

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

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Abstract
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Just under four years ago, 23 researchers representing 8 natural and social science disciplines set out to examine how the combined effects of climate change, oil development, tourism, and government cutbacks might change the sustainability of Arctic villages in the range of the Porcupine Caribou Herd. In so doing, we stepped into the world of integrated assessment. We have been working with four communities: Aklavik, Fort McPherson, Old Crow, and Arctic Village. We have worked together to incorporate research and local knowledge-based understanding in a common tool - a synthesis model - to examine the sensitivity of relationships and assess levels of uncertainty. We are discussing with our partner communities possible futures, local policies, and the limitations of science and local knowledge to predict the future. Along the way, we have contributed to our disciplines by modeling vegetation changes, caribou population dynamics, local labor markets, mixed subsistence and cash economies, and oil field-caribou interactions.

In many respects, we believe that the Sustainability Project is a model for a regional integrated assessment (IA). We attempted to build on solid, disciplinary science, and to develop simple, reduced-form models that focus on only the relationships important to the finite set of questions we undertook to examine. We worked with stakeholder groups directly to ensure the relevance of study questions, and we combined science and local knowledge. We focused on the value of assessments as a springboard for understanding alternative futures rather than trying to predict the future. While most IA's focus solely on climate change, we examine the effects of climate change in the context of other global changes that are important to Arctic residents. And, while most IA's focus on national and international abatement policies, we are researching local and regional policy options to mediate the effects of climate change and shape the impacts of other global changes to benefit Arctic residents. Our scale of analysis also allows us to explore ways to represent values in parametric terms without reducing them all to dollar terms. The high degree of interaction between disciplines and between researchers and community members provides a great incentive to work on developing ways to make relationships in our models more obvious. We can advance IA methods while addressing some of the most important issues facing Arctic communities.

While we think that aspects of the Sustainability Project can serve as a model for integrated assessments, we also think that the lessons learned during the course of the project may be as valuable as its successes. We organized the project by discipline, and later learned that the most important relationships within a discipline are not necessarily the most important when integrating across disciplines. We constructed a synthesis model at the beginning of the project to promote integration, but found that researchers did not use the model because it was written with unfamiliar software. We were committed to focusing much of the project on discussions with communities rather than model building, but found ourselves working into the fourth year on modeling tasks. In this paper we report our successes and the lessons learned. We conclude that integrated assessment is an effective tool for promoting learning among researchers of different disciplines and between researchers and communities. IA is also useful for identifying major uncertainties and associated research needs.

For additional materials regarding this study, please visit our project website at:
<http://www.taiga.net/sustain> .

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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, we decided to focus our core research on the combined effects of future climate change and oil development on barren ground caribou (*Rangifer tarandus granti*) and on Native people who 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. It is an important lesson for integrated assessments.

In the winter of 1994-95, NSF issued an announcement of opportunity for research on the Human Dimensions of Global Change. We decided that we should apply our collective thinking to a proposal. Our first step was to invite the Inupiat 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 Native people collaborate. Fortunately, four Native communities - Old Crow, Arctic Village, Aklavik, and Fort McPherson - later joined the project.

We submitted a proposal without the NSB. NSF awarded us a four year grant, "Sustainability of Arctic Communities: Interactions Between Global Changes, Public Policies, and Ecological Processes" (OPP-9521459, Kruse and White 1995). Our original project team consisted of 23 researchers representing eight natural and social science disciplines and nine research institutions.

The purpose of this paper is to report on both the process and outcomes of the project. 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.

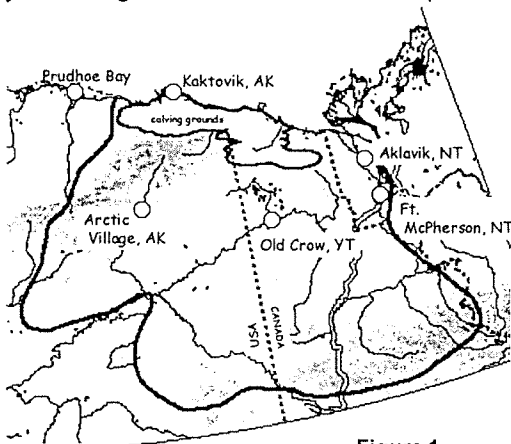


Figure 1

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. We therefore invited communities that are the primary users of the PCH to become study partners. Figure 1 to the left 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 we had not anticipated such a collaboration 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 20 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 have focused 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 impacts 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 are examining 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 are targeting local to multi-regional policy choices (e.g., types of tourism encouraged; extent of petroleum development; and 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. We started by asking communities to explicitly define community goals - the dimensions of sustainability for their community. We sought community advice on how to represent these values 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 three geographic 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; and, (3) a single community. To date, we have modeled the community of Old Crow, Yukon Territories. These scales permit us to represent all relationships in a single SYNTHESIS MODEL developed in an environment (Excel) familiar to the entire research team. This in turn 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 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 global warming, 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. We should not presume, however, that our community partners share these assumptions. To be credible, our IA has 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 expert, 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 realities of decisionmaking in science. In this case, we were choosing 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 (LAI 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 global warming on the availability of caribou to communities through the more direct effects of global warming on vegetation.

In 1994, Natives 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. We believed that the best way to address their 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 not come without 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 them¹.

Petroleum development is probably the most-debated issue concerning the U.S. and Western Canadian Arctic². Concerns about the potential effects of oil development on the Porcupine Caribou Herd were the motivation for sustained caribou research programs by the U.S. and Canada. We therefore decided to include petroleum development as a major force for change. 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 backburner³. We also worried that NSF would see petroleum development as too politically charged an issue for research. Our concern proved to be unfounded.

The third force for change addressed in our project, tourism. We subsequently found that our each of our four partner communities are keenly interested in the potential of tourism to provide a compatible economic base for sustaining their communities.

¹ 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 have submitted a proposal to NSF for a second phase that will include a major marine component in collaboration with the North Slope Borough.

² For background on the debate, see <http://borealis.lib.uconn.edu/ArcticCircle/ANWR/anwrdebate.html>

³ 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, two Iñupiat residents of Kaktovik participated in a community review of the project in April. Mayor Sonsalla of Kaktovik has invited us to come to Kaktovik to discuss the project. We hope Kaktovik will rejoin the project if it is funded for a second phase.

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 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. 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 Native people to science planning committees, and supporting research on human dimensions of the Arctic system (ARCUS 1997). NSF does not currently have a process that funds researcher-community proposal negotiations, although 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.

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. Forty years appears to be at the outer limit of community policy interest. 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 caribou⁴. 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

We entered the project having decided to focus on climate change, oil development, tourism, and government cutbacks as forces for change. We also knew that we wanted to simulate future conditions under different combinations of these forces for change. To do this, we had to describe each force for change in terms of attributes important to model relationships.

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 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 intraseasonal and interseasonal 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.

⁴ 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).

We constructed five oil development scenarios based on an analysis of USGS assessments of oil potential in the 1002 Area⁵ of the Arctic National Wildlife Refuge (ANWR) and changing worldwide petroleum markets (Tussing and Haley 1999:www). The scenarios, ranging from subsurface drainage of oil on the boundary with no surface activity in 1002, to development throughout the entire 1002 Area, span the range of assumptions made by ANWR 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. The only community likely to experience employment effects, Kaktovik, dropped out as a partner community. To date, we have therefore not modeled the effects of oil development on employment, focusing exclusively on effects on caribou and availability of caribou to communities.

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. The most important point to keep in mind is that we are examining relationships between oil development and caribou, not conducting an impact assessment of ANWR oil development. We hope that our work can inform an impact assessment, but it should not be seen as drawing conclusions.

When we recently reviewed these scenarios with our community partners, however, one community asked us to remove all the oil development scenarios from our analysis. Working through this issue crystallized 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." Our four community partners met alone to try to reach a consensus. They recommended that we drop the oil scenarios from our analysis. We met as a combined group to discuss the implications of such a change, and we reviewed the process we had followed to date that included an oil development analysis and multiple scenarios. We ultimately decided that for the near term we would include just one scenario - displacement of herd concentrations from the entire coastal plain and 1002 Area. Inclusion of this scenario allows us to present the analysis methods used in all the scenarios and allows us to discuss the principal relationships analyzed.

Our partner communities were keenly interested in a more detailed look at alternative tourism scenarios. We 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-tourism"; (3) the addition of a road to the community to small scale eco-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 and Haley 1999:www; Young 1998:www). We consider the decision of whether or not to have a permanent road connecting ANWR development to the Alaska highway network to be a regional policy decision. We envision all the tourism scenarios as results of community 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. In a real sense, the communities became clients. They decide if the project is relevant to their concerns.

⁵ The term 1002 refers to Section 1002 of the 1980 Alaska National Interest Lands Conservation Act. Federal law currently prohibits exploration, development, or production of hydrocarbons in the Area, which encompasses the ANWR coastal plain and calving grounds for the PCH.

This raises the question of "Who is the community?" We 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 we envision the goal of the project is to help communities make informed policy choices, we decided that we would work with the formal institutions most likely to make - or attempt to influence - policy choices relevant to forces for change in this study. We therefore worked with village natural resource committees⁶.

Working with small groups of village residents suggested by the natural resource committees, we asked communities in the first year of the project to define "sustainability". We expected to get unique definitions from each community. We found that we could represent all definitions in terms of 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, (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).

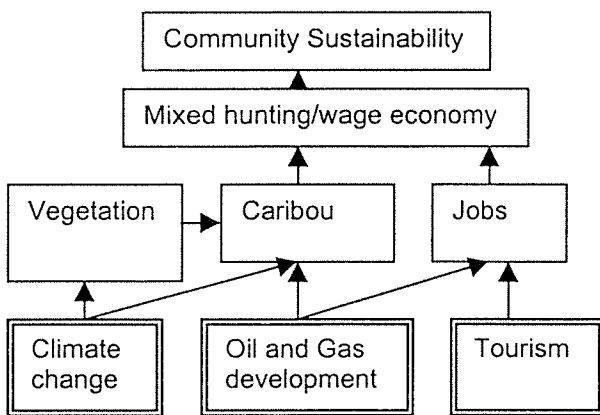
Identifying Major Relationships

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. We started our discussions two years before the funding opportunity. After deciding to focus on vegetation-caribou-community relationships, we obtained approval from the U.S. MAB Committee to advertise position descriptions for additional HLED members with expertise in Native hunting, modeling, and caribou ecology. We had completed this recruitment process when the funding opportunity arose, so our project 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.

The make-up of the project team has a great deal to do with the choice of major relationships to be studied. 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.

Figure 2: Principal Study Relationships



Our 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.

⁶ The specific institutions vary by village. In the case of Alavik and Fort McPherson there are both Inuvialuit and Metis land claims groups and associated natural resource committees.

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).

The grouping of disciplinary expertise by participating institution 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 hope to test them in a 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 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). However, the challenge of effectively modeling transient dynamics (changes over a period of decades) at a regional scale is still largely unanswered (Shugart et al. 1992).

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.

We were 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. Our intent in developing a prototype model was to promote integration of the project components. We distributed the model to the project team along with a guide for its use.

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 exercise 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

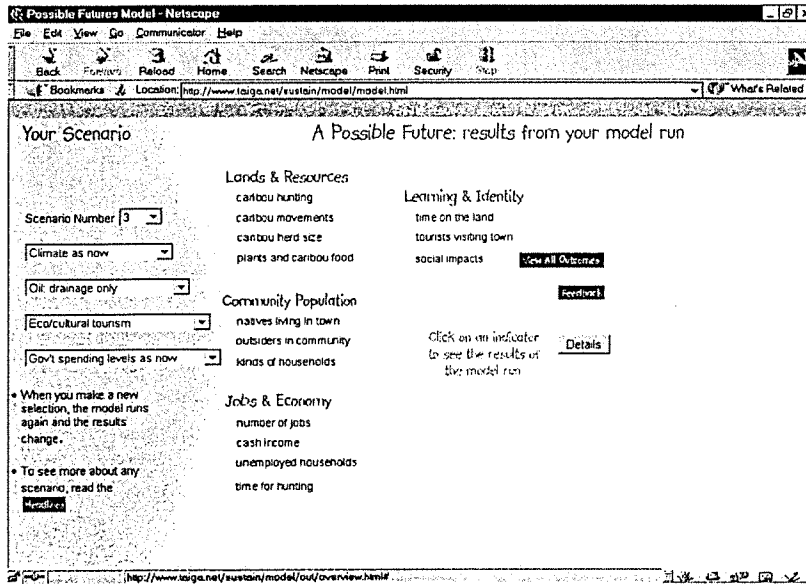
assessment, we certainly would argue that the discipline of modeling should be established at the very beginning of the project with the understanding and expectation that the model would evolve.

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)⁷. 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 1999: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).

⁷ The model is available to researchers on CD-Rom. To request a copy, email Jack Kruse at afjak@uaa.alaska.edu



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 platforms⁸. Our intent is to encourage model users to exchange their reactions and ideas with the researchers. 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.

We end our synthesis discussion by noting that we did not budget for enough face-to-face contact among members of the research team. 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.

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. 1998:www). 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,

⁸ 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.

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, Kramsater et al. 1989, Kramsater 1991, Russell 1991, White 1991, 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. 1999a) and to more closely link body condition to reproductive performance (Russell and White 1998, Gerhart et al. 1997c, 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).

We completely changed 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. 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 are consistent with the hypothesis that calving cows avoid the oilfield for a 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 a 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 analysis 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 assumptions 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 hunting participation and subsistence 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 our SYNTHESIS MODEL to be grounded on local knowledge as well as science-based research. Native 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). 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 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 communities. 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 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, 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 model variables, parameters and our development of scenarios.

We asked a few community representatives to attend the annual project meetings. The researchers vastly outnumbered the community representatives in the first two annual meetings. We constrained researcher participation in the third and fourth years for budgetary reasons, and we came to realize the benefits of increased participation by community representatives. In our most recent three-day meeting, we asked a dozen participating community representatives to meet separately one morning to review the project and to recommend changes. To our delight, they had assembled some 15 pages of newsprint containing constructive criticisms and recommendations. We also came to realize that direct contact between researchers and community representatives beyond Kofinas and Braund led to significant insights and changed perceptions by others on the research team. 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.

We should note that academic incentives tend to reward disciplinary advances, not interdisciplinary work. We recognized this in the project and have tried to counter traditional incentives by devoting project time to identifying and writing multidisciplinary articles. The situation is far from ideal, however, and the lack of incentives for multidisciplinary collaboration deserves attention.

Simulation Results

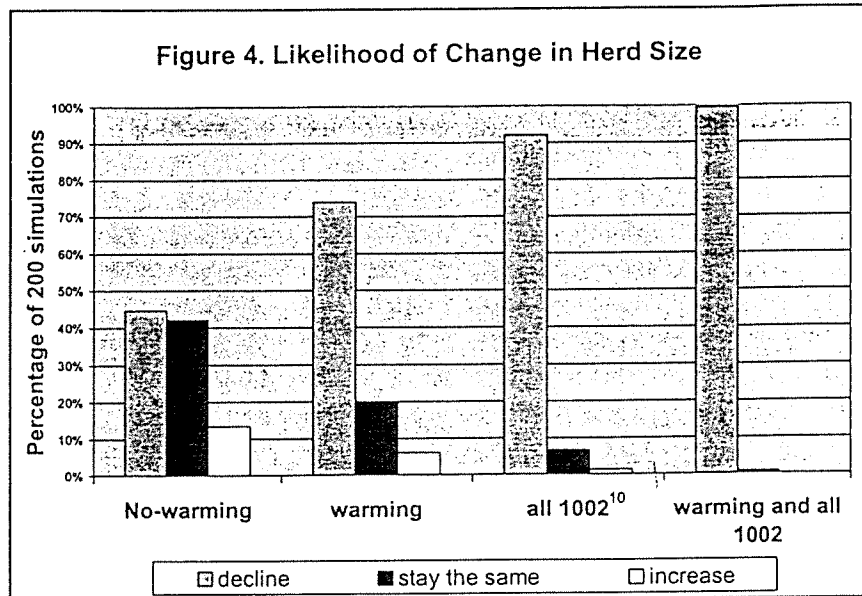
Herd Population - Caribou continues to be an important food source for communities in the range of the PCH. More than 20 years of research has shown that northern people choose to continue to harvest and consume substantial local resources despite an increasing importance of a cash economy (Kruse 1991). Caribou also has a cultural importance beyond its food value. People share resources to hunt, they hunt together, and they share harvests. Children learn cultural values by observing and participating in harvesting and processing activities. Perceived threats to the continued presence of caribou and to the integrity of the environment they occupy are taken very seriously by Native people in the range of the PCH. They have organized politically to influence national policies about oil development in ANWR⁹.

Changes in the size of the Porcupine Caribou Herd are therefore of great interest to Native people living in the range of the PCH. 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

⁹ See <http://borealis.lib.uconn.edu/ArcticCircle/ANWR/asrcadams.htm> 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.htm> regarding the Porcupine Caribou Management Board.

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 (above) compares the percentage chance that the PCH will show a decline over 40 years with and without climate warming.

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. We certainly need to consider the possibility that climate warming could raise the probability that the PCH will increase.

Figure 4 (above) also compares the percentage chance that the PCH will show a decline over 40 years based on 200 replicates of two scenarios in which concentrations of cows and calves avoid the entire 1002 area of ANWR during a two week period in June. The first scenario shows the effect of displacing herd concentrations from the entire 1002 area.¹⁰ The second scenario combines the effects of displacement with the effects of climate warming. Warming would tend to offset development effects if we assumed no increase in deep snow years or high insect harassment years.

¹⁰ This scenario displaces caribou beyond the outer perimeter of our analytically derived area of maximum oil development. (Tussing and Haley 1999, www)

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 its 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.

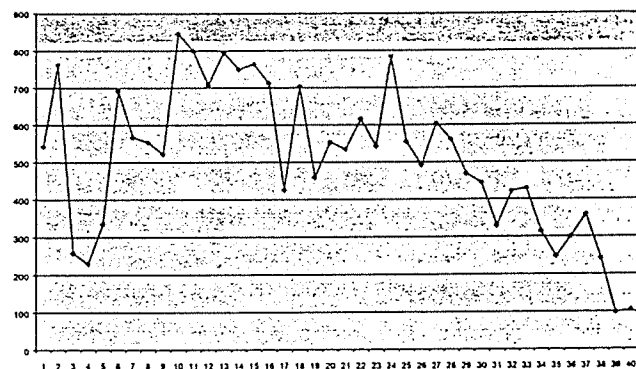
We are modeling the community of Old Crow where fall is the primary hunting season. While hunters try to make-up for poor fall hunting with winter and spring hunts, we can get an idea of changes in caribou availability over time by counting the number of falls in which hunters see only a few caribou.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

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.

Suppose herd concentrations were displaced from the entire 1002 area? Since we don't think oil development in ANWR will increase job opportunities for Old Crow residents, the time and money available for hunting is about the same with and without oil development.

At what combination of climate warming and oil development would we probably see major shortfalls in caribou harvested? Under most simulations, producing a decline in community harvests would take climate warming coupled with a form of oil development that displaces concentrations of cows and calves from all of the coastal plain during the two-week period they tend to avoid oil development activity. Figure 5 illustrates a typical simulation under these conditions.

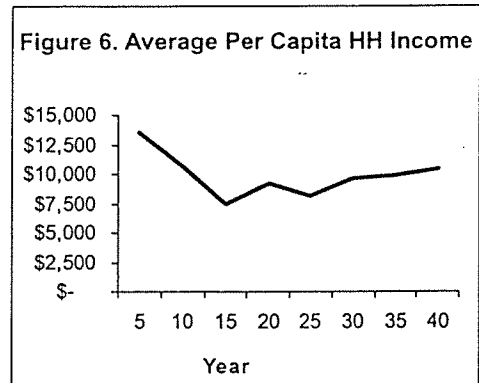
Figure 5. Total Harvest by Community Under Climate Warming and Displacement from All of 1002



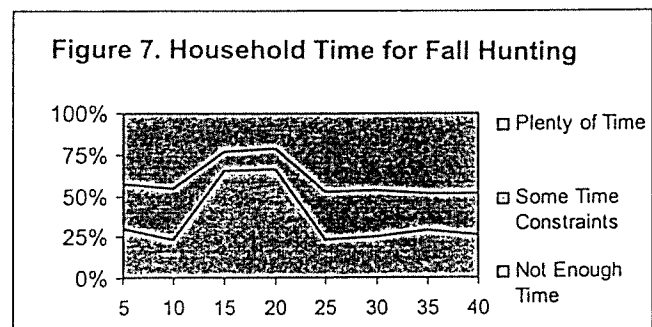
As we will see below, tourism development - particularly with the construction of roads to communities - tends to increase community populations and associated harvest pressure on the herd. When modeled in combination with oil development, this increases the likelihood of harvest shortfall. These simulations do not assume any self-regulation of harvest when the herd declines.

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-tourism" scenario to include combinations of enterprises (e.g. outfitters, lodges, gift shops) based on the experiences of other communities and local knowledge in Old Crow (Martin et al. www). 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 a policy of eco-tourism development, we think that one-in-three adults would be unemployed in 2040 compared with over half of all adults 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 would increase - both in absolute numbers and as a proportion of all households in Old Crow.



Our first eco-tourism scenario assumes that Old Crow will remain off the Yukon road net. If we assume that in addition to eco-tourism Old Crow decides to build a 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. 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 7). The reason the decreased time for hunting for some households does not cause the overall community harvest to decline is that these households are able to use wage income to help other households with 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-tourism would probably not offset 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.

Both we and our partner communities want to build on our investment in working together on issues of common concern. We would like to test our new understanding of the importance of iterative modeling in the identification of key relationships. We are proposing to 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 want to explore how policies can shape simulation outcomes. We are particularly interested in how regional policies can be used to more widely distribute employment 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, not just repeating. We would like to test the hypothesis that placing the synthesis component in a position of authority in the project, and using modeling in a more iterative process would be more efficient and increase 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. As a result our future research efforts should be better targeted and more relevant.

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