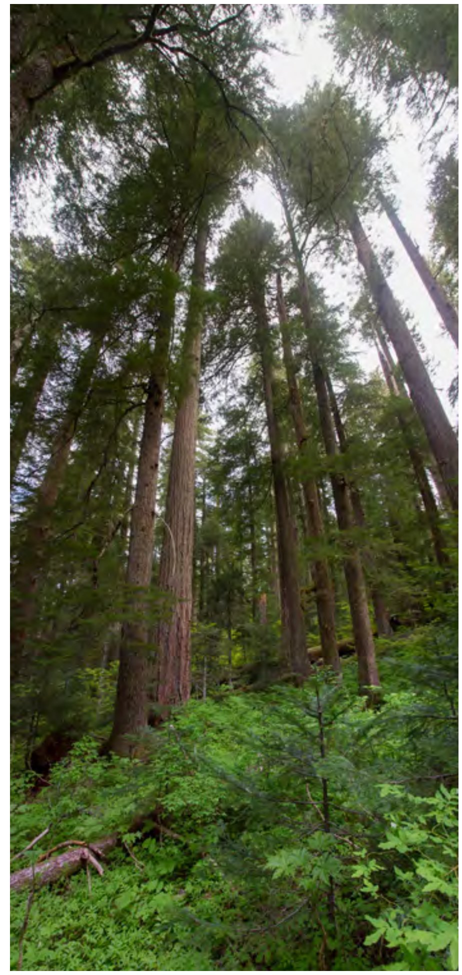
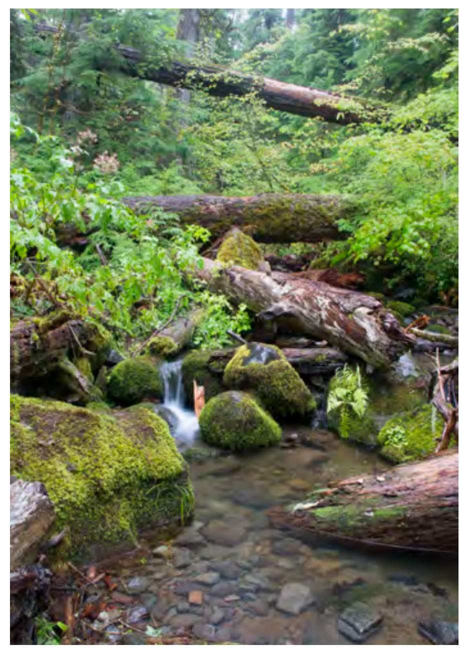


Long-Term Ecological Research at the H.J. Andrews Experimental Forest (LTER7)

proposal to the
National Science Foundation
March 2014



HJA
HJ ANDREWS EXPERIMENTAL FOREST

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PROJECT SUMMARY

Overview. The Andrews Forest LTER program integrates research, outreach and education, and research-management partnerships to investigate forest and stream ecosystems in the Pacific Northwest. Climate change forecasts in the Pacific Northwest region portend drought, decreased snow packs, and increased wildfire. Observed rates of climate change in the Pacific Northwest, however, vary with season and location, posing major challenges for predicting ecosystem response. Land-use change, dictated by forest governance systems under pressure to provide timber, restore ecological processes, maintain biodiversity, and facilitate adaptation of forests to climate change, is an additional variable complicating efforts to understand ecosystem dynamics. **The overall goal of Andrews Forest LTER7 (2014-2020) is to apply our strengths in long-term research, outreach and education, and research-management partnerships to characterize the mechanisms that determine how forested mountain ecosystems respond to changes in climate, land-use, and their interactions**.

Intellectual Merit. In LTER7 we re-examine our guiding central question and conceptual framework using the lens of "connectivity," focusing on how intermittent, spatially variable flows of air, water, nutrients, organisms, and information may mitigate or accentuate the expression of regional and global climate change and land-use in mountain ecosystems. We will link new studies and modeling efforts to long-term measurements, spanning processes ranging from individual organisms and diel cycles to regional, multi-decadal dynamics of climate, hydrology, and vegetation in the temperate conifer forest biome. We will also continue leadership of cross-site synthesis work, especially in areas of climate, hydrology, stream chemistry, vegetation, arts and humanities, and LTER Network level information management.

In LTER7 we focus on the central question: **How do climate, natural disturbance, and land use as controlled by forest governance interact with biodiversity, hydrology, and carbon and nutrient dynamics?** Consideration of forest governance is essential for the understanding of long-term ecosystem dynamics, because we recognize that a truly mechanistic understanding of land use and its impacts on the ecosystem, and how those impacts feedback into the decision-making process, is not possible without a better understanding of how humans and institutions make decisions affecting forest governance. Synthesis efforts in LTER7 include analysis of the Andrews Forest LTER as part of a social-ecological system, mapping changes in science-policy-management networks, and conservation ethics-based analyses of arguments about forest policy premised on Andrews Forest science.

Broader impacts. Many aspects of LTER7 will have broader social impacts. We will continue the strong tradition of fostering public engagement with science and technology through our research-management partnership with regional and national forest policymakers. We will continue to produce policy-relevant information about the role of science in society by engaging the public, resource managers, and policymakers in studies of changing social networks influencing forest landscapes and conservation ethics analyses of arguments used in forest governance. Our arts and humanities program aims to enhance public literacy about science, to interpret and convey the value of long-term ecological research, and to share the beauty and magnificence of our ecosystem with a wider audience to inspire awe, wonder, and action to improve the well being of individuals in society. We will continue education and outreach and STEM development for K-12, undergraduate, and graduate students and teachers as well as the public, with explicit emphasis on enhancing participation of women, people with disabilities, and under-represented minorities to be trained as part of a globally competitive STEM workforce. We will continue to develop and enhance the infrastructure for science and education, especially efforts to increase digital and virtual access to the Andrews Forest through continued information management, a cyber-networked forest, and social media outlets. We will continue to lead partnerships and cross-site efforts within and beyond the LTER Network that interpret, synthesize, and disseminate the findings of long-term ecological research to help the public and policymakers understand how the ecosystems on which humans depend are functioning at broad temporal and spatial scales.

1.0 RESULTS FROM PRIOR SUPPORT

The Andrews Forest LTER program is a center for mountain forest and stream ecosystem research in the Pacific Northwest. We collaborate with dozens of university and federal scientists, students, and managers to support ecosystem science, education, natural resource management, and the arts and humanities. The program has its roots in the establishment of the H.J. Andrews Experimental Forest (Fig. 1) (hereafter referred to as the Andrews Forest) in 1948 by the US Forest Service. In the early decades, Forest Service researchers focused on timber and watershed management. Beginning in 1969, university scientists became active at the site and research began to focus on forest ecosystems, especially old-growth forests and streams. The Andrews Forest became a charter member of the LTER program in 1980, and long-term measurement programs continued on experimental sites and watersheds with a focus on questions about climate, streamflow, water quality, vegetation succession, biogeochemical cycling, and effects of forest management (Fig. 2). For over 65 years the Andrews Forest has served as a major source of discovery about the pattern, dynamics, and functions of mountain forest and stream ecosystems (Fig. 3).

Our understanding of the ecosystem is the product of six LTER cycles. **LTER1–2** focused on establishing long-term measurements and understanding fundamental ecosystem structure and processes related to old-growth forests, streams, and effects of logging on watersheds. Since LTER3, research has been guided by a central question: *How do land-use, natural disturbances, and climate change affect three key ecosystem properties: carbon and nutrient dynamics, biodiversity, and hydrology?* Subsequent LTER cycles have continued to examine this question and have adopted specific scientific themes**: LTER3**—process-based understanding of landscape dynamics; **LTER4**—effects of early succession on ecosystem dynamics and the impact of species attributes on ecosystem dynamics; and **LTER5**—synchronous temporal behaviors and drivers of biogeochemical cycling in small watersheds.

LTER6 focused on the theme of complex topography and its influence on interactions between drivers and ecosystem responders. Major findings include: 1) flows of air and water are episodically coupled to, and decoupled from, regional patterns; 2) ecosystem processes and biodiversity in upper elevations were expected to be most sensitive to climate change, but interactions of topography and atmospheric dynamics limit generalizations about elevational effects; 3) tree mortality in mature and old-growth forests is increasing, possibly as a result of climate change, but the mechanisms are not well understood; 4) leaf and insect emergence varied by >40 days between years and from low to high elevation within a year, and birds seek sites of low temperature variability; 5) recent policy and land-use change may be leading to decreases in biodiversity associated with meadows and early successional habitats; 6) disturbance and land-use history have a lasting imprint on carbon and hydrology that may be overriding climate change and topographic controls; 7) social forces have strongly limited use of ecologically-based forest practices, and a decision point for determining the future of forestry on federal lands appears imminent, setting the stage for new applications of Andrews Forest ecological and social science. Here we briefly describe the key findings of component studies and their links to LTER7 plans. Our 10 most significant products are listed once in **bold**.

CLIMATE. In LTER6 we hypothesized that systematic cold-air pooling would dampen or obscure the expression of regional climate change in mountain landscapes. Topographic position (e.g., sheltered valley, exposed ridge) can be as important as elevation in determining local climate variability, because cold-air pools forming in small valleys and depressions can effectively decouple microclimates from the free atmosphere for prolonged periods during some portions of the year, and projected future changes in regional circulation patterns could increase the frequency of conditions promoting cold-air pooling (**Daly et al. 2010**). Changes in the elevation of the rain/snow threshold would further increase sensitivity of high-elevation ridges to future climate change. Contrary to our hypothesis we found that valleys experiencing transient cold-air pools, and transient cold-air pools near the rain/snow threshold, may be particularly sensitive to future climate change (Pepin et al. 2011, Daly et al. 2012). The effectiveness of valleys in containing cold-air drainage and pools likely varies with season and time of day (Daly et al. 2012). For example, the Lookout Creek drainage experienced a coherent spring warming signal and earlier springs from 1958 to 2009 in the valley, consistent with the expected behavior of transient spring compared to persistent winter cold-air pools (**Jones et al. 2012**), but the signals are variable throughout other parts of the forest and the exact mechanisms remain unknown. To better understand these results, in LTER7 we will examine flows of air and moisture governing spatial and temporal patterns of air temperature and their sensitivity to climate change.

DISTURBANCE AND LAND-USE. The Cascade Mountains have high spatial variation in microclimate and fuel moisture, leading to variable fire regimes and multiple pathways of forest development strongly influenced by topography (Tepley 2010). Multiple successional pathways can lead to the development of old-growth (**Tepley et al. 2013**), a finding that has major implications for current stand-development models, and conservation and restoration of old-growth, previously based on a single-pathway model. Current forest harvest practices and plans will result in decreasing area of early successional forest (Spies and Duncan 2009). Land-use, such as clear-cut harvesting, has multi-decade influences on hydrology (Jones et al. 2009, Creed et al. 2011): including increased magnitude of rain-on-snow flooding (Perkins and Jones 2008, Jones and Perkins 2010), on stream habitat by reducing stocks and inputs of large wood in streams (Czarnomski et al. 2008), and on forest understory diversity and structure (Dovčiak and Halpern 2010, **Halpern and Lutz 2013**). In LTER7 we will explore how land-use may override or obscure influences of climate on ecosystem processes and biodiversity.

HYDROLOGY. Using continuous discharge data from 1952 to present, we showed that spring streamflow in old-growth reference watersheds at the Andrews Forest has declined, especially at high elevation where seasonal snowpacks contribute to spring runoff (Moore 2010, Jones et al. 2012), although the magnitude and directionality of trends can depend on record length (Argerich et al. 2013). Models predict that snowpack between the elevations of 1000 and 1800 m (mid- to upper-elevations) is most sensitive to climate warming (Mazurkiewicz et al. 2008, Nolin 2012, **Sproles et al. 2013**), and seasonal snowpack above 1000 m has declined by 30 to 50% since 1950 (Fig. 2). Studies of hydrologic connectivity between hillslopes, vegetation, and streams demonstrated ephemeral links between soil moisture and transpiration (Moore et al. 2011b, 2011a). An innovative summer-long sprinkling experiment using isotopic tracers showed that water used by plants in the summer is decoupled from water that drains to streams (Barnard 2009, Barnard et al. 2010, **Brooks et al. 2010**), and deep seepage in permeable bedrock influences the precipitation-runoff threshold (Graham et al. 2010a, 2010b, Graham and McDonnell 2010). These findings motivate us to measure and model soil-water balances in small watersheds in LTER7.

VEGETATION DYNAMICS. Climate change may be contributing to increased tree mortality as shown by a two-fold increase in the proportion of stems dying annually in old-growth forests across the western US (**van Mantgem et al. 2009**). The mechanisms responsible for this increased mortality are not understood. Analysis of long-term data revealed that individual tree growth continuously increased with tree size (Stephenson et al. 2014), contradicting the long-held theory that the rate of individual tree biomass accumulation decreases with age. Studies of succession in forest plantations indicate that, contrary to successional theory, canopy closure exerted weak influences on understory dynamics (Halpern and Lutz 2013), and canopy gaps had long lasting influences on forest growth and mortality (Seidl et al. 2012a, Gray et al. 2012). Mountain ecosystems have high variation in carbon stocks, which is only partially controlled by topography (Seidl et al. 2012a) and soil characteristics (Griffiths et al. 2009). These findings provide further evidence that responses to climate and land-use are variable in space and time, often not predictable from current theories, and require a deeper understanding of interactions between biophysical processes, land-use, and mountainous terrain**.**

CARBON AND NUTRIENT DYNAMICS. We used an interdisciplinary approach in a small watershed (WS1) to quantify carbon stocks and fluxes in air, vegetation, soils, and streams. We developed a mass balance approach to measure net ecosystem exchange of carbon (NEE), respiration, and evapotranspiration (ET) at the scale of the WS1 basin at an hourly resolution (Thomas et al. in review) (Fig. 4) and showed that disturbance, soils, and topography had cascading influences on primary productivity (Peterson 2012). We quantified aquatic carbon stocks and the proportion of the fluxes derived from terrestrial vs. in-stream production (Argerich et al. in review). Carbon flux towers that extend above the forest canopy allowed us to examine airflows and carbon exchanges in the airshed. Carbon isotopes were used to quantify soil respiration rates (Phillips et al. 2010, Kayler et al. 2010), watershed scale transpiration (Pypker et al. 2009), and sediment export (Smith 2013). Long-term trends in precipitation chemistry showed declining inputs throughout the US and Europe—even at the Andrews Forest, where inputs of nutrients via precipitation are orders of magnitude lower than sites in the eastern US or Europe (Lajtha and Jones 2013). Long-term trends in stream nitrate and ammonium generally declined at the Andrews Forest, while at other sites (e.g., Hubbard Brook) trends varied from positive to negative depending on the period (Argerich et al. 2013). In LTER7 we plan additional cross-site analyses to examine whether stream chemistry responses have similar magnitude and duration to natural versus anthropogenic disturbances.

STREAM ECOLOGY. Trends in stream temperature at the Andrews Forest and throughout the Pacific Northwest were mixed from the 1950s, and flat since the 1990s (Arismendi et al. 2012, 2013a, 2013b); contrary to expectations that regional warming of air temperature would consistently increase stream temperature. Longer water flow paths and residence times diminish stream temperature diurnal fluctuations in small watersheds (Roth 2010) and increase respiration (González-Pinzón et al. 2013). Tracer studies in nine Oregon streams showed unexpectedly high uptake of nitrate by fine benthic detritus and long transport distances for nitrate in forested streams (**Sobota et al. 2012**). Thirty years of data revealed that the abundance of young-of-the-year trout dramatically increased after major floods (**Dodds et al. 2012**), but not after moderate floods. Although prior forest harvest was shown to impact fish and salamander populations, differences were not detectable after 30 years. In LTER7 we will examine how year-to-year interactions of climate, land-use, and disturbance influence the distribution of vertebrates and food resources at the upper ends of stream networks (~80% of drainage length). We also expand research on the influence of water travel times on stream temperature to explore biogeochemical responses to changing water flow paths related to climate change and drought.

BIODIVERSITY. Biodiversity trends of populations and communities differed among taxa. Demographic studies of northern spotted owls by cooperators revealed continuing decline in populations despite cessation of clearcutting on USFS lands in 1990 (Forsman et al. 2011). Spatial patterns of owl prey require owls to occupy larger territories at higher elevations than at lower elevations (Smoluk 2011). Species diversity and biomass of nocturnal moths is related to both vegetation structure and composition (Highland 2011, Highland et al. 2013). Plant-pollinator network structure is nested and related to meadow size and connectivity (Pfeiffer 2012). Pre-logging vegetation influences forest plant diversity for at least 50 years after clearcutting and hot prescribed fire (Halpern and Lutz 2013). Facilitation among woody species promoted tree invasion causing rapid contraction in the size of montane meadows (Rice 2009, Halpern et al. 2010, Rice et al. 2012)—a process that is related to changing climate, land-use, and disturbance regimes (Zald et al. 2012). Five years of phenology studies from LTER6 (Fig. 5) revealed: 1) high plasticity in understory plant budbreak (>40 day range across years examined), 2) sensitivity of stream insect emergence to degree day accumulation of stream temperature (Li et al. 2011), and 3) migratory bird species selection of sites with stable temperature regimes during the breeding season (Fig. 6). During LTER7 phenology studies will focus on mechanisms that may explain varied responses across space, time, and taxa.

EVALUATING FUTURE SCENARIOS. We used three simulation models to evaluate potential effects of land use, natural disturbance, and climate change. LandCarb simulations demonstrated that reduced harvests are increasing forest carbon stores on federal lands (Krankina et al. 2012). LandCarb also revealed that initial conditions strongly influence whether biofuels harvests will be carbon positive, negative, or neutral (Mitchell et al. 2012). iLand simulations revealed that environmental factors explained roughly one-half of the spatial variation in forest carbon stores assessed from LiDAR—with the remaining variability attributable to stand dynamics and composition (Seidl et al. 2012b). VELMA, an ecohydrological model (Fig. 7) was developed, and simulations quantified streamflow response to varying harvest distance from the stream and forest growth response to harvest vs. fire (Abdelnour et al. 2011, 2013). In LTER7 we extend modeling to examine how forest harvest and climate change will influence future ecosystem processes.

HUMAN SYSTEM. Our longstanding interest in interactions between forest processes and policy makers, managers, and society has focused on how land use activities (e.g. forest management) and associated science are perceived. Evidence suggests that the public has limited understanding of natural disturbance regimes, and that the role of science in policy and management decisions is viewed differently by different stakeholder groups (Steel et al. 2009). There is limited public trust of managers to use scientific knowledge to implement new approaches to forest management (Olsen et al. 2012), which may constrain the use of climate change adaptation strategies on federal forests (Spies et al. 2010). In LTER7 we will build on science-society research by studying the role of governance networks in determining the variable roles that Andrews Forest ecological science has played in social, policy, and management processes over the past half century—many of which have brought sweeping changes to federal forest land management (Spies and Duncan 2009) (Fig. 8).

TECHNOLOGICAL INVESTMENTS ENABLING NEW RESEARCH. We enhanced the sensor network by adding new capabilities (e.g., carbon isotope analyzers, sonic anemometers, net radiometers, acoustic profilers), expanded existing measurement networks (e.g., temperature), and developed a tower-based wireless communication infrastructure providing high-speed connectivity from the headquarters' cyber-infrastructure to ca. 80% of the Andrews Forest. This infrastructure enables near real-time streaming of large data volumes—critical to many of the results reported here and to the proposed work in LTER7. Through direct links to networked cameras and sensors, researchers have been able to remotely monitor environmental and biotic dynamics across the site year round, thereby improving the capacity to understand processes operating at multiple timescales. In the digital forest project we used LiDAR coverage for the entire Andrews Forest to develop bare-earth models at high spatial resolution (1 m), allowing us to characterize fine-scale topography and stream networks, and to observe previously undetected landslides. We also used LiDAR to develop high-resolution maps of vegetation structure and biomass, enabling us to quantify how biomass varies in relation to topography, disturbance history, and forest structure (Seidl et al. 2012b). These data improve our ability to perceive connections between vegetation, microclimate, and geomorphology.

OUTREACH AND EDUCATION. On average >1500 people participate annually in classes, research, tours, and conferences at the Andrews Forest. The Schoolyard LTER involved >60 K-12 teachers in phenology and carbon research who, in turn, reach over 6,000 K-12 students annually. The Canopy Connections program introduces underprivileged middle school students to forest ecology by exploring natural history lessons through tree climbing into the canopy of old-growth trees. We published a unique illustrated children's book about forest and stream phenology called *Ellie's Log: Exploring the Forest Where the Great Tree Fell* (**Li 2013**). This project included a Teacher's Guide and a website (*ellieslog.org*).

ARTS AND HUMANITIES. The Long-Term Ecological Reflections program hosted >50 authors and artists and established a website (*ecologicalreflections.com*) to profile arts-humanities-science collaborations at >20 sites, including many LTER sites. With BNZ, NTL, and HFR, we co-led four network workshops for arts and humanities, and organized art exhibits at ESA and NSF in 2012 and 2013. In LTER7 we will more formally assess the perceived value of, and challenges to, these efforts.

CROSS-SITE SYNTHESIS. Synthesis activities are diverse and include conceptual syntheses of topics with international importance, networking among networks (USFS, ILTER, Canadian, European), primary analysis of multisite experiments, and database development. We have authored or coauthored 10 major syntheses (3 in the 2012 LTER special issue of *BioScience*), including disturbance across sites (Peters et al. 2011), the roles of LTERs in informing policy and management (Driscoll et al. 2012), scenario analysis to promote synthesis and integration (Thompson et al. 2012), long-term intersite stream ecology (Dodds et al. 2012), climate change and hydrologic responses (Creed et al. in press, 2011, National Research Council 2008, Jones et al. 2009, 2012), causes and consequences of trends in atmospheric deposition at LTER and NADP sites and in Europe (Lajtha and Jones 2013), stream chemistry trends at nine Experimental Forests (Argerich et al. 2013), the intersite LIDET experiment (Harmon 2009), science of carbon and forests (Ryan et al. 2010), and high-profile discoveries about tree mortality and growth (van Mantgem et al. 2009, Stephenson et al. 2014). We also have participated in cross-site measurement programs, such as NutNet (Firn et al. 2011, Adler et al. 2011, Lind et al. 2013, O'Halloran et al. 2013, Hautier et al. 2014, Borer et al. 2014) and the Lotic Intersite Nitrogen Experiment (LINX) (Hall et al. 2009, Mulholland et al. 2009, Bernot et al. 2010). We have been a leader in database development, including the StreamChem database with extensive metadata, the LINX data and metadata archival project, and initial efforts to develop a cross-site vegetation database.

SUMMARY OF LTER6. In LTER6 we showed that ecosystem processes respond to flows of air, moisture, organisms, information, and nutrients that are transiently connected both within and beyond the boundaries of the Andrews Forest. Moreover, Andrews Forest science affects social processes and thus affects the ecosystems that we study. Hence, LTER7 focuses on how physical, biological, and social processes are connected, and how these connections change over multiples scales of space and time.

2.0 PROPOSED RESEARCH

The overall goal of Andrews Forest LTER7 (2014-2020) is to apply our strengths in long-term research, outreach and education, and research-management partnerships to characterize the mechanisms that determine how forested mountain ecosystems respond to changes in climate, land-use, and their interactions.

The world's ecosystems are responding to a changing global climate in many ways: from global shifts in species distributions, to altered timing of critical spring phenological events in North America, to earlier snowmelt and increase in the number and severity of wildfires in the western United States (IPCC 2013). Climate change forecasts in the Pacific Northwest region are consistent with these trends (Mote and Salathé Jr. 2010, Rogers et al. 2011, Hamlet 2011), but observed rates of climate change vary with season and location within the region, especially in the mountains (Abatzoglou et al. 2013). Compounding the potential effects of a changing climate, forest governance systems in the Pacific Northwest are under growing pressure to balance demands to provide timber, restore ecological processes, maintain diversity, and facilitate adaptation of forests to climate change. Although recent regional forest management policies and plans were intended to be long-term and adaptive, it is not clear how successful they will be under climate change, or how adaptive they can be in a dynamic biophysical and social environment characterized by high levels of uncertainty and mistrust of public land managers by some segments of society (Spies et al. 2010).

These observations pose major challenges for understanding and predicting change in forested mountain landscapes (Dettinger 2014), which represent 23% of the Earth's forest cover (United Nations 2011). Long-term research at the Andrews Forest addresses these challenges, focusing on ecosystem responses to climate change and land use change, and factors that condition those responses. Given the long history of Andrews Forest science influencing forest managers' decision making, we also focus on the variable role of ecosystem science in forest governance.

The **conceptual framework** for LTER7 reflects these foci by incorporating more explicit and mechanistic links between mountain ecosystems and the human component of land-use in our system. We also use *connectivity* as a conceptual device to represent networks and predict processes in physical, biological, and social systems.

We employ a central question to guide our larger LTER research program, and in each LTER cycle we select a lens or theme to re-examine the central question and we frame research around a series of goals that respond to current ecological and societal needs (Fig. 9). In LTER7 we will adopt a more social-ecological framing (*sensu* Walker et al. (2012), International Council for Science (2010), Committee on Sustainability (2013), National Research Council (2010), Long-Term Ecological Research Program (2007), and others), because we recognize that forest ecosystem processes are intimately connected to how and why humans, through governance networks, make decisions about land-use. Moreover, we adopt this social-ecological framing because we recognize that without a better understanding of how humans make decisions affecting forest governance, a truly mechanistic understanding of land use and its impacts, and how those impacts feedback into the decision-making process, is not possible. As a result, the central question for LTER7 is **How do climate, natural disturbance, and land use as controlled by forest governance interact with biodiversity, hydrology, and carbon and nutrient dynamics?** (Fig. 9). This is a slight rephrasing of the central question guiding our research since LTER3: How do land-use, natural disturbances, and climate change affect three key ecosystem properties: carbon and nutrient dynamics, biodiversity, and hydrology? As such, our conceptual framework has both continuity and flexibility.

In LTER7 our lens is the concept of connectivity: we aim to understand the causes and consequences of connectivity as they relate to ecosystem processes in forested mountain landscapes. Connectivity is a focus of landscape ecology (Bélisle 2005), stream ecology (Miller et al. 2011, Finn and Monroe 2013), climate science (Krinner et al. 2005), and a measure of landscape structure (Peters et al. 2008), specifically the degree to which the landscape facilitates or impedes movement among resource patches

(Taylor et al. 1993). Connectivity refers to the movement (or flow) of cohesive “units” (or “packets”) from one place to another; these units can be in the form of matter and energy (e.g., organisms, nutrients, air, and water) or information (e.g., data sets, scientific facts and value statements). For us, connectivity is a way to represent networks and predict complex, adaptive behavior of linked physical, biological, and social systems. We conceptualize connectivity as flows: flows of matter, energy, and information within the system (Fig. 10). Connectivity allows us to conceptualize changes within the system due to exogenous forces such as a changing climate and land-use practices, and to understand how the system responds and might respond in the future.

We believe that understanding how connectivity changes in both space and time will lead to major advances in the ability to predict how the Andrews Forest (and other mountain systems) will respond to climate change and land-use at the exact time when demand for such research is high (Dettinger 2014). Previous research indicates that connections controlling system behavior and their strength vary in space and time, over multiple scales. Concurrent changes in the spatial and temporal scales at which processes in mountain landscapes facilitate or impede the exchange of organisms, energy, material, and information among landscape elements make it possible for systems to behave in seemingly erratic ways, which seems to match our observations. For example, measurement of carbon concentrations at flux towers appears connected to atmospheric inversions, which depend on local and regional air mass behavior, that in turn feed back to determine how net primary productivity (NPP) changes among trees of different ages, in different parts of the Andrews Forest mountain landscape, among years. Thus, forest NPP does not respond consistently to annual variations in climate (Woolley et al. in review): in most years there seems to be little common climate signal among the sites examined, while in other years there seems to be a common response.

Changing connectivity may provide explanations for other recent findings from long-term research in the steep slopes, tall, old forests, and clear streams of the Andrews Forest landscape. Airflows (e.g., cold-air pooling) episodically decouple portions of mountain landscapes from the free atmosphere, producing temperature anomalies (Daly et al. 2010, Pepin et al. 2011), and possibly contributing to microtopographic climate refuges. These processes may explain the surprising lack of consistent increase in air temperature we have observed under old-growth forest canopies over the past thirty years, and the seasonal and spatial variability in climate and streamflow trends (Jones et al. 2012, Abatzoglou et al. 2013). Changes in connectivity to Pacific Ocean air masses that bring precipitation to the region may also contribute an unanticipated twist to climate dynamics at our site (Luce et al. 2013). Progressive loss of connectivity among montane meadows, which harbor unique plant and animal species in the Central Cascades, jeopardizes plant-pollinator networks and may produce nonlinear responses of biodiversity to incremental landscape change (Halpern et al. 2010, Pfeiffer 2012). The shift from a top-down network of decision-making in federal forest management to a dispersed network of environmental groups (Spies and Duncan 2009) is fundamentally altering how federal forests are managed.

Long-term research at the Andrews Forest addresses these challenges, focusing on climate change and ecosystem responses in mountain landscapes, and the role of ecosystem science in forest governance. Continued long-term climate research will help Andrews Forest scientists and the larger climate community to disentangle several causes of long-term temporal variability in climate and their consequences for hydrology, ecosystem processes, and biotic communities. A major novel hypothesis for climate change in the region asserts that increasing high-pressure systems have exacerbated late summer drought by reducing orographic enhancement of precipitation and winter snowpack, but this signal (a 15% decrease in precipitation over 50 years) has been missed by the observational network in the Pacific Northwest, where high-elevation long-term measurements of climate and streamflow are rare (Luce et al. 2013, Dettinger 2014). By continuing our analysis of the Andrews Forest’s long-term, mountain-based networks of climate and streamflow, which were not included in these published studies, we are uniquely poised to test these and other competing hypothesized mechanisms for regional climate change. Other work suggests that fine-grained thermal variability in mountain ecosystems may contribute to “spatial buffering” of species response to climate change (Lenoir et al. 2013). Long-term studies of plants, insects, fish, birds, and other species at the Andrews Forest, combined with understanding of spatially variable phenology, are crucial for testing the hypothesis that mountain ecosystems are “buffered” (i.e., disconnected) from climate change.

The Andrews Forest is a 64 km^2 area and fifth-order drainage basin spanning 400 to over 1600 m elevation on the west slope of the Cascade Range, Oregon. The Andrews Forest is contained within the Willamette National Forest, and its stream, Lookout Creek, drains to the Willamette River basin. The site lies within the temperate wet forest biome, and is dominated by old-growth Douglas fir and western hemlock forests (Fig. 1). The Andrews Forest program has a 65-year history of research in a continually evolving context of changes in the environment, in science, and in society (Fig. 3). Basic science on old-growth forests in the 1970s and 1980s set the stage for a 1990s shift in federal forest policy from conversion to conservation of old-growth forests, and Andrews Forest research continues to guide restoration efforts and assessment of effects of environmental change. Research on the northern spotted owl in the Andrews Forest in the mid-1970s, led to the discovery of owl avoidance of clear-cuts, contributed to the concept of forest fragmentation and the emerging field of landscape ecology, and laid the groundwork for the cessation of old-growth logging on federal lands. Research on forest-stream interactions since the 1970s has contributed a series of key discoveries—role of large wood input, nitrogen movement between streams and forests, hyporheic influences on stream temperature and nutrients—leading to riparian management guidelines and regional aquatic strategies. Fundamental research starting in the 1970s demonstrated roles of large wood in forests and streams for ecosystem processes and community structure and was adopted to guide wildlife and fisheries management and policy. This work continues in the current context of carbon sequestration and net primary productivity response to climate variability. Work starting in the 1960s revealed influences of forest harvest and roads on landslides, debris flows, and flooding; and has continued to examine implications for disturbance cascades and invasion of non-native plants along roads and stream networks, contributing to federal roadless area policy and court battles about road runoff to streams.

Our long-term studies function as threads upon which we can string the beads of a succession of ideas and shorter-term studies (Fig. 3). In each successive LTER cycle, science questions emerge from long-term experiments and measurements as we evaluate them in a changing context, leading us to ask new questions, which in turn lead to new science discoveries. LTER7 continues this fundamental approach. Consistent with current major challenges in science and society, in LTER7 we will use a social-ecological conceptual framework and the concept of connectivity to describe and quantify mechanisms that determine how forested mountain ecosystems respond to changes in climate and land-use and how those responses shape the future. We organize LTER7 research around the following goals:

2.1 LTER7 Goals

Goal I: To understand the patterns, driving processes, and dynamics of atmospheric and hydrologic connectivity in mountainous ecosystems.

The role of dynamic atmospheric and hydrological processes within the heterogeneous topography of mountainous landscapes is gaining increased attention. The movement of air and water in heterogeneous mountain systems follows topographic networks, but may involve lags, thresholds, and nonlinear behavior contributing to ecological surprises. Airflows (e.g., cold-air pooling) episodically decouple portions of mountain landscapes from the free atmosphere, producing temperature anomalies (Daly et al. 2010, Pepin et al. 2011), and possibly contributing to microtopographic climate refuges. To predict how species and ecosystems respond to climate change in mountainous landscapes we must first investigate the fundamental patterns and drivers of flows of air and water.

Long-term studies at the Andrews Forest provide strong evidence for topographic controls on airflow and temperature. However, we have found limited evidence that recent regional warming patterns in the NW US (Abatzoglou et al. 2013) have translated into temperature increases at our site. Only some metrics, for some periods of record, some seasons of the year, on some portions of the landscape show statistically significant trends. What explains this? Are airflows across the mountainous landscape obscuring the expression of regional temperature signals? Projected changes in regional air circulation patterns may increase the importance of cold-air pooling in small sheltered valleys at some times of year, potentially buffering these sites from some effects of warming (Pepin et al. 2011). Yet climate records indicate that larger valleys are experiencing earlier springs now than in previous decades. In LTER7 we will characterize airflow connectivity and its effects on air temperature patterns in this mountain landscape.

Soil moisture is a critical constraint on forest productivity, but dendrochronology studies indicate variable response to moisture indices (Tepley 2010). Future climate models predict a lengthening summer drought in the western US (Dai 2011), yet headwater streamflow at the Andrews Forest and across North America has not responded as predicted to increased atmospheric input of heat (Creed et al. in press, Moore 2010, Jones et al. 2012). One explanation is that plant water use in late summer (drought period) may be decoupled from prior winter precipitation (Brooks et al. 2010) or from soil moisture (Moore et al. 2011b). However, many flow paths and residence times contribute to the "plumbing" of small watersheds (Bond et al. 2002, McGuire et al. 2005, 2007, Wondzell et al. 2007), which may result in substantial small-scale spatial variability in soil moisture conditions during the dry season. In LTER7 we explore water flow connectivity and its effects on soil moisture in this mountain landscape.

Goal II: To understand the consequences of the patterns, driving processes, and dynamics of biophysical connectivity for ecosystem processes and biotic communities.

Multiple forms of biophysical networks and connectivity in mountain landscapes may diminish or accentuate system response to change. Trophic mismatches may occur when plant phenology responds to climate differently than do consumers, such as insects or birds (Both et al. 2006), or during seasonal extension and contraction of stream networks. Similar decoupling has been found to occur in mutualistic networks—particularly between pollinators and plants (McKinney et al. 2012). In both instances, there is strong potential for phenological mismatches to be exacerbated by landscape fragmentation; restricted movement of higher trophic levels may prevent behavioral adaptations for predators or pollinators to "keep up" with changing plant or insect phenology. For instance, fragmentation of networks of non-forest openings may decouple plants from pollinators (Fig. 10) (Hadley et al. 2014).

Climate change has been linked to drought across the western US, and drought has been linked to increased wildfire (Westerling et al. 2006), decreased net primary production (Zhao and Running 2010), and increased mortality in forests (van Mantgem et al. 2009, Allen et al. 2010). In mountain landscapes, such as the Andrews Forest, topographic shading may decouple water use from carbon fixation (Moore et al. 2011a). The temporal and spatial variability in microclimate that results from the combined effects of dynamic atmospheric processes and subsurface flow paths may result in unexpected patterns of drought and primary productivity response to climate change across mountain landscapes. In LTER7 we will test how topographic position and water availability influence forest productivity.

Climate change is expected to affect the extension and contraction of the stream networks and influence connectivity of habitat for aquatic species at the tips of the network. These hydrologic changes are predicted to reduce the viability of trout populations in headwater streams (Wenger et al. 2011, Penaluna 2013). We are interested in whether the loss of trout, which function as top instream predators in these small streams, will affect headwater ecosystems and food webs (Fig. 11). In LTER7 we test how the presence or absence of fish predators influence trophic dynamics and ecosystem processes.

Species in mountain landscapes display differential phenological sensitivity to environmental variability: some (e.g., plants) are highly sensitive, whereas others (e.g., migratory birds) appear to be less sensitive. Variable phenological responses to climate change could lead to local mismatches between plants (producers) and insects or birds (consumers) (Both et al. 2006), but heterogeneity in mountain landscapes could mitigate this effect (Dobrowski 2011). Forest policies to suppress fire and eliminate clearcutting on federal lands may be leading to declines in biodiversity associated with early successional habitats. Montane meadows have declined drastically in the past half-century. Species dependent on open meadow and early successional habitats, such as rufous hummingbirds, are exhibiting regional population declines (Betts et al. 2010, 2013). Loss of connectivity in networks of non-forest vegetation may alter key trophic interactions, such as pollination. In LTER7 we will examine the implications of timing of trophic connections and landscape connectivity for community structure and function.

Goal III: To understand connections between forest governance and landscape pattern and process, and the ways in which public perceptions and valuations of federal forest landscapes and LTER science influence those connections.

Since 1948, research at the Andrews Forest has focused on the influence of forest management and other types of land-use on forest landscape pattern and process. In the past, we have largely considered the forest policies that influence land management to be outside our biophysical system of study. Social science research has assessed the roles of scientists as advocates (Lach et al. 2003, Steel et al. 2004, 2006, 2009) and social acceptability of federal forest management in and near the Andrews Forest (Brunson 1993, Ribe 1999, 2005, Ribe and Matteson 2002, Shindler et al. 2002, Mallon 2006, Shindler and Mallon 2011). In LTER7 we synthesize and build on these lines of research by analyzing the role that scientists, managers, policymakers and the public collectively play in larger environmental governance structures, which have strong bearing on landscape outcomes. We define environmental governance as "the set of regulatory processes, mechanisms and organizations through which political actors influence environmental actions and outcomes" as well as "interventions aimed at changing environment-related incentives, knowledge, institutions, decision making and behaviors" (Lemos and Agrawal 2006). We will examine how perceptions of the landscape influence societal expectations, social networks, and even social movements, catalyzing institutional change related to law, policy, management, and science. We will also examine the relationship between the arguments underpinning forest policy (some based on Andrews Forest science) and the validity and soundness of those arguments.

To understand long-term social-ecological change and transition, we will analyze the 65-year history of Andrews Forest research in the light of three distinct "eras" corresponding with US Forest Service management objectives and ideologies about the role of forests in society (Fig. 8): the "stewardship era" ending in 1945, the "timber era" ending in 1990, and the "biodiversity conservation era" which is ongoing. Andrews Forest research has three periods: 1) The 1950s-60s, when the Andrews Forest team conducted research on methods and impacts of production forestry, including logging old-growth and effects on watersheds, (Hays 1999); 2) The 1970s-80s, when basic Andrews Forest studies of old-growth forests, the northern spotted owl, and watershed processes, together with changing public values and attitudes, set the stage for subsequent and dramatic policy reversal in the early 90s (Forsman et al. 1993, Duncan 1999, Hays 1999, 2007, Manfredo et al. 2009) (Fig. 8); and 3) mid-90s to present, when scientists are exploring the ecological implications of recent landscape change (e.g., decline in biologically-rich early successional conditions), and the potential for alternative forest practices ("ecological forestry") to enhance ecological resilience to disturbances and climate change, while providing timber flow to local communities (Spies et al. 2010, Franklin and Johnson 2012). Legislation implementing these practices to increase logging and thus support the economic base of formerly timber-dependent communities is currently under review in the US Congress (Fig. 8). We expect that LTER7 research on the changing history of relations between Andrews Forest science, federal forest policymaking, and federal forest management along with the implications of that change for ecosystem function will contribute to theories regarding the role of social networks in governance and landscape transformation, and the functioning of social-ecological systems more broadly.

The Andrews Forest LTER program has long been committed to doing science that is relevant to society: an expression of a moral imperative to engage in ecosystem science linked to challenges in the real world. In LTER7 we think of the connection between our science and society in three ways. First, we strive to understand how the factual foundations we provide through our science have interacted with changing forest policies and change on the ground. Second, we evaluate arguments that utilize our science in policies. Third, we generate stories of connections, wonder, and awe that feed directly into both information about, and a positive valuation of, the world (Nelson and Vucetich in press, Nelson et al. in press).

As we initiate LTER7, the Pacific Northwest region faces future possible drought, declining snow packs, and increased wildfire, as well as changes in forest management on federal lands. All of these are tied to human values, decisions, and actions—and they are all potentially informed by the ecosystem science emerging from the Andrews Forest LTER program.

2.2 General Approach

We will employ a variety of approaches to accomplish our LTER7 goals, combining continued long-term measurements, experiments, and analyses with new empirical studies and short-term mechanistic experiments. We use long-term experiments and measurements (Section 2.3) to generate mechanistic hypotheses that we examine in more detail in short-term studies (Section 2.4). We explore interrelationships among system components through experimentation and analysis of long-term records (e.g., Fig. 2) to gain a holistic understanding of whole-ecosystem and landscape function. We employ the concept of connectivity (Fig. 10) to explain patterns of ecosystem behavior that emerge from long-term records. These efforts will be guided by our proposed central question: **How do climate, natural disturbance, and land use as controlled by forest governance interact with biodiversity, hydrology, and carbon and nutrient dynamics?** (Fig. 9).

MODELING AND UNCERTAINTY. In LTER7 we will use a wide range of models including conceptual, simulation, statistical, and machine learning models, with a principal approach of exploring multiple alternative forms of modeling to estimate model structural uncertainty (e.g., Tepley and Thomann 2012). We also use a variety of approaches including non-parametric models (Elith et al. 2008), dynamic occupancy models (MacKenzie et al. 2002, Kéry 2011), individual based models (Railsback et al. 2009), multi-response permutation procedures (Mielke and Berry 2001), and generalized likelihood uncertainty estimation (Beven and Binley 1992, Beven and Freer 2001, Beven 2006) to test parameter uncertainty and model structure uncertainty.

2.3 Long-Term Studies: Measurements, Experiments, Models, and Analyses

Our long-term studies span all core areas of the LTER program, address the Andrews Forest LTER central question, and provide multi-decade records to test theory and address new questions about ecosystem response to changing biophysical and social contexts. Maintaining long-term records enables discoveries that could not have been anticipated when the studies began, nor could be revealed by only new empirical studies, analyses, and short-term mechanistic experiments. In many cases our datasets are just beginning to be long enough to separate multi-decadal variability from long-term trends (Fig. 2). The Andrews Forest contains the only co-located, long-term observations of major ecosystem components in our region within a 1500-km radius, and we are a sentinel site for detecting environmental changes such as trends in air and stream water quality in national and international comparisons (e.g., Jones et al. 2012, Arismendi et al. 2012, Argerich et al. 2013, Lajtha and Jones 2013). LTER7 builds on our long-term studies, so we first present our long-term studies; we then present our new empirical studies, analyses, and short-term mechanistic experiments.

CLIMATE. Long-term climate research at the Andrews Forest is primed to contribute key insights about how processes and dynamics of mountainous topography and climate dynamics connect to regional and global climate. Continued long-term climate research will help Andrews Forest scientists and the larger climate community to disentangle several causes of temporal variability in climate at decadal time scales. Novel analyses of climate records may reveal important system properties, such as sudden increases in warming, or shifts in response to interdecadal or multi-decadal modes of climate variability. The regional climate science community is weighing alternative and complementary interpretations and phenomena (e.g., Mote 2006, Luce et al. 2013, Abatzoglou et al. 2013). Three principal drivers of Andrews Forest climate are central to these debates: 1) alternating cyclonic (low pressure) and anticyclonic (high-pressure) conditions driven by upper-atmosphere winds; 2) orographically-enhanced precipitation, rain shadows, and seasonal drought; and 3) a rain-snow transition zone that shifts in elevation. Long-term measurements reveal many climate processes operating at multiple spatial and temporal scales at the Andrews Forest. In addition to long-term continuous measurements from six climate stations, we have an unusually rare 35-year record of air and soil temperature beneath the forest canopy (N=7 sites) (Fig. 2). Since the 1970s, land surface temperature has increased at 0.25±0.05°C per decade globally (IPCC 2013) and 0.2°C per decade in the Pacific Northwest (Abatzoglou et al. 2013), but air temperature beneath the canopy of the 100 m tall, 500-year-old forest has decreased at a rate of -0.06±0.04°C per decade. This discrepancy leads to the LTER7 long-term climate research question, *"How are old-growth temperate forests in mountain landscapes connected to regional and global climate?"*

In LTER7 we will test the hypothesis that increasing high-pressure systems associated with climate change have intensified cold-air drainage and mitigated the expression of a regional warming signal at some locations in the forest. A network of distributed temperature sensors at 182 locations initiated in LTER6 reveals dynamic spatial patterns of air temperature within the Andrews Forest (Wilson 2013) (Fig. 5), including periods of cold-air pooling (Daly et al. 2010, Pepin et al. 2011). We will examine high-resolution temperature records to quantify the intensity and duration of nighttime cooling and map its extent in the mountain landscape. After sunset, a period of rapid nighttime cooling is followed by a period of much slower cooling; we interpret the rapid cooling as the sum of radiative, sensible and advective heat loss leading to nighttime cold-air drainage, and the onset of slow cooling as the cessation of cold-air drainage and the onset of cold-air pooling in depressions and valleys. Using functional data analysis (time series of first and second order derivatives) (Ramsay and Silverman 2005), we will quantify the onset, cessation, and intensity (rate of cooling) of cold-air drainage at each station (*N*=182) in the Andrews Forest. We will use results to create maps of cold-air drainage and pooling in the landscape for a range of seasons and weather conditions. We will extrapolate these patterns of cold-air drainage back to the 1950s using long-term records to assess how changes in seasonal duration and frequency of cold-air drainage may have affected air temperature trends over 65 years [Goal I]. We will examine how retrospectively mapped cold-air drainage patterns relate to mapped plant associations (Zobel et al. 1976), and test how rates of tree mortality (e.g., van Mantgem et al. 2009) differ within and outside of cold-air pools [Goal II].

In LTER7 we will also test the hypothesis that increasing high-pressure systems associated with climate change have exacerbated late summer drought by reducing orographic enhancement of precipitation and winter snowpack, or shifting snow to rain. Precipitation at the Andrews Forest is strongly affected by orographic enhancement and rain shadow effects, but climate change and increased frequency of high pressure over NW Canada is hypothesized to block moisture delivery to the region and weaken orographic enhancement of precipitation, reducing high-elevation rain and snow, and exacerbating summer drought (Luce et al. 2013). Winter snowpack and summer precipitation are also coupled to sea surface temperature in the northern Pacific at multi-decadal time scales (Fig. 2). Distributed temperature sensors reveal moderated late summer daytime temperature along N-facing topographic positions downslope of ridges receiving highest precipitation. We will estimate orographic enhancement from long-term precipitation records at multiple landscape positions and determine how orographic enhancement has changed over time in response to changes in air mass types and trajectories. We will apply functional data analysis to daytime high-resolution air temperature records to quantify the rate of heating on various topographic positions and aspects, and compare empirical findings with simple energy-balance models incorporating radiative, sensible, advective and latent heat fluxes. We will extrapolate these findings using long-term records to test how latent heat fluxes (associated with moisture) explain temporal patterns of daily maximum air temperature as well as soil moisture and stream network expansion and contraction over the past 65 years of our long-term records [Goal I]. *(PIs: Chris Daly, Julia Jones, Christoph Thomas, Mark Schulze)*

HYDROLOGY. Andrews Forest long-term hydrology research is poised to make major contributions to theory and practice about how climate change and a growing population will affect future water for ecosystems and people. Extreme floods and seasonal drought characterize hydrology of the Andrews Forest, and past research has addressed logging and road impacts on floods (Fig. 3) using data from 10 instrumented watersheds (Fig. 1). In LTER7 we focus on drought, in response to widespread predictions of climate-change induced drought in the western US (e.g., Barnett et al. 2008) and evidence of a lengthened summer and earlier spring in the Pacific Northwest (Abatzoglou et al. 2013). Although streamflow in old-growth headwaters of the Andrews Forest shows small decreases in the spring snowmelt period over ~60 years, consistent with an earlier spring onset of transpiration, late summer flow has not changed over 50 years (Fig. 2) (Moore 2010, Jones et al. 2012). Increasing energy (heat) inputs would be expected to increase evapotranspiration, but water yield from headwater forest ecosystems did not respond as predicted, based on analysis of long-term records from LTER, USFS, and Canadian sites (Creed et al. in press). Water management in the Pacific Northwest has focused on flood control, but climate change is expected to intensify summer drought, sharpening tradeoffs in reservoir management for flood control versus summer water supply. However, a network of dams and reservoirs provide regional water supply systems with engineered resilience to climate change (Hatcher and Jones 2013).

Andrews Forest long-term streamflow records and paired watershed experiments provide a unique (in the Pacific Northwest) opportunity to determine how forested mountain ecosystems may mitigate or exacerbate water scarcity in a changing climate. LTER7 long-term hydrology research addresses the question, *"How does decoupling of forest transpiration from soil moisture regulate response to drought?"*

In LTER7 we will test the prediction that seasonally dry coniferous forests respond to warming and drought by both an earlier onset and earlier shutdown of transpiration, with no change in seasonal evapotranspiration, and no exacerbation of seasonal drought. We will construct simple water balance models to estimate daily watershed-scale average soil moisture using long-term streamflow measurements at 9 small watersheds with continuous records dating to 1952. We will test how late summer soil moisture and the rate of drying are related to the magnitude, timing, and type of winter precipitation in old-growth forest watersheds. Using long-term paired watershed experiments, we expect to find that late summer streamflow is independent of winter precipitation, reflecting ecophysiological mechanisms to limit drought stress in old-growth conifers (Moore et al. 2004). However, we also expect to show that late summer streamflow in young conifer watersheds is sensitive to winter precipitation and warming, reflecting higher transpiration rates in young compared to old conifers (Jones and Post 2004, Moore et al. 2004, 2011b, 2011a). We anticipate finding that, at the watershed scale, old-growth forests are resilient to climate-induced drought stress, but young forests may be more vulnerable, and we will compare plot- and tree-level mortality in young and old forests [Goal II]. Building on the Willamette River Basin Future Scenarios project (Baker et al. 2004), agent-based modeling will explore consequences for water scarcity of alternative future climate change and land-use scenarios in the Willamette River Basin (ENVISION, Willamette 2100 project, (e.g., Guzy et al. 2008, Bone et al. 2013)), including flood scenario visualization, hydrologic modeling with HBV (i.e., Hydrologiska Byråns Vattenbalansavdelning (Seibert and McDonnell 2010)), and snow modeling validated with SnowModel (Sproles et al. 2013). We will also continue VELMA hydrologic modeling in the McKenzie River basin, into which the Andrews Forest drains (Abdelnour et al. 2011, 2013). *(PIs: Julia Jones, Sherri Johnson, Steve Wondzell)*

NATURAL DISTURBANCE. Andrews Forest research has shown how magnitude of disturbances in forested mountain landscapes depend on interaction of disturbance with the condition of the landscape at the time of disturbance, especially physical connectivity (edges, road and stream networks) and legacies of past disturbances, producing disturbance cascades—forms of connected disturbances that propagate through networks. Network connectivity and legacies provide a unifying framework for examining diverse disturbance types including wildfire (Fig. 2) (Tepley 2010, Tepley et al. 2013), floods (Johnson et al. 2000, Jones and Perkins 2010), landslides (Snyder 2000, Wemple et al. 2001), windthrow (Busby et al. 2006), insect outbreaks (Powers et al. 1999), and snow and ice damage ("snowdown") (Lutz and Halpern 2006). In LTER7 we ask, *"How do physical connectivity and biological legacies influence disturbance propagation in mountain ecosystems?"* We approach disturbance studies using 1) reconstruction (field survey, dendrochronology), 2) documentation and assessment of disturbances, and 3) model intercomparison (Tepley and Thomann 2012). In LTER7 we will continue opportunistic measurement as disturbances occur; in our budget we have set aside a special fund for rapid response research when a new disturbance occurs. *(PIs: Julia Jones, Fred Swanson)*

VEGETATION DYNAMICS. Long-term measurements and experiments on vegetation dynamics at the Andrews Forest are critical for testing theories about future ecosystem response to climate change, land-use, and natural disturbance. Past vegetation research has focused on characterizing old-growth forests, gap dynamics, disturbance/diversity relationships, tree growth, and mortality (Fig. 3). Vegetation in the Andrews Forest must cope with protracted seasonal (late summer) drought, and tree growth is weakly inversely related to warm Pacific sea surface temperature augmentation of summer precipitation (Fig. 2). Tree ring chronologies indicate that soil moisture limits tree growth at low elevation, while high snowpack limits growth at high elevation. In LTER6 climate change was implicated as a likely cause of increased tree mortality (van Mantgem et al. 2009)—reference stands from the Andrews Forest represented almost a third of this sample.

In LTER7 we will continue long-term measurements of live and dead vegetation to examine population, community, and ecosystem dynamics. Long-term vegetation measurements are collected in permanent plot systems in or near the Andrews Forest (Fig. 1) (Acker et al. 1998), some with 100 years of periodic measurements. In LTER7 we will continue measuring the Andrews Forest and regional permanent plots on a 5- to 6-year rotation. We will also resample plots following disturbances, such as extreme drought or cold events, to understand the temporal scales at which vegetation dynamics respond to climate and disturbance [Goal II]. During LTER7 we will add new measurements: 1) heights will be determined for a subsample of trees to characterize vertical structure and aid future analyses of LiDAR and other remotely sensed data; 2) dead standing and downed trees will be re-inventoried to assess how these pools are changing to provide a more complete understanding of wood carbon dynamics; 3) soils will be sampled in pits to improve interpretations of differences in plot biomass and aboveground NPP in terms of water holding capacity and nutrient capital; and 4) dendrochronology will seek evidence of stress preceding mortality in selected individuals. A subset of vegetation plots such as those in WS1 will be used to examine the aboveground NPP consequences of water flow paths [Goal II]. USGS collaborators are using ecosystem models (e.g., LPJ-GUESS, (Smith et al. 2001, Rice 2009, Shafer et al. 2012)) to simulate species and ecosystem responses to climate change as represented by Coupled Model Intercomparison Project phase 5 (CMIP5) coupled atmosphere-ocean general circulation model climate simulations (Taylor et al. 2012). Mathematical modeling of wildfire effects on forest structure (Tepley and Thomann 2012) and individual-based models of forest succession (Seidl et al. 2012b) will be extended to test how drought-induced mortality influences past and future forest stand structure. *(PIs: Mark Harmon, Tom Spies, Charlie Halpern)*

STREAMS. Long-term measurements and experiments in streams at the Andrews Forest has revealed tight connections between forests and streams (Gregory et al. 1991, 2003) involving wood (Gregory et al. 2003, Meleason et al. 2003), nitrogen (Sobota et al. 2012), temperature (Johnson 2004, Arismendi et al. 2012, 2013b), fish population dynamics (Moore and Gregory 1988, Dodds et al. 2012), and flood response (Swanson et al. 1998, Johnson et al. 2000, Faustini and Jones 2003), leading to riparian management guidelines for Pacific Northwest forests (Gregory and Ashkenas 1990, Thomas et al. 1993, Gregory 1997). Fish populations increased the year after major floods (Fig. 2), highlighting that biotic responses to extreme events, such as floods and droughts, do not consistently conform to our expectations. Climate change may enhance summer drought and reduce forest-stream connectivity within the landscape. We will continue the existing long-term study of forest stream interactions in Mack Creek, including fish, amphibians, streamflow, aquatic insects, temperature, and wood in Mack Creek, and interpret these findings to inform short-term studies and experiments in headwater streams (see New Empirical Studies). Individual-based modeling (inSTREAM; (Railsback et al. 2009, Penaluna 2013)) will use long-term data on marked individuals to examine how changing flow, temperature, and food resources and the ordering of extreme events influence salamander and fish population responses to past extreme events and future climate. *(PIs: Sherri Johnson, Stan Gregory, Ivan Arismendi, Brooke Penaluna)*

BIODIVERSITY, PHENOLOGY, AND TROPHIC NETWORKS. Long-term measurements of insects and plants at the Andrews Forest provide an opportunity to test relationships among biodiversity, phenology, and trophic networks. In LTER6 we found that the connectivity among montane meadow fragments influences the size and diversity of plant-pollinator networks (Pfeiffer 2012, Highland et al. 2013). Insect and plant community diversity exhibit transient dynamics over many decades in response to vegetation change (Highland and Jones in press), and characteristics of previous vegetation determine temporal changes in understory plant diversity (Halpern and Lutz 2013). In LTER7 we address the question, *"How do climate, land-use, and disturbance influence connectivity among landscape elements, trophic structure, and biodiversity over multiple decades?"*

In LTER7 we will continue research on long-term population dynamics and community structure of plant, insect, bird, salamander and fish species, which are sensitive to climate and disturbance. We will examine long-term records to quantify factors that influence phenology and relate these to trophic dynamics and biodiversity. Using long-term records, we will test how phenology and diversity of insects and plants have responded to temporal variation in soil water availability and temperature dynamics. We will extend species distribution modeling using multi-label machine learning and boosted regression trees to identify controls on changing bird and lepidoptera distributions (Wilkins 2010, Yu et al. 2011, Shirley et al. 2013). We will refine multi-instance, multi-label machine learning methods for classifying birdsong to relate bird occurrence to phenology (Briggs et al. 2009, 2012a, 2012b, 2013c, 2013a, 2013b, Neal et al. 2011). We will continue to develop interactive visual analytics to visualize long-term biodiversity, phenology, and plant-pollinator data (Pham et al. 2013). *(PIs: Matt Betts, Mark Schulze)*

CARBON AND NUTRIENT DYNAMICS. Long-term paired watershed and decomposition experiments at the Andrews Forest are positioned to contribute to theories about ecosystem regulation of nutrient cycling in response to changing climate and disturbance. High rates of carbon sequestration in very old trees (Stephenson et al. 2014) adds to ongoing work on ecosystem carbon storage (Harmon 2009, Ryan et al. 2010). Research has linked decomposition (Parton et al. 2007), soil respiration (Phillips et al. 2011, 2012), soil microbial activity (Yarwood et al. 2013), solute transport (van Verseveld et al. 2009, González-Pinzón et al. 2013), and nutrient export (Argerich et al. 2013). Synoptic sampling of stream chemistry has revealed high variability in nutrient concentrations among headwater streams. In LTER7 we ask, *"How do decomposition and nutrient export respond to soil moisture and temperature?"*

The Andrews Forest has the longest continuous precipitation and streamwater chemistry records in the western US (Fig. 2) (Argerich et al. 2013, Lajtha and Jones 2013). In LTER7 we will continue long-term measurements of precipitation chemistry and stream chemistry, and examine how biogeochemical processes respond to climate, geology, disturbance, and land-use across headwater sites. We expect declining snowpack and shifts in timing of precipitation to exacerbate summer drought and ecosystem stress, with potential consequences for decomposition, nutrient processing, and transfer of nutrients from hillslopes to streams. We will examine long-term stream chemistry records during wet and dry seasons to test how connectivity between hillslopes and streams and within stream channels influences temporal dynamics of biogeochemistry of headwater streams [Goal I].

Three ongoing LTER-related experiments, established in 1985, have examined long-term dynamics of wood decomposition to determine the long-term pattern of mass loss, moisture change, and nutrient uptake/release as well as how these are controlled by species, size, and micro- and macro-climate. These include a 200-year terrestrial experiment examining 50 cm diameter logs; a 40-year upland-stream contrast examining 25 cm diameter logs; and a 30-year examination of branch wood ranging in diameter of 1 to 8 cm. The 30-year measurements of changes in mass, volume, and nutrient content are scheduled for 2015 (Harmon 1992, Harmon et al. 1994, 1999) and M. Harmon will analyze results as part of an OPUS funded synthesis. Biogeochemical modeling will test alternative hypotheses of vegetation and water flow path controls on stream chemistry using DAYCENT (Hartman et al. 2009) and VELMA (Abdelnour 2011, Abdelnour et al. 2011, 2013). We will continue modeling of ecosystem carbon storage responses to future climate, natural disturbance, and proposed forest management practices (LANDCARB (Mitchell et al. 2009, 2012, Harmon 2009, Campbell et al. 2011)). *(PIs: Mark Harmon, Sherri Johnson, Alba Argerich)*

2.4 New empirical studies, analyses, and short-term mechanistic experiments

AIRSHED: THE BREATHING OF THE ANDREWS FOREST: EXCHANGE OF HEAT AND CARBON IN MOUNTAINOUS TERRAIN

PIs: Christoph Thomas, Chris Daly

General Question: How does systematic air exchange of heat, water, and carbon in small and large mountain watersheds affect ecosystem sensitivity to external climate forcings including extreme events such as drought?

Rationale: The atmosphere exhibits a strong forcing on primary productivity, respiration, and evapotranspiration; in turn, vegetation influences heat storage and redistribution, radiation balance, trace gases, CO_2 and water vapor, both below and above the canopy (Fig. 4). In mountainous ecosystems, the terrain (elevation, topographic position, and aspect) strongly modulates vegetation-atmosphere interaction by controlling spatially and temporally varying airflows and air temperatures (e.g., Pypker et al. 2007, Lundquist et al. 2008, Daly et al. 2010, Pepin et al. 2011, Walley 2013), moisture and transpiration (Thomas et al. in review, e.g., Ashcroft et al. 2009, Pypker et al. 2009), and carbon uptake (Thomas et al. in review, e.g., Pypker et al. 2008). In LTER7 we will characterize airflow connectivity and its effects on air temperature patterns [Goal I] and the effect of topographic shading on drought sensitivity of the forest ecosystem [Goal II] in the mountain landscape. This mechanistic experiment will provide a physical understanding of airflows needed to interpret climate change processes in mountains throughout the

Pacific Northwest and globally, and produce a short-term, continuous record of watershed-scale carbon and water fluxes for comparison with long-term analyses.

Hypothesis: *The degree of sensitivity of Andrews Forest valleys to the effects of climate change and connectivity to regional airflow patterns depend on the type (transient or persistent) of the cold-air drainage and pools.*

Work in LTER6 has suggested that small, sheltered valleys can exhibit diminished responses to changes in upper airflow patterns (Daly et al. 2010), while at the same time the central valley of the Andrews Forest is experiencing markedly earlier springs (Jones et al. 2012). We propose that these apparent contradictions depend upon the contrasting behavior and effects of transient cold pools during seasonal transitions (spring and autumn) versus persistent, stable cold pools during winter. We expect to find that the interactions between solar energy input, topography, moisture, and forest canopy presence lead to identifiable spatiotemporal 'breathing patterns' determined by the direction, strength, and connectivity of the airflows (Fig. 10). In addition to the heat and wind microclimates, we will quantify the effects of the moisture microclimate in the soil and near-surface air, to estimate how latent heat exchange may diminish local climatic extremes. These relationships will be used to interpret temporal patterns of air temperature and hydrology from long-term records (Fig. 2).

Approach: We propose to continue the acoustic sounder measurements of height-dependent wind speeds and directions and vertical mixing at the mouth of the Lookout Creek watershed at Primet and in the center of the Andrews Forest. These unique measurements of wind and vertical mixing will provide mechanistic explanations for observed spatial and temporal patterns of temperature and humidity data at the benchmark sites, reference stands, and the distributed temperature sensor network (Fig. 1). They will also help to refine the physiographic climate-mapping algorithm PRISM (Daly et al. 2008).

Hypothesis: *Topographic shading decreases water use efficiency of mountainous forests by increasing transpiration without significant photosynthesis and thus exacerbates drought stress and sensitivity during the late summer months.*

Although it is well known that mountains can induce strong convective cells that affect the transfer of heat and water vapor from the surface into the atmosphere and thus induce precipitation (Prandtl 1952, Schumann 1990), the ecological implications of this mechanism at the ecosystem scale are not well understood. We expect to find that convective cells that form in a deeply incised valley such as WS1 by topographic shading and consequential differential heating and cooling of the south- and north-facing slopes, respectively, (e.g., Serafin and Zardi 2010), may enhance the evapotranspirative losses from vegetation and thus the forest's vulnerability to seasonal drought stress. We build upon existing work in WS1 (Thomas et al. in review) to compute ecologically meaningful estimates of carbon exchange, evapotranspiration, and sensible heat flux during day and night based on a modified mass balance approach (Thomas et al. 2008, 2013). Analysis and interpretation of fluxes will be linked to the spatial patterns in soil moisture and forest productivity of the soil-water-vegetation activity.

Approach: This study uses the existing eddy covariance tower at the mouth of WS1 (Fig. 1) equipped with 2 levels of eddy covariance flux observations, soil and air temperature and trace gas ($^{12}CO_2$, $^{13}CO_2$, H_2O, CH_4) sampling profile systems, light measurements, and soil respiration chambers. These flux estimates will be combined with the three-dimensional distribution of leaf area and biomass from LTER6 LiDAR data (Fig. 10), as well as imagery acquired in the visible and thermal infrared spectral bands using a camera system mounted on the ridge opposite WS1. This instrumentation will allow us to identify periods of elevated plant drought stress in the late summer months.

SOIL-WATER VEGETATION: THE ROLE OF SUB-WATERSHED SCALE TOPOGRAPHY AND HYDROLOGIC CONNECTIVITY

PIs: Steven Wondzell, Thomas Spies, Christoph Thomas, Thomas Hilker

General Question: Does sub-watershed scale topography distribute soil moisture along hillslopes and thereby influence spatial patterns of forest productivity?

Rationale: Soil moisture availability controls forest productivity (Woolley et al. in review, Littell et al. 2008, Sierra et al. 2009), decomposition (Harmon 2009), and even tree mortality (van Mantgem et al. 2009).

Despite its importance, we have not yet examined the factors that drive spatial patterns in soil moisture availability at the Andrews Forest. However, the movement of water within watersheds is strongly controlled by sub-watershed scale topography in steep, highly-dissected terrain with shallow soils (Jencso et al. 2009). This movement and distribution of water on hillslopes creates and connects resource patches and also controls hillslope connectivity to stream and riparian ecosystems (Fig. 10b). In LTER7, we will test how topography influences hydrologic connectivity by influencing soil moisture distribution [Goal I], modulating forest ecosystem response to seasonal drought and inter-annual variation in climate, and ultimately, influencing long-term ecosystem vulnerability to climate change [Goal II].

Hypothesis: *Movement and distribution of water on hillslopes produces detectable patterns in available soil moisture and primary productivity. Alternatively, movement and distribution of water may have little influence on growing season moisture availability because of the strong seasonality of precipitation or because soils may be too deep for water to be available to trees.*

Approach: We will locate approximately 50 soil moisture monitoring sites in WS1. We will use the LiDAR-based fine-scale DEM constructed in LTER6 (Fig. 10) to map the upslope accumulated area draining through any point in the landscape. Sites will be spatially nested in a design that stratifies for differences in elevation, slope position, aspect, and other terrain indices from which we can evaluate the relationship between upslope accumulated area and soil moisture as a function of season. We will use time domain reflectometry (following Gray and Spies (1995)) to monitor moisture at each site, installing 2 probes each in the shallow and deep rooting-zone and 2 below the rooting-zone probes to help resolve within-site variation. We will also measure soil depth at each site. Measurements will be made monthly, over two years. We expect to capture the majority of the potential temporal variability in two years because intra-annual variability greatly exceeds inter-annual variability in discharge and, by implication, soil moisture. After two years of monitoring, we will identify a small subset of sites that can be maintained for long-term measurements.

We will relate stream discharge to observed spatial patterns of soil moisture and then use historical precipitation and stream discharge records (Fig. 2) as a proxy measure of soil moisture, integrated over the entire watershed, to reconstruct historical seasonal and inter-annual variations in soil-moisture patterns. We will test how modeled and measured soil moisture are related to tree growth and mortality using existing tree-ring records (Tepley 2010); LiDAR-based measurements of tree height, canopy diameter, and modeled biomass (Seidl et al. 2012b); and growth and mortality in 50-year permanent vegetation plots in WS1 (Lutz and Halpern 2006, Halpern and Lutz 2013). Ground-based multispectral and thermal-infrared remote sensing imagery will be collected from sampled areas to relate fine-grained soil moisture measurements to canopy attributes, providing a way to diagnose drought stress as a function of location and microclimate, and providing a method to transfer intensive, site-based measurements to larger areas.

A more extensive soil-moisture monitoring network of approximately 20 sites will be initiated in a subset of the existing long-term vegetation plots and phenology plots established in LTER6 (Fig. 1). The vegetation plots will allow us to test soil-moisture relationship to tree growth and mortality across a wider suite of environmental conditions than is present in WS1. Air temperature is already being monitored at phenology plots; however, soil moisture can mediate air temperatures via evaporation (Ashcroft and Gollan 2013), and moisture may mediate species response to temperature. The extensive monitoring network will explore the influence of moisture availability on ecosystem productivity and phenology at larger spatial scales and across larger environmental gradients at the Andrews Forest.

TROPHIC DYNAMICS IN RELATION TO CLIMATE AND LAND-USE IN A MOUNTAIN ECOSYSTEM

PIs: Matthew Betts, Mark Schulze, Judith Li

General Question: How do patterns of microclimate and vegetation variability influence trophic dynamics among plants, insects, and birds, and thereby long-term population dynamics?

Rationale: Models used to project future climate impacts to biodiversity predict more extinction and less resilience than has been observed (Botkin et al. 2007, Moritz and Agudo 2013). In mountain ecosystems, species and trophic responses to climate change likely are mediated by topographic effects on moisture and atmospheric processes that vary on diel to interannual time scales, as well as land-use and associated patterns of vegetation structure and composition (Fig. 6). Climate change-induced "phenological mismatches" and consequent long-term population declines have been reported in systems with relatively low vegetation species diversity and simple topography (e.g., Both et al. 2006). However, phenological mismatches may be less likely in mountain landscapes where vegetation diversity is high, insect herbivore and vegetation species richness are correlated, and insect taxa have varied phenology (e.g., Highland et al. 2013). Further, the capacity of organisms to capitalize on such phenologically heterogeneous sites should depend on their mobility, which is a function of landscape connectivity. In LTER7 we will undertake new measurements to determine how climate and landscape structure interact to drive population and community structure [Goal II].

Hypothesis: *Spatial patterns of microclimate that influence plant and animal phenology vary seasonally depending on stable (e.g., topographic shading, vegetation structure) and dynamic factors (e.g., air and water flows), and breeding birds track food resources (abundance, diversity) associated with seasonally stable microclimates.*

Approach: We will continue measurements initiated (by S. Hadley, PhD candidate) in LTER6 on bird distributions and microclimate across gradients in elevation and successional stage, using an established network with 184 points (Fig. 1). At a subset of these points we will quantify insect food availability (*N*=40), vegetation phenology and soil moisture (see soil-water-vegetation, *N*=20). We will automate long-term data collection using bird songmeters (*N*=16) and time-lapse phenocams (*N*=55). We will use machine-learning algorithms to automate identification of bird song for 13 common species of the Andrews Forest and create high-resolution information on the timing of bird song as well as territory establishment (Briggs et al. 2012b). We will use phenocams to monitor phenological stages associated with initiation and duration of seasonal plant growth and to identify canopy metrics for scaling up phenology observations using remote sensing. Changes in bird distributions both within seasons and among years (e.g., Fig. 6) will be modeled using dynamic occupancy modeling, which incorporates variability in detection probability into spatial models of within-season distribution patterns (Betts et al. 2008). Distribution and apparent movement will be modeled as a function of both climate and vegetation variables (derived from LiDAR and on-site vegetation measurements). We will also sample bird diets to test the degree to which trophic networks vary spatially and temporally across gradients in microclimate. Pilot data suggest that the diversity of insect orders found in bird diets may be lower at sites that experience greater microclimate variability.

Hypothesis: *Landscape connectivity will mediate the degree to which organisms can exploit spatial heterogeneity to mitigate effects of climate variability or directional change.*

Approach: The rufous hummingbird, a migratory species and generalist pollinator, may be vulnerable to combined effects of phenological mismatches from climate change and loss of pollination from meadow fragmentation. We will test how meadow loss and fragmentation interact with climate variability to affect the abundance and movement of this generalist pollinator and pollination success of montane meadow herb species. We will continue work in 16 study meadows at the Andrews Forest and surrounding landscape designed to represent a gradient in meadow patch size, connectivity and topography (Pfeiffer 2012). At each of these meadows, we will monitor the phenology of five dominant meadow herbs that are pollinated by hummingbirds. Concurrently, we will monitor snowpack, soil moisture, temperature regimes and green-up and dormancy of herbaceous communities by expanding existing networks of environmental sensors and time-lapse cameras to cover the 16 meadow transects. We will use two field experiments to study pollinator movement and pollination success: a) Capture and mark hummingbirds with Radio-frequency Identification Devices (RFIDs) that allow individuals to be recognized when they visit feeders distributed across gradients designed to test the independent effects of moisture versus fragmentation/connectivity. Feeders (programmed to deliver nectar at similar levels to naturally occurring flower species) will be distributed across the meadow complexes to enable us to determine movement patterns among the meadow fragments, b) Conduct a pollen limitation experiment for two focal plant species. We will statistically model movement (transitions from $patch_i$ to $patch_j$) as a function of landscape-scale variables (patch size *x* isolation + flower resource availability).

TROPHIC AND ECOSYSTEM RESPONSES TO CONTRACTIONS OF STREAM NETWORKS

PIs: Sherri Johnson, Alba Argerich, Ivan Arismendi, Dana Warren, Brooke Penaluna, Judith Li, Stan Gregory

General Question: Does reduced hydrologic connectivity and absence of fish alter the transfer of matter and energy among trophic levels within small streams?

Rationale: Stream networks expand and contract seasonally (Fig. 10); these changes in stream network connectivity affect transfer of matter and energy across trophic levels and between aquatic and terrestrial ecosystems (Ward 1989, Gregory et al. 1991). Although many organisms that live in the headwaters of the stream network are well adapted to seasonal low flows (Frady et al. 2007, Banks et al. 2007), some organisms (e.g., trout) may experience stress from reduced summer habitat and instream food, increased water temperature, and increased vulnerability to predators (Berger and Gresswell 2009). Climate change is expected to further contract summer stream networks and lead to reduced viability of trout populations in small streams (Wenger et al. 2011, Penaluna 2013) (Fig. 11). Long-term research at the Andrews Forest on two co-occurring aquatic vertebrate species, Mack Creek cutthroat trout, and Pacific giant salamander, has revealed complex population dynamics and variable responses to hydrologic variability, including immediate and lagged responses to droughts and floods (Dodds et al. 2012). Trout and salamanders might be expected to have very different responses to climate change and stream drying because of their habitat requirements and mobility—with salamanders able to inhabit smaller or more disconnected streams than trout. In LTER7 we will extend our study of these predators by examining how stream trophic structure and ecosystem processes differ across multiple headwaters in the stream network when one or both of these predators are present. This research will allow us to examine how varying instream and aquatic-terrestrial connectivity influences the ways in which instream predators, fish and salamanders, shape food webs and ecosystem dynamics. [Goal II].

Hypothesis: *Small streams accessible by fish predators during low summer flows have distinct trophic dynamics and food web composition that result in measurable differences in ecosystem processes. Alternatively, absence of fish in headwater reaches may have minor effects on stream ecosystem processes, which may instead be regulated by nutrient cycling, availability and uptake controlled by instream hydrologic connectivity and inputs from groundwater and riparian forests.*

Approach: The effects of fish as top predators on food web structure and ecosystem processes will be investigated across headwaters and during 6-week experimental exclusions. The limits of fish distributions and their consequences for food web structure and ecosystem processes in small streams (80% of stream length) have not been previously examined. Eight to ten small streams will be selected for study based on prior sampling of nutrients and biota, proximity to long-term stream gages, and the STREON experimental site. During summer lowflow period in each of four years, we will determine the upstream limit of cutthroat trout distribution (Fig. 11) by electro-shocking in each study stream. Above and below the upstream limit of fish distribution, we will measure length and mass of fish and salamanders and collect diet samples using gastric lavage (Romero et al. 2005). We expect salamanders to take better advantage of terrestrial resources and linkages and to have more terrestrial insects in their diets while trout are expected to feed selectively on the largest available benthic invertebrates. Therefore we will compare species diversity and abundance of large benthic invertebrates above and below the upstream limit of fish distribution. We will quantify nutrients and instream resources (chlorophyill a, fine benthic organic matter, and epilithon biomass) between sites with fish and salamanders and with only salamanders. We will measure stream temperature, habitat, hydraulics and streamflow to assess how thermal conditions and flows influence year-to-year variability in the distribution of these vertebrate predators. In year 4 we will test how experimental removal of fish or salamanders or both alters the transfer of matter and energy among trophic levels. We will use block nets to establish a series of randomized experimental reaches using a factorial design of fish and salamander removal in a subset of study streams. All fish and salamanders within the experimental reaches will be individually marked, measured and weighed at the beginning and end of the experiment. We expect that salamander diet will shift and growth will decrease when co-located with cutthroat trout. We also expect stream reaches without fish or salamanders will have larger insects and therefore more activity by grazing insects, and reduced instream primary productivity.

To assess ecosystem responses to distribution of instream predators, we will measure whole stream metabolism, to calculate primary productivity and respiration (Sobota et al. 2012), and nutrient spiraling, to determine the uptake rates and travel distances of available instream nutrients. We will use a combination of metabolic tracers (RAZ, (Argerich et al. 2011)) and nutrient additions injected above and below the termini of vertebrate distributions to assess respiration and nutrient spiraling. We will use conservative or hydraulic tracers to calculate travel times of water, as a metric of instream connectivity, and to quantify lateral or subsurface inputs of water, as a metric of forest-stream connectivity.

SOCIAL SCIENCE: FOREST GOVERNANCE, SOCIAL NETWORKS, AND LANDSCAPE DYNAMICS IN THE WESTERN CASCADES

PIs: Hannah Gosnell, A. Paige Fischer, Cassandra Moseley, Troy Hall

General Question: How do science-policy-management networks influence and respond to changing landscape dynamics; and how do they prohibit or encourage adaptive governance?

Rationale: Social science has sought to understand interactions between social systems and ecological systems through investigations of environmental governance: the set of formal and informal processes, mechanisms, and institutions through which actors influence environmental decision making and behavior (Ostrom 1990, Lemos and Agrawal 2006). Theory suggests that governance systems change over time in response to interacting social and ecological variables, and that social networks play an important role in triggering “thresholds” in certain key variables that can result in new forms of governance (Gunderson and Holling 2002, Christensen and Krogman 2012). Governance regimes have direct bearing on the resilience of social-ecological systems, and theory suggests that *adaptive* governance systems, characterized by (among other things) connectivity among actors across scales and sectors (government, local communities, civil society), provide advantages for the management of ecological systems by enabling social learning, experimentation, and flexibility under uncertainty (Walters 1997, 1998, Peterson et al. 1998, Folke et al. 2005, Huitema et al. 2009). However, empirical evidence to support these theories is limited, and it is unclear under what conditions and in what geographical contexts adaptive governance systems emerge. In LTER7 we will identify how scientific findings about landscape pattern and process influence patterns of social relations among actors, which in turn influence forest governance regimes and future stand management and landscape dynamics [Goal **III**]. Analysis of the tumultuous history and current politically charged status of federal forest management in the Pacific Northwest (Fig. 8) may yield important insights into the evolution of governance systems and the ways in which transformations in governance, manifested in changing science-policy-management networks, are linked to changing landscape dynamics. The research will also shed light on how flexible institutions and adaptive governance structures can be devised, so as to sustain and enhance the capacity of ecosystems to produce valuable ecosystem services and cope with uncertainty (Bodin and Prell 2011). This research builds on a rich and diverse body of science from the Andrews Forest that has strongly influenced public and policymaker perceptions of old-growth, watershed processes, road hydrology, and the role of dead wood in forests and streams (Fig. 3). These findings have been central players in the evolving issue environment that frames debate about federal forest policy. Lessons from this research will inform the Andrews Forest and other similar programs about how such sustained, place-based, highly interdisciplinary programs can more successfully serve society.

Approach: We will use social science methods to 1) identify social processes that explain the changing relationship of Andrews Forest science to federal forest policymaking; 2) reveal social mechanisms that decouple federal forest policy from actual management practices; and 3) evaluate the potential for the emergence of an adaptive governance system characterized by tight connections and feedbacks between scientific discovery and forest management. To accomplish these objectives we will analyze existing documents and other qualitative data (including transcripts from the Andrews Forest History Project) to construct a narrative chronology of federal forest governance in the Pacific Northwest that characterizes relationships between key actors (local, regional, national), institutions (including laws and policies), and resource users—and describes shifts in these relationships over time. We will confer with appropriate Andrews Forest scientists to identify trends in forest pattern and process related to changing management practices over the past 65 years, and consider methods for integrating research findings with spatial data depicting land cover change. Based on these preliminary analyses we will use social network theory (Bodin and Prell 2011) to analyze the changing structure and function of social networks connecting biophysical scientists to land managers, the public, regulators, policymakers, and the media from the stewardship era through the timber harvest era and the biodiversity conservation era (Fig. 8). We will collect and analyze new qualitative and quantitative data regarding science-policy-management networks using semi-structured interviews, social network analysis (a quantitative approach to the study of social relations) (Wasserman and Faust 1994, Henry 2011) and institutional mapping (Stimie et al. 2001, Aligica 2006). These empirical analyses will yield visualizations of changing social network structure and will identify variables that explain changes in network structure over time, informing the development of theories about relationships between forest governance and landscape dynamics, an elusive goal in social-ecological systems research (Tompkins and Adger 2004, Bodin et al. 2006, Crona and Hubacek 2010). These findings will inform a collaborative analysis with landscape ecologists of connections between social and ecological thresholds and the identification of key variables along which thresholds have been crossed, along with important drivers of these regime shifts. Finally, we will use triangulation to synthesize data and identify pathways and barriers to a more adaptive federal forest governance system (Patton 2002, Stake 2010).

CONSERVATION ETHICS: ECOLOGY, FORESTRY, AND ARGUMENT ANALYSIS IN THE PACIFIC NORTHWEST

PI: Michael P. Nelson, and Andrews Forest researchers in relevant subject areas

General Question: What is the relationship between the adoption of a forest policy and the soundness of the arguments underpinning that policy; including the truth or controversy of the scientific premises, and the types of values evoked to support those arguments?

Rationale: A key justification for NSF's LTER program is that wise environmental management depends on science (Callahan 1984). However, it is difficult for the LTER program to wholly demonstrate the truth of this statement because it lies in the realm of philosophy (ethics), as much as in ecological and social science. Ethical analysis involves the systematic and rigorous alignment and assessment of science with explicit notions of value (Nelson and Vucetich in press, 2009, 2012, Vucetich and Nelson 2007). For example, although the Andrews Forest LTER program has a long-standing commitment to informing natural resource decision-making in the Pacific Northwest, we have little systematic understanding of this process of transference; many other LTER sites share this dilemma. Consideration of ethics is an important but underused component of engaging in and understanding environmental decision-making (Minteer and Collins 2005, Doak et al. 2008, Ripple et al. 2014). Analysis of implicit and influential values guiding policymaking will complement social science analysis of why and how the influence of science on policy varies over time [Goal III].

Hypothesis: *We will explore the null hypothesis that there is no discernible relationship between the soundness of an argument, the truth or controversy of premises, and the adoption of a given course of action. Alternatively, arguments premised on value statements involving intrinsic value (e.g., ecosystems are valued for themselves) have been judged as more persuasive than arguments based on instrumental values (ecosystems valued as means to some end).* The intellectual merit of this effort includes at least two outcomes: evidence supporting the alternative hypothesis would 1) provide a broader approach to arguments than the current, perhaps limited, focus on ecosystem-services-type arguments prevalent in the LTER Network, and 2) suggest that LTER research can influence decision making by cultivating a sense of awe or wonder (intrinsic valuation) about the ecosystems we study.

Approach: In LTER7, building on expertise of the lead PI, we will use methods of ethical argument analysis—developed from formal tools in critical thinking (Copi et al. 2011)—to formally evaluate arguments about management involving Andrews Forest science and ecosystems (e.g., Nelson and Vucetich 2012) (Table 1). The first step in a conservation ethics approach is to identify pernicious and inherently interdisciplinary natural resource challenges, and to list reasons for and against a given policy direction. In the Pacific Northwest, current environmental changes (e.g., rising human population, changing land-use, and climate change and coupled strain on natural resources) appear to be intensifying pressure on natural resources such as forests (Hays 2007, Spies and Duncan 2009, Spies et al. 2010) (Fig. 8). At such times, policy prescriptions can become confused, even perverse, losing the connection to thoughtful engagement. Key challenges facing federal lands in the Pacific Northwest—and closely connected to Andrews Forest science—include the prospect of increased logging to reduce fuels and increase wood production, jobs, and early successional habitat; and the killing of barred owls to increase numbers of spotted owls, which are listed under the Endangered Species Act. Arguments examined in this analysis will be selected based on historical and current material in paid advertisements, lawsuits, legislation, media coverage, publications, and other forms of public and private discourse archived by the Andrews Forest History Project. The second step is to turn each of these reasons into a formal argument for a given policy prescription (e.g., Table 1). Any proposed forestry practice, for example, is premised upon an argument or set of arguments meant to justify it. Such arguments, however, are almost never formally and systematically assessed or subjected to rigorous argument analysis. These arguments include premises, or claims, from many areas of expertise including ecological and social science and ethics (Table 1). The third step is to assess those arguments for their validity and soundness, to point out mistakes in both inferences and assertions made in the premises provided. We will draw on our scientific and ethical expertise to lay out arguments involving ecology, social science, and values, and evaluate their truth or appropriateness, as well as associated controversy. A fourth step would make the analysis available to decision makers and the public through publications, presentations, and workshops at the Andrews Forest involving various stakeholders in the process of argument creation and critique.

Conservation ethics analysis requires knowledge of ecology and social sciences, as well as ethical theory, environmental ethics, and formal critical thinking. The Andrews Forest LTER program (combining ecologists, social scientists, and ethicists) is uniquely positioned to accomplish this form of synthesis. This work is a logical extension of long-term ecological research at the Andrews Forest because the use of Andrews Forest science in forest management and policy changes the structure of the landscape and hence strongly influences drivers of change in forest ecosystems (Lade et al. 2013). This effort will draw on a variety of Andrews Forest long-term measurements because various arguments in favor of a given forestry policy, for example, will be premised, at least in part, upon claims about ecosystem functioning and impacts that Andrews Forest research is uniquely positioned to evaluate (Table 1, col. 3).

2.5 Cross-Site Collaborations

Researchers at the Andrews Forest LTER have been catalysts and leaders of major cross-site synthesis activities involving climate, hydrology, biogeochemistry, future scenarios, vegetation, arts and humanities, and site program histories, at regional, national, and international scales (Fig. 12). In LTER7 we plan to continue promoting cross-site analysis to increase mechanistic understanding of biological responses to past and present environmental changes. We also will continue to explore social-ecological responses to environmental change at multi-decadal time scales.

The Andrews Forest is the only LTER site in the temperate conifer forest biome. We are a major node for regional observation systems, research activities, and science and social networks related to climate (the PNW Climate Impacts Research Consortium), water (Willamette Water 2100 project, Columbia River basin US-Canada treaty review process), vegetation (Forest Service Inventory plots and the network of long-term vegetation plots and experimental watersheds arrayed north-south along the Cascade Range), northern spotted owl demography, and ecological observatories (NEON, Streon). Cooperators in these efforts include the USFS, USGS, NEON Inc., and Oregon Climate Change Research Institute.

At the national scale, as part of the LTER Network, information managers and scientists at the Andrews Forest have led development of Clim/hydroDB, StreamchemDB, and are designing VegDB including software development, populating the databases, and conducting synthesis analyses. With regard to climate, we plan to continue to lead the LTER climate committee synthesis efforts and expand participation of sites in ClimDB and in the US historical climate data network. With regard to hydrology, we will continue cross-site efforts promoting analysis of streamflow trends related to climate change, disturbance and vegetation dynamics in headwater ecosystems (Creed et al. in press, Jones et al. 2012), and work with sites across LTER, USFS EFR, and Canadian networks to link their data using common HydroDB database. We recently started cross-site stream chemistry syntheses to examine long-term trends (Argerich et al. 2013) and standardized data into a common publically available database (StreamchemDB). In LTER7 we plan to extend these analyses to evaluate stream responses to disturbances and behaviors of reference basins and expand participation (EarthCube, CUAHSI). We hope to build a cross-site VegDB, using a framework developed in several LTER cross-site workshops.

Andrews Forest researchers have been extremely active in developing arts-humanities-ecology collaborations within the LTER Network over the past few years, and now more than half of the LTER sites are engaged in these arts and humanities efforts. In LTER7 we will continue to provide leadership along with several other sites in the development of site-scale programs and network function and in seeking funding for network activities, sustaining the webpage for Ecological Reflections (*ecologicalreflections.com*), advancing the prototypic Andrews Forest program, and communicating broadly about the program. We will also lead an effort, funded by a network supplemental grant, to more formally assess the perceived values of, and challenges to, arts-humanities-ecology collaborations.

Led by a team of ecological historians, we are undertaking an Andrews Forest History Project, which is providing leadership for LTER Network-level efforts on history. In order to better understand the evolution of our program, research themes, and impacts on science, management, and policy, we have begun to inventory, archive, and conduct history scholarship on archival material collected since the early 1930s. Swanson and Guerrini have initiated discussions with other LTER sites (e.g., BNZ, HFR) about featuring the history of the LTER Network at the centennial meeting of ESA in 2015. We are also participating in LTER Network history work including Hauckens' (MCM) and Ramore's (CDR) book on LTER Network history, and a book led by Willig and Walker (under contract to Oxford University Press) on impacts of LTER on science. Three Andrews Forest PIs (Swanson, Johnson, Stafford) have been invited to contribute to this book. Building on a session at the 2012 ASM on science-society research and public engagement, Andrews Forest PI Gosnell, Nik Heynen (CWT), and Nathan Sayre (JRN) will seek supplemental funds to explore the potential for expanding the Coweeta Listening Project model to other sites.

Cross-site activities with Andrews Forest leadership have been funded through multiple mechanisms: 1) workshops at LTER All-Scientists Meetings; 2) LTER Network Office funding for working groups; 3) supplemental funding from NSF LTER directly to sites (e.g., LINX database development, arts and humanities, the Maps and Locals [MALs] Project); 4) Forest Service funding (HydroDB, StreamChemDB, LTEReflections), and 5) private foundation funding.

2.6 Synthesis

For nearly 35 years, the Andrews Forest LTER program has been structured to promote synthesis. Our conceptual framework includes a stable, but evolving, central question; a unifying theme reflecting our developing ideas about the ecosystem; an ongoing commitment to maintaining and analyzing long-term measurements; and a set of integrated new analyses and experiments tied to long-term studies but attentive to current ecological theory and societal needs. Past examples of key Andrews Forest contributions to concepts, questions, and theories in ecology include the structure and function of old-growth forest ecosystems; the roles of dead wood in forests and streams; forest-stream interactions connecting communities and ecosystem processes; species and community responses to forest landscape fragmentation; and cascading effects of forest harvest and roads on hydrology, geomorphic processes, and species invasion (Fig. 3).

The seventh Andrews Forest LTER proposal (LTER7) continues this synthetic tradition. It provides a research plan focusing on major ecological questions that build upon our conceptual framework (Fig. 9). It proposes new work to explore evolving questions emerging from analyses of long-term measurement programs, while sustaining our long-term commitment to understanding dynamics of forested mountain ecosystems. We will re-examine our central question and conceptual framework (Fig. 9) using the lens of "connectivity," focusing on how intermittent, spatially variable flows of air, water, nutrients, information, and organisms (Fig. 10) may mitigate or accentuate the expression of regional and global climate change and land-use in mountain ecosystems. We will link new studies and modeling efforts to long-term measurements spanning processes ranging from individual organisms and diel cycles to regional, multi-decadal dynamics of climate, hydrology, and vegetation a forested mountain ecosystem. In LTER7 we also continue leadership of cross-site synthesis work, extending concepts, questions, and theories in climate, hydrology, stream chemistry, vegetation, and arts and humanities, as well as LTER Network level information management, to the LTER Network and national and international networks of long-term ecological research sites.

Broader impacts. Many aspects of LTER7 benefit society and advance desired societal outcomes. We will continue our strong tradition of fostering public engagement with science and technology through our active research-management partnership with regional and national forest policymakers. Moreover, we seek to understand how our science may contribute to society by engaging the public, resource managers, and policymakers in explicit studies of changing social networks and conservation ethics analyses of arguments used in forest governance. Our arts and humanities program aims to enhance public literacy about science, to interpret and convey the value of long-term ecological research, and to share the beauty and magnificence of our ecosystem with a wider audience to inspire awe, wonder, and action, to improve the wellbeing of individuals in society. We will continue to lead partnerships and cross-site efforts within and beyond the LTER Network that interpret, synthesize, and disseminate the findings of long-term ecological research to help the public and policymakers understand how the ecosystems that humans depend on are functioning at broad temporal and spatial scales. We will continue education and outreach and STEM development for K-12, undergraduate, and graduate students and teachers as well as the public, with explicit emphasis on enhancing participation of women, people with disabilities, and under-represented minorities to be trained as part of a globally competitive STEM workforce. Similarly, we continue to engage an increasingly diverse team of researchers with respect to disciplinary background, age, gender, culture, and ethnicity. We will continue to develop and enhance the infrastructure for science and education, especially efforts to increase digital and virtual access to the Andrews Forest through continued information management, a cyber-networked forest, and social media.

3.0 RELATED RESEARCH PROJECTS

Strong institutional support from our partnership between OSU, the USDA Forest Service Pacific Northwest Research Station (PNW), and the Willamette National Forest provides the foundation upon which LTER activities are built (Fig. 12). Details of this foundational partnership are described in section 5.0. In addition to fostering a strong foundational partnership, we actively seek ways to leverage LTER dollars. The Andrews Forest LTER leverages funding support from related research projects at a rate of about 1:4. Although many related research projects that contribute to the success of our LTER program, we describe only those efforts that are essential to address the questions posed in this renewal.

PNW has funded and staffed the Andrews Forest small watershed hydrology program since the 1950s. PNW also co-supports, with LTER, the Andrews Forest aquatic chemistry research and the forest vegetation measurements. The continuous records of streamflow, chemistry, sediment, and vegetation dynamics are crucial core data that are web-available in near-real time and used by researchers at the Andrews Forest and throughout the world. These data will be used in LTER7 to address questions related to effects of land-use and climate change on vegetation growth, biodiversity, and water availability; as baseline data for studies of connectivity in stream ecosystems and across hillslope and stream hydrological networks; and for extending the scope of inference to multi-decadal time scales from short-term high spatial and temporal resolution observations of soil moisture and vegetation productivity patterns. PNW also co-supports, with LTER, the Andrews Forest information management program, through staffing of the lead Information Manager (Henshaw) and the spatial data manager and GIS analyst (Valentine). PNW is committed to continuing its essential collaborative role in LTER7.

OSU faculty provide essential contributions to Andrews Forest LTER through success at obtaining competitive grants. For example, a current Department of Defense award (C. Thomas) will increase our understanding of how weak-wind airflow patterns in mountain ecosystems directly and indirectly influence patterns of hydrological and biological connectivity in a variable and changing climate. Using this grant, Thomas has established two stations to monitor height dependent wind speeds and direction to better monitor and model airflow patterns within the Lookout Creek watershed. The PRISM Climate Group also supports enhancements of our climate data quality assurance systems and climate infrastructure.

4.0 EDUCATION AND OUTREACH ACTIVITIES

SCHOOLYARD LTER (SLTER). The goal of the sLTER program is to increase K-12 teachers' understanding of environmental science research by involving them in LTER research projects, and to expand their capacity to involve their students in similar field-based science inquiry. During LTER7, sLTER will connect Oregon K-12 teachers with Andrews Forest research to expand teachers' capacity to lead students through field-based science inquiry inspired by Andrews Forest science, and to integrate reading and writing into their science teaching. Andrews Forest sLTER continues to partner with the Oregon Natural Resources Education Program (ONREP), a state-wide program housed at OSU that prepares educators to engage students in relevant and inspiring classroom and outdoor learning experiences. Funding will be used to support a part-time position at ONREP held by Kari O'Connell to accomplish the following in LTER7: 1) Engage middle and high school teachers with Andrews Forest researchers in the Teachers as Researchers (TAR) professional development model. Through workshops, participants will explore elements of the scientific process, examine current research with Andrews Forest researchers (from graduate students to faculty), practice field investigations based on Andrews Forest research that can be used with students, and collaborate with fellow teachers; 2) Coordinate extended experiences for teachers who desire further training in field-based research through the Research Experience for Teachers (RET) program; 3) Provide follow-up communication, resource ideas, and further training to current and past participants in TAR and RET programs to support their classroom activities and field investigations; 4) Enhance grades 5–8 teacher understanding of forest ecosystems by hosting teacher workshops using *Ellie's Log* (Li 2013), our new children's book (described below) as a resource for integrating scientific observation, nature writing, journaling, and art; 5) Design and implement assessments to measure project outcomes and incorporate lessons learned, including workshop evaluations, teacher reflection papers, and homework assignments; 6) Report and share results of this work at education conferences and peer-reviewed journals, and submit teacher-developed student activities to the LTER digital library.

The sLTER activities will help Oregon teachers support students in attaining proficiency in the practice of science, in keeping with educational standards in Oregon and with national science standards (NGSS Lead States 2013), and in reading content-rich texts and evidence-based writing as key components of the adopted Common Core State Standards. We will recruit teacher participants, giving priority to those working with underserved audiences including Title I Schools and those with high populations of English Language learners, and from a mix of rural and urban districts.

LTER SCHOOLYARD SERIES BOOK. *Ellie's Log: Exploring the Forest Where the Great Tree Fell*, written by Judith Li and illustrated by M.L. Herring, is a richly illustrated, seven-chapter book aimed at 8–12 year olds. The descriptions in the book about biodiversity, decomposition, and seasonal change are based on decades of research at the Andrews Forest. Complementing the book is a website, *www.ellieslog.org*, sponsored by the Oregon State University Valley Library, and a Teacher's Guide (also available at ellieslog.org); both encourage children to investigate natural habitats where they live.

RESEARCH EXPERIENCE FOR UNDERGRADUATES (REU). The REU program is one of the most valued educational and research components of our program. REU students provide meaningful contributions to projects while learning about scientific research. Our previous REUs have benefited from their experiences; many if not most go on to graduate school, and we frequently encounter them either as graduate students at OSU, at universities associated with other LTER sites, or working with advisors whom they met through some connection established during their REU experience. Many of our former REUs have gone on to become outstanding educators, researchers, and administrators. In LTER7 we will engage two REU students per year to conduct supervised research and, with faculty guidance, design and implement individual projects. We actively seek academically qualified, minority and underserved students for these positions. We advertise REU positions on our website and email list serves, as well as through announcements sent to colleges and universities across the country. Based on references and phone interviews with student applicants, we select finalists from the pool of applicants based on compatibility between project activities and student goals, academic success of the students, and the ability of students to work successfully in a field research environment. Each year, with support from other projects, the Andrews Forest hosts 15–20 REU students (including an Eco-Informatics Summer Institute REU program, 2006–2015) and we facilitate group-learning experiences to teach skills of working in teams. Projects draw on ongoing Andrews Forest long-term research, including sampling and modeling plant-pollinator networks in montane meadows, and flow turbulence and fish habitat in wood jams.

GRADUATE STUDENTS. In LTER7 we remain committed to graduate student involvement, mentorship, training, and scholarship. The Andrews Forest Graduate Student Committee, chaired by two students, connects graduate students with Andrews Forest researchers and leadership. Graduate students are involved with planning and hosting symposia and field tours, helping cultivate their future science leadership skills. Graduate students share and present posters at the Andrews Forest symposium, held on the OSU campus, and they present their science at Andrews Forest monthly meetings. We also prioritize funding travel for graduate students to attend the LTER All-Scientists Meeting.

PUBLIC OUTREACH. We continue our commitment to engage the general public and increase public understanding of the value of long-term ecological research through tours and site programs, media interactions, and links with arts and humanities. We publish a semi-annual newsletter (*andrewsforest.oregonstate.edu/newsletter*) that is distributed widely and features highlights of Andrews Forest findings and activities. We employ our website (*andrewsforest.oregonstate.edu*), Facebook (*facebook.com/AndrewsForest*), and Twitter to communicate with colleagues, the public, students, managers, and the broader research community. *The Hidden Forest* (2006) continues to connect readers to the Andrews Forest site and science.

TOURS AND SITE PROGRAMS. The Andrews Forest attracts ~1,500 visitors annually from around the region and world. Andrews Forest personnel give tours and field classes for U.S. and international university courses (~20 per year), resource managers (100–200) and the general public (100–200). An annual public field day draws between 120–140 people, with field presentations focused on themes of our research and afternoon field trips with interactive activities that provide a sense of discovery. During LTER7, we will continue to develop and assess learning opportunities using our new interpretive Discovery Trail. This trail is regularly used for public outreach, teacher training, and for the innovative Canopy Connections middle school education program, conducted in collaboration with the Environmental Leadership Program at University of Oregon and Pacific Tree Climbing Institute.

MEDIA INTERACTIONS. We actively engage with the media by serving as sources for regional media (e.g., newspaper articles and Public Broadcasting stories); providing Science Finding reports of the PNW Research Station (e.g., *fs.fed.us/pnw/publications/scifi.shtml*: Issues 115, 110, and 105); working with OSU's News and Research Communications; hosting field tours with media groups; and informing articles in the OSU research magazine and blog, *Terra* (Sherman 2010).

ARTS AND HUMANITIES. The Long-Term Ecological Reflections program is a partnership between the Andrews Forest program and the Spring Creek Project at OSU (Swanson et al. 2008). Co-funded by LTER and the Forest Service, the program has brought ~50 writers into one-week residencies at the Andrews Forest and has supported gatherings of writers and scientists to work on issues such as the meaning of watershed health and new metaphors for restoration. Our researchers will continue to lead the Ecological Reflections network of >20 science/arts/humanities programs, including most LTER sites. During LTER7 we will continue to lead the LTER arts and science efforts, formally assess those programs, and explore new and innovative linkages between science, the arts and humanities.

CITIZEN SCIENCE AND EXTENSION. A partnership between OSU Extension and the Andrews Forest, supported by the Renewable Resources Extension Program, is developing collaborative climate change-related research and educational activities within existing Extension networks (e.g., Master Woodland Managers, 4-H). The project will utilize two existing national citizen science programs: National Phenology Network (NPN)'s Nature's Notebook, *usanpn.org*; and Community Collaborative Rain Hail & Snow Network, *cocorahs.org*, to help train volunteers, manage data collection, and create an interface with researchers.

APPLICATIONS TO POLICY AND MANAGEMENT. Our relationship with policy and management will continue to build on the decades-old foundation of the research-management partnership between the Andrews Forest science community and the Willamette National Forest, organized formally under the Central Cascade Adaptive Management Partnership (CCAMP). Through CCAMP, researchers and managers collaborate to conduct applied studies and experiments involving forest management. These projects include demonstrations that serve as focal points for field discussions concerning the future of forest ecosystems and management. CCAMP also organizes workshops and seminars engaging researchers and managers on current topics (e.g., the science of riparian management, early seral forest, landscape analysis, and how social science and ethics can inform public discussions of resource issues). Andrews Forest researchers play a critical role in these workshops. A longstanding emphasis on using understanding of historic disturbance regimes to guide future landscape management (e.g.,Halpern and Spies 1995, Cissel et al. 1999) is of wide interest in the US and Canada, and is central to current discussion and proposed legislation concerning the future of forestry on public lands in Oregon. The Andrews Forest is a core site for northern spotted owl demographics studies, which are part of the Northwest Forest Plan Monitoring Program, funded by USFS Region 6, BLM, USGS, and other agencies. Other significant collaborative science-management efforts include restoration of montane meadows and riparian habitats, management of dead wood in terrestrial and aquatic systems, and carbon sequestration. We are often consulted about how this research-management partnership functions and have published a guide on these collaborations (Swanson et al. 2010). During LTER7 Andrews Forest researchers will explore more deeply the influence of science-policy-management networks on landscape pattern and process through an emerging social-ecological research program.

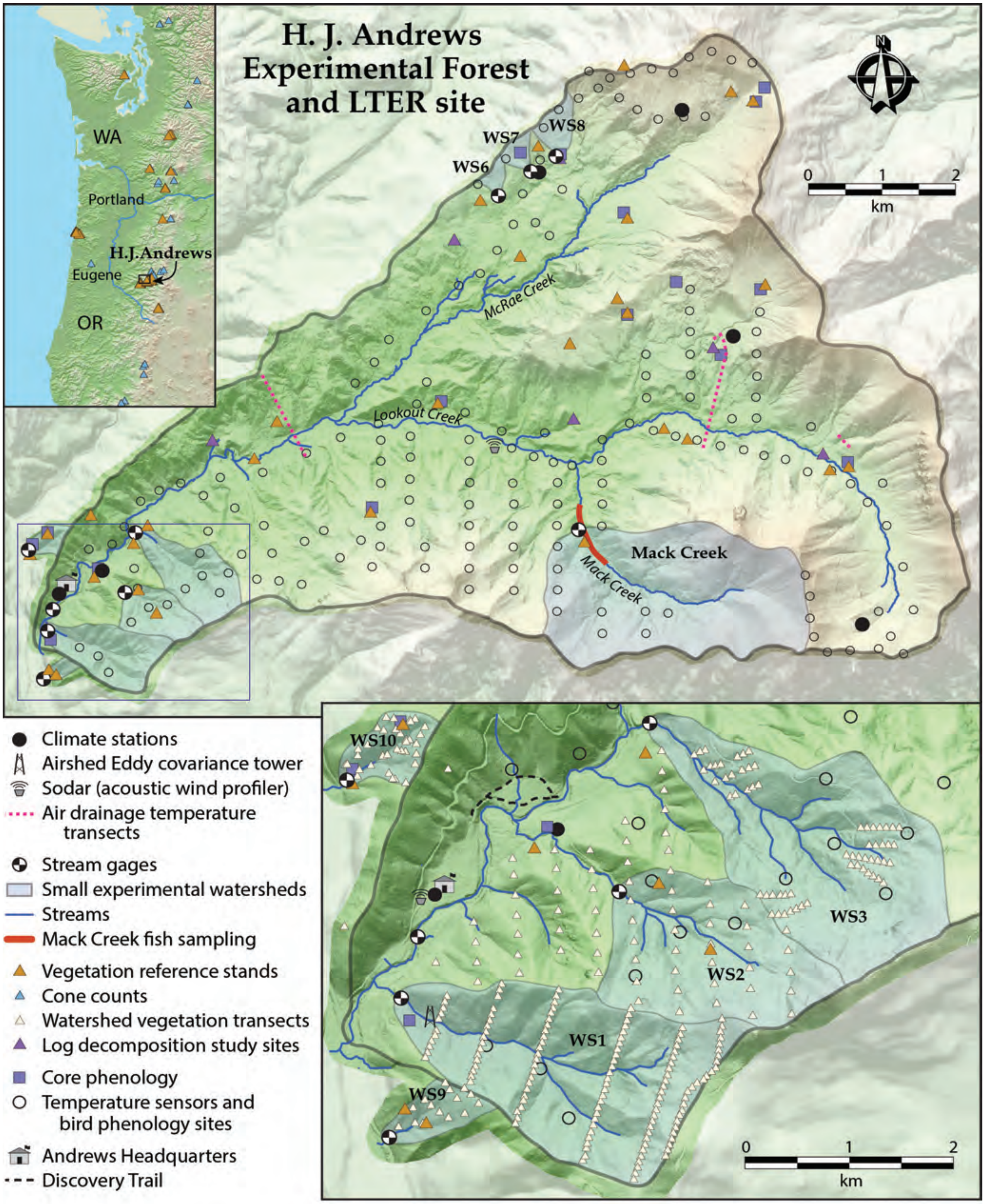


Figure 1. The Andrews Forest LTER covers 6400 ha and is located in the western Cascade mountains of Oregon. The site ranges from 400 to over 1600 m in elevation. Vegetation is dominated by conifer forests. Climate measurements include 6 climate stations, long-term temperature measurements in reference stands, a distributed temperature sensor network including phenology and air drainage sites, acoustic wind profilers, and an eddy covariance tower. Hydrology and stream measurements include 10 gaged streams ranging from 9 to 6200 ha, 8 small gaged watersheds in three paired watershed experiments at low, intermediate, and high elevation; and long-term fish sampling. Vegetation measurements include a network of old-growth forest reference stands, permanent vegetation study plots, and log decomposition experimental plots.

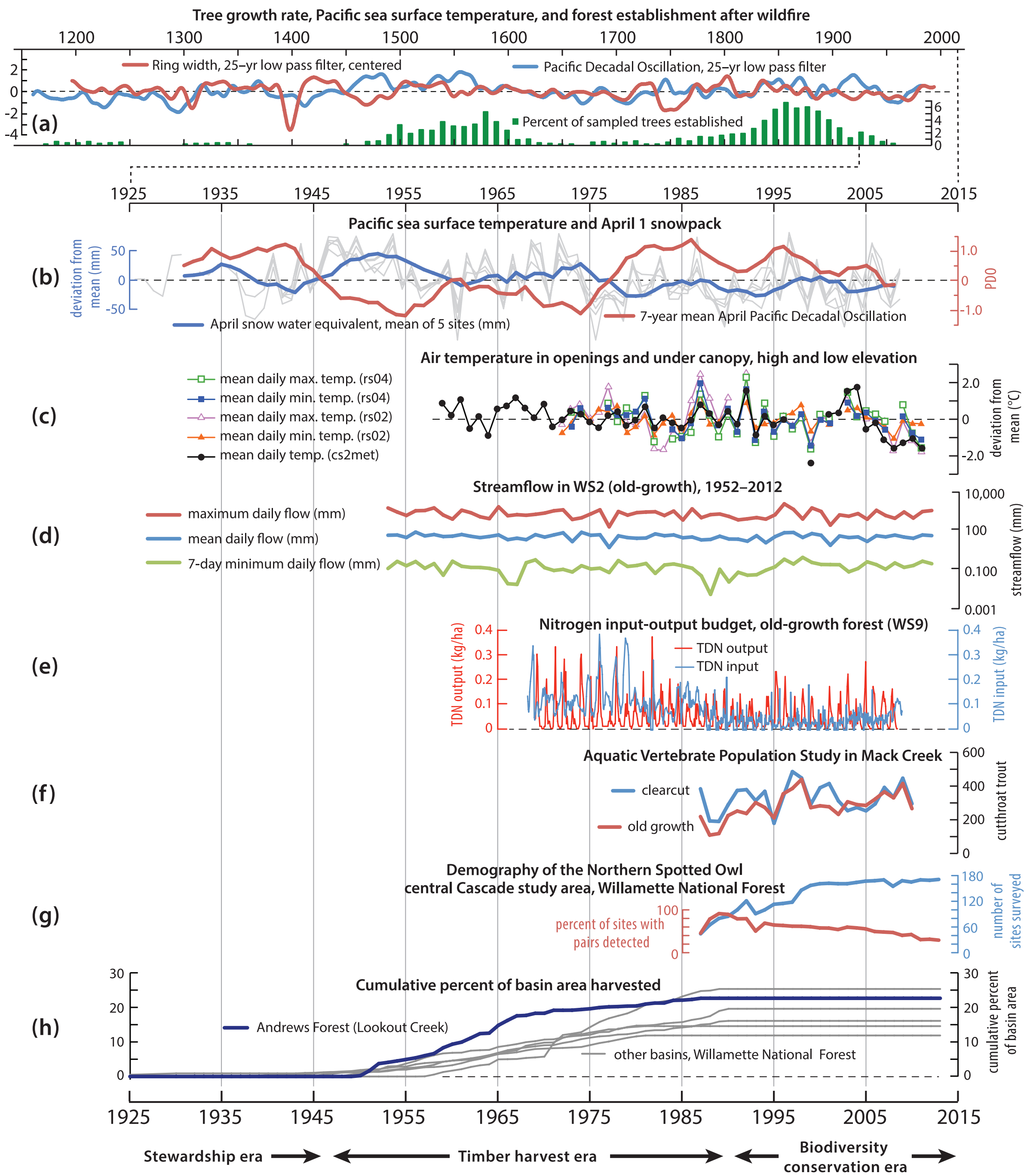


Figure 2. Long-term records from the Andrews Forest cover all elements of our central question (Fig. 9), and span the major periods of forest governance on federal forest lands in the Pacific Northwest. (a) Forests at our site and our region regenerated after major wildfires in the early-1500s and mid-1800s; mean tree growth (n>4000 individuals) anomalies and their inconsistent relationship to PDO reflect both winter and summer moisture limitations on net primary productivity (Tepley 2010). (b) Spring snowpack is inversely related to PDO, a measure of warm sea surface temperature, with lower snowpack since 1976. (c) Mean daily temperature anomalies at our long-term climate station (cs2met) and under forest canopy at high (rs04) and low (rs02) elevation do not display long-term increasing trends at annual, monthly, or daily time scales. (d) Daily annual maximum, mean, and 7-day minimum streamflow under old-growth forest (WS2) since 1952 shows extreme floods (1964 and 1996), dry years (1977, 2001) and extreme summer lowflows (1967-68 and 1988) that are not associated with snowpack. (e) Watershed budgets show very low and declining N inputs and seasonal pulses of outputs associated with winter precipitation. (f) Cutthroat trout populations increased after flood disturbance in 1996. (g) Northern spotted owl populations continue to decline despite cessation of clearcutting in 1990 (Dugger et al. 2014). (h) The Andrews Forest (Lookout Creek basin) experienced early old-growth logging relative to other National Forests in the Pacific Northwest, making it an example of a regenerating landscape in our region.

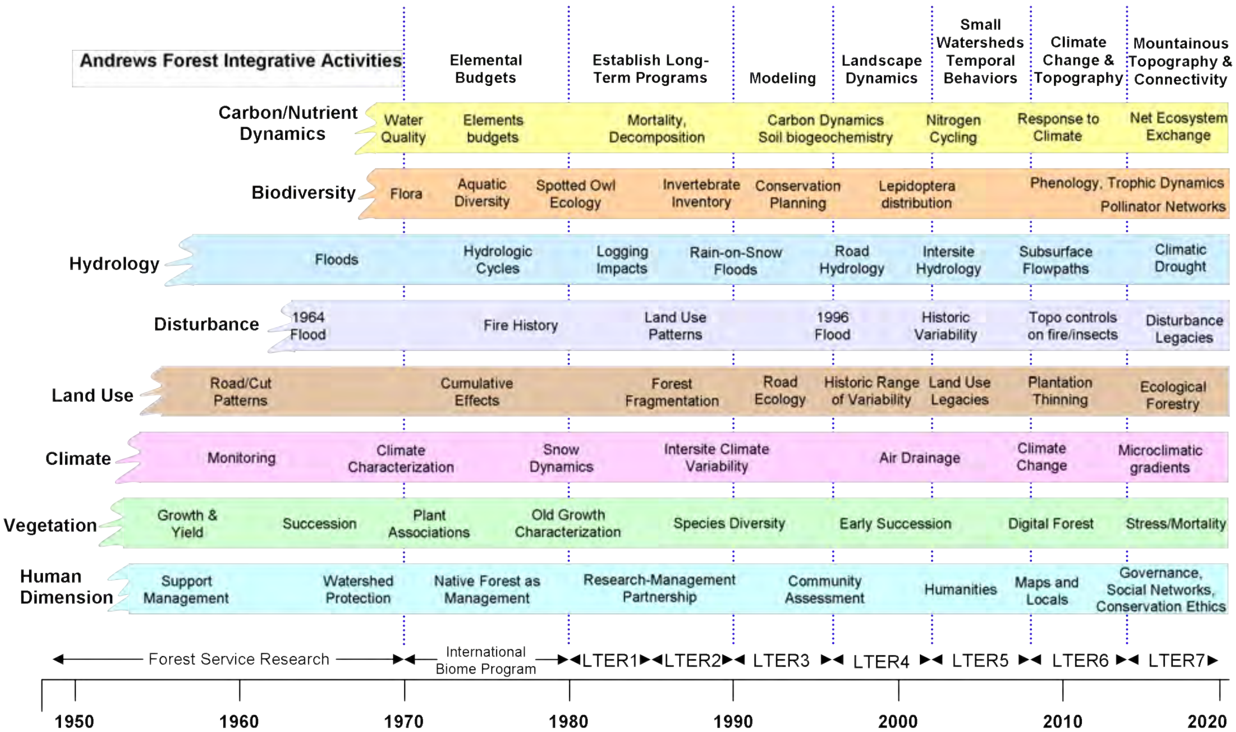


Figure 3. History of the Andrews Forest program, showing major long-term measurement and analysis programs corresponding to components of the central question (horizontal colored bars), the administrative history of the program dating from 1948 and including six prior LTER cycles, the evolving questions examined in each successive LTER cycle (topics in horizontal bars), and the integrative themes in each LTER cycle.

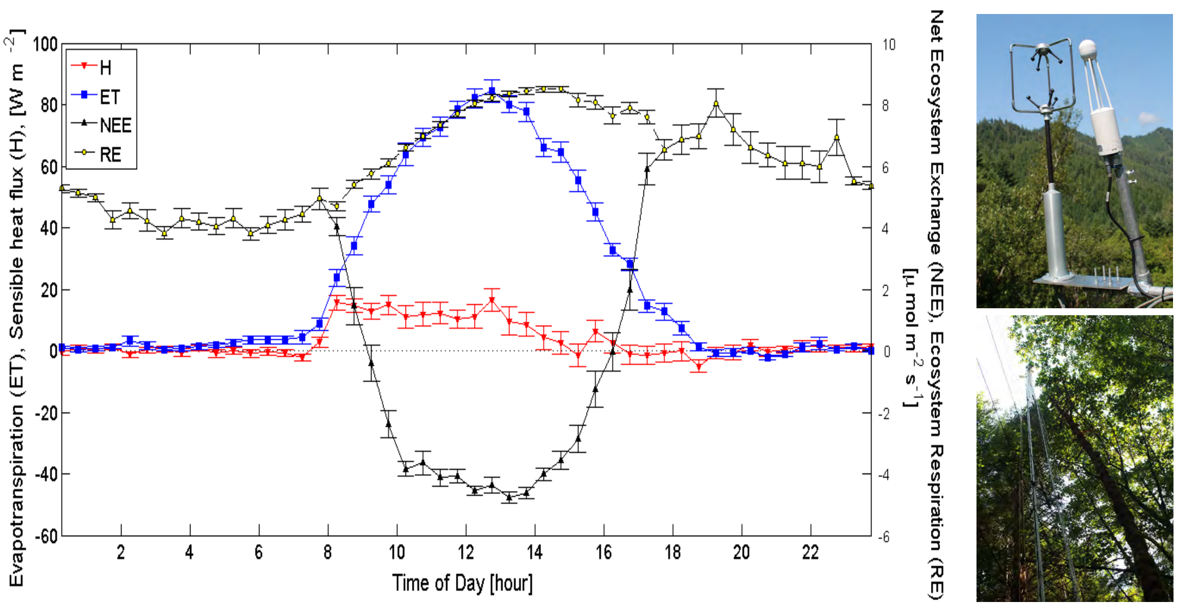
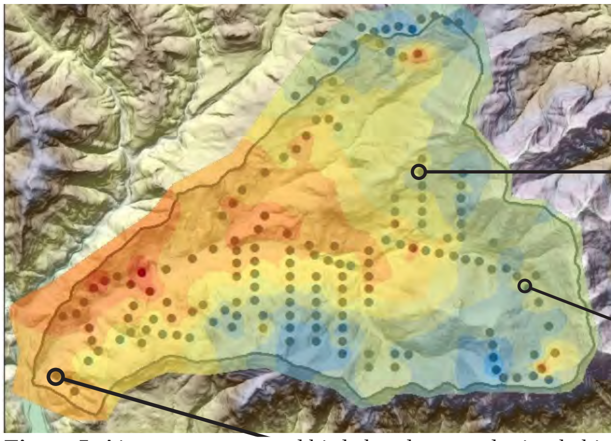


Figure 4: a) Mean diurnal courses of net ecosystem exchange of CO_2 (NEE), ecosystem respiration (RE), evapotranspiration (ET), and sensible heat (H) and standard error (vertical bars) for the dry summer period July 25–October 2, 2012 measured at the WS1 eddy covariance tower computed using the modified mass balance approach that accounts for advective losses of carbon dioxide in the carbon mass balance (Thomas et al., 2008; 2013; 2014, submitted) due to limited vertical mixing and the persistent cold-air drainage; b) The eddy covariance system at the top of the WS1 tower above the main forest canopy; c) View of the 38.5m tall ecosystem flux tower that features 8 levels of concentration measurements of $^{13}CO_2$, $^{12}CO_2$, CH_4, H_2O, and air temperature in a vertical profile, and 2 eddy covariance systems (at 38.5m and 4m).



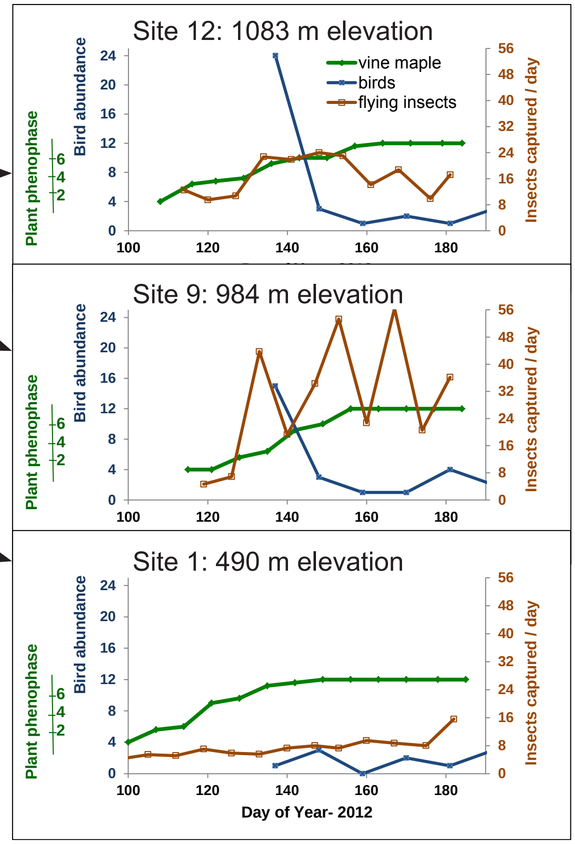
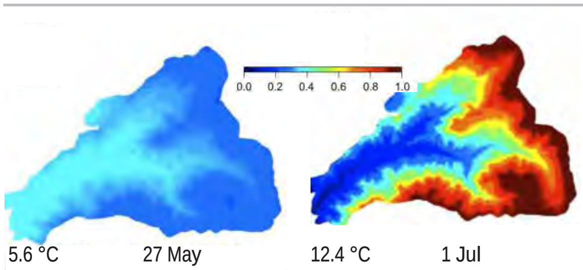


Figure 5. Air temperatures and bird abundance and microhabitat use during breeding season were sampled across a network of 182 sites (*map*). Plant phenology and insect sampling were co-located at 16 of these sites. Site locations are shown on a map of mean maximum daily temperature in June 2012 (Wilson 2013). Spatial patterns of microclimate varied by time of year and among years; in this example from June 2012, elevation and topographic shading strongly influenced mean maximum daily temperatures. Example time series (*right*) of plant phenophase, bird abundance and flying insect activity in 2012 at three of the phenology sites. Plant, insect and bird phenology had very different associations with local air temperature. Plant phenology was influenced by both winter and spring temperature. Activity of flying insects was highly variable across sites and not well correlated with air temperature. Breeding birds shifted occupancy among sites in response to temperature shifts during the breeding season.



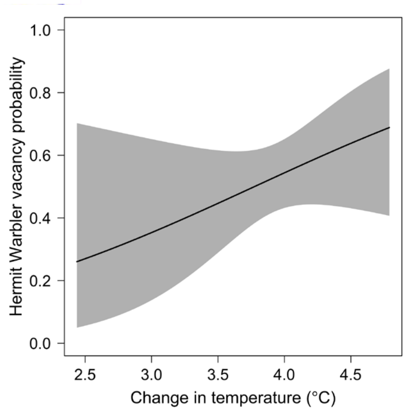


Figure 6. Distribution of hermit warbler across the Andrews Forest on two dates in 2010 (*top*). Mean weekly temperature shown for each sampling period. Note low occupancy at high elevation at early date and shift in occupancy to high elevations by later date. Dynamic occupancy model showing higher probability that a hermit warbler will vacate a site with a greater change in air temperature over duration of the breeding season (*right*).

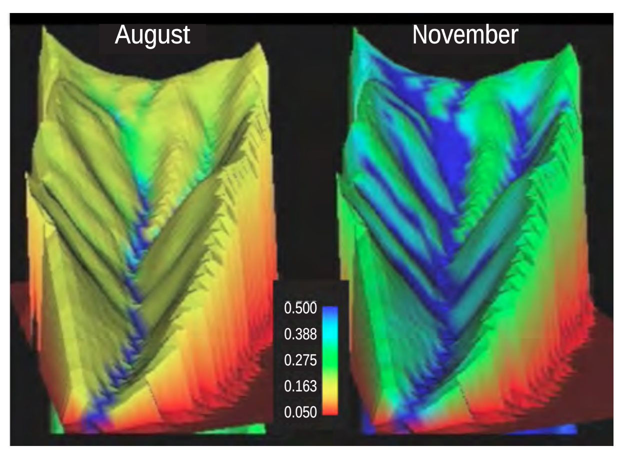


Figure 7. Soil moisture content by volume fraction simulated by VELMA (Abdelnour et al. 2012, 2013) for the steep forested slopes of Watershed 1 in the Andrews Forest. This visualization of model output shows the contraction of the stream network and associated area of moist soils in late summer (mid-August) and the expansion of the stream network and moist areas during the wet season (November to April). An extensive soil moisture monitoring network in LTER7 will provide data to test and refine models of spatiotemporal patterns of moisture and to relate small-scale moisture variability to plant productivity.

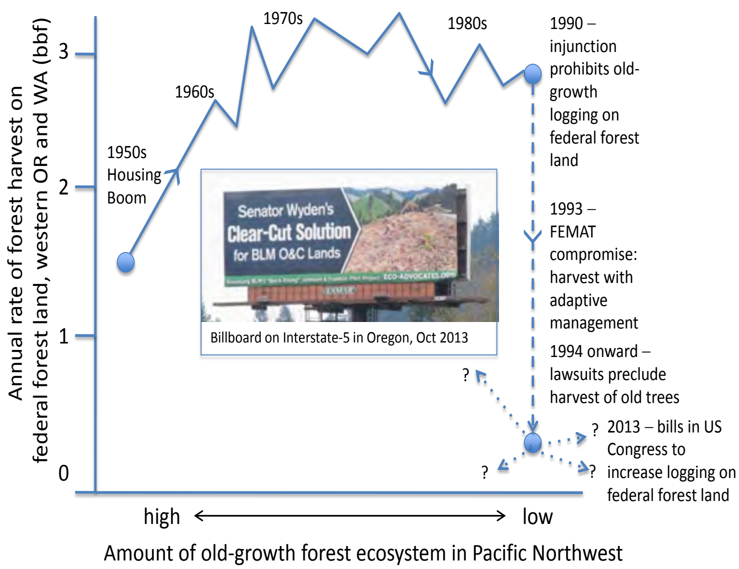


Figure 8. Social and ecological thresholds and abrupt changes in forest management in the Pacific Northwest. LTER7 Goal III examines how changing social networks influence abrupt transitions in federal forest land management in the Douglas-fir region of western Oregon and Washington. Key variables include cumulative increase in harvest (bbf- billion board feet) of old-growth forest after WWII, gradual decline of the northern spotted owl, changing public values, the accretion of federal legislation for managing public lands (NEPA-1969, ESA-1973, and NFMA-1976), legal decisions, mill closures, and media events. Andrews Forest science contributed through research on effects of forest harvest and roads on northern spotted owl, old-growth forest biodiversity, large wood, forest-stream interactions, and hydrology and geomorphic processes. Andrews Forest scientists also contributed to FEMAT, a federal forest harvest plan. (Data on harvests from Spies & Duncan 2009).

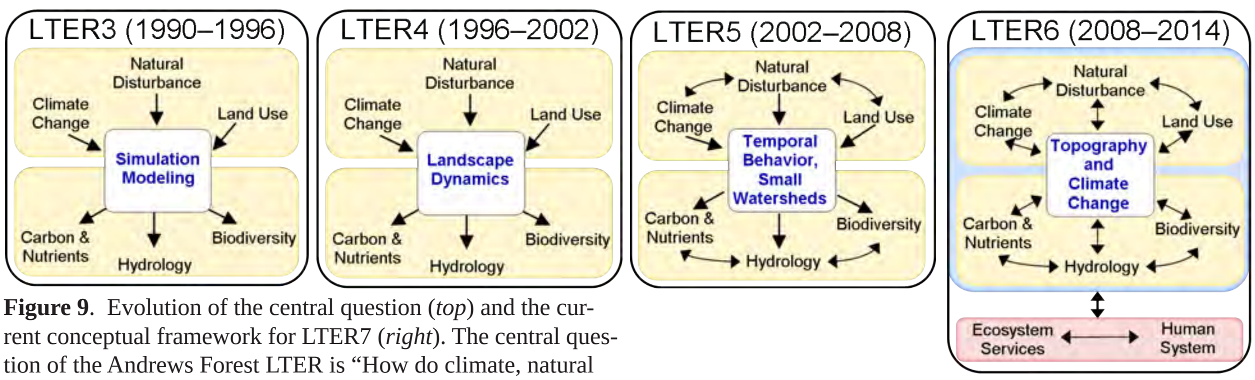
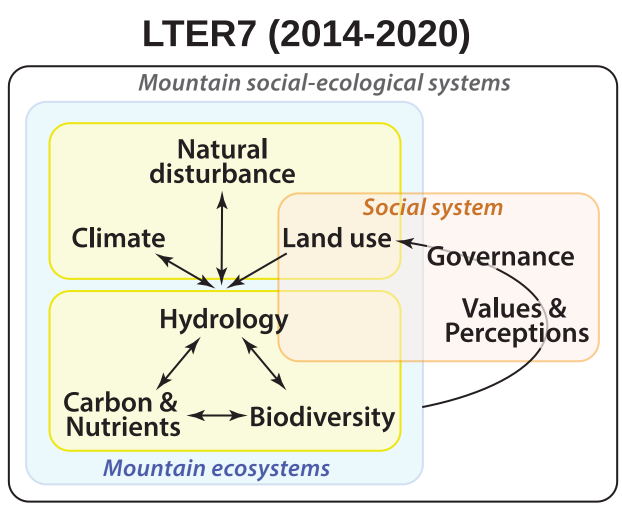


Figure 9. Evolution of the central question (*top*) and the current conceptual framework for LTER7 (*right*). The central question of the Andrews Forest LTER is "How do climate, natural disturbance, and land use as controlled by forest governance interact with biodiversity, hydrology, and carbon and nutrient dynamics?" This broad question provides a conceptual framework for studying mountain ecosystems as a social-ecological system (biophysical processes, yellow boxes; social system, pink box), and for framing the system as a social-ecological system through links between values and perceptions, forest governance and land use (overlapping boxes). Long-term and new research in LTER7 continues to examine interactions among climate, natural disturbance, land-use, hydrology, carbon & nutrients, and biodiversity.



In LTER7 we have three goals:

Goal I: To understand the patterns, driving processes, and dynamics of atmospheric and hydrologic connectivity in mountainous ecosystems.

Goal II: To understand the consequences of the patterns, driving processes, and dynamics of biophysical connectivity for ecosystem processes and biotic communities.

Goal III: To understand connections between forest governance and landscape pattern and process, and the ways in which public perceptions and valuations of federal forest landscapes and LTER science influence those connections.

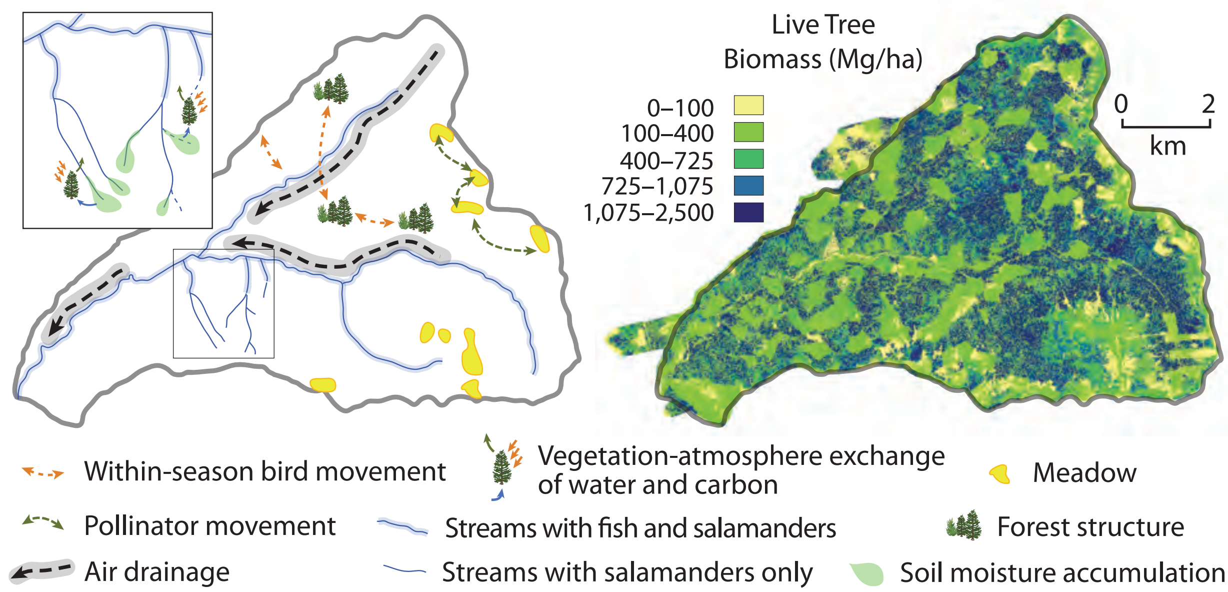


Figure 10. (a) Schematic diagram of forms of biophysical connectivity in the Andrews Forest landscape which we propose to study in LTER7, including airflows and air drainage in steep valleys and moisture flows and expanding and contracting stream networks (goal I); flows of organisms and nutrients in headwater streams, breeding bird movement among forest patches, and movement of pollinators among montane meadows (goal II). (b) Connectivity of flows of air, moisture, nutrients and organisms is influenced by spatial patchwork of vegetation as mapped from LiDAR in LTER6, including high biomass old-growth forests (blue), young forests (green), and very low biomass areas of early successional forest vegetation and montane meadows (yellow).

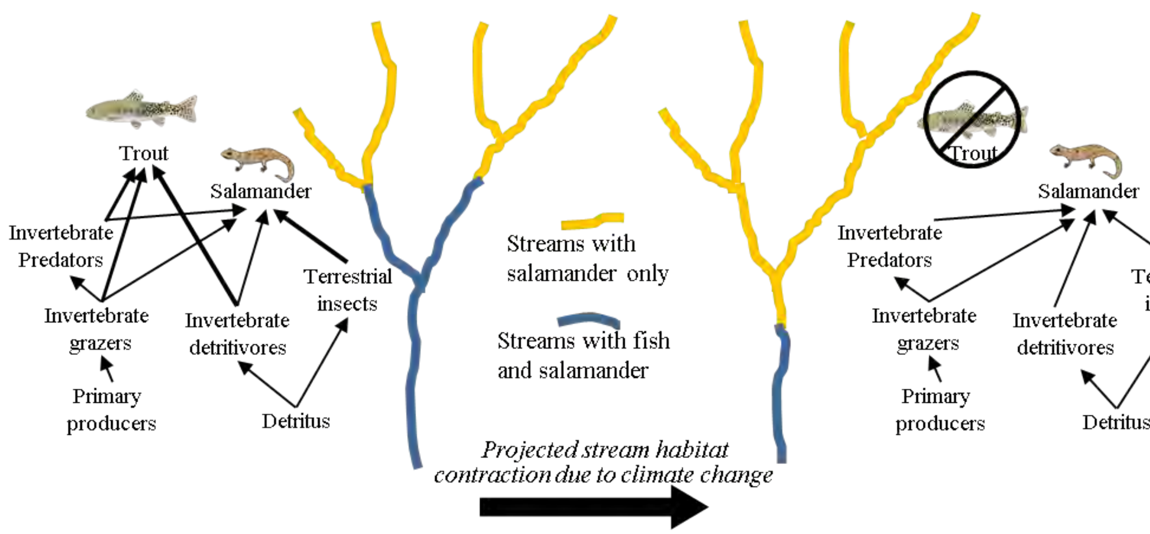


Figure 11. With changing climate, stream headwaters are expected to contract and lead to reduced connectivity of habitat for trout, which may then impact trophic connectivity through changes in food webs and instream productivity. Quantifying the tradeoffs and ecosystem impacts of shifts in top predators throughout large portions of the stream network is relevant for riparian forest harvest, which is determined by the presence or absence of fish.

Table 1. An argument includes a series of premises together with a conclusion (column 1): here using the example of biodiversity and early successional habitat. Analysis of an argument includes evaluating the inference (i.e., whether the conclusion follows logically from the set of premises, this argument is structured with appropriate inferences), and the truth of premises (evaluated by a community of relevant experts). Various kinds of premises (column 2) are required to make arguments about managing social-ecological systems. This particular argument includes ecological, and normative/ethical premises. Other arguments might include sociological, economic, historical, or other premises. The truth of a premise (column 3) is distinct from the controversy surrounding it (column 4).

1 - Argument	2 - Kind of Premise	3 - True/Appropriate?	4 - Controversial?
(P1) Adequate early successional habitat supports important biodiversity	Ecological	True	No
(P2) We ought to act to support important biodiversity	Ethical	Probably true in general	Not very
(C1) Therefore, we ought to maintain adequate early successional habitat			
(P3) We are currently lacking adequate early successional habitat	Ecological/ Normative	Supported by expert opinion, little empirical evidence	Unclear
(P4) Ecological forestry creates adequate early successional habitat	Ecological	Yes	Unclear
(C3) Therefore, we ought to engage in ecological forestry			

Figure 12. Examples of major elements of the larger Andrews Forest program linked with the Long-Term Ecological Research Program. Acronyms: OSU: Oregon State University; PNW: Pacific Northwest; USFS: US Forest Service; USGS: US Geological Survey; NASA: National Aeronautics and Space Administration; UNESCO: United Nations Educational, Scientific and Cultural Organization; IGERT: NSF Integrative Graduate Education and Research Traineeship.

5.0 FACILITIES, EQUIPMENT, AND OTHER RESOURCES FOR THE ANDREWS FOREST LTER

RESEARCH AREA

HISTORICAL CONTEXT: Since its establishment in 1948, the H.J. Andrews Experimental Forest has been a site of major research contributions to the advancement of environmental science, management, policy, and education (Fig. 3). In 1980, the Andrews Forest became one of the first sites funded through NSF's Long-Term Ecological Research (LTER) Program. Today the Andrews Forest Program has grown into a multifaceted, interdisciplinary group of researchers from around the world with more than 85 research projects underway in any given year. LTER research continues to be the core of the Andrews Forest Program. Science and education activities at the forest are also funded by US Forest Service, NSF, NASA, EPA, US Geological Survey, and other agencies. Educational programs exist for all ages including K-12, undergraduate and graduate students, and continuing education for managers and public. Close working ties with US Forest Service natural resource managers enhance the science program, fuel numerous large-scale, applied studies, and facilitate application of research findings to natural resource management and policy.

UNIQUE ASPECTS OF THE ANDREWS FOREST SITE: Located at 44.2^{0}N and 122.2^{0}W, the Andrews Forest is in the western Cascade Range of Oregon (Fig. 1). The Andrews Forest is situated within the 6400 ha drainage basin of Lookout Creek, which drains to the McKenzie River. Elevation ranges from 410 m to 1630 m. Broadly representative of the rugged mountainous landscape of the Pacific Northwest, the Andrews Forest contains excellent examples of the region's conifer forests and associated wildlife and stream ecosystems. Lower elevation forests are dominated by Douglas-fir, western hemlock, and western red cedar. Upper elevation forests contain noble fir, Pacific silver fir, Douglas-fir, and western hemlock. Low- and mid-elevation forests in this area are among the tallest and most productive in the world. Cold, clear, fast flowing mountain streams are the primary type of aquatic ecosystem. When it was established in 1948, the Andrews Forest was covered with native conifer forest ranging in age from 120 to 450 years, as well as a network of small meadows and shrubfields at higher elevations. Since then, clearcutting and shelterwood cuttings over 30% of the Forest have created young conifer plantation forests varying in composition, stocking level, and age. Management experiments installed in and adjacent to the Andrews Forest over the last 15 years directly test the application of ecosystem and disturbance ecology to land management (see Other Resources—Ecosystem Management, below), and have created opportunities for LTER7 social science and landscape connectivity research. Old-growth forest stands with dominant trees over 500-year-old still cover about 40% of the area.

PARTNERSHIPS AND SUPPORT

The Andrews Forest Program is managed cooperatively by Oregon State University (OSU), the Pacific Northwest Research Station (PNW) of the U.S. Forest Service, and the Willamette National Forest (Fig. 12), on which the Andrews Forest is located.

OSU and the College of Forestry (COF) leverage the LTER grant funding with support of two positions. The Forest Director (currently Mark Schulze, OSU) coordinates research at the site, leads tours and other educational activities, and supervises long-term environmental measurements and maintenance staff. The Forest Director oversees operation of the Forest and the facilities in collaboration with the PNW lead scientist for the Andrews Forest. COF also provides support for the LTER Program Coordinator (currently Lina DiGregorio, part-time OSU), who coordinates LTER program and grant activities. OSU provides support in terms of basic office facilities and grant oversight.

The LTER grant, managed through OSU, supports field technicians and information managers. A climate technician (currently John Moreau, LTER) is in charge of maintenance of climate equipment and related field data for the long-term climate program. A research assistant (currently Rob Pabst, funded through LTER and PNW) is in charge of the long-term vegetation study. A database and Information Manager (currently Suzanne Remillard, LTER) is housed at OSU and a data manager for streaming data (currently Adam Kennedy, LTER) is based on site at the Andrews Forest. The Schoolyard LTER coordinator (currently Kari O'Connell, part-time OSU position funded through LTER) oversees LTER Schoolyard activities and teacher programs including Research Experience for Teachers.

The PNW provides support for field technicians, information managers and a site manager. The Site Manager (currently Kathy Keable, PNW) is responsible for day-to-day operations of the Andrews Forest headquarters, for facilities reservations, for providing information to the many users of the headquarters, and serves as the safety officer on site. The maintenance staff on site (which includes a caretaker/maintenance worker, a custodian, and a summer maintenance assistant) is funded through a cost reimbursement agreement between the PNW and OSU. A hydrology technician (currently Greg Downing, PNW) manages the stream gaging and water chemistry program at the 10 experimental watersheds. Information management and technology activities are overseen by an Information Technology Specialist (currently Don Henshaw, PNW) and a Spatial Information Manager (currently Theresa Valentine, PNW). The PNW also funds the maintenance and improvements for the headquarters facilities at the Andrews Forest.

The Willamette National Forest *(*WNF*)* is primarily responsible for management of the forest property, including roads, trails, invasive species, and NEPA (National Environmental Policy Act) processes for research-related activities. A Science Liaison (currently Cheryl Friesen, WNF), works regularly with Andrews Forest Scientists to facilitate communication between managers and scientists, to find opportunities for scientists and managers to interact about new and emerging science issues, to plan regional workshops, to share applications of research findings to management strategies, and to plan joint experiments and demonstrations.

Management decisions concerning the Headquarters facilities as well as the Experimental Forest as a whole are made cooperatively by the Forest Director, the PNW Andrews Forest Scientist, the LTER Principal Investigator, and representatives from the WNF.

FACILITIES

THE ANDREWS FOREST HEADQUARTERS FACILITIES: Headquarters facilities are used year-round for research, short courses, workshops, overnight field trips, retreats, etc. The facilities at the Headquarters comprise ~40,000 sq. ft. of offices, residences, conference hall, teaching lab, dining hall, storage facilities, shop, and other space. Wi-Fi is available throughout the Headquarters. The computer lab has eight workstations, internet access, printers, and direct LAN connections to OSU servers and networks. Five laboratories (watershed, vegetation, vertebrate, water chemistry, soils) are provided for scientist and student use in the office building. Each lab is equipped with basic equipment appropriate for the primary use, such as pH and conductivity meters, and fume hood in the watershed lab; microscopes, herbarium cabinet, and a refrigerator in the vegetation lab; a vacuum pump, bottles, graduated cylinders and fume hood in the water chemistry lab; and a muffle furnace, a drying oven, and a fume hood in the soils lab. A large laboratory-style classroom is equipped with microscopes, a TV/DVD, and a videoconferencing unit. The cafeteria has capacity for 80-plus users. Each year, average annual use of field station facilities is ~3500 user days plus more than 1500 students, researchers, managers and others who participate in tours, field classes, and meetings at the Andrews Forest.

Housing is available in 14 furnished apartments that range in size from 2-5 bedrooms. New in 2013, a NSF FSML-funded building, the GREENhouse, has three apartments that are available for long-term residents including sabbatical housing, visiting scholars, writers, and the Site Director. Total maximum overnight capacity at the Headquarters site is 80 people.

Field vehicles and machinery include a backhoe, pick-up trucks, snowcats, and snowmobiles. The staff operates a wood shop and small technology shop that serves as the center for equipment design and building maintenance.

LABORATORIES

The Cooperative Chemical Analytical Laboratory (CCAL) is a water chemistry laboratory operated by OOSU College of Forestry and the U.S. Forest Service PNW. CCAL was started in 1976 by Andrews Forest researchers to meet the need for a dedicated laboratory that would specialize in high quality, trace level analyses. CCAL provides precise and reliable analysis of aqueous constituents including ammonia, nitrate, nitrite, total nitrogen, orthophosphorus, total phosphorus, sulfate, chloride, organic carbon, inorganic carbon, pH, alkalinity, specific conductance, silica, sodium, potassium, calcium, magnesium, iron, silicon, manganese, dissolved solids, suspended sediment, and more. CCAL participates in Quality Assurance Programs in collaboration with USGS Standard Reference Water Survey Program, EPA surface water chemistry criteria, and the National Water Research Institute's (NWRI) Environment Canada Proficiency Testing (PT) Program.

NADP. Andrews Forest has hosted a precipitation sampling station (OR10) for the National Atmospheric Deposition Program since 1980. Weekly wet deposition samples are collected and mailed to the NADP Central Analytical Laboratory housed at the Illinois State Water Survey for precipitation chemistry analysis. These data are publically available and used as baseline data for numerous biogeochemistry projects the Andrews Forest. The Andrews Forest has participated in the Mercury Deposition Network within NADP over the last 30 years, and has provided baseline information on concentrations over time. The NADP Central Laboratory reserves a portion of precipitation samples for future analysis, and occasionally conducts additional analyses, such as evaluating radioactive isotope deposition following the Fukushima disaster.

INFORMATION ACQUISITION AND MANAGEMENT

Site communications equipment: The computing facilities at the Andrews Forest headquarters consist of a local area network (LAN) with servers and workstations and wireless network. A T1 connection (1.5 Mbs) links the LAN with the internet and campus computer network through the OSU College of Forestry. The LAN includes a domain controller, application server, file server, web server, and backup server. Servers are mirrored onsite and to an OSU College of Forestry server on campus, with backups made daily to tape drives. Public workstations are located in the computer lab with additional computers available in offices. Computer software includes SAS, StatGraphics, S-Plus, and Microsoft Office. Full scanning, printing and plotting capabilities are available to lab users. The wireless network includes a series of access points and wireless bridges that allow connection through the headquarters compound including the classroom, conference room, office building, and apartment buildings. A high-precision GPS unit, laser range finder and rugged laptop are used extensively by researchers, students and staff to geo-reference research plots and archive locations of field sensors.

Automated data acquisition and wireless data transmission: Recent modernization of the wireless radio infrastructure (NSF FSML and LTER supplemental funding) has greatly increased the volume of data that can be transmitted from field to headquarters. This infrastructure has facilitated deployment of new ecological and meteorological sensors that generate large data files, such as phenocams, infrared cameras, and acoustic profilers.

Data from dataloggers are sent to headquarters hourly through a workstation equipped with Loggernet software and transferred to the OSU campus via T-1 line. Data are processed using Matlab GCE toolbox for initial QA/QC routines. Questionable data are flagged and metadata added, then uploaded to the Forest Sciences Databank for additional processing then published as provisional for 90 days. Provisional data and plots are uploaded hourly on the website to facilitate monitoring of stations and timely detection/prediction of significant or extreme hydrometeorological events. There has been significant investment in these automated QA procedures in recent years in order to provide high quality data as quickly as possible to researchers and the public.

Data Management and Andrews Forest Data Archives. Virtual servers for the website and associated databases (as well as shared disk space for Andrews Forest staff) are provided by the Computing Resources Group from the College of Forestry at OSU on the Corvallis campus. A full description of data management and archiving is detailed in the Data Management Plan.

Digital Forest and GPS and Maps. Light Detection and Ranging (LiDAR) flights of the Andrews Forest (2008) and upper Blue River (2011) watersheds have dramatically improved our geographical information system. The resulting products included bare earth and highest hit digital elevation models at one-meter resolution. These products were used to update the stream and road layers, slope and aspect grids, and provided vegetation height data. The raw LiDAR point cloud data was used to create biomass estimations (Fig. 10a), canopy point density metrics, and tree stem locations. In conjunction with the LiDAR processing we have undertaken extensive mapping of research sites using high-precision GPS units. LiDAR imagery and precise mapping of study sites have opened new opportunities for spatial analyses in a wide range of research areas including: geomorphology, landscape ecology and wildlife habitat characterization, carbon dynamics, ecosystem modeling, and atmospheric-topographic interactions. A new Andrews Forest research map was produced using the updated roads, streams, and administrative features. The research map is available on-line and can be combined with other data to make customized field and project maps. The LiDAR data and associated products are available online.

OTHER RESOURCES

INSTRUMENTED SITES AND LONG-TERM STUDY PLOTS

Data and metadata from climate stations, stream gages, long-term experiments and study plots are available online and to new and visiting scientists and students for use in research, novel collaborations, and education projects. These data and studies are a valuable resource to all researchers and public and we will present them in that light.

Climate Stations. The Andrews Forest Program operates one of the few climatic observing systems in the forests of the Pacific Northwest that has long periods of record (beginning 1956), high station density, and wide variations in topographic position and canopy cover. Four primary climate stations continuously measure air and soil temperature, precipitation, relative humidity, wind speed and direction, solar radiation, soil moisture, barometric pressure, snow depth, and snow water equivalence. Net radiometers, sonic anemometers, and snowmelt lysimeters are installed at a subset of the stations. Three secondary climate stations measure a smaller suite of parameters, including precipitation, and air temperature. In addition, 10 long-term (since 1970) sites for air and soil temperature are associated with long-term vegetation plots distributed throughout the Andrews Forest. Air temperature is also measured at the gages of each of the 10 experimental small watershed-gaging stations (described in next section). More recent research on cold-air drainage patterns and phenology have established more than 200 air temperature stations within Lookout Creek watershed, as well as 29 in the adjacent Blue River watershed. In addition to precipitation measured at all climate stations, precipitation is measured at two additional sites on the south-bounding ridge of the Andrews Forest and five in Blue River watershed. Precipitation is collected and chemistry analyzed at a low and medium elevation climate station. Climate data are collected year round at intervals of 5 to 60 minutes, depending on the sensor. Primary climate stations provide data in near real-time to Andrews Forest Headquarters and the World Wide Web (WWW) via wireless radios. The climate measurements and data management are staffed primarily through the LTER grant.

Hydrology: At the Andrews Forest, ten gaged watersheds have been used to study the long-term effects of forest harvest and management on water quality and quantity, through streamflow, sediment, stream chemistry, and vegetation since 1952. The gaged watersheds range in size from 10 – 6400 ha and are located across elevational gradients. Prior research in these watersheds has been very productive and provides a strong foundation of site-based information for current and future studies. Research topics have evolved from an early focus on water quality responses to silvicultural treatments to current innovative examinations of water, carbon, and nutrient fluxes in response to disturbances and vegetation succession. Stream gaging stations provide real time data to Andrews Forest Headquarters and the WWW via wireless radios. Stream stage height, stream temperature, and specific conductivity are measured continuously and stream chemistry is collected in proportion to streamflow at each gage. To facilitate extrapolation of snow monitoring data at climate stations to estimates of snow hydrology patterns across Lookout Creek watershed, a set of paired open-canopy and forest-understory snow stakes are distributed across elevation and topographic gradients. Data are openly available online and are used broadly by hydrology and ecology researchers, land managers and policy makers. The hydrology measurements and data management are staffed primarily by PNW and the costs of aquatic chemistry analyses are shared by LTER and PNW.

Forest Dynamics, Disturbance, and Vegetation Plots. Several long-term studies examine forest dynamics and disturbance processes. More than three-dozen one-hectare permanent vegetation plots within and around the Andrews Forest are regularly visited to survey forest changes in plant abundance, mortality, growth, and stores. These plots were established to provide typical examples of many major forest communities commonly found in Oregon's central western Cascade Mountains. Similar measurements are also undertaken in systematically placed 0.1 ha plots within eight of the gaged watershed within the Andrews Forest that provide insights into changes in water quantity and quality. In addition, the Andrews Forest LTER collaborates with PNW Research Sciences and the University of Washington, Washington State University, and University of Montana to maintain plot systems that represent many of the major forest types in the PNW (Acker et al. 1998). All these plot systems serve as resources for scientists of many disciplines to understand forest dynamics and their underlying processes at multiple temporal and spatial scales (van Mantgem et al. 2009, Stephenson et al. 2014). These measurements and data management are supported through a combination of support from LTER, PNW, and other related research grants.

Additional Research that leverages LTER Funding

The wide array of researchers involved in work at the Andrews Forest use a combination of their own resources in conjunction with data and infrastructure from the Andrews Forest Program. Andrews Forest LTER resources are extensively leveraged through these related research projects. In any given year, 50-60 research projects in addition to those funded by the LTER are active at the forest; below, we describe those that are long-term, cross-site or of particular interest to LTER7.

Biogeochemistry. A long-term soil experiment located at the Andrews Forest is the DIRT (Detrital Input and Removal Treatments) study. This research, which examines processes of soil organic formation, was established in 1997 as part of an international network of similar studies. The understanding of soil nutrient cycling and storage gained from this project helps inform nutrient budgets and productivity research conducted through the LTER program. The Andrews Forest participates in a second international program, the Nutrient Network, that examines the interacting effects of nutrients and herbivory in determining productivity of meadows and grasslands.

Andrews Forest researchers have been leading a cross-site LTER and Experimental Forest synthesis project to develop a stream chemistry database and to facilitate large-scale studies of trends in stream chemistry in relation to climate and land-use and implications for stream ecosystem function. This effort adds great value to ongoing stream chemistry measurements and readies the LTER Network for major advances across sites over the next several years.

STREON. The Andrews Forest will host the Stream Experimental Observatory Network (STREON) Northwest site, one of ten across the country, beginning in LTER7 (ca. 2016). In addition to monitoring of nutrient dynamics and ecological interactions within a control reach, the program will experimentally examine the effects of eutrophication and loss of large consumers on aquatic ecology and ecosystem function. This work will complement the larger scale observational and experimental studies of hydrologic connectivity, trophic interactions and nutrient budgets of headwater streams that are planned for LTER7.

Ecosystem Management. Through the Central Cascades Adaptive Management Partnership (CCAMP) the Andrews Forest continues its role as a regional and national leader in testing the application of ecosystem science to design of alternative resource management systems and to forest policy. A number of long-term ecosystem management experiments have been established through this partnership of federal land managers and Andrews Forest scientists.

Two long-term thinning experiments (Young Stand Thinning and Diversity; Uneven Aged Management) were established in the 1990s to evaluate the ecological, operational, social, and economic consequences of alternative methods for managing young forest plantations. Application of disturbance ecology to a landscape-scale strategy to accomplish the conservation and economic objectives of the Northwest Forest Plan is being tested through the Blue River Landscape Study. The approach adopted in this study is now the focus of proposed national legislation to regulate harvests of a portion of Bureau of Land Management lands in Oregon.

Restoration of meadow biodiversity and function in areas where conifer encroachment threatens the persistence of this ecosystem is examined through the Bunchgrass Ridge Restoration Project. While meadows account for less than 5% of the area in the Andrews Forest and surrounding Central Cascades, they are biodiversity hotspots and play a critical role in maintaining populations of species dependent on non-forest and early seral forest; many of the species have displayed dramatic population declines over the last decade as fire suppression, meadow encroachment and changes in federal forest management have changed the proportion and connectivity of open habitats no the federal landscape.

Baseline monitoring for an experimental study of riparian forest and stream restoration began in 2013, as did preparatory work for a demonstration of treatments to create early seral forest in 50-60-year-old timber plantations. This suite of experiments has played a key role in stimulating and informing adaptive management of federal lands, and will continue serve as a resource for public engagement and social science experiments planned in LTER7.

Data Visualization: Scientists (McKane, Bolte, and Thomas) conducting ecological research at the Andrews Forest are collaborating with computer scientists and social scientists on the NSF-funded VISTAS (Visualization of Terrestrial and Aquatic Systems) project. Together they are developing visual analytics software to visualize in an interactive, 3D environmental data at several spatial and temporal scales. VISTAS PIs hypothesize that spatially- and temporally-explicit visualization of ecosystem states, processes, and flows across topographically complex landscapes and under varying climatic conditions will enhance scientists' and other stakeholders' (e.g., resource managers and policy makers) capacity to comprehend relationships among ecological processes, ecosystem services and environmental conditions, and to pose testable hypotheses.

Disturbance studies. A longstanding emphasis on reconstructing fire and forest history (partially funded through LTER) has resulted in the accumulation of a tree-ring archive from thousands of trees spanning a history of 800 years. This resource will be used by several LTER7 investigations of climate and hydrologic connectivity influences on forest productivity, stress and disturbance.

Site REU program. The EcoInformatics Summer Institute (EISI) is an NSF-funded Site REU program that has provided interdisciplinary research training for students in ecology, mathematics and computer science since 2007. A number of student projects related to LTER have been conducted. Ongoing projects investigating plant-pollinator networks in meadows and the role of log jams in fish ecology are particularly relevant to new research planned in LTER7

Additional Phenology Research. Two research projects complement current and planned LTER research on phenology and trophic interactions by developing new sensors and analysis capabilities for monitoring plant phenology. An NSF-funded sensor development project is testing a budbreak sensor and the use of accelerometers to monitor plant phenology and biomass. USFS PNW researchers are using the STAR-FM blending algorithm for MODIS and LANDSAT images to track canopy phenology at large scales.

Northern Spotted Owl Demography. The first studies of spotted owl ecology and demography began at the Andrews Forest in the 1970s. The Andrews Forest is at the center of one of eight spotted owl demography study areas, in which spotted owl populations have been monitored in detail since 1980s. This research provides a long-term record of how climate variability, land-use and interspecific interactions (predator-prey dynamics and competition resulting form range expansion of congeneric barred owl) influence populations of an avian top predator in old-growth forests.

Arts and Humanities. Interdisciplinary inquiry at the Andrews Forest has expanded beyond biophysical and even social science to include the arts and humanities. Over the past decade writers and artists have begun a long-term study of the Andrews Forest as a place and a community through residencies. The Long-term Ecological Reflections program also brings writers, artists, philosophers, scientists and managers together to explore some of the critical questions of time, including climate change. A recent NSF synthesis grant will be tracking the arts and humanities programs that have appeared at over half of the LTER sites around the country. The Ecological Reflections program complements and will intersect with LTER7 research to increase the broader impacts of our investigation of governance and social connectivity, underscoring that science is but one of the necessary components for sound decision-making regarding conservation and sustainable development.

6.0 DATA MANAGEMENT PLAN

Introduction

The mission of Andrews Forest LTER Information Management is to ensure that all LTER research data will be archived and openly available for the future. The primary goals are to 1) preserve high-quality and well-documented data collections that are both secure and accessible, 2) serve the Andrews Forest and broader research community through the development and management of informational products and tools, and 3) provide leadership and participation in relevant committees and activities at both the site and LTER Network level.

Objectives

- Assure preservation of high quality metadata and data products through the direction and maintenance of a long-term data repository that adheres to LTER standards and best practices and provides security through regular maintenance and backup procedures.
- Maintain and adhere to a Data Access Policy in compliance with LTER standards to assure that data and accompanying metadata are freely and publicly available electronically within two years of collection at both the local site and within the LTER Network Information System (NIS).
- Assure regular contributions of research data into the long-term data repository through strong integration of the IM Team with site science including 1) participation and regular reporting at site executive meetings and monthly meetings, 2) annual reviews of Information Management, and 3) regular interactions and trainings conducted with co-PIs and community members.
- Develop and maintain the Andrews Forest LTER web pages and associated user interfaces providing access to data and metadata, research publications, programs and projects, site and personnel information, education and outreach programs, community events, and other site information.
- Provide leadership to the LTER Network in the development of standards and best practices for the NIS and participation in community projects and systems that promote the discovery, use, and integration of LTER data, both within the network and throughout the broader research community.

Information Management System

The Andrews Forest LTER Information Management Team (IM Team) has developed an information system (*http://andrewsforest.oregonstate.edu/research/component.cfm?comp=infom&topnav=36*) to support the collection, documentation, management, and archival of a rich and diverse collection of Andrews Forest LTER and other environmental data. The central component of the information system is the Forest Science Data Bank (FSDB), a long-term data repository initiated in 1983 (Stafford et al. 1984, 1988, Henshaw and Spycher 1998, Henshaw et al. 2002), which is supported by the Andrews Forest LTER in partnership with the US Forest Service Pacific Northwest Research Station (PNW) and the OSU College of Forestry (COF). The FSDB includes approximately 160 active LTER study databases including all “signature” data. Signature data refers to core Andrews Forest LTER databases including all key long-term and ongoing data collections (see Data Sets Table in Supplementary Documents). Ongoing long-term data sets such as meteorological station, stream gauging station, stream chemistry, fish population, permanent vegetation plot, and decomposition plot data are collectively managed by LTER PIs, staff and the IM Team. Workflow paths are established to assure data updates, quality control, and archival into the FSDB and the LTER NIS on a frequent basis. Data contributions from individual LTER PIs and graduate students require more specific planning and interaction between the PI and IM Team, and software tools are used to facilitate capture of these data. In addition to continuing updates of existing data, five new LTER study databases are added each year on average.

The FSDB features a highly-structured database that contains metadata content for all study databases including detailed entity (data table) and attribute (variable) descriptions. Metadata are established within a comprehensive SQL relational database that is tailored to accommodate all necessary elements within the Ecological Metadata Language (EML), the current LTER metadata standard. EML files are generated from a locally-developed, web-based computer program that maps elements from our relational metadata database into EML using style sheet transformation scripts. A similar program is used to map ESRI ArcGIS metadata from the federal FGDC spatial standard into EML descriptions of spatial entities. Recent enhancements allow these programs to produce EML documents that adhere to LTER EML "best practice" recommendations and assure a standardized approach is followed for consistency with other LTER sites.

The LTER NIS consists of the LTER metadata catalog in the Metacat EML repository and PASTA, the recently developed central data archive for LTER. The Andrews Forest IM Team has deposited EML files for all on-line Andrews Forest LTER data into Metacat, and is actively depositing data with associated EML into PASTA. PASTA provides tools to evaluate all EML files to assure compliance with best practices and validates congruence between the metadata and data before uploading. The IM Team is using the requirement to upload data into PASTA as incentive to fine tune and improve metadata including attribute descriptions and study methods associated with each data set. This transition is over 50% complete and the remaining data sets are being archived into PASTA during 2014.

The IM team has focused on improving the efficiency needed to manage increasing volumes of data being collected by the LTER project. As the central metadata database contains all relevant study metadata, it conveniently serves as the driver for many generic applications that broadly apply to all data. For example, the EML-generating programs previously described assure that any changes to metadata content are instantly incorporated into new EML files. Additionally, FSDB data are stored in relational SQL database tables and a software application generates new text versions for public access when necessary. A data versioning system assures that all versions of both the EML metadata and described data are archived and that any new versions are immediately generated for public access. A web-based administrative interface allows any researcher associated with a study to enter and revise descriptive metadata for that data, relieving the information manager of this effort. A metadata-driven quality control system provides another example of an efficient software tool relying directly on the metadata database.

The metadata-driven quality control system consists of a set of procedures that provide generic data validation for any data set. A desktop control program uses relevant metadata to validate that the attributes for each table in a data set are properly described in the metadata. Problems are recorded in an error report and validation includes checks for illegal null values or duplicate records (entity integrity), checks against listed numeric ranges for extreme values and against enumerated domains for undefined codes (domain integrity), and special database rules that are pre-determined in discussion with the data set PI for individual data sets. The quality control system provides valuable data checks for researchers and students as well as helps prepare data for delivery into the LTER NIS central data archive (PASTA), which requires each data set pass a series of similar quality checks demanding exact congruence of the metadata with each data table.

Besides the efficiencies described by populating a single, separate database with all study metadata, the Andrews Forest IM Team also builds data structures that can be shared across multiple study sites and similar study data collections. For example, climate data from six benchmark meteorological stations are accessible through more than twenty tables organized by the type of measurement within one single database. These data table structures are also shared with other climate data sets to streamline processing and management. Similarly, data from several large, long-term vegetation growth and mortality studies are being reorganized into sharable structures. This is cost-effective and allows common programs for creation of field collection forms, data processing, and calculations of biomass and summary data for these collections. Efficiencies in management of climate and vegetation data are essential given their time-consuming nature and inherent complications in properly documenting and processing. Analogously, increasing volumes of streaming sensor data require standardized approaches in data management.

CYBERINFRASTRUCTURE: In the LTER6 proposal, we identified the need to increase cyberinfrastructure capacity as a future challenge at our site. We have made significant advancements in developing our "cyber forest," a comprehensive communication system for our sensor networks that stream data over the 6400 ha, high-relief (1200 m) landscape (Henshaw et al. 2008). Wireless communication capabilities within the forest are vastly improved with new towers and high-bandwidth radios. Increasingly, data are collected and transmitted using radio telemetry to stream high-temporal resolution data to the Andrews Forest Headquarters. Standard naming conventions across hydrometeorological data sets are employed on more than 60 data loggers to improve data management efficiency. The GCE Data Toolbox in Matlab has been adopted and now provides web access to provisional data with near real-time graphics of streaming data. A quality control (QC) system for streaming data is under development and will prescreen data and assign flags to qualify potential errors. Problem data will be more quickly identified and alerts posted as problems occur, assuring faster delivery of final data products for public access and improving user confidence in these data streams. Andrews Forest personnel are working with the broader community to develop best practices for managing streaming sensor data (Campbell et al. 2013).

Web page development has been an important activity for the site as it acts as an organizational framework for the display of research products and is a primary source of site information for both local and broader research community users. Andrews Forest LTER personnel maintain and update extensive web pages describing the Andrews Forest, ongoing LTER and collaborative research, personnel, site data sets and associated metadata, publication lists with links to scanned documents, education and outreach, and other current events and activities. All site web pages are written dynamically with web integration software taking advantage of metadata tables that describe content, page templates and navigation bars. A web site search engine is employed and various interfaces permit additional searching for data and publications using either simple search strings or established relations with researcher, place or theme keywords. Social media (Facebook, Twitter, RS feed) have been incorporated into the web presence. Google Analytics software has been added to the web pages to track visitor numbers, user access flow, and highly trafficked pages.

Integration of Information Management with Site Science:

Information Management continues to be an important and unifying theme at the Andrews Forest LTER and the availability of long-term data provides incentive for researchers to conduct further research at the site. A representative from the IM Team serves as a regular member of the Andrews Forest LTER Executive Committee and participates in new proposal planning. The IM Team works with site leadership in establishing priority and inventory lists of all LTER data. Contributions of data are required when any LTER funding is involved and expected for all approved site research projects. Individual consultations with PIs and graduate students begin with study and database design and are common through the data collection, quality control processing, and archival of the data. Researchers understand the value of curating data sets in the long-term data repository, and the importance of early interaction of the IM Team with new research efforts has been identified over several funding cycles (Stafford 1993).

The IM Team facilitates the collection of general metadata and provides a web page describing the data submission process. IM training workshops for LTER graduate students and researchers are conducted annually as a means of assuring data contributions and providing IM education. Metadata writing "parties," where PIs are assembled together and collectively use software tools under Information Manager guidance, have proven to be effective in collecting and improving data set titles, abstracts, methods and other study metadata. Additionally, the IM Team is developing dynamic systems for capturing and assuring quality of streaming data from environmental sensors.

Data Access Policy:

The Andrews Forest data access policy (*http://andrewsforest.oregonstate.edu/data/access.cfm?topnav=98*) is compliant with the LTER Network data policy (*http://www.lternet.edu/data/netpolicy.html*) and includes three sections: the release policy for data products, user registration requirements for accessing data, and the licensing agreement specifying conditions for data use.

Highlights include specification that data and information derived from publicly funded research in the Andrews Experimental Forest will be made available online within two years of collection. Andrews Forest LTER scientists make every effort to release data in a timely fashion and with attention to accurate and complete metadata. Databases will be available on-line through the Andrews Forest website and the LTER NIS. Some data will be restricted due to institutional or legal requirements of the owner, but these occurrences are exceptional and the access constraints are documented.

While the intention of the Andrews Forest LTER policy is to promote maximum availability for ecological data, resource constraints have led to establishing criteria for prioritizing data for release. Primary observations collected for core research activities directly supported by LTER funding receive the highest priority for data release. Data collected with partial LTER support or where the LTER program has added value to resulting data products will also receive high priority for release. Other types of data including student thesis data, schoolyard LTER data, or non-LTER data that was acquired for LTER research may be ranked at a lower priority. Legacy data will be released as resources become available.

DOWNLOADS: A registration and tracking system has been employed since 2003 to document data downloads from the site web pages. While the mandatory requirement for one-time user registration is being relaxed to optional, the tracking of data table downloads will continue and has been very useful in identifying the data receiving the most use. Currently, 160 LTER databases are online representing 950 tables or spatial entities, and nearly half are long-term collections of at least 10 year duration.

Table IM_1. Downloads of Andrews Forest LTER 2003-2012. Increasing numbers of data downloads are likely due to improved data access and greater demand for this data; the increase may also reflect increasing numbers of online data tables. IM Team downloads for routine checking and testing are excluded, and the number of online databases is approximated for each two-year period.

Research Area	Number of Downloads of LTER Data Tables					
	2003-2004	2005-2006	2007-2008	2009-2010	2011-2012	Total
Climate	450	820	1130	1503	1206	**5109**
Hydrology	349	620	775	951	1446	**4141**
Vegetation	315	465	262	655	527	**2224**
Carbon/Nutrients	210	295	280	278	417	**1480**
Biodiversity	217	220	224	347	302	**1310**
Soils	159	170	143	203	196	**871**
Disturbance	57	200	135	163	276	**831**
Stream-Forest	48	36	91	116	177	**468**
Total Downloads	**1805**	**2825**	**3040**	**4215**	**4550**	**16,435**
LTER Databases online	**110**	**125**	**140**	**150**	**160**	

Information Management Resources

Information Management (IM) is an essential component of the Andrews Forest LTER program and benefits from institutional partnerships with the Oregon State University College of Forestry (COF) and the USFS Pacific Northwest Research Station (PNW). The LTER grant funds two full-time IM positions, including a data manager and a systems administrator. The Andrews Forest IM team benefits through long-term and continued support provided by the US Forest Service for two additional positions.

The current Andrews Forest LTER Information Management Team is composed of the following individuals: Don Henshaw (*IM Team Leader*, PNW, 1978-Present), Suzanne Remillard (*Database/Web Developer*, LTER, 2000-Present), Theresa Valentine (*GIS Specialist*, PNW, 1999-Present), Adam Kennedy (*System Administrator/Wireless Communications*, LTER, 2011-Present), Hans Luh (*Programmer*, LTER, .25 FTE 2011-Present). Henshaw and Valentine hold permanent PNW positions with a primary focus on Andrews Forest LTER activities. Remillard and Kennedy are OSU employees funded through the LTER grant. Remillard is dedicated to LTER database and web development at the university site, and Kennedy is responsible for Andrews Forest on-site system administration and communication networks including the Local Area Network (LAN), local web server, wireless LAN, and radio telemetry for wireless sensors. Luh has been funded part-time through LTER supplemental grants for specific application development, but support will continue into the future through LTER base funding. Two field technicians (one from PNW, one from LTER) serve IM roles in supporting data loggers and field computers used in routine data collection, describing methods and providing data.

The Andrews Forest LTER has agreements with COF for computer system administration, backup of production servers, and other information technology services including system administration support for LTER campus computer servers, production and development web servers (IIS and LINUX), production and development database servers (MS SQLServer), shared file server directories, and two tape backup servers. The COF description of network systems has additional information on services and backup policies (*http://helpdesk.forestry.oregonstate.edu/about-our-network*).

LTER Network-Level Participation:

The Andrews Forest IM Team serves key roles at the LTER Network level with Henshaw (IM Executive Committee co-Chair, 2009-2012), Valentine (chair GIS subcommittee, 2003-2010, LTER Spatial Data and Analysis Committee, 2009-present), and Remillard (IM Executive Committee, 2008-2011, NIS Advisory Committee (NISAC), co-IM Chair of NISAC, 2012-Present). The IM Team also assures participation in network-wide administrative databases (PersonnelDB, All-site Bibliography, SiteDB) and were the lead developers in the ClimDB/HydroDB synthetic research database (Henshaw et al. 1997, 2006)

As LTER Network standards and best practices have been developed and incorporated into the LTER NIS, the Andrews Forest information management system has been modified to comply with accepted NIS standards. Metadata best practices for EML, the unit dictionary, webpage recommendations, and the network-developed IM review criteria have all shaped the evolution of the Andrews Forest system. The Andrews Forest IM Team, both currently and historically, have played strong leadership roles in the development of these standards (Michener et al. 1997, 1998, Baker et al. 2000, Brunt et al. 2005).

Milestones and deliverable products for LTER 7:

Table IM_2. Ongoing annual work activities, the completion of two major ongoing projects and the development of new databases are planned. Milestones include intensive evaluation of progress, priority setting and specific data/web enhancements every third year.

Year of grant cycle	Milestone / Deliverable product
Annually	Update and archive of all ongoing LTER signature data and metadata; update study data and metadata for individual LTER researcher collections; post all LTER data on the site webpage and deposit into the LTER NIS
	Update personnel, publication databases, research activities, site events and other site information on the site webpage
	Conduct internal site review of data management activities and prioritize development of LTER data sets for depositing in the LTER NIS; conduct IM training on data submission procedures and policies for the LTER community
	Participate in the annual IM Committee meeting, related video teleconferences and committee activities; synchronize local with network databases
Year 1	Complete development of QC system for streaming sensor data to allow for 1) near real-time posting and access of telemetry data on the site webpage and 2) annual deposition into the LTER NIS. Post all LTER data from previous LTER Grant on site webpage and deposit into the LTER NIS.
Year 2	Complete reorganization of data structures and processing code for vegetation growth and mortality data to allow timely posting on the site webpage and deposition into the LTER NIS
Year 3	Identify and design metadata and data structures for new grant data collections, post Year 1 data on the site webpage and deposit into the LTER NIS; review priorities for information product delivery and make necessary updates and enhancements to the site webpage in preparation for mid-term review
Year 6	Assure update, archival, web posting and depositing into the LTER NIS for any LTER-funded data set collected within the grant cycle; preparations for renewal

7.0 PROJECT MANAGEMENT PLAN

INSTITUTIONAL PARTNERSHIP. The overall Andrews Forest Program is administered cooperatively by Oregon State University (OSU), the US Forest Service Pacific Northwest Research Station (PNW), and the Willamette National Forest (WNF) (Fig. 12). The Andrews Forest Program includes research and education activities funded by the Andrews Forest LTER, the USFS Pacific Northwest Research Station, and other grants that occur at the H.J. Andrews Experimental Forest. A highly collaborative relationship exists between the three institutions. Individuals from each institution play critical roles in the program and each institution contributes importantly to research, education, and maintenance of the Andrews Forest Program. This partnership results in more students, technical staff, and information managers than would be possible with LTER funding alone.

RESEARCH COMMUNITY. The Andrews Forest LTER program brings together interdisciplinary groups of researchers from a variety of institutions and agencies. Our immediate community (see Senior Personnel biosketches) includes faculty and researchers from OSU, US Forest Service PNW, EPA Western Ecology Division, University of Oregon, University of Michigan, and University of Washington.

MANAGEMENT PHILOSOPHY. While the Andrews Forest LTER program is the highly visible focal point for a wealth of research and educational activities, the Andrews Forest is also a USFS Experimental Forest and a UNESCO Man and the Biosphere Reserve. In keeping with those varied designations, we consider and manage the Andrews Forest as a regional, national, and international research and educational resource. The open sharing of data from ongoing and long-term studies—funded by LTER and USFS PNW—provides a platform that attracts broad interest, encourages new studies, and results in the significant leveraging of research dollars in innovative ways.

PROGRAM ADMINISTRATION. As Lead PI, Michael P. Nelson is responsible for project administration, site representation in the LTER Science Council, and coordination of the Andrews Forest LTER Executive Committee (EC) (Fig. PMP_1). The EC is composed of researchers from multiple disciplines, as well as from the partner institutions of OSU and PNW. The committee is chaired by the Lead PI (Nelson) and includes four signatory co-PIs (Johnson, Jones, Gosnell, and Betts). Also serving on the EC is the Andrews Forest Director (Schulze) and the lead of the Information Management Team (Henshaw). A researcher from the list of Senior Personnel serves on the EC as a rotating member, to allow newer scientists access to leadership experience and to provide new perspectives and expertise to the EC. The EC governs the Andrews Forest LTER program with input from the broader Andrews Forest science community. EC members are responsible for financial and research decisions, inter-site collaborations, and data management policies. The EC meets monthly or more frequently as needed.

Staffing for the Andrews Forest LTER program is described in the "Site Administration and Staffing" section of the *Facilities, Equipment, and Other Resources for the Andrews Forest LTER* section of this proposal. Both OSU and PNW partners have agreed to provide critical staffing resources.

FUNDING AND RESEARCH DECISIONS

Funding Decisions: Decisions about funding are made at multiple levels: the EC, and specifically the Signatory PIs, are responsible for final decisions; the broader group of EC and Senior Personnel provide input for major decisions. During years 1–4 of LTER6, we invested 20% of the LTER budget on long-term studies, 20% on information management, and 27% on integrative science activities particular to the current grant cycle (the remaining investments went toward graduate student support, program support, and covered indirect expenses). We anticipate a similar investment allocation in LTER7. In addition to funding long-term studies, a long-standing tradition of the Andrews Forest program is to invest core LTER strategically in activities, infrastructure, faculty, students, and products toward current LTER goals and objectives. Investment decisions are made through review of proposals submitted by the broader Andrews Forest research community and through discussions by the EC.

Research Decisions: The broader Andrews Forest research community, with coordination and guidance by the Andrews Forest LTER EC, creates research directions for the Andrews Forest LTER program. Proposals for new research at the site are submitted through an on-line system, are reviewed by the Forest Director and others in the Andrews Forest science community for compatibility with existing and prospective research, and are conducted under the Andrews Forest research guidelines. An annual meeting of all LTER PIs and senior personnel is convened to review progress on LTER research, to report on past and future spending, and to discuss research opportunities. This management style, based on transparency and distributed leadership, has served the Andrews Forest LTER well over its history, and is expected to continue to be productive in the future.

ADVISORY GROUPS. The Andrews Forest LTER has several Advisory Groups (Fig. PMP_1). A local Partners Group facilitates communication among LTER PIs and Deans of OSU Colleges, the Station Director and Line Officers of PNW, and the Forest Supervisor and Science Liaison from the WNF. The EC meets with this group approximately once a year to discuss common goals, new directions, funding possibilities, and outreach efforts. The LTER External Advisory Committee pulls in national experts to provide broad input and guidance on research directions as well as financial, institutional, and tactical perspectives.

COMMUNICATIONS. Communication is facilitated through general Andrews Forest Program monthly meetings, regular EC meetings, meetings of disciplinary groups, tours and field visits for various visitors and groups, and annual large group events. Monthly meetings are open to all and cover business (e.g., site administration, data management, events planning, graduate student activities, and proposed research projects) and a science hour with an invited presentation and discussion by an Andrews Forest LTER, campus, or visiting scholar. Notes of monthly meetings are posted on the Andrews Forest webpage. We host annual events that provide colleagues a variety of accessible introductions to the Andrews Forest community. Our annual symposium is a full-day event on the OSU campus featuring oral presentations, a group lunch, and a poster session that highlights current Andrews Forest LTER research. Graduate students are especially encouraged to share their study plans or findings. An annual public field day, HJA Day, introduces researchers, students, partners, and visitors to the site, to one another, and to the current program of work. The field day draws between 120-140 people annually and features stations at the headquarters focused on large themes of our work and afternoon field trips where researchers create interactive activities that provide a sense of the their field work and findings. Our website (*http://andrewsforest.oregonstate.edu*) is an important means of communication to our research community and beyond. Our semi-annual *Andrews Forest Newsletter* reaches >900 subscribers.

INTEGRATING NON-LTER SCIENTISTS INTO RESEARCH ACTIVITIES. The long history of research at the Andrews Forest, and the NSF-funded LTER Network that links with researchers at other sites around the country and world, makes the Andrews Forest an attractive place to conduct research. We actively integrate non-LTER scientists into our program through collaborative projects and efforts that leverage the Andrews Forest and/or LTER resources. Because of the strong partnership between OSU and PNW, and because of OSU's proximity to EPA and USGS labs, we have close and productive collaborations with federal and university scientists. Non-LTER scientists are integrated into the planning and activities of the site through regular group meetings and events, and through shared resources.

RECRUITMENT OF NEW SCIENTISTS TO THE PROJECT. Recognizing that the success of our program requires a large, diverse, and collaborative group of participants, we actively encourage researchers at various career stages at OSU and other institutions and agencies to participate in the Andrews Forest LTER program, to initiate research that involves the Andrews Forest site, and to utilize Andrews Forest data. In response to our 2011 midterm review, we created, and shared with NSF, a mentoring plan that laid out a clear and comprehensive strategy for 1) recruiting and supporting new researchers to participate in the Andrews Forest LTER program and, 2) encouraging and mentoring early- and mid-career researchers to become future leaders of the Andrews Forest LTER. Since that time we have enthusiastically implemented that plan; including offering multiple opportunities and events that allow potential participants to learn about the program, making individual connections, providing seed money to start new projects, REU funding, sharing LTER technician time, GRA positions, and encouraging and assisting in the development of new proposals to expand funding to support a wider community of researchers. As we seek out and meet individually with new researchers and scholars, 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 LTER data. Our events, field tours, and classes provide an introduction to research at the Andrews Forest and are successful outreach tools to local, regional, or distant researchers.

EFFORTS TO INCREASE DIVERSITY AMONG SITE PARTICIPANTS. We promote diversity at our LTER by being welcoming to all and through active recruitment and support of researchers, educators, faculty and students from underrepresented populations. We advertise graduate and REU positions broadly and target sites that provide connections to minority and underrepresented groups. Our RET, Canopy Connections, and LTER schoolyard programs work closely with teachers from schools with diverse demographies. Female scientists fill key leadership positions at the Andrews Forest (e.g., in LTER7, 3 of the 5 signatory PIs are female). The training of diverse students as future scientists and professors is an important function of the Andrews Forest Program, providing a multicultural perspective to the LTER science community. We will continue to attract and retain diversity among site participants by strategic recruitment of new members and through research investments of LTER funds.

Continuity of Leadership and Succession Planning. An LTER program must plan for changes while maintaining continuity. Our lead PI has traditionally served for a 6-9 year term as Lead and then continued as a signatory co-PI. In 2012 Michael P. Nelson took over as lead PI from Barbara Bond. Bond took over from Mark Harmon in 2006. Harmon had served as lead PI since 1999 (signatory co-PI or lead LTER3-6), when he took over from Fred Swanson. Swanson served as signatory co-PI or Lead during LTER2-5; he retired from PNW in 2012 and continues to be active in research and outreach with the program. Johnson and Jones are continuing as signatory co-PIs, having served in that capacity since LTER 5. Harmon and Tom Spies will be retiring in the next few years and have stepped down as signatory co-PIs, though both plan to stay closely involved as researchers. Forest ecologist Matthew Betts, who has been engaged in LTER research at the Andrews Forest since the beginning of LTER6, will be a new signatory co-PI. Betts' expertise is in landscape ecology, phenology, and pollinator networks. Our commitment to social science is reflected by the addition of Hannah Gosnell as a new signatory co-PI. Gosnell, who also worked on LTER6, brings expertise in environmental governance to our group. We are beginning to plan for the next lead PI to follow Nelson, by looking both inside and outside our current LTER group. Several promising young OSU faculty are being encouraged to become involved in leadership roles in LTER. We expect to have continued seamless transitions in leadership.

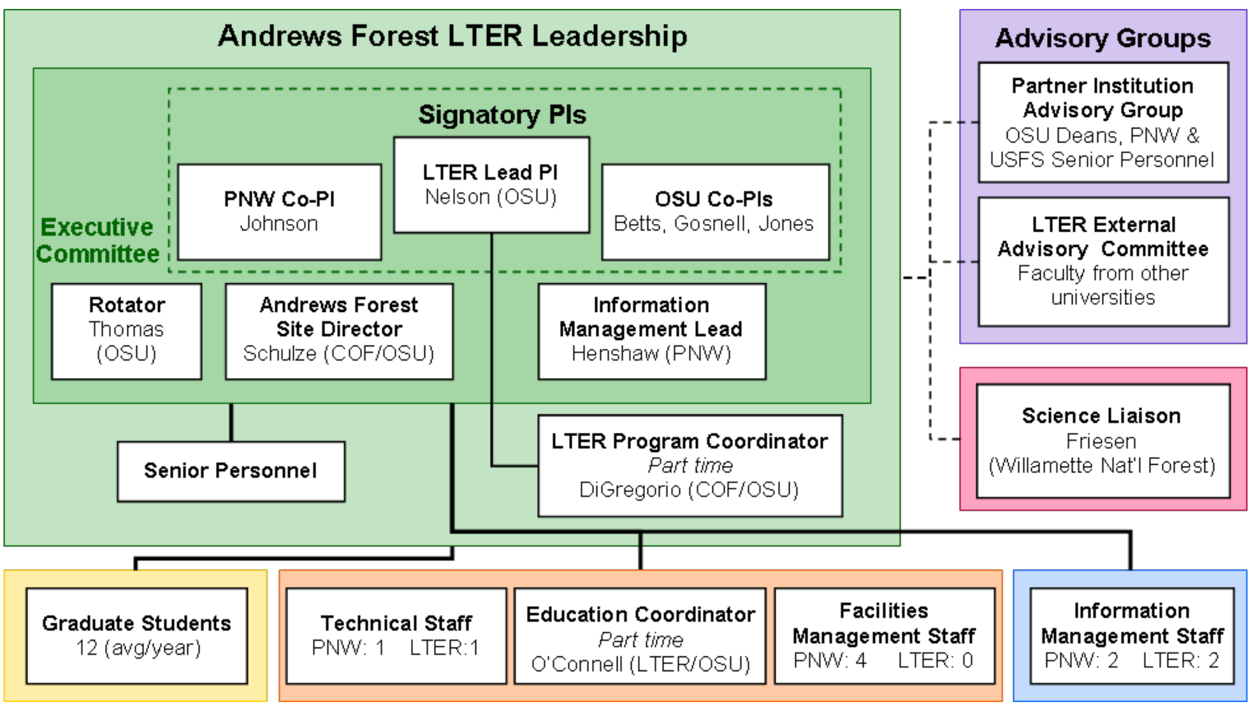


Figure PMP_1. Organizational structure of the administration, leadership, and staffing of the Andrews Forest Program, showing LTER leadership and co-funding of staff. The College of Forestry (COF) at Oregon State University (OSU) and the Pacific Northwest Research Station (PNW) support personnel that fill collaborative roles throughout our program. Connecting lines denote oversight, advice, and other forms of cooperative effort, rather than supervision. Graduate student numbers are shown as the average number per year supported by LTER and LTER-related funding.

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SUPPLEMENTARY DOCUMENTS: DATA SETS TABLE

Andrews LTER databases in LTER NIS (Metacat and or Pasta) as of Feb 2014. Signature or core databases are of greatest importance to the site and shown in **bold**. * indicates new datasets planned to online in 2014.

CLIMATE	CODE
Meteorological data from benchmark stations at the Andrews Experimental Forest, 1957 to present	**MS001**
Air and soil temperature data from the Reference Stand network at the Andrews Experimental Forest, 1971 to present	**MS005**
Snow depth and snow water equivalent measurements along a road course in the Andrews Experimental Forest, 1978 to present	**MS007**
Air temperature, cold air drainage - mobile transect studies, 2002 to 2012	**MS036**
Airshed tower data in Watershed 1 in the Andrews Experimental Forest from streaming data, 2005-2010	**MV001**
Ecohydrology and Ecophysiology intensively measured plots in Watershed 1, Andrews Experimental Forest, 2005-2011	**TW006**
Sap flow measurements to estimate overstory water use in Watersheds 1 and 2, Andrews Experimental Forest, 1999-2002	TW003
Micrometeorlogical data in Watershed 1 Tower, Andrews Experimental Forest, 1 minute intervals from 1 Hz streaming data, 2012 to present *	MV004
Throughfall and Isotopic Ratios on WS1 at the Andrews Experimental Forest, 2010-2011 *	MV003
Spatial data	
Mean monthly maximum and minimum air temperature spatial grids (1971-2000), Andrews Experimental Forest	**MS029**
Radiation spatial grids, Andrews Experimental Forest, 1995-2000	**MS033**
Meterological station locations, Andrews Experimental Forest, 1994 - 2011	MS026
Average monthly and annual precipitation spatial grids (1980-1989), Andrews Experimental Forest	MS027
Average monthly and annual temperature spatial grids (1980-1990), Andrews Experimental Forest	MS028

HYDROLOGY	
Stream discharge in gaged watersheds at the Andrews Experimental Forest, 1949 to present	**HF004**
Bedload data from sediment basin surveys in small gauged watersheds in the Andrews Experimental Forest, 1957 to present	**HS004**
Stream and air temperature data from stream gages and stream confluences in the Andrews Experimental Forest, 1950 to present	**HT004**
Stream and air temperature at phenology sites in the Andrews Experimental Forest, 2009	**HT006**
A Study of Hyporheic Characteristics Along a Longitudinal Profile of Lookout Creek, Oregon, 2003	HF020
Nutrient and microbial characteristics of mountain stream fine benthic organic matter in the H.J. Andrews Experimental Forest, 1995 to 1996	HS005
The effects of debris flows on stream fine benthic organic matter (FBOM), characteristics, 1996	HS006
Periodic stream temperature data (1957-1983) in the Andrews Experimental Forest	HT001
Stream and air temperature data from stream network in the Andrews Experimental Forest, 1997-2001	HT002
Peak flow responses to clear-cutting in small and large basins, western Cascades, Oregon, 1933 to 1991	HF007
Stream stage and water table elevation in hyporheic and ground water from McRae Ck well network, Andrews Experimental Forest, 1989-1993	HF010
Stream tracer experiments to assess channel and hyporheic residence times of streams in the Andrews Experimental Forest in 2001 & 2002	HF011
Longitudinal profiles and geomorphic descriptions of twelve randomly selected stream reaches in the Andrews Experimental Forest, 2000-2001	HF012
Spatial data	
Stream network (1976 survey), Andrews Experimental Forest	HF013
Experimental watershed boundaries and gaging station locations, Andrews Experimental Forest, 2011	HF014
Hydrologic response units (base units for PRMS streamflow model), Andrews Experimental Forest, 1993	HF015
Flow accumulation grid,10 meter DEM, Andrews Experimental Forest, 1998	HF016

NUTRIENTS AND DETRITAL DYNAMICS	
Stream chemistry concentrations and fluxes using proportional sampling in the Andrews Experimental Forest, 1968 to present	**CF002**
Precipitation and dry deposition chemistry concentrations and fluxes, Andrews Experimental Forest, 1969 to present	**CP002**
Long-term log decay experiments at the Andrews Experimental Forest, 1985 to 2185	**TD014**
Comparison of terrestrial versus aquatic decomposition rates of logs at the Andrews Experimental Forest, 1985 to 2050	**TD017**
Dimensions, cover, volumes, mass and nutrient stores of Coarse Woody Debris (bark and wood from logs, snags, and stumps) from forests plots in the western United States and Mexico, 1977 to 2005	**TD012**
Nitrogen fixation and respiration potential of conifer logs at Andrews Experimental Forest, 1987 to 2006	**TD018**
Fine wood decay studies at the H.J. Andrews and other Forests across the world, 1989 to 2006	**TD021**
LTER Intersite Fine Litter Decomposition Experiment (LIDET), 1990 to 2002	**TD023**
Fine woody detritus volume and mass in small watersheds at Andrews Experimental Forest, 2002 to 2003	**TD024**
Mass of forest floor litter from cores in reference stands and inventory plots in the Pacific Northwest, 1992 to 2003	**TD028**
Fine woody debris inventory data from reference stands and inventory plots in the Pacific Northwest, 1992 to 2000	**TD030**
Decomposition of Fine Woody Roots: a Time Series Approach, 1995 to 2006	**TD031**
A chronosequence of woody root decomposition in the Pacific Northwest, 1995-97	**TD032**
Coarse woody debris volume and mass from line transect inventory from reference stands and inventory plots of the Pacific Northwest, 1997 to 2005	**TD035**
Nutrient Concentrations of Vegetation in Small Watersheds at H. J. Andrews Experimental Forest, 2005 to 2006	**TN025**
Soil solution chemistry in Detrital Input and Removal Treatments (DIRT) from the Andrews Experimental Forest, 1999-2011	TN021
Stream, hyporheic, and ground water chemistry of McRae Creek in the Andrews Experimental Forest, 1989 to 1992	CF004

NUTRIENT AND DETRITRAL DYNAMICS (cont)	
Storm nutrient dynamics at Andrews Experimental Forest stream gages, 2001-2003	CF006
Stream nutrient sampling during winter baseflow conditions in the Andrews Forest and Willamette River Basin, February 2009	CF008
Conversion factors to predict the volume of the tree bole that is converted to forest products in the Pacific Northwest (1993)	FS111
Origin of large woody debris in streams in the western Cascades of Oregon and Washington and the Oregon Coast Range, 1981	TD010
Respiration patterns of logs in the Pacific Northwest, 1986-1996	TD020
Coarse woody debris density and nutrient data across western USA, 1982-2001	TD022
Log leachates from the Andrews Experimental Forest, 1986-1992	TD025
Moisture content of logs from the Andrews Experimental Forest, 1985-1988	TD026
Radial thickness of structural-anatomical components of woody plant parts, 1985-2005	TD027
Comparision of native litter species occurring at the Andrews Experimental Forest to LIDET standard species, 1993-2003	TD029
Fall directions and breakage of trees along streams in the Pacific Northwest, 2000-2002	TD042
Litterfall rates in Reference Stand within the Andrews Experimental Forest, 1977 to 1985	TL001
A study of selected ecosystem parameters potentially sensitive to air pollutants in the Olympic Peninsula, 1984-1987	TL003
Soil descriptions and data for soil profiles in the Andrews Experimental Forest, selected reference stands, Research Natural Areas, and National Parks, 1962 & 1996	SP001
Soil Moisture and vegetation cover patterns after logging and burning an old-growth Douglas-fir forest in the Andrews Experimental Forest, 1960-1983	SP002
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	SP004
Synoptic soil respiration of permanent forest sites in the Andrews Experimental Forest (1993 REU Study)	SP005

NUTRIENT AND DETRITAL DYNAMICS (cont)	
Chemical and microbiological properties of soils in the Andrews Experimental Forest (1994 REU Study)	SP006
Disturbance effects on soil processes in the Andrews Experimental Forest (1995 Stand Age Study)	SP007
Effect of thinning pole stands on soil processes in southern Oregon, central Coast Range, and central western Cascades of Oregon (1994-1995 BLM Study)	SP008
Role of vegetation and coarse wood debris on soil processes and mycorrhizal mat distribution patterns at the Hi-15, Andrews Experimental Forest, 1994-1995	SP009
Respiration in soils collected from the REU synoptic sample grid in the Andrews Experimental Forest, 1994-1995	SP010
The relationship between early succession rates and soil properties in the Andrews Experimental Forest, 1999	SP012
Seasonal soil respiration using permanent gas chambers in the Andrews Experimental Forest, 1994-1996	SP014
Influence of coniferous tree invasion on forest meadow soil properties on Bunch Grass Ridge and Deer Creek near the Andrews Experimental Forest, 1998	SP016
Influence of tree-fall gaps on soil characteristics in gaps of varying sizes in the Andrews Experimental Forest, 1995	SP017
Influence of microclimate gradients on soil characteristics within tree-fall gaps in the Andrews Experimental Forest, 1997	SP018
Influence of tree-fall gaps on soil characteristics in the Andrews Experimental Forest, 1999	SP019
Effects of topography on soil characteristics in the Andrews Experimental Forest, 1998	SP020
Chemical and biochemical characteristics of soils along transects in stands with different vegetation and successional characteristics in the Andrews Experimental Forest, 1996	SP021
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	SP022
Soil respiration associated with ectomycorrhizal mats in an old-growth stand along lower Lookout Creek, HJ Andrews Experimental Forest (2008-2009)	SP033

NUTRIENTS AND DETRITAL DYNAMICS (cont)	
Spatial Data	
Soil survey (1964, revised in 1994), Andrews Experimental Forest, 1991-1996	SP026
Willamette National Forest soil resource inventory (SRI 1992) clipped to the Andrews Experimental Forest	SP027
Fungal mat transect mapping, High 15 in the Andrews Experimental Forest, 1994-1995	SP029
Mycorrhizal map sampling data in different age class plots of Douglas-fir forests, Andrews Experimental Forest, 1992-2005	SP030
BIOTA AND DIVERSITY	
Aquatic Vertebrate Population Study in Mack Creek, Andrews Experimental Forest, 1987 to present	**AS006**
Plant succession and biomass dynamics following logging and burning in Watersheds 1 and 3, Andrews Experimental Forest, 1962 to Present	**TP073**
Post-logging community structure and biomass accumulation in Watershed 10, Andrews Experimental Forest , 1974 to present	**TP041**
Ecosystem dynamics in a mature (Hagan block) and old-growth (Watershed 2) forest, Andrews Experimental Forest, 1981 to present	**TP091**
Plant biomass dynamics following logging, burning, and thinning in Watersheds 6 and 7, Andrews Experimental Forest, 2002 to present	**TP114**
Plant biomass dynamics in old-growth Watersheds 8 and 9, Andrews Experimental Forest, 2003 to present	**TP115**
Long-term growth, mortality and regeneration of trees in permanent vegetation plots in the Pacific Northwest, 1910 to present	**TV010**
Bird Arrival and Activity Phenology at the Andrews Experimental Forest *	**SA024**
Terrestrial Insect Activity Phenology with trap collections at HJ Andrews	**SA025**
Aquatic Insect Emergence Phenology at HJ Andrews Experimental Forest	**SA027**
Vegetative Phenology observations at the Andrews Experimental Forest	**TV075**
Invertebrates of the Andrews Experimental Forest: An annotated list of insects and other arthropods, 1971 to 2002	**SA001**
Spatial and temporal distribution and abundance of moths in the Andrews Experimental Forest, 1994 to 2008	**SA015**

BIOTA AND DIVERSITY (cont)	
Spatial and temporal distribution and abundance of butterflies in the Andrews Experimental Forest, 1994-1996	**SA016**
Forest metrics derived from the 2008 Lidar point clouds, includes canopy closure, percentile height, and stem mapping for the Andrews Experimental Forest *	**TV081**
Species interactions during succession in the western Cascade Range of Oregon, 1990 to present	TP103
Ecology and restoration of montane meadows at Bunchgrass Ridge near the Andrews Experimental Forest, 1999-2009	TP112
Post-fire succession study, Torrey Charlton RNA, 1997 to present	TV045
Ground-dwelling vertebrates, birds, habitat data on the Willamette National Forest, Oregon (Young Stand Thinning and Diversity Study), 1991-2012	WE008
Plant Pollinator data at HJ Andrews Experimental Forest *	SA026
Lichen abundance and biodiversity along a chronosequence from young managed stands to ancient forest, 1993	SA011
Mycorrhizal belowground fungi species list of the Andrews Experimental Forest, 1992 to 1994	SA014
Aquatic insect sampling in Lookout Creek at the H.J. Andrews Experimental Forest, 2001	SA017
Epiphytic macrolichens in relation to forest management and topography in a western Oregon watershed, 1997-1999	SA021
Headwater Stream Macroinvertebrates of the H.J. Andrews Experimental Forest, Oregon, 2003-2004	SA022
Dynamics of montane and subalpine meadows in the Three Sisters Wilderness Area and Biosphere Reserve, 1981-1993	TP064
Pacific Northwest Plant Biomass Component Equation Library	TP072
Population dynamics of young forest stands as affected by density and nutrient regime in the Andrews Experimental Forest, 1981-1997	TP088
Annual tree productivity in permanent plots within the H.J. Andrews Experimental Forest, 2000-2004	TP120
Overstory biometrics from Watershed 1 at the Andrews Experimental Forest, derived from TP072 and TP073, 1980-2008	TP121

BIOTA AND DIVERSITY (cont)	
Comparison of arthropod densities on young-growth and old-growth foliage in the Andrews Experimental Forest, 1986	TS015
Dendrometer studies for stand volume and height measurements of trees of the western US, 1976 to 1993	TV009
Ecosystem responses to the creation of tree-fall gaps in the western Cascades of Oregon and Washington (Experimental Gap Study)	TV025
Decay in standing trees of the Pacific Northwest, 1982-1992	TV030
Streamside mosses at the Andrews Experimental Forest, 1994	TV036
Forest structure and biomass in early successional harvest units of the Andrews Experimental Forest (ESSA), 1999 to present	TV052
Monitoring small mammal and amphibian abundances on the Willamette National Forest, Oregon (Long-Term Ecosystem Productivity experiment), 1995-1999	WE026
Vertebrate-habitat relationships: Logistic regression models predict probability of occurrence of bird and small mammal species in western Oregon, 1998-1999	WE027
Species Lists	
Vascular plant list on the Andrews Experimental Forest and nearby Research Natural Areas, 1958 to 1979	SA002
Bird species list for the Andrews Experimental Forest and Upper McKenzie River Basin, 1975 to 1995	SA003
Amphibian and reptile list of the Andrews Experimental Forest, 1975 to 1995	SA004
Mammal species list of the Andrews Experimental Forest, 1971 to 1976	SA005
Fish and Amphibians species list of the Andrews Experimental Forest, 1975-1995	SA006
Benthic algal species list of the Andrews Experimental Forest, 1991/1992	SA007
Moss species list of the Andrews Experimental Forest, 1991	SA008
Riparian bryophyte list of the Andrews Experimental Forest, 1994/1995	SA009
Epiphyte species list of Watershed 10, Andrews Experimental Forest, 1970-1972	SA010
Macroinvertebrate species list of the Andrews Experimental Forest, 1992	SA012
Aquatic Invertebrate species list of Lookout Creek in the Andrews Experimental Forest, 1988	SA013

BIOTA AND DIVERSITY (cont)	
Spatial Data	
Aboveground Live Biomass (2008), Andrews Experimental Forest	**TV080**
Vegetation history classification for Watersheds 1, 2, and 3, Andrews Experimental Forest, 1959-1990	TP119
Vegetation classification, Andrews Experimental Forest and vicinity (1988,1993,1996,1997,2002)	TV061
Plant community typing (2009 update), Andrews Experimental Forest	TV062
DISTURBANCE	
Age structure, developmental pathways, and fire regime characterization of Douglas-fir/western hemlock forests in the central western Cascades of Oregon *	**DF028**
Stream cross-section profiles in the Andrews Experimental Forest and Hagan Block RNA 1978 to present	GS002
Archival records of fire history, 1910-1977, central western Cascades, Oregon	DF001
Fire history database of the western United States, 1994	DF005
Dendrochronology study of fire history, Andrews Experimental Forest and central western Cascades, Oregon, 1482-1952	DF007
Dendrochronology study of fire history, Blue River watershed, Oregon, 1475 to 1996	DF014
Road-related erosion from the February 1996 flood in the Lookout Creek and Blue River watersheds, Oregon	GE008
Dynamics of large wood in streams: Tagged log inventory, Mack Creek, Andrews Experimental Forest, 1985 to 2008	GS006
Coarse woody debris, amount and distribution of in Lookout Creek, Andrews Experimental Forest 1991	GS016
Landslide chronosequence: Tree, site and vegetation factors in the Andrews Experimental Forest, 1981	GV002

DISTURBANCE (cont)	
Spatial data	
Landslide inventory (1953-1996), Andrews Experimental Forest and Blue River Basin	**GE012**
Spot fire locations (1991), Andrews Experimental Forest	DF018
Fire history reconstruction (1482 - 1952), Andrews Experimental Forest and vicinity	DF019
Fire history dendrochronology study, super old growth data, central western Cascades, Oregon, 2002	DF020
Potential rapidly moving landslide hazards in Western Oregon, clipped to Andrews Experimental Forest, 1999 to 2002	DF026
Upper Blue River geology clipped to the Andrews Experimental Forest, 1991	GE009
Mass movement assessment: cascade hazards ratings, Andrews Experimental Forest, 1992	GE010
LANDUSE	
Spatial data	
LiDAR data (August 2008) for the Andrews Experimental Forest and Willamette National Forest study areas	**GI010**
Road construction history (1952 - 1990), Andrews Experimental Forest	DH001
Historic salvage sale locations (1954 - 1974), Andrews Experimental Forest	DH002
30 meter digital elevation model (DEM) clipped to the Andrews Experimental Forest, 1996	GI002
10 meter digital elevation model (DEM) clipped to the Andrews Experimental Forest, 1998 **Spatial Dataset**	GI003
Adminstrative boundary, Andrews Experimental Forest, 1997 survey, 2009 update	GI006
Transportation network system including trails, road construction history, and gates for the Andrews Experimental Forest, 1952-2011	GI007
Land use designations, Andrews Experimental Forest, 1998-2011	GI008