Decadal Scale Estimates of Forest Water Yield After Bark Beetle Epidemics in Southern Wyoming

(Mar 2012 – Feb 2015)

PIs Brent E Ewers, Elise Pendall, Urszula Norton, Ramesh Sivanpillai

Final Report

Abstract

The forests in Wyoming are undergoing profound changes in their hydrologic partitioning of precipitation due to an ongoing epidemic of bark beetles. These forests are key components of major river watersheds and could magnify any impacts on downstream users of water. Recent research at the forest stand scale has shown that while the trees die over the first several years of an outbreak, evapotranspiration declines, soil moisture increases, soil nitrogen increases and snowpack increases and melts faster. These changes in forest hydrology strongly suggest that streamflow should increase. However, ongoing streamflow measurements show no increase. This conundrum between stand processes and watershed processes was directly addressed by this project. Further, the length of time in which hydrological changes at the stand scale will persist is unknown because of lack of knowledge about how these stands will experience succession during and after bark beetle epidemics. To address these issues we 1) quantified tree, seedling, sapling and other understory species composition in forest stands to characterize succession and 2) utilized multiple remote sensing tools to improve scaling between well-instrumented forest stands and watersheds. In addition to these two objectives we will synthesize a large amount of prior and ongoing data collection into an explicit data informatics framework. This framework will serve two purposes 1) novel data syntheses can occur in near real-time, enabling model-data fusion to improve predictions of streamflow and 2) rapidly serve data and model results for public and land manager use. This project builds on previous work that quantified and predicted water yield from bark beetle infested stands in the first five years of an outbreak and extends the time frame of predictions out to multi-decades. This work will enable both State and Federal water managers to make crucial predictions of streamflow from infested mountain ranges on time-frames that are relevant to land management decisions.

Objectives

1) Establish a web service for public and water management use that will provide direct access to data and model predictions

2) Predict the impact of forest succession from lodgepole and spruce-fir forests after bark beetle mortality on forest water yield and nitrogen loss from stands

3) Use ongoing stand and catchment scale measurements with remote sensing tools and mechanistic models to estimate bark beetle impacts on water yield at the mountain range scale

Methodology

We adopted the Terrestrial Regional Ecosystem Exchange Simulator-Cavitation (TREESCav) model for all the simulations for this project. The TREESCav model has the appropriate tree hydraulic and photosynthesis mechanisms to simulate bark beetle attacks. The model also has a full water budget including snow melt, sublimation, interception, soil moisture, drainage, tree transpiration and evaporation. The model includes Bayesian model-data fusion so that parameterization rigorously uses data. The hydrology community has begun to recognize that simulation of water budgets from vegetated watersheds must include carbon and nitrogen cycles for mechanistic and thus predictive understanding. Such an approach is necessary when projecting forest changes after a disturbance because carbon and nitrogen cycling co-limit forest production along with water. Thus, we have implemented new algorithms of soil carbon and nitrogen processing that can be compared to soil measurements of both processes from a recently finished NSF grant. This project supplied ongoing measurements of soil carbon and nitrogen pools and fluxes to constrain TREESCav as succession continues.

Our remote sensing approach utilizes Modis data as an appropriate compromise between spatial and temporal resolution based on preliminary analyses comparing the data to MODIS, Landsat and Aerocam.

The testing of both the TREESCav model and remote sensing data sets requires multiple data sets interacting at various temporal and spatial scales. To facilitate these comparisons and prepare the data for public sharing, we adopted Structured Query Language (SQL) approaches. We implemented SQL databases for all of the vegetation data from the Chimney Park and GLEES research sites which was funded by a grant from this agency that ended in Feb. 2013 (see final report for details). The database for the stand level fluxes, water budgets and vegetation are now completed. We have also finished the work with UW IT to allow serving of data. The spatial interface for querying data became available July 1, 2014 at http://wycehg.wygisc.org/. Analyses of downloaded data shows that members of state government have accessed the data. Work from this project provided the initial conceptualizations and seed money to start the server; it is now sustained by the Wyoming Center for Environmental Hydrology and Geophysics (WyCEHG).

Principal Findings (Cited Papers are in Publications Section)

Remote sensing of Leaf Area Index (LAI) shows that the footprint scale of the eddy covariance can be successfully analyzed with MODIS data during the mortality event (Figures 1 and 2). The bark beetle effect on basal area and leaf area occurs within a few years and is reflected at the individual stands as increased water filled pore space of soils, all of which is over within 3-5 years (Figures 3-4). This is less than half the time expected prior to collecting the data. We built a quantified response of water budgets to bark beetles over the first three years of the mortality event and found no increase in streamflow (Figure 5). Surprisingly, our results show that streamflow, when normalized by annual precipitation, actually decreases as mortality increases in contrast to hypotheses and some other watershed data. Our explanation for this difference includes the following components 1) forest succession is happening faster than expected and while the trees are dying, 2) the morality of 80% is not consistent within the flux tower footprint or watersheds, some patches are higher or lower, 3) the timing of each patch of mortality is not synchronized so that when one patch is at peak mortality (2-3 years), other patches that were attacked earlier are already recovering. In fact, studies of bark beetle infestation rates in watersheds show an average of 5-7 years to reach maximum mortality supporting our contention.

Moreover, the relationship between carbon and water exchange does not change (Figure 6) and even the long term stand-scale data set at GLEES only shows one year that is different in this relationship during the height of the beetle epidemic (Figure 7). Fine roots play a key role in these responses (Figure 8) and suggest that root dynamics need to be included in our model work, which we incorporated into TREESCav in the past six months.

Objectives two and three required successful testing of the TREESCav model against the bark beetle mortality datasets from the Chimney Park and GLEES research sites. The Bayesian approach to model parameterization via fusion with data is superior for processes that have uncertainty in both the processes and data (Ewers et al 2013). With this conceptual framework in place, we have tested the model against tree transpiration, evapotranspiration, tree hydraulic and tree nonstructural carbohydrates and total net ecosystem exchange of CO2. The model has been very successful in simultaneously simulating all of these processes except for one (see next paragraph). Our Bayesian model-data fusion analyses now show that the model is simulating the data as best as possible at the individual tree level given the uncertainties in the data itself . We were only able to simulate these fluxes successfully when appropriate root and microbial response to soil moisture and nitrogen were included showing the link to stand water budgets and water quality. The resulting posterior distribution of major parameters after testing the model against data is shown in Figure 9. The effort required to obtain these results has been significant in both coding and processing time. With the help of Jared Baker from UW-ARCC, TREESCAv is now running on Mt Moran HPC reducing the time to run a full Bayesian simulation of one year from 10 days to 8 hours. Using this improvement in simulation time, we have made longer term estimates of ecosystem water and carbon fluxes beyond 10 years.

An unexpected finding from our work is the enormous amount of water vapor fluxes that occur during the winter (Figure 10). The relationships between SWE and runoff is not altered by bark beetles (Figures 11 and 12) providing another empirical data set supporting lack of bark beetle impacts. If we run TREESCav using incoming snow fall, the model is only able to simulate about 25% of this winter water vapor flux from snow. Other models that rely on a basic snow energy balance perform just as poorly. We now have a new water vapor isotope laser purchased using NSF EPSCOR funds (a project that was funded partially due to previous funding from this agency). This laser allows partitioning of water vapor fluxes every half hour during the entire year. Thus, we can determine when water vapor flux is occurring from snow in either the pack or the canopy with little liquid water present (sublimation). We will formulate a mechanistic snow sublimation submodel in TREESCav to appropriately simulate these enormous winter water vapor fluxes.

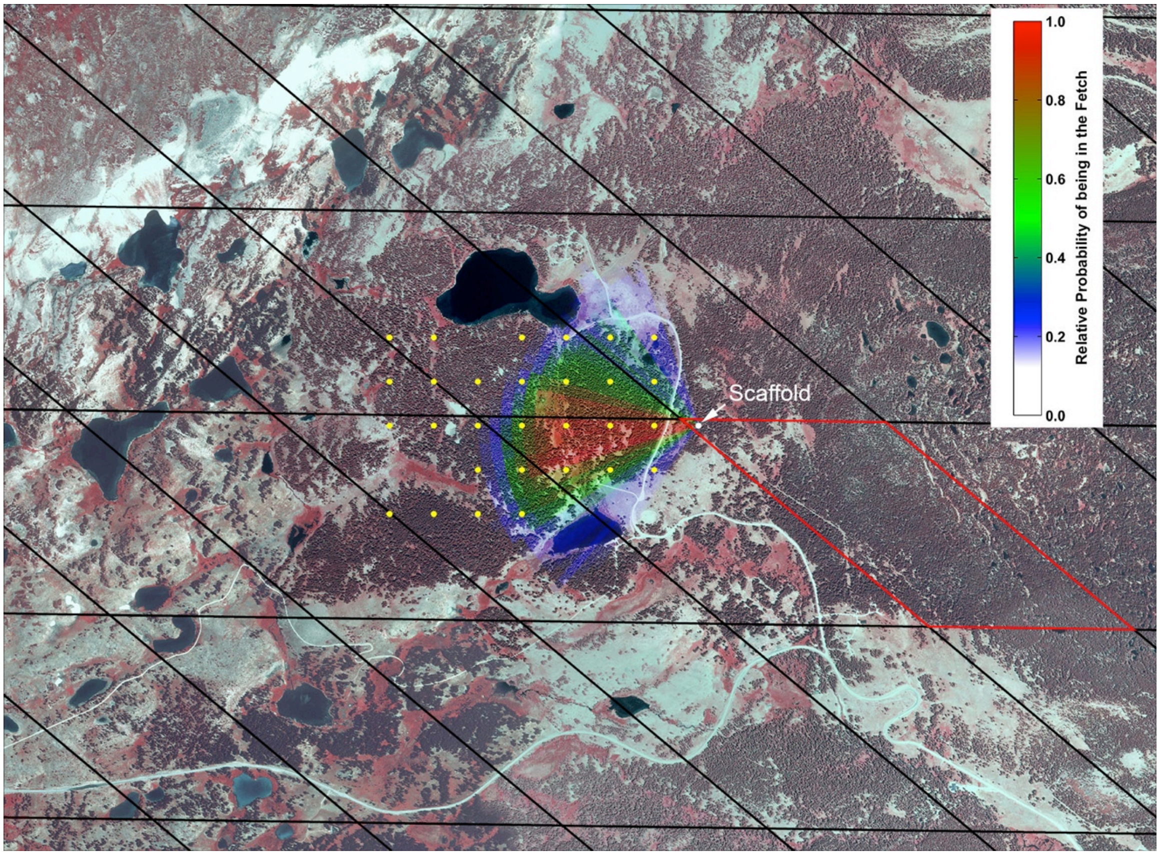

Figure 1. MODIS scene of the GLEES area showing the location of the scaffold holding the eddy covariance, micrometerological and isotope laser instruments. The colors are the relative probability of the flow footprint of the tower, which is mostly spruce and fir forest undergoing back beetle mortality. The red trapezoid to the SE of the tower was used to quantify the change in land cover over time because it is nearly all forest with no lakes. From Frank et al. 2014.

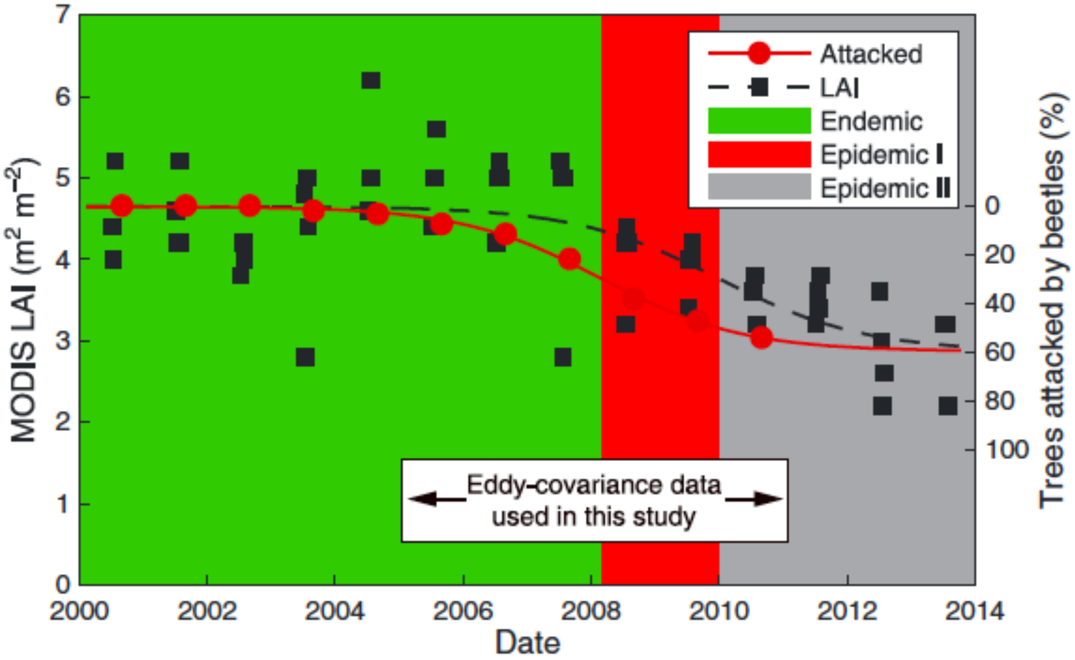

Figure 2. Time series of MODIS LAI estimated from the pixel identified in Figure 1. The data clear shows that LAI changes lag the timing of attack by beetles by about two years. From Frank et al 2014.

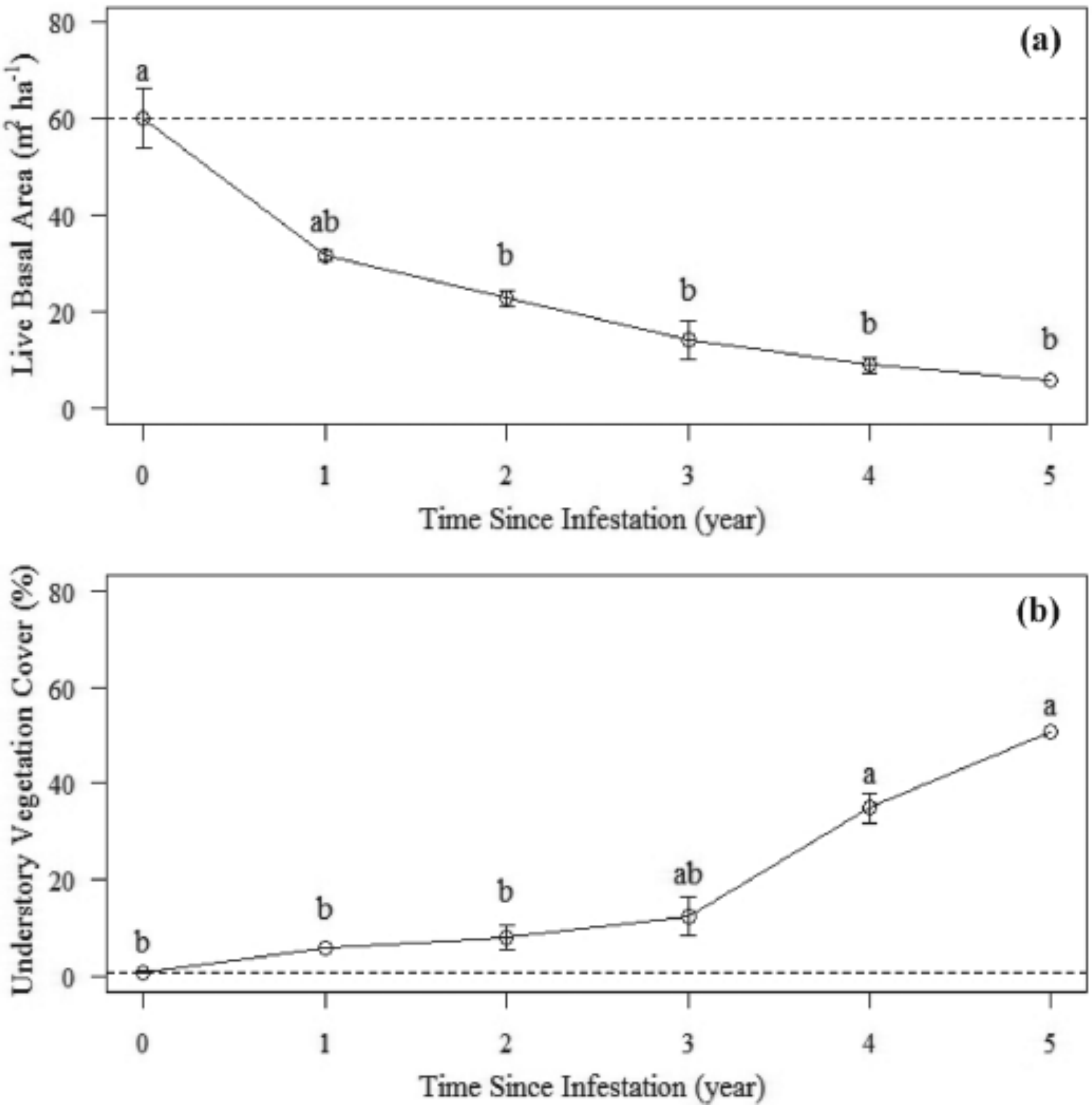

Figure 3. Effects of the beetle infestation on (a) Live Basal Area and b) understory vegetation cover as a function of time since infestation (year) in lodgepole pine forest, southeastern Wyoming. From Norton et al 2015.

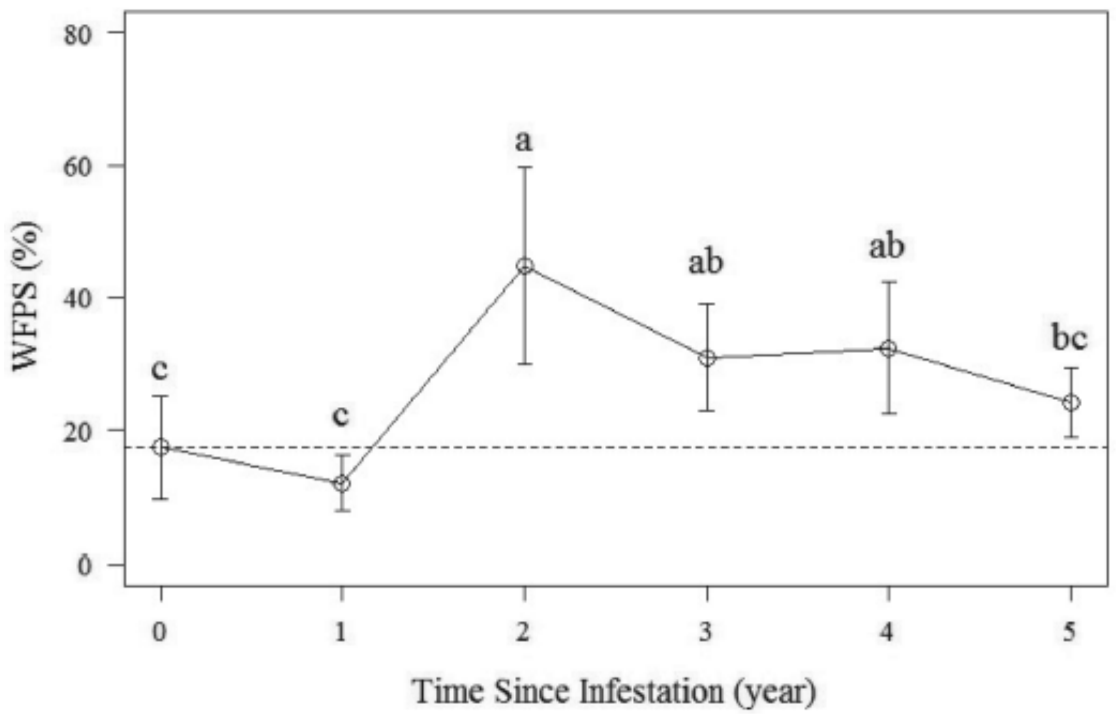

Figure 4. Effects of the beetle infestation on water filled poor space (WFPS). The bark beetle impact occurs within two years and is gone quickly within 3 to 5 years. From Norton et al 2015.

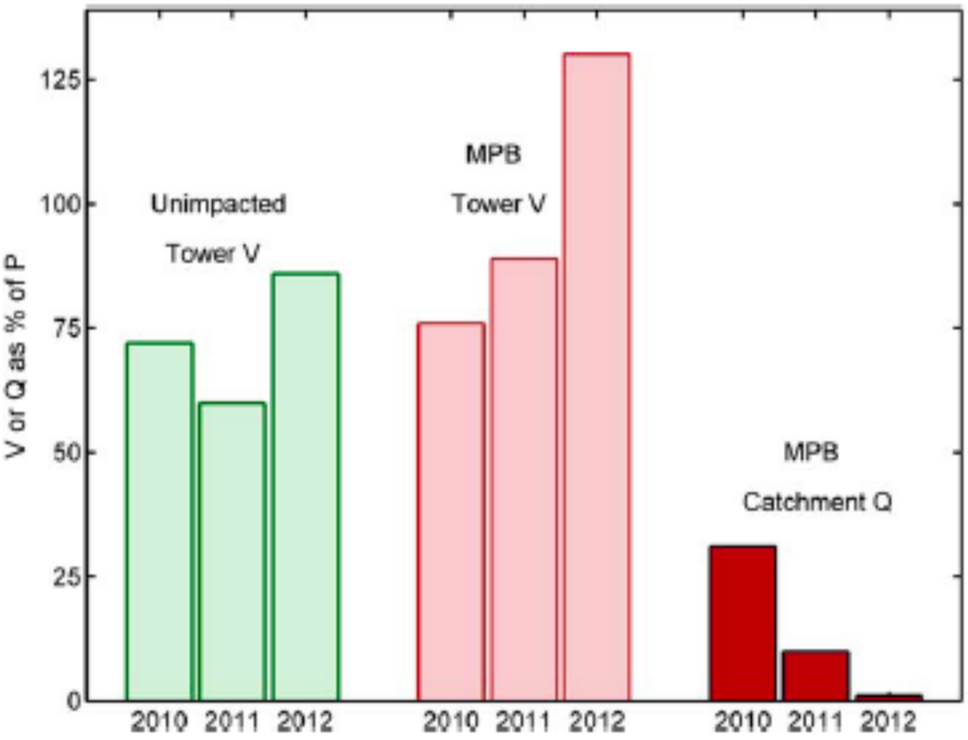

Figure 5. Annual observation of hydrologic paritioning to vapor loss V and streamflow Q expressed as a percentage of precipitation P (i.e. V: P = vapor loss coefficient and Q: P = runoff coefficient). Partitioning was less variable at the Unimpacted site and followed the pattern of interannual climate, with V: P inversely related to annual P (Table 3). The MPB site showed greater partitioning and less to Q in 2011 as compared to 2010 in spite of larger P. In 2012, which was very dry at the MPB site, tower V exceeded P, in part due to a release of stored water, and very little Q was observed. From Biederman et al In 2014.

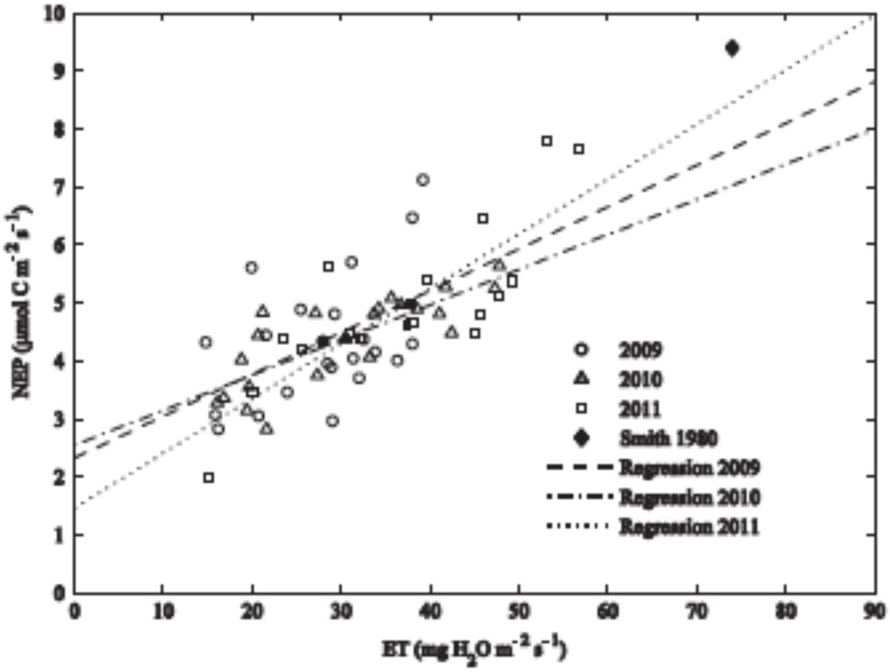

Figure 6. Relationship between Net Ecosystem Productivity (NEP-net storage of CO2 into the forest) and evapotranspiration (ET) over a lodgepole pine forest. There is no statistical difference in this relationship as bark beetle mortality increases from 30% in 2009 to 75% in 2011 indicating that mortality does not impact water use efficiency of CO2 uptake. From Reed et al 2014.

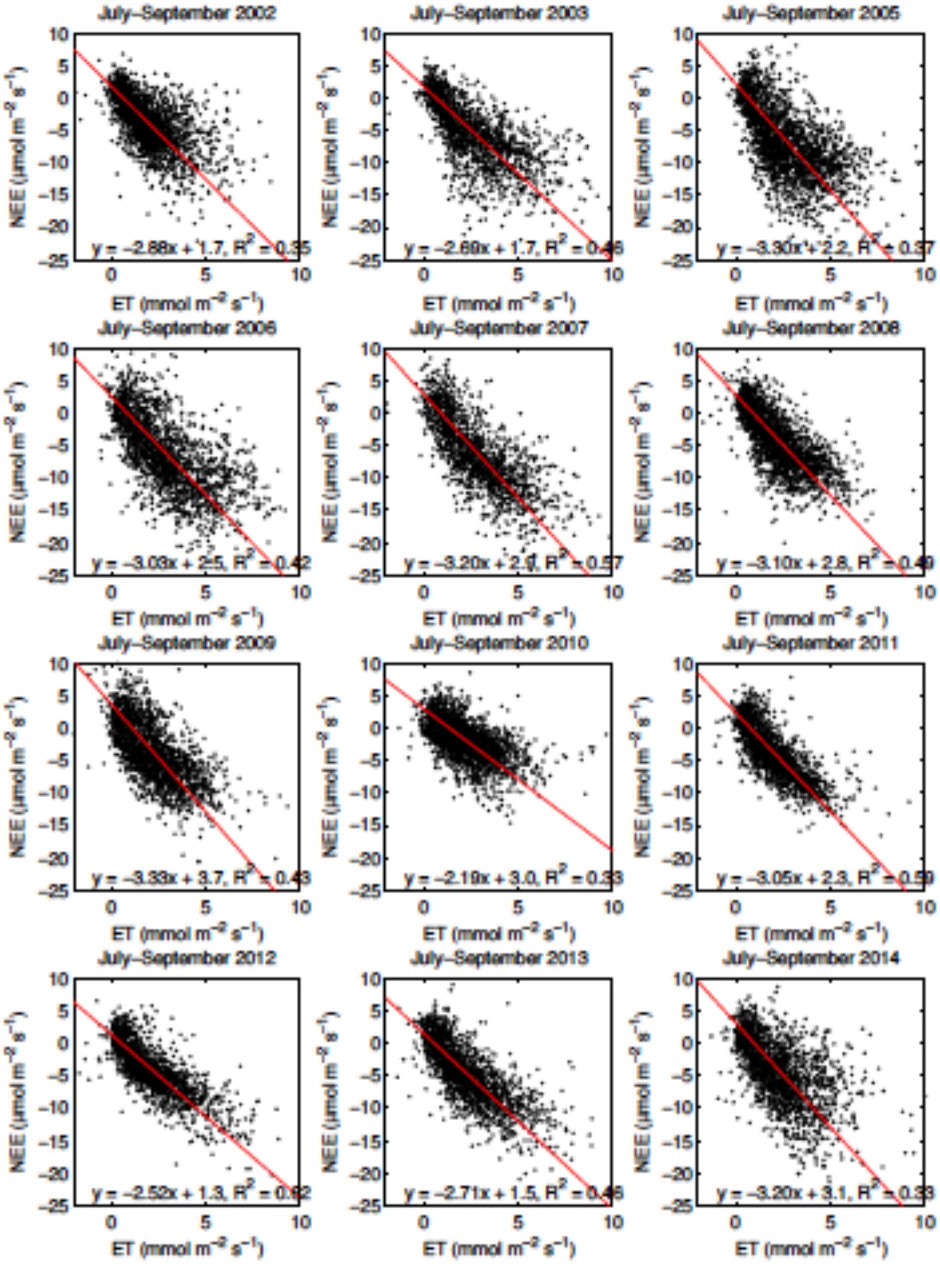

Figure 7. Relationships between net ecosystem exchange of CO2 (NEE) and evapotranspiration (ET) over a spruce-fir forest. Bark beetle mortality started in 2008 and reached it's peak in 2010 (see Figure 2). The relationship between NEE and ET showed a lower ET loss in 2008 and 2009 and lower NEE and ET in 2010. Both NEE and ET were back to pre beetle levels a year later in 2011 and have stayed as high through 2014. Frank et al In Preparation.

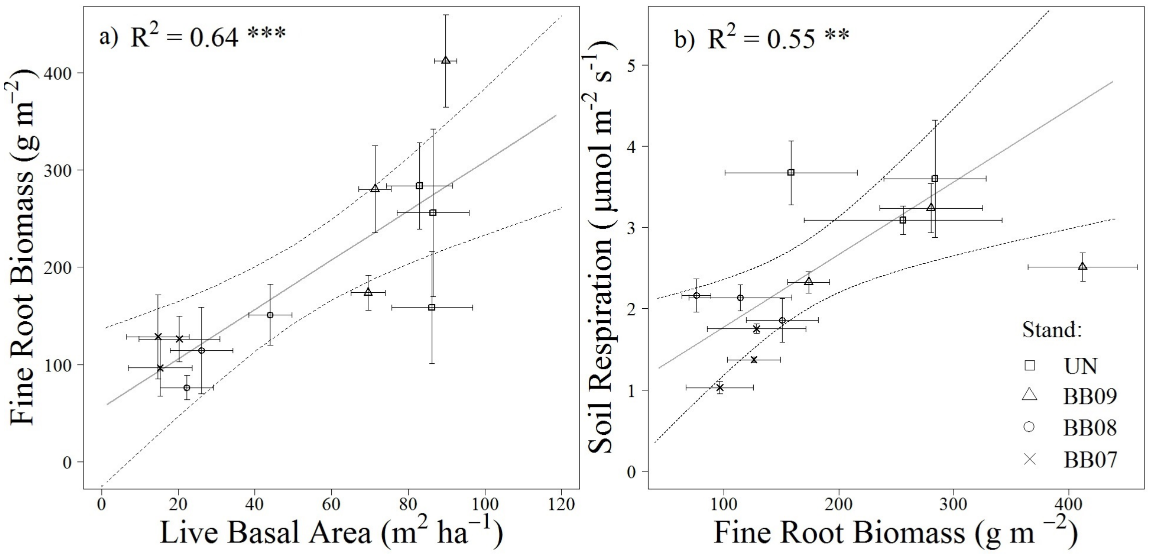

Figure 8. Relationships between live basal area and fine root biomass and fine root biomass and soil respiration across four stands of lodgepole pine that were invested in 2007, 2008 or 2009 measured three to five years later. The relationships indicate that loss of living tree impacts carbon fluxes at the stand scale but these response is muted at the forest scale (Figure 6). From Borkhuu et al Accepted.

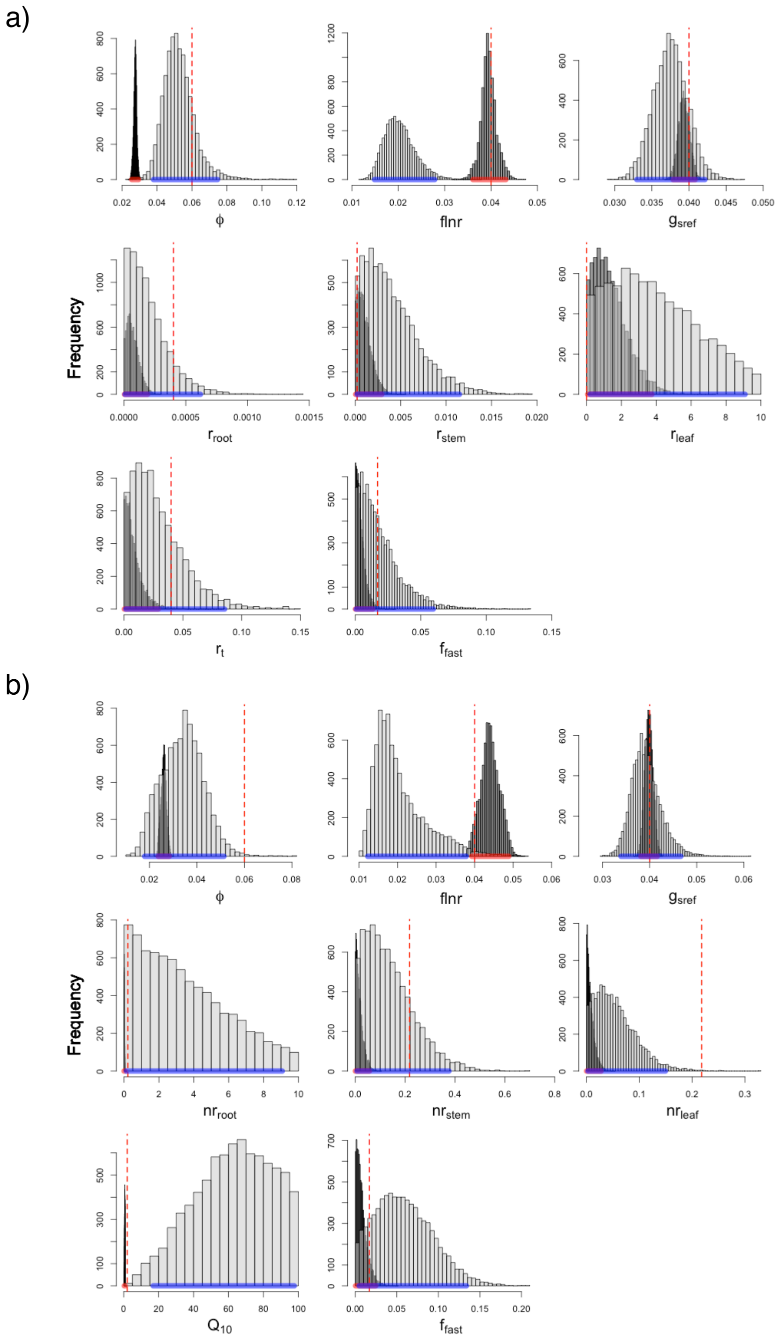

Figure 9. Posterior distributions for TREESCav to test the model ability to simulate the CO2 exchange of the forest based on the data from Figures 6 and 7. The two sets of parameters in (a) and (b) are from a parsimony analysis that supports the parameterization in (a) more. Parameter distributions from hourly aggregation are shown in darker grey with 95% credible intervals highlighted in red, while distributions from daily aggregation are shown in lighter grey with 95% credible intervals highlighted in blue. Overlap in 95% credible intervals is displayed in purple. Parameter values taken from literature or measured are shown with a red dashed vertical line. The parameters include the major carbon, water and nitrogen cycling components in the TREES model. Gsref is most

relevant to evapotranspiration because it is the total canopy conductance that is responding to the mortality event. From Peckham et al In Review.

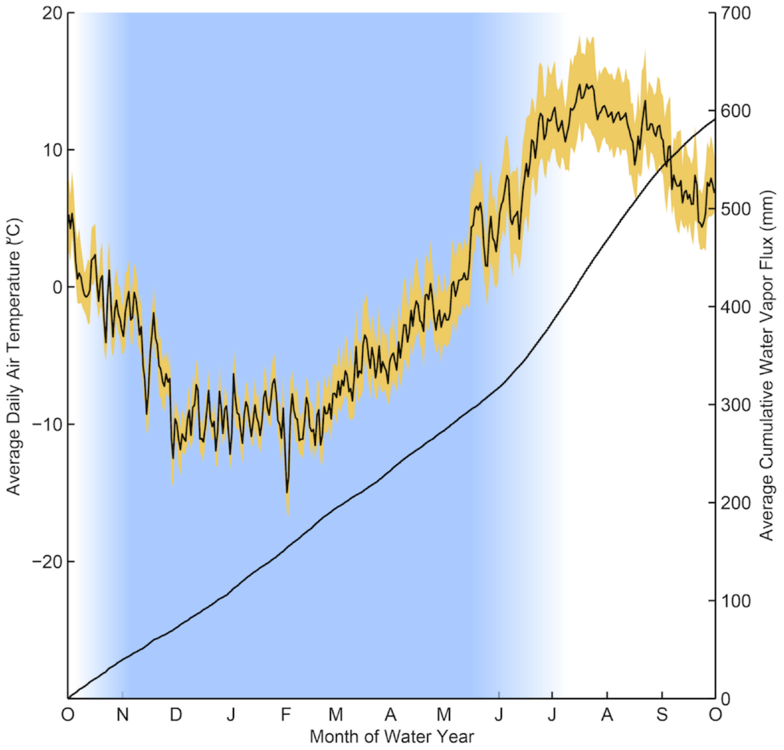

Figure 10. Average cumulative water vapor flux (solid line) for the past eight years at GLEES. The snowpack persists for an average of eight months per year (blue shading) while the climate is below freezing a majority of that time (lines with yellow shading: average daily minimum, mean, and maximum air temperatures). Sublimation accounts on average for 50 +/- 10% (SD among years) of the total annual water vapor flux. From Schaepfer et al 2014.

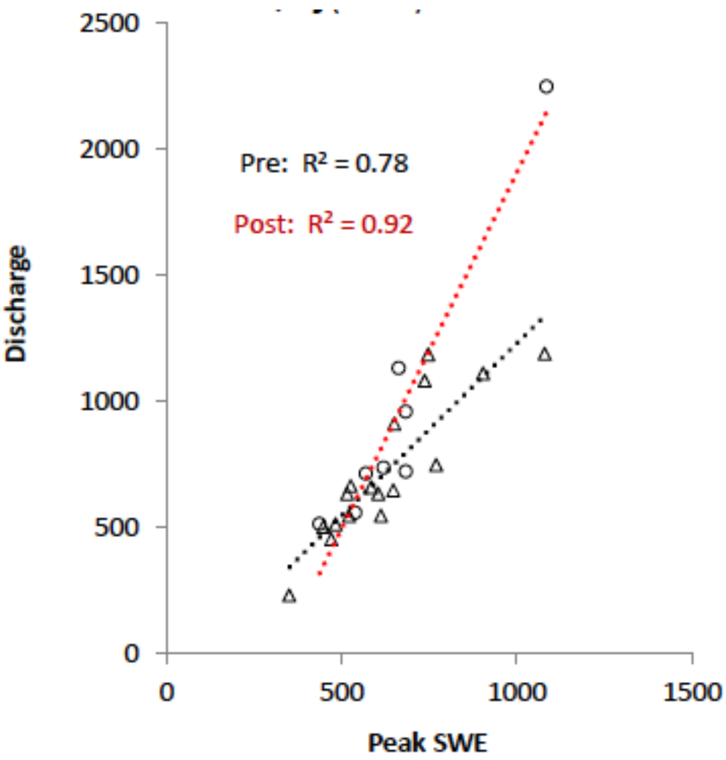

Figure 11. Discharge vs Peak Snow Water Equivalent from the Little Laramie Watershed from 1989-2013. There was no statistical difference in the pre and post-bark beetle relationship. From Hyde et al In Prep.

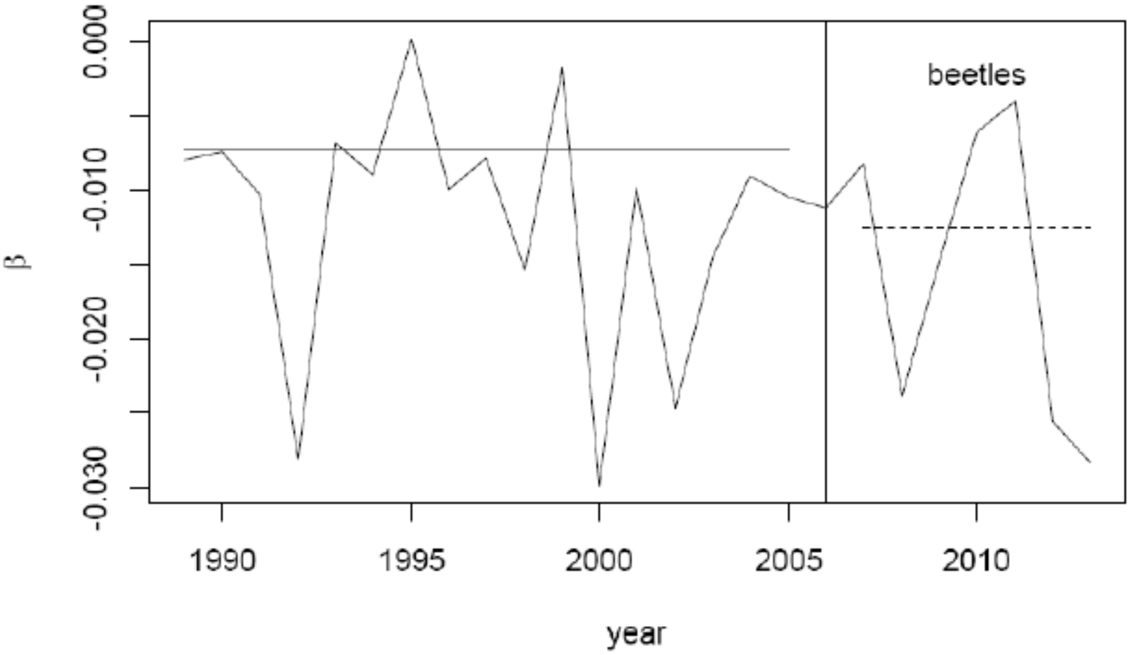

Figure 12. Analyses of the slope (Beta) vs water year for the Little Laramie Watershed from 1989-2013 (same as Figure 11). No statistical difference was found after bark beetle mortality in the response of discharge to SWE. These analyses suggest that the mechanism that prevent increased streamflow at the individual watershed scale (Figure 5) also occur at the mountain range scale.

Thus, we expect that successful TREESCav predictions of watershed should translate to the mountain range. From Hyde et al In Prep.

Once the stand scale analyses are complete, we will run the model at the watershed and mountain range scale using Landsat data sets tested against ground data. The Landsat analyses are funded by the Wyoming Weather Modification Project. Ongoing analyses of this data have shown that dead trees are well correlated to several individual spectral bands and indices. However, no spectral analyses have been able to distinguish between spruce/fir and lodgepole pine dead trees so we are adding ancillary data on slope, aspect and elevation to produce final maps. The stand-scale version of TREESCav will then be run at the watershed and landscape/mountain range scale using these final maps.

Simulating the impact of tree mortality at decadal scales required continued refinement of the soil carbon and nitrogen processes and the implementation of a canopy competition and root expansion algorithms in TREESCav. We know have data from 3-4 years of recovery in some stands which shows a dramatic increase in understory vegetation including tree saplings and seedlings as well as increased nitrogen and loss in soils. We have now run TREESCav over many years (Figure 13), but the model overestimates the beetle mortality impact (Figures 14-15). Our model analyses show that TREESCav misses these vegetation and thus hydrology dynamics unless soil nitrogen processes, light competition and root dynamics are appropriately captured. Our model results provide another piece of evidence that bark beetles do not increase streamflow because including the bark beetle effect on individual trees without appropriate compensating mechanisms dramatically underestimates ET and thus overestimates streamflow. This problem is common to all model studies without appropriate feedbacks during and after the mortality event.

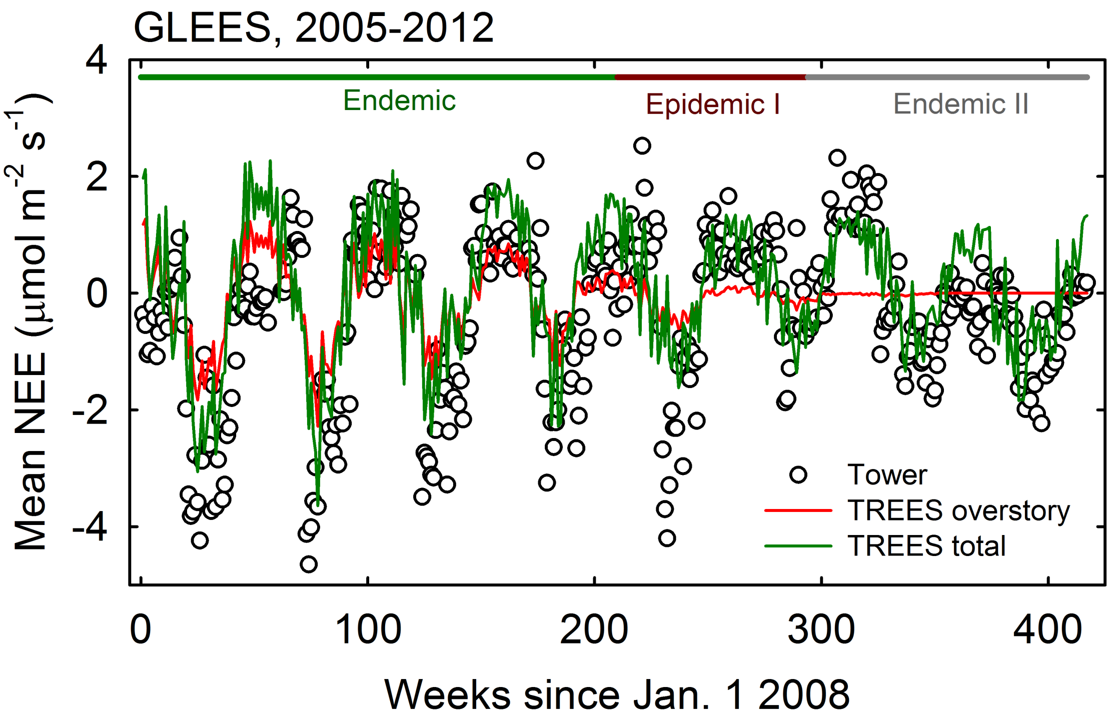

Figure 13. TREESCav simulations of net ecosystem exchange of CO2 using an algorithm of canopy competition. Notice that during the prior to the beetle mortality (Endemic) the fluxes are similar for overstory and total because the large trees outcompete the understory. When the overstory dies in Epidemic I and the understory begins to recover in Epidemic II, the competition shifts more to non-trees (see flat red line) but TREEScav still capture the overall CO2 fluxes. CO2 fluxes are an appropriate first testing phase of this algorithm because total ecosystem photosynthesis must be appropriately simulated with respect to competition before we can expect to successfully simulate ET and waterbudgets.

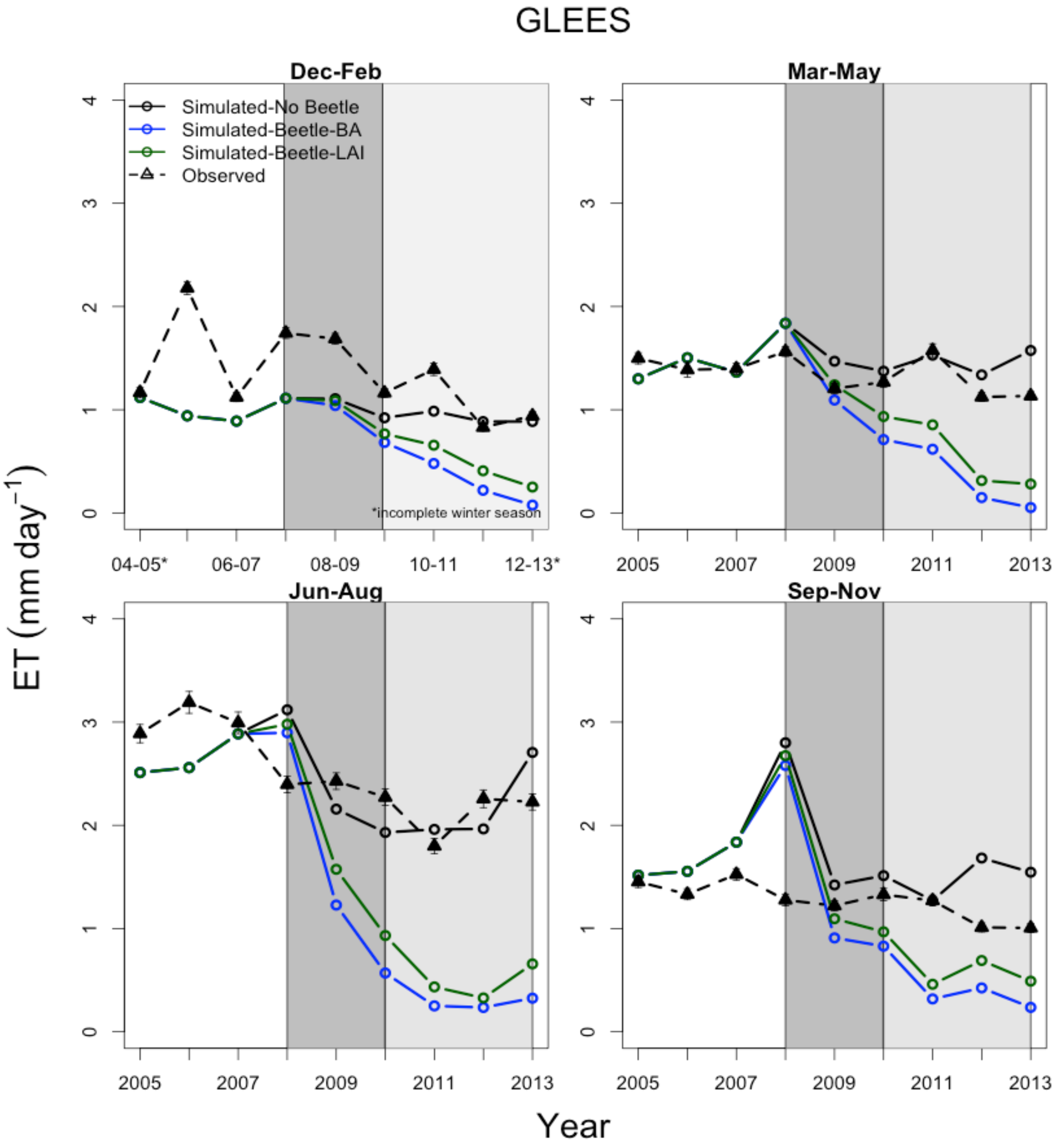

Figure 14. TREESCav simulations of evapotranspiration (ET) showing systemic overestimation of the beetle effect during (dark gray) and after (light gray) the mortality event. Millar et al In Preparation.

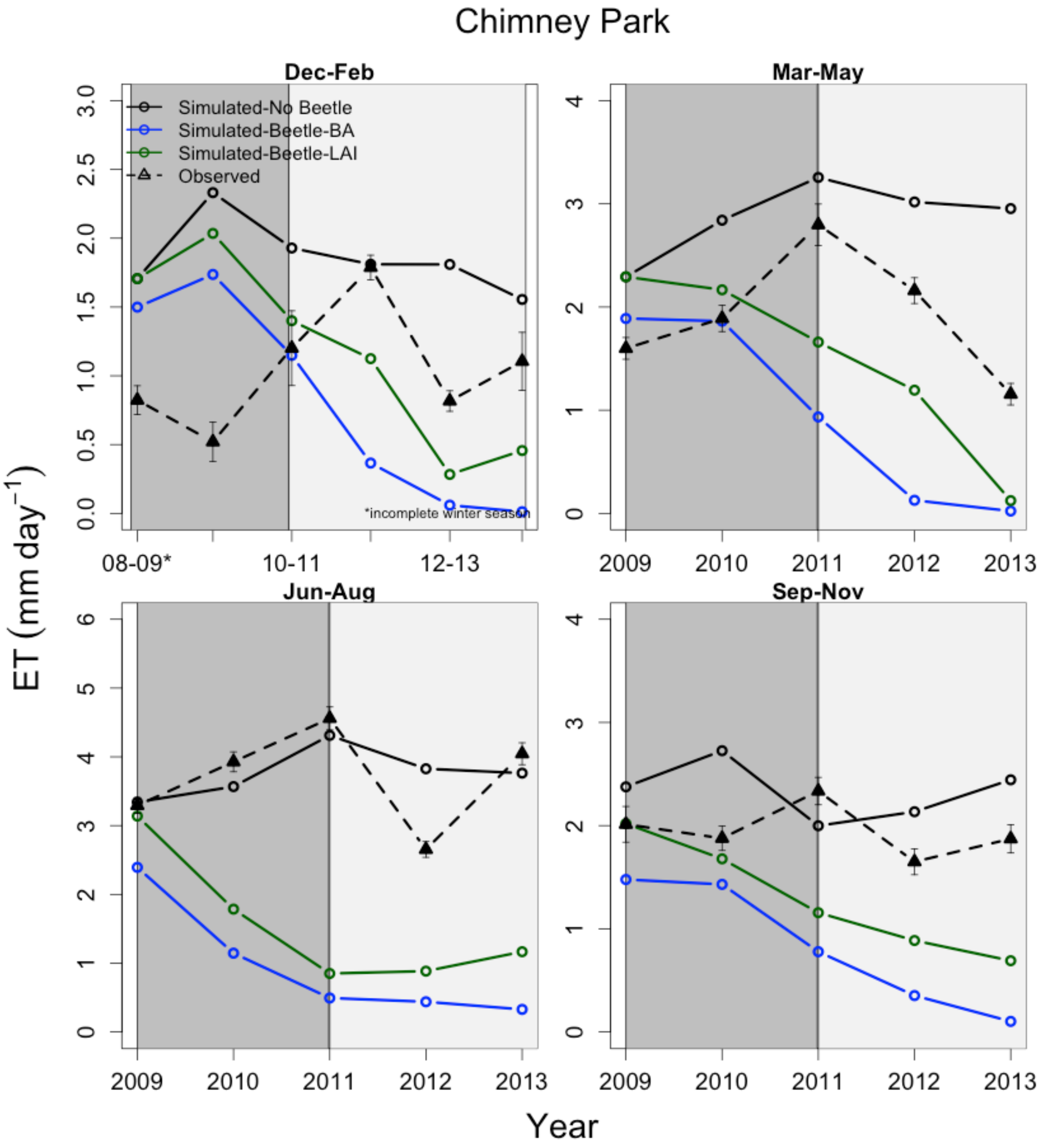

Figure 15. Figure 7 TREESCav simulations of evapotranspiration (ET) showing systemic overestimation of the beetle effect during (dark gray) and after (light gray) the mortality event. Millar et al In Preparation.

Significance

Many studies over the past 10 years have documented increased mortality of forests globally. However, none of these studies have truly mechanistic connections between tree mortality and larger scale consequences such as water yield and quality. Our study is making these connections by rigorously testing a simulation model with stand data from two different forests in Wyoming experiencing mortality from bark beetles. By starting with the stand-scale of data and incorporating carbon and nitrogen cycling, we have much more confidence when we infer changes at larger spatial scales in watersheds and landscapes/mountain ranges and longer temporal scales as the forests recover from the disturbance.

Surprisingly, we found relatively little impact of the mortality event on watershed responses due to the spatial and temporal patchiness of the mortality and the fast recovery of the individual patches. These spatial and temporal scaling issues provides an explanation for why our results are different from many other studies that focus on forested watersheds that have more uniform mortality or simulate mortality as uniform. At the very least, our results suggests extreme caution should be taken when simulation models assume that bark beetle remove tree transpiration in the same manner as clearcutting or fires.

We also found that winter water vapor fluxes (nominally snow sublimation) were an enormous component of total annual water vapor fluxes. These large winter water vapor fluxes cannot be simulated by any model, so future work is developing a new snow sublimation model for TREESCAv. These large winter water vapor fluxes also suggest that water managers can not just use incoming snow to predict streamflow in any mechanistic manner. These results also have implications for the Wyoming Weather Modification Project because the small potential increases in snowfall predicted by that project may be offset by sublimation.

Our serving of data from this project enables policy implications to occur faster. Any policy maker who disagrees with our interpretation of the data is free to download all the data presented in this report and conduct their own analyses. We have leveraged funds from the WyCEHG project (see leveraged funding below) to support this distribution of data with links to other relevant water projects around southern Wyoming.

Students/Post-Docs Supported

Bujidma Borkhuu- PhD student finished December 2014, main responsibilities were soil measurements and assistance with atmospheric measurements. Received partial funding from this project.

Stan Devore- undergraduate student doing lab processing of field samples, plans to graduate in Spring 2016

Bridger Huhn- undergraduate student doing lab processing of field samples, plans to graduate in Spring 2016

Ben Ingold- undergraduate student collecting field samples, graduated Spring 2014 currently employed as field technician for USFS

Kaleb Kenneaster-undergraduate student doing lab processing of field samples, enrolled in WWAMI program for medical school

Andrew King-ongoing MS student, main responsibilities are remote sensing image analysis and comparison to vegetation databases established through this project. Receives partial funding from this project.

Nick Brown-ongoing MS student, main responsibilies are soil measurements of nitrogen and carbon cycles. Receives partial funding from this project.

John Frank- ongoing PhD student, main responsibilities are all of the flux measurements from the spruce and fir bark beetle site (note: John Frank is a full time employee of the USFS RM Exp St in Ft. Collins, and does not receive any salary support from this project). Support from this project is used for field visits and site maintenance through a USFS subcontract.

David Reed-PhD student finished May 2014, main responsibilities were the atmospheric and streamflow measurements. Received partial funding from this project. David received a position as a visiting assistant professor at Dickinson College and obtained an NSF post-doc fellowship to work at the University of Wisconsin-Madison startin in May, 2015.

Scott Peckham- post-doctoral scientist, main responsibilities were coding modifications to the TREES model and model-data fusion analyses as well as supervision of the Chimney Park lodgeople pine site. Received full support from this project. Dr. Peckham is a big game ecologist for the USFS in Oregon.

Publications (*Students and Post-Docs in Bold*)
Biederman, J, A Harpold, D Gochis, BE Ewers, **D Reed**, S Papuga, P Brooks. 2014. Compensatory vapor flux reduces water for streamflow following severe bark beetle-induced forest mortality. Water Resources Research 50(7):5395-5409.

Borkhuu, B, SD Peckham, U Norton, BE Ewers, E Pendall. Accepted with Major Revisions. Soil respiration declines following beetle-induced forest mortality in a lodgepole pine forest. Agriculture and Forest Meteorology.

Ewers, BE. 2013. Understanding stomatal conductance responses to long-term environmental changes: A Bayesian framework that combines patterns and processes. Tree Physiology. 33:119-122

Frank JM, WD Massman, BE Ewers, L Huckabee, J Negron. 2014. Ecosystem CO2/H2O fluxes are explained by hydraulically limited gas exchange during tree mortality from spruce beetles. Journal of Geophysical Research-Biogeosciences. 119:1195-1215

Frank, JM, WJ Massman, E Swiatek, HA Zimmerman, BE Ewers. Accepted with Major revisions. Lack of transducer/structure shadowing correction explains observed underestimates in vertical wind velocity from some non-orthogonal sonic anemometers. J Atm & Oceanic Tech.

Hyde K, **S Peckham**, T Homes, BE Ewers. 2015. Bark beetle-induced forest mortality in the North American Rocky Mountains. Mortality effects in Forests. Elsevier ed. R Sivanpillia. Accepted pending revisions.

Norton, N, *BE Ewers*, **B Borkhuu**, E Pendall. 2015. Soil and litter nitrogen and greenhouse gas fluxes during five years of bark beetle infestation in a lodgepole pine forest. Soil Science Society of America Journal 79(1):282-293.

Peckham, SD, BE Ewers, DS Mackay, E Pendall, **JM Frank**, WJ Massman. Are simple models better? Bayesian analysis of a carbon cycle model and its respiration components. In preparation for Global Change Biology.

Reed, D, BE Ewers, E Pendall. 2014. Impact of mountain pine beetle induced mortality on forest carbon and water fluxes. Environmental Research Letters. 9:105004. Doi:10.1088/1748-9326/9/10/105004

Schlaepfer, DR, BE Ewers, BN Shuman, DG Williams, **JM Frank**, WJ Massman, WK Lauenroth. 2014. Terrestrial water fluxes dominated by transpiration: Comment. Ecosphere. 5:art61. Doi: 10.1890/ES13-00391.1

Presentations (*Students and Post-Docs are bolded*)
(Invited participant) BE Ewers Workshop on Plant Mortality, Jena Germany, Oct 2014.

Frank, JM, Massman WJ, Williams DG, Ewers BE, Kipnis E. Does sublimation decline after a spruce beetle outbreak? Agriculture and Forest Meterology Meetings, Portand OR, May, 2014.

(Invited) Ewers BE. Hydraulic Limitations Help Explain the Behavior of Plants: from clocks to mortality to ghosts. Department of Biology, University of Northern Colorado. January, 2014.

Massman, WJ, **Frank, JM**, Swiatek, E, Zimmerman, H, Ewers, BE. Which are more accurate, orthogonal or non-orthogonal sonic anemometers? American Geophysical Union Meeting, San Francisco, CA. Dec, 2013.

Bowling, DR, Ewers, BE, et al. Land-atmosphere carbon cycle research in the southern Rocky Mountains. American Geophysical Union Meeting, San Francisco, CA. Dec, 2013.

Kipnis, E, Chapple, WD, Traver, E, **Frank, JM,** Ewers, BE, Miller, SN, Williams, DG. Spatial variability of snow water isotopes in montane southeastern Wyoming. American Geophysical Union Meeting, San Francisco, CA. Dec, 2013.

Brooks PD, Harpold, AA, Biederman JA, Gochis DJ, Litvak, ME, Ewers, BE, Broxton, PD, **Reed, DE**. Non-linear feedbacks between forest mortality and climate change: implications for snow cover, water resources, and ecosystem recovery in western North America. American Geophysical Union Meeting, San Francisco, CA. Dec, 2013.

Ewers BE, et al. Bark beetle impacts on ecosystem processes are over quickly and muted spatially. American Geophysical Union Meeting, San Francisco, CA. Dec, 2013.

Mackay, DS, Ewers, BE, Peckham, SD, Savoy, P, Reed, DE, Frank, JM. Towards scaling interannual ecohydrological responses of conifer forests to bark beetle infestations from individuals to landscapes. American Geophysical Union Meeting, San Francisco, CA. Dec, 2013.

Biederman, Ewers, BE, Reed, D, et al. Compensatory vapor loss and biogeochemical attenuation along flowpaths mute the water resources impacts of insect-induced forest mortality. American Geophysical Union Meeting, San Francisco, CA. Dec, 2013.

Peckham, SD, Ewers, BE, Mackay, DS, Pendall, E, Frank, JM, Massman, WJ. Simulating stand-level water and carbon fluxes in beetle-attacked conifer forests in the Western US. American Geophysical Union Meeting, San Francisco, CA. Dec, 2013.

(Invited) Ewers BE. Quantifying how bark beetles impact forest hydrology. Presentation to American Association for the Advancement of Science External Advisory Committee to UW EPSCOR.

(Invited) Ewers BE. Causes and consequence of bark beetle-induce mortality on water, carbon, and nitrogen cycling. Ecological Society of America Annual Meeting. Minneapolis Minnesota. August, 2013.

Peckham, SD, BE Ewers, DS Mackay, E Pendall, HN Scott, JM Frank, MG Ryan and WJ Massman. Bayesian analysis of a carbon cycle model: Implications for parameter estimation, model selection, and simulation of beetle-caused forest mortality. Ecological Society of America Annual Meeting. Minneapolis Minnesota. August, 2013.

Mackay, DS, BE Ewers, **SD Peckham**, PR Savoy, **D Reed**, **JM Frank**, NG McDowell. Plant hydraulic controls over the susceptibility of trees to mortality following climate-enhance disturbances. Ecological Society of America Annual Meeting. Minneapolis Minnesota. August, 2013.

(Invited) Ewers BE. Impacts of bark beetle outbreaks from stands to watersheds. Public Lecture Sponsored by UW Ruckelhaus Institute. Laramie, WY May 2013.

(Invited) Ewers BE. Impacts of bark beetle outbreaks from stands to watersheds. Public Lecture Sponsored by UW Ruckelhaus Institute. Steamboat Springs, CO May 2013.

(Invited) Ewers BE. Impacts of bark beetle outbreaks from stands to watersheds. Public Lecture Sponsored by UW Ruckelhaus Institute. Saratoga, WY May 2013.

(Invited) Ewers BE. Hydraulic Limitations Help Explain the Behavior of Plants: from clocks to mortality to ghosts. Department of Biology, U. of New Mexico, February, 2013

(Invited) Ewers BE. Hydraulic Limitations Help Explain the Behavior of Plants: from clocks to mortality to ghosts. Department of Biology, Los Alamos National Labs, February, 2013

(Invited) Ewers BE. Impact of Fire and Insect Disturbance on Water Cycling in Ecosystems. Land Managers of the Laramie District of the Medicine Bow National Forest. February 2013

(Invited) Ewers BE. Surprising effects of bark beetle-induced mortality on snowpacks and water yield. Wyoming Weather Modification Technical Advisory Team Meeting, Cheyenne, WY January, 2013.

(Invited) Ewers BE. Impact of bark beetle outbreaks on forest water yield. Wyoming Association of Conservation Districts. Casper, WY, December, 2012.

P.D. Brooks; A.A. Harpold; J.A. Biederman; M.E. Litvak; P.D.Broxton; D. Gochis; N.P. Molotch; P.A. Troch; B.E. Ewers. Insects, firests, and climate change: implications for snow cover, water resources and ecosystem recovery in Western North America. American Geophysical Union Meeting, San Francisco, CA, Dec. 2012.

Ewers, BE, DS Mackay, C Guadagno, **SD Peckham**, E Pendall, B Borkhuu, **T Aston**, **JM Frank**, WJ Massman, **DE Reed**, Y Yarkhunova, C Weinig. Nonstructural carbon dynamics are best predicted by the combination of photosynthesis and plant hydraulics during both bark beetle induced mortality and herbaceous plant response to drought. American Geophysical Union Meeting, San Francisco, CA, Dec. 2012.

King A, BE Ewers, R Sivanpillai, E Pendall. Testing remote sensing estimates of bark beetle induced mortality in lodgepole pine and Engelmann spruce with ground data. American Geophysical Union Meeting, San Francisco, CA, Dec. 2012.

Peckham, SD, BE Ewers, DS Mackay**, JM Frank**, WJ Massman, MG Ryan, H Scott, E Pendall. Modeling net ecosystem exchange of carbon dioxide in a beetle-attacked subalpine forest using a data-constrained ecosystem model. American Geophysical Union Meeting, San Francisco, CA, Dec. 2012.

Mackay, DS, BE Ewers, **DE Reed**, E Pendall, NG McDowell. Plant hydraulic controls over ecosystem responses to climate-enhanced disturbances. American Geophysical Union Meeting, San Francisco, CA, Dec. 2012.

(Invited) Ewers BE. Impact of bark beetle outbreaks on forest water yield. Wyoming Water Development Commission. Cheyenne, WY, November, 2012.

(Invited) Ewers BE. Impact of bark beetle outbreaks on forest water yield. Joint meeting of the Wyoming Water Development Commission and the Select Water Subcommittee of the Wyoming Legislature. Casper, WY, November, 2012.

(Invited) Ewers BE. Impact of bark beetle outbreaks on forest water yield. Wyoming Water Association Annual Meeting. Lander, WY, October, 2012.

Reed, DE, BE Ewers, E Pendall, RD Kelly, U Norton, **FN Whitehouse**. Mountain pine beetle epidemic changes ecosystem flux controls of lodgepole pine. Ecological Society of America Annual Meeting, Portland, OR, August 2012.

Brooks, PD, HR Barnard, J Biederman, B Borkhuu, SL Edburd, BE Ewers, D Gochis, E Gutmann, AA Harpold, JA Hicke, DJP Moore, E Pendall, **D Reed**, A Somor, PA Troch. Multi-scale observation of hydrologic partitioning following insect-induced tree mortality: Implications for ecosystem water and biogeochemical cycles. Ecological Society of America Annual Meeting, Portland, OR, August 2012.

Frank, JM, WJ Massman, BE Ewers. Linking bark beetle caused hydraulic failure to declining ecosystem fluxes in a high elevation Rock Mountain (Wyoming, USA) forest. Ecological Society of America Annual Meeting, Portland, OR, August 2012.

Ewers BE, DS Mackay, E Pendall, J**M Frank, DE Reed,** WJ Massman, **TL Aston**, **JL Angstmann, K Nathani, B** Mitra. Use of plant hydraulic theory to predict plant controls over mass and energy fluxes in response to changes in soils, elevation and mortality. Ecological Society of America Annual Meeting, Portland, OR, August 2012.

Barnard, HR, A Byers, A Harpold, BE Ewers, D Gochis, P Brooks. Examining the response of lodgepole transpiration to snow melt and summer rainfall in subalpine Colorado, USA. Ecological Society of America Annual Meeting, Portland, OR, August 2012.

Brown, NR, U Norton, E Pendall, BE Ewers, **B Borkhuu**. High levels of soil and litter nitrogen contents after bark beetle-induced lodgepole pine mortality. Ecological Society of America Annual Meeting, Portland, OR, August 2012.

Ewers BE et al. Use of plant hydraulic theory to predict plant controls over mass and energy fluxes in response to changes in species, soils and mortality. American Society of Plant Biology Annual Meeting, Austin, TX, July, 2012.

(Invited) Ewers BE. Simulation modeling of bark beetle effects on stand water budgets. Wyoming Weather Modification Technical Advisory Team Meeting. Saratoga, WY July 2012.

Leveraged Support to this Project.
NSF ESPSCOR. Water in the West. $20 million total grant, Ewers PI. A major justification for this grant was the lack of correlation between increased water in stands and streams after bark beetle mortality. The TREES model funded by this project will now be tested against other, less biologically sophisticated hydrology models. This grant establishes the Wyoming Center for Environmental Hydrology and Geophysics (WyCEHG).

NSF ETBC Hydrologic Science. ETBC: Collaborative Research: Quantifying the Effects of Large-Scale Vegetation Change on Coupled Water, Carbon, and Nutrient Cycles: Beetle Kill in Western Montane Forests. CoPI Elise Pendall. $219,261. This NSF funding provided partial funding for several of the data sets used to test TREES.

Ag Exp Station and McIntire Stennis. Quantifying the impact of a massive mountain pine beetle outbreak on carbon, water and nitrogen cycling and regeneration of southern Wyoming lodgepole pine forests. CoPIs Elise Pendall and Urszula Norton $60,000. This grant provided partial funding for several of the data sets used to test TREES.