Andrews Forest LTER6

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HJ ANDREWS EXPERIMENTAL FOREST

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PROJECT SUMMARY

This proposal presents plans for the sixth funding cycle of the Andrews LTER Program (LTER6). Our plans maintain the continuity of our long-term experiments and measurement programs, some of which have been in place for more than 50 years, as well as the Central Question that has guided our LTER program for the past three funding cycles: *How do land use, natural disturbances, and climate affect three key ecosystem properties: carbon and nutrient dynamics, biodiversity, and hydrology?* We aim to increase our understanding of the forest and stream ecosystems of the Pacific Northwest, typified by the Andrews Forest, while steering our program to answer critical questions that are relevant today to our region, the LTER Network and the broader society.

One of the goals of LTER6 is to evaluate ecosystem responses to potential future change in drivers – especially climate. Long-term studies at the Andrews Forest show little evidence so far of responses to climate change. However, climate projections for our region suggest that warming trends in the coming half century will greatly exceed changes that have occurred over the last half-century. Our site is well positioned to use long-term ecosystem behaviors to evaluate potential future change. We have measured and proxy records extending to 50 and >500 years, respectively, and our site spans steep and complex climate gradients. We will make a special effort to understand how regional-scale changes in climate might down-scale to affect ecosystem processes at our site. Mountains define our landscape, and during LTER5 we learned that microclimate patterns and processes in our complex terrain are far more complicated than we initially envisioned. These complexities have important implications for the coupling between macroclimate and microclimate, and they influence the ways that biodiversity, hydrology and carbon and nutrient cycling respond to ecosystem drivers. Another important goal of LTER6, therefore, is to understand the influence of complex terrain on ecosystem processes.

Our proposed studies will deepen our understanding of the forest and stream ecosystems of the Pacific Northwest. We will address our Central Question by enhancing our understanding of the responses of phenology, trophic interactions, and carbon, nutrient and water cycles to changes in climate, land use and disturbance, and by understanding influences of complex terrain on these responses. In addition, in LTER6 we will expand our knowledge of our system and its surroundings as a coupled natural and human system, addressing research challenges outlined in the Millennium Ecosystem Assessment. With the overall goal of intensifying connections of our program with society and the social sciences, we will consider relationships between ecosystem change and social change, as mediated by ecosystem services. We will rely on strong partnerships rather than LTER funding to achieve this goal, but we consider them part of our core research. In the past we have pioneered strong science/management and science/humanities connections, and we plan to continue to grow and nurture these partnerships. Our proposal outlines plans to develop closer integration between our science program and our education program, and to create a “Cyber Forest” infrastructure within the Andrews landscape. Our synthesis book is on track for completion in 2008.

Scientific Merits of this proposal include: Continuation of long-term measurements and experiments in one of the LTER network’s longest-running programs; increased understanding of the forest and stream ecosystems of the Pacific Northwest, typified by the Andrews Forest, and contribution of this knowledge to the broader understanding of ecosystems in the LTER network; elucidation of ecosystem responses and feedbacks to potential climate change; developing a foundation for new ecological theory for complex terrain.

Broader impacts of this proposal include: Training and development of scientists and scientific knowledge of citizens on multiple levels, including K-12 teachers and students, undergraduate students, graduate students and early-career researchers; encouragement of multidisciplinary, collaborative research; forging stronger alliances between biophysical scientists and social scientists; dissemination of scientific knowledge through strong science/management partnerships and contribution to adaptive management strategies; fostering science/humanities connections; enhancement of cyberinfrastructure at the Andrews and contribution to important innovations in cyberinfrastructure.

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1.0. PRIOR RESULTS

Below we present highlights of increased understanding from the current funding cycle the Andrews LTER Program (LTER5), with an emphasis on knowledge that is relevant to our proposal for the next funding cycle (LTER6). We first outline the scope and historical context of our work; then we present key findings and summarize how they lead us to our proposed work in LTER6.

SCOPE OF ANDREWS LTER. Our research spans temporal scales of diel to millennial and spatial scales of plot to small watershed (10-100 ha) to meso-scale watershed and landscape (ca. 100 km^2) to the Pacific Northwest conifer forest bioregion. Our system of core long-term measurements and experiments (Table 1.1) provides background and a foundation for individual, discipline-based research projects and also for observing environmental change. Long-term measurements involving climate, land use, disturbance, hydrology, nutrient fluxes, vegetation and biodiversity have yielded a steady stream of published research findings (see below and Supplementary Documentation, Publication list). These long-term studies have stimulated many affiliated projects, thus creating numerous opportunities for integration of multidisciplinary perspectives.

HISTORICAL CONTEXT. Over its 28-year history, the Andrews LTER program has remained a major center for analysis and knowledge of forest and stream ecosystems in the Pacific Northwest. Today, several dozen university and federal scientists use this LTER site as a common meeting ground, working together to gain basic understanding of ecosystems and to apply this knowledge in management and policy. The Andrews Forest program has its roots in the establishment of the H. J. Andrews Experimental Forest (hereafter referred to as the Andrews Forest) by the US Forest Service in 1948 (Figure 1.1). This began two decades of predominantly Forest Service research in the 1950s and 1960s on the management of watersheds, soils, and vegetation. With the inception of the International Biological Programme-Coniferous Forest Biome (IBP) in 1969, university scientists began to play increasingly important roles in the Andrews program. Focus shifted from single disciplines to interdisciplinary research on forest and stream ecosystems, especially old-growth forests. IBP ended in the late 1970s and LTER commenced in 1980. The first decade of LTER work solidified a foundation of long-term field experiments as well as long-term measurement programs focused on climate, stream flow, water quality, vegetation succession, and biogeochemical cycling (See the Supplementary Documentation for a complete list of online databases).

Our Central Question, "*How do land use, natural disturbances, and climate change affect three key ecosystem properties: carbon and nutrient dynamics, biodiversity, and hydrology?"* (Figure 1.2), was developed in LTER3 (our third funding cycle). At the time we knew that addressing this question would require decades of supporting measurements, experimentation, and conceptual advances as well as integration and synthesis across disciplinary boundaries. Integrated concepts that we have investigated include: a process-based understanding of landscape dynamics; effects of early succession on ecosystem dynamics; impact of species attributes on ecosystem dynamics; small watershed behavior; and temporal behaviors. Work under the integrated themes has improved our understanding of the system's behavior. Highlights of research findings during LTER 5 are presented below.

CLIMATE. During LTER5 we documented that microclimatic patterns and processes in mountainous terrain is far more complex than typically envisioned (Greenland et al. 2003) (Figure 1.3, 1.4, 1.5). Our long-term climate measurements have indicated that cold air accumulation in valleys leads to thermal inversions at certain times during the year (Smith 2002) (Figure 1.3); Daly et al. (2007) modeled this process. Katabatic (downhill) and anabatic (uphill) winds, well known in mountainous areas, are associated with patterns of inversions at night and well-mixed conditions during the day. However, this daily pattern is nested within an irregular, multi-day cycle that alternates between inverted and well-mixed conditions extending to the ridgelines, causing the coupling between microclimates, especially in valleys, and synoptic weather patterns to fluctuate substantially over the course of a year. Because of this the normal temperature lapse rate, which is widely used to estimate temperature differences over elevation gradients, is a poor predictor of temperature differences across our site. The difference in daily minimum temperature between two climate stations with an 830m difference in elevation fluctuated by more than 15˚C over the measurement period, and in contrast to predictions from the normal lapse rate (-6.5˚C km^{-1}), the minimum temperature was frequently cooler at the low elevation site than at the high elevation (Figure 1.4). These irregular, multi-day patterns appear to be controlled by the curvature of regional air flow patterns. Temperature lapse rates were most inverted during anti-cyclonic (ridging) patterns with low flow strength, and exhibited the most well mixed (approaching the normal lapse rate) condition during cyclonic (troughing) patterns with high flow strength (Daly unpublished). Precipitation patterns across the Andrews Forest result from strong interactions between topography and wind directions (Figure 1.5). These findings suggest: 1) temporal variations in climate do not always occur synchronously across the mountain landscape, and 2) the degree of climatic asynchrony can be large over small distances and vary strongly with weather regime, season, time of day, topographic position, and other factors. This has great implications for long-term ecosystem monitoring and analysis in LTER6. However, we are gaining a solid understanding of the underlying forcing factors that lead to this spatial and temporal variability.

HYDROLOGY. Long-term paired watershed experiments and many short-term studies improved our mechanistic understanding of interception, transpiration, and water flow paths on hillslopes, channels and in the hyporheic zones. Young forests produce higher winter streamflows but lower summer flows than old forests (e.g., Jones and Post 2004); this work contributed significantly to a forthcoming NAS report (NRC 2008). The presence of snow interacts with slope gradient to control storm peak flow magnitude and synchrony (Perkins and Jones in press). Transpiration rates were not correlated with slope position for trees of the same species, although deciduous trees in moist valleys had significantly higher transpiration than conifers (Moore et al. 2004). Contrary to expectations, seasonal water use was greater for trees on a south-facing than on the opposite north-facing slope, and midsummer water stress was greater for trees on the north-facing slope (Barnard unpublished). Precipitation and $\delta^{18}O$ of precipitation were both higher and more variable at high compared to low elevation. Within gaged watersheds, the mean residence time of water ranged from 0.8 to 3.3 yrs, with longer residence times at gently sloped upper elevations (McGuire et al. 2005). At the hillslope scale, mean residence times of storm water were 10-25 days for shallow and deep soil, respectively (McGuire 2004); much greater than the timescale of storm events. A watering experiment of a hillslope during summer drought showed rapid uptake of labeled water by trees (Barnard et al. unpublished), but surprisingly, the water addition did not increase overall transpiration and the added water fluxed to the stream (Graham unpublished, van Verseveld 2007). Ongoing studies indicate that water in trees, soils, and streams have distinct isotopic composition, indicating that separate pools of water traverse these various flowpaths (Brooks unpublished). In channels, heterogeneity in substrate type and the influence of wood influenced hydraulic residence times (Anderson et al. 2005, Gooseff et al. 2003, 2005, 2006) and flow paths (Kasahara and Wondzell 2003, Wondzell et al. 2007). Flow through the hyporheic zones followed a power law distribution (Haggerty et al. 2002); long storage times in hyporheic zones moderate stream temperature (Johnson 2004).

DISTURBANCE AND LAND USE. Disturbance processes initiating succession in our system include fires, floods, earth movement, windstorms, insect outbreaks, and landuse, including forest management and roads. Synthesis of results from past LTER5 indicated that disturbances and land use legacies persist at site and landscape scales influencing ecosystems over the long-term (Turner et al. 2003, Foster et al. 2003, Swanson et al. 2003). Fire history reconstruction studies indicated climate variability controlled long-term patterns in fire occurrence (Weisberg and Swanson 2003, Greenland et al. 2003). The age structure of shade-intolerant and shade-tolerant tree species in the western Cascades indicated distinct fire regimes and successional pathways occurred as a function of landform cold air drainage patterns (Giglia 2004, Tepley unpublished), suggesting that disturbance patterns are influenced by the topographically-driven complexity of the climate pattern. Dendrochronological analyses revealed relationships between fire and insect outbreaks at the Andrews LTER, and suggest relationships between climate variability and insect disturbance (Figure 1.6). Legacies of land use (clearcuts and roads) facilitated exotic plant invasion along roads. During extreme storm events, landslides carried propagules of exotic plants into streams and facilitated plant invasions from roads throughout the riparian network (Sheehy 2006, Watterson and Jones 2006). Legacies of land use also left a signature of depleted wood in streams, which was exacerbated by wood movement during extreme storm events (Czarnomski et al. in review). Long-term discharge records revealed continued effects of land use change on hydrology. Clearcutting resulted in larger and more persistent water surpluses in the Pacific Northwest compared to other regions (Jones and Post 2004) and continued to produce summer water deficits 30 years after harvest (Perry 2007). During large storms, the presence of a snowpack tended to synchronize peak flows from headwaters, resulting in an increase of flood peaks downstream (Perkins and Jones in press). In collaboration with land manager partners we have continued to implement and monitor the 17,500-ha Blue River Landscape Study, which uses an adaptive management approach to examine the concept of using historical landscape dynamics as a base for managing the future forest landscape (Swanson et al.

2003). Simulation modeling of alternative landscape change scenarios reveals major differences between some contemporary land management systems and the historic wildfire regime in terms of extent of early and late seral habitat and carbon sequestration (Swanson et al. 2003).

VEGETATION DYNAMICS. LTER5 studies of vegetation dynamics enhanced our understanding of a number of biotic processes including parasites on tree growth (Shaw et al. in press), invasion of montane meadows (Haugo and Halpern 2007, Lang and Halpern 2007), and early successional dynamics that were previously poorly known (Yang et al. 2005, Lutz 2005). The high abundance of shade-tolerant conifers in early forest development suggests current models oversimplify young stand development processes (Lutz and Halpern 2006). For the first 40 years of succession after clearcutting, the mean stability of populations of forest herbs was positively related to species richness (Lutz and Halpern 2006). Over 40% of pairwise associations among 33 plant species could be attributed to shared, positive correlations with surrounding vegetation, suggesting that facilitation is of primary importance in this dynamic, early successional environment (Rozzell 2003).

LEPIDOPTERA AND COLEOPTERA. Initial results from sampling for Lepidoptera along topographic and landuse gradients indicated that moth diversity, distributions, and life histories are highly sensitive to interactions among topography, climate and vegetation, and could be possible indicators of climate change. Despite dominance of our system by conifers, 90% of Lepidoptera (moths) species are obligatory angiosperm feeders. Species richness is higher in riparian habitats versus upland habitats and in open canopy versus closed canopy habitats**.** Elevation and seral state of plants are important factors for predicting moth species assemblages. Twenty additional moth species have been recently identified (the total is now 580 species). Although newly observed exotics do not seem to pose a “pest threat”, they do suggest that agents of biological disturbance could establish rapidly. Examination of ground-dwelling beetles indicated communities in old growth stands were relatively stable, while those in early seral stands were changing in a parallel trend to vegetation dynamics (Heyborne et al. 2003, Miller et al. 2003).

CARBON AND NUTRIENT DYNAMICS. Comparisons between the Andrews and Wind River Experimental Forests indicated a similar drop in bole-related NPP in older forests (Janisch unpublished), and that coarse roots decompose more slowly than logs at Wind River (Janisch et al. 2005), the opposite of the pattern at the Andrews Forest. A detailed examination of the carbon budget for an old-growth forest at Wind River (Harmon et al. 2004) allowed reinterpretation of IBP-era work on the Andrews. Estimates of the potential maximum carbon stores in the Pacific Northwest indicated the Pacific Northwest has large potential to store additional carbon if land-use management is altered (Smithwick et al. 2002, Homann et al. 2004, 2005). Analysis of spatial coherence (i.e., the degree of synchrony between sites) indicated interannual variability of bole-related production of individual trees and stands was more temporally variable for faster growing trees and stands than slower growing ones (Woolley et al. 2007, Woolley 2005) (Figure 1.7). The large range in coherence observed (reflected in correlation coefficients from -0.18 to 0.85) has significant implications for modeling and scaling of NPP. Experimental treatments in the DIRT (Detritus Input and Removal Treatments) study indicated root and rhizospheric respiration contributed 23%, aboveground litter decomposition contributed 19%, and belowground litter decomposition contributed 58% to total soil CO_2 efflux, respectively (Sulzman et al. 2005). The experiments also indicated a priming effect when litter inputs were increased, a finding with strong implications for soil C storage under a changing climate. This experiment also provided evidence that root C inputs exert a large control on microbial community composition in forested ecosystems (Brant et al. 2006). In steep terrain, soil respiration rates were significantly greater on south-facing than on north-facing slopes (Kayler unpublished). This may be due in part to differences between slopes in organic matter quality in the topsoil. The temporal pattern of net carbon balance changed from the stand to the landscape scales (Smithwick et al. 2007); this finding has been used in developing a landscape level model based on the frequency, severity, and regularity of disturbances (Ngo 2006). Simulations indicated forests with frequent partial removal of live trees can store as much carbon as those with complete tree harvest on longer rotations (Harmon et al. in review) implying there are multiple ways to increase carbon stores in the forest.

AIRSHED PROCESSES. The chemical constituents of air in nocturnal cold air drainage, especially the isotopic composition of ecosystem-respired CO_2 ($\delta^{13}C_{ER}$), is being used as an indicator of metabolic processes at the whole-watershed scale of WS 1 (Pypker et al. 2007a). Nocturnal cold air drainage within the watershed occurs on most clear nights in spring, summer and fall. Between 2000 h and 2400 h (PST), a pool of cold air forms within the valley that “spills” out of the narrow opening at the base of the watershed. The canopy interacts with the airflow to create two distinct zones of airflow (Pypker et al. 2007b) (Figure 1.8). A deep zone fills the canopy trunk space and mixes with canopy air, and another zone of airflow forms just above the canopy. The air in both zones is turbulent and well-mixed due to physical interactions with trees, but the temperature inversion just above the canopy creates a "lid" that prevents exchange between the canopy airspace and the above-canopy airspace. When the nocturnal cold air drainage is well developed, virtually all of the CO_2 respired throughout the basin is carried with the nocturnal air drainage and exits the watershed advectively, through horizontal downslope flows. Interestingly, eddy covariance towers are typically located in areas with minimal nocturnal air drainage, but advective fluxes still create significant errors in nocturnal flux calculations at most flux sites. Our findings suggest that it may be easier to measure nocturnal fluxes in a deeply-incised basin than on gently-sloping surfaces since virtually all of the net CO_2 flux in the deep valley is advective. Ongoing studies indicate that seasonal variations in canopy physiological processes, including transpiration and carbon assimilation, may be predicted from measurements of $\delta^{13}C_{ER}$ (Pypker et al. in review).

FOREST-STREAM INTERACTIONS. During LTER5, we examined the role of forest-stream linkages in terms of nutrient export at baseflow and during storms, legacies of aquatic invertebrate diversity in previously harvested basins, temporal variation in fish and invertebrate populations, and dynamics of large wood. Experiments measuring aquatic nitrogen uptake and export using ^{15}N nitrate (LINX2; Mulholland et al. in press) showed very little surface or subsurface denitrification in Mack Creek (Sobota 2007). Instream biota have an active role in N uptake. Over a 300-m reach, instream sequestration by biota accounted for 10% of 15-labeled NO_3 and 40% of 15-labeled NH4 (Ashkenas et al. 2004). During storm flows, concentrations of nutrients generally increased, but the quality of dissolved organic carbon (DOC) measured as specific UV absorbance (SUVA) also increased, suggesting that DOC mobilized from soils is more aromatic than instream DOC (Hood et al. 2006). The increase in SUVA was more pronounced in basins that had been previously harvested, highlighting that spectroscopic and chemical characterization of DOC can be used as a tool to better understand changing sources of DOC and water within forested basins. Streams with prior forest harvest (>30yrs previously) did not differ in aquatic macroinvertebrate densities or diversity from old-growth streams (Frady et al. 2007), although emergence was temporally lagged across elevational gradients. Identification of indicator species of macroinvertebrates was not possible due to the high variability among stream communities. Fish size and densities in previously harvested portions of Mack Creek, which were greater in the first decade after harvest in the 1960s, have converged with those in the old growth section in the fourth and fifth post-harvest decades. Fish diets and prey availability are very similar in the old-growth vs. previously clear cut sections despite continued differences in riparian vegetation; diets are primarily (50-70%) on benthic macroinvertebrates. Fluctuations in fish density over time (Figure 1.9) show highest temporally coherence in adjacent reaches than between sections, which are separated by up to 2 km. Higher coherence of density occurs within life stages than between adults and young, yet the abiotic processes likely driving the variation are coherent across the landscape. Our model of dynamics of large wood along stream reaches revealed that land use practices in riparian areas can alter longitudinal patterns of large wood delivery and storage that persist for 50-150 years (Meleason et al. 2003). Public perception of the role of large wood in Oregon was consistent with Germany and Sweden but differed sharply with other countries and regions (Texas, France, Spain, Italy, Poland, Russia, India), illustrating social barriers to development and application of river restoration strategies (Piégay et al. 2005).

SYNTHESIS AREA: SMALL WATERSHED BEHAVIOR. Understanding the processes influencing the behavior of small watersheds has recently been a major synthesis activity for LTER. In LTER5 we developed a synthetic framework for knowledge from past experiments and process studies to gain insights into controls on storage, transformation and losses of N on the small watershed scale, drawing on expert knowledge of 12 co-PIs and dozens of publications. This framework was translated into a simulation model in STELLA to quantify and better display relationships among watershed N cycling and climate variability, disturbance, and anthropogenic deposition, and to help plan the next steps in long-term watershed research. The model accounts for observed seasonal and interannual dynamics of N fluxes from small watersheds and suggests seasonal and interannual variability in climate dominate the dissolved N export signal in this watershed (Figure 1.10). Changes in seasonal climate dynamics are likely future drivers of changes in small watershed biogeochemistry in this ecosystem. Key findings from small watershed synthesis in LTER5 are: 1) fluxes of dissolved N from these watersheds exhibit negligible responses to major disturbances (100% logging of old-growth forest, major floods and debris flows); and

2) this lack of change is explained mechanistically in the model by efficient utilization of N along gravitational flowpaths of water in this topographically complex landscape, whereby various parts of the small watershed ecosystem (vegetation canopy, understory, surface soils, subsoils, riparian zone, hyporheic zone) exercise diverse and mutually compensating roles in N processing (Jones unpublished).

SYNTHESIS AREA: TEMPORAL BEHAVIORS. To complement our understanding of spatial scaling, we began an analysis of temporal behaviors in LTER5. Although a range of temporal behaviors (hysteresis and path dependence) was examined, the focus was on spatial coherence. Our initial analysis of climate, hydrology, stream chemistry, tree growth, and fish populations showed that our original hypothesis – that abiotic variables have greater spatial coherence than chemical or biotic variables – needed to be modified to include the time resolution of the measurements (Harmon et al. 2005). We now hypothesize that for abiotic variables, the spatial coherence or correlation among sites increases as the time step increases. The reverse is true for biotic variables, where longer time steps may have a lower spatial coherence than short. We have concluded that many processes in mountain systems are not as spatially coherent as often assumed. Our 20-year vegetation phenology dataset shows, for example, that bud break lacks spatial coherence across the Andrews Forest landscape (Figure 1.11). We speculate that the lack of spatial coherence arose in part from differences in microclimates among sites caused by topographic complexity. Lack of spatial coherence in different tree species is evident in dendrochronological records (Figure 1.6) and across sites for the same species for fish density (Figure 1.9) and tree growth (Figure 1.7). These temporal behaviors have major implications for how ecological change is measured in a mountainous landscape as well as how we approach relationships between responses and drivers in our Central Question.

GENERAL SYNTHESIS AND INTERSITE ACTIVITIES. Our site has engaged in numerous syntheses and intersite activities during LTER5. These include leadership of the major intersite studies: LIDET (Long-term Intersite Decomposition Experiment Team), (Parton et al. 2007); Intersite Hydrology (Jones and Post 2004, Jones 2005); DIRT (Detrital Input Removal and Treatment) (Lajtha et al. 2005); LINX-2 (Lotic Intersite Nitrogen eXperiment) (Mulholland et al. in press); and collaborative studies in China, Hungary, Japan, Mexico, Russia, Sweden, and Taiwan. We have contributed to intersite synthesis on NPP methods (Kloppel et al. 2007, Harmon et al. 2007), conventions on carbon fluxes (Chapin et al. 2006), wood in world rivers (Gregory et al. 2003), ecological impacts of roads (Forman et al. 2003), land use legacies (Foster et al. 2003), ecological variability (Kratz et al. 2003), and disturbances (Turner et al. 2003). Information managers for our site have been the lead developers of ClimDB/HydroDB, a cross-site climate and hydrology database and data harvester that includes all LTER sites, many USFS Experimental Forest and Range (EFR) sites, and international sites (Henshaw et al. 2006). Andrews LTER researchers organized an international synthesis of wood dynamics and management in river networks (Gregory et al. 2003) that initiated an on-going international series (Scotland 2006, Florida 2009). A long-term goal for the Andrews has been the completion of our synthesis book for the LTER book series, and we have made significant progress. The book will focus on lessons from research at the Andrews Forest, told in part as the development of ideas as they have been shaped by growth of science knowledge, change in societal perspectives, and gradual and abrupt change of the forest itself. These ideas include themes such as the character and ecological importance of old-growth forests, roles of dead wood in forests and streams, the capacity of these forests to conserve nitrogen through severe disturbance, the great capacity of these forests for storing carbon, regulation of streamflow by forests, downstream variation in aquatic ecosystems, and use of understanding of historic disturbance regimes to guide future forest landscape management. A contract has been signed with Oxford Press, and 12 of the 14 chapters are being revised by co-authors. To see the outline and chapters go to: http://www.fsl.orst.edu/lter/webmast/hjabook/hjabook.cfm?next=main.

SUMMARY. During LTER5 we made significant progress in understanding how our system's climate is influenced by topography and how this introduces asynchrony across our forested landscape, phenomena we have observed in our Temporal Behaviors Synthesis Area. Our LTER5 studies have improved our understanding of key ecosystem processes and lead to improvements in many of the models we use to understand how our system responds to key drivers of change. This progress during LTER5 sets the stage for new analyses of our long-term measurements programs and to new activities that will move us closer to more fully addressing our Central Question.

2.0. PROPOSED ACTIVITIES

We face challenges but have many opportunities as we plan the sixth research cycle for the Andrews LTER Program (LTER6). Challenges include maintaining continuity of long-term measurement programs – which become ever more valuable with time – while steering our program to answer critical questions that are relevant today to our region, the LTER Network and the broader society. The opportunities include using our legacy of research, collaborative teams, and strong partnerships (Figure 2.1) to advance our understanding of potential effects of climate change on our ecosystems and to expand our knowledge of our system as a coupled natural/human system. In the pages that follow, we outline a plan for integrated research and outreach that uses scientific understanding from our long-term studies (Table 1.1, Figure 2.1 and Supplementary documentation, Databases), and partnerships to increase our understanding of ecosystems and ecological processes at the Andrews Forest. We will consider possible scenarios for future change – especially climate change – and evaluate potential impacts of these changes on ecosystem processes and services. In so doing, we will provide comprehensive answers to the Central Question (Figure 2.3) that has guided Andrews LTER research for the past three funding cycles: *How do land use, natural disturbances, and climate affect three key ecosystem properties: carbon and nutrient dynamics, biodiversity, and hydrology?*

Evidence is building that ecosystems throughout the world are responding to a changing global climate (IPCC 2007). Permafrost is warming in the Arctic, eliciting large-scale ecological changes (Hinzman et al. 2005); spring phenological events are occurring significantly earlier in the upper midwestern United States (Bradley et al. 1999); earlier snowmelt (Mote et al. 2005) and increased wildfires (Westerling et al. 2006) in the western United States have been linked to climate change; and bird species are arriving earlier in North America (Hitch and Leberg 2007). Long-term studies at the Andrews Forest, however, show little evidence so far of responses to climate change (see Prior Results). Perhaps climate changes have been too small or variable to elicit a detectable response, or the responses are lagged and will occur in the future, or responses to other **drivers** obscure responses to climate change, or ecosystem states and functions are somehow **buffered** from climate change (terms shown in bold on their first use are defined in Table 2.1). It is important to differentiate among these possibilities and understand the underlying mechanisms because the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (IPCC 2007) projects increases in temperature for our region. Will our system suddenly show a large response at some critical point? How will our system respond to interactive effects of climate and change in other drivers, i.e. change in land use and land cover and disturbances from fire or pests? Should forest management practices be altered now to accommodate potential climate change, and if so, how? Will climate change affect ecosystem services, including the quality and quantity of water available to the rapidly growing population for our region? While we will not be able to answer these questions fully, they will guide our research.

In LTER6 we will continue to collect data from our long-term climate, hydrological, and vegetation measurement programs and analyze these data to search for evidence of climate change effects. We will make a special effort, in addition, to understand how regional-scale changes in climate might down-scale to our site. We believe that we cannot undertake this down-scaling effort without understanding how mountainous topography affects local climate and ecological processes (Figure 2.4, 2.5). Mountains define our landscape (Figure 2.2), and they are central to our conceptual development for LTER6 (Figure 1.2). The ecology of mountains has been a focus of scientific research for over 200 years, since von Humboldt (1807) documented change in vegetation and climate with altitude in the Andes. Widely cited research in Oregon documented of the influence of elevational and climatic gradients and disturbance on terrestrial plant communities (Whittaker 1960), and previous work has documented how topography influences vegetation patterns, disturbance history, and hydrology. However, despite a long history of mountain ecology globally and in our region we still have much to learn, especially about how topography affects flows of energy and material and mediates the interaction of regional climate and local ecosystems. In LTER5 we found that that **complex terrain** influences climate and ecological processes in unexpected ways. Consequently, to understand how climate change affects our site we must develop a better understanding of how mountainous terrain affects ecosystem processes and patterns.

In LTER6 we will pursue closer integration of ecological and social sciences, place greater emphasis on integrating education and outreach with research, and create enhanced cyberinfrastructure. These directions are consistent with the concepts of the LTER Network's Decadal Plan: Integrated Science for

Society and Education (ISSE; http://www.lternet.edu/decadalplan). To address research challenges outlined in the Millenium Ecosystem Assessment (Carpenter et al. 2006), we will expand our Central Question to include the human dimension and the concept of our system as a coupled natural and human system that is subject to adaptive behavior (Pickett et al. 2005, Liu et al. 2007). Our program has always maintained close ties between research and management; in LTER6 we will strengthen these ties, and we will also develop new connections with social sciences. To enhance our education and outreach programs, our proposed Schoolyard LTER program will directly involve teachers and students in studies of phenology and trophic interactions, bringing the classroom to the field, and the field to the classroom. An additional new direction is to enhance significantly our cyberinfrastructure, developing a concept of Andrews as a Cyber-Forest. We are enthusiastic about maintaining our site's strong research legacy, and excited about our new directions.

2.1. Goals and objectives for LTER6

Our conceptual organization highlights three complementary goals (Figure 2.3). The complex terrain and dense canopy cover of our site profoundly influence biodiversity, ecosystem processes and services, and their likely responses to climate variability and change. Therefore, in Goal I we aim to develop a deeper understanding of the Central Question in the context of complex terrain (Figure 2.3.A). For Goal II, we will apply this mechanistic understanding to evaluate potential future responses to change scenarios (Figure 2.3.B), and in Goal III we will expand our inquiry to consider the Andrews Forest as a coupled natural/human-based system (Figure 2.3.C). Our research and outreach will provide information to better inform decision-making in society about natural resources locally and regionally. As part of the nationwide observatory network of LTER sites, our site will make important contributions to understanding and predicting responses of our nation's ecosystems to climate change.

Goal I: Understand the influence of complex terrain on ecosystem structure and function (Figure 2.3.A).

Objectives:

1. Understand and model the influence of regional, meso- and micro-scale processes on microclimate in complex terrain.
2. Understand influences of complex terrain on the sensitivity of carbon, nitrogen and water cycle processes to environmental drivers at different scales.
3. Understand influences of complex terrain and microclimatic heterogeneity on phenology and trophic interactions.

Our steep mountains create steep climatic gradients. On the regional scale, storm fronts encounter two major mountain ranges as they travel from the ocean to the high plateau east of the Andrews Forest, first the Coast Range on the western margin of Oregon and then Cascade Mountains about 40 km to the east (Figure 2.2). Due the resulting "rain shadows", precipitation decreases by more than an order of magnitude (>2500 to <200) over this 250 km distance. Topographic variations generate climatic variability on smaller spatial scales as well; variations in moisture, temperature and insolation give rise to patchy patterns of vegetation and, over long time periods, soil development. The spatial variability in precipitation, temperature, soils, and vegetation in the Pacific Northwest is among the highest in the United States (Hargrove et al. 2003). With 1200 m of relief over 6400 ha, the Andrews Forest also encompasses steep climatic gradients and considerable fine-scale spatial heterogeneity in microclimate. Steep mountains also generate flow patterns of air and water. In LTER5 we learned that **cold air drainage** systems can periodically **decouple** microclimates in valleys where the airflows occur from the troposphere and also that cold air drainage systems are strongly influenced by canopy structure (see Prior Results, Climate). Consequently, the coupling between microclimate and macroclimate is different in valleys than on ridges. The structure of the canopy also influences microclimates in important ways, including interception and reflectance of solar energy, interception of rain and snow, and transpiration, and in tall forests the environmental variability in the vertical dimension can be as great or greater as in the horizontal dimension (Ozanne et al. 2003, Nadkarni et al. 2004). Clearly, the macro-, meso- and microscale processes that influence microclimate are highly complex, but our previous research suggests that they may be predictable, giving us a much better ability to project the local consequences of regional climate change under different scenarios.

How do these complex topographic and climatic interactions affect ecosystem processes? In LTER6 we will focus on two consequences of complex terrain and its interactions with forest cover that are particularly relevant to ecosystem structure and function: spatial and temporal heterogeneity in microclimate and multiple, gravity-driven flow paths. Much attention has been paid by other investigators to climatic gradients in mountain ecosystems and to potential impacts of warming of alpine ecosystems. However, the ecological importance of fine-scale spatial heterogeneity in mountain ecosystems is generally not as well recognized (but see Haslett 1997, Zobel et al. 1976). Fine-scale spatial heterogeneity in microclimate leads to spatial variability in the rates and environmental regulation of processes affecting carbon, nutrient and water cycles. Multiple gravity-driven flowpaths of air and water transport organisms, material and energy, creating connections across this patchy landscape. From such complex interactions of structure and function, ecosystems may become self-organized (Perry 1995), and emergent properties may arise at certain ranges of scale (Gunderson 2000). In our small watershed synthesis in LTER5, the low sensitivity of N export to disturbance was explained by such properties. In LTER6 we will examine more closely how heterogeneity and multiple flowpaths affect scaling of C, N and water cycle processes, testing the hypothesis that environmental sensitivity of C, N and water cycle processes is lower at the basin scale than at the average plot scale. The phenologies and tropic interactions of organisms are also impacted by microclimatic heterogeneity in mountain ecosystems. In LTER5 we found that budbreak showed a lack of spatial coherence across the Andrews Forest landscape, and we speculated this might be due to microclimate variability (see Prior Results, Temporal Behaviors). In LTER6 we will explore in greater depth the relationships between microclimate heterogeneity and phenology, testing the hypothesis that phenological phases are protracted at the landscape scale compared with the plot scale, and that this reduces the likelihood that trophic interactions might become asynchronous.

Goal II: Evaluate potential consequences of change scenarios for climate, land use and disturbance for ecosystem states, processes and services (Figure 2.3.B).

Objectives:

1. Compare the relative sensitivity of biota and ecosystem processes in high elevation vs. low elevation environments to climate variability and climate change.
2. Characterize the interactive roles of disturbance, land use and climate on ecosystem responders. Test hypothesis that climate-induced changes in disturbance (fire, pests) will have greater impact on future ecosystem structure and function than will the direct effects of climate change (e.g., responses to changes in temperature, moisture, snowpack).
3. Evaluate likely responses of trophic interactions to scenarios of change for climate, disturbance and land use.
4. Project how ecological states, processes and services might change under alternative scenarios of future climate, disturbance and land use, and consider influences of complex terrain.

In LTER6 we will consider possible scenarios for future change in all three of the drivers in our Central Question, and we will evaluate potential impacts of these changes on ecosystem processes and services. Decades of long-term measurements and observations, in combination with the mechanistic understanding we've gained about our system over this time, provide an ideal basis for making future projections. We can be certain that climate, land use and disturbances will change in the future, but we cannot know with certainty what these changes will be. We have established a set of likely future scenarios for each of the drivers (Table 2.2) based on the best information available. Our objective is to use the scenarios as a template for analysis and synthesis rather than to accurately predict the future.

Although 20- to 50-yr records of snowpack and winter temperatures at the Andrews Forest are closely tied to the El Niño/Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO) ($r>0.70$), they show little evidence of climate warming since 1950 (Jones unpublished). However, the 21st century is projected to have much faster rates of warming compared to the 20th century (IPCC 2007). The Climate Impacts Group at the University of Washington (Salathé et al. in press, Mote et al. 2005) projects warming at the rate of 0.3˚C per decade through 2050, a three-fold increase over observed warming for the region during the 20th century. Most models predict larger temperature increases in summer than in winter. Change in atmospheric airflow patterns are also expected to alter summer temperatures. The Andrews Forest currently sits on the boundary between marine and continental influence in summer; if northerly migration of the subtropical high-pressure zone were to reduce the intrusion of marine air to our site, we could experience greater warming than the regional average. In any event, the Andrews Forest will likely experience an increase in summer heat events, corresponding to an increased frequency of inland temperature regimes, and greater overall variability. In winter, projections call for a possible decrease in winter temperature variability and an increase in the frequency dry days. This would enhance cold air drainage, keeping low-lying areas relatively cold. However, in areas that currently receive significant snow we may see fewer days with snow cover. Projections suggest a small increase in annual precipitation. This, in combination with northward migration of subtropical highs and mean polar jet stream, suggests that storms might impact the Andrews Forest less frequently, but with greater mean strength. With these regional projections in mind, we developed three future climate scenarios for LTER6 (Figure 2.2), based on “current climate”, “moderate change” and “rapid change”. All of these scenarios reflect potential change in regional rather than local climate. As discussed above, the impacts of regional climate change are difficult to interpret locally, especially in complex terrain.

For land use scenarios, we will explore a range of forest management strategies. Presently, forest harvest on federal lands is limited by environmental restrictions to primarily thinning and reducing wildfire risk. On privately held forests in the Pacific Northwest, clearcutting with very short rotations is standard. Alternative strategies that similate disturbance regimes have been applied in adaptively managed national forest land (Cissel et al. 1999). With population growth and potential climate change, demands for water will likely further increase (NRC 2008); we will investigate a future scenario where national forests might be managed primarily for water yield.

In developing future scenarios for disturbance, we restricted ourselves to changes that are likely to be associated with changing climate. For example, with a warming climate, the western United States can expect more severe, extensive wildfires (Westerling et al. 2006), but we will explore how climate warming might affect mixed-severity fire regimes characteristic of the Andrews Forest, building on recent fire reconstructions for our site and the region (Weisberg and Swanson 2003, Weisberg 2004). We also will explore how climate warming might affect insects and pathogens.

Goal III: Intensify integration among the Andrews LTER science program, the social sciences, and society to encompass the coupled, adaptive natural/human system of our region (Figure 2.3.C).

Objectives:

1. Define and evaluate vulnerabilities and capacities of local communities and institutions for adaptation to change imposed by environmental (e.g., climate change) and social (e.g., shifting land use patterns and regulations) forces.
2. Characterize, display and discuss alternative futures of the forest for local communities, institutions, including land managers and agencies, and the public at large to enable these groups to make more informed choices about adapting to environmental and social change.
3. Translate and communicate our knowledge of ecosystems and watersheds in the terms of ecological services, including commodities, to facilitate the adaptive processes of coupled natural/human systems.

In the past two decades, the Pacific Northwest has experienced great conflict about the relationship of humans with forests, especially concerning issues related to conservation of species and old growth forests, water, and wildfire. Although some of these conflicts have calmed, many still remain. The natural/human system is now further complicated by climate and social change. For example, human population is projected to double in 50 years and immigrant “climate-change refugees” from water-deficient areas may accelerate this growth. Changing economics and land use regulations are reshaping landowner patterns, motivations, and capabilities for change. The Andrews Forest LTER program has played many important roles in informing the national public debate on these issues and has become a globally significant example of a science-based, adaptive feedback loop within coupled natural/human systems. In LTER6, responding to research challenges emerging from the ISSE and the Millennium Ecosystem Assessment (Carpenter et al. 2006), we will expand our LTER Central Question to consider ecological services and human behaviors in response to climate change and other drivers of change (Figure 2.3.C). By characterizing responder variables in terms of ecological services, we expect to better inform public decisions about uses of natural resources in the near-term and long-term. Using social science studies, depiction and public discussion of alternative future scenarios, and assessment of ecological services, we will study and participate in the adaptive loop that links natural and human systems. This work on the human dimension of Andrews LTER involves elements of regionalization (the wildland-rural-urban gradient extends well beyond the boundaries of the Andrews Forest) and sets the stage for cross-site studies of the natural/human system under ISSE and other auspices. Note that this work will be funded largely from sources outside the programmed LTER6 budget, but we want to establish the conceptual framework for the integration of social and natural sciences in LTER6 to enhance future opportunities for linkages.

2.2. Overall approach

We will employ a variety of approaches to accomplish our LTER6 goals and objectives, combining continued measurements and analyses of our long-term experiments with the collection of some key new measurements and the construction and application of models in a context that fosters multidisciplinary collaboration. In Section 2.3 we briefly describe ongoing long-term measurements for each of the three drivers and three responders of the Central Question, and explain how we will use these data to address our objectives in Goals I and II. New, interdisciplinary approaches, that build on multiple long-term datasets and require new measurements, will address additional objectives under Goals I and II. These efforts, including details about new measurements, are described in Section 2.4. Because the objectives for Goal III involve efforts that extend beyond our site boundaries and beyond our proposed LTER 6 budget, they are described in the section on regionalization and cross-site collaborations (Section 2.5).

In developing goals and objectives for LTER6, we recognize a need for a quantum leap in our cyber-capacity and other infrastructure improvements. Study of the influences of complex terrain on ecological processes, for example, requires monitoring environmental conditions and ecological responses at a much higher spatial intensity and temporal frequency than we have employed in the past. We envision the Andrews Forest in the future as a Cyber-Forest, employing state-of-the art technology in sensor networks, new sensor design, and advanced approaches to data management and data analysis (Figure 4.1). We are already making significant strides in this direction. Several researchers associated with the Andrews Forest are developing new technologies for sensors and sensor networks (Ayers in press, Khanna et al. 2006, Larios et al. 2007, Le et al. 2006, Selker et al. 2006a,b, Westhoff et al. 2007) and automating quality control for continuous sensor data (Dereszynski and Dietterich 2007). The Andrews Forest is a testing ground for these new developments. Using existing technology, we are currently deploying small wireless sensor arrays and exploring new sensor capabilities, such as fiber optics cables that measure temperature over long distances at high spatial and temporal density, and we have developed the capacity to transmit data automatically from the field to our laboratories. We will extend line power to one of our small watersheds (WS 1) to facilitate more advanced sensor network development. We have designated locations to serve as "test beds" for testing and developing new Cyber-technology (see Section 2.4.3). Over the course of LTER6 we aim to install WiFi capability through some of our most intensively-used field sites, which will advance our communications capabilities for research, education and outreach. In addition, we have contracted for LiDAR imagery of the entire site to be collected in the spring of 2008. The data will be available before the beginning of LTER6, providing highly accurate digital elevation information at 1m resolution. The LiDAR dataset will be processed for additional information as part of the LTER6 research (e.g., the "Digital Forest" in Section 2.3.2, Biodiversity). Moreover, through a graduate Ecosystem Informatics IGERT program (http://ecoinformatics.oregonstate.edu) and Ecosystem Informatics Summer Institute (http://eco-informatics.engr.oregonstate.edu) (Section 5) we are developing the human capacity for our Cyber-Forest.

2.3. Continuing long-term experiments, sampling and monitoring in the Andrews LTER

2.3.1. Approach to long-term studies

Long-term studies at the Andrews LTER are designed to understand the dynamics of ecosystems at temporal scales that exceed the length of most scientific studies. Long-term studies are essential to understand ecosystem dynamics of the forest and stream ecosystems of the Pacific Northwest, individuals of dominant species exceed 500 years in age and major disturbance events recur at 100 to 200-year intervals. Data from our long-term studies are available online to broadly encourage scientists to capitalize on this research (see Supplementary documentation, Databases). With continued collection over time, many long-term data are used to address additional questions that were not even envisioned at the beginning of the study. The histories of science discovery and management/policy impact of the LTER and predecessor programs at Andrews Forest have significantly altered management strategies. Long-term studies begun in the early 1970s of ecological functions of dead wood on land and in streams, for example, rippled through the science community and into land management and policy over succeeding decades. Continued investments in these long-term studies are likely to pay dividends for our LTER science in both predictable and surprising ways long into the future.

All LTER sites face the challenges of maintaining key long-term experiments, sampling, and monitoring, while being open to taking on new studies that arise from these findings or reflect developments in science. At the Andrews Forest, we estimate that 75% of our LTER budget is required to maintain long-term measurements. Thankfully, our USFS partners contribute significantly to the long-term measurement programs, but we need to work actively to maintain a balance between long-term studies and new pursuits as costs inevitably increase. We have informal guidelines to assist us in making difficult decisions about how to design and maintain our long-term studies. We 1) consolidate measurements of multiple properties together at key places, such as the integration of measurements of carbon, hydrology, nutrients, vegetation in small watersheds and reference stands; 2) expand, refine, or collapse measurement networks over time, using shorter term studies to fill in gaps in the spatial distribution of climate and hydrologic data; 3) extend the interval between sampling for some long-term experiments, such as the 200-yr decomposition study, or streamline sampling frequency to link to episodic events, such as resurvey of stream channel cross sections after large floods; 4) build on successful prior small scale projects, such as the airshed study becoming more prominent; and 5) foster the development and adaptation of new technologies (the Cyber-Forest or automated identification of arthropods) and approaches (eco-informatics techniques for identifying data outliers automatically) (Dereszynski and Dietterich 2007).

2.3.2. Continuing long-term studies, and their application to LTER6 goals and objectives

Climate. Climate measurements began in the 1950s and continue to the present at six sites (Table 1.1, Figure 2.2). High temporal resolution measurements include temperature, precipitation, snow, streamflow, relative humidity, and wind speed and direction; real time meteorological data are available on the web (http://www.fsl.orst.edu/lter/about/weather.cfm?topnav=16). Climate stations are distributed over an elevation gradient spanning rain and snow conditions (Figures 2.2, 2.6).

As detailed below, we will use our long-term climate measurements in LTER6 to understand and model the influence of complex terrain and canopy cover on microclimate at fine spatial and temporal scales (Goal 1, objective 1) and to develop projections for future climate conditions at the local level given potential scenarios for our region (Figure 2.5, and Section 2.4.5). Continued long-term climate measurements are integral to many other objectives for Goals I and II (see Section 2.4) as well as Goal III. Climate change may alter snowpack and water resources (Franklin et al. 1992), a key ecosystem service, while human behaviors that modify forest canopy may exert "feedbacks" from the human to the ecological domain (see Section 2.5).

Fundamental to our conceptual framework for LTER6 is the recognition that complex terrain exerts strong controls over the local expression of regional climate (Figure 2.5). Guided by findings from LTER5 (see Prior Results), in LTER6 we will explore climate-topography interactions across three spatial scales: the regional scale (Pacific Northwest), mesoscale (watershed) and microscale (sub-canopy) (Figure 2.4). At regional scales, the mountains of the Cascade Range and their coastal proximity affect how global changes in temperature and precipitation are expressed at the landscape scale. At the mesoscale, the anabatic and katabatic winds generated by cooling and warming of mountain slopes mediate the relationship between regional-scale and local-scale climates, but these local airflow patterns are in turn influenced by regional airflow patterns (Figures 1.3, 1.4, 1.5 and Prior Results, Climate). Variations in slope, aspect and elevation exert strong influence on temperature and precipitation at both the mesoscale and the microscale (Figure 2.4, Figure 2.5). At microscales, variations in forest structure due to topographic characteristics (affecting moisture and temperature as well as soil depth and hydrologic flow paths), disturbance, and land use affect microclimates that influence both physical (e.g., snow dynamics) and biological (e.g., understory species diversity) processes. Much work from our site has already shown how the forest canopy affects microscale processes such as temperature and interception of precipitation, as well as the influence of snow on watershed hydrology at small and large scales (See Prior Results, Hydrology).

To better understand topography-climate-canopy interactions at the microscale, we will combine climate data with modeling to understand surface energy balance and vegetation-snow dynamics (Goal I, objectives 1 and 2). To distinguish between vegetation regrowth and climate change, both of which may reduce snow cover, we will use both empirical and physically based modeling approaches. Building on prior work comparing snow accumulation and melt at forested and open sites (Marks et al. 1998), we will examine how vegetation influences microclimate and snow dynamics during storm and melt events. We will apply a physically based snow model (SnowModel; Liston and Elder 2006) to simulate snow accumulation and ablation at a forested site compared with a nearby meadow using a grid scale of 1-m (the grain of the LiDAR-derived DEM). The model will be calibrated using measurements of snow water equivalent (SWE) from 1987 to 2007, which include both higher and lower than average snowpacks. Once calibrated, we will "remove" and "grow" the vegetation in the model and quantify the change in accumulation/ablation dynamics over the measurement period due to changes in vegetation. In addition, we will use SnowModel to project the impact of future climate scenarios (Table 2.2), on snow cover by keeping the vegetation component static and modifying the meteorological inputs. (Nolin will lead this work.)

At the meso-scale, we will combine long-term climate records at low, intermediate and high elevations with spatial mapping of climate to test the hypothesis that high elevation ecosystems are more coupled to regional climate than low elevation ecosystems, which are more affected by air drainage processes (Figure 2.4) (Goal I, objectives I and 2). We will use our climate records at low, intermediate and high elevations (Figure 2.2, Figure 2.6) to reconstruct periods of temperature inversions versus normal lapse rates (see Figure 1.4), and anabatic (up-slope) versus katabatic (down-slope) winds, and identify the regional climate conditions and mechanisms that generate these conditions (e.g., Figure 1.3, 1.4, 1.5). Analyses of long-term data will help calibrate PRISM (Parameter-elevation Regressions on Independent Slopes Model; Daly et al. 2001) and improve the resolution of existing climate maps of the Andrews Forest (Figure 1.3) to a 50-m grid. Prior hydrologic modeling (e.g., Duan 1996; Perkins and Jones in press) has shown that snow distribution influences hydrology; gridded data will improve spatial resolution of distributed hydrologic models of snowmelt and runoff. Improved snow modeling efforts will allow us to understand process-level changes along gradients in elevation and to explore possible hydroclimatologic impacts under future climate scenarios (Figure 2.6). Taken as a whole, these observations and modeling activities will allow us to better quantify gradient and multi-scale processes related to climate and to distinguish between variability and trends. The predicted temperature and precipitation data will be compared with data from the Carbon and Water Exchange Study (Section 2.4.3.). We will use the discrepancies between the gridded model and measured data, along with information from the "Digital Forest" analyses (see below), to explore more deeply how canopy structure influences climate. (Daly, Jones, and Spies will lead this work.)

At the regional scale, we will use gridded climate datasets (e.g., PRISM, the National Center for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) Reanalysis Project data) to characterize Pacific Northwest climate. We will expand analyses of regional upper-atmosphere airflow patterns on climate in the Andrews Forest (Figure 1.5) to investigate how regional climate is expressed at the meso- and micro-scale, and in particular how regional cyclonic (troughing) and anti-cyclonic (ridging) circulation patterns are correlated with the occurrence and strength of local cold air drainage events at the Andrews Forest (Prior Results). Cold air drainage is likely to play an important role in mediating the expression of future climate change at the Andrews Forest (see Sections 2.0 and 2.1). To date, however, cold air drainage has not been incorporated into downscaled general circulation model (GCM) projections of future climate. We will examine coupled atmosphere-ocean general circulation model (AOGCM) simulations from the World Climate Research Programme's Coupled Model Intercomparison Project phase 3 multi-model dataset to determine which AOGCMs best reproduce observed Pacific Northwest circulation patterns. We will use these simulations to develop downscaled future climate datasets for the Andrews Forest that incorporate the effects of cold air drainage on temperature at approximately the same scale as the PRISM extrapolations (50m or less). These datasets will be used for modeling potential system responses to future climate change (Section 2.4.5). We anticipate that cold air drainage affects many ecosystem processes. (Daly and Shafer will lead this work.)

Disturbance. Our long-term analyses of disturbance include wildfire, windthrow, insects and disease, floods, and landslides (Table 1.1). Disturbance processes at the Andrews LTER interact with topographically driven snowpacks, airflows, temperature and moisture gradients. Historically, wildfire tended to concentrate old-growth forests in topographically protected NE-facing aspects, valleys, and riparian zones, both in the Oregon Cascades and Coast Range (Morrison and Swanson 1990, Impara 1997, Giglia 2004), whereas landslide and flood impacts have been concentrated on lower slopes and streams (Swanson and Dyrness 1975, Wemple et al. 2001).

In LTER6, long-term measurements of disturbance regimes will serve as a baseline for evaluating changes in wildfire and insect outbreaks, floods and landslides (Goal II, objective 2). We will expand our dendrochronological analyses to reconstruct fire and insect outbreaks at the Andrews LTER over the past 400 to 600 years (Figure 1.6), and contrast disturbance histories by topographic position. We will continue and update geomorphic disturbance inventories (e.g., Swanson and Dyrness 1975, Wemple et al. 2001, Faustini and Jones 2003) to examine the topographic controls on landslides and stream channel changes after major events. Using long-term reference stands and permanent vegetation plots (Figure 2.2), we will reconstruct forest stand history in various portions of the landscape and infer how topographic position has influenced disturbance frequency and severity. In LTER5 studies of forest stand dynamics (Lutz and Halpern 2006) revealed important roles of fine-scale disturbance processes in structuring young stands in two small watersheds; in LTER6, we will expand our studies of young stand structure and development to contrast responses to natural thinning vs. silvicultural thinning treatments. We will continue and expand studies of climate effects on the high-elevation forest-meadow edge, where forest encroachment of meadows appears to be in part driven by changes in drought severity, potentially reducing biological diversity through loss of habitat of meadow species (Haugo and Halpern 2007, Lang and Halpern 2007, Rice 2007). (Swanson and Spies will lead this work.)

Land use. Land use changes, the third driver in the Andrews LTER Central Question, are characterized by forest harvest, planting and road construction, and some historical grazing and pre-historic burning of high-elevation meadows (relevant datasets in Table 1.1). The earliest European land use was grazing of high-elevation meadows at least some of which were maintained by Native American burning. Since 1948, forest harvest and roads have occurred in all topographic positions, providing opportunities in LTER6 to examine ecological and geomorphic responses to land use as a function of topographic position and topographic interactions with climate variability and change. Historical disturbance effects tended to concentrate old growth forest in particular topographic positions. This led to early (1950s) harvest and roads at low elevations where old growth was concentrated, and cutting and roads spread upward over subsequent decades.

In LTER6, we will (1) continue to study the long-term effects of past practices including clearcutting, forest roads, and grazing, and (2) explore new forest management practices, focusing both efforts on climate change and complex terrain (Goal II, objective 2). Legacies of past landuse practices are still unfolding, and we will extract their lessons for scientific understanding of forest management in preparation for climate change and variability. For example, we will expand analyses of the history of natural openings (meadows), including historical effects of grazing, climate change, and fire (Takaoka and Swanson in review, Dailey 2007). We will examine the long-term effects of past clearcutting as they interact with climate change and topography: for example, at high elevation forest regeneration is limited by cold winter temperatures (Nesje 1996), and may be enhanced by winter warming, but at low elevation or south facing slopes, forest regeneration may be limited by summer drought, and may be sensitive to changes in summer precipitation. We will explore how the legacies of past clearcutting, i.e. young forest stands, are interacting with climate variability and disturbance using vegetation plots in 1960s- and 1970s-era clearcuts in our experimental watersheds (e.g., Lutz and Halpern 2006). We will examine two types of proposed new forest management treatments that will have science and management value. The first relate to the Blue River Management Plan (Cissel et al. 1999) which is based on the hypothesis that operating within the historic range of variability will help sustain native species, a management scheme that is very different from either the timber production era or the species-conservation-focus of the Northwest Forest Plan. Second, we anticipate designing and undertaking (in an adaptive management framework) forest manipulations, including thinning of young stands, to evaluate forest and stream ecosystem sensitivity to potential climate changes. (Spies, Johnson and Swanson will lead this work.)

Hydrology. Stream gages in eight headwater basins and two larger basins within the Andrews Forest provide a long-term, distributed perspective of hydrologic responses to land use changes, seasonal dynamics and disturbances. Streamflow measurement sites are nested and arrayed by elevation (Figure 2.6) with records extending back to 1952 (Table 1.1). Soil moisture and snow depth and melt are measured at climate stations (Figure 2.2) and sampling sites near or in instrumented watersheds. In LTER5 we initiated use of V-notch weirs to more accurately measure summer low flows in streams, and sapflow measurements were made during summer months in riparian and upslope trees in two watersheds. These new measurements captured diel cycles of transpiration and their effects on streamflow (Bond et al. 2002) and revealed emerging summer droughts under regenerating young forest (Perry 2007).

In LTER6, we will continue all of the streamflow measurements and evaluate the sensitivity of streamflow to climate variability and climate change as a function of elevation (Goal II, objective 1). Continued analyses of paired-watershed experiments at high, intermediate, and low elevation (e.g., Jones and Post 2004, Jones 2005) will allow us to quantify contrasting effects of forest harvest in treated watersheds versus succession in old-growth and mature forest in reference watersheds, as a function of elevation and climate regime. Long-term monitoring of stream temperature has revealed effects of the forest canopy and hyporheic zone on stream temperature (Johnson and Jones 2000); in LTER6 we will expand and intensify stream temperature monitoring using fiber-optic cables in several small watersheds to identify instream upwelling zones, explore water travel times, and create spatially explicit, fine-scale stream and riparian heat budgets. As part of an integrated study of water and carbon cycles at the small watershed scale (see Section 2.4.3, below), we will expand a network of soil moisture measurements in that basin. (Jones, Bond, and Johnson will lead this work.)

Carbon and nutrient dynamics. Carbon and nutrient dynamics are an important focus for research in LTER6 with long-term measurements in watersheds, permanent vegetation plots, and experiments (Table 1.1). Stream chemical fluxes have been a key research focus for the Andrews Forest since before LTER. Andrews Forest anchors the pristine atmospheric deposition end of the LTER network gradient, and contains some of the longest precipitation and stream water chemistry records on the west coast. Since 1968, proportional sampling and analysis of stream water chemistry at 3-week intervals from 6 small watersheds, with comparable precipitation collection and analyses from two climate stations, has served as the basis for watershed-scale nutrient budget studies (e.g., Martin and Harr 1988, 1989, Vanderbilt et al. 2002) (Figure 1.10). Precipitation and streamflow chemistry have been and will continue to be analyzed by an OSU laboratory that specializes in high quality, trace level analysis of nutrients and ions (http://www.ccal.oregonstate.edu). Measurement of dissolved organic carbon has been added as part of the regular chemistry profile. In LTER5, proportional stream chemistry sampling was expanded to include the two additional small watersheds (WS 1, WS 7) and 5th order Lookout Creek, and we can now analyze nutrient and carbon exports in a nested hierarchical manner from 1st order to 5th order streams. In LTER6, we will be examining the immediate as well as long-term effects of land use activities on export of stream solutes from small paired watersheds harvested as early as the 1960s and thinned as recently as 2001. We hypothesize that forest thinning will have had no effect on stream nutrient fluxes. We will compare timing, form and magnitude of high and low elevation precipitation on deposition chemistry and soil solutions to better understand the influences and differences between snow and rain on terrestrial and aquatic ecosystems (Goal I, objective 2). Experimental nutrient addition and hydrologic tracer studies will continue in LTER6 to further examine the abiotic and biotic influences on nutrient dynamics (Mulholland et al. in press, Haggerty et al. 2002) and as part of the Small Watershed Tracer Study (see Section 2.4.4, below). (Jones, Johnson and Lajtha will lead this work.)

During LTER5, new measurements of plant biomass, species composition, fine and coarse woody detritus, and forest floor mass were added in six small watersheds at the Andrews Forest (Figure 2.2). Nutrient concentrations of live plant parts were also determined to allow calculation of macronutrient stores. We will continue these measurements through LTER6. We anticipate that live components of nutrient and carbon stores will be resampled once in all small watersheds during LTER6. Live vegetation biomass dynamics will also be remeasured during LTER6 on plots outside the small watersheds, with a priority placed on those involved in the phenology and trophic interaction study (Section 2.4.2). We will also resample a subset of plots to document changes in the dead wood pool. Preliminary analysis of live biomass changes since these plots were established indicates live biomass has decreased; these measurements will allow us to assess whether dead wood stores have increased to compensate for live losses. A series of long-term experiments on branch and root decomposition were completed during LTER5. These results and those from ongoing log decomposition experiments will be analyzed during LTER6. An ongoing fine litter decomposition experiment to examine the spatial coherence of 16 sites will be continued at least 2 years into LTER6 or until sufficient data to determine site-to-site correlations have been collected. LTER6 resources will be used to help maintain the DIRT experiments, which are primarily funded from other sources. (Harmon, O'Connell, and Lajtha will lead this work.)

Two analysis efforts specific to decomposition and changes in carbon stores will occur during LTER6. We will examine the degree of spatial coherence of litter decomposition across the Andrews Forest (Goal 1, objective 2). We hypothesize that decomposition rates at sites that are extremely wet or exposed to cold-air drainage will not be highly correlated to one another. As part of long-term measurements, a wealth of data on vegetation dynamics is collected across the Andrews Forest (more detail below). Related to Goal II, objective 1, we will continue to analyze long-term trends in live and dead woody biomass and NPP from these studies to test if there has been a response to climate change in the last three decades. Based on a preliminary analysis of the data, we believe there has been a small decrease in biomass (<5%), but no change in NPP. While NPP has not declined, it is likely a greater fraction has been allocated into offsetting mortality. We hypothesize that the decrease in live biomass has been offset by an increase in dead woody biomass. (Harmon will lead this work.)

Biodiversity. At the Andrews Forest, we include studies of species and community dynamics in the general category of Biodiversity. Vegetation measurements, including species abundance (basal area and cover), size (diameters and heights) and frequency, have been taken within plots for woody and non-woody plants within small watersheds and reference stands throughout the site (Figure 2.2). The plots are located in key environments and allow us to examine long-term changes in physical structure, plant populations, community composition and diversity. Lepidoptera have been sampled along topographic and land use gradients. Trout and salamander populations have been quantified annually in Mack Creek for over 25 years to study population variation among years and responses to land use change. Repeated measurements of abundance and diversity of exotic plant species along roads (Parendes and Jones 2000, Sheehy 2006) have shown increases, especially at high elevations. The distribution of sub-alpine meadows, a major habitat for diverse organisms in the predominantly forested landscape, has shown marked contraction over time, and associated loss of plant, insect, and animal species (Haugo and Halpern 2007, Lang and Halpern 2007). A new continuing cross-site experiment (NutNet; Borer and Seabloom are leading this effort) will test fertilization effects on community structure in the high-elevation meadows at the Andrews Forest and other sites.

Continued long-term measurements of biodiversity will play an important role in LTER6 for addressing questions relating phenology and trophic interactions, especially questions relating to the influences of complex terrain and potential impacts of climate change (Goal I, objective 3; Goal II, objective 3). Continued study of vegetation dynamics in LTER6 will help us better understand the interactions of vegetation with microclimate and cold-air drainage (Pypker et al. 2007b). We will test whether tree seedling establishment in high-elevation meadows has been correlated with periods of wetter than average conditions. We will examine how diversity of arthropods is related to diversity of understory vegetation. An individual-based model for trout population dynamics (inSTREAM; http://www.humboldt.edu/~ecomodel/instream.htm) will be used to evaluate scenarios that may have given rise to the patterns in fish populations we observe and to evaluate possible future effects of land use or climate change. (Johnson, Gregory, Spies will lead this work.)

A major effort in LTER6 will be the creation of digital forest composition/structure layers (hereafter referred to as the "Digital Forest") for the Andrews Forest (Goal I, objective 3) (Figure 2.7). Current vegetation layers for Andrews are too spatially and taxonomically coarse to study and represent the complexity introduced by topographic-climate interactions or created by past climate-disturbance interactions. These prior interactions have resulted in the juxtaposition of species that could respond with differing behaviors to a warmer or colder climate. Variation in climate in the past has lead to disturbances that created a mixture of species at a single site that are commonly associated with either low or high elevations (Urban et al. 1993). We hypothesize that this fine grained species heterogeneity will allow the forest to quickly respond if temperatures change and optimal climates of dominant species no longer exist (Goal II, objective 1). The Digital Forest will be a set of spatial models of species composition and structure. It will include tree species as well as major shrub and herb species. It will also describe the live and dead wood biomass and physical structure of forests, including tree diameters. The Digital Forest, with a grain size of one meter to about 30 m (forest structure and composition), will be created by combining remotely sensed data from LIDAR and TM imagery and other GIS layers with on the ground measurements from existing vegetation plots and additional vegetation plots that are needed to characterize undersampled portions of the Andrews Forest watershed. Digital Forest layers will be generated using multiple types of statistical models. For species and community models, we will use a multivariate imputation approach (Ohmann and Gregory 2002). For the structure models (e.g., biomass, and likely diameter distributions), we will use both regression models (Lefsky et al. 1999) and imputation approaches. Models of canopy density, which will be important for our microclimate studies, will be generated using multivariate statistical models and LIDAR. (Spies will lead this work.)

2.4. Analyses, new empirical studies, and planning for short-term mechanistic experiments

2.4.1. Retrospective analyses of interactions of climate, complex terrain, fire, insects, forests

Retrospective analysis has great potential in LTER6 to clarify how ecosystems respond to climate change and variability (Figure 2.4). In LTER6, we propose to explore the drivers and ecosystem consequences of climate change and variability (Goals I and II) using diverse long-term direct and proxy records, including measured climate and hydrology records, dendrochronology, and observations of plants and animals. The existing network of climate and streamflow stations and reference stands, combined with long-term data on climate, hydrology, nutrients, biota and diversity (Table 1.1, Figure 2.2) permit us to conduct retrospective analyses at multiple organizational levels. The analyses are structured to proceed from fluxes of matter and energy, to primary production, to primary and secondary consumers.

We hypothesize that high elevation ecosystems are more coupled to regional climate compared to low elevation ecosystems, which are more affected by air drainage processes (Goal I, objective 1) (Figure 2.4). Once we have established the varying scales of climate processes (in long-term climate studies, Sec. 2.2), we will identify the sensitivity of various ecosystem processes to local versus regional climate. For example, we will test how subcanopy, soil, and stream temperatures relate to the presence/absence of temperature inversions, and whether summer low streamflows are persisting longer at high versus low elevation watersheds, potentially reflecting more rapid high-elevation warming (Goal II, objective 1). (Daly, Jones will lead this work.)

We hypothesize that primary production is more closely coupled to regional climate at high compared to low elevations (Goal II, objective 1). Preliminary data indicate that high-elevation tree growth rates at or near the Andrews Forest are 1) coupled to sea-surface temperatures (hence winter temperatures), whereas low-elevation tree growth rates are coupled to regional drought indices (hence summer precipitation); 2) coupled with tree growth rates in the Coast Range, but not to tree growth rates east of the Cascade Crest (Black unpublished); and 3) sensitive indicators of past insect outbreaks (Figure 1.6). To test the interactions between forest ecosystem processes, microclimate and regional climate, we will use retrospective analysis of dendrochronology and stand age records, combined with air temperature and records of growth and mortality from reference stands with differing forest structure. We will look for interactions between climate processes at various scales (Figure 2.4) and forest growth and productivity. Using forest structure and dendrochronology records (Figure 1.6) in various landscape positions we will examine the correlations of forest disturbance and tree growth with climate indices. Analyses will use both local and regional tree ring chronologies. We hypothesize that tree species with contrasting life history strategies respond differently to the same climate forcing. To test this, we will contrast tree-ring records between subalpine (mountain hemlock, noble fir) and low elevation (Douglas-fir) species currently found at high elevations (1100-1400 m) to test whether these species show inverse responses to climate trends over time. (Jones, Black, Harmon, Shafer, and Swanson will lead this work.)

Insect and bird species distributions also are sensitive to climate interactions with complex terrain; we will conduct retrospective analysis of long-term moth and climate data (Table 1.1) supplemented by other sources to test how complex terrain, climate, and climate change have affected the distribution and phenology of these organisms (Goal I, objective 3; Goal II, objective 3). Preliminary data indicate that 64 of 84 moth species that occurred consistently from 1994-2007 at the Andrews Forest were found an average of 11 days earlier in 2004-07 compared to 1994-96 (Miller unpublished). These moth species are all "June flyers", i.e., they have overwintered as a cocoon, and emerge from diapause based on temperature cues. We will correlate the timing of these moth life history stages with cumulative degree days (Figure 2.8) using our long-term climate records; look for species co-occurrences by topographic position in the moth database (which contains over 500 species sampled over 20 years); examine how topographic heterogeneity is related to moth species richness; and look for new moth species arrivals by location (high, low elevation) and potential source area (east of the Cascades, Willamette Valley). At the regional scale, bird migrations also may be responding to climate warming. Using data for the Pacific Northwest from the Breeding Bird Survey (http://www.pwrc.usgs.gov/BBS), we will test whether bird species found in the Andrews Forest have altered distributions since 1966 in the surrounding region (Oregon and Washington). (Miller, Betts, and Jones will lead this work.)

2.4.2. *PHENOLOGY AND TROPHIC INTERACTIONS IN COMPLEX TERRAIN*

This integrative study is designed to evaluate the influences of microclimatic heterogeneity, associated with complex terrain, on phenology (Goal I, objective 3) and to evaluate potential trophic responses to scenarios of change in climate, disturbance and land use (Goal II, objective 3). We will focus on a simplified model trophic system involving vascular plants, terrestrial and aquatic insects, and migratory neotropical and resident birds. This work will use and extend our long-term studies of plant phenology, climate, Lepidoptera, and aquatic insects in LTER5 and earlier (Table 1.1 and Prior Results), and allow us to expand our biotic studies to include birds. The model trophic system is ideal because the phenological behaviors across trophic levels are both independent (responding to different abiotic drivers) and dependent (due to trophic interactions), potentially leading to complex system behaviors.

Plant phenology is highly dependent on temperature. Hence, the spatially variable microclimate that occurs in complex terrain (Figure 2.8) results in asynchrony (low spatial coherence) of plant phenologic stages across the landscape (Figure 1.11). When this spatial variability is integrated across the entire landscape, phenologic stages become protracted (Figure 2.9). Phenologies of terrestrial arthropods also have wide spatial and temporal variation (Miller unpublished), likely in response to temperature variation across terrestrial microclimates such as cold air drainage patterns and temperature inversions. Aquatic insect emergence is also tied to temperature (Frady et al. 2007; Anderson et al. 1984), but stream temperatures are influenced by different factors than those driving air temperatures (Johnson 2004) and may be less sensitive to complex terrain.

We propose to assess how microclimatic influences on timing of phenological events affect trophic interactions across the landscape. Microclimate variations between forest cover and canopy gaps affect phenology through altered heating (Frady et al. 2007) and snow dynamics (Section 2.3.2, Climate). Leaf nutritional value and palatability for herbivores varies with time since leafout. Timing of insect emergence may be key to avoiding predation by neotropical migrant birds. Bird fecundity depends on food availability at nesting periods (Both et al. 2006). Seasonal behaviors of migratory neotropical birds, and habitat and nest selection by resident species may be regulated by endogenous mechanisms, as well as by local climate (Figure 2.9) (Hagar 1992, Gwinner 1977). Phenologies of predators and prey, or producers and consumers, can become desynchronized if mobile predator species are sensitive to different phenologic cues than local prey species, affecting predation rates (Holtby 1988, Bradshaw and Holzapfel 2006).

In our model trophic system (Figure 2.9), producers (plants) and first-order consumers (caterpillars, aquatic insects) have limited ranges, and microclimatic factors control their phenology. In contrast, birds, which combine an array of well-developed behaviors (personal learning, environmental cues, social information etc.) with great mobility, are adapted for finding good feeding stations in a spatially heterogeneous environment, integrating phenology of many sites. The range of microclimates with differing insect activity and availability typical of complex terrain may “buffer” birds at the Andrews Forest, in comparison to other regions where species (Durance and Ormerod 2007) and trophic interactions (Hitch and Leberg 2007; Bradshaw and Holzapfel 2006) are responding to climate change.

To explore phenology and trophic interactions (Goal I, objective 3; Goal II, objective 3), we will address the following specific questions:

1. What local abiotic drivers (e.g., cumulative degree days, photoperiod) if any, determine the phenology (e.g., bud break, instar development, activity of songbirds) of the biota in our model system?
2. How is the synchrony of phenologies of these biota affected by environmental conditions varying across space and time (within and between years)?
3. What is the extent of correlation between biomass of aquatic and terrestrial food sources at a site and bird fecundity (indicated by activity or the intensity of bird song in the post breeding period)? (Betts et al. in review)

Measurements. Studies of phenology and trophic dynamics will occur at five pairs of sites (asterisks in Figure 2.2) selected to represent a broad range of environmental conditions and elevations in the Andrews Forest; they build on existing long-term study plots wherever possible (vegetation studies, small watersheds, stream gages, climate stations). Each pair of sites will contain a young deciduous stand and closed, mature conifer site, to allow comparisons of land use and microclimates across elevation gradients. We will concentrate our studies in spring, to capture the arrival of migrant songbirds and the increasing activity of insects. Our ability to support new measurements with the LTER6 budget is limited, so we will condense our studies into a concise period of optimal phenological activity and information.

We will focus on several bird species including a neotropical migrant (Orange-crowned Warbler, *Vermivora celata*) and a resident bird species (Black-capped Chickadee, *Poecile atricapilla*). Bird activity and behavior will be observed within 10m plots at each site and songs will be used to document arrival times for the migrant species. We will also experiment with collecting digital bioacoustic data (song rates, dialects) with an automated method that uses signal detection (Dietterich unpublished). Caterpillars are a rich food for birds, so we will document their abundance and size twice each season. Researchers and volunteers will quantify caterpillars on top and underside of 800 understory leaves at each site, estimating size by category and recording taxa by family (Rodenhouse et al. 2003). Emergence of aquatic and riparian insects will be captured using four emergence traps per site (Frady et al. 2007). Malaise traps will be used to collect arthropods. Organisms in traps will be collected twice per week; numbers and biomass will be determined in the lab. Timing of bud break for Douglas-fir (overstory dominant species), and flowering for rhododendron, ocean spray, and colts foot (understory species present at all sites), will be recorded daily using photos. Herbivory on maple leaves will also be monitored from leaves collected at the end of the study period (Shaw et al. 2006, Braun et al. 2002). Diversity and density of vascular plants and trees within study sites will be documented in conjunction with long-term vegetation plot studies. Physical and climatic data collected at all sites will include air, stream and soil temperatures, precipitation, incoming radiation and cover. We will be seeking additional funds to expand the scope of measurements to add additional trophic levels including bats, amphibians, and adult arthropods.

The date of first observation and date of the peak abundance or activity will be determined for birds, dominant aquatic and terrestrial insect taxa within a given year, then compared among years. These data will be assessed for correlation with the phenology, diversity and productivity of overstory and understory plants and abiotic factors, including air and stream temperature, timing and form of precipitation, and snow melt. After four years, we will begin to develop mathematical and computer simulation models to test the hypothesis that habitat selection strategies, patchiness of available prey and climate change interact to influence bird population viability. These models will allow us to test for demographic thresholds associated with rates of climate change and degrees of landscape patchiness. (Principal collaborators include Johnson, Betts, Shaw, Li, Miller, Bond, Jones, Selker, Harmon, and Spies.)

This study will be closely integrated with our Schoolyard LTER6 program (see Section 5.2); the trophic interactions and phenological measurements offer an ideal opportunity to involve K-12 teachers and other volunteers. Teachers and citizen participants will be valuable field assistants for the caterpillar search and malaise trapping; in addition, they will be trained each year to also observe the presence of birds and record vegetation phenology so that they are involved in the full suite of phenological measurements and understand the theory of our trophic interaction study.

2.4.3. Carbon and water cycle processes within in a small watershed: role of complex terrain

Goal 1 for LTER6 is to understand how complex terrain and canopy cover moderate interactions between ecosystem drivers and responders. The extensive set of long-term measurements and rich research history of the Andrews Forest’s Watershed 1 make it an ideal place to pursue this goal. We plan a multidisciplinary collaboration to better understand the influences of complex terrain on the sensitivity of carbon and water cycle processes to environmental drivers at different scales (Goal I, objective 2). We will examine how fine-scale spatial heterogeneity coupled with multiple gravity-driven flowpaths (see Section 2.1) affect scaling of carbon and water cycle processes. We will also examine interactions between carbon and water cycle processes and will establish a foundation for future explorations of the roles of biota in mediating those interactions. For LTER6 our specific objectives are 1) to measure and/or model fluxes of carbon and water at two spatial scales – plot or stream reach and at the whole watershed, and at two time scales, daily and annual, 2) identify environmental controls and sensitivities of processes on these two scales, and 3) test the hypothesis that environmental sensitivity of carbon and water cycle processes is lower at the basin scale than at the average plot scale.

A parallel objective for this project is to create a test-bed for new measurement approaches, sensors and sensor network technologies, as well as a case study for developing new telecommunications and data management and analysis tools to realize our Cyber-Forest vision for the entire site (see Section 4 and Figure 4.1). Such new technologies are particularly important for our mountainous site; we need to employ measurement approaches that capture the high temporal and spatial variability of environmental conditions and processes. The majority of work for this integrated study will be concentrated in a small watershed, WS 1 (Figure 2.2), where we have installed towers for meteorological measurements and a nested sensor network (Figure 2.10). Through complementary NSF-funded projects we have been developing and testing new approaches to measure ecosystem processes on the small watershed scale (Pypker et al. 2007a, b). Before the beginning of LTER6, we will extend line power to the base of the watershed, and during LTER6 we hope to install a "WiFi Cloud" that covers most or all of this 96 ha basin.

Previous work at WS 1 on carbon dynamics has shown high spatial heterogeneity of a variety of microclimate and ecosystem properties as well as evidence for multiple, connected flow paths of air and water. Despite a rather uniform canopy overstory (Moore et al. 2004), there is high spatial variability in soil properties (including respiration, seasonal moisture dynamics, C:N ratios; Kayler unpublished), composition of the understory (Lutz and Halpern 2006) and tree physiological characteristics (including leaf respiration, transpiration, growth rates; Bond unpublished). We are beginning to understand how advective fluxes of matter and energy connect disparate components of the ecosystem. Diel variations in streamflow, for example, appear to be governed by transpiration of trees near the stream (Bond et al. 2002) and transpiration of upslope vegetation affects streamflow over much longer timescales (Barnard unpublished). Carbon dioxide released through nocturnal respiration in upslope areas is transported by a deep, swift and very well-mixed stream of air to downslope positions (Figure 1.8), leading to high CO_2 concentrations within the canopy airspace (to 37m) at night and at times even during the day. At night, more than 90% of ecosystem-respired CO_2 may flow through the watershed advectively (Pypker et al. 2007b). Our long-term records indicate that export of dissolved organic and inorganic carbon in the stream system is low, but it is possible that large amounts of carbon are respired within the stream system and then outgassed (e.g., Mayorga et al. 2005), if so this would represent an important point of connectivity between terrestrial and aquatic carbon cycling processes (Cole et al. 2007).

Plot- and reach-scale measurements. High-resolution climatic and abiotic measurements are a key part of the Cyber-Forest concept and essential to this project. A combination of two instrumented towers and eight instrumented plots provide this information (Figure 2.10 provides details about sensors). The existing plots are arrayed along a ridge-to-ridge transect (Figure 2.10) and are adjacent to permanent vegetation plots. For LTER6 we will install additional plots to create a matrix that represents the WS 1 basin. The selection will be based on the 1m LiDAR DEM and a high-resolution soil map that we will develop in the first year of LTER6. Building on the "Digital Forest" analyses (see Section 2.3.2, Biodiversity), we will map vegetation type and structure, including leaf area index (LAI) on fine spatial scales. We have installed a fiber optic Distributed Temperature Sensor (DTS) system (Selker et al. 2006 a, b) to continuously monitor temperature throughout the stream network to identify, from temperature changes, when and where water is flowing. For LTER6 a paired black and white DTS cable will be installed just above the stream system. Temperature differences between the cables will identify penetration of radiation through canopy gaps from, providing a way to quantify the amount of radiation reaching the stream. In addition, a "DTS net" - a novel technique that employs parallel strands of DTS through an entire cross section of the watershed – will be used to measure distributed air temperature developed during LTER5. The 2D field of air temperature patterns will lead to a better understanding of cold air drainage, and compliment measurements derived from the tall meteorological tower.

Carbon fluxes: *Vegetation.* Annual net primary production and vegetation mortality will be calculated using measurements in the 131-plot network of vegetation sampling plots in this basin (Acker et al. 2000). A simulation model, SPA (Soil Plant Atmosphere, Williams et al. 1996) will be used to estimate carbon exchange by vegetation on daily time scales. We are experimenting with an approach that involves measurements of water use efficiency (C assimilation/H_2O loss) via determination of C isotope discrimination ($\Delta^{13}C$) in combination with measurements of H_2O loss from sapflow measurements; GPP is calculated as the product of water use efficiency and H_2O loss. *Soils.* In a subset of plots we will measure instantaneous respiratory fluxes from soil and foliage at bi-monthly to monthly timesteps, and we will scale these to the plot level at an annual timestep. *Stream*. Whole stream metabolism will be measured across seasons (Roberts et al. 2007) to evaluate GPP and respiration. Exchange of CO_2 between air and water will be explored using sensor technology newly adapted to freshwater from ocean research.

Water fluxes: *Precipitation.* We will use the PRISM model to predict precipitation across the basin (See Section 2.3.2, Climate) and we will test the model using measurements from tipping buckets placed in open areas or above the canopy at the sensor network plots. Also, we will collaborate with Krajewski (Iowa), who is developing a network of four mobile, low-power, scanning weather radars, to generate rainfall maps with high spatial and temporal resolution. *Interception.* Because of high interception of rainfall (Pypker et al. 2005; 2006 a,b) and snow (Storck et al. 2003) by coniferous canopies in the Andrews Forest, and the influence of vegetation on soil water content due to transpiration (Bond et al. 2002) and snowmelt (Marks et al. 1998), vegetation cover is both influenced by and strongly influences the topographic variation in soil moisture and streamflow. Canopy interception and evaporation will be estimated based on Pypker et al. (2006b) and validated using “pulse” measurements of throughfall in small plots. When snow occurs we will compare the influence of the canopy on distribution of snow with predictions generated by Nolin in the Climate studies (see Section 2.3.2, Climate). *Transpiration.* Transpiration will be estimated using a simple hydraulic model (Bond and Kavanagh 1999); we have previously validated the model for several trees in WS 1 (Pypker et al. in review) and we will conduct additional validation studies by measuring sapflow in other parts of the watershed. *Drainage.* Drainage on the plot scale will be estimated from measurements of volumetric soil water content and transpiration. Volumetric water content is continuously measured at four locations and three depths (5, 30 and 100 cm) in plots using Decagon’s ECHO5 sensors.

Basin scale measurements: We will estimate basin-scale inputs and outputs of carbon and water using three independent measures: 1) “Scaling up” from plot-scale measurements (see above) to the whole watershed; 2) Direct measurements of whole-ecosystem fluxes of water and carbon in water and air out of the basin. At the stream gaging station at the mouth of WS 1, DOC, DIC, particulate C and discharge are measured. For carbon in air, we will measure nocturnal, atmospheric fluxes of respired CO_2 (we have not yet verified that it will be possible to measure nocturnal ecosystem respiration on the scale of the entire basin, but our previous NSF-funded research suggests that this will be possible (Pypker et al. 2007a, b); 3) Modeled estimates of daily fluxes for the whole basin using the GTHM-MEL model (see Section 2.4.5. Potential effects of future change, below) to simulate basin-scale fluxes of both carbon and water. (Principal collaborators include Bond, Unsworth, Marshall, Pypker, Kleber, Johnson, Lajtha, Jones, Selker, Harmon, Brooks and McKane.)

2.4.4. SMALL WATERSHED TRACER STUDY: RESOURCE USE EFFICIENCY IN COMPLEX TERRAIN

Because the upper-elevation forests of the Andrews lie at the boundary between transient and seasonal snow (Figure 2.6), our watersheds may experience change in form, timing and quantity of precipitation over the next few decades. With a new multi-disciplinary study centered on an upper elevation watershed (WS 7), we will examine how this change might affect hydrology, nutrient fluxes from the terrestrial landscape to downstream waters, and vegetation, assessing the sensitivity of ecosystem processes in high elevation vs. low elevation environments to climate (Goal I, objective 2; Goal II, objective 1).

We will conduct a whole-watershed tracer experiment to understand the coupling between water and nutrient fluxes and how these connections are affected by changes in forms and amount of precipitation. We will infer mechanistic controls on resource-use efficiency along nutrient flow pathways under conditions of rain vs. snow by applying tracer levels of ^{15}N; monitoring natural variations in DHO and DOM chemistry; and tracing the pathways of water, N, and DOM through the watershed. This work builds on previous long-term analysis and short-term tracer experiments examining gravitational flowpaths in watersheds (McGuire et al. 2005, Weiler and McDonnell 2006); sources of dissolved organic matter (DOM) in soil (Yano et al. 2004); hyporheic zones (Haggerty et al. 2002, Ninneman 2005); seasonal dynamics of nutrient flows in small watersheds (Vanderbilt et al. 2002); and rain vs. snow effects on hydrology in small watersheds (Perkins and Jones in press).

The tracer experiment is a focused study to identify the relative influences of vegetation, soils, hillslope flowpaths, and streams on nutrient and water flowpaths, testing hypotheses from LTER5 (Figure 1.10). Zero-tension and tension (Prenart) lysimeters will be installed at three depths stratified by hillslope position (in parallel with WS1, Section 2.4.3). Tensiometers and a groundwater well will serve as points for application and monitoring of conservative tracers to determine water and chemical residence times. We also will trace pulses of water from snowmelt and precipitation in WS7 (and WS 1, Section 2.4.3) using innovative sensors (a constant-draw wicking lysimeter and small HOBO temperature sensors attached to fine-pore metallic lysimeters) developed by Selker.

Modeling watershed response to climate change will be a key part of this activity. We will explore the wealth of hydrologic and biogeochemical models that have been applied to Andrews Forest watersheds, including RHESSys (Tague and Band 2001), DHSVM (Waichler et al. 2005), Hillvi (Weiler and McDonnell 2006), NUM5 and VS2D (Dutton et al. 2005), MHMS (Perkins and Jones in press), helped by model comparisons (Vache and McDonnell 2006). GEMS and Daycent-Chem (the daily version of CENTURY with a water quality submodel) also will be applied to assess results of this study. (Principal collaborators include Lajtha, Haggerty, McDonnell, Nolin, Selker, Brooks and McKane.)

2.4.5. POTENTIAL EFFECTS OF FUTURE CHANGE

A critical objective of LTER6 is to integrate our knowledge from previous LTER work and current studies to evaluate how our system – considering all three drivers and all three responders of the Central Question – might react to scenarios of future climate change (Table 2.2, Section 2.1.1, and Goal II, objective 4). This task can only be achieved by using simulation models. However, it is not our intention to try to use models to predict the future. Instead, we aim to conduct "desk top" experiments with models to better understand the behavior of complex systems and to test hypotheses that cannot be approached in field experiments. Most of the models we plan to employ for this part of the study have been used in the past at our site, and some were developed at our site specifically. Details of the models we are currently planning to use are available at http://www.fsl.orst.edu/lter6/model_details.pdf).

During LTER6 we are particularly interested in examining the interactions among our drivers (climate, land use and disturbance), as well as the influence of multiple drivers on responders. We hypothesize that the impacts of regional climate change on our ecosystem will be strongly influenced by local topography and canopy cover and that indirect impacts of climate change, because of disturbances, will be more important than direct effects of climate (Goal II, objective 2). To examine the influence of multiple drivers on responders, we will, for example, examine how the interactions of climate change, disturbance, and land-use (as defined by our scenarios, Table 2.2) will force changes in carbon and nutrient dynamics. We will start by comparing the sensitivity of responders to single drivers and then progress to combinations of drivers. We will also examine scenarios in which the disturbance driver is dependent on climate, expecting this will lead to the largest response. Comparisons between responders will be “controlled” by using common datasets to drive models, with all future scenarios such as climate and disturbance history as well as other driving variables. For each responder examined we will contrast the mean response and the spatial and short-term temporal variability of the response under future change scenarios (i.e., treatment) relative to that of the current situation (i.e., control). When models predict the same ecosystem responders, their predictions will be compared to gain insights on uncertainty.

We will examine a range of potential future responses to changes in our three system drivers using multiple scenarios (Table 2.2). The AOGCM simulations described in the IPCC Fourth Assessment Report (IPCC 2007) provide a basis for projecting general climatic changes in our region. Over the next 100 years these projections indicate an overall mean increase in temperature, with temperatures increasing in both summer and winter (Field et al. 2007). While mean annual precipitation may not change or increase slightly, precipitation variability will likely increase. Given projected temperature and precipitation seasonal patterns, it is also likely that the Andrews Forest will experience a longer dry season. We will use a combination of synthetic climate data and downscaled AOGCM simulations of future climate data (Section 2.3.2.) produced under one or more of the IPCC emissions scenario (Nakicenovic 2000). We will contrast these climate scenarios with two extreme cases (Table 2.2): 1) a continuation of the current climate mean and variability and 2) rapid change, a halving in the time for the IPCC Fourth Assessment Report projected changes to occur. Given that interactions between topography and large-scale weather patterns influence how climate is expressed locally, we will translate these regional scale changes to a local level using PRISM-related models.

Land use has important long-term influences on our system, influencing the range of options available and the system’s sensitivity to changes in climatic and disturbance regimes. At our forested site, land use regimes are driven by forest management goals and policies both of which have varied over time and space and we will explore five land-use scenarios (Table 2.2). We will capitalize on our research-management partnership (Swanson et al. 2003) and obtain spatial databases describing management plans from the Willamette National Forest. Land use and climate change scenarios interact in two important ways. First, impacts of land use on canopy cover will affect micro-climate, so we will explore how altered land use affects the local climate projections. Second, land use change is a primary source of human influence in the feedback loop from the human dimension to ecological processes (Figure 2.3.C). Although not explicitly funded in LTER6, we plan to use EnvisionAndrews, an spatial agent-based modeling system that links ecological conditions, human values and policy making to analyze future scenarios linking climate change to land use policies (Hulse et al. in review, Bolte et al. 2007; see Section 2.5) and then incorporate this feedback into subsequent modeling and projections.

While there are many important disturbance processes impacting our site, we will focus on fire and insect outbreaks because these are the most likely to respond to changes in climate and land use. Disturbance scenarios will contrast increased versus current frequency and severity of disturbance (Table 2.2). For example, a system with complete fire suppression (the current situation) will be contrasted with one having an increased frequency and severity of fire. While these scenarios will be defined a priori, they will nonetheless provide insights into the sensitivity of the system to changes in the disturbance regime. As described below, we will also predict the frequency and severity of these disturbances from climate and system state conditions (e.g., plant stress). This will allow us to test the hypothesis (above) that indirect impacts of climate change mediated through disturbances will be more important than direct effects of climate. We will use LANDSUM 4.0 (Keane et al. 2006) to characterize how changes in disturbance regimes under climate change might affect landscape and successional dynamics. This model is a spatial state and transition model that can simulate wildfire fire, succession, management actions and insect and disease outbreaks. This model is well suited for examining strongly differentiated scenarios, can take into account wind direction, vegetation state, complex terrain, and has been used to evaluate climate change effects in the Rocky Mountains (Keane et al. 2008). Despite being currently rare, insect outbreaks have the potential to have major impacts under a changed climate (Volney and Fleming 2000). We will parameterize the insect outbreak component of LANDSUM using principles similar to those developed by Keane et al. (2008) for spruce budworm. (This effort will be led by Kennedy and Spies.)

The responder models (http://www.fsl.orst.edu/lter6/model_details.pdf) that we will focus our initial efforts will project changes in hydrology and nutrients (Georgia Tech Hydrological Model-Multiple Elemental Limitation Model: GTHM-MEL), carbon and tree biodiversity (LANDCARB), tree communities and structure (Lund-Potsdam-Jena Dynamic Global Vegetation Model: LPJ-DGVM), and stream communities (M & C Stream Ecosystem Model). Before use, each model will be verified against existing field observations and empirically based models (the Digital Forest). We will also incorporate new concepts on system controls and behaviors as field projects develop them during LTER6. GTHM-MEL has been recently used in WS 10 at the Andrews Forest to simulate the cycling and transport of water and nutrients (C, N, P) within hillslopes and out of small watersheds (Herbert et al. 2003, Rastetter et al. 2005). GTHM-MEL is being modified so that it can simulate responses of larger basins. (This effort will be led by McKane.) LANDCARB has been used to predict changes in carbon stores as a function of land use (Cohen et al. 1996, Wallin et al. 1996) and to examine stand to landscape scaling (Smithwick et al. 2007). It is being modified to respond to climate change and to be able to predict changes in the disturbance regime as a function of climate and current system state (e.g., fire fuel amounts) in a manner similar to Landscape Disturbance Simulator (LaDS; Wimberly 2002, Wimberly and Spies 2002). (This effort will be led by Harmon.) LPJ, a dynamic global vegetation model, is currently being used to predict responses of tree communities, related ecosystem processes, and disturbance regimes (e.g., fire) to climate change (Sitch et al. 2003). The current version is being run at a 1-km resolution for the Pacific Northwest and will be modified to run at sub-1-km scales. (This effort will be led by Shafer.) FORCLIM will be used to simulate the effects of climate change on forest structure and composition at the stand level and then scaled up to the entire Andrews Forest using the digital forest layers to initialize the simulations. This model will enable us to look at interactions of complex terrain, forest management, and climate change. (This effort will be funded separately and led by Spies.) The M & C Stream Ecosystem Model (McIntire 1983, McIntire et al. 1996) has been used at the Andrews Forest to investigate instream processes and the roles of functional groups. The riparian version of the model will be used to investigate the effects of climatically driven changes in riparian zone canopy structure on small stream process dynamics. The model will also be modified to explore the effects of increased temperatures on stream ecosystem processes, including decomposition and stream metabolism. (This effort will be led by Johnson.)

2.5. Regionalization, cross-site, and other collaborative efforts in the LTER network.

2.5.1. Regional and cross-site studies of biophysical processes

The Andrews Forest LTER program has a strong history of study of biota and ecological and geophysical processes across the Pacific Northwest to test science concepts beyond the confines of the Andrews Forest and to explore phenomena operating at larger scales. Some studies capitalize on the regional network of research sites (e.g., Experimental Forests and Research Natural Areas) crossing the strong west-to-east environmental gradient characteristic of the region (e.g., decomposition studies by Harmon) and other studies evaluate large geographic areas (e.g., the Willamette River Basin Futures project in which the Andrews Forest has a role (Baker et al 2004)). We also continue to utilize a system of long-term vegetation plots widely distributed across the region (Acker et al. 1998) and experimental watersheds arrayed north-south along the Cascade Range (Jones 2000), although due to ongoing budget cuts, funding for both programs is tenuous. In LTER6 we plan to continue observations and conduct retrospective analyses of data produced from our numerous long-term experiments and measurement programs to the degree possible (see Section 2.4.1).

The Andrews Forest LTER program has been an important leader and participant in LTER Network science and development of cyber infrastructure to encourage inter-site science (Figure 2.1). We will continue this commitment in LTER6 by completing data analysis and publication for several important cross-site studies, notably LIDET (Harmon extending Parton et al. 2007), LINX II (Johnson and Gregory extending Mulholland et al. in press), hydrology (Jones extending Jones and Post 2004), which involve substantial numbers of LTER sites. New science networks are in early stages of development, such as international NutNet project (Borer and Seabloom; http://web.science.oregonstate.edu/~seabloom/nutnet) as well as collaboration between scientists at small groups of LTER sites. We will also continue to participate in the Eco-trends book project and to work at LTER-Forest Service interface to advance data harvester systems that facilitate cross-site science, especially development of ChemDB for precipitation and streamwater chemistry from experimental watersheds to complement HydroDB and ClimDB. The Long-Term Ecological Reflections program at Andrews Forest, a collaboration with humanists, mainly environmental writers and philosophers (see Section 5.0, Outreach and Education) has expanded to Bonanza and North Temperate Lakes LTER sites to promote engagement of arts and humanities at LTER sites, leading ultimately to cross-site studies in environmental humanities. We foresee extending these collaborations and additional new ones across the LTER network in the coming years.

2.5.2. INTENSIFYING CONNECTIONS WITH SOCIETY AND SOCIAL SCIENCES – REGIONALIZATION AND CROSS-SITE WORK

Goal III of LTER6 is to intensify integration among the LTER ecological science program, the social sciences, and society. Humans are powerful agents in the ecological processes we study, both as responders and as drivers, but in order to understand the societal context of the Andrews Forest program we must take a broad view that extends into local communities and the region (Liu et al. 2007, Carpenter et al. 2006, Pickett et al. 2005, Swanson 2004, Lach et al. 2003). The social components of our research include the science community, local communities and institutions, natural resource policies, and management activities. This goal is critical to both the Andrews Central Question and also participation in inter-site work. We plan to focus on two questions: (1) How do vulnerabilities and capacities influence how local communities and institutions adapt to climate and social change? (2) How do social linkages among social components and participation in knowledge sharing influence the adaptive behaviors of local communities and institutions? Because none of this work is explicitly funded by the LTER budget, all of the proposed activities are based on collaborations with other organizations or groups.

The parallels and potential interactions between the questions we address in the biophysical and social sciences are remarkably strong because of common interests in the vulnerabilities, resilience, and adaptability of both natural and human systems. In our biophysical studies in LTER6, we will concentrate on how anticipated changes in future drivers, especially climate change, may impact our system. Likewise, in the social context we focus on several key drivers and influences that operate at multiple scales including: climate change, policy shifts in federal forest management, population change, changes in state land-use policies, and changing status of private land ownership. This latter driver involves shifts in control of forest lands from forest companies to financial institutions, which may change owner intentions and production of ecosystem services. The local communities of interest in LTER6 studies range from the unincorporated, dispersed, low-density residential areas within 60 km to the Eugene-Springfield metropolitan area of approximately 200,000 people near the mouth of the McKenzie River 80 km downstream. Institutions influencing natural resources management and ecosystem services include federal agencies such as the Forest Service and BLM, municipalities and utility districts, and an active watershed council. However, ill-defined social networks of opinion leaders, activists, and other attentive community members may be particularly influential in shaping policy and public perception.

Objective 1: Define and evaluate vulnerabilities and capacities of local communities and institutions for adaptation to change imposed by environmental (e.g., climate change) and social (e.g., shifting land use patterns and regulations) forces.

Based on our previous science-management-policy interactions we expect to find that social networks and research-management partnerships are critical in developing policies for forest management and future climate change. Some of our previous work has included assessment of characteristics and attitudes of members of local communities in the context of the past forest conflicts (Shindler et al. 1996). Recent work, for example, includes an assessment of the social acceptability of using historic landscape disturbance patterns to guide future forest management practices (Mallon 2006) and the evaluation by public of the roles of LTER science and scientists in policy decisions about natural resources (Lach et al. 2003). However, climate change and changes in the social context of local communities and institutions pose challenges that require a fuller understanding of social systems, especially the role of social networks and partnerships (LTER Decadal Plan 2007, Carpenter et al. 2006, Pickett et al. 2005).

The work under this objective would involve interdisciplinary study of rural community dynamics taking into account Andrews Forest science and exchange of information among the local public, land manager, and science communities and institutions. This social networking will provide venues for discussion of research findings, field demonstrations of forest management anticipating climate change, model projections of alternative future landscapes, evaluations of ecological services, other types of knowledge, and the processes for exchanging it most effectively. To accomplish this work we will engage faculty leaders in Sociology, Political Science, and other departments in five colleges of OSU who have established the Sustainable Rural Communities Initiative (SRCI) with private foundation, OSU, and other State of Oregon support (http://oregonstate.edu/leadership/strategicplan/rural.html). SRCI now has several proposals in review (including a full IGERT proposal) that would develop a Long-Term Community Research (LTCR) program modeled loosely on LTER and explicitly linked with the Andrews Forest LTER Program. They also propose a program to provide “usable” climate information for water resource managers in the McKenzie River watershed. This work seeks to understand local communities, institutions, and social networks crossing them in terms of vulnerabilities and adaptive capacities to climate change and the program seeks to foster those capacities. In LTER6 we look forward to close coupling of LTER and LTCR at Andrews and other LTER sites.

Objective 2: Characterize, display and discuss alternative futures of the forest for local communities, institutions, including land managers and agencies, and the public at large to enable these groups to make more informed choices about adapting to environmental and social change.

We expect that exploration of alternative futures will help communities and institutions make choices, openly and adaptively. These types of analyses are needed because it is very difficult to visualize how powerful environmental and social forces will change our coupled natural and human system. By developing and discussing alternative futures for our Pacific Northwest forests with the public and land managers we can all better understand likely future scenarios, uncertainties around them, and possible, fruitful adaptive strategies.

The alternative futures work will use two approaches. First, our long-standing research-management partnership involves academic and Forest Service science staff and Willamette National Forest staff, who together carry out long-term experiments, demonstration projects, and outreach with the public and policy makers (Table 5.1). In LTER6 this partnership work will take on the new dimension of addressing climate change. Our public outreach through field tours, public workshops and processes for science input to policy (Table 5.1), and other venues has been a continuing public dialog about the future of our forests and watersheds in a changing environment. We will work with the Willamette National Forest to establish demonstration sites and long-term experiments using an adaptive management approach (i.e., monitoring and adaptation) to serve as focal points for learning about ecosystem resilience to climate change. Second, we will model alternative future scenarios of forest and social landscape change using an agent-based modeling system (Bolte et al. 2007) adapted for application in the upper McKenzie River basin, including the Andrews Forest. This modeling, termed EnvisionAndrews, is a LTER5-funded pilot project nested within the Willamette Futures project for the entire Willamette River basin (Baker et al. 2004). Shifting land use patterns and vegetation dynamics are being simulated for specified changes in environmental and social forces. The resulting maps of potential future landscapes will be discussed with local communities and institutions. In these ways the Andrews Forest will serve as a critical node in the social network guiding adaptation of local human and natural systems to the changing environment.

Objective 3: Translate and communicate our knowledge of ecosystems and watersheds in the terms of ecological services to facilitate the adaptive processes of a coupled natural/human system.

Based on our previous experience we expect that increasing the awareness of ecological services can alter societal decisions about natural resources. Services including carbon sequestration, wood production, water supply, and habitats to support biodiversity have potentially high but poorly documented value in our region. The high but unmeasured value of habitat services is clear in our region where habitat for species was protected despite the very high value of older forests for timber production. The ecosystem services question is complicated by a number of factors including the fact that tradeoffs among services are not well understood and services are scale dependent. For example, water supply and jobs from timber harvesting are local services and benefits, some aspects of provision for sustaining biodiversity may be regional, and carbon sequestration is a global matter. Therefore, the interactions of local communities with changing natural resource management and climate change occur through a complex portfolio of ecological services, over which they have quite varied influence.

We plan to translate our scientific knowledge of wood growth, carbon sequestration, water supply, and provision of habitat for key species into the currency of ecological services, so we can pursue the new social dimensions of our Central Question and also collaborate within LTER (e.g., efforts initiated by Chapin and Carpenter and those that may emerge in ISSE). Locally, we will work with university and Forest Service social and political scientists and economist colleagues to do this translation. This information, along with other relevant social, economic and demographic data, will then be incorporated into a Ford family Foundation and OSU Rural Studies Program funded "Rural Community Explorer" portal through the OSU Library website. The Rural Community Explorer will allow community residents and officials, agencies and businesses, universities and philanthropic organizations to access county and community specific information. The specific information will include: (1) social, economic and ecosystem services indicators of community vitality, incorporated into a community prosperity model for each community; (2) relevant social, economic, ecosystem services and demographic profiles of each community; and, (3) related community-specific spatial/map data, relevant reports and documents, news articles, maps, and photos. The Rural Community Explorer will be linked to other related data sources.

2.5.3. Collaborations and cross-site work in the arts/humanities

During LTER5 we have collaborated with humanists – mainly environmental writers and philosophers – in a program called the Long-Term Ecological Reflections (see Section 5.0, Outreach and Education), and in the past year we have encouraged such collaboration at other LTER sites, especially BNZ, NTL, and HFR. During LTER6 we expect substantial progress in helping spread such collaborations across other sites and developing inter-site collaborations to examine how the senses of awe, hope, environmental ethics, and other points raised by the humanists play out in different environmental and social contexts.

2.6. Synthesis

In LTER6, we will deepen our understanding of the forest and stream ecosystems of the Pacific Northwest, typified by the Andrews Forest (Figure 2.11), through continued long-term studies, some of which exceed 50 years. Strategic addition of new measurements, experiments, and modeling will increase our knowledge of key linkages and processes in order to address our Central Question. The primary synthesis theme for LTER6 is to examine how the distinctive characteristics of our site, including its mountainous topography, relatively pristine condition, and massive forest canopy, shape ecosystem processes and potential responses to variability and change in the global climate. We anticipate that our studies will contribute to development of a conceptual framework for "ecology of complex terrain", and that this conceptual framework will guide a deeper understanding of similarities and differences in ecological processes throughout the LTER network. In addition, we will expand our program in several important ways. In particular, we have modified our Central Question to recognize that our site is part of a coupled natural/human system and we plan to intensify integration among our biophysical studies, the social sciences, and society. We have pioneered strong science/management and science/humanities connections, and we plan to continue to grow, nurture and disseminate these concepts. Our proposal outlines plans to develop much closer integration between our science program and our education program, and to create a Cyber-Forest infrastructure within the Andrews Forest landscape. Our plans for LTER6 maintain the continuity of our long-term measurement programs while steering our program to answer critical questions that are relevant today to our region, the LTER Network and the broader society.

3.0 SITE AND PROGRAM MANAGEMENT

The Andrews LTER is comprised of interdisciplinary groups of researchers from a variety of institutions and agencies. The majority of scientists are faculty at OSU, affiliated with 15 departments in five Colleges. Our immediate science community (see CVs of Senior Personnel) also includes researchers from US Forest Service Pacific Northwest Research Station, USGS Biological Resources Division, EPA Western Ecology Division, as well as from University of Oregon, Western Oregon University, University of Washington, University of Idaho, Portland State University, and Michigan Technological University.

3.1 Management Philosophy. We manage the Andrews Forest as a regional, national, and international research and educational resource in keeping with the site's designation as a LTER site, a Forest Service Experimental Forest, and a UNESCO Man and the Biosphere Reserve. The Andrews LTER program is the highly visible focal point for a multitude of research and educational activities. The open sharing of data from ongoing and long-term studies, funded through LTER and USFS PNW, provides a platform that attracts broad interest, encourages new studies and results in leveraging of research dollars in new ways.

3.2 Decision Making within LTER. The Andrews LTER is led by an Executive Committee (Figure 3.1), which governs by consensus and seeks input from the broader Andrews Forest science community. The Executive Committee is composed of scientists from multiple disciplines and the partner institutions of OSU and PNW and includes prior LTER leaders. The Executive Committee is chaired by the lead PI (Bond) and includes the four signatory co-PIs. Also serving on the Executive Committee is the Andrews Forest Director (O'Connell) and the lead of the Andrews Information Management Team (Henshaw). During LTER 6, a rotating researcher from the list of Senior Personnel will join the Executive Committee so that newer scientists will get leadership experience.

Communications are facilitated through general monthly meetings, Executive Committee discussions, small meetings of disciplinary groups such as climate committee or graduate students, tours and field visits, and semi-annual and annual large group events. Monthly meetings are open to all and cover business, including site administration, data management, communications, graduate student activities, and proposed research projects at the site; notes of these meetings are distributed and posted on the Andrews Forest Web page. Executive Committee meets quarterly or more frequently as needed. Committee members help manage the details of the overall Andrews Forest Program and share in science and education leadership as well as supervision of LTER and PNW staff (Figure 3.1). Semi-annual meetings of all senior co-PIs are convened to review progress on LTER objectives and associated research and to discuss budgets. Decisions about funding are made at multiple levels: the Executive Committee, and specifically the Signatory PIs are responsible for final budget decisions; the broader group of Executive Committee and Senior Personnel use consensus for major decisions. This management style, based on consensus and distributed leadership, has served the Andrews Forest Program well over its LTER history, and is expected to continue to be productive in the future.

The Andrews LTER has several Advisory Groups (Figure 3.1). A local Partner Advisory Group facilitates communication among PIs and Deans of OSU Colleges, Station Director and Line Officers of PNW, and Forest Supervisor and Science Liaison from the Willamette National Forest. The Executive Committee meets with this group once a year to discuss common goals, new directions, funding possibilities and outreach efforts. The LTER External Advisory Committee pulls in national experts to meet with PIs once a year. These Advisors provide broad input and guidance on Andrews LTER research direction as well as financial, institutional and tactical perspectives. Current members of the committee are Jill Baron (USGS), Alan Covich (University of Georgia), Cliff Dahm (University of New Mexico) and David Mladenoff (University of Wisconsin).

3.3 Encouraging New Research and New Researchers. Many new research projects begin at the Andrews Forest because of the investment from National Science Foundation through LTER (Figure 3.2). We encourage researchers in various career stages at OSU and other institutions and agencies to capitalize on the framework of the Andrews Forest and to participate in LTER. Because of the long history of relevant research at the Andrews and because the LTER network provides a framework to link with scientists and students at other sites around the country and world, the Andrews Forest is an attractive place to conduct research. Our multiple annual events provide a variety of easy introductions to the Andrews Forest community for interested colleagues. The annual symposium is a full day event on OSU campus that features oral presentations on an emerging research theme, a group lunch and a poster session that highlights current Andrews Forest research. Graduate students are especially encouraged to participate and share their study plans or findings. An annual summer field day is open to all and introduces summer researchers, students, and visitors to the site, to one another, and to the current program of work. The field day features talks in various field venues by as many of the approximately 100 participants as possible.

We also meet individually with new OSU faculty and Federal researchers to encourage participation in research and education at the Andrews Forest. We highlight the long-term nature of studies that are useful in providing background or foundational information for new investigations and discuss the open availability of climatic, hydrologic and spatial data. Field tours for classes are often an introduction to research at the Andrews Forest for the instructors as well, and are successful outreach tools to local, regional or distant scientists. Providing funding to new scientists is challenging, but we encourage site use by new researchers through allocation of seed funds, REU and graduate student funding, sharing of LTER technician time, and other means. All are welcome and diversity is especially encouraged. In the past 6 years, women scientists have filled key leadership positions at the Andrews Forest, including LTER lead PI, PNW Lead Scientist, and Andrews Forest Site Director. Training of diverse students as future scientists and professors is an important function of the Andrews Forest Program and provides a multicultural perspective to the LTER science community. Former graduate students are encouraged to initiate projects at the Andrews Forest.

3.4 Institutional Relations. The Andrews Forest is administered cooperatively by the Pacific Northwest Research Station, Oregon State University, and Willamette National Forest. Individuals from each institution have critical roles in the Andrews Program and each institution contributes significantly to research, education and maintenance of the Andrews Forest Program. LTER funds are leveraged by the collaborative partnerships. As a result, more students, technical staff and information managers are part of the program than would be possible with LTER funding alone (Figure 3.2). The Andrews Forest has positive relationships with all three institutions. During LTER5, we expanded efforts to encourage relationships among our partners. The Partner Advisory Group (see above) has helped raise the profile of Andrews Forest within the OSU and in the US Forest Service. In the spring of 2007, we completed a Memorandum of Understanding between the three partners that guides the collaborative management of the Andrews Forest (in Supplementary Documentation). Also, we have been working with OSU Foundation to broaden the support for the Andrews LTER and entire Andrews Forest Program. These efforts have led to increased awareness and interest in the Andrews Forest Programs, especially on the OSU Campus.

3.5 Change in Leadership and Participants. To succeed, an LTER program must plan for changes while maintaining continuity. Our lead PIs have generally served 6-9 yr terms and prior PIs continue to serve the Andrews LTER as part of the Executive Committee. Bond took over from Harmon in 2006. Harmon had served as PI since 1999, when he took over from Swanson. Swanson will be retiring from PNW within two years and is stepping down as a signatory co-PI for LTER6; he expects to continue to be active in research and outreach with the Andrews Forest. Tom Spies, a research forester with PNW, will be replacing Swanson as a signatory PI. Spies has a long history of research at the Andrews Forest and brings his expertise in landscape dynamics, vegetation modeling and studies of coupled natural/human systems to the Executive Committee. We are also beginning to plan for the next lead PI to follow Bond, by looking both inside and outside our current LTER group. Several promising young faculty who have recently joined OSU are being encouraged to become involved as leaders. In addition, we are watching for opportunities to recruit a senior PI from outside our group as new positions at OSU open. We will be rotating senior personnel from the grant onto the Executive Committee, so that they can be introduced into leadership position in Andrews LTER group. We expect continued seamless transitions in leadership.

4.0 INFORMATION MANAGEMENT

<u>4.1 Introduction</u>. Information Management (IM) is an important and unifying theme for the Andrews LTER. The IM system seeks to provide broad data services, including high-quality, environmental and research data and metadata. This is accomplished through a long-term data repository, information-sharing infrastructure at site and LTER network levels, training and development of IM expertise, and network-level leadership. Commitment to long-term research and environmental monitoring and recognition of IM as an essential component of the LTER program underlie the strong partnership of the USDA Forest Service Pacific Northwest Research Station (PNW) and OSU College of Forestry (CoF), which is manifest in the support of IM personnel, computing infrastructure, and activities. This partnership enables a rich, interdisciplinary information research infrastructure and supports the long-term data repository, the Forest Science Data Bank (FSDB) (Stafford et al. 1984, 1988). The FSDB has transitioned into an integrated data production and distribution system with a growing diversity of information products (Henshaw et al. 2002). The Andrews Forest information managers have consistently provided leadership to the LTER Network and the broader IM community through consultation, presentations on system design, and ecoinformatics research, including development of a data harvester for building multi-site and multi-institutional databases (Henshaw et al. 2006). The Andrews Forest IM program has been a base for establishing educational programs in ecosystem informatics, including the local, NSF-sponsored Ecoinformatics IGERT and Ecosystem Informatics Summer Institute. The Andrews Forest Program is well-positioned to address future challenges presented by emerging technologies and other cyberinfrastructure issues. We intend to continue assuming network-level responsibilities and leadership roles as the LTER Network begins implementing its Decadal Plan.

<u>4.2 Commitment to LTER Information Management.</u> The IM Team for the Andrews LTER:

- includes OSU and PNW staff (Figure 3.1). Currently four permanent positions are completely or largely devoted to LTER IM with several other LTER staff providing key support in related activities;
- maintains a repository of quality data sets that is broadly inclusive of both long-term and short-term studies data collections from the Andrews Forest and allied sites, and also includes spatial data, a bibliography of all Andrews publications, locally developed models and software, an image and photograph library, and a document archive;
- complies with the LTER review criteria for IM systems through an information system that features online LTER study databases and provides web interfaces to enhance discovery and access of comprehensive study metadata and other information products;
- engages scientist and IM Team interaction in all aspects of LTER study planning and project implementation with information manager representation on the Andrews LTER Executive Committee, and PI and monthly business meetings;
- participates in LTER Network-level IM activities through regular attendance at IM Committee meetings, compliance with network standards, and participation in network-level databases;
- provides leadership within the Network and broader scientific community through service on the IM Executive Committee or the Network Information System Advisory Committee, leadership of ecoinformatics research efforts, and publications and presentations of relevant work at national and international conferences and training forums.

<u>4.3 Historical Perspective.</u> Management of scientific information for the Andrews Forest was initiated in early efforts of the USFS-PNW Watershed Project (1960's) and the International Biological Program (1970's) (Figure 1.1). The resulting legacy is a rich and diverse collection of long-term data and metadata (see Supplementary Documentation, Databases), and an established practice of managing data and information (Henshaw and Spycher 1999). The Andrews has played an ongoing leadership role within the LTER Network in the development of standards for documenting and managing research information (Stafford et al. 1986, Michener et al. 1994, 1997, 1998, Brunt et al. 2004) and in development of the Network Information System (Baker et al. 2000). Similarly, early PNW research established mechanisms to ensure preservation of long-term streamflow, water chemistry, and climate databases, and this experience ultimately resulted in the Andrews Forest Program taking a lead development role in the multi-site ClimDB/HydroDB data harvester and warehouse (Henshaw et al. 1998, Henshaw et al. 2006).

The FSDB has also evolved in response to advancing technologies from an early mainframe tape library (1980s) to a PC-based Local Area Network (1990s) to the employment of more powerful tools such as Relational Database Management Systems on high-speed database servers (2000s). Since 2000 we have designed, developed, and successfully completed transition to a new information system. The goals for this transition were to (1) improve search capability and access to spatial and tabular databases, models, publications, and the image library; (2) extend and improve metadata content to comply with the new LTER metadata standard, the Ecological Metadata Language (EML); (3) allow web users to interactively and dynamically query and retrieve databases and other web content; and (4) better integrate and manage Geographical Information System (GIS) spatial data.

4.4 Data and Information Management System. The information system includes archived study databases of the FSDB, a structured metadata database, a system for quality assurance, a management system for migrating existing data sets and capturing new or legacy databases, and a dynamic web delivery system. Metadata are developed in compliance with LTER and national standards (EML, NBII Biological Data Profile, and the FGDC spatial data standard) for all study databases. The information system allows access to study databases (including spatial data) with associated metadata and publications, and is extensible to our other information products such as the image library, analytical tools, and collections of voucher specimens.

The Andrews Forest LTER maintains and updates extensive web pages (http://www.fsl.orst.edu/lter) describing research and activities on the site, and currently provides access to 140 study databases (Supplementary documentation, Databases) and the Andrews Forest bibliographic database. Web interfaces are used to facilitate public identification and access of information, and permit searching for products by person, theme keyword, location, or taxonomic unit. Software is employed to track general web page use and a user registration system is in place to track downloads of data sets. System development and implementation have been directed toward integration of our many research products and providing a primary source of site information for users within and outside our research community.

4.5 Integration with Site Science. The Andrews Forest LTER employs a systematic approach to IM in ecological research (Stafford 1993). This approach encourages interaction between research scientists and information managers beginning with study and database design, continuing through data capture and quality assurance, facilitating data analysis or synthesis, and concluding with data archival and web posting. This interaction is demonstrated through representation of IM on the Andrews Forest Executive Committee and regular reporting at monthly business meetings. New research proposals specify requirements for archival of data sets into FSDB and describe critical metadata elements including study title and abstract, study locations, and contact information. An administrative interface allows Andrews Forest LTER members to update personnel and contact information, and a new feature allows editing of study metadata by the data provider. Archival support and a comprehensive metadata-driven quality assurance system (Spycher et al. 1996) provide key incentives for contributions of research data. The system can generate metadata in compliance with LTER Network standards, allows publishing of data sets online, and records a history of data set use. The delivery of data in convenient formats for investigator use, dynamic preparation of value-added products, and contributions of data to network-level databases and synthesis efforts provide additional incentives to contributors.

4.6 Data Access Policy and Online Data. Our data access policy is compliant with LTER Network policy and includes a data release policy, a data use agreement, and specification of data access requirements (http://www.fsl.orst.edu/lter/data/access.cfm?topnav=98). The goal of the Andrews Forest data release policy is to make most data available online within 2 years after collection, and most online datasets are updated annually or as needed. Certain data may be restricted with specific justification from the researcher for a limited period of time. Typically, restricted data sets are made available by direct request to the lead investigator, and ultimately, all LTER data sets will be made publicly available online. Time and staffing constraints force the IM Team to prioritize preparation of new incoming data sets and updates to existing long-term data for online placement. Criteria for prioritizing data sets for processing include (in order of decreasing priority): 1) update of critical corporate data sets integral to LTER, 2) data sets from research explicitly committed to in the current funding cycle, 3) data sets supporting work planned in LTER6, and 4) other research projects important to the Andrews Forest program. Our data catalog is online and searchable at http://www.fsl.orst.edu/lter/data/research.cfm?topnav=135.

Data access requires users to provide their name, email and general purpose for use of data, and these requirements allow tracking of data downloads within our user registration system. A history of data downloads is provided (Table 4.1). Data downloads have approximately doubled during this current 6-year funding cycle and have increased more than 10-fold from the previous funding period. Part of this increase is likely a result of incomplete tracking with only an optional access form from 1999-2002, and also due to a greater number of data sets online from 2005-2007. Ten new or legacy data sets are added online each year on average.

4.7 Computing Environment. The Andrews Forest shares production web and database servers, development servers, and backup servers with the OSU CoF. System and database administration and other services are provided through agreements with OSU CoF Computing Resources. This environment is very beneficial in that it largely frees the IM Team from the burden of system administration and security issues, provides access to state of the art equipment and software programs, enhances digital communication between the field site and campus, and accommodates the cross-institutional diversity among Andrews Forest members. The Andrews Forest Program provides system administration for the on-site local area network that is integrated with the campus network, has established wireless communication at the Andrews Forest Headquarters, and maintains a base station for radio telemetry capture of sensor array measurements.

The current computing environment has allowed the FSDB to expand its LTER data resource holdings into a regional data center that includes key USFS, OSU CoF, and other campaign data, such as from Demonstration of Ecosystem Management Options (DEMO) and Mount St. Helens. The ecosystem informatics IGERT and the summer institute (EISI) programs have also broadened the campus-wide IM perspective to address cyberinfrastructure issues, including sensor networks and quality control of high volume streaming data.

4.8 Network-level Activities. The Andrews Forest LTER program remains very active in LTER Network activities through compliance with network standards, such as the EML harvester and the central searchable database at LTER Network Office, and participation in network-level databases including personnel and the all-site LTER reference bibliography. The lead information manager (Henshaw) chaired the Network Information System Advisory Committee (NISAC) from 2003-2007 and was a member of writing teams on both the LTER Decadal Plan and the LTER Cyberinfrastructure Strategic Plan from 2005-2007. Henshaw currently represents the LTER IM Committee on the LTER Executive Board and is a member of the IMC Executive Committee. The Andrews IM Team participates in NIS research modules and leads development and implementation of the cross-site climate and hydrology harvester and data warehouse (ClimDB/HydroDB). ClimDB/HydroDB (http://www.fsl.orst.edu/climhy) currently includes meteorological and climate data from 39 LTER and USFS sites and two ILTER sites (Taiwan), and we are in the early stage of extension to include stream and precipitation chemistry data and interactive watershed maps of participating sites. In this context and several others, the Andrews Forest LTER and especially its IM program serve as an important conduit for information flow between LTER and USFS and to national and international researchers.

4.9 Future Challenges. New and planned research at the Andrews Forest presents significant cyberinfrastructure challenges that will require increased cyberinfrastructure capacity and the development of new IM approaches to accommodate developing science. We are addressing options to dramatically improve communications by increasing bandwidth between the site and the university and by establishing a wireless cloud encompassing the entire Andrews Forest. The Cyber-Forest goals of LTER6 imply large volumes of data that will require increased efficiency to support data quality and timely flow of data into FSDB (Figure 4.1). New tools for sensor network management, metadata generation, and data visualization will be needed. The demand for near real-time access to these collections will require enhancements of quality control systems (QA/QC) to provide screening of streaming data and to minimize delays in QA/QC and online posting. Solutions to these cyberinfrastructure challenges, which are shared by other LTER sites, will be explored as we acknowledge that a new way of thinking and working is needed to accommodate this new trend in sensor networks, and that information systems need to advance in step with measurements and data.

5.0 OUTREACH AND EDUCATION

5.1. Description of the Program. As home of iconic old-growth forest, headwaters of municipal water supplies, and a principal source of knowledge about Pacific Northwest forests and watersheds, the Andrews Forest attracts public interest and serves as a stage for many forms of outreach and education. Outreach has been a major part of the Andrews Forest program for decades. The foundation of this work is the robust stream of publications in the science literature (See the Supplementary Documentation for a complete list of publications). Also, during LTER5 we added new programs through collaborations with new education partners and colleagues in disciplines with which we had little previous contact, such as engineering, math, computer sciences, and philosophy. The Andrews Forest experiences a continuing stream of more than a thousand visitors per year from around the region and the world, and we employ a great variety of media for communications beyond the forest.

Books documenting the Andrews Forest program and its history have made important steps during LTER5. Jon Luoma's highly readable book *The Hidden Forest* (originally published by Henry Holt in 1999) quickly went out of print and was republished in 2006 by OSU Press (Luoma 2006). A history of the Andrews Forest and especially its community of scientists and land managers was published in 2007 by history professor Max Geier with significant input from Andrews Forest scientists. This book, *Necessary Work* (Geier 2007), is based on 40 recorded oral histories and a wealth of archival material (http://www.fs.fed.us/pnw/publications/gtr687/). The Andrews Forest synthesis volume for the Oxford University Press LTER Network Series is nearing completion. The theme of this book is the development of ideas about how the forest, biota, the watershed, and biogeochemical cycles function, culminating in our current understanding derived from 60 years of work at the forest. (To review the chapters see: http://www.fsl.orst.edu/lter/webmast/hjabook/hjabook.cfm?next=main).

The Andrews Forest education program addresses the full spectrum of student and teacher audiences (Figure 5.1). The core of our Schoolyard LTER has been a collaboration with SMILE (Science and Math Investigative Learning Experiences), an OSU program targeting schools in minority (especially Native American and Hispanic) communities. Many of our K-12 activities focus on teacher training, which allows us to most efficiently reach many students. LTER scientists, graduate students, and technicians work with teachers through the Oregon Natural Resource Education Program, the SMILE program, Teachers in the Woods (based at Portland State University), and NSF's Research Experience for Teachers. During LTER5, we started a new partnership with the local school district with programs involving elementary and junior high science students, and the Teachers in the Woods program has expanded to involve other LTER sites, including CAP, Shortgrass Steppe, Luquillo, and Jornada. Over the period of LTER5 the Andrews Forest has continued to be a destination for field trips, field courses, and tours for more than 15 colleges and universities and many other organizations. Important new, interdisciplinary endeavors, the NSF-sponsored Ecosystem Informatics (EI) IGERT (for 30 PhD students) and the EI Summer Institute for undergraduates (13 students from 12 universities in 2007, its first of 4 years), have brought together students from math, computer science, engineering, and the biophysical sciences. Much of these EI endeavors are based on the Andrews Forest place and allied with its program. For more information about our current education programs, see: http://www.fsl.orst.edu/lter/edu.cfm?topnav=12.

Communication activities related to natural resource management and policy continue to be a hallmark of the Andrews Forest program. These efforts build on the decades-old foundation of the research-management partnership of the Andrews Forest science community and the Willamette National Forest, now called the Central Cascade Adaptive Management Partnership (http://www.reo.gov/ecoshare/ccamp/index.shtml). Andrews Forest scientists participate in the adaptive aspect of the coupled natural/human system through their continuing engagement in this research-management partnership, which is constantly developing and testing new ideas about natural resource management, and also through shorter-term processes for input to policy at state and federal levels (Table 5.1). Through the partnership researchers and land managers conduct applied studies and experiments of forest stand, watershed, and landscape management, which are focal points for many field discussions and publications for public readers (e.g., Rapp 2002, Thompson 2007) concerning the future of forest ecosystems and management in the region. The Blue River Landscape Plan and Study (Cissel et al. 1999) continues to be conducted in an adaptive management manner, with periodic updates drawing in current science. The concepts behind this project, using an understanding of historic disturbance regimes to guide future landscape management, are of wide interest in the US and Canada.

The Blue River project is one of a very small set of case studies using this history-based approach, so we are asked to present lessons in national and international scientific meetings such as ESA, IALE, as well as at National Forest Service meetings. Other collaborative science activities with policy and management impact include restoration of montane meadows experiencing forest encroachment, management of dead wood in terrestrial and aquatic systems, and carbon sequestration in forests (Table 5.1). We are often consulted about how this research-management partnership functions – most recently by visiting delegations of research and forestry leaders from Sweden and Tasmania.

Important new programs linking the Andrews Forest with the humanities combine scholarship with outreach. The Long-Term Ecological Reflections program is a collaboration of the Andrews Forest ecosystem program with the privately-endowed Spring Creek Project in the Philosophy Department in OSU (Swanson et al. in press, http://www.fsl.orst.edu/lter/research/related/writers.cfm?topnav=167). Funded in part by the Forest Service, the Reflections program has brought 13 writers (as of fall 2007) into one-week residencies at the Andrews Forest and also supported two- to four-day gatherings of writers and scientists to ponder issues such as the meaning of watershed health and new metaphors for restoration of watersheds. A body of evocative and provocative writings is emerging in print (see webpage). We have begun a scholars-in-residence program for scientists and writers working on books of relevant subject matter to spend quiet, productive time at the Andrews Forest. This work in the humanities is reaching audiences we have never addressed before.

As the Andrews Forest Program has aged and grown over the decades, the list of active workers, veterans, alumnae, and interested observers has also grown. We now use a twice-yearly newsletter (http://www.fsl.orst.edu/lter/pubs/newsletter.cfm?topnav=170) to keep these folks informed about the program, and to encourage their contributions to the Andrews Forest Fund in the OSU Foundation, which supports important work not funded through other sources.

Outreach to the public takes place through interactions with regional media (e.g., newspaper articles and Public Broadcasting stories); Science Finding reports of the PNW Research Station (e.g., Thompson 2007); field tours with public groups; articles in Terra the OSU research magazine); public lectures; the Lookout Old-growth trail (interpretive trail complemented by a web-based virtual field tour). Several of these public communication events have featured our long-term experiments, such as log decomposition and DIRT, which are in their third and second decades of implementation.

5.2. Future Plans. We plan to continue most of our current outreach and education programs. A major change in our program for LTER6 will be with our partner for Schoolyard LTER. While we have had a very successful partnership with the SMILE Program, we will be refocusing our Schoolyard LTER activities during LTER6 to provide greater integration of our education and research programs. During LTER6, we will collaborate with the Oregon Natural Resources Education Program (ONREP) to develop a Secondary Teacher-Researcher Partnership, and this will serve as our main Schoolyard LTER activity for the coming funding cycle. ONREP focuses entirely on natural resources (vs. SMILE which focuses on math, and physical sciences as well as biological sciences), so they are a better fit for this goal. The Teacher-Researcher Partnership will be developed in two phases. The first phase will engage secondary teachers in workshops located at Experimental Forests in the Pacific Northwest (Andrews Forest, Starkey Experimental Forest and Range, and Wind River Experimental Forest). At all three workshops, teachers will learn about studies of phenology, trophic interactions and climate, which are major foci of the proposed research for LTER6. Researchers and mentor/master teachers will be resources as teachers develop a schoolyard phenology research project to be conducted with their students. The second phase of the project will involve participants from the teacher workshops and a team of their students in LTER6 phenology field data collection at the Andrews Forest (see Section 2.4.2). We are currently developing plans to seek external funding to expand this partnership.

Table 1.1. Long term core measurements at the Andrews Forest LTER, grouped by the topics of the central question.

Core Measurements	# sites >10yrs	Start year	Specific Parameters	Descriptive publication (see webpage)	Data codes
Climate					
Precipitation	5	1952	volume	Bierlmaier & McKee 1989	MS001
Air temperature	33	1958	4 heights	Bierlmaier & McKee 1989; Smith 2002	MS001, MS005
Incoming radiation	4	1972	net and PAR	Bierlmaier & McKee 1989, Greenland 1997	MS001
Wind	5	1973	speed and direction	Pypker et al. 2007a, b	MS001, TW002
Relative humidity	6	1958	percent	Bierlmaier & McKee 1989	MS001
Stream temperature	7	1958	paired stream/air temperature	Johnson & Jones 2000	HT004
Soil temperature	28	1971	4 depths	Rothacher et al. 1967	MS001, MS005
Disturbance					
Mass movements	survey	1964	landslides, debris flows	Swanson & Dyrness 1975; Snyder 2000	GE007, GE012
Floods	5	1978	channel cross-sections	Faustini & Jones 2003	GS002
Fire	survey	1979	tree rings and cores, stump scars	Burke 1979; Weisburg & Swanson 2003	DF014, DF020
Landuse					
Harvest history	survey	1952	year and stand density, GIS		TP054, TP073
Roads	survey	1990	year constructed, GIS	Wemple et al. 1996	GI007
Hydrology					
Streamflow	10	1951	stage height, discharge	Jones & Grant 1996; Jones 2000	HF004, HF007
Snow melt	5	1978	snowmelt, depth, and water equiv		MS001, MS007
Soil moisture	4	1985	potential, fractional	Rothacher et al. 1967	MS001
Transpiration	6	1999	sapflow - 10 trees per site	Bond et al. 2002; Moore et al. 2004	TW003
Carbon and nutrients					
Water chemistry	9	1968	precip and stream, C, N, P, ions	Martin & Harr 1988, 1989; Vanderbilt et al. 2002	CP002, CF002
Sediment export	10	1958	bedload, suspended sediment	Grant & Wolfe 1991	HS003, HS004
Soil - DIRT experiments	1	1997	soil leachates, respiration, stores	Holub et al. 2001; Lajtha et al. 2005	SP031, TN021
Wood decomposition	6	1985	mass, volume, N, P, and cations	Harmon et al. 2000; Harmon et al. 1986	TD014, TD021
Root decomposition	6	1995	mass, volume, N, P, and cations	Chen et al. 2001	TD017
Litter and decomposition	12	1995	inputs and mass remaining	Harmon et al. 1999; Gholz et al. 2000	TL001
Streamwood	2	1985	location, decay class, movement	Faustini & Jones 2003; Gregory et al. 2003	GS006
Biodiversity					
Unmanaged vegetation	35	1912	biomass, mortality, NPP, vascular	Smithwick et al. 2002; Acker et al. 2002	TV010, TP115
Post harvest vegetation	5	1966	biomass, mort, NPP, C stores, vascular	Halpern & Franklin 1989; Lutz & Halpern 2006	TP073, TP114
Vegetation phenology	3	1979	leaf out/off, flowering		TV073
Exotic plants	survey	1994	road presence/absence 11 spp	Parendes & Jones 2000; Sheehy 2006	SA023
Arthropods	12	1994	numbers and species	Parsons et al. 1991; Lattin & Miller 1996	SA015
Fish	2	1987	numbers and sizes	Bisson et al. 2003; Van Sickle et al. 2004	AS006, SA001

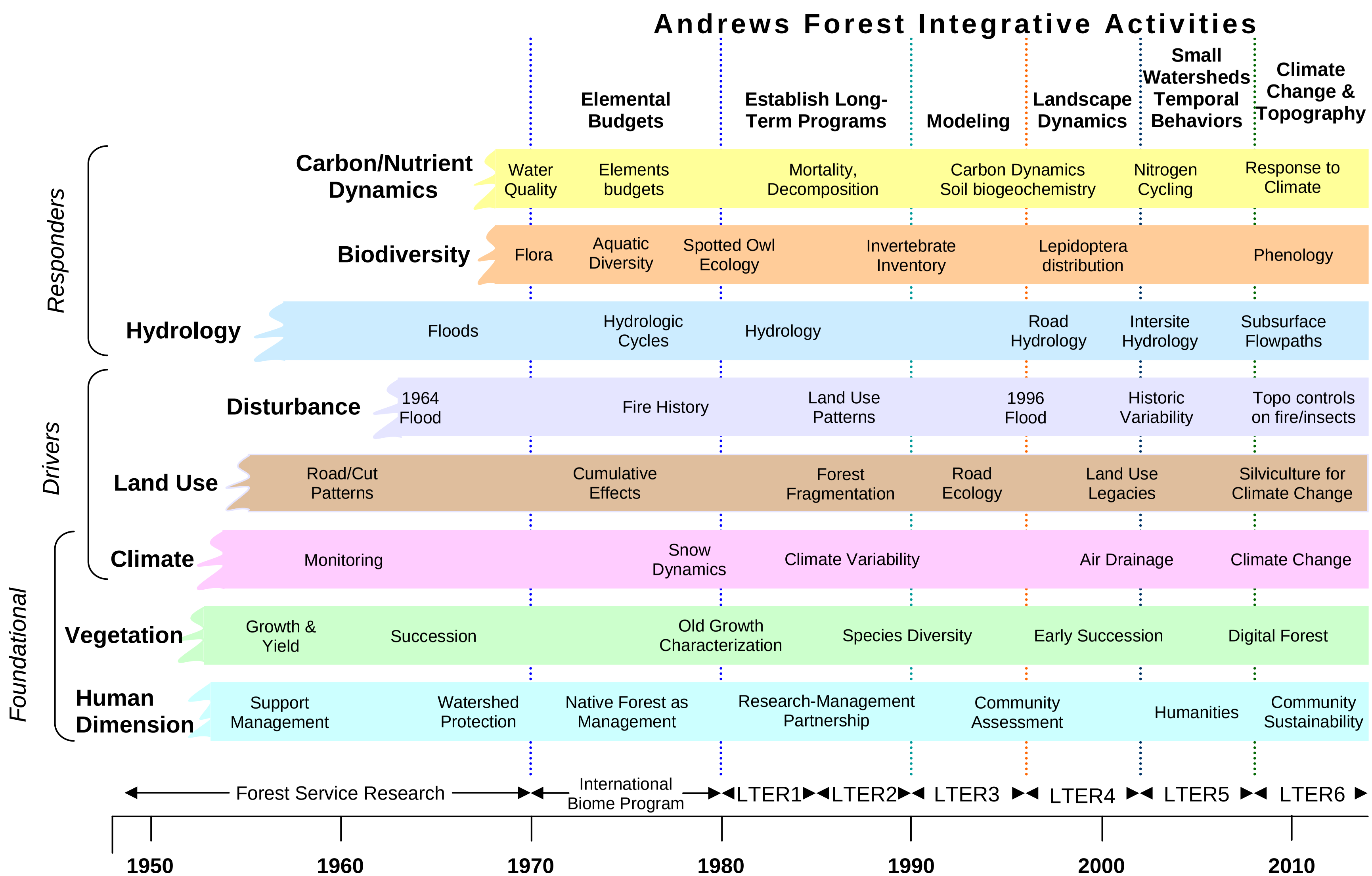


Figure 1.1. Timeline of major research themes (horizontal bars), prominent topics within each theme (e.g., Water Quality within Carbon/Nutrient Dynamics theme bar), and integrative activities (integration across several themes during a grant period, such as LTER5, as a vertical time slice through the themes). Over time the level of integration has increased, weaving the individual themes into a more holistic, interdisciplinary view of ecosystem structure and function. See http://www.fsl.orst.edu/lter/about/site/history/HJA_Timeline_0708.pdf for more detail.

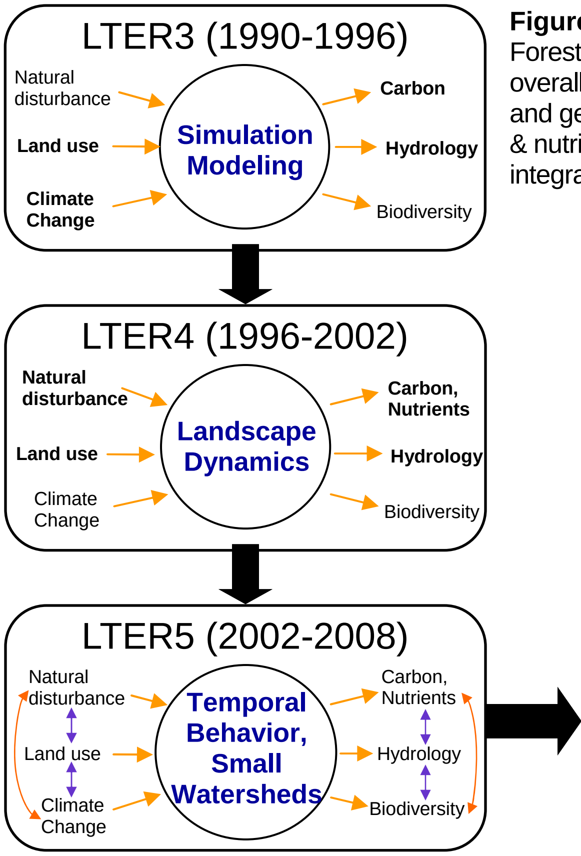
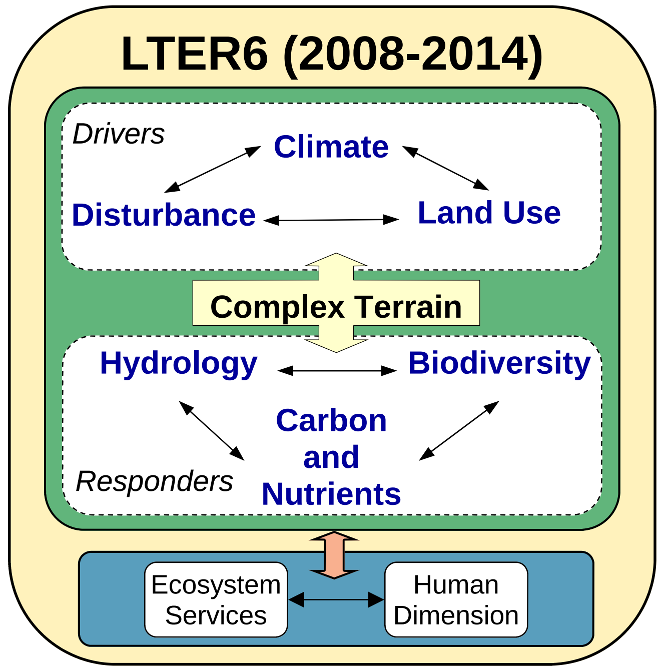
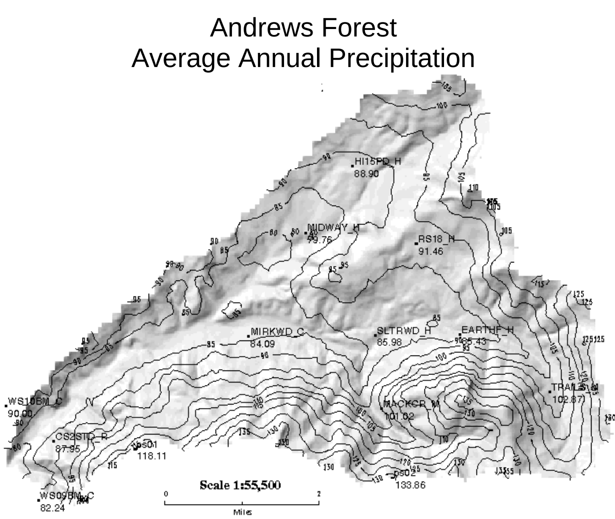


Figure 1.2. Evolution of the central question for the Andrews Forest LTER since 1990, showing the drivers from outside the overall system (natural disturbance, land use and climate change) and general classes of response variables or responders (carbon & nutrients, hydrology, and biodiversity). Major research integrative themes for LTER3-5 are within circles.





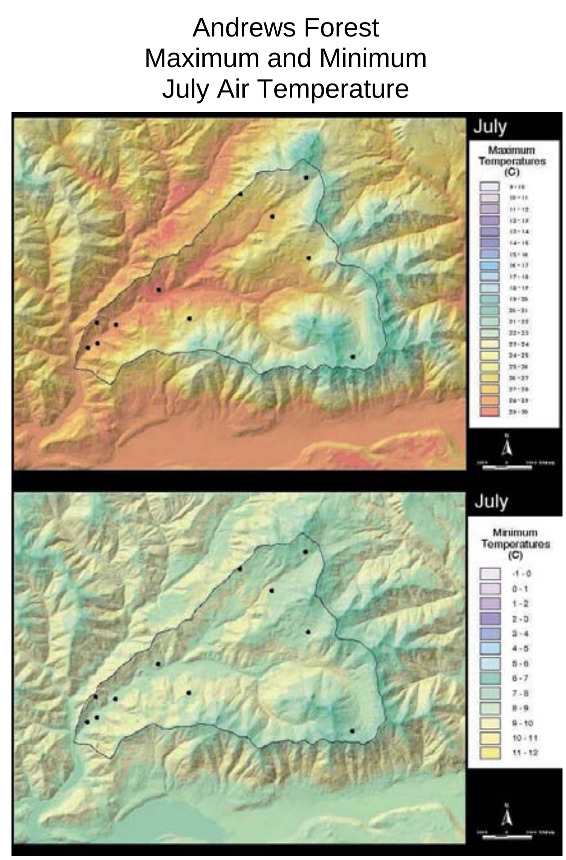


Figure 1.3. Precipitation and temperature are strongly influenced by complex terrain at the Andrews Forest. Orographic effects produce 50% more annual precipitation at high vs. low elevation along the southern bounding ridge, but the northern ridge, in a rain shadow, has similar precipitation to the valley. Daily maximum temperatures in July vary over 10°C with elevation, whereas nighttime minimum temperatures in July vary by only 4°C and show ponding of cooler air (pale green) in the valley, due to cold air drainage. Black dots are long-term temperature measurement sites.

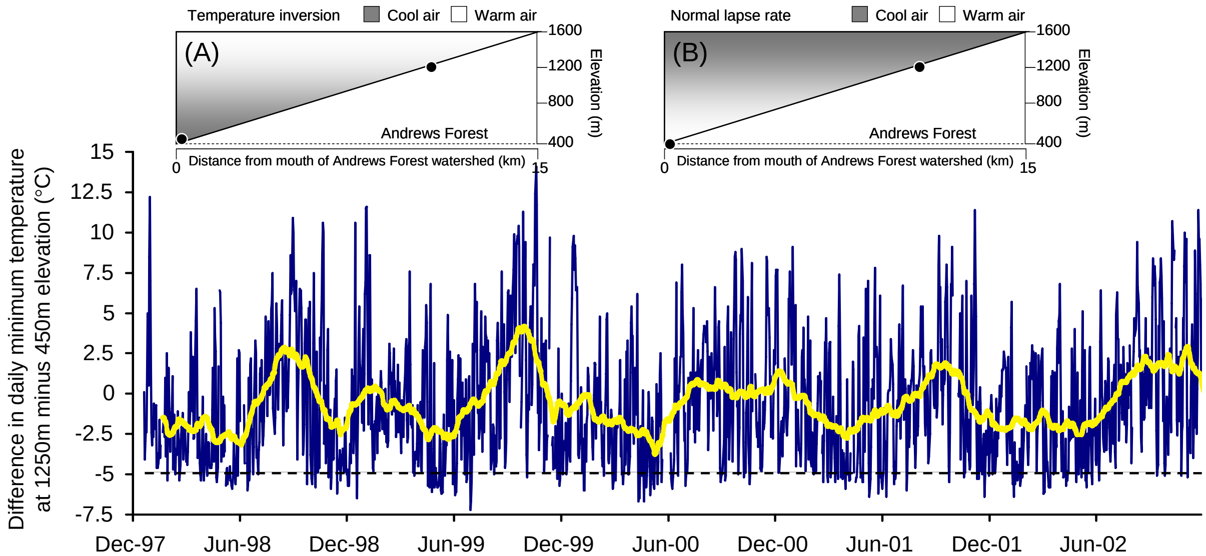
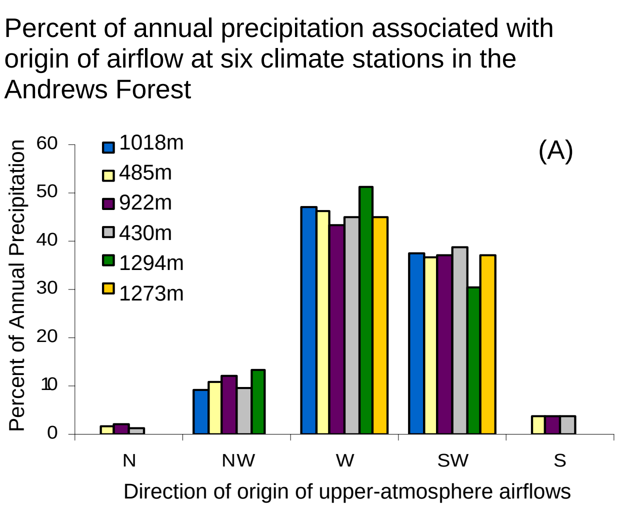


Figure 1.4. For much of the time, minimum temperatures at 1250m are higher than at 450m in the Andrews Forest, contrary to what would be expected from the global mean (or "normal") lapse rate (-5.1° C over 800m, dashed line). On average (60-day running mean, pale line) temperature inversions occur in September during anti-cyclonic flow (high pressure descending dry air), and cold air drainage accumulates in the valley of the Andrews Forest (inset A). In April/May, cyclonic flow (low pressure, rising moist air) and surface heating mixes atmospheric layers more effectively (inset B). High variability in the graph indicates dynamic local atmospheric conditions.



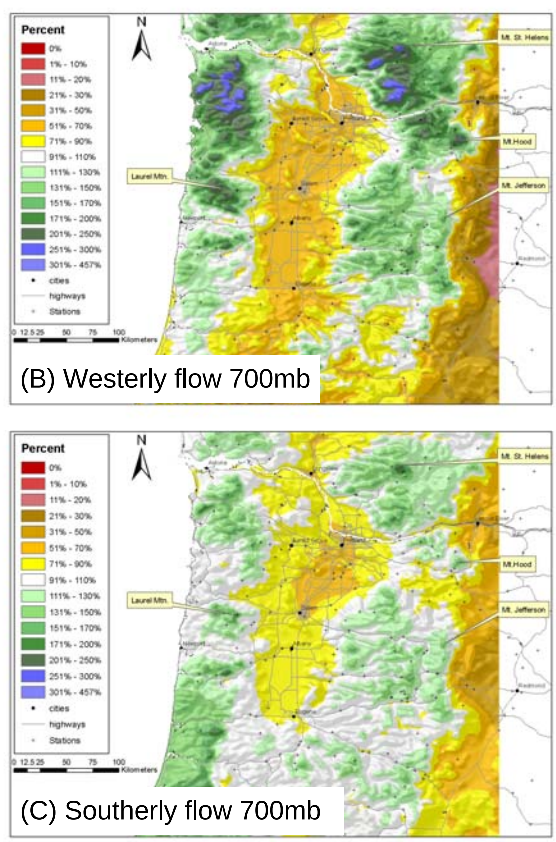
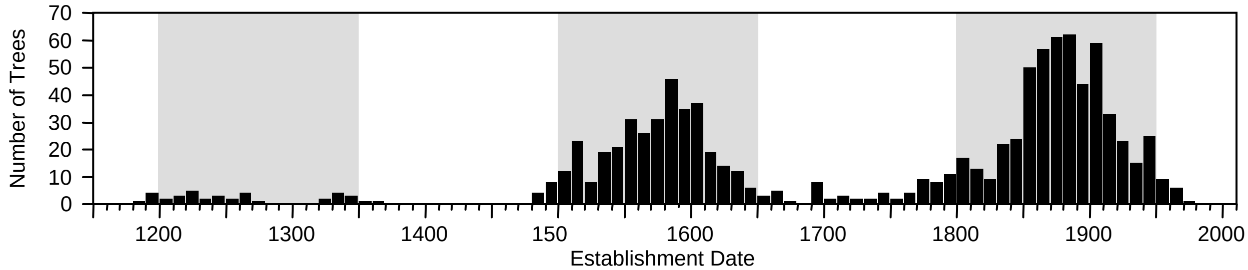


Figure 1.5. Upper-atmosphere airflows originating from the Pacific Ocean bring winter precipitation to the Andrews Forest, but the direction of origin of these airflows influences the strength of the orographic effect (graph A). For storms originating from the W and NW, precipitation is greater at high (green bars) vs. low (grey bars) elevation (map B), but for storms originating from the SW, precipitation is lower at high (green bars) vs. low (grey bars) elevation (map C).



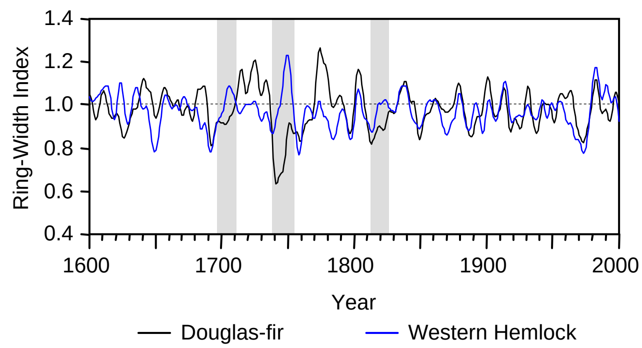


Figure 1.6. Dendrochronologic records indicate fire and insect defoliation in Andrews Forest and vicinity. Above: Douglas-fir age distribution showing ca. 150-yr periods (shaded) of high and low incidence of fire that may in part reflect climate influence. Right: Tree-ring chronologies for Douglas-fir and western hemlock, which are host and non-host species, respectively, for the defoliator western spruce budworm. Shading indicates major budworm outbreaks inferred from criteria of growth reduction for host species and neutral or positive response of non-host trees.

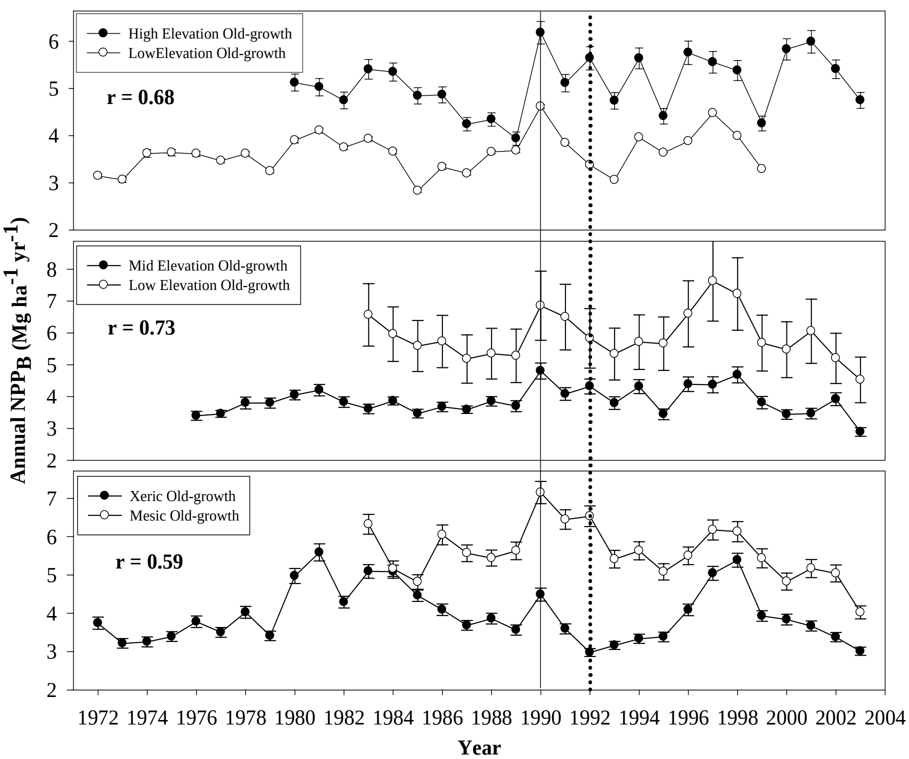


Figure 1.7. Annual net primary productivity of tree boles (NPP$_B$) over time for six sites of varying age, elevation, and moisture regime. Panels represent comparisons within age classes. Vertical solid lines indicate high degree of spatial coherence in that year for all sites. Dotted lines indicate decreased spatial coherence in that year. Error bars are the SD of 10,000 Monte Carlo simulations.

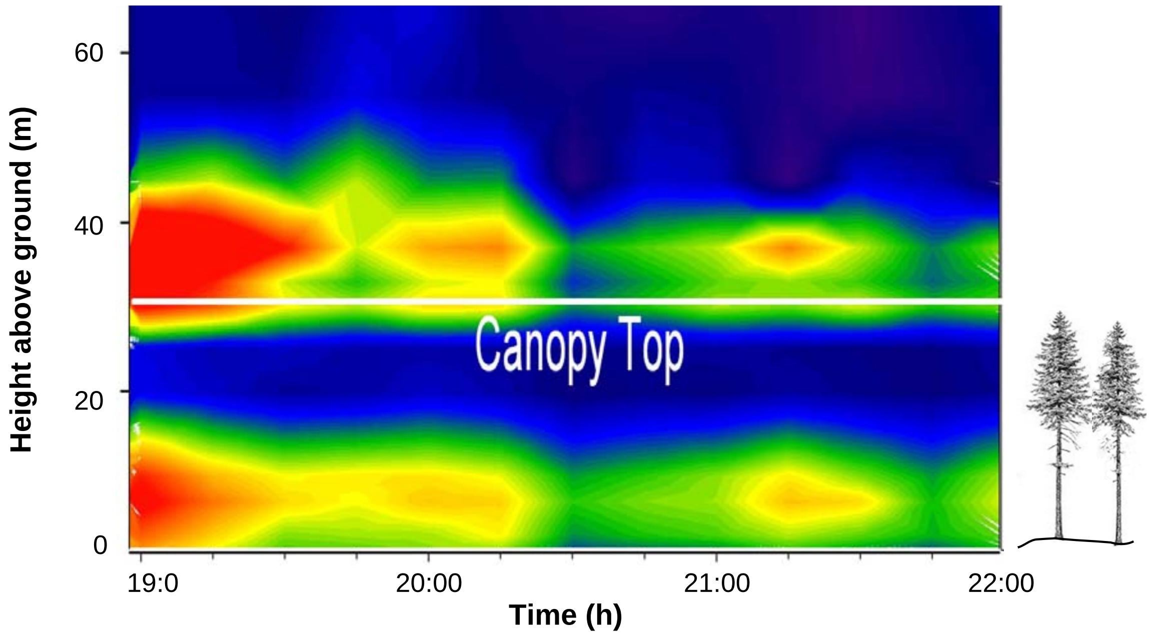


Figure 1.8. Nocturnal cold air drainage (i.e., "katabatic flow") at the base of an Andrews Forest small watershed (Watershed 1) is manifest as two distinct jets of air, one just above the canopy and one in the canopy trunk space. The colors in the figure indicate windspeed, ranging from nearly still air (blue) to swift (1.0 ms-1) (red). These measurements and others indicate that there is a strong "inversion cap" on the watershed that isolates the air in the drainage flow from the bulk air. As a result, the net exchange of gases between the canopy and the atmosphere in the entire 96-ha basin is nearly 100% advective at night. These conditions occur on almost all clear nights in the spring through fall.

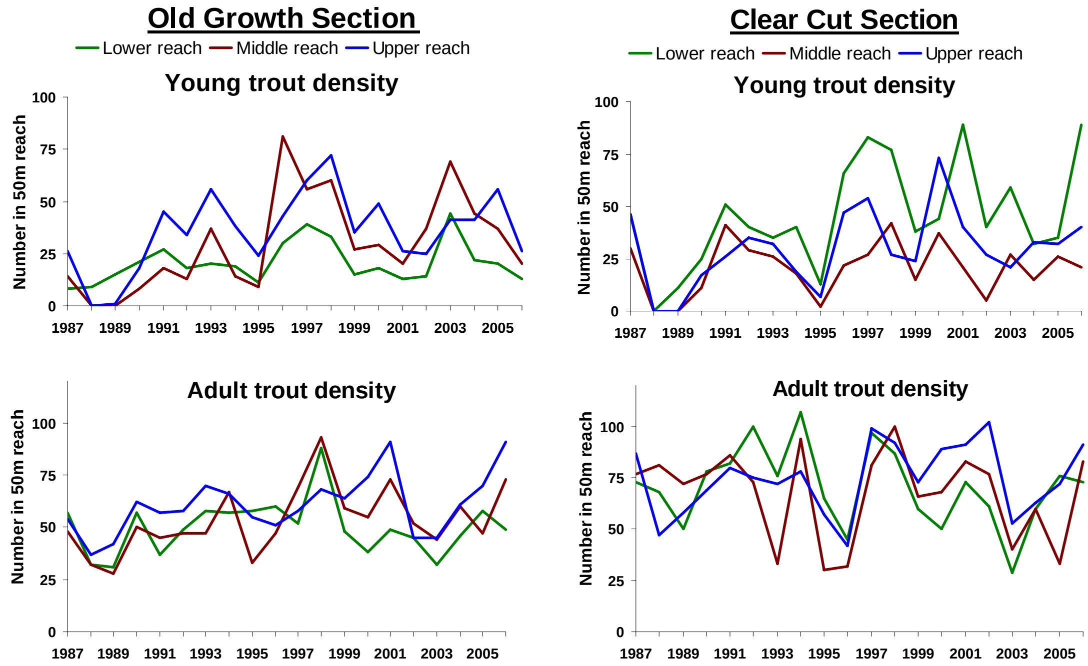


Figure 1.9. Densities of cutthroat trout in Mack Creek at the Andrews Forest have higher correlations (more coherent) at fine spatial scales and for specific life stages (young of year versus adult) but less so between life stages or with distance between sites. However, the abiotic processes likely driving the variation are coherent between sections.

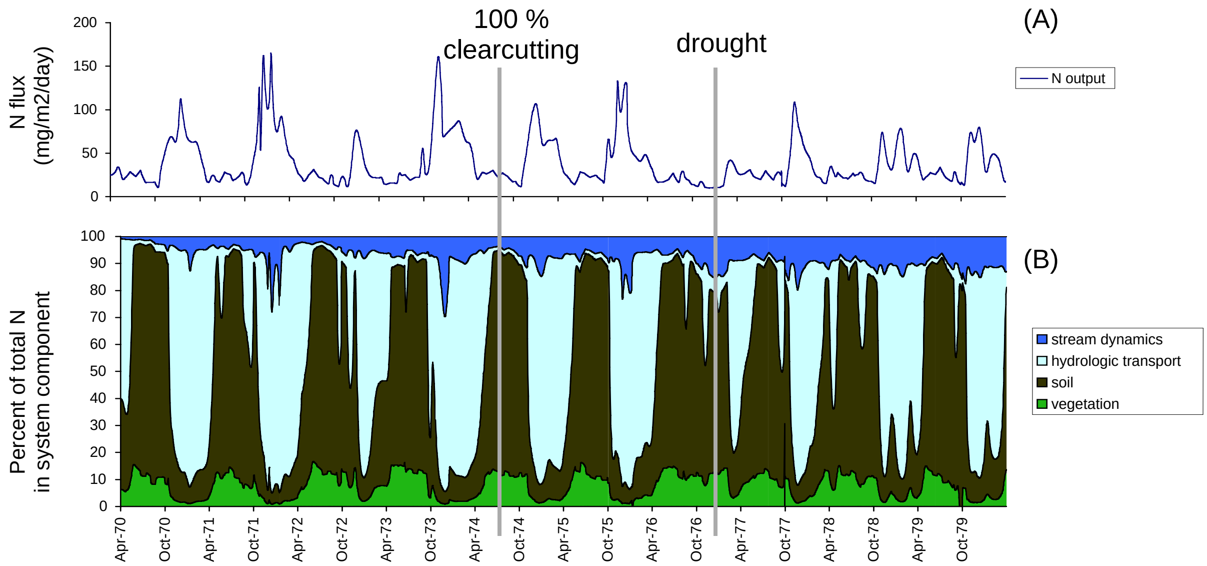


Figure 1.10. Efficient utilization of N along gravitational flowpaths appears to explain insensitivity of N cycling to major disturbances. (A) Total N export, 1970-1980 and (B) percent of N in fluxes within various components of a small watershed at the Andrews Forest, based on models from small watershed synthesis in LTER5. N output and dynamics were insensitive to 100% clearcutting, somewhat sensitive to drought, and very sensitive to seasonal summer/winter differences. Roughly 80% of N processing occurs in soil (in summer) and "hydrologic transport" (water flowpaths) (in winter); 10% occurs as instream processing ("stream dynamics"), although streams occupy 1% of watershed area; and only 10% occurs in vegetation (despite high biomass before cutting). N output is highest in winter, when high precipitation produces high hydrologic transport of DON in soils, hillslopes, and the stream. During summers, N is taken up in soil and vegetation and output is low.

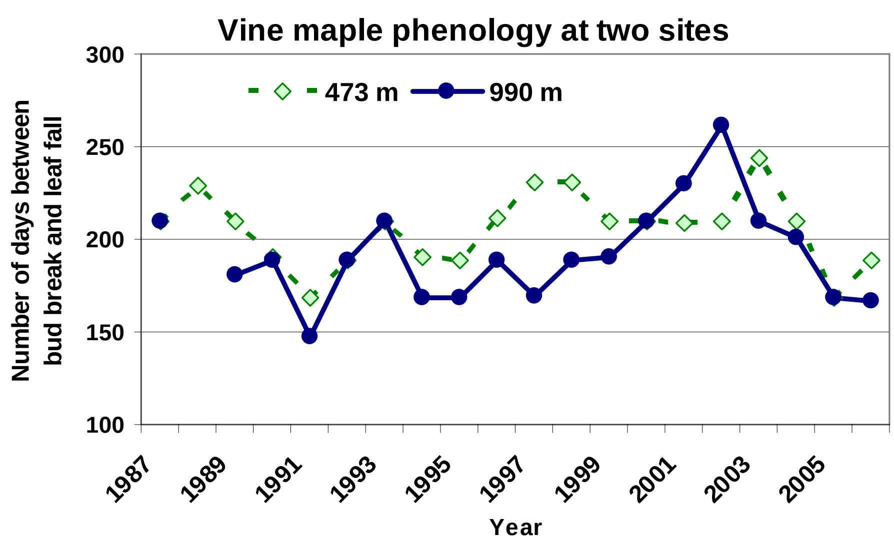


Figure 1.11. The length of the active growing season for a single species at different locations provides a metric of the biological integration of microclimate. For vine maple, a widely-occurring shrub, the active growing season varies widely from year to year and also between sites, reflecting the spatial and temporal complexity of microclimate at the Andrews Forest. There is no indication that these plants have responded to long-term climate change over the past 20 years, and there is no consistent difference in growing season with elevation.

Table 2.1. Glossary of Terms.

<u>Buffered</u>: Decreased sensitivity (see below) of response variables to controlling variables.

Cold air drainage: Winds that blow downslope in mountainous areas as a result of local, gravitational influences. Occurs when radiation of energy from the surface (e.g., top of canopy) causes surrounding air to cool, and gravity causes the denser air to sink (Simpson 1997). The process is most pronounced at night, although it also occurs on shaded slopes in daylight, and in stable atmospheric conditions, although air within the drainage flow may be turbulent

<u>Complex terrain</u>: A region having irregular topography, such as mountains or coastlines. Complex terrain often generates local circulations, or modifies ambient synoptic weather features, to create unique local weather characteristics such as katabatic winds, anabatic clouds, and sea breezes (American Meteorological Society 2000).

<u>Coupled</u>: Two things that are joined together (Webster's New World College Dictionary 2004); often used in biology to describe stimulus-response relationships (e.g., Gates 2003) and in climate studies to describe land surface-atmosphere relationships. We use this term in two ways: 1) to describe the sensitivity (see below) of properties of the of the land surface to the atmosphere, and 2) to denote relationships between natural and human systems.

<u>Ecosystem Driver</u>: A driver is any natural or human-induced factor that directly or indirectly causes a change in an ecosystem. A driver comes from outside the system (Millennium Ecosystem Assessment 2005).

<u>Ecosystem Responders</u>: A part of the ecosystem that could potentially respond to a driver of change. A responder is within the system (Millennium Ecosystem Assessment 2005).

<u>Sensitivity</u>: A measure of the amount of change in a response variable relative to change in a controlling variable: i.e., the characteristics of the response function.

Table 2.2. Future scenarios to be used in simulation model experiments related to Goal II. Scenarios for the drivers will initially be examined separately and then in combination.

<u>Climate Change Scenarios</u>

1. Current climate scenario: Temperature and precipitation conditions similar to the past 30 years in terms of average and variability
2. Moderate change scenario: Summer mean temperature + 3˚C/century; little change in summer precipitation; longer summer dry season. Winter mean temperature + 2.5˚C/century; fewer cold events; 15% change in precipitation totals, intensity over fewer events, greater inter-annual variability
3. Rapid climate change scenario. Summer mean temperature + 4.5˚C/century. Winter mean temperature + 2.5˚C/century. Otherwise, same as scenario 2

<u>Land Use Scenarios</u> (all include fire suppression)

1. Current policy of limited harvest to enhance late successional structures
2. No forest harvest
3. Forest harvest that simulates historic disturbance regime of fire in terms of interval and area
4. Intensive industrial-style management of frequent and complete harvest with rapid restocking
5. Thinning harvests of forest to reduce water demand and replace species rapidly

<u>Disturbance Regimes</u>

1. Current fire frequency and severity but without fire suppression
2. Increased fire frequency and severity due to longer, drier summer season
3. Increased insect outbreaks from spruce budworm, Douglas-fir bark beetle, or gypsy moth

<u>Combined Scenarios</u>

1. Fire frequency/severity predicted from climate change scenarios and fuel levels
2. Other combinations

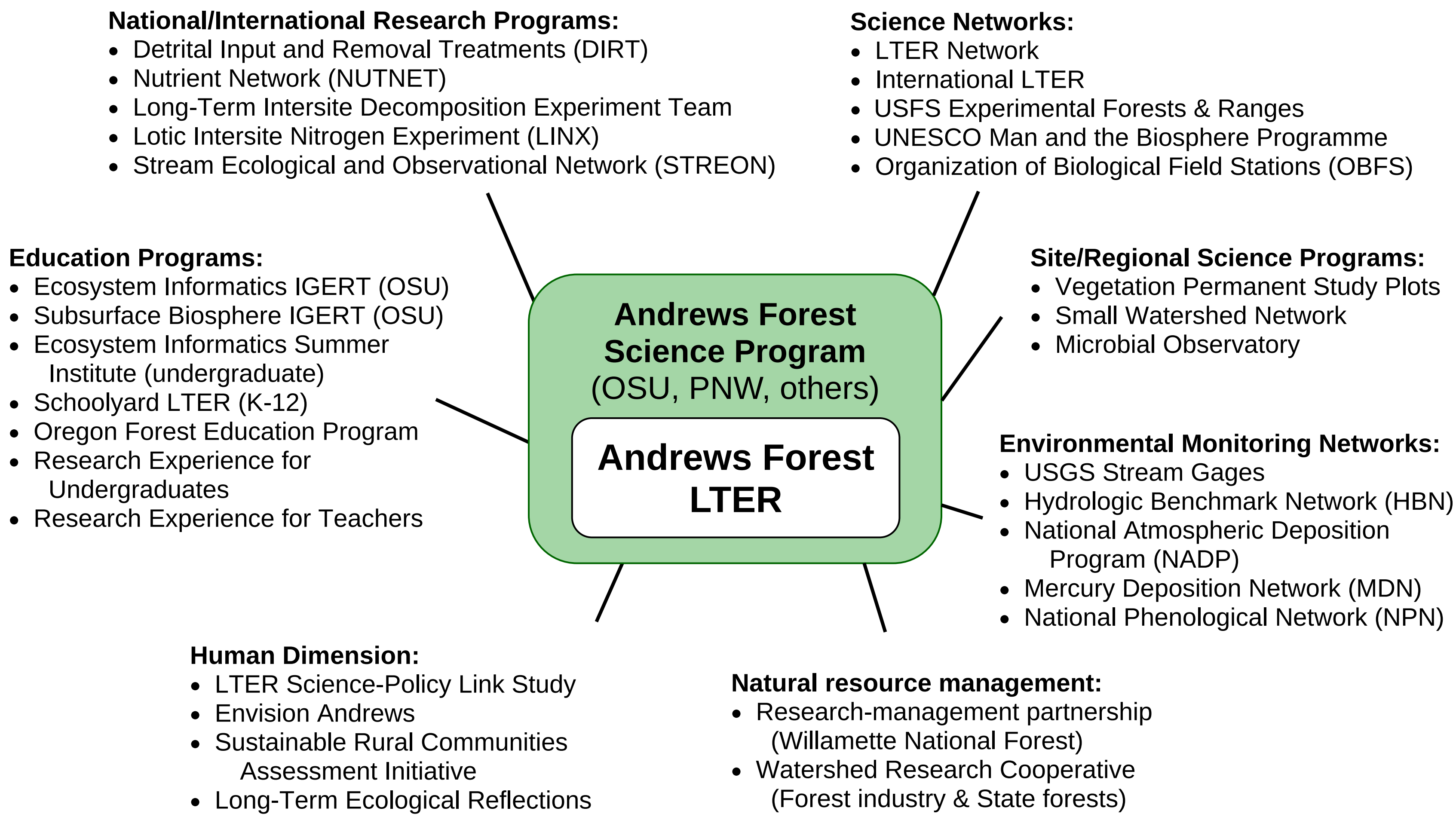
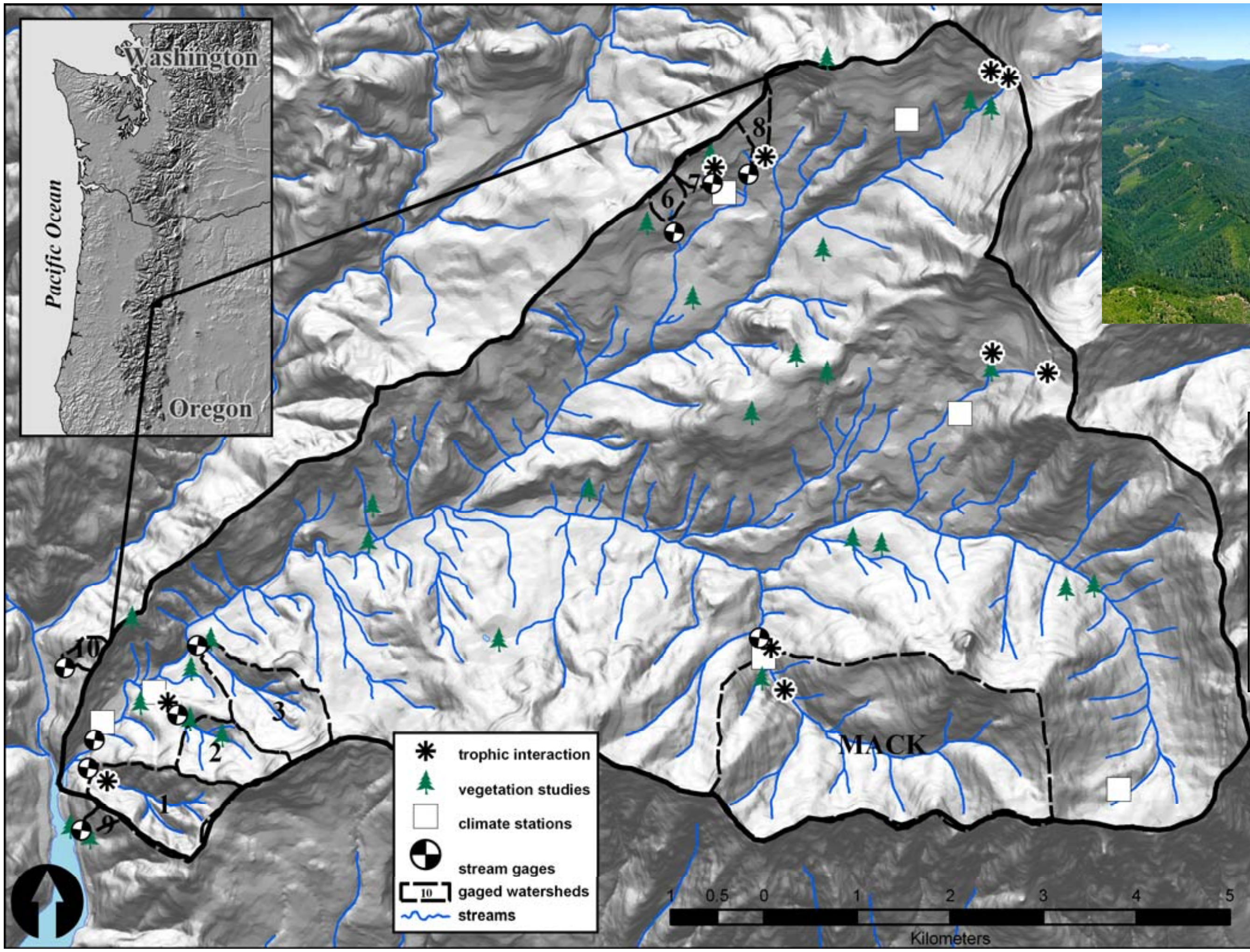


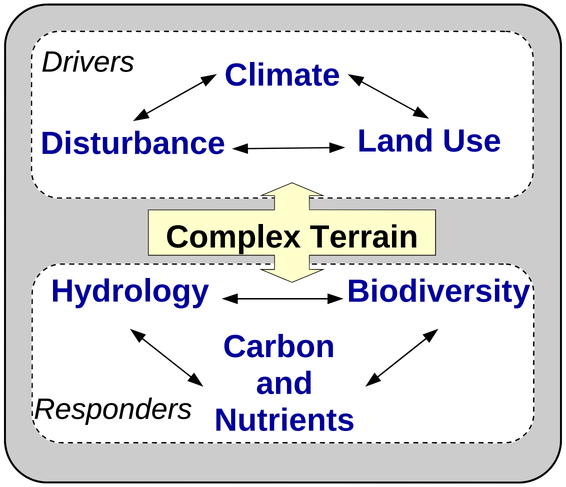
Figure 2.1. Examples of major elements of the larger Andrews Forest program linked with the Long-Term Ecological Research Program. This is a partial list to represent our commitment to: (1) participating and where appropriate leading intersite and regional work, (2) operating within key efforts of intersite science networks including things like providing leadership in IM in LTER/ILTER, including data harvester systems, and (3) pushing intersite work during LTER6, such as LTEReflections and human dimension programs. *Acronyms*: OSU: Oregon State University; PNW: Pacific Northwest Research Station; USFS: US Forest Service; UNESCO: United Nations Educational, Scientific and Cultural Organization; USGS: US Geological Survey; IGERT: NSF Integrative Graduate Education & Research Traineeship.



Aerial photograph of the Andrews Forest.

Digital orthophoto of the Andrews Forest from Google Earth.

Figure 2.2. Digital elevation image of the H.J. Andrews Experimental Forest showing boundary and location of important study sites. Note that trophic, vegetation, climate, and stream measurements are collocated in several places. The Andrews Forest (64 km2) is part of the upper Blue River basin (175 km2) located on the western slope of the Cascade Mountain Range which is characterized by steep terrain and bouldery streams. Long-term records are maintained at meteorological stations, gauging stations, and reference forest stands. The Andrews Forest is also the repository for long-term datasets from vegetation plots and small watersheds within the region. Roughly ¾ of the Andrews Forest and Blue River is covered by unmanaged Douglas-fir and western hemlock forest ranging from 120 to over 500 years in age. The remaining area is occupied by forest plantations established mostly between 1950 and 1980.



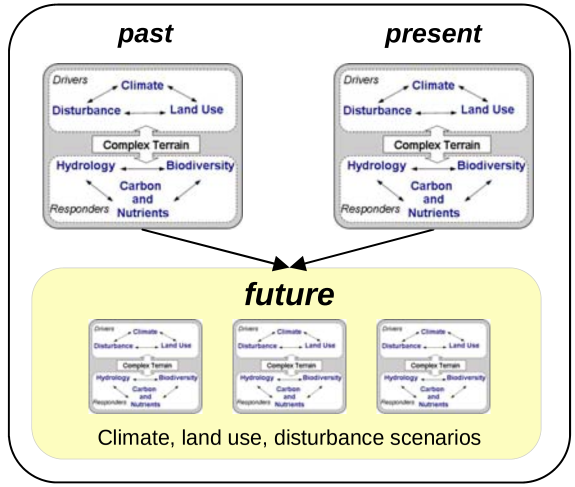
(A). **Goal I: Complex terrain and canopy cover moderate interactions between drivers and responders**

Multiple processes at micro-, meso-, and regional scales affect relationships between microclimate and regional climate.

Cold air drainage transiently decouples low elevation microclimates from regional climate; hence low elevation is less sensitive than high elevation to climate variability.

Heterogeneity and multiple flow paths of C, N and water cycle processes at small scales reduce sensitivity of fluxes and flows at larger scales to variability in drivers.

Complex terrain alters the sensitivity of trophic interactions to drivers.

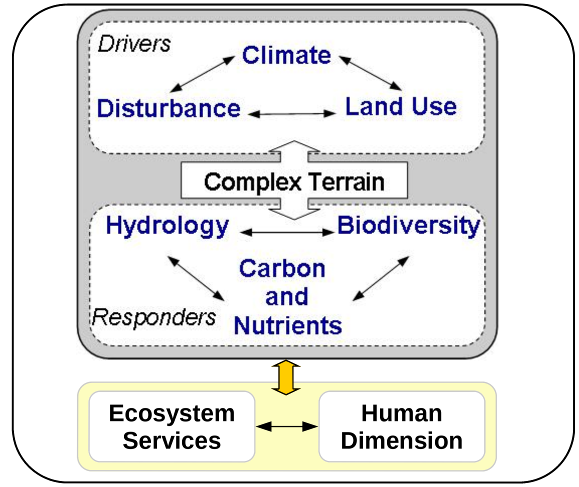


(B). **Goal II - Complex terrain moderates ecosystem responses to future change**

High elevation will be more sensitive than low elevation to climate change due to tighter atmospheric coupling and rain/snow threshold

Climate-induced changes in disturbance (fire, pests) will have greater impact on future ecosystem structure and function than will the direct effects of climate change.

Complex terrain will mitigate potential trophic responses to climate change, such as asynchrony in phenology.



(C). **Goal III - Shared understanding of roles and capacities among environmental scientists, social scientists and local communities and institutions promotes adaptive management for future change.**

Social networks and research-management partnerships are required to develop policies for forest management for future climate change.

Exploration of alternative futures helps communities and institutions make choices, openly and adaptively.

Societal decisions about natural resource use depend on awareness of ecological services

Figure 2.3 Goals for the Andrews Forest LTER6 with abstracts of key ideas.

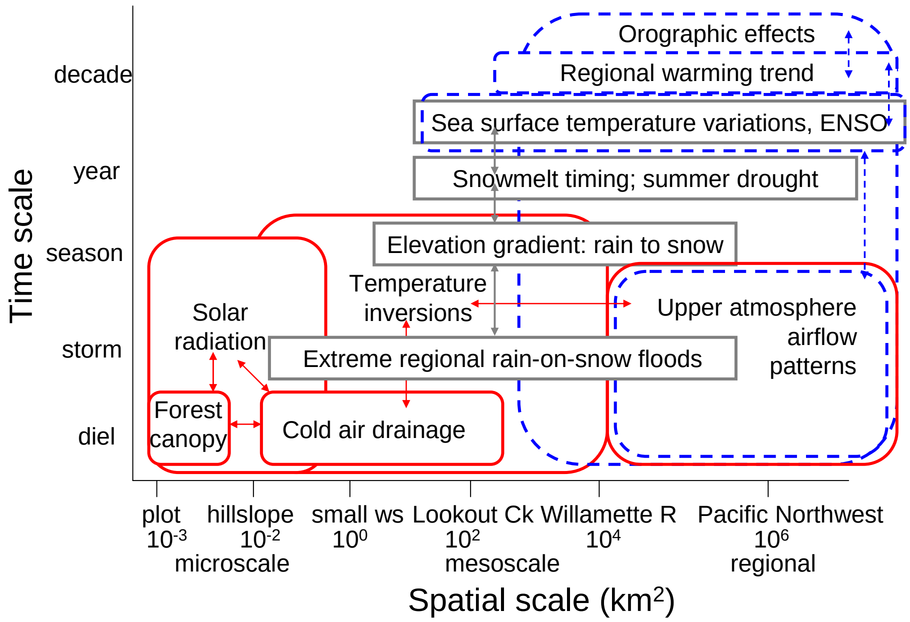


Figure 2.4. In LTER6 we aim to understand and model the influence of regional, meso- and micro-scale processes on microclimate in complex terrain (Goal I) in order to project potential impacts of regional climate change on our site (Goal II). We will examine (1) how solar radiation at forest canopy and hillslope microscales produces differential heating, cooling, and cold air drainage, which in turn lead to temperature inversions and how the canopy also affects miroclimate by altering the hydrologic cycle (red solid lines); (2) coupling of Andrews Forest microclimates to mesoscale and regional climate dynamics (blue dashed lines); and (3) how regional, long-term climate trends influence snowmelt timing, summer drought, snow elevation, and extreme floods (gray lines).

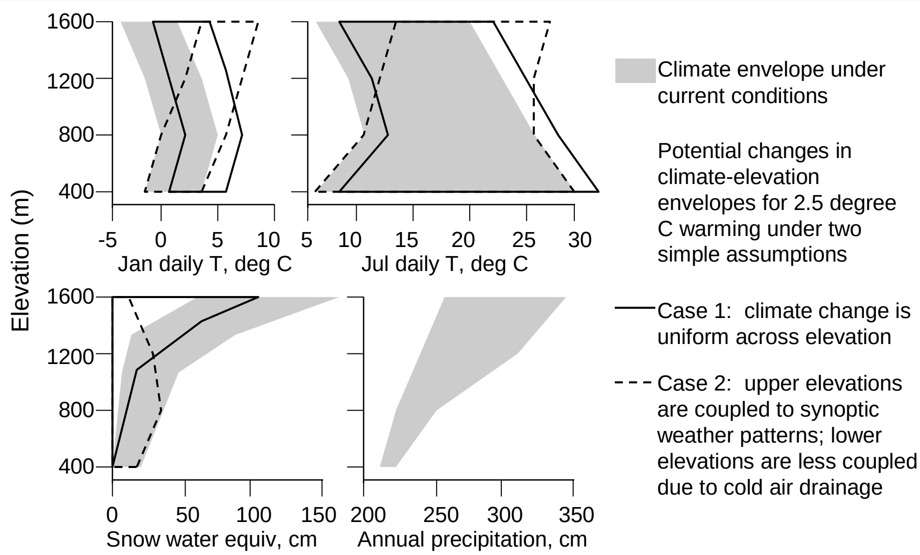


Figure 2.5. Complex terrain produces nonlinear gradients in current climate conditions across complex terrain (grey shading) at the Andrews Forest (Goal I). Cold air drainage produces inversions in January and July and higher variability of July temperatures at low elevation. Combined orographic and rain-shadow effects produce higher variability of precipitation (and snowpack) at high vs. low elevation. Complex terrain may interact with climate warming to moderate or exacerbate climate warming effects, depending on elevation (Goal II). A 2.5°C warming might shift climate envelopes consistently at all elevations (solid outlines); however, if high elevations are strongly coupled with regional climate they may experience more warming, whereas low elevations may be insensitive to regional warming because of cold air drainage (dashed outlines).

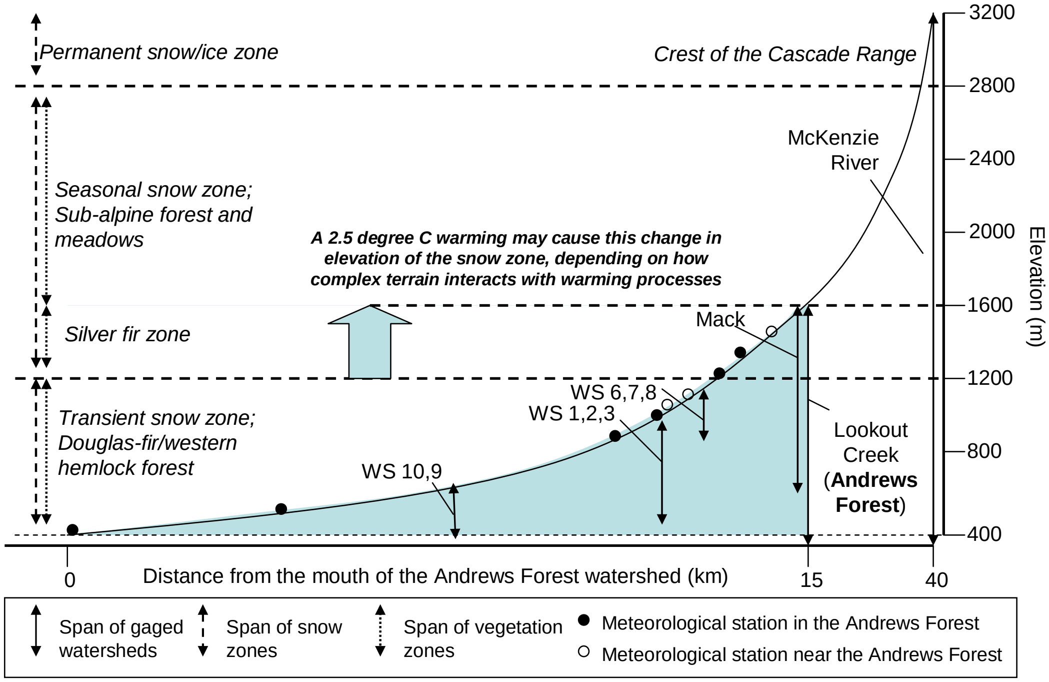


Figure 2.6. Climate interactions with topography within the Andrews Forest (shaded area) and surrounding landforms in the high Cascades are displayed by a schematic hyposmetric curve, and captured by an array of climate stations and stream gages spanning the major rain/snow and vegetation zones. Most of the area of the Andrews Forest is in the transient snow zone with Douglas-fir and western hemlock forest. We expect climate change to affect the boundary of the transient and seasonal snow zones, associated ecotones, and rain-on-snow flooding.

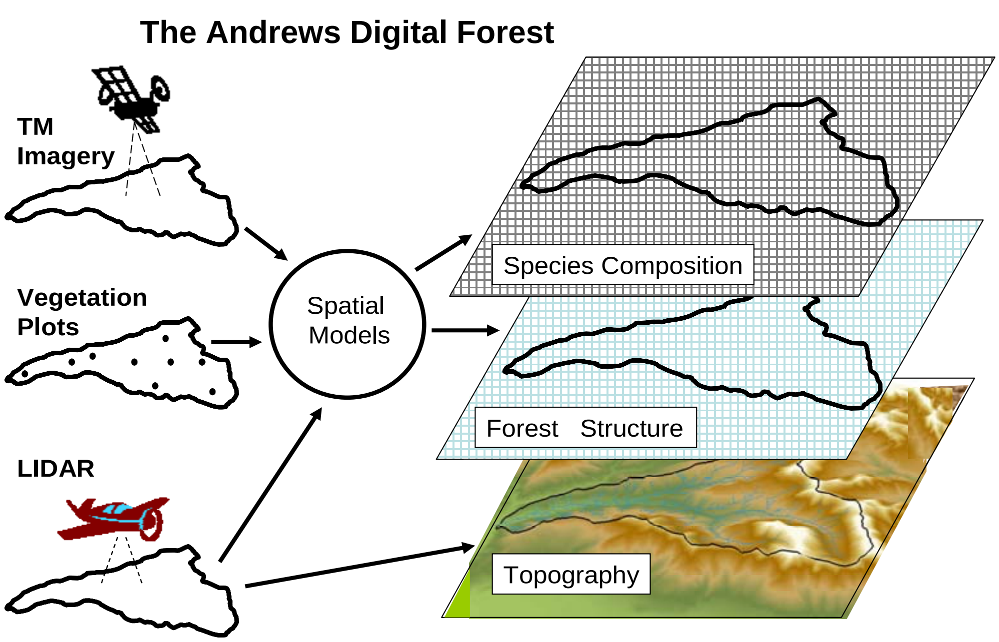


Figure 2.7. The Andrews Digital Forest will be created using spatial models of topography, forest structure, and plant species composition at minimum resolutions ranging from 1m for Digital Elevation Model (DEM) to 30m for vegetation characteristics. Forest structures will include height, biomass, and canopy density. Species composition will include abundance of key tree and shrub species and plant community types.
(For further information and examples, see http://www.fsl.orst.edu/lemma/)

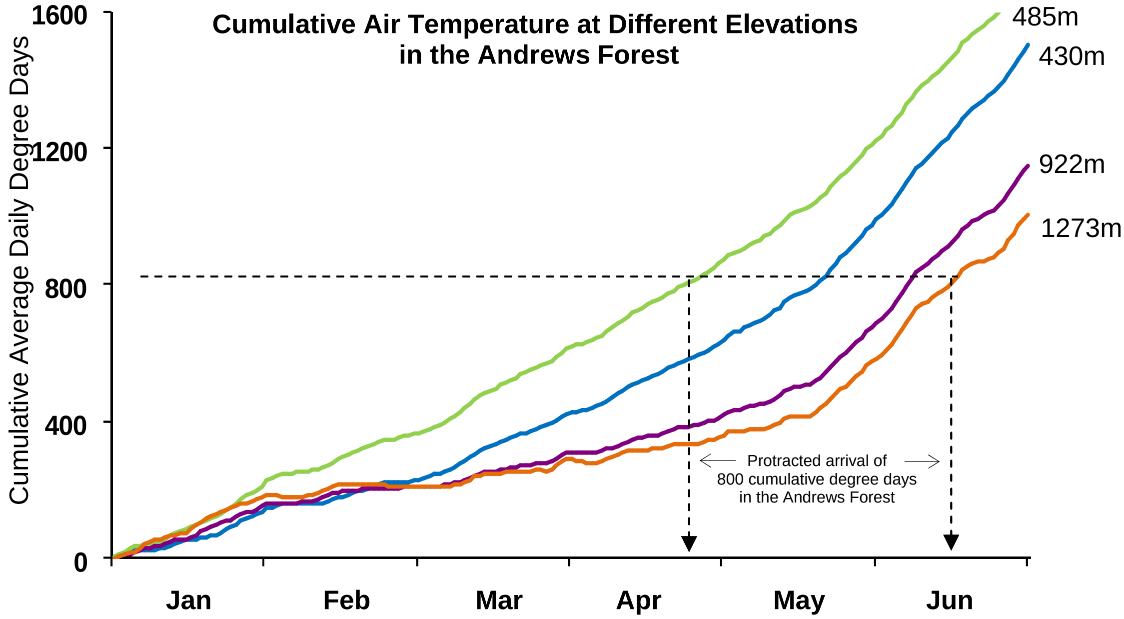


Figure 2.8. At four climate stations across the Andrews Forest, cumulative degree days at lowest elevation site (430m) are less than from a site at a slightly higher elevation (485m) that is out of the cold air drainage. Complex terrain leads to wide availability of particular microhabitat conditions. For example, by moving between varied elevations, springtime conditions (800 cumulative average daily degree days) occur between April 23 and June 15.

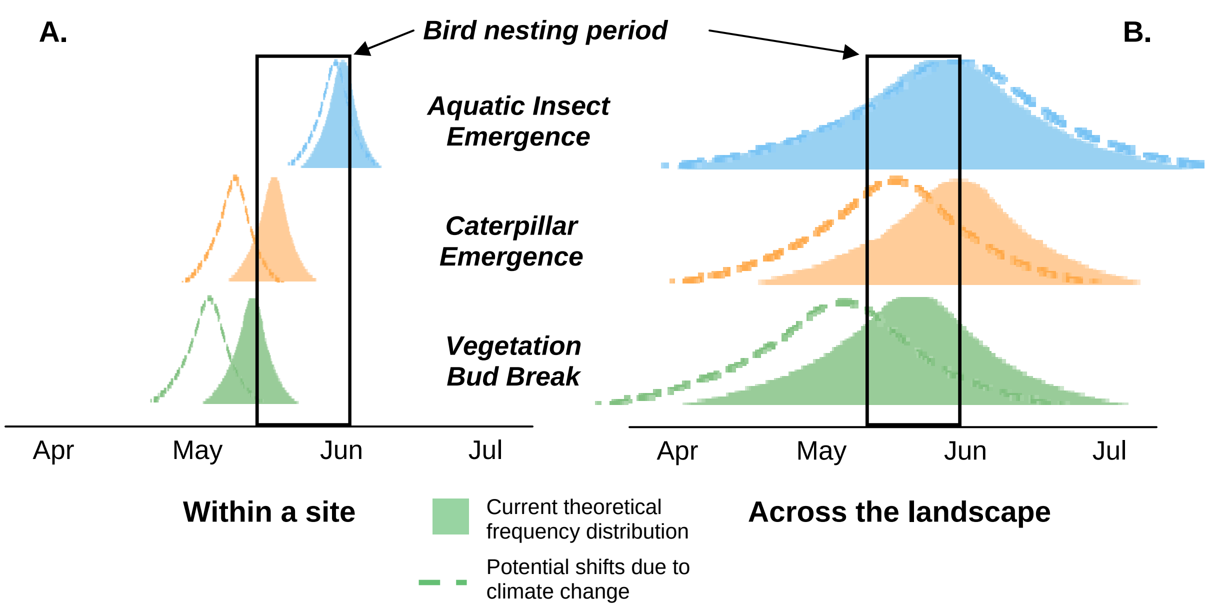


Figure 2.9. Potential spring phenology of key trophic levels within a site (A) and across a landscape with complex topography (B). Arrival of migratory birds is controlled by factors outside of our system and may shift from year to year independently from the life cycles of resident prey. Caterpillar phenology is linked to vegetation bud break, which is influenced by microclimatic conditions. With climate change, desynchronized trophic interactions and reduced food availability for birds could occur at a site (A) due to earlier emergence of caterpillars, but across a complex landscape (B), a mobile predator could still find caterpillar prey.

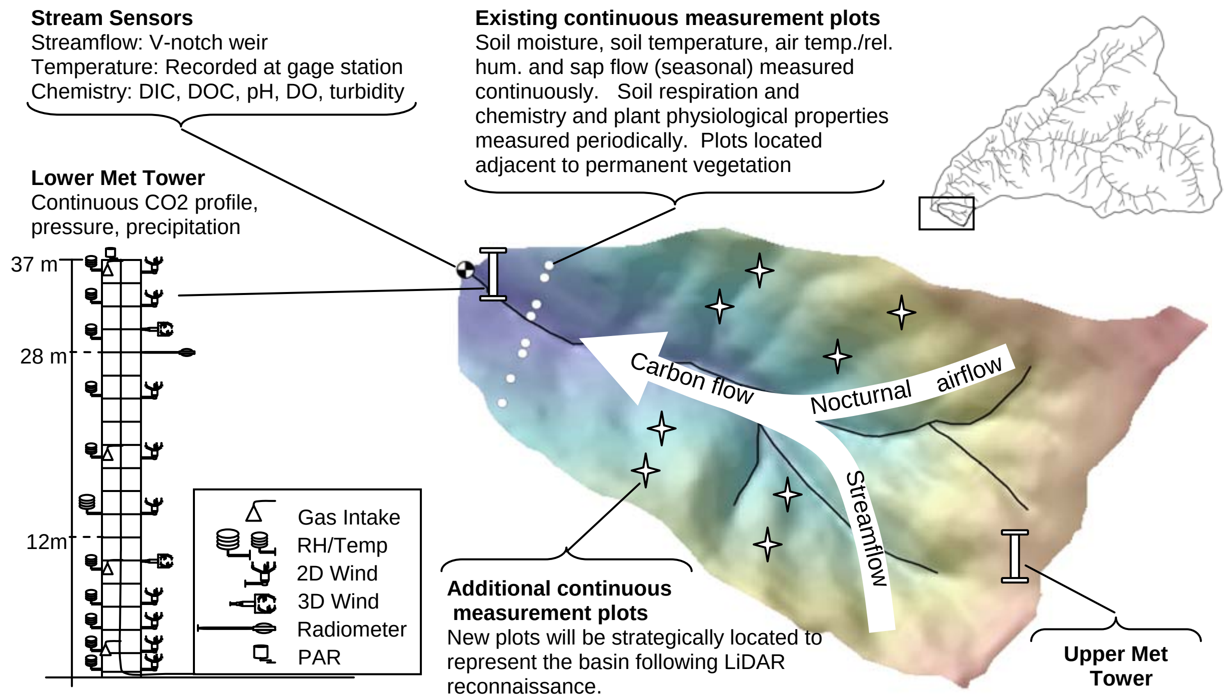


Figure 2.10. Existing and planned sensor deployment and measurements in Andrews Forest Watershed 1 that will be used to support the integrated carbon and water cycle studies. Not shown in this image is an array of 131 permanent sampling plots that will be used to measure carbon dynamics of vegetation; all of the continuous measurement plots are co-located with permanent sampling plots. Watershed 1 covers 96ha and ranges from 450 to 1000m elevation.

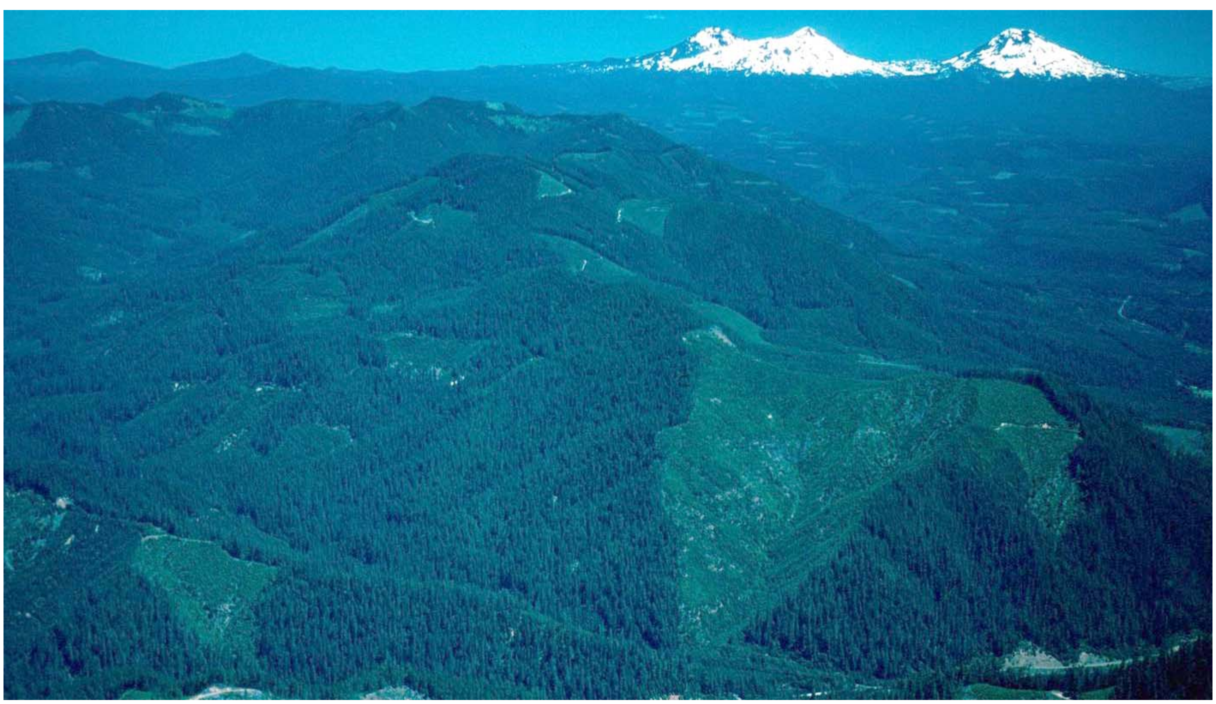


Figure 2.11. The Andrews Forest (in foreground, 400 to 1600m elevation) located in the western Cascade Range and about 40km west of the crest of the High Cascades. Dark green vegetation is mature and old-growth coniferous forest, light green is young stands in former clearcuts.

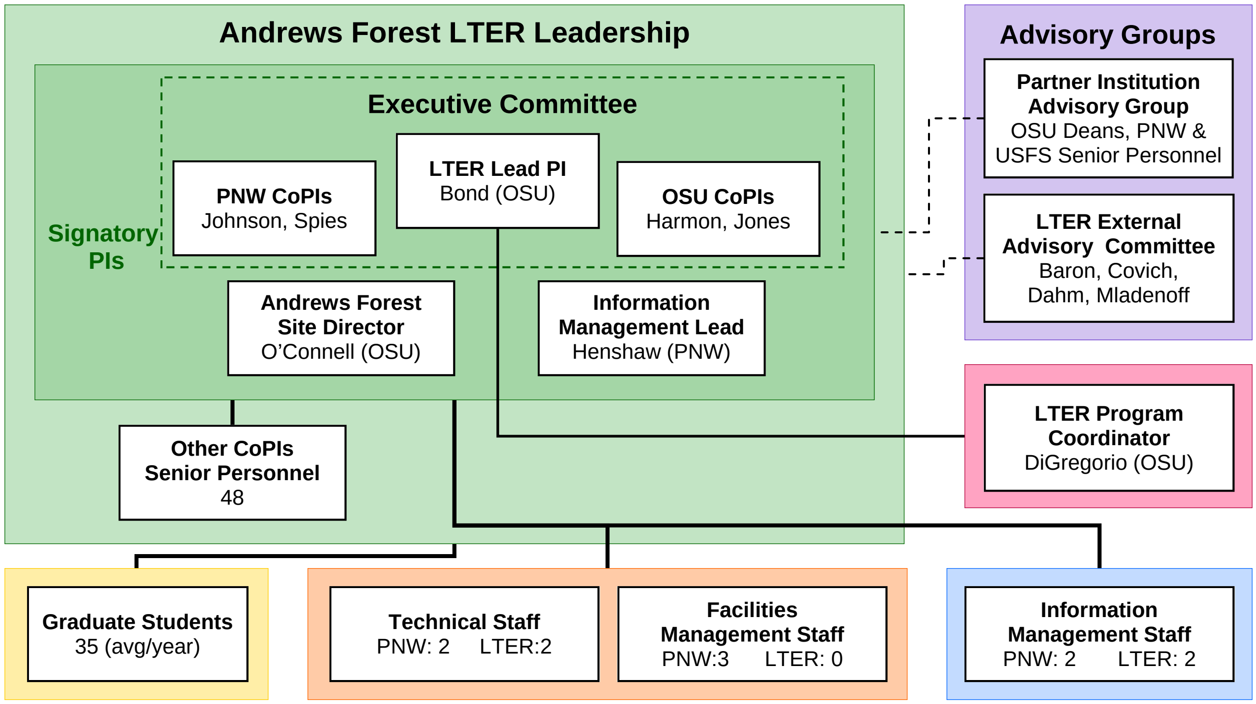


Figure 3.1. Organizational structure of the administration, leadership, and staffing of the Andrews Forest LTER Program. Oregon State University and the USDA Forest Service Pacific Northwest Research Station (PNW) personnel play various roles throughout the leadership organization. Connecting lines do not necessarily denote supervision, but rather oversight, advice, and other forms of cooperative effort. Graduate student numbers are shown as the average number per year supported by LTER and LTER-related funding.

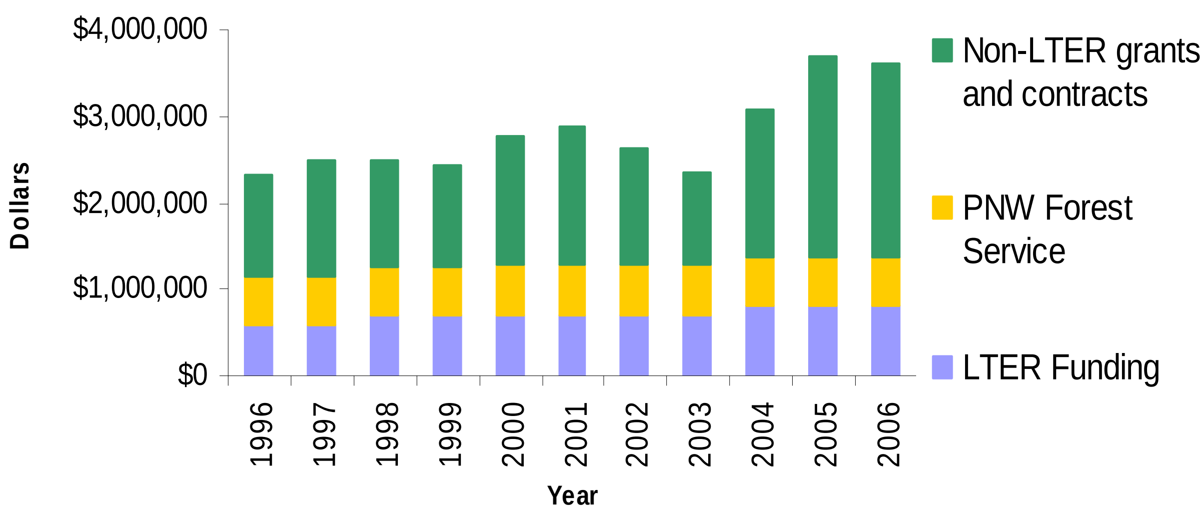


Figure 3.2. Direct support from NSF for the Andrews Forest LTER program is currently leveraged nearly five-fold by funding for research and education from other sources. Increased funding in 2004 was due to the NSF-funded IGERT in Ecosystem Informatics, which is tightly linked with the Andrews Program. Other major funding sources include USDA Cooperative State Research and Extension, the National Aeronautics and Space Administration, and the Bureau of Land Management. This figure includes only financial support and does not reflect the considerable contributions that our program enjoys from its many partnerships (see Figure 2.1).

Table 4.1. The number of online LTER databases and documented downloads of data tables by research study area is increasing. Data downloads include both local investigator and public downloads, but exclude all web maintenance downloads by the IM Team. A data registration system automatically records data downloads beginning in 2002. The earlier optional registration form, used solely from 1999-2001 and in part from 2002-2004, likely underestimates the actual number of downloads. Data downloads of Andrews data through network-based modules such as ClimDB/HydroDB not included.

Research Study Area	Online Databases		Data Downloads		
	2005	2007	1999-2001	2002-2004	2005-2007
Climate	5	7	70	500	1450
Biota/diversity	40	44	90	615	970
Nutrients/detritus	43	51	95	580	955
Hydrology	12	15	110	325	725
Disturbance	14	16	20	140	270
Landuse	4	7	15	35	250
Total	**120**	**140**	**400**	**2195**	**4620**

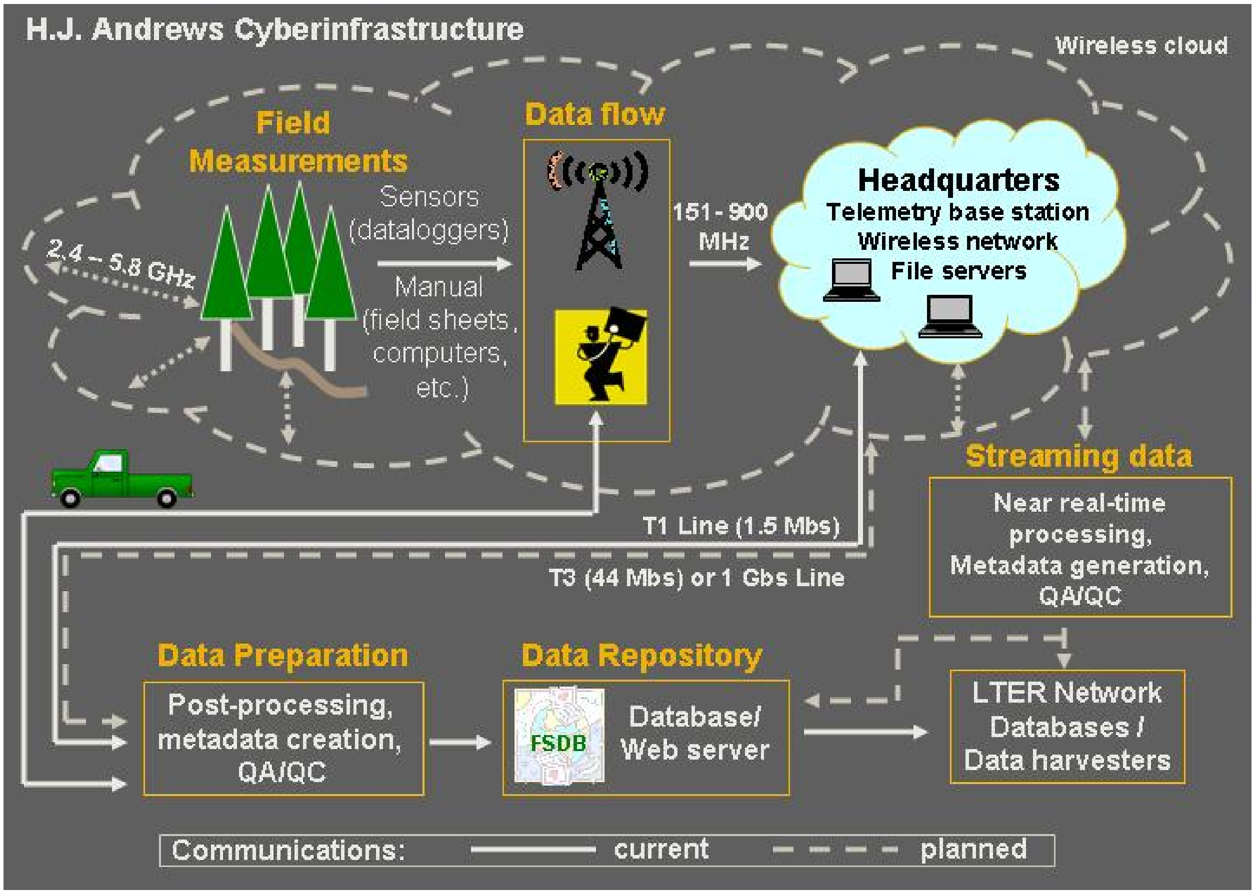


Figure 4.1. The current and planned cyberinfrastructure to support the Andrews Cyber Forest. Field measurements consist of both manual collections and sensor networks using both VHF radios at a licensed frequency of 151.65 MHz and modern 900 MHz spread spectrum wireless modems. A wireless cloud blanketing the Andrews Forest is envisioned allowing transmission of sensor network data and internet access throughout the mountainous topography. The current T1 line communication from site to institution could be upgraded to T3 or Gigabit speed. Current data preparation methods will begin to be replaced by near real-time processing of streaming sensor data. New applications will provide QA/QC and dynamic generation of metadata to allow direct posting of data into the data repository and into network-level databases and data harvesters reducing collection-to-web posting time.

Table 5.1. Examples of input to natural resources policy and management through short-term consultations and panel membership. Together with continuing partnership with land mangers, this amounts to participation in the adaptive dimensions of the coupled human-natural system.

Year	Activity	Participant(s)
2002	NAS/NRC Committee on Riparian Functions/Management (member)	Gregory
	Committee member, Oregon Dept Forestry re: riparian management and water quality (2002-2007)	Johnson
2003	Oregon DEQ Stream Temperature Advisory Committee	Johnson
2005	Interagency Blue Green Algae taskforce	Johnson
	Briefing for Oregon Department of Forestry, Committee on Sustainability Indicators	Harmon
2006	NAS/NRC Committee on Forestry Effects on Water Supply (member)	Jones
	Science Advisory Team members for western Oregon BLM plan revision	Spies, Swanson
2007	Consultation with Oregon Dept Forestry re: Federal forest management	Swanson
	Consultation with Oregon Dept Forestry re: carbon management	Harmon
	Evaluation letter to California Air Quality Board re: forest carbon accounting protocols	Harmon

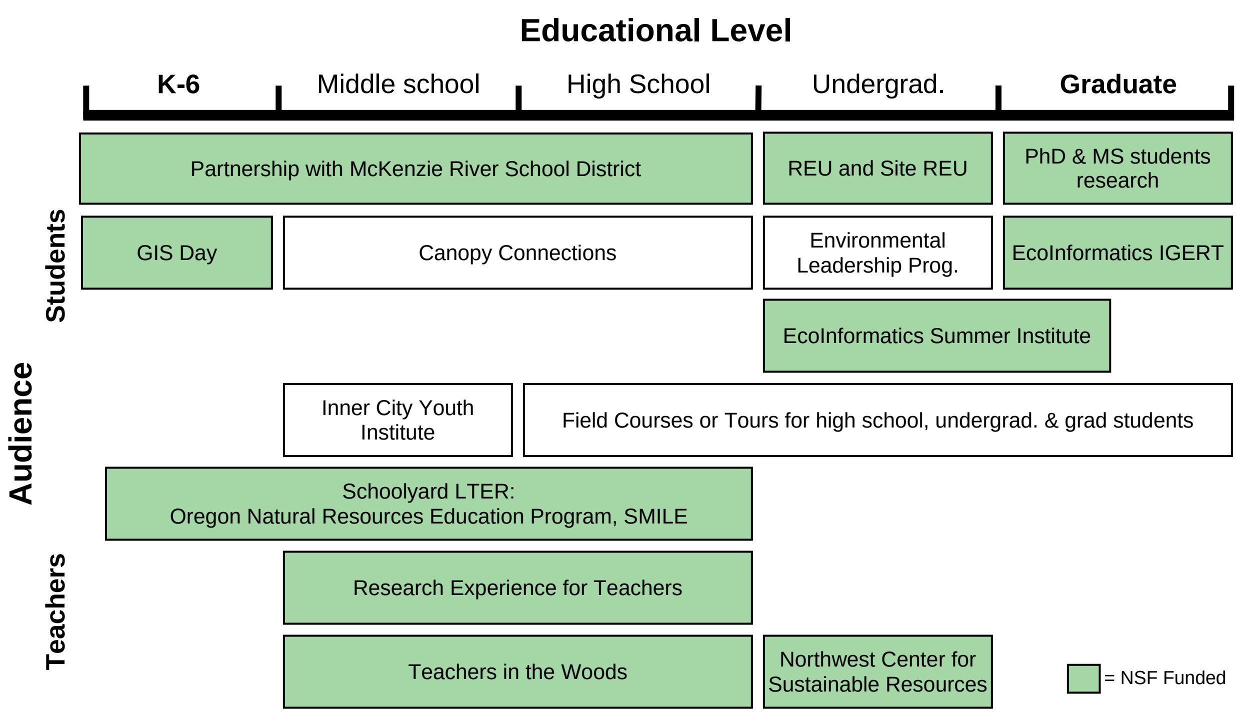


Figure 5.1. Andrews Forest education activities reach a spectrum of teacher and student audiences. The width of each box is representative of the audience that each activity reaches.

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Supplementary Documentation: Databases of Andrews Forest LTER5

The following web address displays a catalog with links to each online database:
http://www.fsl.orst.edu/lter/pubs/grants/lter/lter6/template.cfm?next=dblist08&topnav=120

CODE	TITLE	BEGIN	END
Climate			
MS001	Meteorological data from benchmark stations at the Andrews Experimental Forest	1957	Present
MS005	Reference Stand air and soil temperature network at the Andrews Experimental Forest	1971	Present
MS007	Snow depth and snow water equivalent measurements along a road course in the Andrews Experimental Forest	1978	Present
MS027	Average monthly and annual precipitation spatial grids (1980-1989), Andrews Experimental Forest (GIS)	1995	1999
MS028	Average monthly and annual temperature spatial grids (1980-1990) (Rosentrater thesis), Andrews Experimental Forest (GIS)	1995	1999
MS029	Mean monthly maximum and minimum air temperature spatial grids (1971-2000), Andrews Experimental Forest (GIS)	2002	2002
MS033	Radiation spatial grids, Andrews Experimental Forest (GIS)	1995	2002
MS036*	Cold air drainage - mobile transect studies	2002	Present
Disturbance			
DF001	Archival records of fire history, 1910-1977, central western Cascades, Oregon (Burke thesis)	1910	1977
DF005	Fire history database of the western United States	1994	1994
DF007	Dendrochronology study of fire history, Andrews Experimental Forest and vicinity, Oregon (Teensma thesis)	1984	1987
DF010*	Master tree-ring chronology developed for the Andrews Experimental Forest	1996	1998
DF014	Dendrochronology study of fire history, Blue River watershed, Oregon (Weisberg thesis)	1996	1998
DF018	Spot fire locations (1991), Andrews Experimental Forest (GIS)	1991	1991
DF019	Fire history reconstruction (1482 - 1952), Andrews Experimental Forest and vicinity (GIS)	1993	1997
DF020	Fire history dendrochronology study, super old growth data, central western Cascades, Oregon (Giglia thesis) (GIS)	2002	2002
DF026	Potential rapidly moving landslide hazards in Western Oregon, clipped to Andrews Experimental Forest (GIS)	1999	2002
GE007*	Landslide hazard evaluation in the Upper Blue River watershed, Oregon	1948	Present
GE008	Road-related erosion from the February 1996 flood in the Lookout Creek and Blue River watersheds, Oregon	1999	1999
GE009	Upper Blue River geology clipped to the Andrews Experimental Forest (GIS)	1991	1991
GE010	Mass movement disturbance cascade hazards ratings, Andrews Experimental Forest (GIS)	1992	1992
GE012	Landslide inventory (1953-1996), Andrews Experimental Forest and vicinity (GIS)	1953	1996
GS002	Stream cross-section profiles in the Andrews Experimental Forest and Hagan Block RNA	1978	Present

* Planned to be online in 2008

CODE	TITLE	BEGIN	END
Disturbance (cont.)			
GS016	Amount and distribution of coarse woody debris in Lookout Creek, Andrews Experimental Forest	1991	1991
GV002	Landslide chronosequence: Tree, site and vegetation factors in the Andrews Experimental Forest	1981	1981
Landuse			
DH001	Road construction history (1952 - 1990), Andrews Experimental Forest (GIS)	1991	1992
DH002	Historic salvage sale locations (1954 - 1974), Andrews Experimental Forest (GIS)	1993	1996
GI002	30 meter digital elevation model (DEM) clipped to the Andrews Experimental Forest (GIS)	1996	1996
GI003	10 meter digital elevation model (DEM) clipped to the Andrews Experimental Forest (GIS)	1998	1998
GI006	Adminstrative boundary, Andrews Experimental Forest (GIS)	1997	1997
GI007	Transportation network locations, Andrews Experimental Forest (GIS)	1991	2005
GI008	Land use designations, Andrews Experimental Forest (GIS)	2005	2005
Hydrology			
HF004	Small watershed streamflow summaries at the Andrews Experimental Forest	1949	Present
HF006*	Small watershed storm history with peak flows (derived from HF04 summaries) at the Andrews Experimental Forest	1953	1998
HF007	Peak flow responses to clear-cutting in small and large basins, western Cascades, Oregon	1933	1991
HF010	Stream hyporheic and ground water (water table) elevation data from McRae Creek well network, Andrews Experimental Forest	1989	1993
HF011	Stream tracer experiments to assess channel and hyporheic residence times of streams in the Andrews Experimental Forest	2001	2001
HF012	Longitudinal profiles and geomorphic descriptions of twelve randomly selected stream reaches in the Andrews Experimental Forest	2000	2001
HF013	Stream network (1976 survey), Andrews Experimental Forest (GIS)	1976	1976
HF014	Experimental watershed boundaries and gaging station locations, Andrews Experimental Forest (GIS)	2004	2004
HF015	Hydrologic response units (base units for PRMS streamflow model), Andrews Experimental Forest (GIS)	1993	1993
HF016	Flow accumulation grid generated from 10 meter DEM, Andrews Experimental Forest (GIS)	2003	2003
HF020*	Hyporheic characteristics along a longitudinal profile of Lookout Creek, Andrews Experimental Forest, Oregon	2003	2003
HF024*	The role of topography on catchment-scale water residence time, western Cascades of Oregon (McGuire thesis)	2000	2003
HS003	Suspended sediment grab samples in small gauged watersheds in the Andrews Experimental Forest	1956	1988
HS004	Bedload data from sediment basin surveys in small gauged watersheds in the Andrews Experimental Forest	1958	Present
HS005	Effects of stand age, season, and elevation on the nutrient and microbial characteristics of mountain stream fine benthic organic matter	1995	1996

* Planned to be online in 2008

CODE	TITLE	BEGIN	END
Hydrology (cont.)			
HS006	The effects of debris flows on stream fine benthic organic matter (FBOM) characteristics	1996	1996
HT001	Periodic stream temperature data (1957-1983) in the Andrews	1956	1983
HT002	Half-hour instantaneous air and stream temperature data from the H.J. Andrews Experimental Forest, 1997-2001	1997	2001
HT004	Stream and air temperature network at the Andrews Experimental Forest	1976	Present
Nutrients and detrital dynamics			
CF002	Long-term stream chemistry concentrations and fluxes: Small watershed proportional samples in the Andrews Experimental Forest	1968	Present
CF004	Stream, hyporheic, and ground water chemistry of McRae Creek in the Andrews Experimental Forest	1989	1993
CF006	Storm nutrient data from Watersheds 1, 2, 9, 10 at the Andrews Experimental Forest	2001	2003
CP002	Long-term precipitation and dry deposition chemistry concentrations and fluxes: Andrews Experimental Forest rain collector samples	1968	Present
FS111	Conversion factors for forest products in the Pacific Northwest	1993	1993
SP001	Soil descriptions and data for soil profiles in the Andrews Experimental Forest, selected reference stands, Research Natural Areas, and National Parks	1962	1996
SP002	Soil Moisture and vegetation cover patterns after logging and burning an old-growth Douglas-fir forest in the Andrews Experimental Forest	1960	1983
SP004	Seasonal relationships between soil respiration and water-extractable carbon as influenced by soil temperature and moisture in forest soils of the Andrews Experimental Forest	1992	1993
SP005	Synoptic soil respiration of permanent forest sites in the Andrews Experimental Forest (1993 REU Study)	1993	1994
SP006	Chemical and microbiological properties of soils in the Andrews Experimental Forest (1994 REU Study)	1994	1994
SP007	Disturbance effects on soil processes in the Andrews Experimental Forest (1995 Stand Age Study)	1995	1995
SP008	Effect of thinning pole stands on soil processes in southern Oregon, central Coast Range, and central western Cascades of Oregon (1994-1995 BLM Study)	1994	1996
SP009	Role of vegetation and coarse wood debris on soil processes and mycorrhizal mat distribution patterns at the Hi-15, Andrews Experimental Forest	1994	1995
SP010	Respiration in soils collected from the REU synoptic sample grid in the Andrews Experimental Forest	1994	1995
SP012	The relationship between early succession rates and soil properties in the Andrews Experimental Forest	1999	2000
SP014	Seasonal soil respiration using permanent gas chambers in the Andrews Experimental Forest	1994	1996
SP016	Influence of coniferous tree invasion on forest meadow soil properties on Bunch Grass Ridge and Deer Creek near the Andrews Experimental Forest	1998	1998

* Planned to be online in 2008

CODE	TITLE	BEGIN	END
Nutrients and detrital dynamics (cont.)			
SP017	Influence of tree-fall gaps on soil characteristics in gaps of varying sizes in the Andrews Experimental Forest	1995	1995
SP018	Influence of microclimate gradients on soil characteristics within tree-fall gaps in the Andrews Experimental Forest	1997	1997
SP019	Influence of tree-fall gaps on soil characteristics in the Andrews Experimental Forest	1999	1999
SP020	Effects of topography on soil characteristics in the Andrews Experimental Forest	1998	1998
SP021	Chemical and biochemical characteristics of soils along transects in stands	1996	1996
SP022	Association of ectomycorrhizal mats with Pacific yew and other understory trees at the Andrews Experimental Forest and the southern and western Cascades, Oregon	1992	1994
SP026	Soil survey (1964, revised in 1994), Andrews Experimental Forest (GIS)	1991	1996
SP027	Willamette National Forest soil resource inventory (SRI 1992) clipped to the Andrews Experimental Forest (GIS)	1992	1992
SP029	Fungal mat transect mapping, High 15 in the Andrews Experimental Forest (GIS)	1994	1995
SP030	Mycorrhizal map sampling data in different age class plots of Douglas-fir forests, Andrews Experimental Forest (GIS)	1992	2005
TD010	Origin of large woody debris in streams in the western Cascades of Oregon and Washington and the Oregon Coast Range (Helen McDade thesis)	1981	1981
TD012	Dimensions and volumes of bark and wood from logs, snags, and stumps from multiple forests in the United States and Mexico.	1984	2006
TD014	Long-term log decay experiments at the Andrews Experimental Forest	1985	Present
TD017	Comparison of terrestrial versus aquatic decomposition rates of logs at the Andrews Experimental Forest	1985	Present
TD018	Nitrogen fixation and respiration potential of conifer logs at Andrews Experimental Forest	1987	2005
TD020	Respiration patterns of logs in the Pacific Northwest	1986	1996
TD021	Dimensions and volumes of bark and wood from logs, snags, and stumps from multiple forests in the United States and Mexico	1989	2007
TD022	Coarse woody debris density and nutrient data with age determined using the Chronosequence method	1982	1994
TD023	LTER Intersite Fine Litter Decomposition Experiment (LIDET)	1990	2002
TD024	Fine woody detritus volume and mass from line transect inventory	2002	2006
TD025	Log leachates from the Andrews Experimental Forest	1986	1992
TD026	Moisture content of logs from the Andrews Experimental Forest	1985	1988
TD027	Radial thickness of structural-anatomical components of woody plant parts	1985	2007
TD028	Mass of forest floor litter from cores in reference stands and inventory plots in the Pacific Northwest	1992	2006
TD029	Comparision of native litter species occurring at the Andrews Experimental	1993	2003
TD030	Fine woody debris inventory data from reference stands and inventory plots	1992	2000
TD031	Decomposition of Fine Woody Roots: a Time Series Approach	1995	2006
TD032	A chronosequence of woody root decomposition in the Pacific Northwest	1995	1997
TD035	Coarse woody debris volume and mass from line transect inventory from	1997	2006

* Planned to be online in 2008

CODE	TITLE	BEGIN	END
Nutrients and detrital dynamics (cont.)			
TD042	Fall directions and breakage of trees along streams in the Pacific Northwest	2000	2002
TL001	Andrews Experimental Forest Reference Stand component litterfall study	1977	1985
TL003	A study of selected ecosystem parameters potentially sensitive to air pollutants in the Olympic Peninsula	1984	1987
TW003	Sap flow measurements to estimate overstory water use in small watersheds at the Andrews Experimental Forest	1999	2002
TW006	Eco-hydrology of Watershed 1 at the Andrews Experimental Forest (telemetry transect)	2004	Present
Biota and diversity			
AS006	Aquatic Vertebrate Population Study, Mack Creek, Andrews Experimental Forest	1987	Present
SA001	Invertebrates of the Andrews Experimental Forest: An annotated list of insects and other arthropods	1971	Present
SA002	Vascular plant list on the Andrews Experimental Forest and nearby Research Natural Areas	1958	Present
SA003	Bird species list for the Andrews Experimental Forest and Upper McKenzie River Basin	1975	1995
SA004	Amphibian and reptile list of the Andrews Experimental Forest	1975	1995
SA005	Mammal species list of the Andrews Experimental Forest	1971	1976
SA006	Fish species list of the Andrews Experimental Forest	1975	1995
SA007	Benthic algal species list of the Andrews Experimental Forest	1991	1992
SA008	Moss species list of the Andrews Experimental Forest	1991	1991
SA009	Riparian bryophyte list of the Andrews Experimental Forest	1994	1995
SA010	Epiphyte species list of Watershed 10, Andrews Experimental Forest	1970	1972
SA011	Lichen abundance and biodiversity along a chronosequence from young managed stands to ancient forest (Neitlich thesis)	1993	1993
SA012	Macroinvertebrate species list of the Andrews Experimental Forest	1992	1993
SA013	Aquatic Invertebrate species list of Lookout Creek in the Andrews Experimental Forest	1988	Present
SA014	Mycorrhizal belowground fungi species list of the Andrews Experimental Forest	1992	1994
SA015	Spatial and temporal distribution and abundance of moths in the Andrews Experimental Forest	1994	2004
SA016	Spatial and temporal distribution and abundance of butterflies in the Andrews Experimental Forest	1994	1996
SA017	Aquatic insect sampling in Lookout Creek at the H.J. Andrews Experimental Forest	2001	2001
SA021	Epiphytic macrolichens in relation to forest management and topography in a western Oregon watershed (Berryman thesis)	1997	1999
SA022	Headwater Stream Macroinvertebrates of the H.J. Andrews Experimental Forest, Oregon	2003	2004
SA023*	Exotic plant species distribution along the road network at the Andrews Experimental Forest, 1994-2005 (GIS)	1994	2006
TP041	Post-logging community structure and biomass accumulation in Andrews Experimental Forest Watershed 10	1973	Present

* Planned to be online in 2008

CODE	TITLE	BEGIN	END
Biota and diversity (cont.)			
TP072	Pacific Northwest Plant Biomass Component Equation Library	1961	2000
TP073	Plant biomass dynamics following logging and burning in the Andrews Experimental Forest Watersheds 1 and 3	1962	Present
TP088	Population dynamics of young forest stands as affected by density and nutrient regime in the Andrews Experimental Forest	1981	1997
TP091	Ecosystem dynamics in a mature and an old-growth forest stand (WS02, HGBK)	1981	1993
TP103	Species interactions during succession	1990	Present
TP110	Chanterelle productivity responses to young stand thinning in the western Oregon Cascades	1994	2010
TP112	Ecology and restoration of montane meadows on Bunchgrass Ridge near the Andrews Experimental Forest	1999	Present
TP114	Plant biomass dynamics following logging, burning, and thinning in watersheds 6 and 7 at the Andrews Experimental Forest	2002	Present
TP115	Plant biomass dynamics in old-growth watersheds 8 and 9 at the Andrews Experimental Forest	2003	Present
TP119	Vegetation history classification for watersheds 1, 2, and 3 (1959-1990), Andrews Experimental Forest (GIS)	1997	1997
TP120*	Annual productivity study (Woolley thesis)	2000	2004
TS015	Comparison of arthropod densities on young-growth and old-growth foliage in the Andrews Experimental Forest	1986	1986
TV009	Dendrometer studies for stand volume and height measurements of trees of the western US	1978	Present
TV010	Tree growth and mortality measurements in long-term permanent	1910	Present
TV019	Cone production of upper slope conifers in the Cascade Range of Oregon and Washington	1959	Present
TV030	Decay in standing trees of the Pacific Northwest	1982	1992
TV033	Retrospective Studies of Green Tree Retention in the Pacific Northwest	1993	1993
TV036	Study of streamside mosses at the Andrews Experimental Forest	1994	1995
TV045	Post-fire succession study, Torrey Charlton RNA	1997	Present
TV052	Early Succession Study	1999	2000
TV056	Comparisons among five canopy-cover estimating methods in five Douglas-fir/western hemlock structure types in the western Oregon Cascades	2001	2001
TV061	Vegetation classification, Andrews Experimental Forest and vicinity (GIS)	1993	2002
TV062	Plant community typing (1990), Andrews Experimental Forest (GIS)	1992	1992
TV063*	Western Oregon and Washington rasters of potential vegetation (modeled), clipped to the Andrews Experimental Forest (GIS)	2001	2005
TV073*	Long-term Plant Phenology Observations at the Andrews Experimental Forest	1979	Present
WE008	Ground-dwelling vertebrates, birds, habitat data on the Willamette National Forest, Oregon (Young Stand Thinning and Diversity Study)	1991	2001
WE026	Monitoring small mammal and amphibian abundances on the Willamette National Forest, Oregon (Long-Term Ecosystem Productivity experiment)	1995	1999
WE027	Vertebrate-habitat relationships: Logistic regression models	1998	1999

* Planned to be online in 2008