2011 Project Abstract
For the Period Ending June 30, 2014

PROJECT TITLE: Change and Resilience in Boreal Forests in Northern Minnesota
PROJECT MANAGER: Lee Frelich
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FUNDING SOURCE: Environment and Natural Resources Trust Fund
LEGAL CITATION: M.L. 2011, First Special Session, Chp. 2, Art.3, Sec. 2, Subd. 03i
APPROPRIATION AMOUNT: $150,000

Overall Project Outcome and Results

This project addressed the stewardship of forests in Minnesota's most renowned and iconic natural area—the Boundary Waters Canoe Area Wilderness (BWCAW)—under a changing climate. Forests of the BWCAW are at the very southern edge of the boreal forest biome (cold adapted forests of spruce, fir, pine, birch and aspen), with temperate forest species (primarily red maple) from the south, as well as exotic invasive species poised to invade in a warming climate. The purpose of the study was to map these species and temperatures across the BWCAW to gain insight into change that may occur in the BWCAW as the climate warms. For this purpose, PhD student David Chaffin placed 106 temperature sensors across the landscape, which measured temperature hourly for two years, accompanied by 106 plots on which all tree species abundances were measured. Also, 100 transects totaling nearly 16 miles in length were placed across the landscape to sample for the presence of temperate tree species and invasive species. Results show that European earthworms are a common invasive group of species; about 70%, and 33% of the forests within the BWCAW are at minimal and high stages of invasion, respectively. Earthworm invasion is related to distances from campsites, portage trails and motorized lakes, but not to temperature. Summer (June, July and August) daily maximum temperatures show a west (warm) to east (cool) gradient of about 12-13 degrees F across the BWCAW. Red maple abundance was positively related to summer temperature, being highest in the west. The main synthesis from all of the data collected during the project is that boreal conifers like black spruce, balsam fir, and jack pine may find a cool-temperature refuge and persist in the eastern BWCAW, even in a very warm future climate, but would be co-dominant with expanding red maple populations. Earthworms will continue to expand and facilitate these changes in tree species composition.

Project Results Use and Dissemination

The project was highlighted in presentations by project manager Frelich at several prominent venues: (1) Minnesota Soil and Water Conservation Districts webinar (statewide audience of MSAWCD staff), October 2, 2013; (2)The National Extension Educators Workshop, Cloquet, MN October 29, 2013; (3) Minnesota Climate Change Adaptation Workshop, Science Museum of Minnesota November 7, 2013 (very broad audience including many land managers from throughout the state; this also resulted in coverage in the Star Tribune and Minnesota Public Radio); (4) Climate Science Workshop for Teachers, University of Minnesota St.Paul Campus, November 9, 2013; (5) discussions with state staff directors in offices of U.S. Senators Amy Klobuchar and Al Franken, December 11, 2013; (6) Citizens Climate Lobby (Training in climate impacts on northern forests for ca 120 people, Minneapolis, January 25, 2014); (7) Jackson Middle School (A science immersion school in Champlin, MN), Expert Day presentations and workshops with ca 50 students, January 29, 2014; (8) Osher Life Long Learning Institute,

Coffman Union, University of Minnesota, Minneapolis, lecture to ca 40 retired faculty, February 28, 2014; (9) Minnesota Master Naturalist Annual Meeting Keynote to ca 150 people, May 16, 2014, Camp Friendship, MN; and (10) Climate change adaptation planning workshop for National Park Service staff at Voyageurs NP, July 30, 2014, also attended by U.S. Forest Service and other agency personnel. Publication in the form of a PhD thesis (David Chaffin) and at least 3 peer-reviewed journal articles will follow within about 2 years.

Agenda Item: 07a

Environment and Natural Resources Trust Fund (ENRTF)
M.L. 2011 Work Plan—Final Report

Date of Status Update: **06/30/2014**
Date of Next Status Update: **08**/31/2014
Date of Work Plan Approval: 6/23/2011
Project Completion Date: 6/30/2014 **Is this an amendment request?** __

Project Title: Change and Resilience in Boreal Forests in Northern Minnesota

Project Manager: Lee Frelich
Affiliation: U of MN
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City: St Paul **State:** MN **Zipcode:** 55108

Telephone Number: (612) 624-3671
Email Address: freli001@umn.edu
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Location:

Counties Impacted: Cook, Lake, St. Louis

Ecological Section Impacted: Northern Superior Uplands (212L)

Total ENRTF Project Budget:	**ENRTF Appropriation $:** 150,000
	Amount Spent $: **148,242**
	Balance $: **1,758**

Legal Citation: M.L. 2011, First Special Session, Chp. 2, Art.3, Sec. 2, Subd. 03i

Appropriation Language:
$75,000 the first year and $75,000 the second year are from the trust fund to the Board of Regents of the University of Minnesota to assess the potential response of northern Minnesota's boreal forests to observed and predicted changes in climate conditions and develop related management guidelines and adaptation strategies. This appropriation is available until June 30, 2014, by which time the project must be completed and final products delivered.

Agenda Item: 07a

I. PROJECT TITLE: Change and resilience in boreal forests in northern Minnesota

II. PROJECT SUMMARY:

Boreal forests of spruce, fir, paper birch, aspen and jack pine cover more than 2 million acres of land on the Border Lakes Ecological Subsection of northern Minnesota. These forests are near the southern edge of their geographic range. With a warmer climate boreal tree species will be under increased stress from heat, drought, fires, storms, and insect pests. Therefore, the health and productivity of these forests may be jeopardized by a warmer climate. To plan for these changes, we need to know whether the forest is poised to respond in a resilient fashion as the boreal tree species decline. We can accomplish this goal by answering these questions:

1. Will temperate forest species now at the northern edge of their range in the Border Lakes, such as red maple, sugar maple, American basswood, bur oak, pin oak, red oak, and white pine expand to take the place of declining boreal species such as spruce and fir?
2. Are sufficient seed source populations already present for these temperate species to fill in the niche vacated by boreal tree species, and are those temperate populations already expanding?
3. Will invasive plant species (e.g. buckthorn) be able to jump in and take advantage of the warming climate and changing forest situation, possibly displacing native species?
4. Will boreal species like spruce, 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?

With this project we will obtain the information necessary to answer these questions and provide the scientific basis for climate change adaptation plans for a variety of scenarios (from low to high magnitudes of change) that may occur over the next century. These goals will be accomplished by surveying the forest to assess the abundance of colonies of temperate species at the northern edge of their range, the potential for these colonies to expand, and whether invasive species are present that may interfere with forest adaptation to climate change. We will also measure temperature in areas with varied physiographic settings (e.g. bogs, and north and south facing hillsides), for 2 years to assess whether cool microclimates exist that may allow persistence of boreal tree species on some parts of the landscape. This information will be used to prepare adaptation and management options for commercial and BWCAW wilderness forests, as well as for seven national parks in the region (Voyageurs, Grand Portage, St.Croix Scenic River, Isle Royale, Apostle Islands, Pictured Rocks, and Sleeping Bear Dunes), through a related grant from the National park Service. Finally, via presentations and workshops in the Border Lakes Ecological Subsection, we will inform forest managers regarding future scenarios for forest health and resilience, and options for adaptation to climate change. The audience will include staff of the Superior National Forest, National Park Service, Minnesota DNR, County and Tribal forestry divisions. We will also reach out to the public via lectures and the media.

III. PROJECT STATUS UPDATES:

Project Status as of December 31, 2011: The project has progressed as planned, with funding that has been spent on salary of the project manager and graduate student for purposes of planning the summer 2012 field season. The Ph.D. student David Chaffin started as planned in September 2011, and has taken classes that will give him the necessary background to do the field work and analyze the project data when it is collected. He is well qualified for this project, having much field experience in the border lakes region.

Project Status as of June 30, 2012: The project has progressed as planned, with funding that has been spent on salary of the project manager and graduate student David Chaffin for purposes of planning the summer 2012 field season, and carrying out the first portion of the fieldwork, namely placing the temperature sensors in 100 locations across the landscape of the Border Lakes Ecological subsection during May 2012, and during June characterizing the vegetation around each of the temperature sensors, as well as planning for July-August fieldwork that will consist of a preliminary characterization of temperate tree species and invasive species presence across the BWCAW and surrounding landscape.

Project Status as of December 31, 2012: The project continues to progress as planned, with funding spent on project manager salary and graduate student David Chaffin as well as field assistants. Money was also spent on travel for Chaffin and assistants, who spent much of the summer surveying invasive species, temperate tree species invading the boreal forest, and obtained the first summer of hourly temperature data from 100 sites around the Boundary Waters. New batteries were placed in the Hobo temperature sensors so that they were ready to continue measuring during the current winter season. We will do preliminary analyses of the first summer temperature and invasive species data during winter 2012-2013 in preparation for the 2013 summer field season.

Project Status as of June 30, 2013: The project continues to progress as planned. However, related projects funded by other sources have developed, and the project is becoming regional in scope, with details given under activities 1 and 2 below. Funding in the last 6 months was spent on project manager and Ph.D. student David Chaffin salary, and field work for the current season began during May, so a small amount has also been spent for field assistant salary. During the winter months, Dave Chaffin was able to put together the first preliminary analyses of summer temperatures from 2012, as well as data summaries on extent of invasive species and temperate tree species invading the boreal forest in the BWCAW. This spring he downloaded the winter temperature data, and all of the >100 Hobos were still present and functioning properly, reading temperature every hour! We were able to install several additional temperature sensors for a total of 108 at this point. As of the date this report was written, Dave is in the field starting the summer 2013 transects to examine extent of invasive species and temperate tree species in the BWCAW.

Amendment Request (June 30, 2013): Rebudget to zero out activity 3 and transfer that funding to activities 1 and 2, as shown in amended attachment A. Reason: It will be possible to carry out activity 3 using University of Minnesota funds, due to synergies with other projects that developed as a result of this LCCMR grant. Activities 1 and 2 also cost more than originally planned, and using funds from activity 3 we can also extend the analyses of temperate species, invasive species, and temperature data compared to what we originally envisioned for Activities 1 and 2, which makes sense given the other related projects that have developed. Request that this rebudget be retroactive because the budget for activities 1 and 2 have been slightly exceeded as of June 30, 2013.

Amendment Approved: July 10, 2013

Amendment Request (Sept 20, 2013): Move small remaining amounts of money in undergraduate student salary ($4873), PI salary ($1050) and equipment ($751) to Grad student salary ($2528) and travel ($4146). Reason: Grad student salary and fringe went up slightly since the first budget in was developed in 2010 due to higher than average inflation in tuition. Travel costs to visit each of the 100 temperature sensors scattered across a large landscape several times during the project have higher mileage than originally envisioned. The graduate student working on the project (David Chaffin) has been highly efficient, so that less money was needed for undergraduate hourly help, therefore the extra money from undergraduate salary can be used for higher than expected travel expenses. Small savings were also realized in Frelich salary and equipment purchases that can be used for travel. All of these small transfers will enable a balanced budget at the end of the budget period (June 30, 2014).

Approved by LCCMR, September 23, 2013

Project Status as of December 31, 2013:

The project continues to progress as planned (given the amendments approved in July and September 2013). At this point all of the salary and equipment budgets have been spent, and the remaining $1,758 will be spent in spring 2014 for travel expenses to get the final temperature data from over 100 Hobo temperature data loggers distributed around the BWCAW. Download of summer 2013 temperature data by PhD student Dave Chaffin was successful, and not one of the Hobos temperature data loggers has gone missing or malfunctioned. In addition, a new project funded by the National Park Service has added 200 more data loggers on Isle Royale national Park and Voyageurs National Park, so that the project has become regional in scope. During summer of 2013, Dave Chaffin also completed the survey of temperate tree species (e.g. maple, oak) invasion into the boreal (i.e. spruce, fir, jack pine, birch and aspen) forest, as well as invasive species (earthworms and others) into the BWCAW. Data analyses for

temperatures through summer 2013 and spatial patterns of invasion of the boreal forest will occur during winter 2013-2014.

Final project Status as of September 15, 2014 (agreed on date for final report):
The project progressed as planned, except that the retrieval of the temperature data took place in early August 2014, rather than June. Preliminary analyses of the data on temperature, temperate tree species invasion into boreal forest, and invasive species presence in the Boundary Waters has been completed for this final report to LCCMR, and more detailed analyses will be completed over the next two years for PhD student Dave Chaffin's thesis and eventual publication in peer-reviewed journals..

IV. PROJECT ACTIVITIES AND OUTCOMES:

ACTIVITY 1: Survey abundance of temperate species (e.g. maple and oak) and invasive species within Border Lakes boreal forests.

Description:
A graduate student and undergraduate student assistant will survey large tracts of forest via transects to assess the number and geographical distribution of outlying colonies of temperate tree species and invasive plant species (e.g. buckthorn), as well as evidence regarding current or future potential expansion of their populations within the southern margin of the boreal forest. This data will allow us to assess whether temperate tree species are poised to expand as the climate warms, and the extent to which invasive species may interfere with forest adaptation to climate change. These data will likely also be related to Activity 2 (see below), since temperate and invasive species are more likely to invade areas on the landscape with warmer temperatures. To the extent possible, we will develop models of temperate and invasive species expansion for various future scenarios. Regarding timeline (which will apply to Activities 1 and 2), we will hire a graduate student beginning in September 2011, who will then be prepared during the 2011-2012 academic year to carry out the field work during the field seasons (May-October) of 2012 and 2013. An undergraduate student field assistant will be hired during the field seasons of 2012 and 2013.

Summary Budget Information for Activity 1:

ENRTF Budget:	**$75,939**
Amount Spent:	**$75,939**
Balance:	**$0**

Activity Completion Date:

Outcome	Completion Date	Budget
1. Map showing distribution of temperate tree species	December 31, 2013	$ 25,000
2. Map showing distribution of invasive species	December 31, 2013	$ 25,000
3. Models of temperate and invasive species expansion	June 30, 2014	$ 25,939

Activity Status as of December 31, 2011: We have assembled as much data on occurrence of various tree species and invasive from previous inventories and satellite analyses as possible (although this process will continue through May 2012), to help get a good understanding of where to sample the landscape when we start field work in May/June 2012. The student's coursework in GIS and statistics will ensure high quality work in the field.

Activity Status as of June 30, 2012: The fieldwork consisting of transects across the landscape to locate temperate tree species and invasive species has just begun as of June 2012. The field assistant has been hired and has been working with the graduate student David Chaffin during the month of June.

Activity Status as of December 31, 2012: Several transects across the BWCAW to characterize the distribution of temperate tree species invading the boreal forests as well as invasive species in forests were completed by late August 2012. The data from these transects will be used during winter 2012-2013 to plan summer field work for 2013.

Activity Status as of June 30, 2013: Field work to complete transects for the second summer of data on extent of invasive species and temperate tree species has just started. Based on preliminary analyses of last summer's data, the field protocol used last summer has proved to be adequate and this summer's methods will be the same. Invasion by the temperate tree species red maple and exotic European earthworms were found to be quite extensive in the boreal forests of the BWCAW.

Activity Status as of December 31, 2013: Field work was completed during summer 2013, and data analyses are underway during winter 2013-2014. Maps of species distribution should be available shortly.

Activity Status as of September 15, 2014: Analyses and maps of earthworm invasion are shown below. The temperate tree portion of Activity 1 will be addressed alongside the temperature data in Activity 2. Final Report Summary:
100 straight-line transects were surveyed during the summers of 2012 and 2013. Transects were randomly placed throughout the BWCAW and they ranged in length from 20m (straight into a cliff) to up to 500+ meters. In total, David Chaffin and his field assistants bushwhacked 25.18km (15.65 miles) through the wilderness as they surveyed the forest for both temperate tree species and invasive earthworms.

Invasive Earthworms
To characterize the extent of earthworm invasion along transects, we used the Invasive Earthworm Rapid Assessment Tool (IERAT). IERAT is a visual method of determining the stage of earthworm invasion at a site on 5-point scale. The following is a simplified summary of each invasion stage in terms of key species present and level of ecological impact:

- Stage 1 – Presumed earthworm free
- Stage 2 - *Dendrobaena octaedra* present. This very small species lives strictly in the litter layer where it feeds on fungi and bacteria. Because it does not consumer the litter layer, it has less of an impact on the forest floor and the native plant communities that inhabit it. It also spread faster than the other earthworm species, so has been found in previous studies to occupy the largest proportion of the landscape, and we expect the same for the BWCAW.
- Stage 3 – *Lumbricus rubellus, Aporrectodea* ssp. and *Dendrobaena octaedra* present. *Lumbricus rubellus*, commonly referred to as "beaver tails," is a popular fishing bait. It lives in, and feeds on, the litter layer and can rapidly remove the forest floor after invading a site. Its presence is associated with significant reductions in native plant communities that rely on the litter layer for germination and rooting. At the same time, *Aporrectodea* species invade the mineral soil beneath the duff, and compact the soil and change the horizon structure.
- Stage 4 – Juvenile *Lumbricus terrestris* present in addition to the previously mentioned species. *Lumbricus terrestris*, commonly referred to as "night crawlers," is the most popular species of fishing bait sold across the Great Lakes region. Stage 4 represents the initial stages of *Lumbricus terrestris* invasion. *Lumbricus terrestris* is a deep burrowing species that comes to the surface at night to feed on the previous season's fresh leaf litter only. It is capable of eating all leaf litter (except for jack and red pine and spruce) that falls each year, and can thus maintain bare soil conditions that promote erosion and may facilitate invasive plant species.
- Stage 5 – Fully invaded. Adult *Lumbricus terrestris*, *Lumbricus rubellus*, *Aporrectodea* species, and *Dendrobaena octaedra* present. An established population of *Lumbricus terrestris* can easily consume all the leaf litter produced in a forest each year. Working together, *Lumbricus rubellus* removes the original litter layer that took many years to develop, and *Lumbricus*

terrestris keeps it from recovering by consuming any and all new leaves that fall, leading to large and long-term ecological impacts.

Each transect was divided into 10m segments, and each segment was visually inspected for signs of earthworm invasion and assigned an IERAT score. A total of 2,518 transect segments were scored. The following graphs detail the extent of earthworm invasion across those segments (Figures 1, 2, and 3). Seventy percent of the segments had earthworms present (Figure 1), while 1/3 had reached a high stage of invasion (3, 4 or 5, Figure 2), and 15% had reached very high stages of invasion (4 or 5, Figure 3).

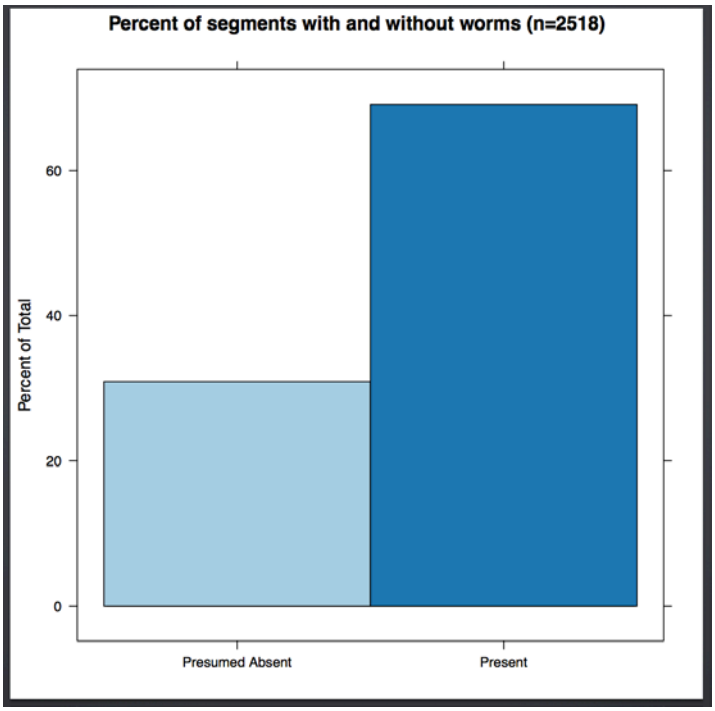

Figure 1. Approximately 70% of the segments sampled showed signs of earthworm invasion.

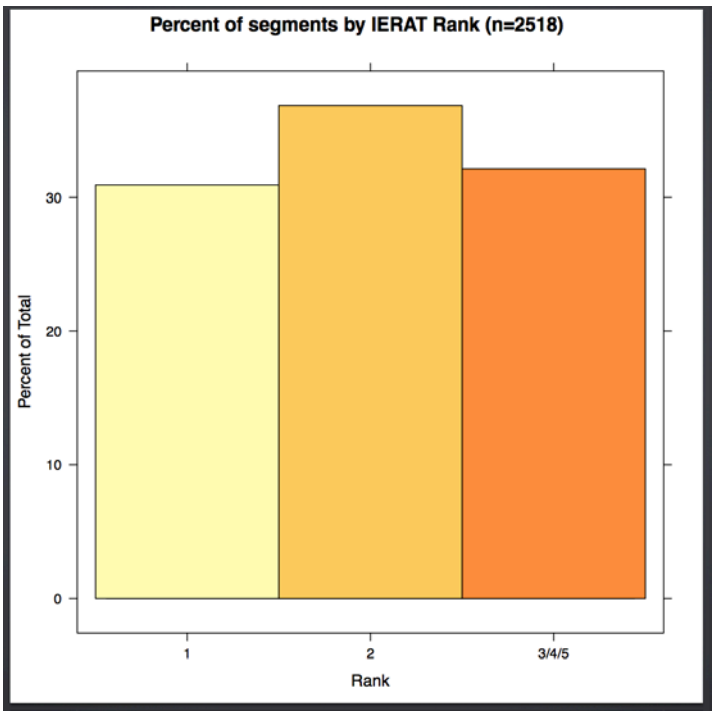

Figure 2. Approximately one-third of the segments sampled had reached an invasion stage associated with loss of the forest floor and significant negative impacts on native plant communities.

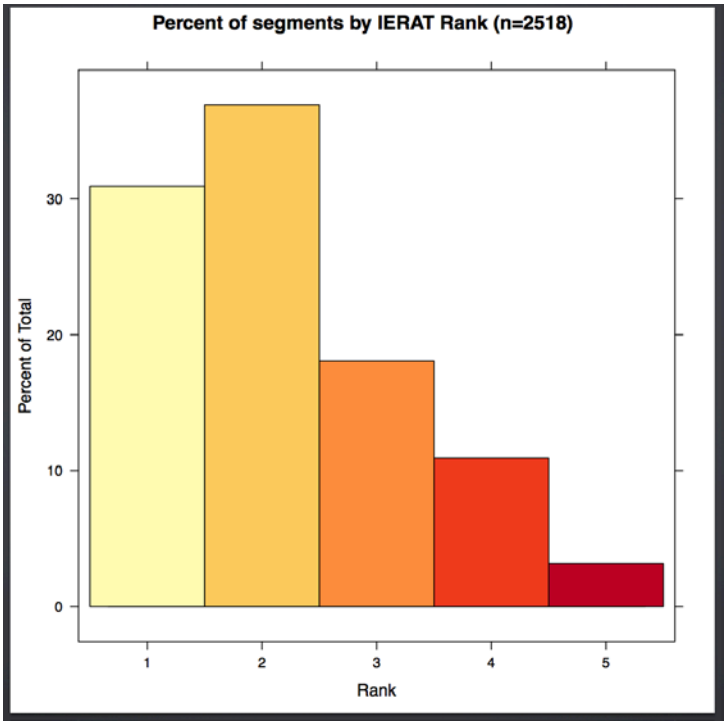

Figure 3. Approximately 15% of the segments sampled showed signs of *Lumbricus terrestris* invasion (Ranks 4 and 5).

To understand the spatial pattern of invasion across our transects, we investigated possible relationships between IERAT rank and a host of likely predictor variables including:

- Distance from the segment to the nearest campsite
- Distance from the segment to the nearest portage trail
- Distance from the segment to the nearest lakeshore
- Distance from the segment to the nearest motorized lake
- Distance from the segment to the nearest road

- Distance from the segment to the nearest entry point
- Popularity rank of the nearest entry point
- # of daily permits issued for the nearest entry point
- Elevation above sea level
- Aspect (direction a slope faces, N, S, E, W).
- Slope (steepness of slope in degrees)
- Stand age (age of older trees, generally represents time since last major disturbance).

Initial analyses found a significant relationship between IERAT rank and distance to the nearest campsite, portage trail and motorized lake. For all three predictors, as the distance from a segment to any of these three features increases, the odds that the segment will be ranked in a higher invasion stage decreases. We developed a statistical model of these relationships and used that model to predict the extent and spatial pattern of earthworm invasion throughout the entire BWCAW (Figure 4). As the map shows, earthworm invasion in the BWCAW is extensive, but incomplete, with campsites and portage trails serving as epicenters of invasion. Not surprisingly, invasions are also more extensive near motorized lakes, which receive higher fishing pressure. Further analyses will seek to refine this invasion map by including forest stand type data in the predictions, given earthworm's preference for deciduous leaf litter (aspen, birch, maple, basswood) versus conifer needles (red pine, white pine, balsam fir, black spruce). Fortunately, very few observations of invasive plant species was found in the BWCAW.

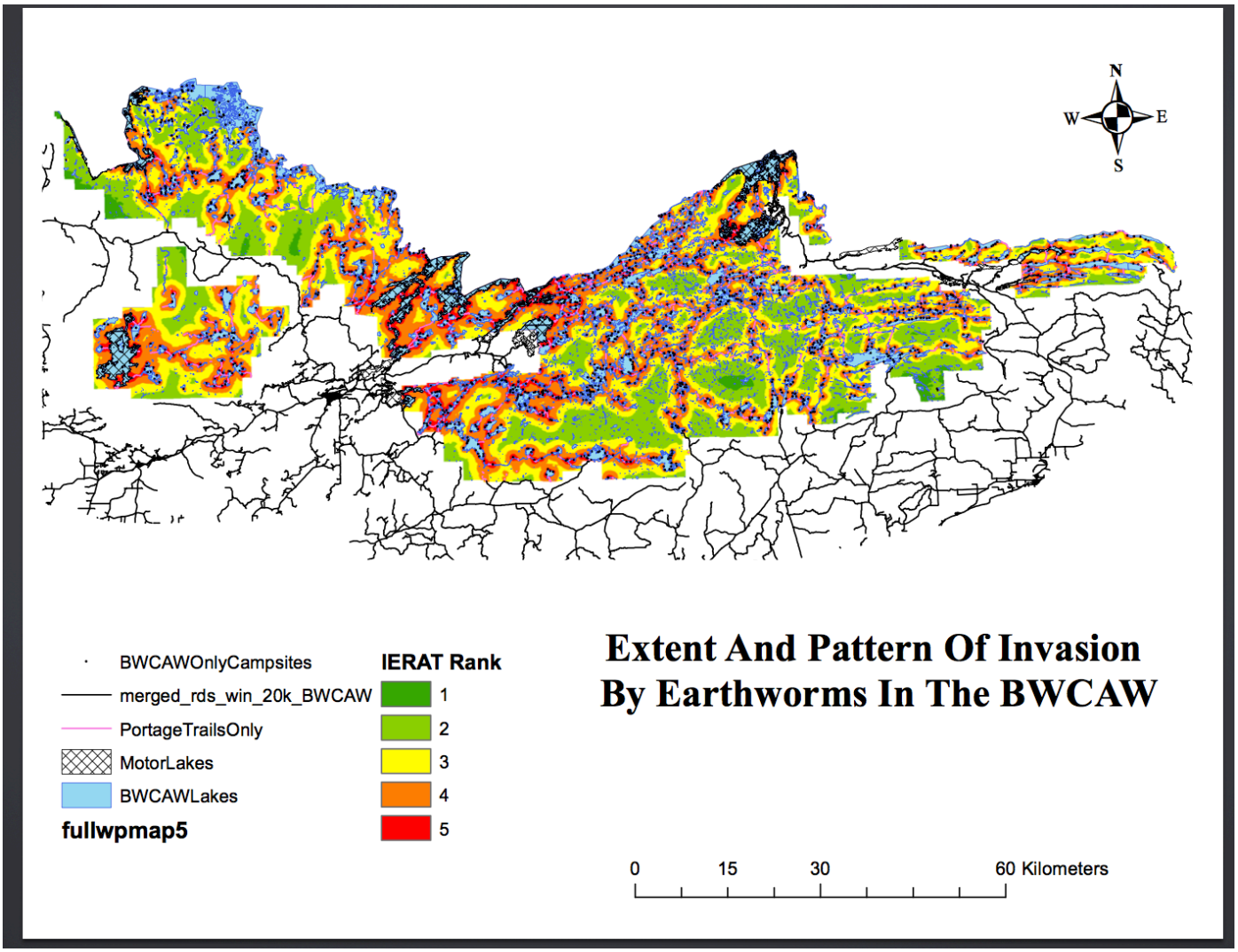

Figure 4. Predicted European earthworm distribution in the BWCAW.

ACTIVITY 2: Characterize temperature distribution on the forested landscape.

Description:
The graduate student and assistant will place 100 HOBOs (small devices originally developed for NASA space programs, that record temperature on an hourly basis and store the data for up to a year for later download to a computer) in the field to measure the effect of topographical features, such as south and north facing slopes, bogs and lakeshores on local climate. This data will be collected for two years, starting in May 2012 and including the 2012 and 2013 growing seasons (for three years if possible; we will seek funding from other sources to continue data collection through the 2014 field season). Analyses of this data will allow us to make maps showing observed temperature distribution as well as to develop models to predict temperatures across the landscape. The temperature analyses will in turn allow us to predict areas that could serve as refuges for boreal species (cold areas) in a warming climate and areas where invasion of temperate and invasive species is more likely (warm areas). The data will be supplemented by 150 additional HOBOs placed in Isle Royale National Park and 45 placed in Voyageurs national Park. Although not funded by this project, these HOBOs funded by other sources will contribute greatly to temperature analyses applicable to this LCCMR project.

Summary Budget Information for Activity 2:

ENRTF Budget: $74,061
Amount Spent: $ 72,303
Balance: $ 1,758

Activity Completion Date:

Outcome	Completion Date	Budget
1. Maps of observed temperature	December 31, 2013	$ 30,000
2. Maps and models of cold (boreal species refuges) and warm (temperate species invasion) areas on the landscape	June 30, 2014	$44,061

Activity Status as of December 31, 2011: We have started consultation with climate experts at the University of Minnesota to ensure that we place and use the HOBOs (for temperature measurement) correctly in the field during summer 2012.

Activity Status as of June 30, 2012: Temperature sensors were purchased and placed across the landscape during May 2012. We stratified the landscape into North, South, East and West facing slopes, ridgetops and valley bottoms, and deciduous versus conifer dominated forest, to get a representative sample of landscape temperature.

Activity Status as of December 31, 2012: The first growing season hourly temperature data were obtained from 100 sensors as of early November 2012. Preliminary analyses will be conducted during winter 2012-2013.

Activity Status as of June 30, 2013: The first winter temperature data was downloaded and all sensors were functioning properly through the winter. Field work to get started on the second summer of temperature data has been completed—temperature sensors were checked and fitted with new batteries during May 2013. The second summer data will be downloaded during October 2013. There is much interest in the data we are collecting, and we have started discussions with other potential users of the temperature data, for example entomologists interested in winter minimum temperatures in the forest that may control insect pests such as emerald ash borer and mountain pine beetle.

Activity Status as of December 31, 2013: Hourly temperature data from inception of the project the end of summer 2013 is in hand, and analyses will occur during winter 2013-2014. The final data download will occur in May 2014, and the remaining funding is allocated for that final field work. Temperatures during summer vary by 4-5 degrees F across the BWCAW, with the western part much warmer than the east, and the west also has much more extensive invasions by temperate tree species—red maple is becoming ubiquitous in the western BWCAW and has a significant presence in the east. South slopes are also 2-4 degrees warmer than north slopes, indicating that topographic heterogeneity will be important for temperature refugia for boreal species to hang on in a warming climate.

Activity Status as of September 15, 2014 (Final Report Summary):
A total of 106 HOBO Pendant temperature sensors were placed around the border of the BWCAW. The sensor placements spanned the length of the Wilderness from east to west, and were also placed across a variety of landform types (ridge tops, north slopes, south slopes, bogs) to represent the topographical complexity of the landscape.

The sensors were deployed in the spring of 2012. They were visited in the fall of 2012, spring of 2013, and fall of 2013 to replace sensor batteries and download data. The sensors were removed from the field in August, 2014. Note that it was anticipated to remove the sensors during June 2014, but due to injury of PhD student David Chaffin, that trip was cancelled, and the sensors were retrieved after the deadline for spending money on the project, so that $1,758 were left at project end. All 106 sensors survived the full two years in the field, giving us a complete 27 month temperature record for analysis. To date, our analyses have focused on the spatial variation in average summer maximum temperature in an effort to locate potential “cold spots” on the landscape where boreal tree species might hide from the heat as the climate warms. There was a strong summer temperature gradient from west (relatively warm) to east (relatively cool, Figure 5).

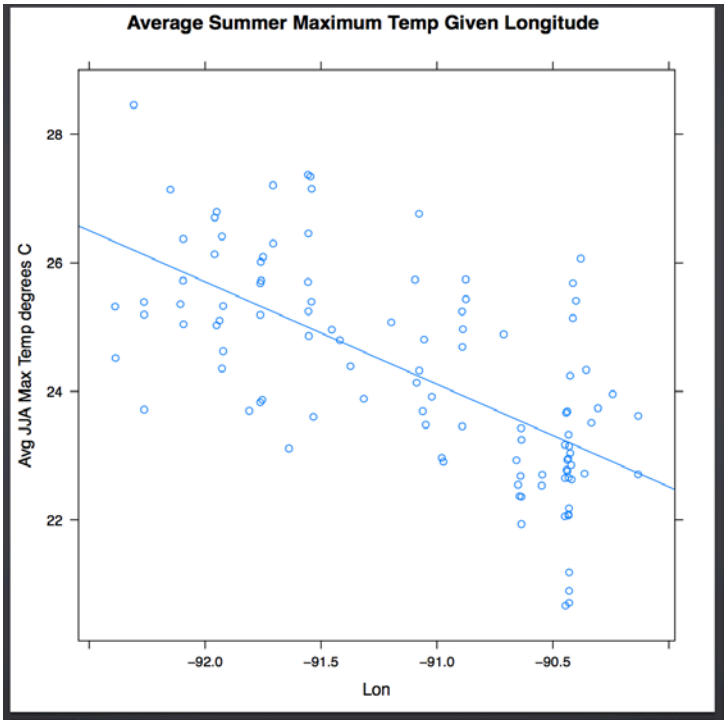

Figure 5. Each dot represents the average summer maximum temperate at one of our 106 sensor sites. As one moves from the end of the Echo Trail (longitudes ca -92) to the end of the Gunflint Trail (longitudes ca -90.5), average summer max temps decrease considerably.

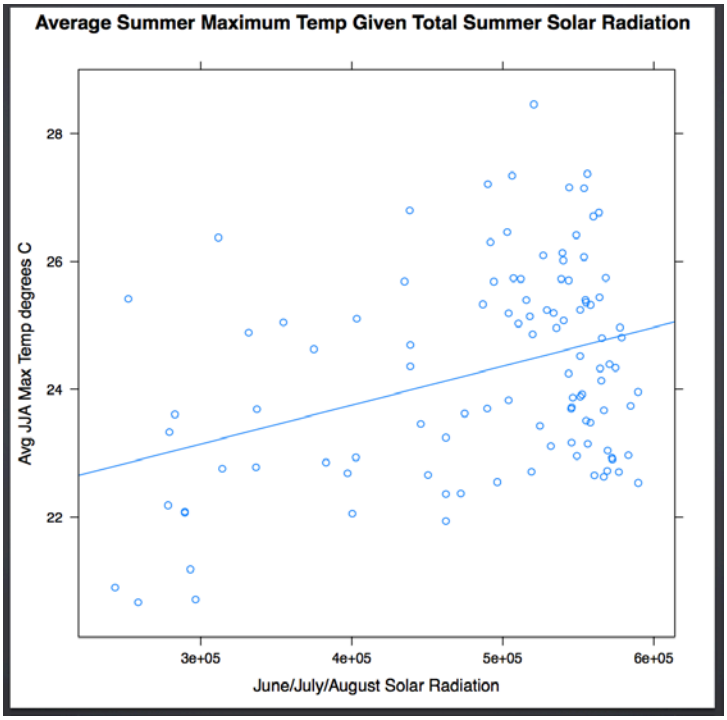

Figure 6. A positive relationship exists between the average summer maximum temperature at a site and the total amount of solar radiation that site receives during the summer, which is influenced primarily by aspect and slope.

We used longitude and total summer radiation to model average maximum summer temperature for the entire BWCAW (Figure 7). As the Figure 7 map shows, average summer maximum temperatures have a range of approximately 7 degrees C and decrease from west to east. Based on this initial analysis, the far eastern BWCAW is the most likely area to hold thermal refugia for boreal tree species given its far eastern location and the east-west orientation of the lakes, which creates steep north slopes that experience less solar radiation. Because summer maximum temperature is very important for regeneration and growth of boreal conifers like black spruce, white spruce, jack pine, and balsam fir, at least as a preliminary result, it seems likely that those species could persist in the eastern BWCAW with as much as 6-7 degrees C in summer warming. The rational for this is that with 7 C of warming in the future, the eastern BWCAW would have a summer thermal regime like that in the western BWCAW today, and those conifers are present in the western BWCAW today. On the other hand, 7 C warming would clearly make the western BWCAW too warm for the boreal conifers. Summer temperature projections underway for the National park Service Climate Adaptation Project (Frelich and Moen, Principle Investigators), will show the expected magnitudes of summer temperature increase for low and high warming scenarios, and combined with the data from this LCCMR project, we will be able to project where boreal conifers will persist within the BWCAW, and in the surrounding region, at a spatial grid size of 1 km (0.6 miles).

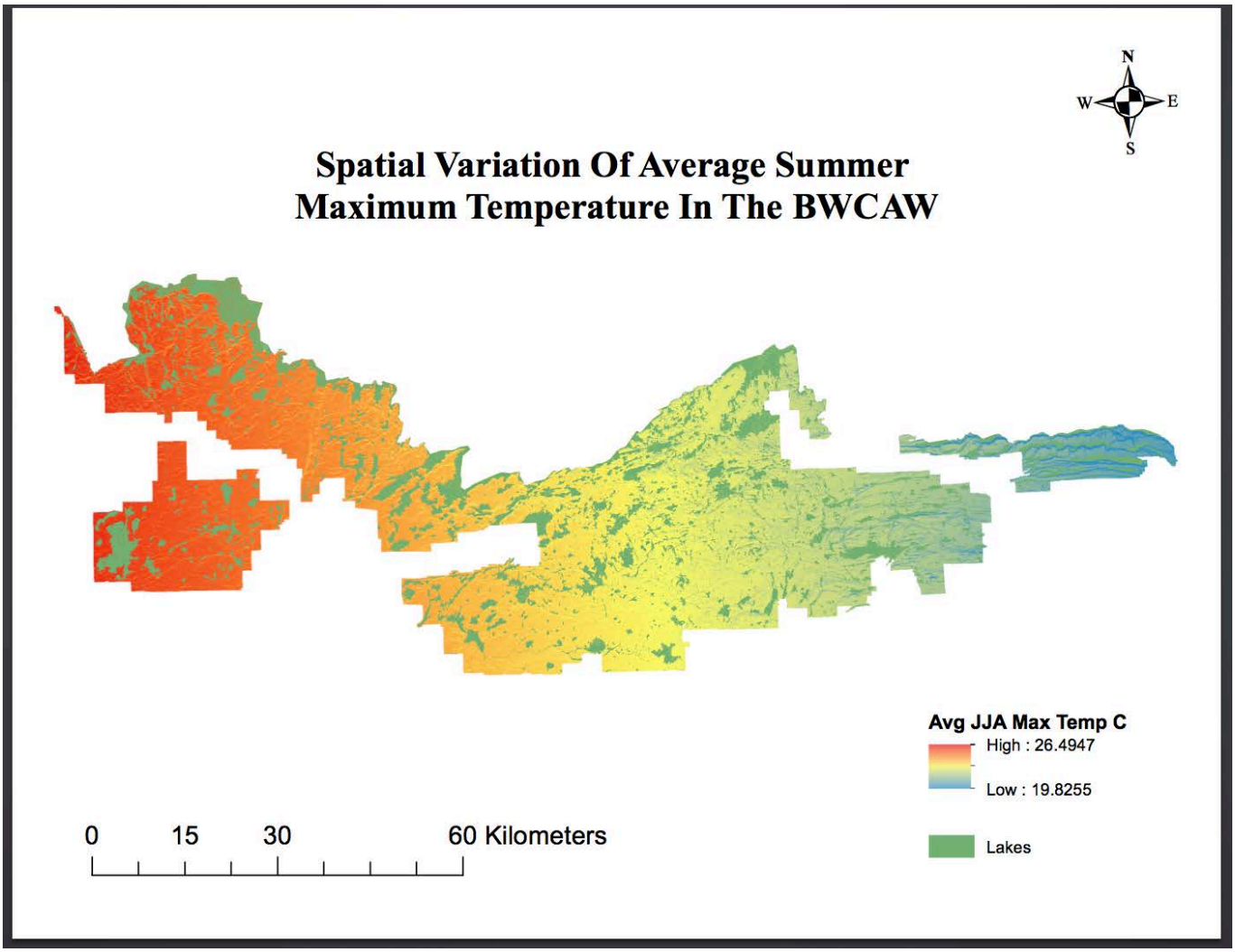

Figure 7. June, July and August average high temperate in the BWCAW.

We are currently working on more complex analyses and model building that will take into account additional site factors such as elevation, distance to Lake Superior, distance to lakeshore, basal area, canopy cover, and other factors, that can influence the temperature experienced at a site.

These more detailed models will be part of David Chaffin's PhD dissertation and will more accurately pinpoint potential thermal refugia within the BWCAW as well as in the surrounding region.

Temperate Tree Survey

Returning to Activity 1, we collected two sources of temperate tree species data for the region. The first comes from the 100 transects within the BWCAW. As we walked into the woods on each transect, we recorded the perpendicular distance from the transect line for every occurrence of a temperate tree species that we could see without leaving the line. Over two summers, we recorded over **16,000** occurrences of temperate tree species within the BWCAW, the vast majority of which were red maple. We will use those perpendicular distance measurements to estimate density of each temperate tree species across several size classes within the BWCAW. Given the large amount of data, those analyses are still underway.

The second source of temperate tree species data comes from the plot surveys we conducted at our 106 temperature sensor sites. At each site we measured the basal area of all trees larger than 2.5cm diameter within a 12m radius circular plot. Within a nested 3m radius circular plot, we counted the number of saplings and seedlings for each tree species present.

On the following map (Figure 8), each red dot represents a temperature sensor site, and the size of the dot represents the percentage of total basal area occupied by red maple. The larger the dot, the more red maple trees present at a site. When included with the map of average maximum summer temperature within the BWCAW, we can see a spatial relationship between red maple basal area and higher average maximum summer temperatures (Figure 8). Although there is variability in red maple abundance at warm temperatures in the central, southern, and western BWCAW, due to the fact that any one species is never present everywhere even in optimum climates, the abundance is uniformly small in the coolest parts of the BWCAW (far eastern portion). That same relationship holds with the total number of red maple saplings and seedlings counted at each sensor site (Figure 9). It is likely that the eastern BWCAW will, in the future, become as warm as the western BWCAW today, and given the observed relationship between red maple abundance and temperature, we can project that under those conditions, red maple would become an abundant species in the eastern BWCAW. A second temperate tree species, northern red oak, was also found during the study, and although the numbers of trees were much smaller than for red maple, the trends with temperature were very similar (data not shown).

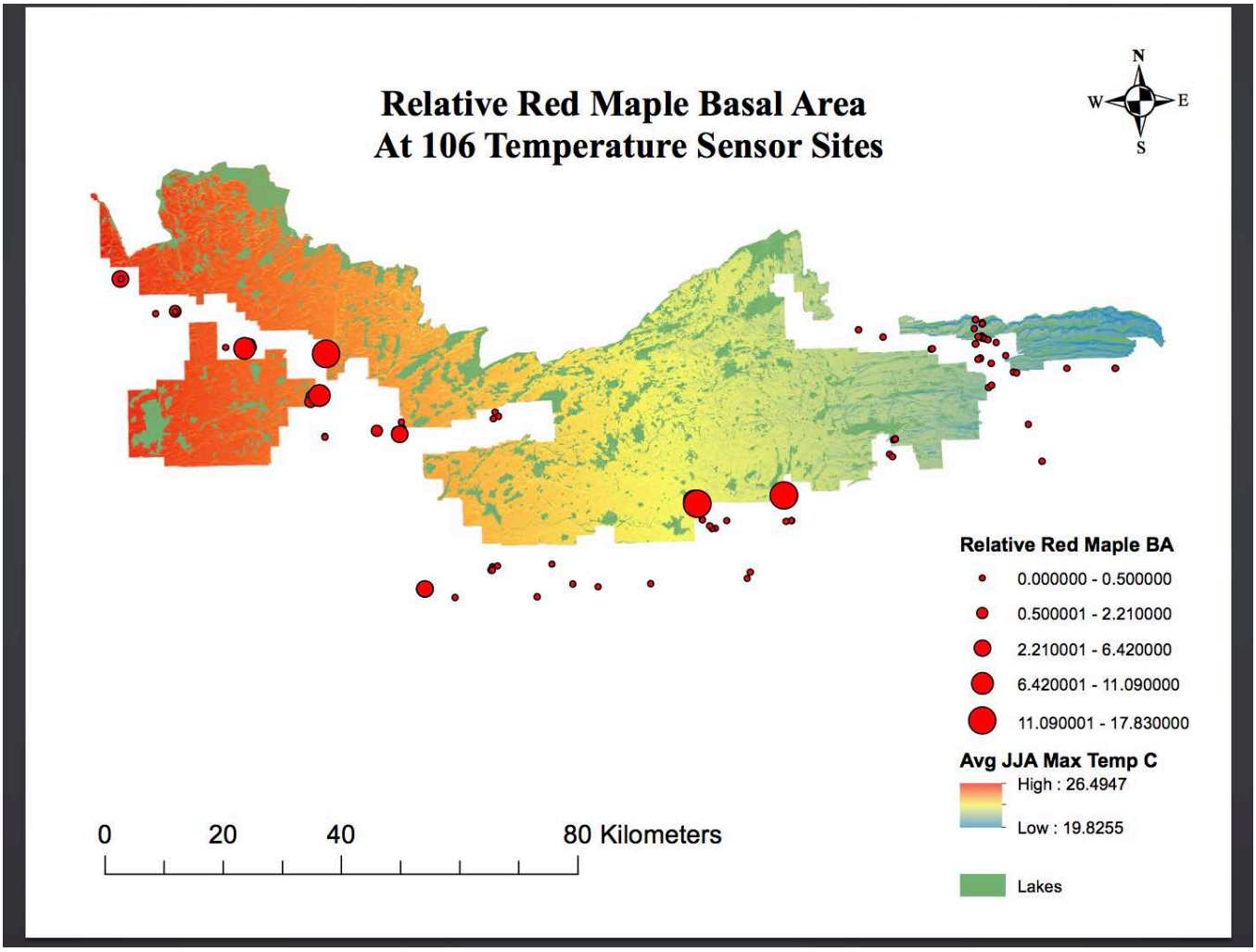

Figure 8. Red maple basal area as related to summer temperature in the BWCAW.

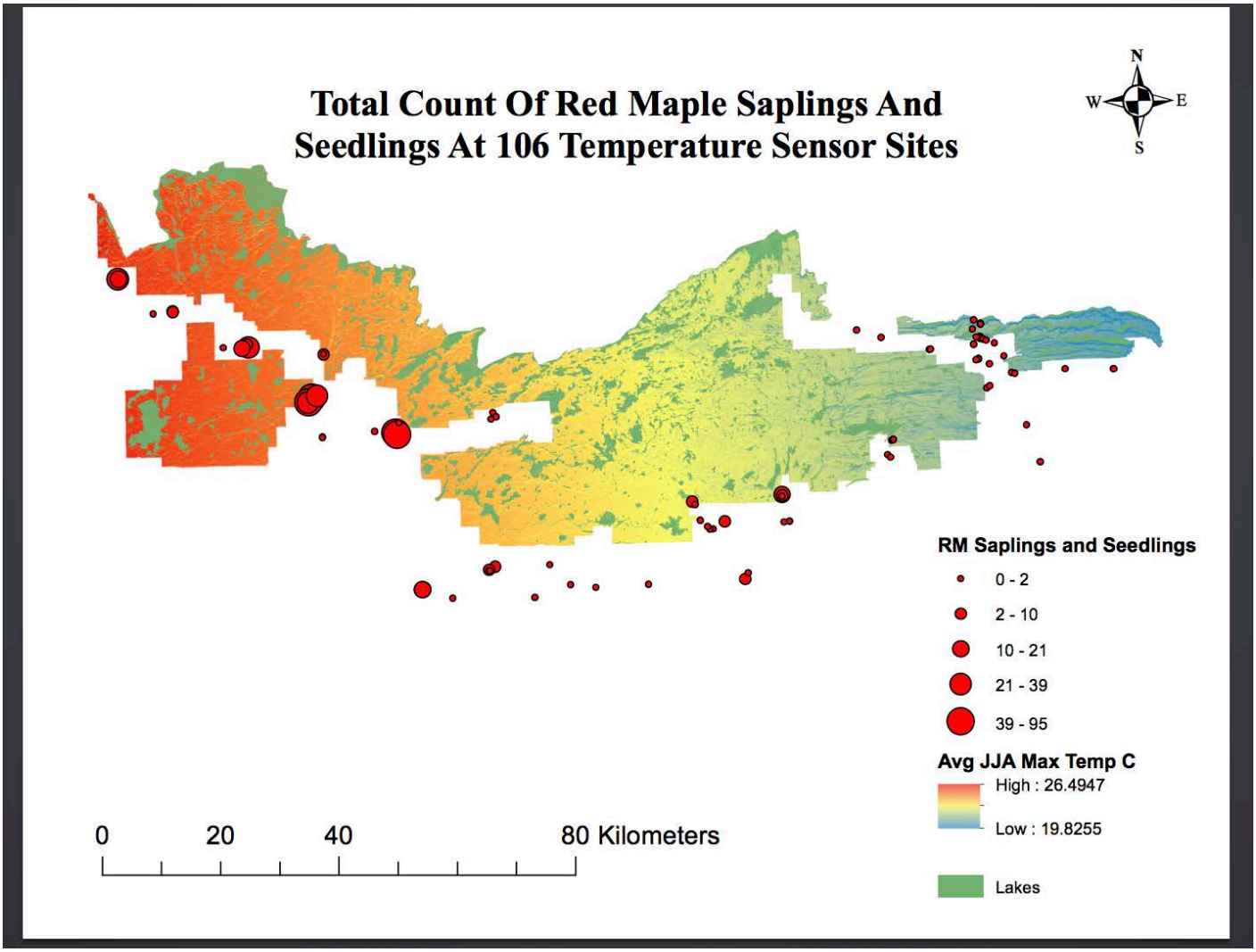

Figure 9. Red maple seedling and sapling abundance as related to summer temperature.

ACTIVITY 3: Outreach and education on forest adaptation options.

Description:
Develop and present at least two workshops, one each for managers of commercial forests and managers of the Boundary Waters Canoe Area Wilderness, National Park Service and other forest managers. Develop a public lecture to be presented at 10 or more locations throughout the state. The workshop for forest managers will be geared towards Forest Service, State, County, National Park Service and Tribal forest managers and will be offered through the University of Minnesota Sustainable Forests Education Cooperative at Cloquet Forestry Center. The workshop for wilderness managers will be offered at a location convenient for Superior National Forest staff (probably their Duluth headquarters). The public presentation will be aimed at small landowners and wilderness users and presented at venues throughout the state (e.g. Vermilion Community College in Ely).

Summary Budget Information for Activity 3: **ENRTF Budget: $ 0**

Amount Spent: $ 0
Balance: $ 0

Activity Completion Date:

Outcome	Completion Date	Budget
1. Adaptation guidelines for forest managers	January-June 2014	$ 0
2. Presentations and workshops	January-June 2014	$ 0

Activity Status as of December 31, 2011: This activity has not started yet.

Activity Status as of June 30, 2012: Although not budgeted to start yet, we have engaged local residents on the Echo, Sawbill and Gunflint trails to help place the temperature sensors. We did not spend any of the funding allocated for this activity, but this did start the public engagement a bit earlier than we originally envisioned.

Activity Status as of December 31, 2012: As planned, the budgeted portion of this activity has not started yet.

Activity Status as of June 30, 2013: In the amendment request above, we have proposed to zero out the budget for this activity. Because of the other related projects that have developed, we are fairly certain that we can carry out activity 3 with other funding. Media interest in the project is already occurring, with reporters having already talked with project manager Frelich and accompanying Dave Chaffin in the field during summer 2013.

Activity Status as of December 31, 2013: Outreach to the public and stakeholders has begun, based on very early results with respect to temperatures and invasion of the boreal forest by temperate tree species and invasive species. The project was highlighted in The Minneapolis Star Tribune with a front-page Sunday-Edition article on October 20, 2013—"Saving the Great Northwoods", by Josephine Marcotty. This article had a front page picture of LCCMR-funded PhD student Dave Chaffin engaged in field work, and it put the project in perspective with other climate change research in northern Minnesota forests. The project was highlighted in presentations by PI Frelich at several prominent venues: (1) Minnesota Soil and Water Conservation Districts webinar (statewide audience of MSAWCD staff), October 2, 2013; (2)The National Extension Educators Workshop, Cloquet, MN October 29, 2013; (3) Minnesota Climate Change Adaptation Workshop, Science Museum of Minnesota November 7, 2013 (very broad audience including many land managers from throughout the state; this also resulted in coverage in the Star Tribune and Minnesota Public Radio); (4) Climate Science Workshop for Teachers, University of Minnesota St.Paul Campus, November 9, 2013; (5) discussions with state staff directors in offices of U.S. Senators Amy Klobuchar and Al Franken, December 11, 2013.

Activity Status as of June 30, 2014: Presentations and outreach in addition to the 5 listed in the December 31, 2013 update include: (6) Citizens Climate Lobby (Training in climate impacts on northern forests for ca 120 people, Minneapolis, January 25, 2014); (7) Jackson Middle School (A science immersion school in Champlin, MN), Expert Day presentations/workshops with ca 50 students, January 29, 2014; (8) Osher Life Long Learning Institute, Coffman Union, University of Minnesota, Minneapolis, lecture to ca 40 retired faculty, February 28, 2014; (9) Minnesota Master Naturalist Annual Meeting Keynote to ca 150 people, May 16, 2014, Camp Friendship, MN. We have one more event planned, a workshop for national Park Service employees, scheduled for July 30, 2014 in Voyageurs NP.

Final Report Summary: In addition to the 9 outreach activities reported above, we have also completed a climate change adaptation planning workshop for national Park Service staff at Voyageurs NP, which featured the products funded by this LCCMR grant. Because we had an approved amendment to this project to, in part, continue outreach through another project funded by the National Park Service that continues until 2017, many additional outreach activities that will feature LCCMR funded products will take place in the future. This will include several additional National park Service workshops, a workshop for Native American Reservation staff, presentations at scientific meetings, and a number of media events, including Minnesota Public Radio.

V. DISSEMINATION:

Description:
Activity 3 **"**Outreach and education on forest adaptation options**"** above integrates dissemination to the public and forest managers within Minnesota into the project. In addition, we will publish at least two research papers in the peer-reviewed scientific literature, and seek media outlets that will more widely disseminate the findings. Once the data is complete and in its final form, it will be available from the University of Minnesota Center for Forest Ecology upon request.

Status as of December 31, 2011: No dissemination activities will occur until late 2013.

Status as of June 30 2012: No dissemination activities will occur until late 2013.

Status as of December 31, 2012: No dissemination activities will occur until late 2013.

Status as of June 30 2013: No dissemination activities will occur until late 2013, continuing into 2014.

Status as of December 31 2013: Some early dissemination activities have begun—see activity 3 above.

Status as of June 30, 2014: See activity 3 above.

Final Report Summary: see final report summary for activity 3 above.

VI. PROJECT BUDGET SUMMARY:

A. ENRTF Budget:

Budget Category	$ Amount	Explanation
Personnel:	$131,105	Frelich, project manager, advise graduate students, supervise undergraduate students, analyze data, write papers and co-write papers with graduate student, present workshops on climate adaptation (0.3 FTE for 2.0 years, $34,508 salary, $11,348 benefits, on soft money). Graduate student, collect and analyze field data, write papers (0.5 FTE for 2.0 years, $39,158 salary, $32,963 benefits). Undergraduate assistant, help collect field data during summer, assist with analysis in the lab during academic year (0.23 FTE for 2.0 years, $16,000 salary, $523 benefits).
Professional/Technical Contracts:	$0	
Service Contracts	$0	
Equipment/Tools/Supplies:	$4,749	100 Hobo units to record temperatures on an hourly basis at remote field sites, approximately $42 each, and two GPS units for navigation in remote areas.
Capital Equipment over $3,500:	$0	
Fee Title Acquisition:	$0	
Easement Acquisition:	$0	
Professional Services for Acq:	$0	
Printing:	$0	
Travel Expenses in MN:	$14,146	Summer field work for graduate student and undergraduate assistant, including lodging (camp grounds and university field station facilities will be used as much as possible to reduce costs), car rental and mileage for 4 months (2 months for each of 2 summers). Also included is mileage for visits while field work is in progress by project manager Frelich. All travel will be in state.
Other:	$0	Materials for workshops and public education, including duplication and dissemination of results. This will be covered by other sources as described under activity 3 and the June 30, 2013 amendment request.
TOTAL ENRTF BUDGET:	**$150,000**	

Explanation of Use of Classified Staff: N/A

Explanation of Capital Expenditures Greater Than $3,500: N/A

Number of Full-time Equivalent (FTE) funded with this ENRTF appropriation: 1.03 for each of two years, total 2.06

Number of Full-time Equivalent (FTE) estimated to be funded through contracts with this ENRTF appropriation: N/A

B. Other Funds:

Source of Funds	$ Amount Proposed	$ Amount Spent	Use of Other Funds
Non-state			
In kind contribution, U of MN	$30,000	$	Peter Reich, Regents Professor ($20,000 in kind salary), and Rebecca Montgomery, Associate Professor ($10,000 in kind salary). See project partners below for details.
State			
	$0	$	
TOTAL OTHER FUNDS:	**$30,000**	**$**	

VII. PROJECT STRATEGY:

A. Project Partners: Lee Frelich is the project manager, partially supported by project funds, and will be the advisor/supervisor to the graduate and undergraduate students, and will participate directly in the field work and data analyses. Peter Reich will collaborate and provide expertise on forest ecology, tree population dynamics and landscape ecology, and help with data analyses. Reich will not receive support from this grant and will contribute $20,000 of in-kind services. Rebecca Montgomery is a new addition to the project partners since preliminary version of the proposal was submitted. She will collaborate by providing expertise on forest ecology and co-advise a graduate student. A graduate student, likely to be David Chaffin, who has been accepted by the Natural Resource Science and Management Ph.D. Program at the U of MN, to start during September 2011, will be supported by project funds for two years as a 50% Research Assistant, and take on this project as part of his Ph.D. research. An undergraduate student to be determined will be hired with project funds as a field assistant during the summers of 2012 and 2013.

B. Project Impact and Long-term Strategy: This project will capitalize on results from a previous workshop on Climate Change Adaptation and Biodiversity Conservation in Minnesota (Co-Organized by Frelich, June 2008), by using the Border Lakes forests as the first area to undergo detailed analyses for climate change adaptation using principles gathered from the scientists at the 2008 meeting. Also, the results with public education and policy will be carried forward after the termination of this project by Greater Quetico-Superior Climate Change Adaptation Plan Alliance, a coalition of environmental groups that has held preliminary organizational meetings and is pursuing their own funding. This project will also serve as a pilot for future climate change adaptation plans for other ecoregions of the state, and as a national model for this type of planning. This project will also provide the first instance where researchers have had detailed data on temperatures in a forested region where trees actually grow (rather than from flat paved areas such as airports, where trees don't grow), as well as a more detailed assessment of the status of invasive species in the boreal forest than has been previously published. The Forest Ecology Lab at the University of Minnesota has had a world-class research program in northern Minnesota since 1992, and this will continue indefinitely into the future. This LCCMR funded project will be an integral step in this long-term forest ecology program.

C. Spending History: N/A This specific project has no ENTRF spending history.

VIII. ACQUISITION/RESTORATION LIST: N/A

IX. MAP(S): Map submitted with original proposal is attached.

X. RESEARCH ADDENDUM: See research addendum

XI. REPORTING REQUIREMENTS:
Periodic work plan status update reports will be submitted not later than December 31, 2011, June 30 2012, December 31, 2012, June 30 2013, and December 31, 2013. A final report and associated products will be submitted between June 30 and August 1, 2014 as requested by the LCCMR.

Final Attachment A: Budget Detail for M.L. 2011 (FY 2012-13) Environment and Natural Resources Trust Fund Projects

Project Title: Change in resilience in boreal forest in northern Minnesota
Legal Citation: M.L. 2011, First Special Session, Chp. 2, Art.3, Sec. 2, Subd. 03i
Project Manager: Lee E. Frelich
M.L. 2011 (FY 2012-13) ENRTF Appropriation: $ *150,000*
Project Length and Completion Date: 3.0 years, July 1, 2011-June 30, 2014
Date of Update: Sept 15, 2014

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND BUDGET	Revised Activity 1 Sept. 20, 2013	Amount Spent	Balance	Revised activity 2 Sept. 20, 2013	Amount Spent	Balance	Revised Activity 3 July 1, 2013	TOTAL BUDGET	TOTAL BALANCE
BUDGET ITEM									
Personnel (Wages and Benefits)	68,539	68,539	0	62,566	62,566	0	0	131,105	0
Frelich, project manager, advise graduate students, supervise undergraduate students, analyze data, write papers and co-write papers with graduate student, present workshops on climate adaptation (0.3 FTE for 2.0 years, $43,682, ~~$44,732,~~ 75% salary, 25% benefits).									
Graduate student, collect and analyze field data, write papers (0.5 FTE for 2.0 years, $74,649, ~~$72,121,~~ 54% salary, 46% benefits).									
Undergraduate assistant, help collect field data during summer, assist with analysis in the lab during academic year (0.23 FTE for 2.0 years, $11,650, ~~$16,523,~~ 97% salary, 3% benefits).									
Equipment/Tools/Supplies 100 Hobo units to record temperatures on an hourly basis at remote field sites, approximately $42 each, and two GPS units for navigation in remote areas.		0	0	4,749	4,749	0	0	4,749	0
Travel expenses in Minnesota Summer field work for graduate student and undergraduate assistant, including lodging (camp grounds and university field station facilities will be used as much as possible to reduce costs), car rental and mileage for 4 months (2 months for each of 2 summers). Also included is mileage for visits while field work is in progress by project manager Frelich, mileage for travel by Frelich, Reich and Montgomery to present workshops. All travel will be in state.	7,400	7,400	0	6,746	4,988	1,758	0	14,146	1,758
Other Materials for workshops and public education, including duplication and dissemination of results.		0	0		0	0	0	0	0
COLUMN TOTAL	**$75,939**	**$75,939**	**$0**	**$74,061**	**$72,303**	**$1,758**	**$0**	**$150,000**	**$1,758**