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CHAPTER 6

LONG-TERM RESEARCH ON FOREST DYNAMICS IN THE PACIFIC NORTHWEST: A NETWORK OF PERMANENT FOREST PLOTS

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INTRODUCTION

Changes in the composition, structure, and functions of forest ecosystems typically occur over long periods of time. In the Pacific Northwest region of the United States, for example, it is not unusual for individual dominant trees to survive for 500 years or longer (Franklin and Dyrness, 1973; Waring and Franklin, 1979). Significant compositional and structural changes may continue to occur 750 years after a stand-initiating disturbance (Franklin and Spies, 1991).

Documenting and understanding these changes requires a variety of approaches. At least five complementary approaches have been taken to increase scientific understanding of these intrinsically slow changes: chronosequences (Pickett, 1989); palynology and other paleoecological methods (e.g. Davis, 1981); stand reconstruction (e.g. Henry and Swan, 1974); simulation models (e.g. Shugart, 1984); and direct, long-term observations of permanent plots (e.g. Peet, 1981). All five techniques provide unique opportunities and limitations.

Long-term observation of permanent sample plots is the only approach that provides real data on patterns and rates of change in forest ecosystems. Information collected on permanent plots provides the ultimate test of the validity of the other approaches. Therefore, the knowledge of natural ecosystem dynamics provided by permanent plot data is necessary in developing sustainable approaches to ecosystem management (Lubchenco *et al.*, 1991; Swanson and Franklin, 1992). For example, long-term observations can quantify levels and dynamics of natural forest structures for use as guides in ecosystem management (e.g. Franklin *et al.*, 1981). Long-term observations provide the definitive measure of long-term productivity and, thus, sustainable harvest levels. In addition, repeated observations on permanent plots provide data about the relationships of disturbance frequency and intensity to persistence of different plant and animal species. Dynamic relationships between forests and aquatic ecosystems can also be documented in long-term plots.

Long-term observations provide a basis for monitoring effects of global climatic change as well as other changes (Franklin, 1989; Magnuson, 1990). Processes observable in permanent forest plots that may respond to global climate change include tree regeneration, growth, and death; changes in species composition and diversity; and decay of dead wood. Long-term observations are the only direct means of obtaining such data; other approaches are inferential.

For these and other reasons, researchers associated with the H.J. Andrews Experimental Forest Long-Term Ecological Research program (Andrews LTER) and the Cascade Center for Ecosystem Management maintain an extensive network of permanent forest plots in western Oregon and western Washington and in several other locations in the western United States. The Cascade Center is a cooperative effort among researchers and land managers at Oregon State University (OSU), the Pacific Northwest Research Station of the US Forest Service (USFS), and the Willamette National Forest. Through funding to OSU and the Andrews LTER, the National Science Foundation is also a participant in the Cascade Center. The Center is an outgrowth of 45 years of research and application that has centered on the H.J. Andrews Experimental Forest in the western Cascades of Oregon. Other universities and agencies have contributed resources to the network of permanent plots, especially the University of Washington, the National Park Service, the USFS Rocky Mountain Forest and Range Experiment Station, and Idaho National Engineering Laboratories.

Plots in the network vary widely in time since establishment, with some plots established as long ago as 1910. The original purposes in setting up the plots were also diverse, with early plots oriented to forest growth and yield and more recent plots focused on ecosystem processes. Observational design (e.g. size, shape, and number of plots) varies among the study areas. Nevertheless, the entire collection of long-term plots is managed as a network, providing insights into most forest types and successional stages in western Oregon and western Washington. The network has helped expand understanding of ecological patterns and processes and has provided essential information for forest management.

This paper describes the network and illustrates the ways in which information from the network has been used in the past and can be used in the future.

HISTORY OF THE NETWORK

Most of the permanent plots were established during two intervals: 1910 to 1948, and 1970 to 1989 (Figure 6.1). The earlier plots were established by researchers from USFS to quantify timber growth in young stands of important commercial species and to help answer other applied forestry questions (Munger, 1946; Williamson, 1963). One key objective was to quantify gross timber yield; i.e. including trees that die before harvest (Staebler, 1955). This is a basic component of forest productivity (Franklin *et al.*, 1987) and can be measured accurately only on permanent plots. The oldest plots in the network (established in 1910) are still active and were measured for the twelfth time in 1992.

The more recent period of permanent plot establishment began as part of the Coniferous Forest Biome (CFB) program of the International Biological Program

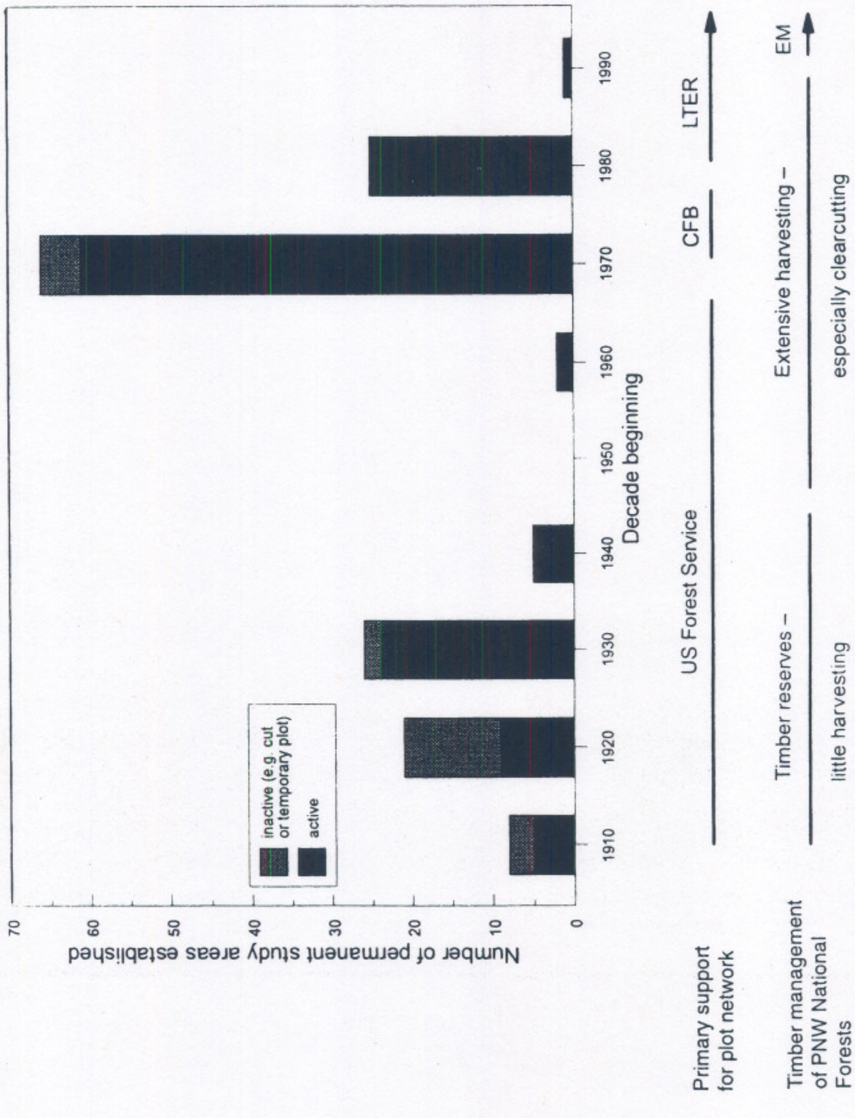

Figure 6.1 Time trends of establishment of permanent forest plots in the Cascade Center for Ecosystem Management network, primary source of support for the permanent plot network, and focus of timber management for national forests in Washington and Oregon. CFB refers to the Coniferous Forest Biome program of the International Biological Program; LTER refers to the H.J. Andrews Experimental Forest Long-Term Ecological Research program (funded by the National Science Foundation); and EM refers to ecosystem management (see Swanson and Franklin, 1992)

during the 1970s, with funding from the National Science Foundation (Edmonds, 1982). A broader set of objectives motivated plot establishment since 1970 (e.g. Hawk *et al.*, 1978; Franklin, 1982; Riegel *et al.*, 1988), the primary objective being quantification of composition, structure, and population and ecosystem dynamics of natural forests. This information was intended to support ecosystem research, enable monitoring of long-term change, and aid in developing ecologically sound management. In two areas with a concentration of permanent plots (H.J. Andrews Experimental Forest and Mt Rainier National Park), an additional objective was to include representative samples of most of the important environments and associated forest types. Since conclusion of the CFB program, the plot network has continued as part of the Andrews LTER (Figure 6.1; Callahan, 1984, Franklin *et al.*, 1990).

Support for long-term studies under the CFB program began at a time when the focus of USFS research and monitoring shifted to intensively managed stands (Williamson, 1963; Franklin, 1989). During this period (1960s and 1970s), the plots from the earlier interval were measured infrequently, and some were lost to logging. Surviving plots have been returned to a regular schedule of measurement by researchers in the CFB and Andrews LTER programs, with cooperation from USFS personnel.

The most recently established permanent plots (1990s) are intended to further the integration of ecosystem science into forest management. These areas will help increase understanding of forest–stream interactions and the dynamics of multi-age stands, a silvicultural goal that may be increasingly important in managing future Pacific Northwest forests.

As described below, the network of permanent plots has been used to investigate a broad variety of basic scientific questions (e.g. concerning ecology of populations, communities, and ecosystems) and has helped shed light on a variety of land management issues. Use of the network for a multitude of complementary purposes is one of our primary aims; the information is too costly and too valuable to be dominated by a single use.

CHARACTERISTICS OF THE NETWORK

The majority of the plots are located in western Oregon and Washington in both the coastal mountain ranges and the Cascade Mountains (Figure 6.2). The portion of the Cascade Range from about Willamette Pass in Oregon, north to Mt Rainier in Washington is especially well represented. Public land management units containing permanent study areas include national forests (Willamette, Siuslaw, Deschutes, Mt Hood, Gifford Pinchot, and Olympic), national parks (Mt Rainier and Olympic), and the state of Washington. Many of the plots are within areas designated for research: USFS Experimental Forests (57 study areas), Research Natural Areas (24), and UNESCO Man and the Biosphere Reserves (47). Permanent plots on federal land and outside of national parks, wilderness areas, and Research Natural Areas are within areas recently designated for management

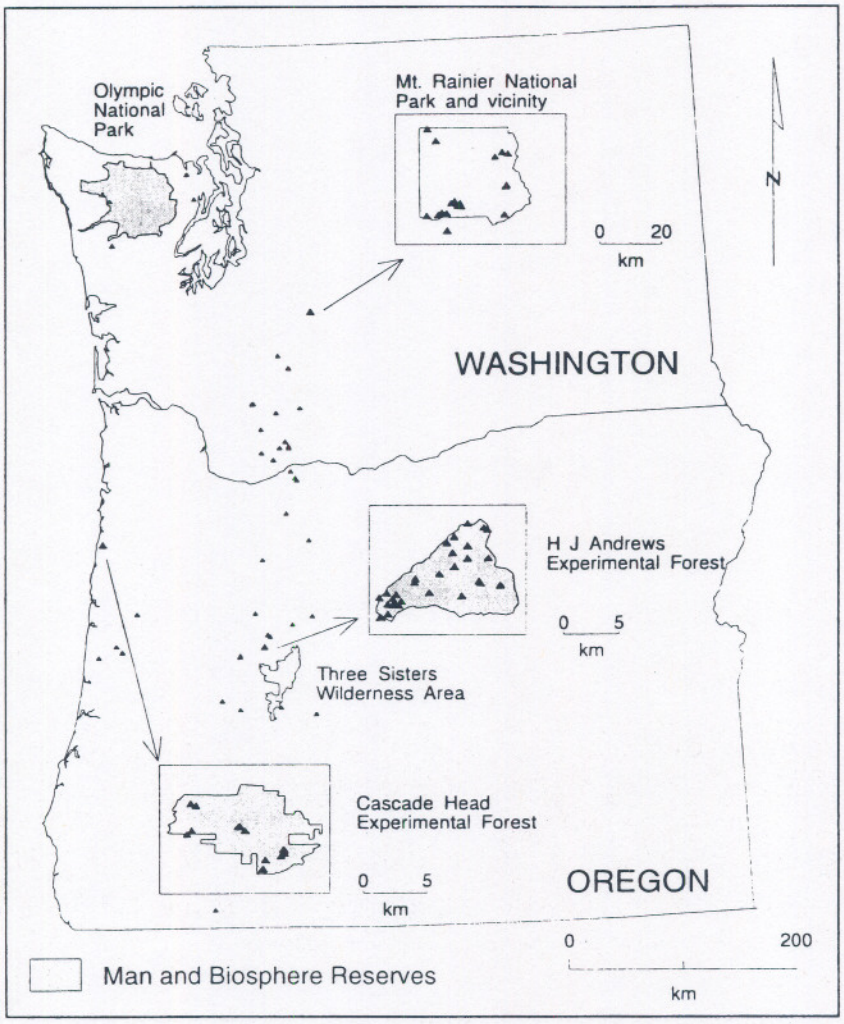

Figure 6.2 Location of permanent forest plots in the Cascade Center for Ecosystem Management network and Man and the Biosphere Reserves in Washington and Oregon

as late-successional forest (30), or for multiple uses (57–48 in 'Adaptive Management Areas' and 9 in 'matrix land') (USDA Forest Service and USDI Bureau of Land Management,1994). There are concentrations of permanent study areas at H.J. Andrews, Cascade Head, and Wind River Experimental Forests and at Mt Rainier National Park (Figure 6.2). Additional permanent study areas are located in California (Sequoia National Park), Colorado (Fraser Experimental Forest), and Wyoming (Bridger-Teton National Forest).

Table 6.1 Distribution of permanent study areas in Oregon and Washington by forest zone and successional stage

	*Successional stage**			
Forest zone	*Herb/shrub* (< 40 years old)	*Young forest* (40–80 years old)	*Mature forest* (80–200 years old)	*Old-growth forest* (> 200years old)
Picea sitchensis	–	–	15 (11.4)**	5 (5.0)
Tsuga heterophylla	3 (4.8)	31 (11.0)	15 (18.0)	26 (30.0)
Cascade Mountain subalpine	–	–	16 (16.6)	20 (18.8)
Pinus ponderosa	–	–	–	4 (13.5)
Mixed evergreen	–	–	1 (0.5)	–

*Successional stage at establishment of permanent study area
**Number of areas (number of ha)

The network includes numerous examples of the most widespread forest zones of western Oregon and Washington (Table 6.1): the *Picea sitchensis*, *Tsuga heterophylla*, and Cascade subalpine zones (Frenkel, 1985). The *T. heterophylla* zone is both the most widespread in the region and the best represented in the permanent plot network. The network also includes examples of forest zones more common to the east (*Pinus ponderosa*) and to the south (mixed evergreen) of the region.

Most of the study areas were established in natural, closed-canopy forest (Table 6.1), including young (40 to 80 years old), mature (80 to 200 years old), and old-growth forests (more than 200 years old) (Spies and Franklin, 1991). Plots have one of three spatial arrangements. They are contiguous rectangles subjectively placed within an area of homogeneous forest, circular plots subjectively placed within an area of homogeneous forest, or circular plots systematically located on long transects to cover an entire watershed, ridge, or reserve. Rectangular study areas are mostly 1.0 ha or 0.4 ha in size, but range from 0.25 ha to 4.7 ha. Circular plots are 0.1 ha.

The tree stratum is the focus of work in closed-forest study areas. All trees larger than a minimum diameter at breast height (dbh) – 5 cm for most areas – are permanently tagged. Tree diameters are remeasured and mortality recorded, along with conditions and contributing factors, every 5 or 6 years. For some of the study areas, tree mortality is recorded annually. Tree heights are measured for a subsample of tagged trees. In more than half of the rectangular study areas, all living trees were mapped when the study areas were established. Stem maps are currently being converted to geographic information system data layers to facilitate updating of maps and spatial analysis. For two of the closed-forest watersheds sampled with long transects, understory vegetation (species composition, cover, and basal diameters of most woody plants) is remeasured every 10 years. For many of the other study areas, understory vegetation was measured at plot establishment, providing the opportunity to monitor understory vegetation in the future. Coarse woody debris (i.e. snags and downed logs) has been inventoried on most of the closed-forest study areas.

The network also includes plots in early successional forest on three small (10- to 100-ha) watersheds within the H.J. Andrews Experimental Forest that were harvested in the 1960s and 1970s as part of two watershed experiments. The focus of study has been on early plant succession and hydrologic and geomorphic processes. Plots are distributed throughout the cutover areas of the watersheds, either regularly spaced along transects (one study) or randomly placed within plant-community-type strata (second study). Seedlings, saplings, trees, and cover as well as biomass and species composition of vascular understory plants have been measured on these plots beginning prior to harvest. Measurements were recorded annually for 5 to 10 years after harvest and are now taken every 3 to 4 years. Records for these three cut watersheds now extend for 18 to 31 years after harvest.

Data and documentation of methods and study locations are stored in the computerized Forest Science Data Bank at the Department of Forest Science, Oregon State University (Stafford *et al.*, 1984, 1988). These data and background information are also included among the 'core data sets' of the National Science Foundation's Long-Term Ecological Research Program (Michener *et al.*, 1990). Information on the Andrews LTER and the permanent plot network are accessible on the Internet via the World-Wide Web (URL address: http://wvw.fsl.orst.edu/lterhome.html).

Nearly all of the study areas are located on lands managed by two federal agencies – USFS and the National Park Service. Numerous local offices and individual agency employees are involved. Although maintaining communication with management personnel over such a wide area is often a challenge, the agencies have generally been very helpful. We hope to build even stronger links to local managers in the future.

CONTRIBUTIONS TO SCIENCE AND LAND MANAGEMENT FROM THE PERMANENT STUDY AREA NETWORK

Studies of vegetation patterns along environmental gradients and of the three-dimensional distribution of trees and their canopies in *Pseudotsuga menziesii* forests have utilized the permanent study area network. Zobel *et al.* (1976) used direct environmental measurements and data from the permanent plot network to identify the factors responsible for the distribution of forest types and plant species in the central western Cascades of Oregon. Kuiper (1988) recorded the spatial distribution of trees and the vertical distribution of canopies for five *P. menziesii* stands ranging in age from 50 to more than 500 years (ages from tree cores; see also Franklin *et al.*, 1988), three of which are from plots in the permanent plot network. His analysis identified differences in three-dimensional structure of stands of various ages that may be essential for biological diversity and ecosystem function.

A number of different aspects of forest dynamics have been documented using the permanent plot network. Analyses of direct observations of forest succession have focused on changes of species composition and diversity in post-logging stands in the *T. heterophylla* zone (Dyrness, 1973; Halpern, 1988, 1989; Halpern and Franklin, 1990; Halpern and Spies, 1995), the demography and growth of an old-growth stand in the *T. heterophylla* zone (DeBell and Franklin, 1987; Franklin and DeBell, 1988), and mortality and population dynamics in mature stands in the *P. sitchensis* zone (Harcombe, 1986; Harcombe *et al.*, 1990; Greene *et al.*, 1992). Regional generalizations concerning rates of tree mortality in natural stands have been drawn from the network (Franklin *et al.*, 1987; Spies *et al.*, 1990). Study areas from the network have been used to estimate rates of canopy gap formation in mature and old growth *P. menziesii* forests (Spies *et al.*, 1990). Dynamics of coarse woody debris (Sollins, 1982; Harmon *et al.*, 1986, 1987; Krankina and Harmon, 1994) and nutrient cycling (Grier, 1976, 1978; Sollins *et al.*, 1980; Binkley and Graham, 1981; Gholz *et al.*, 1985) have been quantified using data from permanent plots in the network.

Computer simulation models provide a means to summarize hypotheses concerning processes that control forest dynamics (Dale *et al.*, 1986) and to explore the implications of those hypotheses. Projections of two forest simulation models – CLIMACS (Hemstrom and Adams, 1982) and ZELIG (Garman *et al.*, 1992) – have been corroborated using data from the permanent study area network. These models have been used to assess the likely effects of wildfire, logging, climate change, and other disturbances on forest production (Dale *et al.*, 1986, Dale and Franklin 1989, Garman *et al.*, 1992) and the quality of wildlife habitat (Garman *et al.*, 1992).

Researchers from a variety of other disciplines have obtained useful information from the permanent plot network. Questions as diverse as population structure of forest canopy arthropods (Schowalter, 1995) and simulation modeling of regional distribution of leaf area index (D. Turner personal communication) have drawn on the network's permanent plot information. Plots in the network have also been used for studies of age structure of young *Abies amabilis* (Wilson, 1991) and autecology of moss species (Peck *et al.*, 1995).

Scientifically based management of Pacific Northwest forests has been facilitated by information generated from the network of permanent study areas. The areas have been used to quantify the potential yield of timber of both *P. menziesii* (McArdle *et al.*, 1949, Williamson, 1963) and *P. sitchensis–T. heterophylla* forests (Meyer, 1937; Smith *et al.*, 1984). Such information is necessary to judge whether timber management activities are economically and ecologically sustainable (McArdle *et al.*, 1949).

Study areas in the network have provided critical information concerning old-growth forests. Definitions of old-growth forests for inventory and planning

(Old-growth Definition Task Group, 1986), identification of key components of old-growth structure to preserve or enhance in site management (Franklin *et al.*, 1981), and documentation of dynamics of old-growth forests (DeBell and Franklin, 1987) all have been drawn, in part, from the network. Autecology of *Taxus brevifolia*, a significant component of old-growth forests, has been documented using data from the plot network (Busing and Spies, 1995; Busing *et al.*, 1995). Information on structure and dynamics of riparian forests in the network helped the Oregon Department of Forestry shape new rules intended to promote ecological attributes of managed streamside forests (Lorensen *et al.*, 1994; J. Runyon personal communication). In addition, permanent plots in the network are included in monitoring programs at Olympic and Sequoia National Parks.

The plot network has also been used to enhance understanding of the effects of forest management on plant diversity. Changes in diversity following clear-cut logging and slash burning were mostly reversed in two decades; however, some species became locally extinct (Halpern and Spies, 1995). Maintenance of the full range of understory plant diversity may require allowing several centuries to elapse between harvests in some areas (Busing *et al.*, 1995; Halpern and Spies, 1995).

FUTURE OF THE NETWORK

In the future, we plan to continue the measurement program, tap more of the potential of the study area network for addressing basic and applied ecological questions, and strengthen collaboration with other institutions and agencies. Such collaboration has been and will continue to be essential in maintaining the network of permanent plots and exploiting the data for research and monitoring. We hope that future collaborative efforts will include regional syntheses and cross-biome research and monitoring.

Analyses now underway will provide more details on forest dynamics in the *T. heterophylla* zone and document dynamics of *A. amabilis* zone forests. Dynamics of *P. menziesii* stands in the *T. heterophylla* zone older than 100 years of age are poorly known (Curtis and Marshall, 1993). However, in the future the interval between harvests of federal forests in the Pacific Northwest may be 150 years or longer (Forest Ecosystem Management Assessment Team, 1993). Furthermore, current silvicultural research seeks manipulations to speed development of older forest habitat characteristics (McComb *et al.*, 1993). To help fill these information gaps, we have analyzed the temporal trends over four to eight decades from study areas established in young *P. menziesii* stands (Acker, 1994; S.A. Acker, T.E. Sabin, L.M. Ganio, and W. A. McKee manuscript in preparation). Another project underway is assessing biological agents of tree mortality in *P. menziesii* forests and associated effects of mortality on tree population structure (K. Bible personal communication).

The study areas may be ideal for certain additional, non-destructive investigations. Some such studies have already occurred (e.g. Wilson, 1991; Peck *et al*., 1995). Studies of other plant groups (e.g. bryophytes, fungi, lichens, understory vascular plants) or animals with small home-range sizes may be appropriate.

Since the network encompasses much of the geographic and ecological variation within the Pacific Northwest, there is considerable potential for regional syntheses and comparisons with other biomes. For example, Harcombe (1987) demonstrated that examination of the demographic characteristics of tree species across a biome can identify groups of species with similar successional roles. Use of demographic data from sites throughout a biome can also indicate whether ecological functions of species shift over their geographic ranges. However, inconsistencies in study design can mask or be mistaken for ecological differences (see Harcombe, 1987). The consistency of methods across our network is an important strength.

We would welcome additional collaborative comparisons of Pacific Northwest forests with other biomes. Such studies can identify critical gaps in understanding global ecological cycles (e.g. Harmon and Chen, 1991) or identify generalizations across biomes that can facilitate modeling of global cycles; for example, the similar ratio of dead wood to live wood in forests of Pacific Northwest and northwestern Russia (Krankina and Harmon, 1994). Finally, monitoring in conjunction with networks in other biomes could provide early indications of biological effects of global climate or other change (e.g., Phillips and Gentry, 1994).

CONCLUSION

The network of permanent forest plots has contributed extensively to ecological understanding of forest ecosystems in the Pacific Northwest and scientifically-based land management. We plan to continue the program of long-term, direct observations of forest dynamics. We hope to continue the collaboration with other institutions and individuals that has been essential for maintaining the study areas, collecting the data, and extracting useful information. Future analyses should emphasize regional syntheses and comparisons with other biomes.

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