Andrews LTER5 Proposal
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Project Summary

The Andrews LTER program seeks to understand the long-term dynamics of forest and river ecosystems of the Pacific Northwest. The Central Question guiding Andrews LTER research is: **How do land use, natural disturbances, and climate change affect three key sets of ecosystem services: carbon and nutrient dynamics, biodiversity, and hydrology?** These ecosystem services represent scientifically and socially important, tractable variables, and their responses are posited to represent different classes of ecosystem behavior at the landscape scale. Climate, land use, and natural disturbances are the major drivers of change in the Pacific Northwest region. The approach used to address this question will be multi-faceted involving retrospective analysis, time series observations, experiments, and use of simulation models for synthesis, extrapolation in time, and interpolation in space. The principal spatial scale of inference for LTER studies is the Andrews Forest and adjacent upper Blue River watershed, an area of 16,000 ha. Work associated with the LTER will be coordinated with studies aimed at regional questions. The principal temporal extent of proposed LTER studies spans the past 500 yr and to several centuries projected into the future. This proposal represents the strategic plan of activities designed to advance science for individual disciplines, integration, and cross-site comparisons. Thus, the Andrews LTER is used as the core of a larger set of integrated studies.

Essential long-term studies will be continued and others added to increase spatial and temporal overlap of scales. The standard 5 LTER core activities will be addressed by work in seven component areas: (1) climate, (2) hydrology, (3) disturbance, (4) ecophysiology, (5) carbon and nutrient dynamics, (6) biodiversity, and (7) stream-forest interactions. In this grant cycle, studies continue to examine the interaction of the drivers of change and responding processes and taxa, but the conceptual emphasis will be on **temporal behavior, its causes, and its consequences for ecosystem change**. We will examine temporal behavior over time scales of days to hundreds of years focusing on: (1) modulation, (2) temporal lags, (3) spatial coherence, (4) path dependence, (5) hysteresis, and (6) alternative stable states. Exploring these aspects of temporal behavior help to address the Central Question by quantifying natural temporal variability and providing insights into mechanisms that control processes. A major goal will be to test predictive rules (i.e., hypotheses) regulating temporal behaviors. Another focus of synthesis will be **small watersheds,** an important landscape unit providing opportunity for integration of climatic, ecosystem, and hydrological processes as well as knowledge of temporal and spatial scaling. The ultimate goal in this integration is to create a spatially 3-dimensional (including subsurface and air flow) understanding of the temporal dynamics of the 3 states of matter involved in biogeochemical and hydrologic cycles within a watershed. Past experiments, long term records of climate, stream flow, nutrient exports, and vegetation change, as well as modeling will enhance this integration effort. By understanding this key landscape unit, future broader-scale efforts will be strengthened.

Andrews science and scientists continue to advance understanding and management of forests and streams of the Pacific Northwest through communication with students, teachers, policy makers, land managers, and the general public. Information management, an essential activity for both research and education, emphasizes ease of use, increased accessibility, and portability of many forms of information.

LTER5 Proposal

1.0 Prior Results. Over its 22-year history, the Andrews LTER program has become a major center for analysis of forest and stream ecosystems in the Pacific Northwest. Today, several dozen university and Federal scientists use this LTER site as a common meeting ground, working together to gain basic understanding of ecosystems and to apply this knowledge in management and policy. The Andrews LTER program has its roots in the establishment of the H. J. Andrews Experimental Forest by the US Forest Service in 1948 (Figure 1.1). This began two decades of predominantly Forest Service research in the 1950s and '60s on the management of watersheds, soils, and vegetation. With the inception of the International Biological Programme-Coniferous Forest Biome (IBP-CFB) in 1969, university scientists began to play increasingly important roles in the Andrews program. Focus shifted from single disciplines to interdisciplinary research on forest and stream ecosystems, especially old-growth forests. IBP-CFB ended in the late 1970s and LTER commenced in 1980. The first decade of LTER work developed a foundation of long-term field experiments as well as long-term measurement programs focused on climate, stream flow, water quality, and vegetation succession (Figure 1.1, Table 1.1; See the Supplementary Documents for a complete list of databases and publications). Developing data and information management systems to support this science program remains an important activity (Section 4). In LTER4 our Central Question was: **How do land use, natural disturbances, and climate change affect three key ecosystem properties: C dynamics, biodiversity, and hydrology?** (Figure 1.2) To address this question we divided our research efforts into Component Areas and Synthesis Areas. Although they overlap, Component Areas are the basic data-generating part of our LTER and are most directly tied to LTER core areas (Table 1.2). Synthesis Areas are cross-component projects where we integrate results and ideas stemming from Component Areas. We summarize the key results below; a more complete description can be found on our website (http://www.fsl.orst.edu/lter/).

1.1 Component Areas. Observations and analysis of **climate** have provided a strong basis for defining its temporal and geographic context. Using long-term records, maps of precipitation distribution have been prepared, and temperature maps are in progress (Smith & Daly in prep). Data from the Andrews Forest and nearby Weather Service stations have been used to characterize climatic gradients among LTER sites (Greenland in review) and ENSO- and Pacific Decadal Oscillation-related phenomena (Greenland 1996a, b, Greenland 1998). We have started to examine climatic variability and ecosystem response at the Andrews LTER site, an activity leading directly to our emphasis on temporal variability in LTER5 (see Greenland et al. 1999).

Studies of **hydrology** and geomorphology produced new insights by linking upstream disturbance and vegetation effects to downstream responses. Effects of forest harvest on peak flows appear to extend to large basins, in part due to the role of roads (Jones & Grant 1996). Although their conclusions sparked analysis by others (Thomas & Megahan 1998, Beschta et al. 2000, Jones & Grant 2001a, b), these findings have been corroborated elsewhere in the region (Jones 2000). Road networks contribute to peak flows (Wemple 1994, Wemple et al. 1996, Wemple 1998) and modify landscape-scale response to floods (Wemple et al. 2001). Rain-on-snow flood mechanisms were examined (Figure 1.3), with the distinctive behaviors of event types separated to reveal emergent behavior caused by precipitation-landscape interactions (Perkins 1997; Perkins & Jones in prep). In an intersite hydrology synthesis, we compared Andrews to records from Caspar Creek, Coweeta, Hubbard Brook, and Luquillo (Post et al. 1998). These five sites have distinct time scales of precipitation-stream flow coupling (Post &

Jones 2001) (Figure 1.4), and differ markedly in their long-term response to forest harvest, leading to general hypotheses about site controls on hydrologic response (Jones & Post in prep).

Highly contrasting **disturbance** regimes of natural and human origins affect the Andrews and surrounding landscapes. In LTER4 this component addressed controls, temporal and spatial patterns, and consequences of disturbance processes common in the Cascade landscape—principally fire, flood, and forestry land use. Studies of a major flood in February 1996: (1) revealed the importance of refugia in increasing the resilience of stream and riparian ecosystems to intense flood disturbance (Swanson et al. 1998); (2) highlighted interactions between road and stream networks during floods (Wemple et al. 2001); (3) indicated that the amount and conditions of floating wood strongly influenced patterns of riparian forest disturbance (Johnson et al. 2000); and (4) provided evidence that geomorphic disturbances move through stream networks as a cascade of processes with varying ecological impacts along flow paths (Nakamura et al. 2000) (Figure 1.5). The response of watersheds to hydrologically similar floods differed with land-use history (Swanson et al. 1998, Johnson et al. 2000). We examined long-term measurements of landslides (Snyder 2000) and channel change (Lambert 1997, Faustini 2000, Faustini & Jones 2000) (Figure 1.6), riparian vegetation (Acker et al. in press), and other factors integral to interpreting disturbance regimes and their consequences. Landscape-scale, dendrochronology-based, fire history studies in western Oregon revealed that wildfire across the region was extensive in the 1500s and 1800s and relatively restricted in the 1600s, 1700s, and 1900s, reflecting both climate and human influences (Weisberg 1998, Berkley 2000, Weisberg & Swanson in press). This suggests that periods of extensive stand establishment were episodic (Figure 1.7), and today's old-growth forest established under a warmer, drier climate. Understanding fire and flood disturbance regimes places management in the historic range of ecosystem variability (Swanson et al. 1997, Landres et al. 1999), and has been incorporated into landscape management plans (Cissel et al. 1998, 1999) (Section 5).

Studies of **vegetation succession** have provided important insights into natural processes of succession, tree mortality, biomass accumulation, and timber growth as well as validated growth-and-yield and mechanistic succession models (Acker et al. 1998a). Highest mortality rates for Douglas-fir occur in young to mature stands due largely to suppression, whereas in old growth, mortality rates are substantially lower and are density-independent (Bible 2001). In contrast, western hemlock mortality is lowest in young and mature stands (despite a lower canopy position) and highest in old-growth, due to a combination of suppression, snow loading and physical damage from falling trees. Analysis of long-term plot records indicate bolewood net primary production (NPP_b) of western hemlock/Sitka spruce declined 2-fold between 85 and 145 yr, with 6% of this decline accounted for by increases in autotrophic respiration; thus gross primary production declined significantly during this period (Acker et al. 2000). In a comparison of young (10-35 yr), mature (100-120 yr), and old (450+ yr) Douglas-fir and western hemlock forests, bole biomass accumulation rate increased over time in the young forest as leaf area increased, remained constant in the mature forest, and varied between positive and negative in the old forest (Acker et al. 2002). Decreasing NPP_b and increasing tree mortality contributed equally to the decline in biomass accumulation with stand age. Annual variation in NPP_b and litterfall varied annually between 1971 and 1998 (±30%), but were not correlated; NPP_b generally increased and appears correlated to increases in precipitation in May to July (Fraser 2001). Twenty permanent plots yielded insights into the degree to which extended rotations influence structural diversity and timber production (Acker et al. 1998b).

Studies of **biodiversity** have examined the response of organisms to changes in climate, land use, and natural disturbance. To date, studies have focused on plants and insects (Lepidoptera and Coleoptera), although we continued to update species lists and collections of many other taxa. Exotic, invasive plant species are widely distributed along roads, streams and trails in the Andrews, with distributions strongly correlated with light levels and disturbance intensity (Parendes 1997, Parendes & Jones 2000). Road use and proximity to clearcuts interact with moisture and temperature to limit exotic abundance at higher elevations, while seed size and dispersal appear to control fine-scale patchiness of exotic plants (Parendes 1997). A total of 535 and 80 species of moths and butterflies, respectively, are documented from the Andrews. Lepidopteran richness is closely coupled to plant life form: 10% of moths feed on conifers, whereas most feed on broadleaf trees and shrubs (48%) or herbs (22%). Spatially, lepidopteran communities are correlated to vegetation zones, reflecting, in part, feeding preferences on plants (Miller & Hammond 2000). Both lepidopteran and coleopteran communities respond to forest age; ground beetle fauna in recently disturbed forests have become more similar to those in old-growth communities as succession proceeds (Heyborne 2000).

Controls on **carbon and nutrient dynamics** have been investigated at several levels of spatial and temporal resolution, with major emphases on the C dynamics of Pacific Northwest forests, integrating data on forest production, decomposition, succession, and disturbance. The potential of PNW forests to store C, based on total ecosystem C (TEC) stores of 43 old-growth forest stands, was ~750 Mg C/ha or about 3 times the current store (Smithwick et al. in press). Long-term, ground-based measurements of C dynamics in an old-growth forest indicate the system is nearly in balance, in marked contrast to eddy flux results that indicate significant C uptake (Harmon et al. in review). This discrepancy may be attributable to mismatches in temporal scale; better estimates of annual variation in NPP and decomposition are needed to test this hypothesis. Successional trends in C stores indicate forests become C sinks 10-50 yr after disturbance; this period lengthens as more dead matter is left on site (Janisch & Harmon 2002). Simulation models indicated increasing the harvest interval and leaving more live and dead trees increases C stores more than does increasing the rate of regeneration (Harmon & Marks in press). Economic costs of altering forest management are between $15-25 per Mg C and can be achieved by fertilization, thinning, and longer harvest intervals (Zyrina 2000). Rules for scaling C sequestration results have been developed (Harmon 2001, Randerson et al. in press), and we have developed a new, broad-scale simulation model that estimates the effect of climate and disturbance regimes on potential C (Smithwick 2002). Studies of root decomposition along a coastal to east-side Cascade transect indicated little environmental control of root decomposition rates (Chen et al. 2000, 2001). We found major differences in decomposition among species of roots, but these were not associated with chemical properties, suggesting decomposer control of rates. Field, laboratory, and simulation model studies of N fixation indicate that: (1) N fixation in dead wood amounts to 10-35% of N inputs into the ecosystem over succession; (2) O_2 diffusion limitations to respiration may not be as severe as assumed previously; and (3) accurate estimates of N fixation in logs require consideration of temperature, moisture, and oxygen interactions (Hicks 2000, Hicks and Harmon in press). Our intersite work and leadership on wood decomposition and stores continues (Harmon et al. 2000, Krankina et al. 1999, 2000) and has allowed us to estimate global stores at 100 to 150 Pg globally (Harmon et al. 2001) as well as to contribute to estimates of C sequestration in the USA (Pacala et al. 2001).

The **stream-forest interactions** component continued long-term studies of riparian forests and wood. A simulation model of stand dynamics, wood input, decomposition, and redistribution in riparian systems was developed (Meleason 2000, Meleason et al. in review). Riparian forest structure determined wood abundance in streams, which was also sensitive to rates of decomposition and physical breakdown. Longitudinal transport rates influenced the time required to reach maximum wood abundance. Long-term dynamics of cutthroat trout populations (Figure 1.6) indicate that forest harvest increases the temporal variance of trout populations (Bisson et al in press). Responses of trout, sculpins, and salamanders to large wood manipulation and ecological restoration revealed that wood influences vertebrate abundance less in streams with large sediment sizes (cobbles and boulders) than in those with fine particles. Physical heterogeneity influences sampling efficiency and population estimators for fish; we developed a method to correct for habitat complexity (Burgess 2001). Intersite experiments on N dynamics in streams (LINX-the Lotic Intersite Nitrogen Experiment) demonstrated that streams retained ~51% of the inorganic N added as ammonium (Mullholland et al. 2001, Peterson et al. 2001). Plant uptake and consumption of invertebrates by spiders transferred a small portion of the N from the stream to the forest (Sanzone 2001). After complete removal of forest cover in the early 1960s, maximum daily stream temperatures increased by 6°C, but stream temperatures recovered within 10-15 yr; however, a debris flow associated with the 1996 flood raised temperatures only slightly despite major impacts on channel structure (Johnson & Jones 2000).

1.2 Synthesis Areas. We have examined the influence of **species attributes on ecosystem function** with an initial emphasis on plant attributes influencing C sequestration, including decomposition, mortality, and woody tissue respiration. A new technique to rank respiration potential of species was developed and used to explore variations within trees (Pruyn et al. 2002, Pruyn et al. in press). Respiration rates varied radially and longitudinally within pondersosa pine and Douglas-fir trees, and with tree ages for these two species. Bark and sapwood respiration rates varied significantly and consistently among 10 tree species common to the Andrews. Preliminary analysis indicates a tradeoff between sapwood volume and respiration potential, with species with low sapwood volume having high per mass respiration and vice versa.

To better understand the ecological consequences of land-use and natural disturbances, we examined the variability of the **early phase of vegetation succession**. Remote sensing studies on the Andrews (Nesje 1996) indicate the rate of development of conifer dominance after clear-cut harvest varies considerably from the assumed “model” (e.g., Franklin & Dyrness 1988, Halpern & Franklin 1990, Harmon et al. 1990). Elevation and aspect interact to affect conifer development: at low elevations, S- and E-facing slopes are more likely than N-facing slopes to regenerate slowly; at high elevations the opposite is true. This suggests that non-forest alternative stable states are possible in both elevation zones, but for potentially different reasons. A conceptual model to explain why conifers establish at different rates after disturbance has been developed (Halpern 2002). The rate of conifer development significantly affected above-ground live C stores: above-ground biomass was significantly higher in fast than in slow plantations. However, rate of conifer development had no significant effect on dead C stores (coarse and fine woody debris and forest floor litter) or understory C. No significant differences existed in live or dead C stores in adjacent old-growth controls, suggesting that the inherent productivity of slow and fast stands was similar. Preliminary estimates indicate that 40 yr after harvest, fast plantations have a positive C balance, whereas slow plantations have a negative C balance.

Collaborative, synthetic studies of **small watershed** behavior focused on hydrology (see above), vegetation-water interactions, and export of C and N. On a sapwood area basis, Douglas-fir in an old-growth watershed used <50% the water of Douglas-fir in a 35-yr-old watershed (Figure 1.8), consistent with analysis showing that older forests are less productive than younger forests (Acker et al. 2002). Species also differed in water use; red alder and western hemlock used significantly more water and later into the summer drought than did Douglas-fir. Day-to-day variation in sapflow influenced stream flows, indicating close temporal coupling of sapflow and stream flow (Figure 1.8). This relationship allowed us to make a novel estimate of the "effective zone of vegetation influence" which ranged from 0.3% of the total watershed in late June to ~0.1% by late summer (Bond et al. in press). Vanderbilt et al. (in press) analyzed long-term records of precipitation and stream water chemistry in 6 small watersheds. Dissolved organic N (DON) was the predominant form of N exported in streams, followed by particulate organic N, NH_4-N, and NO_3-N, with DON having consistent inter-watershed, seasonal concentration patterns. Total annual DON flux was positively correlated to annual stream discharge in all 6 watersheds, suggesting climatic controls at this time scale (Vanderbilt et al. in press). In contrast, NO_3-N, NH_4-N, and PON annual fluxes were not consistently related to annual discharge, with concentrations of NO_3-N and NH_4-N seasonally constant and quite low regardless of time since harvest. Peak stream water DON concentrations occurred in November-December after the onset of fall rains, but before the peak discharge. This pattern may reflect: (1) flushing of decomposition products accumulated during summer, (2) water table fluctuations in near-stream, high-N soils, or (3) alterations of within-stream retention. Dissolved organic C and DON concentrations, as well as C:N ratios, exhibited strong hysteresis at storm event and seasonal time scales (Figure 1.9).

Landscape dynamics examined the effects of spatial arrangement of landscape elements on ecosystem function. Improved understanding of structure-function relations of networks in landscapes is critical to advancing ecosystem science and management (Swanson et al. 1997, Swanson & Jones in prep). Many LTER4 studies provide examples of how stream and road networks interact with environmental gradients across the landscape, with each other, and with patchworks of vegetation in areas between network segments (Parendes & Jones 2000, Jones et al. 2000, Wemple et al. 2001). We are expanding on these studies to develop a functional taxonomy of network properties and roles in landscapes (Swanson & Jones in prep). Potential influences of spatial interactions on C dynamics were explored using a simulation model, indicating significant spatial interactions at the scale of gaps and between stand-level patches, although the latter effect is an order of magnitude smaller (Smithwick 2002). The consequences of landscape pattern on key ecosystem properties were examined in several studies (Cissel et al. 1999, Garman et al. 1999), revealing that proposed future management schemes differ from each other and historical conditions. A spatially-explicit simulation system (LANDMOD) was developed to assess patch connectivity and potential habitat quality (Urban et al. 1999, Garman et al. 1999). Simulations of wildfire at the scale of the entire Oregon Cascade Range indicate that the current landscape has significantly greater young and less old-growth forest than historical conditions (Pennington in prep).

1.3 Overall Synthesis Activities. Our site has engaged in numerous other synthetic work and intersite activities over the course of LTER4. These include leadership of the major intersite studies LIDET (Long-term Intersite Decomposition Experiment Team, Gholz et al. 2000); Intersite Hydrology (Post et al. 1998, Post & Jones 2001, Jones & Swanson 2001); and DIRT (Detrital Input Removal and Trenching); participation in LINX-1 (Peterson et al. 2001) and LINX-2 (Findlay et al. in press); and collaborative studies in China, Hungary, Japan, Mexico, Russia, Sweden, and Taiwan (Table 1.3). We have contributed to intersite synthesis for specific projects such as the soils methods book (Robertson et al. 1999) and to 3 of the 6 BioScience manuscripts for the 20-year LTER review. We organized an international conference on Wood in

World Rivers, with a book and special issues of two journals to be published. A major goal has been completion of a synthesis volume for the Andrews, and we have made significant progress (http://www.fsl.orst.edu/lter/webmast/hjabook.cfm Username: LTER; Password: hjabook).

2.0 Proposed Activities.

The Andrews LTER program has been productive both scientifically and in service to society. We have made significant progress during LTER4 by successfully integrating a wide range of processes and scales of spatial and temporal resolution to address our Central Question. The key findings from LTER4 have set the stage for LTER5 and have helped to guide our selection of new research topics. What follows is the overall strategic plan of activities for the next 6 years; detailed plans and methods have been placed on our website (http://www.fsl.orst.edu/lter). We acknowledge that not all the activities described can be directly supported from LTER funds. In the past, we have successfully supported LTER-related efforts with a mix of funding from USFS-PNW, NSF, NASA, and others. LTER5 planning anticipates a similar arrangement and we specify existing non-LTER contributions in our budget justification (Section 7). Our activities are designed to advance science at multiple levels: (1) individual disciplines, (2) integration of disciplines at our site, and (3) cross-site comparisons and integration. Most of the activities described hereafter focus on the second level; however, where relevant, we discuss key advances in individual disciplines that address our Central Question. We also address investments required to make advances in future LTER funding cycles, to provide the basic information required to participate and lead intersite science, and to create serendipitous science opportunities.

2.1 Conceptual Framework. The Andrews LTER program seeks to **understand the long-term dynamics of forest and river ecosystems of the Pacific Northwest**. The Andrews LTER site is typical of this region, where the steep, rugged topography, massive forests with high C-stores, and seasonally wet/dry climate create strong interactions between biotic and abiotic systems and between forests and streams. These systems are dynamic, yet in some ways are remarkably resilient, despite major disturbances. Wildfire, wind, landslides, floods, and other natural disturbances have created the template on which succession plays out over seres spanning many centuries. Over the last two centuries, this region of extensive public lands has experienced profound changes in management policy that have repeatedly shifted the balance between succession and disturbance. A pre-settlement wildfire period (pre-1850) in which the interplay of natural disturbance and succession dominated the landscape, gave way to the pre-exploitation period (1900-1950) when fire suppression and limited logging on Federal lands created a landscape dominated by reduced disturbance and relatively uninterrupted succession. This was followed by a period of dispersed-patch clearcutting (1950-1990) in which wildfire was suppressed, small disturbance patches were regularly spaced across the landscape, and succession was truncated. Since 1990, dispersed clearcuts have been replaced by smaller, partial cuts with retention of live trees and greater attention on landscape level planning.

Set in this biophysical and social context, the Central Question of the new Andrews LTER proposal remains: **How do land use, natural disturbances, and climate change affect three key sets of ecosystem services: carbon and nutrient dynamics, biodiversity, and hydrology?** We selected these ecosystem services because they are scientifically and socially important, tractable, and their responses are posited to represent different classes of ecosystem behavior at the landscape scale (Swanson et al. 1997). In LTER3, we selected climate, land use and natural disturbances as the major drivers of change because they are dominant factors in the Pacific Northwest region. These drivers also interact, potentially leading to larger changes in landscape conditions than when considered individually. Our Central Question was developed for LTER3 and remains very relevant today. We realized then that fully answering this question would take several decades and LTER grant cycles. Our strategy has been to emphasize a major part of the Central Question during each grant cycle and to focus on a crucial area of conceptual development (Figure 1.2). In LTER3, we separately examined the effects of long-term climate change and natural disturbances on the three sets of ecosystem services and began the process of synthesis through modeling. In LTER4, modeling was extensively used to analyze the effects of land use and natural disturbances on these ecosystem services. Our major conceptual emphasis was to understand the effect of spatial controls (particularly at the landscape scale) on ecosystem behavior. In LTER5, we will again shift our emphasis while continuing to pursue our long-term goals. In this grant cycle, we will continue to examine the interaction of system drivers and responding processes, but the conceptual emphasis area will be **temporal behavior, its causes, and its consequences for ecosystem change**. We will examine temporal behavior over time scales of hours to thousands of years. To some degree, our exploration of the temporal dimension in LTER5 is analogous to our exploration of spatial interactions during LTER4. We will examine many aspects of temporal behavior (Figure 2.1, Table 2.1), but will focus on: (1) modulation, (2) temporal lags, (3) spatial coherence, (4) path dependence (i.e., the effect of the order of events), (5) hysteresis, and (6) alternative stable states, with an emphasis on forest versus non-forest conditions (Scheffer et al. 2001). We will also focus synthesis efforts on **small watersheds** as they represent a critical landscape unit allowing integration of climatic, ecosystem, and hydrological processes, as well as our knowledge of temporal and spatial scaling. By understanding the behavior of these key landscape units, our future broader-scale efforts will be strengthened.

Many reasons compel us to focus on temporal behavior to address our Central Question. First, natural temporal variability of properties must be known before a directional change can be detected (Knapp & Smith 2001, Foster & Aber in press). Second, ecosystem properties may respond to change by shifts in variability rather than shifts in mean response (Palmer et al. 1997). Detecting ecosystem change, therefore, requires that we understand the baseline average and variability of system states and processes at appropriate temporal scales. Third, understanding temporal behavior yields insights into mechanisms that control processes and suggests experiments to test these mechanisms. A major goal will be to develop and test predictive rules (i.e., hypotheses) regulating temporal behaviors. Finally, focusing on temporal behavior allows us to look at our system differently, putting many long-term measurements in a new context, and compelling us to reexamine old conceptual models. We have already reexamined the current temporal scale of sampling at our site and complemented ongoing activities with sampling at shorter or longer intervals to maximize the temporal overlap of studies.

Improved understanding of temporal variability will greatly enhance our ability to address our Central Question regarding ecosystem services because it improves understanding of system stability—we consider two aspects of stability: resistance to change, and resilience once disturbed (Holling 2001). Studies at the North Temperate Lakes LTER have been an inspiration for our own temporal analysis (Kratz et al. 1991, Baines et al. 2000, Benson et al. 2000, Webster et al. 2000). We seek to build on their examination of spatial coherence by examining five additional temporal behaviors (Figure 2.1). Understanding which responses are **modulated** relative to driver signals indicates which parts of the system are resistant to change. Understanding **temporal lags** will help to pinpoint when we should be looking for system response. Lack of **spatial coherence** can lead to temporal stability at the landscape scale, giving a system more resistance to change than apparent from a single location. An understanding of **path dependence** and subsequent emergent behaviors (non-additive) is crucial to properly scale results in time. It also helps us to understand system resistance as some sequences of events may lead to more change than others. **Hysteresis** is common in our system, yet we have not systematically explained its basis or incorporated it into our modeling. **Alternative stable states** appear to be rare in our system currently, but may become more evident with shifts in management and climate change, and thus have major implications for predicting system resilience (Scheffer et al. 2001).

Our approach is multi-faceted, involving retrospective analysis; time series observations and experiments at our site and throughout the region at other research sites (Experimental Forests, Research Natural Areas); and simulation models for synthesis, extrapolation in time, and interpolation in space. We use models to predict responses, but in LTER5 we will primarily use models as heuristic and synthetic tools to learn about general system behaviors. Corroborating complex models with independent data is challenging, but we will seek data for such tests. As a complementary approach, we will focus our studies to narrow the uncertainty of parameters and relationships between subsystems as a way to reduce the degrees of freedom associated with our models. While parts of most ecological models are calibrated from empirical data, we will avoid calibration to variables that are predicted (tuning the model) as this largely eliminates any heuristic and predictive value.

To address our Central Question and new areas of conceptual development and synthesis, we will examine a broad range of spatial and time scales. The principal spatial scale of inference for LTER studies is the Andrews Forest and adjacent upper Blue River watershed, an area of 16,000 ha (Figure 2.2, 2.3). This work will be tightly coordinated with larger-scale studies aimed at regional questions. The Andrews represents a relatively pristine part of the region. Our intent is to connect to broader-scale studies such as the Willamette Basin Study (Gregory PI) and the NASA-LCLUC Regional Examination of Carbon Dynamics (Krankina PI). While detailed examination of the social/human system is not possible at the scale of the Andrews, we realize at the broader-scale human response is crucial (and the two studies mentioned above do incorporate these considerations). Thus, we will continue to collaborate with social scientists (e.g., Shindler) to understand how our science is perceived and used by the public. As part of intersite research within LTER and the international community, our research extends beyond the Pacific Northwest to continental and global scales. The principal temporal extent of LTER studies spans the dendrochronologically accessible past (500 yr) to several centuries into the future. At longer temporal scales, Andrews LTER coordinates closely with paleoecological studies of Holocene vegetation and fire history in western Oregon (Sea & Whitlock 1995).

2.2 Component Areas. This section describes the specific measures, experiments and other activities to be conducted in each of the 7 Component Areas of LTER5: (1) climate, (2) hydrology, (3) disturbance and landscape dynamics, (4) ecophysiology, (5) carbon and nutrient dynamics, (6) biodiversity, and (7) stream-forest interactions. Although the Component Areas address the standard 5 LTER core activities (Table 1.2), we have reorganized activities to enhance synthesis. In addition to Component Areas, we also have two synthesis areas that emphasize understanding temporal behavior and integration within small watersheds.

Climate. The purpose of this Component Area is to understand the complex climate patterns in our mountainous landscape from the micrometeorological (within stand) to the regional spatial scales, and from the diurnal to the multi-century temporal scale. Climate is a key system driver that is often viewed as extrinsic to the system. Our goal in LTER5 is to move beyond that view, including aspects of climate that are intrinsically controlled by the Cascadian landscape. This change in perspective is necessary if we are to understand the basis of spatial coherence among meteorological variables that in turn drive key ecosystem processes. It requires that we understand the dynamic processes that control local climate. In LTER5, we will initially focus on further development of our landscape models of radiation, temperature, and precipitation, examining how climate variability/change varies topographically. This will provide high-quality meteorological data for projects using the Andrews Forest and vicinity, allowing a high-resolution examination of many aspects of temporal behavior ranging from modulation to alternative states. We will also reconstruct past climatic patterns using dendroclimatology studies that are linked to current ecophysiological and tree-growth studies. Toward the end of LTER5, we expect to be well positioned to begin linking with the airshed study being conducted by Bond, Unsworth, and Mix with separate funding. This fortuitous, small watershed-based project will further enhance our understanding of the mechanisms controlling climate within the landscape in addition to climate controls over the landscape.

Landscape meteorological models of temperature and precipitation that have been used to analyze and map Andrews climate are based on PRISM (Parameter-elevation Regressions on Independent Slopes Model) (Daly et al. 1994, 1997, 2001, in press; Daly & Johnson 1999), an approach specifically designed for mountainous terrain. We will refine these models to account for temperature variations caused by solar radiation, canopy effects, cold-air drainage, and riparian zone influences. It has become clear that spatial predictions of temperature using uniform lapse rates can be quite misleading (Rosentrater 1997). Daly and a graduate student are quantifying canopy and topographic shading effects using existing temperature data. In LTER5, we will distribute a large array of temperature recorders to analyze cold-air drainage and riparian influences at diurnal and seasonal scales. In addition to allowing us to predict climate over the Andrews landscape, these efforts will allow us begin to examine the spatial coherence of climate change. We will explore the hypothesis that cold air drainage and inversions may ameliorate regional and global climate variation by comparing climate records at sites within and near the Andrews. This knowledge will significantly improve our early climate change assessments, which were based on the assumption of uniform change over the landscape (Urban et al. 1993).

To extend our knowledge of past climate trends and to examine the relationship between disturbance and forest establishment, we will analyze tree-ring growth at several spatial and temporal scales. To conduct this research, we will collaborate closely with leading dendrochronologists (e.g., Malcolm Hughes, Univ. of Arizona) seeking funding to extend the work of Graumlich & Brubaker (1986) and Graumlich (1987) to western Oregon. We will capitalize on our climatic network and ecophysiological measures to help interpret the climatic signals controlling tree-ring width.

Hydrology. The objective of the hydrology Component Area is to understand how hydrologic processes interact with land use, climate change, and natural disturbance. Hydrology work in LTER5 will draw upon 50-yr records of stream flow from small watersheds, Lookout Creek, and Blue River, as well as short-term process studies using tracers, water aging techniques, and a continuation of ongoing hydrologic modeling efforts. In LTER5, we will examine canopy interception in old-growth forests at the Andrews. Unique aspects of old-growth vegetation structure, such as high lichen and moss biomass, may increase interception relative to younger forests. Retrospective analyses (Post & Jones 2001) indicate that evapotranspiration greatly exceeds sapflow measurements (Bond unpub.) and estimates based on increases of water yield following complete removal of old-growth (Jones & Post in prep) (Figure 1.8). Moreover, these estimates of old-growth evapotranspiration are at the high end of model estimates from the nearby Wind River site (Link 2001). Because lichens and mosses are poikilohydric and may absorb up to 10 times their dry weight in water, the epiphyte communities in old-growth forest canopies at the Andrews could potentially account for this difference (McCune & Berryman unpub.). In LTER5 we will measure canopy interception and estimate cloudwater interception following the methods of Harr (1982), Schellekens et al. (1999), and Link (2001) and relate these measurements to water storage by canopy epiphytes.

We also will examine how the hydrologic cycle is affected by vegetation changes associated with climate change and natural disturbance, an extension of current studies of forest harvest effects (Jones & Grant 1996, Jones 2000, Jones & Post in prep). Using more in-depth analysis of climate and vegetation records, we will test alternative explanations for 35-yr trends of increasing water use in old-growth stands (Figure 1.8). Possible explanations include: increasing interception or transpiration associated with changes in vegetation or a shift in precipitation from winter to spring and fall (seasons when interception and transpiration are high).

To understand the storage and transport of water and solutes, we plan to reinvigorate process studies of water storage and transport in soils and hillslopes, and extend them to first-order channels. Despite their limited depth and fine texture, hillslope soils at the Andrews are able to both drain very rapidly and store water for multiple months (Post & Jones 2001). Using hillslope tracer tests, we will examine how the physical properties of the deeper part of the soil profile influence water storage and release, and relate these properties to the observed soil moisture retention curve. Hillslope hydrologic behavior will be characterized using the distribution of residence times of subsurface water in hillslopes. Process studies using isotopic tracers, including ^{18}O, will allow us to determine when water is isotopically “young” or “old,” revealing the role of fast versus slow flowpaths. Parallel tracer analyses (e.g., Haggerty et al. in review) will characterize residence time distributions in channels with different character (e.g., bedrock, alluvial). These studies will contribute to mechanistic interpretations of the effects of storm, seasonal, and interannual precipitation patterns on stream flow chemistry records (e.g., Kirchner 2000) and thus contribute to our small watershed integration.

We will continue to examine the processes that influence the behavior of floods, such as those observed in 1996 (Figure 1.6). Using modeling and retrospective analysis, we will explore hypothesized alternative explanations for the emergent behavior evident in rain-on-snow floods: (1) spatial coherence of small basin discharge peaks (Perkins 1997), (2) replacement of old growth with young stands (Jones & Grant 1996), (3) spatial coherence of snowmelt (Marks et al. 1998), (4) arrangement of road-stream connections (Jones et al. 2000), and (5) flood routing. Our retrospective analysis will benefit from ongoing modeling efforts conducted by collaborators in Sweden (Seibert) and Germany (Uhlenbrook).

Disturbance and Landscape Dynamics. The general objective of this Component Area is to understand the disturbance regimes affecting forests and watersheds in the Andrews and vicinity. These principally include natural processes of wildfire, landslides, and wind, and the management practices of forest cutting and road construction. Our overall approach is to combine direct observation, retrospective analysis of recent and historical events, and modeling. In LTER5 we plan three areas of work: (1) continued analysis of long-term disturbance data, including temporal patterns that contribute to our understanding of temporal variability of disturbance and its relation to climate; (2) examination of significant, new disturbance events; and (3) continued participation in a long-term, large-scale landscape management study. Land use and natural disturbance processes are major drivers of ecosystem change, affecting all other components of Andrews LTER work. We are concerned with understanding the frequency, severity, spatial pattern, and ecological consequences of the various types and sequences of processes. Additionally, we seek to develop concepts about the cascading effects of disturbance through time and space to develop a more general understanding of ecosystem dynamics than is possible by considering single event-response interactions (Figure 1.5). Records at Andrews Forest are now long enough that we can see multiple dimensions of interactions of natural processes with management at the landscape scale, for example by contrasting managed and unmanaged watershed responses to hydrologically similar floods (Johnson et al. 2000).

We will continue analysis of long-term observations and retrospective analysis of disturbance processes, including comparative analysis of these processes. In LTER5, through modeling and analysis of landscape patterns created by wildfire and alternative landscape management scenarios, we aim to improve understanding of consequences of managed landscapes outside the range of historical landscape conditions. This is an extension of our earlier modeling studies examining landscape pattern inertia (Wallin et al. 1994) and contrasts between coarse-filter, ecosystem-level and fine-filter, individual species-level management schemes (Cissel et al. 1999). We will continue studies on the scope and pace of channel change in stream networks as they interact with disturbance, stream order, large wood, and boulders (Swanson et al. 1998, Snyder 2000, Faustini 2000, Faustini & Jones in press). We will continue to measure geomorphic change in cross-sections at Andrews (Figure 1.6), comparing results to other sites with similar measurement programs (e.g., Redwood National Park and Mount St. Helens). A central theme to be explored is the cascading sequences and consequences of disturbances in which one disturbance event leads to another in time and place (Nakamura et al. 2000) (Figure 1.5).

To support the emphasis on temporal behavior in LTER5, we will enhance our analysis of temporal aspects of disturbance dynamics. We will examine lag effects revealed in long-term records of wildfire, landslides, and river channel change, and examine frequency and persistence in space to explore the basis for spatial coherence in disturbances. Some processes appear to recur frequently in certain locations because of biotic and/or topographic factors, while others may not because of the slow pace of processes required to precondition for the next event. Many disturbances exhibit path-dependent behavior (Figure 1.3). For example, it is known that high antecedent soil moisture combined with high precipitation intensity triggers landslides. We will uncover other path-dependent disturbances by examining the frequency of disturbances versus the events that initiate them. We will also examine climatic controls on disturbance by considering how climate influences establishment and early development of the post-disturbance system. There is evidence that extensive wildfires in the 1500s occurred during drier conditions, which may have slowed forest regeneration (Weisberg & Swanson in press). As this is the period of initiation of much of today’s old-growth forest in the region (e.g., Figure 1.7), it suggests that today’s late seral forests may bear an imprint of the climate conditions present at stand initiation. This has management and policy relevance in terms of guiding contemporary management of forest plantations in areas where re-creation of old-growth forest habitat is a prime objective. Dendroclimatologic research in the PNW region will be used to increase the temporal resolution of these distant events and unravel the interaction of climate, fire, and forest reestablishment (see Climate).

During the next 6 years there is a good probability that a new, significant disturbance event will occur in the Andrews Forest vicinity. In the 1990s, our study area experienced a major flood, a bark beetle outbreak, and a heavy, wet snowfall that toppled young forests. We will capitalize on new disturbance events, using our long-term records of disturbance and ecosystem function to set them in historical context and to evaluate their ecological and geomorphic consequences. Watching disturbance events unfold facilitates understanding of the details of individual events and their precursors with those of disturbance regimes. We have successfully responded to opportunities provided by recent disturbances, such as the 1986 debris flows (Lamberti et al. 1991), the 1991-1993 bark beetle outbreak (Powers et al. 1999), and the 1996 flood (Swanson et al. 1998, Faustini 2000, Johnson et al. 2000, Nakamura et al. 2000, Faustini & Jones in press); we anticipate similar success with new events.

Land use by forest cutting and roads is an integral element of Pacific Northwest forest landscapes. The future use of Federal forest lands in the region is still in dispute. We will continue involvement of LTER science and scientists in a long-term study of landscape management, based in part on the use of historic disturbance regimes (Cissel et al. 1999). This approach explores a coarse-filter, ecosystem counterpart to the fine-filter, species-specific emphasis of the conservation biology plan that currently underlies land management policy in the region. In LTER5 we will continue our work in monitoring, adapting, and modeling as part of the Blue River Landscape Plan and Study (see http://www.fsl.orst.edu/ccem). The direct real-world experience of implementing this management plan has greatly enhanced our learning about landscape processes and applications of science to broad-scale policy (Landres et al. 1999, Swanson & Greene 1999). This management experiment also sets the stage to reexamine the effects of natural disturbance processes on managed landscapes.

Ecophysiology. This Component Area identifies and quantifies the temporal behavior of interactions between plant physiological processes and other biophysical components of our system. Although our past work has also examined woody respiration (Pruyn et al. 2002, Pruyn et al. in press), the emphasis in LTER5 will be on transpirational water use and water-use efficiencies because these processes are key to understanding changes in plant production and flows of water as induced by climate variability, natural disturbance, and management. Our main measurement, sapflow rates, will be determined using Granier sensors (Granier 1985, 1987) for a range of species, forest ages, and topographic positions, allowing us to test for spatial coherence at a number of spatial scales. We hypothesize the overriding effect of climate on plant water use will lead to high spatial coherence. To interpret short-term variations, photosynthetically active radiation, vapor pressure deficit, and temperature will be used from nearby monitoring climatic stations; soil moisture will be monitored using time-domain reflectometry. To scale transpiration spatially to the watershed level, we will use a detailed process-level model (SPA, or "Soil-Plant-Atmosphere"; Williams et al. 1996, 1997). The degree of detail in this model (e.g., inclusion of hydraulic resistance of roots and stems) make it inappropriate for routine predictions of transpiration, but it is an excellent research tool that we have used successfully elsewhere in the Pacific Northwest. SPA was initially designed for uniform vegetation cover, or "single pixel" use, but it has recently been modified for use on a multiple-pixel, landscape scale. We will use existing high-spatial-resolution, remotely-sensed imagery (ADAR) to generate vegetation maps. SPA will be parameterized for representative pixel categories and validated with direct sapflow measurements. Our hope is to couple SPA with a soil hydrology model (initial efforts have resulted in the hybrid "SPLAT") to connect vegetation water use explicitly with soil water flows. Analysis of temporal lags between plant water use and stream flow on time scales from diel to seasonal will provide insights as to how well this coupling of models works.

Major disturbance or management activities on plant water use can last centuries due to altered forest structure and species composition, including rooting depth, LAI, plant density, and plant height. To predict long-term trends we will therefore couple long-term data on changes in structural components (see C & Nutrient Dynamics and Biodiversity) with short-term measures of plant transpiration. For example, common shrub and tree species differ in transpirational water use on scales of hours to years, with hardwoods having greater maximum water use per unit leaf area (hourly averages), but softwoods having relatively greater water use during the late summer, when soil moisture is low (Bond et al. unpub.). Thus, changes in the dominance of one life form to another imply changes in water use. Over interannual time scales, water use of species may not remain constant as roots penetrate to deeper soil layers and hydraulic limitations to water transport develop. Additionally, hydraulic lift by deeply-rooted trees in later-successional forests may provide greater water availability for understory species; coupled with greater light penetration in gaps of older forests, this could lead to significantly greater water use by understory species in late-successional forests (see Hydrology).

In addition to understanding the role of individual species, we also wish to understand how species mixtures affect transpirational water use (per unit ground area) from hourly to inter-annual temporal scales. We hypothesize that mixed-species plots have greater annual water use than do monocultures due to phenological differences in leaf area, root exploration, and growth. On the other hand, the greater structural heterogeneity of species mixtures may result in greater canopy interception, reducing water inputs and therefore reducing total annual transpirational water use. We will test whether water use of species mixtures exhibits emergent behaviors that deviate from an additive model of species interactions by using experimental plots established in 1985 that contain varying mixtures of Douglas-fir and red alder.

Variations in water-use efficiency are inversely correlated with variations in wood production; based on this relationship, we will interpret impacts of climate change on plant production from carbon isotope discrimination on the catchment scale. This provides a mechanistic explanation of tree growth for longer-term studies. As one method of calculating water-use efficiency (carbon assimilation/water consumption), estimates of annual diameter increment of trees will be made with dendrometer bands on the trees with sapflow sensors. This measure has a direct link with dendroclimatological (Climate) and annual plant production (Carbon and Nutrient Dynamics) studies, which calculate long-term growth from tree cores or diameter measures, respectively. We will also estimate water-use efficiency using carbon isotope ratios (Farquhar et al. 1989) in annual rings of tree cores, testing the hypothesis that wood production and water use efficiency are inversely related. In a separately-funded NSF study, Bond, Unsworth and Mix will be developing procedures to analyze catchment-scale isotope discrimination using Keeling Plots (e.g., Flanagan & Ehleringer 1989) of air sampled during night-time cold-air drainage. By combining understanding of relationships between water-use efficiency and productivity on the individual plant level with climate and carbon isotope discrimination on the catchment level, we hope to develop a better understanding of relationships between climate and plant productivity.

Carbon and Nutrient Dynamics. The overall objective of this Component Area is to understand the seasonal to successional dynamics of C, N, and other nutrients in forest ecosystems of the Pacific Northwest. The ultimate aim for LTER5 is to produce data, concepts, and simulation models that can be used to examine the temporal behavior of nutrient cycling and help understand the behavior of small watersheds (Figure 1.8, 2.3). The work is divided into: (1) field studies on plant production and stores; (2) field studies related to detritus decomposition, stores, and dynamics; (3) field studies related to soil stores and dynamics with an emphasis on the formation of stable organic matter, as well as the mobilization of C and N; and (4) simulation modeling at multiple scales of temporal, spatial, and process resolution. Streamwater chemistry, a key variable in understanding broad-scale C and nutrient dynamics, is measured as part of the Stream-Forest Interactions Component Area. This section draws on the Vegetation Succession Component Area of LTER4. While much of this past work continues, we present these efforts here to emphasize the ecosystem context (see Biodiversity for vegetation measurements placed in a population and community context).

Plant Production and Stores. In LTER5, we will use a combination of chronosequence and long-term observations to construct an empirical model of C and nutrient accumulation of Pacfic Northwest Douglas-fir/western hemlock stands from time of stand-regenerating disturbance through the oldest stand ages represented in the region (~1000 yr). This work draws upon our extensive permanent plot system (Acker et al. 1998a). We will expand on the research of Acker et al. (2002), who examined biomass accumulation over a chronosequence. We will complete our estimates of above-ground production in these watersheds by measuring fine litterfall. Given the expense of adding below-ground estimates of NPP, we will defer this activity until we can purchase the requisite equipment. To test the generality of trends observed by Acker et al. (2002), we will add additional age-classes and levels of site productivity to our stand-development chronosequence, drawing on data from a total of 70 stands in Andrews and elsewhere in the region (Figure 1.7, 2.2). We will also use a chronosequence approach to look at accumulations of N and other nutrients in vegetation over succession using nutrient concentration and biomass data from young-, mature-, and old-growth forests in watersheds. Nutrient concentration will be measured for each plant component (stem, branch, root, foliage, new foliage) in each watershed examined in the small watershed synthesis area using C/N analyzer and inductively coupled plasma analysis. As not all our small watersheds with nutrient export data currently have plant biomass estimates, we will expand our standard vegetation measurement program to include these sites. Our new estimates of nutrient stores will be compared to WS10 before it was harvested (Sollins et al. 1980), to help us understand nutrient dynamics in small watersheds over successional time.

To increase our understanding of annual variation in NPP, we will core trees in permanent plots on the Andrews including those in small watersheds (Figure 2.2), and eventually in many of our permanent plots located in the rest of the PNW. Year-to-year variation in tree NPP can be estimated by allocating current measures of long-term NPP (averaged over 5-10 yr) according to variation in tree-ring width (Fraser 2001). Knowledge of temporal variability in NPP will help us to detect directional changes, above and beyond natural variability caused by climate change (Knapp & Smith 2001). We will evaluate annual variation in tree NPP by species, as well as tree and stand age, and look for spatial coherence. The causes of variation will be explored using data from the Climate and Hydrology Component Areas, with an emphasis on late spring/early summer precipitation, which appears to be a key variable (Fraser 2001). We will seek a more mechanistic explanation of the observed variation by linking our results to those found in the Ecophysiology Component Area (sampling in the same locations and time periods).

Detritus Decomposition, Stores, and Dynamics. We will continue to maintain experiments initiated in the past on long-term patterns of log, branch, stump, leaf, and root decomposition—one of the world's most comprehensive examinations of long-term detritus dynamics. Our past emphasis has been on C loss; we will build on that strength by examining the dynamics of N and other key nutrients. This information will allow us to incorporate N dynamics into our existing C models for specific types of detritus (as opposed to the common practice of assuming all forms of detritus have similar dynamics) and will help to predict long-term changes in C and N terrestrial stores within the small watersheds. To estimate fluxes, we will combine estimates of decomposition and nutrient accumulation/release rates with new inventories of detritus stores in most of the small watersheds. Measurements of fine and coarse woody detritus, as well as forest floor, will be made in watersheds inventoried for plants (Harmon et al. 1999).

The majority of our decomposition experiments focus on long-term dynamics (i.e., years to centuries). We will analyze year-to-year variation in these rates using existing data. To understand the full range of scales required for our proposed examination of temporal behavior, we will initiate work on hourly, daily, and seasonal scales. Our general approach will be to measure respiration of various substrates (litter, fine and coarse wood, soil) in the field using a combination of portable and continuous infrared gas analyzers (we will seek funding for the latter item). Air temperature as well as substrate temperature, moisture, and mass will be recorded and used to explain short-term variations in respiration of these pools. Past work at the Andrews and elsewhere in the region suggests that the moisture dynamics of fine and coarse litter are sufficiently asynchronous that temporal variability for detritus as a whole is modulated (Greenland et al. in prep). Measurement of short-term dynamics will also allow fuller examination of decomposition path dependencies caused by the sequence of precipitation input relative to temperature variation (Irvine & Law 2000).

Soil Stores and Dynamics. In 1997 Lajtha and Sollins installed a major, long-term experiment on controls of soil organic matter (SOM) formation and stabilization using USDA funding. This is the DIRT (Detrital Input Removal and Trenching) experiment, which is part of a larger network of similar experiments funded in part via LTER supplements. Treatments that remove litter input, double litter input, trench to remove fine root input, add woody detritus, and remove the A horizon were installed. Currently, dissolved organic C and respiration are measured. The DIRT manipulations allow us to examine the complete detritus-soil organic matter continuum at Andrews and to analyze which fractions of SOM are most sensitive to changes in detritus chemistry and quantity over decadal time scales. In LTER4 we also completed a major effort to estimate C and N stores to 1 m depth in old-growth forests spanning a range of site productivity and elevation (Remillard 1999, Smithwick in press). We will add to this work by similarly sampling soils in younger-aged forests, concentrating efforts in small watersheds with carbon and nutrient export sampling. Given the large spatial variation in soil, it is unlikely that we will be able to directly detect changes in stores by only comparing among forest ages (Davidson et al. 1995, Schlesinger 1990, Johnson & Curtis 2001, Schlesinger & Lichter 2001). This is also unlikely even for the DIRT treatments. Changes in SOM and DOC constituent fractions for the chronosequence and DIRT treatments, however, are more likely to be detected. Soil collected as part of these efforts will be analyzed using several laboratory fractionation schemes (e.g., light fraction vs. heavy fraction-SOM [Strickland & Sollins 1987] and pyrophosphate extraction) and ^{13}C-NMR (Harmon & Lajtha 1999). We will begin an exploration of how soil properties might control the low release of N following timber harvest (Vanderbilt et al. in press). The C/N ratio of Andrews soils (21) is on the threshold (22-24) of net nitrification and potential for NO_3 leaching (McNulty et al. 1991, Lovett & Reuth 1999, Goodale & Aber 2001, Olllinger et al. 2002). In contrast, the C/N ratio of the Andrews forest floor (38) is much higher than those losing inorganic N (less than 10) (Wright 1995, Dise & Wright 1995, Gunderson et al. 1998).

Significant amounts of DOC and DON may be transported into and through the soil profile in moist forested ecosystems, and stabilization of these forms of C and N in the soil provides important insights into soil dynamics. Significant immobilization of DOC and DON can occur in A-horizons (Qualls et al. 2000) and, given the amorphous aluminosilicates in the Andisols at Andrews, we also expect this to occur here. We will therefore measure changes in total DOC as well as hydrophobic and hydrophilic fractions of DOC as it enters and leaves the soil profile in samples collected using lysimeters. Coupled with information on stores, this will allow us to make preliminary estimates of dissolved fluxes of C and N, key variables in understanding small watershed behavior. SOM respiration losses can also be compared to net DOC deposition in the soil, providing a preliminary estimate of whether soil C stores are increasing, decreasing, or remaining stable for various forest ages and locations. Respiration fluxes from DIRT treatments, small watersheds of different forest ages, and woody detritus will be measured using infrared gas analyzers to develop an understanding of environmental versus substrate quality controls of respiration. Finally, we will continue to use DIRT plots to test a method for partitioning below-ground autotrophic and heterotrophic respiration by analyzing ^{18}O and ^{13}C from soil CO_2 efflux.

Simulation Modeling. Simulation modeling has been a key aspect of past work in carbon and nutrient dynamics. Our approach has been to develop a multiple-scale analysis to synthesize information and learn about system behavior. Models now exist to examine dynamics and controls at the level of individual logs (Hicks 2000) and roots (Chen 1999), ecosystems or stands (Harmon and Marks in press), landscapes (Cohen et al. 1996, Wallin et al. 1996), and regions (Smithwick 2002). Although our past emphasis has been on C dynamics, we have also developed models of processes such as asymbiotic N fixation in coarse wood (Hicks 2000). In LTER5, we will fully integrate the N and C cycles. This is timely as our field studies are producing new insights into C and N dynamics in a wide range of substrates and soil. Moreover, we are developing simulation models of N fixation for symbiotic and asymbiotic pathways. Data on C and N dynamics, coupled with N accumulation rates of vegetation, will enhance our ability to develop new coupled C and N cycle models. These models will be compared to observed dynamics in the small watersheds for a preliminary corroboration of predicted behaviors.

Biodiversity. The overall objective of this Component Area is to examine the influence of climate, land use change, and disturbance on the biological diversity of forests and streams. This will be achieved by examining populations and communities of organisms, and how these vary seasonally, annually, and over successional time. In LTER4, we used Lepidoptera and Coleoptera as the major biodiversity indicators, although plant-related aspects of diversity were considered under the Vegetation Succession Component Area. In LTER5, we will develop a more integrated view of this ecological service by examining multiple trophic levels at the same place and time. Given the importance of competition, trophic interactions, and habitat structure in shaping biotic communities, we feel this integration should lead to greater mechanistic understanding of controls on biodiversity than our previous research structure. In addition to ongoing studies of vegetation and insects, we will initiate comparable studies of birds, small mammals, and fungi. (We will seek funding to collect data for these additional taxa.) We will also designate a special area within the Andrews as an “All-Taxa Study Area,” with the aim of establishing as complete an understanding as possible of species presence, abundance, and trophic relationships.

The interaction between the forest canopy and understory plant diversity and abundance has been a long-term interest at Andrews. Long-term data from permanent plots from WS01 and

WS03 (Figures 2.2, 2.3) have been used to examine the roles of initial composition, disturbance intensity, and species' life histories in shaping early successional changes in plant diversity (Halpern 1988, Halpern 1989, Halpern & Franklin 1990, Halpern & Spies 1995). Subsequent field experiments have been used to study the importance of species' interactions during this time (Halpern et al. 1997). During LTER5 we will continue to use these plots (with measurements now extending to 40 yr), to explore spatial and temporal variability in the decline of understory communities during stand closure (~25-40 yr). Current models of understory decline are based on chronosequence and retrospective analyses. We are aware of no studies in the region that use repeated measurements of understory communities on permanent plots. We will address: (1) the variation in rates and patterns of understory decline with respect to loss of biomass and species turnover; (2) the stand characteristics (e.g., canopy cover, tree density or basal area, and overstory composition) correlated most strongly with rates and patterns of understory decline; and (3) the degree to which temporal patterns are mediated by local environment (aspect, topographic position, site productivity), disturbance history (stand-initiating and subsequent disturbances), or initial composition.

We will also continue our studies of insect biodiversity and abundance. Arthropods comprise the majority of species at Andrews (86%) (Parsons et al. 1991). As in LTER4 the emphasis will be on Lepidoptera, as they are diverse (12% of all taxa), major grazers (Hammond and Miller 1998), important prey, and are responsive to changes in habitat and climate. In LTER5, we will sample from three sites representing the range of climates and forest ages present on the Andrews: (1) low elevation, 400 m – WS02; (2) mid elevation, 1000 m – Mack Creek; and (3) high elevation, 1400 m – Frissell Ridge. Furthermore, each site will be sampled for a comparison of young (25-30 yr) and old-growth forest (>150 yr) habitats. These sites will overlap with the proposed "All-Taxa Study Area," and small watershed sampling will be used to examine temporal behaviors of understory vegetation. Moths at each site will be sampled on one night, every other week, from May-September, by deploying UV blacklights. These data will be analyzed to determine consistency of species abundance and synchrony in population trends at and among sites. Weekly temperature and rainfall data will be correlated with the seasonal and annual abundance of species.

Considerable attention has been devoted to the spatial distributions and successional dynamics of forest organisms in the Pacific Northwest (e.g., Ruggiero et al. 1991, Halpern & Spies 1995). However, we have limited understanding of the patterns and correlates of biotic variability at finer temporal scales. For example, it is often assumed that forest understory communities are fairly stable in old-growth forests, but that populations of ectomycorrhizal fungi, insects, and small mammals exhibit high inter-annual variation (Luoma 1991, Luoma et al. 1991, Smith et al. 2002). For most organisms, however, we have limited empirical data to quantify these patterns and there is only a cursory understanding of the degree to which temporal variability is shaped by changes in climate, local environment, and/or biotic interactions. By the middle of LTER5 we will begin to explore the patterns and potential mechanisms of temporal variability of plants and lepidoterans. Ideally we will add other taxonomic groups of fundamental importance (birds, small mammals, and fungi) to this analysis. We intend to seek additional funding to undertake this work. Our objectives each address the underlying theme of temporal behavior in LTER5: (1) quantify the magnitude, timing, and direction of temporal variability in taxa representing different trophic levels; (2) identify for each group the characteristics (e.g., population density, diversity, abundance, morphological or reproductive traits, life histories) that show the greatest sensitivity to annual changes in climate; (3) document the spatial coherence within and among trophic levels; and (4) quantify the extent to which temporal variation correlates with environmental stress (associated with elevation) and forest structure (expressed through differences in microclimatic amelioration in young and old forest).

To explore questions of temporal variability, we will establish replicate sampling locations in low and high elevation sites in both young (35 yr) and old forests (>150 yr). Each elevation-by-forest age “treatment” will be sampled with three spatially distinct plots (replicates), yielding a total of 12 “experimental units.” Although it is desirable to conduct our work in gauged watersheds to increase overlap with other studies, this will only be possible for the low elevation zone (WS01-young forest; WS02-old forest). Sampling of understory plants, lepidopterans, and other taxa that can be added will be conducted at each location, using the sampling schemes (e.g., plot sizes and layout) and frequencies that are most appropriate for each trophic group. Additional measurements of resource availability (light and soil moisture) and seasonal or annual trends in precipitation and temperature will be taken in concert with biological measurements or extracted from meteorological records.

We have made great strides toward understanding the distribution and abundance of many taxa within the Andrews landscape. However, to increase understanding of biological diversity and trophic interactions at a smaller spatial extent, we have designated the old-growth watershed at Mack Creek as our “All-Taxa Study Area.” A wealth of information for aquatic and terrestrial species exists for this location because it was a focal point for IBP, River Continuum, LINX1, and riparian studies. Mack Creek (Fig 2.2, 2.3) is large enough (i.e., third-order) that the full range of trophic levels is present, whereas smaller streams lack many aquatic vertebrates. The first synthesis will be to compile all existing biodiversity records for this location. We will then examine under-sampled taxa and those suspected of changing. New investigators examining specific taxa, communities, and other biodiversity-related questions will be encouraged to include Mack Creek as a study site (this has already happened to some degree). We will use natural abundance of ^{13}C and ^{15}N to begin to examine trophic relationships among all taxa; an initial study will sample multiple taxa representing different trophic levels.

Stream-Forest Interactions. The overall objective of this component is to explore spatial and temporal patterns and processes that shape aquatic ecosystems. We will identify critical links between forests and streams, and examine the influences of natural and anthropogenic disturbances on stream communities and processes including examination of in-stream biogeochemical and biophysical processes, and vertebrate population dynamics. In LTER5, we will continue these long-term studies, explore temporal trends at multiple scales, and use experiments to examine the causes and consequences of temporal variability for nutrients, in-stream wood, and fish populations.

We will continue measurement of stream water chemistry at 7 watersheds (i.e., WS02, WS06-WS10, and Mack Creek) and add sampling water chemistry in WS01, the watershed with our longest record of vegetation succession. Stream flow is proportionally sampled over a 3-week interval, then analyzed for total N, NO_3, NH_4, cations, Cl, SO_4, Si, pH, and conductivity. In LTER5 we will build upon early, limited sampling of DOC (Dahm 1980, Tate & Meyer 1983) and begin measuring DOC in stream water at regular 3-week intervals. To put the watersheds with proportional sampling in context, we will continue periodic synoptic sampling at 30 sites representing the full range of stream orders in the Andrews landscape. To supplement our long-term proportional sampling aimed at nutrient budgets, we will intensively sample during selected storm events, with an emphasis on DOC, DON, NO_3, and NH_4. Our goal is to examine combinations of seasonal variations of soil and stream retention, soil moisture, and temperature at a fine temporal scale to understand controls of path-dependent and hysteresis temporal behaviors influencing C and N exports (Figure 1.9).

Nutrient concentrations in streams have high seasonal variability (Vanderbilt et al. in press), but the mechanisms controlling these fluctuations have not been well established. Concentrations of nutrients could vary in response to several factors such as increased inputs from soils and vegetation or changes in in-stream biotic uptake. The relative impacts of physical versus biological mechanisms in influencing nutrient uptake versus export are not well known and are difficult to separate through simple observations. Throughout the year, changes in physical factors, such as discharge, are accompanied by changes in biomass of primary producers and biofilms. Evidence exists for both mechanisms at Andrews. Previous research at Andrews has examined nutrient transport and uptake through release of ^{15}N tracer (LINX, Lotic Intersite Nitrogen Experiment, Peterson et al. 2001) and of nutrients and solutes for shorter times (e.g., fertilization experiment, EPA spiraling releases on 8 stream reaches), and has documented that increased hydraulic retention decreases the spiraling length of nutrients. LINX experiments in Mack Creek found that uptake of labeled N by primary producers, especially bryophytes, and by biofilms on logs and rocks retained up to half of the N entering as NH_4. We will experimentally examine physical versus biological influences on variability of streamwater nutrient concentrations among seasons. We will test whether increases in nutrient concentrations during fall result from increased flows or decreased biological activity in streams. Background spiraling lengths will be quantified as a function of flow rates and discharge across seasons. Leaves will be introduced at baseflow and spiraling examined before and after microbial colonization. Leaf dams should increase rates of hydraulic retention and decrease spiraling lengths. The presence of microbial biofilms on stream-conditioned leaves should further decrease spiraling distances in comparison to uncolonized leaves. We will quantify maximum potential uptake of nutrients by primary producers based on spiraling distances before and after primary producers have been physically or chemically removed from the bedrock in an open, unshaded channel.

We will use the long-term database on annual wood abundance, input, and movement in Mack Creek and our recently developed Wood Model (Meleason 2001, Meleason et al. in review) to determine if wood abundance exhibits modulation despite major disturbance such as floods. Spatial coherence in wood dynamics across sites will be analyzed using a newly established network of 18 study reaches with marked logs. To examine the historic and temporal dynamics of riparian influences on wood loading, we will model in-stream wood dynamics using historic vegetation cover, from 1850 to the present. Influences of land use changes on in-stream densities and transport linkages among reaches will be explored to examine the degree to which interaction within-stream networks alter temporal patterns of wood in streams.

Based on a 20-yr record of annual observations for 5 reaches in 2 streams, the temporal dynamics of fish populations have high variability at Andrews (Figure 1.6). This population-level variability has implications for the resistance and resilience of these ecosystems. We plan to examine the temporal correlation of densities of these aquatic predators among streams with different riparian vegetation communities and disturbance histories. Synchronous fluctuations among sites would suggest that environmental or exogenous influences drive population variation. Lack of coherence in population densities among sites could result from site-specific influences, such as local disturbance and land use history or endogenous community dynamics. To distinguish between these two factors, we will evaluate temporal lags between driving variables and population responses will be evaluated. We will experimentally examine population responses to annually standardizing trout densities in specific study reaches by determining size-specific densities the following year. By comparing manipulated reaches to those with naturally varying populations, we will be able to determine the importance of exogenous versus endogenous controls. Because we have sampled annually, some of the variation we have observed could be due to seasonal variations associated with fish movements. We will therefore sample seasonally on several reaches to determine how this shorter time variation is influencing our annual measures.

2.3 Synthesis Areas. This section describes the two synthesis areas, temporal behavior and small watersheds, that integrate across the 7 Component Areas of LTER5. These two activities are complementary, as many processes within watersheds can be analyzed for temporal behavior. Moreover, lessons learned from our analysis of temporal behavior outside of small watersheds can be applied within them.

Temporal Behavior. An overall objective of synthesis in LTER5 is to examine rules that govern aspects of temporal behavior (Figure 2.1, Table 2.1). These range in temporal extent from hours to millennia. Some of these behaviors have already been observed for some parts of our system. We will systematically investigate additional behaviors to determine if they are general or specific, aided by measurement of multiple processes across a similar range of temporal scales. Moreover, we seek to understand the causes and consequences of temporal behaviors and whether they are governed by general rules. Analysis of temporal behavior helps to address our Central Question by quantifying the relative resistance and resilience of key ecosystem services to drivers of change, thus informing us of how to better scale and model results, to quantify uncertainty of prediction, and to identify behaviors relevant to managing the system. This knowledge can also be applied during the synthesis of processes within small watersheds. We focus our synthesis on 6 archetypal classes of behavior (Figure 2.1, Table 2.1), although we realize that various combinations of these and other behaviors can also exist. Each behavior is the result of a **driver** of change (e.g., climate) and a **response** to change (e.g., biodiversity). We provide specific examples of each behavior, show how we will test for the behavior, and outline specific applications of this knowledge.

The products of this synthesis activity will be three-fold. First, we will produce a series of journal articles describing the behavior of parts of the system and the mechanisms responsible for these behaviors. Second, we will develop a review article that systematically examines the commonality of mechanisms and generality of behavior examined. Finally, we will begin a comparative examination of temporal behavior among sites representing different ecosystem types, building on the pioneering work of North Temperate Lakes (Magnuson et al. 1991, Baines et al. 2000, Benson et al. 2000, Webster et al. 2000).

Modulation of Driver Signals. Ecosystem responses may modulate (i.e., dampen) or amplify driver signals. With **modulation** the system expresses high resistance; with amplification the opposite occurs (Tilman 1996). We hypothesize that synchronicity of the relevant parts of the system controls this behavior. For example, despite seasonal changes in temperature and moisture, decomposition-related fluxes are probably modulated relative to climate because the specific pools (i.e., soil, forest floor, fine-, and coarse woody debris) are drying and wetting at very different rates. Differences in heat exchange among reach types may explain modulation of stream temperatures (Figure 2.4). Modulation also appears to occur at longer temporal scales at our site. The minor release of N after timber harvest (Vanderbilt et al. in press) may be a form of modulation (Figure 1.8). Modulation may increase as the turnover rate of the system decreases. Low rates of tree mortality cause very gradual replacement of species over centuries, leading to dominance of single species and their characteristics (e.g., water-use, production, decomposition, associated organisms) for 500+ yr. To detect modulation we will express the variation of driver signal and the process of interest in relative terms (Magnuson et al. 1991); a ratio of responder to driver variation less than unity indicates modulation. For responses to climate, variation from the mean will be used; for disturbance, the degree of structural or process alteration (e.g., reduction in uptake) will be used. If these variability ratios differ significantly from unity we will identify the general rule and specific mechanisms controlling the behavior. Understanding these phenomena will be helpful in predicting which parts of the system are most responsive to change and the degree to which management practices are enhancing or reducing system stability.

Temporal Lags. In ecological systems it is not unusual for responses to lag behind drivers (Magnuson 1990). Multiple phenomena cause **temporal lags**, but a general mechanism involves the movement of materials or information from one part of the system to another. Lags may occur at multiple time scales for a process such as hydrologic flow (Figure 1.4), and provide inferences about the nature of storage versus transport. In early summer we have observed a phase shift between sapflow and discharge at WS01 (dominated by 35 yr-old forest), with minimum daily flows occurring 5.5 hours after the sapflow peak (Bond et al. in press). This is caused by the slow flow of water through the soil relative to the stream channel. The overall residence time distribution of flows in 1st-order channels at Andrews indicates multiple flow pathways with different rates of water and nutrient transport (Haggerty et al. in review). We will examine lags in response to our three drivers of change, with emphasis on climatic variation. Understanding temporal lags is important to assessing how and when the system is responding (e.g., measuring at the wrong time can miss the response) and will also improve our ability to more realistically simulate responses.

Spatial Coherence. This behavior considers the degree to which a process occurring in different places is spatially coherent. **Spatial coherence** has been a key focus of aquatic research in the LTER Network (Benson et al. 2000, Kling et al. 2000, Sorrano et al. 1999, Webster et al. 2000). Our analysis will examine both the terrestrial and aquatic realms. We hypothesize that as processes become more spatially decoupled, the degree of spatial coherence decreases and system resistance increases. At North Temperate Lakes, the degree of spatial coherence decreases as one progresses from physical to chemical to biological phenomena (Magnuson et al. 1991, Baines 2000, Benson et al. 2000, Webster et al. 2000). We see examples to support this progression such as the high correlation of daily peak flows among streams and lower correlations for annual trout population numbers (Figure 1.6). Our LTER4 findings suggest that processes within and among network systems should be more coherent than those within and between patchwork systems. Spatial coherence of behaviors may also reflect the spatial scale and coherence of driver variables. We suspect that not all areas will respond similarly to global climate change, decreasing spatial coherence. Spatial coherence will be tested by correlating the temporal variability among locations and spatial scales (Baines et al. 2000, Benson et al. 2000). Spatial coherence has important consequences for landscape scaling; with high spatial correlation of a process, we would model the various locations to be synchronous with each other and vice versa. As temporal variation has implications for susceptibility to disturbance (Scheffer et al. 2001), there is potential to shift from one stable state to another. Finally, knowledge of spatial coherence in the natural system will help us to evaluate whether management practices are influencing system responses at the landscape scale. For example, cutting of timber in the transient snow zone may have increased the frequency of large floods in the Cascade landscape (Harr 1986, Jones & Perkins in prep).

Path Dependence. The particular order of events can strongly influence system behavior. This behavior, known as **path dependence**, represents a temporal analogue of a tenet of landscape ecology, that “spatial pattern matters.” The temporal analogue involves the temporal proximity and sequencing of variations in a single or multiple drivers. Evidence for temporal path dependence has been found for many processes at a number of temporal scales: the response of soil respiration to seasonal changes in temperature and moisture (Irvine & Law 2000), the hysteresis behavior of N and C export in streams relative to precipitation inputs and phenology (Figure 1.9), the outbreak of Douglas-fir bark beetles dependent on windthrow followed by drought and not vice versa (Powers et al. 1999), and emergent behaviors resulting from rain on snow events (Harr 1986) (Figure 1.3). Several strategies will be employed to examine path dependence. By investigating different sequences of events either via direct observation, historical reconstruction, or experimentation (in which particular sequences are introduced), models capable of producing this emergent behavior can be developed. Simulations with different orders of events can be compared to assess the magnitude of emergent behaviors. If emergent behaviors develop, there should be a significant deviation between sequences. Path dependencies imply that the system may be far more variable than our previous work has acknowledged. This variation may make the system more susceptible to change when another driver of change pushes the system. Understanding the degree of path dependence also has major implications for temporal scaling of our short-term results and predicting the frequency of major disturbances. If path dependence is not evident in a process, averages of driving variables can predict responses; otherwise fine-scale variation in driving variables must be included for an accurate prediction. Path dependence would also imply that knowledge of a single system driver may not be sufficient to predict its effect. In the case of disturbances, the degree of path dependence motivates the importance of understanding the temporal and spatial correlation of events that influence the disturbance process of interest.

Hysteresis. This temporal behavior involves lags between the driving and response variables. **Hysteresis** implies the system response may depend on the direction of change in the driver; that is, the value of the driver may not be sufficient to predict the response. This is similar to path-dependent behavior, although hysteresis involves temporal pattern that is frequently repeated (i.e., a hysteresis loop). We recognize that hysteresis occurs when the rate of removal of a pool temporarily exceeds its rate of replacement. Hence the system may no longer able to respond to the driver until replacement of a pool or population has occurred. Hysteresis phenomena occur in both the physical and biological parts of ecosystems (see Small Watersheds). For example, DOC and DON concentrations as well as C:N ratios exhibited strong hysteresis at storm event and seasonal time scales (Figure 1.9), apparently depending on flushing or removal of DOC and DON from soils. We will test for additional hysteresis behavior in other processes, examining controlling mechanisms and ways to incorporate these into our simulation models. Processes in small watersheds are of particular interest, and hysteresis may reveal details of the inner workings of this landscape unit. Understanding hysteresis will allow us to predict if responses to drivers will be modulated and whether the responses will be symmetrical relative to the drivers. It will also improve our modeling efforts because if hysteresis is present, simple single-level response functions may introduce errors.

Alternative System States. Our final behavior of interest involves the presence (or absence) of **alternative system states** in our ecosystem. Compared to other ecosystems

(Scheffer et al. 2001, VanDeKappell et al. 2001), Cascade forests are relatively resilient, typically returning to or at least approaching the same state despite the occurrence of major disturbances, such as fire, floods, and logging (Figure 2.5, path A). Notable exceptions include replacement of forest by meadows after wildfire in high elevation systems, or by shrubfield after timber harvest (Perry et al. 1989, Perry 1994, Halpern 2002). Other alternative states may include dominance by mid-seral tree species in intensively managed plantations through management practices that truncate the early and later stages of succession. More recently, increases in harvest rotation length and reductions in the extent of harvest may be eliminating the early and mid-seral stages in these forests. Changes in climate and management practices may increase the likelihood of alternative states at Andrews. We hypothesize that alternative stable states require the following events and conditions. First, a disturbance disrupts the system, triggering system reorganization (sensu Holling 2001). Second, processes favor the formation of one state over another. While management practices are intended to favor forests, there are sufficient examples of regeneration failure to indicate other processes are also influential (Perry et al. 1998). Finally, once one state is favored over another, other processes (often biologic, e.g. replacement of mycorrhizal fungi by bacteria in soil) maintains the system. In LTER5, we will seek additional examples of alternative stable states and examine the mechanisms that maintain them. Of particular interest are the biological mechanisms (e.g., soil biota and competition) that maintain non-forested systems in the Andrews and nearby landscape. Alternative states have major consequences for understanding the resilience of Pacific Northwest ecosystems; if alternative stable states are uncommon and their probability cannot be increased, we can expect the system to behave similarly in the future.

Small Watershed Synthesis Area. In LTER5 we will build upon synthesis activities begun in LTER4, focusing on small watersheds as a natural arena to integrate our studies of 7 Component Areas. Our ultimate goal in this integration is to create a spatially 3-dimensional (including subsurface) understanding of the temporal dynamics of the 3 states of matter involved in biogeochemical and hydrologic cycles (BGC-3x3). Unlike our general analysis of temporal behavior, small watershed integration requires simultaneous measurements of multiple processes in the same geographic unit (i.e., small watersheds). This represents one reason to unify the sampling times and spatial overlap of many component measures. While large enough to apply the lessons learned about spatial scaling at the landscape scale, small watersheds are small enough to directly measure responses. This will help us corroborate and test process-based models, a major activity in our proposed synthesis. Watersheds are also important landscape units defined by water- and to some extent air-flow. Small watersheds (i.e., headwater basins with 1st-order channels) represent over 80% of the total area of the Andrews. Therefore increased understanding of how small watersheds control climate, stream flow, nutrient flux, and C sequestration will allow better scaling of results to the landscape level. and ultimately identify the minimum patch size needed to represent the larger ecosystem.

We are in an ideal position to begin this integration. Long-term records of stream flow, climate, stream chemistry, and vegetation exist in many of the Andrews small watersheds (Figure 2.3, Table 2.2) and will greatly aid in testing and developing new conceptual and simulation models. After the last small watershed integration at the Andrews (Grier & Logan 1977, Sollins et al. 1980), much of the Andrews effort was dedicated to improving our understanding of the key processes controlling ecosystem behavior. For example, quantifying tree mortality and decomposition of woody detritus were major areas of early LTER work. Although we have not answered all questions raised in the pioneering IBP efforts, the 22-yr research history of LTER provides a wealth of information on many processes. Most recently in LTER4, we began to consider the system in new ways, including how lateral (i.e., X and Y) spatial arrangements and different types of landscape elements (networks versus patchworks) control the system. New studies on airsheds by Bond, Unsworth, and Mix and subsurface flow paths by Haggerty, McDonnell, and Wondzell and are now considering how the vertical (i.e., Z) dimension controls system behaviors. Thanks in part to the LTER program, we have been able to assemble a very skilled, multidisciplinary team with expertise in the key elements required for integration and modeling. Thus, we will be able to approach small watershed studies in ways that have not been possible at Andrews until recently.

Our small watershed integration parallels aspects of work at other sites, such as Coweeta and Hubbard Brook, where small watersheds have traditionally been a major focus (Likens et al. 1977, Likens & Bormann 1995, Swank & Vose 1997, Hornbeck et al. 1997a, b, Martin et al. 2000, Qualls et al. 2000, Swank et al. 2001). Because the Andrews currently has relatively low N inputs, we can test concepts developed at sites with high N inputs. We will also seek to incorporate important lessons from previous studies examining spatial aspects (e.g., Beven 1993, Beven 1996). However, our proposed integration will differ from previous work by simultaneously considering multiple fluxes (water, C, and N) in multiple states of matter (gaseous, liquid or dissolved, and solid), in all three spatial dimensions (X, Y, Z). Work at the interfaces between microclimatology, hydrology, plant ecophysiology, and biogeochemistry will stengthen this potentially novel contribution to ecology.

To achieve the proposed integration we will use multiple, complementary methods. **Retrospective analyses** will examine existing data sets to develop concepts that explain how processes interact, and why our watersheds differ from each other and those at other sites. The **new measurements** and **experiments** proposed in LTER5 will help clarify the remaining major questions for key processes. **Simulation models** will be used to synthesize information and to test the consequences of our concepts and measurements. By taking advantage of all four approaches, our understanding of small watershed behavior will increase rapidly during LTER5. Data from all 8 small watersheds (Table 2.2) can be used in retrospective analyses early in LTER5. However, new measures, experiments, and modeling studies will be concentrated in WS01, WS02, and WS10—watersheds dominated by young- or old-growth forests, facilitating contrasts among early and late stages of succession.

We propose 6 retrospective analyses involving small watersheds (Figure 1.8). We will examine changes in water yield as forests age and explore mechanisms causing this trend. Analysis of the lags between sapflow and stream flow and their causes will lead to greater understanding of how subsurface flows connect these parts of the system. Examination of past hydrologic responses of small watersheds will yield insights into influences of soil depth, riparian zone volume, and vegetation cover. For example, some watersheds at Andrews have had their riparian zone effectively removed by debris flows; comparison to undisturbed watersheds will help quantify the riparian contribution to water and nutrient export. Reconstructions of annual variations in tree NPP will be compared to variations in stream flow and nutrient export from small watersheds to determine if patterns of nutrient uptake by vegetation are reflected in watershed output. We will explore reasons why N export after disturbance is low relative to changes observed in other harvested watersheds (e.g., Dahlgren & Discoll 1994, Hornbeck et al. 1997 a, b, Swank et al. 2001) and whether inclusion of SOM and woody detritus accumulations over succession could modify the classic model of Vitousek & Reiners (1975).

Key measurements and experiments will be conducted during LTER5 to aid integration. New measures of vegetation, detrital stores of C and N, as well as SOM fractions will place bounds on the role of SOM in regulating watershed export of N after disturbance (McNulty et al. 1991, Dise & Wright 1995, Wright et al. 1995, Gundersen et al. 1998, Lovett & Reuth 1999, Goodale & Aber 2001, Ollinger et al. 2002). Preliminary estimates of DOC and DON production and export from surface soil throughout the watersheds (i.e., riparian versus upland sites) will quantify their seasonal availability for transport. Coupling these data with process studies of residence time distributions in subsurface flow paths will allow us to predict C and N delivery to stream channels. Event-based sampling of stream chemistry will provide additional insights into how small watersheds are internally "wired" and how the dominant processes shift over the year. Experiments on nutrient spiraling in streams will quantify how hydraulic versus biological retention modify C and N exports from watersheds.

Modeling will be an important tool in understanding watershed behavior. To maximize the heuristic value of modeling, we will use a bottom-up approach to complement the traditional top-down approach (Hogeweg 1988, Green 1993, 2000). The bottom-up approach allows emergent behaviors (i.e., ones exceeding the additive sum of interacting processes) to occur (Michener et al. 2001). The top-down approach is useful in helping to define problems, but we do not want to limit model behavior *a priori* as it reduces heuristic value. A bottom-up approach will also help identify uncertainties that may be reduced through further experiments and measurements. Several steps will be used to integrate field studies and models. We will start with models of each major process (e.g., SPA for transpiration, see Ecophysiology) and use them to explore scaling in time and space. We will examine if new behaviors emerge as a result of this scaling, and seek to understand the basis of these behaviors. Specific processes will then be coupled (e.g., terrestrial C and N cycling; water flowpaths and N export) to explore for possible emergent behaviors created by process, spatial, and temporal interactions. In addition to coupling processes, we will use simulation experiments to test which combinations of processes match observations. For example, seasonal patterns of nutrient export from watersheds will be simulated by varying the importance of soil, groundwater, or in-stream processes. Those processes not contributing to the behavior of interest will be excluded from the "final" coupled model. When more than one combination of processes yields behavior similar to observations, we will seek alternative methods and experiments to discriminate these alternative hypotheses. At each stage of coupling, predictions will be compared to data of the relevant scale and detail to test if new emergent behaviors are resulting from new interactions. Finally, we see models as part of the process of learning and not as an end unto themselves.

Our new integration at the small watershed scale will look at difficult and enigmatic problems that are not easily addressed by experimentation, but that are needed to answer our Central Question. For example, despite major disturbances and high precipitation, our watersheds retain a large fraction of C and N. To what degree do the soils, vegetation, detritus quality, and in-stream processes contribute to this behavior? Atmospheric N inputs at Andrews are currently low, but steadily increasing. What would happen if N inputs continued to increase? Would watersheds begin to act more like the less pristine watersheds where major concepts of watershed nutrient cycling theory have been developed? Given the highly seasonal nature of precipitation at Andrews, with the majority falling in winter, is some of this water irrelevant to C and N cycling and vegetation? Would changing the seasonal distribution influence the system more than changing the amount of precipitation? Ecologists often think of controls of processes as being mutually exclusive, but what happens when multiple controls switch on and off during the year? Do the complex behaviors of small watersheds result from tradeoffs among processes and what happens when disturbance or climate removes part of the system? Finally, this proposed small watershed integration will help solidify landscape scaling in LTER6, allowing us to turn attention to the network interactions that connect small watersheds and processes that cross their boundaries.

3.0 Site and Program Management

The Andrews Experimental Forest programs of science and education, and their links with land management, are vigorous and diverse. LTER is the primary meeting ground for managing much of the entire enterprise, including work on satellite sites, such as Research Natural Areas and other experimental forests in the region. In addition to LTER, the Andrews science program includes more than 100 related research projects funded by NSF, NASA, EPA, Forest Service, US Geological Survey, and other sources. The science community includes Oregon State University (OSU) faculty from 13 departments in five colleges, PNW Forest Service scientists, USGS Biological Research Division scientists and students and scientists from many universities around the country. Educational activities extend from K-12 students, to primary/secondary teachers, undergraduate and graduate students, and continuing education on many fronts. Close working ties with Forest Service land managers enhance the science program, fuel numerous large-scale applied studies, and facilitate use of science findings in natural resource management and policy.

3.1 Management Philosophy. We manage the Andrews Forest as a regional, national, and international research and educational resource in keeping with the site's designation as a LTER site, a Forest Service Experimental Forest, and a UNESCO Man and the Biosphere Reserve. The LTER program is the hub of this activity, especially for linking in many ways with scientists and students at other sites around the country and world.

3.2 LTER Program Administration. Our LTER administrative structure (Figure 3.1) consists of the lead PI (Harmon) and an Executive Committee composed of signatory co-PIs determined by ballot and a "rotator" member to let others in the group gain administrative experience and the LTER "big picture." The Executive Committee represents the various disciplines and partner institutions (Figure 3.1). Direction of LTER and related research is set by consensus among the large group of senior scientists. The crux of any enterprise as large and diverse as Andrews LTER is communications. Communications are fostered by the monthly meetings, the widely distributed meeting notes, and semi-annual and annual events. Each monthly meeting is an open forum for covering business, including site administration, communications program, graduate student issues, and proposed research projects at the site; notes of these meetings are widely distributed. The meeting closes with a science hour presentation. Semi-annual meetings of PIs are used to review progress, activities, and budgets. Annual events include a one-day symposium to highlight Andrews LTER work activities and to feature an emerging theme of value to the campus. The symposium includes a poster session that focuses on graduate student work. We also hold an annual field day in June to introduce summer researchers and visitors to the site, to one another, and to the current program of work. The field day features 5-minute talks in various field venues by as many of the approximately 100 participants as possible. Our National Advisory Committee provides broad guidance on our research direction as well as methodological and tactical perspectives. Current members of the committee are Terry Chapin

(University of Alaska), Alan Covich (Colorado State University), and David Mladenoff (University of Wisconsin).

3.3 Inter-LTER-site Science and ILTER science, training, and consulting have been important parts of the Andrews LTER (Table 1.3). These efforts are led by individuals with personal commitment on behalf of the site and the LTER Network, such as Lajtha's role as a link with Eastern Europe and roles of Harmon, McKee, and Chen with the Chinese Ecological Research Network forest sites and Taiwan Ecological Research Network.

3.4 Link with Land Managers. Our research-management partnership activities are directed by the Cascade Center for Ecosystem Management Board of Directors, which includes science leaders and Willamette National Forest leaders, including the Research Liaison, who links the research and management communities. We have designated our research-management partnership as the Cascade Center for Ecosystem Management, which we use to plan and implement applied studies and communications with land managers, the public, media, and others. Quarterly meetings and significant overlap of leaders among these committees assure coordination.

3.5 Andrews Forest Site and its Administration. The Andrews Forest is administered cooperatively by the Oregon State University, Pacific Northwest Research Station, and Willamette National Forest (Figure 3.1). The headquarters facilities include over 35,000 ft^2 of offices, labs, library, shops, lecture hall, teaching lab, and beds for 85. Additional field facilities, such as cabins and a campground, are scattered over the 6400 ha forest. A T-1 line links the computer lab to campus 150 km away. We also help manage research properties, such as Research Natural Areas, in locations scattered across the central Cascade Range and which represent ecosystems and environments not present on Andrews Forest.

3.6 Change in Leadership and Participants. To succeed, an LTER program must plan for personnel changes; our management takes advantage of this necessity, recruiting widely for new talent, training candidate PIs in project management, and planning for orderly transitions in leadership. Harmon took over from Swanson as PI in 1999, and Harmon anticipates holding a 6-year term, so we are beginning to think about future PIs. Signatory co-PIs reflect both legacies of past site LTER leadership and new scientists, each of whom has significant experience in LTER. We expect signers to help manage the overall Andrews program, give broad science leadership, and lead a successful science program. The list of senior scientists not signing on the cover page has undergone turnover, but the institutional and disciplinary mixes have remained rather steady. In an important step the PNW Station hired Sherri Johnson to be a new Forest Service scientist with primary responsibility for Andrews and LTER. Art McKee's retirement in May 2002 after 30 years at the site and its only Site Director is a major change. We have begun the process of replacing him.

We continue to encourage others in various career stages at OSU and other institutions to capitalize on the Andrews Forest and to participate in LTER. In addition to graduate student involvement, we have engaged undergraduates in many ways. Post-doctoral fellows have brought fresh perspectives and skills to the group. Important new faculty participants include Bond (Forest Science), Haggerty (Geosciences), Lajtha (Botany), McDonnell (Forest Engineering), Noller (Soil Science), and Sulzman (Soil Science). We encourage site use through allocation of seed funds, technician time, assistance from Research Experience for Undergraduates students, and other means.

Our management style, based on consensus and distributed leadership, has served us well over the history of LTER, and we expect this to continue in the future with our new participants.

4.0 Information Management

4.1 Introduction. Information Management (IM) is a significant and unifying theme for the Andrews LTER. A strong commitment to funding information management personnel and activities was instrumental in the creation and development of the Forest Science Data Bank (FSDB) in the early 1980's (Stafford et al. 1984, 1988) to house data generated from LTER scientists and other collaborating researchers. The FSDB is dedicated to the long-term preservation and availability of environmental databases and features a rich and diverse repository of data and metadata for over 250 ecological studies (Henshaw and Spycher 1999). Andrews data sets see considerable use and are accessed hundreds of times per year (See Database Supplementary Document). The FSDB is part of a broader quantitative computing and information research infrastructure supporting interdisciplinary and inter-agency partners including the OSU College of Forestry, the USDA Forest Service Pacific Northwest Station (PNW), and the Andrews LTER. The Andrews LTER has also provided leadership in LTER Network activities, including development of LTER Network Information System (NIS) research modules (Baker et al. 2000). Additionally, the site has provided outreach through talks, invited papers, and posters to broader national and international forums.

The Andrews Forest site has long employed a systematic approach to information management in ecological research (Stafford 1993). This approach encourages research scientist and information manager interaction beginning with planning statistical and database designs, continuing through employment of automated data entry and quality assurance methodologies, and facilitating analysis and synthesis of the data sets. In a case study of Andrews Information Management activities, the National Research Council concluded that this systematic approach and resulting activities have brought discipline to the collection and organization of the data and metadata (NRC 1995). Substantial savings in data processing and archiving costs, resulting enhanced collections of metadata, and efficient publishing of data sets to the web serve as enticements for investigators to contribute data sets to the FSDB.

4.2 Guiding Principles. The Andrews LTER has several guiding principles for information management:

- The Andrews LTER, in combination with funding from the USFS-PNW and OSU, currently supports 5 permanent USFS-PNW and OSU positions and partly supports an additional 10 LTER members performing some IM activities.
- The IM Team plays a critical role in many site activities and is represented at all Andrews LTER PI and monthly business meetings.
- The Andrews is committed to maintenance of an Information System featuring a web interface to many online data sets and comprehensive metadata and to facilitating the discovery of information including publications, data sets, models, and photographs.
- The IM Team leads and participates in Network level IM activities, interacts with other LTER sites and broader national and international forums to share techniques and approaches to IM, and is active in Ecoinformatics research efforts.

4.3 Historical Perspective. The Andrews site benefited greatly from early efforts of the International Biological Program (IBP) and the USFS-PNW Watershed Project in managing our scientific information. The IBP efforts of the 1970's focused on the development of documentation forms to capture critical study abstract and data set description information, and set the stage for the creation of the FSDB. Additionally, it prepared the Andrews to provide leadership in more formal efforts to develop standards for documenting and maintaining research information for the LTER Network (Stafford et al. 1986a, b). These early efforts initiated the collection of what is now a rich set of metadata for our long-term databases, and led to continued involvement of the Andrews in development of ecological metadata standards (Michener et al. 1996, Porter et al. 1997). Congruently, the PNW research group added staff and established mechanisms to ensure preservation of stream flow, stream chemistry, and climate databases originating in the 1950's and 1960's. Ultimately, the early IBP and LTER data sets were combined with the PNW data sets to form the original core of the FSDB.

New computing hardware, software, and other advancing technologies coupled with emerging new and modified standards for the management of information drive evolutionary development of the FSDB. From an early mainframe tape library to a PC-based Local Area Network (LAN) to the employment of more powerful tools such as Relational Database Management Systems (RDBMS) on high-speed database servers, the FSDB has evolved with computing technology. Geographic Information Systems (GIS) and satellite imagery spatial databases were also established on a shared UNIX (Sun) network. Additionally, the realm of information management continually extends to other more diverse information products than those managed traditionally, such as research publications, models, maps, images, photographs, study plans, proposals, methods manuals, presentations, and web content. The emergence of the internet and the need for improved access to data sets and information has shifted our focus to webpage development and making our core LTER data sets available online.

4.4 The Current Data and Information Management System. We are currently in a transition process to provide improved access and enhanced search capabilities to a diverse array of integrated information products. This transition has been necessitated by (1) the need for improved search capability and access to spatial and tabular databases, models, publications, and the image library; (2) the need to expand metadata content to comply with the new LTER metadata standard, the Ecological Metadata Language (EML); (3) the need to allow web users to interactively and dynamically query and retrieve databases and other web content; and (4) the need to better integrate and manage GIS coverages within the new ESRI geodatabase model.

The new information system resides on a dedicated server running Microsoft's SQL Server 2000, features a structured metadata database established in compliance with national standards for metadata (EML/FGDC/NBII Biological Data Profile), and forms the basis for dynamic web access. The system consists of a catalog of research products such as study databases, spatial databases, models, publications, and images, and will permit searching for these products by author, theme keywords, locations, and species. Interactive web searches for publications and study data sets are now in place, as well as new web prototypes to allow LTER members to submit and update metadata for research study data, and to update their own personnel information. Structured metadata tables and catalogs allow generic programs to assist in data management tasks across all study data. For example, web page generation, quality assurance checking, automatic data entry form setup, and metadata report generation are conducted with generic software tools. The FSDB quality control system itself consists of a set of simple procedures providing flexible, generic data validation based on standard metadata and specific database rules (Spycher et al. 1996). The system also enables close integration of spatial and tabular data types and public access of information.

4.5 Future Plans. The database design of the new information system is fully accomplished, but the transition of our data sets and metadata into the new database will be completed in summer 2002. Metadata for each database are being reviewed before transition to expand and improve content, and we plan to dynamically produce metadata in both readable text files and XML formats that are compliant with EML, and proposed EML exchange strategies. We are beginning use of ESRI's Spatial Data Engine (SDE) software for integrating tabular data sets with spatial databases, and are expanding on current interactive map querying capability using Arc Internet Map Server (ArcIMS). The site web page is also currently being redesigned to improve maintenance and aesthetics, to facilitate searches for information, and to provide much of our web content dynamically from the SQLServer database. Database metadata and data, software tools and models, personnel information, site bibliography, image library, and core research pages are examples of web pages that are or will be dynamically generated from the database. The system design also serves the larger Pacific Northwest ecology community and currently includes data projects from Mount St. Helens, large forestry studies, and intersite hydrology (HydroDB).

4.6 Information Requests. The Andrews website has received more than 1000 documented requests for information since January 1999 (Database Supp), with most requests directly handled by the website. We plan to improve our capability of tracking uses of data sets and other types of information by adding a formal user registration system. This system will reveal our web audience, understand their intended uses of our information, and enable us to better meet their needs. See Table 4.1 for current summaries of web usage and Table 4.2 for a web user profile.

4.7 Data Access Policy. Our goal is to make most data available via the Internet within 2 years after collection in compliance with LTER Network policy. Most of our long-term online data sets are updated on an annual or "as needed" basis. Realistically, however, it is not possible to make all data available in that time frame, but data are not restricted without specific justification from the data set curator. Criteria that may limit immediate access include certain legal issues, data quality assurance issues, and certain publication issues, such as protecting graduate student data, or data collected at long (5-6 year) sampling intervals. Ultimately, all LTER data sets will be made publicly available.

4.8 Local Environment. The LTER shares a computer network with the broader Corvallis forestry community and receives much of its computing support through participation and agreements with the Oregon State University College of Forestry Computing Resources (FCR) Group. FCR provides support for UNIX and PC system administration, LAN, WAN, technical helpdesk, web servers, backup and recovery, database administration, statistical consulting, and computer laboratories. Specifically, the LTER staff provides web and database design and consulting, as well as GIS and remote sensing training and expertise. LTER staff involvement in the larger community issues provides opportunities to leverage LTER investments with additional computing resources and staff.

4.9 Network-level Activities. The Andrews LTER program remains very active with LTER Network activities (personnel, bibliography, EML metadata, and all-site data catalog), and particularly in the development of LTER NIS research modules. Andrews IM staff has provided leadership and extensive development efforts in both the Climate Data Project (ClimDB), a research module developed to provide climatic summaries dynamically over the web (Henshaw et al. 1998) (http://www.fsl.orst.edu/climdb/index.htm), as well as an intersite small watershed hydrology database (HydroDB) with 23 participating Forest Service sites including 6 LTER sites sites (http://www.fsl.orst.edu/hydrodb/index.htm). These modules serve as models for improving access to data across sites. Additionally, Henshaw has been a member of the LTER IM Executive Committee for the past 6 years.

5.0 Outreach

5.1 Description of Program. Outreach has been an essential part of the Andrews Forest program for decades. The majestic, massive old-growth forests; scientists doing innovative things; and headline issues of forest and watershed management in the region have kept Andrews scientists in the public spotlight and intensively involved in outreach to many audiences. Sustained, close working relations with land managers and frequent visits by policy makers and national media have displayed widely the relevance of the work to diverse audiences. We conduct public forums on current topics; annually host over 2000 visitors on tours to the site; contribute to education programs at all grade levels; conduct a public, documented adaptive management process concerning landscape management; and communicate broadly through other means.

An important feature of the LTER4 period was celebration of the 50th anniversary of Andrews Forest in 1998. This milestone was marked by several reviews of the Andrews program and its impact (Duncan 1999). Most notable has been John Luoma's popular book *The Hidden Forest* (1998) that chronicles Andrews Forest science and its impacts on land management and policy. This book builds on Luoma's decade-long relationship with Andrews science, which includes publication of four articles in the New York Times and a long piece in Discover magazine. A book on the history of Andrews Forest scientists and land managers by historian Max Geier (Professor of Western US History at Western Oregon University) has been submitted to the Forest History Society for possible publication in their monograph series. A corner stone of our outreach activities will be the Andrews Forest Synthesis Volume, which covers the history and current status of thinking about forest and stream ecosystems of the Andrews and Pacific Northwest. (For current draft, see LTER webpage; Username: LTER; Password: hjabook).

The Andrews Forest **education** program, spanning K-12 through extension, is an important medium for two-way communication. Schoolyard LTER operates mainly through OSU's SMILE (Science and Math Investigative Learning Experiences) Program, which provides science enrichment for Native American, Hispanic, and disadvantaged students in after-school science clubs and provides teacher workshops for club leaders (who are also classroom teachers). LTER provides funds for three clubs that conduct studies on schoolyard ecological projects (a wildlife hedgerow, a nature trail, and a wetlands area). Sixty students and six teachers participate in these clubs and far more students in their respective schools utilize the schoolyard areas during science classes. In addition, Schoolyard LTER supports SMILE's elementary science camp that is attended by 220 SMILE elementary students and their SMILE teachers each spring at a 4-H Center in Salem. Elementary students, under the guidance of undergraduate mentors, explore characteristics that define a pond, meadow, and forest and they conduct an investigation.

The Andrews site and scientists also participate in a teacher enhancement program for K-12 teachers (Portland State University's Teachers in the Woods program) and an NSF Technology Centers award to Chemeketa Community College for undergraduate teachers that focuses on ecosystem management (McKee is co-PI). Over 20 college classes build significant parts of their classroom material on Andrews findings and have annual field tours of Andrews. In addition to many classes from OSU, University of Oregon, and other regional colleges and universities, recently we have hosted field classes from as far as Alfred University (NY) and Lancaster University (UK). Several OSU faculty have field-based courses for undergraduates at times of the year when Andrews facilities are available and ideally suited for this use.

Communication with the **public** directly and through the **media** has come through numerous field tours, public forums (e.g., public meetings in Eugene, OR, on current topics, such as the 1996 flood), and other media. Work at the Andrews Forest has been in the news consistently for more than a decade by virtue of the interesting science and involvement in current hot topics in natural resource management.

The Andrews Forest LTER program has a long and strong engagement with forest and watershed **management and policy** matters. Andrews Forest scientists and science have played major roles on topics including management of old-growth forests, young stands, northern spotted owl, watershed processes, and riparian systems. This information was used in the early 1990s in the thorough revamping of policy for management of 10 million ha of public lands in the Pacific Northwest. During LTER4 our major management and policy relevance has been on themes of carbon sequestration (Cohen et al. 1996, Harmon 2000, Harmon & Marks in press, Smithwick et al. in press), landscape management systems that incorporate understanding of natural disturbance regimes (Cissel et al. 1998, 1999), and many other topics (Table 5.1).

We work in a close **research-management partnership**, including operating within a formally designated Adaptive Management Area under the Northwest Forest Plan. Our research-management partnership itself, which we term the Cascade Center for Ecosystem Management, is a successful model for collaborative work, and has been the subject of numerous consultations with others. In parallel with our Andrews LTER webpage for science peers, we also manage a webpage for the Cascade Center (http://www.fsl.orst.edu/ccem) aimed at land managers and informed public audiences. A central feature of this collaborative work is a landscape management plan for a 23,000-ha area adjacent to the Andrews Forest. This management plan, termed the Blue River Landscape Plan (Cissel et al. 1999), is an innovative blending of watershed processes, a conservation biology approach of reserves and matrix for species of special interest, and use of historic disturbance regimes to set frequency and severity of forest harvest/cutting. This plan is a form of science synthesis, whereby scientists from diverse fields help in concept formulation, plan development, and monitoring to test landscape-scale hypotheses concerning viability of selected species, stream flow, and balances among ecological goods/services under different management regimes, including no cut/no burn and historical wildfire. The LTER grant funds little of this work, but nucleates the ecosystem science at Andrews and thus feeds a great deal of basic information into the process and benefits from the challenging questions that come from management and public sectors. Products from our science-management partnership include advances in concepts incorporating knowledge of ecosystems in management of streams and riparian zones, watersheds, and forest landscapes (Gregory & Ashkenas 1990, Swanson et al. 1997, Cissel et al. 1998, 1999, Landres et al. 1999).

5.2 Future Plans. During LTER5 we will continue with past activities and also greatly enhance education activities at the college and pre-college levels. A new Fisheries and Wildlife faculty member will lead further development of field-based courses offered at the Andrews by faculty at OSU and other institutions. We also plan to work in collaboration with existing pre-college science education programs at OSU and elsewhere to incorporate LTER science into teacher training and student programming, and to encourage use of the Andrews Forest by groups of teachers. For example, we anticipate that LTER scientists and/or graduate students will share their expertise with SMILE teachers at annual workshops and assist with training camp staff for SMILE's annual elementary science camp. SMILE and LTER will apply for a NSF-EHR grant for this project, which will bring field ecology to all 740 SMILE students and their 74 teachers. Finally, we are making our website more user-friendly for students, teachers, and the public. We hope to recruit teachers to use Andrews data for instruction at all levels. Further details on our plans are available by viewing our Education Plan (see LTER5 webpage).

LTER5 Tables and Figures

Table 1.1. List of selected continuing measurements at the Andrews LTER, in the form of long-term datasets, and key publications. Many datasets are part of several key long-term experiments. Some datasets are used for multiple components, noted “All.” The Databases Supplementary Document contains a complete list of databases that are currently available electronically.

Component	Long-term dataset or experiment (years of record)	Data publication	Dataset code
Climate	precipitation (40) air temperature, solar energy stream temperature	Bierlmaier & McKee 1989, Daly/Smith web page, Johnson & Jones 2000	MS001 MS001 HT004
Hydrology	streamflow - 8 small watersheds (50) streamflow Lookout Creek (50) sediment – 8 small watersheds	Jones & Grant 1996, Jones 2000 Post & Jones 2001, Jones & Grant 1996, Grant & Wolff 1991	HF004, 007 HF007 HS003
Disturbance	wildfire (500) landslides, debris flows (50) channel cross-sections (23)	Berkley 2000, Swanson & Dyrness 1975, Snyder 2000, Faustini, 2000, Faustini & Jones in press	-- GE007 GS002, 019
Ecophysiology	sapflow in trees (3)	Bond et al. in press	--
Carbon-nutrient	log, branch decomposition (16) stream log decomposition (16) root decomposition (6) carbon stores (20) NPP, biomass in permanent study plots (90)	Harmon et al. 2001; Harmon 2000, 2001; Gholz et al. 2000; Chen et al., 2001; Smithwick et al. in press; Acker et al. 2000, 2002	TD014, 021,023 TL001 TD017 TV010, 052
Biodiversity	vascular plants in WS 1, 3, 10 (43) vascular plants at Starrbright (11) amphibians (5) lepidoptera (30)	Halpern 1988, 1989; Halpern & Franklin 1990; Halpern et al. 1992, 1997; Halpern & Spies 1995 -- Parsons et al., 1991; Lattin & Miller 1997; Hammond and Miller 1998	TP041, 073 TP103 WE022, 6 SA001
Stream-forest	trout populations (19) wood inventory (12) stream chemistry (34)	Bisson et al in press Melanson et al in review Vanderbilt et al. in press	AS006 GS006 CF002
All	precipitation chemistry (30)	Martin & Harr 1988	CP001,2
All	soil leachates – DIRT plots (5)	Holub et al. 2001	--
All	young forest stands (6)	Hunter 2001	WE008

Table 1.2. Correspondence between LTER Core Areas (Callahan 1984) and components of the Andrews LTER5.

Core area	Andrews LTER5 component(s)
(1) Patterns and controls on primary productivity	Carbon and nutrient dynamics, Ecophysiology
(2) Spatial and temporal patterns of populations	Biodiversity; Stream forest interactions
(3) Patterns and controls on organic matter accumulation	Carbon and nutrient dynamics
(4) Patterns of inorganic inputs and transport	Climate, Hydrology, Disturbance
(5) Patterns and frequency of disturbances	Disturbance and landscape dynamics

Table 1.3. Selected examples of Andrews Forest participation in inter-LTER-site science and ILTER science, training, and consulting during the LTER4 grant period (1996-2001).

Theme	Activity	Leaders	Funding	Publications
Litter decomp.	LIDET: Field and modeling studies of litter decomposition	Harmon	NSF/LTER, NSF	Gholz et al. 2001
Soil carbon and nitrogen dynamics	DIRT: foster development of the Detrital Input and Removal Treatments sites in Hungary, US	Lajtha, Caldwell, Sollins	NSF	Holub et al. 2001
Hydrology	Comparative analysis of streamflow across four LTER sites; Develop Hydro-DB data harvester system to facilitate intersite hydrology studies (see Section 4)	Jones, Swanson	NSF/LTER Intersite, NSF/LTER, US Forest Service	Post et al. 1998; Post & Jones 2001
Stream nitrogen	Comparative analysis of nitrogen cycling in streams at LINX (Lotic Intersite Nitrogen Experiment) I, II	Johnson, Gregory, Ashkenas	NSF	Peterson et al. 2001
Climate	Intersite climate comparative analysis; Develop ClimDB, a data harvester system to facilitate intersite climate studies and other activities (see Section 4)	Greenland, Henshaw	NSF, US Forest Service	Greenland et al. in prep.
ILTER Eastern Europe	Symposium on soil ecosystem research in Eastern Europe	Lajtha, Vanderbilt	NSF	Lajtha & Vanderbilt 2000
ILTER Taiwan and China	Cross-network exchange visits with ecological research networks (TERN and CERN): decomposition, invertebrate ecology, hydrology	Harmon, McKee, Chen	NSF	
ILTER Russia	comparative regional carbon dynamics	Harmon, Turner, Krankina	NSF	Krankina et al. 1999
ILTER Mexico	administration and science exchange	Harmon, Franklin	NSF	

Table 2.1. Temporal behaviors, inferred mechanisms that produce these behaviors, and examples using processes at the Andrews LTER. Each form of temporal behavior involves a response to one or more drivers (see Figure 2.1).

Behavior	Explanation	Significance	Mechanisms	Examples
1.Modulated response	response has lower amplitude than driver	indicates system resistance to change	a. decoupled processes b. compensatory processes c. slow turnover	a. respiration b. C allocation c. N release from soils
2.Lagged response	response occurs later in time than driver	indicates system capacity for delayed response to change	a. rate of sequence of reactions b. rate of transmission	a. seed production b. hydrograph
3.Spatial coherence	responses are synchronized in multiple locations	indicates system resistance to broad-scale change	a. driver is synchronized b. responses are synchronized	a. airshed mixing in summer vs. winter b. habitat or community differences in sub-populations
4.Path dependency	response depends upon a particular combination of more than one driver in time	indicates inherent variability of system – boundary between stability and instability	a. scheduling: order and proximity of drivers in time	a. rain-on-snow floods b. wind, drought, and bark beetle outbreaks c. closely-spaced storms and N fluxes in streams
5.Hysteresis	falling limb of response is delayed relative to rising limb	indicates system resilience, or speed of recovery to initial state	a. depletable pool	a. discharge v. precipitation (hydrograph) b. DOC v. discharge c. sapflow v. vapor pressure deficit
6.Alternate stable states	alternate responses occur over some range; transition between states is delayed or permanent	indicates system resilience, or capacity to recover to initial state	three steps: a. initial driver b. recovery interrupted c. reinforcing mechanism	a. exceptions to fire-maintained D. fir v. windthrow-maintained hemlock b. forest-meadow transitions

Table 2.2. Records from small experimental watersheds in the H.J. Andrews Experimental Forest for use in small watershed synthesis in LTER5. Prior to treatments, forests were 400 to 500 year old Douglas-fir/western hemlock stands in Watersheds 1, 2, 3, 9 and 10, and 130-yr old Douglas-fir stands in Watersheds 6, 7, and 8.

No.	Area (ha)	Elevation (m)		Management history	Start date for water, climate, stream chemistry, vegetation and sapflow records				
		Min	Max		W[1]	P[2]	C[3]	V[4]	S[5]
1	96	460	990	100% clearcut, 1962-66; prescribed burned 1967	1953	1958	--	1962	1999
2	60	530	1070	control	1953	1958	1981	1981	2000
3	101	490	1070	1.5 km (6%) roads, 1959; 25% clearcut in 3 patches, 1963	1953	1958	--	1962	--
6	13	880	1010	100% clearcut, 1974	1964	1964	1972	--	--
7	15	910	1020	50% selective canopy removal, 1974; remaining canopy removed 1984	1964	1964	1972	--	--
8	21	960	1130	control	1964	1964	1972	--	--
9	9	425	700	control	1967	1952	1969	--	--
10	10	425	700	100% clearcut, 1975	1967	1952	1969	1973	--

[1] W = Streamflow records are continuous up to the present, except for Watersheds 6 and 7, where streamflow was not measured from 1987 to 1994. In LTER4, we began sampling summer flow using V-notch weirs to capture diel fluctuations.

[2] P = Precipitation records began on this date. Air temperature records began in 1958 (WS 9, 10) and solar energy records began in 1972. In LTER4, daily precipitation and temperature records were organized and cleaned for the period 1970-present.

[3] C = Streamwater chemistry sampled using proportional sampler for 3-week intervals. Water chemistry analyses include: NO_3-N, NH_4-N, PO_4, Ca, Mg, K, Na, Si, SO_4, Cl, alkalinity, conductivity, pH, particulate N, particulate P, and suspended sediment. Sampling stopped in 1987 at Watersheds 6 and 7 and will resume in 2002. In LTER 5, sampling will begin at Watershed 1 and analysis of DOC will be added. Storm water sampling will begin at selected watersheds.

[4] V = Vegetation plot samples of species, basal area, mortality in understory and canopy. In LTER5, supplementary studies of historical disturbance (windthrow) and vegetation will be undertaken in Watersheds 6, 7, 8 and 9.

[5] S = Sapflow measurements (April – November) began on this date. Data are collected from Douglas-fir (30-yr and old-growth), western hemlock (old-growth), and red alder (30-yr) trees in Watersheds 1 and 2. In LTER5, sampling will be extended through the year and include hemlock and broadleaf trees in canopy gaps.

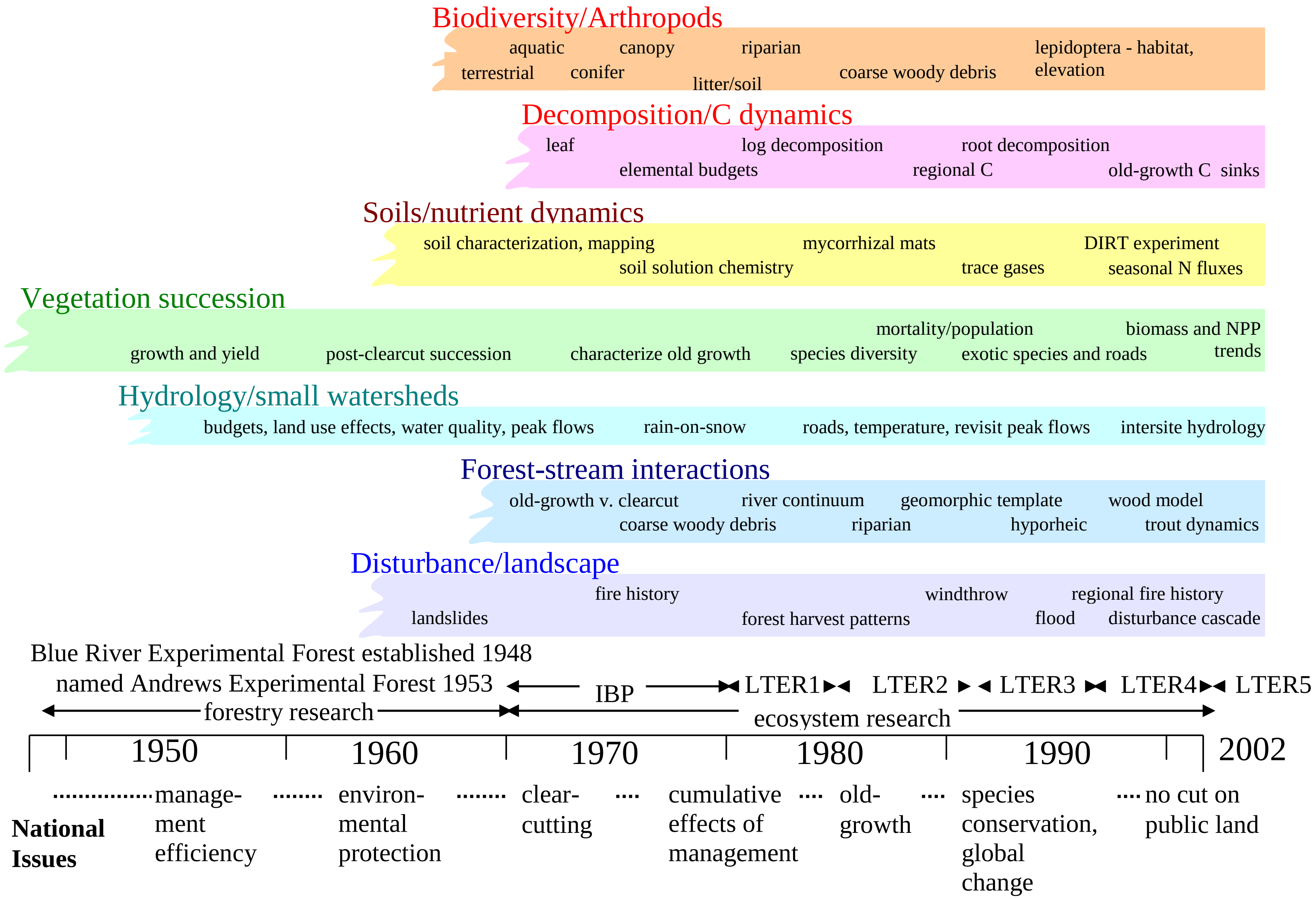


Figure 1.1. Fifty-four years of H.J. Andrews Experimental Forest research and its context. Evolving emphases are shown within each of seven persistent themes (colored bars).

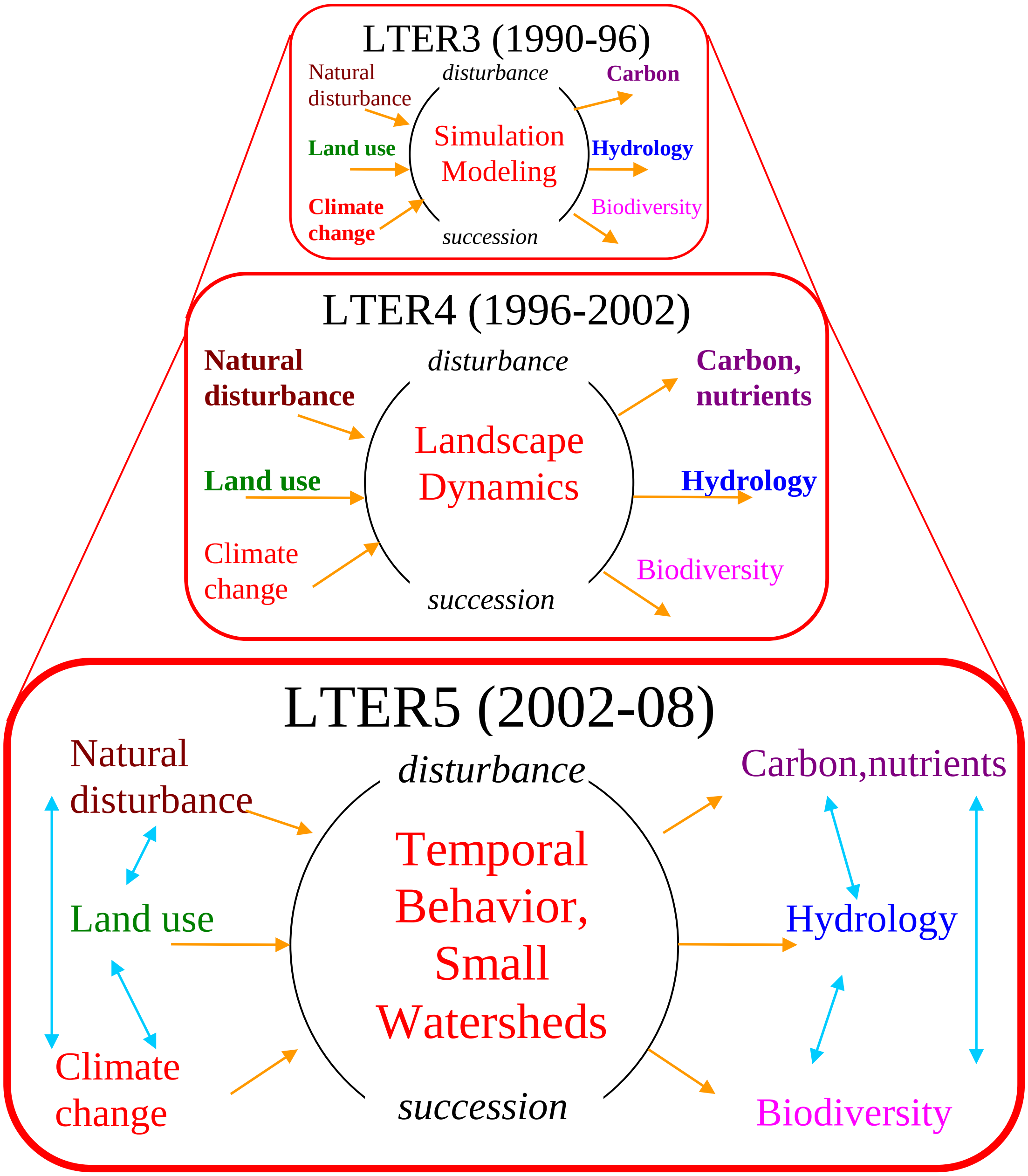


Figure 1.2. Evolution of the central question for the Andrews LTER since 1990, showing the drivers (natural disturbance, land use, and climate change) and responses (carbon & nutrients, hydrology, and biodiversity). In LTER3 we emphasized simulation modeling to link land use and climate change effects on carbon and hydrology. In LTER4 we focused on the landscape dynamics of natural disturbance and land use influences on carbon and nutrients and hydrology. In LTER5 we will use various forms of temporal behavior revealed by our long-term records, and synthesis of records at the small watershed scale, to examine interactions (blue arrows) among drivers and responses.

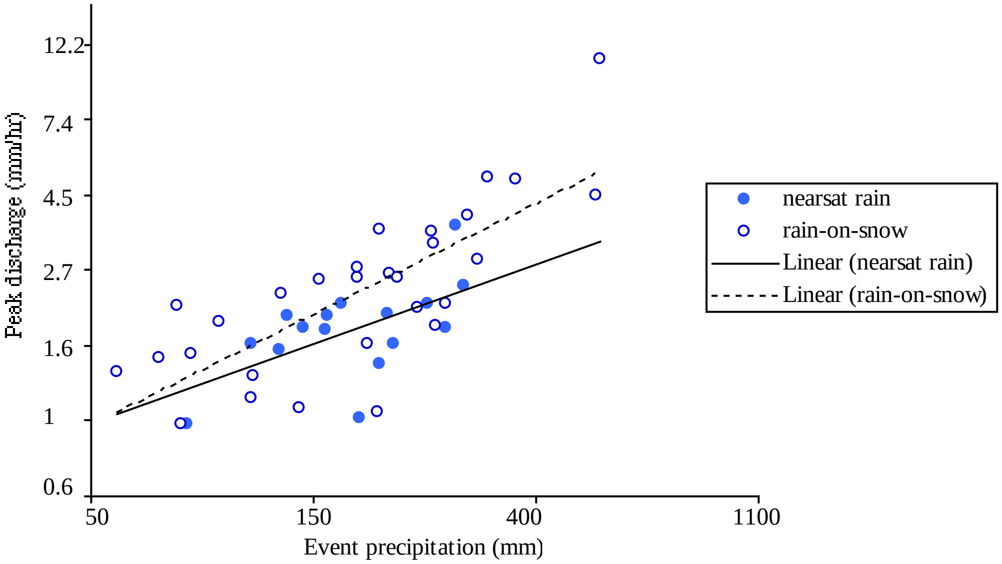
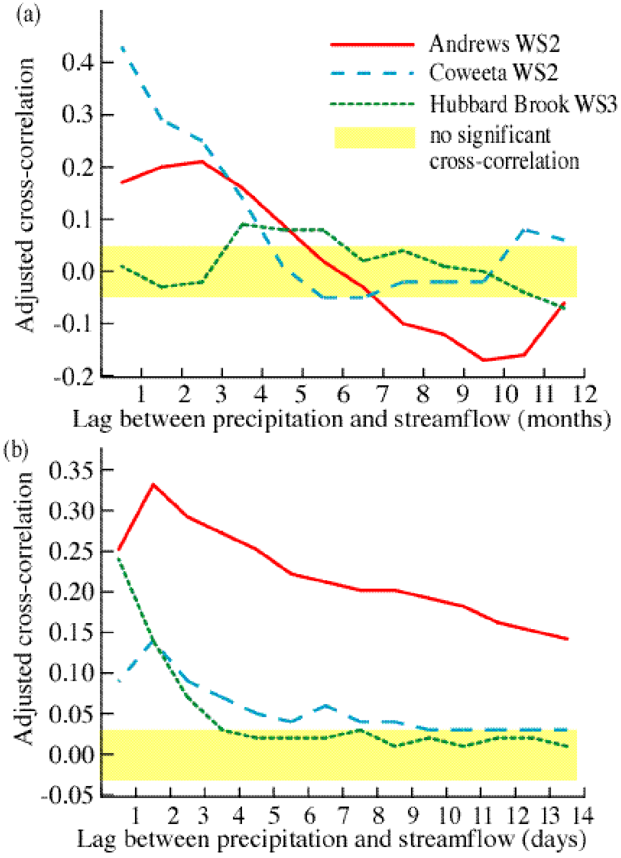


Figure 1.3. Path dependency of peak discharges at Lookout Creek over the period 1963-1992 coded by event type: (1) rain on near-saturated soils, and (2) rain on a snowpack on near-saturated soils. Event type was determined by retrospective hydrologic modeling (Perkins, 1997). The largest precipitation events occur when snowpacks are on the ground, but controlling for event precipitation and antecedent soil moisture, peak disharges during rain-on-snow events are 25% higher than under rain events (Jones & Perkins in prep.).

Figure 1.4. Temporal lags, shown by cross-correlation between precipitation and streamflow at three LTER sites, on monthly (a) and daily (b) time scales (Post & Jones 2001). At the monthly scale, discharge has the shortest lag with precipitation at Coweeta and a longer lag at Hubbard Brook due to snowmelt, but is negatively related to precipitation at months 7 to 11 at the Andrews, perhaps due to vegetation water use. The daily discharge signal has much shorter lags at Coweeta and Hubbard Brook compared with the Andrews, perhaps because of soil moisture holding capacities.



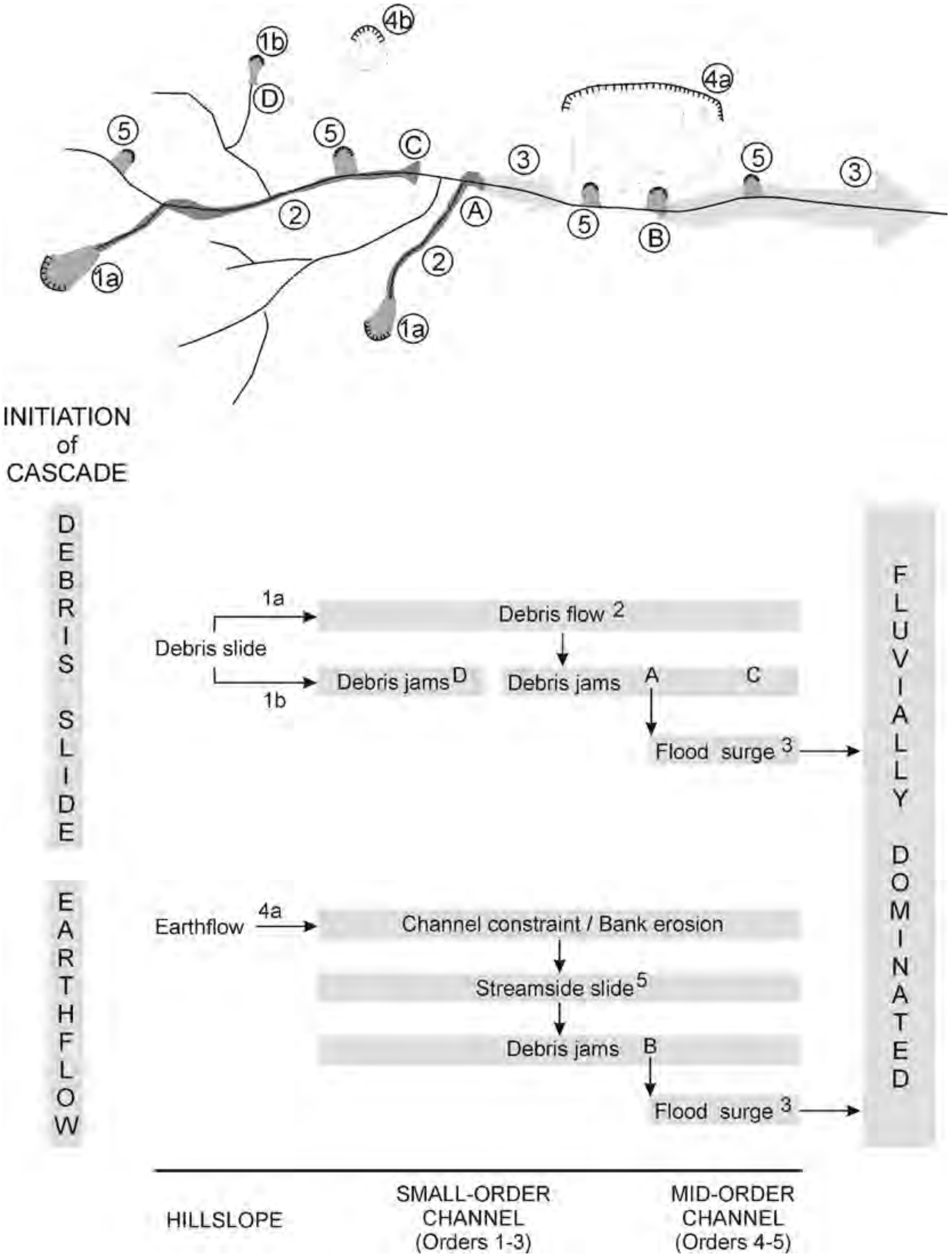


Figure 1.5. Cascading effects of multiple disturbances ranging from mass movements (debris slides, earthflows) to fluvially-dominated processes (debris flows, bank erosion, streamside slides, debris jams, and flood surges) from hillslopes to low-order, to high-order channels, associated with the 1996 flood of record at the Andrews (Swanson et al. 1998, Nakamura et al. 2000). Long-term records facilitate examination of the behavior of multiple disturbance events in space and time.

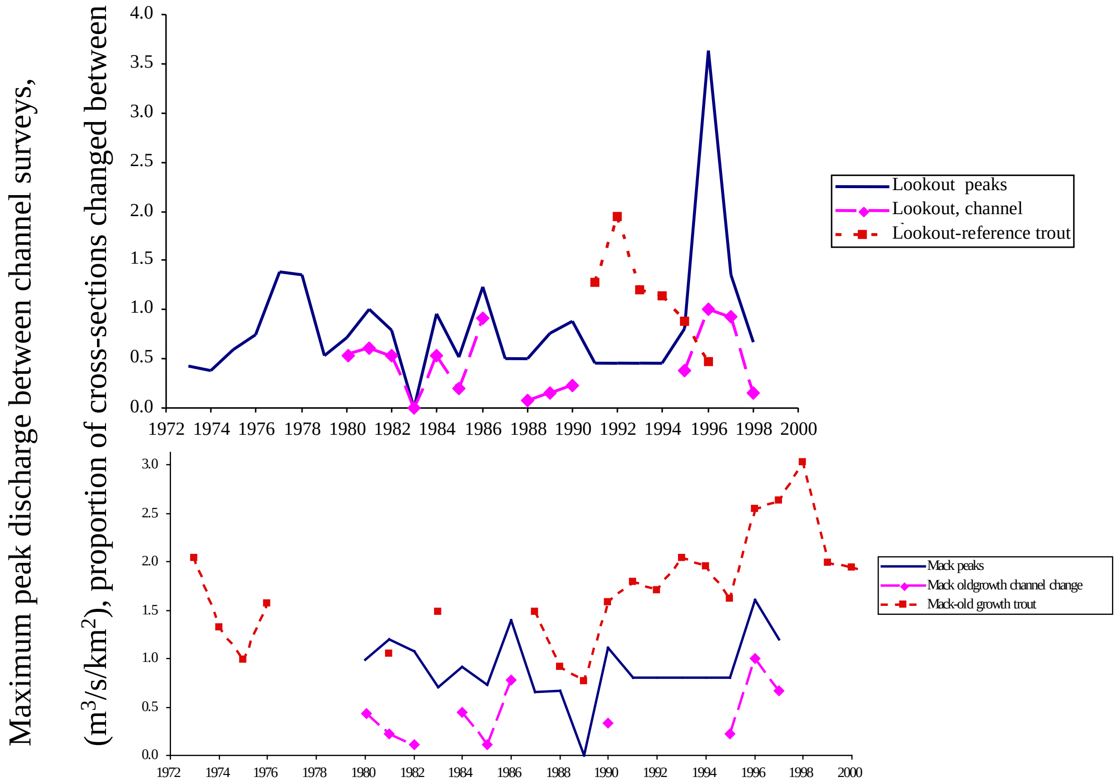


Figure 1.6. Spatial coherence in peak flows and stream channel change (Faustini 2000) and trout populations (Gregory, unpub. data) at Mack Creek and main stem of Lookout Creek. Stream channel change matches peak discharges at each site but the two sites are somewhat desynchonized; trout populations trends are quite desynchronized and do not follow flood or channel disturbance trends consistently between the two sites.

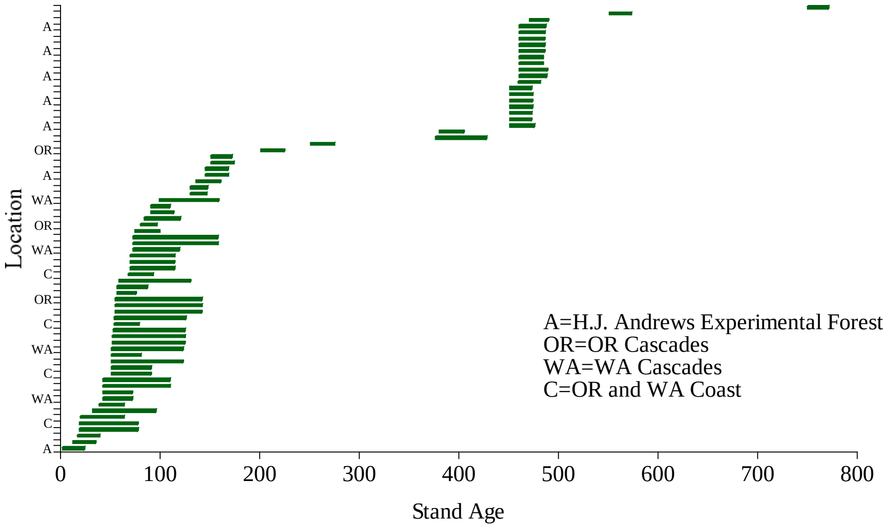


Figure 1.7. Long-term records from monitored forest stands for a chronosequence analysis of biomass, NPP, C and N in Douglas-fir/western hemlock forests of the Pacific Northwest (e.g. Acker et al. 2001). Width of bar indicates length of record. Preponderance of stands aged 500 and <150 years reflects episodes of regional fire history revealed by wildfire disturbance reconstructions (Weisberg and Swanson in press).

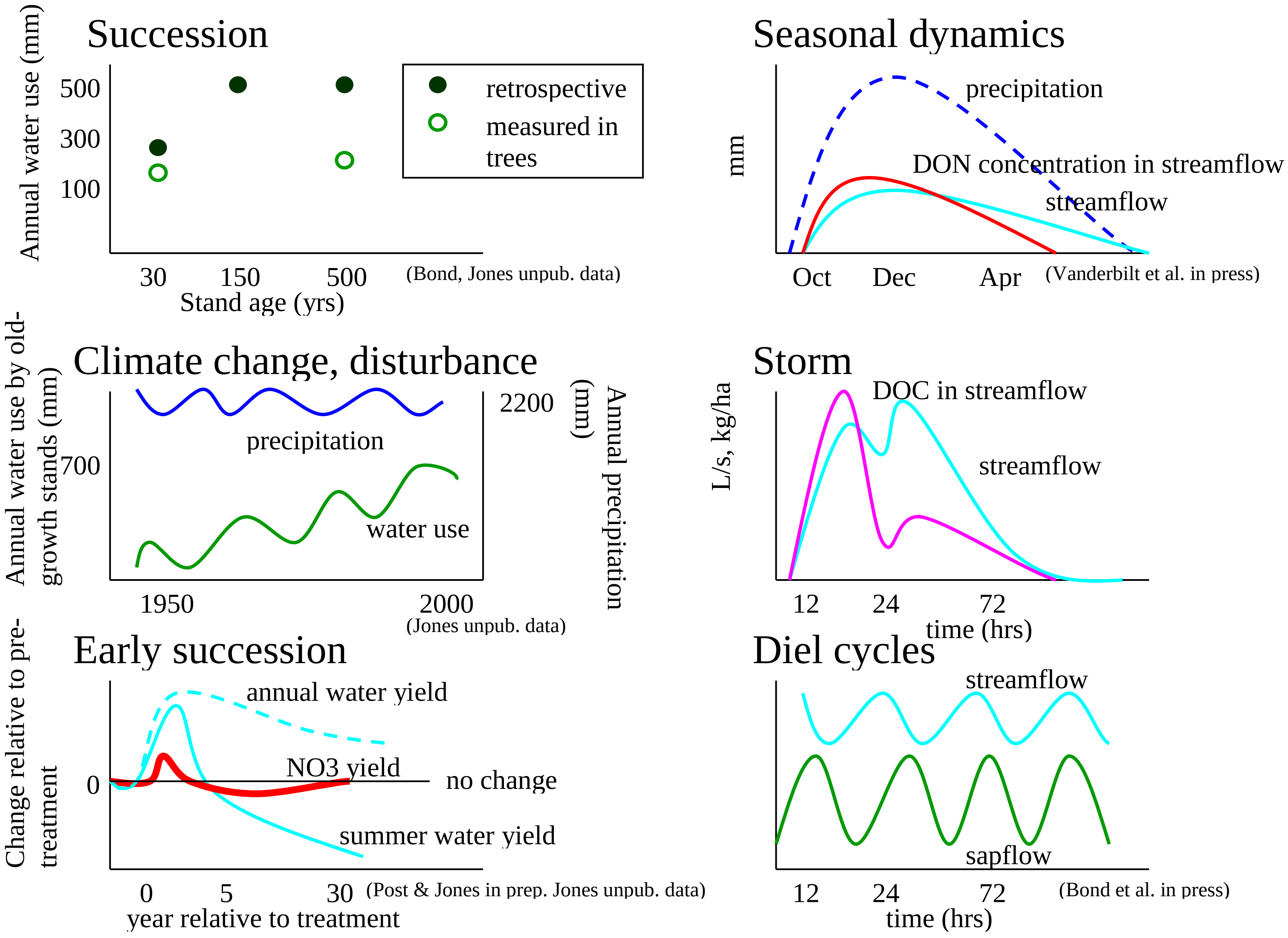


Figure 1.8. Small watershed behaviors from retrospective and ongoing process studies, to be explored in LTER5.

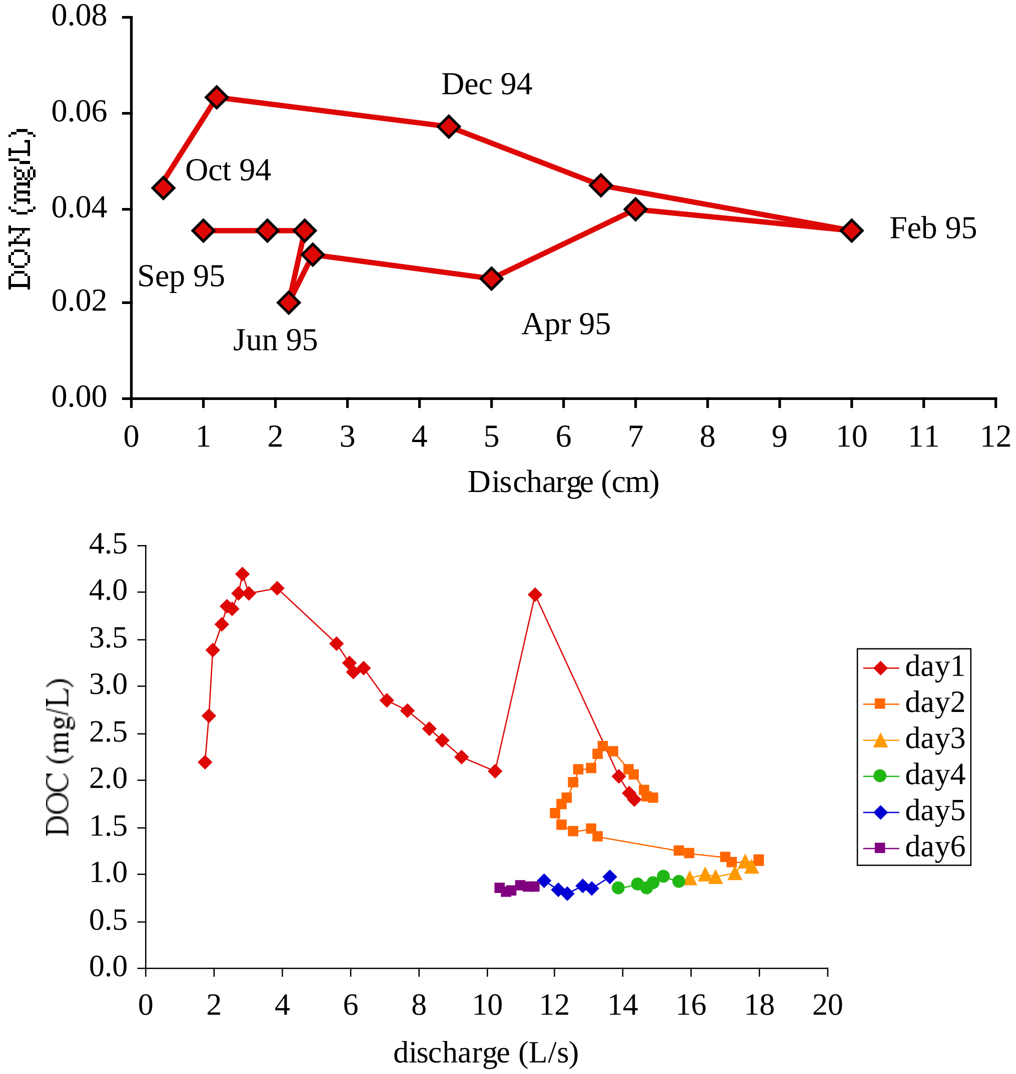


Figure 1.9. Example of hysteresis and path dependence of stream flow chemistry v. discharge for (a) DON over the water year, October 1994 to September 1995, and (b) DOC in storm at WS 10, 14 to 20 May 2001;. We interpret these data to indicate that labile DOM stored during a prolonged dry period is rapidly flushed from soils, hence predicting DOC and DON requires knowledge of the time since the last storm.

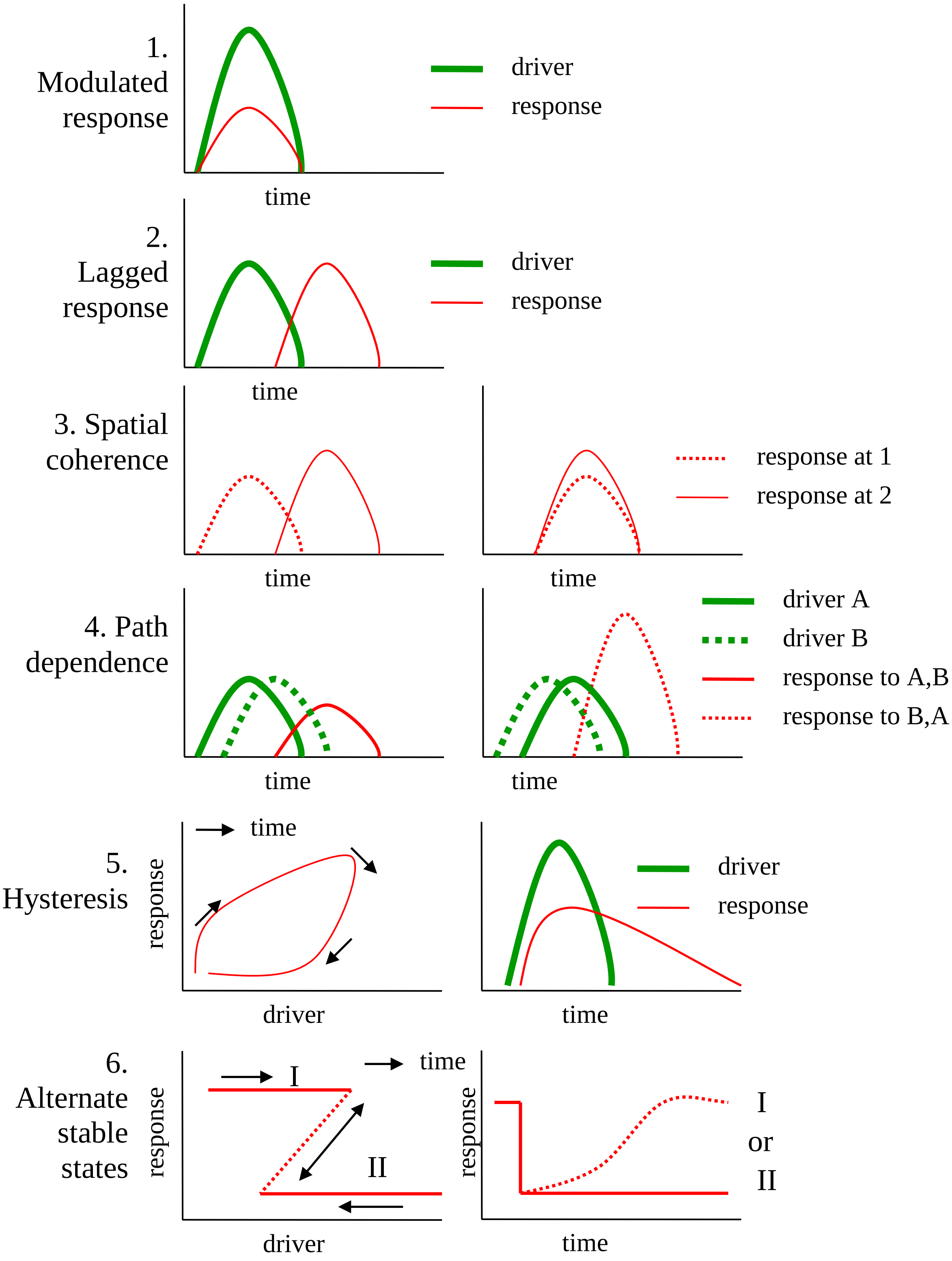


Figure 2.1. Types of temporal behavior to be explored in LTER5 (see Table 2.1).

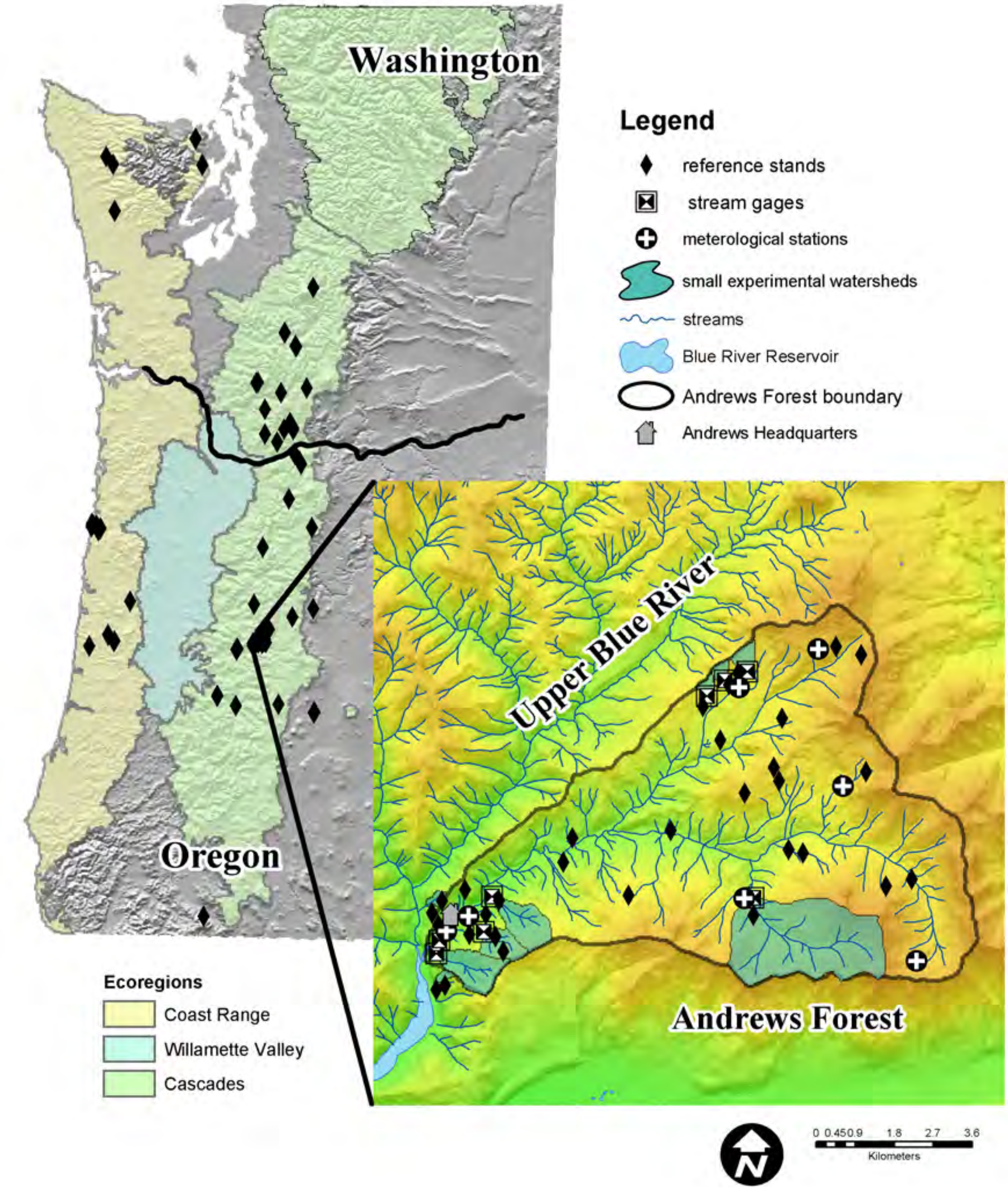


Figure 2.2. The Andrews Forest (6.4 km^2) is part of the upper Blue River (20 km^2) and lies within the Cascadian province. Long-term records are maintained at meteorological stations, gaging stations, and reference stands within the Andrews (see Table 1.1, 2.1). The Andrews is also the repository for long-term datasets from vegetation plots and small watershed records within the region. Roughly 3/4 of the Andrews Forest and Blue River is 500+ yr old Douglas-fir and western hemlock forest draining to steep, bouldery mountain streams. About 1/4 of the area is forest plantations created mostly between 1950 and 1980.

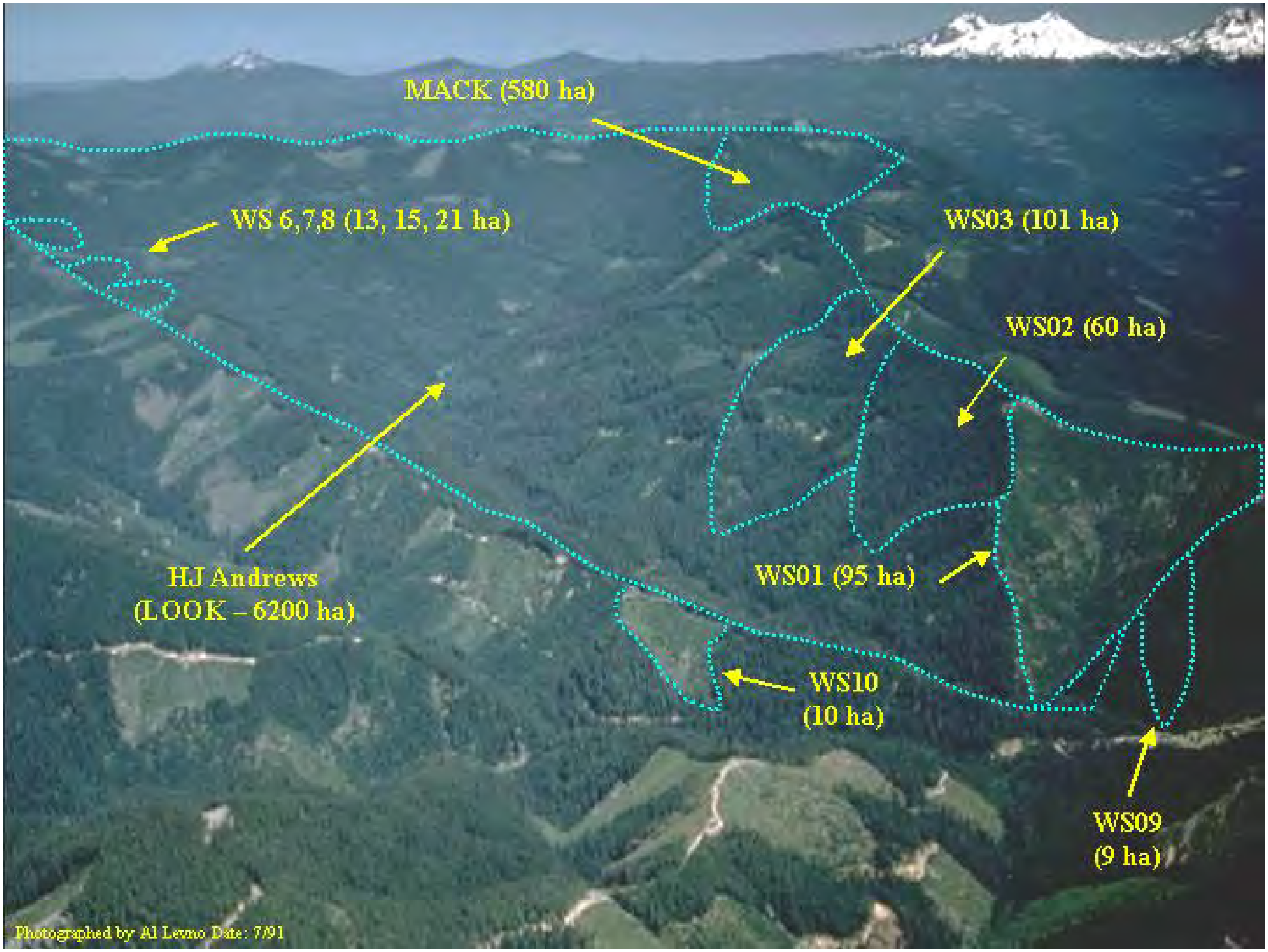


Figure 2.3. Overview of H.J. Andrews looking east, showing locations of small watersheds and Mack Creek.

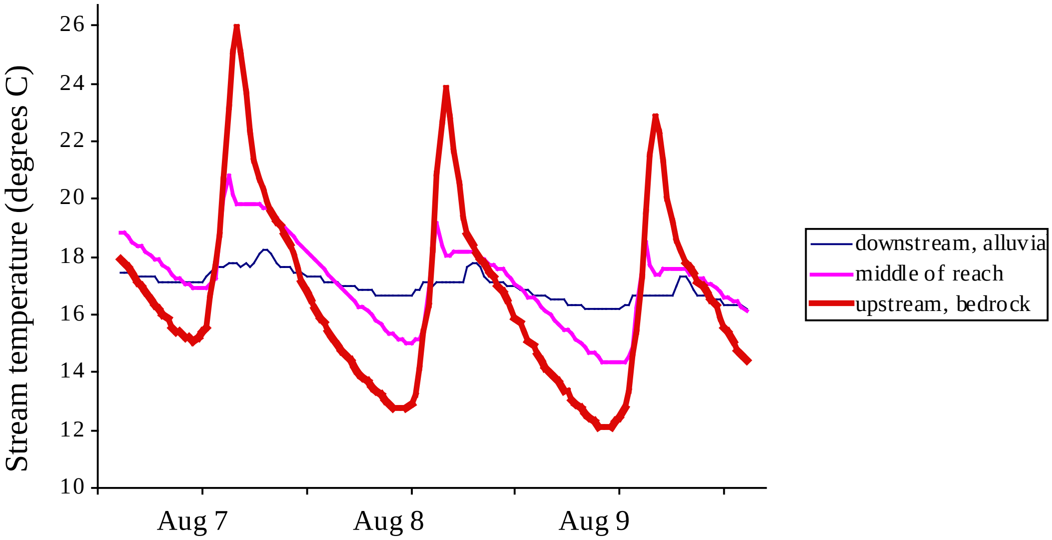


Figure 2.4. Modulation of diel cycles of stream temperature during three clear summer days at a bedrock reach of Watershed 3 by heat exchange with the bed in the middle of the reach and with alluvium in a downstream alluvial reach (Johnson unpub. data).

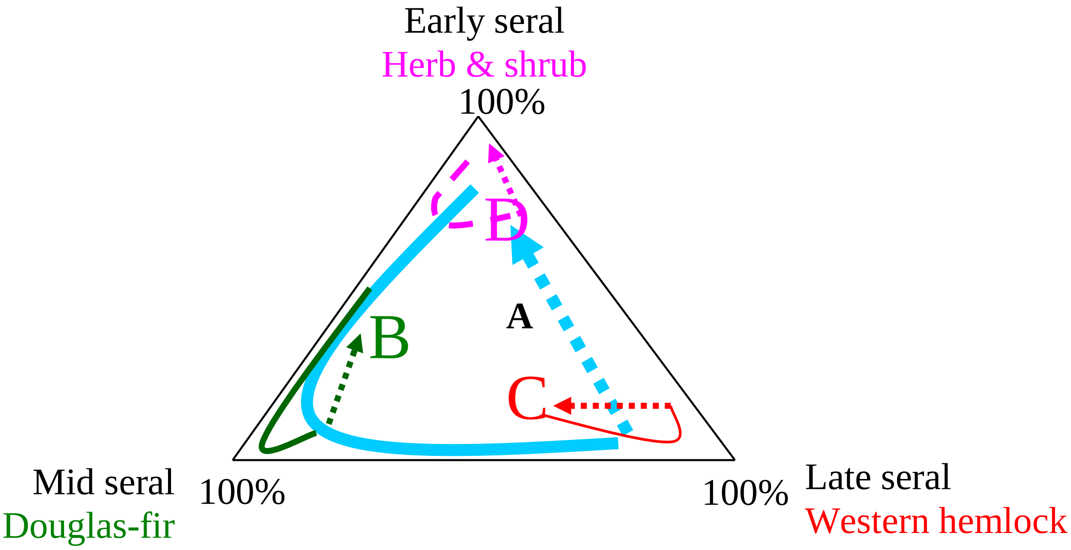
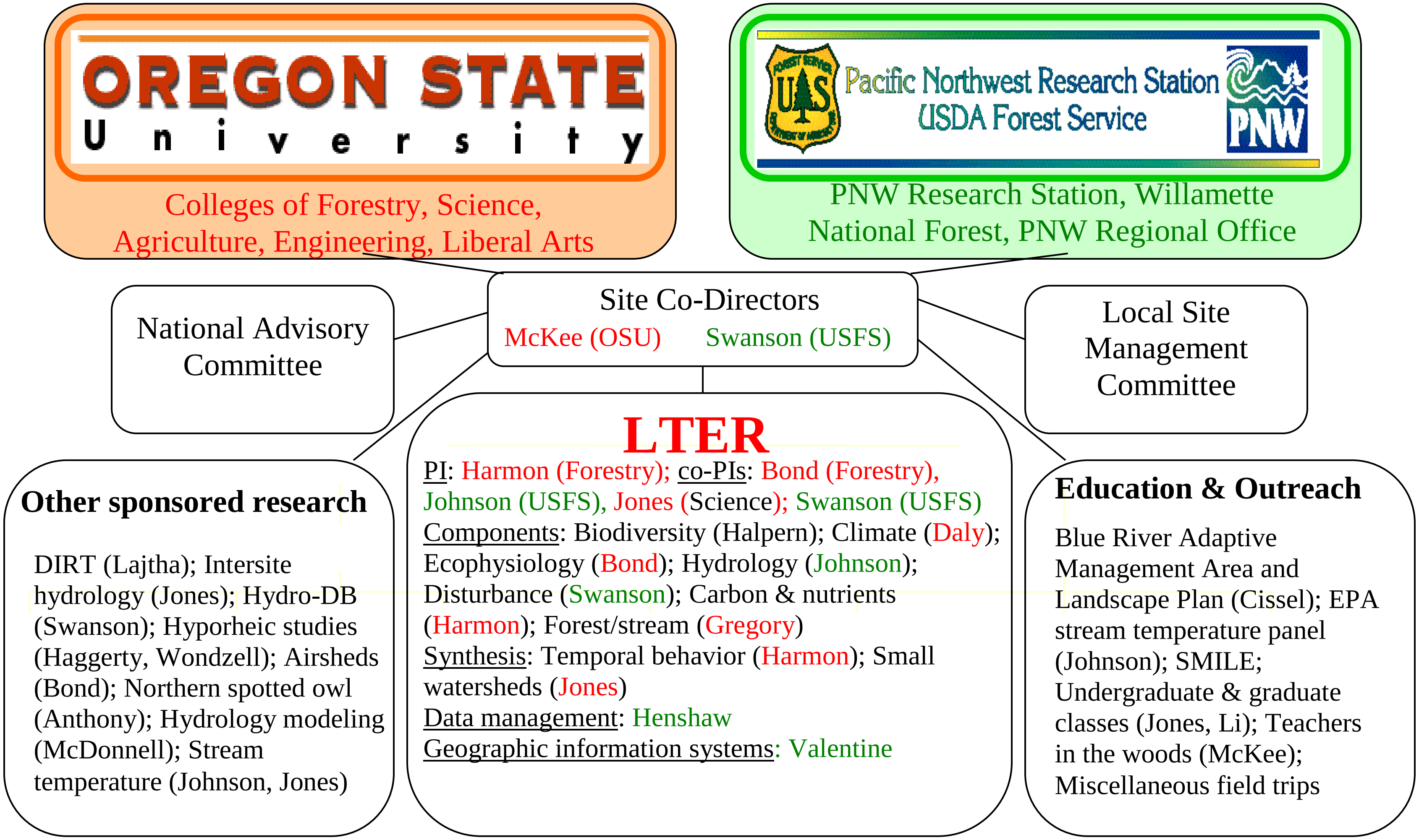


Figure 2.5. Changes over time (lines, arrows) among three possible alternative states for Andrews terrestrial ecosystem (points of triangle) as a result of natural disturbance regime (loop A) and three management regimes (loops B, C, D). In natural disturbance regime (loop A, thick blue line) system moves from herb/shrub to Douglas-fir at ~30 yrs after disturbance, then toward hemlock dominance at >500 yrs, and is reset by stand-replacing wildfire. In intensive plantation management (loop B, green solid line) herb/shrub stages are shortened by herbicides and planting, and the stand is reset by clearcutting at 40-100 yrs, eliminating the late seral state. In current forest management on public lands (Northwest Forest Plan, loop C thin red line) wildfire is suppressed, and only selective harvest occurs. In some areas harvest or fire has produced a protracted herb/shrub stage (loop D, dashed purple line).

Figure 3.1. Andrews LTER research partnership involving the Andrew Forest site, Oregon State University, the US Forest Service, the LTER National Advisory Committee and a local site management committee, other sponsored research, and education and outreach.

H.J. Andrews Experimental Forest



OREGON STATE
University

Colleges of Forestry, Science, Agriculture, Engineering, Liberal Arts

Pacific Northwest Research Station
USDA Forest Service
PNW

PNW Research Station, Willamette National Forest, PNW Regional Office

National Advisory Committee

Site Co-Directors
McKee (OSU) Swanson (USFS)

Local Site Management Committee

Other sponsored research

DIRT (Lajtha); Intersite hydrology (Jones); Hydro-DB (Swanson); Hyporheic studies (Haggerty, Wondzell); Airsheds (Bond); Northern spotted owl (Anthony); Hydrology modeling (McDonnell); Stream temperature (Johnson, Jones)

LTER

PI: Harmon (Forestry); co-PIs: Bond (Forestry), Johnson (USFS), Jones (Science); Swanson (USFS)
Components: Biodiversity (Halpern); Climate (Daly); Ecophysiology (Bond); Hydrology (Johnson); Disturbance (Swanson); Carbon & nutrients (Harmon); Forest/stream (Gregory)
Synthesis: Temporal behavior (Harmon); Small watersheds (Jones)
Data management: Henshaw
Geographic information systems: Valentine

Education & Outreach

Blue River Adaptive Management Area and Landscape Plan (Cissel); EPA stream temperature panel (Johnson); SMILE; Undergraduate & graduate classes (Jones, Li); Teachers in the woods (McKee); Miscellaneous field trips

Table 4.1. Usage of the Andrews Web Site by Year [a]

Year	Homepage "hits"
1995	3,150
1996	4,235
1997	5,555
1998	5,565
1999	7,475
2000	13,330
2001	16,270
Total	**55,580**

[a] Use of the Andrews web site is summarized by the approximate number of times the homepage has been accessed, and likely underestimates of the use of the site as a whole.

Table 4.2. User Profile of the Andrews Web Site [b]

User classification	%	Most common (% of total profile)
Educational (.edu)	56	Oregon State University (28%)
Government (.gov, .us, .mil)	6	U.S. Forest Service (2%)
Non-government (.com, .org., .net)	16	Commercial (.com) (9%)
Foreign countries (65 countries)	9	Canada (2%)
Andrews LTER IM Team	13	Webmaster (8%)

[b] This profile is developed by summarizing the client browser domain name, 1996-early 2000, and disregarding unknown IP addresses.

Table 5.1. Selected policy-related activities of Andrews Forest LTER scientists to public and policy makers at state and national levels during LTER4 grant period (1996-2002).

Year	Activity	Participants
1996	• Extensive participation in media coverage of February 1996 flood on issues of public safety and forestry effects.	Grant, Swanson, Cissel
	• Public Forum on Floods and Forestry – Eugene	Cissel
	• Technical assistance to State agencies and National Forest System concerning forestry-flood interactions.	Swanson, Grant, Johnson, Jones, Cissel
1997	• General Accounting Office study of effectiveness of Northwest Forest Plan in protecting municipal water supplies.	Grant, Swanson
	• Forest Service Roads Policy document	Swanson, Grant
1998	• Congressional briefing on management of floods organized by Ecological Society of America.	Swanson
	• Perry (1998) published review article “The Scientific Basis of Forestry”	
1999	• Book published from 1995 conference on Bioregional Assessments: Science at the Crossroads with Policy and Management (Johnson et al. 1999).	Swanson co-leader
1999-2002	• Independent Multidisciplinary Science Team for salmon recovery in Oregon. Assess conditions of stocks and restoration potential.	Gregory team member
2000	• NAS/NRC Committee Forest Ecosystem Management in the Pacific Northwest.	Gregory co-author
	• State of the Environment report for Oregon. Gregory author of fish and riparian forest sections.	Gregory
2000-	• ESA Issues in Ecology. Applying Ecological Principles to Management of the U.S. National Forests.	Franklin, Perry.
2000-2001	• Scientific Peer-Review Panel for EPA Region 10 Stream temperature panel	Johnson lead
2001	• Field tour for US District Court Judge Michael Hogan.	
	• Consultations on carbon sequestration – State Board of Forestry	Harmon
2001-2002	• NAS/NRC Committee on Riparian Areas: Function and Strategies for Management	Gregory

HJA Databases

A. External Data Requests by Request Type, 1999-2001[1]

Request Type	Number of Requests	Percent	Most Popular
Research Databases			
Hydrology	105[2]	30	HF04: Streamflow
Climate	68	19	MS01: Meteorological Stations
Carbon & Nutrients	57	16	TD23: Fine Litter (LIDET)
Biodiversity	46	13	SA002: Vascular Plant list
Vegetation	42	12	TV010: Reference Stand System
Disturbance	15	4	DF05: Fire History
Soils	13	4	SP01: Soil Descriptions
Stream-Forest	8	2	AS06: Trout Population Studies
Total			
Research Databases	354	100	
GIS maps	34		
Models / Software	573[3]		
General[4]	60		
Total Requests	1021		

[1] This table represents documented requests external to the Andrews LTER (1999-2001) for FSDB databases by research area, and additional requests for GIS maps, models and software, and general information. The majority of databases are accessible directly to users through the Andrews webpage, however certain types of requests require involvement from the information manager. Database download registration is requested but voluntary (unless otherwise noted) using web forms, and probably underestimates actual database downloads.

[2] Access to Andrews streamflow data requires the user to register using a web form, where other databases have voluntary registration.

[3] This value includes 565 downloads of the popular BIOPAK software and biomass equation library, which requires registration.

[4] General information requests include those for photo images and publications, as well as requests regarding database access, database methods, database clarification, and information management processes.

B. List of On-line Databases for the Andrews Experimental Forest LTER

Study Code	**Study Title**	**Lead PI**	**Begin - End Year Year**	**On-Line Status**[1]
1. Climatology				
CP001	National Atmospheric Deposition Program (NADP site OR10): Precipitation chemistry for the Andrews Experimental Forest	Johnson	1980-present	O
CP002	Long term precipitation chemistry patterns and dry deposition chemistry: Andrews Experimental Forest rainwater samples	Johnson	1968-present	O
MS001	Andrews Experimental Forest meteorological data	Johnson	1972-present	O
MS005	Andrews Experimental Forest air and soil temperature network	McKee	1971-present	O
GIS	Raingage network site locations	McKee	1990	O
GIS	Thermograph network site locations	McKee	1990	O
GIS	Mean monthly precipitation (1980-89)	Daly	1995	O
GIS	Mean annual precipitation (19980-89)	Daly	1995	O
GIS	Mean monthly temperature (1980-89)	Swanson	1997	O
GIS	Mean annual temperature (1980-89)	Swanson	1997	O
GIS	Andrews Experimental Forest meteorological station locations	McKee	1996	O
2. Hydrology/Small Watersheds				
CF004	Stream, hyporheic, and ground water chemistry of McRae Creek	Wondzell	1989-1993	O
GS002	Stream cross-section profiles: Andrews Experimental Forest & Hagan Block	Johnson	1978-present	O
GS009	Stream channel unit descriptions on four western cascade streams: Lookout Cr., Mack Cr., Quartz Cr., French Pete Cr.	Grant	1986-1988	P
GS019	Andrews Experimental Forest stream cross-section summary (see GS02)	Faustini	1978-1998	P
HF001	Subsurface flow and soil moisture: Andrews Experimental Forest WS 10, south aspect	McDonnell	1972-1987	P
HF004	Andrews Experimental Forest watershed stream flow summaries	Johnson	1953-present	O
HF006	Andrews Experimental Forest watersheds: WS 1,2,3 storm history with peak flows derived from HF04 summaries	Jones	1955-1988	O

HF007	Peak flow responses to clear-cutting in small and large basins, western Cascades, Oregon	Jones	1933-1991	O
HF009	Andrews Experimental Forest Watershed 3 road runoff	Jones	1995-1996	P
HF010	Stream hyporheic and ground water (water table) elevation data from McRae Creek well network	Wondzell	1989-1993	O
HS003	Andrews Experimental Forest suspended sediment grab samples	Grant	1956-1988	P
HS004	Andrews Experimental Forest bedload data (sediment basin surveys)	Grant	1958-present	O
HT001	Historic Andrews Experimental Forest stream temperature data	Johnson	1956-1983	O
HT002	Andrews Experimental Forest stream and air temperatures along elevational gradients	Johnson	1997-present	P
HT004	Andrews Experimental Forest stream temperature network	Johnson	1976-present	O
GIS	Andrews Experimental Forest streams	Grant	1995	O
GIS	Andrews Experimental Forest gaging stations	Grant	1990	O
GIS	Andrews Experimental Forest hydrologic response units	Grant	1992	O
GIS	Andrews Experimental Forest small experimental watershed boundaries	Valentine	1997	O
GIS	Gaged watershed boundaries	Valentine	1992	O

3. Vegetation

TP103	Species interactions during succession	Halpern	1990-2010	O
TP041	Post-logging community structure and biomass accumulation in Watershed 10	Halpern	1973-present	O
TP064	Dynamics of montane and subalpine meadows in the Three Sisters Wilderness Area/Biosphere Reserve	Halpern	1981-1993	O
TP073	Plant biomass dynamics following logging and burning in the Andrews Experimental Forest Watersheds 1 and 3	Halpern	1962-present	O
TP088	Population dynamics of young forest stands as affected by density and nutrient regime in the Andrews Experimental Forest	Perry	1981-present	P
TP089	Plant succession in upland plots in the devastated zone at Mount St. Helens	Halpern	1980-present	P
TV009	Dendrometer studies for stand volume and height measurements	Harmon	1978-present	O
TV010	LTER reference stand system	O'Connell	1910-present	O
TV052	Early succession study synthesis area - live tree data	O'Connell	1999-2000	O
GIS	Andrews Experimental Forest plant communities	McKee	1990	O

GIS	Willamette National Forest current vegetation (clipped to HJA)	Valentine	1997	O
GIS	Potential vegetation	Henderson	Unknown	O
GIS	Vegetation survey	Bond	2000	P
GIS	Andrews Experimental Forest reference stand locations	O’Connell	1991-present	O
GIS	Willamette National Forest vegetation 4 (clipped to HJA)	Valentine	1993	O
GIS	Willamette National Forest vegetation 5a (clipped to HJA)	Valentine	1996	O
GIS	Andrews Experimental Forest stand age image (1988 TM image)	Cohen	1994	O
GIS	Vegetation survey locations	Halpern	1962-present	P
GIS	Early succession synthesis area locations	Harmon	1998	P
GIS	Gap study (TV025) site locations	Hunter	1995	P

4. Biological Diversity/Species Lists

SA001	Invertebrates of the Andrews Experimental Forest: An annotated list of insects and other arthropods	Miller	1971-present	O
SA002	Vascular plant list for the Andrews Experimental Forest and nearby Research Natural Areas	Halpern	1958-present	O
SA003	Bird species list for the Andrews Experimental Forest and Upper McKenzie River basin	Garman	1975-1995	O
SA004	Amphibian and reptile species list for the Andrews Experimental Forest	Garman	1975-1995	O
SA005	Mammal species list of the Andrews Experimental Forest	Garman	1971-1976	O
SA006	Fish species list for the Andrews Experimental Forest	Gregory	1975-1995	O
SA007	Benthic algal species list for the Andrews Experimental Forest	Gregory	1991-1992	O
SA008	Moss list for the Andrews Experimental Forest	O'Connell	1991-1991	O
SA009	Riparian bryophyte list for the Andrews Experimental Forest	O'Connell	1994-1995	O
SA010	Epiphyte list for the Andrews Experimental Forest, Watershed 10	McCune	1970-1972	O
SA011	Epiphytic macrolichen list for the Andrews Experimental Forest and Blue River Watershed	McCune	1992-1993	O
SA012	Macroinvertebrate list for the Andrews Experimental Forest	Li	1992-1993	O
SA013	Aquatic invertebrate list for Lookout Creek in the Andrews Experimental Forest	Gregory	1988-1990	O
SA014	Mycorrhizal belowground fungi list for the Andrews Experimental Forest	Smith	1992-1994	O
TS15	Comparison of arthropod densities on young-growth and old-growth	Schowalter	1986-1986	O

	foliage			
TV036	Study of streamside mosses at the Andrews Experimental Forest	Jonsson	1994-1995	O
WE008	Willamette NF: Young stand thinning and diversity study: Ground-dwelling vertebrates, birds, habitat data	Garman	1991-present	P
WE021	Blue River Watershed stream amphibians	Hunter	1995-1996	P
WE022	Blue River landscape study stream amphibian monitoring	Hunter	1998-present	P
WE024	Blue River Watershed herpetological observations	Hunter	1995-1995	P
WE026	Monitoring small mammal and amphibian abundances on the Willamette NF: Long-Term Ecosystem Productivity (LTEP) experiments	Garman	1995-1999	O
WE027	Vertebrate-habitat relationships: Logistic regression models	Garman	1998-1999	O
GIS	Butterfly survey locations	Miller	1949-1979	P
GIS	Moth backlight survey locations	Miller	1994-present	P
GIS	Mushroom study site locations	Smith	1992-1994	O
GIS	Chanterelle study site locations	Dunham	Unknown	P
GIS	Canopy arthropod study	Schowalter	Unknown	P

5.Carbon and Nutrient Dynamics/Decomposition

FS111	Conversion factors for forest products	Harmon	1993-present	O
MS008	Andrews Experimental Forest log decomposition thermograph data	Harmon	1985-1989	P
TD012	Log and snag dimensions	Harmon	1984-present	P
TD014	Long-term log decay experiments at the Andrews Experimental Forest	Harmon	1985-2185	P
TD017	Stream -upland wood decay experiment	Harmon	1985-present	P
TD018	Nitrogen fixation and respiration potential of conifer logs	Harmon	1987-present	O
TD020	Respiration patterns of logs in the Pacific Northwest	Harmon	1986-present	P
TD021	Fine wood decay studies	Harmon	1989-present	P
TD022	Coarse woody debris density and nutrient data	Harmon	1982-present	P
TD023	LTER Fine Litter Decomposition Experiment (LIDET)	Harmon	1990-2002	P
TD025	Log leachates from the Andrews Experimental Forest	Harmon	1986-present	O
TD026	Moisture content of logs	Harmon	1985-present	O
TD027	Structural-anatomical components of woody plant parts	Harmon	1995-present	O
TD028	Forest floor data for decomposition studies	Harmon	1992-present	O
TD029	Comparison of native litter species occurring at the Andrews Experimental	Harmon	1993-present	P

	Forest to LIDET standard species.			
TD030	Fine woody debris inventory data	Harmon	1992-present	O
TD032	Root chronosequence study	Harmon	1995-1997	P
TD035	Coarse woody debris line transect inventory	Harmon	1997-present	O
TL001	Andrews Experimental Forest reference stand component litterfall study	Harmon	1976-present	P
TL003	A Study of selected ecosystem parameters potentially sensitive to air pollutants	Harmon	1984-1987	P
TP107	Reference stand and early succession synthesis area understory vegetation	O'Connell	1979-present	P
TV030	Decay in standing trees	Harmon	1982-1992	O
GIS	Andrews Experimental Forest log decompositions site locations	Harmon	1985-1989	O
GIS	Fine litter decomposition experiment (LIDET) locations	Harmon	1990-present	P

6. Stream-Forest Interactions

AS006	Population studies of rainbow and cutthroat trout in Andrews Experimental Forest	Gregory	1975-present	P
CF002	Long term stream chemistry patterns: Andrews Experimental Forest proportional samples	Johnson	1968-present	O
GS006	Andrews Experimental Forest tagged log inventory (stream wood)	Gregory	1982-present	P
GS016	Amount and distribution of coarse woody debris in Lookout Creek	Swanson	1991-1991	O
HS005	Effects of stand age, season, and elevation on the nutrient and microbial characteristics of mountain stream fine benthic organic matter	Griffiths	1995-1996	O
HS006	The effect of debris flows on stream fine benthic organic matter (FBOM) characteristics	Griffiths	1996-1996	O
GIS	Geology of the Andrews Experimental Forest	Swanson	1993-1994	O
GIS	Long-term channel dynamics and alder study location	Wondzell	1997-1998	P
GIS	Hyporheic study site location	Wondzell	1997-1998	P
GIS	Stream trace experiment locations	Wondzell	1997-1998	P
GIS	Landscape nutrient synoptic survey locations	Johnson	2000-present	P
GIS	Stream temperature sensor locations	Johnson	1997-present	P
GIS	Lookout Creek cross section locations	Valentine	1996	O
GIS	Floodplain channel mapping	Ashkenas	1998	P
GIS	Nutrient uptake and hydrographic study	Ashkenas	1998	P

GIS	LINX research study area	Ashkenas	1998	P
GIS	Riparian study mapping	Valentine	1986	O
7. Landscape Dynamics and Disturbance				
DF001	Historical fire data summaries for Central Western Cascades 1910-77 from archival sources	Swanson	1910-1977	P
DF005	Fire history database of the Western United States	Swanson	1200-1994	O
DF006	Oregon coastal range fire regime study	Swanson	1993-present	P
DF008	Fire history and fire regimes of the Little River Watershed, Douglas Co., OR	Swanson	1496-1996	P
DF013	Fire history, fire regimes, and development of forest structure in the Central Western Cascades	Swanson	1998	P
DF014	Blue River fire history	Swanson	1998	P
DF015	Master fire chronology based on fire history data from Teensma/Morrison	Swanson	1998	P
GE007	Upper Blue River landslide hazard evaluation	Swanson	1948-present	P
GE008	Road-related erosion - February 1996 flood (Blue River and Lookout Creek Basins)	Jones	1999-1999	P
GV009	Riparian geomorphic surface - vegetation relationships: Mack Cr., Lookout Cr., Quartz Cr., French Pete Cr.	Grant/Swanson	1986-1986	P
GV015	Recovery of riparian vegetation following debris torrent	McKee	1986-1989	P
TD010	Origin of large woody debris in streams (H. McDade thesis)	Swanson	1981-1981	O
TP054	Andrews Experimental Forest: Forest management history	Swanson	1980-present	O
GIS	Large organic debris mapping	Valentine	1996	O
GIS	10 meter contours from 30 meter DEM	Valentine	1996	O
GIS	30 meter contours from 30 meter DEM	Valentine	1996	O
GIS	50 meter contours from 30 meter DEM	Valentine	1996	O
GIS	Lattice created from 10 meter DEM	Valentine	1998	O
GIS	Lattice created from 30 meter DEM	Valentine	1996	O
GIS	50 foot contour created from 10 meter DEM	Valentine	1996	O
GIS	Andrews Experimental Forest slope grid generated from 30 meter DEM	Valentine	1998	O
GIS	Road construction history of the Andrews Experimental Forest	Valentine	1991	O
GIS	Aspect grid generated from 30 meter DEM	Valentine	1996	O

GIS	1991 spot fire locations	Swanson	1992	O
GIS	Coarse woody debris flood potential	Swanson	1992	O
GIS	Debris flow hazard on the Andrews Experimental Forest	Swanson	1992	O
GIS	Earthflow susceptibility in the Andrews Experimental Forest	Swanson	1992	O
GIS	Streamside slide hazard in the Andrews Experimental Forest	Swanson	1992	O
GIS	Salvage sales in the Andrews Experimental Forest	McKee	1954-present	O
GIS	Andrews Experimental Forest landslide locations	Swanson	1992	O
GIS	Slide inventory of Andrews Experimental Forest and vicinity	Swanson	1953-1996	O
GIS	Uneven age management study locations	Tucker	1997	O
GIS	1996 flood channel mapping	Wondzell	1996	P
GIS	Fire history of the Andrews Experimental Forest	Valentine	1997	O
GIS	Large organic debris mapping	Valentine	1996	O
GIS	Slicer laser altimeter study plots	Means	1996	O

8. Soils

SP001	Soil descriptions and data for profiles in the Andrews Experimental Forest, selected reference stands, RNA's, and National Parks	Dyrness	1962-1996	O
SP004	Seasonal relationships between soil respiration and water-extractable carbon as influenced by soil temperature and moisture in forest soils	Griffiths	1992-1993	O
SP005	Andrews Experimental Forest 1993 REU synoptic soil respiration of permanent forest sites	Griffiths	1993-1994	O
SP006	Andrews Experimental Forest 1994 REU study of soil chemical and microbiological properties	Griffiths	1994-1994	O
SP007	Disturbance effects on soil processes (stand age study)	Griffiths	1995-present	O
SP008	Effect of thinning pole stands on soil processes (BLM study)	Griffiths	1994-1996	O
SP009	Role of vegetation and coarse wood debris on soil processes and mycorrhizal mat distribution patterns at the High 15 site	Griffiths	1994-1995	P
SP010	Long-term respiration in soils collected from the REU synoptic Andrews Experimental Forest sample grid	Griffiths	1994-1995	P
SP012	The relationship between early succession rates and soil properties	Griffiths	1999-2000	P
SP014	Seasonal soil respiration using permanent gas chambers	Griffiths	1994-1996	O
SP016	Influence of coniferous tree invasion on forest meadow soil properties	Griffiths	1998-1998	P

SP017	The influence of tree-fall gaps on soil characteristics in gaps of varying sizes	Griffiths	1995-1995	P
SP018	The influence of microclimate gradients on soil characteristics within tree-fall gaps	Griffiths	1997-1997	P
SP019	The influence of tree-fall gaps on soil characteristics	Griffiths	1999-1999	P
SP020	The effects of topography on Andrews Experimental Forest soil characteristics	Griffiths	1998-1998	P
SP021	Chemical and biochemical characteristics of soils along transects in stands with different vegetation and successional characteristics	Griffiths	1996-1996	P
SP022	Association of ectomycorrhizal mats with Pacific yew and other understory trees	Griffiths	1992-1994	P
GIS	Andrews Experimental Forest 1964 revised soil survey	Sollins	1964	O
GIS	Andrews Experimental Forest soil resource inventory	Valentine	1995	O
GIS	Andrews Experimental Forest soils synoptic sampling grid	Griffiths	1993-1998	P
GIS	High 15 surface features on plot	Griffiths	1994-1995	P
GIS	Mycorrhizal mat mapping	Griffiths	1992	P
GIS	Detrital input and removal treatment (DIRT) plot locations	Lajtha	1999	P
GIS	Gas flux study sample locations	Griffiths	1996	O

9. Ecophysiology

TW003	Andrews Experimental Forest vegetation water use (sapflow)	Bond	1999-present	P
GIS	Sap flow study locations	Bond	2000	P

10. Base Information				
GIS	GPS point locations	Valentine	1994	P
GIS	Digital orthophotography of Andrews Experimental Forest	Valentine	1994	O
GIS	Black and white shaded relief of Andrews Experimental Forest (10 meter DEM)	Valentine	2001	O
GIS	Black and white shaded relief of Andrews Experimental Forest (30 meter DEM)	Valentine	1996	O
GIS	Andrews Experimental Forest GPS monument locations	Valentine	1993	O
GIS	Boundary of the Andrews Experimental Forest	Valentine	1997	O

[1] On-line status codes:

O= On-line. Data and metadata are available on-line. Note: some data sets may be partially restricted, but any restrictions will be described and justified on the web site.

P= Pending Status. Data and metadata are currently in transition into the new information system and will be on-line by June 2002.

References Cited

Acker, S. A.; McKee, A. W.; Harmon, M. E.; Franklin, J. F. 1998a. Long-term research on forest dynamics in the Pacific Northwest: a network of permanent forest plots. In: Dallmeier, F., J. A. Comiskey, eds. Forest biodiversity in North, Central, and South America and the Caribbean: Research and Monitoring; 1995 May 23-25; Washington, DC. New York, NY: The Parthenon Publishing Group, Inc.: 93-106. (Jeffers, J. N. R., ed. Man and the Biosphere Series. Vol. 21).

Acker, S. A.; Zenner, E. K.; Emmingham, W. H. 1998b. Structure and yield of two-aged stands on the Willamette National Forest, Oregon: implications for green tree retention. Canadian Journal of Forest Research 28(5): 749-758.

Acker, S. A.; Harcombe, P. A.; Harmon, M. E.; Greene, S. E. 2000. Biomass accumulation over the first 150 years in coastal Oregon *Picea-Tsuga* forest. Journal of Vegetation Science 11: 725-738.

Acker, S. A.; Halpern, C. B.; Harmon, M. E.; Dyrness, C. T. 2002. Trends in bole biomass accumulation, net primary production, and tree mortality in *Pseudotsuga menziesii* forests of contrasting age. Tree Physiology 22: 213-217.

Acker, S.A.; McKee, W.A.; Lienkaemper, G.; Miller, S.C.; Swanson, F.J.; Gregory, S.V. In press. Composition, complexity, and tree mortality in riparian forests in the central western Cascades of Oregon. Forest Ecology and Management.

Baines, S. B.; Webster, K. E.; Kratz , T. K.; Carpenter, S. R.; Magnuson, J. J. 2000. Synchronous behavior of temperature, calcium and chlorophyll in lakes of northern Wisconsin. Ecology 81: 815-825.

Baker, K. S.; Benson, B. J.; Henshaw, D. L.; Blodgett, D.; Porter, J. H.; Stafford, S. G. 2000. Evolution of a multisite network information system: the LTER information management paradigm. BioScience 50(11): 963-978.

Benson, B. J.; Lenters, J. D.; Magnuson, J. J.; Stubbs, M.; Kratz, T. K.; Dillon, P. J.; Hecky, R. E.; Lathrop, R. C. 2000. Regional coherence of climatic and lake thermal variables of four lake districts in the Upper Great Lakes Region of North America. Freshwater Biology. 43: 517-527.

Berkley, E. L. 2000. Temporal and spatial variability of fire occurrence in western Oregon, A.D. 1200 to present. Eugene, OR: University of Oregon. 110 p. M.S. thesis.

Beschta, R. L.; Pyles, M. R.; Skaugset, A. E.; Surfleet, C. G. 2000. Peakflow responses to forest practices in the western cascades of Oregon, USA. Journal of Hydrology 233: 102-120.

Beven, K. 1993. Prophecy, reality, and uncertainty in distributed hydrological modeling. Advances in Water Resources 16: 41-51.

Beven, K. 1996. Equifinality and uncertainty in geomorphological modeling. pp. 289-313 in Rhoads, B.L.; Thorn, C.E. The Scientific Nature of Geomorphology: Proceedings of the 17th Binghamton Symposium in Geomorphology. New York, John Wiley.

Bierlmaier, F.A.; McKee, A. 1989. Climatic summaries and documentation for the primary meteorological station, H.J. Andrews Experimental Forest, 1972 to 1984. Gen. Tech. Rep. PNW-242. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 56 p.

Bible, K. J. 2001. Long-term patterns of Douglas-fir and western hemlock mortality in the western Cascade Mountains of Washington and Oregon. Seattle, WA: University of Washington. 85 p. Ph.D. dissertation.

Bisson, P. A.;. Reeves, G.H.; Gregory, S.V. In press. Trends in Using Wood to Restore Aquatic Habitats and Fish Communities in Western North American Rivers. In: Gregory, S.V.; Staley, K. eds. Ecology and Management of Wood in World Rivers. American Fisheries Society, Bethesda, MD.

Bond, B.J.; Jones, J.A.; Moore, G.; Phillips, N.; Post, D.; McDonnell, J. In press. The zone of vegetation influence on baseflow revealed by diel patterns of streamflow and vegetation water use in a headwater basin. Hydrological Processes Today.

Burgess, J.A. 2001. Response of trout, sculpins, and salamanders to experimental manipulation of large wood in Cascade Mountain streams. Oregon State University. 95 p. M.S. Thesis.

Chen, H. 1999. Root decomposition in three coniferous forests: effects of substrate quality, temperature, and moisture. Ph.D. dissertation, Oregon State University. 218 p.

Chen, H.; Harmon, M. E.; Griffiths, R. P. 2001. Decomposition and nitrogen release from decomposing woody roots in coniferous forests of the Pacific Northwest: a chronosequence approach. Canadian Journal of Forest Research 31: 246-260.

Chen, H.; Harmon, M. E.; Griffiths, R. P.; Hicks, W. 2000. Effects of temperature and moisture on carbon respired from decomposing woody roots. Forest Ecology and Management 138: 51-64.

Cissel, J. H.; Swanson, F. J.; Grant, G. E.; Olson, D. H.; Gregory, S. V.; Garman, S. L.; Ashkenas, L. R.; Hunter, M. G.; Kertis, J. N.; Mayo, J. H.; McSwain, M. D.; Swetland, S. G.; Swindle, K. A.; Wallin, D. O. 1998. A landscape plan based on historical fire regimes for a managed forest ecosystem: the Augusta Creek study. Gen. Tech. Rep. PNW-GTR-422. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 82 p.

Cissel, J. H.; Swanson, F. J.; Weisberg, P. J. 1999. Landscape management using historical fire regimes: Blue River, Oregon. Ecological Applications 9(4): 1217-1231.

Cohen, W. B.; Harmon, M. E.; Wallin, D. O.; Fiorella, M. 1996. Two decades of carbon flux from forests of the Pacific Northwest: estimates from a new modeling strategy. BioScience 46(11): 836-844.

Committee for a Pilot Study on Database Interfaces, U. S. National Committee for CODATA Commission on Physical Sciences Mathematics and Applications National Research Council. 1995. The H.J. Andrews Experimental Forest Long-Term Ecological Research Site. In: The Committee finding the forest in the trees: the challenge of combining diverse environmental data. Selected case studies. Washington, DC: National Academy Press: 46-55.

Dahlgren, R. A., and C. T. Driscoll. 1994. The effects of whole-tree cutting clear-cutting on soil processes at the Hubbard Brook Experimental Forest, New Hampshire, USA. Plant and Soil 158:239-262.

Dahm, C.N. 1980. Studies on the distribution and fates of dissolved organic carbon. Oregon State University. 145 pp. Ph.D. Dissertation.

Daly, C.; Johnson, G.L. 1999. PRISM spatial climate layers: their development and use. Short Course on Topics in Applied Climatology, 79th Annual Meeting of the American Meteorological Society, 10-15 January, Dallas, TX. 49 pp. http://www.ocs.orst.edu/prism/prisguid.pdf.

Daly, C.; Taylor, G.H.; Gibson, W.P. 1997. The PRISM approach to mapping precipitation and temperature. In: Proc., 10th AMS Conf. on Applied Climatology, Amer. Meteorological Soc., Reno, NV, Oct. 20-23, 10-12..

Daly, C.; Neilson, R.P.; Phillips, D.L. 1994. A statistical-topographic model for mapping climatological precipitation over mountainous terrain. Journal of Applied Meteorology 33: 140-158.

Daly, C.; Gibson, W. P.; Taylor, G.H.; Johnson, G. L.; Pasteris, P. In press. A knowledge-based approach to the statistical mapping of climate. Climate Research.

Daly, C.; Taylor, G.H.; Gibson, W. P.; Parzybok, T.W.; Johnson, G. L.; Pasteris, P. 2001. High-quality spatial climate data sets for the United States and beyond. Transactions of the American Society of Agricultural Engineers 43: 1957-1962.

Davidson, E. A.; Nepstad, D. C.; Klink, C.; Trumbore, S. E. 1995. Pasture soils as carbon sink. Nature 376: 472-473.

Dise, N. B.; Wright, R. F. 1995. Nitrogen leaching from European forests in relation to nitrogen deposition. Forest Ecology and Management 71: 153-161.

Dunn, A. L. 2001. Carbon cycle response to climate variability using a statistical model. EOS Trans. AGU 82(20) Spring Meeting Suppl Abstract B42A-05:S92

Farquhar, G.D.; Ehleringer, J.R.; Hubick, K.T. 1989. Carbon isotope discrimination and photosynthesis. Annu. Rev. Plant Physiol. Plant Mol. Biol. 40: 503-537.

Faustini, J. M.; Jones, J. A. 2000. Influence of large wood on the morphology and dynamics of a 3rd order mountain stream, western Cascades, Oregon [Abstract]. In: International conference on wood in world rivers; 2000 October 23-27; Corvallis, OR. Oregon State University: 32.

Faustini, J. M. 2000. Stream channel response to peak flows in a fifth-order mountain watershed. Oregon State University. 339 p. Ph.D. dissertation.

Faustini, J. M.; Jones, J.A. In press. Influence of large woody debris on channel morphology and dynamics in steep, boulder-rich mountain streams, western Cascades, Oregon. Geomorphology.

Findlay, S.; Tank, J.; Dye, S.; Valett, H.M.; Mullholland, P.; McDowell, W.H.; Johnson, S.L.; Hamilton, S.K.; Edmonds, J.; Dodds, W.K.; Bowden, W.B. In press. A cross-system comparison of bacterial and fungal biomass in detritus pools of headwater streams. Microbial Ecology.

Flanagan, L.B.; Ehleringer, J.R. 1998. Ecosystem-atmosphere CO_2 exchange: interpreting signals of change using stable isotope ratios. Trends Ecol. Evol. 13: 370-374.

Franklin, J.; Dyrness, C.T. 1988. Natural Vegetation of Oregon and Washington. Oregon State University Press, Corvallis, OR.

Fraser, V. D. 2001. Biomass and productivity in an old-growth Douglas-fir/western hemlock stand in the western Cascades of Oregon. New Haven, CT: Yale University; project report for a non-thesis M.S. degree. 15 p.

Garman, S. L.; Swanson, F. J.; Spies, T. A. 1999. Past, present, and future landscape patterns in the Douglas-fir region of the Pacific Northwest. In: Rochelle, J. A.; Lehmann, L. A.; Wisniewski, J., eds. Forest fragmentation: wildlife and management implications. Leiden, The Netherlands: Koninklijke Brill NV: 61-86.

Gholz, H.L.; Wedin, D.A.; Smitherman, S.M.; Harmon, M.E.; Parton, W.J. 2000. Long-term dynamics of pine and hardwood litter in contrasting environments: toward a global model of decomposition. Global Change Biology 6: 751-765.

Goodale, C. L.; Aber, J. D. 2001. The long-term effects of land-use history on nitrogen cycling in northern hardwood forests. Ecological Applications 11: 253-267.

Granier, A. 1985. Une nouvelle methode pour la mesure de flux de seve brute dans le tronc des arbres. Ann. Sci. For. 42: 193-200.

Granier, A. 1987. Evaluation of transpiration in a Douglas-fir stand by means of sap flow measurements. Tree. Physiol. 3: 309-320.

Grant, G.E.; Wolff, A.L. 1991. Long-term patterns of sediment transport after timber harvest, western Cascade Mountains, Oregon, USA. In: Peters, N.E.; Walling, D.E.; eds. Sediment and stream water quality in a changing environment: trends and explananation, Proceedings of the Vienna IAHS symposium, 1991 August 12-23; Vienna, Austria. IAHS Publication No. 203. Oxfordshire, United Kingdom: international Association of Hydrological Sciences: 31-40.

Graumlich, L. J.; Brubaker, L.B. 1986. Reconstruction of annual temperature (1590-1979) for Longmire, Washington, derived from tree rings. Quaternary Research 25: 223-234.

Graumlich, L. J. 1987. Precipitation variation in the Pacific Northwest (1675-1975) as reconstructed from tree rings. Annals Associat. Amer. Geographers 77: 19-29.

Green, D. G. 2000. Self-organisation in complex systems. Pages 12-50 *in* T. R. J. Bossomaier and D. G. Green (eds.). Complex Systems. Cambridge Unviersity Press, Cambridge, UK.

Green, D. G. 1993. Emergent behaviour in biological systems. Pages 24-35 *in* Green, D. G., and T. R. J. Bossomaier (eds.). Complex Systems - From Biology to Computation. IOS Press, Amsterdam.

Greenland, D. 1996a. Offshore coho salmon populations near the Pacific Northwest and large-scale atmospheric events. In: Isaacs, C. M.; Tharp, V. L., eds. Proceedings of the twelfth annual Pacific Climate (PACLIM) workshop; 1995 May 2-5; [Place of meeting unknown]. Tech. Rep 46. [Place of publication unknown]: Interagency Ecological Program, California Department of Water Resources: 109-119.

Greenland, D. 1996b. Salmon populations and large scale atmospheric events. In: Keefe, MaryLouise, ed. Salmon ecosystem and restoration: myth and reality. Proceedings of the 1994 Northeast Pacific chinook and coho salmon workshop; 1994 November 7-10; Eugene, OR. Corvallis, OR: American Fisheries Society, Oregon Chapter: 103-114. [This paper has been republished under the title "Offshore coho salmon populations near the Pacific Northwest and large-scale atmospheric events" in the Proceedings of the twelfth annual Pacific Climate (PACLIM) workshop.].

Greenland, D. 1998. Variability and stability of climatic/oceanic regimes in the Pacific Northwest. In: McMurray, Gregory R.; Bailey, Robert J., eds. Change in Pacific Northwest coastal ecosystems: Proceedings of the Pacific Northwest coastal ecosystems regional study workshop; 1996 August 13-14; Troutdale, OR. NOAA Coastal Ocean Program Decision Analysis Series No. 11. Silver Spring, MD: NOAA Coastal Ocean Office: 91-179.

Greenland, D.; Bierlmaier, F.; Jones, J.; McKee, A.; Means, J.; Swanson, F.; Whitlock, C. In prep. Ecological response to climate variability at the H.J. Andrews Experimental Forest. In: Greenland, D.; Goodin, D.; Smith, R., eds. Climate variability and ecosystem response at Long-Term Ecological Research sites. Oxford Press.

Greenland, D. In review. Climatic gradients in the U.S. Long-Term Ecological Research (LTER) network. Annals of the Association of American Geographers.

Grier, C. C., and R. S. Logan. 1977. Old-growth Pseudotsuga menziesii communities of a western Oregon watershed: biomass distribution and production budgets. Ecological Monographs 47:373-400.

Gundersen, P.; Emmett, B. A.; Kjonaas, O. J.; Koopmans, C. J.; Tietema, A. 1998. Impact of nitrogen deposition on nitrogen cycling in forests: a synthesis of NITREX data. Forest Ecology and Management 101:37-56.

Haggerty, R.; Wondzell, S.M.; Johnson, M.A. In review. Power-law residence time distribution in the hyporheic zone of a 2nd-order mountain stream. Geophysical Research Letters.

Halpern, C.B. 1988. Early successional pathways and the resistance and resilience of forest communities. Ecology 69: 1703-1715.

Halpern, C.B. 1989. Early successional patterns of forest species: interactions of life history traits and disturbance. Ecology 70 (3): 704-720.

Halpern, C.B.; Franklin, J.F. 1990. Physiognomic development of *Pseudotsuga* forests in relation to initial structure and disturbance intensity. Journal of Vegetation Science 1:475-482.

Halpern, C. B.; Franklin, J.F.; McKee, A. 1992. Changes in plant species diversity after harvest of Douglas-fir forests. The Northwest Environmental Journal 8:205-207.

Halpern, C.B.; Spies, T.A. 1995. Plant species diversity in natural and managed forests of the Pacific Northwest. Ecological Applications 1:475-482.

Halpern, Charles B.; Antos, Joseph A.; Geyer, Melora A.; Olson, Annette M. 1997. Species replacement during early secondary succession: the abrupt decline of a winter annual. Ecology 78(2): 621-631.

Halpern, C.B. 2002. Constraints on conifer regeneration: A review of the literature and a conceptual model for the Pacific Northwest region. Web report. http://www.fsl.orst.edu/lter.

Hammond, P. C.; Miller, J. C. 1998. Comparison of the biodiversity of Lepidoptera within three forested ecosystems. Annals of the Entomological Society of America 91(3): 323-328.

Harmon, M. E.; Bible, K.; Ryan, M. J.; Shaw, D.; Chen, H.; Klopatek, J.; Li, X. In review. Production, respiration, and overall carbon balance in an old-growth Pseudotsuga/Tsuga forest ecosystem. Ecosystems.

Harmon, M.E.; Ferrell, W.; Franklin, J.F. 1990. Effects on carbon storage of conversion of old-growth forests to young forests. Science 247: 699-702.

Harmon, M. E. 2000. Decomposition and movement of wood in Lookout Creek, Oregon. 2000. p 42 In: Abstracts of the International Conference on Wood in World Rivers. Oregon State University, Corvallis, OR (http://riverwood.orst.edu)

Harmon, M. E. 2000. Decomposition of the third kind: results from the LIDET project [Abstract]. In: Communicating and advancing ecology: The Ecological Society of America 85th annual meeting; 2000 August 6-10; Snowbird, UT. Washington, DC: The Ecological Society of America: 114.

Harmon, M. E. 2001. Carbon sequestration in forests: addressing the scale question. Journal of Forestry 99(4): 24-29.

Harmon, M. E.; Krankina, O. N.; Yatskov, M.; Matthews, E. 2001. Predicting broad-scale carbon stores of woody detritus from plot-level data. In: Lal, R.; Kimble, J. M.; Follett, R. F.; Stewart, B. A., eds. Assessment methods for soil carbon. Boca Raton, FL: Lewis Publishers/CRC Press LLC: 533-552.

Harmon, M. E.; Krankina, O. N.; Sexton, J. 2000. Decomposition vectors: a new approach to estimating woody detritus decomposition dynamics. Canadian Journal of Forest Research 30: 76-84.

Harmon, M. E.; Lajtha, K. 1999. Analysis of detritus and organic horizons for mineral and organic constituents. In: Robertson, G. P.; Coleman, D. C.; Bledsoe, C. S.; Sollins, P., eds. Standard soil methods for long-term ecological research. New York, NY: Oxford University Press: 143-165.

Harmon, M. E.; Marks, B. In press. Effects of silvicultural treatments on carbon stores in forest stands. Canadian Journal of Forest Research

Harmon, M. E.; Nadelhoffer, K. J.; Blair, J. M. 1999. Measuring decomposition, nutrient turnover, and stores in plant litter. In: Robertson, G. P.; Coleman, D. C.; Bledsoe, C. S.; Sollins, P., eds. Standard soil methods for long-term ecological research. New York, NY: Oxford University Press: 202-240.

Harr, R.D. 1982. Fog drip in the Bull Run Municipal Watershed, Oregon. Water Resources Bulletin 18(5): 785-789.

Harr, R.D. 1986. Effects of clearcutting on rain-on-snow runoff in western Oregon: a new look at old studies. Water Resources Research 22(7): 1095-1100.

Henshaw, D. L.; Stubbs, M.; Benson, B. J.; Baker, K.; Blodgett, D.; Porter, J. H. 1998. Climate database project: a strategy for improving information access across research sites. In: Michener, W. K.; Porter, J. H.; Stafford, S. G., eds. Data and information management in the ecological sciences: a resource guide; 1997 August 8-9; Albuquerque, NM. Albuquerque, NM: LTER Network Office, University of New Mexico: 123-127.

Henshaw, D. L.; Spycher, G. 1999. Evolution of ecological metadata structures at the H.J. Andrews Experimental Forest Long-Term Ecological Research (LTER) site. In: Aguirre-Bravo, C.; Franco, C. R., eds. North American science symposium: toward a unified framework for inventorying and monitoring forest ecosystem resources; 1998 November 2-6; Guadalajara, Mexico. Proceedings RMRS-P-12. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 445-449.

Heyborne W. H. 2000. Ground Dwelling Beetles in Early and Late Successional Forests in the Western Cascades of Oregon. Oregon State University. 100 p. M.S. Thesis.

Hicks, W. T. 2000. Modeling nitrogen fixation in dead wood. Oregon State University. 160 p. Ph.D. dissertation.

Hicks, W. T.; Harmon, M. E. In press. Diffusion and seasonal dynamics of O2 in woody debris from the Pacific Northwest, USA. Plant and Soil.

Hogeweg, P. 1988. Cellular automata as a paradigm for ecological modeling. Applied Mathematical Computation 27:81-100.

Holling, C. S. 2001. Understanding the complexity of economic, ecological, and social systems. Ecosystems 4: 390-405.

Holub, S.M.; Spears, J.D.H.; Lajtha, K. 2001. A reanalysis of nutrient dynamics in coniferous coarse woody debris. Canadian Journal of Forest Research 31: 1894-1902.

Hornbeck, J. W.; Martin, C. W.; Eagar, C. 1997a. Summary of water yield experiments at Hubbard Brook Experimental Forest, New Hampshire. Can. J. For. Res. 27: 2043-2052.

Hornbeck, J. W.; Bailey, S. W.; Buso, D. C.; Shanley, J. B. 1997b. Streamwater chemistry and nutrient budgets for forested watersheds in New England: variability and management implications. Forest Ecology and Management 93: 73-89.

Hunter, M.G. 2001. Management in young forests. Communique: Cascade Center for Ecosystem Management. Corvallis, OR: Department of Forest Science, Oregon State University; U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station; Willamette National Forest. 27 p.

Irvine, J.; Law, B. 2000. Contrasting soil respiration in young and old ponderosa pine stands. [Abstract]. In: Communicating and advancing ecology: The Ecological Society of America 85th annual meeting; 2000 August 6-10; Snowbird, UT. Washington, DC: The Ecological Society of America: 292.

Janisch, J. E.; Harmon, M.E. 2002. Successional changes in live and dead wood stores: Implications for Net Ecosystem Productivity. Tree Physiology 22: 77-89.

Johnson D.W.; Curtis P.S. 2001. Effects of forest management on soil C and N storage: meta analysis. Forest Ecology and Management 140: 227-238.

Johnson, S. L.; Swanson, F. J.; Grant, G. E.; Wondzell, S. M. 2000. Riparian forest disturbances by a mountain flood -- the influence of floated wood. Hydrological Processes 14: 3031-3050.

Johnson, S.L.; Jones, J.A. 2000. Steam responses to forest harvest and debris flows in western Cascades, Oregon. Can. J. Fish. Aquat. Sci. 57: 30-39 Suppl 2.

Jones, J. A. 2000. Hydrologic processes and peak discharge response to forest removal, regrowth, and roads in 10 small experimental basins, western Cascades, Oregon. Water Resources Research 36(9): 2621-2642.

Jones, J. A.; Post, D. A. 1999. Ecological hydrology--intersite comparison of long-term streamflow records from forested basins in Oregon, New Hampshire, North Carolina, and Puerto Rico. LTER The Network News 12(2): 10, 15.

Jones, J.A.; Post D.A. In prep. Long-term streamflow responses to forest canopy removal in Oregon, New Hampshire, and North Carolina. For submission to Water Resources Research.

Jones, J. A.; Grant, G. E. 1996. Peak flow responses to clear-cutting and roads in small and large basins, western Cascades, Oregon. Water Resources Research 32(4): 959-974.

Jones, J. A.; Grant, G. E. 2001a. Comment on "Peak flow responses to clear-cutting and roads in small and large basins, western Cascades, Oregon: a second opinion" by R.B. Thomas and W.F. Megahan. Water Resources Research 37(1): 175-178.

Jones, J. A.; Grant, G. E. 2001b. Comment on "Peak flow responses to clear-cutting and roads in small and large basins, western Cascades, Oregon" by J.A. Jones and G.E. Grant. Water Resources Research. 37(1): 179-180.

Jones, J.A.; Perkins, R.M. In prep. Forest harvest effects on rain-on-snow floods, western Cascades, Oregon. For submission to Water Resources Research.

Jones, J. A.; Swanson, F. J.; Wemple, B. C.; Snyder, K. U. 2000. Effects of roads on hydrology, geomorphology, and disturbance patches in stream networks. Conservation Biology 14(1): 76-85.

Jones, J. A.; Swanson, F. J. 2001. Hydrologic inferences from comparisons among small basin experiments. Hydrological Processes 15: 2363-2366.

Kirchner, J.; Feng, X.; Neal, C. 2000. Fractal stream chemistry and its implications for contaminant transport in catchments. Nature 403: 524-527.

Kling, G.K.; Kipphut, G.W.; Miller, M.M.; O'Brien, W.J. 2000. Integration of lakes and streams in a landscape perspective: the importance of material processing on spatial patterns and temporal coherence. Freshwater Biology 43: 477-497.

Knapp, A. K.; Smith, M. D. 2001. Variation among biomes in temporal dynamics of aboveground primary production. Science 291:481-484.

Krankina, O. N.; Treyfeld, R. F.; Harmon, M. E.; Spycher, G.; Povarov, E. D. 2001. Coarse woody debris in the forests of the St. Petersburg region, Russia. Ecological Bulletins (Sweden) 49: 93-104.

Krankina, O. N.; Harmon, M. E.; Griazkin A. V. 1999. Nutrient stores and dynamics of woody detritus in a boreal forest: modeling potential implications at the stand level. Can. J. For. Res. 29: 20-32.

Krankina, O. N.; Yatskov, M.; Harmon, M. E. 1999. Woody detritus in the forest ecosystems of Russia [Abstract]. In: Kim, Eun-Shik; Oh, Jeong Soo. Proceedings of the 3rd international conference on Long-Term Ecological Research (LTER) in the East Asia-Pacific Region; 1999 October 11-16; Seoul, Korea. Seoul, Korea: Kookmin University: 156.

Kratz, T. K.; Benson, B.J.; Blood, E.; Cunningham, G.L.; Dahlgren, R.L. 1991. The influence of landscape position on temporal variability in four North American ecosystems. American Naturalist 138: 355-378.

Lajtha, K.; Vanderbilt, K. eds. 2000. Cooperation in long term ecological research in central and eastern Europe: Proceedings of the ILTER regional workshop; 1999 June 22-25; Budapest, Hungary. Corvallis, OR: Oregon State University: 128 p.

Lambert, B. C. 1997. The effects of hillslope and fluvial processes on particle size of the stream bed at the watershed, reach, and within-reach scales in a fifth-order mountain stream. Oregon State University. 68 p. M.S. thesis.

Lamberti, G. A.; Gregory, S.V.; Ashkenas, L.R.; Wildman, R.C.; Moore, K. M. S. 1991. Stream ecosystem recovery following a catastrophic debris flow. Canadian Journal of Fisheries and Aquatic Sciences 48: 196-208.

Landres, P. B.; Morgan, P.; Swanson, F. J. 1999. Overview of the use of natural variability concepts in managing ecological systems. Ecological Applications 9(4): 1179-1188.

Lattin, J.D.; Miller, J.C. 1997. Pacific Northwest Arthropods. Pp. 1-106 In: Smith, J.P.; Collopy M.W., eds. Status and Trends of US Biota.USDI, National Biological Service, Washington, D.C.

Likens, G. E., and F. H. Bormann. 1995. Biogeochemistry of a forested ecosystem. Springer-Verlag, New York.

Likens, G. E., F. H. Bormann, R. S. Pierce, J. S. Eaton, and N. M. Johnson. 1977. Biogeochemistry of a forested ecosystem. Springer-Verlag, New York.

Link, T.E. 2001. The water and energy dynamics of an old-growth seasonal temperate rain forest. Oregon State University. Ph.D. dissertation.

Lovett, G. M.; Rueth, H. 1999. Soil nitrogen transformations in beech and maple stands along a nitrogen deposition gradient. Ecological Applications 9: 1330-1344.

Luoma, D.L. 1991. Annual changes in seasonal production of hypogeous sporocarps in Oregon Douglas-fir forests. Pp. 83-89. *In:* Wildlife and vegetation of unmanaged Douglas-fir forests. Tech. coords., Ruggiero, L. F.; Aubry, K. B.; Carey, A. B.; Huff, M. H. USDA Forest Service Gen. Tech. Rep. PNW-GTR-285. Pac. Northwest Res. Stn., Portland, OR. 533 p.

Luoma, D.L.; Frenkel, R.E.; Trappe, J.M. 1991. Fruiting of hypogeous fungi in Oregon Douglas-fir forests: seasonal and habitat variation. Mycologia 83:335-353.

Magnuson, J. J. 1990. The invisible present. BioScience 40: 495-501.

Magnuson, J.J.; Kratz, T.K.; Frost, T.M.; Benson, B.J.; Nero, R.; Bowser, C.J. 1991. Expanding the temporal and spatial scales of ecological research and comparison of divergent ecosystems: roles for LTER in the United States. pp 45-70 in Risser, P. G. (ed.) Long-term Ecological Research. Wiley & Sons.

Marks, D.; Kimball, J.; Tingey, D.; Link, T. 1998. The sensitivity of snowmelt processes to climate conditions and forest cover during rain-on-snow: A case study of the 1996 Pacific Northwest flood. Hydrological Processes 12:1569-1587.

Martin, C.W.; Harr, R.D. 1988. Precipitation and streamwater chemistry form undisturbed watersheds in the Cascade Mountains of Oregon. Water, Air, and Soil Pollution. 42: 203-219.

Martin, C. W.; Hornbeck, J. W.; Likens, G. E.; Buso, D. C. 2000. Impacts of intensive harvesting on hydrology and nutrient dynamics of northern hardwood forests. Can. J. For. Res. 57(Suppl. 2): 19-29.

McNulty, S. G.; Aber, J. D.; Boone, R. D. 1991. Spatial changes in forest floor and foliar chemistry of spruce-fir forests across New England. Biogeochemistry 14: 13-29.

Meleason, M.A.; Gregory, S.V.; Bolte. J.P. In review. Simulation of Wood Dynamics in Streams of the Pacific Northwest. Ecological Modeling.

Meleason, M. A. 2001. A simulation model of wood dynamics in Pacific Northwest streams. Oregon State University. 158 p. Ph.D. Dissertation.

Michener, W. K.; Brunt, J. W.; Helly, J. J.; Kirchner, T. B.; Stafford, S. G. 1997. Nongeospatial metadata for the ecological sciences. Ecological Applications 7(1): 330-342.

Michener, W. K., T. J. Baerwald, P. Firth, M. A. Palmer, J. L. Rosenberger, E. A. Sandlin, and H. Zimmerman. 2001. Defining and unraveling biocomplexity. BioScience 51:1018-1023.

Miller, J. C.; Hammond, P. C. 2000. Macromoths of Northwest forests and woodlands. FHTET-98-18. Morgantown, VW: U.S. Department of Agriculture, Forest Service, Forest Health Technology Enterprise Team. 133 p.

Mulholland, P.J.; Fellows, C.S.; Tank, J.L.; Grimm, N.B.; Webster, J.R.; Hamilton, S.K.; Marti, E; Ashkenas, L; Bowden, W.B.; Dodds, W.K. 2001. Inter-biome comparison of factors controlling stream metabolism. Freshwater Biology 46(11): 1503-1518.

Nakamura, F.; Swanson, F. J.; Wondzell, S. M. 2000. Disturbance regimes of stream and riparian systems--a disturbance-cascade perspective. Hydrological Processes 14: 2849-2860.

Nesje, A.M. 1996. Spatial patterns of early forest succession in Lookout Creek basin. Oregon State University. M.S. Research Paper. 46 p.

Ollinger, S. V.; Smith, M. L.; Martin, M. E.; Hallett, R. A.; Goodale, C. L.; Aber, J. D. 2002. Regional variation in foliar chemistry and N cycling among forests of diverse history and composition. Ecology 83: 339-355.

Pacala, S. W.; Hurtt, G. C.; Baker, D.; Peylin, P.; Houghton, R. A.; Birdsey, R. A.; Heath, L.; Sundquist, E. T.; Stallard, R. F.; Ciais, P.; Moorcroft, P.; Caspersen, J. P.; Shevliakova, E.; Moore, B.; Kohlmaier, G.; Holland, E.; Gloor, M.; Harmon, M. E.; Fan, S.-M.; Sarmiento, J. L.; Goodale, C. L.; Schimel, D.; Field, C. B. 2001. Consistent land- and atmosphere-based U.S. carbon sink estimates. Science 292: 2316-2320.

Palmer, M.A.; Hakenkamp, C.C.; Nelson-Baker, K. 1997. Ecological heterogeneity in streams: why variance matters. Journal of the North American Benthological Society 16: 189-202.

Parendes, L.A. 1997. Spatial patterns of invasion by exotic plants in a forested landscape. Oregon State University. 208 p. Ph.D. dissertation.

Parendes, L. A.; Jones, J. A. 2000. Role of light availability and dispersal in exotic plant invasion along roads and streams in the H.J. Andrews Experimental Forest, Oregon. Conservation Biology 14(1): 64-75.

Parendes, L.A.; Jones, J.A. In prep. Landscape factors, disturbance, and exotic plant invasion along a forest road network in western Oregon. For submission to Annals of the AAG.

Parsons, G.L.; Cassis, G.; Moldenke, A.R.; Lattin, J.D.; Anderson, N.H.; Miller, J.C.; Hammond, P.; Schowalter, T.D. 1991. Invertebrates of the H.J. Andrews Experimental Forest, Western Cascade Range, Oregon. V: An annotated list of insects and other arthropods. U.S.D.A., U.S.F.S., P.N.W. Research Station, General Technical Report, PNW-GTR-290. 168pp.

Pennington, D. In prep. Forest landscape change in the Oregon Cascade Range – A simulation analysis. Corvallis, OR: Oregon State University. Ph.D. dissertation.

Perkins, R. 1996. Student intersite comparison: streamflow hydrology at five LTER sites. LTER Network News. Spring/Summer (19): 12-13.

Perkins, R.M.; Jones, J.A. In prep. Climatic and physiographic controls on peak discharges in small forested basins, western Cascades, Oregon. For submission to Water Resources Research.

Perkins, R. M. 1997. Climatic and physiographic controls on peakflow generation in the western Cascades,Oregon. Oregon State University. 190 p. Ph.D. dissertation.

Perry, D. A. 1994. Forest ecosystems. Baltimore and London: Johns Hopkins University Press. 649 p.

Perry, D. A. 1998. The scientific basis of forestry. Annual Review of Ecology and Systematics 29: 435-466.

Perry, D. A.; Amaranthus, M. P.; Borchers, J. G.; Borchers, S. L.; Brainerd, R. E. 1989. Bootstrapping in ecosystems. BioScience 39(4):230-237.

Peterson, B.J.; Wollheim, W.M.; Mulholland, P.J.; Webster, J.R.; Meyer, J.L.; Tank, J.L.; Martí, E.; Bowden, W.B.; Valett, H.M.; Hershey, A.E.; McDowell, W.H.; Dodds, W.K.; Hamilton, S. K.; Gregory, S.; Morrall, D.D. 2001. Control of nitrogen export from watersheds by headwater streams. Science 292: 86-90

Porter, J. H.; Henshaw, D. L.; Stafford, S. G. 1997. Research metadata in Long-Term Ecological Research (LTER). In: Second IEEE metadata conference; 1997 September 16-17; Silver Spring, MD. [Online]. Available: http://computer.org/conferen/proceed/meta97/list_papers.html [1999 February 2].

Post, D. A.; Grant, G. E.; Jones, J. A. 1998. New developments in ecological hydrology expand research opportunities. EOS, Transactions, American Geophysical Union 79(43): 517-526.

Post, D.A.; Jones, J.A. 2001. Hydrologic regimes of forested, mountainous, headwater basins in New Hampshire, North Carolina, Oregon, and Puerto Rico. Advances in Water Resources 24(9-10): 1195-1210.

Powers, J. S.; Sollins, P.; Harmon, M. E.; Jones, J. A. 1999. Plant-pest interactions in time and space: a Douglas-fir bark beetle outbreak as a case study. Landscape Ecology 14: 105-120.

Pruyn, M. L.; Gartner, B. L.; Harmon, M. E. In press. Within stem variation of respiratory potential in Douglas-fir tree from two sites in Oregon: Technique development and results. New Phytologist

Pruyn, M. L.; Gartner, B. L.; Harmon, M. E. 2002. Respiratory potential of old versus young ponderosa pine trees in the Pacific Northwest. Tree Physiology 22: 105-116.

Pruyn, M. L.; Gartner, B. L.; Harmon, M. E. In prep. Variation in tree stem respiratory potential and its relation to sapwood quantity in six softwoods and four hardwoods at an LTER site in Blue River, Oregon. Dissertation chapter in prep.

Qualls, R. G.; Haines, B. L.; Swank, W. T.; Tyler, S. W. 2000. Soluble organic and inorganic nutrient fluxes in clearcut and mature deciduous forests. Soil Sci. Soc. Am. J. 64: 1068-1077.

Randerson, J. T.; Chapin III, F. S.; Harden, J.; Neff, J. C.; Field, C.B.; Harmon, M. E. In press. Net Ecosystem Production: A Comprehensive Measure of Net Carbon Accumulation by Ecosystems. Ecological Applications.

Remillard, S. M. 1999. Soil carbon and nitrogen in old-growth forests in western Oregon and Washington. Oregon State University. 121 p. M.S. thesis.

Robertson, G. P.; Coleman, D. C.; Bledsoe, C. S.; Sollins, P., eds. 1999. Standard soil methods for long-term ecological research. New York, NY: Oxford University Press, Inc. 462 p.

Rosentrater, L. D. 1997. The thermal climate of the H.J. Andrews Experimental Forest, Oregon. Eugene, OR: University of Oregon. 133 p. M.S. thesis.

Ruggiero, L. F.; Aubry, K. B.; Carey, A. B.; Huff, M. H. 1991. Wildlife and vegetation of unmanaged Douglas-fir forests. USDA Forest Service Gen. Tech. Rep. PNW-GTR-285. Pac. Northwest Res. Stn., Portland, OR. 533 p.

Sanzone, D.M. 2001. Linking communities across ecosystem boundaries: the influence of aquatic subsidies on terrestrial predators. University of Georgia: Athens, GA. Ph.D. Dissertation.

Sanzone, D.M. In review. The influence of stream subsidies on spider communities in eight riparian forests. Environomental Entomology.

Sanzone D. M.,; Meyer, J. L.; Tank, J. L.; Gardiner, E. P.; Peterson, B. J.; Mulholland, P. J.; Gregory, S.V.; Grimm, N.; McDowell, W. H.; Bowden W. B.; Dodds, W. K. In review. Stable isotopes provide evidence that stream subsidies influence the spatial distribution of terrestrial predators in eight biomes. Ecology.

Scheffer, M.; Carpenter, S.; Foley, J. A.; Folkes, C.; Walker, B. 2001. Catastrophic shifts in ecosystems. Nature 413: 591-596.

Schellekens, J.; Scatena, F.N.; Bruijnzeel, L.A.; Wickel, A.J. 1999. Modeling rainfall interception by a lowland tropical rainforest in northeastern Puerto Rico. Journal of Hydrology 225:168-184.

Schlesinger, W. H. 1990. Evidence from chronosequence studies for a low carbon-storage potential for soils. Nature 348: 232-234.

Schlesinger, W. H.; Lichter, J. 2001. Limited carbon storage in soil and litter of experimental forest plots under increased atmospheric CO_2. Nature 411: 466-469.

Sea, D.S. ; Whitlock, C. 1995. Post-glacial vegetation and climate of the Cascade Range, central Oregon. Quaternary Research. 43:370-381.

Sinton, D.S.; Jones, J.A.; Ohmann, J.L.; Swanson, F.J. 2000. Windthrow disturbance, forest composition, and structure in the Bull Run basin, Oregon. Ecology 81(9): 2539-2556.

Smith, J.E. In prep. Mapping the Thermal Climate of the HJ Andrews Experimental Forest, Oregon. Oregon State University. Ph.D. Dissertation.

Smith, J.E.; Molina, R.; Huso, M.M.P.; Luoma, D.L.; McKay, D.; Castellano, M.A.; Lebel, T.; Valachovic, Y. In Press. Species richness, abundance, and composition of hypogeous and epigeous ectomycorrhizal fungal sporocarps in young, rotation-age, and old-growth stands of Douglas-fir (*Pseudotsuga menziesii*) in the Cascade Range of Oregon, U.S.A. Canadian Journal of Botany.

Smithwick, E.A. 2002. Potential Carbon storage at the landscape scale in the Pacific Northwest, U.S.A. Oregon State University. 290 p. Ph.D. Dissertation.

Smithwick, E. A. H.; Harmon, M. E.; Remillard, S. M.; Acker, S. A.; Franklin, J. F. In press. Potential upper bounds of carbon stores in forests of the Pacific Northwest. Ecological Applications.

Snyder, K. U. 2000. Debris flows and flood disturbance in small, mountain watersheds. Oregon State University. 53 p. M.S. thesis.

Sollins, P.; Grier, C.C.; McCorison, F.M.; Cromack, K. Jr.; Fogel, R.; Fredriksen, R.L. 1980. The internal element cycles of an old-growth Douglas-fir ecosystem in western Oregon. Ecological Monographs 50(3): 261-285.

Soranno, P. A.; Webster, K. E.; Riera, J. L.; Kratz, T. K.; Baron, J. S.; Bukaveckas, P.; Kling, G. W.; White, D.; Caine, N.; Lathrop, R. C.; Leavitt, P. 1999. Spatial variation among lakes within landscapes: ecological organization along lake chains. Ecosystems 2: 395-410.

Spycher, G.; Cushing, J. B.; Henshaw, D. L.; Stafford, S. G.; Nadkarni, N. 1996. Solving problems for validation, federation, and migration of ecological databases. In: Global networks for environmental information: Proceedings of Eco-Informa '96; 1996 November 4-7; Lake Buena Vista, FL. Ann Arbor, MI: Environmental Research Institute of Michigan (ERIM): 11: 695-700.

Stafford, S. G.; Alaback, P. B.; Waddell, K. L.; Slagle, R. L. 1986. Data management procedures in ecological research. In: Michener, W. K., ed. Research data management in the ecological sciences. The Belle W. Baruch Library in Marine Science No. 16. Columbia, SC: University of South Carolina Press: 93-113.

Stafford, S. G.; Klopsch, M. W.; Waddell, K. L.; Slagle, R. L.; Alaback, P. B. 1986. Optimizing the computational environment for ecological research. In: Michener, W. K., ed. Research data management in the ecological sciences. The Belle W. Baruch Library in Marine Science No. 16. Columbia, SC: University of South Carolina Press: 73-91.

Stafford, S. G.; Spycher, G.; Klopsch, M. W. 1988. Evolution of the Forest Science Data Bank. Journal of Forestry 86(9): 50-51.

Stafford, S. G.; Alaback, P. B.; Koerper, G. J.; Klopsch, M. W. 1984. Creation of a forest science data bank. Journal of Forestry 82(7): 432-433.

Stafford, S. G. 1993. Data, data everywhere but not a byte to read: managing monitoring information. Environmental Monitoring and Assessment 26: 125-141.

Strickland, T. C.; Sollins, P. 1987. Improved method for separating light- and heavy-fraction organic material from soil. Soil Sci. Soc. Amer. J. 51: 1390-1393.

Swank, W.T.; Vose, J.M. 1997. Long-term nitrogen dynamics of Coweeta forested watersheds in the southeasten United States of America. Global Biogechemical Cycles 11(4): 657-671.

Swank, W.T.; Vose, J.M.; Elliott, K.J. 2001. Long-term hydrologic and water quality responses following commercial clearcutting of mixed hardwoods on a southern Appalachian catchment. Forest Ecology and Management. 143: 163-178.

Swanson, F.J.; Dyrness, C.T. 1975. Impact of clear cutting and road construction on soil erosion by landslides in the western Cascade Range, Oregon. Geology 3(7): 393-396.

Swanson, F. J.; Jones, J. A.; Grant, G. E. 1997. The physical environment as a basis for managing ecosystems. In: Kohm, K. A.; Franklin, J. F., eds. Creating a forestry for the 21st century: the science of ecosystem management. Washington, DC; Covelo, CA: Island Press: 229-238.

Swanson, F. J.; Johnson, S. L.; Gregory, S. V.; Acker, S. A. 1998. Flood disturbance in a forested mountain landscape. BioScience 48(9): 681-689.

Swanson, F. J.; Greene, S. 1999. Perspectives on scientists and science in bioregional assessments. In: Johnson, K. N.; Swanson, F. J.; Herring, M.; Greene, S. Bioregional Assessments. Island Press. Washington, DC. 55-69.

Swanson, F. J.; Jones, J.A. In prep. Network structure and function – a view for ecosystem science. To be submitted to Ecosystems.

Tate, C.M.; Meyer, J.L. 1983. The influence of hydrologic conditions and successional state on dissolved organic carbon export from forested watersheds. Ecology 64: 25-32.

Thomas, R. B.; Megahan, W. F. 1998. Peak flow responses to clear-cutting and roads in small and large basins, western Cascades, Oregon: a second opinion. Water Resources Research 34(12): 3393-3403.

Tilman, D. 1996. Biodiversity: population versus ecosystem stability. Ecology 77:350-363.

Urban, D.; Harmon, M. E.; Halpern, C. B. 1993. Potential response of Pacific Northwestern forests to climate change, effects of stand age and initial composition. Climatic Change 23: 247-266.

Urban, D. L.; Acevedo, M. F.; Garman, S. L. 1999. Scaling fine-scale processes to large-scale patterns using models derived from models: meta-models. In: Mladenoff, D. J.; Baker, W. L., eds. Spatial modeling of forest landscape change: approaches and applications. Cambridge, UK: Cambridge University Press: 70-98.

VanDeKoppel, J.; Herman, PMJ; Thoolen, P.; Heip, C.H.R. 2001. Do alternate stable states occur in natural ecosystems? Evidence from a tidal flat. Ecology 82(12): 3449-3461.

Vanderbilt, K. L.; Lajtha, K.; Swanson, F. In press. Biogeochemistry of unpolluted forested watersheds in the Oregon Cascades: temporal patterns of precipitation and stream nitrogen fluxes. Biogeochemistry.

Wallin, D.O.; Swanson, F.J.; Marks, B. 1994. Landscape pattern response to changes in pattern generation rules: land-use legacies in forestry. Ecological Applications 4(3); 569-580.

Wallin, D. O.; Harmon, M. E.; Cohen, W. B.; Fiorella, M.; Ferrell, W. K. 1996. Use of remote sensing to model land use effects on carbon flux in forests of the Pacific Northwest, USA. In: Gholz, H. L.; Nakane, K.; Shimoda, H., eds. The use of remote sensing in the modeling of forest productivity. Dordrecht, The Netherlands: Kluwer Academic Publishers: 219-237.

Webster, K.K.; Soranno, P.A.; Baines, S.B.; Kratz T.K; Bowser, C.J.; Dillon, D.J.; Campbell, P.; Fee, E.J.; Hecky, R.E. 2000. Structuring features of lake districts: geomorphic and landscape controls on lake chmical responses to drought. Freshwater Biology 43: 499-516.

Weisberg, P. J. 1998. Fire history, fire regimes, and development of forest structure in the central western Oregon Cascades. Oregon State University. 256 p. Ph.D. dissertation.

Weisberg, P. J.; Swanson, F.J. In press. Regional synchroneity in fires regimes – Pacific Northwest, USA. Forest Ecology and Management.

Wemple, B.C. 1994. Hydrologic integration of forest roads with stream networks in two basins, western Cascades, Oregon. Oregon State University. 88 p. M.S. thesis.

Wemple, B. C.; Jones, J. A.; Grant, G. E. 1996. Channel network extension by logging roads in two basins, western Cascades, Oregon. Water Resources Bulletin 32(6): 1195-1207.

Wemple, B. C.; Swanson, F. J.; Jones, J. A. 2001. Forest roads and geomorphic process interactions, Cascade Range, Oregon. Earth Surface Processes and Landforms 26: 191-204.

Wemple, B. C. 1998. Investigations of runoff production and sedimentation on forest roads. Oregon State University. 168 p. Ph.D. dissertation.

Wemple, B.C.; Jones, J.A. In prep. Runoff production on forest roads in a mountain watershed, western Cascades, Oregon. For submission to Water Resources Research.

Williams, M.; Rastetter, E.B.; Fernandes, D.N.; Goulden, M.L.; Wofsy, S.C.; Shaver, G.R.; Melillo, J.M.; Munger, J.W.; Fan, S.-M.; Nadelhoffer, K.J. 1996. Modelling the soil-plant-atmosphere continuum in a *Quercus-Acer* stand at Harvard Forest: the regulation of stomatal conductance by light, nitrogen and soil/plant hydraulic properties. Plant, Cell, and Environ. 19: 911-927.

Williams, M.; Rastetter, E.B.; Fernandes, D.N.; Goulden, M.L.; Shaver, G.R.; Johnson, L.C. 1997. Predicting gross primary productivity in terrestrial ecosystems. Ecol. Appl. In review.

Wright, R. F.; Roelofs, J. G. M.; Bredemeier, M.; Blanck, K.; Boxman, A. W.; Emmett, B. A.; Gundersen, P.; Hultberg, H.; Kjonaas, O. J.; Moldan, F.; Tietema, A.; van Breemen, N.; van Gijk. H. F. G. 1995. NITREX: responses of coniferous forest ecosystems to experimentally changed deposition of nitrogen. Forest Ecology and Management 71: 163-169.

Vitousek, P. M. and W. A. Reiners. 1975. Ecosystem succession and nbutrient retention: a hypothesis. BioScience 25:376-381.

Zyrina, O. 2000. Measuring costs of sequestering carbon in forest stands with different management regimes in western Oregon. Oregon State University. 78 p. M.S. thesis.