Environment and Natural Resources Trust Fund

Research Addendum for Peer Review

Project Manager Name: Lee E. Frelich

Project Manager Email address: freli001@umn.edu

Project Title: Climate change and resilience in boreal forests

Project number: 135-F1+2+5

The research addendum should provide concise but also comprehensive information so that peer reviewers have the appropriate level of information to provide helpful comments. Each project should include the following information:

1. **Abstract** - Summarize the research and its essential qualities including a clear statement on the purpose of the research.

Forests of the Border Lakes Ecological Subsection of northeastern Minnesota are at the southern margin of the boreal forest, and although they cover a small portion of the state, they contain many boreal species that constitute a significant proportion of the state's biodiversity. The boreal tree species—currently the foundation of the ecosystem—are likely to decline with continued warming of the climate, and be replaced by temperate species. Therefore, the main purposes of the research are to: (1) assess the status of temperate tree species in the southern margin of the boreal forest (e.g. sugar maple, red maple, American basswood, northern red oak, bur oak, white pine, yellow birch), whether these species are currently expanding in response to warming that has already occurred, and whether sufficient seed sources are present to allow them to expand and fill the niche currently occupied by boreal species; (2) examine the distribution and potential expansion of invasive plant species (e.g. buckthorn, Canada thistle, garlic mustard) that may expand and compete with native species in a rapidly changing environment; and (3) examine the potential for cold temperature refuges on the landscape to continue to harbor boreal species in a future warmer climate. Extensive field surveys along transects that cross the landscape will be conducted to collect information for (1) and (2) above, and 100 hobos will be placed on the landscape to measure temperature variation (e.g. compare bogs with uplands and south slopes with north slopes) on an hourly basis for two years (for (3) above). This information will be used to prepare adaptation and management options for commercial and Boundary Waters Canoe Area Wilderness forests. Finally, via presentations and workshops, we will inform forest managers regarding future scenarios for forest health and resilience, and options for adaptation to climate change. The audience will include wilderness users and managers of the Boundary Waters Canoe Areas Wilderness, and managers of commercial forests, such as staff of the Superior National Forest, Minnesota DNR, County and Tribal forestry divisions.

2. **Background** - Provide the basic information and other relevant work that are the context for this research.

Northern Minnesota has already experienced a relatively large magnitude of climatic warming, and is projected to experience a larger magnitude of future warming than the global average; it is typical for mid-continental regions to experience larger changes in climate than the rest of the world (Frelich and Reich 2009, note that references cited are given below under description of Project Manager Frelich). Because the forests of the Border Lakes Subsection are at the southernmost extent of the boreal forest biome, where they are juxtaposed with the northernmost extent of the temperate forest biome, they are more susceptible to change than other forests in the interior of a biome. Thus, the forests in the Border Lakes Ecological Subsection study area are both more susceptible to changing climate, and are likely to experience a large magnitude of climate change (Frelich and Reich 2010). Projected climates by the middle of the 21st Century are not expected to support boreal forest (Galatowitsch et al 2009).

The existing boreal forests support a large number of boreal plant and animal species that could be lost to Minnesota if the forests disappear; in essence Minnesota could go from a three biome state (grassland, temperate forest and boreal forest) to a two biome state (grassland and temperate forest) if a warmer climate will no longer support the boreal forest (Frelich and Reich 2010). Such a scenario would lead to large changes for users of the Boundary Waters Canoe Area Wilderness and would be economically important for the tourism and timber industries. Therefore, we need a better understanding of potential responses to a warming climate.

The boreal forests of the Border Lakes Ecological Subsection are dominated by jack pine, black spruce, balsam fir, white spruce, white cedar, aspen and paper birch, with some red and white pine. Temperate tree species which reach their northern range limit in or near the study area include sugar maple, red maple, red oak, American basswood, yellow birch and bur oak (Frelich and Reich 2009). Currently there are some small outposts of these temperate species within the southern part of the boreal forest, but we know little about their frequency or potential to spread to fill the niche vacated by the retreating boreal forest in a warmer climate. A common phenomenon in ecological systems, is for invasive plant species to expand rapidly when a system is undergoing some type of disturbance or transition. A number of invasive species could compete with native temperate species at the time of transition from boreal to temperate forest; however, we have little systematic information about their distribution and potential to spread in the remote forests of the Boundary Waters Canoe Area Wilderness and surrounding commercial forests (Frelich and Reich 2009).

Background on climate change (added to clarify for one of the peer reviewers).
CO_2 concentration in the atmosphere is higher than at any point in the last 800,000 years (Figure 1 below shows the last 400,000 years), using air bubbles trapped in ice cores from Antarctica. The isotopic signature of CO_2 from fossil fuel burning (C12 to c13 ratios, as well as dilution of C-14 by C-14 free fossil fuel carbon) is different than that from CO_2 in the atmosphere from natural causes including volcanoes (the latter only emit about 1% as much CO_2 as fossil fuel burning), proving that the increasing CO_2 content of the atmosphere is a result of fossil fuel use. The Keeling curve (Figure 2) shows that the rise in CO_2 in the atmosphere since 1958 (this is the longest measurement series done directly from air samples, Figure 2), is proportional to the human population and known human emissions. The slope from 1990-2008 is twice that of the 1960s, when human population and emissions were lower.

CO_2 is a heat trapping gas that holds infrared radiation close to the surface of the earth, warming the surface and making the stratosphere cooler. The heat trapping property of CO_2 was discovered by Fourier in 1824 and Tyndall in 1858 discovered that CO_2 can make the planet warmer than it would be without CO_2 in the atmosphere. Svante Arrhenius (the 'father' of human caused global warming), was the first to connect fossil fuel use by humans with increasing CO_2 concentration in the atmosphere and with the potential to warm the climate. He published the first analyses of how much the climate would warm by doubling CO_2 content of the atmosphere in 1896. Although not recognized for this while he was alive (Arrhenius won the Nobel Prize in Chemistry in 1903 for other work that he did), this was one of the greatest insights in the history of science, and the basic science still stands today after many others examined it closely and in light of the much more massive data on the climate and better instruments for measuring the atmosphere we have today. Modern estimate of the impact of doubling CO_2 concentration in the atmosphere are slightly lower than Arrhenius estimated (Arrhenius, 4-6 degrees C, today 3-5 degrees C). Today, modeling the regional impacts of climate change using computer models (see below) is an active area of research that has made large strides in the last decade. We know that the Upper Midwest warmed more than other regions of the U.S. during past episodes of warming (from the fossil record), and it is nice to see that downscaled climate projections (GCM output projected on the sale of a region like the Midwest) agree with those trends as well as with the observed trends in climate that have occurred in the last several decades, as observed from weather station data.

The sun cannot be responsible for warming we have seen in the last few decades. Increased energy input from the sun would warm the stratosphere and troposphere, as opposed to the observed pattern of warming the troposphere and cooling the stratosphere, which is consistent with warming caused by CO_2. Energy output from the sun varies on a somewhat regular cycle (the sunspot cycle) of about 11 years. This variation makes a difference of about 0.1 C in mean temperature of the lower atmosphere (i.e. the temperature fluctuates up and down 0.1 degrees C), but those minor fluctuations are superimposed on a systematic upward trend since the middle 1800s, which is accelerating in recent decades in proportion to human emissions of greenhouse gases (Figures 3, 4 and 5).

Global circulation models (GCMs) are the contemporary tool used to model how changes in the atmosphere and surface of the earth will change the climate. These became feasible in the 1980s with the advent of powerful computers. The basic patterns predicted by the early runs in the late 1980s are still the same today, with much more powerful computers and better input data, allowing models with better spatial resolution. James Hansen's GISS model, published in 1988 using a business as usual CO_2 emission scenario, predicted the actual observed world-wide annual mean temperature in 2005 almost dead on. Models that hind cast the climate from 1900-2000 (we know the progression of climate changes from actual weather station data during the 20th Century), can duplicate what actually happened at a world-wide scale when CO_2 and other greenhouse gases emitted by humans are incorporated, but not if only natural forcings on the climate from volcanoes, the sun, etc, are taken into account (Figure 4).

Massive evidence has accumulated that world-wide mean temperatures for the last few decades are the warmest in the last 3000+ years (Figures 5, 6, 7). This includes glacier data from 1600 to the present (169 glaciers on 3 continents), borehole data from 1500 to the present (more than 350 sites on six continents), tree ring data (14+ studies on three continents, from trees growing at tree line in mountains or the arctic where cold climate is the limiting factor, and trees respond to increasing temperatures with increased growth). Weather station records since about 1850 also are consistent with the trends from these longer-term data sets (Figure 5).

Overall conclusions. That: (1) CO_2 is a heat trapping gas; (2) that CO_2 concentration is increasing in the atmosphere; and (3) that the increase in CO_2 is caused by humans, is sufficient to prove human caused global warming. These 3 items were proven decades to almost 2 centuries ago. There is massive evidence that the climate today is the warmest in the last 3000 years, and that the warming of recent decades is caused by human impacts on chemistry of the atmosphere, and that models for future projections of a warming climate are well validated. Analyses of fossil evidence for the prairie forest border in Minnesota show that it moved to the north and east, and that temperate tree species replaced boreal tree species during past episodes of warming climate, and there is no reason to believe this won't also happen for future warming.

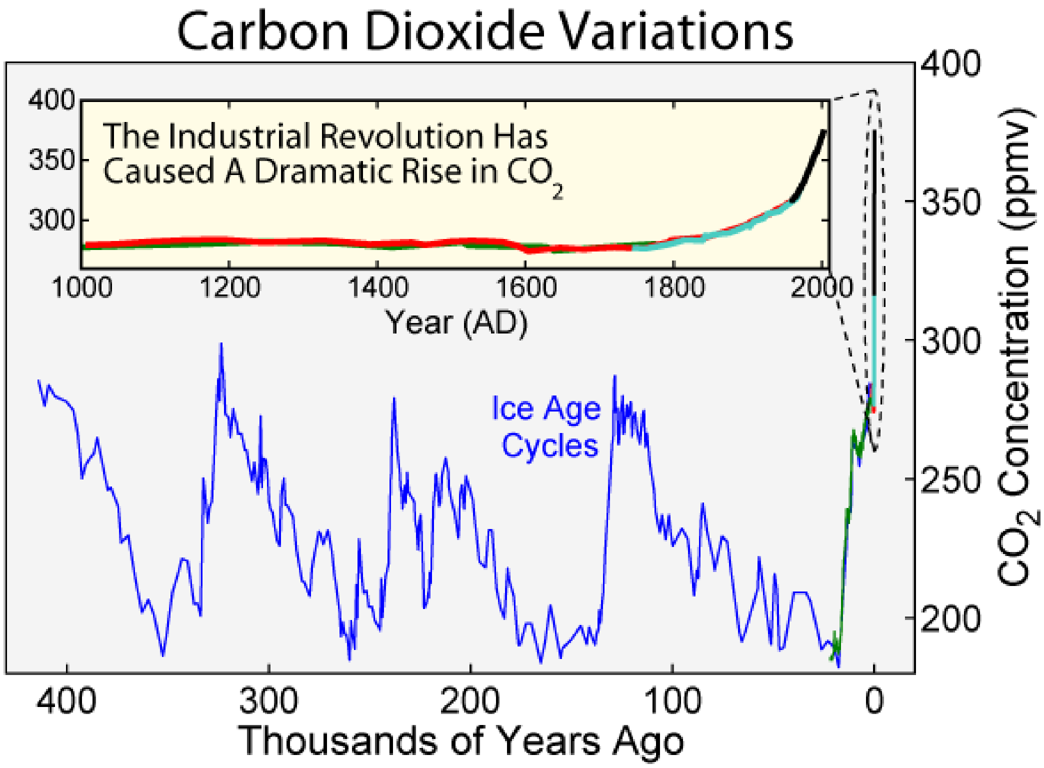

Figure 1. CO2 content of the atmosphere over the last 400,000 years, showing the rise well beyond the natural range of variability in the last century.

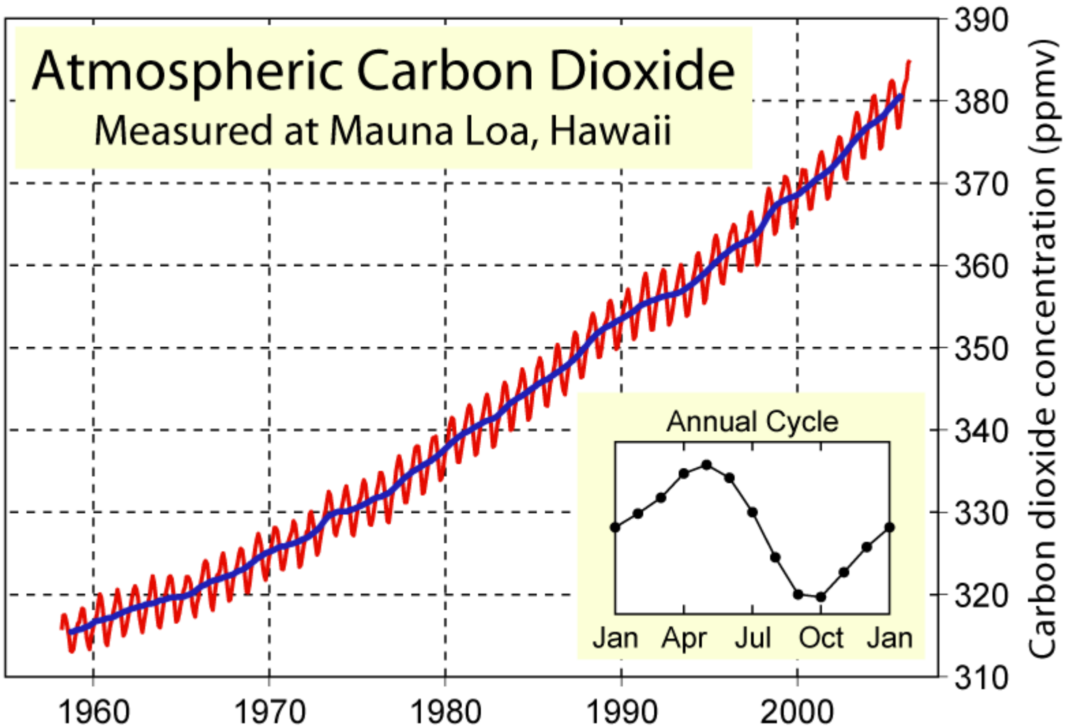

Figure 2. Keeling curve of direct CO2 concentration measurements, 1958-2009.

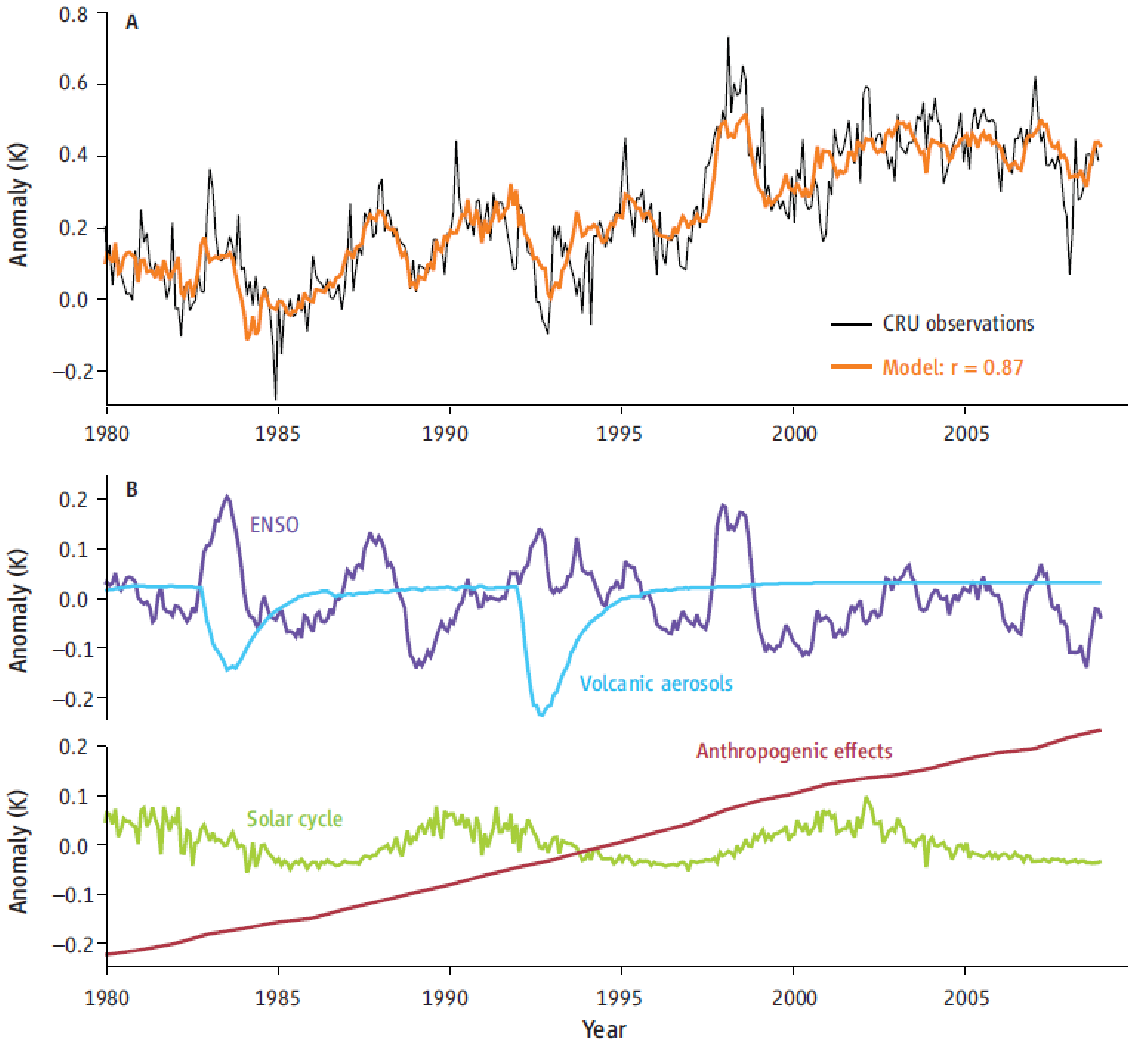

Fig. 7. Reconstructing Earth's recent climate. (**A**) Observed monthly mean global temperatures (black) and an empirical model (orange) that combines four different influences. (**B**) Individual contributions of these influences, namely El Niño–Southern Oscillation (purple), volcanic aerosols (blue), solar irradiance (green), and anthropogenic effects (red). Together the four influences explain 76% (r^2) of the variance in the global temperature observations.

Figure 3. Influence of solar cycle, volcanoes, El Nino and human impacts (chiefly through CO2 emissions), on mean world-wide temperature, 1980-2008). Note that climate models based on the four climate influences (orange line in top panel) predict actual observed temperature (black line). From McCarthy, J.J, 2009. Science 326: 1646-1655.

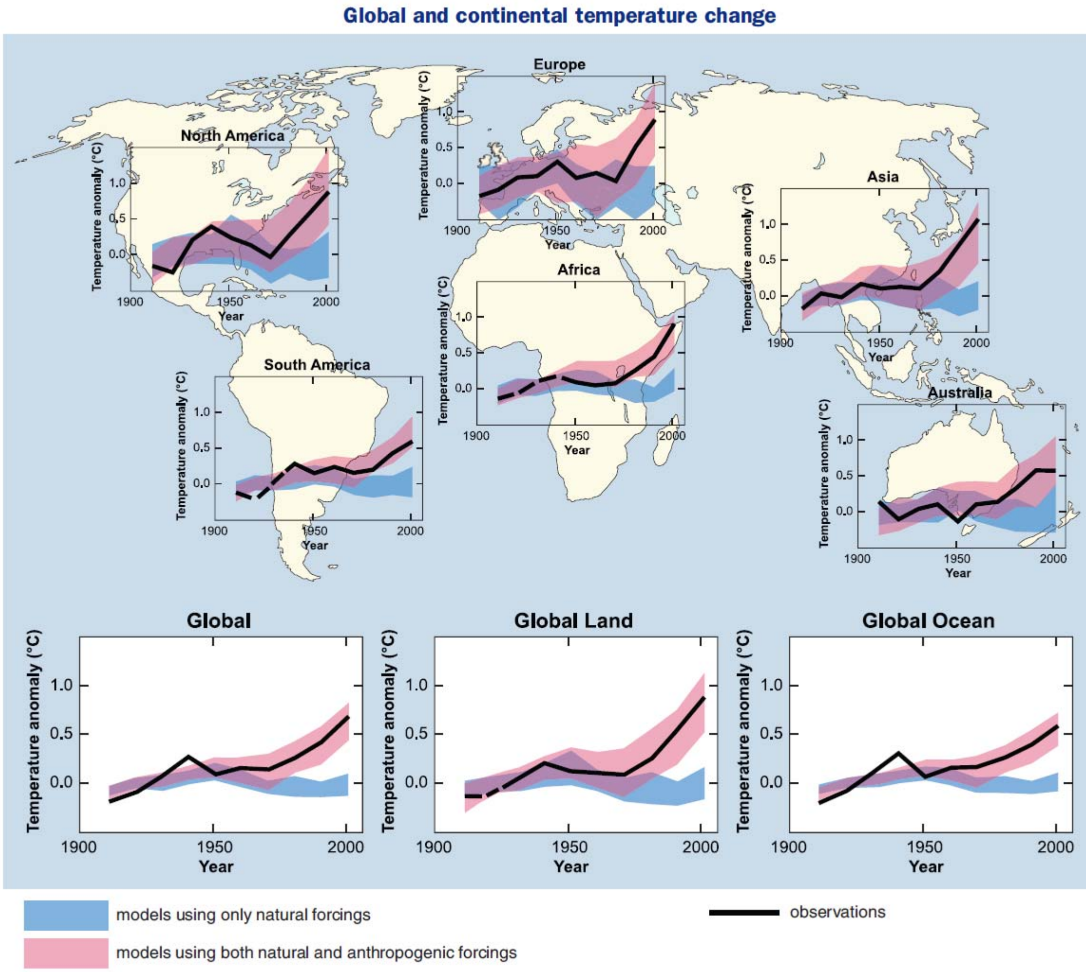

Figure 4. Models of climate from 1900-2000 using only natural forcings (blue envelope), including human impacts (mostly CO2 emissions, pink envelope), and actual temperature from weather station data (Black line), for each continent and world-wide for land, ocean and land+ocean. From IPCC AR4 report.

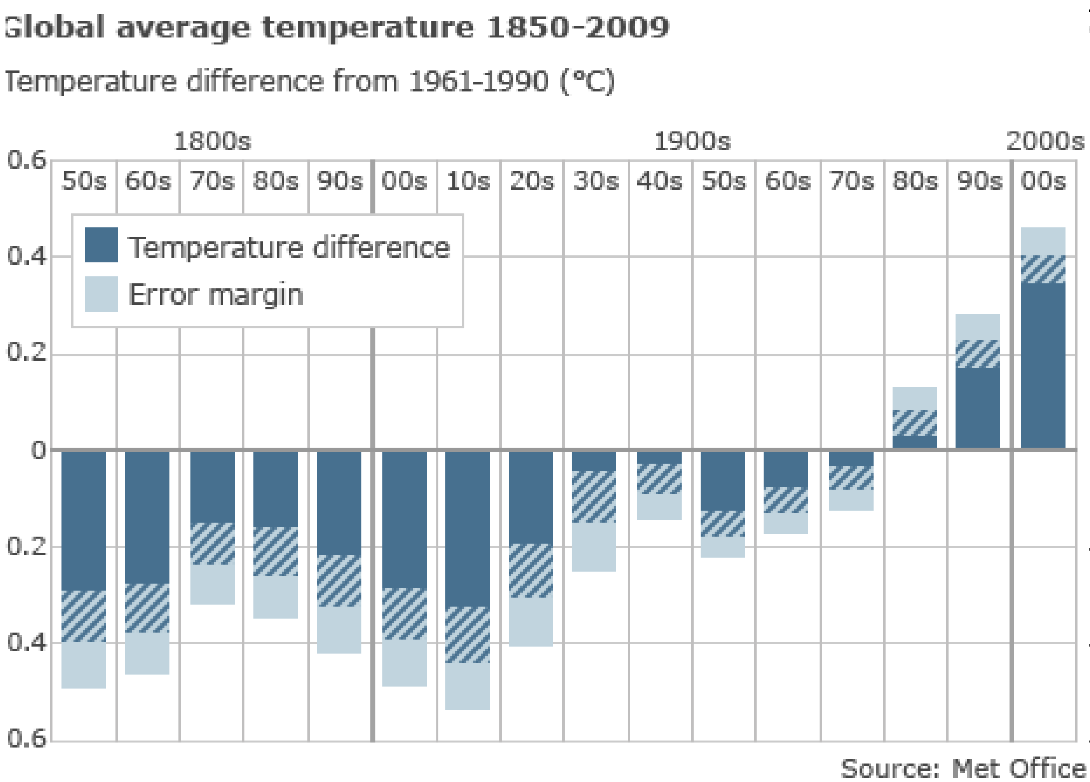

Figure 5. Global average temperature 1850-2009, from weather station data, British Meteorological Office.

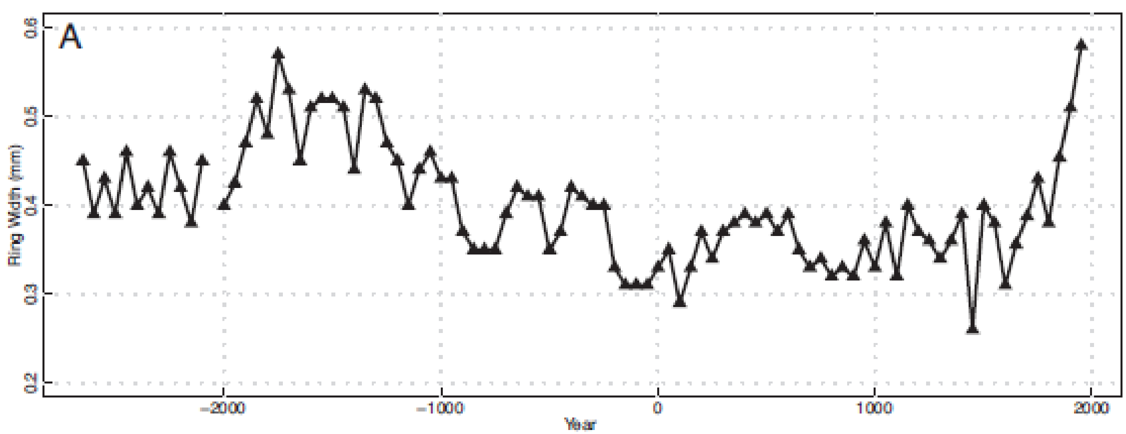

Figure 6. 4000+ year record of tree ring width of bristle cone pines at tree line in mountains of California and Nevada, showing that climate is now warmer than it has been in ca 3700 years. From Salzer et al. Proceedings of the National Academy of Science, 2009.

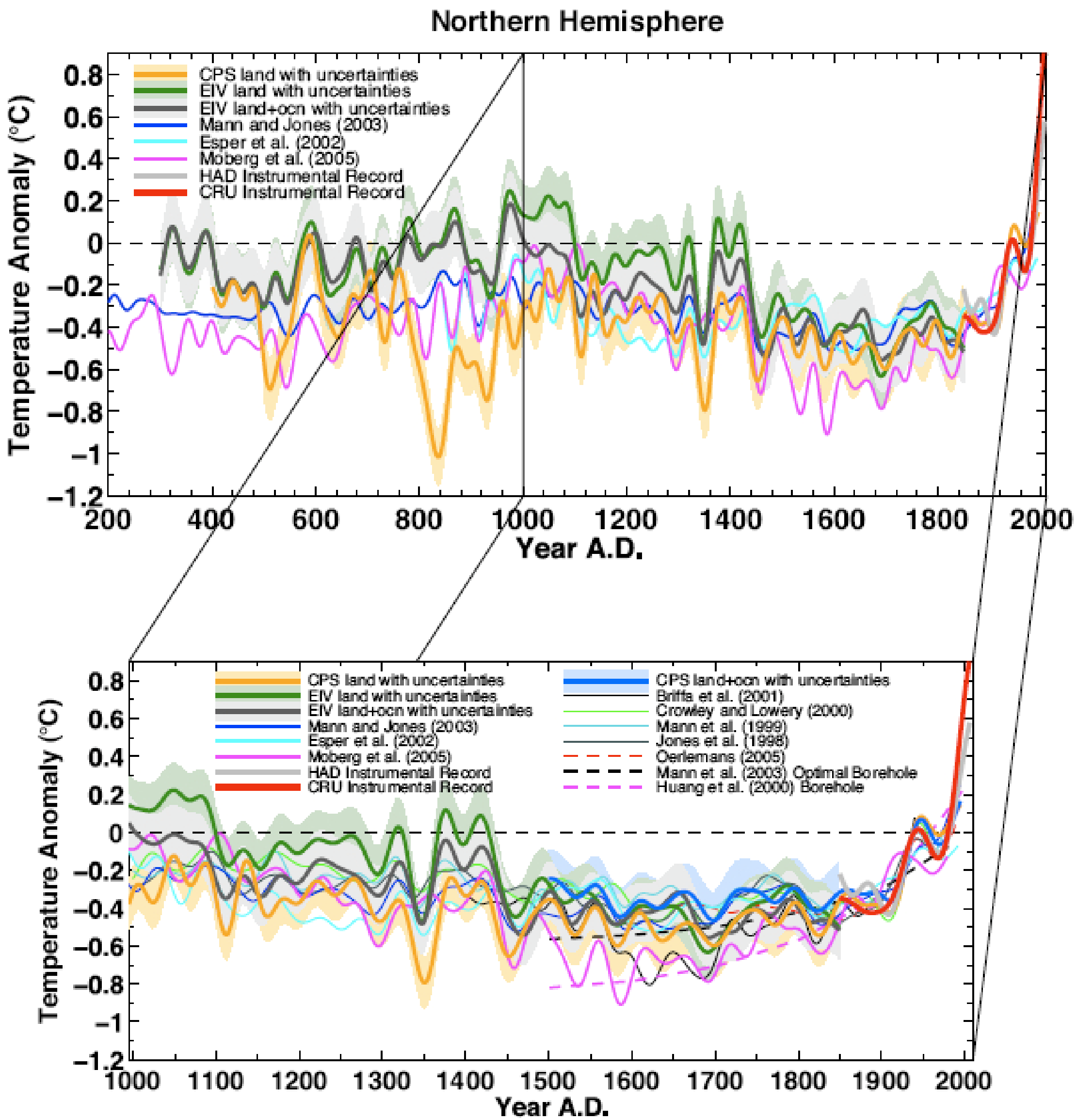

Figure 7. Reconstruction of climate from the year 200-2000 (upper) and 1000-2000 (lower), using a variety of independent methods including, among others, tree rings, glacier size, and boreholes. From Mann et al. 2008, Proceedings of the National Academy of Science.

3. **Hypothesis** - State the premise or propositions set forth to explain and achieve the described outcome of the research.

The overarching hypothesis is that a relatively large magnitude of change is expected during climate warming at the boreal-temperate forest interface in the Border Lakes of northern Minnesota.

Subhypotheses are: (1) that native temperate and exotic plant species will both advance at the expense of boreal species, and (2) that local cold temperature refuges may exist that could allow boreal species to persist after temperate species occupy most of the landscape.

Three main questions that will be answered are:

1. Are sufficient seed source populations already present for temperate species such as red maple, sugar maple, American basswood, bur oak, yellow birch and white pine to potentially fill in the niche vacated by boreal tree species, and are those temperate species populations already expanding?
2. Will invasive plant species (e.g. buckthorn, Canada thistle) be able to jump in and take advantage of the warming climate and changing forest situation, possibly spreading faster than native species?
3. Will boreal species like black spruce, balsam fir and jack pine be able to persist under a future warmer climate in areas with locally cooler climates (thermal refuges) such as bogs and north-facing hillsides?

4. **Methodology** - Describe the methodology to be employed to carry out the proposed research. Including descriptions of the sample design(s), if applicable.

The landscape will be systematically surveyed by placing transects in numerous locations (Rich et al 2007) in such a way as to obtain a representative sample of the entire landscape. Lengths of transects will be limited by the distances between lakes, but these could be up to a few miles in length. We will use a modified version of the landscape sampling scheme from Rich et al (2007), which had ca 9 miles of transect in 52 transects that were located perpendicular to lake shores with lengths of 250-400m, and which intensively sampled the Seagull/Saganaga/Alpine Lake are of the BWCAW. For this study there will be a lower density of longer transects spread over a larger landscape, and we anticipate about 45 miles of total transect length. Primary and secondary forests within the wilderness as well as commercial forests outside the wilderness will be sampled to obtain data for a variety of landscape contexts and degrees of remoteness. A graduate student will walk along each transect and record all instances where temperate tree species (including seedlings) or invasive plant species occur. For these occurrences GPS coordinates will be recorded, and each population of the temperate species or invasive species will be characterized, including soil depth and texture, and the context of the surrounding vegetation and landscape. GIS analyses of the surrounding landscape will be used to reveal the influence of various measures of human influence, such as disturbance to campsites, roads, structures and towns, as was done for a previous analysis of exotic earthworm distribution (Holdsworth et al 2007). For temperate tree species, sizes and densities of mature trees will be measured, as well the density and extent of surrounding seedlings via subtransects that radiate out in the four cardinal directions from the point at which the population is encountered along the main transect. A similar sampling scheme will be used to characterize the local abundance and extent of invasive plant species that are encountered. The details of transect placement, length, and width of the main transects as well as substransects will be worked out during a 2-3 week trial period during the first field season. Past experience with many landscape scale studies previously published by Frelich and Reich indicates that these details can seldom be worked out in advance; instead it is necessary to do some pilot transects and then adjust the details to maximize the capture of the data of interest and efficiency of the field work. We will compare the incidence of temperate and invasive species in our data to inventory data that is available (e.g. FIA or U.S. Forest Service Forest Inventory and Analysis), which is less detailed than the data collected for this project, since there is one plot per several thousand acres. Comparing the two sources of data will illuminate the efficacy of FIA samples to characterize invasive plant species and tree species occurrence at the edge of their range.

We will characterize air temperature variation across the landscape using Hobos (small units developed for the space industry that automatically measure temperature at specified intervals and store the data) to measure temperature on an hourly basis at 100 points for at least two years. We will try, if at all possible, to continue to take measurements for a third season; if this extends beyond the LCCMR funded period, we would use supplemental funds from other sources. To get a representative sample of the landscape, we will choose forested N, S, E, and W slopes, flat upland locations, hilltops, bogs, and other forested wetlands, and have several replicate temperature records for each landform. The data are stored within the Hobo unit until downloaded to a computer; we will download data twice a year. The results of this will enable us to model temperature variation across the landscape, depending on local landform, using digital elevation models, so that we can produce a map of likely cold temperature refuges throughout the landscape. We will compare the results with PRISM data (Oregon State University), which attempts to model temperatures on a fine scale grid that takes into account topographical effects throughout the U.S. The number of Hobos that we think we can install and monitor (ca 100) is not sufficient to model all aspects of temperature across a large landscape, however, it is the maximum we can do given budgetary and other constraints, and will be a significant advance over what has previously been done. The density of Hobos will give us spatial detail in temperatures far beyond that of even the most densely populated areas of the U.S. (large metro areas have the highest densities of weather stations). At this point, we actually don't know temperatures where trees actually grow, all we have are extrapolated/modeled values from weather stations that are not vegetated. We will seek advice from climatologists at the University of Minnesota with regard to placement of Hobos and data analyses. If some areas are present on the landscape that are colder than the landscape average temperature, and the magnitude of the difference is more than the degree of warming projected for a given future scenario (probably at least 2-4 degrees C), then there is evidence that boreal species may persist in some locations. We will use downscaled Global Circulation Model warming scenarios for the mid 21st Century from Galatowitsch et al (2009) for estimates of future climates.

5. **Results and Deliverables** - Describe in detail the expected outcomes of each of the results and deliverables.

Results 1 and 2. Map and analyses of the distribution of temperate tree species within the boreal forest, and Maps and analyses of the distribution of invasive plant species. While it is not possible to find every occurrence of temperate species and invasive species on the landscape, we can get a representative sample of their frequency of occurrence (how many occurrences intercepted per mile of transect line) as well as the types of sites on which each occur. This sampling scheme will detect temperate species, especially understory seedlings, at a much finer scale than existing Forest Inventory and Analysis data or remote sensing, and will provide a more detailed description of the relationship to landscape factors and seed sources. It should be noted that seed source density (i.e. density of colonies) and location for invading species (whether native species spreading into new areas in a changing climate or invasive species) is a fundamental piece of information without which it is impossible to estimate the rate of invasion. We recognize that a variety of assumptions can be made with regard to rate of spread from initial seed sources. For example, Canada thistle appeared in the middle of the BWCAW on one of our study sites for another project, and with its plumed seeds, dispersal is essentially unlimited, whereas buckthorn and oaks can be bird dispersed up to a few miles, and other species like garlic mustard require dispersal by ground-based animals or humans. Therefore, we will take into account a variety of scenarios that bracket the range of possibilities for spread from the existing seed sources. Given the frequency of temperate tree species and probable rates of spread deduced from the distribution of seedlings around the adult trees, and seed dispersal distances and growth rates from the scientific literature, we should be able to estimate how fast temperate species may possibly fill the landscape niche vacated by retreating boreal species. A similar assessment will estimate whether invasive species have the potential to spread as fast as temperate species, thus indicating to managers the level of effort that would be needed if a decision is made to limit their advance across the landscape.

Result 3. Map and analyses of potential cold temperature refuges where boreal species might persist in a warmer climate. This map will allow us to examine the potential refuge areas to assess the extent to which boreal tree cover may persist under various future warming scenarios. The map will also be useful for other biologists (e.g. natural heritage, Nature Conservancy, National Forest Service staff) to assess which boreal-forest dependent plant an animal species are present within potential refuge areas. Such species may persist in a warmer climate, while those present only in other areas may not. A number of endangered species such as the Lynx may or may not have sufficient future habitat under various future warming scenarios.

Result 4. Presentations, workshops, and publications. See details under dissemination and use below.

6. **Timetable** - Layout the proposed times for completing the proposed research including proposed dates for individual results and deliverables.

Transects to estimate frequency of temperate tree species and invasive plant species will be established on maps prior to the July 1, 2011 start date of the project, so that field work can begin immediately on July 1, 2011. Transects will be surveyed in the field from July-September 2011 and May-September 2012. Analyses of the transect data will take place from September 2012 through December 2013.

Hobos to measure temperature will be placed in the field during July and August 2011, and remain in the field until the end of the field season in 2013 (and if possible 2014), so that we will have at least two field seasons of temperature data. Downloading of data will occur in spring 2012, fall 2012, spring 2013, fall 2013, and if possible Spring and fall 2014. Preliminary analysis and mapping of the temperature data from the first year will be done during winter 2012-2013, and analyses including both years will proceed immediately upon finishing data collection in

October of 2013 (and another analysis in October 2014 if we area able to run a third field season).

Presentations and workshops will be prepared during fall 2013, in parallel with analyses of the transect data, so that they can be presented during January-June 2014. Publications will be prepared from January-June 2014.

7. **Budget** - Update the budget sheet from the original proposal based on the amount of funding recommended. Additional details can be added to the budget sheet to more fully describe the budget (The budget sheet is expandable so that additional information can be provided). Additional narrative on the budget can also be provided to more fully explain how the funds will be spent. The "Other Funding" section of the budget sheet should also be updated and include sufficient detail so that the source and amount of contribution is clear.

Budget explanation and justification (See also the accompanying excel file with budget worksheet).
This project will involve extensive field work to document the expansion of native tree species at the northern edge of their range in the Boundary Waters and surrounding forests. We visualize this as a Ph.D. project. Therefore, we have included 2.5 years of Research Assistant funding (standard 50% RA, total $90,671) and funding for a field and lab assistant (undergraduate hourly, fringe benefits for the summer period only, total $20,653). PI Frelich would supervise the entire project, advise the student, visit the filed sites, help analyze the data, and co-author several papers as well as prepare and present several workshops in northern Minnesota, therefore 30% of his salary is included for 2.5 years (total $67,216).

Equipment needed includes Hobos to measure temperature for 2 years on an hourly basis. 100 of these miniature units will be needed (plus a few extras in case of failure), at a cost of about $42 each and GPS equipment to locate study plots in remote areas (total $5,200).

Significant expenses related to dissemination of results and materials for workshops are necessary to carry out the project, therefore we are budgeting $2,760 for these expenses.

Travel for 2 months each summer to northern Minnesota would be necessary for the graduate student and undergraduate assistant, as well as occasional visits by the project manager Frelich. Frelich would also travel around northern MN towards the end of the project to present workshops (total $13,500).

8. **Credentials** - Provide brief background of the principal investigators and cooperators who will carry out the proposed research and selected publications (targeted/abbreviated resumes are acceptable).

Lee E. Frelich—project manager

Lee E. Frelich is Director of the University of Minnesota Center for Forest Ecology. He received a Ph.D. in Forest Ecology from the University of Wisconsin-Madison in 1986.

Frelich teaches courses in Forest Fire Ecology and Landscape Ecology on St.Paul Campus. He has advised 20 graduate students, and is a senior member of the Conservation Biology, Natural Resource Science and Management, Ecology, and Invasive Species Graduate Programs. Frelich has published numerous papers on forest ecology and has been listed among the top 1% of all scientists in the world in the Science Citation Index, Ecology and Environment Category. He has appeared in the news media 250 times including *The New York Times*, *Newsweek*, *National Geographic*, and many TV and radio stations. Current research interests include fire and wind in boreal forests, long-term dynamics of old-growth hemlock and maple forests, invasive earthworms in forests, and global warming.

Contact information
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1530 Cleveland Ave. N. St.Paul, MN 55108
E-mail: freli001@umn.edu
Phone: office, 612-624-3671, cell, 612-991-1359

Grants
Approximately $5,000,000 in grants since 1991, including major grants from National Science Foundation, USDA Forest Service, Joint Fire Science Program, MN Department of Natural Resources, and University of Minnesota.

Publications
Total of 87 publications (59 in peer reviewed journals, 7 books/book chapters, and 21 other). Publications appear in 28 peer-reviewed journals with 60 coauthors from six countries. Top 1% of scientists in the world list, Science Citation Index, Essential Science Indicators, *Ecology and Environment* category (2007, 2008, 2009).

Selected publications relevant to the Border Lakes study area in which this LCCMR project will take place:

Frelich, L.E. and P.B. Reich. 2010. Will environmental changes reinforce the impact of global warming on the prairie-forest border of central North America? *Frontiers in Ecology and Environment* 8: 371-378. DOI: 10.1890/080191.

Frelich, L.E. and P.B. Reich. 2009. Wilderness conservation in an era of global warming and invasive species: a case study from Minnesota's Boundary Waters Canoe Area Wilderness. *Natural Areas Journal* 29: 385-393.

Galatowitsch, S., Frelich, L.E., and L. Phillips-Mao. 2009. Regional climate change adaptation strategies for biodiversity conservation in a midcontinental region of North America**.** *Biological Conservation* 142: 2012-2022.

Holdsworth, A.R., P.B. Reich, and L.E. Frelich. 2007. Regional extent of an ecosystem engineer: earthworm invasion in northern hardwood forests. *Ecological Applications*, 17:1666-1677.

Rich, R.L., L.E. Frelich, and P.B. Reich. 2007. Wind-throw mortality in the southern boreal forest: effects of species, diameter and stand age. *Journal of Ecology*, 95: 1261-1273.

Frelich, L.E., C. M. Hale, S. Scheu, A.Holdsworth, L.Heneghan, P.J. Bohlen, and P.B. Reich. 2006. Earthworm invasion into previously earthworm-free temperate and boreal forests. *Biological invasions* 8: 1235-1245.

Weyenberg, S.A, L.E. Frelich, and P.B. Reich. 2004. Logging versus fire: how does disturbance type influence the abundance of eastern white pine (*Pinus strobus*) regeneration? *Silva Fennica* 38:179-194.

Mehta, S., L. E. Frelich, M. T. Jones, and J. Manolis. 2004 . Examining the effects of alternative management strategies on landscape-scale forest patterns in northeastern Minnesota using LANDIS. *Ecological Modelling* 180: 73-87.

Reich, P.B., P.Bakken, D.Carlson, L.E. Frelich, S.K. Friedman, and D. Grigal. 2001. Influence of logging and fire on boreal forest biodiversity and productivity. *Ecology* 82: 2731-2748.

Tester, J., A. Starfield, and L.E. Frelich. 1996. Modeling for ecosystem management in Minnesota pine forests. *Biological Conservation* 80: 313-324.

Frelich, L.E. and P.B. Reich. 1995. Spatial patterns and succession in a Minnesota southern-boreal forest. *Ecological Monographs* 65:325-346.

Peter B. Reich, Cooperator

Education

Ph.D. (1983) Department of Natural Resources
Cornell University, Ithaca, New York
Major in environmental biology and plant ecology

M.S. (1977) School of Forestry, Fisheries and Wildlife
University of Missouri, Columbia, Missouri
Major in forest ecology

B.A. (1974) Goddard College, Plainfield, Vermont
Majors in creative writing and physics

Positions held, University of Minnesota:

Professor and F.B. Hubachek, Sr. Chair (1991- present),
Distinguished McKnight University Professor (2003- present)
Regents Professor (2007- present)
Resident Fellow, Institute on the Environment Institute on the Environment

Graduate Faculty appointments: Ecology, Evolution and Behavior; Natural resource Science and Management, Plant Biological Sciences; and Conservation Biology Programs; University of Minnesota, St. Paul, MN

Mentoring

>25 graduate students and 30 additional scientists from 20 countries.

Grants

>20 million dollars in grants as PI or Co-PI since 1991, including several major grants from Department of Energy, National Science Foundation, and USDA Forest Service.

Publications:
320 peer reviewed publications, including 300 papers in journals and 20 book chapters. Institute for Scientific Information, Science Citation Index, top 20 most cited scientists in the world (out of 500,000) in the Ecology and Environment category. Publications relevant to this project coauthored with project manager Frelich are listed above.

9. **Dissemination and Use** – Describe how the findings of the research will be disseminated and describe the expected audience and potential use.

There will be two separate outreach efforts within Minnesota, one for users and managers of the BWCAW and a second for managers of surrounding commercial forests. A powerpoint presentation and a more detailed half-day workshop will be prepared for each of these two audiences. We will present these in northern Minnesota (Grand Marais, Ely) for the public and for agency personnel from the Minnesota Department of Natural Resources, Superior National Forest, and tribal and county forests. Three publications for peer-reviewed science journals will also be prepared, and will correspond roughly to the three questions listed above to be answered during the study.

7/26/2010