Sustainability of Arctic Communities: An Interdisciplinary Collaboration of Researchers and Local Knowledge Holders

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Abstract
Sustainability of Arctic Communities: An Interdisciplinary Collaboration of Researchers and Local Knowledge Holders

Twenty-three researchers representing eight natural and social science disciplines and four partner communities - Aklavik, Fort McPherson, Old Crow, and Arctic Village - examine how the combined effects of climate change, oil development, tourism, and government cutbacks might change the sustainability of Arctic villages. We would like to thank our partner communities for joining us on this study. We worked together to incorporate research and local knowledge-based understandings in a common tool - a SYNTHESIS MODEL - to examine the sensitivity of relationships and assess levels of uncertainty. We discussed possible futures, local policies, and the limitations of science and local knowledge in predicting the future. We modeled vegetation changes, caribou population dynamics, local labor markets, mixed subsistence and cash economies, and oil field-caribou interactions.

The Sustainability of Arctic Communities Project is a new approach to regional integrated assessment. We attempted to build on solid, disciplinary science, and a wealth of local knowledge concerning environmental change and human adaptations to such changes. We developed simple models that focus on only the relationships important to the small set of questions we undertook to examine. We focused on the value of assessments as a springboard for understanding alternative futures rather than trying to predict the future. In this paper, we report our successes and the lessons learned. For additional materials regarding this continuing study, please visit our project website at: http://www.taiga.net/sustain .

Key Words: Sustainability, Integrated Assessment, Climate Change, Oil Development, Tourism, Indigenous Communities, Alaska, Canada, Caribou

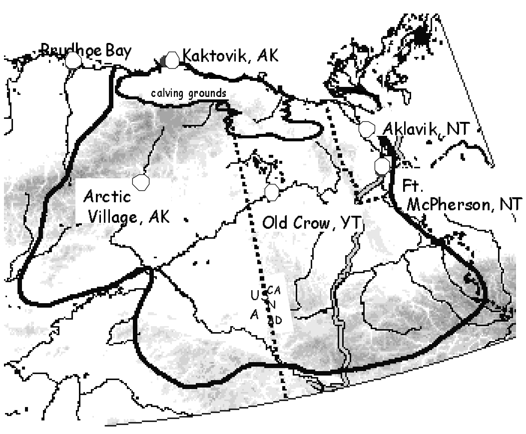
Sustainability of Arctic Communities: An Interdisciplinary Collaboration of Researchers and Local Knowledge Holders

Scientists writing a science plan for the National Science Foundation (NSF), Arctic System Science (ARCSS) Program recently wrote: "*For the last few decades the scientific community has expressed concern about the vulnerability of the Arctic and its residents to environmental, social and economic changes…Recent research results show the arctic climate and ecosystems are indeed changing substantially with impacts on people living in and outside the Arctic* (ARCUS 1998)." Five years ago, natural and social scientists sharing membership in the High Latitude Ecosystems Directorate (HLED) of the U.S. Man and the Biosphere (MAB) program acted on a growing concern about the vulnerability of the Arctic to global changes. After several discussions, this group decided to focus on the combined effects of future climate change and oil development on barren ground caribou (R*angifer tarandus*) and on indigenous communities that depend on caribou as a major source of food. In retrospect, we think that the opportunity offered by the HLED experience was critical to the definition of the problem and to the establishment of an effective interdisciplinary team. The need for pre-project discussions is an important lesson for integrated assessments.

In the winter of 1994-95, the National Science Foundation (NSF) issued an announcement of opportunity for research on the Human Dimensions of Global Change. The MAB group decided that we should apply our collective thinking to a proposal. Our first step was to invite the Iñupiat North Slope Borough (NSB) Wildlife Department to collaborate. We envisioned a regional-scale analysis working closely with the NSB. Just before submitting the proposal, the NSB decided that other priorities intervened and the borough withdrew as an active participant. The withdrawal of the NSB was a major setback to our intent to have researchers and indigenous people collaborate. Fortunately, four Indigenous communities - Old Crow, YT, Arctic Village, AK, Aklavik, NT, and Fort McPherson, NT - joined the project in the first year.

We submitted a proposal without the NSB. NSF awarded us a four-year grant (OPP-9521459). Our original project team consisted of 23 researchers representing eight natural and social science disciplines and nine research institutions.

Figure 1:Study Region



The purpose of this paper is to report on both the process and outcomes of the first four years of an NSF grant entitled, "Sustainability of Arctic Communities: Interactions Between Global Changes, Public Policies, and Ecological Processes" (Kruse and White 1995). We would like to thank our partner communities for joining us on this study. The study process and the lessons we learned are important to improving the methods of integrated assessment. The study outcomes are important to our understanding of the Arctic system.

We expect to publish other, more specialized, articles on the project. For a current list of available materials, please see our project website at: http://www.taiga.net/sustain . We also refer to web-based supporting documents in this article by including "www" as a suffix to the publication year.

Our major decision at the first meeting of the full project team in the fall of 1995 was that understanding caribou-human relationships requires a community-level focus. The research team therefore invited communities that are the primary users of the PCH to become study partners. Figure 1 shows these communities, the range of the PCH (outer line), and the area heavily used during a two week period in June that is important to calf survival and cow pregnancy rates the following spring (inner line). Since the research team had not anticipated collaborating with communities in our proposal, however, we faced the immediate challenges of re-allocating funds and securing additional funds. Ultimately, the community collaboration component of the project constituted 15 percent of the grant as a whole.

Advancing the Science of Integrated Assessment

The emerging field of Integrated Assessment (IA) has not yet established an authoritative practice for conducting IA's, and the broad consensus is that there is value in having a diverse portfolio of parallel efforts to advance the field (Parson 1995:472). Parson notes that most IA's have been undertaken at a national or global scale. Our work starts at the opposite end of the spatial scale - the community. By working up from the community level, we have been able to focus on IA issues that are difficult to address in studies that work down from national or international scales.

One such IA issue is human response to changing conditions. We focus on human responses to changing employment and hunting conditions. Parson (1995:465) identifies the representation of human adaptive responses to climate change as "highly problematic," and notes that "disaggregated" (i.e. focusing on the affected individuals and communities) impact studies may be the best way of improving our understanding of these responses. This study and the MacKenzie Basin Impacts Study (Cohen 1997) that preceded it are examples of disaggregated impact studies.

Whereas many IA's focus only on climate change, we examine the combined effects of climate change, petroleum development, tourism, and government cutbacks on the sustainability of Arctic communities. Rotmans and Van Asselt (1996:329) write that there is an urgent need for IA's of sustainable development, and that we need to examine, "cross-linkages between various global phenomena." Our study deals with such cross-linkages.

Most IA's focus on national and international policy choices concerning the abatement of greenhouse gases (Dowlatabadi 1995). We target local to multi-regional policy choices (e.g., types of tourism encouraged; extent of petroleum development; and management responses to climate effects on caribou). We set these policy choices in the context of a national- and international-policy environment (Young 1999).

A major challenge in IA has been the formal representation of values and meaningful outputs. IA's have been criticized for their representation of diverse impacts in dollar terms (Risbey, Kandikar and Patwarhan 1996:379). Morgan and Dowlatabadi (1996:338) write that the treatment of values should be explicit, and if possible, parametric. The term "sustainability" is particularly problematic in integrated assessment studies, given its ambiguity and normative qualities. (Robinson, 1996 et al.) The partner communities defined sustainability in terms of community goals - the dimensions of sustainability that communities perceive to be most important for their future. Together, researchers and communities decided to represent these community goals as outputs in a simulation model. We still have much to learn in this area. The approach we report on in this paper involves a combination of qualitative outputs in sentence form, graphic representations of quantitative outputs, and short explanations of model simulation results.

Our modeling simulations operate at four spatial scales: (1) the summer range of the Porcupine Caribou Herd on the coastal plain; (2) the entire range of the PCH, including hunting areas important to each community; (3) a single community; and, (4) households. To date, we have developed our model to reflect conditions in the community of Old Crow, Yukon Territory. These scales permit us to represent all relationships in a single SYNTHESIS MODEL developed in a series of spreadsheets. The relatively familiar spreadsheet environment has greatly enhanced our ability to exchange ideas between disciplines and incorporate both research-based and local-based knowledge.

One of the surprises in this study has been how even our simple representation of the Arctic system can produce dramatically different outcomes over 40 years as a result of chance differences in the sequence of annual conditions. Based on over 20 years of field, laboratory, and modeling research on the relationships of varying forage conditions, insect harassment, and snow depths to caribou calf survival and cow pregnancy rates, inter-annual variations can account for qualitatively different herd population trends large enough to affect caribou availability at the community level. We express this uncertainty in model simulations and attempt to overlay the substantial uncertainties of climate change, petroleum development, tourism, and government cutbacks.

Rotmans and Van Asselt (1996:335) write that, "perhaps the greatest challenge for IA is that of gaining credibility." Closely tied to the goal of gaining credibility is how we handle uncertainty. The challenge is greater even than that of handling cumulative uncertainty within the model framework; it also concerns differences in the fundamental paradigms brought to the IA by researchers and our community partners. As Morgan and Dowlatabadi point out (1996:364), IA is usually based on researchers' assumptions of causation, probability, and rational expectations. As a diverse project team of researchers and community partners, we do not presume to share the same assumptions about how the world works. To be credible, we have to be able to represent community views of how the world works as well as the researchers' views. In fact, it is the give and take between researchers and community partners that we think adds the most value.

Choosing Among Forces for Change

What forces for change are most important to the sustainability of Arctic communities? Our modeling team leader, Tony Starfield, strongly advised us to tackle this question head-on for ourselves, and to test our thinking in an early round of modeling. Our actual approach was considerably less efficient, but reflected the priorities of funding agencies' current science agendas. In this case, we chose forces for change in the context of funding opportunities in the U.S. Human Dimensions of Global Change (HDGC) program (Committee on the Human Dimensions of Global Change 1994) and the NSF Arctic System Science (ARCSS) Program (ARCUS 1993). A major focus of both programs has been on climate-related changes.

One of three substantial research initiatives in ARCSS has been to understand Land-Atmosphere-Ice Interactions (OPP 1991), focusing in particular on the question of a potential positive feedback to global warming through the release of greenhouse gases from the tundra to the atmosphere (Kane, Reeburgh et al. 1998). In the process of understanding this gas flux, natural scientists examined the effects of varying climate conditions on tundra plant communities. We decided that the most logical relationship between ARCSS program research and northern peoples is the potential indirect effect of climate change on the availability of caribou to communities through the more direct effects of climate change on vegetation.

In 1994, indigenous people in Alaska were more concerned about contaminants, offshore oil development, climate change and commercial fisheries effects on marine resources, hunting and fishing rights, and self-determination than they were about the effects of climate change on vegetation and caribou. The research team believed that the best way to address indigenous concerns, however, was to work within the HDGC and ARCSS programs, incorporating climate change effects on caribou as a major focus of study. This decision did come with a cost. The North Slope Borough Wildlife Management Department withdrew as an active participant in our proposal because climate change effects on caribou was not a top priority for them. The North Slope Borough Fish and Wildlife Management Committee subsequently endorsed the project. They also encouraged us to focus in addition on the effects of offshore oil development and climate change on the marine environment. We recently received a renewal grant for a second phase that will include a major marine component. The North Slope Borough is a collaborator in the second phase.

Arctic petroleum development is probably the most-debated issue concerning the U.S. and Western Canadian Arctic. For background on the debate, see http://borealis.lib.uconn.edu/ArcticCircle/ANWR/anwrdebate.html . Concerns about the potential effects of oil development on the Porcupine Caribou Herd have been the motivation for sustained caribou research programs by the U.S. and Canada since the early 1970's. Recognizing this area of concern, and that a shift in climate is likely to occur concurrently, the research team decided to include petroleum development as a major force for change in the study. The fact that an issue is contentious, however, does not mean that stakeholders welcome research on the issue. Both supporters and opponents of oil development in the Arctic National Wildlife Refuge worried that we would be biased or that we would

invite new development initiatives at a time when the issue was on a backburner. Kaktovik was initially a community partner. Unfortunately, we were unsuccessful in developing an effective working relationship with Kaktovik's consultant. The loss of Kaktovik as a partner community increased concerns among those in favor on ANWR oil development that we were biased. More recently, three Iñupiat residents of Kaktovik participated in project workshops. Mayor Sonsalla of Kaktovik has invited us to come to Kaktovik to discuss the project. We hope Kaktovik will rejoin the project for the second phase of the study. We also worried that NSF would see petroleum development as too politically charged an issue for research. While our expectation regarding the sensitivity of the ARCTIC REFUGE issue with stakeholders proved to be accurate, our concern regarding NSF was unfounded.
The third force for change addressed in our project is tourism. We included tourism because each of the project's four partner communities are keenly interested in its potential in providing an economic base that is compatible with community sustainability goals.

To these three forces for change - climate change, oil development, and tourism - we added government cuts in support to communities. We estimate that currently government supports account for at least 30 percent of the cash economies of these communities. Reductions in overall government spending and/or policy decisions to reduce spending on remote northern settlements are among the more likely forces for change to affect arctic communities over the next 40 years.

The important lesson we learned about choosing which forces for change to study is that we should view the choice as a negotiation in which all parties - researchers, communities, and funding agencies - are aware of each other's priorities. For example, several local leaders from Arctic Village suggested that our analysis of possible futures be framed in terms of changes in Alaska's state economy, and the need to capture greater revenues from natural resources through incentives for more value-added industries. Given the focus of our project and the research team assembled, the project was unable to pursue this line of inquiry. We found that there is room for considerable give-and-take if there are opportunities to exchange perspectives. In practical terms, this translates to incorporation of community concerns in science plans that form the basis of funding priorities, and to funding face-to-face negotiations between researchers, communities and regional organizations during the proposal development process. NSF has taken steps to incorporate community concerns through support of the Alaska Native Science Commission, appointing indigenous people to science planning committees, and supporting research on human dimensions of the Arctic system (ARCUS 1997). NSF science planning groups are exploring ways to support researcher-community proposal discussions, and NSF does fund open workshops that could lead to proposals Given the usual short deadlines for proposal development, perhaps the best approach is to fund periodic open workshops with proceedings and follow-up contact information that are published on the web and are hence accessible to potential researchers. For an example of such a process, see the Wildlife Management Advisory Council (North Slope) Research Plan for the Inuvialuit Settlement Region of Yukon, posted at http://taiga.net/wmac/plans.html. Also see www.rangifer.net/ .

Choosing a Time Scale

The principal tension in choosing a time scale came between the 100-plus year time scale over which vegetation composition changes might be expected to affect the caribou population, and the 20-year time scale over which we might venture to anticipate technological changes. We ultimately decided to focus most of our attention on a 40-year time scale. Given the uncertainties, forty years appears to be at the outer limit at which we could hope to model with any semblance of relevance to today's perceived problems. What we did not anticipate, and what ultimately made the 40-year time scale an overall reasonable choice, is that year-to-year variations in timing of green-up, snow depths, levels of insect harassment, and caribou harvests appear to have significant effects on caribou population trends over a 40-year period. Results from global climate model simulations for Alaska and the Western Canadian Arctic most often predict increases in the frequency of years with climate conditions that result in early green-up, deep winter snows, and higher summer temperatures (Maxwell 1992, Rowntree 1997) that increase insect harassment of caribou. The evidence for warming is much stronger than the evidence for increased frequency of deep snow years and for the combination of summer precipitation and warmer temperatures associated with high insect harassment. See Serreze et al (in press). When we combine these increased probabilities in a simulation, we can see major changes in the likelihood of a caribou population decline over 40 years.

Building Scenarios and Policy Alternatives

A key goal in the project has been to simulate future conditions under different combinations of forces for change. We understood, however, that our success depended on limiting the combinations tested. This, in turn, required limiting the number of scenarios for each force for change.

We limited our treatment of climate change to two scenarios: warming and continuation of current climate. We expressed climate change in terms of altered probabilities that a given year will have: (1) deep, normal or shallow snows; (2) high, medium, or low levels of insect harassment; (3) early, late, or normal time of freeze-up; and, (4) colder than average, average, or warmer than average summer temperatures. Deep snows affect the distribution and movements of caribou and the energy expended by caribou. High insect harassment also affects caribou energy expenditures, energy intake and ultimately caribou fecundity. Timing of freeze-up affects the ability of hunters to travel to caribou hunting areas. The differences in summer temperatures explain intra-seasonal and inter-seasonal variability in plant activity, which in turn are associated with short-term variations in forage biomass and long-term variations in plant community composition and biomass.

We constructed five oil development scenarios based on an analysis of USGS assessments of oil potential in the Arctic National Wildlife Refuge and changing worldwide petroleum markets (Tussing 1999:www). The scenarios are: (1) limited oil development just west of the Arctic Refuge in the Canning River Delta with some "drainage" of oil beneath the Arctic Refuge; (2) oil development within the Arctic Refuge north of 70 degrees latitude and on associated Native corporation lands; (3) the same assumptions as (2) with the addition of a permanent road from the development to the Alaska highway system; (4) oil development throughout most of the Arctic Refuge; and, (5) oil development throughout all of the Arctic Refuge. These scenarios collectively span the range of assumptions made by Arctic Refuge stakeholders and test the question of how large the developed area would have to be to substantially increase the likelihood of a decline in the caribou population. We constructed them to be at least plausible, but not necessarily likely. We initially anticipated that we would be modeling the effects of oil development on both employment and caribou. When we were not working with Kaktovik, the only community likely to experience significant employment effects, we did not model the effects of oil development on employment, focusing exclusively on effects on caribou and availability of caribou to communities. The community of Aklavik may also experience some employment effects in a 1002 oil development scenario. A small number of families of this community have moved to Kaktovik in recent history to take advantage of its employment opportunities. We expect to model employment relationships in the second phase of the study.

We also found that we had no basis for projecting a particular field layout for a given oil development scenario. We therefore identified zones of likely development activity associated with each scenario. Since the effects of development on caribou are linked to heavily used roads and other high use areas, our use of zones probably overstates the "footprint" of relevant development. At the same time, the possible location of high-use areas toward the southern and eastern portions of the coastal plain could have the effect of displacing high-use areas outside our identified zones. The most important point to keep in mind is that we are examining relationships between oil development and caribou, not conducting a formal impact assessment of Arctic Refuge oil development. We hope that our work can inform an impact assessment, but it should not be seen as drawing conclusions.

When the research and community team recently met to discuss the project simulations, the partner communities asked that all the oil development scenarios be removed from the analysis. The communities' decision was based on two factors – community members' perceptions that the Possible Futures Model over simplified the complexity of caribou population ecology dynamics, and their belief that the public would perceive model outputs as science-based predictions, and not as a tool for discussing and advancing collective knowledge. Working through this issue has served to crystallize the concept of partnership. Our partnership agreements state, "We will only conduct research, education, or public involvement in the community with the approval of the community. We will seek such approval by fully informing the community about the purpose of the activity; its sponsors; the methods to be used, including the participation of, or contact with, residents of the community; the person in charge; and the potential benefits and possible problems associated with the activity for community residents and their environment." Local leaders and residents from the partner communities met alone to reach consensus on the issue,. We later met as a combined group to discuss the implications of such a change, and reviewed the process that we had followed to date that included an oil development analysis and multiple scenarios. We ultimately decided that for the near term, the project would include just one scenario - displacement of herd concentrations from the entire coastal plain during a two week period. Inclusion of this scenario allows us to present the analysis methods used in all the scenarios and allows further discussion of the principal relationships analyzed. We further decided that the full set of oil development scenarios would be reviewed and discussed in each of the partner communities.

Partner communities were keenly interested in a more detailed look at alternative tourism scenarios. The research team built four tourism scenarios from combinations of enterprises, each of which are associated with specific jobs (Martin et al. 1999:www). The scenarios are: (1) no additional tourist activity; (2) small-scale "eco/cultural tourism"; (3) the addition of a year-round road to the community to small-scale eco/cultural –tourism; and, (4) large-scale tourism, coupled with a road to the community.

We decided to treat policy alternatives as explicit scenarios. Petroleum development scenarios assume changes in national policy (Tussing 1999:www; Young 1999:www). We consider the decision of whether or not to have a permanent road connecting Arctic Refuge development to the Alaska highway network to be a regional policy decision. We envision all the tourism scenarios as results of community-controlled policy decisions. The warming scenario assumes no effective abatement policies while the no-warming scenario assumes such policies are put in place. There are a total of 80 scenario combinations.

Defining Sustainability

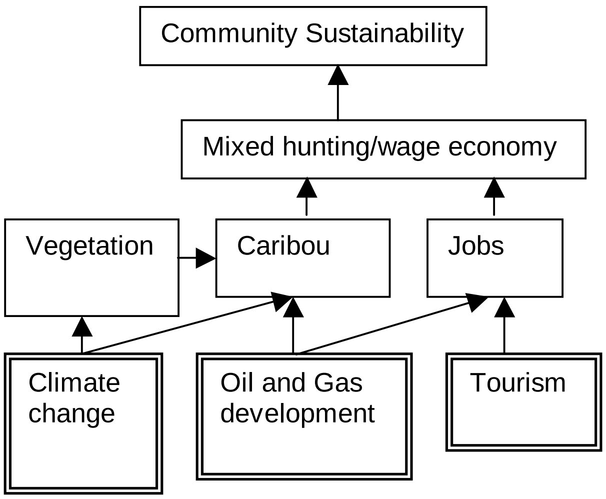
The nature of our project changed when we decided to form partnerships with individual communities by shifting the focus of the project to address concerns that are relevant to local communities. This raises the question of "Who is the community?" The research team rejected the approach of viewing the community as an aggregation of individuals, each of whom could be expected to have a different definition of sustainability. Since the goal of the project is to help communities make informed policy choices, the team decided to work with the local organizations most likely to make - or attempt to influence - policy choices relevant to the forces for change considered in this study. We therefore worked primarily with local renewable resource committees and councils. The specific organizations vary by community. In the case of Aklavik there are both Inuvialuit and Gwich'in land claims groups and associated renewable resource committees.

Working with small groups of village residents suggested by the renewable resource committees, two research team members (Kofinas and Braund) asked partner communities in the first year of the project to define "sustainability". The research team expected to get unique definitions from each community. While there were differences, there was consensus on five community goals: (1) continued use of, and respect for, the land and animals; (2) a cash economy that is compatible with their relationship with the land and animals; (3) local control and responsibility for their homelands and resources; (4) education of young people in the twin areas of traditional knowledge and western science; and education of the outside world about community goals and ways of living; and, (5) a thriving culture with a strong, clear identity, based on language, time on the land, and which honors and respects elders (Kofinas and Braund 1996:www).

Identifying Major Relationships

Again our modeling expert had the wise advice of using an iterative modeling approach to identify the relationships that: (1) affect community goals; and, (2) are likely to change. Before this step, however, we had to assemble an interdisciplinary team. The MAB HLED provided an exceptional opportunity for us to avoid the more usual situation of a frantic effort to quickly assemble a research team following an announcement of funding opportunity. The MAB group started discussions two years before the funding opportunity. After deciding to focus on vegetation-caribou-community relationships, the MAB group obtained approval from the U.S. MAB Committee to advertise position descriptions for additional HLED members with expertise in indigenous hunting, modeling, and caribou ecology. They had completed this recruitment process when the funding opportunity arose, so the research team was virtually complete. We can't overstate the importance of the HLED-type venue for interdisciplinary exchanges of ideas to the success of integrated assessments.

Figure 2:Principal Study Relationships



The make-up of the research team has a great deal to do with the choice of major relationships to be studied (see Figure 2). Each investigator brings to such a project a particular area of expertise, research experience, and prior expectations about key relationships. Most importantly, proposals are usually required to name specific senior investigators to all funded positions. This requirement presupposes that the selection of the interdisciplinary team is based on a knowledge of which relationships are most important and therefore which expertise is most needed.

The HLED discussions led to logical choices of key relationships, but we needed to exercise our collective ideas in order to discover the ones that matter most. In other words, our thinking evolved over the course of the project. In the ideal situation then, we would have initiated the project with an interdisciplinary team including community partners. We would have used modeling to discipline ourselves to reveal our best guesses on relationships between forces for change and community sustainability. This modeling effort would have, in turn, helped us to identify relationships to focus on for the remainder of the project. These decisions would be reflected in the allocation of project resources.

In actuality, our proposal allocated all resources we expected to receive for the project prior to any formal interdisciplinary modeling effort. The different participating research institutions also largely defined the different disciplines contributing to the project (social and economic - University of Alaska Anchorage; caribou ecology - University of Alaska Fairbanks and Canadian Wildlife Service; vegetation ecology - University of Colorado, Boulder; U.C. Berkeley; modeling - University of Minnesota; policy studies - Dartmouth College).

The grouping of disciplinary expertise by participating institutions made it an easy decision to organize the project by disciplinary component. In hindsight, the decision to organize the project by discipline should have made ***less*** sense, rather than ***more*** sense, given the grouping of disciplines by institution. Our natural tendency as researchers is to build on our work and to work with people having similar interests. We could have organized the project to introduce more counterbalancing incentives to work across disciplines. We now have hypotheses about such counterbalancing incentives and will test them in the second phase of the project.

Synthesis and Modeling

Learning from the experience of the MacKenzie Basin Impact Study (Cohen 1997), we organized the project to include a synthesis component. We further decided that our principal synthesis tasks were to develop a formal model linking all project components and to exercise this model to better understand relationships. As Parson writes, "Since researchers working within their fields do not normally attend to borders of other fields, achieving this attention shift requires some form of authority in an assessment project, at least a coordinating mechanism and a common language for communicating across boundaries." (Parson 1995:468). While, as we explain below, we encountered pitfalls in the modeling effort, our central focus on developing a single SYNTHESIS MODEL proved to be the most important factor in achieving a truly integrated assessment.

The synthesis exercise of this project challenges modelers to combine the interactions between the different subsystems (vegetation ecology, caribou ecology, human economics and population) over a regional scale in a way that effectively addresses policy questions. There are two aspects to this challenge: system modeling and spatial modeling. System modeling has its roots in the work of Forrester (1973), Meadows (1974), and the ecosystem modeling of the International Biological Program in the 1970s (e.g., Innis 1978). Ecosystem models, with either an implicit or explicit spatial dimension have been used to address questions of vegetation response to climatic change (e.g., Davis and Botkin 1985). We are starting to model transient dynamics (changes over a period of decades) at a regional scale (Rupp, Starfield and Chapin 2000a, 2000b, 2000c).

There is a tension in any modeling effort of this kind between simplicity and detail (Constanza and Sklar 1985; Starfield and Bleloch 1991). Most system models take a bottom-up approach, i.e. start with the finest level of detail in the hierarchy and build the model upwards. Starfield et al. (1993) argue that this approach locks one early on into possibly unnecessary and potentially confusing details; they argue for a top-down approach where one starts with a very simple model that reflects gross dynamic changes and then successively refines this model down to the appropriate level of detail, defined in terms of the goals or objectives of the model, to address the policy questions that have been posited.

The MAB group was drawn to Starfield's approach and asked him to join the MAB HLED and to become part of the project team. During the first year of the project, Starfield, Berman, and Kruse worked over a three-day period to design a conceptual representation of a SYNTHESIS MODEL. Starfield subsequently produced a working version of the model. The intent in developing a prototype model was to promote integration of the project components.

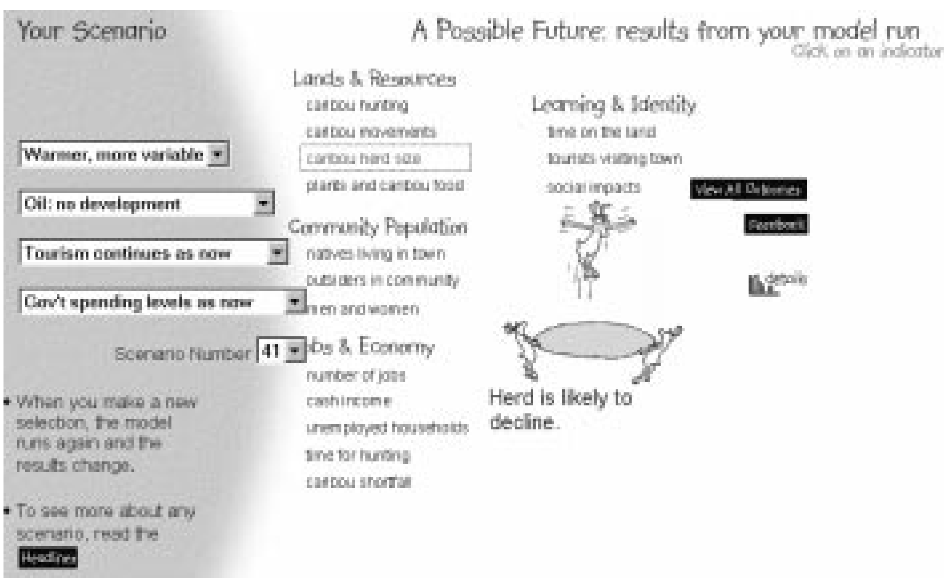
We made two mistakes at this stage of the project. First, we produced a model in a language (Pascal) unfamiliar to most of the project team. Second, we did not reallocate project funds to bring component team members together to be a part of the initial model building process and later to exercise and refine the model. As a result, component groups ignored the prototype SYNTHESIS MODEL and proceeded to plan component-specific work that could subsequently be integrated. While the approach of organizing by discipline ultimately did come together to produce an integrated assessment, we certainly would argue that the process of synthesis modeling should be established at the very beginning of the project, with the understanding and expectation that the model would evolve.

In our second year, Starfield brought to the project a post-doc (Nicolson) to work full-time on synthesis modeling. This commitment of time proved to be invaluable. Nicolson worked with each component group to understand within-component relationships. He earned the trust of each group by developing SYNTHESIS MODEL components that accurately reflected these relationships. He then developed prototype links between components, thereby facilitating cross-component exchanges. We now have a functioning SYNTHESIS MODEL that is best explained as an interacting cluster of four components (Nicolson 1999a:www). The model is available to researchers on CD-Rom. To request a copy, email Jack Kruse at afjak@uaa.alaska.edu. The **vegetation component** integrates changes in climate with disturbance and plant growth characteristics. It models changes in biomass of 20 plant types. The **caribou component** integrates the effects of climate, environmental conditions, vegetation and forage changes and oil development. It models the total herd population, herd distribution, and the relative abundance of caribou for hunting by communities. The **household economies component** integrates the effects of tourism, employment, government spending and caribou availability. It models the mixed wage-subsistence economy, and the distribution of household income and household caribou production and consumption. The **village population component** integrates the effects of employment, time on the land, and rural-urban migration. It models village population, household formation, and movement of both local people and outsiders to and from a village. Taken together, these four components represent major social, economic and environmental processes affecting the human dimensions of change in Arctic communities. In keeping with the community goals described earlier, the SYNTHESIS MODEL outputs include caribou harvest, time on the land, employment, and proportions of local and non-local populations in the community (Nicolson 1999a:www).

We developed the model as a set of linked Excel workbooks. This modeling format has provided a common framework for integrating the disciplinary contributions and for communicating across disciplinary boundaries. For example, it has allowed us for the first time to understand the relative importance of winter energetic costs, forage intake, summer activity and location-dependent calf-survival on the overall population dynamics of the PCH. In doing so, we have integrated the complementary work of six investigators in the natural and social sciences (Walker, White, Murphy, Griffith, Russell and Tussing). Similarly, with our household economies model we integrated our understanding of how job availability, demographics, household formation, caribou migration and preferences for subsistence resources all interact. In so doing, we brought together the complementary expertise of seven natural and social science researchers(Kofinas, Russell, Kruse, Berman, Haley, Huskey, Martin). A standard criticism of many IA projects (Rotmans and Van Asselt 1996, Parson 1995) is that they ignore essential social, cultural, demographic and economic processes. Working with local communities, we initiated a process in which the SYNTHESIS MODEL prompts an exploration of these more difficult-to-measure social processes (e.g., social costs related to rapid culture change). In this respect, our research is not only interdisciplinary, but has the added dimension of seeking to complement science-based research with local knowledge.

The Excel-based SYNTHESIS MODEL helps project researchers to exchange ideas and, we hope, will help other researchers to review and build on our work. It is not suitable, however, for use by people unfamiliar with spreadsheets. Since the main goal of this project is to help communities make informed choices, we therefore needed to develop an effective means of exchanging ideas between researchers and community residents. The result is an interactive web site that we refer to as the POSSIBLE FUTURES MODEL: http://www.taiga.net/sustain (Eamer 1999:www).

Figure 3: Possible Futures Model



We designed the POSSIBLE FUTURES MODEL to work either from a web-server, a CD, or from a hard disk. It includes an interactive capability that normally would not be possible from all these platforms (see Figure 3). Many northern communities still only have internet access by paying long-distance charges and using modem connections involving satellite links that reduce the reliability and speed of data transfer. Our intent is to encourage model users to exchange their reactions and ideas with the project team. The first layer of outputs is qualitative. Users can then select an output category and view quantitative graphs and read an explanation relating the chosen scenario with the output category results.

It took much longer than anticipated to build a SYNTHESIS MODEL that could serve as a discussion tool among the research team. Delays primarily resulted from unanticipated work within the disciplinary components and the difficulty of bridging component work in the model itself. As a result of these delays, we did not have a capability to test the sensitivity of different relationships reflected within the SYNTHESIS MODEL and the component models until the fourth year. We also had to wait until the fourth year to use the SYNTHESIS MODEL as a tool for identifying missed assumptions and relationships - particularly changes in technology and values that might alter simulation results substantially. At the same time, we are finding that the SYNTHESIS MODEL does serve these purposes well, although we have not had enough time to test it exhaustively and build confidence in it.

We end our synthesis discussion by noting that we did not budget for enough face-to-face contact among members of the project team, including both researchers and community partners. Our proposal included funds for annual project meetings, which have proven valuable. In addition, however, we found it absolutely necessary to hold work sessions involving small numbers of researchers from components to develop specific component linkages at two points. Email exchanges work once there is a common understanding of the problem, common assumptions, and a negotiated set of task assignments. Face-to-face meetings are indispensable for these groundwork decisions. Face-to-face meetings with component researchers are also critical to the work of the synthesis modeler. When we began to hold these meetings despite the lack of budgeted funds, we gained considerable momentum. They should be part of any integrated assessment budget in which team members are dispersed. In addition, it was unreasonable to expect community partners to think through the implications of the project based on one or two work shops a year.

Disciplinary Component Advances

We decided at the outset that the tasks of integrating existing knowledge would require our full attention. We could not realistically expect to additionally conduct field research. Knowing this, we designed the project to take advantage of existing research.

Vegetation - We developed a unique model -ArcVeg - for simulating transient dynamics in arctic vegetation and the response of tundra plant communities to climatic warming (Epstein et al. in press). One unique feature of the model is that it incorporates a relatively detailed set of plant functional types including mosses, lichens, graminoids, evergreen and deciduous trees, and a variety of forbs, sedges, evergreen and deciduous shrubs. Plant types are distinguished in the model by a set of five parameters that describe a wide range of growth, competition and survival strategies. Climate and disturbance are stochastic elements in the model. The model is nutrient-based because many arctic ecosystems are limited by plant-available nutrients, especially nitrogen (Shaver et al. 1992, Shaver and Chapin 1995, Schimel et al. 1996) and respond relatively quickly to changes in nutrient availability. The ArcVeg model is contained as a worksheet in the Excel-based SYNTHESIS MODEL.

Our simulations of climatic warming (an increase in ~3 °C in mean summer temperatures and a lengthening of the growing season) suggest an increase in total plant biomass for high and low Arctic tundra ecosystems over 200 years, and an increase in shrub biomass at the expense of other plant functional types. The initial responses of vegetation to climatic warming (~0-50 years) were controlled by the dominant plants and were not indicative of longer-term changes (~50-200 years). In addition, warming resulted in the formation of novel, stable plant communities that were not typical of current zonal vegetation types in the Arctic of northwestern North America.

Caribou - This project builds on 15 years of Porcupine Caribou modeling work (Hovey et al. 1989, Kremsater et al. 1989, Kremsater 1991, Russell 1991, White 1991, Daniel 1993, Luick and White 1995). We used a refined version of the CARIBOU Model (Russell et al. 1999:www) to assess the energetic and population impacts of community harvesting (Hanley and Russell 1998), climate change (White et al. 1999) and oil development (Murphy et al. 1998, Griffith and Russell 1999) within the range of the Porcupine Caribou Herd. We incorporated new research findings from concurrent and recently completed projects (Russell et al. 1998a,1998b, Allaye Chan-McLeod et al. 1999) into the model structure. We used validation data to assess the ability of the model to accurately reflect caribou body conditions measured in the field (Russell et al. 1999 www) and to more closely link body condition to reproductive performance (Russell and White 1998, Gerhart et al. 1997b, Cameron et al. 1998). We linked the CARIBOU model with the vegetation model ARCVEG to explore the implications of a greener north over a 40 year time horizon. In the process, we developed a comprehensive dataset, linking plant quality and phenology variables with plant biomass for the 10 plant groups we considered in the project (Johnstone et al. 1999). We also developed an algorithm to predict diet shifts with changes in plant community structure (White et al. 1999).

Colin Daniel at ESSA Technologies Ltd. took the lead in changing the model interface from DOS-based Basic format to Visual Basic so that the model is compatible with Windows applications. This is more than a cosmetic change; it makes the CARIBOU model accessible to the entire project team and other researchres. The new interface supports batch runs that generate tables directly required by the SYNTHESIS MODEL. We can now shift data files from an ASCII format to Excel and Access allowing model users to run simulations based on project scenarios. We rewrote the ENERGETICS model from Basic to C++ to increase its speed and make scenario runs under different model conditions more feasible. The shift also allows us to port the model to different platforms. For more details, please see our draft manuscript on the model (Russell et al. 1999:www).

We also needed a model of the relationship between oil development and caribou. The 1002 area of ANWR overlaps the area used most heavily by the Porcupine Caribou Herd (PCH) for calving (see Figure 1). Calf survival is highly correlated with forage available during the 2-3 week calving period (Griffith et al. 1997a, 1998a 1998c). We re-analyzed data (Cameron et al. 1992, Cameron and Griffith 1997, Griffith et al. 1998a, Griffith and Cameron 1998, Wolfe et al. 1998) on Central Arctic Herd (CAH) cow-calf concentrations during the period that the Prudhoe Bay/Kuparuk oilfield was developed (Griffith 1999a:www). The data support the hypothesis that calving cows avoid the oilfield for an approximately two-week period. We concluded that it is appropriate to simulate the effects of the hypothesized avoidance for the PCH.

We developed a model that shifts observed concentrations of PCH cows and calves over an 12 year period (1985-1996) to avoid hypothetical development zones derived from the petroleum scenarios (Griffith 1999b). We demonstrated a strong relationship between measures of biomass and the rate of biomass increase (based on NDVI as measured from satellite photos) and calf survival (Griffith 1999c). By comparing observed NDVI measures for actual and displaced calving areas for the 12 analyzed years, we simulated the effects on calf-survival of the oil development (Griffith 1999d). Also, we have evidence that caribou in proximity to oilfield infrastructure have a different pattern of energy use (Murphy and Griffith 1999:www). We used our energetics model to simulate the effect of these new energy budgets on cow fat weights (Murphy et al. 1998). We ran combinations of climate, oil development scenarios within the CARIBOU energetics model to develop sets of caribou population parameters that serve as inputs to a reduced-form of the energetics model in the SYNTHESIS MODEL (Nicolson 1999b:www).

Household Economies - We took an interdisciplinary social science approach to the community modeling, embedding the local economy in an institutional economic framework of the study communities (Polanyi 1944, 1957; Halperin 1994) and following rules of household and individual behavior that are empirically based (Quigley and McBride 1987). Theories consistent with economic models of behavior are derived from relevant survey data and local knowledge to explain and understand observed patterns. We attempted to model, in simplified form, a dynamic interaction between institutional change and individual actions over time. While one could theoretically examine potential endogenous changes in every model assumption, we focused efforts on several critical to community sustainability. These include the interaction of the wage economy with the subsistence economy (VanStone, 1960; Stabler, 1990; Kruse, 1991; Kirkvliet and Nebesky, 1997), sharing of wildlife harvests (Wolfe, et al, 1984; Brown and Burch, 1992; Sahlins, 1972), and human migration (Hamilton and Seyfrit 1994; Huskey 1998). Finally, the COMMUNITY MODEL disaggregates the community into component parts -- individuals, households -- in order to assess explicitly the distribution of outcomes within the community.

The COMMUNITY MODEL consists of two of the three SYNTHESIS MODEL components: household economies and village population. The household economies component in turn includes two sub-components: (1) the **local labor market sub-component** allocates household time to wage work and subsistence, given assumptions about jobs, environmental conditions, and development scenarios (Berman 1998:www; Kirkvliet and Nebesky 1997); and, (2) the **subsistence harvest sub-component** projects hunting participation and harvest success based on the environmental conditions and the labor market outcomes, taking into account a set of rules for sharing of gear and harvest among households based on local knowledge.. The village population component includes: (1) a **demographic sub-component** that projects household formation, births, deaths, aging, and the distribution of educational attainment; and, (2) a **human migration sub-component** that projects population movements into and out of the community, based on demographics, income opportunities and harvest shortfalls (Huskey 1998; Huskey, Hill and Berman 1999), and tracks the ratio of non-local to local community residents, and their respective employment roles.

The basic model has been completed, using caribou hunting as the most important component of subsistence harvests. The model incorporates spatially explicit hunting relationships and incorporates relationships for wage employment, hunting participation, and subsistence harvest sharing based on data for North Slope Iñupiat communities. This version of the COMMUNITY MODEL has been validated, using data for Old Crow (Kofinas 1998).

***Community Involvement and Local Knowledge* –** We want the SYNTHESIS MODEL to be grounded on local knowledge, as well as science-based research. Indigenous communities of the North American Arctic increasingly expect that research endeavors will address community concerns and incorporate local and traditional knowledge in the research process (TKWG 1991). While many researchers acknowledge these expectations as valid, research methods that serve to meet these objectives are currently underdeveloped (Ferguson and Messier 1997; Huntington 1998; but see Kofinas et al 1997). Our work has sought to advance the understanding of how local knowledge and science can contribute to interdisciplinary research.

We identified five areas of research to which local knowledge would contribute. These are: (1) defining community sustainability; (2) modeling community caribou availability; (3) developing and refining scenarios; (4) helping to explain model outputs; and, (5) exploring policy alternatives. We also formulated and continue to refine a project policy on research information sharing and dissemination (see Kofinas 1996:www).

We initially designed the community involvement component with the idea of minimizing the burden of the project on communities. Two members of the project team (Kofinas and Braund) worked directly with community research associates Johnny Charlie, Sr., Joe Tetlichi, Billy Archie, and Kias Peter in selecting local discussion group participants, conducting interviews, and reviewing project products. This approach worked well to define community sustainability and to document local knowledge.

Our most extensive work with communities focused on documenting local knowledge to model community caribou availability. Based on our initial discussions with local hunters, we soon realized that while changing environmental conditions (e.g., fall storms, snow depth, rate of spring snow melt) may affect the PCH's seasonal and annual distribution and movements (Eastland 1991; Russell et al.1993), so may associated environmental conditions (e.g., timing of freeze-up and break-up, shallow snow cover, and the presence of "candle ice" on lakes) affect hunters' access to hunting grounds. To capture key relationships of community caribou availability, local experts from the four partner communities participated in focus group discussions and completed a mapping exercise to document current-day hunting patterns and conditions affecting herd movement and distribution. We used an iterative process of multiple small-group interviews in which locals worked with us to generate and refine qualitative propositions about community caribou availability (Kofinas and Braund 1998:www). We presented findings of former studies (e.g., annual harvest data, GIS displayed harvest locations, caribou survey data (Russell et al., 1992), and socio-economic data on household and community sharing (Kofinas 1998) for locals' interpretation and to prompt discussions. We then used maps and locally-generated propositions as the basis for delineating 12 PCH range-wide zones and 38 community-specific hunting zones, to derive values that augment research-based data on PCH distributions, and to establish values driving hunting effort in the SYNTHESIS MODEL. Local knowledge also informed our selection of COMMUNITY MODEL variables, parameters and our development of scenarios, and regularly served as the basis for questioning model assumptions and relationships derived solely from the analysis of quantitative datasets.

We asked community representatives to attend annual project meetings. The researchers vastly outnumbered the community representatives in the first two annual meetings. Increasingly, the research team came to realize the benefits of increased participation in project work sessions by community representatives. At one three-day workshop in April 1998, community representatives met separately from researchers to review the project and to recommend changes. The outcome was most constructive in furthering the researcher-community dialogue. Upon returning to the meeting room, community representatives presented researchers with 15 pages of flip chart sheets, listing constructive criticisms and recommendations on topics such as the allocation of financial resources, the use of the project's final products in local school classrooms, and the direction of future studies. Workshop interactions also led researchers to appreciate community reviews of research results as a valuable addition to the traditional scientist-to-scientist peer-review process. We conclude that holding workshops in which the number of researchers and community representatives is roughly equal is worth the tradeoffs of the increased burden on community members of dealing with larger numbers of researchers and the necessity of limiting participation to a subset of the research team.

Simulation Results

Herd Population - Caribou continues to be an important food source for communities in and adjacent to the range of the PCH (Wein and Freeman 1992; Wein 1995). More than 20 years of research have shown that northern people choose to continue to harvest and consume substantial local resources despite an increasing importance of a cash economy (Kruse 1991). The Porcupine Caribou Herd also has a cultural importance beyond its food value (Kofinas 1998). People share resources to hunt, they hunt together, and they share harvests. Children learn cultural values by observing and participating in hunting and processing activities. Moreover, expressions of caribou in Old Crow, Arctic Village, Aklavik, and Fort McPherson are closely linked to cultural identify and community well-being. Perceived threats to the continued presence of caribou and to the integrity of the environment they occupy are taken very seriously by communities of the region. They have organized politically to influence national policies about oil development in ANWR. See http://borealis.lib.uconn.edu/ArcticCircle/ANWR/asrcadams.html regarding the Iñupiat people of the North Slope, http://www.mosquitonet.com/~naec/refuge/html/gwichin.htm regarding the Gwich'in Steering Committee, , and http://borealis.lib.uconn.edu/ArcticCircle/ANWR/anwralbert1.html regarding the Porcupine Caribou Management Board.

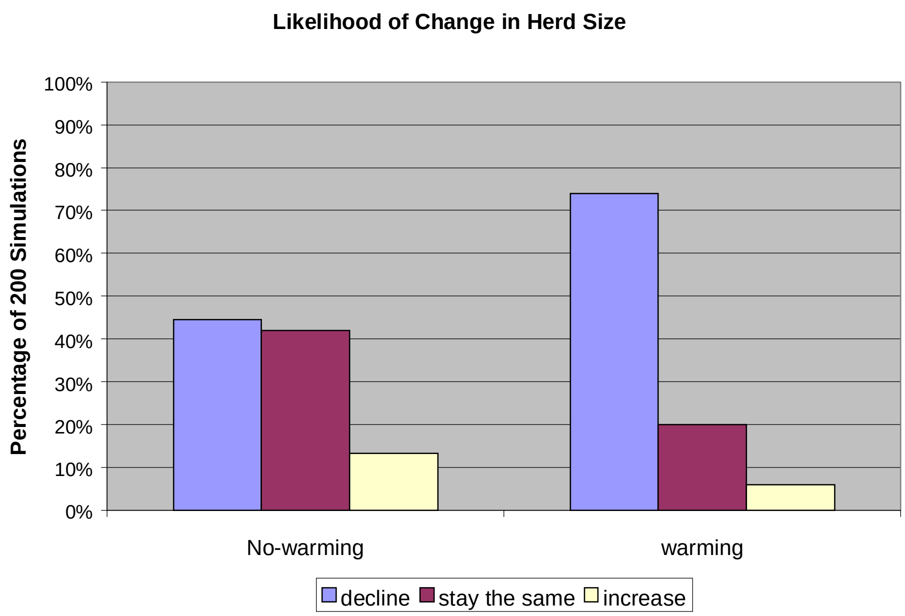
Changes in the size of the Porcupine Caribou Herd are therefore of great interest to communities that depend on the herd. The sequence of inter-annual variations in summer temperatures, snow depth, harvest, and insect harassment is important to the 40-year simulation results for the PCH. When we hold the probabilities of warm summers, deep snows, and high insect harassment years constant, successive runs of the SYNTHESIS MODEL can produce 40-year simulations that vary from increases in excess of 2 percent per year to decreases of the same magnitude as well as curves of intermediate shapes. These results raise the important point that year-to-year variations can mask or accentuate the apparent effects of oil development or the effects of increased hunting that results from population increases associated with more tourism.

We made 200 repeated simulations while keeping the probability of warm summers, deep snows, high insect harassment and high harvests constant. We can express simulation results as a probability of caribou population increases and decreases (see Figure 4). In some simulations, chance occurrences of a sequence of "bad" years sets in motion a large population decline. In other runs, an absence of such strings of bad years produces a large population increase. The important point of this exercise is that what happens to the Porcupine Caribou Herd over the next 40 years appears to be highly uncertain. We must overlay our analysis of climate change, oil development, and tourism on this uncertainty.
Our initial attempts at integrating the form and function of interactions have shown that caribou populations are quite sensitive to a warming climate through its influence on summer forage and resulting calf survival (Griffith et al. submitted, Griffith 1997a, Griffith et al. 1997a, Griffith et al. 1998b, Griffith 1999a:www), and through its effect on late summer insect harassment and winter snow depths which

may influence body condition and subsequent parturition rates (Russell and Griffith 1995, Gerhart et al.1997a).

Our simulations of the effects of climate warming on the PCH show a large increase in probability that the herd would decline over the next 40 years (see Figure 4). Our prior expectation was that warming would tend to increase herd size due to earlier spring green-up and higher forage biomass. When we combine this effect with the simulated effects of an increased frequency of years of deep snows and high insect harassment, however, the net effect is to increase the risk of population decline with climate warming. Figure 4 (below) compares the percentage chance that the PCH will show a decline over 40 years with and without climate warming.

Figure 4:



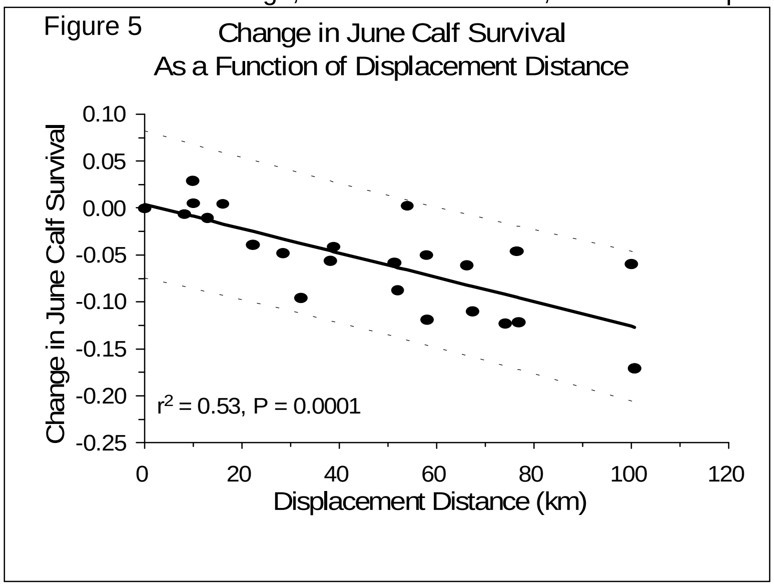
As mentioned earlier, we are more certain about biomass changes than we are about the frequency of deep snow years and high insect harassment years. Global climate models appear to be better at predicting temperature than precipitation, and the latter is relevant to both snow depths and insect harassment levels. Community hunters who have reviewed our model have also noted the shortfalls in making broad generalization in possible changes in snow depth, and suggested that regional variability in precipitation levels is also an important factor. We certainly need to consider the possibility that climate warming could raise the probability that the PCH will increase in population size.

The research team also wanted to compare the likelihood that the PCH would show a decline over 40 years based on four oil development scenarios in which concentrations of cows and calves avoid progressively larger parts of the coastal plain during a two week period in June. The team developed scenarios based on a new assessment of oil potential prepared by the US Geological Survey (1998) coupled with an assessment of changing worldwide petroleum markets (Tussing and Haley 1998). As reported earlier, the partner communities asked that we drop the oil scenario analysis. The ensuing discussion was educational for both researchers and community partners. The researchers had not foreseen the communities' concern that including multiple oil development scenarios would imply community acceptance of incremental development of the Arctic Refuge (a position they oppose). The communities had not foreseen the large professional investment by researchers implied by the earlier reviews of oil development scenarios and analyses.

Our interim compromise for the 1999 Arctic Science Conference was to leave out the oil scenarios and compare the effects of displacement on caribou calf survival as a function of distance (see Figure 5). We would continue to discuss how to treat oil development in further visits to individual partner communities.

The discussion in Old Crow also raised concerns among the researchers about the validity of basing our analysis of oil development effects on only four, simplified scenarios out of an infinite number of possible scenarios. The discussion with communities also highlighted the problem of pushing our analysis too far in order to simulate changes directly relevant to communities (i.e. changes in caribou population size).

The researchers, in fact, had focused their analysis on what they think is the most important potential relationship: the effect of a potential two-week displacement of concentrations of cows and calves on calf survival through its effects on forage quality and predation. Other relationships, including interactions between climate change, caribou movements, and oil development could also affect caribou population dynamics. The original approach unintentionally conveyed a certainty not warranted by the analyses conducted to date.



As of this writing, the final treatment of oil development scenarios is still a matter for discussion with communities. The important point is not to present our simulations of oil development; but to stimulate discussion about alternative futures among community stakeholders. We have certainly accomplished this goal. We have also stimulated the thinking of researchers, both with regard to new research approaches and with regard to the problems associated with competing values of dissemination of new knowledge and building trust with communities.

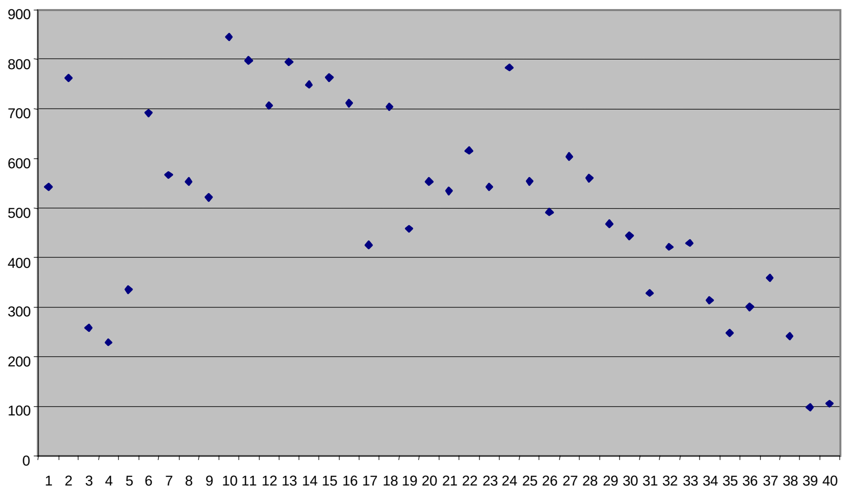
Caribou availability to communities and caribou harvest - Communities are dispersed widely in the range of the PCH. We constructed probabilities for different herd movement patterns based on documentation of past herd movements and local knowledge. The SYNTHESIS MODEL uses these probabilities to simulate year-to-year differences in herd concentrations. These probabilities vary between no-warming and warming scenarios. Hunters in the model see "lots", "few", or "no" caribou in a given area and season depending on the herd distribution and it's overall population size. The number of caribou seen affects the likelihood of hunting, the effort required (treated as day, overnight, or multi-night trips) and harvest success. Hunters also need time to hunt and enough money to buy equipment and supplies. Employment conditions affect both time to hunt and money, depending on the types and numbers of jobs. Sharing of equipment and harvests are important ways in which the community tries to optimize hunting effort and meeting household needs for caribou.

We are modeling the community of Old Crow where fall is the primary hunting season. While hunters try to make-up for poor fall hunting with winter and spring hunts, we can get an idea of changes in caribou availability over time by counting the number of falls in which hunters see only a few caribou. In our simulation model, about one-in-four years show bad fall hunting under a no-warming scenario.

The simulations start with a high degree of uncertainty about what would happen to the caribou herd size. In half the simulations, the herd population decreases with climate warming to about 20,000 animals by year 40. But we don't think that such a decrease in herd size would produce substantially more years in which there is a major harvest shortfall at the community level. One of the reasons for this is what we call a "community hunt". Individual hunters would be more likely to see few caribou and less likely to meet their own harvest needs. When enough hunters experience poor hunting success (which we estimate in the model is when less than 50 percent of the community need for caribou is met), the community decides to pool its resources and travel to the fewer remaining areas where caribou have been seen in sufficient numbers. Over time, such a harvest strategy would further depress herd size and would not be sustainable.   It is important to point out that the SYNTHESIS MODEL holds the unrealistic assumption that no self-regulating harvest policy will be implemented to limit the number of caribou harvested. The rationale here is not to assume that community hunters are inclined to hunt the herd to ruin, but rather, to highlight what changes would be necessary under these scenarios.

At what combination of climate warming and displacement of herd concentrations from areas of the coastal plain would we probably see major shortfalls in caribou harvested? Under most simulations, producing a decline in community harvests would take climate warming coupled with displacement of concentrations of cows and calves from all of the coastal plain during a two-week period in June. Figure 6 illustrates a typical simulation under these conditions.

Figure 6: Total Harvest by Community Under Climate Warming and Displacement of Herd Concentrations from Entire Coastal Plain

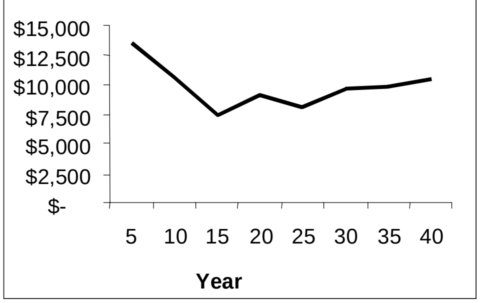


As we will see below, tourism development - particularly with the construction of roads to communities - tends to increase community populations and associated harvest pressure on the herd. When modeled in combination with the displacement of caribou from the entire coastal plain, this increases the likelihood of harvest shortfall.

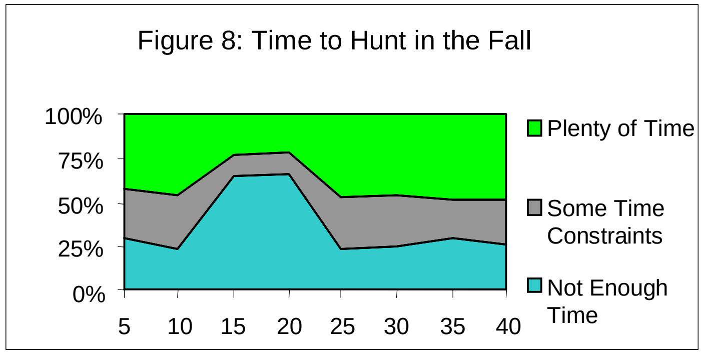
Employment

Increased tourism and government cutbacks affect employment conditions. Communities prefer tourism scenarios that increase local employment without bringing large numbers of tourists through the community. We designed an "eco/cultural-tourism" scenario to include combinations of enterprises (e.g. outfitters, lodges, gift shops) based on the experiences of other communities, management planning documents, and through discussions with people of Old Crow (Martin et al. www). In the model, locals compete with each other and with non-locals for jobs based on their educational qualifications and job preferences. If Old Crow was successful in implementing an eco/cultural-tourism industry, we think that one-in-three adults would be unemployed in 2040 compared with over half of all adults unemployed with no tourism development and continued government supports. In addition, however, First Nation members not currently living in Old Crow would be likely to move there under the eco-tourism scenario, increasing Old Crow's local population from about 230 to 320. The types of jobs created would on average pay lower wages than current jobs in Old Crow. This would mean that the number of low income households may increase - both in absolute numbers and as a proportion of all households in Old Crow (see Figure 7). This model simulation of unemployed in the community is also affected by an anticipated increase in the number of adults twenty years from now.

Figure 7:Average Per Capita Income



Our first eco-tourism scenario assumes that Old Crow will remain off the Yukon road network. If we assume that in addition to eco-tourism Old Crow decides to build a year-round road to the community - and is successful - we think the population increase in Old Crow -and other villages making the same decisions - might increase by another 100 people, almost doubling in size by 2040. This would increase demand for caribou by perhaps 30 percent by 2040, assuming that per-household needs for caribou do not change and that policies would prohibit road hunting. Under these conditions, over half the simulations show a decline in the herd, but not enough over the next 40 years to cause more shortfalls in caribou harvest. The SYNTHESIS MODEL does show a relationship between the increased employment demand during construction of the road in the second decade and increased numbers of households not having enough time for fall hunting (see Figure 8). The reason the decreased time for hunting for some households does not cause the overall community harvest to decline is that households with employed hunters and no time for hunting are able to use their wage income to help hunters of other households who have more time to hunt.



What would happen if government supports of Arctic communities were cut back? Obviously the answer depends on the scale of the cutback. We assumed about a 30 percent cut in government supports in our "retrenchment" scenario. Interestingly, our simulations show about the same high level of unemployment with and without government cutbacks (50 percent); the difference is that simulations show the population - and with it the number of unemployed - dropping with government cutbacks to under 200 residents. We looked to see if a policy of promoting eco-tourism might offset this level of government cutbacks. As the cutbacks occurred, the average wage income in the community would continue to drop. Jobs in cities would become increasingly attractive as their wage rates would be comparatively higher. We think that the difference in relative wage rates is a major factor in determining the amount of in- and out-migration. Eco/cultural-tourism would probably not offset the employment effects of government cutbacks because most of the jobs created would pay too low a wage.

Where do we go from here?

The SYNTHESIS MODEL and its simulation results are grist for discussions, ***not*** conclusions. We had hoped to have a synthesis model to take to communities by the end of the second year of the project. It took much longer than we expected to create operational linkages in the model. As we near the end of the fourth year of the project, we are finally in a position to use the model as a basis for discussing our understanding of the Arctic system. Our first step, then, will be to take the POSSIBLE FUTURES MODEL to our partner communities for feedback and include their reviews as a part of the final product. We also now need to conduct a systematic set of sensitivity tests to understand the relative importance of assumptions and how conclusions are related to these assumptions. Finally, we need to complete documentation of all model components.

Both researchers and our partner communities want to build on our investment in working together on issues of common concern. Fortunately, NSF has given us the opportunity to do so in a three-year renewal of the grant (OPP-9909156). We will test our new understanding of the importance of iterative modeling in the identification of key relationships. We will use the relationships between climate change, offshore oil development, and bowhead and beluga whaling as the focus of these experiments. We also want to identify the differences between communities and caribou populations that need to be reflected in subsequent versions of the SYNTHESIS MODEL. An understanding of these differences will enable us to scale up from a single community to a region. Finally, we will explore in more detail how policies can shape simulation outcomes. We are particularly interested in how regional policies can be used to more widely distribute economic benefits of development while increasing community involvement in the management of risks to fish and wildlife.

The Sustainability of Arctic Communities project was seen by the National Science Foundation as a risky experiment in interdisciplinary research. We think it has been an experiment worth building on. We will test the hypothesis that placing the synthesis component in a position of authority in the project, and using modeling in a more iterative process is more efficient and increases the rate of discovery of key relationships. At the same time, we recognize the importance of building on sound science and local knowledge. The building process itself is an invaluable opportunity for advancing our understanding of complex relationships, and building stronger relations between researchers and local communities.

References

ALLAYE CHAN-MCLEOD, A.C., WHITE, R.G., and RUSSELL, D. E. 1999. Comparative body composition strategies of breeding and non-breeding female caribou. Manuscript Accepted. Canadian Journal of Zoology.

ARCTIC RESEARCH CONSORTIUM OF THE UNITED STATES (ARCUS) 1993. Arctic system science: a plan for integration. A report of the Arctic System Science Executive Committee to the National Science Foundation. Fairbanks, Alaska. See http://www.arcus.org

ARCTIC RESEARCH CONSORTIUM OF THE UNITED STATES (ARCUS) 1997. People and the Arctic: A prospectus for research on the human dimensions of the arctic system (HARC). A science plan for the National Science Foundation Arctic System Science (ARCSS) Program. Fairbanks, Alaska.

ARCTIC RESEARCH CONSORTIUM OF THE UNITED STATES (ARCUS). 1998. Toward prediction of the arctic system: predicting future states of the arctic system on seasonal-to-century time scales by integrating observations, process research, modeling, and assessment. A science plan for the National Science Foundation Arctic System Science (ARCSS) Program. Fairbanks, Alaska.

BERMAN, M. D. 1998. Sustainability and subsistence in Arctic communities. Paper presented to the annual meeting of the Western Regional Science Association, Monterey, California, February 1998. http://www.taiga.net/sustain/lib/cites.html

BROWN, T., and BURCH, E. JR., 1992. Estimating the economic value of the subsistence harvest of wildlife in Alaska. In: Valuing wildlife in Alaska, Peterson, G., editor. Boulder, Colorado: Westview

CAMERON, R. D., and GRIFFITH, B. 1997. Detecting shifts in the distribution of calving caribou. Paper presented at the 4th Annual Conference of The Wildlife Society, Snowmass, Colorado, 22-27 September 1997. (Abstract published).

CAMERON, R.D., REED, D.J., DAU, J.R., and SMITH, W.T. 1992. Redistribution of calving caribou in response to oil field development on the arctic slope of Alaska. Arctic, 45(4):338-342.

CAMERON, R. D., SMITH, W. T., FANCY, S. G., GERHART, K. L., and WHITE R. G. 1993. Calving success of female caribou in relation to body weight. Canadian Journal of Zoology 71:480-486.

CAMERON, R. D., RUSSELL, D. E., WHITE, R. G.,. GERHART, K. L., and VERHOOF, J. 1998. A model for predicting parturition status in arctic caribou. Presented at 8th North American Caribou Workshop April 1998. Whitehorse Yukon.

COHEN, S. 1997 What if and so what in Northwest Canada: could climate change make a difference to the future of the Mackenzie Basin? Arctic 50(4):293-307.

COMMITTEE ON THE HUMAN DIMENSIONS OF GLOBAL CHANGE 1994. Science priorities for the human dimensions of global change. National Academy Press: Washington D.C.

CONSTANZA, R., and SKLAR, F H. 1985. Articulation, accuracy and effectiveness of mathematical models; a review of freshwater wetland applications." Ecological Modeling, 27:45-68.

DANIEL, C.J. 1993. Computer simulation models for the Porcupine Caribou Herd: user'sgGuide. Prepared by ESSA Ltd., Richmond Hill, Ontario for Canadian Wildlife Service, Environment Canada, Whitehorse Yukon. 17 pp.

DAVIS, M.B., and BOTKIN, D.B., 1985. Sensitivity of cool-temperate forests and their fossil pollen record to rapid temperature change. Quaternary Research 23:327-340.

DOWLATABADI, H. 1995 Integrated assessment models of climate change. Energy Policy 23(4/5):289-296.

EAMER, J. 1999. Possible futures model. http://www.taiga.net/sustain

EASTLAND, W. G. 1991. Influence of weather on movements and migration of caribou. M.S. Thesis, University of Alaska Fairbanks: 111pp.

EPSTEIN, H.E., WALKER, M.D., CHAPIN III, F.S., and STARFIELD, A.M. 2000. A transient, nutrient-based model of arctic plant community response to climatic warming. Ecological Applications 10:824-841. See also draft manuscript. http://www.taiga.net/sustain/lib/cites.html

FERGUSON, M. A. D., and MESSIER, F., 1997. Collection and analysis of traditional ecological knowledge about a population of arctic caribou. Arctic 50(1): 17-28.

FORRESTER, J. 1971. Principles of systems. Wright-Allen Press, Cambridge, MA. 178pp.

GERHART, K. L., WHITE, R. G., CAMERON, R. D., RUSSELL, D. E., and VAN DE WETERING, D. 1997a. Pregnancy rate as an indicator of nutritional status in Rangifer: implications of lactational infertility. Rangifer 17 (1). 21-24.

GERHART, K. L., RUSSELL, D. E., VAN DE WETERING, D., WHITE, R. G., and CAMERON, R. D. 1997b. Pregnancy of adult female caribou (Rangifer tarandus): evidence for lactational infertility. Journal of Zoology (London). 242:17-30.

GRIFFITH, B. 1997a. Implications of a greener north for Arctic caribou. Invited Paper, Yukon North Slope, Wildlife Management Advisory Council, Long Term Research Planning Workshop. Dawson City, Yukon. 3 October 1997.

GRIFFITH, B. 1999a. "Effects of recent climate warming on caribou habitat and calf survival." Invited Paper, Workshop on Biota and Climate Change, Ecological Society America Annual Meeting, Spokane, WA. 11 August 1999 http://www.taiga.net/sustain/lib/cites.html

GRIFFITH, B. 1999b. Habitat and foraging ecology of the Bathurst caribou herd on their calving grounds. West Kitikmeot Slave Study Society, Investigators Meeting, 14 April 1999, Yellowknife, NT, Canada.

GRIFFITH, B. 1999c. The need for herd specific predictive models that integrate effects of climate and development on caribou as a subsistence resource for Arctic communities. Invited Plenary Lecture, Workshop on Human Role in Caribou/Reindeer Systems, Sponsored by International Arctic Science Comm., Rovaniemi, Finland, 10-14 February, 1999.

GRIFFITH, B. 1999d. Integrating the effects of climate and development on a subsistence resource for Arctic communities. President's Seminar, Institute of Arctic Biology, Univ. Alaska Fairbanks, 29 January 1999.

GRIFFITH, B., and CAMERON, R. D. 1998. Shifts in the distribution of calving caribou: developing a model for assessing the impacts of development. Poster presented at: (1) Annual Conference, Alaska Chapter of The Wildlife Society, Girdwood, Alaska. 16 January 1998; and, (2). 8TH North American Caribou Workshop, YT, 21-25 April 1998.

GRIFFITH, B., and RUSSELL, D. E. 1999. Herd-specific predictive models that integrate effects of climate and development on caribou as a subsistence resource for Arctic communities. Poster presented at 10th Arctic Ungulate Conference, Tromso, Norway. 9-12 August 1999.

GRIFFITH, B., DOUGLAS, D. C., RUSSELL, D. E., WHITE, R. G., MCCABE, T. R., and WHITTEN, K. R. (submitted). "Implications of a greener north for an Arctic herbivore." Submitted to Global Change Biology.

GRIFFITH, B., DOUGLAS, D. C., RUSSELL, D. E., WHITE, R. G., MCCABE, T. R., and WHITTEN, K. R. 1997a. Implications of a greener north for an Arctic herbivore. Seminar Series, Inst. Arctic Biol., Univ. Alaska, Fairbanks. 7 November 1997.

GRIFFITH, B., WHITE, R. G., CAMERON, R. D., RUSSELL, D. E., and MCCABE, T. R. 1998a. A methodology for predicting effects of displacement on caribou populations: integrating behavior, habitat value, and population dynamics. Paper presented at the 8th North American Caribou Workshop, YT, 21-25 April 1998.

GRIFFITH, B., DOUGLAS, D. C., RUSSELL, D. E., WHITE, R. G., MCCABE, T. R., and WHITTEN, K. R. 1998b. Effects of recent climate warming on caribou habitat and calf survival: implications for management. Poster presented at Annual Conference, Alaska Chapter of The Wildlife Society, Girdwood, Alaska. 16 January 1998

GRIFFITH, B., DOUGLAS, D. C., RUSSELL, D. E., WHITE, R. G., MCCABE, T. R., WHITTEN, K. R. 1998c. Effects of recent warming on caribou habitat and calf survival. Presented at 8th North American Caribou Workshop April 1998. Whitehorse Yukon.

HALPERIN, R. H. 1994. Cultural economies past and present. Austin: University of Texas Press, 1994.

HAMILTON, L., and SEYFRIT, C. 1994. Coming out of the country: community size and gender balance among Alaskan natives. Arctic Anthropology 31(1), 16-25.

HANLEY, T., and RUSSELL, D.E., 1998. Ecological impacts of hunting and its effects on co-management on the Porcupine Caribou Herd. Presented at 8th North American Caribou Workshop April 1998. Whitehorse Yukon.

HOVEY, F.W., KREMSATER, L.L., WHITE, R.G., RUSSELL, D.E., and BUNNELL, F.L. 1989. Computer simulation models of the Porcupine Caribou Herd: II. Growth. Technical Report #54, Canadian Wildlife Service, Pacific and Yukon Region, B.C.

HUNTINGTON, H. P., 1998. Observations on the utility of the semi-directive interview for documenting traditional ecological knowledge. Arctic 51(3): 237-242.

HUSKEY, L. 1998. Leaving Home: Transfers, Public Goods, and Migration from Arctic Villages. Paper presented to the annual meeting of the Western Regional Science Association, Monterey, California, February 1998.

HUSKEY, L., HILL, A., and BERMAN, M. 1999. Potential Earnings, Labor Force Participation, and Migration for Alaska Natives from the 1990 U.S. Census Public Use Microdata Sample. Unpublished manuscript, Institute of Social And Economic Research, University of Alaska, 3211 Providence Drive, Anchorage, Alaska, 99508. April 1999.

INNIS, G.S., 1978. Editor. Grassland Simulation Model, Ecological Studies, 26, Springer-Verlag, New York. 298 pp.

JOHNSTONE, J., RUSSELL, D. E., and GRIFFITH, B. 1999. Modeling caribou response to seasonal and long-term changes in vegetation: II. Estimating seasonal changes in forage quality. Poster presented at 10th Arctic Ungulate Conference, Tromso, Norway. 9-12 August 1999.

KANE, D., REEBURGH, W. ET AL. 1998. ARCSS/LAII Flux Study. Journal of Geophysical Research 103(D22):28,913-29,106. Collection of 18 articles. American Geophysical Union.

KIRKVLIET, J., and NEBESKY, W., 1997. Whaling and Wages on Alaska's North Slope: A Time Allocation Approach to Natural Resource Use. Economic Development and Cultural Change 46, 651- 665.

KOFINAS, G.P., 1996. Policy on Information Sharing and Dissemination. http://www.taiga.net/sustain/lib/cites.html

KOFINAS, G. P. 1998. The Cost of Power Sharing: Community Involvement in Canadian Porcupine Caribou Co-management. Ph.D. dissertation, Faculty of Graduate Studies. Vancouver, University of British Columbia: 471pp.

KOFINAS, G., and BRAUND, S.R. 1996. Defining Community Sustainability: A Report from Community Involvement, Phase 1 of the NSF Community Sustainability Project. See http://www.taiga.net/sustain/lib/cites.html

KOFINAS, G., and BRAUND, S.R. 1998. Local Caribou Availability: A Report from Community Involvement, Phase 1 of the NSF Community Sustainability Project. See http://www.taiga.net/sustain/lib/cites.html

KOFINAS, G.R., TETLICHI, J., TETLICHI, G.,AREY, C., PETERSON, D., and NERSHOO, M. 1997. Community-Based Ecological Monitoring: A summary of 1996-97 Observations & Pilot Project Evaluation. Whitehorse, North Yukon Ecological Knowledge Co-Operative: 29pp. http://www.taiga.net/sustain/lib/cites.html

KREMSATER, L.L. 1991. Brief description of computer simulation models of the Porcupine Caribou Herd. In Butler, C.E. and Mahoney, S.T. (editors). Proceedings of the 4th North American Caribou Workshop, St Johns, Newfoundland, p. 299-314.

KREMSATER, L.L., HOVEY, F.W., RUSSELL, D.E., WHITE, R.G., BUNNELL, F.L., and MARTIN, A.M. 1989. Computer Simulations of the Porcupine Caribou Herd: 1. Energy. Technical Report Series No. 53. Canadian Wildlife Service, Pacific and Yukon Region, British Columbia.

KRUSE, J. A., 1991. Alaska Iñupiat subsistence and wage employment patterns: understanding individual choice. Human Organization 50, 317-26.

KRUSE, J.A., WHITE, R.G. 1995 Sustainability of Arctic Communities: Interactions Between Global Changes, Public Policies, and Ecological Processes. Proposal, NSF OPP-9521459. See http://www.iser.uaa.alaska.edu/projects/

OFFICE OF POLAR PROGRAMS, NATIONAL SCIENCE FOUNDATION 1991. Land/Atmosphere/Ice Interactions: Science Plan. Arctic System Science. 23p.

LUICK, B.R., and WHITE, R.G. 1995. Computer simulation models for jet aircraft disturbance of free ranging caribou. Final Technical Report AL/OE/MN-1994-001 U.S. Air Force, 48pp.

MARTIN, S., HALEY, S., EAMER, J., 1999. Baseline oil development and tourism scenarios. http://www.taiga.net/sustain/lib/cites.html

MAXWELL, B. 1992. Arctic climate: potential for change under global warming. Pages 11-34 in Chapin, F.S. III, Jefferies, R.L., Reynolds, J.F., Shaver, G.R., Svoboda, J., and Chu, E.W. editors. Arctic ecosystems in a changing climate: an ecophysiological perspective. Academic Press, Inc. San Diego, CA.

MEADOWS, D.H., MEADOWS, D.L., RANDERS, J., and BEHREMS, W.W., 1974. Limits to growth. Universe Books, NY. 205pp

MORGAN, M. G., and DOWLATABADI, H. 1996 Learning from integrated assessment of climate change. Climatic Change 34:337-368.

MURPHY S., and GRIFFITH, B. 1999. Effects of oil development on caribou energetics. Presentation at Whitehorse community meeting. http://www.taiga.net/sustain/lib/cites.html

MURPHY, S., RUSSELL, D. E., and WHITE, R. G., 1998. Modeling energetic and demographic consequences of caribou interactions with oil development in the Arctic. Presented at 8th North American Caribou Workshop April 1998. Whitehorse Yukon.

NICOLSON, C., 1999a. Overview of the synthesis model. http://www.taiga.net/sustain/lib/cites.html

NICOLSON, C., 1999b. Overview of caribou components in the synthesis model. http://www.taiga.net/sustain/lib/cites.html

PARSON, E. 1995 Integrated assessment and environmental policy making. Energy Policy 23(4/5):463-475.

POLANYI, K., 1944. The great transformation. New York: Holt, Rinehart and Winston.

POLANYI, K., 1957. The economy as instituted process. In: Trade and market in the early empires. Polanyi, K., Arensberg, C., and Pearson, H.W., eds, 243-270. New York: The Free Press.

QUIGLEY, N.C., and MCBRIDE, N.J., 1987. The structure of an Arctic microeconomy. Arctic 40(3), September 1987.

RISBEY, J., KANDILIKAR, M., and PATWARDHAN, A. 1996 Assessing integrated assessments. Climatic Change 34:369-395.

ROBINSON, A. D. J. B., Ed. 1996. Achieving sustainable development. Vancouver, UBC Press.

ROTMANS, J., VAN ASSELT, M., 1996 Integrated assessment: a growing child on its way to maturity. Climatic Change 34:327-336

ROWNTREE, P.R. 1997. Global and regional patterns of climate change: recent predictions for the Arctic. Pages 82-112. In: Oechel, W.C., Callaghan, T., Gilmanov, T., Holten, J.I., Maxwell, B., Molau, U., and Sveinbjörnsson, B., editors. Global change and arctic terrestrial ecosystems. Springer-Verlag New York, NY.

RUPP, T.S., A.M. STARFIELD, AND F.S. CHAPIN, III. 2000a. A frame-based spatially explicit model of subarctic vegetation response to climatic change: comparison with a point model. Landscape Ecology 15:383-400.

RUPP, T.S., CHAPIN III, F.S., and STARFIELD, A.M. 2000b (in press). Modeling the influence of topographic barriers on treeline advance at the forest-tundra ecotone in northwestern Alaska. Climatic Change.

RUPP, T.S., CHAPIN III, F.S., and STARFIELD, A.M. 2000c (in press). Response of subarctic vegetation to transient climatic change on the Seward Peninsula in northwest Alaska. Global Change Biology

RUSSELL, D.E. 1991. "The Porcupine caribou model – real life scenarios." In Butler, C.E. and Mahoney, S.T. (editors). Proceedings of the 4th North American Caribou Workshop, St Johns, Newfoundland, p. 316-334.

RUSSELL, D. E. (1999). Research status and priorities for North American migratory caribou. Invited Plenary Lecture, Workshop on human role in caribou/reindeer systems. Sponsored by Internat. Arctic Science Comm., Rovaniemi, Finland, 10-14 February, 1999

RUSSELL, D. E., and GRIFFITH, B. 1995. The Porcupine Caribou Herd: a comprehensive study of ecosystem-level relationships. Invited Plenary Lecture, Second International Arctic Ungulate Conference, University of Alaska, Fairbanks, 13-17 August 1995.

RUSSELL, D. E., and WHITE, R.G. 1998. Surviving in the north - a conceptual model of reproductive strategies in arctic caribou. Presented at 8th North American Caribou Workshop April 1998. Whitehorse, Yukon.

RUSSELL, D. E. GERHART, K.L., WHITE, R.G., and VAN DE WETERING, D. (In Prep.) Maternal investment of arctic caribou: the relative roles of fat and protein. Ecology

RUSSELL, D.E., WHITTEN, K., FARNELL, R., and VAN DE WETERING, D. 1992. Movements and Distribution of the Porcupine Caribou Herd, 1970-1990. Canadian Wildlife Service, Pacific and Yukon Region, British Columbia.

RUSSELL, D.E., MARTELL, A., and NIXON, W. 1993. The Range Ecology of the Porcupine Caribou Herd in Canada. Rangifer*,* Special Issue No. 6: 168.

RUSSELL, D. E., CAMERON, R. D., WHITE, R. G., and GERHART, K. L. 1998a. Mechanisms for summer weight gain in arctic caribou. Presented at 8th North American Caribou Workshop, April 1998. Whitehorse, Yukon.

RUSSELL, D. E., GERHART, K. L., and WHITE, R. G. 1998b. Detection of early pregnancy in caribou: evidence for embryonic mortality. Journal of Wildlife Management 62(3): 1066-1075.

RUSSELL, D. E., WHITE, R. G., and DANIEL, C. 1999. Caribou simulation models of the Porcupine Caribou Herd. I. ENERGETICS. Draft manuscript. 58 pp. http://www.taiga.net/sustain/lib/cites.html

SAHLINS, M. 1972. Stone age economics. Chicago: Aldine.

SERREZE, M., WALSH, J., CHAPIN III, F.S., OSTERKAMP, T., DYURGEROV, M., ROMANOVSKY, V., OECHEL, W., MORISON, J., ZHANG, T., BARRY, B. (in press). Observational evidence of recent change in the northern high-latitude environment. Climatic Change.

SCHIMEL, J.P., KIELLAND, K., and, CHAPIN III, F.S., 1996. Nutrient availability and uptake by tundra plants. In: Reynolds, J.F., and Tenhunen, J.D., editors, Landscape function and disturbance in arctic tundra. Springer-Verlag, Berlin.

SHAVER, G.R., and CHAPIN III, F.S., 1995. Long-term responses to factorial NPK fertilizer treatments by Alaskan wet and moist tundra species. Ecography 18:259-275.

SHAVER, G.R., BILLINGS, W.D., CHAPIN III, F.S., GIBLIN, A.E., NADELHOFFER, K.J., OECHEL, W.C., and RASTETTER, E.B., 1992. Global change and the carbon balance of arctic ecosystems. BioScience 42:433-441.

STABLER, J. 1990. A Utility Analysis of Activity Patterns of Native Males in the Northwest Territories. Economic Development and Cultural Change 39: 47-60.

STARFIELD, A.M. AND BLELOCH, A.L. 1991. Building Models for Conservation and Wildlife Management, 2nd ed. The Burgess Press, Edina MN.

STARFIELD, A.M., and CHAPIN, III, F.S. 1996. A dynamic model of arctic and boreal vegetation change in response to global changes in climate and land-use. Ecological Applications 6:842-864.

STARFIELD, A.M., CUMMING, D.H.M., TAYLOR, R.D. AND QUADLING, M.S. 1993. A frame-based paradigm for dynamic ecosystem models. A I Applications 7(2&3): 1-13.

STARFIELD, A.M. 1990. Qualitative, rule-based modeling. Bioscience, 40(8): 601-604.

STARFIELD, A.M., FARM, B.P., and TAYLOR, R.H. 1989. A rule-based ecological model for the management of an estuarine lake. Ecological Modeling 46:107-119.

TUSSING, A. 1999. Scenario structure and rationale: petroleum development in the eastern Alaska Arctic in and around ANWR Coastal Plain. http://www.taiga.net/sustain/lib/cites.html

TKWG 1991. Traditional knowledge working group. Report of the traditional knowledge working group. Government of the Northwest Territories: 116.

USGS (1998). Arctic National Wildlife Refuge, 1002 Area, Petroleum Assessment, 1998. U.S. Geological Survey Factsheet FS040098. Denver, Colorado.

TUSSING, A., and HALEY, S., 1999. Drainage Pierces ANWR in Study Scenario, Oil and Gas Journal, July 5.

VANSTONE, J. 1960. A successful combination of subsistence and wage economies on the village level. Economic Development and Cultural Change 8: 174-91.

WEIN, E. E., and FREEMAN, M. R. 1992. Inuvialuit food use and food preferences in Aklavik, Northwest Territories, Canada. Arctic Medical Science, Canadian Circumpolar Institute, The University of Alberta. 51: 159-172.

WEIN, E. E., and FREEMAN, M. R. 1995. Frequency of traditional food use by three Yukon First Nations living in four communities. Arctic 48(2): 161-171.

WHITE, R.G. 1983. Foraging patterns and their multiplier effects on productivity of northern ungulates. Oikos 40:377-384.

WHITE, R.G. 1991. Validation and sensitivity analysis of the Porcupine Caribou Herd model. In Butler, C.E. and Mahoney, S.T. (eds). Proceedings of the 4th North American Caribou Workshop, St Johns, Newfoundland, p. 334-356.

WHITE, R. G., JOHNSTONE, J., RUSSELL, D. E., GRIFFITH, B., EPSTEIN, H., WALKER, M., CHAPIN III, F. S., and NICOLSON, C. 1999. Modeling caribou response to seasonal and long-term changes in vegetation: I. Development of an algorithm to generate diet from vegetation composition and application to projections of climate change. Poster presented at 10th Arctic Ungulate Conference, Tromso, Norway. 9-12 August 1999.

WOLFE, R. J., GROSS. J. J., LANGDON, S. J., WRIGHT, J. M., SHERROD, G. K., ELLANNA, L. J., SUMIDA, V., and USHER, P. J. 1984. Subsistence-based economies in coastal communities of Southwest Alaska. ADF&G Division of Subsistence Technical Paper No. 89.

WOLFE, S.A., GRIFFITH, B., CAMERON, R. D., WHITE, R. G., and MURPHY, S.M. 1998. Habitat selection by calving caribou of the Central Arctic herd. Poster presented at the 8th North American Caribou Workshop, Yukon Territory, 21-25 April 1998.

YOUNG, O.R. 1999. Is ANS oil economically recoverable? policy assumptions of the petroleum development scenarios. Draft. http://www.taiga.net/sustain/lib/cites.html