Observing carbon fluxes and potential climate change impacts from forest land management

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A. Abstract

Forestry is a major industry in Wisconsin, and there is growing interest in learning how to align forestry with adaptation to and mitigation of climate change. Yet, little is known about whole ecosystem carbon fluxes in typical forest management scenarios. The **goal** of this research proposal is to quantify the flux of carbon in Wisconsin forests undergoing land management. The **objective** is to understand how land management alters the carbon cycle of forest ecosystems in Wisconsin and investigate how well we can predict carbon cycle impacts of differing land management scenarios.

I **propose** to 1) measure pre-, during, and post- harvest carbon fluxes in a Wisconsin hardwood forest, 2) analyze the impact of this management on carbon fluxes, and 3) compare these findings to a state-of-the-art landscape ecosystem model. I **hypothesize** that the harvest will initially cause the ecosystem to release carbon, but soon sequester carbon at rates larger than pre-management. Comparison with forest product lifecycle analyses and bioenergy potentials will be used to place these carbon flux changes in economic context.

Currently, the U.S. Forest Service (**USFS**) is planning a large forest thinning and harvest in the Chequamegon-Nicolet National Forest (**CNNF**) near Park Falls, WI. In the same area, atmospheric flux observations have been made by the Desai lab from 2000-2006 to quantify the land-atmosphere CO_2 flux. Seed funding from the USFS is restarting this tower site in late 2009. However, the funding is only sufficient for initial observations in the pre-management phase.

This proposal would support instrumentation, labor, data analysis, and reports about land management and impact on carbon fluxes at this hardwood site and compare findings to other non-managed forest carbon fluxes and a state-of-the-art forest landscape model parameterized for N Wisconsin. Cost sharing in terms of supplementary research activities by the lab and partners is expected.

I expect to produce 2-3 peer-reviewed publications, a guide to measurement of carbon fluxes during management, and data output products and figures available by public website. Additionally, relevant implications of our findings will be reported to the U.S. Forest Service and Wisconsin Focus on Energy and presented at regional and national meetings.

B. Program Area to be Addressed

This proposal is aligned with the RFP's goal to provide sound research data useful for Wisconsin policy makers and specifically addresses interest area C.1 to understand the flux of carbon in Wisconsin's environment and ramifications for forest management, policy, and bioenergy. This project precisely aims to cover this interest area by conducting a high profile, novel observational study of carbon fluxes before, during, and after forest management. By working with U.S. Forest Service partners in Park Falls, WI and conducting observations at an existing research site in northern Wisconsin, this proposal supports the RFP's desire to use existing research and analytical capabilities in Wisconsin.

Additionally, a number of regional partners have expressed interest in collaborating and supporting other observations and models, centered on this field site. Federal funding for some of these observations has already been acquired. Thus, this project also meets the RFP's stated intent to leverage out-of-state and federal resources.

C. Usefulness and Value of Project Results

Terrestrial ecosystems absorb ~1/3 of fossil fuel emissions in the U.S. Carbon cycling in these ecosystems is the largest natural source of uncertainty to future projections of atmospheric CO_2 and consequently future climate change. Prediction is difficult because ecosystems are strongly sensitive to climate variability and human land management. While ongoing research has shed much light on the former sensitivity (climate), the impact of human land management on terrestrial carbon cycling continues to be less well understood. Given that the majority of land in the world and the U.S. is managed land and bioenergy production is likely to increase that, it is imperative to better improve predictions of how land management impacts carbon cycling.

Forests make up one-third of the U.S. landscape, of which the U.S. Forest Service (**USFS**) and other public agencies manage nearly 45%. Given ongoing climate change and interest in the future U.S. forest carbon sequestration and bioenergy, the USFS actively supports research on climate and carbon cycles on managed forests. In particular, the USFS Northern Research Station (**NRS**), as part of its Climate Change Response Framework, is engaging researchers to bridge the gap between research and management in eastern U.S. national forests. The goal is to improve science-based management decisions in light of future climate uncertainty.

This proposed project would focus on forest management in Wisconsin. More than 45% of Wisconsin is covered by forest, and an even larger percentage in Northern Wisconsin, where more than 1.5 million acres of land is managed by the Chequamegon-Nicolet National Forest (**CNNF**). In light of ongoing and predict future climatic change in Wisconsin and expected future forest management and potential bioenergy development, CNNF and NRS are both interested in supporting carbon cycle research in Wisconsin.

Over the past decade, a number of researchers have heeded this call and begun investigations of carbon cycling in the forest. Over time, one group has informally assembled as the Chequamegon Ecoystem Atmosphere Study cooperative (ChEAS; http://cheas.psu.edu and http://flux.aos.wisc.edu). Eddy covariance flux and micrometeorology towers have been constructed in CNNF and surrounding lands to directly quantify land-atmosphere exchanges of CO_2 and impacts of climate variability. Currently, the forested sites are inoperative. This proposal remedies the observational deficiency in advance of a planned major forest management encompassing a hardwood forest site.

Whole ecosystem carbon exchange and ancillary measurements will be made before, during, and after commercial harvest around the tower site. This series of measurements would be one of the only continuous observations of fluxes during management, and the only in Wisconsin represetning hardwood forests typical of the upper Midwest. These measurements will then be used to estimate how well current generation forest landscape and ecosystem models correctly capture land management impacts on photosynthesis, respiration, and decomposition.

NRS provided one-year seed funding and CNNF reauthorized a special use permit so that we could operate the hardwood forest flux tower in advance of land management. However, the funds are primarily designated to restart the tower and collect baseline data. This proposal picks up where that one ends to advance observations through the management phase. If funded, this small project, supporting the measurements, labor, and data comparisons, will give us significant leverage for additional measurements and projects with a number of research partners. Reports, publications, and website data access will be of great value to scientists, land managers, and policy makers who are considering the intersections of greenhouse gas cycling, carbon sequestration, bioenergy, and forest land management in Wisconsin.

D. Soundness of Project Methods

Tasks in this proposal include collaboration on joint research-management activity, field measurement and analysis, and model-data comparison. Methods for each are described briefly below.

Planned Forest Management

The USFS CNNF is planning a commercial harvest and thinning activity in the Medford-Park Falls district in N Wisconsin. This management will occur most likely starting winter 2011, depending on speed of the approvals process. The area of management completely encompasses our Willow Creek research site (Fig. 1). USFS is managing these lands for Northern Hardwoods and expects harvesters to use best practices in silviculture for minimizing environmental impact.

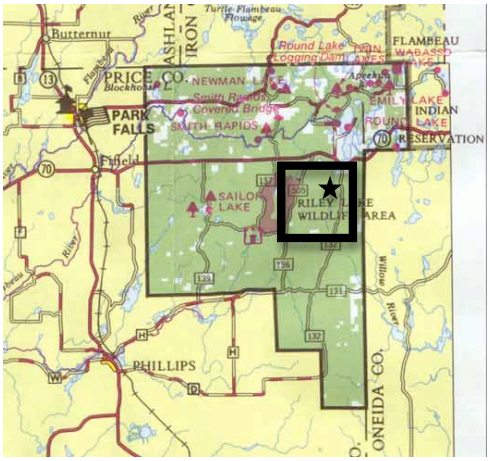


Figure 1. General region of planned management activity. Star denotes flux tower.

This is a large management action for CNNF. It is also unique in the incorporation of research partners at the early phase of planning. The integration of research and management is partly in response to the USFS NRS Climate Change Response Framework and Model Forest Initiative. The Model Forest Initiative seeks to understand how forest carbon sequestration varies with management and climate, with the goal for future management policy to be informed by research. Because of our long research partnership in ChEAS, the Desai lab is well poised to conduct this kind of research. We have met several times with CNNF foresters and NRS scientists and would continue to do so in this project.

Field Observations and Analysis

Eddy covariance flux towers measure high-frequency (> 10 Hz) fluctuations of atmospheric trace gases and vertical velocities. These measurements when applied to CO_2 and entreated to a number of time-series analyses, can be used to compute whole ecosystem net carbon exchange on scales of ~1 km^2 and time resolution of 30 min. This technique is well established (Baldocchi, 2003) and there are now nearly 500 towers worldwide. We have adopted the best practices used by the flux tower community at our sites (Desai *et al.*, 2005).

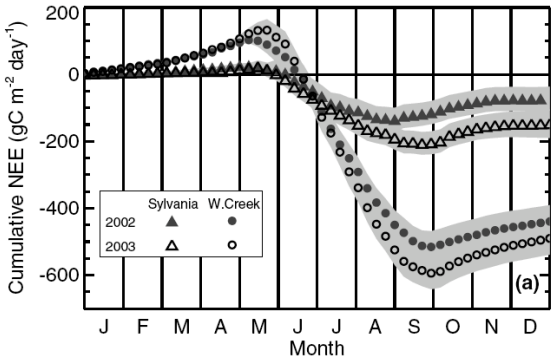


Figure 2. Cumulative annual net carbon uptake at WC (circles) over two years compared to a nearby old-growth forest (triangles). Reprinted from Desai *et al.* (2005)

The Willow Creek flux tower was instrumented in 1999 and operated continuously from 2000-2006 to study hardwood forest carbon exchange in response to climate variability, as described in Cook *et al.* (2004). In addition to flux tower observations, micrometeorological observations of temperature, radiation, precipitation, humidity, wind speed, soil temperatures, and ecological observations of component (soil, tree, etc…) fluxes were made.

In fall 2009, we restarted the tower with one-year seed funding from NRS. This proposal would continue flux tower observations and data processing for an additional three years, by supporting material and supplies, technician time, and a contract with NRS for data collection (see support letter). Additionally, we would continue to work closely with CNNF to measure carbon exchange during management. We will collaborate with CNNF (see support letter) to ensure the harvest around the footprint of the tower is carefully controlled to maximize the land management signal and minimize micrometeorological noise, as previously demonstrated in Scott *et al.* (2005). We will compare management fluxes to the baseline observations of carbon uptake at the site over the previous decade (e.g., Fig. 2) using statistical analysis.

Forest Landscape Modeling

To better place into context the observations made at one research site, and to test theories of forest management and carbon cycling, we will compare the findings from our observations to a well-tested, parameterized forest landscape and succession model. The LANDIS-II model (Scheller *et al.*, 2007) is designed to model forest production and biogeochemical cycling in heterogeneous regions undergoing disturbance, succession, and management (Fig. 3).

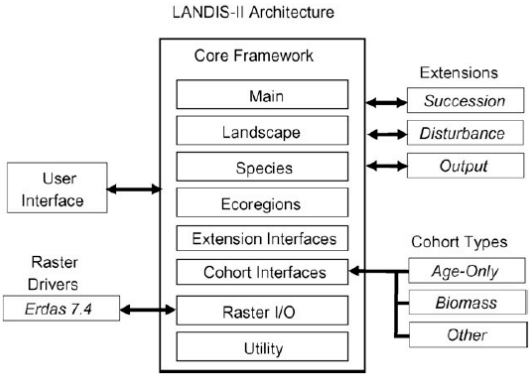


Figure 3. LANDIS-II model architecture. Reprinted from Scheller *et al.* (2007).

We will work with Dr. David Mladenoff (see support letter) who is one of the principal authors of the model and a leading expert on forest landscape processes. LANDIS-II has been used in the past in N Wisconsin and parameterized at the Willow Creek site. However, it has not been compared to flux tower data across a management activity, which would be done here. Model runs will be provided by Dr. Mladenoff and analyzed by a post-doctoral scholar partially supported by this proposal. Additionally, a graduate student in the PI's lab is actively involved in running this model for a different project and would lend assistance in analyzing results.

References

Baldocchi, D.D., 2003. Assessing the eddy covariance technique for evaluating carbon dioxide exchange rates of ecosystems: past, present and future. *Global Change Biol.*, 9: 1-14.

Cook, B.D., *et al.*, 2004. Carbon exchange and venting anomalies in an upland deciduous forest in northern Wisconsin, USA. *Agric. Forest Meteorol.*, 126(3-4): 271-295.

Desai, A.R., et al., 2005. Comparing net ecosystem exchange of carbon dioxide between an old-growth and mature forest in the upper Midwest, USA. *Agric. Forest Meteorol.*, 128(1-2): 33-55.

Scott, N.A. *et al.*, 2005. Impact of a shelterwood harvest on the net carbon balance of a spruce/hemlock dominated forest in Maine, In: Kenefic, L.S. and Twery, M.J., eds. Changing Forests - Challenging Times: Proceedings of the New England Society of American Foresters 85th Winter Meeting, Newtown Square, PA, 2005 March 16-18, USFS NRS Gen. Tech. Rep. NE-325.

Scheller, R.M., *et al.*, 2007. Design, development, and application of LANDIS-II, a spatial landscape simulation model with flexible temporal and spatial resolution. *Ecol. Modelling,* 201: 409-419.

E. Statement of Work and Schedule

Task 1. Collaborate with USFS on planned management

Objectives: Coordinate planned research with planned forest management to maximize gain of scientific understanding.

Researchers: Desai (UW), USFS CNNF (Geoff Chandler/Linda Parker)

Methods: Desai will meet regularly by telephone and in person with CNNF foresters on the management planning (see support letter). We will specifically focus on management activities to occur within the footprint of the tower. One goal is to minimize the effect that large removals can have on local micrometeorology, which can degrade the quality of flux data, without sacrificing the management objectives. Additionally, there are options to expedite this portion of the forest management to prevent the research timeline from being delayed. Finally, Desai will produce an online guide for best practices on operation of carbon flux observations during active management.

Deliverables: Website documentation on a "working guide" for eddy covariance flux observations during active management.

Task 2. Maintain and operate the Willow Creek flux tower

Objectives: Continuously operate the Willow Creek flux tower and associated micrometeorological measurements before, during, and after management.

Researchers: Desai (UW), Thom (UW), Kubsike (NRS)

Methods: Eddy covariance flux towers run continuously; but to maintain high uptime, they require routine monthly maintenance, seasonal quality control, emergency repairs, and regular collection of high rate data (~100 MB/day). Desai, working with UW flux tower technician Jonathan Thom will continue to operate the tower and collect high-quality turbulent flux and micrometeorological observations throughout the entire proposal period. We also propose to continue a long-standing support agreement with the USFS NRS (see support letter) to have NRS personnel from Rhinelander, WI visit the site on a biweekly basis to collect data and perform simple maintenance.

To further improve uptime and provide a data portal to the public, we plan to install a packet-radio based real-time monitoring system. This system consists of a data logger, packet-radio modem, and high-gain antenna at Willow Creek pointed a receiver placed on the nearby (20 km line of sight) 447 m WLEF-TV transmitter tower, where we have flux tower observations and an Internet connection by DSL. This system would allow us to monitor the site remotely by Internet. Eventually, we plan to develop a web platform for quick-look public data access.

Deliverables: High uptime, continuous flux data collection for three years. Real-time data monitoring on public website.

Task 3. Collaborate with research partners for ancillary carbon cycle observations

Objectives: Leverage tower data collection to develop new projects that further understanding of forest management impacts at the Willow Creek site

Researchers: Desai (UW), Swanston (NIACS)

Methods: The tower measurements to be supported by this proposal provide one high-resolution picture of whole ecosystem forest carbon fluxes and how they respond to climate

variations and management. However, these measurements can be significantly aided by ancillary observations of component ecosystem fluxes, biometric observations, and laboratory incubations. Working with Chris Swanston of NIACS (see support letter), who has expertise in ecosystem biogeochemical process observations, we will seek to identify researchers and funding opportunities to provide some of these observations. One planned measurement already underway with Swanston involves ^{14}C (radiocarbon) observations of soil carbon to quantify how turnover rates of soil organic matter decomposition change with management. A recent call to the internatonal flux tower listserv found at least half a dozen interested partners.

Deliverables: Reports to highlight benefit of additional measurements, meeting with Swanston, and additional measurements and funding.

Task 4. Process flux data

Objectives: Process high rate turbulent observations into gap-filled quality-controlled half-hourly carbon, water, and energy flux data

Researchers: Thom (UW), Brooks (UW)

Methods: Using standard eddy covariance data processing routines, we will compute whole ecosystem exchange of CO_2, H_2O, temperature, and momentum from high frequency observations of trace gases, energy, and wind velocities collected at the tower site. Fluxes will be screened for low-turbulence conditions and non-stationary conditions, especially during management, when tower sampling conditions are changing. Additionally, our current screening of data for non-representative wind directions will be applied and modified depending on the heterogeneity of the proposed land management. We will identify changes to our screening or tower design by applying commonly available flux tower footprint influence models.

Quality controlled 30-minute flux data will be gap filled using standard, developed algorithms that regress environmental variables against observed fluxes. These routines also output estimates of gross primary production and ecosystem respiration. Final, quality-controlled, gap-filled carbon, water, and energy fluxes and contemporaneous micrometeorology measurements will be organized into ASCII files, which will be made available on the project website.

Deliverables: Multi-year half-hourly flux and meteorology data and figures on the project website.

Task 5. Analyze flux data for impact of management

Objectives: Understand how carbon and water fluxes change during and after forest harvest

Researchers: Desai (UW), Brooks (UW)

Methods: Carbon flux data from the tower will be aggregated into three time periods: 1) baseline (2000-2006, and 2009-2010), 2) management (2010-2011), and 3) post-management (2012-2013). For each time period, mean diurnal, monthly, seasonal, and annual fluxes of net ecosystem exchange, gross primary production, and ecosystem respiration will be computed and compared. To correct for climate anomalies during the latter two phases, a correction factor will be developed based on observed climate variability impacts on the nine-year baseline record.

For each time period, we will also aggregate and compare biometric and environmental variables such as total biomass, leaf area index, soil organic carbon, absorbed solar radiation, which we will estimate using standard field and remote sensing techniques. These observations

will help place the change in carbon fluxes in context with the change in carbon stocks. Climate variables such as air temperature, soil temperature, incoming radiation, and wind speeds will also be compared in each period to test for changes in micrometeorology due to forest management or regional climatic change. Flux and meteorological data will be compared against baseline flux observations collected at a nearby old-growth forest and several other sites of various stand age.

Finally, to further understand how management impacts carbon fluxes, we will conduct several case studies of particular removals and their effects. We will rely on previously completed lifecycle analyses to estimate the amount of removed carbon that goes into wood products and the atmosphere, and compare that to the change in forest carbon sequestration and fossil fuel used in the management operation. Bioenergy potential of harvest will also be considered here. This case study will provide a clearer picture beyond ecosystem carbon fluxes and will likely be of relevant interest to policy makers.

Deliverables: At least one peer-reviewed publication on observed impacts of management on whole ecosystem carbon cycling in northern hardwood forests, and reports to CNNF and Wisconsin FOE.

Task 6. Acquire model output to compare predicted and observed impacts

Objectives: Assess how well a forest landscape model captures carbon cycle response to forest management at the Willow Creek site and extrapolate findings to other Wisconsin northern hardwood forests

Researchers: Desai (UW), Brooks (UW), Mladenoff (UW)

Methods: In collaboration with Dr. David Mladenoff (see support letter), we will acquire existing output from the LANDIS-II model parameterized 1) specifically for Willow Creek and 2) for the entire management area. Carbon flux estimates for this model will be compared to baseline observations to test how representative Willow Creek is of the larger region and how natural forest landscape disturbance and succession processes (as captured in the model) compare to management (as captured in the observation) in terms of carbon cycling.

Our lab also is growing expertise in running the LANDIS-II model as part of another project in Michigan. We thus hope to be able to test management scenarios in the Willow Creek parameterized model. We will prescribe the actual management scenarios in the model and compare modeled to observed carbon fluxes while testing various parameters and theories of carbon cycle-management interactions. These findings should lead to improved insight into the mechanistic processes by which management impacts carbon cycle and eventually lead to improved predictions of future management on regional carbon cycling.

Deliverables: At least one peer-reviewed publication on model evaluation of mechanisms of management impacts on carbon cycling, and reports to CNNF and Wisconsin FOE

Task 7. Reporting and information transfer

Objectives: Publish peer-reviewed manuscripts, prepare reports, and present data to communicate results to the public, scientists, Focus on Energy, USFS and other stakeholders.

Researchers: Desai (UW), Brooks (UW)

Methods: As described in the above tasks, a number of peer-reviewed publications on how carbon cycle pathways change from this particular management and in general from forest

management in Wisconsin will likely emerge. These findings will also be presented at national scientific venues such as the American Geophysical Union fall meeting in San Francisco, CA.

To make findings accessible to the public, we intend to make reports, publications, and figures available via our public lab website, on http://flux.aos.wisc.edu . This website will also host the public facing portion of our real-time monitoring system and flux data download. Flux data will also be archived in global flux tower repositories hosted by the U.S. Department of Energy. The flux tower community has adopted liberal fair-use agreements, which we intend to follow here and will allow for rapid and easy data sharing.

In addition to presenting our results at the FOE sponsored Environmental Research Forum and other events organized by Focus on Energy, we will prepare progress and final reports for FOE outlining accomplishments and major findings. Additionally, reports to CNNF, NRS, and/ooor NIACS on conducted research and implications for forest management will be prepared in consultation with them.

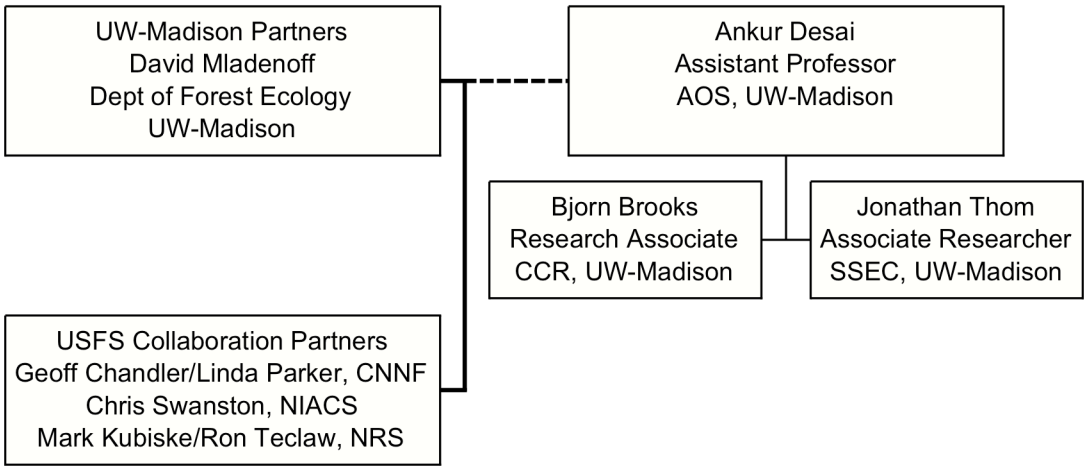
Deliverables: 1) At least two peer-reviewed publications and two presentations at national conferences, 2) public website with real-time observations, processed fluxes, figures, reports, measurement guide, and 3) reports and presentations to USFS and FOE

Master Schedule

Months	0-6	7-12	13-18	19-24	25-30	31-36
	2010 *Jun-Dec*	**2011** *Jan-May*	*Jun-Dec*	**2012** *Jan-May*	*Jun-Dec*	**2013** *Jan-May*
Task 1						
Management planning	x	x	x			
Task 2						
Operate tower	x	x	x	x	x	x
Task 3						
Collaborations		x	x	x	x	
Task 4						
Data processing		x	x	x	x	x
Task 5						
Data analysis			x	x	x	x
Task 6						
Model comparison				x	x	x
Task 7						
Presentations	x		x		x	
Publications					x	x
Website		x		x		x
Reports			x		x	x

F. Management Plan and Qualifications

Organizational Chart



Dr. Ankur Desai, PI, is Assistant Professor of Atmospheric and Oceanic Sciences and faculty affiliate at the Center for Climatic Research (CCR), Nelson Institute for Environmental Studies, UW-Madison. He will be responsible for overall project management, supervision of Bjorn Brooks and Jonathan Thom, coordinating with CNNF, NRS, NIACS, and the Mladenoff lab, and meeting all reporting requirements. Dr. Desai has extensive experience in eddy covariance flux tower observations and carbon cycle models.

Dr. Bjorn Brooks is a post-doctoral Research Associate in CCR at UW-Madison, supervised by Dr. Desai on several carbon cycle projects. Dr. Brooks has expertise in geostatstical and observational data regression. He will be responsible on this project for the observational data analysis and assisting in the flux data processing.

Jonathan Thom, Associate Researcher in Space Sciences and Engineering Center at UW-Madison, will be assisting with observation data collection and field site maintenance. He will coordinate the efforts of USFS NRS in the data collection and analysis.

Primary research partners:

Dr. David Mladenoff, Professor of Forest and Wildlife Ecology at UW-Madison is a leading expert on forest landscape processes and modeling. He will provide LANDIS-II model output and assist in experimental design and data analysis.

U.S. Forest Service, Chequamegon-Nicolet National Forest: Geoff Chandler and Linda Parker will coordinate with Dr. Desai on the planned forest management and integration of research activities into the management.

Northern Institute of Applied Carbon Science: Dr. Chris Swanston will coordinate with Dr. Desai on the Climate Change Response Framework goals and assist in developing and supporting additional field measurements.

Northern Research Station: Mark Kubiske and colleagues will assist in field site maintenance, data collection, and research coordination with CNNF.