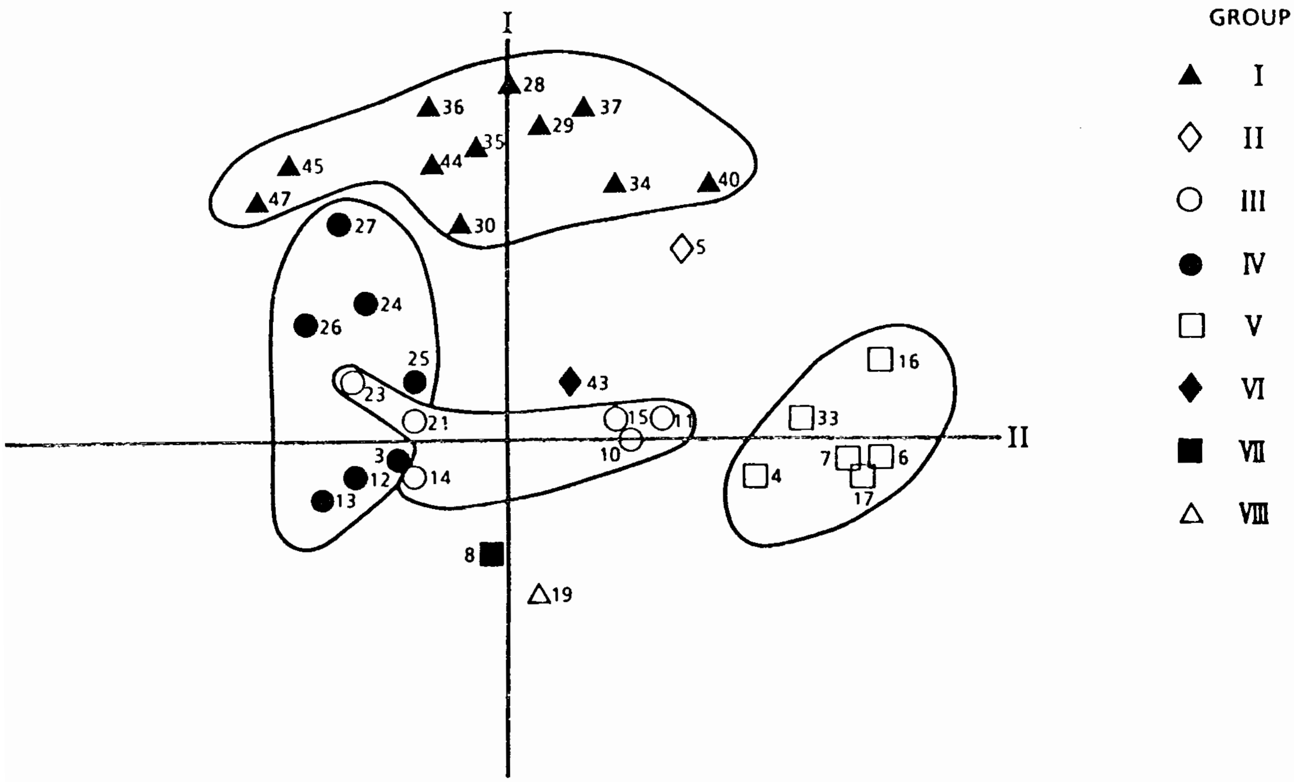

Figure 3. Principal coordinate analysis. Plot of loadings on coordinate axes one and two.

Anadyr/Bering water, after it passes through the Bering Strait (now called Bering Water by L. Coachman, K. Aagaard and R. Tripp), has been traced as it moves northward toward Point Barrow. Preliminary analysis of data by W. Johnson suggests that this water mass approaches the Alaska coast just north of Icy Cape (Figure 10). The highest biomass values recorded in the present study occur approximately north and northwest of the 32.4 0/00 isohaline (10.3 gC/m^2 north of the "front"; 6.3 gC/m^2 south of the "front") (Figure 7). It is tentatively suggested that the carbon rich waters identified in the southeastern Chukchi Sea (i.e. the mixed Anadyr/Bering water) extend into the northern Chukchi, and supply a rich and persistent food supply to the benthos there as well. The 0° bottom isotherm also seems to coincide with the southern edge of the high biomass values in the northern Chukchi. Summer aggregations of feeding walrus occur along the coast from the southern edge of this isotherm to Point Barrow where they feed on the abundant polychaetes and amphipods present in this region (unpub. data from S. Hills, R. Merrick, and F. Fay).

Preliminary data from the study area extending from the Bering Strait to Point Hope and extending into Kotzebue Sound appear to substantiate earlier studies by Feder and the just completed investigations by J. Grebmeier. High biomass values for fauna obtained by grab are apparent at all of the new stations occupied under Bering/Anadyr Water north of the Bering Strait (Figures 1 and 9), while low values seem to describe most stations to the east of the frontal system. In fact, relatively depauperate bottom regions with active chemical reducing

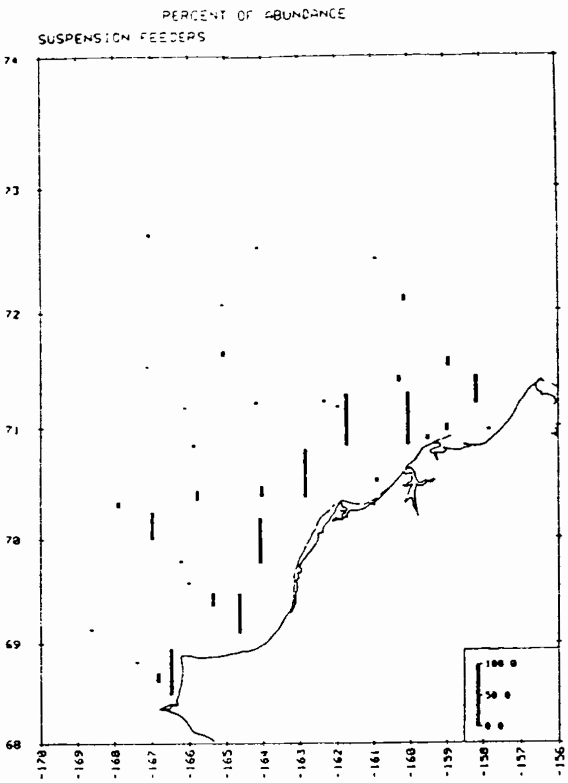

Figure 4. The percent abundance of suspension-feeding benthic fauna at stations occupied in the northeastern Chukchi Sea.

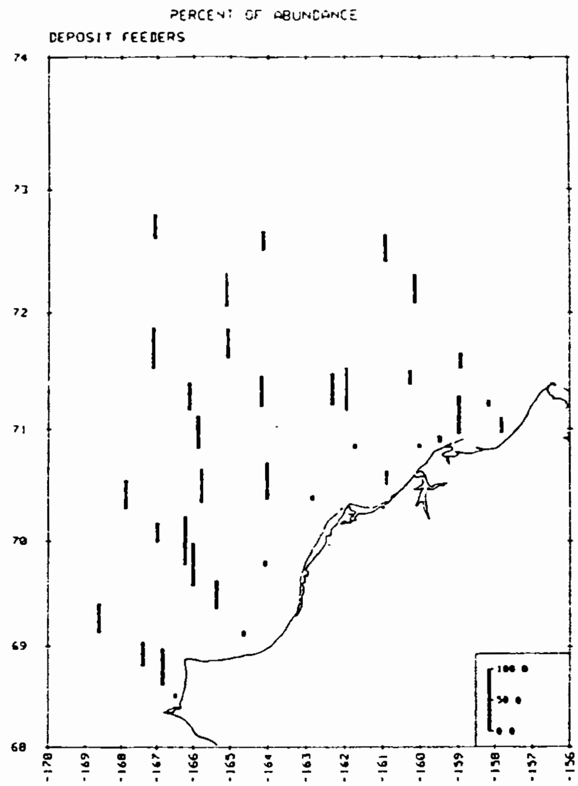

Figure 5. The percent abundance of deposit-feeding benthic fauna at stations occupied in the northern Chukchi Sea.

conditions and numerous dead Tanner crab (*Chionoecetes opilio*) have been observed within Kotzebue Sound. Nevertheless, it is apparent that there are regions in and adjacent to the Sound that are organically enriched, oxic, and faunistically rich. The locations of these areas are suggested indirectly by the regional increase in abundance of the epifaunal predators of sediment-dwelling fauna. Specifically, the sea star, *Asterias amurensis* and the crabs, *C. opilio* (the Tanner crab) and *Hyas coarctatus* dominate in outer Kotzebue Sound in waters immediately outside the Sound (Figure 11). Additional species dominant in the study area appear to reflect availability of particulate organic resulting from coastal turbulence (the basket star *Gorgonocephalus caryi*) or from flux to the bottom from the overlying Bering/Anadyr Water (the large whelk *Neptunea heros*, the predatory sea star *Leptasterias polaris acervata*) (Figure 12).

In conclusion, the studies reported here have expanded our understanding of the benthos of the eastern Chukchi Sea as far north as Point Barrow. In particular, they have suggested that a portion of the carbon-rich Bering/Anadyr Water flows well above 71° north latitude and that the high standing stocks of benthic organisms in these northern waters represent a response to the flux of some of this carbon to the bottom. Further, the unexpected presence of high standing stocks of some benthic species (e.g. polychaete worms and amphipods) in these northern waters

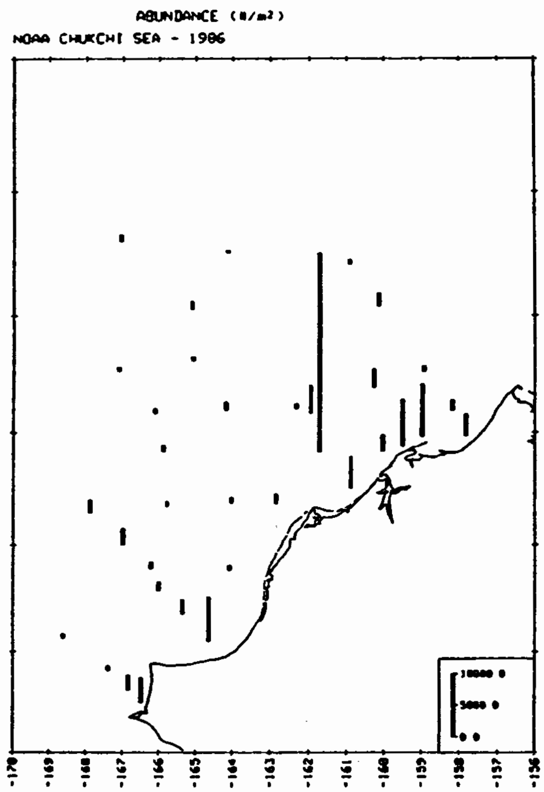

Figure 6. The abundance (no./m²) of benthic fauna at stations occupied in the northeastern Chukchi Sea.

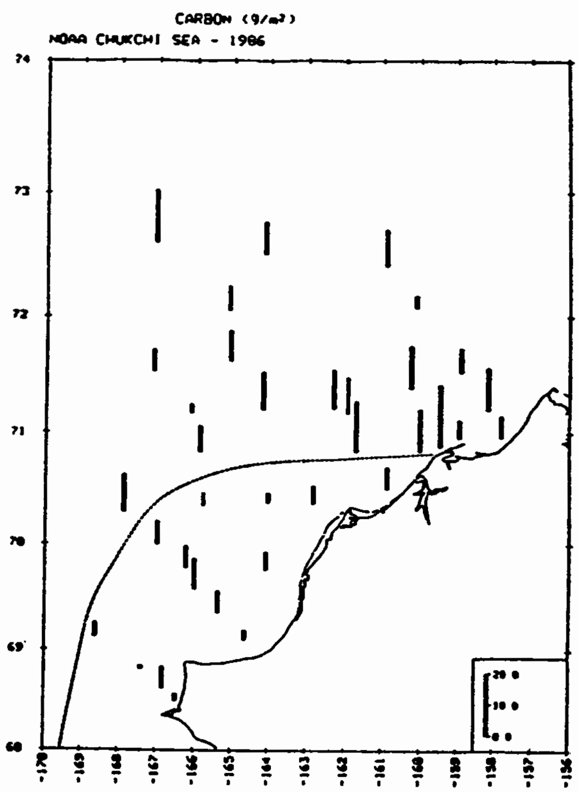

Figure 7. Distribution of biomass (gC/m²) in the northeastern Chukchi Sea. The postulated frontal zone (shown by the dashed line) presumably separates the mixed Bering Shelf/Anadyr Water in the west and north from the Alaska Coastal Water.

presumably explains, at least in part, the success of the summer feeding populations of walrus and gray whales along the Alaska coast north of 71° latitude. Localized concentrations of epifaunal predators in and adjacent to Kotzebue Sound suggest the presence of high standing stocks of food benthos that would also be available to the populations of bottom-feeding marine mammals in this region.

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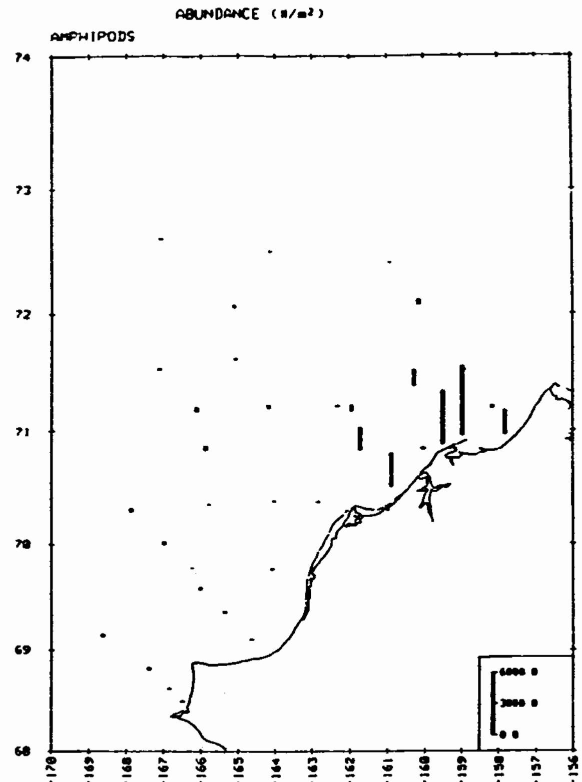

Figure 8. The abundance (no./m²) of amphipods at stations occupied in the northeastern Chukchi Sea.

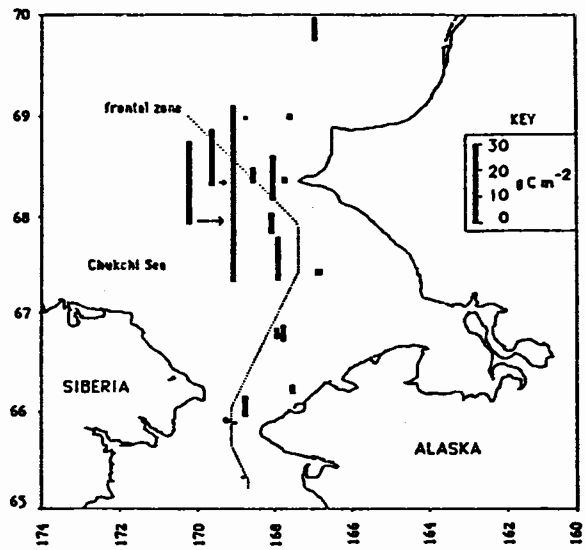

Figure 9. Distribution of biomass (gC/m²) in the eastern Chukchi Sea. The frontal zone (dotted line) separates the Bering Shelf/Anadyr Water in the west from the Alaskan Coastal Water in the east (Grebmeier, Unpub. Ph.D. Dissertation).

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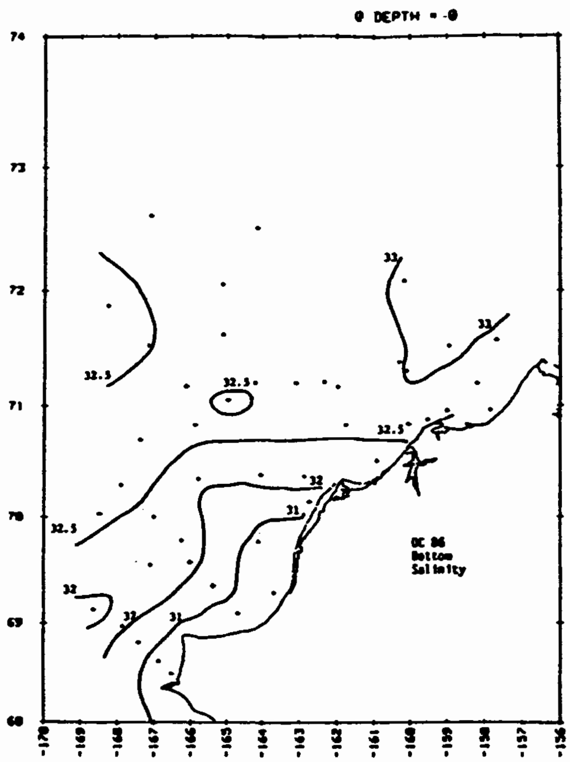

Figure 10. Bottom salinity in the eastern Chukchi Sea.

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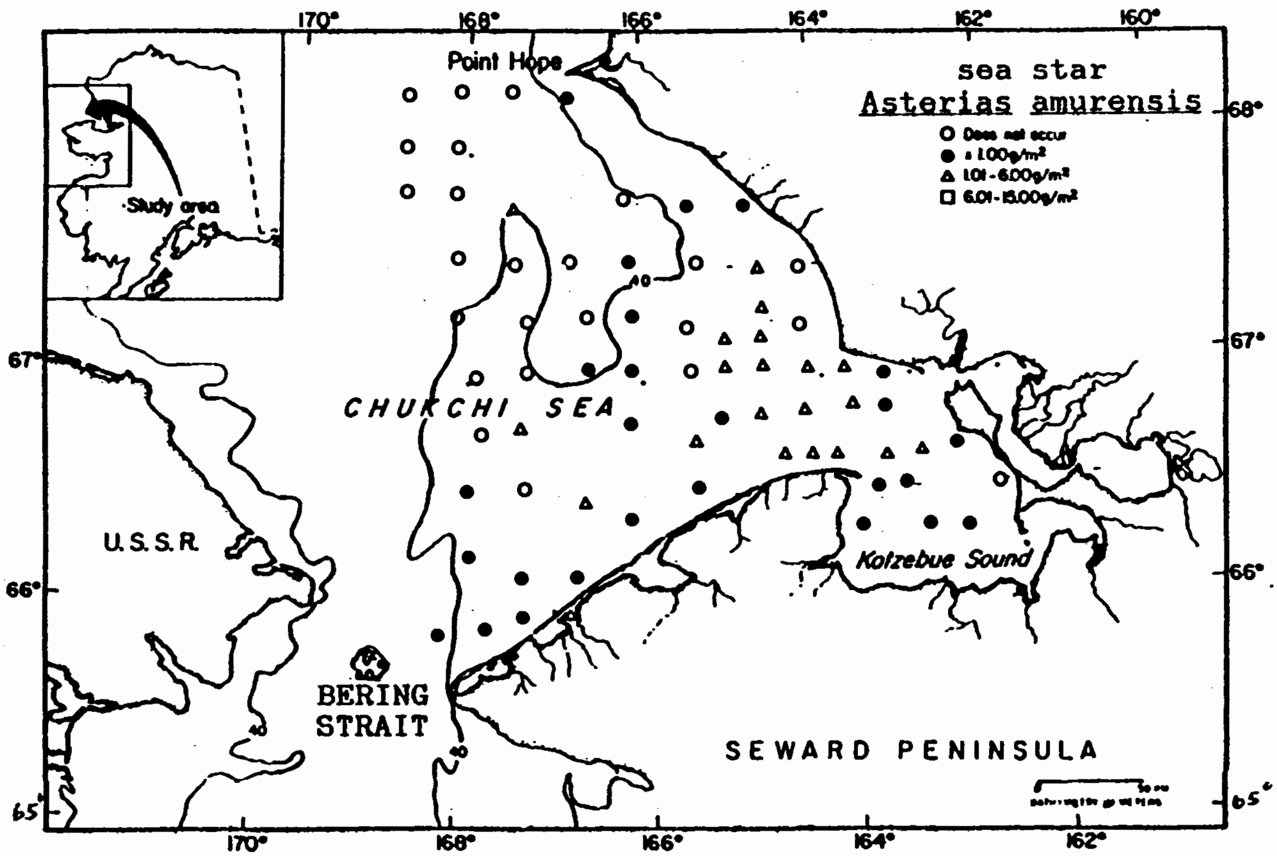

Figure 11. Distribution and wet weight biomass of the sea star *Asterias amurensis* from the southeastern Chukchi Sea and Kotzebue Sound in September-October 1976.

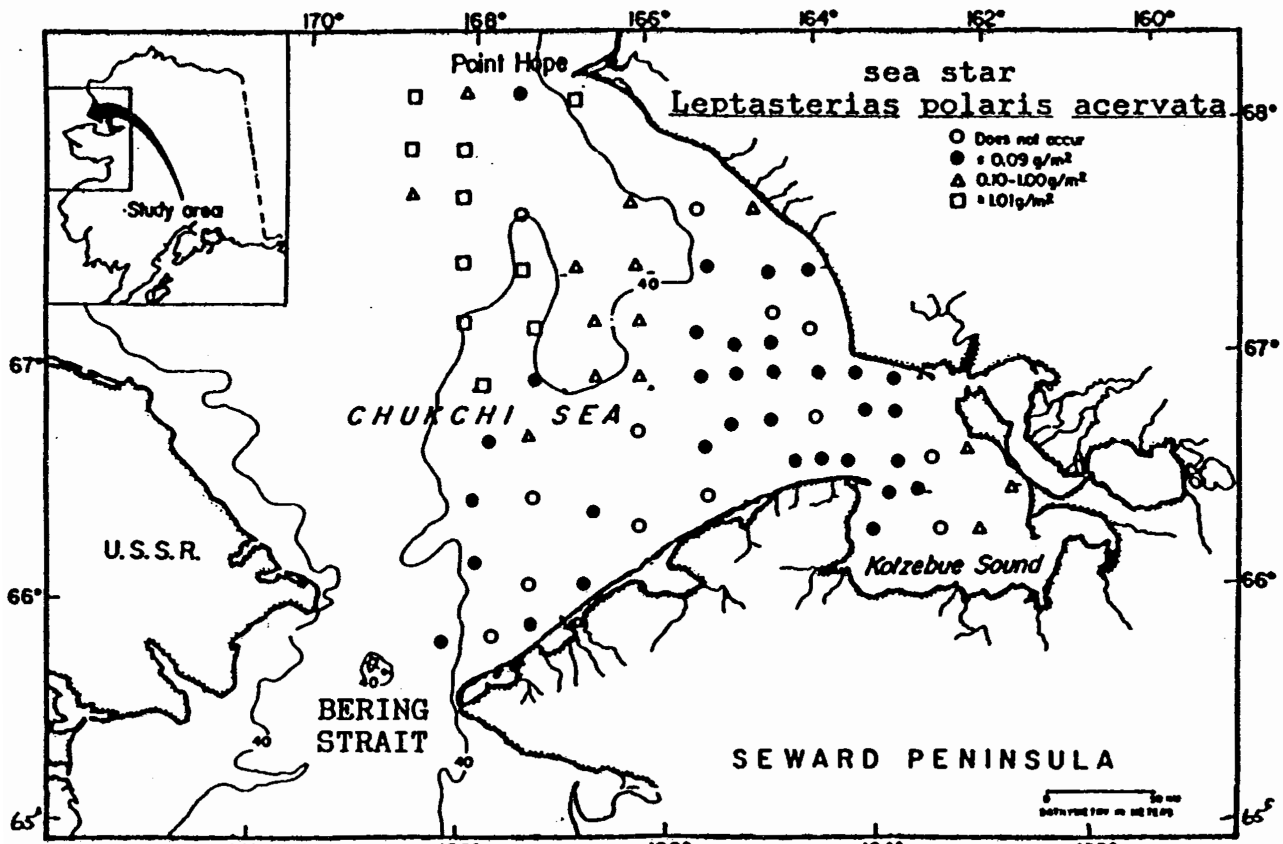

Figure 12. Distribution and wet weight biomass of the sea star *Leptasterias polaris acervata* from the southeastern Chukchi Sea and Kotzebue Sound in September-October 1976.

Question (Newbury): A question for Susan Saupe. Is there an alternative explanation for why the C13/C12 ratio may work? Again, I want to repeat, I'm impressed by your data but I think it needs confirmation by some other method. I think it is open to other explanations.

(Referring to slides) If the bowheads feed very infrequently during the summer feedings, where this is the amount of carbon coming in, and during the winter, there is essentially no carbon input, and the baleen is formed from body carbon plus food carbon where the amount coming from the body carbon is X and the amount coming from the food carbon is Y, you then get a pattern in baleen of X broken by X + Y, then X, then X + Y, it would produce a pattern in the baleen. Yet there is no assumption of winter feeding there. I don't believe that, but I think it could explain the pattern. It may be a combination, it may be somewhere between that and what you're presenting. In other words, let's say a quarter of the carbon comes from fall feeding.

Response (Saupe): Just one point that I want to make. On some of the oscillations, we do see a double peak. We do attribute this small lightening again, we see a depletion in carbon isotope values, then a small lightening, then a continued depletion. If the bowhead is making his baleen from body carbon it's going to be mobilized in lipids from its blubber. Lipids are quite a bit isotopically lighter than baleen or muscle tissue. So we believe those small peaks that we see are the mobilization of body carbon. But the heavy depletions that we do see we believe were from winter feeding.

Comment (Schell): The major problem is oscillation on the animal living all winter is: If he ate all this food in the summer, then his average body composition would not change. So, you wouldn't expect to see the amount of oscillation in isotopic content, because you are what you eat. If you've got it all from the eastern Beaufort Sea, you're going to have that signal year round.

The second piece of evidence is that if you take LGL's calculations of energetics, it would take a substantial amount of his body lipid supply to carry him over the winter and we don't see whales on the Nutrisystem. Unlike gray whales, which go north, and the Eskimo whalers will tell you, you can count the ribs when they get there. Bowheads morphologically are no different in spring than in the winter, which implies they are keeping themselves fed year-round. Although we do see a small peak in some winters, in some whales, that could result from mobilization of light lipid that was laid down the previous summer, that is typically a very small peak. Secondly, on most of the large whales you don't really see much of it at all. Once again the other thing, the final piece of information is that the larger the whale, the isotopically heavier it becomes. It becomes looking more and more like a western and southern Arctic range isotopic signal. So even the oscillations are damped and act like it would be actually the other way around. The animal is drawing on reserves. He may be drawing on winter feeding to carry him through the summer.

Question (Fishman): Susan, on some of your slides, the eastern most station, the isotopic ratio curve dropped again. Was that station east of Mackenzie? How would you explain that?

Response (Saupe): That was kind of an average sample from the western Canadian, some were right off the Mackenzie Delta, some were off the Yukon coast. There is too little data to see a significant difference with the standard deviations we have, so I don't know if that's real.

Question (Fishman): So those values weren't significantly different from the next one west?

Response (Saupe): No. And you would expect that if it is influence of Mackenzie water to see the isotope ratios remain depleted for a ways east from the eastern Alaskan Beaufort.

Question (Mate): I was rather surprised with all the discussion about all the zooplankton and where it is going and so forth. I put out essentially a straw man based on some datum and I would like to have a comment as to whether you think this seems to hold together or whether it seems to be a reasonable story or what. I seemed to be biased when I listened to all that discussion this morning on where the zooplankton going, when it gets there, it seems to me that's where it was going. If there are any comments, I would like to hear them now.

Comment (Paine): A comment I felt would be appropriate this morning - there was some discussion, and I take it that yesterday and the day before there was discussion, about brine generation off of the polynyi and in leads (maybe not in leads but in polynyi along the coast). Neither Lon nor I had the opportunity to present this data here today. However, we just recently completed our final report for OCSEAP. In 1985, we did a study off Peard Bay (Chukchi). I'm bringing this up now because of the discussions that suggested that there is a lot of feeding going on in the bottom waters or the sediments along that area. We hypothesized based on some salinity data that Lon and John Valli collected in 1982 and 1984 and also based on Aagaard's data and some other work, that if you had brine generation during a freezing process in a lead and you had an oil spill in that lead, that the aromatic hydrocarbons present could dissolve into that brine and then sink to the bottom and be advected along the bottom as a discrete bottom boundary layer. It has been demonstrated that you have bottom boundary layers of dense brine in a lot of these areas and they are fairly stable and exist. So, Lon Hachmeister and I did some model studies, first in tanks, to show that this process could at least be modeled and that the flow would go as we predicted. Then we went out into the Chukchi in March 1985 and did a field study where we released a 38 liter cocktail of aromatic hydrocarbons into a refreezing lead, tagged that with acoustic seabed bottom drifters, and then measured waters samples in downcurrent areas from these areas. We did, in fact, determine that we could document the dissolution and transport of aromatics in these bottom waters. I bring that up today because of the feeding in the sediments in these areas and it is a mechanism that heretofore we hadn't considered for getting these materials down there where they can persist over time. Normally in open ocean oil spills or in ice covered waters, the toxic fractions are limited to the upper mixed layer where they are removed by advection processes.

POPULATION GENETIC STRUCTURE OF ARCTIC CHAR FROM RIVERS OF THE NORTH SLOPE OF ALASKA

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Potential problems with oil and gas development in the Beaufort Sea area include the effects of offshore construction of causeways and other structures on anadromous species such as arctic char (*Salvelinus alpinus*). By studying the amount and pattern of genetic variation in the populations while they are associated with their natal drainages, we can make inferences about the evolutionary history of northern arctic char, and predict their ability to respond to changing environmental conditions.

Electrophoretic detection of protein variation makes it possible to discriminate among stocks using quantifiable characters having a genetic basis. This proven method requires a relatively small sample of fish from different populations for baseline data. Further, electrophoretically distinguishable characters have generally proven to be stable characteristics of fish stocks that have been studied. If the species of concern has a suitable stock structure, biochemical genetics methods can be used to estimate the percent composition of various stocks represented in samples from mixed aggregations.

The objectives of this project are to:

- Characterize the amount and pattern of genetic variation in populations of anadromous arctic char from major drainages of the North Slope of Alaska.
- Determine whether the population structure of North Slope char is such that genetic stock identification of mixed populations collected from offshore waters would be possible.
- Describe how a sampling program would be designed to use genetic stock identification to determine which stocks would be affected by specific development projects.

Samples from fifteen populations of juvenile arctic char were collected from ten tributaries to the Beaufort Sea. We used horizontal starch-gel electrophoresis to identify protein products of forty-one loci coding for twenty enzymes in three tissues. We measured the amount of variation, the pattern of variation (genotypic distribution) within population samples, the similarity between populations, their heterogeneity, and the degree of gene diversity among groups.

Northern Alaska arctic char have more genetic variation than might be expected given the relatively narrow range of waters they inhabit and the harsh environmental conditions. With an average heterozygosity per locus of 5.1%, they are typical of fish species in general; at the upper end of the range observed in other salmonid fishes; and higher than most other arctic char populations that have been studied.

The genetic identities among North Slope arctic char populations are high (>.987), indicating fairly recent common ancestry. High similarity values do not imply lack of significant differences between populations. Heterogeneity tests indicate the distinctness of the populations and the complexity of the relationships between them. Almost all North Slope arctic char populations are significantly genetically distinct from each other. Thus, fish from different drainages are not freely interbreeding, and are most likely true to their spawning streams. There is no simple correlation between genetic relationships and geographical proximity.

It is not possible to determine the underlying cause of the observed relationships among North Slope arctic char populations from protein studies. Selection, migration, mutation, behavioral isolation, founder effects, random genetic drift (chance changes due to small populations size) and combinations of these and other forces may all contribute.

North Slope arctic char do not have the magnitude of difference between groups exhibited by the non-migratory char of northern Europe. They do, however, compare with the population structure of anadromous Pacific salmon. This is relevant because genetic stock identification methods have been successfully applied to these salmonids, and can apparently be applied to North Slope arctic char.

To do genetic stock identification there must be sufficient detectable genetic variation between populations of different major drainages, combined with a low within-group variability. our data indicate that North Slope char have a relatively large amount of genetic variation; there are significant differences among populations; and the observed variation is partitioned such that there is as much difference between char from different drainages as there is among populations of sockeye (*Oncorhynchus nerka*) and chum salmon (*Oncorhynchus keta*) where genetic stock identification has been used successfully. As such, we can anticipate successful application of this technique to the identification of char at specific offshore sites.

MANAGEMENT IMPLICATIONS

We have determined that North Slope arctic char have a relatively large amount of genetic variation, and that populations are genetically distinct from each other. From this we know that different stocks are currently reproductively isolated from each other. Since they do mix to some unknown degree in feeding areas, the differences that have been established between stocks are maintained by homing behavior. Populations of each drainage are probably discrete, locally adapted units. It is not clear at this time how non-migratory forms are related to anadromous stocks.

It is unlikely that loss of any one stock would be mitigated by substitution of another. While the actual loci we have studied may be selectively neutral, underlying variation that is marked by these loci may be highly selected for in different environments, corresponding generally to different drainages. As such, arctic char stocks of the North Slope should be managed as individual, unique gene pools.

Further work is needed to understand the relationships among populations. To get a complete picture of the resource, we should consider deliberately sampling resident populations. It is important that we identify and sample additional populations making major contributions to the Beaufort Sea admixture, as it is an important assumption of the Genetic Stock Identification (GSI) model that all major contributors to a mixed stock be represented in the baseline. It is also important to understand that genetic stock identification estimates the percent composition at only one point in space and time.

Distribution of offshore stocks of fish is related to environmental conditions which are highly variable from year to year. Also, arctic char are highly mobile in offshore areas, so estimates should be made of stock composition at several times during the short summer feeding season. It must be realized that there will be considerable variation, regardless of study method used, between data from different years and different areas and at different times during the season. This means that stock identification must be done on a site-specific basis, with repeated sampling during the summer, and that data from more than one year will be required to establish the pattern of use by the fish.

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PELAGIC FOOD WEBS IN THE CHUKCHI SEA

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The northward flow of water from the Bering Sea through the Bering Strait creates contrasting ecosystems on the eastern and western sides of the Chukchi Sea, neither of which are typical of the Arctic Ocean in general. In the east, Alaskan Coastal Water (a seasonally warm coastal jet originating in the eastern Bering Sea and Norton Sound) transforms the coastal zone into a warm, low-salinity environment that fosters the development of a boreal, neritic community of zooplankton and planktivirous fishes important to higher trophic levels. In the west, Anadyr Water, which originates along the continental slope of the Bering Sea, advects abundant nutrients and boreal, oceanic zooplankton into the Chukchi Sea, leading to rich pelagic and benthic food webs.

The neritic community along the coast of the eastern Chukchi is subject to the effects of environmental fluctuations, particularly of water temperature. Oceanographic responses to climatic forcing are manifested in the timing of breakup of sea ice in spring and the rate of warming of the coastal jet, both of which vary widely between years. In environmentally cold years, the pelagic food web is uncoupled, and energy flow to higher trophic levels is interrupted, while in warm years, the community flourishes. Among the prominent nearshore zooplankters are the small copepods *Pseudocalanus* spp. and *Acartia* spp., cladocerans *Podon* spp. and *Evadne* spp., and meroplankton. Their predators are primarily the medusan *Aglanthe digitale*, chaetognath *Sagitta elegans*, and planktivorous fishes, particularly young age classes of sand lance (*Ammodytes hexapterus*), capelin (*Mallotus villosus*), saffron cod (*Eleginus gracilis*), and arctic cod (*Boreogadus saida*). These fishes support large colonies of breeding seabirds in the eastern Chukchi Sea.

One species of seabird, the black-legged kittiwake (*Rissa tridactyla*), is very sensitive to changes in prey availability. Adults are primarily piscivorous, feeding on a variety of young age-classes of pelagic fishes during the breeding season. Over the past decade, kittiwake reproductive success has varied between failure and high levels compared to elsewhere in the species range (Figure 1). Reproductive success is well-correlated with water temperature, and the failures are symptomatic of food shortage; few eggs are laid, laying occurs late in the season, and chicks generally starve to death at an early age. One of the most important prey species of kittiwakes is sand lance (*Ammodytes hexapterus*), which also fluctuates in abundance in the coastal eastern Chukchi seasonally and annually.

The biology of sand lance and their zooplankton prey are under the influence of water temperature. In most years, both are more abundant in the late summer, following the warming of the coastal water, than early summer (Figure 2). In the cold years, the stocks of sand lance could be adversely affected because of the metabolic effects of temperature on fish growth rates and productivity, and these effects could be aggravated by reduced zooplankton populations. In warm years, sand lance grow faster, are more abundant, and support a much higher level of seabird productivity.

Contrasting with this highly seasonal, warm coastal ecosystem along the coast of the eastern Chukchi Sea, is the oceanic-based ecosystem in the west. The flow of Anadyr Water creates a plume of exceptionally high phytoplankton and zooplankton biomass on the shallow shelf of the Chukchi Sea, the effects of which on arctic food webs are not well known. Much of the biomass of oceanic zooplankton consists of large calanoid copepods (Figure 3), including *Neocalanus cristatus* and *N. plumchrus*, and euphausiids, which are the major prey of the immense numbers of planktivorous least auklets (*Aethia pussilla*) and crested auklets (*A. cristatella*) at island breeding colonies in the Bering Strait region, the western Chukchi, where the bulk of Anadyr Water flows, is an important feeding area in fall for auklets, and is probably important summer-long for non-breeding auklets and other planktivorous birds.

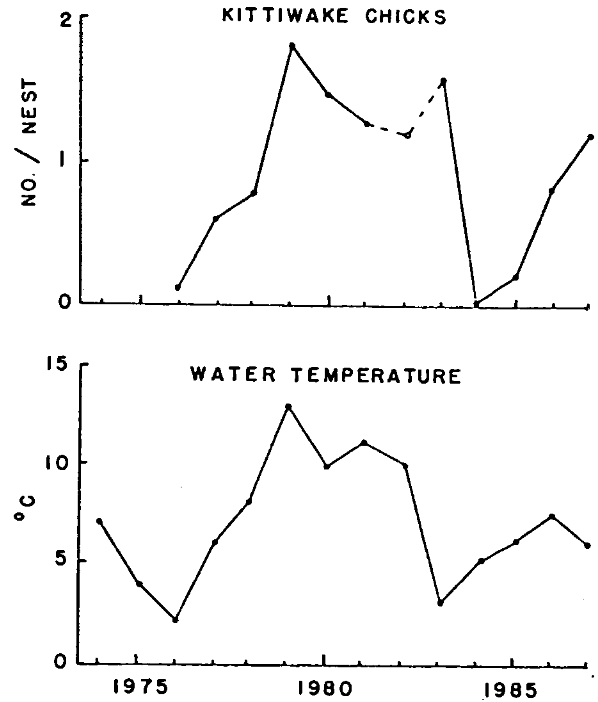

Figure 1. Reproductive success of black-legged kittiwakes at Cape Lisburne, and nearshore water temperature in mid-July. From Springer *et al.* (1985, unpubl. data).

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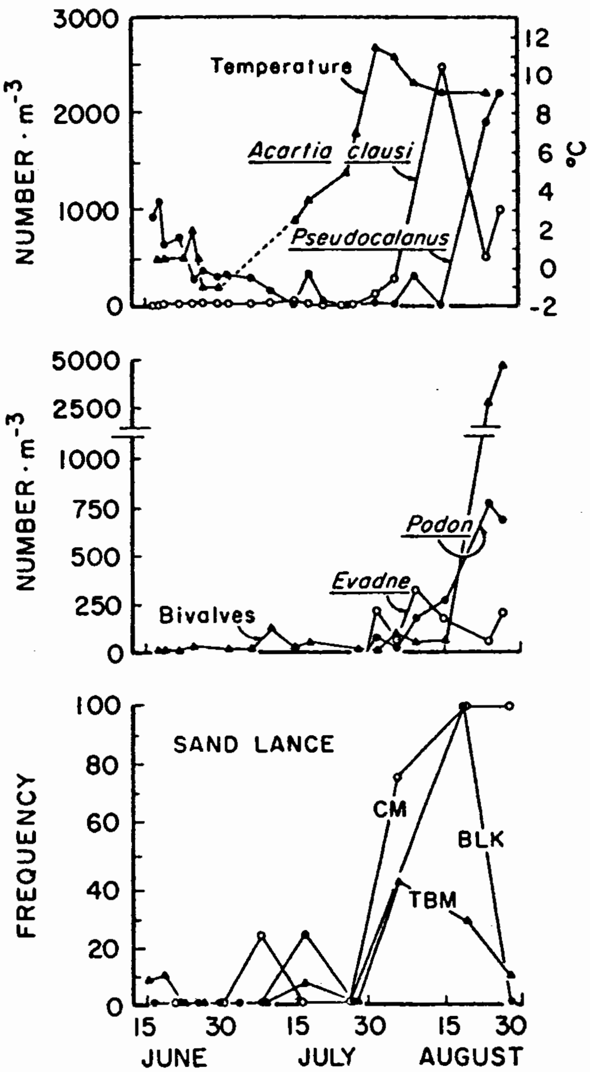

Figure 2. Water temperature, water column concentrations of zooplankton prey of sand lance and the frequency of occurrence of sand lance in diets of murres and kittiwakes at Cape Lisburne in 1983. From Springer *et al.* (1987).

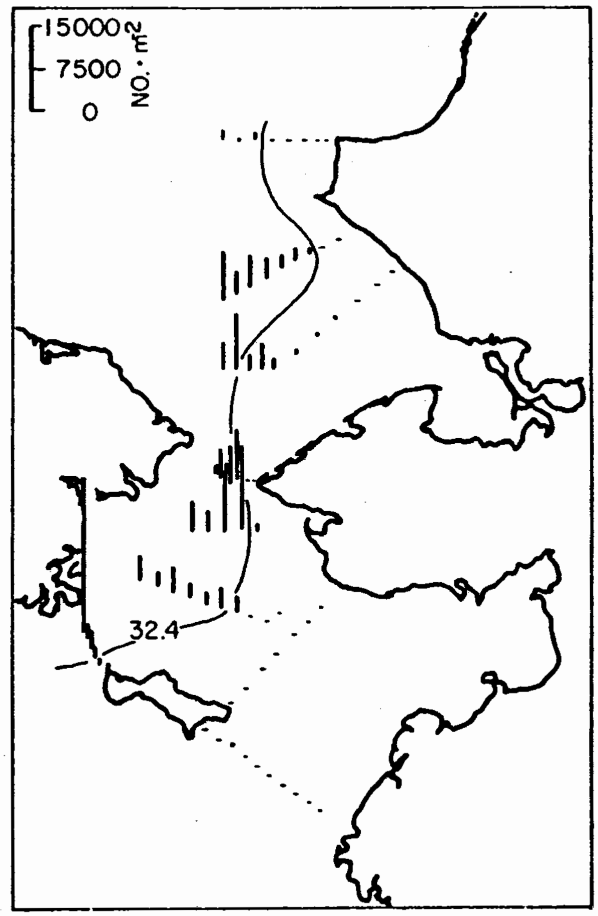

Figure 3. Areal distribution of abundance of oceanic copepods, 11-26 July 1986. Combined number of *Neocalanus cristatus*, *N. plumchrus*, *Eucalanus bungii* and *Metridia pacifica*). From Springer (1987).

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Question (Mate): Have you considered isotopic analysis for bird flesh and the areas where the birds forage? In particular, auklets? Do you think you might find signatures?

Response (Springer): Yes and no. I haven't done any isotopic analysis on pelagic birds. At this point, only very general sorts of patterns exist between the southern Bering Sea and the northern Bering Sea. We haven't really fine tuned it.

Comment (Hameedi): I have an observation on some of the data that Alan showed on the small copepods, *Acartia* and the *Pseudocalanus*, where the population goes up very markedly in the later part of summer. The reproductive strategies of these animals are such that they have to eat before they can reproduce. If there is a fair amount of food available it then reflects in the size of the next generation, the amount of eggs produced, and the amount of larvae, and so on. What is not quite clear from the data that Alan showed is how much of the small zooplankton (i.e. *Acartia, Pseudocalanus)* may have been advected on the eastern side of the Bering Strait. How much of that biomass could have been the result of *in situ* generation of new animal tissue. Have you looked at the nauplii and copepodite stage distributions of these? That would be one way to determine whether the production is occurring right there or it's being advected.

Response (Springer): We got out of having to do that as a matter of sort of fortune and misfortune. You have to fish very small mesh net to catch eggs and nauplii because *Acartia* and *Pseudocalanus* are very small. We didn't fish such a small net. We were looking at adults as it turned out. So, we don't have the ability to reconstruct that data. But sampling the copepodites and nauplii would be very valuable. You mentioned that relative contribution of advection and *in situ* production in terms of the biomass, and that you can see it any place along that whole coast. This is subject to a lot of interpretation and unknown sort of questions. They both probably play important roles in determining any population size during the summer up there. A lot of that originates in Norton Sound, and we've been trying to do some zooplankton work associated with the studies we've been doing at Cape Thompson or at Cape Lisburne in Norton Sound. Presently, all the data are not analyzed, but it's in the mill.

Comment (Hameedi): Most of the sampling gear you used perhaps captured the larger forms. I'm wondering what sort of mesh size you used, because it tends to overplay the size of the larger copepods on the general ecosystem and the nutritional relationships.

Response (Springer): In the coastal zone, we sampled with smaller mesh nets (333 microns). In the rest of the domain, we sampled with 505 micron mesh screens. Again, because we had a variety of reasons for selecting these things. One is we were bootlegging the project. It wasn't a zooplankton component of any study and so we had to do it as best we could and the other part of it was to try and separate out what we thought to be immediately most important to the planktivores, i.e. those large sizes of animals. It hampers your ability to interpret observations between years and differences in distributions if you don't know sort of what the lesser age classes, the younger stages are doing, from one season to the next. We missed young age classes of all of these guys in both our sampling regimes, with both sizes of nets because they are proportionally larger and smaller.

Comment (Hameedi): I'm used to zooplankton samples collected with a 110 micron net. We had a very extensive collection of zooplankton from the Washington-Oregon Coast, over three years duration. There also you have *Calanus plumchrus* and *Calanus cristatus*. It's the whole idea about suppression of the spring bloom. You do some computer simulations on the data and then knowing the relationship between the ingestion rates and the body size, the metabolic rate and the body size. If you have the data on small zooplankton and can have some gauge on the metabolic activities such as ingestion, you could not mask the effect of the small copepods, no matter how much comparable larger zooplankton biomass you had. Unless you are able to project what these small copepods are doing, because they do the same thing much faster, it becomes very hard to evaluate what the larger zooplankton really are doing in terms of suppressing the bloom, becoming available to other animals for food and so on. It's not a criticism.

Response (Springer): No, no it's a problem. We've tried to begin to deal with some of that this last summer in the sampling program that we did on ISHTAR where we nested a 202 micron net inside a 505 micron net so that we could get the smaller organisms to see how that was related to the distribution of the larger and older zooplankton, and then variability. We haven't been able to get that all completed. We've begun to address that and we tried to couple that sampling scheme with zooplankton to get various size classes of plankton with fractionating the phytoplankton to look at C14 rates of carbon uptake. We fractionated the phytoplankton into two size classes. First we looked at the whole sample to determine the gross carbon fixation rates of the phytoplankton in this region. We also looked at the less than 10 micro size fraction which consisted of very small diatoms, and flagellates in particular; presumably works into heterotrophic loop and becomes food for a lot of these nauplii and copepodites, the small cilliates and ultimately small zooplankton.

ENDICOTT DEVELOPMENT AND ENVIRONMENTAL MONITORING PROGRAM AND INDUSTRY PERSPECTIVE

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Eight companies (Amoco Production Company; ARCO Alaska, Inc.; Cook Inlet Region Inc.; Doyon Limited; Exxon Corporation; Nana Development Company; Standard Alaska Production Company; and Union Oil Company of California) are in the process of developing the Endicott hydrocarbon reservoir. This joint venture has been named the Endicott Development Project and is the first offshore oil development in the Alaskan Beaufort Sea. Standard Alaska Production Company (SAPC) is the designated "Operator" of the venture.

The development consists of facilities designed to: recover oil and gas from the Endicott Reservoir; separate the oil, gas and water; and transport the oil to Pump Station #1 of the Trans-Alaska Pipeline located near Prudhoe Bay. Construction of the Endicott Project began in early 1985. Drilling of the proposed 100 wells began in April 1986, and the first oil produced in October 1987. The Endicott Reservoir is estimated to produce approximately 100,000 barrels/day of oil, and 200 million cubic ft/day of natural gas. Currently, natural gas, with the exception of that used for fuel, is being reinjected into the Endicott Reservoir as part of the reservoir pressure maintenance program.

Total reserves in the Endicott Reservoir are estimated at 1 billion barrels of oil in place, with 350 million barrels of that estimated as recoverable by current technology. The field also contains approximately 1.3 trillion cubic ft of gas in place, of this it is estimated that 690 billion cubic ft of gas is recoverable with current technology. At this time, there are no immediate plans for gas sales.

The project area is located on the North Slope of Alaska about 15 miles east of Prudhoe Bay (Figure 1). Project facilities are located approximately 2.5 miles off the coast of the Sagavanirktok (Sag) River Delta, shoreward of the barrier islands, in water depths up to 14 ft. The development includes two man-made gravel islands: a main production and a satellite drilling island built in state waters of the Beaufort Sea. The gravel islands provide stable surfaces for drilling and production systems, the base operations center, drilling camps and other facilities.

Included is a three-mile solid-fill inter-island causeway connecting the two artificial islands. The inter-island causeway provides vehicle access between the islands. In addition, several pipelines are carried on pipe supports. A second 1.9-mile causeway extends from the outer shore of the Sag Delta to the inter-island causeway. This causeway provides year-round vehicle access from the mainland and continues the support of the sales oil line on its route to the Trans-Alaska Pipeline System (TAPS). Two permanent breaches are installed in this causeway. A 500 ft breach positioned to encompass a channel-like feature is located approximately 1500 ft from shore. The second breach measuring 200 ft is located further offshore nearer the junction of the inter-island and the breached causeways. The final section of the causeway system referred to as the onshore approach is about 1.5-miles in length and extends from the southern end of the breached causeway across the Sag Delta shoreline to the

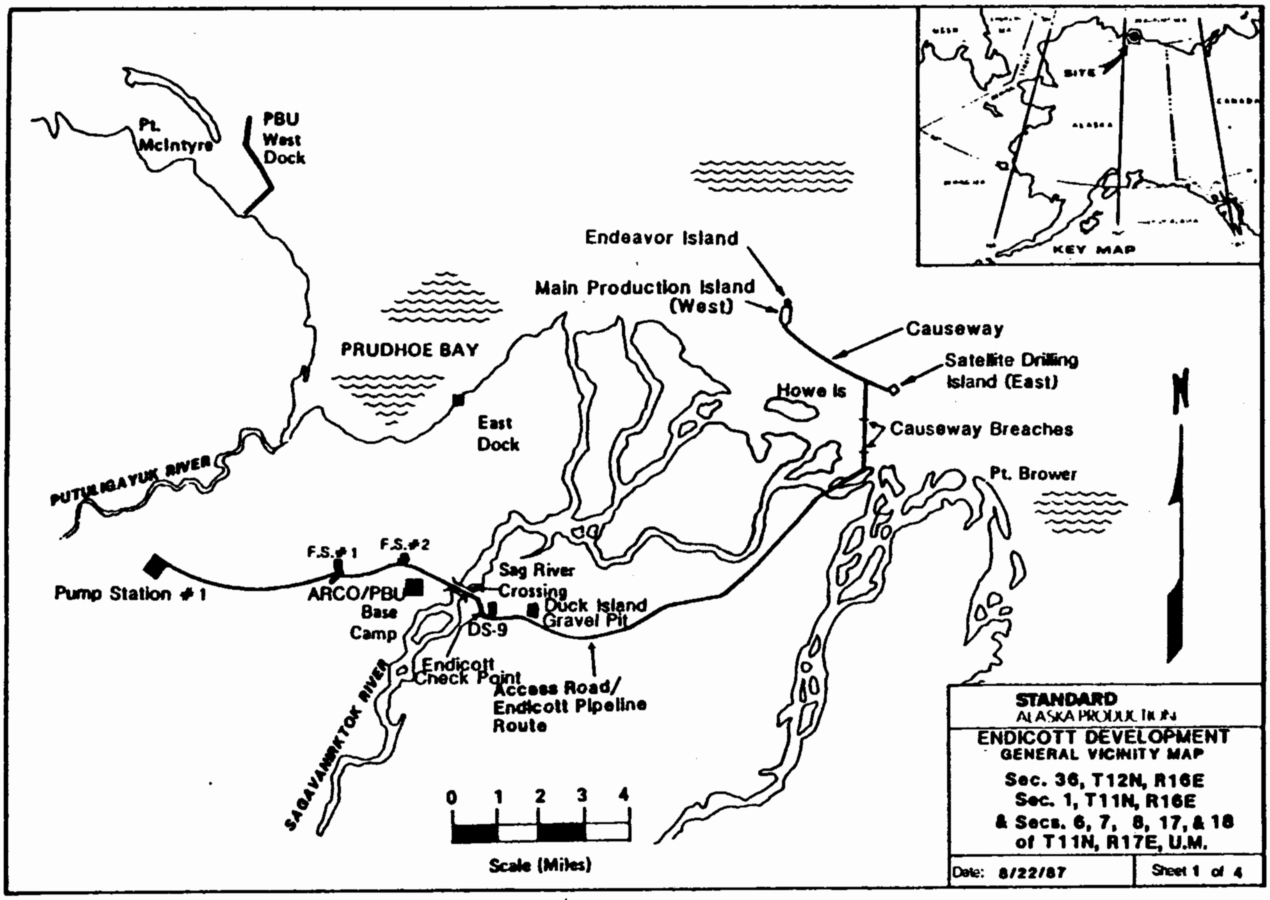

Figure 1. Endicott Development.

Sag Delta uplands. The approach connects the causeway system with a 10-mile gravel access road that extends through the Sag Delta to the Prudhoe Bay vicinity.

The 26-mile long sales oil pipeline was constructed during the early winter months of 1987. The above ground line extends from the Main Production Island to Pump Station #1 of TAPS. There are three caribou crossings located along the 10-mile onshore portion of the line which runs parallel with the Endicott onshore road. The line shares existing pipe support space with the Prudhoe Bay and Lisburne units for the remaining distance to pump Station #1 of TAPS. An Endicott sales gas line if constructed would be placed on the same pipe supports as the Endicott sales oil line.

The Endicott Development Project received the U.S. Army Corps of Engineers (COE) Section 404 and 10 permits in spring of 1985 after a 3-year permitting effort and a 1250 page Environmental Impact Statement were developed. A number of environmental mitigative measures were attached as stipulations to this permit. These measures required actions such as: design and construction of 700 ft of breaching for fish passage, establishment of air traffic corridors and surface traffic control plans for the summer season, caribou ramps for the onshore sections of the pipeline and environmental monitoring requirements. The environmental monitoring programs associated with the Endicott Development have totaled over $5 million per year, with the COE stipulated Endicott Environmental Monitoring Program averaging over $3.2 million per year in direct contract value.

The COE stipulated Endicott Environmental Monitoring Program is stipulated for the life of the Endicott field and includes a 7-year fish program. The direction of the program is the responsibility of the COE District Engineer, with assistance from a technical committee made up of one representative from the U.S. Fish and Wildlife Service, National Marine Fisheries Service, Environmental Protection Agency, Alaska Department of Fish and Game, the North Slope Borough and Standard Alaska Production Company. The overall scope of the monitoring program is to determine the effects of the Endicott Development on aquatic and terrestrial environments in the central nearshore Beaufort Sea, including the Sagavanirktok River Delta. The monitoring program consists of two main components: 1) marine, and 2) terrestrial.

The marine component is divided into biological and physical programs. The biological programs involve regional and local fish distribution and abundance studies, and examination of fish overwintering in the Sagavanirktok River Delta. Arctic cisco are the focus of fish research because of their importance to local subsistence and commercial fisheries. Other species under scrutiny include arctic char, broad whitefish, and least cisco. The physical programs include studies of regional and local oceanography, river discharge, sedimentation/erosion, meteorology, and ice breakup/freezeup and are intended to provide data to support the fish studies.

The terrestrial program is directed to evaluating the response of caribou and snow geese to the Endicott Development. Specifically, the effectiveness of caribou ramps is being assessed and snow geese behavior, population success and habitat are being monitored.

Monitoring of the terrestrial environment and marine physical and biological environment began in 1985 with the initiation of construction of the Endicott causeway. The monitoring program just completed the third summer field season. Results of monitoring studies conducted in 1985 and 1986 indicate that there have been no biologically significant impacts to the marine or terrestrial ecosystems within the program study area. Minor changes in nearshore water quality have occurred; however, these changes are considered of short duration and within the range of natural variation. The program results have not indicated any detrimental impacts to regional distribution, migration patterns, reproductive success, population size, productivity, or other biologically important characteristics of anadromous fish populations in the area either directly or indirectly influenced by the Endicott causeway.

COASTAL PROCESSES AND OCEANOGRAPHIC PROPERTY DISTRIBUTIONS IN STEFANSSON SOUND

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INTRODUCTION

A comprehensive investigation of the Stefansson Sound physical environment was undertaken by the Endicott Environmental Monitoring Program to study those areas potentially impacted by construction of the Endicott Development Project. Field studies were conducted during the open water seasons of 1985 and 1986 to collect data on regional meteorology, oceanography, sea ice breakup and freezeup, river discharge, and sedimentation and erosion. The objective of these studies was to develop and refine the existing understanding of physical processes and water property distributions in a region of Stefansson Sound extending between Gwydyr Bay in the west and Foggy Island Bay in the east. This discussion summarizes the findings of the physical processes portion of the Endicott Monitoring Program.

Environmental Setting

Meteorological conditions along the Alaskan Beaufort Sea coast are a major controlling factor in determining the physical environment of Stefansson Sound. Winds control the mixing and distribution of the physical properties through wind induced turbulence, water movement patterns, and upwelling of offshore water types. The dominant wind direction in the study area during the open water season is east-northeasterly (winds coming from approximately 65° true). However, in some years the occurrence of west wind conditions are more frequent than normal and distributions of water properties have been observed to vary considerably in response to the different meteorological conditions.

A continuous cover of sea ice typically dominates the surface of Stefansson Sound for nine months of the year. Spring breakup begins in the latter part of May and early June as the major rivers feeding into Stefansson Sound flood and freshwater runs out over the sea ice. By the first week of July, the nearshore floating fast ice is typically gone and by the third week in July ice free conditions occur throughout the study region. Freezeup normally begins in late September with the formation of shorefast ice. By the first week of October, coastal freezeup has occurred and the lagoons and bays are completely ice covered.

Freshwater, discharged from the Sagavanirktok (Sag), Kuparak, and Putuligayuk (Put) Rivers, is an important element of the coastal oceanography of Stefansson Sound. Besides initiating the breakup of the shorefast ice, it also significantly affects nearshore circulation patterns and temperature and salinity distributions during the open water season. River discharge begins in late May, peaks in early June, and then rapidly declines to average mid-season levels by the beginning of July. Large temporary peaks in river discharge can occur that double or triple the mid-season average discharge values as precipitation falls on the foothills of the Brooks range or on the coastal plain.

Water Movement Patterns/Hydrographic Distributions

The wind is the dominant driving force for water movement in the study region. This wind driven movement of water, however, tends to parallel the local bathymetric contours. Tidal current velocities are generally quite small except in the narrow channels between the nearshore barrier islands. Gravitational flow initiated near the river deltas typically adds only a small onshore or offshore component to the wind induced flow.

East winds (winds with an easterly component) occur over 60% of the time during the open water season. In response, water movement is generally toward the west in both the nearshore and offshore environments. Reference to nearshore and offshore environments includes those waters landward and seaward of the 3 meter isobath, respectively. Less saline nearshore water also acquires an offshore velocity component from the wind due to the Ekman effect that is added to its existing westward movement. As the nearshore water moves offshore it overrides the more marine offshore water and the marine water responds by acquiring a compensating onshore velocity component. An estuarine type circulation pattern is established by this process. Under stronger east wind conditions, the onshore movement of deeper marine water becomes a high latitude, shallow water variant of the process known as coastal upwelling. Under these conditions the coastal zone becomes vertically stratified and there is considerable exchange of properties between the nearshore and offshore marine environments.

West winds (winds with a westerly component) occur less than 30% of the time but are equally as important. Water movement under west winds is to the east. Nearshore surface water acquires an onshore velocity component from the west wind Ekman effect and offshore marine water is excluded from the nearshore environment. Whereas the east winds bring offshore water and nutrients into the nearshore and produce strong vertical stratification, the west winds tend to break down the stratification and vertically mix the nearshore and offshore waters to produce broad regions of relatively warm, low salinity water which are important to maintaining biological habitat.

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HABITAT USAGE AND MOVEMENT PATTERNS OF ANADROMOUS FISH IN THE PRUDHOE BAY REGION OF THE CENTRAL BEAUFORT SEA

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INTRODUCTION

Movements patterns and habitat associations of fish in the central Beaufort Sea were investigated. These studies were conducted during the 1985, 1986 and 1987 summer open water season (as part of the Endicott Environmental Monitoring Program). The study area included the nearshore waters extending from Gwydyr Bay in the west to Foggy Island Bay in the east and included Prudhoe Bay and the Sagavanirktok River delta (Figure 1).

The major species found in the area were arctic char (*Salvelinus alpinus*), arctic cisco *Coregonus artedii*), least cisco (*Coregonus sardinella*), broad whitefish (*Coregonus nasus*), fourhorn sculpin (*Myoxocephalus quadricornis*), and arctic cod (*Boreogadus saida*). Emphasis was placed on the four anadromous species which are potentially more affected by the distribution of brackish water in the nearshore area.

RESULTS

Movement Patterns

The major anadromous fish movements in the study area during the open water season are the dispersals of fish from overwintering rivers in early summer into summer feeding grounds, summer movements in response to changing habitat conditions, and return movements into overwintering areas in the late summer. In addition to these movements, there is the early summer migration of mature arctic cisco from the central Beaufort Sea to their spawning grounds in the Mackenzie River, the midsummer spawning migration of mature arctic char into the spawning rivers, and the late summer migration of young arctic cisco from the Mackenzie River into and through the central Beaufort Sea to nursery and overwintering areas in the Sagavanirktok and Colville River deltas.

Early season anadromous fish movements typically follow the coastline from the Colville, Kuparuk, and Sagavanirktok Rivers in association with the warm (6-12°C), low salinity [0-5 parts per thousand (ppt)] water which originates from spring river runoff and which predominates the region. During this time, cold (1-5°C) melt water is frequently found near the edge of the ice pack and in areas where accumulations of ice occur. This cold water may restrict the early season dispersal of ciscoes and whitefish. Broad whitefish may move away from the immediate river deltas during the early season, but most remain in close association with the river channels and will continue to do so throughout the summer. Arctic char are not restricted by the colder water and disperse quickly from overwintering rivers at breakup into cooler, low salinity water along the ice edge and near the freshwater-marine water interface where food is abundant.

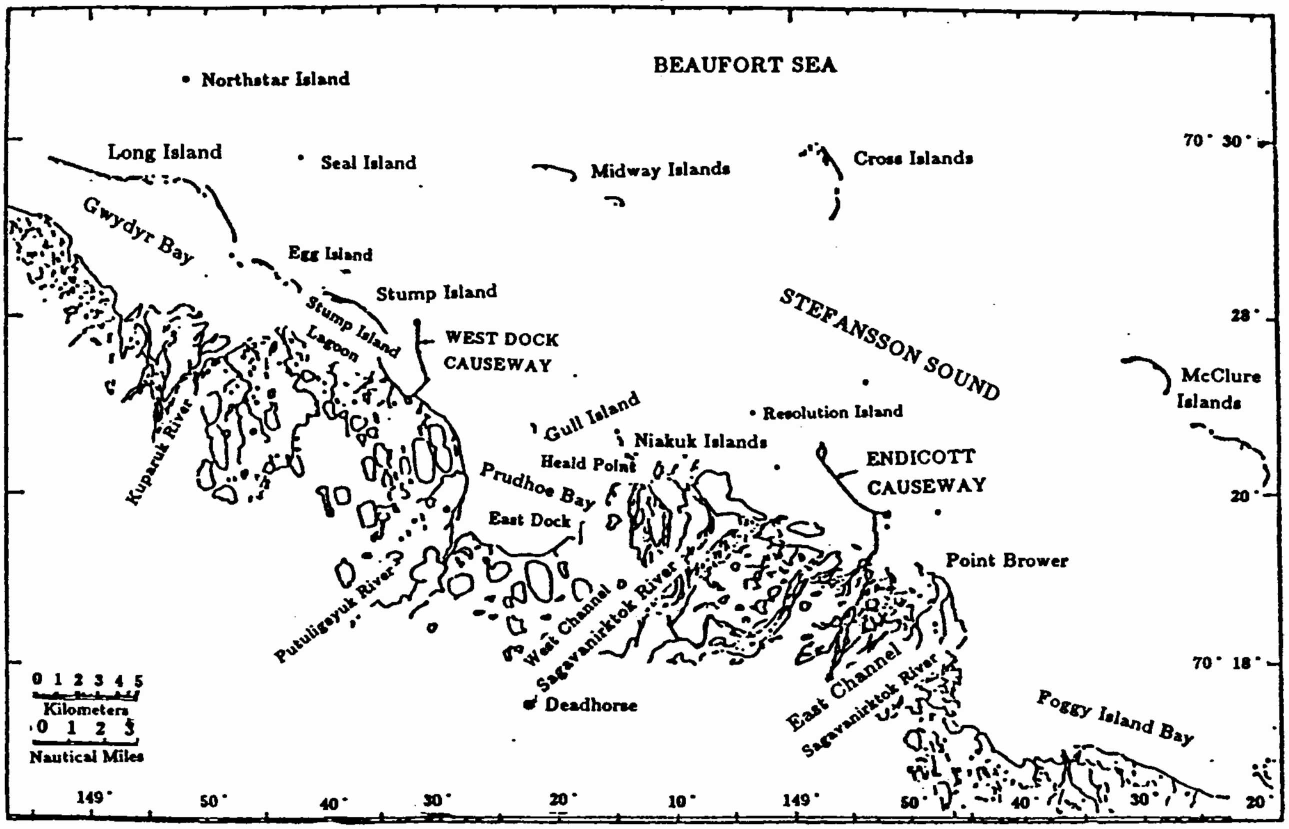

Figure 1. Endicott study area.

Mid-season movement patterns are predominately driven by fish response to rapid changes in environmental characteristics resulting from shifts in meteorological conditions. During this period, the influence of the river runoff diminishes rapidly and intrusions and upwellings of marine water become an important factor in the distribution and movement patterns of the anadromous species. Under east wind conditions, which predominate during the summer season, marine water upwells along the west side of the Endicott causeway that result in the intrusion of high salinity water inshore, west of the causeway. West of West Dock, marine water intrudes and sometimes displaces the brackish water in the east end of Simpson Lagoon. During westerly wind conditions, the high salinity water west of West Dock intrudes into Prudhoe Bay and at times reaches the western side of the Sagavanirktok River delta.

These discontinuities in the warm brackish coastal waters and the intrusion of marine water elicit large changes in the distribution of anadromous fish. The fish move away from the marine water into the warmer, lower salinity regions of Simpson Lagoon, and the river deltas. Large arctic char and most of the smaller char remain with the cooler brackish water.

By the end of the summer feeding season, marine water begins to dominate the region. Fish movement back to overwintering areas begin as water temperatures drop and salinity starts to rise. The coastal band of lower salinity waters made up of accumulated ice melt and river discharge provides the pathway along which this migration occurs. Variations in wind patterns and the corresponding shifts in hydrological conditions can result in discontinuities in the brackish plumes or the offshore diversion of those plumes. The extent to which these diversions and discontinuities affect fish migrations is dependent upon the extent of the discontinuities in time and space, and the specific salinity and temperature tolerances of each species and life stage. The extent to which these changes ultimately affect fish abundance and yields to domestic and commercial fisheries is difficult to determine and not presently known.

Habitat Associations

Water temperature, salinity, and prey abundance appear to be the most important habitat parameters for the anadromous species common in the central Beaufort Sea. All the species exhibit, to one degree or another, a preference for warmer, brackish water. With the exception of the young-of-the-year arctic cisco, the younger fish typically associate more closely with warmer, fresher water than do the older fish of any species.

Each species of anadromous fish as well as different life stages within species have different habitat use patterns and preferences. Broad whitefish tend to associate closely with warm, low salinity water, and therefore are most frequently found in or near the river mouth and delta channels. There they feed on invertebrates common to the rivers and deltas (chironomids and low salinity amphipods). Char appear to be the least sensitive to cold temperatures and are frequently found near the edge of ice packs or along the outer margins of the brackish plumes where turbidity is usually low and prey is abundant. They feed primarily on amphipods which live near or on the under side of the ice or on small fish. The habitat preferences of arctic cisco vary broadly with age. Young fish that migrate from the Mackenzie River are found in the full range of available salinities and temperatures but will tend to avoid the freshest waters and are seldom found in extreme marine conditions. Young arctic cisco prefer cool, moderate salinity, coastal water which have high concentrations of planktonic crustaceans. In their second and third year, arctic cisco exhibit a marked preference for warmer, low salinity water and will often concentrate in stratified water where river plumes flow over more marine water. Such areas often have abundant invertebrate prey. Their tolerance for higher salinities and colder water increases as they reach maturity, although they continue to prefer warmer brackish (<20 ppt) water. Least cisco prefer habitat conditions similar to that of the arctic cisco, although they appear to be less tolerant of colder temperatures and thus are more prevalent in protected nearshore waters of the bays and lagoons. There they feed primarily on mysids and shallow water amphipods. Small least cisco generally remain in or near the Colville River delta. When extended westerly winds push the Colville River plume into Simpson Lagoon and Prudhoe Bay, the small least cisco may follow that plume and disperse eastward. Anadromous fish seek out the coastal waters of the Beaufort Sea in the summer to feed on the higher concentrations of prey found there.

The quantity, quality, and availability of prey in coastal waters may affect fish preference toward certain areas or locations, although we have not found clear evidence of this. The prey species eaten by each of the anadromous fish species generally reflect the area in which the fish are found, and it is uncertain how habitat preferences as described by water parameters is affected by prey abundance.

CONCLUSION

The preferred habitat of the anadromous species of the central Beaufort sea is closely associated with the distribution of the coastal and river plumes and is strongly influenced by the characteristics of the offshore marine water. Each of these factors is driven by the wind regime during the summer open water season and the input of freshwater into the nearshore region. Between and within year variability in the distribution of habitat and the characteristics and availability of continuous migratory pathways is very high, which results in diverse movement and variable fish distribution patterns observed during the summer feeding period.

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Comment (Augustine): Mr. Chairman, I'm Gene Augustine from the Army Corps of Engineers (COE). I am the program coordinator for the Endicott Project. The Corps of Engineers is basically the technical director of it. We agreed to allow the participation of Lon Hachmeister and Domoni Glass here and also at the American Fisheries Society (AFS) meeting yesterday in Fairbanks as a means to getting a little more public input on the direction of Endicott and what we have accomplished to date with the program. Primarily, the results that you have heard are from the 1986 field season. This was the second season that the program was underway. The 1987 season was just completed. The program will continue for another four years, which will include an intensive fisheries program. The basic reason for the monitoring program is decisions yet to be made. The project report is for the COE - for their decision-making. In that regard, it is basically a gray piece of literature. We don't have a real good system of putting the report out. It's not a public document in the way that an EIS is; it's not a disclosure document, but yet it is public information. In the future, there might be some interesting monographs and papers written and submitted to journals. For now, I keep copies of the report at my desk and we try to fill needs of people whenever they ask for it.

Question (Newbury): Domoni made the point that the cisco and whitefish migrate through that warm relatively freshwater. Lon, in your diagrams of the effect of the causeways on the alongshore flow of water, I think you accurately showed that it deflects some of that warm, relatively freshwater offshore. But I think the satellite photograph that you showed indicated that the band is not discontinuous; it is continuous. I would like to see two of your slides and show not the contradiction, but that the offshore deflection doesn't break the band of water that Domoni mentioned which is important to fish. I think it was slide #8. I think that the satellite photograph shows that Endicott Causeway deflects coastal water offshore, but I think that the satellite photo also shows that the band of coastal water is continuous.

Response (Hachmeister - discussion summary): Hachmeister reiterated that there was a continuous band of fresh and warm water on both sides of the causeway, and the causeway is not going to break it up. The low salinity water along the coastline of Foggy Bay Island (10-20 ppt, depending on the year) is what gets deflected offshore and then comes into contact with upwelling water from beneath. The breaches do a pretty good job of accommodating the river water from the East Channel.

Question (Paluszkiewicz): Am I correct that the depth range that you're dealing with is from 2 to 20 m?

Response (Hachmeister): No, from 10 m to a little less that 1 m.

Question (Paluszkiewicz): What's the order of magnitude of your wind stress during an upwelling event?

Response (Hachmeister): I'm not sure exactly what that is. We've got about 10 m per sec type winds in order to produce this type of event. The upwelling event that I showed (where that plume goes around the outside, and we have the strong movement of water onshore) is partially enhanced by the fact strong layering is occurring. There is a lot of energy input into that surface water mass. It sends it straight offshore at high speeds, and return water comes up underneath that doesn't mix. They don't mix very well at all. It's just two layers.

Question (Paluszkiewicz) In this particular environment this is extremely unusual. Anywhere else in the world where you have upwelling winds of the order of magnitude of 10 m/sec in shallow waters, you'll find extreme vertical homogenization of the properties. This is one of the rare instances where I've seen the stratification preserved under that kind of mixing energy. I think an interesting calculation would be to determine how much wind stress you'll need to overcome that stratification and homogenize the water.

Response (Hachmeister): We did the drogue study this year. We followed the plume taking CTD casts throughout the tracking period and looked at the distribution of the drifters and took vertical velocity and density profiles. We'll look at the water stability.

Question (Paluszkiewicz): I think you could safely say that stratification is dominating your physics here. Even more so than the wind forcing.

Response (Hachmeister): Definitely in the region behind the causeway. We had some shielding from the east winds by the causeway. It is a very thin layer of water with horrendous stratification.

Question (Paluszkiewicz): Do you have data that exists before the building of the causeway?

Response (Hachmeister): Yes, there is some data from that area.

Question (Paluszkiewicz): Have you compared the degree of stratification under similar conditions before and after the causeway?

Response (Hachmeister): That first upwelling transect slide that I showed was pre-causeway in 1982. There were some east winds. The problem was that the pre-causeway monitoring program occurred in 1982 which was "a west wind year". So, the surface salinities tended to be less than 15 ppt. We didn't get the strong stratification. The other problem is that who can take CTD casts with 10 cm resolution? We can do that now.

Question (Paluszkiewicz): The concern is that if indeed there is not free exchange with the open ocean because of these causeways, they act to retain water and increase the stratification that normally wouldn't occur. I suppose that's one of the questions you are working on.

Response (Hachmeister): It changes the physics. The physics is fantastic when these heavy stratifications occur and all this energy is in little layers.

Question (Paluszkiewicz): It's absolutely amazing that you don't have homogenized water.

Response (Hachmeister): It's like a big laboratory out there. It's not that large. We don't talk ocean here. Really, we have to be a little careful. I call this thin film oceanography. It's really not even shallow water oceanography. The deepest cast we have is to 6 m. We don't even go out beyond that. So, all this is occurring on a really small scale.

Question (Paluszkiewicz): You don't have a data storage problem do you?

Response (Hachmeister): Well, we do because we take so many casts. Remember how far north we are. The scales up here occur at about 5 km type scales. This is upwelling occurring over scales of several kms and I think it really is upwelling. It's a little bit different than what occurs off shelf break. It's not classic upwelling. But it's surface divergence and replacement of deeper water.

Question (Paluszkiewicz): It would be difficult to see a classic upwelling structure in water that shallow. People might be tempted to just say you have an actual physical head, a fluid dynamic head build up and you are just moving water back and forth, you're not really upwelling. But the distribution of your isotherms and your isohaline lines do look like classic upwelling on a very tiny scale.

Comment (Pope): If any one is interested in copies of the draft reports, Standard Alaska Production has a large distribution list and we will make the report available. We will copy the 1985-1986 draft report for anyone who would like a copy.

INFORMATION MANAGEMENT SESSION

Speakers

M. J. Hameedi

W. Danforth

A. Robertson

M. Crane

B. Smiley

D. Aurand

OCSEAP DATA AND INFORMATION MANAGEMENT

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The objectives of data and information management activities in the Outer Continental Shelf Environmental Assessment Program (OCSEAP) are:

- To establish a repository of quality-controlled data obtained as part of the program.
- To provide data services and products to all interested users.

The preparation and distribution of principal investigators' final reports, synthesis reports, comprehensive bibliography, photographs, remotely-sensed imagery, and voucher specimens also constitute important information management functions. A number of documents are on display at the meeting, and some are available for distribution upon request.

Several new file types and formats have been developed under OCSEAP for input and archival of data in digital form, particularly for biological observations and records. These new formats, along with extensive new data from Alaska, have added significantly to the regional coverage and overall data management capabilities of several national data repositories, for example, the National Oceanographic Data Center (oceanographic and marine biological data), the National Geophysical Data Center (seismological data), and the National Institute of Health (microbiological data).

Data quality control, including inspection of systematic errors, development of digital data products, and pertinent operational support have been performed through contractor support. Efforts are presently underway to establish an Alaska marine database at the Ocean Assessments Division's (OAD) Alaska Office using the newly acquired PRIME 9755 computer. This computer will be the principal means of data storage, dissemination and exchange, and for digital modeling, statistical analyses, and development of products requested by the users. This new capability will improve the quality of data holdings, products and our responsiveness to the users. The computer is continually accessible via a number of communicating links and networks worldwide.

Biological specimens collected as part of OCSEAP are systematically identified and archived to develop a reference collection of Alaska biota. Biological voucher specimens, provisionally identified in the field by project scientists, are archived as a special collection at the California Academy of Sciences. This collection consists of nearly 10,000 lots. Starting in FY86, steps have been taken to upgrade, confirm, or correct taxonomic status of various faunal groups. To date, 11 taxonomic groups have been partially or completely examined by specialists. The collection is available to the public for examination and non-consumptive use. All archival data have recently been converted to a microcomputer database, which will improve data retrieval and periodic status reporting, and facilitate the data entry process.

DESIGN AND MANAGEMENT OF THE ALASKAN MARINE DATABASE

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The Laboratory for the Study of Information Science (LSIS) was contracted by the National Oceanic and Atmospheric Administration (NOAA), Ocean Assessments Division (OAD), Alaska office to design a customized database consisting of marine data stored in National Oceanic Data Center (NODC) formatted file types. Under the terms of an agreement between the Alaska office and the NODC, data relating to the Alaskan marine environment currently held at the NODC would be shipped to the Alaska office of OAD in order to set up a regional repository of Alaskan marine data. NODC file types provide a large pool of digital data collected over the last 10-15 years by investigators studying the marine environment. The NODC file format is standardized, thus eliminating inconsistencies between datasets, and making the NODC files a valuable aid in studying various aspects of the marine environment.

The Alaska office of OAD purchased a Prime Model 9755 minicomputer to process the data acquired from the NODC. The primary responsibilities of LSIS consist of archiving the NODC data files on the Alaska office computer, and creating a data retrieval system that would allow easy access to the NODC file types stored on the computer. As a first step, a data management program, INFORMATION, was purchased from Prime Computer. INFORMATION is a program which allows users to access data from various data files and to then generate reports (or output) in which the data requested by the user is listed and grouped according to criteria provided beforehand by the user. INFORMATION can be customized and tailored to the specific needs of individual users, allowing LSIS to set up an environment that enables computer users to gain access to the stored NODC data with relative ease. LSIS personnel are presently merging the data from the NODC file types with INFORMATION, allowing users to access a wide variety of physical, chemical, and biological oceanographic data.

The major task that first confronted LSIS was an incompatibility between the format that the NODC uses to store their data and the data format required by INFORMATION to access and process the data. Therefore, a "conversion" process had to be created that would rearrange the NODC data into a form that INFORMATION could utilize. The conversion of the NODC data formed the basis from which LSIS made their decisions concerning the overall design of the Alaskan Marine Database; what the data structure should be, and the best methods for data retrieval.

All of the data catalogued by the NODC are contained in various file types on the basis of data type, and are identified both numerically and by content. An example of two of the file types are: Trace Metals (file type 021) and Phytoplankton Species (file type 028). Each of the individual file types in turn have a series of single line "records" that contain pertinent information about the file type, arranged in a hierarchical manner. For example, the first several records within a file type will be a location, text or header record, master data record, etc., containing such information as cruise number, senior investigator, start and end dates, station number, latitude and longitude, time of day, meter number, to name a few. Immediately following the above descriptive records are detailed records that contain data relating to the specific location or pace in time described in the first several records. The various records within an

NODC file are related or "linked" to each other by a particular item, such as gauge or meter number.

The data management program, INFORMATION, does not support the type of multi-level hierarchy described above, making it necessary for the LSIS programming staff to create a single INFORMATION data file for each NODC record type. The conversion process recognizes the different record types within a particular NODC file type, and creates new INFORMATION files each time a new record type is encountered. Therefore, in order to retain the hierarchy (and data integrity) of the NODC format, LSIS created a "parent-child" relationship between INFORMATION files that contain data from a particular NODC file type. Thus, there may be a number of files stored in the Anchorage Prime that relate to a single NODC file type, but each is linked in such a manner so as to preserve the original format of the NODC file.

The reorganization, or conversion, of the NODC format described above constitutes a procedure that LSIS designed to be run as a semi-automated process on the Prime 9755. When a new tape is received from the NODC, the computer operator need only supply the NODC file type and the physical tape specifications to the LSIS conversion program, which will then run unattended until the entire tape is processed. After the conversion is completed, the data received from the NODC is then available to the users in the Alaska office.

Conversion of the NODC data into a format compatible with INFORMATION also helps with quality control procedures. As all of the data processed by LSIS to date is supplied by the NODC, quality control of the data has not been actively applied in the Alaska office. Although data supplied to the NODC is subject to quality control at the time of initial data submission by a principal investigator, the LSIS conversion program helps locate any data inconsistencies that may have been missed during the initial quality control procedure. For example, if particular data records are missing, such as text records describing location or time of day, the LSIS conversion program would detect this and alert the LSIS staff to potential problems. Contacting the principal investigators or requesting additional data information from the NODC is the usual method of investigating any problems with data quality. Future additions of data sources other than the NODC, as well as inconsistencies in the NODC dataset, will be quality controlled by the LSIS staff.

Archival of data, which has been converted from the NODC format, is accomplished through two mediums, magnetic tape and disk. Data is thus stored in two locations to guard against data loss inherent when dealing with magnetic media. If a particular disk begins to develop problems, LSIS can restore data from the associated tape onto another disk before the situation becomes critical. These archival procedures require that each associated disk and tape be updated regularly as changes or additions are made to a particular file type.

At present, the LSIS staff is working on a user program which will facilitate data access and retrieval from the NODC data stored on the Prime 9755. The user program will have several facilities: Data can be formatted for quick perusal on a terminal screen, for use in reports or can be output for use in other programs such as those available for data analysis on personal computers. LSIS took advantage of a product developed by Stauffer Information Systems entitled INTERCEPT, which reduces the time it takes the computer to retrieve a set of data, helping to make the database retrieval system more "user friendly". The Arctic Marine Database will be accessible through TELENET or by direct dialing the number of a modem hooked to the Prime.

Any person owning a personal computer with a modem hookup, or working at an institution that has a central computer hooked into the phone system will be able to access the data.

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ARCTIC LIVING MARINE RESOURCE DATABASE - INTERACTIVE ASSESSMENT CAPABILITY

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A great deal of information has been obtained, particularly recently, concerning the oceanographic characteristics of the environment off the coasts of Alaska. This is especially due to the large number of studies that have been conducted in this area over the past 15 years as part of the Outer Continental Shelf Environmental Assessment Program (OCSEAP), which has been conducted by NOAA since 1973 with reimbursable funds transferred from Minerals Management Service (MMS). However, despite efforts to synthesize aspects of the available information for specific purposes, such as oil and gas lease sales, much of it has remained scattered and poorly organized, thus restricting its effective and timely use to aid in making resource management decisions.

This paper briefly describes and illustrates a computer-based data system designed to help improve this situation. The system synthesizes the best available life history information about important living resources of the Bering-Chukchi-Beaufort Seas and provides ready access, manipulation, retrieval, and display of the temporal and spatial distributions of these resources in this area. This data system is one regional component of a larger system being developed to synthesize and analyze the best available information on the distributions of living marine resources in all U.S. coastal and ocean regions.

The data system is composed of life history data for 93 marine resource species, including 31 invertebrates, 20 fishes, 28 birds, and 14 mammals (Table 1). The data in the data system are based primarily on information obtained from published and unpublished (gray literature) reports, many of them final reports from the OCSEAP. Based on this information, experts concerning the biology of each species have prepared maps to illustrate the spatial and temporal characteristics of the life history of these species. At least four types of areas are identified for each species, i.e. adult area, reproductive area, pre-adult (juvenile) area, and exploitation area. These living resource maps have been combined with comparable maps depicting physical environments, biotic environments, economic activities, and jurisdictions for the Bering, Chukchi, and Beaufort Seas area, and the entire series published as an atlas of 107 maps. The living resources maps have also been digitized into a computer-based grid system of equal area squares of approximately 10 mile by 10 mile covering the entire Bering-Chukchi-Beaufort area. These digitized data are stored in the automated data system. This makes each map available to be produced by the computer as needed.

However, the system is designed to allow much more than the simple reproduction of these maps. One capability is to provide composite maps of the presence or absence of any combination of species, their life history states, and their seasonal distributions for the entire grid system or any portion of it. This composite mapping allows the development of schematic maps showing the occurrences of the living resources with the characteristics selected. The results can be displayed in two ways, either as maps with a number in each grid cell showing the total number of occurrences with the selected characteristics in that cell or as maps with

Table 1. Species included in the Bering, Chukchi, and Beaufort Seas data system.

Species	Scientific Name
<u>Invertebrates</u>	
Arrow worms	Sagitta elegans
Euphausiids	Thysanoessa inermis
	Thysanoessa rashii
False Calanus Copepods	Pseudocalanus spp.
Feathery Calanus Copepod	Neocalanus plumchrus
Dragonfly Amphipod	Themisto libellula
Small Crangonid Shrimps	Crangon communis
	Crangon dalli
	Crangon septemspinosa
Large Crangonid Shrimps	Argis dentata
	Argis lar
	Sclerocrangon boreas
	Sabinea septemcarinata
Northern Pink Shrimp	Pandalus borealis
Other Pandalid Shrimps	Pandalus goniurus
	Pandalus tridens
	Pandalopsis dispar
Opossum Shrimps	Mysis litoralis
	Mysis oculata
	Mysis polaris
	Mysis relicta
Korean Hair Crab	Erimacrus isenbeckii
Red King Crab	Paralithodes camtschatica
Golden King Crab	Lithodes aequispina
Blue King Crab	Paralithodes platypus
Bairdi Tanner Crab	Chionoecetes bairdi
Opilio Tanner Crab	Chionoecetes oplio
Red Squid	Berryteuthis magister
Chalky Macoma	Macoma calcarea
Greenland Cockle	Serripes groenlandicus
Iceland Cockle	Clinocardium ciliatum
<u>Fishes</u>	
Pacific Herring	Clupea harengus pallasi
Pink Salmon	Oncorhynchus gorbuscha
Chum Salmon	Oncorhynchus keta
Coho Salmon	Oncorhynchus kisutch
Sockeye Salmon	Oncorhynchus nerka
Chinook Salmon	Oncorhynchus tshawytscha
Capelin	Mallotus villosus
Eulachon	Thaleichthys pacificus
Rainbow Smelt	Osmerus mordax
Saffron Cod	Eleginus gracilis
Pacific Cod	Gadus macrocephalus
Walleye Pollock	Theragra chalcogramma
Yellowfin Sole	Limanda aspera
Alaska Plaice	Pleuronectes quadrituberculatus
Starry Flounder	Platichthys stellatus
Greenland Turbot	Reingardtius hippoglossoides
Rock Sole	Lepidopsetta bilineata
Arrowtooth Flounder	Atheresthes stomias
Flathead Sole	Hippoglossoides elassodon
Bering Flounder	Hippoglossoides robustus
Pacific Halibut	Hippoglossus stenolepis
<u>Birds</u>	
Northern Fulmar	Fulmarus glacialis
Shearwaters	Puffinus griseus
	Puffinus tenuirostris
Tundra Swan	Cygnus columbianus columbianus
Emperor Goose	Chen canagica
Black Brant	Branta bernicia
Greater White-fronted Goose	Anser albifrons
Canada Goose	Branta canadensis minima
	Branta canadensis parvipes
Oldsquaw	Clangula hyemalis
Common Eider	Somateria mollissima
King Eider	Somateria spectabilis
Bald Eagle	Haliaeetus leucocephalus
Peregrine Falcon	Falco peregrainus harterti
	Falco peregrinus tundrius
Western Sandpiper	Calidris mauri
Red Phalarope	Phalaripus fulicarius
Glaucous-winged Gull	Larus glaucescens
Glaucous Gull	Larus hyperboreus
Black-legged Kittiwake	Rissa tridactyla
Red-legged Kittiwake	Rissa brevirostris
Arctic Tern	Sterna paradisaea
Murres	Uria aalge
	Uria lomvia
Horned Puffin	Fratercula corniculata
Parakeet Auklet	Cyclorrhynchus psittacula
Least Auklet	Aethia pusilla
<u>Mammals</u>	
Caribou	Rangifer tarandus
Brown Bear	Ursus arctos
Polar Bear	Ursus maritimus
Northern Fur Seal	Callorhinus ursinus
Steller Sea Lion	Eumetopias jubatus
Pacific Walrus	Odobenus rosmarus divergens
Pacific Harbor Seal	Phoca vitulina richardsi
Spotted Seal	Phoca largha
Ringed Seal	Phoca hispida
Ribbon Seal	Phoca fasciata
Bearded Seal	Erignathus barbatus
Bowhead Whale	Balaena mysticetus
Gray Whale	Eschrichtius robustus
White Whale	Delphinapterus leucas

the amounts of shading in the grid cells based on intervals in numbers of occurrences. As there is a great deal of information contained on each atlas map, a wide variety of composite maps can be developed. For example, a map can easily be made showing the composite distributions of the reproductive areas of the top five commercially important fish species or of all fish species or a composite map of the major areas of occurrence of the commercially important shrimp species.

A second capability enables the user to assess specific attributes of marine species within selected areas described by any combination of grid cells. For example, the life history attributes of species that occur within an oil and gas lease planning area such as the Navarin Basin can be listed. For any specified area, the system can provide a listing of the life history stages of each species found within the area, the season occurrence of the individual life history stages, and the total number of cells within the area occupied by each life history stage of each species for each season. The system can also compare areas. For example, the spatial and temporal distributions of living marine resources in the Beaufort Sea can be compared to the distributions in the Chukchi Sea or the Norton Basin compared to the Barrow Arch.

In conjunction with these basic operations, the system has the ability to include weighting schemes to bring out the relative importance of particular species, group of species, life history states, or other attributes. For example, species can be weighted by their relative economic value or by the spatial extent of a specific sensitive life history stage. The weighting scheme and the individual weights can be varied to meet the requirement of the problem involved and thus add greatly to the flexibility of the system to respond to specific needs and questions.

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MARINE DATA AND INFORMATION - AN ALASKAN PERSPECTIVE

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National Data Centers have participated in arctic programs for many years. These national centers are part of the National Environmental Satellite Data and Information Service of NOAA and each center has arctic information. Each national office has been an active, vital link and will expand its role in the future. Continuity - the hallmark of national scale services - is a major contribution to arctic data. The National Oceanographic Data Center, created in 1960, has participated in the studies program since 1975 when the Outer Continental Shelf Environmental Assessment Program (OCSEAP) started. NODC and the Ocean Assessment Division of NOAA have agreed to develop joint services for the Arctic. The international connection is nurtured through the 'World Data Centers' located within each data center. Multi-agency coordination at the national level provides exchange of material and resources which are not available at the regional level. The National Data Centers become a clearinghouse for data standards in formats, codes and parameters. The Minerals Management Service (MMS) office in New Orleans uses the same formats and codes as the MMS office in Alaska. Data collected in 1980 will be archived and merged with data collected in 1990. A national perspective spans the globe in area and decades in time. The National Environmental Satellite Data and Information Service has three data centers which are your gateway to arctic information, to the historical record and to uniform standards of exchange. The National Climatic Data Center joins the National Geophysical Data Center and the National Oceanographic Data Center in providing services to the OCSEAP and the Minerals Management Service nationwide.

As the study programs change and the research priorities evolve, the data centers have been stable and dependable. The data centers are committed to Alaska and the Arctic for the long term. For 12 years the NODC considers local support a key element and has maintained an office in Anchorage. In 1984, the Anchorage office expanded its capacity for arctic support under the sponsorship of the Ocean Pollution Data and Information Network. Connected to the National Data Centers via terminals and modems, access to arctic information can be coordinated within Alaska to computers in Asheville, North Carolina or Boulder, Colorado or Washington, D.C. A call to the local office is the same as a call to the National Data Center.

The National Oceanographic Data Center has 12 years of data from the OCSEAP and the MMS study projects. To support that database, the NODC has developed formats, codes and data standards for oceanographic data, chemical data, and biological data. A key element in the biological data is the internationally accepted taxonomic code system developed in part as an arctic science requirement. Over 60,000 entries in the taxonomic code are now defined. NODC adapted the chemical abstract services' code for toxic substances for use in the chemical databases. NODC receives data from other governmental agencies and the National Science Foundation requires that NSF grantees send data to the NODC. The Environmental Protection Agency has adopted the NODC formats in the Ocean Data Evaluation System (ODES), plus the Biostoret Program within EPA uses the NODC taxonomic code. Within NOAA the Ocean Pollution Data and Information Network supports Information Services with offices in Washington, D. C. and five other locations. Arctic marine pollution services are available from the Anchorage office. The National Aeronautical and Space Administration is working with NODC on data networks for the oceanographic research community and NODC is a member of the Space Physics Analyses Network (SPAN) operated by NASA.

The National Climatic Data Center in Asheville, North Carolina maintains the historical records of the National Weather Service and provides specialized services. The revised marine climatic atlas is a joint production of NODC and the University of Alaska funded by the OCSEAP. Besides the traditional weather measurements, the Climatic Data Center will be servicing new parameters from future satellite programs. Sea ice data and sea surface temperature measurements will be expanded. The Climatic Data Center will take the lead in developing data dictionaries for all National Data Centers. To improve the access to these data, the plan for 1990 includes a new communication capacity. As the technologies advance, the Climatic Data Center will adopt appropriate technologies at the operational level.

The National Geophysical Data Center located in Boulder, Colorado has serviced geological and geophysical requests, plus maintained the geological database for the OCSEAP since 1975. The MMS has funded a new database on marine geology bibliographies which is a national program. Within the global datasets maintained at NODC, there are portions of the database which contain arctic data. Bathymetric survey data files of the arctic marine waters are particularly valuable. Other marine geological parameters include grain size data, plus geophysical data of gravity and magnetic. Earthquake data services have been requested in hazard assessment work.

The three data centers also maintain the international connection via the 'World Data Centers' for oceanography, climatology, solid earth geology, marine geophysics, solar/terrestrial geophysics, and snow and ice data. Under the Snow and Ice Data Center category several new data services will be introduced soon. The Defense Meteorological Satellite Program has new sensors which will improve the ice edge detection capability. New products are planned from analyses of these data. Arctic data buoys will send data to the Snow and Ice Data Center under another expanded program. Research on snow melt will be conducted for sea ice environments.

Future programs will also drive new data services in the Arctic. The Global Change Research Program will have a major arctic component for data. The NODC will be an active participant in the global change arena. With the interest in networks, NOAA has begun a study of arctic networking from an agency wide perspective. Each NESDIS Center is submitting ideas to this arctic network plan. The World Ocean Circulation Experiment (WOCE) will have arctic data and NODC will support researchers in the future.

New scientific instruments will have an enormous affect on data services in the future. New satellites will expand the scale and type of measurements in the ocean domain. Profiling current meters will map subsurface currents from surface mounted platforms. Remote sensing will adopt new technologies and provide exciting new data for the research community and the operational community. Synthetic aperture radar devices will be the first to address sea ice roughness on a continuing basis.

From a national perspective the issues of information service are linked to mission requirements. Solving problems on the global scale will address problems on the regional scale. Becoming a partner with regional programs will help the national center solve the information concerns on the regional scale. Each NESDIS Center would like to continue its good relationship with the OCSEAP and MMS while seeking new areas of cooperation.

Question (Sokolov): I'd like to ask Andy Robertson about the availability of the NOAA atlases.

Response (Robertson): Our atlases are primarily available for sale through the government printing office. We usually make some available to congressmen and others like that, but atlases are primarily through the printing office. For the Gulf of Mexico, we mailed out about 20,000 flyers and I assume, if we get pretty good results, we'll do the same thing for the Arctic atlas, to make as many people as possible aware of its availability and how to get it.

Question (Sokolov): Is there any possibility of distributing to Arctic libraries?

Response (Robertson): I think there are some libraries. I am sure the University of Alaska will get at least one free copy, as well as some of the organizations who have cooperated with us.

Question (Lockert): You didn't mention how people from Alaska will be able to use the database. Is a copy of that database going to be up here that people can use?

Response (Robertson): The database is on a Bernouli cartridge. I think that the system plus the database will be on a cartridge. Assuming you've got the hardware to take that, it's available for people to use.

Question (Lockert): How big is it? What size memory does it require?

Response (Robertson): I think it's all on one - 20 cartridge. You do have to have an upgrade, like I've got an SE, and I have to have some storage added to take it. I don't exactly know how much it takes, but it isn't just the regular storage, you have to have some extra. I think Mac2 would probably run it without any extra storage.

Question (Prentki): I have a question for Bill Danforth, on the chemical database. Will there be anything on these to identify the techniques used in the analysis?

Response (Danforth): There are text records associated with this. If the investigators themselves submitted the information, it will be in there and be made available.

Comment (Prentki): We at MMS have had problems with that in the past in that some different types of techniques have been used.

Response (Danforth): Well, the data we've received so far - it would be file type 144 - there are text records in there indicating the type of techniques. It's very abbreviated but you can tell what they used to arrive at the various numbers they came out with.

Comment (Crane): And as part of that request, we're also generating copies of the documentation forms which our investigators supplied which go into a little more detail on what particular instruments and procedure they used.

Question (T. Johnson): I wanted to ask you, Andy, what the primary data sources were that you used for the atlases. Did you get most of your data through NODC?

Response (Robertson): The primary way that information was acquired was to identify several experts for each species and basically have them go to the data sources that they were most familiar with, knew most about, and could use most. We roughed out the maps and then sent them back for them to correct in an iterative process. Because practically all the major biological investigators from the program were part of our expert staff, I'm sure the data is used a lot. I don't imagine usually, however, it was obtained through NODC. I imagine the people had direct access themselves.

Question (Smiley): I noticed that some of the data suggests that the Canadian Arctic is included in this Arctic Living Resources Map and database. I was wondering whether that has been the case for all of the attributes - the species, etc.?

Response (Robertson): It overlaps into the Canadian Beaufort but not far enough that it would be useful for your purposes. It is enough of an overlap that we certainly could look at this merge zone and see where we agreed, where we didn't agree, and how to merge things more. It also extends over to the Siberian side. One of the things I didn't mention was that we have a code of about 50 different categories by area and for each species, by area and time of year, and different areas with a number from 1-5 attached on how reliable the data is. One is very reliable and at five is highly speculative. I suspect the Siberian side has a lot of fives, and I suspect for some of the data, it may get more speculative as we move into the Canadian Beaufort. However, for many of the people involved in this project, it wouldn't get more speculative at all. In fact, I'm not sure that all of the experts we involved in this project with this were even Americans. I think there were some Canadian experts involved too.

Question (Smiley): Did the experts give you an audit of their source materials they used? Did they use empirical data or extrapolated data?

Response (Robertson): Yes.

Question (Fishman): So, it is possible to glean from the atlas?

Response (Robertson): Only partially from the atlas. The major things are there, but you'd have to go back to the information that we have to get all the details of that.

CATALOGUING AND APPRAISAL OF OCEANOGRAPHIC DATA AND INDUSTRY ACTIVITIES IN ARCTIC CANADA

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There is a growing need for directories to ocean measurements. The pressure emanates from scientists, engineers, impact assessors, planners, regulators, and resource managers who must exploit historical data, often for applications never conceived of by those originally acquiring these data. Before environmental decisions can be made defensibly or actions taken with confidence, two underlying questions are often asked -- "How complete and reliable are the existing data, and where can they now be located?". Past attempts to resolve these basic questions usually demand substantial time and money, and often are incomplete and duplicative.

In response to these shortcomings, the Data Assessment Division at the Institute of Ocean Sciences initiated, in 1979, two aggressive programs of preparing comprehensive directories to: 1) existing oceanographic data, and 2) historical offshore industrial activities.

The objectives of one program, the Arctic Data Cataloguing and Appraisal Program (ADCAP), are:

- To compile the available documentation about the collection, analysis and status of all historical oceanographic studies (datasets) in Canada's arctic waters;
- To judge objectively the reliability of the various measurements reported in each dataset, based on careful scrutiny of the methods-and-materials documentation;
- To summarize the most pertinent details of each dataset in published catalogues containing tables, maps, references, sources and indexes.

The aims of ADCAP are being realized by conducting inventories of all existing data -- published or unpublished, analyzed or stored, public or proprietary, government- or industry-generated, of good/poor/suspect quality -- and by publishing the end product as "one-stop" directories, made available to everyone.

The Program began by cataloguing physical oceanographic data (temperature, salinity, currents, water levels), and then proceeded to chemical data (nutrients, heavy metals, hydrocarbons, dissolved oxygen and turbidity - in sea ice and water, sediments and biota). More recently, with the cooperation of the Freshwater Institute in Winnipeg, ADCAP has expanded into biological oceanography (bacteria, plankton, zoobenthos, fishes, whales, seals and walruses). To date, the inventories have compiled, described, and evaluated several hundred datasets with about 600 different types of measurements, ranging from sea temperature to blubber thickness. So far, greatest attention has been directed to the Canadian Beaufort Sea and Northwest Passage regions (Figure 1), because of the many important decisions and actions concerning environmental protection and marine safety demanded by oil and gas development in these areas.

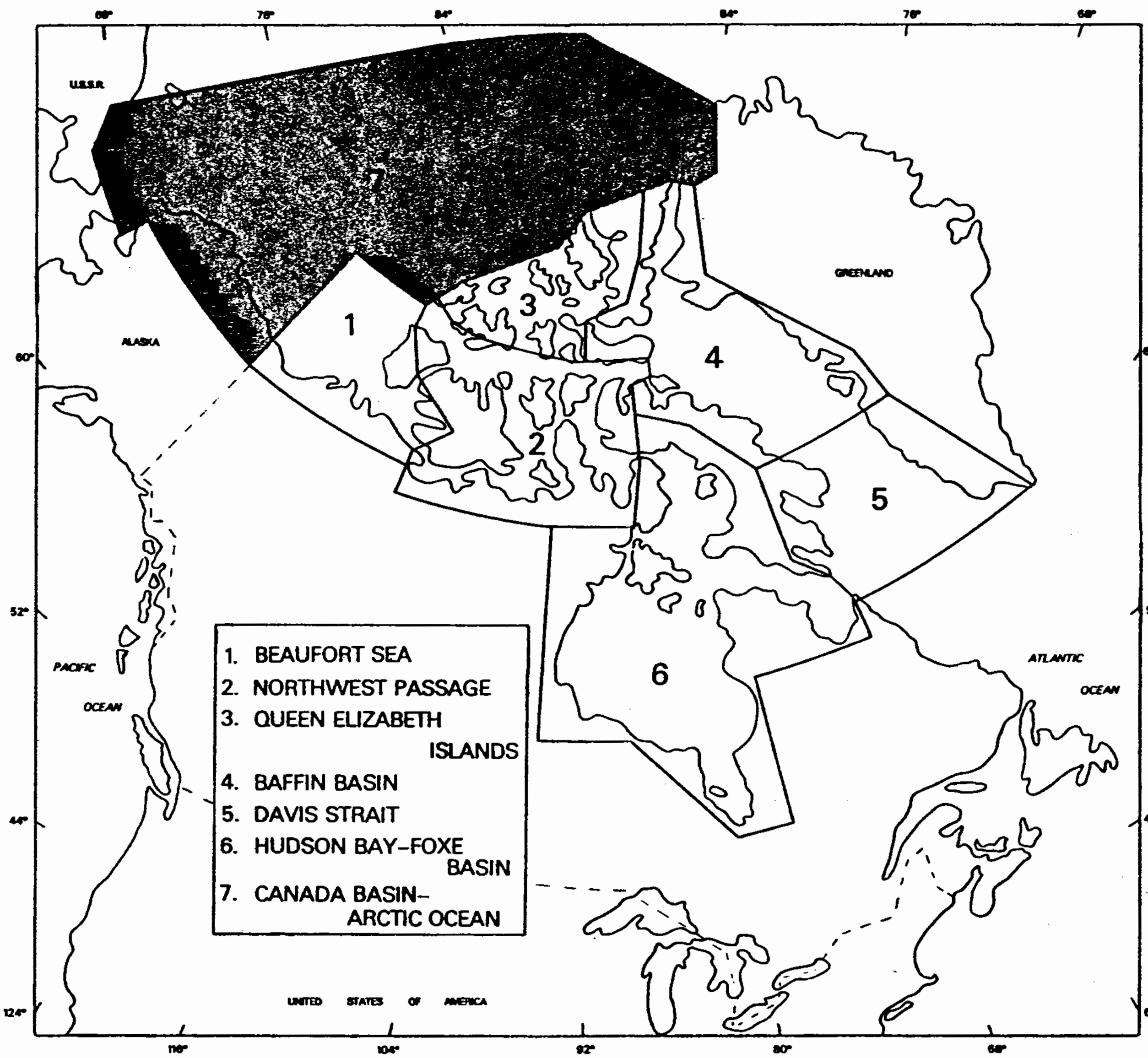

Figure 1. Subregions of the Arctic data cataloguing and appraisal program (ADCAP).

Much of the Program's cataloguing and appraisal has been carried out under contract to reputable consulting companies (such as Arctic Sciences Ltd., Seakem Oceanography Ltd., ESL Environmental Sciences Ltd. and P. N. Research Projects), relying on the expertise and guidance of Institute researchers as scientific authorities.

Special care and deliberation has been expended on devising a semi-hierarchical data rating system. Somewhat elementary and ordinarily objective, the ratings are based on the judged thoroughness and completeness of each dataset's documentation about each type of measurement. Although the specific appraisal criteria vary considerably between disciplines, the same five rating categories have been used uniformly throughout the Program:

"0" Data are found or judged to be wrong.

"1" Data are suspect and probably not internally consistent.

"2" Data were not or could not be investigated because sufficient documentation was not available.

"3" Data are internally consistent trends within the data are probably real, but comparison with other datasets may be difficult or impossible.

"4" Data are internally consistent and sufficiently standardized or tied to a reference; comparison with other "4" rated data should be possible.

The present status of the Program is summarized in Table 1. The ADCAP catalogues are published as separate volumes in the Canadian Data Report series of Hydrography and Ocean Sciences (Table 2).

Table 1. Status of ADCAP inventories.

Region	Discipline	Catalog Volume #	Period	Status (November 1987) Compile	Appraise	Publish
Beaufort Sea	Physics	1	1935-1981	complete	complete	1982
		12	1935-1986	complete	complete	1987
	Chemistry	2	1950-1981	complete	complete	1987
	Plankton	9	1913-1986	complete	complete	1987
	Zoobenthos	11	1914-1986	complete	complete	1987
	Fishes	15	1955-1986	draft	draft	1987
	Seals	8	1823-1985	complete	complete	1987
	Whales	10	1848-1986	complete	complete	1987
Northwest Passage	Physics	3	1908-1982	complete	complete	1983
		14	1908-1986	complete	complete	1987
	Chemistry	4	1928-1981	complete	complete	1983
	Zoobenthos	19	1936-1982	draft	--	1988
	Fishes	17	1819-1985	draft	draft	1988
	Seals	18	1850-1986	draft	draft	1988
	Whales	13	1820-1984	complete	complete	1987
Queen Elizabeth Islands	Physics	6	1948-1980	complete	complete	1983
	Chemistry	16	1952-1986	complete	complete	1987
	Fishes	17	1819-1985	draft	draft	1987
Canada Basin & Arctic Ocean	Physics	7	1883-1983	complete	complete	1984
	Chemistry	20	1926-1983	complete	--	1988
Baffin Bay	Physics	5	1900-1981	complete	complete	1983

ADCAP is a sister program to WESCAP (the Canadian West Coast Data Cataloguing and Appraisal Program). Together, these programs contribute the information contained in the Institute's geo-referenced computer database called the Oceanographic Data Information System

(ODIS). The System operates on a MicroVax II computer and Tektronix 4107 or 4014 terminals, relying on ORACLE and DISSPLA software.

The second program is called the Arctic Industrial Activities Compilation Program. It is imperative to have a reliable log of historical offshore industrial development such as oil exploration, for purposes of impact assessment, planning, regulation, and research of the arctic marine environment. Although the details of such activities are routinely recorded in applications, leases, licenses and permits required by government regulators, this information is of varying completeness, and is archived in different formats and amongst the offices of several agencies and companies in northern and southern Canada. This makes it arduous for anyone to gain a prompt grasp about what industrial activities (most often implicated as environmental threats) have occurred where, when, how, by whom and for what purposes.

This Program's objectives are to compile assiduously, examine first-hand, synthesize simply, and depict clearly the operational facts of major offshore activities associated with past oil and gas development in the Canadian Arctic. Hundreds of hours were spent compiling and transcribing, into standard format, the most important documents such as vessel logs, company internal correspondence, land leases and applications, marine licenses and permits, government inspection reports, contractors' reports and monitoring study documents. Most information was mustered from the Yellowknife offices of Indian Affairs and Northern Development Canada, Environment Canada and the Canadian Oil and Gas Lands Administration, and is published as volumes of the Canadian Data Report of Hydrography and Ocean Sciences series (Table 3).

Our attention was given first to over 100 marine dredging operations authorized from 1959 to 1983 in the Beaufort Sea, involving the loading and dumping of over 46 million cubic meters of seabottom materials, mostly by petroleum companies such as Dome Petroleum and Esso Resources. The purposes of these dredging requirements included construction of harbours and piers, navigation channels, artificial islands for drilling, glory holes for well protection, and community landfill. Using a computer database, the operational details (company, dredge type and name, purpose and dates, dredged materials, load and dump site coordinates, volumes loaded, and dumped, water depth, information sources, and so on) were archived and organized into tables, and plotted on graphs and maps. These, together with descriptive overviews, line drawings and photographs of the dredges, were issued in a catalogue. The dredging database was revised and updated in 1986, and programmed to run on an IBM/PC-compatible computer as an interactive search and sort routine with mapping capability.

In 1984, the Division next turned its attention to the Sverdrup Basin (more commonly called the Canadian High Arctic) where extensive seismic surveys and well drilling have occurred for several decades, mostly during Panarctic Oil's search for oil and gas. Again, the challenge was to closely scrutinize hundreds of government and industry records for all pertinent details (company, period and timing, equipment used, survey location or well site, water depth, associated discharges, information sources and so on). For the period 1974 to 1984, a total of 45 seismic surveys logged nearly 25,000 km of transects, most of which (75%) were shot offshore from the sea ice. Eighty wells were drilled for wildcat exploration and discovery delineation, many (31%) spudded offshore. A synthesis of this information is also published in a volume containing maps, tables, graphs, overview, and database listing. A computer database was not prepared for these industrial activities.

Two new compilations are in preparation, dealing with information on chemical drill waste discharges for all offshore wells spudded from 1976 to 1986 in the Beaufort Sea, Arctic Islands and Davis Strait, and on aircraft/vessel traffic and seismic surveys from 1980 to 1986 in the Canadian Beaufort Sea.

For copies of the catalogues or more information about the Programs, you are encouraged to contact:

Data Assessment Division
Institute of Ocean Sciences
Fisheries and Oceans Canada
P.O. Box 6000
Sidney, British Columbia, V8L 4B2
Attention: Brian Smiley (604) 356-65

Table 2. Volumes of the Arctic Data Compilation and Appraisal Series: *In*: Canadian Data Report of Hydrography and Ocean Sciences. No. 5.

Published (November 1987):

Cornford, A. B., D. D. Lemon, D. B. Fissel, H. Melling, B. D. Smiley, R. H. Herlinveaux, and R. W. MacDonald. 1982. Arctic Data Compilation and Appraisal. Beaufort Sea: Physical Oceanography - Temperature, Salinity, Currents and Water Levels. Vol. 1, 279 p.

Thomas, D. J., R. W. Macdonald, and A. B. Cornford. 1982. Arctic Data Compilation and Appraisal. Beaufort Sea: Chemical Oceanography. Vol. 2, 243 p.

Birch, J. R., D. B. Fissel, D. D. Lemon, A. B. Cornford, R. A. Lake, B. D. Smiley, R. W. Macdonald, and R. H. Herlinveaux. 1983. Arctic Data Compilation and Appraisal. Northwest Passage: Physical Oceanography - Temperature, Salinity Currents and Water Levels. Vol. 3, 262 p.

Thomas, D. J., R. W. Macdonald, A. G. Francis, V. Wood, and A. B. Cornford. 1983. Arctic Data Compilation and Appraisal. Northwest Passage: Chemical Oceanography. Vol. 4, 200 p.

Birch, J. R., D. B. Fissel, D. D. Lemon, A. B. Cornford, R. H. Herlinveaux, R. A. Lake, and B. D. Smiley. 1983. Arctic Data Compilation and Appraisal. Baffin Bay: Physical Oceanography -- Temperature, Salinity, Currents and Water Levels. Vol. 5, 372 p.

Fissel, D. B., L. Cuypers, D. D. Lemon, J. R. Birch, A. B. Cornford, R. A. Lake, B. D. Smiley, R. W. Macdonald, and R. H. Herlinveaux. 1983. Arctic Data Compilation and Appraisal. Queen Elizabeth Islands: Physical Oceanography -- Temperature, Salinity, Currents and Water Levels. Vol. 6, 214 p.

Birch, J. R., D. B. Fissel, A. B. Cornford, and H. Melling. 1984. Arctic Data Compilation and Appraisal. Canada Basin - Arctic Ocean: Physical Oceanography - Temperature, Salinity, Currents and Water Levels. Vol. 7, 624 p.

Harwood, L. A., L. A. Turney, L. de March, B. D. Smiley, and P. Norton. 1986. Arctic Data Compilation and Appraisal. Beaufort Sea: Biological Oceanography -- Seals, 1826 to 1985. Vol. 8, (Part 1, 352 p.; Part 2, 301 p.)

Woods, S., and B. D. Smiley. 1987. Arctic Data Compilation and Appraisal. Beaufort Sea: Biological Oceanography -- Bacteria, Plankton and Epontic Community, 1914 through 1985. Vol. 9, 412 p.

Norton, P., B. D. Smiley, and L. de March. 1987. Arctic Data Compilation and Appraisal. Beaufort Sea: Biological Oceanography -- Whales, 1848 to 1983. Vol. 10, 407 p.

Wainwright, P. F., B. D. Smiley, and A. Blyth. 1987. Arctic Data Compilation and Appraisal. Beaufort Sea: Biological Oceanography--Marine Zoobenthos, 1914 to 1986. Vol. 11, 367 p.

Birch, J. R., D. D. Lemon, D. B. Fissel, and H. Melling. 1987. Arctic Data Compilation and Appraisal. Beaufort Sea: Physical Oceanography -- Currents, Water Levels and Waves. 1914 to 1986. Vol. 12 (revised and updated Volume 1). 452 p.

Norton, P. N., B. D. Smiley, and L. de March. 1985. Arctic Data Compilation and Appraisal. Northwest Passage: Biological Oceanography -- Whales. 1820 to 1984. Vol. 13 (Part 1, 253 p; Part 2, 494 p.)

Birch, J. R., D. B. Fissel, D. D. Lemon, and R. A. Lake. 1987. Arctic Data Compilation and Appraisal. Northwest Passage: Physical Oceanography -- Currents, Water Levels and Waves. 1820 to 1986 (revised and updated Volume 3). Vol. 14, 309 p.

Unpublished (November 1987):

Ratynski, R., L. de March, A. Thompkins, and B. D. Smiley. Arctic Data Compilation and Appraisal. Beaufort Sea: Biological Oceanography -- Fishes. 1896 to 1985. Vol. 15 (draft). 400 p.

Thomas, D. J., P. F. Wainwright, and M. Yunker. 1986. Arctic Data Compilation and Appraisal. Queen Elizabeth Islands: Chemical Oceanography -- Metals, Hydrocarbons, Nutrients and Oxygen. 1933 to 1985. Vol. 16 (draft). 130 p.

Ratynski, R., and L. de March. 1987. Arctic Data Compilation and Appraisal. Northwest Passage and Queen Elizabeth Island regions: Biological Oceanography -- Fishes. 1819 to 1985. Vol. 17 (draft). 300 p.

Harwood, L. A., P. Norton, L. de March, and B. D. Smiley. 1987. Arctic Data Compilation and Appraisal. Northwest Passage: Biological Oceanography -- Seals. 1834 to 1985. Vol. 18 (draft). 114 p.

Wainwright, P. F., and B. D. Smiley. 1986. Arctic Data Compilation and Appraisal. Northwest Passage: Biological Oceanography -- Marine Zoobenthos. 1936 to 1982. Vol. 19 (draft). 92 p.

Thomas, D. J., R. W. Macdonald, and M. Robinson. 1986. Arctic Data Compilation and Appraisal. Canada Basin - Arctic Ocean: Chemical Oceanography -- Metals, Hydrocarbons, Nutrients and Oxygen. 1926 to 1983. Vol. 20 (draft). 91 p.

Table 3. Volumes of the Arctic industrial activities compilation series: *In*: Canadian Data Report of Hydrography and Ocean Sciences. No. 32.

Published (November 1987):

Taylor, D. A., M. G. Reed, B. D. Smiley, and G. S. Floyd. 1985. Arctic Industrial Activities Compilation: Volume 1. Beaufort Sea: Marine dredging activities 1959 to 1982. Vol. 1. 192 p.

Sackmann, T., and B. D. Smiley. 1985. Arctic Industrial Activities Compilation: Volume 2. Sverdrup Basin: Hydrocarbon exploration 1974 to 1984. Vol. 2. 181 p.

Unpublished (November 1987):

Wainwright, P., and J. McDonald. 1987. Compilation of historical drilling chemicals data associated with offshore hydrocarbon exploration in the Canadian Beaufort Sea, Arctic Islands and Davis Strait regions, 1973 to 1986. Vol. 3 (draft) 52 p.

Wainwright, P., J. McDonald, and A. Blyth. (in preparation). Arctic industrial activities compilation for the Canadian Beaufort Sea: seismic surveys, vessel movements, aircraft traffic and offshore marine research. 1980 to 1986. Vol. 4.

THE ENVIRONMENTAL STUDIES DATA SYSTEM (ESDS)

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One of the main goals of the Environmental Studies Program (ESP) is the effective dissemination of information obtained through studies sponsored by the Minerals Management Service (MMS). Currently, we have two major initiatives underway to improve our ability to accomplish that task: the preparation of Technical Summaries and the development of an automated database to inventory and catalog all reports associated with the ESP. Each of these efforts is described briefly in the following paragraphs.

The Technical Summary program began approximately three years ago and is intended to produce standardized 3-5 page summaries of all ESP contracts. At present we have completed slightly over 150 of an estimate 600+ summaries, and have another 200 in preparation. The effort will be completed in 1989. At present we require all contractors to prepare a Technical Summary as a deliverable product unless the contract does not involve the preparation of publishable results. These two approaches will allow us to assemble a complete file of fairly detailed summaries for distribution to users of ESP information, which will allow them to identify reports which they may wish to review in detail. In other cases, users may find that the summaries themselves provide sufficient information. It is our intention to begin publishing summary volumes containing approximately 150 Technical Summaries, each in the spring or summer of 1988. These volumes will contain author, geographic and subject indices. Once we have eliminated the backlog of contracts, we will publish annual Technical Summary volumes, as well as periodic cumulative indices. When used in conjunction with the new database system, the Technical Summary volumes should significantly improve access to ESP information.

The Environmental Studies Data System (ESDS) is several database files and custom menu programs developed to manage basic program information for the MMS Branch of Environmental Studies. At headquarters (HQ), the primary concern is to manage information at the level of procurement actions, a basic suite of individual contract facts, and a record of reports and other products resulting from contract efforts. ESDS information management does not involve treatment of field or experimental data generated by studies.

Conceptually, ESDS is designed to manage two types of information:

- **HQ Files:** current planning and procurement data more or less exclusive to HQ operations.

- **National Files:** records of studies and products which provide a history of basic contract and report information used by all offices.

Considerations in developing the system were a need for staff to utilize the system at short notice, a lack of professional ADP staff or support group, and a potential for information requests and/or direct electronic transfer of records from a diverse user group of federal, state or private groups.

Desktop personal computers (PCs) were an obvious choice for immediate access and minimal support requirement. Database software, a more difficult decision, needed to be capable of manipulating largely text data, with either inherently simple commands or programmable menu and control language. Lastly, the PC/software system needed to be in general use and widely accepted as a 'standard.' IBM-type PCs with a DOS operating system were selected (in 1985) as the preferred system for database management (versus Apple or CPM). dBase III was chosen as the software, primarily because of being text-oriented, having a strong program language, and being the most widely used database software.

The National Files portion of ESDS was developed first and consists of two databases for maintaining contract information (CONTRACT. DBF) and document information (LIBRARY.DBF). An auxiliary database of name, address, and phone numbers for staff, vendors, and MMS panel members (ADDRESS.DBF) was also developed. Specific fields in the CONTRACT and LIBRARY files were developed through a series of meetings with MMS headquarters and regional ADP representatives. Essentials of the system are an ability to rapidly identify contracts by region, planning area, technical topic, vendor, contract-type or status, and list costs and/or report associated with any combination of studies identified. dBase program files (menu driven) provide options for the most common information searches and options for formatted printer/screen output. As such, ESDS can be operated with minimal computer skills. The ability to use direct dBase commands greatly enhances the potential use of EDS for more skilled operators.

Both LIBRARY and ADDRESS are menu linked to CONTRACT to provide data on reports produced under a given contract or vendor addresses. In addition, these files can be queried independently for direct listings of references by topic, author, region, etc. or people by name, affiliation, interest, or special group. Additional references and addresses are stored in these files beyond direct contract associated data.

The records portion of ESDS is intended to quickly provide basic program information to HQ, regional offices, or other interested parties. Effective linkage to a telecommunications package is presently underway. The LIBRARY file is approximately 65% complete and will be completed under a contract to the University of Rhode Island's Laboratory for the Study of Information Science (LSIS). During FY88, LSIS will complete final editing of approximately 3,500 records and refine a technical keyword index. CONTRACT records are maintained by MMS HQ staff and are complete through FY87. The ESDS system has been upgraded to dBase III Plus and AT-type PCs.

The HQ Files portion of ESDS tracks assignments, procurement actions, and proposed studies. When a contract is awarded, a record is entered into the CONTRACT database.

Specific information on ESDS file structures, programs, and operations may be obtained from either Norman Hurwitz or William Lang at (202) 343-7744.

QUESTIONS AND DISCUSSION: *Information Management Session*

Question (Banks): This one is for Don. My question is sort of technical and maybe not really appropriate for this forum. It has to do with how records are edited. I know the emphasis so far has been to make the database accessible and somewhat user friendly and be able to get information into it. What happens if we have distributed databases in two different regions? As regions begin editing and headquarters begin editing, how is that going to be managed?

Response (Aurand): Regions aren't going to edit, at least not directly. We are going to try and put a section in the quarterly reports where data discrepancies are identified and then we'll (headquarters) make the changes to the master file. The only reason we're doing that is because we are afraid that something will get lost and we'll have two different versions of the same dataset floating around and they won't be consistent. It's not because we don't think the regions can update accurately. So, ultimately the system just stays on-line and you can just tap in and get Bill to update the record. Right now, the information that the University of Rhode Island works on obviously is sent out to you, it's proofed here, it goes back to URI. Then, after the data is originally put in and any updates we can identify (either by people just telling us something is wrong or for existing contracts), we work off the quarterly status reports to try to keep the information up-to-date regarding what the status of publications is. The one thing we haven't figured out is how to deal with our desire to keep track of publications which result from our work and how we will continually update that information if somebody has a new publication. I'm not sure what we'll do with that yet.

Question (Mendenhall): Question for Brian: Is there anything done on marine birds in your database?

Response (Smiley): No. Nothing on marine birds, polar bears, or white foxes. The areas that we addressed primarily were those that the Department of Fisheries and Oceans somewhere along the line has taken a direct measurement of. We felt that was our first priority area. I'm working with some of the biologists in the Canadian Wildlife Service to see whether it would make sense to move into those other areas, but they keep saying they need $150,000/year for new studies, rather that fooling around with cataloguing historical ones.

Comment (Mendenhall): David Nettleship is working on the Eastern Seaboard catalogue (formerly the Marine Environmental Lab). They are working on a computer database. My comment was that in Fish and Wildlife Service here in Alaska we have a database on seabird colonies which allows us to get a printout on all the colonies in the state if we want or a map of all the colonies. You can get it by species, by area, by USGS map. It's fully operational. Art Sowls developed it, I just inherited it, so I should give him credit. Anybody can send for data. It wasn't designed to be hooked into other computer systems, it's on a Data General, which makes it somewhat restricted access, but Nettleship sent for our formats with the intent that they would be compatible with each other, probably with some conversions if they went from one system to another, of course. We also have another database which is much larger, but still in somewhat a development stage, on pelagic surveys of marine birds. That has a lot of data that was obtained from NODC and converted to our format and also surveys that have been going on in the recent past. The colony catalogue has about 10,000 records and the pelagic seabird survey database has about 250,000. I'm hoping we'll get that to the state where we can actually reliably offer people a product, when they ask a question of us, in about six months at the most.

Comment (Crane): One of the associations that those of us in the room participants in is the Committee on Northern Information Resource Management. And our leader is here, Barbara Sokolov, and several of the topics that you have identified in your cataloguing process are action items that our committee has addressed for the Alaskan area. We would like to work with you in the future on additional cataloguing activities and getting your expertise.

Question (Mate): I know a number of people in the room at the investigator level have talked about this over coffee, because I've overhead some of the conversations. There is a general pessimism about the utility of some of the cataloguing efforts. We realize that people have to make decisions on the best available information. But in the process of pigeon-holing information (particularly raw data), a lot of the skepticism that an investigator might have; some of the quality characteristics get swept by the boards. I know that each group that does this kind of activity has an extreme concern for the quality of the data. Many of the systems that I have looked at do have quality indicators. Some of the comments that I've heard this morning outside have been to the effect that: "Gee, there's a lot of money being spent on this data cataloging. Maybe some of it might be better spent in a better collection of quality information, know that we know what went wrong this first few times around." I guess I'm making this as a general comment that there is a concern that some of the information, particularly some of the historical information, where the records may not have even indicated some of the limits of the utility of the information, might be of limited value and might actually misguide us if we depended on them from too automated a system. I guess I would be interested in other peoples' reaction to that kind of thought. I know each of you consider it independently in your work; I'm not trying to say that you don't.

Response (Smiley): I guess the last sentence was fairly key: Using historical data in an automated sense, particularly through atlasing I think can be very dangerous. The way I use them, for example, is I receive EISs, environmental atlases, or the industry's perspective on the issues related to dumping the drill wastes. They usually refer to the information that they use for that kind of a decision, that kind of prediction or forecast. Without even having the data in hand, one can determine whether they used the most complete historical datasets that are available. Often they use only the ones that they know about or have access to, and they could do a better job with more data. It would support even better their particular decision or prediction. Or, in some cases, they may have used datasets which we think are at this point weak because of the documentation problem and we are able to state that. But, in no way does that mean that the decision shouldn't go ahead. I don't want to say that this has been obstructive to making decisions, planning science or carrying out studies. This is a tool for us to all go ahead, knowing what we do know and how well we do know it. I find it to be much more fun being involved in decision making if everybody has more of an objective understanding of what we do know and everybody can go ahead with that same level of knowledge. It's a useful teaching tool. For example, because so many of the aerial survey work for marine mammals has received such dismal rating in the historical sense, there have been a number of workshops directly stimulated by this exercise to work on standardized techniques of aerial survey work for whales and seals. Again, people note that we shouldn't end up with datasets that we can't compare just because of surveyor inconsistencies.

Comment (Robertson): I wanted to just comment on Bruce Mate's comment. I agree with what Brian said; I basically agree with Bruce Mate's cautionary statement. I know we're very aware of the atlas and the database limitations that we have developed. If someone just went ahead and used that without understanding the strengths and weaknesses of what was done, they could end up with some real bad decisions. We've had to make a lot of compromises with the data to come up with any kind of consistent dataset. There have to be a lot of compromises made that one does not like to make; it must be done and the reason I feel it must be done and why I felt I had to get up and comment is that sometimes people say: "Well, the data is still so incompatible there isn't enough of it, and we're not ready to do anything." The point is that decisions go ahead anyway and we do have to use the information that we have and the imperfect information that we have in the catalogues and atlases, etc. Use the atlas and database definitely with caution but you can't bury your head in the sand and say: "Well, I'm just going to have to wait ten years to decide whether we're going to do any oil and gas leasing until we get some better information." At least in the United States things don't work that way and I don't think they work that way in Canada either, Brian.

Comment (Mendenhall): Basically I agree with what people have been saying, that you have to be concerned about the quality of the data. The USFWS seabird colony catalogue has these quality indicators in it. The value of some of the imprecise data still has a high qualitative value; namely, there was a seabird colony there when they were there. For some species it may not be there any more which is also information, although you don't know how many were there. For all species in parts of this state, in 1976 when the OCSEAP surveys began, nobody knew where any of these seabird colonies were. Unfortunately, for quite a lot of the colonies, that's how old the data is. On the other hand, some of it is last year's data and you can request only the most recent information or you can request the entire historical business.

FISHERIES STUDY PLANNING SESSION

SUMMARY
FISHERIES STUDY PLANNING SESSION

The MMS Alaska OCS Region is planning a five-year Arctic Fisheries Study to begin in FY 1989. The primary objective of the study is to gather and synthesize information on ecological processes affecting fisheries resources in the Arctic that will allow MMS to better assess and evaluate potential effects of OCS oil and gas development activities on these resources.

The goal of this Fisheries Study Planning Session was to gather input from fisheries researchers in the area that would enable MMS to refine the proposed project description into a more specific project definition.

At present there appears to be no adequate database for Arctic fisheries resources. A number of studies have been completed over the last decade, and a number of studies are on-going. Most of these studies, however, are site specific, the result of regulatory permit requirements, and therefore limited in the types of data collected and geographic range. Additionally, the majority of the available data is for nearshore areas and is primarily concerned with anadromous fishes. With respect to marine species very little data exists other than species presence. Stock size and distribution data are virtually non-existent.

Present workers are confounded by the lack of an adequate regional database that would enable them to make definitive evaluations of the potential impacts of activities associated with oil and gas development in the Arctic.

The paucity of information extends to even the most basic ecological information and life requirements of many of the species. While some information is available for the stocks sizes in specific watersheds, little information is available for the general geographic area and there are no data on the sizes of the marine stocks or the magnitude of the fisheries. Available habitat, particularly over-wintering habitat, appears to be an important factor in regulating the populations; however, little data are available for the distribution and extent of such habitat.

On-going efforts by the U.S. Fish and Wildlife Service to assemble and synthesize the available database collected in the Arctic Refuge are continuing, but the future is uncertain due to budgetary restrictions. A major synthesis report by Dave Norton of the University of Alaska is scheduled to be completed in the spring of 1988.

Presently it appears that the fisheries information has been acquired on a site specific basis, without particular attention to the regional needs. The result has been a mosaic of variable data types. To develop a usable database it is important that there be an entity, or group, that can oversee and coordinate fisheries ecology work in the Arctic.

The first step should be assembling, integrating, and synthesizing the database at hand to evaluate and identify information gaps either in knowledge or geography that would be needed to adequately address potential fisheries impacts from oil and gas development. The second step would be to define the tasks and priorities to be accomplished and coordinate the implementation with other governmental agencies and industry studies.

It was proposed that these initial steps be accomplished by a Fisheries Studies Workshop which would bring together those individuals currently working in the Arctic to exchange information and produce an integrated and specific work plan.

APPENDIX I

INFORMATION TRANSFER MEETING AGENDA

APPENDIX I

AGENDA

TUESDAY, NOVEMBER 17, 1987 - ALASKA/DENALI ROOMS

8:00 AM Registration (Continuous until end of meeting; there is no charge, but all attendees are requested to register.)

8:30 AM Welcoming Remarks - A. Powers, Regional Director, MMS Alaska OCS Region Procedures - MMS and MBC Applied Environmental Sciences

9:00 AM Summary of Offshore Oil and Gas Activities in the U.S. Beaufort Sea - J. Walker, MMS/Field Operations

PHYSICAL SCIENCES SESSION

9:30 AM The Arctic Ocean - M.J. Hameedi, NOAA/Ocean Assessment Division, Alaska Office

9:45 AM Arctic Remote Sensing - W. Stringer, UAF/Geophysical Institute

10:15 AM Question and Answer Period

10:30 AM Break

10:45 AM Sea Ice Motion - R. Pritchard, Naval Postgraduate School

11:15 AM Arctic Circulation and Physical Oceanography - K. Aagaard, NOAA/Pacific Marine Environmental Laboratory

11:45 AM Question and Answer Period

12:00 PM Lunch - on your own

1:15 PM Ocean Circulation and Oil Spill Trajectory for Alaskan Coastal Waters - M. Spaulding, Applied Science Associates

1:45 PM The MMS Coastal Zone Oil Spill Model - M. Reed, Applied Science Associates

2:15 PM Question and Answer Period

2:30 PM Break

2:45 PM Beaufort Sea Technology Update - D. Padron, Han-Padron Associates

3:15 PM Beaufort sea Monitoring Program: Analysis of Trace Metals and Hydrocarbons from OCS Activities - M. Steinhauser, Battelle Ocean Sciences

3:45 PM Question and Answer Period

4:00 PM Arctic Coastal Geomorphology - A.S. Naidu, UAF/Institute of Marine Science

4:30 PM Arctic Boundary Issues - S. Ashmore, MMS/Leasing Activities

5:00 PM Question and Answer Period

5:15 PM Adjourn

WEDNESDAY, NOVEMBER 18, 1987 ALASKA/DENALI ROOMS

8:00 AM Registration Continues

ENDANGERED SPECIES SESSION

8:30 AM Bowhead Whale Feeding - W.J. Richardson, LGL Ltd.

9:00 AM Bowhead Whale Growth Rates and Habitat Usage as Estimated by Stable Isotope Techniques - D. Schell, UAF/Institute of Marine Science

9:15 AM Question and Answer Period

9:30 AM Oil and Euphausiids: Laboratory Results, Ecological Notes, and Oil Spill Implications - P. Fishman, Environmental Sciences

9:45 AM What We Can Learn by Tracking Whales with Satellites - B. Mate, Oregon State University

10:15 AM Question and Answer Period

10:30 AM Break

10:45 AM Aerial Surveys of Endangered Whales - S. Moore, Seaco, Inc.

11:15 AM Question and Answer Period

SOCIAL AND ECONOMIC SESSION

11:30 AM Sociocultural and Socioeconomic Changes in Barrow - R. Worl, Chilkat Institute

12:00 PM Question and Answer Period

12:15 PM Lunch - on your own

BIOLOGICAL SCIENCES SESSION

1:15 PM Arctic Marine Ecosystems - D. Schell, UAF/Institute of Marine Science

1:45 PM Arctic Fisheries: Distribution, Abundance and Uses - R. Bailey, U.S. Fish and Wildlife Service

2:15 PM Coastal Marine Birds - D. Troy, LGL Alaska Research Associates, Inc.

2:45 PM Question and Answer Period

3:00 PM Break

3:15 PM Effects of Industrial Activities on Ringed Seals in Alaska as Indicated by Aerial Surveys - K. Frost, Alaska Department Fish and Game

3:45 PM Marine Mammals of Kotzebue Sound - P. Becker, NOAA/National Ocean Service, Alaska Office

4:00 PM Question and Answer Period

4:15 PM Summary of ISHTAR Results - C.P. McRoy, UAF/Institute of Marine Science

5:00 PM Question and Answer Period

5:15 PM Adjourn

THURSDAY, NOVEMBER 19, 1987 - ALASKA/DENALI ROOMS

8:00 AM Registration Continues

ARCTIC INFORMATION UPDATE: Beaufort and Chukchi Seas

8:30 AM Introductory Remarks and Procedures - T. Johnson, MMS/Environmental Studies, and M.J. Hameedi, NOAA/OAD Alaska Office

8:45 AM A Study of Possible Meteorological Influences on Polynya Size - W. Stringer, UAF/Geographic Institute

9:15 AM Ice Flow Along the Coasts - C. Pease, NOAA/Pacific Marine Environmental Laboratory

9:45 AM Circulation - K. Aagaard, NOAA/Pacific Marine Environmental Laboratory

10:15 AM Questions and Discussion

10:30 AM Break

10:45 AM Chukchi Sea Current Meters - W. Johnson, UAF/Institute of Marine Science

11:15 AM Chukchi Sea Zooplankton - R. Cooney, UAF/Institute of Marine Science

11:45 AM Questions and Discussion

12:05 PM Lunch - on your own

12:10 PM Lunch Break - On your own

1:30 PM Isotope Studies of Arctic Zooplankton - S. Saupe, UAF/Institute of Northern Engineering

1:50 PM Continental Shelf Sediments - A.S. Naidu, UAF/Institute of Marine Science

2:10 PM Benthos of the Southeastern Chukchi Sea - H. Feder, UAF/Institute of Marine Science

2:30 PM Questions and Discussion

2:50 PM Population Genetic Structure of Arctic Char from Rivers of the North Slope of Alaska- R. Everett, U.S. Fish and Wildlife Service

3:10 PM Bird-Zooplankton Feeding Relationships - A. Springer, UAF/Institute of Marine Science

3:30 PM Questions and Discussion

3:45 PM Break

4:00 PM Endicott Project: An Industry Perspective - P. Pope, Standard Alaska Production Company

4:15 PM Coastal Processes and Oceanographic Property Distributions in Stefansson Sound - L. Hachmeister, Envirosphere Company

4:45 PM Habit Usage and Movement Patterns of Anadromous Fish in the Prudhoe Bay Region of the Central Beaufort Sea - D. Glass, Envirosphere Company

5:15 PM Questions and Discussion

5:30 PM Adjourn

FRIDAY, NOVEMBER 20, 1987 - ALEUTIAN ROOM

8:00 AM Registration Continues

INFORMATION MANAGEMENT

8:30 AM The Importance of Information Management - T. Johnson, MMS/Environmental Studies

8:45 AM OCSEAP Data and Information Management - M.J. Hameedi, NOAA/OAD Alaska Office

9:00 AM Design and Management of the Alaskan Marine Database - W. Danforth, University of Rhode Island

9:20 AM Arctic Living Marine Resource Database Interactive Assessment Capability - A. Robertson, NOAA/National Ocean Service

9:40 AM Marine Data and Information: An Alaskan Perspective - M. Crane, NOAA/National Environmental Satellite Data and Information Service

10:00 AM Question and Answer Period

10:15 AM Break - Visit the INFORMATION MANAGEMENT DISPLAYS

10:30 AM Cataloguing and Approval of Oceanographic Data and Industry Activities in Arctic Canada - B. Smiley, Department of Fisheries and Oceans

11:00 AM The Environmental Studies Database System - D. Aurand, MMS/Environmental Studies

11:30 AM Question and Answer Period

11:45 AM Adjourn - Thank you for participating in the Arctic Information Transfer Meeting!

ALSO ON FRIDAY:

The Regional Technical Working Group will meet from 9:00 AM to 4:00 PM in the Dillingham Room.

The Fisheries Studies Planning Session will be held from 9:00 AM to 11:30 AM in the King Salmon Room (see draft schedule attached).

APPENDIX II

INFORMATION TRANSFER MEETING

SPEAKER BIOGRAPHIES

APPENDIX II

INFORMATION TRANSFER MEETING SPEAKER BIOGRAPHIES

AAGAARD, KNUT; Oceanographer

NOAA/Pacific Marine Environmental Laboratory
7600 Sand Point Way, N.E.
Seattle, Washington 98115-0070

Education:

Ph.D., 1966
M.S., 1964
A.B., 1961

Alaska OCS Research or Related Studies:

Alaska OCS research and ocean circulation.

ASHMORE, STANLEY; Geographer

Minerals Management Service
949 East 36th Avenue
Anchorage, Alaska 99508-4302

Education:

M.A., 1972
B.S., 1963

Alaska OCS Research or Related Studies:

Alaska Federal/State Boundary Project, 1983-1987.

AURAND, DONALD; Chief, Branch of Environmental Studies

Minerals Management Service
Branch of Environmental Studies
12203 Sunrise Valley Drive
Reston, Virginia 22091

Education:

Ph.D., 1975
M.S., 1968

BAILEY, RANDY; Chief, Fisheries Division

U.S. Fish and Wildlife Service
1011 East Tudor Road
Anchorage, Alaska 99503

Education:

M.S., 1974
B.S., 1973

Alaska OCS Research or Related Studies:

Arctic char genetic stock identification; Bristol Bay salmon genetic stock identification.

BECKER, PAUL; Biologist

NOAA, National Ocean Service, Ocean Assessments Division
701 C Street, Box 56
Anchorage, Alaska 99513

Education:

Ph.D., 1972
M.A., 1969
B.S., 1967

Alaska OCS Research or Related Studies:

Alaskan Marine Mammal Tissue Archival Project; A review of information on Alaskan oil seeps.

COONEY, ROBERT; Associate Professor Marine Science

University of Alaska
Institute of Marine Science
231 Irving, Bldg. II
Fairbanks, Alaska 99701

Education:

Ph.D., 1971

Alaska OCS Research or Related Studies:

NEGOA zooplankton studies 1973-1974; Bering Sea zooplankton studies 1975-1976; Hydroacoustics applied to zooplankton studies; fisheries oceanography.

CRANE, MICHAEL L.; Alaska Liaison Officer

NOAA/NESDIS
707 A Street
Anchorage, Alaska 99501

Education:

M.S., William and Mary, 1974.
B.S., William and Mary, 1969.

Alaska OCS Research or Related Studies:

Managed information service office in Anchorage for the OCSEA Program 1976-1983; Marine pollution information networking 1981-present; Sea ice information analysis showing ice edge boundaries in time series; satellite data services in the Arctic; Arctic information networking activities.

DANFORTH, WILLIAM; Anchorage Liaison

NOAA
Laboratory for the Study of Information Science (LSIS)
701 C Street, P. O. Box 56
Anchorage, Alaska 99513

Education:

M.S., University of Rhode Island, 1986
B.S., University of Rhode Island, 1981

Alaska OCS Research or Related Studies:

Seismic data analysis and applications of geology to microcomputer graphics.

EVERETT, REBECCA; Fishery Biologist

U.S. Fish and Wildlife Service
1011 East Tudor Road
Anchorage, Alaska 99503

Education:

M.A., 1986
B.S., 1976

Alaska OCS Research or Related Studies:

Genetic stock identification of Arctic char; genetic stock identification of Pacific salmon.

FEDER, HOWARD; Professor of Marine Science

Institute of Marine Science
University of Alaska
1752 Red Fox Drive
Fairbanks, Alaska 99709

Education:

Ph.D., Stanford University, 1956
M.A., UCLA, 1951
B.A., UCLA, 1948

Alaska OCS Research or Related Studies:

Benthic studies including distribution and feeding interactions in the northeast Gulf of Alaska, Cook Inlet, southeastern Bering Sea, northeastern Bering Sea, and the southeastern Chukchi Sea (including Kotzebue Sound); Fjord benthic biology: intertidal and subtidal; Seastar brittle star and clam biology; biology of fishes of southern California.

FISHMAN, PAUL; Owner

Fishman Environmental Services
P. O. Box 19023
Portland, Oregon 97219

Education:

Ph.D. Candidate, 1971
M.S., 1968
B.S., 1965

Alaska OCS Research or Related Studies:

Distribution of larval and juvenile red king crabs in Bristol Bay, Alaska 1984; lethal and sublethal effects of oil on food organisms of the bowhead whale 1985; marine fish communities; estuarine ecology, development and mitigation.

FROST, KATHRYN J.; Marine Mammals Biologist

Alaska Department of Fish and Game
1300 College Road
Fairbanks, Alaska 99701

Education:

M.S., University of California, 1976
B.S., Tulane University, New Orleans, LA, 1970

Alaska OCS Research or Related Studies:

Wide variety of marine mammals studies including natural history and ecology of ice seals; food habits and feeding ecology of ice seals, belukha whales, walruses and bowheads; distribution and abundance of ringed seals and belukhas and walruses; radio tagging of belukhas; winter ecology of ringed seals; fishery-marine mammal interactions; biology of prey species.

GLASS, DOMONI; Biological Consultant

Envirosphere Company
10900 N.E. 8th Street
Bellevue, Washington 98004

Education:

M.S., in progress
B.S., 1982

Alaska OCS Research or Related Studies:

Endicott Environmental Monitoring Program - fisheries investigations 1985-1987; Yukon River Delta, distribution of salmonids; fisheries production models.

HACHMEISTER, LON E.; Physical Oceanographer/Manager, Marine Sciences

Envirosphere Company
10900 N.E. 8th Street
Bellevue, Washington 98004

Education:

M.S., 1973
Graduate Work in Physics, 1967-1969
B.S., 1967

Alaska OCS Research or Related Studies:

Endicott Monitoring Program - physical studies (SAPC); Chukchi Sea coastal oceanographic studies (OCSEAP); eastern Beaufort Sea coastal and lagoon characterization (OCSEAP); northeast Gulf of Alaska physical oceanography studies (OCSEAP); ice dynamics; estuarine processes.

HAMEEDI, M. J.; Oceanographer

NOAA, Ocean Assessments Division
701 C Street, Box 56
Anchorage, Alaska 99513

Education:

Ph.D., 1974
M.S., 1970

Alaska OCS Research or Related Studies:

Ecological study of the southeastern Chukchi Sea; modeling of plankton dynamics; application of scientific data for management use; arctic oceanography.

JOHNSON, WALTER R.; Assistant Professor

University of Alaska
Institute of Marine Science
117 O'Neill Bldg.
Fairbanks, Alaska 99775-1080

Education:

Ph.D., 1981
M.S., 1975
B.S., 1972

Alaska OCS Research or Related Studies:

Kotzebue Sound ecosystem study; Chukchi Sea benthos; numerical modeling of storm surges in Norton Sound; Alaska coastal current near Seward; Prince William Sound circulation.

LANG, WILLIAM; Team Leader

Minerals Management Service
5931 Highmeadow Road
Alexandria, Virginia 22310

Education:

Ph.D., 1977
M.S., 1973
B.A., 1971

MATE, BRUCE; Associate Professor

Oregon State University
Hatfield Marine Science Center
Marine Science Drive
Newport, Oregon 97365

Education:

Ph.D., 1973
B.S., 1968

Alaska OCS Research or Related Studies:

Radio tracking large whales; development of satellite monitored radio tags for large whales; marine mammal: migrations, feeding, navigation; diving and competition with fisheries.

MCROY, C. PETER; Professor

University of Alaska
Institute of Marine Science
232 Irving, Bldg. II
Fairbanks, Alaska 99701

Education:

Ph.D., 1970
M.S., 1966
B.S., 1;963

Alaska OCS Research or Related Studies:

PROBES; ISHTAR; ecosystems of the continental shelf.

MOORE, SUSAN; Project Manager

SEACO, Inc.
2845-D Nimitz Boulevard
San Diego, California 92106

Education:

M.S., 1979
B.S., 1976

Alaska OCS Research or Related Studies:

Endangered whale aerial surveys in the Beaufort, Chukchi and Bering Seas since 1981; cetacean bioacoustics and population dynamics.

NAIDU, A. SATHY; Professor

University of Alaska
Institute of Marine Science
112 O'Neill Bldg.
Fairbanks, Alaska 99775-1080

Education:

Ph.D., 1968
M.Sc., 1960

Alaska OCS Research or Related Studies:

Stability of barrier islands, sediments and depositional processes in Alaskan Arctic region; baseline heavy metal contents in Beaufort Sea sediments; Chukchi Sea benthic ecosystem; quaternary history of the Alaskan Arctic marine environment; sources and transport of fine grain sediments.

PADRON, DENNIS V.; Partner

Han-Padron Associates
1270 Broadway
New York, New York 10001

Education:

M.S.C.E., 1966
B.S.C.E., 1964

Alaska OCS Research or Related Studies:

Update of cost data for petroleum development in Alaska OCS; Beaufort Sea petroleum technology assessment; evaluation of Bering Sea crude oil transportation systems; deepwater mooring systems; rapid deployment offshore cargo transfer systems.

PEASE, CAROL H.; Oceanographer

NOAA/Pacific Marine Environmental Laboratory
7600 Sand Point Way, N.E.
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Education

Ph.C., University of Washington, 1985
M.S., Atmospheric Sciences, University of Washington, 1981
M.S., Physical Oceanography, University of Washington, 1975
B.S., University of Miami, 1972

Alaska OCS Research or Related Studies:

Autumn freeze-up in the Bering/Chukchi system, ONR and NOAA; polynyas and coastal ice interactions, ONR and NOAA; vessel icing, NOAA.

POPE, PAMELA; Environmental Scientist

Standard Alaska Production Company
P. O. Box 196612
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Education:

M.S., University of Alaska, Anchorage, 1985
B.S., California State University, Long Beach, 1977
Limnology Institute, Uppsala, Sweden, 1976/1977

PRITCHARD, ROBERT; Professor

Naval Post Graduate School
Department of Oceanography
Code 68-PR
Monterey, California 93943

Education:

Ph.D., University of New Mexico, 1970
MSME, University of New Mexico, 1965
BSME, Lehigh University, 1962

Alaska OCS Research or Related Studies:

Several buoy deployment in Beaufort, Chukchi and Bering Seas; modeling of ice behavior in Beaufort and Chukchi Seas; transport of oil on and under sea ice; modeling sea ice behavior; noise generation by sea ice.

REED, MARK; Senior Scientist

Applied Science Associates, Inc.
70 Knauss Drive
Narragansett, Rhode Island 02882

Education:

Ph.D., 1980

Alaska OCS Research or Related Studies:

Potential interaction of endangered whales with oil spills; impacts of oil spills on Alaskan fur seals; development of a coastal zone oil spill model.

RICHARDSON, W. JOHN; Vice President - Research

LGL Ltd.
22 Fisher Street, P. O. Box 280
King City, Ontario L0G 1K0, Canada

Education:

Ph.D., 1975
B.S., 1968

Alaska OCS Research or Related Studies:

Bird migration - part of Simpson Lagoon ecological process study, 1977; bowhead behavior and disturbance study, Cdn Beaufort, 1980-1985; bowhead feeding study, E. Alaska Beaufort, 1985-1987; subcontractor in BBN site-specific noise and disturbance study, 1985-1987; four ongoing contracts related to site-specific noise and disturbance; bird hazards to aircraft; general ornithology; research design, computing, statistics.

ROBERTSON, ANDREW; Chief, Ocean Assessments Branch

NOAA/NOS
Rockwall Building, Room 652
Rockville, Maryland 20852

Education:

Ph.D., 1964
M.A., 1961
B.S., 1958

Alaska OCS Research or Related Studies:

Ecology, taxonomy and zoogeography of microcrustaceans.

SAUPE, SUSAN; Graduate Student

University of Alaska
Institute of Marine Science
Fairbanks, Alaska 99775

Education:

B.S., 1985

Alaska OCS Research or Related Studies:

North Aleutian Shelf - environmental characterization of (with Don Schell and LGL, Inc.; Kotzebue Sound ecosystem; stable isotope rations of Arctic/Subarctic zooplankton and relation to bowhead whales.

SCHELL, DONALD M.; Associate Professor

University of Alaska
Institute of Marine Science
312 Duckering Bldg.
Fairbanks, Alaska 99775

Education:

Ph.D.

Alaska OCS Research or Related Studies:

Kotzebue Sound, North Aleutian Shelf, Eastern Beaufort lagoons, bowhead whale feeding, Beaufort Sea energy flow, Chukchi Sea primary productivity, Simpson Lagoon-Colville River ecosystem; nitrate contamination of groundwaters; coral reef nutrient dynamics; intramolecular catalysis of aromatic esterhydroysis.

SMILEY, BRIAN D.; Marine Advisor

Institute of Ocean Sciences
Data Assessment Division
Box 6000
Sidney, British Columbia V8L4B2, Canada

Education:

M.S., 1972

Alaska OCS Research or Related Studies:

Impact assessment methodology; ocean data management.

SPAULDING, MALCOLM; President

Applied Science Associates, Inc.
70 Dean Knauss Drive
Narragansett, Rhode Island 02882

Education:

Ph.D., 1972
M.S., 1970

Alaska OCS Research or Related Studies:

Circulation and oil spill modeling for Alaskan coastal waters; oil shoreline interaction modeling - SMEAR use of drifters to represent oil spill movement; numerical modeling of coastal processes computational fluid dynamics.

SPRINGER, ALAN; Graduate Student

University of Alaska
Institute of Marine Science
2621 Lingonberry Lane
Fairbanks, Alaska 99775

Education:

Ph.D, 1987

Alaska OCS Research or Related Studies:

Ecology of seabirds in the Bering and Chukchi Seas.

STEINHAUER, MARGARETE; Principal Research Scientist

Battelle Ocean Sciences
397 Washington Street
P. O. Drawer AH
Duxbury, Massachusetts 02332

Education:

Ph.D., 1977
M.S., 1972
B.S., 1970

Alaska OCS Research or Related Studies:

Beaufort Sea Monitoring Program: Analysis of trace metals and hydrocarbons from outer continental shelf activities; marine monitoring programs; ocean incineration.

STRINGER, WILLIAM; Associate Professor

University of Alaska
Geophysical Institute
611 East Elvey Bldg.
903 Koyukuk Avenue, North
Fairbanks, Alaska 99775

Education:

Ph.D., 1971

Alaska OCS Research or Related Studies:

Statistics of fast ice edge and major nearshore ridging; statistical behavior of Chukchi Sea ice edge; statistics of ice behavior in Norton Sound, Bering Strait; ice displacement studies in the Bering and Chukchi Seas; distribution of floe sizes; analysis of breakup sequence of Norton Slope Rivers; frequency of multi-year ice along the Beaufort Sea coast.

TROY, DECLAN M.; President

LGL Alaska Research Associates, Inc.
505 West Northern Lights Boulevard
Anchorage, Alaska 99503

Education:

M.Sc., 1980

Alaska OCS Research or Related Studies:

Marine birds and mammals, Unimak Pass; marine birds and mammals, North Aleutian Shelf; Beaufort Sea old squaws; Alaska snow geese; population estimates; habitat use; taxonomy.

WALKER, JEFFREY; Operations Unit Supervisor

Minerals Management Service
Alaska OCS Region
947 East 36th Street
Anchorage, Alaska 99510

Education:

B.S., 1970

APPENDIX III

INFORMATION TRANSFER MEETING ATTENDEES

LIST OF ATTENDEES
MMS ARCTIC INFORMATION TRANSFER MEETING
ANCHORAGE HILTON HOTEL
NOVEMBER 17-20, 1987

**Denotes Speaker

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Minerals Management Service
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Minerals Management Service
Alaska OCS Region
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Stanley Ashmore **
Leasing Activities Section
Minerals Management Service
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U.S. Army Corps of Engineers
Regulatory Branch/Special Actions
P.O. Box 898
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(907) 753-2724

Don Aurand **
Minerals Management Service
Branch of Environmental Studies
12203 Sunrise Valley Drive
Reston, Virginia 22091
(703) 648-7729

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U.S. Fish and Wildlife Service
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Anchorage, Alaska 99508
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Suzanne M. Ban
Woodward-Clyde Consultants
701 Sesame Street
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Kevin Banks
Minerals Management Service
Alaska OCS Region
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Anchorage, Alaska 99508-4302
(907) 261-4080

Tom Barnes
North Slope Borough
Planning Department
P.O. Box 69
Barrow, Alaska 99723
(907) 852-2611

Richard Beasley
Department of Natural Resources
Division of Oil and Gas
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(907) 762-2567

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NOAA/NOS Alaska Office
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Alaska OCS Region
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Standard Alaska Production Company
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Robert Brock
Minerals Management Service
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Mike Bronson
University of Rhode Island at NOAA
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Anchorage, Alaska 99513
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ICA5/AEWC
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Barrow, Alaska 99723
(907) 852-2392

Charles D. N. Brower
North Slope Borough
Department of Wildlife Management
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Barrow, Alaska 99723
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A.C. Brown
U.S. Geological Survey
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Department of Wildlife Management
North Slope Borough
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Jack Colonell
Environmental Science & Engineering
2900 Boniface Parkway, #210
Anchorage, Alaska 99504
(907) 337-5833

Earl Comstock
Bering Sea Fishermen's Association
725 Christensen Drive
Anchorage, Alaska 99501
(907) 279-6519

Jack Connelly
Texaco, Inc.
4800 Fournace Place
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Max Coon
BDM Corporation
16300 Christiansen Road
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Seattle, Washington 98188
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University of Alaska, Fairbanks
Institute of Marine Science
231 Irving, Bldg. II
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Alaska Biological Research
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Wayne M. Crayton
U.S. Fish and Wildlife Service
411 West 4th Avenue, Suite 2B
Anchorage, Alaska 99516
(907) 271-4575

William Danforth **
NOAA/NOS Alaska Office
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(907) 276-7600

M. Thomas Dean
Arctic District Office/BLM
1541 Gaffney Road
Fairbanks, Alaska 99703
(907) 356-5132

David Densmore
U.S. Fish and Wildlife Service
Fairbanks FWE Office
101 12th Avenue, Box 20
Fairbanks, Alaska 99701
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George Dickison
North Slope Borough
508 West Second Street
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Pamela L. Dickson
Hughes, Thorsness, Gantz, Powell & Brundin
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Paul Dubsky
Minerals Management Service
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Laurie J. Duker
2805 Breezewood Drive
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Curt Ebbesmeyer
Evans-Hamilton, Inc.
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David J. Friis
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Kathryn Frost **
Alaska Department of Fish and Game
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Fairbanks, Alaska 99701
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Minerals Management Service
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Karen Gibson
Minerals Management Service
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Larry Gilbertson
Envirosphere Company
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Domoni Glass **
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Lon Hachmeister **
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David A. Hale
NOAA/NOS/OAD
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U.S. Geological Survey
4230 University Drive
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Jawed Hameedi **
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Joel Hubbard
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Jerry Imm
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Joel A. Ivey
State of Alaska
Department of Natural Resources
Division of Oil and Gas
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Toni M. Johnson **
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Fred King
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Steve Klein
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Jack Lentfer
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Maureen McCrea
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APPENDIX IV

ACRONYM LIST

LIST OF ACRONYMS USED DURING THE ITM TALKS

Acronym	Definition
ACW	Alaska Coastal Water
ADCAP	Arctic Data Cataloguing and Appraisal Program
ADCP	Acoustic Doppler Current Profiling
AIDJEX	Arctic Ice Dynamics Joint Experiment
ANOVA	Analysis of Variance
ARGOS	Trade name for ARGOS Satellite Telemetry System
ASA	Applied Science Associates
AVHRR	Advanced Very High Resolution Radiometer
AW	Anadyr Water
BOPD	Barrels of Oil Per Day
BSMP	Beaufort Sea Monitoring Program
BSW	Bering Shelf Water
BWG	Boundary Working Group
C&GS	Coastal and Geodetic Survey
CDS	Conical Drilling Structure
COE	Corps of Engineers
COZOIL	Coastal Zone Oil Spill
CPS	Conical Production Structure
CRI	Caisson Retained Island
CTD	Conductivity Temperature Depth (profiles)
DMSP	Defense Meterological Satellite Program
DNR	Department of Natural Resources (Alaska)
EPA	Environmental Protection Agency
ESDS	Environmental Studies Data Program
ESP	Environmental Studies Program
FGGE	First Global GARP Experiment
FNOC	Fleet Numerical Oceanographic Center
GARP	Global Atmospheric Research Program
GC-FID	Flame Ionization Gas Chromatography
GC/MS	Gas Chromatography/Mass Spectrophotogrametry
GEOSTAT	Geostationary Satellite
ISHTAR	Inner Shelf Transfer and Recycling Program
LSIS	Laboratory for the Study of Information Science
MCF	Million Cubic Feet
MMS	Minerals Management Service
NBS	National Bureau of Standards
NESDIS	National Environmental Satellite and Data Information Service
NOAA	National Oceanic and Atmospheric Administration
NODC	National Oceanographic Data Center
NOS	National Ocean Service
NSF	National Science Foundation
NWS	National Weather Service
OAD	Ocean Assessments Division
OCS	Outer Continental Shelf
OCSEAP	Outer Continental Shelf Environmental Assessment Program

List of Acronyms - continued

Acronym	Definition
ODES	Ocean Data Evaluation System
ODIS	Oceanographic Data Information System
PAH	Polychlorinated Aromatic Hydrocarbons
PMEL	Pacific Marine Environmental Laboratory
PROBES	Processes and Resources of the Bering Sea
PSU	Salinity Units
RMS	Root Mean Square
RU	Research Unit
SAR	Synthetic Aperture Radar
SBI	Sacrificial Beach Island
SEACAT	A trade name for a recording CTD instrument
SPAN	Space Physics Analysis Network
SSDC	Single Steel Drilling Caisson
SWEPI	Shell Western Exploration and Production, Inc.
TAPS	Trans-Alaska Pipeline System
TOC	Total Organic Carbon
UHF	Ultra-High Frequency
VHF	Very-High Frequency
WOCE	World Ocean Circulation Experiment
WSF	Water Soluble Fraction
WESCAP	Canadian West Coast Data Cataloguing and Appraisal System

APPENDIX V

CONVERSION TABLE

CONVERSION FACTORS

To Convert	Into	Multiply By
millimeters (mm)	inches	0.03937
centimeters (cm)	inches	0.3937
meters (m)	feet	3.281
meters (m)	fathoms	0.5867
kilometers (km	miles	0.6214
kilometers (km)	nautical miles	0.5397
square meters (m^2)	square feet	10.76
square kilometers (km^2)	square miles	0.3861
hectares (ha)	acres	2.471
liters (L)	gallons	0.2642
cubic meters (m^3)	cubic feet	35.31
cubic meters (m^3)	acre-feet	0.0008106
milligrams (mg)	ounces	0.00003527
grams (gm)	ounces	0.03527
kilograms (kg)	pounds	2.205
metric tons (mt)	pounds	2205.0
metric tons (mt)	short tons	1.102
kilocalories (kcal)	BTU	3.968
inches (in.)	millimeters	25.40
inches (in.)	centimeters	2.54
feet (ft)	meters	0.3048
fathoms (fm)	meters	1.829
miles (mi)	kilometers	1.609
nautical miles (nm)	kilometers	1.853
square feet (ft^2)	square meters	0.0929
square miles (mi^2)	square kilometers	2.590
acres	hectares	0.4047
gallons (gal)	liters	3.785
cubic feet (ft^3)	cubic meters	0.02831
acre-feet	cubic meters	1233.6
ounces (oz)	milligrams	28353.00
ounces (oz)	grams	28.35
pounds (lbs)	kilograms	0.4536
pounds (lbs)	metric tons	0.0004536
short tons (ton)	metric tons	0.9078
BTU	kilocalories	0.2520
Fahrenheit degrees (°F)	1.8 x °C + 32	
Celsius degrees (°C)	0.5556 x °F - 32	

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interest of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in Island Territories under U. S. Administration.