Resilience of Athabascan subsistence systems to interior Alaska's changing climate [1]

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Abstract: Subsistence harvesting and wild food production by Athabascan peoples is part of an integrated social-ecological system of interior Alaska. We describe effects of recent trends and future climate change projections on the boreal ecosystem of interior Alaska and relate changes in ecosystem services to Athabascan subsistence. We focus primarily on moose, a keystone terrestrial subsistence resource of villages in that region. Although recent climate change has affected the boreal forest, moose, and Athabascan moose harvesting, a high dependence by village households on moose persists. An historical account of 20th century socioeconomic changes demonstrates that the vulnerability of Athabascan subsistence systems to climatic change has in some respects increased while at the same time has improved aspects of village resilience. In the face of future climate and socioeconomic changes, communities have limited but potentially effective mitigation and adaptation opportunities. The extent to which residents can realize those opportunities depends on the responsiveness of formal and informal institutions to local needs. For example, increases in Alaska's urban population coupled with climate-induced habitat shifts may increase hunting conflicts in low-moose years. This problem could be mitigated through adaptive co-management strategies that project future moose densities and redirect urban hunters to areas of lower conflict.

Résumé : La récolte de subsistance et la production de nourriture sauvage par le peuple athapascan fait partie d'un système socio-écologique intégré de l'intérieur de l'Alaska. Nous décrivons les effets des tendances récentes et des projections de changements climatiques à venir sur l'écosystème boréal de l'intérieur de l'Alaska et nous relions les changements dans les services de l'écosystème à la subsistance des athapascans. Nous mettons principalement l'accent sur l'orignal, une ressource terrestre de subsistance clé des villages de cette région. Bien que les changements climatiques récents aient affecté la forêt boréale, l'orignal et la récolte d'orignaux par les athapascans, les ménages des villages continuent à dépendre fortement de l'orignal. Un compte rendu historique des changements socioéconomiques survenus au 20e siècle démontre que la vulnérabilité des systèmes de subsistances des athapascans aux changements climatiques a à certains égards augmenté alors que des aspects de la résilience des villages se sont améliorés durant la même période. Face aux changements climatiques et socioéconomiques à venir, les communautés ont des possibilités d'adaptation et d'atténuation limitées mais potentiellement efficaces. Dans quelle mesure les résidants peuvent concrétiser ces possibilités dépend de la capacité de réaction des institutions formelles et informelles aux besoins locaux. Par exemples, des augmentations de la population urbaine de l'Alaska couplées à des changements d'habitat induits par le climat peuvent augmenter les conflits de chasse les années durant lesquelles l'orignal est peu abondant. On pourrait atténuer ce problème par des stratégies de cogestion adaptative qui prédisent la densité des orignaux et redirigent les chasseurs urbains vers des zones moins conflictuelles.

[Traduit par la Rédaction]

Introduction

Indigenous Peoples have occupied interior Alaska for 6000–9000 years (Aigner 1986; Langdon 2004). They include Gwich'in, Denaakk'e, Kuskokwim, Tanana, Han, and other culture groups (referred in this paper as "Athabascan

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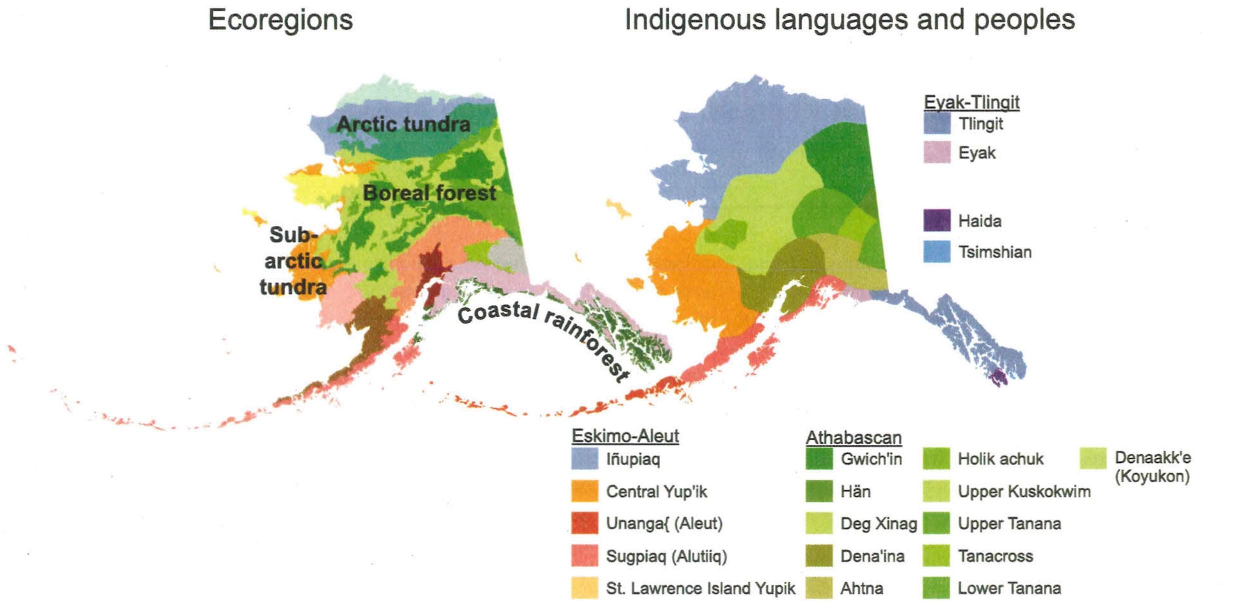
Fig. 1. Maps of ecosystems and cultural (linguistic) groups in Alaska. The close correspondence between these maps demonstrates the tight linkage between ecosystem and society. Redrawn from Gallant et al. (1996) and Krauss (1982). Reprinted with permission from Springer (Chapin et al. 2009).



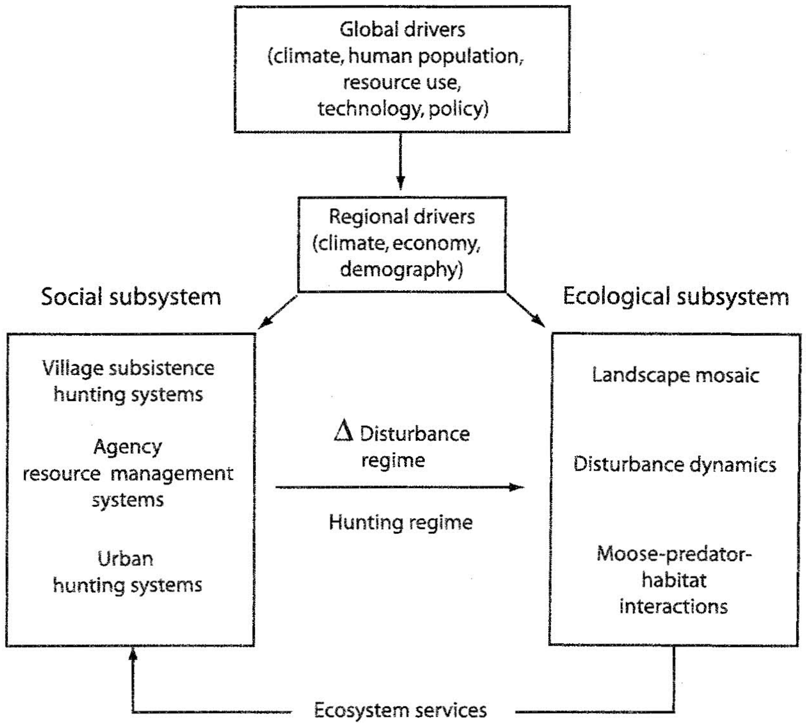
Peoples") (Fig. 1), with their ancestors being the second of three major migrations from Asia to cross the Bering Land Bridge to North America. The arrival of Athabascan Peoples preceded or coincided with the arrival of black spruce *(Picea mariana* (Mill.) BSP) dominated fire-prone vegetation that developed in interior Alaska about 6000 years ago (Lynch et al. 2002; Lloyd et al. 2006). Throughout the subsequent millennia, people have interacted with and depended on the same suite of ecosystems for food, shelter, and cultural identity (Nelson 1973, 1983). Prior to the late 1800s, neither the predominant indigenous cultures (Athabascan) nor the vegetation (black spruce dominated vegetation mosaic) had undergone large persistent changes in the previous 6000 years, despite substantial climatic changes, including the Medieval Warm Period and the Little Ice Age. Athabascan stories of distant time also indicate strong cultural continuity with the past (Nelson 1983; Langdon 1992; Natcher et al. 2007), although there were shifts in harvesting of some species with changes in resource availability, the distribution of some culture groups, and broad-reaching interactions with outsiders through trading and travel. Given the types of shocks experienced in the region, this persistence suggests substantial social-ecological resilience at regional scales, at least at the coarse temporal resolution revealed by paleoecological, archaeological, genetic, linguistic, and oral historical records.

Like most continental regions, the boreal forest of eastern interior Alaska has a variable climate. However, over the last half century, it has warmed to a level unprecedented in at least the last four centuries (Overpeck et al. 1997), substantially altering ecosystem processes (McGuire et al. 2010), fire regime (Kasischke et al. 2010), and abundances of key plant and animal species on which people depend (Kielland et al. 2010). Historical accounts by Athabascan Peoples note the absence of moose in parts of interior Alaska 100 years ago, with moose hunting emerging as a relatively new tradition to the culture groups of the region (Nelson 1983; Huntington 1993). Canadian fur traders colonized the region in the 19th century followed by American gold miners and other colonists in the 20th century who brought a very different culture, systems of governance, and land ethic to interior Alaska (Naske and Slotnick 1987). The process of contact with nonindigenous peoples has significantly transformed many aspects of Athabascan life while leaving other traditions strong. Given the past interdependence of people with nature in this system (Fig. 1), current rapid climatic and socioeconomic changes raise questions about the future of the boreal forest as a social--ecological system. Can Athabascan subsistence systems persist in the face of projected warming and concurrent socioeconomic changes? What are the major sources of vulnerability and resilience of this system? What is the potential for adapting to these changes? How might resilience be fostered and vulnerability reduced? How does reliance on moose, the primary large game species in the area, affect the resilience of the system? We address these questions in the context of ecological studies conducted by the Bonanza Creek Long Term Ecological Research (LTER) program and associated social---ecological research projects.

Conceptual framework and knowledge sources

We view the boreal forest as a dynamic integrated social-ecological system in which social and ecological processes are linked by important interactions (Fig. 2) (Berkes et al. 2003; Chapin et al. 2006), a research framework that has been broadly adopted by the US LTER network. The ecological subsystem provides a variety of ecosystem services, which are the benefits that people derive from ecosystems (Millennium Ecosystem Assessment 2005). These include

Fig. 2. Interactions of social and ecological components of a social–ecological system (the Alaskan boreal forest) as affected by global and regional climatic and socioeconomic changes. Village and urban hunting systems include informal institutions, such as traditional rules for sharing among Athabascan groups, and typically interact with formal policies through agencies and management councils. The ecological subsystem's landscape mosaic, land activities, and moose–predator–habitat interactions are shown.



products that people harvest from ecosystems (provisioning services such as food and woody fuels), the regulation of interactions among ecosystems (regulatory services such as climate amelioration and protection from fire spread), and the recreational and culturai benefits that people derive from ecosystems (cultural services). The social subsystem functions to maintain the cultural system and provide for continuity or to modify human behavior through the introduction of new motivations and actions. The social changes can *in* turn influence ecosystems through the harvest of resources such as food and water, changes in land use, addition of pollutants, and changes in the disturbance regime (Fig. 2). We assume that the social-ecological system of interior Alaska is dynamic but consider it sustainable if the structure and functioning of the social and ecological components of the system persist through time, as they appear to have done for the last 6000 years. This "emerging scientific paradigm" of coupled social-ecological systems (Berkes et al. 2003) is remarkably similar to the traditional Athabascan paradigm of people as an integral component of nature, as described below.

In interior Alaska, there are both social and climatic drivers of change that affect the social and ecological components of the system and therefore the social-ecological interactions that link people to nature (Fig, 2). The resilience of this system is its capacity to maintain its fundamental structure and functioning despite perturbations to the system. The most important drivers of boreal change are global in scope. These include increases in the global population and its use of resources, which influence climate, economy, and demography, both globally and regionally. These global drivers of change are likely to persist or accelerate over the next half century (Intergovernmental Panel on Climate Change 2007). The sustainability of desirable attributes of the boreal social-ecological system will therefore likely depend more on resilience and capacity to adapt than on a relaxation of the global drivers of change.

Two complementary sources of information inform us about the boreal system and its recent changes. People living on the land and dependent on its resources are in most cases well aware of the biophysical changes occurring around them because they generally spend extensive time on the land and are directly affected by the changes that occur there. In addition, people with a long association with a place are informed by oral sources, such as elders, who provide stories of how things used to be (Krupnik and Jolly 2002; Huntington et al. 2005). This local and traditional knowledge includes many of the same elements as conventional western science, including observations of change, rules of thumb about causality, and general theories underpinned with a paradigm of knowledge. Observations of change by local knowledge are not confined to ecological dimensions but also include social elements and their interactions with the ecological.

Western science can potentially contribute a complementary knowledge based on field observations and experiments, remote sensing, and modeling. These two sources of knowledge are equally important in documenting change, understanding the critical relationships of the social-ecologicaJ system, and exploring adaptation options. They sometimes provide similar types of information and conceptual models, based on different tools and "observing systems" (Berkes 2008). and in contemporary cases, they often interact to shape the perspectives of local knowledge holders. However, they are based on different paradigms of human-nature interactions and therefore can also lead to differences in perspective and understanding. For example, the traditional Athabascan perspective views land and animals as sentient beings in which the respect that people have for nature influences the biophysical and social outcomes (Berkes 2008; McNeeley 2009). Western science tends to view people as apart from nature, with human impacts on ecosystems occurring purely through biophysical mechanisms. Both indigenous and western knowledge paradigms are important because they influence human perceptions and therefore the actions that people choose for adapting to change. Mutual respect for these and other forms of knowledge provides a platform for collaboration, knowledge coproduction, and innovation (Kofinas et al. 2002, 2007; Miller et al. 2008).

Changes in boreal ecology and ecosystem services

The boreal forest of interior Alaska is a landscape mosaic dominated by black spruce forests interspersed with wetlands, productive upland forests (white spruce *(Picea glauca* (Moench) Voss)), Alaska paper birch *(Betula neoalaskana* Sarg.), and trembling aspen *(Populus tremuloides* Michx.)), riparian forests (balsam poplar *(Populus balsmifera* L.) and white spruce), and alpine tundra (Viereck et al. 1983; Hollingsworth et al. 2010). Wildfire is the major disturbance agent in interior Alaska With a fire return interval of about a century (Kasischke et al. 2010). Black spruce forests are the most flammable vegetation type in this mosaic. The less flammable early-successional, wetland, and alpine ecosystems act as fuel breaks that reduce the spread of fire across the landscape (a regulatory ecosystem service).

Another important subsistence land cover type in Alaska is wetlands, which provide habitat for waterfowl, moose, and some furbearers, Like the boreal forest, the wetlands of interior Alaska, too, are already experiencing change. From the 1950s to 2002, many wetlands across interior Alaska shrank by up to 31% of their surface area (Riordan et al. 2006). This is linked to warmer temperatures that result in thawing of permafrost (Rouse et al. 1997) and greater evapotranspiration unaccompanied by greater precipitation (Riordan et al. 2006). Estimates of the June to August water deficit show that it has increased by 5.5 $mm{\cdot}year^{-1}$ in interior Alaska since 1960 (Oechel et al. 2000; Hinzman et al. 2005). The projected changes in temperature for Alaska in the next century suggest that wetland drying due to increased evapotranspiration and changes in permafrost will continue, with additional water loss during an extended growing season.

Recent and projected trends of warming, drying, and increases in wildfire have important consequences for ecosystem services in interior Alaska. These changes relate primarily to changes in habitat and the accessibility of this habitat to subsistence harvesters. We first discuss habitat changes, then access issues, and finally the indirect effects and surprises that might modify these direct effects of climate warming. We focus especially on moose because their preferred habitat is strongly affected by wildfire (Peek 1974; MacCracken and Viereck 1990; Nelson et al. 2008) and they illustrate the impact of climatic and ecological changes on the subsistence lifestyle of rural communities. The recent findings reported above and below have been corroborated and elaborated through the documentation of local knowledge of villagers (Arctic Boarderlands Ecological Knowledge Coop 2008). Villagers often report observations at a fine scale of resolution and describe specifically how changes are affecting their village's and household's well being (Table 1). These findings reflect local understandings that are not currently captured with science-based ecological research.

The immediate impact of wildfire is a reduction in most ecosystem services on which local residents depend. This includes subsistence resources that people harvest, ecosystem effects on water quality, and the cultural and aesthetic services provided by the landscape. These services gradually recover over time periods of years to decades (Fig. 3) (Nelson et al. 2008). Moose. which constitute the largest nonfish subsistence meat source in interior Alaska (median harvest of 39 $kg{\cdot}person^{-1}{\cdot}year^{-1}$) (Scott et al. 2001; Nelson et al. 2008), avoid burned areas immediately after fire but gradually increase to a maximal abundance 10-25 years later (Maier et al. 2005; Nelson et al. 2008). Moose have a high reproductive potential (Bubenik 1998) and their populations respond strongly to increased forage availability (Renecker and Hudson 1986), so moose populations can rebound quickly after fire, if relieved from predation. High forage availability and moderate predation pressure have recently led to moose exceeding their apparent carrying capacity in areas with predator-control programs, such as the Bonanza Creek LTER study area, resulting in decreased growth rates of calves, delayed age of first reproduction, and reduced twinning rates (Boertje et al. 2007). Thus, vegetation and population constraints place an upper limit on the moose densities that might develop in response to increased wildfire, an ecological source of resilience.

Snowshoe hares, lynx, and blueberry production show a timing of posrfire recovery that is similar to that described for moose (Fig. 3). Winter habitat of caribou (median harvest 3.5 $kg{\cdot}person^{-1}{\cdot}year^{-1}$), in contrast, requires 80-100 years to recover because of the slow growth of lichens, the primary caribou winter forage. These broad patterns of change in wildlife and plants are reported by both subsistence hunters and wildlife biologists (Chapin et al. 2008). Species differences in habitat preference suggest that moose will become more abundant but caribou less abundant in interior Alaska in response to warming-induced increases in wildfire.

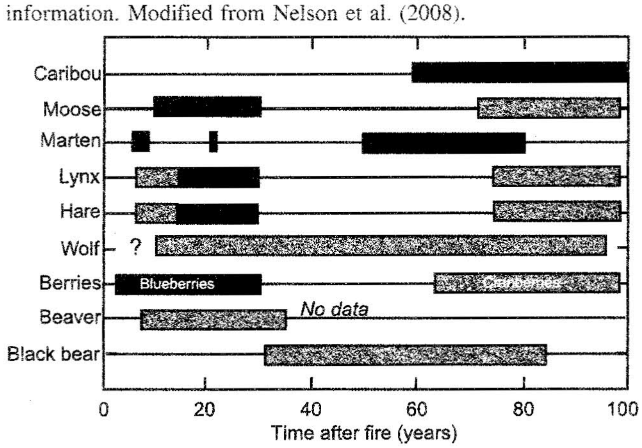
Climate warming has, in general, reduced hunter access to subsistence resources. Hunters customarily use rivers as their primarily access routes, supplemented by traplines and other winter trails; most interior villages have no roads. Rivers are accessible by boat in the summer and by snow machine in winter but are largely inaccessible during autumn freezeup and spring breakup (Rattenbury et al. 2009). Traplines, lakes, and wetlands are most accessible during the snow-covered season. Lower water levels make some areas inaccessible and increase the risk of damaging river equip-

Table 1. Summary of local observations of social–ecological change in Venetie, Alaska.

Observations
Noted as important edible subsistence resources: moose, caribou, beaver, ground squirrel, ducks and geese, berries, king salmon, grayling, dog salmon, rabbits, ptarmigan, muskrat, grouse, black bear, porcupine, Dall sheep
Important nonedible resources: wood pitch, dry wood for woodstoves, river water, house logs for log cabins, furs from trapping, birch wood for sleds
Observations of change
Increase in grizzly and wolf populations
Increase in number and extent of fires (2003 fires burned half of the tribe's traditional lands)
Increased difficulty for on-land travel due traditional use trails degraded by fires
Increase travel distance to find quality wood from village, increase occurrence of beetle kill of trees
Drying of rivers and lakes throughout use area, less willingness to travel on rivers due to potential damage to outboard motors
Fewer moose and more difficult to harvest. Stated causes: overhunting by outside hunters, out of season hunting, predation by bears, warmer conditions, lower water on rivers
Change in migration patterns of caribou. Stated causes: burnt habitat from recent fires, change in vegetation due to warmer conditions, nonlocal hunter activities
Decrease in body condition (less fat) and increased frequency of abnormalities and parasites
Decrease in number of porcupines (eaten as delicacy by elders)
Increase in salmon
Dramatic increase in fuel and shipping costs
Concerns
Regional competition and disturbance by nonlocal hunters
Effects of climate change of predators and their effects on moose
Loss of heritage sites due to fires
Loss of traditional language
Loss of traditional skills
Safety when traveling on the land
Social and economic problems affecting villagers' participation in subsistence
Loss of caribou due to possible development in northern Alaska

Note: Nineteen active subsistence harvesters and elders of Venetie, Alaska (population 202, Gwich'in Indians, no road access) were interviewed in December 2007 to document observations of social–ecological change.

Fig. 3. Approximate optimal periods postfire for density or productivity of key boreal forest subsistence species according to the ecological literature. Gray bars indicate uncertain or hypothetical information. Modified from Nelson et al. (2008).



ment (e.g.. outboard motors), thus making it less likely for hunters to travel. The slower freezeup of rivers has lengthened the interval of unsafe liver ice in autumn, an important season for hunting moose and trapping marten. In some cases, increased variability of temperature during and after these transition seasons has increased water overflow on frozen rivers, adding to access problems. In addition, wildfires burn shelter cabins that are critical for safe winter travel and topple burned trees across trapline trails, further reducing access to the land (Chapin et al, 2008). Wildfires also threaten historic sites that are perceived as important for cultural identity.

The broad patterns of climate effects on subsistence resources described above are complicated by species interactions, unusual climate events, and inevitable surprises. Annual mortality for moose, for example, is often about 80% for calves (mostly from bears) and 10%-20% for adults (mostly from wolves or weather-related conditions and secondarily from hunters) (Gasaway et al. 1992; Bertram and Vivien 2002). Variation in predation pressure can therefore amplify or counteract the effects of climate and habitat on subsistence resources.In the Tanana Flats, where Bonanza Creek LTER studies have focused, human predator control has substantially reduced predation rates, leading to a high moose population that overbrowses its food resource (Young et a1. 2006; Boertje et al. 2007). This contrasts with the Yukon Flats where high numbers of predators relative to moose (e.g., moose to wolf ratio <20) keep moose in a "predator pit" that severely constrains the population growth, abundance, and thus availability of moose to subsistence hunters. Winters of unusually deep snow can create massive mortality of moose, particularly if they are nutritionally stressed (Coady 1974). Rain-on-snow events, which are expected to occur more frequently with climate warming, reduce access by caribou to lichens during winter, creating a critical food stress. Local hunters report a cascading set of effects, with lower water levels increasing salmon mortality in river bottoms, which brings bears to these areas for feeding, which in turn forces hunters to use the more difficult on-the-Iand moose hunting methods in the nonsnow months. These and other indirect effects of climate change are currently recognized as important but speculative in terms of their future impacts on subsistence resources (Huntington et al. 2005).

Climate change will also create novel conditions and surprises that cannot be forecasted from currently available climate change scenarios. Beaver, for example, which expanded unexpectedly into westem Alaska in the last 20 years, have radically modified fish habitat by building dams and have introduced *Giardia* to water supplies that were formerly safe to drink. Deer, which are a host for wasting disease, have recently appeared in eastern interior Alaska, with unknown consequences for moose and caribou, which are also susceptible to the disease. Recent community observations suggest new occurrences of moose ticks and new pathogens in the more northern latitudes of western Canada (S. Kurtz, personal communication (2008)). Moreover, climate-induced asynchrony between animal life history events driven by photoperiod (e.g., molt) and seasonality phenomena (e.g.. greenup or snowmelt) could render both mammals and birds more susceptible to predation (Kielland et al. 2010). These unanticipated changes introduce new uncertainties and related vulnerabilities that are not readily anticipated, suggesting that flexibility to respond to unexpected change will be a key component to maintaining resilience.

Changing boreal social systems

Interior Alaska, which we define as the communities within the Fairbanks North Star census area and the Yukon Flats and Middle Yukon-Koyukuk census subareas, has a population of about 97000 (Alaska Department of Labor and Workforce Development 2008). with 94% living near Fairbanks and along the roads that connect Fairbanks with Anchorage (south), Prudhoe Bay (north), and Canada (east). The remaining 6100 people of interior Alaska live in 28 remote villages ranging in size from 12 to about 580 people (Alaska Department of Labor and Workforce Development 2008). Remote villages are accessible by river and air but have no connection to the rest of the state by road or to the electrical grid. Cash employment opportunities in remote villages are extremely limited, and approximately 85% of households depend substantially on their local environment for food, using rivers and trapline trails for access,

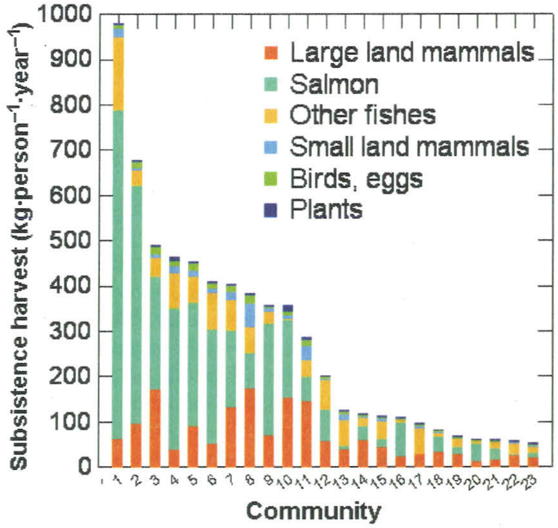
The village subsistence system: past and present

Before contact with Europeans, Athabascans lived primarily in small family bands that moved seasonally to access different resources when they were most available (Nelson 1973; Caulfield 1983; Langdon 1992: Natcher 2004). When fires or postfire succession reduced the suitability of habitat in one place, bands adjusted their seasonal migration accordingly. This enabled people to continue to access a wide range of successional habitats, although the specific locations changed over time. Subsistence foods constituted a critical cultural as well as food resource. The foods that people ate and the social organization and process of their harvest played a central role in the stories and oral traditions of local groups (Cruikshank 1998). Successful harvest of a wildlife and fish, for example, occurred when the animal "gave itself" to the harvester. People believe that this harvest success depends on both the skill of the hunter and respect demonstrated for animals and their habitat. Human-animal relationships of respect and reciprocity also extended to other members of the community, with the sharing of harvest with other community members a central principle. Subsistence has therefore been grounded in the ability to access enough resources in space and time but also in complex social relationships that playa role in how the harvest is distributed, processed, and shared among hunters, their extended family members, and the wider community. In today's context, sharing extends to other communities as well as those living in rural areas.

Many cultural and economic changes during the 20th century acted as a series of shocks to Athabascan society. During the 20th century, people settled into permanent villages based on a combination of both pulls and pushes. Economic opportunities (trading posts, permanent houses, and transportation) attracted families to settle. Public policies requiring formal schooling of youth required that families live in villages during portions of the year. Competition between Athabascans and nonindigenous settlers over land rights and the imposition of new definitions of economic "progress" also acted to push Athabascans into settlements. Although this movement into villages provided access to many of the "necessities" and benefits of 20th century westem life, it radically restricted mobility on the landscape and therefore challenged the earlier resilience achieved through spatial adjustment to disturbance events (Chapin et al. 2008).

Early social scientists suggested that subsistence hunting and gathering and the sharing of food resources as a component of it would decline as communities engaged more fully with the market economy (Murphy and Steward 1956), However, this unidirectional transition from a subsistence mode of production to a market economy has not occurred. Recent (1982-1990) data from 23 villages across interior Alaska (Fig. 4) illustrate that villages are still actively engaged in subsistence (Nelson et aI. 2008) while participating in the cash economy (Langdon 1986). A majority of the harvest in rural villages of interior Alaska consists of salmon combined with other fish species (grayling and whitefish) followed by large mammals (i,e., moose and caribou) and waterfowl (ducks and geese). Some small mammals are trapped (marten, fox, and wolf) for cash or traded as crafts within or between households. Average subsistence harvest (kilograms per capita per year) varies widely among villages, but this basic harvest pattern by species is regionally consistent. Salary and wage employment opportunities in interior villages have grown through time, but they are still relatively rare (Alaska Department of Labor and Workforce Development 2008). Only about 50% of the working age population of interior villages has jobs. Transfer payments, such as those coming from Alaska Native Corporation Dividends or the Alaska Permanent Fund, contribute in important ways to household budgets (Huskey and Morehouse 1992). Transfer payments make up about 38% of total personal income in rural Alaska (Bureau of Economic Analysis 2007) and help households meet expenses and provide cash needed to buy fuel, snow machines, rifles, and ammunition

Fig. 4. Composition of annual subsistence harvest for 23 rural communities in interior Alaska based on Alaska Department of Fish and Game Subsistence Division surveys conducted during 1982–1990. Reprinted from Nelson et al. (2008) where the identity of each community is given.



for subsistence. In the context of rural Alaska, the high cost of purchasing store-bought food and fuel represents an economic hardship for many households, particularly given the recent spike in the prices of both commodities (Alaska Department of Labor and Workforce Development 2008). Permanent settlement implies that hunters must now travel from a home base to their hunting areas or family bush camps, which requires access to higher levels of cash for snow machines or boats, their maintenance, and fuel. For those who have jobs, this suggests a trade-off between working and having the time necessary to engage in subsistence, although empirical evidence (Berman et al. 2004) suggests that jobs provide faster and more efficient travel through the acquisition of better hunting gear (i.e., a larger snowmobile or a larger outboard motor for a boat), which compensates for long travel distances. This compensation, however, does not correct for the access and safety issues associated with many of the climate change constraints. This combination of circumstances, climate and changing economic conditions, underscores why many families in interior villages continue to depend on a fluid interdependence between subsistence harvesting of wild foods and employment.

Subsistence has long been part of a mixed cash-subsistence economy and remains a significant source of food and cultural well-being in interior Alaskan villages (Wolfe and Utermohle 2000; Loring et al. 2008). The role of subsistence continues in spite of a host of social problems in communities related to substance abuse, violent crime, and a sense of limited efficacy that follows from unemployment and persistent poverty. Similarly, the cultural beliefs underlying subsistence described briefly above still frame many of the discussions and behaviors of contemporary Athabascan communities. Current harvest traditions also continue to reflect a connection to specific places. Although people adjust their hunting routes in response to social and ecological changes (such as wildfire), both families and communities tend to revisit areas and maintain hunting and fish camps that have been used for multiple generations and beyond. Given the Athabascan worldview of close reciprocal interaction between people and the rest of nature, these traditional connections to specific locales generate a sense of place that is an important part of cultural identity and continuity. Stories and oral histories are often quite specific in terms of their connections to these places. The interruption of connections to specific places by extensive wildfires, settlement into permanent communities, loss of language and hunting skills, or other causes can weaken these ties to specific places.

Interactions of rural hunting with the urban hunting system

Since 1977, the number of moose hunters in Alaska has nearly doubled as a result of a near doubling (l.6 times) of the state population, largely due to immigration from other states associated with employment opportunities. Another source could also arise from improved reporting rates; however, during this time interval, the percentage (6%-8 %) of the Alaskan population that hunts moose has not changed. In addition, success of moose hunters in Alaska declined as the ratio of hunters to moose increased (Schmidt et al. 2005). Because most of Alaska's population growth has occurred in cities, the number of urban moose hunters now far exceeds the number or rural or non-Alaskan hunters. In much of interior Alaska, rural residents constitute the minority of moose hunters (Fig. 5), creating conflict between local rural hunters and nonlocal hunters from cities or from outside Alaska. There is substantial overlap in the areas where rural and urban hunters hunt, although urban hunters make up a particular large proportion of the hunters along the road system and are more likely to use transportation modes, such as airplanes, that allow greater access to remote hunting areas. Rural hunters are more likely to predominate on remote rivers or in areas like western Alaska where moose densities are extremely low. Adding to the conflict is a perception among some village hunters that indigenous subsistence is more focused on food production whereas urban hunting is focused on recreation and trophies.

Agency resource management system

State and Federal resource management agencies directly influence the interactions between people and ecosystems through the formulation and implementation of policies that govern fire regime, habitat management, access, hunting, and predator control (Fig. 6). Other agencies influence human-environment interactions indirectly through employment opportunities, subsidies, and transfer payments that affect the village economy. For example, both State and Federal funds support the Alaska Energy Authority, an umbrella group that substantially subsidizes the cost of energy in rural communities. Alaska Energy Authority administers and (or) funds programs that include rural power system upgrades and the Power Cost Equalization program that directly subsidizes electrical rates for rural residents. Even with these subsidies, the cost of electricity, heating fuel, and gasoline in remote villages is often twice that along the road network.

Of critical importance in understanding agency management of subsistence resources and moose in particular are

Fig. 5. Urban or nonresident moose hunting in locations of Alaska where the percentage is greater than 50% or about equal by group.

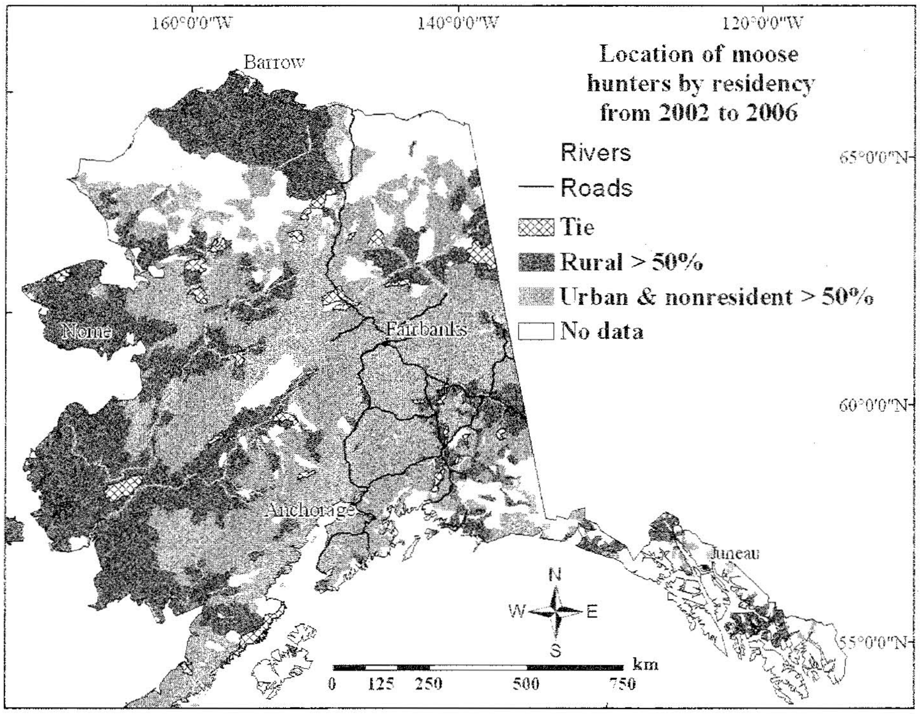
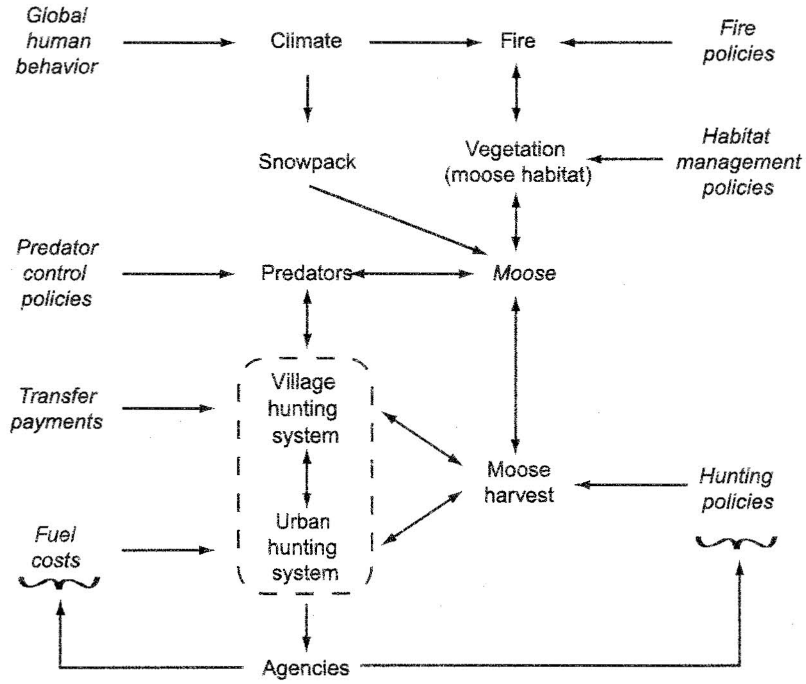


Fig. 6. This figure represents many of the key components of the system studies in this paper. Policy dimensions of the system are located on the left and right. Village and urban hunting systems are represented with two-headed arrows to reflect the differing ways these systems interact with moose.



the limited rights and authority afforded to Alaska Natives of rural villages, resulting in an agency resource management system that is in part sensitive to rural issues but commonly dominated in the policy formation and implementation process by urban interests. The Alaska Board of Game is an advisory stakeholder body, and while Alaska Natives have served on the board. board membership is determined by the Governor of Alaska and has been dominated by nonnative interests. The consequence is that agencies typically have limited annual hunter harvest data for many villages of interior Alaska (low reporting of harvest, many hunters refusing to acquire licenses) and encounter a sense of animosity and suspicion from villagers when trying to work in these areas.

Managing vulnerability and resilience in a changing climate

Changes in vulnerability and resilience

Climatic and socioeconomic changes are altering both the ecological and human landscapes of interior Alaska, creating a constantly shifting dynamic of vulnerabilities. Although these changes differ from many of the challenges encountered in the past, radical change is nothing new. In the past, widespread regional starvation occurred during periods of low fish and game abundance (Langdon 1992; Burch 1998), the Athabascan population declined substantially following arrival of European diseases (Krech 1978), and market hunting in some areas reduced populations of moose. and caribou during the gold rush of the early 20th century. Strong cultural traditions of subsistence have survived these and other crises. Athabascans are proud of their ability to adapt as a result of their long history of coping with highly variable climate and subsistence opportunities. For example, historical accounts by Alaska Natives indicate the absence of moose in parts of interior Alaska 100 years ago, with subsistence hunting shifting from caribou to moose as moose became more available and caribou less available (Nelson 1983; Huntington 1993). Sources of resilience for managing changes have included sharing networks that buffer both individuals and communities from fluctuations in harvest success, provide cultural markers important in distinguishing from urban hunters, and reflect an indigenous worldview of human-environment reciprocity. In the modem context, sharing of subsistence extends between households and rural communities but also between rural communities with access to country foods and urban relatives with greater access to wages and commercial goods. Sharing also represents a form of cultural identity (i.e., Alaskan Native subsistence harvesters share), which reinforces these behaviors.

The gradual shift from a seasonally nomadic lifestyle, in which people moved to access subsistence resources at times when they were seasonally abundant to nonnomadic lifestyles in permanent villages has made communities more vulnerable to ecological changes occurring in their immediate vicinity (e.g., erosion) while appreciating the benefits that have come with living in villages (e.g., medical care). Modern living and modem technologies have generated new vulnerabilities associated with the high cost of equipment, maintenance, and fuel and the resulting need for cash income. There has been a gradual change from seasonal movements to different areas (the traditional seasonal round) to week-long trips (common among the elders) to 1-day or weekend trips that are more compatible with wage-paying jobs (Nelson 1973; Alexander 1996).

Historical assimilation policies of the 20th century, motivated by the humanitarian goals of providing basic health, educational, and socioeconomic opportunities, have substantially affected the cultural resilience of Indigenous Peoples throughout the world, including interior Alaska. As importantly, missionaries in the 19th and 20th centuries introduced Christianity as a new value system that sometimes complemented and sometimes confronted traditional Athabascan worldviews (Jette 1911; McNeeley 2009). At the same time, fur traders from the Hudson Bay Company and later gold miners who invaded the interior in large numbers provided income opportunities for the local population. These opportunities typically built on the traditional skills of Athabascan hunters and provided access to new technology (guns and traps) that made this harvest more efficient, creating both economic returns and social and ecological vulnerabilities. During the mid-20th century, compulsory education, first through boarding schools that removed children from their families and later through village schools, eroded Native language by prohibiting its use in schools and disseminated a new knowledge system that represented a sharp break from traditional knowledge and wisdom. These educational initiatives undermined use of traditional languages and knowledge and the oral transmission of traditional culture from elders to youth. In 1970, the Alaska Native Claims Settlement Act extinguished aboriginal claims to traditional lands in return for a settlement of cash and tribal ownership of selected village and regional lands that were mandated to be used for commercial purposes. The institution implementing regional and village Native corporations imposed both new values associated with corporate structure and incentives that undermined traditional values while also supporting a resurgence of "Native pride" that strengthened cultural resilience in many parts of Alaska (Dayo and Kofinas 2010). As a part of these changes, several recent village initiatives have been undertaken to reduce vulnerabilities and strengthen resilience as well as persistent institutional challenges and barriers. These are described in the next section.

Current village and tribal adaptation initiatives

Village residents and the formal leaders are acutely aware of the current and possible future issues with climate change. The opportunities for adaptation initiatives are limited in many villages by high unemployment and low human capital. In spite of these limitations, numerous village and tribal initiatives seek to foster cultural identity by strengthening sense of place and traditional ties to the land and documenting local knowledge. Many communities organize culture camps in which elders share knowledge and stories about traditional patterns of use of ecosystem services and cultural ties to the land. Elders and others in many villages have also initiated language and cultural programs within the schools. The occurrence and success of these programs vary among communities, depending on interest and leadership by village elders and receptivity of school administrators and teachers. In some cases, these camps have been set up in cooperation with government agencies in an effort to integrate traditional and science-based knowledge education for youth. In Arctic Village, students of the US Fish and Wildlife Elders-Science camp have reduced the effects of climate change by reducing the cover of willows on grayling spawning streams in an effort to keep them productive, Regionally organized efforts to strengthen culture include the Gwich'in Gathering, which provides a venue for sharing of culture, politics, and social ties, development of an indigenous resource management educational program by the

Athabascan Tribal College, collaboration between communities and the Bonanza Creek LTER to document climatic impacts on availability and use of subsistence resources, participation in the Arctic Borderlands Ecological Knowledge Coop, which links to Canadian communities and agencies seeking to document climate change on a regional level, the World Indian Eskimo Olympics, which fosters traditional games, dances, and skills, and tribal programs that manage forest resources on tribal lands (e.g., the Tanana Chiefs Conference).

Moose abundance in the Yukon Flats region of interior Alaska is relatively low because of high predation rates, and village residents recognize predator reduction as one means to improve the availability of moose for subsistence. To meet this objective, several villages in the area have initiated a contest that awards a prize for the largest bear skull harvested each year. Since hunters are most likely to harvest bears in their traditional hunting areas, this selectively reduces bear populations in regions most important for enhancing subsistence. Anecdotal reports from hunters suggest that moose populations have increased in response to this localized predator control. Other villages harvest predators near their communities as part of traditional practices. In either case, these predator harvests tend to reduce predation rates in traditional use areas. These village-organized predator harvest programs differ from the controversial aerial wolf hunting programs of the Alaska Department of Fish and Game, which seek an area-wide predator reduction. This approach of encouraging harvest of bears for cash reward is in some respects inconsistent with the traditional values of some Athabascan Alaska Native hunters. This strategy does, however, indicate the significant capacity of Athabascan Peoples to create local policies that adapt to emerging conditions, create innovate solutions, and appreciate that while traditional values are important in guiding behavior, so are economic incentives.

The global rise in energy cost is exacerbated in rural Alaska where high transportation costs for fuel delivery raise the price of heating oil and gasoline three to five times above the national average. Costs are further increased in those communities where climate-driven drops in river level require a shift from barge to air delivery of fuel, Interior Alaska has one of the lowest household incomes in the country, making them particularly vulnerable to rising fuel costs. A few communities (e.g., Tanana and Fort Yukon) have begun paying local residents for firewood to heat public buildings with modern high-efficiency wood stoves (Fresco and Chapin 2009). In other communities, individuals have increased harvest of firewood for donations to elders or sale to other community members. The impact of these individual and community efforts has been local in scale, reducing village vulnerability to rising fuel costs, providing new income sources within the community, and creating early-successional habitat near communities that is favorable for moose (Chapin et al. 2008).

Initial analyses suggest that most villages in interior Alaska could meet most of their heating and electricity needs with a wood harvest that would be ecologically sustainable and economically profitable (Fresco and Chapin 2009). An assessment of the feasibility of switching power generation from fossil fuels to wood energy in 33 rural Alaskan commuruties in forested regions of interior Alaska found that the installation costs of biomass systems would be recouped within 12 years for at least 28 communities in the region. In addition, all but the largest remote villages in the interior could theoretically meet all of their electrical demand and some heating needs with a sustainable harvest of biomass within a radius of approximately 8 km of the village. Such a change might potentially improve community resilience, not only by reducing the magnitude and volatility of energy costs but also by creating much-needed local employment and reducing fire risk in areas where past fire suppression coupled with increased flammability due to climate change has made communities vulnerable (Chapin et al. 2008).

Overall, more communities of interior Alaska are seeking partnership with agency resource managers, university projects, and nonprofit groups that share their objectives. These efforts are matched with a greater awareness of these organizations of the need and opportunity to work with rural villages to achieve social-ecological sustainability, especially as related to subsistence. There remain problems, such as the limited flexibility of federal and state management boards to be highly responsive to changes in harvesting season due to changes in seasonality, but that said, there are signs of movement in a good direction (McNeeley 2009).

In summary, general recognition by Athabascan communities that climatic and social changes will be an ongoing source of vulnerability has led to a diverse array of strategies that reduce local vulnerability to these changes.

Cross-scale institutional challenges

Anthropogenic climate change is the cumulative result of changes in fossil fuel consumption and human actions throughout the world. There is little that Athabascans, with their small populations and impacts on the climate system, can do to reverse these trends. Climate change, with its global causes and disproportionately large northern consequences, is a crucial human rights issue that is not addressed by economically motivated efforts to mitigate climate change (Adger 2004; Trainor et al. *209b)*. This remains one of the greatest challenges to society in the 21st century. This challenge has particularly strong implications for human rights because the people most vulnerable to climate change are generally those who live in persistent poverty, depend most directly on climate-sensitive ecosystem services, and have fewest resources to support adaptation (Millennium Ecosystem Assessment 2005).

Given that continued climate change is highly likely in interior Alaska for the next half century and beyond, adapting to these changes will be essential. However, many of these options are strongly constrained by institutional arrangements that are rigorously defined by state and federal governments. The State of Alaska, for example, grants all residents of the state equal rights to hunt anywhere in Alaska and defines the regulations that determine the timing and amounts of harvest that are allowed. This seriously constrains the effectiveness of traditional informal institutions or "customary law" that defined the timing, location, and rules for harvest in the past (Caulfield 1983; McNeeley 2009). Further confusion arises because of the "dual management" regime in Alaska in which federal laws give hunting priority to local residents on federal lands when animals are scarce. These conflicts between informal institutions, Alaskan laws. and federal laws create a confusing regulatory framework over which local users have minimal influence. Moving from the existing conditions of conflict and confusion to an approach that encourages better cooperation, social learning, and adaptation is critical to meeting the challenges of climate change. "Adaptive co-management" is a model of decision making worthy of consideration. Adaptive co-management has been defined as a process in which cross-scale institutional arrangements facilitate a dynamic and reflexive process of learning-by-doing (Armitage et al. 2007; Kofinas et al. 2007). One promising way of realizing adaptive co-management in interior Alaska is strengthening the existing system of local advisory councils, composed of regional residents, who provide nonbinding advice to state and federal regulatory agencies about actions that could both protect wildlife resources and meet local community needs. Building the capacity of these councils will require allocation of resources for day-to-day operations of councils and stronger linkages with management agencies and advisory bodies. While there are several examples of success in the work of local advisory councils, to date, there has been less success in empowering local residents to participate in discussions about how to modify wildfire management to address climate change (Trainor et al. *2009a).*

Conclusions

The Athabascan subsistence hunting system of interior Alaska is a tightly integrated social-ecological system in which people depend on nature for a wide range of ecosystem services, including subsistence resources, protection from fire risk. and cultural ties to their traditional lands. Human actions, in turn, influence nature through their respect for animals and the land (the Athabascan paradigm) and through patterns and regulation of harvest and fire regime (the western paradigm). The 6000-year history of this subsistence system indicates substantial resilience. This resilience has been challenged by several transformational changes, including a shift from a nomadic to a village-based lifestyle, introduction of a new religious worldview, a land claims agreement that extinguished aboriginal rights to the land, and educational and economic opportunities that have substantially modified the local systems of knowledge and incentives. Each of these changes has created positive (amplifying) feedbacks that challenge the system in its traditional form but that open opportunities for sustaining some of the basic values of the traditional system in a new context.

Negative (stabilizing) feedbacks counteract the impacts of climate change on the ecological system through vegetation-induced declines in flammability and population regulation of important subsistence resources. Sharing networks sustain cultural ties to the land and social relationships among people, including the coordination of activities and respect for elders who have been important in maintaining the core values that have enabled this subsistence system to persist. New incentives, such as awarding of prizes for harvesting of bears, raise questions about how such strategies will interact with traditional values of respect and reciprocity. The persistence of the Athabascan subsistence system through so many massive changes provides reasons for optimism about its future. Working toward an adaptive co-management model of learning-by-doing may better ensure the long-term sustainability of Athabascan subsistence systems in the face of climate change.

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