FOREWORD

A major challenge facing society is to understand and predict the patterns and rates of change in regional systems in response to directional changes in physical, biological, and social drivers (Chapin et al. 2009). The boreal forest is an ideal region in which to explore the dynamics of change for several reasons (Berkes 2008; Chapin et al. 2006; Hinzman et al. 2005; McGuire et al. 2006). (1) Its cultures and natural ecosystems are relatively intact, making it easier to understand the natural coupling of physical, biological, and social components of regional systems. (2) The biophysical and social drivers of regional processes are changing rapidly. In particular, there has been substantial climate warming in the last 30 years. (3) Climatically sensitive processes include permafrost dynamics, fire dynamics, movement of the forest–tundra boundary, and outbreak behavior of key forest mammals and insects; the boreal forest is the northernmost forested biome and is expected it to be sensitive to recent warming. (4) The boreal region is among the most extensive biomes on Earth and plays a major role in the global climate system.

Long-term research by the Bonanza Creek (BNZ) Long Term Ecological Research (LTER) program has documented natural patterns of interannual and successional variability of the boreal forest in interior Alaska against which we can detect changes in system behavior. Between 2004 and 2010 the BNZ LTER program focused on understanding the dynamics of change through studying the resilience and vulnerability of Alaska's boreal forest in response to climate warming. The overarching question in this endeavor has been **How are boreal ecosystems responding, both gradually and abruptly, to climate warming, and what new landscape patterns are emerging? The resilience concept** (Chapin et al. 2009; Gunderson and Holling 2002) is an ideal theoretical framework for understanding the dynamics of change in Alaska's boreal forest. Resilience is the capacity of a system to absorb disturbances so as to maintain its structure, functioning, and feedbacks (Folke et al. 2004; Walker et al. 2004). Vulnerability is the degree to which a system is likely to experience harm due to exposure and sensitivity to a specified hazard or stress and its adaptive capacity to respond to the stress (Turner et al. 2003). Ecosystems are often quite resilient to stochastic variation or even directional changes in driving variables, until some threshold is exceeded, causing them to shift to a fundamentally new state (Folke et al. 2004; Walker et al. 2004). The resilience framework requires that we reach beyond the assumptions of steady-state dynamics to ask what changes in drivers might trigger a change in ecosystem state (Gunderson and Holling 2002; Scheffer and Carpenter 2003).

The strategy of the BNZ LTER in studying resilience and vulnerability has been to investigate three aspects of change in Alaska's boreal forest: (1) **climate sensitivity** of the physical and biological processes to temporal variation in the environment, which defines the limits of resilience to climate change; (2) changes in the **successional dynamics** caused by changes in climate and disturbance regime, which define the points in the adaptive cycle of disturbance and recovery at which ecosystems are most vulnerable to change; and (3) **threshold changes** that are likely to cause the boreal forest to function in a qualitatively new way. The BNZ LTER has also conducted synthesis investigations in which these modes of climate response have been integrated across multiple temporal and spatial scales. The research has combined long-term observations, long-term experiments, and process studies to identify ecological changes and to document controls over ecosystem processes and successional dynamics in three landscape units: floodplains, uplands, and wetlands. The BNZ LTER has tested hypotheses about controls over ecosystem dynamics by manipulating selected interactive controls. These plot-level studies were extended to larger spatial scales (watersheds, regions, and the state of Alaska) in a hierarchical research design, using extensive measurements, remote sensing, and modeling. Temporal scales of the research span hours (weather), years (growth, populations), successional cycles (stand-age reconstructions), and millennia (vegetation and climate reconstructions).

The papers in this Special Issue of the *Canadian Journal of Forest Research* represent synthesis studies that have been conducted by the BNZ LTER to ascertain the progress that the program has made in using the resilience framework to understand the dynamics of change in Alaska boreal forests in response to climate change. We have arranged the papers in the special issue into three groups. The first group focuses primarily on various aspects of climate sensitivity including threshold changes. Papers in this group examine the vulnerability of white spruce tree growth to climate variability (McGuire et al. 2010), the long term response of stream flow to climatic warming (Jones and Rinehart 2010), the resilience and vulnerability of permafrost to climate change (Jorgenson et al. 2010), the role of mosses in boreal ecosystem dynamics (Turetsky et al. 2010), and the demography of snowshoe hares in relation to regional climate variability (Kielland et al. 2010).

The second group of papers evaluates responses of disturbance and successional dynamics to climate change. Papers in this group evaluate hypothesized floodplain successional dynamics by examining 25 years of vegetation change in floodplain plant communities along a putative chronosequence (Hollingsworth et al. 2010); the resilience and vulnerability of fungal communities in boreal forest soils (Taylor et al. 2010); interactions among fire, climate change, and forest resilience in interior Alaska (Johnstone et al. 2010); and the implications of Alaska's changing fire regime for the vulnerability of its boreal forests (Kasischke et al. 2010).

The third group of synthesis papers evaluates different aspects of regional resilience and vulnerability and, in particular, explores societal consequences by identifying past and potential future changes in ecosystem services that boreal forests provide both locally (e.g., subsistence resources) and globally (e.g., carbon sequestration). Papers in this group examine regional dynamics in the context of long-term monitoring of climatic and nutritional effects on tree growth in interior Alasks (Yarie and Van Cleve 2010), the changing effects of Alaska's boreal forests on the climate system (Euskirchen et al. 2010), and the resilience of native subsistence systems in interior Alaska's changing climate (Kofinas et al. 2010). A fourth paper in this group represents an overall synthesis of the BNZ LTER research program to understand the dynamics of change through studying the resilience and vulnerability of Alaska's boreal forest in response to climate warming (Chapin et al. 2010).

Together, the papers in this Special Issue of CJFR highlight the strength of using the resilience framework to study and

understand change in ecological systems. This framework is applicable beyond the boreal forests of interior Alaska and can serve as a means of understanding changes in regional dynamics of forest ecosystems throughout the globe.

References

Berkes, F. 2008. Sacred ecology: traditional ecological knowledge and resource management. 2nd ed. Taylor & Francis, Philadelphia, Pa.

Chapin, F.S., III, Oswood, M.W., Van Cleve, K., Viereck, L.A., and Verbyla, D.L. (Editors). 2006. Alaska's changing boreal forest. Oxford University Press, New York.

Chapin, F.S., III, Kofinas, G.P., and Folke, C. (Editors). 2009. Principles of ecosystem stewardship: resilience-based natural resource management in a changing world. Springer, New York.

Chapin, F.S., III, McGuire, A.D., Ruess, R.W., Hollingsworth, T.N., Mack, M.C., Johnstone, J.F., Kasischke, E.S., Euskirchen, E.S., Jones, J.B., Jorgenson, M.T., Kielland, K., Kofinas, G.P., Turetsky, M.R., Yarie, J., Lloyd, A.H., and Taylor, D.L. 2010. Resilience of Alaska's boreal forest to climatic change. Can. J. For. Res. **40**. This issue. doi:10.1139/X10-074.

Euskirchen, E.S., McGuire, A.D., Chapin, F.S., III, and Rupp, T.S. 2010. The changing effects of Alaska boreal forests on the climate system. Can. J. For. Res. **40**. This issue. doi:10.1139/X09-209.

Folke, C., Carpenter, S., Walker, B., Scheffer, M., Elmqvist, T., Gunderson, L., and Holling, C.S. 2004. Regime shifts, resilience, and biodiversity in ecosystem management. Annu. Rev. Ecol. Syst. **35**(1): 557–581. doi:10.1146/annurev.ecolsys.35.021103.105711.

Gunderson, L.H., and Holling, C.S. (Editors). 2002. Panarchy: understanding transformations in human and natural systems. Island Press, Wash.

Hinzman, L.D., Bettez, N.D., Bolton, W.R., Chapin, F.S., Dyurgerov, M.B., Fastie, C.L., Griffith, B., Hollister, R.D., Hope, A., Huntington, H.P., Jensen, A.M., Jia, G.J., Jorgenson, T., Kane, D.L., Klein, D.R., Kofinas, G., Lynch, A.H., Lloyd, A.H., McGuire, A.D., Nelson, F.E., Oechel, W.C., Osterkamp, T.E., Racine, C.H., Romanovsky, V.E., Stone, R.S., Stow, D.A., Sturm, M., Tweedie, C.E., Vourlitis, G.L., Walker, M.D., Walker, D.A., Webber, P.J., Welker, J.M., Winker, K.S., and Yoshikawa, K. 2005. Evidence and implications of recent climate change in northern Alaska and other arctic regions. Clim. Change, **72**(3): 251–298. doi:10.1007/s10584-005-5352-2.

Hollingsworth, T.N., Lloyd, A.H., Nossov, D.R., Ruess, R.W., Charlton, B.A., and Kielland, K. 2010. Twenty-five years of vegetation change along a putative successional chronosequence on the Tanana River, Alaska. Can. J. For. Res. **40**. This issue. doi:10.1139/X10-094.

Johnstone, J.F., Chapin, F.S., III, Hollingsworth, T.N., Mack, M.C., Romanovsky, V., and Turetsky, M. 2010. Fire, climate change, and forest resilience in interior Alaska. Can. J. For. Res. **40**. This issue. doi:10.1139/X10-061.

Jones, J.B., and Rinehart, A.J. 2010. The long term response of stream flow to climatic warming in headwater streams of interior Alaska. Can. J. For. Res. **40**. This issue. doi:10.1139/X10-047.

Jorgenson, M.T., Romanovsky, V., Harden, J., Shur, Y., O'Donnell, J., Schuur, E.A.G., Kanevskiy, M., and Marchenko, S. 2010. Resilience and vulnerability of permafrost to climate change. Can. J. For. Res. **40**. This issue. doi:10.1139/X10-060.

Kasischke, E.S., Verbyla, D.L., Rupp, T.S., McGuire, A.D., Murphy, A.D., Jandt, R., Barnes, J.L., Hoy, E.E., Duffy, P.A., Calef, M., and Turetsky, M.R. 2010. Alaska's changing fire regime-implications for the vulnerability of its boreal forests. Can. J. For. Res. **40**. This issue. doi:10.1139/X10-098.

Kielland, K., Olson, K., and Euskirchen, E. 2010. Demography of snowshoe hares in relation to regional climate variability during a 10-year population cycle in interior Alaska. Can. J. For. Res. **40**. This issue. doi:10.1139/X10-053.

Kofinas, G.P., Chapin, F.S. III, BurnSilver, S., Schmidt, J.I., Fresco, N.L., Kielland, K., Martin, S., Springsteen, A., and Rupp, T.S. 2010. Resilience of Athabascan subsistence systems to Interior Alaska's changing climate. Can. J. For. Res. **40**. This issue. doi:10.1139/X10-108.

McGuire, A.D., Chapin, F.S., III, Walsh, J.E., and Wirth, C. 2006. Integrated regional changes in arctic climate feedbacks: implications for the global climate system. Annu. Rev. Environ. Resour. **31**(1): 61–91. doi:10.1146/annurev.energy.31.020105.100253.

McGuire, A.D., Ruess, R.W., Lloyd, A., Yarie, J., Clein, J.S., and Juday, J.P. 2010. Vulnerability of white spruce tree growth in interior Alaska in response to climate variability: dendrochronological, demographic, and experimental perspectives. Can. J. For. Res. **40**. This issue. doi:10.1139/X09-206.

Scheffer, M., and Carpenter, S.R. 2003. Catastrophic regime shifts in ecosystems: linking theory to observation. Trends Ecol. Evol. **18**(12): 648–656. doi:10.1016/j.tree.2003.09.002.

Taylor, D.L., Herriott, I.C., Stone, K.E., McFarland, J.W., Booth, M.G., and Leigh, M.B. 2010. Structure and resilience of fungal communities in Alaskan boreal forest soils. Can. J. For. Res. **40**. This issue. doi:10.1139/X10-081.

Turetsky, M.R., Mack, M.C., Hollingsworth, T., and Harden, J.W. 2010. The role of mosses in ecosystem succession and function in Alaska's boreal forest. Can. J. For. Res. **40**. This issue. doi:10.1139/X10-072.

Turner, B.L., II, Kasperson, R.E., Matson, P.A., McCarthy, J.J., Corell, R.W., Christensen, L., Eckley, N., Kasperson, J.X., Luerse, A., Martello, M.L., Polsky, C., Pulsipher, A., and Schiller, A. 2003. A framework for vulnerability analysis in sustainability science. Proc. Natl. Acad. Sci. U.S.A. **100**(14): 8074–8079. doi:10.1073/pnas.1231335100.

Walker, B., Holling, C.S., Carpenter, S.R., and Kinzig, A. 2004. Resilience, adaptability, and transformability in social-ecological systems. Ecology and Society, **9**(2): 5.

Yarie, J., and Van Cleve, K. 2010. Long-term monitoring of climatic and nutritional affects on tree growth in interior Alaska. Can. J. For. Res. **40**. This issue. doi:10.1139/X10-114.

A. David McGuire
Guest Editor
US Geological Survey
Alaska Cooperative Fish and Wildlife Research Unit
University of Alaska Fairbanks
Fairbanks, AK 99775, USA

F.S. Chapin III
Guest Editor
Institute of Arctic Biology
University of Alaska Fairbanks
Fairbanks, AK 99775, USA

R.W. Ruess
Guest Editor
Institute of Arctic Biology
University of Alaska Fairbanks
Fairbanks, AK 99775, USA