9. Justification and Problem Selection

Linkages among canopy development, assimilation (net photosynthesis), transpiration, tree growth and the acquisition of essential nutrients and water are regulated by the genetic architecture of populations of trees, climate and atmospheric composition, soil properties, microbial transformations of soil organic matter, and animals (e.g. soil invertebrates). These ecosystem processes feedback and influence one-another via complex and poorly understood pathways, especially below the soil surface where it is often difficult to directly observe and measure the interactions among organisms and their biophysical environment. The Belowground Processes that Sustain Productivity and Ecosystem Function in Northern Forests Research Work Unit (RWU 4159) will develop a more comprehensive understanding of the above-, and especially, the belowground processes that regulate the dynamics of carbon, nutrients and water in forests. This knowledge will enable us to better predict and model the consequences of forest management, natural disturbance, and global change.

In forest ecosystems, the production and mortality of tree roots accounts for a significant portion of ecosystem net primary productivity, and aside from canopy assimilation, soil respiration accounts for the single largest flux of C. In many northern forests, fine roots account for more than one-half of the total annual C budget. The death and decay of fine roots are also important components of terrestrial nutrient cycles. Even though it is widely recognized that roots play key roles in ecosystem C and nutrient cycling, our understanding of the fundamental relationships among tree root system structure and ecosystem function is very limited. Carbon allocation to roots and root respiration are very poorly understood at the ecosystem level compared to photosynthesis and C allocation to the shoot system. It is currently impossible to reliably estimate C allocation to roots from standard forest inventories. The effects of forest management practices on C allocation to root systems is so poorly understood that most models of forest productivity simply assume that a fixed proportion of photosynthate is allocated to root systems. However, limited experimental evidence suggests simple assumptions about how roots grow are often flawed. Such assumptions fail to recognize that assimilate partitioning to roots is actually the outcome of diverse physiological and ecological processes. <u>Our poor understanding of the factors regulating C allocation to root systems limits our ability to successfully apply new management systems designed to enhance or sustain ecosystem productivity, while maintaining biodiversity and ecosystem function</u>.

Theoretical and empirical analyses indicate the composition of biological communities, whether composed of animals, plants, or microbes, is controlled by the availability of growth-limiting resources. The amount and types of organic compounds contained in above- and belowground plant litter control resource availability for soil microbes and soil fauna. Because plant communities differ in the amount and types of organic substrates entering soil, the composition and

function of soil microbial communities should differ in a manner consistent with changes in the plant community. It is also plausible that changes in plant production or plant community diversity could increase the range of organic substrates that limit, and thus control, the composition and function of microbial communities. Regardless of the conceptual linkages between plant and microbial communities, our understanding of the relationship between plant species composition, ecosystem productivity, and the dynamics of soil microbial communities is very limited. This is unfortunate, because soil microbes are the gatekeepers that decompose and transform plant litter, form stable soil C, and regulate the availability of essential nutrients bound in organic matter.

Human activities, including forest management, have the potential to alter the composition and function of soil microbial communities because human activities change the rates and types of organic substrates entering the soil. Although there is a rudimentary understanding of how microbial function changes following some forest management activities, there is virtually no information on how management practices influence soil community composition. In other words, soil biodiversity and the linkages between soil biodiversity and ecosystem function are very poorly understood. We do not understand how human activities alter the function and biodiversity of soil organisms, organisms that regulate carbon and nutrient cycling and the formation of stable soil organic matter.

Another major research problem is to further our understanding of belowground biogeochemical cycles, evaluate how they are being altered by human activities and design management systems that maintain or enhance ecosystem function and maintain biodiversity. The list of issues relevant to forest management is long. Humans are actively altering the composition of the earth's atmosphere, but our ability to make reliable predictions in terms of altered forest composition, structure and function is not impressive. It is clear from hundreds of experiments that tree growth under controlled conditions is enhanced as a direct effect of elevated atmospheric CO_2. However, it is unclear if these growth responses are transient and if they will be sustained under field conditions, especially when other resources such as N and water are limiting to growth. It is possible that elevated atmospheric CO_2 will result in the production of litter that is a relatively poor substrate for microbes. This could result in a decline in soil nitrogen availability, which, at the ecosystem level, could dampen the positive growth responses observed when trees are exposed to elevated atmospheric CO_2 in nutrient rich pots or chambers. It is also unclear how atmospheric CO_2 will interact with rising tropospheric ozone to influence forest ecosystem productivity. Much of our uncertainty in terms of predicting how forest ecosystems will grow and function in the future lies belowground and centers on understanding how root growth, altered organic substrate inputs and microbial communities respond to increasing photosynthesis and aboveground biomass production.

In the same sense, we have much to learn about how forest management practices alter biogeochemical cycling. In this region, plantation management is

intensifying in some portions of the landscape and there is increasing pressure to actively manage forested wetlands, which contain valuable softwood fiber. We need a better understanding of how forest management practices alter productivity, biogeochemical cycling and biodiversity to make wise management decisions. We lack sophisticated methods and inventory and monitoring tools that include the ecological factors necessary to predict how ecosystems will respond to forest management at various scales and levels of intensity. We need specific information that will enable managers to fill regional-scale gaps in our knowledge and ability to predict and model the consequences of forest management. We must meet the increasing demand for fiber and other forest resources in ways that sustain productivity and biodiversity. It is important that we improve our ability to forecast the growth and productivity of forests into the future. Managers question how a variety of management practices influence ecosystem processes, and it is critical we develop tools and methods to transfer the latest knowledge of ecosystem function to practitioners. All of these demands require an improved understanding of the biogeochemical processes that control productivity.

The North Central Region has an abundance of fresh water. At the watershed scale, we must develop a more comprehensive and cumulative understanding of how human activities influence litter production and decomposition, soil microbial composition and function, the production of dissolved organic matter and nutrients, and the mobilization and transport of organic compounds and ions to freshwater streams and lakes. Only by understanding the mechanisms that regulate biogeochemical cycling can we design better, sustainable, forest management practices.

The Sustaining Productivity and Ecosystem Function in Northern Forests Research Work Unit will work within the context of North Central's Integrated Programs: Forest Productivity, Riparian Landscapes, and Landscape Change. Planned accomplishments are directly relevant to multidisciplinary research programs designed to understand, predict, and monitor the effects of land use on riparian areas and to manage forests more productively, while improving our ability to sustain ecosystem function and biodiversity.

Besides working collaboratively with other NC Research Work Units and Integrated Programs in North Central, the unit will cooperate with other Forest Service Research Stations. Collaborative arrangements are also planned with staff scientists from Oak Ridge National Laboratory, forest products companies, and professors and students from several universities. We plan to extend the results of our studies to National Forests, forest products companies, state agencies, the Nature Conservancy, and to public schools via workshops, publications, software, and internet-based technical transfer products.

The program of research will provide new and fundamental knowledge of the belowground processes that regulate biogeochemical cycling in northern forests.

It will also benefit policy makers, planners, and resource managers who deal with managing forest productivity, allocating land to different uses, designing and improving sustainable forest management practices, and predicting the consequences of human activities at local, regional and global levels. Products resulting from the research will enable technical transfer of new and existing knowledge to the customers and supporters of the North Central Research Station.