EMERGING ISSUE SUMMARIES

Science Technical Advisory Panel

Presented to the North Slope Science Initiative Oversight Group

Barrow, Alaska
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Bill Streever, PhD (Past Chair) and Scott Pegau, PhD (Chair)
Science Technical Advisory Panel

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Cover Memo

To: North Slope Science Initiative Oversight Group

Through: John Payne, Executive Director

From: Bill Streever, Science Technical Advisory Panel

Date: October 8, 2009

Re: Submission of 13 Emerging Issue Summaries

The Science Technical Advisory Panel (STAP) is pleased to submit these thirteen final draft emerging issues summaries.

As a reminder, these summaries are the result of a process that included:

1. Identification of important emerging issue topics by the Oversight Group.
2. Development of management questions, concerns and needs related to each topic by the Senior Staff Committee.
3. Meetings of subgroups from both the STAP and the Senior Staff Committee to "workshop" each emerging issue topic into notes and in some cases outlines or initial rough drafts of the emerging issue summaries. Results from these subgroup meetings were then further worked by one or more members of each subgroup to develop a draft that could be circulated to all STAP and Senior Staff Committee members for comment.
4. In all cases, draft summaries went through multiple iterations.
5. Draft summaries were submitted to the Oversight Group for comments.
6. Draft summaries were revised by a subset of STAP and Senior Staff Committee members to address comments provided by the Oversight Group.
7. During the July STAP meeting in Deadhorse, draft summaries were revised once again in an attempt to ensure that Oversight Group comments were thoroughly addressed, that the summaries were to some degree standardized, and that those present at the Deadhorse meeting were satisfied with the content of each summary.
8. The summaries were finalized and approved for submission to the Oversight Group during the September STAP meeting in Fairbanks.

9. Throughout the process, Denny Lassuy (Deputy Director) and Bill Streever managed the comments and revisions, acting as both gate keepers and editors, but always with the input and approval of STAP members.

In addition to these thirteen summaries, an emerging issue summary on arctic fish and fisheries will be drafted after the International Arctic Fisheries Symposium in October and a working session during the annual meeting of the Alaska Chapter of the American Fisheries Society this November. The emerging issue summary on socioeconomic structure requested by the Oversight Group has been delayed due to unforeseen circumstances and will be submitted as soon as reasonably possible.

The STAP understands that the Oversight Group may provide additional comments on these final draft summaries. The STAP welcomes these comments and looks forward to finalizing the summaries based on the next round of Oversight Group comments.

In reviewing these summaries, Oversight Group members are urged to bear in mind the following points:

- At the request of the Oversight Group, each emerging issue summary begins with a few highlights, presents an overview and management relevance section, and ends with recommendations. Beyond this, the emerging issue papers vary somewhat in format. For example, some of the overview sections include a small number of citations to support specific statements while most do not. Also, several of the summaries contain the original "questions, concerns and needs" provided to the STAP by the Senior Staff Committee while others do not. Because of differences in the nature of each topic and in some cases the approach taken in drafting each summary, the STAP felt that minor differences in formatting were less important than an appropriate focus on content.
- Review and revision by a professional technical writer will occur after the Oversight Group's final comments have been incorporated. This review will ensure consistent usage, grammar, and spelling among summaries.
- During the final revision and preparation, a representative figure may be added to each emerging issue summary.

Individual members of the STAP have suggested that additional Emerging Issue Summaries may be needed. For example, a paper on the restoration of disturbed habitat could provide useful guidance on a topic that is likely to become increasingly important in the coming years. Time constraints prevented broad discussion of this particular suggestion during the STAP meetings, but nevertheless I feel compelled to bring it to the Oversight Group's attention. I urge the Oversight Group to encourage the STAP to consider this and possibly other gaps in the current list of emerging issues.

The STAP and Senior Staff Committee have also begun to consider a synthesis paper, or "connectivities paper," intended to summarize and link information and

recommendations from among the emerging issues summaries. Even a cursory review of the emerging issue summaries suggests connections between topics. For example, an understanding of changes in climate will lead to improved understanding of changes in shallow permafrost, which has obvious links to changes in hydrology, lake drying, and land cover/vegetation change. Similarly, many of the recommendations in each summary complement one another. For example, development of predictive models for coastal salinization will benefit from the increased precision in our understanding of climate change that results from an improved weather network.

At least two broad recommendations appear in many of the emerging issue summaries. First, improved coordination among researchers is repeatedly recommended. For example, a concerted coordination effort is needed to improve the usefulness of the many meteorological stations scattered across the North Slope. Similarly, a coordination effort could inventory the many vegetation monitoring sites scattered across the North Slope and move toward development of standard methods to detect land cover/vegetation change. Second, improved data management is repeatedly recommended. Many of the emerging issue summaries recognize the need for centralized data management that will ensure data accessibility. Both coordination and improved data management are part of the NSSI mission, and their frequent appearance in the emerging issue summaries underscores the relevance of this mission.

While the STAP has provided some indication of priority within each summary by providing a shortlist of recommendations, the STAP has not thoroughly considered prioritization of recommendations between issues. Nevertheless, it seems obvious that the recommendations made in the Weather and Climate emerging issue summary—which primarily call for improved coordination—should be given a high priority. Improved weather and climate data will be relevant to all emerging issues and can be accomplished relatively straightforwardly by implementing the steps outlined in the recommendations section of that summary. In addition, it seems obvious that an assessment of development scenarios that "bookends" the most likely 20-year future for the North Slope is badly needed. That is, an assessment that describes the range—from least to most—of development scenarios likely to occur in the next 20 years is needed. This recommendation appears in the Increasing Marine Activities emerging issue summary but will have relevance to all emerging issues if it is extended to terrestrial settings.

Lastly, on several occasions the STAP discussed recommended actions that could be pursued relatively easily to yield meaningful results. One example is development of an inventory of long-term vegetation sites and development of a database to archive data from these sites. Pursuit of recommended actions likely to yield meaningful and visible results in a short timeframe will add to the NSSI's credibility and visibility.

The STAP looks forward to the Oversight Group's comments and further direction.

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Updated Content
June 2, 2014

The original Emerging Issue Summaries were released in late 2009, followed by minor revisions in 2010. Since 2010, there have been three additional summaries completed by the Science Technical Advisory Panel: Cultural, Fisheries and Restoration, which are included in this update.

Since the initial release of the summaries there has been considerable effort by the North Slope Science Initiative, its member agencies, and outside organizations to address many of the recommendations in the summaries. In some cases the recommendations fall within the mandate of an individual agency and budget planning to address these is on-going (and usually multi-year in scope). From the very beginning of the development of the summaries it was recognized the sheer number of recommendations, the cost and the manpower required to address each is, and will continue to be a challenge, as well setting priorities for those that are multi-agency in nature. To help with prioritization, the North Slope Science Initiative Oversight Group recommended scenario planning. To that end, the North Slope Science Initiative, with the support of its membership and a grant from the National Fish and Wildlife Foundation, entered into an agreement with the University of Alaska Fairbanks for the North Slope Scenarios Project. The purpose of this project is to help prioritize the multitude of science and monitoring recommendations in the summaries through the year 2040.

The Science Technical Advisory Panel, Senior Staff Committee, Oversight Group, and outside expertise that developed the summaries recognize they are a “point-in-time” and are “fluid” in implementation. Meaning there are multiple entities addressing portions of most of the summaries requiring periodic revisiting and updating. Typically, budget planning takes from two to five years in advance of a project to receive the necessary funding to implement. We are at the five-year mark since the initial release of the emerging issue summaries and the Science Technical Advisory Panel is being asked to revisit some of the recommendations to bring them current.

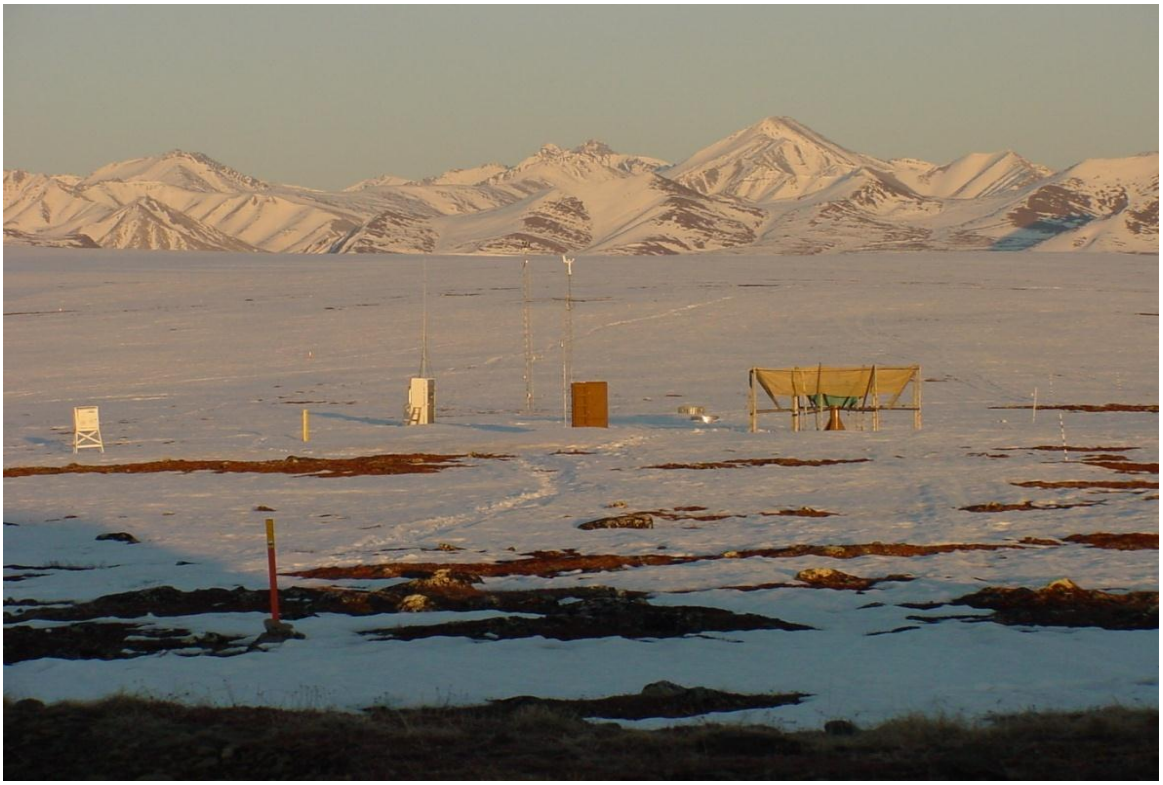
Emerging Issue Summary
WEATHER AND CLIMATE

Highlights:

- North Slope weather data collection is currently ad hoc at best; a systematic approach to data collection, data storage, data management, data dissemination, and equipment maintenance is critically needed for accurate assessment and prediction of weather and climate patterns.

- Agencies and other entities responsible for and in need of weather data need to work together in a concerted effort to inventory existing weather stations, undertake a gap analysis, and invest in an improved, well-coordinated, and centrally managed (or at least coordinated) system.

- The pressing need for improved weather data collection and management cannot be overemphasized. The current state of affairs is troubling and in need of immediate rectification.



Meteorological station on the North Slope. (Doug Kane, UAF)

Overview and Management Relevance:

Weather and climate are among the most pressing environmental issues facing society in general. Climate change is impacting arctic people, wildlife, and habitat while also affecting industrial operations. Many of the other emerging issues are directly related to expected changes to the local climate. In short, we must make substantial improvements in how we undertake the most essential task of understanding and modeling climate if we are to achieve much progress on other issues. These improvements require improved weather data that will allow both downscaling of models and ground truthing of models. Improved weather data will also provide benefits beyond their use in climate change studies, such as improved logistical planning for field operations.

First, two definitions: Weather is the measurable day-to-day variation in temperature, wind, precipitation, and so on at discrete locations. Human activity is strongly influenced by the weather. It determines if flying will be safe, and when roads need to be plowed. Climate is the derived long-term trend in the weather, the variation in average conditions over months and years on a regional basis. It determines how many plows might need to be purchased and maintained based on the expected amount of snowfall and number and severity of winter blizzards. Knowledge of the weather is essential in human operations. Knowledge of the climate is essential in human planning. The two are connected in a practical way because climate data are derived from weather data.

The "weather station," be it a single temperature recording device or a complex 1st order NOAA weather station, is the unit on which both types of information are based. With climate warming underway, understanding both the weather and climate are equally important at this juncture on the North Slope. Weather and climate play a role in many short-term and virtually every long-term management decision on the North Slope.

On the North Slope, there are multiple independent stations and networks recording the weather. Some of the stations are part of formal national weather and climate networks while others are part of small private and/or research networks (e.g., UAF/WERC). Since these stations have different purposes and funding sources there is little to no coordination of efforts. No single individual or agency knows the totality of what is in place and operating, nor who is operating it. A wide range of instrumentation is employed with varying degrees of success. The spacing of the existing weather networks and individual stations is the result of specific project-driven needs, logistical realities, and in some cases, the legacy of past practices (e.g., one network operated by the USGS is located at NPRA boreholes). Measured parameters, protocol, quality, and maintenance vary widely from station to station.

Despite a lack of information on existing weather stations and their capabilities, it is clear that current efforts to measure weather are not adequate. Even if existing

disparate networks could be integrated into a single well-operating network with exemplary data reporting, we would still be under-sampling the weather and climate conditions of the North Slope. Moreover, the existing data cannot be found in any single one-stop location. In fact, prior attempts to consolidate data from multiple sources have resulted in frustration and ultimately failure.

Finally, the current ad hoc network includes within it ephemeral stations and ghost stations. Ephemeral stations are operated by individuals or agencies for which the means for long-term continuity does not exist, and which are likely to cease operation after just a few years. Ghost stations are those that were once operated, perhaps even generating a lengthy record, but which are no longer operating. Ephemeral and ghost stations both could contribute significantly to our understanding of weather and climate change on the North Slope, but in their current state, they are unlikely to do so. Therefore, steps need to be taken to rescue data from ghost and ephemeral stations. It is also important to establish a mechanism for temporarily supporting stations and systematically assessing their importance and developing a long-term solution to keep them operating if appropriate.

The end result is that the meteorological data may be under sampled in large regions and well sampled in smaller areas. The diversity of approaches requires a fair amount of effort to allow comparisons. The ephemeral nature of a majority of measurements severely hampers the ability to derive climate information which requires long-term, consistent measurements.

Why is this issue so important and fundamental? A few anecdotal bullets may illustrate the problem:

- Research or work crews try to fly into a remote location on the North Slope, but are forced to return because while the weather was good at the nearest weather station, it was bad at the remote site. Such flights waste time and resources, but beyond cost concerns, these situations are potentially dangerous for the personnel involved. Clearly, weather prediction for the North Slope is hampered by a low density of reporting sites, yet many existing sites are not being used or are not known to weather prediction agencies.

- In the face of unprecedented changes in the cryosphere, weather patterns across the North Slope are changing markedly. For example, snow melt arrives two weeks earlier now than it did 30 years ago. Baselines from past years may thus no longer be valid as a basis from which to compare future change with current conditions.

- Current weather and climate forecasts are used by both agencies and industry for planning on when to start and demobilize projects. DNR and BLM currently use data from a limited number of stations along the road system to make

tundra opening and closing decisions. Having greater access to real time data from a properly designed network of weather stations across the North Slope would allow both industry and the agencies to make more informed, and hopefully more accurate and operationally efficient decisions.

In short, this emerging issue of weather and climate cuts across all agencies and stakeholders living and working on the North Slope, and is absolutely fundamental to what they do. Although existing data collection networks are inadequate, rapid and much-needed progress could be made with relatively little outlay in money and effort. This progress could serve as a shining example of the value of the NSSI.

The following recommendations focus on collection of the weather measurements that are required to provide a credible basis for the climate change information needed to address several other emerging issues. We leave the effects of climate change on particular issues, such as coastal erosion and sea ice, to those emerging issue documents. Efforts to improve and downsize climate models appropriate to the North Slope region are being conducted through various national and international research programs. These programs recognize a need to provide results on a scale appropriate to answer regional questions, but the quality of local and regional information to feed these efforts is what needs immediate attention.

Recommendations:

1. Inventory all of the meteorological data and stations and do not judge them while performing the inventory. Other such inventories have proven useful and worth the time. For example, the Western Regional Climate Center (WRCC) completed inventories for all of the NPS networks in the country (http://www.wrcc.dri.edu/nps/reports.php) which address measurements, consistency, maintenance, standards, QA/QC, and so on. This will take a real person (or persons) doing a lot of detective work in the form of phone calls and site visits. Give them the necessary time and resources to do this well. The inventory should include information about type of data, length of record, source of funding, likelihood of continued operation, annual cost, method of data transmission (GOES, radio, collected on visits), and so on.

2. Determine the degree of flexibility in station design to assess whether modifications in design and deployment are feasible that allow the stations to provide more consistent data while still achieving their intended purpose.

3. Canvas the various NSSI agencies and groups and from this process develop a list of what these groups need in the way of a) operational weather data, b) weather forecasting, including short- and long-term and local and broad-scale wind condition, c) climate forecasting, d) data to test empirical, physical, and hybrid models (of natural systems and biota) and e) other

research applications. Allow these needs to vary from group to group, but look for common areas within the needs.

4. Using the information from the canvas, engage in a "gap" analysis: Where are new stations needed? Gaps exist only when questions or issues are defined. For an example of this kind of analysis, see the work of the WRCC and interagency Program for Climate, Ecosystem and Fire Applications which assessed the Great Basin Remote Automated Weather Stations network and produced both criteria and recommendations for new stations to fill gaps in that region (http://www.cefa.dri.edu/Publications/gbreport.pdf).

5. Determine how best to use gridded model products (for example, the Oregon State University PRISM climatology or the North American Regional Reanalysis) in conjunction with station data to produce better, more spatially explicit weather and climate products, as well as to explore where to best augment future measurement networks.

6. Collectively pool resources and begin to install new stations as identified in Step #4 above. A climate network may best be built through efforts from the multiple groups currently collecting weather data. This may require some creative management to successfully maneuver through likely controversies with regard to financing and operating stations and managing data.

7. Explore what would constitute a nationally satisfactory way of making the data accessible to users with a minimum of cost and effort, and how this would be integrated with existing national archiving efforts. Be sure to address the issue of credit: every individual, group, or agency wants their efforts to be recognized and acknowledged. The data should be archived and disseminated through an appropriate entity (e.g., WRCC).

8. With the weather network improvements that result from the above described steps, better and more reliable downscaled climate predictions will result. This will present an excellent opportunity for agencies to then collaborate on the acquisition and use of shared forecasts that can be used to assess climate impacts on activities and resources in their respective areas of responsibility.

We understand that some progress is already being made, under the aegis of the National Weather Service, on Recommendations 1, 2, 4, and 7. However, it is our belief that if the steps outlined above were undertaken with vigor and with sufficient human and financial resources in a coordinated manner by all NSSI entities, a more complete and very positive result would be produced in a reasonable period. We add one perhaps obvious caveat: in the process outlined above care needs to be taken to avoid placing too much of a time and money burden on the operators of the networks that are

already in place—that is, it is important to avoid discouraging participation. With this in mind, having sufficient staff to direct and implement the project is crucial.

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Emerging Issue Summary
INCREASING MARINE ACTIVITIES

Highlights:

- There is an immediate need to identify the likely range of human activities (e.g., oil and gas development, fishing, and tourism) in the coastal and offshore waters of the North Slope over the next 20 years. The Arctic Council's "Arctic Marine Shipping Assessment 2009 Report," the National Research Council's assessment of cumulative effects from oil and gas development, and various NEPA documents offer reasonable starting points for the prediction of future scenarios.

- Once plausible scenarios are understood, potential environmental effects should be modeled in a manner that is relevant to decision makers but also recognizes uncertainties inherent in development trajectories.

- For many issues, a need for Arctic-specific baseline information on current conditions (e.g., community composition, noise levels, water quality, invasive species) and risk assessment (e.g., for oil spills, shipping accidents, bird strikes) was apparent, as was the need for such information to be made accessible to the public (e.g., through GINA).

- Because consideration of cumulative impacts will be important, effective short- and long-term monitoring of human activities and the physical and biological environments will be needed. Development of standardized methods will be required to make appropriate comparisons over time.

U.S. Coast Guard icebreaker Healy in the Arctic Ocean. (USCG)

Overview and Management Relevance:

NSSI Senior Staff Committee provided the STAP with questions relevant to increased marine activity and these are specifically addressed below. Although each question was addressed individually, a number of other approaches to organizing information contained in responses was discussed; for example, information could be organized by the type of physical, biological or social driver most affecting each question; by the nature of the questions presented by agency staff (e.g., information gap filling, impact assessment, or mitigation/regulation); or by timeline for the need for the information (1-3 years, 3-10 years, and 10-20 years). No single approach was chosen, but aspects of each of these approaches are woven into the findings presented below in association with each question.

Cumulative effects were discussed as a general topic of relevance to this emerging issue and others and is covered in part under Question 3. It is worth noting that practicable short- and long-term monitoring that retains comparability over time will be needed in any approach to assessing cumulative impacts. MMS efforts such as ANIMIDA and COMIDA provide good examples of affordable methods that can be consistently applied to produce relevant results. Similar efforts will be needed throughout the foreseeable future to support any approach to assessing cumulative effects. However, the whole issue of how to assess cumulative effects is broader than North Slope or even Alaskan concerns. Also, although cumulative effects analyses are a routine part of the planning

process, and although a large literature describes various approaches to assessing cumulative effects, it remains a subject that generates debate throughout the scientific and management communities, especially with regard to the cumulative effects of underwater sounds associated with marine activities. Any effort to assess cumulative effects should begin with a thorough understanding of the methodological literature on cumulative effects analyses and a thorough knowledge of past work assessing North Slope cumulative effects, including work associated with various National Environmental Policy Act (NEPA) documents as well as work undertaken by the National Research Council. However, unique new ways to assess cumulative effects may be necessary to address North Slope issues.

Finally, some of the questions from the staff were in fact not issues that warranted scientific or technical advice, but rather were issues that needed management action or legal interpretations beyond the purpose of the STAP. The STAP's responses to individual questions follows.

1. *In what ways will increased access enable increased development?*

   In the absence of restrictive legislation, increased access likely to result from reduced ice cover will enable increased development and increased activity (including, for example, mining and additional oil and gas exploration and development), but the degree to which this is likely to occur is not known. Despite significant challenges associated with forecasting future development trends, there is an immediate need to gain a basic understanding of the likely range of exploration and development and operational scenarios (including energy development, shipping, and tourism activities) in the 1-20 year timeframe using economic research techniques, perhaps including assessments of historical trends, surveys, interviews, and workshops and by drawing from the Arctic Council's "Arctic Marine Shipping Assessment 2009 Report," the National Research Council's assessment of cumulative effects from oil and gas development, and various NEPA documents. Climate drivers should be a part of these considerations. The goal is to understand, to the extent possible, the likely future of North Slope activities so that research can be planned to address potential impacts in a manner that will allow adjustment of regulatory frameworks as appropriate to manage expected impacts. As an example, if shipping activity is likely to substantially increase, research geared toward understanding underwater sounds associated with shipping, the response of marine mammals and other marine life to these sounds, and approaches toward assessing cumulative effects of multiple sound sources would be justified. All findings would require ongoing assessment and revision as the economic and environmental landscapes change. It should be noted that the North Slope Borough intends to hold a workshop in 2009 to develop a quantitative approach to measuring cumulative effects of industrial activities on bowhead whales. The results of the Arctic Marine Shipping Assessment and this cumulative effects workshop could be combined to suggest a

way forward for research relevant to the management of impacts from underwater sounds associated with shipping.

2. *How will infrastructure expand to serve development and what may be the effect of this expansion?*

   As noted in number 1, above, it is difficult to predict how infrastructure will expand to support development. As a subset of work undertaken to understand likely future development and operational scenarios, research should be undertaken to better understand methods of predicting the trajectory of economic development, including but not limited to oil-and-gas development. That is, while work moves forward to better understand likely future scenarios, additional work needs to be undertaken to better understand methods of modeling and the information needed to populate and interpret the models used to predict scenarios. For example, some models are based on back-casting development patterns. Rather than relying solely on historical trends, a thorough understanding of innovative options for development, along with information on their potential cost-effectiveness, will be needed. Understanding the effect of expansion will require an interdisciplinary systems analysis considering social and ecological factors. In the short-term—that is, over the next 1 to 3 years—the focus needs to be on predictions of future scenarios, and, during that same period, on developing methods for improving predictions. Once plausible development and operations scenarios are understood, the potential environmental effects of development should be modeled and compared in a manner relevant to decision makers. Information needed to feed into the "potential effects" modeling includes informed mapping of sensitive sites and an understanding of how these may change as the climate changes.

3. *What are, and how will we measure, the cumulative effects of increases in various marine activities?*

   To best address this question for North Slope offshore issues, a clear definition of what is meant by "cumulative effects," especially in a changing climate, should be developed, probably through a dedicated workshop with participants capable of considering additive effects, nonlinear effects, nested effects, and other subcategories of cumulative effects. Human health and societal health should be explicitly considered. In parallel with organization of a workshop to better define cumulative effects, an inventory of the existing approaches to cumulative effects assessment should be developed. Consideration of cumulative effects assessment should include transboundary issues (political boundaries as well as community and ecosystem boundaries), various development scenarios, a range of climate change scenarios, and interactions between offshore and terrestrial systems. In addition to these efforts, a retrospective study or studies should compare predicted cumulative effects from past Environmental Impact Assessments or Environmental Impact Statements with actual observed effects in an effort to learn from past mistakes and

successes. Armed with a clear definition, empirical evidence, the inventory of existing approaches to cumulative effects, and information from retrospective studies, simulation models should be developed to identify situations in which cumulative effects are likely to be important. These models should be developed as interactive decision support tools (i.e., useful as part of an adaptive management program) and in this sense they will be different than but complementary to cumulative effects assessments that are legally required as part of the NEPA process.

4. *Baseline information is lacking for many categories of information (species, habitats, water quality . . .); to the extent it exists, is there adequate access to the data?*

   Despite strong efforts undertaken by agency and industry research programs, environmental conditions in many areas likely to face increased marine activity in the coming years have been sparsely documented. Significant regional programs of data acquisition on currently existing conditions, including data on seasonal and interannual variability, are needed for areas likely to be affected by increased marine activities. Each program should establish priorities that are relevant to the potential scenarios for increased activity and to regulatory requirements. In general, priorities are likely to include collection of climate data, marine wildlife and fish population dynamics data (including abundance estimates and seasonal locations of marine mammals, key fish species, migrating and molting sea ducks, and key invertebrate prey species), habitat mapping, and inventories of human use (both subsistence and commercial). General species inventories may also be warranted to better understand the potential spread of species transported on vessel hulls and in ballast water. Programs should focus on understanding both open water and ice-covered season conditions. All entities undertaking environmental research potentially relevant to public agency decision-making should be required to make data publicly available either directly through or linked to the Geographic Information Network for Alaska (GINA) or comparable databases. Existing sources of information should also be more fully accessed and used – for example, 'gray literature' reports by agencies and industry reports.

5. *Will the spread of invasive species increase? If so, which species and which pathways will be important? How can the spread of invasive species be reduced?*

   Although information on native species is incomplete and it is not known to what extent significant invasions have already occurred on the North Slope, it is apparent that increasing marine activity coupled with climate change will result in the increased introduction and spread of invasive species. Which species are likely to be important invaders and which pathways are likely to be most prominent are currently not well studied, though some pathways are obvious, such as shipping (through ballast or hull fouling) and the re-use of marine equipment from other locations without sufficient cleaning between uses. Establishment of an adequate baseline, acceptable sampling protocols, and credible monitoring systems are

needed. For an Alaska marine example for baseline determination, see the work of the Smithsonian Environmental Research Center (SERC) done in Prince William Sound (available at: http://www.pwsrcac.org/docs/d0032100.pdf). Once a baseline is established, research will be needed to understand risks associated with species invasions. An important component of this will be to establish a cost-effective early detection monitoring network, for example by engaging a network of citizen scientists. These immediate needs should be addressed before significant increases in marine activities begin—that is, within the next one to three years. Potential pathways for species introductions should be identified and inventoried, with initial emphasis on shipping pathways through the Northern Sea Route and Northwest Passage. Once pathways are identified, species likely to be transported via these pathways should be identified and those species with the greatest likelihood of becoming established should be determined. Methods to prevent transport of species will have to be prioritized on a risk basis, with the majority of effort targeting those species most likely to aggressively colonize new areas and those pathways most likely to facilitate species invasions.

6. *How will oil spill risk for production operations and for transport operations change in the coming years?*

   Assuming that offshore development of oil and gas fields moves forward, or that shipping activity increases, spill risk will increase. The risk of transport spills (spills from vessels transporting goods, supplies, or products) may be greater than the risk of production spills (spills associated with oil and gas production) at least in terms of catastrophic (rather than chronic) spill events, so to some degree research should focus on transportation risk. Recognizing that spills may include substances other than oil, management and related research should not be limited to oil spills. Probabilities for different sizes of spills of various materials associated with a wide range of activities in different locations should be estimated. Substantial work on spill trajectories is needed, including further work to understand surface currents. A standard risk assessment method should be developed. Risk assessments, including those undertaken during contingency planning, should include consideration of spill response capacity, including consideration of seasonal conditions, availability of personnel and equipment, and emerging methods, especially during severe weather or in broken ice, where response capability is limited at best.

7. *How will the 'acoustic ecology' change and what is the comparability of prior studies (e.g., Gulf of Mexico versus Arctic)?*

   If marine activity levels increase, the anthropogenic acoustic footprint will inevitably increase, especially in the frequency range below 1,000 hertz. Furthermore, as ice cover recedes and ice thickness decreases, ambient sound conditions will change. Understanding ambient sound conditions will be a necessary step toward better understanding potential impacts from anthropogenic sounds. Acoustics and

biological work done in the Gulf of Mexico and other regions has very little application to the acoustic ecology of the Beaufort and Chukchi Seas because of differences in physical conditions that affect sound transmission, differences in species that occur in the Arctic, and differences in the degree to which Arctic species have become habituated to anthropogenic sounds. Regionally specific acoustic studies are needed to account for differences in oceanographic, bathymetric, and other environmental conditions as well as differences in species-specific and situation-specific responses to anthropogenic sounds. Behavioral studies of migrating and feeding marine mammals are needed to understand reactions to sounds associated with increased marine activity. At a minimum, long-term monitoring of sound is needed throughout the Chukchi and Beaufort Seas on a year-round basis to allow understanding of change as development progresses and the climate changes (which is likely to result in changes in ambient sound levels as a result of decreased ice cover, increased fetch, and perhaps increased wind speeds and precipitation). The field of acoustics, perhaps more so than most other fields, suffers from the absence of standard methods—effective long-term acoustic monitoring requires development of standard methods. For further information, see the Marine Mammals Emerging Issue Summary.

8. *How will shipping and other marine operations interfere with species and their pursuit by subsistence hunters (e.g., will whale migrations be deflected and whaling access thus be altered)?*

   The degree to which increased marine activities will impact subsistence species and subsistence hunters depends to a large degree on the extent and nature of the increased marine activities and implementation of appropriate mitigation measures. At a minimum, the presence of increased facilities and vessel traffic will limit access to areas in the immediate vicinity of the facilities and traffic. Increased vessel traffic will inevitably lead to collisions with whales. Regarding impacts to marine mammals important to subsistence hunters, currently available information from studies associated with BP's Northstar production island suggests that at least some bowhead whales respond to continuous anthropogenic sounds that are slightly above ambient levels by moving away from the sound source or changing calling behavior. Additional data from studies associated with seismic shoots suggest that some bowhead whales avoid impulsive sounds with levels greater than about 120 dB RE 1µPA (broadband) and that most bowhead whales avoid impulsive sounds with levels approaching 180 dB RE 1µPA (broadband). Limited data suggest that ringed seals are substantially less responsive to anthropogenic sound than bowhead whales. Data on other marine mammal species – including beluga whales, walrus, and the various other whales and seals that occur in the Arctic – is limited. Very little is known about long-term effects of chronic exposure to anthropogenic sounds in bowhead whales and other species that occur in the Arctic. In short, existing information suggests that unfettered increases in marine activities will eventually lead to changes in the behavior of some marine mammals that will reduce their

availability as subsistence food. Information needed to more thoroughly address the question includes the current patterns of habitat use by bowhead whales (especially west of Point Barrow) and other species, an improved understanding of avoidance or migration deflection responses for most species, improved understanding of behavioral responses such as changes in diving patterns in the presence of anthropogenic sound, and improved understanding of the chronic effects of exposure to anthropogenic sound that might change fecundity and growth rates. To some degree, research on bowhead whales and beluga whales should be prioritized in recognition of their apparent sensitivity to anthropogenic sound and their importance to subsistence hunters. Additionally, spatially explicit quantitative research focusing on social and ecological interactions is needed to understand subsistence use patterns. "Anxiety studies" should be undertaken to understand industry impacts on the quality of the subsistence hunting experience and way of life. For further information, see the Marine Mammals Emerging Issue Summary.

9. *To what degree will increased marine discharges of pollutants affect water quality (e.g., for prey species)?*

   The degree of impact associated with marine discharges will depend on the species exposed and the type, magnitude, timing, and location of discharges, as well as other factors. Research should estimate risk associated with various kinds and quantities of discharges under various conditions, including risks to important subsistence species or their prey. Research should also include analyses of the likelihood of reaching various levels for each kind of discharge. Emerging technologies that will limit or eliminate discharges should be reviewed and opportunities for research and development that will limit or eliminate discharges and thus reduce the likelihood of reaching levels that can meaningfully harm the environment should be pursued.

10. *What are the risks from the increasing presence of non-ice hardened cruise ships?*

    The suite of risks associated with non-ice hardened ships, such as cruise ships, is similar to other shipping and includes oil spills, spills of other materials, invasive species transfers, loss of human life, capacity for response and rescue, direct and indirect impacts on coastal communities and coastal ecosystems, and potential interference with subsistence, industry, and scientific operations. Incident Management Team exercises could be mounted as a "research tool" to better understand the consequences of sinking's, collisions, or other accidents, including the consequences for local communities, hunters, researchers, and others likely to be involved in search and rescue efforts. In addition, impacts from shipping in the absence of accidents should be considered, probably as part of other impact studies.

11. *Will increased activity cause more bird strikes?*

Greater marine activity will increase the number of obstacles present in the near shore and offshore environments and will therefore increase the number of bird strikes. Detailed satellite tracking studies can identify movement patterns of birds and yield insight on areas where collision risk might be high enough to justify mitigation efforts. Bird strikes on existing structures or vessels should be monitored and quantified as a low-cost method of understanding the severity of the problem. Methods to decrease the likelihood of collisions, such as warning lights, should be developed and assessed, perhaps using methods similar to those used in BP's Northstar Avian Radar Study. It should be noted that marine mammal strikes will also increase as marine traffic increases (and as marine mammal populations or densities increase).

12. *What are the Law of the Sea implications?*

    U.S. participation, or continued non-participation, in the United Nations Convention on the Law of the Sea may affect the legal framework within which marine activities operate and may even have some implications for the coordination and implementation of arctic studies. However, the STAP does not see this as a scientific or technical issue, but rather as an issue best addressed by policy makers and attorneys.

13. *We will need even greater federal/state/local coordination to avoid regulatory uncertainty for activity management.*

    It seems reasonable to believe that increased marine activity will lead to a need for greater intergovernmental coordination. However, the STAP does not see this as a scientific or technical issue, but rather as an issue best addressed by managers.

Recommendations:

1. As soon as possible and as a first step to understanding potential impacts and management needs, the NSSI should undertake or encourage assessment of the likely range of development and operational scenarios in the 1-20 year timeframe.

2. Once the likely range of development and operational scenarios is understood, environmental effects likely to be associated with these scenarios should be assessed.

3. In areas likely to face increased development pressure, the NSSI should encourage continuing and new data collection efforts using standard methods. Methods standardization is critical to ensure comparability of data collected over time.

4. The NSSI should promote requirements to make environmental data publicly available through GINA or similar databases.

5. While research needs associated with future development scenarios are under development, and while standard methods are developed, the NSSI should encourage ongoing and new research related to contaminants, anthropogenic sounds, bird strikes, and similar potential impacts. That is, neither the development of likely future scenarios and their associated impacts nor development of standardized methods for use in monitoring should be used as an excuse for deferring research efforts.

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Emerging Issue Summary
CHANGING SEA ICE/OCEAN CONDITIONS

Highlights:

- Sea ice extent, type, and concentration information is available daily from the National Ice Center (NIC) for the North Slope adjacent ocean areas. These observations are derived from a suite of satellite data that, depending on cloud cover, varies from 200 m to 25 km in spatial resolution. Improved resolution is desirable.

- Historical ice data derived from satellites for the North Slope go back to 1979 and are available through the National Snow and Ice Data Center (NSIDC), National Oceanographic Data Center (NODC), and the Canadian Ice Service (CIS).

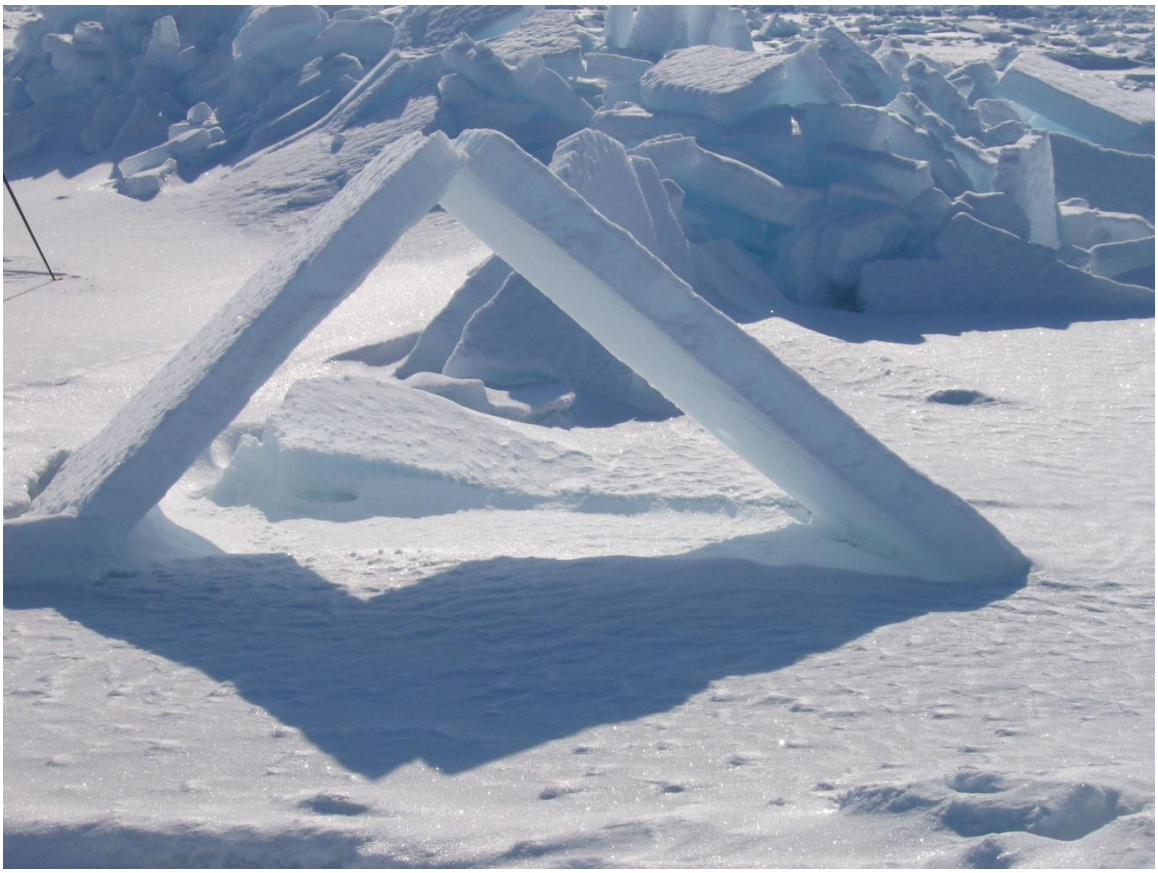
- Wind, wave, and ice observations for the open ocean are provided daily during the open water season from a combination of satellite observations and National Oceanic and Atmospheric Administration (NOAA) buoys; however, there is not the long historical record of these observations as in the case of sea ice.

- There is an overarching need for high quality, user-friendly access to data and model projections for sea ice and ocean changes that are specific to local conditions.

- Historic information (both remotely sensed and local traditional ecological knowledge) can be useful in assessing ice conditions.

- More research is needed to understand fate and effects of oil spills in sea ice during freeze-up and spring melts.

- A series of actions, beginning with a synthesis workshop, is recommended.



Chukchi Sea ice buckling under changing sea conditions. (Ben and Deb Greene, NSB)

Overview and Management Relevance:

Changing sea ice and ocean conditions will affect marine ecosystems and resource access, development and management. Each potential impact presents its own unique set of questions and need for data acquisition and model development. For instance, oil spill response requires evaluation of existing technologies as well as scenario modeling and risk assessment in the context of potential ice conditions. Alaska Clean Seas (ACS) presently has a contingency planning process for oil spills in ice covered waters, but these plans do not account for the rapidly changing ice conditions projected over the next decade. In the case of sea ice as a platform for subsistence hunting, data must be collected in the form of traditional local knowledge as well as correlation of changing ice conditions with records of changing harvest locations and success. Effects of wave regime on erosion patterns will depend on detailed local bathymetry. Understanding the potential effects of ice melt on contaminant load requires models of ice changes as well as atmospheric models of airborne contaminants and deposition on snow and ice. All of these issues share an overarching need for high quality, user-friendly access to present and historical data and model projections for sea ice and ocean changes that are specific to local conditions. The website for the "Sea Ice Outlook"

(http://www.arcus.org/search/seaiceoutlook) is a step in the right direction. We understand the Alaska Ocean Observing System (AOOS) is also addressing this problem; NSSI-GINA personnel should coordinate their efforts with AOOS to avoid duplication.

In the Arctic, much of the focus to date has been on changes in sea ice, water temperatures, and related water movements (currents). However, ocean acidification may become increasingly important or even as important as changes in sea ice, water temperatures, and related water movements in the coming decades. The importance of ocean acidification in the Arctic and the need for monitoring or research needs to be assessed.

Aside from the issue of ocean acidification, the emerging issues related to sea ice and ocean condition all require that historic ice records be extracted and compiled in a user-friendly form to be made available across agencies, recognizing the important distinctions between shore-fast and pack ice. Some recent ice extent mapping projects have recognized the distinction between shore-fast and pack ice; however the historical data sets typically do not make this important distinction. Reliable satellite data exist since 1979. There are also other less quantitative data sources that provide some information into the 1800s, including traditional and local knowledge, whaling records, and submarine observations. For example, see the work of Shapiro and Metzner (1979) on this topic.[1]

The National Ice Center (NIC) provides daily estimates of sea ice cover. According to the NIC, "The resolution of the initial product is 25 km. However, this resolution is relative due to the nature of the shape file in GIS software. Further, inputs to the data can range in resolution from 200 m to 25 km. These inputs include RADARSAT, DMSP OLS, AVHRR, and QUIKSCAT. The SSM/I contour uses the NASA Team 2 algorithm and is contoured using the 10.1% value. In the Lowgrain Ice Edge, the information is removed at a 2,000 meter interval to provide a smaller, more portable product." The NIC has acquired data back to 2004. Weekly ice charts similar to these dating back to the 1970s can be obtained from the Canadian Ice Service. The National Snow and Ice Data Center, located at the University of Colorado, maintains the passive microwave data of ice extent dating back to 1979.

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[1] Shapiro, L.H. and R. C. Metzner. 1979. Historical references to ice conditions along the Beaufort Sea Coast of Alaska. Environmental Assessment of the Alaskan Continental Shelf (OCSEAP) Annual Reports, 1979, Volume 9 (Hazards), pp. 632-682.

Identification, evaluation, and recommendation of applicable models and nested models are needed for regions of interest. Where necessary, these models will have to be downscaled to address specific issues and local conditions (e.g., Beaufort and Chukchi Seas), and produce user friendly projections (e.g., 2, 5, 10, 20 years) that can be used across agencies. There are many models available – the task would be to identify which models can be downscaled to regional and local resolution and to determine how

reliable they are when applied on a local level. Where reliable models do not exist, historical, hind-cast, and re-analysis of data can be used to project future trends.

From these models and trend analyses we foresee an increased ability to proceed to impact modeling, allowing better prediction of things like erosion, species distribution, oil spill response, infrastructure needs, subsistence impacts, etc., by incorporating the unique variables and approaches necessary to address individual issues. The models need to provide an estimate of the range of conditions of changing sea ice, wave regime, and open water extent to support engineering design of offshore and coastal land structures.

Recent reconstruction of sea ice historical extent reveals that recent conditions represent the lowest ice extent in 800 years (Journal of Climate Dynamics). If recent changes in sea ice cover and increasing temperatures in the Bering Sea persist, they will have profound effects on marine communities. Development and maintenance of a data base of the spatial extent and characteristics of sea ice as well as indices of timing and extent of the spring bloom is a high priority.

Many of the emerging issues are interrelated. In order to foster a system science approach that would provide information needed for design and management to support NSSI stakeholders, a series of Synthesis/System workshops is needed to bring together scientists and agencies across disciplines under the umbrella of NSSI, allowing consideration of whole systems as they relate to sea ice.

The success of these endeavors will depend on a strong commitment to sustainable long-term monitoring.

Recommendations:

1. Assess the importance of ocean acidification in the Arctic and the need for monitoring and related research.

2. Conduct under NSSI sponsorship a series of interdisciplinary synthesis/system workshops to discuss specific emerging issues and their relationship to sea ice.

3. Continue the research needed to better understand ice fate and effects of oil spills in sea ice during fall freeze up and spring melt.

4. Task NSSI-GINA to compile North Slope relevant data from NIC, NSIDC, NODC, and MMS information on sea ice and open ocean conditions. These data should be put in a format that is user-friendly, accessible, and can be easily visualized.

5. Based on synthesis meetings, identify additional model needs and output locations, time scale, and spatial resolution of relevance to North Slope users. Candidate models then need to be evaluated and an appropriate model(s) recommended.

6. Use the selected models to make 2, 5, 10, and 20 year projections of changes in sea ice and, to the extent that it is possible, biological communities.

7. In the absence of appropriate models, use historical data and other means to create retrospective hind casting relevant to North Slope users. This should be done in parallel to the modeling effort.

8. The sea ice and wave climate predictions resulting from the modeling effort should then be coupled with specific impact models such as ocean circulation, changing food web, contaminant transport, shore erosion, anthropogenic near-shore operations, habitats, oil spill response, and subsistence hunting.

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Emerging Issue Summary
PERMAFROST

Highlights:

- Existing data and current techniques for permafrost measurement are not yet sufficient to address most management concerns.

- Active layer depth and subsidence, and their relation to threshold conditions in the active layer-permafrost system, may be of more immediate importance to land managers than broad permafrost conditions.

- All relevant data should be centralized in an accessible location.

- Combining ground observations with remote sensing techniques may hold some promise. For example, Synthetic Aperture Radar (SAR) combined with active layer monitoring results may lead to improved understanding of permafrost dynamics relevant to land managers.

Permafrost degradation on the North Slope. (Alaska Stock 2008)

Overview and Management Relevance:

The most important and basic finding of the STAP is that the current measurement techniques and extent of monitoring as well as data availability for permafrost are not adequate. Current permafrost science has only a limited understanding of the distribution of permafrost on the North Slope and a similarly limited sense of the trajectory of change of that permafrost. In other words, current knowledge of the distribution of permafrost, and an understanding of how it is changing, is insufficient to address most of the more specific management concerns and questions. Prediction and detection of subsidence is especially problematic. Furthermore, before advances can be made in the ability of predicting future conditions and detecting change, a better understanding and to some degree a standardization of how permafrost is monitored and where it is monitored is needed.

Currently available information comes primarily from index sites operated by USGS, boreholes monitored by the Permafrost Laboratory at the University of Alaska in Fairbanks, and a network of roughly 125 index sites throughout the arctic (see Circumpolar Active Layer Monitoring Network, http://www.udel.edu/Geography/calm) where the active layer thickness is measured at the end of each summer. Industry also monitors a number of sites, but the data from these are not widely distributed. All relevant data should be centralized in one accessible location if at all possible, in part because development of change trajectories and model testing require large, spatially distributed data sets. Only then can science begin to address questions both general (e.g., how widespread is thermokarsting?) and local (e.g., will the permafrost thaw under a specific section of pipeline?).

A noteworthy STAP observation is that while questions of permafrost trends across the North Slope seem to be of general interest, it may well be that site-specific issues will drive agency agendas as the permafrost thaws. For example, the thawing of permafrost near a critical habitat lagoon could lead to sudden drainage. If this is the case, it will be important for managers to clarify these specific concerns, identify sensitive areas, and consider whether there are potential confounding factors. For example, an ice cellar may thaw because of urban heat island effects rather than because of global warming.

Hybrid methods combining several types of measurements may offer the best hope for future monitoring. For example, combining Circumpolar Active Layer Monitoring (CALM) data with SAR data has shown some potential to augment traditional measures of active layer change. Preliminary examination of SAR data collected near CALM active layer depth measurements show a positive correlation—an increase in active layer thickness correlates with an increase in backscatter return. Therefore the opportunity may exist to extend the area coverage of the CALM measurements by combining them with SAR derived values. Other remote sensing techniques may allow spatial extrapolation of spot measurements and therefore help to address management issues such as changes in habitat and vegetation due to changing permafrost and the effects of fire on

permafrost. It should be borne in mind, however, that currently there are no stand-off technologies that can directly determine the state of the ground, and even on-the-ground geophysical methods (Ground Penetrating Radar and Resistivity) have limitations.

Another important STAP observation, again relevant to the discussion of whether the focus is on broad scale and long-term or finer scale and short-term, is that 10- to 20–year-out questions actually relate to the active layer rather than specifically the permafrost itself. In 20 years, North Slope permafrost will almost certainly still be regionally intact, but the active layer may change in either thickness and/or the degree to which frost heave and thaw subsidence occur. It is these changes to the active layer and shallow permafrost, rather than overall changes to permafrost, that have the most important implications for ecosystem change and relevant management and engineering concerns.

Perhaps a critical question relevant to management concerns is "Is there some threshold state or thickness of the active layer beyond which current rates of change might accelerate?" Similarly, "Are there threshold conditions in the active layer-permafrost system that triggers rapid ecosystem change?" These questions are really at the heart of the issue of rate of change. There is a strong sense among permafrost scientists that this threshold might occur when the active layer begins to thaw deeper each year than can freeze back the following winter, leaving a thawed gap or discontinuity between the active layer and deeper soils and earth that remain permanently frozen.

Recent observations suggest that one impact of accelerated thickening of the active layer is, in fact, changes in ecosystem structure through altered hydrology. For example, a change in active layer thickness may lead to a rapid down slope sliding of the organic layer and thawed mineral soil, exposing the underlying permafrost. This in turn begins to thaw rapidly, leading to several meters of down-wasting of ice rich soils, a process known as thermal erosion. The change in surface topography alters the drainage network, which feeds back into changes in vegetation. These changes may occur in just a few years. In sum, the altered drainage network means the hydrology of the area is now different. The incidence of these types of change appears to be increasing, and to have been particularly notable in relation to recent large tundra fires on the North Slope.

Finally, there are regulatory issues that need to be considered. For example, to move forward with new research on permafrost conditions and winter travel, there will need to be a serious consideration of the rules used to open tundra travel and the assumptions that underlie those decision-making tools. Thus, the potential ramifications of any new science (e.g., finding that the results indicate a shortening or lengthening of the season) will provide an important context for resource commitment decisions.

Recommendations:

1. Inventory and evaluate existing data and document monitoring techniques.

2. Centralize these data in an accessible location.

3. Support research that explores hybrid techniques in which stand-off (remote sensing) technology is combined with in-situ measurements to achieve wider spatial coverage.

4. Recognizing the heterogeneity of permafrost (especially variability in ice content), identify sensitive areas where changes in the active layer or soil ice content could result in important ecosystem or infrastructure changes and take measures to better monitor changes in these areas.

5. Undertake work on threshold conditions in active layer state beyond which thawing accelerates.

6. Develop a more integrated understanding of how thermokarst and thermal erosion impact vegetation and hydrology.

Emerging Issue Summary

COASTAL AND RIVERINE EROSION

Highlights:

- The rate of North Slope coastal erosion, to the extent that it has been measured, is among the highest in the world and is increasing.

- Coastal and riverine erosion will most likely increase due to sea level rise, decreased amounts of shorefast ice and near shore pack ice, increased depth of the active layer, and more intense storms.

- An accurate coastline and river corridor map, along with a program to remap selected targeted regions of the coastline every three to five years, would allow future estimates of North Slope erosion rates.

- Accurate risk assessment (e.g., for loss of cultural sites, contaminant release, damage to infrastructure, and similar risks) will depend on development of a robust erosion model used in combination with accurate mapping of existing resources at risk.

Erosion block fault. (Ken Dunton, University of Texas)

Overview and Management Relevance:

A recent study by USGS scientists and their partners noted that shoreline erosion rates along the Arctic coastline are among the highest in the world, with observed average erosion rates along the coast of the NPR-A in excess of 6m/year.[1] Although there was considerable variation from site to site, with some sites seeing deposition, 60% of the study's sites saw an increasing rate of erosion. Another study reported a doubling of the rate of loss of coastal land area over the last 50 years.[2] This erosion pattern has resulted in the loss of cultural and historic sites as well as the loss of modern infrastructure and can validly be described as "a major landscape altering mechanism"[1] of urgent concern to arctic resource managers and native cultures. It was in this context that the list of concerns, questions, and needs were generated by agency staff. The following paragraphs organize some of the STAP's thoughts on what kind of science can be brought to bear.

Coastal and riverine erosion will most likely increase on the North Slope due to sea level rise, decreased amounts of shorefast ice and near shore pack ice, increased depth of the active layer, and more intense storms. In some areas (such as portions of the Sagavanirktok River delta), accretion rates may increase in response to climate change and development. Recent increased human use of the coastal area has accelerated the importance of knowing the current rates of change as well as predicting future scenarios. Given this need a dedicated monitoring and modeling program is warranted.

Models that use sea ice extent, freeze-thaw cycles, soil variables, exposure, wind, wave, and extreme storm events should be generated to explain the observed 3-5 year erosion rates at selected test sites. Appropriate measurements (for example wind, wave, ice scouring, thermal processes) need to be collected to help develop and validate the models. Measurement sites should be selected based on the recommended baseline coastline survey and a range of expected erosion conditions, with input from local people familiar with the environment. These smaller sections then provide a means to establish erosion rates that will help determine the appropriate time scale for remeasuring the entire coastline.

The logical starting point for a coastal erosion monitoring program is related to an issue raised by the agency staff, "how and where is erosion being measured; is it adequate; and is the data accessible?" The answer to the latter two parts of this question appears to be "no," at least not yet. NSSI-GINA is currently tasked with collecting the existing and historical shoreline data sets. To the extent that differences in methods and

[1] Jones, B.M., K.M. Hinkel, C.D. Arp, and W.R. Eisner. 2008. Modern erosion rates and loss of coastal features and sites, Beaufort Sea coastline, Alaska. Arctic 61(4): 361-372.

[2] Mars, J.C. and D.W. Houseknecht. 2007. Quantitative remote sensing study indicates doubling of coastal erosion rate in the past 50 yr along a segment of the Arctic coast of Alaska. Geology 35(7): 583-586.

resolution allow, the most up-to-date data and any historical shoreline data that exist can then be compared within a GIS to generate rates of erosion for the period between the respective coastline sections under investigation. This should be step one and has actually already been accomplished to some extent for certain sections of the North Slope coastline, as noted above.

To determine the existing extent and rate of erosion across the North Slope, an expansion of these types of studies will be needed. The STAP recommends that a new remote sensing survey be undertaken. NSSI through NOAA, USGS, industry, and/or the USACE could request a coastal mapping mission using standard photography, satellite imagery, high resolution Synthetic Aperture Radar (SAR) data, or the Compact Hydrographic Airborne Rapid Total Survey (CHARTS) system which will also potentially provide water depth out to approximately 10 m depth or greater depending on water clarity. Due to turbidity concerns in Arctic Ocean waters, as well as weather and solar illumination constraints, prior to mapping the entire coastline, a feasibility test using satellite imagery, aerial photography, SAR data or the CHARTS system should be conducted over a manageable test site to ascertain the most accurate and cost effective method to map the entire coastline. For example, SAR data that can be acquired independent of cloud cover and solar illumination could be collected using the high resolution mode on RADARSAT II as well as an airborne interferometric SAR system to evaluate whether the output product will satisfy the mapping accuracy requirements.

CHARTS is operated by a multi-government center called the Joint Airborne LIDAR Bathymetry Technical Center of Expertise (JALBTCX). JALBTCX executes survey operations using the CHARTS system. CHARTS sensors include an Optech, Inc., SHOALS-3000 LIDAR instrument integrated with an Itres CASI-1500 hyperspectral imager, which is capable of mapping surface and subsurface bottom types. The CHARTS system collects either 20 kHz topographic LIDAR data or 3 kHz bathymetric LIDAR data, each concurrent with digital RGB and hyperspectral imagery. Survey operations support the USACE National Coastal Mapping Program and NAVOCEANO nautical charting missions (see http://shoals.sam.usace.army.mil/).

With an accurate coastline location and continually improving erosion rate estimates, along with well-populated data layers in GINA, the agency questions pertaining to threats to cultural sites, communities/subsistence activities, and contaminant risk can be addressed. GIS software has the capability to generate threat maps to various land-based features based on erosion rates, topography, and soil material.

It will be important to try to improve temporal resolution of mapping efforts. Historical remote sensing data (both unclassified and restricted) could be used to help generate historical rates of both coastal and riverine erosion that can be compared to present rates to better predict future changes to coastal and riverine structures.

A number of the emerging issues raised by the agencies addressing mechanisms to adapt to or mitigate erosion will require a comprehensive modeling approach. For example, addressing how erosion rates will vary with climate induced wave, wind, sea level, and ice cover change and changes to habitat will require new models. For model predictions to be realistic, good inputs are needed that include not only the rate of erosion but information on the wave, wind, and freeze-thaw cycle as well as sea ice climatology. However, there are limited wave and wind data for the near shore of the North Slope.

The importance of year round wind and wave data of North Slope coastal conditions needs to be given greater emphasis. Erosion models use wind and wave statistics as input. NOAA should be encouraged to implement a buoy system to provide the required data and data from other sources, including industry, should be shared with researchers.

In addition, modeling efforts would benefit from detailed data on a limited area or areas that could be used in model development and testing. That is, if an area can be identified for which substantial historical data are available a set of accurate coastline and river corridor maps (both present and historical) could be generated for use in model development. To some degree, data such as these may exist for the area around Prudhoe Bay and may be available from industry. A dedicated monitoring program with repeated data collection every three to five years could add to the value of this dataset. To further increase the value of this exercise, the area selected should be an area subject to high risk of habitat or infrastructure loss.

The issue of increasing rates of coastal erosion on fresh and salt water redistribution and its relationship to changes in the active layer, as well as the impacts to the water quality of freshwater and near shore environments, need to be addressed through a monitoring program. Until the cause-and-effect relationship between increased erosion, active layer thickness, coastal salinization, and water redistribution is quantified, the consequences cannot be addressed. Thus NSSI and its partners need to start documenting the changes in water parameters of the freshwater and near shore waters.

The use of remote sensing data such as the PALSAR Polametric Synthetic Aperture RADAR (SAR) satellite data to monitor changes in the active layer may warrant further investigation (see also Emerging Issue paper on Permafrost). Additionally, hyperspectral imagery can detect subtle changes in vegetation around lakes that may be a result of coastal salinization (see also Emerging Issue paper on Vegetation Change).

In respect to the agencies emerging issues on mitigation and remediation, there are generally two ways to handle coastal erosion: move infrastructure of interest back from the water's edge or (to protect infrastructure that cannot be moved or to protect habitat) construct engineering structures to slow down the erosion.

Recommendations:

1. Aerial and satellite imagery from all accessible sources should be inventoried.

2. For a localized area that can be easily accessed and that has reasonably good historical aerial photographs or comparable information, current and historical shoreline data should be collected and stored in GINA. The data should be used to generate a set of accurate coastline and river corridor maps (both present and historical). These will serve as the baseline for models of future erosion and will be useful in model development and testing. A dedicated periodic monitoring program focused on the same area with repeated data collection every three to five years would increase its value over time. To further increase the value of this exercise, the area selected should be an area subject to high risk of habitat or infrastructure loss or known sites of contaminant release risk.

3. A North Slope wide accurate coastline and river corridor map should be generated as a baseline for generating rate of erosion information and data collection should be repeated over selected test sites every three to five years to determine a monitoring rate for the entire coastline. The entire coastline should be remapped on a time interval determined by the modeling effort and the selected coastal areas that were re-surveyed.

4. Parts of the North Slope coastline should be instrumented with autonomous sensors that measure wind and waves.

5. A modeling effort needs to be undertaken that considers sea level rise, shorefast ice, near shore pack ice, increasing active layer thickness, and more intense storms in conjunction with climate models to estimate future erosion rates, which can then be used as input into adaptive management of the coast.

6. Local knowledge should contribute to the development and assessment of models and monitoring programs.

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Emerging Issue Summary
HYDROLOGY AND LAKE DRYING

Highlights:

- The short- and long-term information from hydrological and meteorological networks in the Arctic is critical to the management of the North Slope given the ongoing industrial development and environmental change. This information need applies to all waters from rivers and streams to lakes, ponds, and wetlands.

- Remote sensing technologies useful for understanding and monitoring hydrology have yet to mature but warrant further research and development.

- The current status and trends of hydrological processes on the North Slope are poorly understood. Also, changes expected to occur due to climate change are difficult to predict and, given the current paucity of information on status and trends, may even be difficult to document.

Ice and water flow over ice road on the North Slope. (Doug Kane, UAF)

Overview and Management Relevance:

The following concerns were raised in regard to the general topic of Arctic hydrology:

- What are the needed water resource engineering design data requirements associated with conservation needs and industrial growth on the North Slope?
- Can we make surface water withdrawals while satisfying instream flow needs?
- How can we guarantee instream flow amounts or even establish minimum required flow rates to sustain existing habitat?
- In light of climate variability and change and increased water use related to development, can we maintain critically important habitat in the drainage network?
- Can we meet future water demands associated with spatial expansion of resource exploration and development?
- Will we be able to ensure habitat protection/maintenance for water-related subsistence resources?
- Is lake drying widespread, and if so, how will it impact water availability, fish and wildlife habitat, and the food chain?

These broad concerns translate into more specific management questions which are discussed below and followed by STAP recommendations on the highest priority needs to advance management supportive science related to hydrology and lake drying.

1. *What kind of network of long-term stream gauging stations is needed on the North Slope of Alaska?*

   Clearly, our present stream gauging program is not robust enough for the ongoing activities and anticipated future activities on the North Slope. Most stations have been installed after development has been initiated and stations are often impacted by logistical concerns. Because gauges were not installed prior to exploration and development, we do not have a record of adequate length to make reasonable decisions regarding streamflow. This problem persists for large streams where bridges may be constructed and also small streams that recharge lakes where water withdrawals are made for a variety of uses. These uncertainties, due to lack of data, result in decisions being made that are unnecessarily costly in terms of time and money. In addition to better distributed and long-term (>25 years) streamflow data, we desperately need other complementary meteorological data (addressed in detail

in the “Weather and Climate” issue paper). These meteorological stations need to be distributed from the headwaters to the gauged outlet of the basin. At present, most meteorological stations are at low elevations along the coast.

A workshop involving the important contributors and users should be held to evaluate the present hydrometeorological data collection system and to identify future needs. The final product would be a vision of what the network should be to meet present and future demands, plus a plan to fund this system. Oil and gas exploration and development are the major drivers of environmental data collection at this time, but other resources like coal, subsistence resources, and wildlife habitat need to be considered when evaluating and designing a data collection program. This would include a discussion of improved methods of measurement for better quality hydrometeorological data.

2. *Is the Arctic hydrologic cycle undergoing significant and rapid change in response to climate change and is it well understood how this will affect cycle complexity (floods, drought, etc.)?*

There is no doubt that change is occurring in the Arctic: spatial and temporal sea ice extent and thickness is decreasing, permafrost is warming, vegetation change is ongoing, glaciers are mass wasting, later freeze-up and earlier break-up are occurring, and mean annual air temperatures are increasing. To date we have not seen strong trends in hydrometeorological variables, but model predictions indicate increases in precipitation. Although we have not done an adequate job of documenting extreme hydrologic events in the Arctic, these may become more prevalent. The fact that we do not have long-term, good quality, hydrometeorological data makes it difficult for us to discern trends that may already be occurring. Climate change has the potential to alter the hydrologic response of watersheds; this change can further cascade down to the Arctic’s biological system (wildlife and vegetation). However, right now we do not have a complete understanding of how warming may affect the current processes of lakes and streams.

In Russia, some of the large north-draining rivers have shown an increase in streamflow to the Arctic Ocean, while elsewhere, for example in Canada, flows have decreased. The likelihood of mid-winter snowmelt or rain-on-snow events increases as the climate warms. These types of events would be very detrimental to both small and large animals. Will the pattern of floods and droughts continue or will they become more severe and frequent? Drought is probably more damaging because it impacts the entire watershed (or even several watersheds) while floods mainly impact the channel and adjacent floodplain.

It has been observed in some parts of the Arctic that lakes are drying up (e.g., Seward Peninsula with warm permafrost) at the same time lakes are expanding

elsewhere (e.g., Northern Russia with cold permafrost). Remote sensing of various modes is the best tool to observe this change; but again, the lack of quality, long-term data prevents us from pinpointing the exact cause of these processes. Drainage due to thawing of permafrost below the lakes or a reduction in precipitation minus evapotranspiration could be possible causes. The expansion of lakes could be caused by warming of cold permafrost that triggers thermokarst and eventual lake development. If lake drying (or even lake expansion) is widely distributed and governed by climate change, management actions to control these processes will be futile. We should continue to monitor lake evolution, both drying and expansion. In the case of drying, studies should include lakes, ponds and all forms of vegetated and non-vegetated wetlands to determine if drying is more widespread than currently thought.

3. *Are alternative technologies for better quality data collection being developed? If so, will they lead to alternative regulatory requirements?*

The quality of data presently being collected in the Arctic is average at best. We still struggle in this environment to make simple measurements of solid precipitation, minimal seasonal streamflows, and many other variables. We should not, however, stop collecting data because of the less than optimal quality. Real data is still the only yardstick that we have to compare and evaluate model output. There are some improvements being made (like various unmanned vehicles) that allow us to collect much more data than was previously logistically possible. Presently we do a very poor job of capturing spatial variability. Although it is maturing very slowly, remote sensing is still our best hope for wide scale hydrologic measurements of snowcover, evapotranspiration, precipitation, and other important attributes. As this time, it is impossible to know how alternative technologies for better data collection will change regulatory requirements, but it seems reasonable to believe that regulatory requirements will change as technology and data collection methods improve.

4. *Hydrologic data for individual small headwater hydrologic systems (streams and lakes) are severely lacking, but might these systems, collectively, be very important?*

These headwater systems are an integral part of the ecosystem. It is in the headwaters where much of the runoff is generated and they are often the most biologically productive systems. What transpires in headwater systems is transported down through the whole system. Because they are small (although quite numerous), they receive very little attention from a monitoring viewpoint. It is challenging to study these basins on the coastal plain because they are very low gradient watersheds, making it very difficult to accurately delineate the watershed boundary (a small snow drift can divert water into the adjacent watersheds). High quality digital elevation data (DEM) is needed to define these low gradient watershed boundaries.

On the coastal plain, many of these small watersheds have lakes that are repeatedly pumped winter-after-winter. There are two relevant questions to be determined: are the lakes completely recharged the next spring during snowmelt and are there any cumulative effects? If discharge emanates from a lake during snowmelt, it can reasonably be assumed that the lake has fully recharged. However, the occurrence of recharge one year is not a guarantee that it will occur every year. Natural year-to-year variability may result in years when complete recharge does not occur, even though the volume of pumping was similar each year. Climate change adds another unknown to this equation.

5. *Are there significant data gaps in relating annual surface runoff to annual precipitation?*

There are only a few watersheds (approximately 40) in the whole of the circumpolar Arctic where sufficient hydrologic data have been collected so that water balance computations can be completed. These studies have been done on small watersheds (less than 400 km^2, most much smaller), of short duration, and using quite different instrumentation. Today, there are only about one dozen that are active. The quality of the data collected in these studies is the best that we have, but still there are limitations to the data used in these water balance studies. The major weaknesses of these studies are the poor quantification of the various storage terms (active layer, surface lakes, ponds and wetlands, snowpack, snowfields, glaciers, groundwater, etc.) and the evapotranspiration fluxes at the watershed scale. Measuring the snowpack at winter's end at a watershed scale where redistribution by the wind and sublimation have been ongoing over the winter is also a challenge. Data have been collected for three watersheds on the North Slope (Imnavait Creek (2.2 km^2) and Upper Kuparuk River (142 km^2) in the foothills and Putuligayak River (471 km^2) on the coastal plain), showing considerable variability from year-to-year and between the three studied catchments.

6. *How does snow water equivalent (SWE) vary on a local scale? How accurately can we determine how much water is available in the snowpack at the watershed scale?*

The relatively shallow snowpack in the Arctic undergoes significant redistribution by the wind and is subjected to potential sublimation throughout the winter. It is relatively easy to quantify SWE at a small scale, but we need to know what the distribution is along transects crossing tens of kilometers or more (for tundra travel and ice roads) and over watersheds (for lake recharge where winter pumping has occurred). Sublimation of the snowpack is challenging to measure and estimates range from 0 to 50 % of the SWE. Because arctic snowpacks are so light, moderate sublimation rates can be significant. Automated snow depth sensors are useful for the local scale, but interference from blowing snow and shrub vegetation makes it

difficult to analyze data. Quantifying spatial variation is the main problem. For example, SWE is currently being estimated using various sensors on aircraft and satellites with some success. Remote sensing may have some improved future contributions here.

7. *Spatially and temporally, how does water availability vary on the North Slope? Will energy exploration and development be able to move forward in water challenged environments?*

There is no doubt that water availability on the North Slope depends on location. Securing a reliable water source over the winter months is one of the largest challenges as much of the freshwater is in the ice phase during the winter season. Lakes represent the most reliable source at any time of the year. Unfortunately, lakes are not evenly distributed on the North Slope. Rivers in the winter time are not reliable because of the low baseflows (the only flow in some streams during the winter may be subsurface flow in the thawed bed below the channel). Every year streams do have an abundance of water during break-up. Can this be captured and used later as an over-winter source? Spatially, lakes that provide storage are more abundant on the coastal plain than in the foothills and mountains. Reliable year-around water supplies will require innovations if development proceeds in the foothills and other areas with few or no deep lakes.

Lack of water may force energy developers to consider new alternatives such as using steel platforms typically associated with offshore development on the tundra. In some cases, water may be imported. What transpires in these cases will be dictated by the economics of each operation.

8. *How important are ephemeral streams to fish?*

Fish are pervasive on the North Slope and they use various pathways to move around. They over-winter in bodies of water (lakes and deep pools in rivers mainly) that do not completely freeze during the winter months and have sufficient oxygen. During the warm season fish disperse widely, probably in search of food and/or spawning habitat. In the fall they need to return to their over-wintering sites. In the spring there is plenty of water from snowmelt to aid with dispersal. However, this may not be true for the fall return. Drought, which we have experienced in 2005 and 2007, can make it difficult for fish to return and congregate at over-wintering sites. Will climate change alter past patterns of drought? We have no answer for this question yet. Studies of the patterns of fish movement, habitat use, and stream flow requirements on the North Slope can document the life history needs of native fishes and help model how these species may respond to various climate change scenarios. However, there is very little we can do about controlling drought and its direct impact on stream fishes other than through protection of stream flow needs as they are identified. In sum, ephemeral streams can be very important to fish

dispersal during spring and to the return of fish to overwintering sites during autumn, but are of unknown value for example as fish rearing areas.

Recommendations:

1. The STAP recommends scheduling a workshop to identify and define hydrological and meteorological data needs, including a detailed planning design of an arctic wide stream gauging and complementary meteorological station network and that this design reflect the biological considerations for which the data will be used.

2. The STAP further recommends supporting the development of remote sensing technologies that can supplement measurements from gauging stations and other conventional hydrological and meteorological methods. However, high quality field data is still needed for ground truthing the remotely collected data.

3. Local knowledge should be incorporated into the planning and assessment of monitoring and modeling efforts.

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Emerging Issue Summary
COASTAL SALINIZATION

Highlights:

- Coastal salinization will change plant and animal species composition and may reduce water available for ice road construction.

- Little is known about this phenomenon on the North Slope and current data are as yet inadequate to fully assess trends. However, with additional field measurements, it may be possible to model future coastal salinization.

- Research is needed on the salinity tolerances of local plant species, site-specific conditions for trapping water and salt from melting ice, and the use of snow trapping to mitigate salt content of melt water.

- Although coastal salinization is not known to have impacted large areas, it is known to occur in areas where native communities, subsistence fishing and hunting activities, and the oil industry are concentrated.

Coastal areas are threatened with salt water spray from increased storm activity

Overview and Management Relevance:

Coastal salinization of terrestrial or freshwater environments may be an issue to land managers for at least two reasons. First, it will cause changes in habitat structure, such as plant species composition, which in turn may cause changes in how or which animals use the land or waters. This in turn could impact subsistence use of those resources. Second, large quantities of freshwater are often necessary for ice road/pad construction during oil and gas exploration drilling, development, and maintenance, and coastal salinization could reduce the availability of or access to such waters.

There are at least six pathways, the first five of which are sensitive to climate change, for introduction of marine salts into the terrestrial environment:

1) Certain wind conditions, such as winds from the west on the North Slope or onshore winds in general, push seawater into freshwater systems. The frequency and strength of storm systems during the open water season, and the resulting storm surges, have increased in recent years. Sea level rise of 0.3-1 m during the next century will increase the extent of coastal flooding and extend the areas affected during storms.

2) Increased wave action during storms, related to decreased extent of sea ice, can result in increased airborne salts moving onto the land and into freshwaters.

3) Coastal erosion can result in the breaching of freshwater lakes by the ocean. Also, by moving the shoreline position further inland, coastal erosion moves the effects of processes in pathways 1, 2, 4 and 5 further inland.

4) Increased active layer/permafrost thawing may allow ocean water to percolate through the upper substrate (i.e., active layer) and reach nearby freshwater lakes.

5) Plumes of ocean water may move upriver during periods of reduced stream flow, an effect that may be enhanced by sea level rise. This plume is a natural event each winter and is sensitive to periodic drought conditions during summer, and could thus be altered by any changes in seasonal weather pattern affected by climate change.

6) In the oil fields, spills from pipelines carrying seawater or produced water and leaching from marine sediments used in gravel pads and roads may introduce salts to the environment. However, this is a localized phenomenon and is not further considered in this summary.

The extent of coastal saline habitats and salt-killed tundra along the Arctic coast is poorly known. On the Colville and Fish Creek deltas, coastal habitats (salt marsh, coastal dwarf shrub) cover approximately 24 km^2 (Jorgenson, pers. comm.). However, no data are yet available to assess trends in the extent of these habitats across the North Slope.

In addition, there currently exists about 26 km^2 of recently (i.e., within the past few decades) salt-killed vegetation on the Colville and Fish Creek deltas due to storm surges in tapped lake basins, and there may be as much as 100 km^2 of salt-killed vegetation along the entire coast (Jorgenson, pers. comm.). This phenomenon is sensitive to climate change (e.g., through sea level rise or changing weather patterns) and increasing rates of shoreline erosion. Coastal salinization, where it occurs, changes plant species composition and may subsequently impact some birds and mammals.

The studies needed to assess the trade-offs that would be involved in allowing saline water for ice road construction have not been done. Such studies would include the effects on vegetation of differing levels of salinity, the potential for melt water from ice roads to be trapped and concentrated through evapotranspiration, and the potential for diluting salinity during the spring thaw by trapping additional snow in the immediate vicinity throughout winter.

Coastal salinization would not affect groundwater in the sense the latter term is normally used. Due to the extent and depth of permafrost on Alaska's arctic coastal plain, there is no hydraulic connection from the surface through permafrost to any groundwater below. Salinization would affect only the "groundwater" in the active layer, normally only tens of centimeters deep. This is important, however, because this is where most biological activity occurs.

In addition to these broad concerns, the NSSI Senior Staff Committee provided the STAP with specific questions relevant to coastal salinization. STAP responses to these individual questions are presented below.

1) *What is currently known about the level of coastal salinization on the North Slope; who's measuring it; where; is it being measured adequately?*

   Some measurements have been taken in lakes north and east of Teshekpuk Lake as well as in the vicinity of Barrow (e.g., through the NSSI-funded water quality study). Many already contain some salt, likely from storm surges that allow seawater into lakes or from deposition of airborne salts. Pond salinity is low in spring when water levels are recharged from runoff, but increases throughout summer as water evaporates, suggesting that the salt is functionally trapped. If salt is repeatedly introduced into closed systems, it will remain trapped and become increasingly concentrated. In summary, little is known about coastal salinization, and while some sampling has occurred, no one is yet actively measuring it on a slope-wide scale. Current data are thus inadequate to assess trends.

2) *Can we predict or model coastal salinization for the future? What is the geographic variability?*

Components of such a model would have to include surface topography and near shore bathymetry (both of which are currently poorly quantified at sufficient resolution), lake geography (location and elevation above sea level, which for the most part is known), current salinity of lakes (known for relatively few lakes), the extent of future sea ice during the fall storm season (can be modeled), predictions of sea-level rise and storm surge (can be modeled), and rates of permafrost melting (uncertain). To the extent that this information is either available or can be projected, models of future coastal salinization could be produced, with model confidence constrained by the accuracy of the data and the other models incorporated. Such an effort could benefit from USGS efforts to acquire new LIDAR digital elevation model (DEM) data along the U.S. Beaufort Sea and northern U.S. Chukchi Sea coasts in 2009 and 2010, although this effort may not adequately measure river deltas. Complete DEMs for the coastal plain of the North Slope could greatly extend the utility of these models.

3) *How will increasing salinity in near shore waters affect fish species? How will it affect fish in areas that are currently freshwater habitats? What species of freshwater fish and fish predators are more/less tolerant of salt intrusion?*

Near shore marine waters currently maintain a relatively low salinity due to river input being kept near the coast by prevailing winds. Not much effect on fish is expected in this area unless climate change produces significant shifts either in wind regime or freshwater outflow. Salinity tolerant freshwater fish species include arctic cisco, dolly varden, and the stickleback species group. The fall fishery for arctic cisco at Nuiqsut is dependent on a saltwater wedge moving up the Colville River's delta; the farther upriver it goes, the closer to town arctic cisco can be caught. Alternatively, salt-sensitive fish in rivers would move upstream (down the salinity gradient) until finding suitable levels. For lakes that overflow during breakup, the salt can be flushed out. For lakes that do not overflow during breakup, any salt that enters is functionally trapped. Thus the issue may not be what fish species can tolerate various levels of salinity, but what fish are present in salinized lakes near the coast. Least cisco are the freshwater species most frequently associated with near shore fresh waters, but most lakes near the coast are shallow and contain sticklebacks or no fish at all. Not much, if any, coastal salinization effect on fish is expected in rivers or lakes beyond the immediate coastal areas.

4) *How does increasing coastal salinization influence plant species composition and forage plant nutrient composition?*

In some areas of obviously salt-killed tundra, there are dense stands of salt-tolerant plant species (e.g. *Carex subspathacea*, *Puccinellia phryganodes*). These salt-tolerant species may be preferred forage for some birds and mammals in certain seasons. These shifts in plant communities may be responsible for an observed shift in brant (geese) molting distributions.

5) *To what extent may ice road construction need to rely on the use of saltwater?*

Currently, the only ocean water used for ice road construction is for roads located on the sea ice, and we assume this question refers to construction of ice roads on land. Therefore the answer to this depends on where on land oil and gas exploration may occur in the future, and the amount and distribution of water of varying salinity in that area. The answer also depends on the level of salinity in the "saltwater." Ocean water kills terrestrial vegetation, and the impacts are long lasting. Use of ocean water for ice road construction on land is not currently justified or reasonable. Water in coastal plain lakes varies in salinity, and some lake water may be saline enough to impact terrestrial vegetation. The extent to which lake water with elevated salinities is likely to be used for ice roads and ice pads is not known.

6) *How will the use of saltwater for ice roads impact vegetation over time?*

Depending on the salinity of the water, the effect could be immediate (i.e., plant mortality during the first summer), or the impacts could take years to develop. Even low levels of salt trapped annually in closed lake basins would tend to concentrate over time and could reach levels toxic to the vegetation present.

Recommendations:

1. Explore the potential to develop a predictive model of coastal salinization on the North Slope over the next few decades. The model should include the timing, extent and geographic variability of this change, and should incorporate local knowledge on coastal salinization.

2. Use of ocean water for ice road construction on land is not currently justified or reasonable.

3. In areas where freshwater resources are limited, alternatives other than the onshore use of saline water for ice road construction (e.g., use of snow roads) should first be considered. Before the use of ocean water or even brackish water can be seriously considered for ice roads, studies are needed to assess the potential impacts on the plant community and related impacts on thermal stability, as well as the potential for mitigating those impacts through dilution with snow or other means.

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Emerging Issue Summary

SOCIAL AND ECONOMIC DIMENSIONS OF NORTH SLOPE COMMUNITIES

Highlights

- Increasing oil and gas activities and climate change are critical issues facing people living on the North Slope.

- There is a growing need to integrate knowledge of social and natural sciences with local and traditional knowledge when monitoring, researching and making decisions about land use, natural resources management, and industrial development on the North Slope.

- The evaluation of decisions for land- and maritime-use should be reoriented to include a focus on systems-based concepts such as ecosystem services, food security, and sustainable local livelihoods.

- There currently is an increase in social science research activities on the North Slope and limited coordination, review, and endorsement of studies. These conditions may negatively influence the quality of social data by creating problems such as informant burnout.

- Local / traditional knowledge is recognized by many as valuable, yet there remains a need to develop methods that facilitate community engagement in studies and resource management. Such efforts should be linked regional, statewide, national, and international scale programs.

- The practice of “adaptive co-management” in a changing North Slope social-ecological system is critical in times of rapid change, and could inform the design and implementation of resource management policies on the North Slope.

- Changes in the infusion of cash to villages from past North Slope oil and gas development have dramatically affected life for Iñupiat. Plans for future development concurrent with declining production of existing oil fields suggest the need to identify strategies that ensure the long-term sustainability of North Slope villages and local and regional government and non-government organizations.

Background and Overview

The future is likely to bring dramatic social, economic, and ecological changes to North Slope communities. At present, oil and gas production extends west of the Kuparik oil fields and south to the northern foothills of the Brook Range. Proposals for new roads linking development sites and some villages with the existing road system are being seriously considered. Near-shore oil and gas exploration is underway, with off shore lease sales and exploration for Chukchi and Beaufort Seas initiated. Chukchi off-shore development is likely to require supporting on-shore infrastructure that could bring new people and cash to local communities and have an adverse effect on subsistence. In the far western portion of the North Slope, there is speculation about exploitation of the region's huge low-sulfur coal reserves. In Area 1002 of the Arctic National Wildlife Refuge there is interest by many Alaskans for development. Concurrently, the trends of climate change are projected to continue, bring a continued decrease in multi-year and summer sea ice, a warming and thawing of permafrost, and an increase in storm surges and coastal erosion. The ecological implications of climate change suggest that the future will have an increase in shrub vegetation, and a shift in the range and abundance of several wildlife species. The effects on migratory subsistence species are unknown. Some species, like walrus, the ringed seals, and polar bears, are likely to face conditions that drive populations both or even threaten their long-term survival. These and other rapid and extensive changes are likely to create new challenges for local communities of the North Slope, while testing the capacity of existing resource management systems to adapt to these challenges.

At present, resource management deliberations, such as decisions about oil and gas activities and climate change, on the North Slope typically focus on ecological dynamics and environmental impacts with less attention to social and economic issues. Ecological and social systems of the North Slope, however, are tightly coupled. There is an increase in connectivity of villages to the outside world. People's historic and close relationship with land, sea and animals, their on-going dependence on harvesting subsistence resources, and the potential implications of land use and climate change suggest that decision makers should view the North Slope holistically as a "social-ecological system". In the context of the North Slope, the social dimensions of this system include a broad range of elements, such as (but not limited to) household and village livelihoods, mixed cash-subsistence village economies, sources of cash inputs including employment, dividend and transfer payments, infrastructure needs and maintenance such as housing and water and sewer systems, urban-rural migration, social conditions, cultural identity, human health and well being, government policies and institutional arrangements such as Native land claims, and social networks and organization. One legal rationale for considering this type of questions is the Environmental Justice and Executive Order 12898 of February 11, 1994, which states:

> "*To the greatest extent practicable and permitted by law, and consistent with the principles set forth in the report on the National Performance Review, each Federal agency shall make achieving environmental justice part of its mission by identifying and addressing, as appropriate, disproportionately high and adverse human health or environmental effects of its programs, policies, and activities on minority populations and low-income populations in the United States and its territories and possessions….*"

Other rationales can be found in CEQ regulations for implementing NEPA (1502.3, 1508.8, 1508.14, and 1508.27) which address the human environment and of duration, intensity, and context of impacts.

Community social systems of the North Slope are nested within regional, national and global systems. Policy decisions at one level have the potential of affecting another level. The multi-scaled and tightly coupled nature of these systems requires that researchers and decision makers understand better how activities and or policies at one level cascade through the system creating up- and down-scale effects to the North Slope.

<u>Increase in social science research and lack of coordination, review, and approval</u>

There is a long history of social and economic research on the North Slope. At present several entities are involved in monitoring and analyzing North Slope social conditions including the North Slope Borough; the Alaska Department of Fish and Game; the

Department of Interior's Bureau of Ocean Energy Management (formerly Minerals Management Service); the University of Alaska, other academic institutions, the US Fish and Wildlife Service, private consulting firms, and oil and gas corporations. Coordination of these efforts has been limited and informal, when done at all.

Recently there has been a significant increase in the number of studies collecting social data in North Slope villages. This increase in research activity, as well as an increase in the number and diversity of organizations that are funding and leading research, raises serious questions about data quality, competition or overlap among studies, possible respondent burnout, and the role of local communities in the review and conduct of research involving human subjects. If not addressed, this situation may confound future efforts to make sound decisions and lead to internal conflicts among stakeholders. The role of industry initiating its own social science research programs (e.g., documenting subsistence harvesting) without external oversight or review is of special concern, given recent activities,

The reason for the current lack of coordination and oversight follows from several conditions. At present there is no legal arrangement requiring researchers involving human subjects and focused on social and economic conditions to gain approval or review of their work from local communities or the North Slope Borough. For example, at present a researcher can simply arrive in a community and start conducting interviews, given that residents will talk to the researcher. As well, residents are increasingly confused by the parade of researchers, not knowing differences between the various groups doing research and which ones have the blessings of the village authorities and which ones do not. In some cases this blur extends to media (e.g., film crews) who may be in villages asking questions similar to those of researchers (such as questions about climate change or oil development). Because village residents have no legal standing in approving this research and there is a history of bad experience, there is a level of mistrust for social science research. The current increase in studies involving community residents raises the possibility that residents may refuse to participate in projects that may be informative and relevant for the community, scientists, and decision-makers. Adding to the problems is that results are commonly not reported back to village residents. An additional aspect of the problem is related to how data from these studies are made available to communities and other researchers, and how they are archived. In some cases no data sharing agreements with communities or agencies are articulated and left to the discretion of researchers.

The increase in number of social and economic studies also creates problems for researchers. The local political and leadership structure (i.e., tribal, city, borough, and corporate entities) is complex and can present a challenge to the well meaning researcher who is seeking a village partnership or approval for a study. Remuneration to respondents can also be problematic. A critical problem lies in the fact that the question, what is an appropriate payment, has not typically been collectively addressed. Because there is no standard, the payment of respondents can create incentives to

report inaccurate information or lead to an unspoken race among researchers to outbid each other in order to capture the attention of respondents. There is also the problem of communities maintaining the proprietary nature of data gathered by outside researchers who have little accountability to communities.

A system is needed to coordinate social and economic North Slope research involving human subjects at the village level. There are several models that may provide useful insights and guidance. Yukon Territory, Northwest Territories, and Nunavut have legal requirements. In the Yukon and Northwest Territories territorial legislation (The Explorers' Act) requires that researchers involving humans in research complete a permitting process that undergoes review and letters of approval from local communities. (http://www.tc.gov.yk.ca/scientists_explorers.html). No such laws or entities exist in Alaska to coordinate such a process. An appropriate organization to lead a research review and coordination program is needed. It seems logical that the organization be regional in orientation and that the effort will require adequate human and financial resources to operative effectively.

Community-Based Social-Ecological Monitoring

Monitoring of social, economic, and ecological conditions at the community level has been shown to provide a rich understanding of how forces of change are affecting ecosystems, people's livelihoods, human health, and well being. Significant funding has been provided in the past by agencies such as the Bureau of Ocean Energy Management (BOEM), the National Science Foundation, and others to study North Slope social and economic conditions, but in most cases these funds are for short-term studies (three to five years). Recently there has been interest among arctic social scientists to identify social measures that are reliable indicators of change for long-term monitoring. Currently a long-term "Observation System", sponsored by the National Science Foundation, is being established, with some inclusion of human dimensions. The National Science Foundation "Social Indicators Project" funded during the International Polar Year has led the way in the study and identification of social indicators (http://www.svs.is/ASI/ASI.htm). That project continues today in a second phase, but has limited funding for data collection. At the time of this writing, BOEM is funding a social indicators study for North Slope coastal communities, which integrates concepts developed by The Survey of Living Conditions and the Arctic Social Indicators Project. The North Slope Borough's census program provides some on-going data collection related to economic, demographic, and social conditions.

An evaluation of social indicators should be undertaken regularly to reflect changing conditions in the Arctic, new research methods, and new knowledge on social-ecological system dynamics. For example, subsistence studies have focused historically on the quantity of wild foods harvested (e.g., number of animals and pounds of meat) and in some cases not adequately captured the accuracy of harvests. These studies have not

adequately documented social processes that are central to the subsistence food production and cultural ties. The application of social network analysis to study subsistence sharing and information exchange patterns among households and communities is a cutting edge research effort and may help to fill this information gap and provide important insights into the structure of subsistence systems and their resilience in conditions of rapid change. Another area of critical importance in monitoring and research is spatial analysis of land-use and occupancy patterns. Recent studies in which harvesters use GIS technologies to document their marine travels in the Beaufort Sea is one example of new approaches to social-ecological monitoring communities. These studies require significant trust relations with scientists. Other examples include the recent mapping of subsistence resource use areas in Beaufort Sea communities, Chukchi sea mammal hunting, and Cross Island subsistence bowhead whaling. Some studies also incorporate an important time series element, a significant variable in modeling. In Nunavut, GIS technology has been advanced not only to document human travel, but also to capture harvesters' observations of environmental conditions such as the location of key species and sea ice conditions. To capture aspects of community adaptation, future approaches to monitoring should document community responses to change. These kinds of responses will be important in understanding social-ecological trajectories and potential tipping points which are not be captured with conventional social and economic indicators.

Documentation of Local and Traditional Knowledge

Climate change, the limitations of available ecological data, and limited understanding of social-ecological dynamics have led to a greater interest in documenting local and traditional knowledge. In many cases, ecological research projects, environmental impact assessments/statements, and other studies have made important contributions by including these sources of evidence. Local and traditional knowledge has demonstrated its value in identifying data gaps, generating hypotheses, making cross-scale linkages (i.e. global to regional to local) and demonstrating the relationships between ecological and social dynamics. In spite of this good progress, there remains confusion about the utility of traditional knowledge in studies because of limited methods for its collection and "integration" with western science. For example, some view traditional knowledge purely as anecdotes while others see it as expressions of cultural belief. The segregation of information from its cultural context can result in misunderstandings and limit insights to science and management. An important element in successfully including different forms of knowledge in studies is cross-cultural communication, which is inherently difficult. In spite of these challenges, the introduction of traditional knowledge as a source of understanding social-ecological dynamics can enhance mutual learning, help in developing mitigation and adaptation strategies, and ensure robust decisions where parties are vested in outcomes.

Understanding the Implications of future "development" to North Slope community sustainability

The development of oil fields on the North Slope of Alaska has had a significant impact on the lives of residents of the region. North Slope Borough "Home Rule" as provided by the Alaska State constitution, along with the development of industry infrastructure, has generated tax revenues to the North Slope Borough that have funded multiple borough- and village-level services, such as water and sewer utilities, subsidies for living expenses such as fuel costs, schools, and improved housing conditions . Dividend payments through the Arctic Slope Regional Corporation, the State of Alaska Permanent Fund, and in some cases village corporations have provided cash resources to individuals. Employment opportunities have also been generated through oil and gas field activities, at the borough, and regional and village corporations. Past research has shown that the infusion of cash to households from oil development has increased participation in subsistence and funded cultural activities that are important to the Iñupiat. Future on-shore development is generally supported by residents of the North Slope, to the extent that it is not perceived as threatening subsistence resources, human health, traditional pursuits, and the overall well being of communities. Possible future development, including increases in on-and off-shore exploration and production, raises difficult but important questions about the effects of rapid economic change on community residents. Can too much cash at too fast a rate have negative impacts on individual and community well being? To what extent if at all do high levels of cash inputs undermine traditional culture? How should communities manage a potential high influx of non-locals when development occurs? What constrains village residents from capturing high paying employment opportunities that come with development? What are the strategies that allow for wealth creation and sustain healthy families? Are their better ways of leveraging investments and cash inputs to villages to improve local economic development? How will the decline of revenues because of post-peak production of maturing oil fields affect the long-term sustainability of villages? Are there opportunities for increased energy self sufficiency by villages from future development activities? Good compilation of available social and economic data for research is an important step in answering these questions. Systematic research into past and future social, cultural, economic change in villages is needed to understand potential future problems and identify strategies for avoiding and or mitigating potential problems.

Role of Communities is Development and Use of Scenarios

The NSSI Science Technical Advisor Panel has recommended the development and use of scenarios to explore the implications of possible futures on the North Slope ecosystem and its people. Scenario analysis has been used effectively with local residents and policy makers in a number of settings to inform adaptation strategies. A key ingredient to successful participatory scenario analysis is two-way communication between researchers and residents and a strong partnership designed for shared learning. We suggest that local knowledge of North Slope village residents can greatly inform the development and use of scenarios, and can be helpful in linking science with

decision making. Before embarking on this work, it would be helpful to study past experiences with participatory scenario analysis to be sure that the program design is culturally appropriate and relevant.

Towards Transdisciplinary Frameworks

Resource management conventionally focuses almost exclusively on the biophysical dimensions with analyses of societal issues and impacts being more limited. We suggest that the evaluation of land-use decisions be reoriented to include more integrated approaches that focus on systems-based concepts such as ecosystem services, food security, and sustainable local livelihoods. *Ecosystem services* are defined as the benefits to humans generated by ecosystems, including provisioning services (e.g., harvested wildlife), regulating (e.g., the factors controlling climate), supporting services (e.g., pollinators), and cultural services (e.g., recreation and cultural identity). (Millennium Ecosystem Assessment at http://en.wikipedia.org/wiki/Millennium_Ecosystem_Assessment). Some ecosystem services can be equated to dollar values (replacement value of meat) whereas others cannot (cultural value of whaling). By explicitly linking ecosystems with humans in a systems framework, decision makers can examine underlining human implications and human feedbacks, such as vulnerabilities to human food security, human health, the sustainability of village economies, and issues of human out- and in-migration. For example, loss of sea ice is affecting marine mammal hunting techniques and adaption to new conditions, such as hunting oogruk (bearded seal) in the water or on gravel bars rather than when on the ice. How will the loss or reduction of multi-year ice and summer ice floes affect these important services, along with increased fuel costs and conditions of low employment, impact the availability of wildlife food resources to households that depend on a mixed cash-subsistence economy? Might a loss of availability of critical resources increase out-migration patterns from the village to urban areas? How might the concentration of people in settlements (e.g., Barrow) affect ecosystems?

Human health issues related to North Slope industrial development are also understudied, yet this issue is regularly stated by residents as being of great concern. For example, what are the social and health implications of a pipeline landfall for communities in the Chukchi Sea region in the event of off-shore oil development. What are the human health implications of the stress associated with oil and gas activities or an oil spill? Unfortunately, current stove piping of some funding agency missions adds to the problem of addressing these concerns (i.e, National Science Foundation: only basic science vs. National Institute of Health: only human health). The psycho-social dimensions of stress and exposure to risk related to village residents from *proposed* industrial development has been identified by the North Slope Borough as an important problem, but the topic is not clearly understood or well studied. Understanding these social-ecological dynamics requires the application of transdisciplinary perspectives and

development of new tools that integrate for a more holistic analysis of past and future conditions.

Adaptive Co-Management

Involvement of North Slope Borough and North Slope tribal organizations in research, monitoring, and policy making ensures that local needs, values, culture, and traditional knowledge are considered appropriately. Involvement generally follows from formal institutional arrangements that provide authority of local communities to affect decision outcomes. When adequately involved, local communities can contribute both to the design of studies and decision making processes. In times of rapid change, community involvement is especially critical in allowing communities to review and shape plans for monitoring and research, and resource exploration and development. Ideally, communities should be part of a multi-scaled *adaptive co-management* process in which they review and inform the design of proposed projects, participate in data collection, experiment with alternative approaches to their implementation, and are actively part of on-going evaluation process of activities. The limited role of the North Slope Borough in near and off shore development permitting is one example in which there is an institutional deficiency for strong community involvement. Implementation of adaptive co-management will require a change in the current resource management paradigm to one of supporting participatory research, management, and collaboration. The concepts of "adaptive management" and "co-management", while much lauded in the literature, are, however, challenging to execute successfully. A clearly articulated set of management objectives is a prerequisite for the success of adaptive management. From a process perspective, adaptive management facilitates social-ecological modeling that supports an on-going reflection on past actions (e.g., policy decisions), the reevaluation of basic assumptions and understandings about the system (i.e., development and modification of one or more models), and the willingness to experiment. Co-management is defined as the sharing of responsibility and authority by resource user communities and agencies. In adaptive co-management, the on-going evaluation of baseline conditions, models, and their assumptions is conducted collectively by co-managers and is a part of the "adaptive cycle." Such an approach requires local communities and their representative governments and organizations (e.g., village councils, North Slope Borough) to have the capacity to engage in these processes, through adequate human resources, funding, and time.

Current Problems of Community Involvement

Today community leaders of the North Slope indicate that the demands on local organizations to engage in various governance processes (e.g, review of environmental impact assessments) exceed their capacity because of being flooded with too many documents or proposals, limited time, limited technical expertise, and limited financial resources. This differs, for example, from funded Renewable Resource Councils and Hunter Trapper Committees in northern Canada, which were established for this

purpose through land claims and have some capacity to address a broad range of resource management issues. The Alaska Native Claims Settlement Act provided no such local-level structure and support. While co-management bodies (e.g., Alaska Eskimo Whaling Commission) and councils (e.g., NSB Fish and Game Management Committee) do function at the regional level, communities often can't participate beyond making statements at public hearings and/ or providing information to non-local consultants. As a result traditional and local knowledge is sometimes lost or misinterpreted in decision-making. Village leaders have expressed their wish to be more actively involved and in some cases conduct their own studies. Increased engagement in resource management could also add to the adaptive capacity of rural communities to respond to changes and thus help ensure village sustainability. Politicians, policy makers, and residents need to think creatively and proactively about alternative institutional arrangements that can meet this need. Some experimentation with the efficacy of this and other adaptive co-management models would be useful in the short-term to inform future management decision planning and investment.

Beyond Villages

Clearly, the interest and needs of the Iñupiat People are of high importance when considering the social and economic dimensions of the North Slope. However, the Iñupiat are not the only stakeholders of the North Slope. To comprehensively address social, economic, and ecological concerns and needs for Alaska's North Slope, it is important to consider industry, environmentalists, tourism operators, and transporters and others. Recent research at the University of Alaska Fairbanks, documenting the local knowledge of oil field workers on avian ecology is one example of how a broader view on "stakeholders" and local knowledge can change the way research is undertaken on the North Slope.

Resource management agencies of the North Slope have a tremendous opportunity to create a world-class model for decision making that ensures that the critical elements of the North Slope environment and its residents are sustained into the future. Integrating social and economic considerations into management with good information and processes will make that model more robust.

Recommendations

- Develop an institution, organization, or entity with strong local involvement, which would coordinate, review, and approve social and economic studies in North Slope villages. This organization's task will not be trivial. A strong commitment by agencies to empower the organization and provide financial resources will be needed to do the job effectively.

- Provide NSB and local communities a more central role in the evaluation, endorsement, and implementation of research proposals. The present structure

and allocation of resources to villages do not provide communities the capacity to participate in this type of review.

- Encourage objective research on community economic development that examines trade-offs associated with scenarios of future oil and gas activities.

- Systematically review the approaches and success of including local and traditional knowledge in monitoring, research, environmental impact statements, and the decision making process that would provide a better understanding of the pitfalls and best practices of this work, and provide guidance to the growing community of North Slope residents, researchers and agencies.

- The evaluation of land- and maritime-use decisions should be oriented to include more integrated approaches that focus on systems-based concepts such as ecosystem services, food security, and sustainable local livelihoods.

- Explore opportunities for expanding the capacity of local communities to be involved in the evaluation of research, monitoring, and review of technical documents that may help to create a system that facilitates community engagement in adaptive co-management.

Emerging Issue Summary
CONTAMINANTS

Highlights:

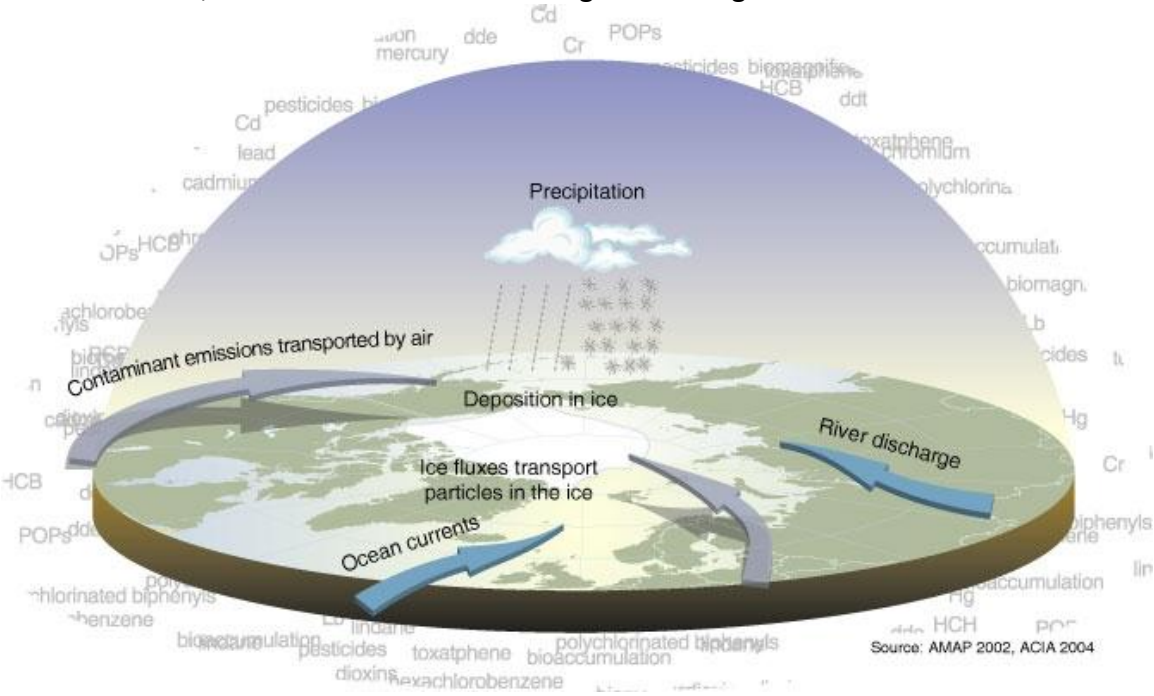
- Accurate data are required on the release and distribution of contaminants into the arctic environment to develop effective management strategies.

- Oceans, rivers, sea ice, and migratory fauna are additional transporters of contaminants to the Arctic, but transport in the atmosphere is most significant.

- It is imperative that we continue to monitor contaminant levels in the Arctic if we are to sufficiently understand the extent to which people and the environment are exposed.

- Some research has been done to identify biological responses to contaminants in the Arctic, but significant dose-response data for arctic animals are too limited to draw clear conclusions.

- There are opportunities to monitor contaminants in the tissues of fishes, seabirds, and marine mammals through co-management councils.



Overview and Management Relevance:

The general contaminant concerns of the NSSI members were considered within the framework of three broad categories provided by the Senior Staff Committee:

1. Impacts to water and air quality;
2. Impacts to natural and subsistence resources and their users; and
3. Differentiating natural from anthropogenic contributions.

Within that framework, the STAP considered more specific management questions, concerns, and needs as they related to these six categories:

1. Status of knowledge on current baselines;
2. Additional baseline data needs;
3. Sufficiency of information on ice, currents, and winds to inform spill models;
4. Risks to human health;
5. Risks associated with energy development; and
6. Risks associated with industry activities other than oil and gas.

Many of the questions that need to be answered involve information needs that can be satisfied only by long-term observations, detailed familiarity with the environment, and continued sampling and monitoring. There is also a growing recognition that traditional knowledge can contribute effectively to program planning and management.
Human activities are the main sources of contaminants to the Arctic. Therefore, accurate data are required on the release and distribution of contaminants into the aquatic and terrestrial environment, as well as into the biota, so that managers can understand sources, pathways, and fates and develop effective strategies to reduce the input to the Arctic.

Within the total contaminant loading to the Arctic, the specific proportion and effects of anthropogenic versus natural sources of specific contaminants can be difficult to determine or may not as yet have been measured. For example, localized naturally elevated concentrations of heavy metals in areas undisturbed by human activities may result in elevated concentrations in resident biota but appear to have little consequence to the health of the biota. Detectable levels of radioactivity appear to result mostly from natural radioactivity decay from uranium and thorium minerals, but the impact of ocean disposal of nuclear waste remains unmeasured. Generally, levels of radionuclides in air, water, and soil in the Alaskan Arctic are similar to or lower than levels in more temperate areas.

Local sources of contaminants include industrial areas, abandoned radar sites, northern mining activities, and garbage dumps. Although such sites are not the principal cause of widespread distribution of contaminants in the Alaskan Arctic, they are of concern to

the health of local ecosystems because they emit a variety of contaminants (including heavy metals and persistent organic pollutants (POPs)). The atmosphere is the most important pathway to the Arctic for POPs, heavy metals, and radio nuclides and their transport is dependent on a number of factors, including temperature, the process of cold condensation, and the circulation patterns of global and arctic air masses.

An increase in arctic air temperature results in a corresponding increase in the carrying potential of the arctic air mass. However, a build-up in moisture and increase in rainfall may remove contaminants from air masses and deposit them on the ground and in the water.

Oceans, rivers, sea ice, and migratory fauna are additional transporters of contaminants to the Arctic, but the atmosphere is the most significant. Contaminants released into the atmosphere in other parts of the world reach the Arctic in a matter of days, whereas transport by ocean currents and sea ice takes considerably longer.

Marine mammals, fish, and other native species are staples across the Arctic. Organochlorine levels are generally higher in marine mammals that feed at high levels in the food chain and tend to accumulate large fat reserves. Average intakes of organochlorines may thus be higher in people who consume more of these higher trophic level marine mammals than terrestrial mammals. The major organochlorines in the marine biota are polychlorinated biphenyls (PCBs) and toxaphene and their concentrations are similar among most marine mammals. There are opportunities to monitor contaminants in the tissues of fishes, seabirds, and marine mammals through co-management councils – for example, the Alaska Marine Mammal Tissue Archival Project (AMMTAP) at the National Institute of Standards and Technology.

Hexachlorobenzene and PCBs seem to be the most consistently distributed contaminants in snow samples. However, reported levels are subject to large variations attributed to a combination of factors, such as methods of analysis, seasonality, dust contamination of snow pack, and depositional trends.

Conflicting evidence from sediment core data for mercury highlights the difficulty in determining whether its source is anthropogenic or natural. However, global atmospheric concentrations of mercury have been increasing for the past several hundred years and anthropogenic releases to the atmosphere have been identified as the cause of increases in global air and ocean surface water concentrations. Many freshwater fish have high mercury levels; however, based on very limited studies no adverse health effects to the fish or human population have thus far been noted in the Alaskan Arctic. Nevertheless, it is imperative that we continue to monitor contaminant levels in the Arctic if we are to understand more completely the extent to which people and the environment are exposed.

There is a positive linear relationship between increasing rates of organic carbon remineralization and methylated mercury concentrations. The near-term rise in Asian anthropogenic emissions and deposition in coastal waters of the western Pacific may now be affecting basin-wide mercury levels of the North Pacific Ocean. Such increases could have serious implications for resulting contaminant burdens in pelagic marine fish in the Arctic. Both air and water monitoring should be developed and implemented, and observations should be made of the concentration of methylated mercury species in sub-surface, low-oxygen thermocline waters known to have high levels of bacterial activity.

Evidence for ecosystem effects in the Arctic as a result of contaminants is currently derived from comparisons of contaminant levels in arctic wildlife with those in the same or similar species in locations where effects have been observed, and from studies of biological responses based on biochemical indicators. Some research has been done to identify biological responses to ecosystem stress in the Arctic, but significant dose-response data for arctic animals is too limited to draw clear conclusions. The effects of organochlorines on the health of arctic wildlife, in particular marine mammals at the individual or population level, are inconclusive. The reports on the effects of exposure to heavy metals are also inconclusive, but it may be that the arctic biota have adapted to the relatively high levels of heavy metals naturally occurring in the Arctic.

Indigenous people and scientists across the circumpolar Arctic agree that a diet based on traditional foods has important nutritional, cultural, and economic benefits. At present, the literature suggests there may be some risk associated with the consumption of traditionally harvested foods due to exposure to certain organochlorines, especially chlordane, toxaphene, and PCBs, and to the heavy metals including cadmium and mercury. Concern about these contaminants has led to assessments of human health risk. Very little is known about the inter-generational effects associated with long-term exposure to these contaminants. However, decisions based on risk management procedures do not always result in recommendations to limit consumption, in part because known benefits of a traditional diet are often judged to outweigh uncertainties and risks with such a diet.

The STAP identified certain contaminants, but not all, of concern for further monitoring and investigation. They include: methylmercury, total mercury, organochlorine and pesticides, PCBs, dioxins, polycyclic aromatic hydrocarbons (PAHs) and brominated fire retardants plus the metals arsenic, cadmium, chromium, lead, nickel, and selenium. An appropriate management strategy would be to sample polybrominated diphenyl ethers (PBDEs) and polychlorinated dibenzofurans (PCDFs). POPs have been identified around the globe including the Arctic. Because there are known international anthropogenic sources, radionuclides should also be monitored in the air, land, and sea.

Airborne contaminants can cause serious health threats to wildlife and humans. Some airborne toxic compounds tend to “biomagnify.” Biological effects include impacts on

reproductive success, growth, behavior, disease, and survival. Airborne contaminants of concern that accumulate by the cold-condensation effect include POPs, dichlorodiphenyltrichloroethane (DDT), hexachlorocyclohexanes (HCHs), and mercury.

Among the primary concerns about contaminants from off-shore oil and gas activities are anthropogenic inputs of metals and hydrocarbons. In particular, there is a need to measure and statistically characterize the concentrations of 12 metals (vanadium, chromium, copper, nickel, zinc, arsenic, cadmium, lead, antimony, barium, iron, manganese) in the mud fractions, and mercury and hydrocarbons in gross sediments for the past several decades across the Beaufort and Chukchi Seas, to the extent that this has not been done through various programs, such as the MMS Arctic Nearshore Impact Monitoring in the Development Area (ANIMIDA) program.

The earlier MMS Outer Continental Shelf Environmental Assessment Program sponsored monitoring design workshops recommended that MMS develop multiyear contaminant guidelines prior to offshore development. In 2008 MMS initiated the "Chukchi Offshore Monitoring in Drilling Area (COMIDA): Chemistry and Benthos" project which implemented a two-year sampling strategy to collect offshore sediments for baseline measurements of Polyaromatic Hydrocarbons, EPA priority metals, and other parameters such as diagnostic hydrocarbon ratios.

Recommendations:

1. Biological studies conducted on the North Slope and offshore should archive biological samples under an agreed upon protocol (e.g., AMMTAP, for marine mammals) that can be used in contaminant and other analyses to establish baselines retrospectively. It is acknowledged that their will be a cost associated with such a program.

2. Because the near-term rise in Asian anthropogenic emissions and deposition may be affecting mercury levels, both air and water monitoring for mercury should be developed and implemented in the areas of the Chukchi and Beaufort Seas, following the model of the North Pacific Basin studies.

3. Working with local communities, gather data and monitor contaminants in subsistence resources.

4. To better understand contaminant redistribution and fate, collect seasonal and long-term data on underwater currents and data to improve bathymetric resolution in Arctic seas.

5. Develop an understanding of the fate of spilled oil in the varying conditions that occur in the Arctic, including broken ice conditions.

6. Closely coordinate efforts on contaminant monitoring among federal, state, and North Slope Borough efforts to understand and assess the effects of environmental contaminants.

7. Given the accelerated rate of coastal erosion (see Erosion issue paper), it is particularly important to map known and suspected contaminant sites near the coastline and use this information in combination with erosion models to minimize contaminant release risks.

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Emerging Issue Summary
FIRE REGIME

Highlights:

- Despite the large and highly publicized Anaktuvuk River tundra fire in 2007, the basic question "Is fire regime changing on the North Slope; and if so, how?" cannot be answered at this time. Basic data requirements to support modeling to address this question are identified in the Emerging Issues Summaries for "Vegetation Change" and "Weather and Climate."

- Urgent management questions about human safety, village protection planning, communications during the fire season, protection of coal deposits, protection of energy development infrastructure, potential changes in fire management plans, and funding for fire suppression can be addressed annually or in-season, as necessary, by the Alaska Wildland Fire Coordinating Group and its member agencies.

Anaktuvuk Pass fire in 2007. (Alaska Fire Service)

Overview and Management Relevance:

The 2007 Anaktuvuk River Fire was a unique event in the known fire regime of the North Slope that occurred concurrently with a record low sea ice extent and a record late summer drought. Its significance as a portent of change is unclear and we are unable to forecast whether it was the beginning of a trend.

For the purposes of this summary, fire regime was defined as the occurrence, number, extent, and severity of fires. Fire observations have been recorded since 1956. Prior to 1993, only fires greater than 1000 acres were recorded, with a threshold of greater than 100 acres since. The fire return interval for the Arctic Coastal Plain and foothills was estimated to be 10,000 or more years based on records collected during 1957-79. More recently, the fire return interval has been estimated to be approximately 3500 years for the foothills, but as short as about 600 years for other tundra areas in Alaska (e.g., Seward Peninsula). In areas that have reburned, tundra is 4.5 time more likely to reburn than forested areas.

Some paleoecological work assessing fire-deposited charcoal in lake cores is underway and should contribute to improved understanding of fire regime on the North Slope. For tundra fires, inference from coring sites is limited to a fairly small area around the coring sites. As fire return intervals have historically been on the order of several hundred years, detecting less than very dramatic changes in long-term fire regime may not be possible.

The measurable or observable factors that influence annual fire regime include: frequency of lightning, length of snow free period, temperature, and precipitation. Lightning activity levels have been monitored since the 1950's and a noticeable sustained increase in activity on the North Slope was detected beginning in 2002, but lightning data may not be very reliable. The instrumentation to detect lightning has improved in recent years but greater coverage is desirable, particularly in the Central Arctic. Information on spatial extent of snow cover on specific dates is available through remote sensing (NDVI). The need for a better distribution of sites for collecting temperature and precipitation data to meet a variety of emerging issue data needs is discussed in the "Weather and Climate" summary.

Weather patterns in Alaska are influenced by the Pacific Decadal Oscillation (PDO), a 20-30 year pattern of Pacific Ocean temperature variability that is poorly understood. The PDO is a relatively short-term phenomenon influencing weather and climate within the much longer-term pattern of increases in average global temperatures. The warm phase of the last PDO contributed to the warmer, drier Alaska weather observed in 1976-2006. As the PDO cycles to the cool phase, cooler and wetter summer weather is expected for Alaska, including the North Slope. The wildland fire management issues that arise from variation in summer weather tend to be manifested at a statewide level and are not

isolated to the North Slope. The Alaska Wildland Fire Coordinating Group helps deal with coordination of these management issues at a statewide level.

The 2007 Anaktuvuk River Fire was described as a variable stage fire (rapid surface burn while the ground smoldered longer), with reburning occurring in some areas after wet vegetation matter dried out. Following most North Slope fires, resprouting of vascular plants (tussocks and forbs) is often nearly immediate unless, as with some portions of the Anaktuvuk River Fire, the fire burns down to mineral soil. In contrast, lichen communities recover slowly and make take up to 80 years or longer to recover to prefire biomass abundance. Woody species (willow, poplar, and aspen) respond well to disturbance and increases in the parameters defining fire regime, if they occur, are expected to support the spread of these species.

The 2007 Anaktuvuk River Fire has not prevented the seasonal migration of caribou through that area. However, research indicates that caribou foraging on winter range in the boreal forest and tundra ecosystems will tend to decrease use in burned areas for up to 50 years post burn in mid-winter. There is the potential for large-scale burns to result in changes in the seasonal distribution of caribou which thus affect their availability to subsistence users. However, the geographic extent of winter range used by Alaskan arctic caribou herds is large and range use varies annually. Most caribou of the Western Arctic and Porcupine herds and typically over half of the Central Arctic Herd winter in forest and tundra habitats south of the Brooks Range. In most years, less than 10% of the Teshekpuk Herd caribou will winter south of the Brooks Range. Credible prediction of the potential effects of changes in fire regime, or fire management policy, on caribou distribution and subsistence use is not possible in the foreseeable future.

Recommendations:

1. Monitoring of the pattern of vegetation recovery in the 2007 Anaktuvuk River Fire, including its relationship to burn severity, should continue and similar monitoring should be undertaken for future fires.

2. The NSSI-partnered land cover (vegetation mapping/classification) effort should be completed and planning should begin for an effort to detect change from that classification. The map is a necessary foundation for further work to describe plant communities, which will in turn support improvements to North Slope tundra and other fuel models necessary for fire modeling software used by managers.

3. See recommendations under Emerging Issues Summaries: a) Vegetation Change, and b) Weather and Climate.

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Emerging Issue Summary
VEGETATION CHANGE

Highlights:

- Much of the vegetation on the North Slope has been mapped in one form or another, but there are technical issues related to scale, accuracy, density of field checking, and continuity of coverage that limit their complementary application. Completion of a single, North Slope-wide land cover map such as the current effort by NSSI will help address many of these issues and provide a basis for starting a slope-wide change detection program.

- No formal change detection plan currently appears to be in place. We therefore recommend moving as soon as possible beyond the inventory stage in this area and beginning formal programs to delineate change. This will, at worst, show the shortcomings of the data and methodology, and at best, provide change trajectories.

- Long-term (multi-decadal) monitoring sites may provide the highest level of detail for detecting vegetation change. We currently do not know the number or types of long-term sites that are present on the North Slope. We recommend an inventory of such sites, compilation of the standard sizes and methodologies for the sites, and development of recommendations for establishing additional sites.

- A mechanistic model of vegetation response to climate change and disturbances could be useful for predicting future rates of change.

- The implications and ramifications of changing North Slope vegetation are widespread and complex, and so interwoven with other management concerns (e.g., migratory birds, fire regime, and caribou) that it would be helpful to the STAP, after NSSI has formulated a slope-wide plan for vegetation change detection and monitoring, to see a more focused and reduced list of pressing management questions that the STAP could then use to convene experts to produce a “vegetation-change ramification” model.

Changing vegetation on the North Slope (U.S. Fish and Wildlife Service)

Overview and Management Relevance:

Significant efforts have been undertaken to produce baseline maps of North Slope vegetation. These efforts have included work by the USFWS, USGS, and BLM with Ducks Unlimited, the LandFire Program, Alaska Geobotany Center, BP, ConocoPhillips, and others. In addition, Torre Jorgensen of ABR Inc. has produced an ecotype map of the North Slope that can be used to infer vegetation community composition based on landscape parameters. These map-based products, combined with a completed NSSI land cover map (which is being coordinated with many of these same entities) and perhaps some additional baseline mapping on State and private lands, will provide an excellent starting point for developing a change detection program at the North Slope regional scale.

In some cases, differences in scale, vegetation classes, and other aspects of methods will make it difficult to combine maps from different sources. Nevertheless, the logical next step for the NSSI is to integrate the various baseline maps into a regional product. This would consolidate existing data, lead to suggestions for a standardized mapping approach, and identify areas that may need further mapping. Part of this effort would include an assessment of the methods used, including the degree to which ground truthing has been done, as well as some attempt to deal with the problem of

heterogeneity of vegetation within pixels (typically 30 by 30-m) that make up the smallest units in many of the map products.

One recommended approach for addressing vegetation heterogeneity within pixels is to develop fractional vegetation cover products for key vegetation types (e.g., percent shrub cover, percent bare ground, percent herbaceous cover). Fractional vegetation cover products have the advantage of increased flexibility (for example, land managers could choose their own threshold values to create maps identifying vegetation of interest) and are potentially more sensitive to subtle changes in vegetation cover. Development of fractional vegetation cover products for the entire North Slope will likely require additional field data. Using other remote sensing datasets in addition to Landsat can enhance vegetation mapping efforts. Finally, acquisition of remote sensing data with matching vegetation phenology can enhance North Slope-wide vegetation mapping.

However, compilation of map data is not the only important step forward. It is also important right now to ascertain whether we have captured enough detail in the existing map inventories to allow for the sort of change detection that is needed to address management questions. Unfortunately, actual use of the expensive and extensive map-based vegetation data for change detection has to date been largely absent. As a result, many issues related to the scale, level of detail, and accuracy of the map products have yet to be fully resolved. North Slope lands include tundra, barrens, and shrublands. Trajectories of change within each of these ecotypes differ markedly, but through a regional approach, broad trends are likely to be delineated.

Most of our current understanding of broad trends in changing North Slope vegetation has been the result of academic research programs, and has been based on satellite remote sensing (specifically temporal changes in NDVI), comparative photography, or have resulted from limited studies in or near Barrow, Prudhoe Bay, and Toolik Lake that have been undertaken for project-specific purposes, rather than historic inventory maps.

Long-term monitoring sites may provide a level of detail that cannot be seen through mapping programs or other methods. Information about existing long-term vegetation sites has not been compiled. While the number of sites and their locations are not known, it is reasonable to assume that more permanent sites are needed and that, ideally, a standard method should be established. Therefore, we recommend as the next step that NSSI tackle directly the problem of compiling existing long-term vegetation site locations and data as well as work toward the development of a minimum standard methodology for data collection. One advantage of tackling this problem at the NSSI level is that it will allow for regional detection of change.

The recommended detection of change alone could prove to be extremely useful in management decision-making where North Slope vegetation is involved, but of even

greater utility would be mechanistic models of vegetation response to climate change, disturbance (human or natural), and fire that could be used to predict future rates of change. Two approaches to mechanistic modeling that might be worth exploring rely on a) retrospective studies, and b) climate-based models of vegetation distribution (often known as the Köppen Climate Classification, these climate based models are already being investigated by a group from Woods Hole).

The issue of changing vegetation has direct impact on a number of high-profile management issues and is therefore important to pursue. These impacts include:

1. Ramifications on the opening and closing dates of the tundra for oil and gas exploration.

2. The routing of ice and snow roads.

3. Impacts on the range and timing of animal migrations.

4. Direct impact on active layer depth and therefore ground water conditions.

5. Costs of snow removal.

6. Identification of rare plant species and their supporting habitats, which could lead to regulatory impacts through the Endangered Species Act (ESA) if allowed to decrease to the point of warranting listing under the ESA.

No formal change detection plan currently appears to be in place. We therefore recommend moving as soon as possible beyond the inventory stage in this area and beginning to attempt to delineate change through formal programs. This will, at worst show the shortcomings of data and methodology and at best provide change trajectories.

Another group of management concerns revolves around the ramifications of changing vegetation on permafrost, herbivores, food-webs, birds and so on. Sadly, we are still struggling to figure out what the "new" vegetation community composition is likely to be, and until we can master that, determining ramifications of future changes remains elusive. What might be possible is to assemble a group of experts and have them work out an "intuitive" system model wherein ramifications of changes in vegetation on other systems can be suggested, similar to an effort funded by BP and undertaken by The Nature Conservancy about 5 years ago. This would basically be an exercise in scenario modeling, largely based on analogies, but it could prove quite informative.

Recommendations:

1. Complete the NSSI slope-wide land cover mapping effort.

2. Begin formal vegetation change detection programs now by using, to the extent practicable, both existing and ongoing mapping efforts and products.

3. Use results from these vegetation change programs to assess whether existing baseline map products are sufficient and to standardize methods used in vegetation mapping projects.

4. Based on these initial steps, adjust the current products as needed, while also addressing continuing technical issues related to these, including scale issues, field checking, and so on.

5. Concurrent with the above, complete an inventory and archive of existing on-the-ground long-term vegetation sites and compare the methods being used in different projects. The archive should be accessible and updatable. Determine if additional on-the-ground sites and standardization of methods is needed to better understand change.

6. Produce a "reduced" list of pressing management questions relating to vegetation change and return it to the STAP who will plan how best to convene experts to produce a "vegetation-change ramification" model.

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Emerging Issue Summary

REHABILITATION AND RESTORATION OF DISTURBED TUNDRA

Highlights:

- Return of a damaged site to a functional habitat for plants and animals without necessarily restoring the original species and processes is usually considered to be "rehabilitation," while re-establishment of habitat features, species, and processes that were present prior to disturbance is usually considered to be "restoration." While most North Slope projects are focused on rehabilitation over time spans of ten years and longer, many may eventually (over many decades) evolve into restoration projects as plant communities, ground ice conditions, and other site characteristics mature. On the North Slope, the terms "rehabilitation" and "restoration" are often used interchangeably.

- The number of rehabilitation and restoration sites has increased dramatically over the past ten years. Currently, industry and agencies monitor well over 100 discrete rehabilitation sites on the North Slope.

- Many sites have footprints of less than one acre, and large sites are typically no bigger than 5 or 10 acres with the exception of gravel mine sites that can exceed 140 acres.

- Types of tundra disturbance commonly leading to a need for rehabilitation or restoration include removal of abandoned gravel surfaces (including pads, roads, and airstrips), excavation and burial of reserve and flare pits, oil spill cleanup, trenching to bury cables or pipelines, off-road travel, and gravel mining.

- Performance standards based on vegetation cover and species richness have become the norm, but the amount of cover, the number and kinds of species, and the time to achieve performance standards vary from site to site. Occasionally, other performance standards must be met, such as stabilization of ground surfaces and absence of flooding during the growing season.

- No substantial effort has been made to synergistically assess North Slope rehabilitation needs at the landscape level that accounts for water flows, habitat fragmentation, and other factors beyond the site specific scale.

Overview and Management Relevance

To some degree, the terms “rehabilitation” and “restoration” are used interchangeably on the North Slope. However, for clarity in this document “rehabilitation” is the return of a damaged site to a functional habitat for plants and animals without necessarily restoring the original (pre-damage) species and processes, while “restoration” is the re-establishment of habitat features, species, and processes that were present prior to disturbance. Most North Slope projects are focused on rehabilitation over time spans of ten years and longer, but many may eventually (over many decades) evolve into restoration projects as plant communities, ground ice conditions, and other site characteristics mature.

Recovery of disturbed sites in the Arctic depends on the nature and the extent of the disturbance and the type of habitat affected, but even sites suffering from relatively minor damage, such as tire tracks, often require active rehabilitation efforts. Rehabilitation projects are challenged by environmental conditions on the North Slope, such as generally limited precipitation during the growing season, a growing season of less than ten weeks a year, low soil nutrient availability, extreme cold winter temperatures, slow rates of soil development, the presence of shallow permafrost, grazing by geese and caribou, and the scarcity of plants that routinely spread onto disturbed ground by seed (Chapin et al. 1992, Jorgenson and Joyce 1994, UC 2009).

Protecting soil from hydraulic and thermal erosion (themokarst) has been one goal of tundra rehabilitation. Often, this goal has led to a desire for establishment of plants as quickly as possible with the belief that plant cover will restore soil thermal equilibrium and will prevent hydraulic erosion, but neither of these beliefs is universally correct. In

the past ten years, rehabilitation efforts emphasizing erosion control have been replaced or supplemented by efforts emphasizing improved aesthetics of disturbed sites (McKendrick 1999a), with performance standards typically focusing on establishment of plant cover likely to lead to a gradual return of plant communities typical of those found in the surrounding tundra (Streever et al. 2001).

Although large scale field abandonment and the subsequent rehabilitation or restoration of the greater than 10,000 acre infrastructure footprint on the North Slope lies in the indefinite future, various activities lead to ongoing needs for rehabilitation and restoration. These activities include intentional removal of abandoned gravel infrastructure (roads, pads, and airstrips), excavation and burial of reserve and flare pits, oil spill cleanup, trenching to bury cables or pipelines, off-road travel, and gravel mining. About five to ten new rehabilitation or restoration projects are initiated on the North Slope each year. Earthworks are typically followed by seeding, fertilization, and other attempts to improve growing conditions, in general accompanied by ten years of monitoring, with each site usually monitored once every two to three years. Monitoring reports are completed by the private sector and submitted to relevant agencies for approval. In addition, an annual joint agency-industry meeting and site visits facilitate ongoing communication about site development.

Questions Provided by the Senior Staff Committee

The NSSI Senior Staff Committee provided the Science Technical Advisory Panel (STAP) with six key questions relevant to restoration and rehabilitation practices on the North Slope. These questions are addressed below:

1. ***Under what circumstances is actual restoration to pre-disturbance conditions reasonably likely to succeed within less than twenty years?***

   Existing experience suggests that restoration within a reasonable time frame (less than ten years) may be possible where impacts do not damage the vegetative mat and shallow permafrost. For example, restoration may be possible after ice roads, pads, and airstrips melt, after winter seismic trails have been abandoned, after some tundra fires, and, occasionally, after light damage by off-road traffic.

   Ice Road Restoration: Ice roads, pads, and airstrips (for convenience, referred to collectively here as "ice roads") have been built since the mid 1970s and are the preferred method of logistical support for exploration access on the North Slope. Ice roads are also used extensively for the pipeline construction and maintenance. The construction of ice roads may damage tundra vegetation by affecting the plant's thermal environment at the base of the ice road or through scraping or compression. Experience

shows that the greatest impact occurs when ice roads are constructed in low snow areas on dry upland tussock tundra sites, where the ice can damage graminoids, shrubs, forbs, and bryophytes. Wetland areas show little or no impact from ice road construction because these areas are seasonally inundated with water and at the time of ice road construction are already frozen. Studies of an ice road constructed in 1978 showed that twenty four years later species composition and density of the vegetation had fully recovered comparable to undisturbed reference area conditions (Guyer, BLM Tech Rpt 2005). Analysis of soil profiles showed no significant variation in active layer thickness on multiple ice road locations and no evidence of thermokarst formation. Alaska Department of Natural Resources has monitored active layer depths on ice road routes the summer after construction since 2003. In all cases but one they found no significant difference in active layer depths between the ice road and the adjacent undisturbed tundra (Schultz, DNR, pers. comm.). In several cases DNR did see high levels of tussock damage from roads constructed during low snow winters. In all of these instances there was very little exposure of bare ground and no sign of thermokarst formation. Due to the low level of impacts associated with ice roads, vegetation damaged from ice road construction typically requires no restoration treatments and recovers naturally within ten years.

Seismic Trails Restoration: Research shows that the vegetation impacted by winter seismic trails can recover without intervention within eight years (Emers et al. 1995, Jorgenson unpublished). Critical factors affecting the impact on vegetation caused by seismic trails are depth and character of snow, ground pressure, number of passes by vehicles, vehicle types, terrain conditions, and types of vegetation. In recent history, improved methods for seismic exploration (e.g., low pressure tires for vehicles, use of tracked vibrators, and use of tracked vehicles with less aggressive tracks) have reduced the damage to tundra by reducing the weight, tracks, or number of vehicles used. In the Arctic National Wildlife Refuge, studies showed minor effects and rapid recovery on trails in flat areas of wet tundra. About one percent of seismic trails cause disturbances that require a much longer recovery period or may cause permafrost subsidence and erosion (Emers et al. 1995, Jorgenson unpublished). Current permit stipulations and common practices have reduced tundra damage from seismic activities and in most cases restoration does not require active intervention. In some cases survey areas have been reduced or surveys canceled due to inadequate snow. On those sites where damage does occur, the most appropriate method of restoration is to replace dislodged areas of tundra vegetation and apply fertilizer to the disturbed area.

Burn Site Restoration: Observations of vegetative recovery of the Anaktuvuk River Fire (2007) have shown that virtually no lichen cover remained in the burn area. In some areas extensive thermokarsting developed. Willows and grasses resprouted and by 2009 some willows were more than 25 cm tall. Normally, tundra fires burn the low-lying vegetation and surface of the peaty soils and rarely affect the thick organic mat, encouraging the re-sprouting of plants sometimes within days or weeks after the fire. As the climate on the North Slope warms and if the tundra environment dries, it is anticipated that more severe fires may burn away the surface peat and organic-rich soils. This may require decades for damaged areas to recover and in some cases may permanently alter plant composition. To date, sites burned by tundra fires have been allowed to naturally restore without intervention, but if fire severity increases intervention may be necessary.

Light-damage by Off-road Traffic: Tundra is occasionally damaged by off-road traffic—for example, by vehicles breaking through ice roads, by inappropriate use of tundra-approved vehicles (such as rolligons), and by vehicles that accidentally leave the approved road system. When damage is light, such as crushed vegetation, restoration can be achieved without intervention or with a combination of seeding and fertilization. Heavier damage can require rehabilitation approaches similar to those used following tundra excavation.

2. Under what circumstances is rehabilitation likely to succeed?

Rehabilitation efforts on the North Slope are most often associated with removing unused gravel (abandoned roads, pads, and airstrips), excavation and burial of reserve and flare pits, oil spill cleanup, trenching to bury cables or pipelines, and abandonment of gravel mines.

Gravel Pad Rehabilitation: Gravel pads left in place generally support little vegetation, probably because of a lack of essential nutrients, low organic matter content, and poor moisture retention. When gravel pads are surrounded by typical North Slope tundra, the absence of a seed source for upland species capable of surviving on gravel may also be a factor. In general, natural revegetation of gravel pads without active intervention usually leads to less than 1% vegetative cover after three or more growing seasons (Kidd et el. 2004). Nevertheless, experiments at BP's Put 1 gravel pad and growth at BP's Seed Nursery Pad show that substantial vegetation cover can be achieved on gravel pads under some circumstances if appropriate seeds and fertilizer are introduced.

Beginning around 2000, removal of all or part of the gravel constituting abandoned pads, roads, and airstrips became a common practice. Although

achieving elevations comparable to those of the surrounding tundra remains challenging, this approach offers some promise as a means of achieving rehabilitation objectives. Early concerns about massive ground ice loss and subsequent formation of lakes following gravel removal have not materialized. Gravel removal, followed by some melting of shallow ground ice (especially within ice wedges) leaves behind an uneven surface and leads to a polygonized landscape similar to that of natural tundra in at least some cases. The removal of gravel makes nutrients, organic matter, and soil moisture available for seeds, possibly increasing the number of species that can be planted successfully (Jorgenson, Joyce 1994). Some studies of treatments on gravel removal sites showed a total live vascular cover of 15 percent following seeding of native grass cultivars and three growing seasons. In some cases, grass cultivars die off after 7 to 10 years, allowing replacement by locally abundant species. Since about 2004, seeding of native grass cultivars has only been used in areas where rapid plant cover is desired, in part because grass cultivars may slow the development of a more natural plant community. Instead, fertilizer is applied and seeding occurs by natural recruitment or active seeding of selected native species, including, at a few sites since 2010, sedge seeds. Experience suggests that 10 percent plant cover by native species after ten years is a realistic projection, on average.

Excavation and Burial of Reserve and Flare Pits

Gravel pads are often accompanied by reserve pits and flare pits, and when gravel pads are removed reserve and flare pits are often also excavated (to remove contaminated material) and then backfilled to slightly above grade. Backfilling to above-grade elevations prevents ponding of surface waters and limits the spread to tundra of any contaminants inadvertently left behind. Backfilling is usually accomplished with a combination of gravel and mineral soils, with about 20 cm of mineral soils placed on top of gravel backfill. Often, grass cultivars are seeded to encourage rapid establishment of plant cover and to prevent erosion, although the actual benefits of seeding with grass cultivars have not been documented.

Tundra Rehabilitation after Spill Cleanup

The tundra rehabilitation methods used at spill sites vary depending on the nature of the spill and the approach to spill cleanup. In the most extreme cases, spill cleanup requires excavation of tundra to remove fluids that have migrated into the soil. The excavated area can be backfilled with gravel topped with overburden, and the overburden can be seeded with grass cultivars or allowed to recover naturally. Since 2006, tundra sodding has been attempted on several spill sites. Sodding involves harvesting native

tundra from an area slated for destruction (such as a site where mining is planned), transporting sod to the spill site, and placing the sod, usually with fertilizer. Based on very limited experience, this approach seems to lead to rapid rehabilitation and possibly even restoration of communities similar to those of the surrounding tundra within a few years. However, it is labor intensive and expensive, and only a limited quantity of sod is available from donor sites slated for destruction (e.g., mine sites). In at least two instances, lemming grazing led to extensive but temporary damage. This method would work equally well on many excavated and backfilled sites, but to date has only been used on spill sites. Only one site—the ~0.15 ha L3 spill site—has been entirely sodded.

Pipeline and Power Cable Trenches

Pipelines and power cables are occasionally buried in trenches cut into tundra. Trenching, under some circumstances, leads to thermokarsting one to several seasons after ground disturbance, leaving behind linear depressions that can trap water and alter surface hydrology. Repeated backfilling of entire trenches or portions of trenches, sometimes supplemented by seeding with native grass cultivars or placement of sod in selected areas, can arrest thermokarsting and stop water flow, eventually allowing recovery of vegetation. Although trench restoration sites do not typically cover large areas, they can stretch for long distances across remote tundra that is difficult to access. Also, thermokarsting can be insidious; occurring from several to many years after initial trenching and even recurring after stabilization appears to be complete, thus requiring ongoing monitoring. On the other hand, narrow trenches that are not substantially affected by thermokarst can support communities similar to those of the surrounding tundra within a few years

Mine Site Rehabilitation

The opening of the North Slope to petroleum development led to a need for large quantities of gravel for the construction of gravel roads and infrastructure. In the early 1970s, most gravel was collected from shallow scrapes in river floodplains that presumably recovered as new gravel moved along river beds. However, concerns over floodplain impacts led to a state policy in support of gravel pit mines. Developing a gravel pit mine changes the hydrology and soil properties of the mined area so drastically that the original vegetation cannot be restored. Some gravel pits were allowed to flood after all usable gravel had been removed. It was discovered that many of the deep flooded gravel pit sites that do not freeze to the bottom can provide overwintering habitat for fish. Stream channel access, flooding and shoreline modification creating littoral zones have been used to enhance

aquatic ecosystems in the Arctic to create fish and migratory bird habitat in rehabilitated gravel pits. Shallow areas in flooded mine pits, as well as the surrounding disturbed tundra, can be rehabilitated using methods similar to those used for gravel pad rehabilitation.

3. What are appropriate monitoring methods (how often and to what degree)? What measuring techniques should be used?

Monitoring of North Slope rehabilitation sites is undertaken almost exclusively to track progress toward performance standards stipulated in plans and permits. In general, North Slope rehabilitation performance standards, and therefore monitoring, focus on plant cover, plant species richness, and ground surface stability.

Most plant cover monitoring relies on variations of the walking point method, in which a trained botanist records the number and species of "hits" along a transect or transects. The point may be the tip of a cane or, as has become common over the past decade, the tip of a laser light held in an easily moved frame; the frame projects the light downward, the point is read, and the frame is moved to the next point. For most sites 500 points are sampled, usually at roughly 1-m intervals along 5 or more transects. In some cases, only the first hit (the "canopy hit") is counted, but in other cases multiple hits are counted, making it possible to achieve more than 100% cover. In comparing plant cover among sites, it is important to understand the methods used and, especially, whether or not multiple hits or only canopy hits are counted.

Species richness counts are often done using data from walking point transects, but they can also be done using random searches (or "drunken walk" searches). In some cases, only those plant species occurring with some pre-established frequency—such as 0.2%—are included in species richness counts, so that "trace" species do not contribute to the overall species richness on restoration and rehabilitation sites.

While mosses, liverworts, and lichens may contribute substantially to ground cover at some sites, and while they contribute to soil development over time, in general only vascular plants are included in plant cover and species richness assessments. This convention was established some time around 2001.

Monitoring of surface stability can be done subjectively—for example, by looking for obvious signs of thermokarsting—or by undertaking surveys of transects or grids across entire sites. Some surveys are conducted using laser levels while others are undertaken by specialized survey crews using

survey-grade differential GPS to establish actual elevations relative to a known stable benchmark.

A repeated sampling effort undertaken over two summers showed that plant cover estimates vary seasonally and among sampling crews. Although no repeated sampling method has been attempted for elevation monitoring, frost heave and differences in the approaches used by different crews almost certainly lead to inconsistencies. Although plant cover, plant species richness, and surface elevation assessment methods are not entirely consistent, they can provide a reasonable assessment of site progress provided that the possibility of inconsistency is understood by field crews, regulators, and managers.

Prior to about 2000, monitoring was often required for as little as three years, but early experience showed that three years of monitoring did not adequately document site performance, especially for gravel removal sites. For some trenching sites, monitoring may be required for less than five years. On gravel removal sites and other sites involving excavation and backfilling, monitoring is commonly required for ten full growing seasons, especially on gravel removal sites. However, requirements do not usually call for annual monitoring, but rather for monitoring every three years.

4. Is one performance standard appropriate, or are different standards needed for different vegetation types?

In general, North Slope restoration and rehabilitation performance standards focus on plant cover, plant species richness, and ground surface stability.

The predominant parameter for gauging the success of plant establishment in the Arctic has been total live vascular cover (TLVC). Over the past twenty years performance standards or the expected result of TLVC has varied based on the goals of each rehabilitation/revegetation project, but in general there has been a transition from a focus on rapid revegetation without regard to species composition to a focus on slower revegetation moving toward plant communities that are similar in species composition and cover to undisturbed sites, with the recognition that many decades may be required for plant cover to even approach that of undisturbed sites.

The document *North Slope Plant Establishment Guidelines Table,* developed by industry with input from numerous sources, recommends treatments based on both “wet” and “dry” conditions. On all treatments except for ponds and pond margins the guidelines recommend a predicted outcome of not more than 10% TLVC after ten years. While the long-term goal may call for greater cover, reaching the goal of 10% TLVC offers reasonable assurance

that the vegetation will survive and spread over time. The 10% TLVC recommendation can be traced to work undertaken by the Corps of Engineers in the 1990s, in which all available data on North Slope restoration and revegetation cover data were regressed using multiple regression methods, with time (years since project inception) as a primary factor.

Plant species richness is typically set at 5 species with at least 0.2% cover each. This standard, which has become to some degree a convention, appears to be entirely arbitrary and likely resulted from discussions between industry and regulatory agencies during the establishment of rehabilitation and restoration plans between 2000 and 2004.

Standards for surface stability are often subjective, suggesting, for example, that the ground surface should not show evidence of extensive thermokarsting. In some trenching projects, more quantitative standards have been put in place. For example, some trenching projects have standards that prohibit subsidence and flooding during the growing season along trench lines greater than ten meters long. This standard, which has become to some degree a convention for trenching sites, again appears to be arbitrary and likely resulted from discussions between industry and regulatory agencies during the planning of gas pipeline trenching trials at two North Slope sites (MS3 and Put 27) and one site about 40 kilometers north of Fairbanks (the Washington Creek site).

Performance standards should be consistent with management goals (which should be clearly stated in rehabilitation and restoration plans), appropriate for the ecology of the site, and realistic based on the specific techniques administered. For example, one project's goal was to establish 35% TLVC after three years from the date plants were broadcast. The evaluation three years later showed TLVC was only 15% and ten years from the date had only achieved a TLVC of 18%.

5. Is fertilizing effective and under what conditions?

Even though nitrogen and phosphorous are naturally occurring in arctic soils they are not in organic forms in high concentrations and they are not readily available to seedlings. To compensate for the lack of available nutrients, fertilizer has been used to help reestablish vegetation. Fertilization applied to grass cultivars on gravel rehabilitation sites has been shown to increase plant cover for up to several years, possibly facilitating soil development and enhancing the moisture regime. Important factors affecting the success of fertilization are soil properties, amount and timing of fertilization, presence of contaminants, and density of seed application, seed quality, grazing, and weather. In almost all cases fertilization has a beneficial effect on seeding

projects of native cultivars or on projects where indigenous plants are established through natural colonization. Experience and some studies suggest that seeding grass cultivars followed by fertilization on gravel pads may also inhibit the natural colonization of other indigenous plant species.

6. Seeding: What, when, where, and how much?

Seeding of restoration and rehabilitation sites with native seed and cultivars is a common practice. The seed used depends on a number of factors, including seed availability, site conditions, and project goals and performance standards.

Since the late 1990s it has been apparent that planting grasses on dry gravel sites is not self-sustaining. On sites at tundra grade with mineral or organic soils, seeding native grass cultivars often promotes rapid establishment of plant cover but probably delays development of plant communities typically found in natural tundra. Native grass cultivar seeds are commercially available and are commonly applied to sites where rapid plant establishment is considered desirable, such as sites where potentially contaminated soils have been capped, leaving above-grade elevations.

Seeding of indigenous forbs that naturally colonize gravel along arctic streams has been found to be successful in establishing plant cover on drier gravel sites. In most cases North Slope native forbs are not commercially available and must be collected from donor sites. At least one donor site has been intentionally cultivated in the Prudhoe Bay oilfields—that is, one abandoned pad near the Prudhoe Bay Operations Center, known as BP's Seed Nursery Pad, has been heavily seeded with *Oxytropis*.

Projects where gravel has been removed must allow time (up to two years) for the soil thermal regime to stabilize before successful planting can occur. Removing all of the gravel accelerates thaw subsidence, which has the desirable affect of leading to a broken and natural tundra appearance while also providing differing dry and hydric soil conditions. Determining the "dry" and "wet" conditions of the soil is critical in seed selection and planting strategies.

Numerous site preparation techniques to improve soil moisture and nutrient availability, and therefore seeding success, are being investigated. Of all site preparation treatments, the addition of organic soil shows the greatest promise, at least on restoration and rehabilitation sites with only a gravel substrate or a mineral soil substrate. In some instances organic-rich soil has been used to provide a bed for reseeding. The addition of organic soil improves soil moisture retention and increases nutrient availability. Even

without fertilization the amount of available nitrogen remains high in areas treated with organic topsoil.

Seeding density depends on the species being planted, the conditions in which they are planted, and site goals and objectives. Industry, with input from numerous sources, has provided written guidelines on seeding rates under different circumstances.

Recommendations

1. Guidelines that address rehabilitation of gravel roads and pads and rehabilitation of gravel mine sites have been written by the state of Alaska and the oil industry. These guidelines, the *North Slope Plant Establishment Guidelines Table* (BP and ConocoPhillips, 2004) and the *North Slope Gravel Pit Performance Guidelines* (ADF&G 1993) should be used when planning and implementing rehabilitation projects. These guidelines should be reviewed at ten-year intervals to incorporate new information based on monitoring results.

2. Industry, state, federal and local agencies currently meet annually to discuss progress on existing rehabilitation projects and plans for future restoration projects. In addition, managers and regulators jointly visit restoration and rehabilitation sites annually. These annual meetings and site visits should continue.

3. Over the past ten years, restoration and rehabilitation methods have evolved rapidly, but no single report or paper has been generated to summarize these advances. A summary report or paper should be prepared to summarize the status of the science, possibly using this issue paper as a starting point but providing more detailed information and data analyses from monitoring reports on numerous different sites of different ages.

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Emerging Issue Summary
SPECIES OF INTEREST – MIGRATORY BIRDS

Highlights

- Habitat use/selection is incompletely known for most migratory birds on the North Slope. A more complete understanding of migratory bird use of Arctic habitats, including offshore habitats, is needed in order to identify appropriate mitigation measures in areas of oil and gas development and to more accurately predict the potential impacts of climate change and land management decisions. The lack of data on rare species (existing species in low numbers) is a major concern, given their significant influence on management decisions.

- Understanding population status and trends is also critically important. Inter-annual and seasonal data are necessary to describe the natural range and variation in population dynamics parameters for target species.

- An oil spill into Arctic waters could be devastating to migratory birds, particularly if it occurs during a key life cycle event (e.g., molting). A spill occurring in the Outer Continental Shelf (OCS) during a period of broken ice could be problematic in that the oil could be concentrated at the water surface in open leads, directly impacting resting birds. As these leads close or shift, oil could be forced down into water column, thus impacting prey or the ability of these birds to successfully forage. An onshore spill into a waterbody could also affect birds in key life cycles such as described above.

- Limited information is available about migratory corridors and wintering areas for many bird species using the North Slope. Understanding impacts in areas farther south and cumulatively will be important for making management decisions on the North Slope.

Red-necked phalarope (Brad Winn)

Overview and Management Relevance

The seasonal distribution and abundance of migratory birds using Alaska's Arctic habitats is dependent on the amount of high quality, intact and undisturbed habitat for breeding, rearing and molting. With climate change and the expansion of industrial activity on the North Slope, we can expect changes in the availability and distribution of seasonal habitats used by migratory bird populations. Changes in habitat availability and use may result in changes in population dynamics parameters including initial productivity and causes and rates of mortality for both juvenile and adult birds. For example, development of the area near Teshekpuk Lake will require an understanding of molting goose responses to industrial activities, including overflights and the construction of infrastructure. The time required to establish meaningful pre-development information should not be underestimated. In many cases, data will have to be collected for ten years or more to acquire a reasonable understanding of natural variation in seasonal bird habitat use, productivity, and population trends. Populations may already be impacted by climate change, but we cannot yet discern these impacts.

Understanding population status and trends is also critical in determining if mitigation efforts are effective and to identify the level of risk that a population can tolerate and be sustainable. Understanding natural variation in population status is also necessary for determining what levels of change in populations can be detected using standard

accepted methods for monitoring population status and trends. Although habitat use is understood on a coarse level for many species, further research is needed to understand the use of estuarine areas by species such as long tailed ducks, red phalaropes, red-throated loons, and others. Finally, birds that use the North Slope in summer may be impacted by anthropogenic stressors in transit to/from and within their winter habitats. It is therefore also important to understand the threats to birds across their entire migration routes, including storms, contaminants, loss of habitat, and predators.

In addition to these broad concerns, the NSSI Senior Staff Committee provided the STAP with specific questions relevant to migratory birds. STAP responses to these individual questions follow below.

1. Are current breeding bird surveys sufficient to meet management needs in a changing environment?

A waterbird breeding population survey conducted annually by the USFWS provides an index of trend and numbers of breeding pairs for roughly one-third of the bird species and their distribution along the Arctic Coastal Plain. These surveys are conducted only once in the summer and do not specifically estimate population size nor determine trends in abundance. Their design works best for species with more uniform distributions, but is less well suited for species with more clumped distributions, such as brant and lesser snow geese. While these surveys do show the distribution of breeding pairs, they do not capture complete information about habitat use and trends. Habitat use data are critical for understanding climate change impacts. New studies need to reconcile differences in scale between the way data are collected and the way they are applied. For example, waterbird surveys are generally broad-scale aerial counts, while industry often conducts site-specific aerial monitoring.

An important step in establishing a well designed breeding bird monitoring program would be to begin by compiling existing data, with an eye towards data collected for industry (which may be poorly incorporated into the public knowledgebase) within the broader bird survey database.

Other considerations in designing an adequate migratory bird monitoring program include:

- Collecting data before, during, and after construction. Studies should be designed to address both short-term and long-term changes associated with industrial activities. In addition, broader scale experimental designs are needed for identifying trends driven by factors such as climate change.

- Aerial surveys need to be ground truthed. There is currently little long-term consistent ground monitoring on the North Slope at a regional scale. This is especially needed on barrier islands and other key habitats. Ground surveys would allow estimates of productivity to provide data on population status and trends. Also, surveys need to be expanded into the late spring and early fall to understand the importance of Alaskan waters for birds migrating through to the Canadian High Arctic

- To allow for the improved design of monitoring studies, managers should identify the degree of change that is important; for example, a study intended to detect a ten percent change in the number of birds occupying a particular area would have a different design than a study intended to detect a thirty percent change in the same area.

- Monitoring needs to be further expanded beyond waterfowl surveys to include other migratory species; current breeding surveys consider approximately one-third of the North Slope bird species. Unmanaged species are not typically treated as being of concern until they near a critical threshold, and then it is difficult to know what is normal or sustainable. To make investments in such an expanded effort most efficient, it will be necessary to develop lists of species of potential management concern and/or to identify appropriate 'sentinel' or focal species.

- Other issues besides oil and gas development, including issues related to subsistence and sport hunting, should be considered.

2. Are there likely to be shifts in species composition and how will this affect subsistence use patterns?

Shifts are already occurring as a result of industrial activity and possibly climate change. Ravens, gulls, foxes and other predators appear to be concentrating around infrastructure and villages, and in turn may be affecting some bird species at a local scale. Recent studies on the role of these predators on tundra nesting birds were not able to discern an adverse impact. Long-term monitoring plots and ongoing monitoring of bird species is important for interpreting dynamics of change. It is also important to understand subsistence use patterns to capture social implications (cultural importance, nutrition and economics), including public perception of industrial impacts (e.g., Nuiqsut). Species important to subsistence include white fronted geese, king eiders, common eiders, Canada geese, snow geese, black brant and others.

3. Is there sufficient data on rare species to credibly advise whether a specific management action is/isn't needed?

In some cases the answer is no. However, in some areas over 10 years of data on ESA-listed or proposed species (Steller's and spectacled eiders, yellow-billed loons) have been collected prior to infrastructure development. Site-specific monitoring is always appropriate and necessary to understand habitat use in proposed development areas before infrastructure development or other management activities that may alter habitat are undertaken. Rare species (existing species in low numbers) need to be the focus of specific surveys at the appropriate spatial and temporal scale. Lack of data on rare species is a major concern, given their significant influence on management decisions. However, managers with limited resources will need to prioritize data collection on rare and common but important species.

4. Are any species headed toward ESA listing? If so, which ones and how may their listing affect management?

Potentially, yes. The listing of yellow-billed loons as a threatened or endangered species under the ESA was recently found to be warranted by the USFWS, but precluded by other higher priority listing actions. Other species whose populations may be of concern include dunlin, ruddy turnstones, other loon species, and long tailed ducks. The STAP's listing of these species is not intended to reflect any specific knowledge of their suitability for ESA listing, but simply to provide the requested heads up on which species may bear watching. Indeed, other species may face significant threats and subsequent ESA listing as habitat and other conditions continue to change.

5. How might water use patterns (e.g., lake pumping versus recharge) affect waterfowl habitat quantity and quality?

This is an important question related to both industry and climate change. Impoundment research and water withdrawal studies related to fish also need to be expanded to consider migratory birds. To understand the cumulative effects, improved understanding of the amount of water needed to sustain key habitats is needed, including the balance between inputs and losses. Issues behind this question are closely linked with other emerging issues, including hydrology and lake drying emerging issues. Waterfowl may be useful as a biological indicator (or 'sentinel') species, but habitat selection data and site specific data before and after water withdrawal will improve knowledge of impacts. It would be useful to review existing data on recharge, water quality, and water quantity and overlay these with species use data. Industry datasets may be helpful to this data mining effort in support of modeling efforts to improve impact projections

6. Is more robust subsistence harvest data needed, what kind, which species, how will it be used?

Legalization of spring and summer harvests resulted in some studies to address migratory bird harvest, which provide estimates of take for commonly harvested species. However, data are sparse for rare and endangered species. The Alaska Migratory Bird Management Council (AMBCC) has a Subcouncil on Subsistence Harvest Documentation that advises on collection of subsistence data. There is concern over the accuracy of data on subsistence users' recollection of seasonal take when these data are collected only periodically. These data are sufficient for detecting change in subsistence use of common species, but better data are needed for rare species.

7. Will the nature of ice edges as locations of food gathering and/or resting places change, and what will be the effect of this change on species' bioenergetics?

Conditions have already changed, especially since the extreme sea ice late summer minima of 2007 and 2008. The Pacific Arctic has shifted to a 'new state' with regard to sea ice. Most of the multi-year ice is gone, with the remaining first year ice easily moved and shifted by wind. Predictions are now for a summer/autumn ice-free Arctic by 2040, with increased inter-annual variability. Understanding the impacts of changing conditions along the ice edge requires information on both bird energetics and how birds use the ice edge, neither of which is well understood. There is some dietary information for Bering Sea populations, but not for the Chukchi and Beaufort Seas (with the possible exception of guillemots). Species that use ice edges and warrant further study include eiders (all), ivory gulls (potential candidate species) and Ross gulls, long-tailed ducks, and black guillemots.

8. What changes may be in store for ice leads as habitat and what may be the effect of any changes in oil spill risks on the likely function/value of ice leads?

Springtime lead systems remain a key feature to winter/spring conditions offshore of the North Slope as migratory birds seek open water for resting and feeding. An oil spill will make a lead unsuitable habitat if it reaches the lead. Oil on the surface of an open lead will directly impact resting waterfowl, and as ice leads open and close, oil can be forced down into the water column, impacting bird food sources. However, the extent to which migratory birds use leads or lead edges for more than a staging ground is not well documented for most species.

Data needs include:

- Physical data on leads should be linked to bird studies, especially energetics;
- Compile existing data (e.g., from long-term studies in Chukchi Sea) and develop better characterizations of the benthos, and gaps in our knowledge of benthos, in order to describe important feeding areas;

- Collect productivity data that account for interactions between warming on the one hand and sub-ice and open water productivity on the other hand.

9. *How & where will oil spill risks to birds (from rig operation, loading/transport, pipelines) be altered if additional energy development occurs?*

Oil and other fluid spills can occur in association with all aspects of exploration, development, and production. Smaller spills associated with construction and minor spillage from ships associated with energy development can potentially impact smaller numbers of birds. Much larger numbers of birds could be impacted from pipeline leaks, and especially from catastrophic failure of pipelines, especially if offshore or onshore near waterbodies frequented by waterbirds. Major spills associated with serious shipping accidents could also impact large numbers of birds. Lastly, although the likelihood of loss of control at the wellhead (a blowout) is extremely small, if quantities of oil in the water associated with loss of control at the wellhead are high and difficult to control, a large number of birds could be impacted.

10. *Will an increase in energy infrastructure (OCS oil/gas rigs, wind energy structures) increase bird strikes?*

An increase in energy infrastructure will lead to an increased number of bird strikes. Power lines seem to be especially problematic, but birds are also known to collide with offshore and coastal infrastructure. Some information on bird strikes is currently collected (USFWS, discreet industrial studies), but data are not organized in a way that allows a definitive understanding of bird strikes and are not intended to answer questions of population level impacts. It is recognized that current techniques are not sufficient to accurately quantify bird strikes, as predators could remove a carcass before it can be counted. At best, only qualitative analyses, which are likely under-reporting, are being used to assess bird strike frequency. In addition to developing techniques or technologies to assist with quantifying the impacts the number of bird strikes, there is a need to further develop technologies to mitigate bird strikes (e.g., lighting and paint/color, diverters, flagging).

11. *How will any changes in migratory waterfowl numbers or distribution alter risks to aircraft from bird strikes?*

Increases in migratory waterfowl will clearly increase the risk of aircraft strikes, as will an increase in flights. To understand how to mitigate this impact, habitat use, locations of strikes, and timing of bird activity (diurnally and seasonally) needs to be better understood. Understanding how to manage waste and site infrastructure in order to discourage congregation is also needed.

Recommendations

1. Site-specific monitoring needs to be implemented well in advance of industrial activity. Information needed to understand productivity, recruitment, longevity and survival rates should be collected for sufficient time to establish pre-development conditions. Once infrastructure construction/installation begins, data on disturbance should be collected in a way that allows quantification of impacts to populations as well as thresholds of disturbance/tolerance. This is not possible for all bird species. Monitoring programs should initially focus on the minimum number of species for which we can adequately collect data, with a priority on those birds with high potential for listing under the Endangered Species Act or of those of other conservation concern (e.g., species important for subsistence use).

2. Collection of subsistence use data, especially for rare or uncommon species, may not be adequate for some purposes. To the extent that co-management councils and others are not adequately addressing this issue, additional effort should be made to improve collection of subsistence use data,

3. Because of the broad range of impacts migratory birds face across their migration routes, quantifying these impacts is critical. For example, climate, weather and habitat quality across the migration route may impact individual and population responses to conditions in the Arctic.

4. Changes in Arctic climate and habitat quality will also impact migration success. Conceptual models that describe key drivers and processes are needed to develop hypotheses that direct research designs to detect and interpret impacts. To assess each of these impacts and their relative risk, it is recommended that a database is designed and filled for key species with key variables derived from the conceptual models. From this effort, it should then be possible to identify data gaps, including monitoring needs for rare species, and determine how to fill these gaps. This process will lead to development of conceptual models.

5. Understanding the risks from oil spills to onshore and offshore populations needs to be improved through monitoring and appropriate experimentation prior to development, and this understanding should be re-evaluated as development proceeds. Monitoring programs need to be designed so that significant oil spill impacts can be quantified and to guide oil spill impact mitigation.

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Emerging Issue Summary
SPECIES OF INTEREST – CARIBOU

Highlights:

- Many of the concerns raised for this issue dealt with perceived differences in the management of the four herds that calve on the North Slope. While there are valid scientific issues of consistency for comparing data, these are primarily management concerns and could be addressed by initiating and/or participating in collaborative management planning processes for the four North Slope herds, to the extent that this is not already occurring.

- A meeting or mini-conference should be supported to identify and prioritize data needs, and to identify data currently being collected. The meeting would recommend parameters for cooperative annual data collection planning and the data structure necessary to design a data sharing network. The earlier work of the NPR-A Research and Monitoring Team (e.g., monitoring strategy, caribou model, and subsistence access model) may serve as a useful starting point for identifying some of the core data needs and planning work.

- Directed research projects, informed by the above meeting and supported individually or collaboratively by NSSI members or affiliates, will be needed to address some management concerns.

Caribou on the North Slope. (Alaska Department of Fish and Game)

Overview and Management Relevance:

A number of challenging research questions came up in the discussion of caribou on the North Slope, but much of the exchange focused on the need for data sharing, study coordination, and the timely dissemination of results. Similarly, the health of caribou herds and their supporting ecosystems on the North Slope were important parts of the discussion, but it was the potential effects of industrial development and climate change on the use of those herds, particularly for subsistence harvest, that drove the discussion. Therefore, this summary focuses first on some of the perceived needs for management action and then in a more general way addresses the full suite of management questions, concerns, and needs discussed by the group.

The Senior Staff Committee of the NSSI presented over a dozen specific caribou related management concerns for STAP consideration. These management concerns have been condensed into three statements of need:

- For each North Slope herd, individual management plans are needed that consider herd health, access to and uses of each herd by various user groups, population dynamics parameters, each herd's unique challenges (threats, uses,

and management goals), and account for common uses of seasonal ranges among herds and potential movements between herds.

- Interagency monitoring and research plans need to be developed for each North Slope caribou herd. Monitoring and research plans should be a product of and consistent with collaborative management planning efforts, and should elaborate on data currently being collected (including information on who is collecting data), on how existing data can be accessed, and on data not yet being collected.

- A network is needed to share caribou information between and among herd managers, researchers, and user groups.

The STAP concurs with these statements of need. The STAP recognizes that caribou herd management plans are in place for the North Slope herds, but that the collaborative (both public and interagency) processes associated with these plans are varied. The STAP also recognizes that basic population dynamics and harvest information are being collected for each of these herds, in some cases as a result of interagency efforts. However, it is not clear that the existence or the availability of these data are apparent to agency, academic, industry, and public stakeholders in the management or research activities associated with the four caribou herds that calve on the North Slope: Western Arctic Herd (WAH), Teshekpuk Herd (TCH), Central Arctic Herd (CAH), and Porcupine Herd (PCH).

Each herd presents a somewhat unique set of challenges. The WAH is the largest herd in the State, has numerous users and thus potential user conflicts, is harvested across multiple state Game Management Units and by many villages, calves in a high coal potential area, and has seen population decreases in recent years. There is already a well developed collaborative management process in place for the WAH, the Western Arctic Caribou Herd Working Group.

The TCH may be the most important herd to several North Slope villages (Barrow, Nuiqsut, Atqasuk, and Wainwright) in terms of subsistence harvest, and while it calves in an area with high oil and gas potential, it has up to now been exposed to relatively little oil and gas development. Therefore, it is a herd that is likely not habituated to this form of human disturbance (see Topic 3 below).

The CAH calves in or near currently developed oilfields and might have been a “learning herd” for interactions with oil and gas development, but this ability to learn was limited because little baseline data were collected prior to oil and gas development. Nonetheless, research on this herd has helped to identify and mitigate some of the problems associated with development. Importantly, the TCH and CAH are the only two herds in North America which in general whose numbers have been increasing since the 1980s.

The PCH calves in the 1002 area and the western Canadian coastal plain and is jointly managed between the Alaska Department of Fish and Game (ADFG), the US Fish and Wildlife Service (USFWS), and the Canadian government through the International Porcupine Caribou Board. Also, Canadian users have an established collaborative management process in place, the Porcupine Caribou Management Board. The PCH presents unique logistical challenges for population censuses, with the last successful census completed in 2001. The PCH had been in consistent decline prior to the 2001 census and there is concern that the population has continued to decrease.

Despite their differences, all of these herds share some common challenges (e.g., climate change), and the STAP strongly suggests coordination among research, monitoring, and management planners for each herd in order to maximize comparability (e.g., for monitoring protocols, study design, data format, etc.) and maximize the opportunity to jointly learn from and understand these shared challenges. The earlier work of the NPR-A Research and Monitoring Team (e.g., its monitoring strategy, caribou model, and subsistence access model) may serve as a useful starting point for identifying some of the core data needs and planning work. A focus on increased monitoring is promoted in the 2008 Arctic Report Card (http://www.arctic.noaa.gov/reportcard/biology.html), which notes that recent estimates indicate that many arctic caribou populations "may be entering a period of declining numbers" and that "the increased threats of climate change, increased industrial expansion in the north and the increased sophistication and mobility of harvesters will require more careful monitoring and analysis of population response."

Certain types of data are uniformly needed and can serve more than one purpose. For example, population dynamics data (population size, data on initial calving rates and recruitment, and natural mortality and harvest information) are central to wildlife population modeling. Data on habitat condition (vegetation type and distribution) are key to implementing land management decisions. However, both of these core data types can also be used together for other purposes – for example, in assessing the response of wildlife populations to climate-driven vegetation changes. Notably, this latter type of data (vegetation type and distribution) overlaps nicely with ongoing NSSI-funded land cover work on the North Slope, reinforcing the value of current NSSI efforts to underpin and assist with needed future studies.

Other important types of data that are needed include:

1. distribution and movement data obtained from satellite collared animals across all herds and seasons;

2. animal condition data, including sex and age, from harvested animals, as well as information on herds targeted by sport and subsistence hunters (e.g., which herds are being harvested by particular communities);

3. improved documentation of subsistence and sport harvest data;

4. potentially correlative weather data (temperature, wind speed and direction, precipitation, snow cover and persistence, icing events, and other factors); and

5. accessible and spatially explicit data on the location and timing of ongoing and planned industrial activity (seismic operations, ice roads, pad development) across all seasons.

The management concerns discussed above and the science and information needs to address them were grouped by the STAP into five topics, each discussed below.

1. *Topic 1. Development of Management Plans for Each Herd*

   The STAP supports the development, to the extent they do not already exist, of collaborative management planning processes for each of the four caribou herds that calve on the North Slope. The NSSI could facilitate initial communications to identify stakeholders, and potentially even underwrite facilitation and travel support for stakeholder meetings necessary to generate these management plans, particularly as such coordination will enhance scientific understanding of the shared challenges of all four herds (e.g., challenges associated with climate change). It will be important in the development of such management plans to involve all appropriate stakeholders (e.g., users, managers, and industry) and to evaluate the consistency of stipulations for oil and gas development and other anthropogenic impacts on North Slope ecosystems. Finally, given the concern for communications clarity, it will be important for each management plan to address how it will enable and maintain communications among stakeholders.

2. *Topic 2. Herd-Specific Data Requirements*

   To support management planning processes and provide a sound basis for research and monitoring plans, it will be necessary to identify existing caribou data and the entity that collects and has access to these data. A directed caribou meeting could help accomplish this. In addition, the meeting would identify data not yet being collected to assist with identifying high priority data needs. A plan can then be developed in cooperation with GINA for identifying raw data and summary statistics structures, metadata requirements, and protocols and timelines for populating databases. This would help determine what, if any, pre-development measurements are needed.

3. *Topic 3. Directed Studies*

A number of the management concerns presented to the STAP pointed to the need for specific directed studies. Among the issues that fit in this category were:

1. information on the winter ecology of caribou;

2. assessing the appropriateness of land use stipulations and their value to caribou;

3. seasonal variation in caribou food production under changing climate conditions;

4. response of caribou herds not habituated to oil and gas exploration and development;

5. how changing fire regimes and fire response may affect caribou distributions and caribou food sources; and

6. evaluation of current data collection methods and opportunities for improvement using advanced technologies

Many of these specific investigations could use remote sensing data combined with targeted on-the-ground monitoring for verification. Present methods of aerial surveys, photocensus, and use of radio collars could be re-examined to assess whether remote sensing technology/satellite tracking and GIS could play a significant role in monitoring herd movements and seasonal range use.

It was also noted that some study opportunities arise when unusual events occur. For example, if there were catastrophic winter die-off of caribou, the NSSI could facilitate communications and help pool resources among agencies to document and monitor the event. Finally, the STAP believes that continued development of modeling efforts initiated by the NPR-A Research and Monitoring (RMT) team may serve as a critical first step in an effort to decouple local or regional anthropogenic impacts to caribou from those of climate change.

4. *Topic 4. Data Reporting and Sharing*

There has been a clear benefit from data sharing among the various caribou managers and key stakeholders. Agency management could pursue the assistance of GINA to design a usable data sharing network. GINA may also be an appropriate entity to store and share spatially explicit and associated metadata. Access to these and other relevant data (e.g., vegetation mapping) would assist wildlife managers with evaluating cause and effect relationships and

gain a more complete understanding of anthropogenic and environmental impacts to caribou and their associated user groups.

5. *Topic 5. Anthropogenic and Subsistence Issues*

   There is a perception that climate change, harvest, and industrial activities have had, or are having, a negative impact on caribou despite the fact that some populations of caribou that calve on the North Slope are near or at historic highs. Perhaps the most important way to address this perception is to investigate the historic extent and variability in seasonal range use and harvest among subsistence villages and sport hunters. This information can then be used to predict potential impacts of anthropogenic and environmental changes. An important component of this understanding will be a contemporary assessment of both western and traditional ecological knowledge. Direct dialogue among the land and caribou managers about the variability in population, distribution, harvest, and implications to the subsistence harvest is needed. By its nature, this dialogue will not be independent of current monitoring efforts conducted by land and wildlife managers, or of an evaluation of land use stipulations.

Recommendations:

1. Identify a means of improving the collaborative management process for each of the four caribou herds calving on the North Slope. Where necessary, consider the proper level of financial support for collaborative management processes.

2. Organize a meeting with land and wildlife managers, industry, and other stakeholder groups to:

   - identify existing data and its accessibility;
   - coordinate data collection planning; and
   - assess and prioritize specific directed studies.

   Additional meetings may be required, as necessary, to complete these tasks.

3. Develop an understanding of the historic extent and variability in seasonal range use and harvest by subsistence and sport hunters. This assessment must incorporate and reflect both western and traditional ecological knowledge.

Emerging Issue Summary

SPECIES OF INTEREST -- MARINE MAMMALS AND THEIR PREY

Highlights

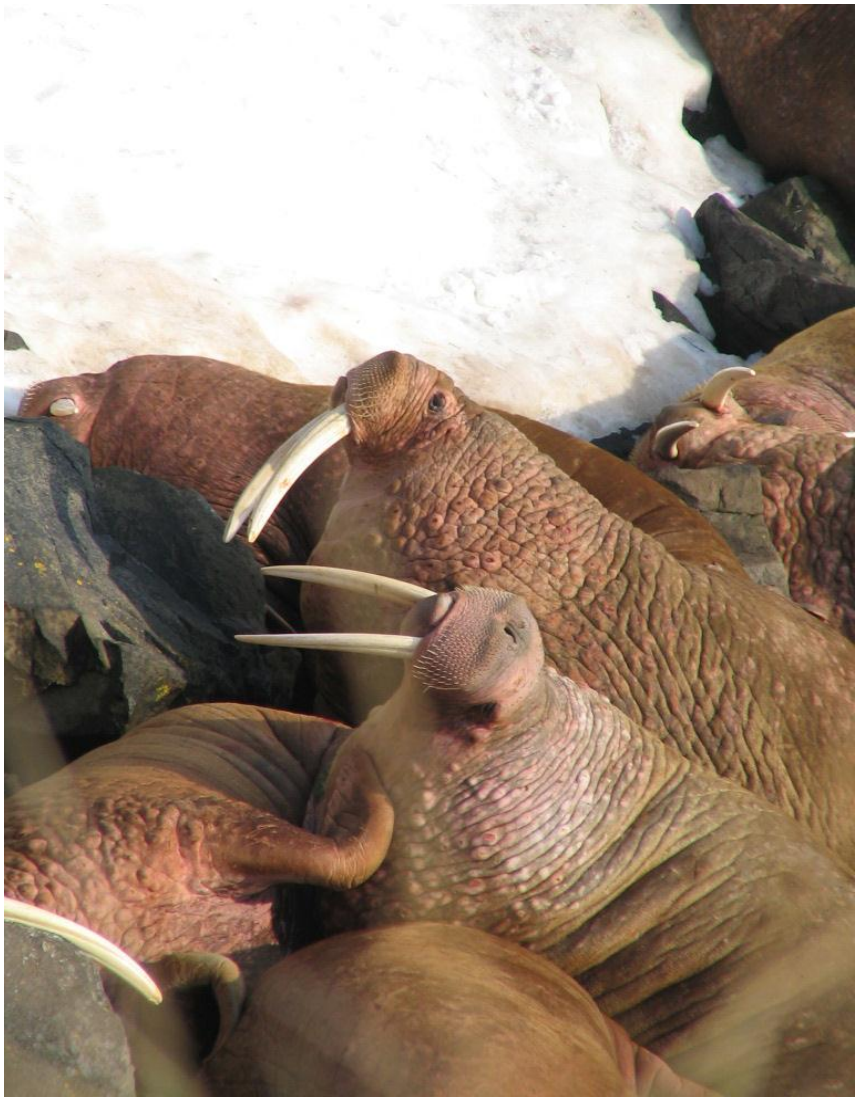
- For some species of marine mammals and marine mammal prey, there is a need for better information on species abundance, seasonal distribution, seasonal movements, and human-animal interactions to support management decisions. Information on species abundance in the Arctic is often unavailable or out of date (>8 yrs old) and information on seasonal distribution and movements is often not at the spatial scales or in the areas where managers need to make decisions. The spatial scale at which distribution and movements are important will depend on the specific management question.

- At this time, there is still a need for more systematic monitoring of the subsistence harvest of marine mammals and their prey. There is some harvest monitoring of bowhead and beluga whales, polar bears, ice seals, walrus, and fish. There is also systematic monitoring of polar bear and walrus harvest by the U.S. Fish and Wildlife Service. Nevertheless, monitoring for many species must be enhanced and conducted in a systematic manner that will allow managers to fully understand existing harvest practices and changes in existing harvest practices.

- To assist management decisions, it may be necessary to focus data collection on species that are listed as endangered or threatened under the ESA, depleted under the MMPA, or are the focus of a subsistence harvest.

- Incorporation of Traditional Ecological Knowledge (TEK) should be a priority when assessing historical information on animal and fish distribution and will be critical to understanding changes in the subsistence harvest.

- Modeling is needed to focus and integrate studies, develop hypotheses, and predict likely future states.



Pacific walrus haulout on the North Slope. (Wendy Loya, TWS)

Overview and Management Relevance:

The immediate and overwhelming conclusion of the STAP to the set of management questions reviewed is that more baseline information (past and current information on basic population parameters) for both biological and physical environments is urgently needed to understand marine mammal population dynamics and elucidate the effects of development, climate change, subsistence harvest, and other stressors on marine mammal populations. As these studies are designed and data are collected, it is imperative that data be made accessible within and across agencies, as well as to stakeholders through avenues such as a central database (e.g., GINA), key conferences, and peer-reviewed papers. When possible, Alaska Natives should be given the opportunity to participate in research projects in their region.

Many concerns and questions raised by managers require integration across a range of spatial scales, multiple stressors to marine mammals or their prey, multiple trophic levels, and multiple years. This is consistent with a broader interest on the parts of many agencies to shift from single species management to ecosystem management, but the roadmap to accomplishing this shift is not clear. It is clear that the types of studies needed will often be expensive and will take years to complete. Uncertainty in how to proceed should not cause paralysis, but will certainly require a combination of careful elucidation of management needs, research planning, modeling to ascertain how best to focus the studies, substantial funding, and long-term programmatic support.

In addition to these broad concerns, the NSSI Senior Staff Committee provided the STAP with specific questions on marine mammals and their prey. STAP responses to these individual questions follow below.

1. *How do we differentiate and assess the separate and combined effects of climate change and development on various species and their interaction?*

   Analysis of cumulative impacts of multiple stressors is a critical need that has not been well addressed. However, despite voluminous literature on cumulative effects and frequent application of the National Environmental Policy Act (NEPA) process, there is no existing guidance on how to conduct quantitative analyses of monitoring data to differentiate between various types of disturbances. The following approaches may be useful:

   - Resource selection models that incorporate movement data with habitat data;
   - Population dynamics modeling that incorporates subsistence harvest and predation as well as other stressors, such as incidental take and contaminants;
   - Establish disturbance coefficients that incorporate species responses to industrial activity and other human and natural disturbances;
   - Model habitat availability under a range of foreseeable development and habitat changes as a result of climate predictions.

   Given the paucity of data on current abundance, seasonal distribution, movements, population dynamics, and other basic biological information for many species, collection of these types of information should be a priority. It would be useful to identify examples of integrative studies that adequately addressed these issues as a starting point.

   Considerable additional information on the independent effects of natural variation, climate change, and anthropogenic activities on species of interest will be needed before cumulative effects can be assessed. Typically, the effect of stressors on

animal health are not incorporated in cumulative impact studies. Understanding individual animal health has implications both to the species' health and survival, as well as to human health in the subsistence harvest communities.

2. *How might a shift in species distribution from sea to land affect land management?*

An already apparent shift in species distribution from sea to land involves increased use of land by polar bears and ice-dependent pinnipeds, especially those whose existing behavioral repertoire includes hauling out on land (walrus, spotted seals). Additional coastal surveys and tagging should be conducted to understand how walrus are using the coastline, and disease surveillance should be improved to document whether the shift to land results in transmission of novel diseases to the marine mammal populations. This kind of shift in distribution may result in an increase in subsistence harvest for some species; again, information on recent historical and current harvest levels and practices will be necessary to understand if an increase in harvests might strain populations.

In the case of polar bears, the change in distribution (with more animals on land, especially in summer) is expected to result in increased bear-human interactions that may lead to an increase in take of bears in defense of life and property.

Human activities onshore should be identified and examined to predict how they could affect land usage by marine species. Management will have to adapt operations to incorporate new areas being used by marine mammals. Changes in the level of protection for key pinniped haulout areas may be necessary.

3. *How may this shift affect predator/prey relations on land and/or marine waters?*

In general, the shift of polar bears from sea to land is not expected to result in negative impacts to terrestrial prey resources such as caribou or muskoxen. However, some prey shifting may occur; for example, severe predation of seabird chicks has been attributed to the presence of polar bears on a coastal island in at least one case. To detect a change in prey selection requires long-term (5-10 years) monitoring of seasonal abundance, diet, distribution, and movement of both predators and prey. Stable isotope analyses can be useful in differentiating animals that rely on marine source prey from those that rely on terrestrial source prey.

There is potential for depletion of local benthic resources if walrus occupy new coastal haulout sites and compete with other benthic feeders such as gray whales, sea ducks, and demersal fish. The benthos in these areas should be inventoried over multiple years to detect local depletion effects.

Routine monitoring of subsistence use patterns will be critical to determine whether changes in marine mammal prey distribution results in changes in subsistence harvest.

4. *Will changes in ocean currents affect species distribution and recruitment (e.g., nearshore currents and larval drift)?*

Changes in physical and biological oceanography will change species distribution and recruitment. Evaluating these changes will require interdisciplinary, integrated studies where currents, plankton, and marine mammal (or their prey) densities and behaviors are being studied simultaneously and analyzed together so that relationships between oceanography and marine mammal (or prey) distribution can be understood. A change in fish distribution could be used to highlight a probable change in distribution or population dynamics of marine mammals that forage on that fish; or alternatively, a change in the distribution of a higher predator could be used to identify an underlying change in prey distribution. Most non-commercially important prey species are not being monitored. Small and large-scale changes in distribution of a variety of species will be needed to assess these factors. A multi-disciplinary site specific monitoring program was initiated by ConocoPhillips and Shell in the Chukchi Sea in 2008, focusing on the collection of data as described above. A second year of pre-development data is scheduled to continue in 2009 and should continue at some level as long as plans exist for exploration drilling and development. Understanding the interannual and seasonal differences of the physical and biological oceanographic conditions may assist in determining the potential changes in these conditions due to anthropogenic stressors, in combination with other 'natural' stressors and/or climate change.

The MMS-funded "BOWFEST" project and the BP and ConocoPhillips Arctic cisco monitoring programs attempt to relate marine mammal and fish distribution to oceanographic conditions, and were identified as good examples of the types of integrative studies needed. Both studies should be continued.

5. *Can prey species shifts in distribution and abundance be better modeled, how and with what precision?*

We are unaware of any modeling being done to estimate future shifts in distribution of prey species, so it was not clear how to "better model" shifts in distribution. There is likely to be insufficient data for modeling shifts in prey at this point, but models would still be important for developing and testing hypotheses about how a system works, so the development of models should not be postponed indefinitely. Substantial new information on prey species in the Arctic will have to be collected, as very little is known about the distribution of marine mammal prey species. Monitoring will have to be species-, location-, and season-specific.

Some work has already been done to identify and implement monitoring programs to collect data to drive the models. For instance, in 2008 the MMS funded a field study that attempts to broadly survey marine fish distribution and their assemblages in the Beaufort Sea, with concurrent collection of salinity, temperature, and plankton data. This work is expanding and will be integrated with multi-year studies of the Beaufort and Chukchi Seas.

Work will be needed to develop integrated databases and to develop, validate, and apply prey species models.

6. *What will be the ecosystem level effects on shifts in the distribution and abundance of fish and other species?*

Investigating this should first involve the development of conceptual models that start with a single species and show interactions between species and their environment (e.g., a food web, augmented by known anthropogenic impacts). The conceptual model can be used to prioritize assessment and monitoring efforts. As for other questions, major metrics to monitor include seasonal abundance, distribution and movements of animals, and underlying causes of population dynamics. Climate monitoring will also be necessary for understanding historic and current ecology, and for predicting future scenarios. Eventual development of a quantitative ecosystem model would be beneficial.

7. *If fish species shift north, will fishing (including commercial fishing) patterns change and what will the effect be on management options and on non-target species?*

At this time, NMFS has largely prohibited commercial fishing in the federally-managed waters of the Arctic north of the Bering Strait. As such, there would not be a major shift in large commercial fisheries in federal waters in the foreseeable future even if the fish move dramatically north. Further, a shift of commercially-important fish to the north is not likely to substantially change commercial fisheries managed by the State of Alaska because there are no local processing options for fish on the North Slope and there are not likely to be large-scale state-managed fisheries in the foreseeable future.

There is likely to be an increase in the subsistence harvest of commercially important fish as new species become available farther north. Because of the potential for subsistence harvest to affect commercial fish stocks, some understanding of changes in subsistence harvest of fish would be required. However, at this time, there are relatively few programs to monitor fish on the North Slope. The NSB monitors subsistence fisheries in North Slope villages and ConocoPhillips monitors subsistence fisheries in Nuiqsut, but additional details

about such fisheries are needed. Traditional Ecological Knowledge will be key to understanding changes in subsistence harvest species and patterns.

8. Will shipping affect whale migration and hunter access?

At this time, there is limited information on whether and to what extent whale migration will be affected by changes in shipping. However, BP's bowhead whale study around Northstar suggests that at least some whales will move away from or otherwise respond to low-level anthropogenic sounds, including those associated with routine vessel traffic. It is possible that shipping may have direct (e.g., ship strikes, avoidance of areas with high sound levels, or changes in calling behavior) or indirect (e.g., release of contaminants which are ingested by whales via lower tropic levels) impacts on whales. Studying the direct impacts will require more information on fine-scale movements of whales in response to received sound levels, improved reporting of ship strikes, and focused acoustics studies. This issue is of concern world-wide, so studies on similar marine mammal populations (e.g., right whales, humpback whales) may be directly relevant to what can be expected for bowhead whales.

The Arctic Council recently completed the Arctic Marine Shipping Assessment (AMSA). The AMSA 2009 Report is posted at: http://arcticportal.org/pame/amsa. It provides the best compilation to date of current arctic marine shipping uses and is based primarily on a thorough analysis of arctic shipping in the year 2004. This 2004 database may serve as a baseline for future comparisons. To the extent that the information compiled in this report overlaps with NSSI agency missions and specific management concerns, there may be fertile ground for identifying shared priorities and opportunities for collaboration.

There was specific concern in the discussion of this issue about routine assessments of the acoustic profile environment of all ships. Agencies involved in the NSSI may not have the ability to require that acoustics data be collected on all ships; vessels such as icebreakers and commercial barges may "fall through the cracks" because there may be no federal nexus to require measurements. The NSSI might specifically be able to help by encouraging that measurements of these vessels be collected. Standards for measuring the acoustic signatures of vessels must be developed, as the lack of standards currently precludes understanding comparisons between vessels.

If shipping is likely to meaningfully impact whale populations, it might be preferable to use resources to focus on reducing the likely impacts of shipping in lieu of studying the impacts. For instance, technologies that could reduce vessel noise should be identified and/or investigated.

To assess whether hunter access is being affected by shipping (or more broadly, by any perturbation), more data must be collected on hunter success and hunting patterns over time. It will be important to maintain a long-term database to monitor hunter access to subsistence resources and results of harvest attempts. MMS has a study under procurement that will attempt to accomplish this for communities in the Chukchi Sea, as well as the ongoing study on Cross Island.

9. Can we identify species/habitat conservation refugia?

Identification of important habitat that might require additional protection will be relatively easy to do for animals that are switching to a more terrestrial way of life (walrus/polar bears); this will be much harder to do for species that remain pelagic. The types of studies previously mentioned, including studies on distribution and movements of animals, will be needed to assess habitat use and changes in habitat use. It has been clear from studies of other animals (Steller sea lions, northern fur seals) that assessing habitat use can take many years, so if assessing changes in habitat use is critical to responsible management of species, a major commitment of resources will be necessary and results will likely not be immediately forthcoming. Some historical sources of information – such as that collected by BWASP and COMIDA surveys as well as data from historical accounts recorded by 19th and 20th century whalers – may provide information on where dense concentrations have occurred in the past. However, these (and other) data will be of most use if there is concurrent information on the oceanographic conditions which are likely causing the aggregations.

10. What will be the metric of successful management in the future (for example, under ESA)?

Both NOAA and the USFWS have very specific measures for whether management measures are successful for ESA-listed species (e.g., specific downlisting and delisting criteria, and specific actions called for in recovery plans). Management for ESA listed species is, of course, most successful when species are downlisted or delisted. However, arresting the decline and stabilizing the population of a listed species is also a measure of success, as is a measurable reduction in the factors that led to the species listing – for example, the elimination of an invasive species that contributed to the decline of the native listed species. Other possible measures for success are that current resource users continue to have the same access to the species at the same time that other stakeholders gain access to other resources, or that species are sufficiently abundant that traditional harvests are sustainable.

Recommendations:

1. Data on marine mammals, their prey, current habitat use, current impacts of perturbations (climate, anthropogenic operations), and the subsistence

harvest must be understood before changes in current conditions can be measured or the causes of the changes identified. Priorities should be for species listed as endangered, threatened, or depleted, species where human-related mortality is suspected as the cause of a decline, or species that are the focus of a subsistence harvest. Despite the numerous and varied studies that have occurred over the years, researchers lack baseline data at the appropriate temporal and spatial scales for many species. The NSSI can help by identifying the most important management questions to guide researchers towards projects and programs at the appropriate spatial and temporal scale.

2. The types of long-term integrative studies typified by the MMS-funded "BOWFEST" and BP and ConocoPhillips's Arctic cisco studies will need to be more common in order to understand why animals are distributed in particular ways. Ideally, carrying out such studies in the relative absence of anthropogenic impacts (i.e., a defined pre-development baseline of ecosystem function) will be necessary to understand natural variation before a complete understanding of how changes in climate of anthropogenic effects can be assessed.

3. Studies that allow the assessment of cumulative impacts of multiple types of stressors (including climate change, contaminants, underwater sounds, and human-animal interactions) over multiple years must be pursued.

4. The partnership between the North Pacific Research Board and the National Science Foundation on integrated studies of the Bering Sea ecosystem (see: http://bsierp.nprb.org) may serve as a model for the Arctic. The NSSI and its member agencies should explore potential collaborative opportunities with various organizations, including the North Pacific Research Board.

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Emerging Issue Summary

SPECIES OF INTEREST - FISHERIES

Highlights

- There is a great need for better information on abundance, seasonal distribution, and subsistence use of fish in the Arctic. Information on Chukchi Sea drainages, marine fish, and winter distribution of freshwater and anadromous fish are particularly lacking. Both scientific and Traditional Ecological Knowledge (TEK) studies will be important in improving our understanding of Arctic fish species.

- Priority species should include those important to subsistence harvests, or those that are prey for marine mammals or birds that are listed as endangered or threatened under the ESA or as depleted under the MMPA. A key management goal regarding subsistence use would be to maintain populations of existing subsistence target species at levels that will ensure sustainable subsistence harvests.

- There have been very few TEK studies directed at Arctic fish. TEK studies should be initiated to improve understanding of historical information on fish abundance and distribution, observed changes in fish abundance and distribution over time, and substantial details about fish subsistence practices (e.g., net type, mesh sizes used, net length, soak time, distances traveled to fish).

Overview and management relevance

The group of fish experts and the STAP agreed that there is a broad need for improved information on marine and freshwater fish abundance, distribution (particularly winter distribution), habitat needs, and subsistence use. Although areas north of the Bering Strait are closed to offshore, federally-managed fishing at this time, planning for the collection of baseline information on fish stocks that could eventually become important to offshore fisheries should occur now, and long-term studies using standard sampling gear and protocols should be established to monitor marine fish abundance and distribution.

Currently, there is little to no ability to differentiate between changes in marine or freshwater fish populations due to natural variability, climate change and changes due to development, or to detect synergistic changes from the combined effects of these factors. Current management of freshwater withdrawals for development appears to be appropriate; however, little has been done to project climate or development scenarios 10+ years out to support predictions of how such scenarios – separately or cumulatively - would impact fish populations or subsistence catch of freshwater species. Once these steps are taken, it will be critical to determine whether current management practices will be the best way to manage water use to protect freshwater fish under future conditions.

In addition to these broad concerns, the NSSI Senior Staff Committee and other selected experts in fish management identified the following questions on fish and fisheries of the North Slope. The STAP, along with selected experts on fish, provided the following responses to these questions.

1. **What is the current distribution and relative or total estimated abundance of key marine, anadromous, and freshwater fish species (e.g., Arctic cod, saffron cod, snow crab, salmon, Dolly Varden, Arctic grayling, various whitefish species, Bering/Arctic cisco)?**

   Information on range-wide distribution and abundance does not exist for the majority of freshwater, anadromous or marine fish on the North Slope. Collecting information on fish in Chukchi Sea drainages, and in most drainages during winter months, should be prioritized, particularly in areas where development is likely to occur. Currently, information varies considerably by species, by area, and by season and a review of existing studies on distribution and abundance of freshwater and anadromous fish would highlight obvious data gaps. Long-term studies directed at distribution and abundance, such as those on Colville River cisco, Arctic grayling and Lake Trout at Toolik Lake, and fish near the Endicott facility, provide the best opportunities for understanding how and why fish populations change over time; these studies should continue to receive support.

Long-term monitoring of anadromous Dolly Varden abundance in index drainages has never been undertaken, and should be conducted in order to detect change in this important subsistence resource. There are few existing studies on fish in the offshore marine environment over the past 50 years, and the studies have used a wide range of gear, occurred in different areas and seasons, and cannot be readily compared.

2. **What types of surveys would be needed to monitor the status (including trends in abundance) of these populations, and at what frequency? What recommendations can be made for survey "best practices" to maintain consistency so that results are comparable both spatially and temporally?**

Freshwater: Surveys for freshwater fish could be modeled after one of the many long-term fish studies mentioned above, i.e., the freshwater study near the Red Dog Mine (see ADF&G Technical Report 10-04), or freshwater lake methods adopted by the BLM for the Central Arctic coastal plain. Methods should include routine sampling for periphyton, aquatic invertebrates, and fish, along with the collection of water quality and flow data. Baseline inventories of freshwater fish should start with Traditional Ecology Knowledge (TEK), including community meetings and surveys, to identify what is locally known, both historically and observations of recent changes. Work with communities should continue on a regular basis because local users may have differing observations, may be in the field at different times, and may see different changes in fish species that may be important to managers.

Freshwater fish assessment should include implementation of procedures for routine monitoring and reporting of fish pathology across the North Slope. This may include monitoring of fish kills as well as monitoring oxygen levels in key streams and inlets that may decline due to ice cover.

Marine: It will be critical to follow certain "best practices" to ensure that research on marine fish can be combined and compared across projects, seasons, and years (Box 1). For example, because the 2008 Beaufort Sea marine fish survey (Rand and Logerwell 2010) used the same net and sampling methods as the 2008 AFSC Bering Sea bottom trawl survey and the 1990 AFSC Chukchi Sea bottom trawl survey (Barber et al. 1997), spatial comparisons in species density could be made.

Marine fish surveys should be conducted every 2-3 years, and must include areas sufficiently large to reliably distinguish between changes in abundance and seasonal shifts in distribution. A routine set of

Box 1: Surveys for offshore marine fish should routinely include the following methods

- Bottom trawl surveys for benthic marine fish such as cod, sculpins, flounder, eelpout, snow crab (e.g., AFSC bottom trawl surveys)
- Echo-integration trawl surveys for pelagic fish such as cod, capelin, pollock (e.g., AFSC acoustic surveys)
- Surface trawl surveys for juvenile salmon, capelin, herring, smelt (e.g., BASIS)
- Nearshore beach seine surveys for anadromous fish, capelin (e.g., Scott Johnson et al. see http://www.north-slope.org/departments/wildlife/Fish.php)
- Beam trawl , otter trawl (e.g. Brenda Norcross et al, UAF)

surveys should be conducted at the Distributed Biological Observatory stations in the Arctic, so that a time series of fish distribution at these stations may be correlated with environmental information being collected at the observatory.

Research is needed to identify types of gear and sampling strategies that will enable effective research on marine bottom communities that range from rocky to muddy substrate. This work would need to be done in a way that does not compromise long time series of data.

There are considerable taxonomic uncertainties in the Arctic that need to be resolved, particularly with respect to invertebrates (both marine and freshwater).

3. **What is the current and historical harvest level of marine, anadromous, and freshwater fish species by each user group?**

There is considerable published and gray literature available to address this issue. The only commercial fishery on the North Slope occurred in the Colville River and was directed at Arctic and least cisco; it is not known whether this fishery will continue. There is limited "recreational" fishing on the North Slope, and this is monitored annually by a mail-in harvest survey conducted by the ADF&G. The North Slope Borough has a long-term time series of information on subsistence harvest information for Barrow residents. Though there have been subsistence harvest surveys of most, if not all, North Slope communities, the understanding of the subsistence harvest of fish is more limited for villages other than Barrow and Nuiqsut. There is some subsistence use of marine fish, but nearshore subsistence fishing efforts do harvest marine and anadromous species, including cod, pink and chum salmon, Dolly Varden, capelin, sand lance, and flounder.

Existing time-series on subsistence harvest catches should be maintained, and expanded to include other villages, particularly villages along the Chukchi Sea coast. Routine monitoring of fish subsistence harvest should be initiated at other North Slope villages (e.g. Kaktovik, villages in NW Alaska). Monitoring of subsistence harvest of fish might be easily expanded by adding questions to existing North Slope Borough interviews on subsistence use in villages other than Barrow.

4. **How are subsistence fisheries changing over time? (e.g., fish species, sizes, quantities, fishery seasonality, geographic location, techniques, gear used, relative importance of different fish to the community, etc.)**

Key informant interviews with active fishermen in communities could glean information on gear used historically and currently, and to find out what changes have occurred over the past years. Conducting key informant interviews in villages where oil/gas development has not occurred would be useful for comparison to villages where development and possible impacts have occurred. Important

parameters to understand include species and quantities harvested, and harvest timing. There will be some barriers to implementing successful key informant interviews, as communities are concerned that providing information on subsistence fishery activity may lead to regulatory restrictions.

Changes to subsistence fishing are likely to happen in the future as the environment changes, but it is not yet clear how fishing might change. Species composition and abundance may change. Environmental changes may change peoples' ability to access certain areas: for instance, if frozen lakes are required to promote winter travel to a good winter subsistence area, traveling to that area may be limited if lakes freeze later, or thaw earlier.

5. What marine and freshwater habitat features (or areas) are commonly used by key fish species for basic life history requirements such as spawning, rearing, and overwintering?

There is a tremendous amount of information on habitat needs of freshwater fish species, but the information may be specific to a particular river drainage, a particular season, or a particular life history stage. However, in general, it was felt that there is a good base of knowledge to understand what to look for in a particular drainage to predict where fish are likely to occur seasonally. There is considerably more information available for Beaufort Sea drainages than for Chukchi Sea drainages.

The habitat and dietary needs of most Arctic marine fish species are not well understood. In order to improve our understanding of habitat needs, both freshwater and marine fish surveys should routinely include collection of oceanographic or hydrographic information, along with fish prey information (e.g., invertebrates, prey fish). Winter surveys of both marine and freshwater fish will be needed, and an understanding of habitat needs for spawning and rearing will be needed for key fish species.

During the winter, maintaining minimum water levels is critical to maintaining freshwater fish populations. New methods (e.g. synthetic aperture radar [SAR]) should be studied, field validated, and implemented for assessing water depth, and the results made broadly available in a geographic context for both research and management use.

6. What is the current and future potential for Pacific salmon species to successfully colonize North Slope drainages?

There have been both publications about and personal observations of salmon in the Chukchi and Beaufort Seas. Although some Pacific salmon species are likely to occur – possibly with increasing frequency – in waters of the Chukchi and Beaufort Seas,

the group generally felt that the likelihood of "colonization" (defined as supporting breeding populations) in the next 10 years is quite low. Colonization is not likely to occur in the near future due to overwinter water temperature: because rivers typically freeze and water flow is very limited it would be unlikely that either adult fish or eggs would survive the winter.

Colonization may occur in limited areas where the winter water flow is consistent and adequate, such as the Wulik drainage near the Red Dog Mine. This system is fed by groundwater, which is relatively warm and prevents the drainage from freezing during the winter. The general consensus of the group was that the environment would have to change very dramatically before colonization would be possible. It would be useful to implement a project using existing climate models to investigate whether the criteria for salmon colonization could reasonably be met in Arctic drainages in the next 30-50 years. It would also be useful to collect genetic samples from salmon in the marine environment in the Arctic to understand which stocks are encountered when and where: over the long term, this could be important for management of resource use. New research that looks for temperatures that may sustain spawning or rearing areas should target drainages considered good candidates for colonization; combining modeling with on-the-ground data collection is likely to improve the chances that colonization potential can be successfully identified.

7. **What is the current and future potential for aquatic invasive species to affect Arctic fish populations, and what are effective management options for monitoring and responding to potential introductions?**

There was broad agreement that it will be difficult to monitor for invasive species because of great uncertainty in what species might be invasive and what changes in which ecosystem parameters might signal the appearance of a particular invasive species. Monitoring for northward changes in distribution may be easier for some species (e.g. mammals) than for other species (e.g. cryptic or small species, such as mussels and snails). The group identified ballast water of ships and the road system as the two most likely vectors for bringing invasive species to the Arctic. There was general agreement that the current Arctic environment may preclude survival and reproductive success of many potential invasive species, with the exception of species that survive well in other cold climates.

The best way to monitor for most invasive species would be to use existing monitoring programs for other species. In addition, researchers and the general public should be able to easily access a central point of contact for reporting novel species. The ADF&G already has an invasive species list that could be used for this purpose; significant outreach may be necessary to highlight the program to current Arctic fish researchers so they know to report potential invasive species. Surveys of areas that are likely to be hotspots for introductions (e.g., ballast tanks of ships,

truck washing stations or lakes with substantial float plane traffic) may also be helpful.

8. **How might hydrological changes due to development in the Arctic (e.g., gravel mining, culverts, bridges) impact fish populations in both small and large watersheds?**

   The major hydrological issue is that water removal from drainages for human use as ice roads or in the course of processing materials has the potential to impact freshwater fish, particularly during the winter. This problem is exacerbated east of the Coleville River, where the amount of water available for human use in lakes decreases because there are fewer lakes and the lakes are shallow. This is also a major issue in the North Slope foothills, where there are no lakes, so gravel pits must be excavated to collect water that can later be used. The need for fresh water may be particularly critical in Chukchi Sea drainages, as there are few lakes and, if industry elects to try to process natural gas on shore, there may be a need for fresh water for both industrial processing and human use. It will be important to conduct studies to assess whether existing knowledge of the impacts of hydrological changes on fish in Beaufort Sea drainages can be applied to drainages of the Chukchi Sea.

   Mitigation measures are currently in place for water removal by industry. Water removal from streams is not permitted during the winter. A proportion of the water in lakes may be removed, and that proportion varies depending on whether the lake is inhabited by fish. Features such as culverts and bridges are typically mitigated so that there is little impact to fish populations. It is unknown how a future hydrological system will provide for water needed by both fish and industry. It will be important to project what hydrological changes are likely to occur with both increasing industry needs and changes in water flow, and assess what lakes and river systems may become more (or less) important to fish over time (and thus what areas might require more restrictive regulation).

   Many culverts in existing North Slope oilfields cause stream bed and bank erosion, have extensive deposits of outwash gravel downstream that alter hydrology, and impair or impede fish movements due to being perched at low flows or having inadequate conveyance of water. These problems with culverts in the Arctic may be exacerbated by unstable ground and road jacking or sinking due to permafrost. New research directed at redesigning culverts to improve fish passage is needed.

9. **Can reasonably foreseeable withdrawals of fresh water for energy development be sustained without diminishing fish habitat (particularly overwintering habitat)?**

   There is an expectation that, at some point, there will be greater water needs than can reasonably be supplied without impacting fish populations, even without considering anticipated long-term changes in hydrology patterns over time. Along

the Chukchi Sea coast, there are few lakes from which water can be withdrawn, and there is some concern that managers may be asked by industry to reconsider the current prohibition of removing water from streams in western Alaska. The group believed there is probably sufficient information on current fish use of streams to know how much water can currently be removed without impacting fish populations, but information should be synthesized, assessed, and made available to managers well in advance of industry development in a new area.

In order to assess whether withdrawals are sustainable in the future, it will be important to inventory fish species, particularly in areas near an existing or proposed industry development. Once the fish species are known, evaluating likely preferred habitats for the fish in that drainage is likely straightforward given existing data on habitat preferences for many freshwater fish species. Existing hydrological data will need to be re-assessed on some routine schedule to ensure that the data are sufficient to ensure that problems with water removal will be detected before they are at a critical level. Thresholds used to regulate the amount of water that can be removed from various components of the freshwater ecosystem should be re-evaluated as new data on fish habitat needs becomes available, or if the hydrology of a system changes significantly. There should be sufficient data to ensure that the thresholds remain appropriately conservative given changes in short- and long-term human use and changes in the environment. It may be helpful to identify the most sensitive fish species in each drainage and understand its water needs in detail. Thus, managing water to avoid impacts on this species could be an alternative to managing just to allow specific proportions of water in a system to be removed.

Finally, it will be critical to understand the threshold at which there will likely be population-level effects of water withdrawals on fish populations, both currently and under likely projected future hydrological conditions. Understanding this issue will be a requisite first step in understanding whether winter water withdrawals have the potential to affect subsistence harvest. Dedicated work should be undertaken to understand whether possible increases in subsistence needs can continue to be met if increased withdrawals of water have minor to moderate impacts on freshwater fish populations.

10. What factors should be assessed as indicators of whether marine habitat conditions have changed to a point that could affect fish populations and community structure (i.e., what information can we gather now that will help us understand the changes associated with loss of sea ice)?

It is not yet clear what factors should be assessed as indicators of whether the marine habitat has reached a “tipping point” that would dramatically alter fish populations and community structure. The best course of action is to collect a variety of biological, chemical, and physical oceanographic measurements in conjunction with periodic marine fish surveys at least once every three years in

order to start making correlations and predictions after several surveys, such as described in the Distributed Biological Observatory (DBO) sampling plan. Hypothesis-driven process studies, such as the BEST/BSIERP study or BOWFEST, could be implemented, but will be expensive and difficult to pursue until baseline data on fish in the Arctic are much improved. However, more information should be collected about the distribution of production between pelagic and benthic habitats.

11. How will changes in inland precipitation affect freshwater fish habitats on the North Slope?

This question essentially has two parts: how do we detect changes in inland precipitation with sufficient precision, and what will be the impacts of these changes on freshwater fish.

The expectation based on University of Alaska Fairbanks predictions is that the amount of precipitation over the inland areas will increase over time, and may become more variable. While there are many hydro-meterological stations on the North Slope, they do not collect the same information with the same precision and are not easily combined. Further, it is not known whether the stations have the capacity to detect changes that might have an effect on fish. The emerging issues paper on this topic should be consulted for specific recommendations about how to improve this situation.

The effects of changes of inland precipitation on fish are likely to be species specific. Grayling spawning is directly related to the amount of water in the system and when it is released. In contrast, there is very little information on how changes in precipitation would affect Dolly Varden. The timing of ice breakup on rivers dramatically affects water flow and has an effect on fish. Effects of changing precipitation is the subject of the recent NSF study supported at Teshekpuk Lake. In particular, the research will look at how changes in precipitation will affect fish migration duration and timing.

12. What kind of ecosystem-level marine trophic changes are likely to occur from ocean acidification, and how will those changes affect anadromous and marine fish populations?

It is not yet clear what kinds of ecosystem-level marine trophic changes – if any - will be likely to occur in the Beaufort and Chukchi Seas due to ocean acidification (OA). Crustaceans may be particularly sensitive to ocean acidification because they require calcium and bicarbonate ions for the mineralization of their exoskeleton after molting. However, the effects of ocean acidification on crabs and shrimps have not been widely documented. In addition, changes in ocean chemistry may have direct effects on the physiology of marine invertebrates and fish by changing their metabolism and possibly reducing growth and reproduction.

This issue can best be approached by ensuring that experimental laboratory research on ocean acidification includes some Arctic species that are similar to sub-Arctic species for which data addressing sensitivity to OA are already available. Moorings have already been installed in various places (including a mooring off Barrow) to monitor pH conditions over time; these moorings must be supported annually so that long-term data are compiled for monitoring pH. Additional research on species-specific responses of a range of taxa to increased pH is needed.

Box 2: Information needed to differentiate between climate-driven and anthropogenic changes in populations, and additional information needed to assess damages in the event of an oil spill (last 2 bullets)

- Correlations of fish distribution with tide, current, bathymetry, seafloor characteristics, water flow, temperature
- Winter season data on fish
- Role of fish in food web
- Variation in fish growth, reproduction and distribution with a variety of environmental covariates
- Biomass of ice-associated flora and fauna
- Background contaminant levels (e.g., in Arctic cod)
- Ice movement
- How oil behaves in Arctic environments
- Uptake and release of oil in ice

13. How can we assess and differentiate the separate and combined effects of climate change and development on key Arctic fish species?

Projections show that both climate change and development may occur quickly over the next 10-20 years, yet analysis of separate and combined effects of multiple stressors on fish has not been well addressed. In order to prepare these types of analyses, long-term studies on fish and their environment will be needed, along with a very accurate assessment of past and projected future states of both the environment and of planned development activities.

Regardless of whether there is interest in understanding chronic or acute changes of either climate or development, the availability of baseline data on fish and their habitat will be critical to evaluating the proximal reasons for changes in fish abundance, distribution, and/or habitat use (Box 2). It may be helpful to set up a clearinghouse for baseline environmental data so that researchers have data available for analyses. Reference sites should be identified in areas where development is not likely to occur to allow studies of changes due to climate change to occur in the relative absence of anthropogenic changes in the system.

In addition, details about the location, severity, and timing of anthropogenic activities must be made easy accessible to researchers so that changes in fish populations can be examined in the context of both changes in habitat and changes in human use of the North Slope.

Recommendations

- Fish are a critical subsistence resource for North Slope communities. Detailed information on fish subsistence use should be collected, both to understand

historical and current use patterns, and how use has changed over time. This information is needed to attempt to predict, given both climate and likely industrial scenarios, how subsistence harvest use may change in the future.

- Information on fish population abundance and distribution should be compiled into a single, easily-accessible database that provides easy access to fish species in a particular area, including limited additional information (e.g. numbers captured, juvenile/adult), and the supporting reference information.

- Differentiating between environmental and anthropogenic changes in fish populations will require long-term studies that collect information on fish, their prey, and their habitat. While some long-term studies of this type have been implemented in freshwater drainages to the Beaufort Sea, there are no long-term studies on marine fish.

- Long-term studies on marine fish need to be implemented using standard gear types and protocols to enable the collection of data that will allow differentiation between natural and anthropogenic changes in fish populations: supporting the Distributed Biological Observatory will be one important step in improving our understanding of marine fish in the Arctic.

- For well-studied fish and systems (e.g. Beaufort Sea river systems), there seems to be a broad understanding of expected changes over the next 5-10 years, and few changes are expected over this time period. However, there seems to be little effort to assess whether anticipated changes in the environment (or with increasing development) will affect fish 10-30 years from now. Modeling anticipated changes over longer time horizons will provide researchers with a better understanding of the types of studies that need to be initiated now to provide managers with advice over the longer term.

- Improve the understanding of the relationships between fish distribution, and foraging and growth and water column characteristics such as temperature and salinity, and the distribution, abundance and species composition of pelagic and ice-associated phytoplankton and zooplankton.