

**U.S. Fish and Wildlife Service / U.S. Geological Survey**  
**Climate Change Forum for Alaska, February 21 – 23, 2007**  
**SUGGESTED READING**

ACIA. 2004. [Impacts of a Warming Arctic: Arctic Climate Impact Assessment – Synthesis Report](#). Cambridge University Press. 146 pp. (Access to this site from a government computer may be limited.)

ACIA. 2005. [Arctic Climate Impact Assessment – Scientific Report](#). Cambridge University Press, 1042 pp.

Aðalgeirsdóttir, G., K.A. Echelmeyer & W.D. Harrison. 1998. Elevation and volume changes on the Harding Icefield, Alaska. *J. Glaciol.* 44(148):570-582

Airborne surface elevation profiles of the Harding Icefield, southcentral Alaska, were made in 1994 and 1996. Thirteen glaciers were profiled, along with the upper region of the icefield. The profiles were compared to U.S. Geological Survey topographic maps made in the 1950s, to obtain elevation and volume changes. Comparison of the changes for the different glaciers shows no significant correlation between volume change and the type of glacier or characteristics such as location, aspect, size, slope or terminus changes. Estimated total volume change for this similar to 43 year period is about  $-34 \text{ km}^3$ , which corresponds to an area-average elevation change of  $-21 \text{ m}$ . The estimated error in this elevation change of 5 m is mainly due to errors in the maps at higher elevations. Our measurements provide an accurate baseline against which future determinations of volume change can be made. ([CSA Illumina](#))

Baker, B.B., T.G.F. Kittel, C.J. Higgins, C.J. Haney, and E.C. Saxon. 2005. Threshold responses to climate change on Alaska's North Slope. The Nature Conservancy's Global Climate Change Initiative. Boulder, Colorado. January 31, 2005. 65 pp.

Bale, J.S., G.J. Masters, I.D. Hodkinson, C. Awmack, T.M. Bezemer, V.K. Brown, J. Butterfield, A. Buse, J.C. Coulson, J. Farrar, J.E.G. Good, R. Harrington, S. Hartley, T.H. Jones, R.L. Lindroth, M.C. Press, I. Symrnioudis, A.D. Watt, J.B. Whittaker. 2002. [Herbivory in global climate change research: direct effects of rising temperature on insect herbivores](#). *Global Change Biology*. 8:1-16.

This review examines the direct effects of climate change on insect herbivores. Temperature is identified as the dominant abiotic factor directly affecting herbivorous insects. There is little evidence of any direct effects of CO<sub>2</sub> or UVB. Direct impacts of precipitation have been largely neglected in current research on climate change. Temperature directly affects development, survival, range and abundance. Species with a large geographical range will tend to be less affected. The main effect of temperature in temperate regions is to influence winter survival; at more northerly latitudes, higher temperatures extend the summer season, increasing the available thermal budget for growth and reproduction. Photoperiod is the dominant cue for the seasonal synchrony of temperate insects, but their thermal requirements may differ at different times of year. Interactions between photoperiod and temperature determine phenology; the two factors do not necessarily operate in tandem. Insect herbivores show a number of distinct life-history strategies to exploit plants with different growth forms and strategies, which will be differentially affected by climate warming. There are still many challenges facing biologists in predicting and monitoring the impacts of climate change. Future research needs to consider insect herbivore phenotypic and genotypic flexibility, their responses to global change parameters operating in concert, and awareness that some patterns may only become apparent in the longer term. ([Bale et al. 2002](#))

Bowyer, R.T., V. van Ballenberghe, J.G. Kie. 1998. [Timing and synchrony of parturition in Alaskan moose: long-term versus proximal effects of climate](#). *Journal of Mammalogy*. 79(4):1332-1344.

We studied timing and synchrony of parturition in Alaskan moose (*Alces alces*) in Denali National Park and Preserve, Alaska, from 1990 to 1994. Mean date of birth was 25 May (SD = 5.7 days) and did not differ significantly among years. Although moose did not congregate to give birth, parturition was highly synchronized (95% of births occurred in 16 days) with no significant differences among years. Most young moose were killed by predators, especially grizzly bears (*Ursus arctos*), but timing of reproduction had no effect on survivorship of young, which was low (ca. 0.2 by 16 June). We reject the hypothesis that moose timed births to avoid predation. We also measured depth of snow in winter, and precipitation, cloud cover, and temperature in spring; none of these variables was related to timing or synchrony of births. Likewise, quality of willow (*Salix pulchra*) in 3 springs in which percent nitrogen and in vitro dry-matter digestibility of this important forage varied markedly was unrelated to timing of births. We reject the hypothesis that moose timed parturition in response to proximal

changes in their environment. We hypothesize that both timing and synchrony of parturition in moose are adaptations to long-term patterns of climate that provide the most hospitable conditions to bear and rear young. Consequently, moose may be more susceptible to climatic change than other ungulates that are more adapted to climatic variability. ([CNRS](#))

Burkett et al. 2005. [Nonlinear dynamics in ecosystem response to climatic change: case studies and policy implications](#). *Ecological Complexity*. 2:357-394.

For assistance with obtaining copies of this paper, please contact the [USGS National Wetlands Research Center Librarian](#).

Calkin, P.E., G.C. Wiles, and D.J. Barclay. 2001. [Holocene coastal glaciation of Alaska](#). *Quaternary Science Reviews*. 20:449-461.

Holocene fluctuations of the three cirque glaciers on the Seward Peninsula and five groups of tidewater- and land-terminating glaciers along the northernmost Gulf of Alaska provide a proxy record of late Holocene climatic change. Furthermore, the movements of the coastal glaciers were relevant to late Holocene Native American migration. The earliest expansion was recorded about 6850 yr BP by Hubbard Glacier at the head of Yakutat Bay in the Gulf of Alaska; however, its down-fjord advance to the bay mouth was delayed until 2700 BP. Similarly, expansions of the Icy Bay, Bering, and McCarty glaciers occurred near their present termini by 3600-3000 BP, compatible with marked cooling and precipitation increases suggested by the Alaskan pollen record. Decrease in glacier activity 2000 BP was succeeded by advances of Gulf coastal glaciers between 1500 and 1300 BP, correlative with early medieval expansions across the Northern Hemisphere. A Medieval Optimum, encompassing at least a few centuries prior to AD 1200 is recognized by general retreat of land-terminating glaciers, but not of all tidewater glaciers. Little Ice Age advances of land-based glaciers, many dated with the precision of tree-ring cross-dating, were centered on the middle 13th or early 15th centuries, the middle 17th and the last half of the 19th century A.D. Strong synchrony of these events across coastal Alaska is evident. ([Calkin et al. 2001](#))

Center for Health and the Global Environment. 2005. [Climate change futures: Health, ecological and economic dimensions](#). P.R. Epstein and E. Mills (eds.). Harvard Medical School. 139 pp.

In 2003, UNDP joined forces with the Center for Health and the Global Environment at Harvard Medical School and Swiss Re to engage in a multi-stakeholder scenario building exercise: Climate Change Futures: Health, Ecological and Economic Dimensions. This international, multidisciplinary project was designed to evaluate health, environmental and economic damages from climate change and associated extreme weather events based on a set of climate projections and development trajectories. UNDP's goal for this study has been to provide critical information that will help countries better adapt to and cope with climate change and lessen its impact on their ecosystems, health, and livelihoods. "Climate Change Futures" focuses on health. The underlying premise of this report is that climate change will affect the health of humans as well as the ecosystems and species on which we depend, and that these health impacts will have economic consequences. The insurance industry will be at the center of this nexus, both absorbing risk and, through its pricing and recommendations, helping business and society to adapt to and reduce these new risks. Our hope is that "Climate Change Futures" will not only help businesses avoid risks, but also identify opportunities and solutions. We believe that an integrated assessment of how climate change is now adversely affecting and will continue to affect health and economies can help mobilize the attention of ordinary citizens around the world, and help generate the development of climate-friendly products, projects and policies. With early action and innovative policies, business can enhance the world's ability to adapt to change and restabilize the climate. ([United Nations Development Programme, Energy and Environment](#))

Chapin III, F.S., G.R. Shaver, A.E. Giblin, K.J. Nadelhoffer, and J.A. Laundre. 1995. [Responses of Arctic tundra to experimental and observed changes in climate](#). *Ecology*. 76(3):694-711.

We manipulated light, temperature, and nutrients in moist tussock tundra near Toolik Lake, Alaska to determine how global changes in these parameters might affect community and ecosystem processes. Some of these manipulations altered nutrient availability, growth-form composition, net primary production, and species richness in less than a decade, indicating that arctic vegetation at this site is sensitive to climatic change. In general, short-term (3-yr) responses were poor predictors of longer term (9-yr) changes in community composition. The longer term responses showed closer correspondence to patterns of vegetation distribution along environmental gradients. Nitrogen and phosphorus availability tended to increase in response to elevated

temperature, reflecting increased mineralization, and in response to light attenuation, reflecting reduced nutrient uptake by vegetation. Nutrient addition increased biomass and production of deciduous shrubs but reduced growth of evergreen shrubs and nonvascular plants. Light attenuation reduced biomass of all growth forms. Elevated temperature enhanced shrub production but reduced production of nonvascular plants. These contrasting responses to temperature increase and to nutrient addition by different growth forms "canceled out" at the ecosystem level, buffering changes in ecosystem characteristics such as biomass, production, and nutrient uptake. The major effect of elevated temperature was to speed plant response to changes in soil resources and, in the long term (9 yr), to increase nutrient availability through changes in N mineralization. Species within a growth form were similar to one another in their responses to changes in resources (light or nutrients) but showed no consistent response to elevated temperature. Species richness was reduced 30-50% by temperature and nutrient treatments, due to loss of less abundant species. Declines in diversity occurred disproportionately in forbs, which are important for animal nutrition, and in mosses, which maintain soil thermal regime. There was no increased abundance of initially rare species in response to any treatment. During our 9-yr study (the warmest decade on record in the region), biomass of one dominant tundra species unexpectedly changed in control plots in the direction predicted by our experiments and by Holocene pollen records. This suggests that regional climatic warming may already be altering the species composition of Alaskan arctic tundra. ([CSA Illumina](#))

Chapin III, F.S., M. S. Bret-Harte, S.E. Hobbie, and H. Zhong. 1996. [Plant functional types as predictors of transient responses of Arctic vegetation to global change](#). *Journal of Vegetation Science*. 7(3):347-358.

Chapin III, F.S., T.S. Rupp, A.M. Starfield, L. DeWilde, E.S. Zavaleta, N. Fresco, J. Henkelmen, and A.D. McGuire. 2003. [Planning for resilience: modeling change in human-fire interactions in the Alaskan boreal forest](#). *Front Ecol. Environ.* 1(5): 255-261.

The development of policies that promote ecological, economic, and cultural sustainability requires collaboration between natural and social scientists. We present a modeling approach to facilitate this communication and illustrate its application to studies of wildfire in the interior of Alaska. We distill the essence of complex fire-vegetation interactions that occur in the real world into a simplified landscape model, and describe how equally complex fire-human interactions could be incorporated into a similar modeling framework. Simulations suggest that fire suppression is likely to increase the proportion of flammable vegetation on the landscape and reduce the long-term effectiveness of wildfire suppression. Simple models that test the consequences of assumptions help natural and social scientists to communicate objectively when exploring the long-term consequences of alternative policy scenarios. ([Chapin et al. 2003](#))

Cruikshank, J. 2001. [Glacier and climate change: perspectives from oral tradition](#). *Arctic*. 54(4):377-393.

In northwestern North America, glaciers figure prominently in both indigenous oral traditions and narratives of geophysical sciences. These perspectives intersect in discussions about global warming, predicted to be extreme at Arctic and Subarctic latitudes and an area of concern for both local people and scientists. Indigenous people in northwestern North America have experienced climate variability associated with the latter phases of the Little Ice Age (approximately 1550-1850). This paper draws on oral traditions passed down from that period, some recorded between 1900 and the early 1950s in coastal Alaska Tlingit communities and others recorded more recently with elders from Yukon First Nations. The narratives concern human travel to the Gulf of Alaska foreshore at the end of the Little Ice Age from the Copper River, from the Alaska panhandle, and from the upper Alek-Tatshenshini drainage, as well as observations about glacier advances, retreats, and surges. The paper addresses two large policy debates. One concerns the incorporation of local knowledge into scientific research. The second addresses the way in which oral tradition contributes another variety of historical understanding in areas of the world where written documents are relatively recent. Academic debates, whether in science or in history, too often evaluate local expertise as data or evidence, rather than as knowledge or theory that might contribute different perspectives to academic questions. ([Cruikshank 2001](#))

DeGange, A., K. Oakley, G. Irvine, G. Mayfield, S. Frenzel, J. Trawicki, D. Lassuy, D. Woodson, S. Talbot, and J. Wenburg. 2005. [U.S. Geological Survey and U.S. Fish and Wildlife Service Future Challenges Project Report](#). August 16, 2005. 72 pp.

Donald, D.B., J. Syrgiannis, R.W. Crosley, G. Holdsworth, D.C.G. Muir, B. Rosenberg, A. Sole, and D.W. Schindler. 1999. Delayed deposition of organochlorine pesticides at a temperate glacier. *Environmental Science and Technology*. 33(11):1794-1798.

Many of the organochlorine pesticides that were once widely used have either been banned or uses have been restricted in Canada and the United States. Near areas of high pesticide use at mid-latitudes in eastern North America, environmental levels of some of these pesticides peaked in the 1960s, and all have declined at least since the late 1970s. We determined depositional trends in a mid-latitude temperate glacier in Alberta, western Canada (52 degree N, 117 degree W). In contrast to trends in eastern North America, capital sigma DDT, dieldrin, and capital sigma chlordane reached peak concentrations (2.57, 0.05, and 0.07 ng/L, respectively) and maximum flux to this cold high elevation environment in the 1980s at least 1 decade after they had been banned and maximum use had occurred in North America. From 1959 to 1995, a significant decline was evident for alpha - HCH ( $r$  super(2) identical with - 0.64,  $p < 0.001$ ). A significant severalfold increase and positive trend ( $r$  super(2) identical with 0.17,  $p < 0.03$ ) was evident for hexachlorobenzene with maximum flux occurring in the 1990s. Lindane and capital sigma chlordane had a distinct bimodal depositional pattern with peak concentrations occurring about 1960 and again in 1989. Meltwater from glaciers may contribute high concentrations of pesticides to cold aquatic ecosystems for decades or centuries. ([CSA Illumina](#))

Dunn, P.O. and D.W. Winkler. 1999. [Climate change has affected the breeding date of tree swallows through North America](#). Proc. R. Soc. Lond. B. 266:2487-2490. ()

Increasing evidence suggests that climate change has affected the breeding and distribution of wildlife. If such changes are due to global warming, then we should expect to see large-scale effects. To explore for such effects on avian reproduction, we examined 3450 nest records of tree swallows from across North America. The egg-laying date in tree swallows advanced by up to nine days during 1959 to 1991. This advance in phenology was associated with increasing surface air temperatures at the time of breeding. Our analysis controlled for several potentially confounding variables such as latitude, longitude, breeding density and elevation. We conclude that tree swallows across North America are breeding earlier and that the most likely cause is a long-term increase in spring temperature. ([The Royal Society](#))

Dyurgerov, M.B. and M.F. Meier. 2000. [Twentieth century climate change: evidence from small glaciers](#). PNAS. 97(4):1406-1411.

The relation between changes in modern glaciers, not including the ice sheets of Greenland and Antarctica, and their climatic environment is investigated to shed light on paleoglacier evidence of past climate change and for projecting the effects of future climate warming on cold regions of the world. Loss of glacier volume has been more or less continuous since the 19th century, but it is not a simple adjustment to the end of an “anomalous” Little Ice Age. We address the 1961–1997 period, which provides the most observational data on volume changes. These data show trends that are highly variable with time as well as within and between regions; trends in the Arctic are consistent with global averages but are quantitatively smaller. The averaged annual volume loss is 147 mm<sub>zyr</sub><sup>21</sup> in water equivalent, totaling 3.7 3103 km<sup>3</sup> over 37 yr. The time series shows a shift during the mid-1970s, followed by more rapid loss of ice volume and further acceleration in the last decade; this is consistent with climatologic data. Perhaps most significant is an increase in annual accumulation along with an increase in melting; these produce a marked increase in the annual turnover or amplitude. The rise in air temperature suggested by the temperature sensitivities of glaciers in cold regions is somewhat greater than the global average temperature rise derived largely from low altitude gauges, and the warming is accelerating. ([Dyurgerov and Meier 2000](#))

Epstein, H.E., Beringer, J., Gould, W.A., Lloyd, A.H., Thompson, C.D., Chapin, III, F.S., Michaelson, G.J., Ping, C.L., Rupp, T.S., and D.A. Walker. 2004. The nature of spatial transitions in the arctic. Journal of Biogeography. 31(12): 1917-1933.

We suggest that vegetation will respond most rapidly to climatic change when (i) the vegetation transition correlates more strongly with climate than with other environmental variables, (ii) dominant species exhibit gradual changes in abundance across spatial transitions, and/or (iii) the dominant species have demographic properties that allow rapid increases in abundance following climatic shifts. All three of these properties characterize the transition between tussock tundra and low shrub tundra. It is therefore not surprising that of the four transitions studied this is the one that appears to be responding most rapidly to climatic warming. ([Blackwell Synergy](#))

Field, C.B., F.S. Chapin III, P.A. Matson, and H.A. Mooney. 1992. [Responses of terrestrial ecosystems to the changing atmosphere: a resource-based approach](#). Annu. Rev. Ecol. Syst. 23:201-235.

Forbes, B.C., J.J. Ebersole, and B. Strandberg. 2001. [Anthropogenic disturbance and patch dynamics in circumpolar arctic ecosystems](#). *Conservation Biology*. 15(4):954-969.

It has been 30 years since environmental concern was first expressed over the prospect of large-scale resource development in the Arctic. Human effects are more extensive within the tundra biome now than at any time in the past. With or without predicted climatic changes, interaction among different natural and contemporary anthropogenic disturbance regimes are bound to have a significant effect on local and regional vegetation patterns and plant migration. We summarize the results of recent studies of patchy anthropogenic disturbance. We pay particular attention to the natural regeneration of plant communities, emphasize patch dynamics over the medium term (20–75 years), and discuss the data in the context of popular models of vegetation change following disturbance. Disturbance is important because it produces patches of partially or totally denuded ground that permit propagule establishment but may also open affected areas to erosion. Even relatively low-intensity, small-scale disturbances have immediate and persistent effects on arctic vegetation and soils. On all but the wettest sites, the patches support new, relatively stable vegetation states. Where slope is minimal, such disturbances are capable of expanding over large areas in as short a time as 4 years. The effects result in an artificial mosaic of patches of highly variable quality and quantity that comprise feeding and nesting habitats for terrestrial herbivores.

([Blackwell Synergy](#))

Francis, C., S.R. Hare, A.B. Hollowed, and W.S. Wooster. 1998. [Effects of interdecadal climate variability on the oceanic ecosystems of the NE Pacific](#). *Fish. Oceanogr.* 7(1):1-21.

A major reorganization of the North-east Pacific biota transpired following a climatic 'regime shift' in the mid 1970s. In this paper, we characterize the effects of interdecadal climate forcing on the oceanic ecosystems of the NE Pacific Ocean. We consider the concept of scale in terms of both time and space within the North Pacific ecosystem and develop a conceptual model to illustrate how climate variability is linked to ecosystem change. Next we describe a number of recent studies relating climate to marine ecosystem dynamics in the NE Pacific Ocean. These studies have focused on most major components of marine ecosystems - primary and secondary producers, forage species, and several levels of predators. They have been undertaken at different time and space scales. However, taken together, they reveal a more coherent picture of how decadal-scale climate forcing may affect the large oceanic ecosystems of the NE Pacific. Finally, we synthesize the insight gained from interpreting these studies. Several general conclusions can be drawn. There are large-scale, low-frequency, and sometimes very rapid changes in the distribution of atmospheric pressure over the North Pacific which are, in turn, reflected in ocean properties and circulation. Oceanic ecosystems respond on similar time and space scales to variations in physical conditions. Linkages between the atmosphere/ocean physics and biological responses are often different across time and space scales. While the cases presented here demonstrate oceanic ecosystem response to climate forcing, they provide only hints of the mechanisms of interaction. A model whereby ecosystem response to specified climate variation can be successfully predicted will be difficult to achieve because of scale mismatches and nonlinearities in the atmosphere-ocean-biosphere system. ([CSA Illumina](#))

Glick, P. 2005. [The waterfowlers' guide to global warming](#). Washington, D.C.: National Wildlife Federation, 2005.

In this report we have endeavored to compile and present the available scientific information on the potential impacts of global warming on the waterfowl resource. We also describe actions to take to minimize potential effects. The genesis for this report was The Wildlife Society's Technical Review "Global Climate Change and Wildlife in North America." ([Inkley 2005](#))

Gregory, R., L. Failing, and A. Leiserowitz. 2006. [Climate change impacts, vulnerabilities and adaptation in Northwest Alaska](#) (No. 06-11). Eugene: Decision Research. 16 pp.

Griffith, B., D.C. Douglas, D.E. Russell, R.G. White, T.R. McCabe, and K.R. Whitten. 2001. [Effects of recent climate warming on caribou habitat and calf survival](#). In *Impacts of Climate Change on Wildlife*. R.E. Green, M. Harley, M. Spalding, and C. Zockler (eds.). Royal Society for the Protection of Birds. 73 pp.

Hansen, J., L. Nazarenko, R. Ruedy, M. Sato, J. Willis, A. Del Genio, D. Koch, A. Lacis, K. Lo, S. Menon, T. Novakov, J. Perlwitz, G. Russell, G.A. Schmidt, and N. Tausnev. 2005. [Earth's energy imbalance: confirmation and implications](#). *Science*. 308: 1431-1435.

Our climate model, driven mainly by increasing human-made greenhouse gases and aerosols, among other forcings, calculates that Earth is now absorbing 0.85 T 0.15 watts per square meter more energy from the Sun than it is emitting to space. This imbalance is confirmed by precise measurements of increasing ocean heat

content over the past 10 years. Implications include (i) the expectation of additional global warming of about 0.6-<sup>o</sup>C without further change of atmospheric composition; (ii) the confirmation of the climate system's lag in responding to forcings, implying the need for anticipatory actions to avoid any specified level of climate change; and (iii) the likelihood of acceleration of ice sheet disintegration and sea level rise. ([Hansen et al. 2005](#))

Hinzman, L.D., N.D. Bettez, W.R. Bolton, F.S. Chapin, M.B. Dyurgerov, C.L. Fastie, B. Griffith, R.D. Hollister, A. Hope, H.P. Huntington, A.M. Jensen, G.J. Jia, T. Jorgenson, D.L. Kane, D.R. Klein, G. Kofinas, A.H. Lynch, A.H. Lloyd, A.D. McGurie, F.E. Nelson, W.C. Oechel, T.E. Osterkamp, C.H. Racine, V.E. Romanovsky, R.S. Stone, D.A. Stow, M. Sturm, C.E. Tweedie, G.L. Vourlitis, M.D. Walter, D.A. Walker, P.J. Webber, J.M. Welker, K.S. Winker, and K. Yoshikawa. 2005. [Evidence and implications of recent climate change in northern Alaska and other arctic regions](#). *Climate Change* 72:251-298.

The Arctic climate is changing. Permafrost is warming, hydrological processes are changing and biological and social systems are also evolving in response to these changing conditions. Knowing how the structure and function of arctic terrestrial ecosystems are responding to recent and persistent climate change is paramount to understanding the future state of the Earth system and how humans will need to adapt. Our holistic review presents a broad array of evidence that illustrates convincingly; the Arctic is undergoing a system-wide response to an altered climatic state. New extreme and seasonal surface climatic conditions are being experienced, a range of biophysical states and processes influenced by the threshold and phase change of freezing point are being altered, hydrological and biogeochemical cycles are shifting, and more regularly human sub-systems are being affected. Importantly, the patterns, magnitude and mechanisms of change have sometimes been unpredictable or difficult to isolate due to compounding factors. In almost every discipline represented, we show how the biocomplexity of the Arctic system has highlighted and challenged a paucity of integrated scientific knowledge, the lack of sustained observational and experimental time series, and the technical and logistic constraints of researching the Arctic environment. This study supports ongoing efforts to strengthen the interdisciplinarity of arctic system science and improve the coupling of large scale experimental manipulation with sustained time series observations by incorporating and integrating novel technologies, remote sensing and modeling. ([SpringerLink](#))

Humphries, M.M., D.W. Thomas, and J.R. Speakman. 2002. Climate-mediated energetic constraints on the distribution of hibernating mammals. *Nature*. 418(6895):313-316.

To predict the consequences of human-induced global climate change, we need to understand how climate is linked to biogeography. Energetic constraints are commonly invoked to explain animal distributions, and physiological parameters are known to vary along distributional gradients. But the causal nature of the links between climate and animal biogeography remain largely obscure. Here we develop a bioenergetic model that predicts the feasibility of mammalian hibernation under different climatic conditions. As an example, we use the well-quantified hibernation energetics of the little brown bat (*Myotis lucifugus*) to parameterize the model. Our model predicts pronounced effects of ambient temperature on total winter energy requirements, and a relatively narrow combination of hibernaculum temperatures and winter lengths permitting successful hibernation. Microhabitat and northern distribution limits of *M. lucifugus* are consistent with model predictions, suggesting that the thermal dependence of hibernation energetics constrains the biogeography of this species. Integrating projections of climate change into our model predicts a pronounced northward range expansion of hibernating bats within the next 80 years. Bioenergetics can provide the simple link between climate and biogeography needed to predict the consequences of climate change. ([CSA Illumina](#))

Hunt, G.L. and P.J. Stabenro. 2002. [Climate change and the control of energy flow in the southeastern Bering Sea](#). *Progress in Oceanography*. 55:5-22.

We examine how coupling between physical and biological processes influences the production and transfer of energy to upper trophic-level species in the southeastern Bering Sea. We review time series that illustrate changes in the marine climate of the southeastern Bering Sea since the mid-1970s, particularly variability in the persistence of sea ice and the timing of its retreat. Time series (1995 – 2001) from a biophysical mooring in the middle domain of the southeastern shelf support the hypothesis that retreat of the winter sea ice before mid-March (or the failure of ice to be advected into a region) results in an open water bloom in May or June in relatively warm water ( $\sim 3^{\circ}\text{C}$ ). Conversely, when ice retreat is delayed until mid-March or later, an ice-associated bloom occurs in cold ( $\sim 0^{\circ}\text{C}$ ) water in early spring. These variations are important because the growth and production of zooplankton and the growth and survival of larval and juvenile fish are sensitive to water temperature. The Oscillating Control Hypothesis (OCH) recently proposed by Hunt et al. (2002), predicts that control of the

abundance of forage fish, and in the case of walleye Pollock (*Theragra chalcogramma*), recruitment of large piscivorous fish, will switch from bottom-up limitation in extended periods with late ice retreat to top-down in warmer periods when ice retreat occurs before mid-March. In support of this hypothesis, we review recent data from the southeastern Bering Sea that show 2- to 13-fold changes in copepod abundance with changes in spring water temperatures of 3 to 5°C. We also provide indirect evidence that the abundance of adult pollock on the eastern Bering Sea shelf negatively affects the abundance forage fishes (including juvenile pollock) available to top predators. Although there is evidence that pollock year-class strength is positively related to temperature, we lack the time series of pollock populations in extended periods (8 – 10 years) of cold-water blooms necessary to test the OCH. ([Hunt and Stabeno 2002](#))

Hunt, G.L., P. Stabeno, G. Walters, E. Sinclair, R.D. Brodeur, J.M. Napp, N.A. Bond. 2002. [Climate change and control of the southeastern Bering Sea pelagic ecosystem](#). Deep-Sea Research II 49:5821-5853.

We propose a new hypothesis, the Oscillating Control Hypothesis (OCH), which predicts that pelagic ecosystem function in the southeastern Bering Sea will alternate between primarily bottom-up control in cold regimes and primarily top-down control in warm regimes. The timing of spring primary production is determined predominately by the timing of ice retreat. Late ice retreat (late March or later) leads to an early, ice-associated bloom in cold water (e.g., 1995, 1997, 1999), whereas no ice, or early ice retreat before mid-March, leads to an open-water bloom in May or June in warm water (e.g., 1996, 1998, 2000). Zooplankton populations are not closely coupled to the spring bloom, but are sensitive to water temperature. In years when the spring bloom occurs in cold water, low temperatures limit the production of zooplankton, the survival of larval/juvenile fish, and their recruitment into the populations of species of large piscivorous fish, such as walleye pollock (*Theragra chalcogramma*), Pacific cod (*Gadus macrocephalus*) and arrowtooth flounder (*Atheresthes stomias*). When continued over decadal scales, this will lead to bottom-up limitation and a decreased biomass of piscivorous fish. Alternatively, in periods when the bloom occurs in warm water, zooplankton populations should grow rapidly, providing plentiful prey for larval and juvenile fish. Abundant zooplankton will support strong recruitment of fish and will lead to abundant predatory fish that control forage fish, including, in the case of pollock, their own juveniles. Piscivorous marine birds and pinnipeds may achieve higher production of young and survival in cold regimes, when there is less competition from large piscivorous fish for coldwater forage fish such as capelin (*Mallotus villosus*). Piscivorous seabirds and pinnipeds also may be expected to have high productivity in periods of transition from cold regimes to warm regimes, when young of large predatory species of fish are numerous enough to provide forage. The OCH predicts that the ability of large predatory fish populations to sustain fishing pressure will vary between warm and cold regimes. The OCH points to the importance of the timing of ice retreat and water temperatures during the spring bloom for the productivity of zooplankton, and the degree and direction of coupling between zooplankton and forage fish. Forage fish (e.g., juvenile pollock, capelin, Pacific herring [*Clupea pallasii*]) are key prey for adult pollock and other apex predators. In the southeastern Bering Sea, important changes in the biota since the mid-1970s include a marked increase in the biomass of large piscivorous fish and a concurrent decline in the biomass of forage fish, including age-1 walleye pollock, particularly over the southern portion of the shelf. Populations of northern fur seals (*Callorhinus ursinus*) and seabirds such as kittiwakes (*Rissa* spp.) at the Pribilof Islands have declined, most probably in response to a diminished prey base. The available evidence suggests that these changes are unlikely the result of a decrease in total annual new primary production, though the possibility of reduced post-bloom production during summer remains. An ecosystem approach to management of the Bering Sea and its fisheries is of great importance if all of the ecosystem components valued by society are to thrive. Cognizance of how climate regimes may alter relationships within this ecosystem will facilitate reaching that goal. ([Hunt et al. 2002](#))

Inkley, D. B., M. G. Anderson, A. R. Blaustein, V. R. Burkett, B. Felzer, B. Griffith, J. Price, and T. L. Root. 2004. [Global climate change and wildlife in North America](#). Wildlife Society Technical Review 04-2. The Wildlife Society, Bethesda, Maryland, USA. 26 pp.

A three-year study released by the Wildlife Society that technically reviews climate change's impact on North American wildlife. The study indicates that warming has already altered migration routes, blooming cycles and breeding habits of animals and plants across the continent. ([Stanford Center for Environmental Sciences and Policy](#))

IPCC. 2007. [Climate change 2007: the physical science basis](#). World Meteorological Organization and United Nations Environment Programme. Geneva, Switzerland. 18 pp.

Kaeriyama, M., M. Nakamura, R. Edpalina, J.R. Bower, H. Yamaguchi, R.V. Walker, and K.W. Myers. 2004. [Change in feeding ecology and trophic dynamics of Pacific salmon \(\*Oncorhynchus\* spp.\) in the central Gulf of Alaska in relation to climate events](#). *Fish. Oceanogr.* 13(3):197-207.

The effects of climate events on the feeding ecology and trophic dynamics of Pacific salmon (*Oncorhynchus* spp.) in offshore waters of the central Gulf of Alaska were investigated during early summers (1994–2000), based on analyses of stomach contents, and carbon and nitrogen stable isotopes ( $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$ ). Gonatid squids (mainly *Beryteuthis anonychus*) were the dominant prey of all salmon species except for chum salmon (*O. keta*). During the 1997 El Niño event and the 1999 La Niña event, squids decreased sharply in the diets of all Pacific salmon except coho salmon (*O. kisutch*) in the Subarctic Current, and chum salmon diets changed from gelatinous zooplankton (1995–97) to a more diverse array of zooplankton species. A  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  analysis indicated that all salmon species occupied the same branch of the food web in 1999–2000. We hypothesize that high-seas salmon adapt to climate-induced changes in their prey resources by switching their diets either within or between trophic levels. To understand the effects of climate change on Pacific salmon in the Gulf of Alaska, biological oceanographic research on *B. anonychus* and other important prey resources is needed. ([Blackwell Synergy](#))

Kaplan, J.O., N.H. Bigelow, I.C. Prentice, S.P. Harrison, P.J. Bartlein, T.R. Christensen, W. Cramer, N.V. Matveyeva, A.D. McGuire, D.F. Murray, V.Y. Razzhivin, B. Smith, D.A. Walker, P.M. Anderson, A.A. Andreev, L.B. Brubaker, M.E. Edwards, and A.V. Lozhkin. 2003. [Climate change and Arctic ecosystems: Modeling, paleodata-model comparisons, and future projections](#). *Journal of Geophysical Research.* 108(D19):8171.

Large variations in the composition, structure, and function of Arctic ecosystems are determined by climatic gradients, especially of growing-season warmth, soil moisture, and snow cover. A unified circumpolar classification recognizing five types of tundra was developed. The geographic distributions of vegetation types north of 55°N, including the position of the forest limit and the distributions of the tundra types, could be predicted from climatology using a small set of plant functional types embedded in the biogeochemistry-biogeography model BIOME4. Several palaeoclimate simulations for the last glacial maximum (LGM) and mid-Holocene were used to explore the possibility of simulating past vegetation patterns, which are independently known based on pollen data. The broad outlines of observed changes in vegetation were captured. LGM simulations showed the major reduction of forest, the great extension of graminoid and forb tundra, and the restriction of low- and high-shrub tundra (although not all models produced sufficiently dry conditions to mimic the full observed change). Mid-Holocene simulations reproduced the contrast between northward forest extension in western and central Siberia and stability of the forest limit in Beringia. Projection of the effect of a continued exponential increase in atmospheric CO<sub>2</sub> concentration, based on a transient ocean-atmosphere simulation including sulfate aerosol effects, suggests a potential for larger changes in Arctic ecosystems during the 21st century than have occurred between mid-Holocene and present. Simulated physiological effects of the CO<sub>2</sub> increase (to >700 ppm) at high latitudes were slight compared with the effects of the change in climate. ([Kaplan et al. 2003](#))

Keyser, A.R., J.S. Kimball, R.R. Nemani, and S.W. Running. 2000. [Simulating the effects of climate change on the carbon balance of North American high-latitude forests](#). *Global Change Biology.* 6(Suppl. 1):185-195.

The large magnitude of predicted warming at high latitudes and the potential feedback of ecosystems to atmospheric CO<sub>2</sub> concentrations make it important to quantify both warming and its effects on high-latitude carbon balance. We analysed long-term, daily surface meteorological records for 13 sites in Alaska and north-western Canada and an 82-y record of river ice breakup date for the Tanana River in interior Alaska. We found increases in winter and spring temperature extrema for all sites, with the greatest increases in spring minimum temperature, average 0.47 °C per 10 y, and a 0.7-day per 10 y advance in ice breakup on the Tanana River. We used the climate records to drive an ecosystem process model, BIOME\_BGC, to simulate the effects of climate change on the carbon and water balances of boreal forest ecosystems. The growing season has lengthened by an average of 2.6 days per 10 y with an advance in average leaf onset date of 1.10 days per 10 y. This advance in the start of the active growing season correlates positively with progressively earlier ice breakup on the Tanana River in interior Alaska. The advance in the start of the growing season resulted in a 20% increase in net primary production for both aspen (*Populus tremuloides*) and white spruce (*Picea glauca*) stands. Aspen had a greater mean increase in maintenance respiration than spruce, whereas spruce had a greater mean increase in evapotranspiration. Average decomposition rates also increased for both species. Both net primary production and decomposition are enhanced in our simulations, suggesting that productive forest types may not experience a significant shift in net carbon flux as a result of climate warming. ([Keyser et al. 2000](#))

Klein, E., E.E. Berg, and R. Dial. 2005. [Wetland drying and succession across the Kenai Peninsula Lowlands, south-central Alaska](#). Canadian Journal of Forest Research 35:1931-1941.

This study documents the scale and intensity of drying over the last half century in the Kenai Lowlands of south-central Alaska. Using historical aerial photos and field sampling of wetlands, including muskegs, kettle ponds, and closed and open basin lakes, we present data on drying and successional changes in woody vegetation between 1950 and 1996. The results of this study suggest that the Kenai Peninsula is becoming both woodier in its vegetation and drier. A regional analysis of 1113 random points indicated increased forest cover and decreased open and wet areas in both burned and unburned areas between 1950 and 1996. A census of water bodies in three subregions indicates that almost two-thirds of water bodies visited show some level of decrease in spatial area. Over 80% of field sites visited have experienced some level of drying, where vegetation transects indicate substantial invasion into former lake beds by facultative upland plants. These results are consistent with a regional change in climate that is both warming and drying as documented in Kenai and Anchorage weather records. ([Klein et al. 2005](#))

Kolbert, E. 2005. [Climate of Man - I](#). Annals of Science, The New Yorker. Published April 25, 2005.

Kolbert, E. 2005. [Climate of Man - II](#). Annals of Science, The New Yorker. Published May 2, 2005.

Kolbert, E. 2005. [Climate of Man - III](#). Annals of Science, The New Yorker. Published May 9, 2005.

Kolbert, E. 2006. [The darkening seas](#). Annals of Science, The New Yorker. Published November 20, 2006.

Koppes, M.N. and B. Hallet. 2002. [Influence of rapid glacial retreat on the rate of erosion by tidewater glaciers](#). Geology. 30(1):47-50.

Glacial erosion rates inferred from total sediment budgets in recently deglaciated fjords, which are the highest reported erosion rates worldwide, have received considerable attention in fields as diverse as tectonics, glacial sedimentation, and climate. These record rates, however, are representative only of tidewater glaciers during their extensive retreat of the post-Little Ice Age period; erosion rates averaged over glacial-interglacial cycles and longer periods are likely to be substantially smaller. We examine the influence of retreat rate on sediment yields from tidewater glaciers by reconstructing the history of sediment output from retreating glaciers necessary to produce sediment packages observed in contemporary fjords. Using a simple numerical model of proglacial sedimentation in front of a retreating glacier, seismic profiles of proglacial sediments, and the history of terminus retreat of Muir Glacier, Glacier Bay, Alaska, we calculate the sediment flux as a function of time from this glacier between 1900 and 1979, and conclude that sediment flux scales with retreat rate. The corresponding basin-wide erosion rate during this 79 yr period averages 37 mm/yr, and exceeds long-term erosion rates by a factor of 5-6. For Muir Glacier and, by inference, for other calving glaciers, the general drastic retreat and the marked regional drawdown of ice since the Little Ice Age are both linked to unusually rapid calving and fast ice motion, which is conducive to rapid erosion. ([Koppes and Hallet 2002](#))

Lau, K.-M. and H. Weng. 1999. [Interannual, decadal-interdecadal, and global warming signals in sea surface temperature during 1955-1997](#). Journal of Climate. 12:1257-1267.

Sea surface temperature (SST) data from the NOAA analysis for the period of 1955-97 are used to identify dominant spatial and temporal patterns associated with interannual, decadal-interdecadal variabilities, and global warming. For the global annual mean SST variation, a linear trend plus pronounced decadal-interdecadal and interannual variabilities are found. The linear trend reflects a slow warming of about 0.18C in the past four decades. Superimposed on the linear trend is a relatively fast warming in the past two decades of approximately 0.28-0.38C, which is associated with the advent of the warm phase of a decadal-interdecadal oscillation. Also noted is the more frequent occurrence of warm events and the dearth of cold events on interannual timescales in the early and mid-1990s. For the last four decades, the tropical oceans have been warming at the faster rate while the extratropical North Pacific and the northwestern North Atlantic has been cooling at the slower rate. The exceptional intensity of the 1997 warm event stems from the superposition of the warm phases of a moderate interannual signal, a decadal-interdecadal oscillation, and a steady warming trend since 1955. The first annual empirical orthogonal function (EOF) mode shows an El Niño signal, modified by a warming trend. In this mode, the tropical eastern Pacific and Indian Oceans are warmed relative to the western Pacific, leading to a relaxation of the climatological east-west SST gradient. The second annual EOF mode shows that there is a secondary cooling trend in the equatorial eastern Pacific, centered near the Niño-3 (5S-5N, 150E-90W) area. This

cooling is most pronounced in the boreal fall and summer. It was strongest in the 1980s, but considerably weakened in the 1990s. The cooling is well correlated with the observed surface wind divergence in the equatorial eastern Pacific cold tongue region and with anomalous surface easterly wind in the equatorial central Pacific, signaling an enhancement of the Walker circulation. The net result of the warming and cooling tendencies in the tropical eastern Pacific produces slightly less warming in the Niño-3 area compared with the equatorial central and eastern Pacific, but with little change in large-scale SST gradient across the Pacific. The implications of the present results on the mechanisms and detection of global warming are discussed. ([Lau and Weng 1999](#))

Leiserowitz, A., and J. Craciun. 2006. [Alaskan Opinions on Global Warming](#) (No. 06-10). Eugene: Decision Research.

Lloyd, A., T.S. Rupp, C. Fastie, and A.M. Starfield. 2003. Patterns and dynamics of treeline advance on the Seward Peninsula, Alaska. *Journal of Geophysical Research. D. Atmospheres*. 108(D2):8161.

Boreal tree species are expected to invade tundra ecosystems as climate warms. Because forested ecosystems differ from tundra ecosystems in a number of climatically relevant characteristics, this advance of the altitudinal and latitudinal tree limit may ultimately feedback on regional climate. We used tree rings to reconstruct the response of the treeline ecotone on the Seward Peninsula in northwestern Alaska to 20th century warming. We further explored the sensitivity of the treeline ecotone to climate change using the spatially explicit, frame-based model ALFRESCO. Our reconstructions of forest response to past warming indicate that in upland tundra spruce have successfully established progressively farther from the forest limit since the 1880s. Shrub tundra has thus been converted to low-density forest-tundra within a band extending approximately 10 km from the forest limit. In lowland sites, where soil thermal and hydrologic properties are the primary constraint on tree distribution, trees began establishing in tundra after 1920, and establishment was restricted to areas that had experienced thermokarst activity in the past. Modeling experiments suggested that changes in disturbance regime and spruce growth response to climate may introduce strongly nonlinear responses to climate change at treeline. Field data and model experiments thus both indicate that large and nearly instantaneous responses to warming are likely at the treeline ecotone but that sensitivity to warming is likely to vary substantially over space and time.

([CSA Illumina](#))

Nelson, R.E. 2001. [Bioclimatic implication and distribution patterns of the modern ground beetle fauna \(Insecta: Coleoptera: Carabidae\) of the Arctic Slope of Alaska, U.S.A.](#) *Arctic*. 54(4):425-430.

Some 56 species of Carabidae have been previously reported on the Arctic Slope of Alaska; of these, only nine have been found at coastal sites in the region. Though for some taxa (e.g., most species of *Bembidion*) this may reflect a lack of suitable habitat in the coastal environment, for most others it probably reflects the summer temperature differences between the relatively cool coastal areas (mean July temp [mJt] of ca. 4°C) and warmer interior sites (mJt of ca. 9– 10°C). The boundary between the relatively species-rich interior fauna and the more depauperate coastal fauna is probably also approximated by the inland limit of incursions of cool summer coastal fogs, which coincides with a sharp vegetational boundary. Additional systematic collecting of specimens and a coordinated effort to gather climate data will be needed to delimit distributional limits more closely and to provide background data for both modern environmental monitoring and paleoenvironmental reconstructions. ([Nelson 2001](#))

Oechel, W.C., G.L. Vourlitis, S.J. Hastings, and S.A. Bochkarev. 1995. [Change in Arctic CO<sub>2</sub> flux over two decades: effects of climate change at Barrow, Alaska.](#) *Ecological Applications*, 5(3):846-855.

A significant difference in net ecosystem carbon balance of wet sedge ecosystems in the Barrow, Alaska region was observed between CO<sub>2</sub> flux measurements obtained during the International Biological Program in 1971 and measurements made during the 1991-1992 growing seasons. Currently, high-center polygons are net sources of CO<sub>2</sub> to the atmosphere of approximately 14 gC/m<sup>2</sup>/yr, while low-center polygons are losing approximately 3.6 gC/m<sup>2</sup>/yr, and ice wedge habitats are accumulating 4.0 gC/m<sup>2</sup>/yr. On average, moist meadow habitats characteristic of the IBP-II site are currently sources of approximately 1.3 gC/m<sup>2</sup>/yr to the atmosphere compared to the reported accumulation of approximately 25 gC/m<sup>2</sup>/yr determined in 1971. This difference in ecosystem function over the last two decades may be due to the recently reported increase in surface temperatures resulting in decreases in the soil moisture status. These results point to the importance of long-term research sites and databases for determining the potential effects of climate change on ecosystem function. ([CSA Illumina](#))

Oerlemans, J., B. Anderson, A. Hubbard, Ph. Huybrechts, T. Johannesson, W.H. Knap, M. Schmeits, A.P. Stroeven, R.S.W. van de Wal, J. Wallinga, and Z. Zuo. 1998. [Modeling the response of glaciers to climate warming](#). *Climate Dynamics*. 14:267-274.

Dynamic ice-flow models for 12 glaciers and ice caps have been forced with various climate change scenarios. The volume of this sample spans three orders of magnitude. Six climate scenarios were considered: from 1990 onwards linear warming rates of 0.01, 0.02 and 0.04 K a<sup>-1</sup>, with and without concurrent changes in precipitation. The models, calibrated against the historic record of glacier length where possible, were integrated until 2100. The differences in individual glacier responses are very large. No straightforward relationship between glacier size and fractional change of ice volume emerges for any given climate scenario. The hypsometry of individual glaciers and ice caps plays an important role in their response, thus making it difficult to generalize results. For a warming rate of 0.04 K a<sup>-1</sup>, without increase in precipitation, results indicate that few glaciers would survive until 2100. On the other hand, if the warming rate were to be limited to 0.01 K a<sup>-1</sup> with an increase in precipitation of 10% per degree warming, we predict that overall loss would be restricted to 10 to 20% of the 1990 volume. ([Oerlemans et al. 1998](#))

Pacala, S. and R. Socolow. 2004. [Stabilization wedges: solving the climate problem for the next 50 years with current technologies](#). *Science*. 305:968-972.

Humanity already possesses the fundamental scientific, technical, and industrial know-how to solve the carbon and climate problem for the next half-century. A portfolio of technologies now exists to meet the world's energy needs over the next 50 years and limit atmospheric CO<sub>2</sub> to a trajectory that avoids a doubling of the preindustrial concentration. Every element in this portfolio has passed beyond the laboratory bench and demonstration project; many are already implemented somewhere at full industrial scale. Although no element is a credible candidate for doing the entire job (or even half the job) by itself, the portfolio as a whole is large enough that not every element has to be used. ([Pacala and Socolow 2004](#))

Parmesan, C. 2006. [Ecological and evolutionary responses to recent climate change](#). *Annu. Rev. Ecol. Syst.* 37: 637-69.

Ecological changes in the phenology and distribution of plants and animals are occurring in all well-studied marine, freshwater, and terrestrial groups. These observed changes are heavily biased in the directions predicted from global warming and have been linked to local or regional climate change through correlations between climate and biological variation, field and laboratory experiments, and physiological research. Range-restricted species, particularly polar and mountaintop species, show severe range contractions and have been the first groups in which entire species have gone extinct due to recent climate change. Tropical coral reefs and amphibians have been most negatively affected. Predator-prey and plant-insect interactions have been disrupted when interacting species have responded differently to warming. Evolutionary adaptations to warmer conditions have occurred in the interiors of species' ranges, and resource use and dispersal have evolved rapidly at expanding range margins. Observed genetic shifts modulate local effects of climate change, but there is little evidence that they will mitigate negative effects at the species level.

([Parmesan 2006](#))

Parmesan, C., and H. Galbraith. 2004. [Observed impacts of global climate change in the U.S.](#) Pew Center on Global Climate Change. 67 pp.

This report assesses the scientific evidence compiled to date on the observed ecological effects of climate change in the United States and their consequences. It evaluates the strength of that evidence and the relationships between observed biological changes and human activities. Although many species and ecological systems of interest have yet to be studied (often due to inherent limitations of available data) and the attribution of ecological changes to a particular cause remains challenging, a number of robust findings emerge from this report.

([Parmesan and Galbraith 2004](#))

Parmesan, C., and G. Yohe. 2003. [A globally coherent fingerprint of climate change impacts across natural systems](#). *Nature* 421:37-42.

Causal attribution of recent biological trends to climate change is complicated because non-climatic influences dominate local, short-term biological changes. Any underlying signal from climate change is likely to be revealed by analyses that seek systematic trends across diverse species and geographic regions; however, debates within the Intergovernmental Panel on Climate Change (IPCC) reveal several definitions of a 'systematic trend'. Here, we explore these differences, apply diverse analyses to more than 1,700 species, and show that recent biological trends match climate change predictions. Global meta-analyses documented significant range shifts averaging

6.1 km per decade towards the poles (or metres per decade upward), and significant mean advancement of spring events by 2.3 days per decade. We define a diagnostic fingerprint of temporal and spatial 'sign-switching' responses uniquely predicted by twentieth century climate trends. Among appropriate long-term/large-scale/multi-species data sets, this diagnostic fingerprint was found for 279 species. This suite of analyses generates 'very high confidence' (as laid down by the IPCC) that climate change is already affecting living systems. ([Parmesan and Yohe 2003](#))

Richter-Menge, J., J. Overland, A. Proshutinsky, V. Romanovsky, L. Bengtsson, L. Brigham, M. Dyurgerov, J.C. Gascard, S. Gerland, R. Graversen, C. Haas, M. Karcher, P. Kuhry, J. Maslanik, H. Melling, W. Maslowski, J. Morison, D. Perovich, R. Przybylak, V. Rachold, I. Rigor, A. Shiklomanov, J. Stroeve, D. Walker, and J. Walsh. 2006. [State of the Arctic Report](#). NOAA OAR Special Report, NOAA/OAR/PMEL, Seattle, WA, 36 pp.

This State of the Arctic Report presents a review of recent data by an international group of scientists who developed a consensus on the information content and reliability. The report highlights data primarily from 2000 to 2005 with a first look at winter 2006, providing an update to some of the records of physical processes discussed in the Arctic Climate Impact Assessment (ACIA, 2004, 2005). Many of the trends documented in the ACIA are continuing, but some are not. Taken collectively, the observations presented in this report indicate that during 2000–2005 the Arctic system showed signs of continued warming. However, there are a few indications that certain elements may be recovering and returning to recent climatological norms (for example, the central Arctic Ocean and some wind patterns). These mixed tendencies further illustrate the sensitivity and complexity of the Arctic physical system. They underline the importance of maintaining and expanding efforts to observe and better understand this important component of the climate system to provide accurate predictions of its future state. ([Richter-Menge et al. 2006](#))

Riordan B, D. Verbyla, and A.D. McGuire. 2006. [Shrinking ponds in subarctic Alaska based on 1950-2002 remotely sensed images](#). Journal of Geophysical Research. 111(G04002): 1-11.

Over the past 50 years, Alaska has experienced a warming climate with longer growing seasons, increased potential evapotranspiration, and permafrost warming. Research from the Seward Peninsula and Kenai Peninsula has demonstrated a substantial landscape-level trend in the reduction of surface water and number of closed-basin ponds. We investigated whether this drying trend occurred at nine other regions throughout Alaska. One study region was from the Arctic Coastal Plain where deep permafrost occurs continuously across the landscape. The other eight study regions were from the boreal forest regions where discontinuous permafrost occurs. Mean annual precipitation across the study regions ranged from 100 to over 700 mm yr<sup>-1</sup>. We used remotely sensed imagery from the 1950s to 2002 to inventory over 10,000 closed-basin ponds from at least three periods from this time span. We found a reduction in the area and number of shallow, closed-basin ponds for all boreal regions. In contrast, the Arctic Coastal Plain region had negligible change in the area of closed-basin ponds. Since the 1950s, surface water area of closed-basin ponds included in this analysis decreased by 31 to 4 percent, and the total number of closed-basin ponds surveyed within each study region decreased from 54 to 5 percent. There was a significant increasing trend in annual mean temperature and potential evapotranspiration since the 1950s for all study regions. There was no significant trend in annual precipitation during the same period. The regional trend of shrinking ponds may be due to increased drainage as permafrost warms, or increased evapotranspiration during a warmer and extended growing season. ([Smithsonian/NASA Astrophysics Data System](#))

Root, T.L., J.T. Price, K.R. Hall, S.H. Schneider, C. Rosenzweig, and A. Pounds. 2003. [Fingerprints of global warming on wild animals and plants](#). Nature. 421:57-60.

Over the past 100 years, the global average temperature has increased by approximately 0.6 8C and is projected to continue to rise at a rapid rate<sup>1</sup>. Although species have responded to climatic changes throughout their evolutionary history<sup>2</sup>, a primary concern for wild species and their ecosystems is this rapid rate of change<sup>3</sup>. We gathered information on species and global warming from 143 studies for our meta-analyses. These analyses reveal a consistent temperature-related shift, or 'fingerprint', in species ranging from molluscs to mammals and from grasses to trees. Indeed, more than 80% of the species that show changes are shifting in the direction expected on the basis of known physiological constraints of species. Consequently, the balance of evidence from these studies strongly suggests that a significant impact of global warming is already discernible in animal and plant populations. The synergism of rapid temperature rise and other stresses, in particular habitat destruction, could easily disrupt the connectedness among species and lead to a reformulation of species communities, reflecting differential changes in species, and to numerous extirpations and possibly extinctions. ([Root et al. 2003](#))

Rupp, T.S., F.S. Chapin III, and A.M. Starfield. 2000. Response of subarctic vegetation to transient climatic change on the Seward Peninsula in northwest Alaska. *Global Change Biology* 6: 451-455.

Understanding the response of terrestrial ecosystems to climatic warming is a challenge because of the complex interactions of climate, disturbance, and recruitment across the landscape. We use a spatially explicit model (ALFRESCO) to simulate the transient response of subarctic vegetation to climatic warming on the Seward Peninsula (80 000 km<sup>2</sup>) in north-west Alaska. Model calibration efforts showed that fire ignition was less sensitive than fire spread to regional climate (temperature and precipitation). In the model simulations a warming climate led to slightly more fires and much larger fires and expansion of forest into previously treeless tundra. Vegetation and fire regime continued to change for centuries after cessation of the simulated climate warming. Flammability increased rapidly in direct response to climate warming and more gradually in response to climate-induced vegetation change. In the simulations warming caused as much as a 228% increase in the total area burned per decade, leading to an increasingly early successional and more homogenous deciduous forest-dominated landscape. A single transient 40-y drought led to the development of a novel grassland–steppe ecosystem that persisted indefinitely and caused permanent increases in fires in both the grassland and adjacent vegetation. These simulated changes in vegetation and disturbance dynamics under a warming climate have important implications for regional carbon budgets and biotic feedbacks to regional climate.

([CSA Illumina](#))

Rupp, T.S., A.M. Starfield, and F.S. Chapin III. 2000. [A frame-based spatially explicit model of subarctic vegetation response to climatic change: comparison with a point model](#). *Landscape Ecology* 15: 383-400.

An important challenge in global-change research is to simulate short-term transient changes in climate, disturbance regime, and recruitment that drive long-term vegetation distributions. Spatial features (e.g., topographic barriers) and processes, including disturbance propagation and seed dispersal, largely control these short-term transient changes. Here we present a frame-based spatially explicit model (ALFRESCO) that simulates landscape level response of vegetation to transient changes in climate and explicitly represents the spatial processes of disturbance propagation and seed dispersal. The spatial model and the point model from which it was developed showed similar results in some cases, but diverged in situations where interactions among neighboring cells (fire spread and seed dispersal) were crucial. Topographic barriers had little influence on fire size in low-flammability vegetation types, but reduced the average fire size and increased the number of fires in highly flammable vegetation (dry grassland). Large fires were more common in landscapes with large contiguous patches of two vegetation types while a more heterogeneous vegetation distribution increased fires in the less flammable vegetation type. When climate was held constant for thousands of years on a hypothetical landscape with the same initial vegetation, the spatial and point models produced identical results for some climates (cold, warm, and hot mesic), but produced markedly different results at current climate and when much drier conditions were imposed under a hot climate. Spruce migration into upland tundra was slowed or prevented by topographic barriers, depending on the size of the corridor. We suggest that frame-based, spatially explicit models of vegetation response to climate change are a useful tool to investigate both short- and long-term transients in vegetation at the regional scale. We also suggest that it is difficult to anticipate when non-spatial models will be reliable and when spatially explicit models are essential. ALFRESCO provides an important link between models of landscape-level vegetation dynamics and larger spatio-temporal models of global climate change. ([Rupp et al. 2000](#))

Rupp, T.S., F.S. Chapin III, and A.M. Starfield. 2001. [Modeling the influence of topographic barriers on treeline advance of the forest-tundra ecotone in northwestern Alaska](#). *Climatic Change* 48: 399-416.

The response of terrestrial ecosystems to climate warming has important implications to potential feedbacks to climate. The interactions between topography, climate, and disturbance could alter recruitment patterns to reduce or offset current predicted positive feedbacks to warming at high latitudes. In northern Alaska the Brooks Range poses a complex environmental and ecological barrier to species migration. We use a spatially explicit model (ALFRESCO) to simulate the transient response of subarctic vegetation to climatic warming in the Kobuk/Noatak River Valley (200–400 km) in northwest Alaska. The model simulations showed that a significantly warmer (+6 °C) summer climate would cause expansion of forest through the Brooks Range onto the currently treeless North Slope only after a period of 3000–4000 yr. Substantial forest establishment on the North Slope did not occur until temperatures warmed 9 °C, and only following a 2000 yr time lag. The long time lags between change in climate and change in vegetation indicate current global change predictions greatly over-estimate the response of vegetation to a warming climate in Alaska. In all the simulations warming caused a steady increase in the

proportion of early successional deciduous forest. This would reduce the magnitude of the predicted decrease in regional albedo and the positive feedback to climate warming. Simulation of spruce forest refugia on the North Slope showed forest could survive with only a 4 °C warming and would greatly reduce the time lag of forest expansion under warmer climates. Planting of spruce on the North Slope by humans could increase the likelihood of large-scale colonization of currently treeless tundra. Together, the long time lag and deciduous forest dominance would delay the predicted positive regional feedback of vegetation change to climatic warming. These simulated changes indicate the Brooks Range would significantly constrain regional forest expansion under a warming climate, with similar implications for other regions possessing major east-west oriented mountain ranges. ([Rupp et al. 2001](#))

Rupp, T.S., A.M. Starfield, F.S. Chapin III, and P. Duffy. 2002. [Modeling the impact of black spruce on the fire regime of Alaskan boreal forest](#). *Climatic Change* 55:213-233.

In the boreal biome, fire is the major disturbance agent affecting ecosystem change, and fire dynamics will likely change in response to climatic warming. We modified a spatially explicit model of Alaskan subarctic treeline dynamics (ALFRESCO) to simulate boreal vegetation dynamics in interior Alaska. The model is used to investigate the role of black spruce ecosystems in the fire regime of interior Alaska boreal forest. Model simulations revealed that vegetation shifts caused substantial changes to the fire regime. The number of fires and the total area burned increased as black spruce forest became an increasingly dominant component of the landscape. The most significant impact of adding black spruce to the model was an increase in the frequency and magnitude of large-scale burning events (i.e., time steps in which total area burned far exceeded the normal distribution of area burned). Early successional deciduous forest vegetation burned more frequently when black spruce was added to the model, considerably decreasing the fire return interval of deciduous vegetation. Ecosystem flammability accounted for the majority of the differences in the distribution of the average area burned. These simulated vegetation effects and fire regime dynamics have important implications for global models of vegetation dynamics and potential biotic feedbacks to regional climate.

([Rupp et al. 2002](#))

Schlyer, K. 2006. [Refuges at risk: the threat of global warming](#). K. Davies (ed.). *Defenders of Wildlife*. Washington, D.C. 23 pp.

Global warming is the single greatest threat imperiling the National Wildlife Refuge system as a whole, according to a Defenders' new report, *Refuges at Risk: The Threat of Global Warming* that identifies 10 refuges facing dire consequences from global warming. While this report focuses on 10 of the most threatened refuges, the entire refuge system faces an uncertain future given the progress of global warming.

([Schlyer 2006](#))

Serreze, M.C., J.E. Walsh, F.S. Chapin III, T. Osterkamp, M. Dyurgerov, V. Romanovsky, W.C. Oechel, J. Morison, T. Zhang, and R.G. Barry. 2000. [Observational evidence of recent change in the northern high-latitude environment](#). *Climate Change*. 46:159-207.

Studies from a variety of disciplines document recent change in the northern high-latitude environment. Prompted by predictions of an amplified response of the Arctic to enhanced greenhouse forcing, we present a synthesis of these observations. Pronounced winter and spring warming over northern continents since about 1970 is partly compensated by cooling over the northern North Atlantic. Warming is also evident over the central Arctic Ocean. There is a downward tendency in sea ice extent, attended by warming and increased areal extent of the Arctic Ocean's Atlantic layer. Negative snow cover anomalies have dominated over both continents since the late 1980s and terrestrial precipitation has increased since 1900. Small Arctic glaciers have exhibited generally negative mass balances. While permafrost has warmed in Alaska and Russia, it has cooled in eastern Canada. There is evidence of increased plant growth, attended by greater shrub abundance and northward migration of the tree line. Evidence also suggests that the tundra has changed from a net sink to a net source of atmospheric carbon dioxide. Taken together, these results paint a reasonably coherent picture of change, but their interpretation as signals of enhanced greenhouse warming is open to debate. Many of the environmental records are either short, are of uncertain quality, or provide limited spatial coverage. The recent high-latitude warming is also no larger than the interdecadal temperature range during this century. Nevertheless, the general patterns of change broadly agree with model predictions. Roughly half of the pronounced recent rise in Northern Hemisphere winter temperatures reflects shifts in atmospheric circulation. However, such changes are not inconsistent with anthropogenic forcing and include generally positive phases of the North Atlantic and Arctic Oscillations and extratropical responses to the El-Niño Southern Oscillation. An anthropogenic effect is also suggested from interpretation of the

paleoclimate record, which indicates that the 20th century Arctic is the warmest of the past 400 years. ([Serreze et al. 2000](#))

Stern, N. 2006. [The Economics of Climate Change: The Stern Review](#). Cambridge University Press. Cambridge.

Stirling, I. 2002. [Polar bears and seals in the eastern Beaufort Sea and Amundsen Gulf: a synthesis of population trends and ecological relationships over three decades](#). *Arctic*. 55(Supp. 1):59-76.

In the eastern Beaufort Sea and Amundsen Gulf, research on polar bear populations and their ecological interrelationships with seals and sea ice conditions began in the fall of 1970. Analysis of movement data from mark-recapture studies and tracking of adult female bears with satellite radio collars indicated that there are two populations of polar bears in the area, one that inhabits the west coast of Banks Island and Amundsen Gulf and a second that is resident along the mainland coast from about Baillie Islands in Canada to approximately Icy Cape in Alaska. Polar bears throughout the Beaufort Sea and Amundsen Gulf were severely overharvested before the establishment of quotas in Canada in 1968 and the cessation of all but subsistence polar bear hunting in Alaska in 1972. Since then, both populations have recovered, and the population estimates currently used for management purposes are 1200 and 1800 for the Northern and Southern Beaufort populations, respectively. However, these population estimates are now dated and should be redone. Most female polar bears in the Beaufort Sea breed for the first time at 5 years of age, compared to 4 years of age in most other populations, and cubs normally remain with their mothers for 2.5 years prior to weaning. Heavy ice conditions in the mid-1970s and mid-1980s caused significant declines in productivity of ringed seals, each of which lasted about 3 years and caused similar declines in the natality of polar bears and survival of subadults, after which reproductive success and survival of both species increased again. The changes in the sea ice environment, and their consequent effects on polar bears, are demonstrable in parallel fluctuations in the mean ages of polar bears killed each year by Inuit hunters. In 1989, the decadal-scale pattern in fluctuations of ice conditions in the eastern Beaufort Sea changed in response to oceanographic and climatic factors, and this change has resulted in greater amounts of open water in recent years. In addition, climatic warming will be a major environmental factor if greenhouse gas emissions continue to increase. It is unknown whether the ecosystem will return to the pattern of decadal-scale change exhibited in previous decades, or how polar bears and seals will respond to ecological changes in the future, but research on these topics is a high priority. ([Stirling 2002](#))

Turner, M.G., S.L. Collins, A.L. Lugo, J.J. Magnuson, T.S. Rupp, and F.J. Swanson. 2003. [Disturbance Dynamics and Ecological Response: The Contribution of Long-term Ecological Research](#). *BioScience* 53(1):46-56. ()

Long-term ecological research is particularly valuable for understanding disturbance dynamics over long time periods and placing those dynamics in a regional context. We highlighted three case studies from Long Term Ecological Research (LTER) Network sites that have contributed to understanding the causes and consequences of disturbance in ecological systems. The LTER Network significantly enhances the ability to study disturbance by (a) encompassing ecosystems subject to a wide range of disturbances, (b) providing a long-term baseline against which to detect change and measure ecosystem responses to disturbance, (c) permitting observation of slow or infrequent events, (d) facilitating the use of multiple research approaches, (e) providing a focus for modeling disturbance dynamics, and (f) contributing to land and resource management. Long-term research is crucial to understanding past, present, and future disturbance dynamics, and the LTER Network is poised to make continuing contributions to the understanding of disturbance. ([BioOne](#))

U.N.E.P. and C.M.S. 2006. [Migratory Species and Climate Change: Impacts of a Changing Environment on Wild Animals](#). UNEP/CMS Secretariat, Bonn, Germany. 68 pp.

U. S. Department of State. 2002. [U. S. Climate Action Report](#). Washington, D.C., May 2002.

In this *U.S. Climate Action Report*, we provide our third formal national communication under the Framework Convention, as envisioned under Articles 4 and 12 of the Convention. We describe our national circumstances, identify existing and planned policies and measures, indicate future trends in greenhouse gas emissions, outline expected impacts and adaptation measures, and provide information on financial resources, technology transfer, research, and systematic observations. ([U.S. Department of State 2002](#))

Walther, G.-R., E. Post, P. Convey, A. Menzel, C. Parmesan, T.J.C. Beebee, J.-M. Fromentin, O. Hoegh-Guldberg, and F. Bairlein. 2002. [Ecological responses to recent climate change](#). *Nature*. 416:389-395.

There is now ample evidence of the ecological impacts of recent climate change, from polar terrestrial to tropical marine environments. The responses of both flora and fauna span an array of ecosystems and organizational hierarchies, from the species to the community levels. Despite continued uncertainty as to community and ecosystem trajectories under global change, our review exposes a coherent pattern of ecological change across systems. Although we are only at an early stage in the projected trends of global warming, ecological responses to recent climate change are already clearly visible. ([Walther et al. 2002](#))

Yom-Tov, Y. and J. Yom-Tov. 2005. [Global warming, Bergmann's rule and body size in the masked shrew \*Sorex cinereus\* Kerr in Alaska](#). *Journal of Animal Ecology*. 74(5):803-808.

It was recently shown that body size of Palearctic shrews decreases with increasing latitude, thus contradicting Bergmann's rule, and this trend was explained by food shortage during the cold northern winter. In Alaska, global warming has resulted in milder winters that may improve food supply. In this study we tested the hypothesis that body size of Alaskan shrews increased during the second half of the twentieth century, in response to global warming. Data on body weight and length of body, tail, hind foot and ear of museum specimens of the masked shrew *Sorex cinereus* Kerr from Alaska were used in order to examine the effects of latitude, longitude, mean ambient temperature in January and July, and year of collection, on these parameters. We found that variation in body size of the masked shrew in Alaska appears to contradict to the prediction of Bergmann's rule, decreasing in high latitudes and in areas cold January temperature. Body size of shrews in Alaska increased significantly during the second half of the twentieth century, apparently due to the higher food availability in winter as a result of improved weather conditions for its prey. ([Yom-Tov and Yom-Tov 2005](#))

### **Abstracts from American Fisheries Society Meeting Presentations, November 2006, Fairbanks**

Arctic change and Alaska's marine fisheries

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At the confluence of mid-latitude storm tracks and Arctic air masses, Alaska is highly susceptible to changes in climate. Changes in storm tracks and reduction in the spatial and temporal distribution of sea ice pose the greatest stresses to marine ecosystems and coastal communities throughout Alaska. Recruitment, growth, and distribution of fish species are already being influenced by increases in ocean water temperatures, storm frequency, and freshwater runoff. Because each predator and prey species adapts differently to these coupled climate variables, reorganization of marine ecosystems is occurring at the same time that managers are increasingly mandated to treat regional ecosystems holistically in setting sustainable harvest goals for target species. Management strategies in a changing climate will need to incorporate human values as well as physical and economic constraints placed upon harvesters responding to transitions in Alaskan fisheries. This presentation will discuss recent findings on climate-driven changes already occurring in Alaskan marine ecosystems and suggest possible issues surrounding system "tipping points" that might be addressed through research and regional management decisions.

Geographical shifts in the spatial distribution of Northeast Pacific groundfish populations: effects of temperature and changes in abundance

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The spatial distribution of many marine populations shifts seasonally, inter-annually, and at longer time scales. There is increasing evidence that the distributions of both terrestrial and marine populations shift in response to climate changes. Here, we used trawl survey data from the Gulf of Alaska and eastern Bering Sea to investigate geographical shifts in the distribution of numerous fish and invertebrate populations. Our results imply significant changes in both the North-South distribution and in the depth distribution of numerous taxa in response to changes in temperature and abundance. In particular, we found a significant increase in the total biomass and in the biomass of individual species in the northern parts of the Bering Sea survey region over the past 25 years. The apparent increase in demersal biomass in the northern part of the survey region was not fully accounted for by the apparent effects of temperature on distribution. Changes in the Gulf of Alaska over the same time period imply an increase in relative biomass during the summer over deeper portions of the shelf, and a corresponding decrease in shallow waters. These changes were primarily attributed to increases in the abundance of slope inhabitants and

secondarily to distributional shifts in response to temperature changes. Our results are discussed in the context of global climate changes.

Long-term trends in annual Bristol Bay & Chignik sockeye salmon scale growth at sea in relation to sockeye abundance and climate change, 1955 – 2000

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Pacific salmon populations rearing in the North Pacific Ocean and Bering Sea increased substantially after the marine climate shift during the mid-1970s. Density-dependent growth has been observed among many stocks of Pacific salmon raising questions about the relationship between salmon ocean growth, survival and production. We measured annual marine scale growth of Bristol Bay and central Alaska sockeye salmon, 1955 to 2000, to test whether annual salmon growth at sea was positively or negatively associated with the large increase in salmon abundance that began after the mid-1970s change in ocean condition. Sockeye runs increased when early marine scale growth increased beyond average scale growth, suggesting that greater growth during both the first and second years at sea were associated with greater survival. Bristol Bay sockeye runs tended to be relatively low when scale-growth during the first and second year at sea was below average. These analyses indicate growth during the first two years at sea was a critical factor in the large abundance of Alaska sockeye following the 1970's regime shift. Density-dependent growth may occur during early marine life however, density-dependent growth was most apparent in the later stages of life when reduced growth likely has less effect on survival.

Global climate change and potential effects on salmonids in freshwater ecosystems of Southeast Alaska

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General circulation models predict increases in temperatures from 1°C to 5°C as atmospheric CO<sub>2</sub> continues to rise. Thermal regimes in freshwater ecosystems will change as air temperatures increase regionally. Changes in precipitation distribution and intensity will alter freshwater hydrology. As continental ice sheets melt, increasing sea-levels will flood low elevation floodplains and wetlands. Although anadromous salmonids exist over a wide range of climatic conditions along the Pacific coast, individual stocks have adapted life history strategies --time of emergence, run timing, and residence time in freshwater-- that are often unique to regions and watersheds. The response of anadromous salmonids will differ among species depending on their life cycle in freshwater. For pink salmon that migrate to the ocean shortly after they emerge from the gravel, higher temperatures during spawning and incubation may result in earlier entry into the ocean when food resources are low. Shifts in thermal regimes in lakes will affect juvenile sockeye salmon growth and survival, whereas, changes in seasonal precipitation distribution and intensity that alter stream flows will affect growth and survival of juvenile coho salmon. Rising sea-levels will inundate low elevation spawning areas for pink salmon and floodplain rearing habitats for juvenile coho salmon. Resulting changes in climatic conditions may not extirpate anadromous salmonids in the region, but it will impose greater stress on many stocks that are adapted to present climatic conditions. Survival of sustainable populations will depend on the existing genetic diversity within and among stocks, conservative harvest management, and habitat conservation.

Glacier loss in the Brooks Range: How will this affect North Slope stream ecology?

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We have measured ice volume change over the past 50 years of about 140 glaciers in the Brooks Range and found nearly all of them to have lost volume. This volume loss began about 1890AD, and our measurements indicate that the rate of volume loss has been increasing with time, at least in the eastern Brooks Range where we have repeated measurements over the past 50 years. Our modeling indicates that even if climate stays the same for the next 150 years, most of these glaciers will disappear, or at least stop contributing to stream flow through further volume loss. If climate continues on the same trend as it has the past 100 years, these glaciers will disappear even sooner, many within the lifetimes of our children. Since streamflow over the past 100 years has been augmented by glacier volume loss, presumably stream ecosystems have had enough time to adapt to this increased water and sediment flux. Therefore, should the glacier influence disappear, it seems worth considering what impact this might have on the flora and fauna that have grown accustomed to it. As a glaciologist, I have no expertise to help answer such questions. The goal of my presentation is simply to present what we know about the glacier response

to recent climate change in hopes that those that study streams and fisheries might find it useful in predicting ecosystem response.

#### Predicting Climate Change Effects on Freshwater Foodwebs

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Many of the predicted direct effects of climate change on freshwater ecosystems, such as habitat loss from drying and warmer water temperature, have some obvious consequences for these ecosystems and their resident biota. However, indirect effects from climate change, such as changes in nutrient cycling, energy flow and food supply that support fishes and other consumers, are far less clear. Freshwater systems in Alaska are generally nutrient-limited, leading to food limitation for upper level consumers like fish. And nutrient and energy flow will change in somewhat predictable ways as a consequence of climate change. Climate affects vegetation cover, and most vegetation cover models predict a northward movement of coniferous tree species, eventually followed by deciduous species in some areas. Consequently, forest type affects amount of solar energy reaching streams and the quality and quantity of plant litter inputs that drive stream foodweb dynamics and productivity. Riparian plant species also affect the flow of terrestrial invertebrates to streams – prey that are crucial for fishes and other aquatic and riparian consumers. Further, warming ocean currents are predicted to push salmon stocks northward, influencing the amount of marine nutrients entering freshwater via salmon runs, further influencing freshwater productivity and fishes. The magnitude and extent of these climate-driven productivity changes and the interactions with other environmental variables are less clear, as well as the specific effects on individual consumer species.

Potential effects of climate warming on production of freshwater and anadromous stocks in the Yukon Territory.

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There is little doubt that we are currently undergoing a period of climatic warming and the effects of this warming are already evident across the North. Although long term data is often lacking in the North, changes in aquatic systems have already been observed by both resource users and biologists alike, and models predict even more dramatic changes than have been observed to date. Temperature is often a key variable in development of hypotheses to explain changes observed in both freshwater and anadromous stocks and our work suggests that even moderate temperature increase could lead to dramatic changes in production in both freshwater and anadromous species alike. Our discussion will focus on potential changes in productivity of both freshwater and anadromous stocks in the North as a result of temperature-driven changes in habitat availability under climate warming.

Does global climate change put Alaska waters at greater risk of biological invasion?

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Global climate change may pose direct risks to Alaska ecosystems by facilitating establishment of specific invaders -- for example, Chinese mitten crabs, purple loosestrife, European green crabs. However, climate change may also play an indirect role in influencing invasion risks. For example, a reduction in sea ice may create new shipping lanes and thus increased risks from ballast water transfer and hull fouling. More open water may also enable new offshore oil and gas drilling opportunities, which would likely require the movement of drilling rigs (notoriously highly bio-fouled) into Alaska waters from locations outside Alaska. These risks, some initial supporting evidence, and options for how to prepare for or avoid such risks will be discussed.

#### Other Sources of Information

University of Alaska, Fairbanks, Bonanza Creek Long-term Ecological Research Center website. Searchable bibliographic database. ([http://www.lter.uaf.edu/bibliography\\_search\\_master.cfm](http://www.lter.uaf.edu/bibliography_search_master.cfm))

World Wildlife Fund, Glacier Decline Bibliography. ([http://assets.panda.org/downloads/glacier\\_references\\_26nov03.pdf](http://assets.panda.org/downloads/glacier_references_26nov03.pdf))