Variable density management in Riparian Reserves: lessons learned from an operational study in managed forests of western Oregon, USA

Samuel Chan[1], Paul Anderson[1], John Cissel[2], Larry Larsen[2] and Charley Thompson[2]

[1] USDA Forest Service, Pacific Northwest Research Station, 3200 SW Jefferson Way, Corvallis, OR. 97331. schan@fs.fed.us, pdanderson@fs.fed.us

[2] USDI Bureau of Land Management, Portland. OR, USA. john_cissel@or.blm.gov, larry_larson@or.blm.gov, charley_thompson@or.blm.gov

Abstract

A large-scale operational study has been undertaken to investigate variable density management in conjunction with riparian buffers as a means to accelerate development of late-seral habitat, facilitate rare species management, and maintain riparian functions in 40–70 year-old headwater forests in western Oregon, USA. Upland variable retention treatments include matrices of four thinning intensities embedded with patch openings and leave islands. Additionally, four types of streamside buffer delineation are being examined. The study includes 13 sites, each averaging about 100 hectares. Metrics of stand structure and development, microclimate, aquatic ecology, invertebrate populations and biology, lichens, and bryophytes, are being evaluated with respect to overstory thinning, patch openings and riparian buffer treatments. Results of this study can contribute to a development of riparian buffer delineations based on ecological functions and linkages to upland forest conditions.

Early findings suggest that the near-stream riparian environment provides critical functions and habitat for diverse populations of organisms. Using large, operational experimental plots we are able to demonstrate statistically significant initial responses to a complex suite of treatments for selected vegetation and environment parameters. It remains to be determined if the experimental design will be robust for long-term temporal trends in vegetation and microclimate, or synthesis with companion studies focusing on invertebrates or aquatic-dependent fauna. Meaningful interdisciplinary inferences are more likely achieved if integration is explicitly incorporated into study design and implementation, rather than post-study component synthesis. Conducting a large-scale interdisciplinary study with adaptive management implications requires a strong commitment to collaboration between management and research partners.

Keywords: density management, thinning, riparian reserves, buffers, upland forests, habitat, microclimate, headwater

1 Introduction

In the Pacific Northwest region of the United States there is continual public, political and professional discussion about how to best manage forest lands to meet society's desires for a wide range of values including ecosystem health, recreation, aesthetics, timber production, and other social and economic benefits. Since the late-1980's there has been a paradigm shift in public forestland management which places greater emphasis on maintaining ecosystem integrity. This shift in emphasis has often been framed as the need to ensure: 1) water quality and yield sufficient to support native fisheries and municipal watersheds, and; 2) forest composition and structure to provide quality habitat for a broad range of flora and fauna.

Provision of these ecological values in many cases involves a trade-off with production of commodities such as timber and wood fiber, historically a very important segment of the regional economy. As a result land managers are interested in developing new knowledge on how to best manage forestlands for the compatible production of ecological values and commodities, such as timber and wood fiber.

Our purpose in this paper is to present an overview of a study that addresses regional forest management information needs by means of a multidisciplinary, operational-scale silviculture experiment. We first present an overview of riparian functions and the ecological basis for establishment of reserves in riparian areas on public forestlands. Compatible production of ecological and commodity values from riparian forests is discussed as an information need of public land managers. Having set the context, we will describe the riparian buffer component of the Density Management Studies as an example of applied, operational-scale ecological research. While briefly addressing initial results, we will discuss in greater detail our experience in meeting the many challenges associated with design, implementation, and coordination posed by large-scale experimentation directed towards practical land-management issues.

Riparian forests are among the most biologically diverse portions of the terrestrial landscape and they provide numerous benefits to stream and terrestrial habitat (SALO and CUNDY 1987; NAIMAN *et al.* 1993; NILSSON *et al.* 1994; POLLOCK *et al.* 1998). Among these important benefits are regulation of input within the stream network of large wood, fine organic material, nutrients, sediment, water and thermal energy. Thus, riparian forest conditions largely determine stream conditions, and therefore the productive potential of streams for a diverse array of organisms such as periphyton, aquatic plants, invertebrates, amphibians and fishes.

In spite of their importance, riparian ecosystems have a long history of degradation by land use activities such as logging, grazing, agriculture, road-building, and urbanization. This has occurred in large part because riparian ecosystems are often productive areas of a landscape and are relatively accessible. During settlement, rivers and higher-order streams served as preferred travel routes through wilderness and mountainous terrain, and thus these riparian features are frequently developed with roads or railways. Numerous economic opportunities have made riparian areas preferred real estate, which, has fequently resulted in a loss of riparian habitat and impaired ecological functions.

In the Pacific Northwest region of the United States, the forest landscape is characterized by extensive networks of small headwater streams that deliver water, nutrients, and substrates to larger streams and alluvial floodplains further down the hydrologic network. Headwater streams drain 70 to 80% of Pacific Northwest watershed area (GOMI *et al.* 2002; MEYER and WALLACE 2001). Yet, little is known about headwater stream interactions with adjacent riparian and upland forests (GOMI *et al.* 2002). Due to their small stream size, and in some cases intermittent stream flows, headwater riparian areas have often been subjected to the same management regime as adjacent upland forests, putting at risk some of the functional characteristics unique to these streams.

1.1 Ecosystem integrity through Riparian Reserves

As a result of growing awareness and knowledge of ecological functions and processes, vast networks of Riparian Reserves encompassing headwater streams on nearly four million hectares of federal land were established with adoption of the Northwest Forest Plan (USDA and USDI 1994). Riparian Reserves are portions of watersheds for which the primary management emphasis would be riparian-dependent resources. The intent of

Riparian Reserve management is to: 1) maintain or restore the structure and functions of riparian systems (including intermittent streams); 2) to enhance habitat for riparian-dependent and riparian-associated species; 3) to enhance habitat for organisms of the riparian-upland transition zone; and 4) provide greater ecological connectivity of travel and dispersal corridors (FEMAT 1993). Within Riparian Reserves, forest management practices such as tree harvesting are severely restricted and often politically and administratively difficult to implement.

Riparian Reserve delineation under the NWFP is stream channel-centered. Reserves are based on a combination of physiographic, hydrologic, or vegetative features that delineate the riparian boundary in terms of lateral distance from stream channel. Delineation based on distance from stream channel was intended to maintain or protect riparian functions and processes by retaining forest vegetation that provides shade, favorable microclimate, water quality, large-wood input, rooting strength for soil stability, and leaf and organic input.

Lateral distance from stream center is often expressed in terms of the potential height attained by a mature, dominant tree on a particular site (site potential tree height, SPTH; HANN 1995; MCARDLE *et al.* 1961; WILEY 1978). Use of SPTH as a lateral buffer delimiting distance metric is derived from a conceptual recognition of distance over which adjacent forest canopy trees affect inputs of energy and matter to the riparian zone. Thus, according to FEMAT (1993): "Riparian Reserves consist of the stream and the area on either side of the stream extending from the edges of the active stream channel to the top of the inner gorge, or to the outer edges of the 100-year floodplain, or to the outer edges of riparian vegetation, or to a distance equal to the height of two site-potential trees, or minimum of approximately 81 m slope distance on each side of the stream, whichever is greatest".

Selection of the maximum reserve width (2 SPTH) was partially driven by the goal to maintain near-stream riparian microclimate conditions (humidity and temperature) favorable to aquatic-dependent organisms (DEMAYADIER and HUNTER 1995). However, there existed little definitive information on riparian microclimate when Riparian Reserve guidelines were formulated under FEMAT. Therefore, scientists and managers established interim Riparian Reserve widths based on available results from microclimate research in upland forests. Specifically, the research of CHEN (1991) indicated that microclimate influences of an adjacent clear-cut penetrated up to 3 SPTH into an old-growth forest (Fig. 1). Although the influence of clear-cutting on soil moisture and radiation was localized to the residual forest edge, alterations in wind speed and relative humidity were apparent well into the interior of the residual stand.

Although intended to capture functional attributes, in practice, federal interim Riparian Reserve boundaries are routinely mapped using simple, uniform guidelines (typically some multiple of SPTH) and do not account for variations in factors such as stream channel geomorphology. The implications of Riparian Reserve delineation for forest management are substantial, given the highly dissected watersheds in the region. Although it is difficult to put specific numbers on the percentage of land area allocated as Riparian Reserve under the NWFP, it is common for 70% or more of watershed area to be allocated to reserve status. In spite of large areas designated as reserves, the effectiveness of Riparian Reserve delineation in meeting the objectives outlined in FEMAT and the Record of Decision (USDA and USDI 1994) is poorly known.

Active management within Riparian Reserves is permitted only after an analysis of watershed conditions to determine risks for degradation of ecosystem integrity. Exclusion of timber harvest from Riparian Reserves is assumed to maintain species diversity, ecosystem integrity and protection of ecosystem functions. However, many of these forests in Riparian Reserves were previously managed for timber production and are characterized by relatively dense, uniform, 40–70 year-old even-aged stands of Douglas-fir (*Pseudotsuga menziesii*

Franco) and western hemlock (*Tsuga heterophylla* [Raf.] Sarg.). These stands typically remain in the stem-exclusion stage (OLIVER and LARSON 1996), lacking in structural and biological diversity, for extended periods of time (perhaps more than 100 years). Lack of complexity makes these young stands poorly suited for supporting many riparian-dependent species, the northern spotted owl *(Strix occidentalis cuarina)*, and many other wildlife species (CAREY 1995; LINDERMAYER and FRANKLIN 2002). Therefore, managers of Riparian Reserves have elected to thin these young stands to create a more heterogeneous forest structure conducive to development of understory vegetation (DEBELL *et al.* 1997; BAILEY and TAPPEINER 1998) and more rapid development of large trees (MCCOMB *et al.* 1993; CAREY *et al.* 1999a; CAREY *et al.* 1999b) than would occur without intervention.

The NWFP Riparian Reserve guidelines were adopted based on an understandably limited scientific knowledge. A more extensive base of knowledge would be useful to assess the interim Riparian Reserve guidelines and to craft possibly more efficient and effective guidelines. The ultimate objective would be to protect riparian functions and processes while allowing for compatible use of other riparian resources.

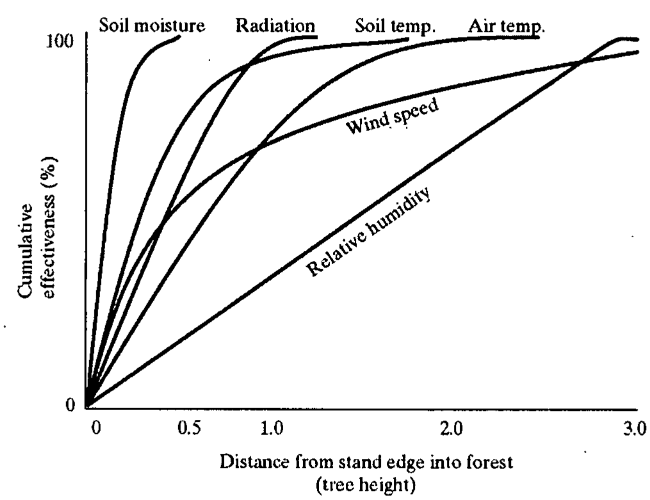


Fig. 1. Generalized curves indicating effectiveness of residual stand in moderating microclimate gradients between a clearcut and the interior of a residual old-growth stand. Percent effectiveness refers to the percentage deviation in observed microclimate values relative to measurements made in the undisturbed interior of the old-growth stand as a function of distance from clearcut edge towards the forest interior (generalized after CHEN 1991 and adapted from FEMAT 1993).

1.2 A fundamental goal: management systems for riparian ecosystem integrity that are compatible with wood production

Land management for competing uses and values is complex, and often, a contentious process. Emphasizing a range of management options that promote production of multiple resource values is an alternative to addressing conflicting uses and values (PETERSON and MONSERUD 2002). In contrast to exclusive production alternatives under "management by zoning", "multiple-use management" strives to optimize the net benefit derived from a mix of values, rather than maximizing production of any single value. However, there is a general lack of knowledge of the compatibilities and tradeoffs associated with the joint production of conflicting values (including commodity and non-commodity values, such as timber production and biodiversity).

Since much of the Riparian Reserves consist of young forest stands having potential for enhanced development of late-seral features through thinning, federal land managers have raised questions about potential stand developmental pathways and attributes under different riparian management scenarios. A passive management option is to delineate reserve boundaries and assume that over time these reserves will naturally develop desired characteristics and functions while foregoing timber harvest for commodity production. However, an alternative active approach to managing forests within and adjacent to reserves to achieve compatible production of ecological services and timber production could be adopted. Are there silvicultural practices that can more rapidly enhance the diversity of specified riparian functions and simultaneously provide for some level of timber or other commodity production?

1.3 A role for large-scale operational studies

Several factors suggest potential benefits from large, operational-scale studies in Riparian Reserves research: the regional significance of the issue; the inherent linkage of riparian and upland forest ecosystems; the scale of relevance for ecologically important variables; and the interest in efficacy of silvicultural treatment application at scales likely to be prescribed by resource managers. The Northwest Forest Plan encompasses the range of the northern spotted owl within the states of Oregon, Washington, and California, an area of approximately 23 million hectares spanning eight physiographic provinces. Heterogeneity is inherent at such a large scale. To effectively address issues of riparian system function and delineation, it is necessary to balance the benefits of detail and accuracy associated with fine-scale process-oriented studies against the benefits of incorporating heterogeneity present at the extensive-scale of natural resource management and policy.

Although some disturbance regimes and successional processes differ between riparian and upland ecosystems, the two ecosystems are linked through exchange of energy and materials. Due to their interaction, it is impossible to accurately address riparian ecosystems without accounting for adjacent upland forest conditions and riparian-upland interactions.

2 The density management and riparian buffer studies: an example of large-scale operational ecological research

The USDI Bureau of Land Management (BLM) has jurisdiction over 880 000 hectares of forested federal lands within western Oregon; 54% with stands less than or equal to 80 years-old and 35% with stands less than or equal to 40 years-old (Fig. 2). These relatively young stands dominated by Douglas-fir and western hemlock are somewhat evenly dispersed across the BLM's ownership. About 80% of these young stands are within areas designated for management as Riparian Reserves (RR), Late-Successional Reserves (LSR), or both, under the NWFP. As many as 140 000 ha are considered by the BLM to be overstocked and in need of thinning (THOMPSON *et al.* 2001).

Under the NWFP, any management activities in stands designated LSR must be done within the first 80 years, and for some site-specific exceptions, within 120 years of stand development (USDA and USDI 1994). This restriction is intended to prevent harvests that might divert more mature stands from a developmental trajectory towards old-growth. However, it is not clear whether the young even-aged stands will attain late-seral characteristics in a reasonable (i.e., will most of the biota dependant upon old growth go extinct in the meantime) time-frame without management intervention (HAYES *et al.* 1997; LINDERMAYER and FRANKLIN 2002). Furthermore, there is interest within the BLM to determine if there are ecological benefits to be derived from limited timber harvest that also generates revenue for local districts and the federal treasury.

To address uncertainty regarding management of young stands to achieve late-successional structure and maintain riparian habitats and functions, the BLM initiated the Density Management Studies (DMS) in partnership with researchers from the USDA Forest Service, Oregon State University and the USDI Geological Survey (THOMPSON and LARSEN 2003).

The objectives of the DMS are to: 1) test alternative stand density and riparian buffer treatments for accelerating the development of late-successional structure in 40-to-70 year-old Douglas-fir forests in the stem exclusion phase of stand development; 2) to assess the impacts of density management on ecological values represented by selected plant and animal taxa (including amphibians, fish, arthropods, non-vascular plants, mollusks, fungi, birds), and their habitats; 3) to provide opportunities to evaluate social and economic acceptability of density management; and 4) to provide opportunities for educating land managers in silviculture and buffer systems for development of late-seral forest structure and riparian functions.

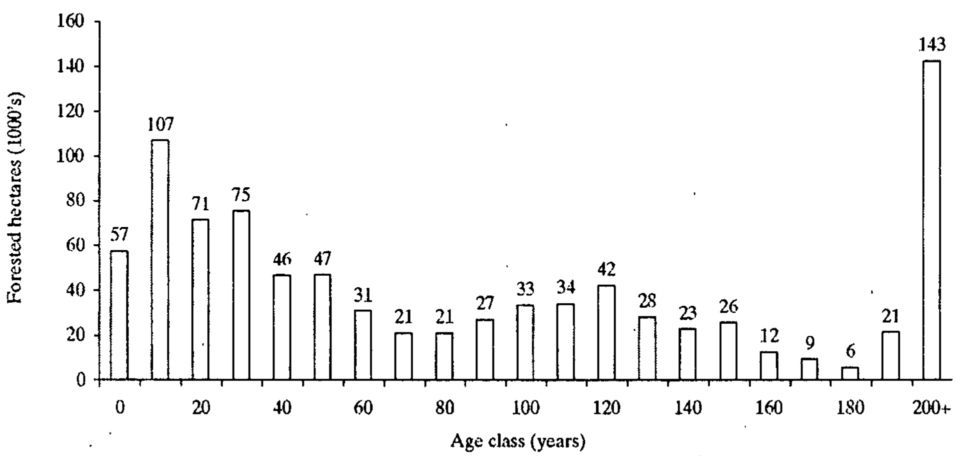


Fig. 2. Over 476 000 hectares –70% of total ownership of BLM lands in western Oregon are 5–80 year old stands. These stands were previously intensively managed for wood and now primarily managed as late successional and riparian reserves.

2.1 Density Management Study (DMS) design

The Density Management Study (DMS) consists of four thinning treatments, each applied to 20 ha or larger treatment units within 80 ha or larger sites. The thinning treatments include (Fig. 3):

1) Unthinned control – 500 to 750 trees per ha (tph) greater than 12.7 cm dbh.
2) High density retention – 70 to 75% of area thinned to 300 tph, 25 to 30% unthinned Riparian Reserves or leave islands.
3) Moderate density retention – 60 to 65% thinned to 200 tph, 25 to 30% unthinned Riparian Reserves or leave islands, 10% circular patch openings.
4) Variable density retention – 10% thinned to 100 tph, 25 to 30% thinned to 200 tph, 25 to 30% thinned to 300 tph, 20 to 30% unthinned Riparian Reserves or leave islands, 10% circular patch openings.

The DMS includes 12 sites dispersed among BLM lands in both the Coast Range and the west-side of the Cascade Mountains in western Oregon. On seven sites, the prescribed thinning treatments were first entries to the regenerating stands. Thinning treatments were applied to an additional five sites that had been previously thinned.

2.2 Goals and objectives of the riparian buffer study component

Within this overarching framework of the DMS, the riparian buffer studies were established to investigate variable density management and riparian buffers as means to accelerate the development of late-seral habitat, facilitate rare species management, and maintain ecological functions within riparian zones of 40–70 year-old headwater forests of western Oregon. Treatments include four types of streamside buffer width delineation adjacent to the mosaic of thinned stands, patch openings and leave islands of the upland treatment areas (Fig. 3). The four riparian buffer width treatments include (Fig. 4):

1) One site-potential-tree-height width (1 SPTH, ~ 80 meters);
2) Two site-potential-tree-height (2 SPTH, ~ 160 meters);
3) Variable-width buffer – Minimum 16 m wide; delineation based on site factors such as major change in topography or vegetation;
4) Streamside retention buffer – Retention of first streamside tree; thinning treatments applied to within 6 m of the stream (buffer extends approximately through the zone of canopy coverage of first streamside tree).

The 1 SPTH and 2 SPTH buffer delineations correspond to standards and guidelines established in the NWFP (USDA and USDI 1994). The variable-width buffer delineation corresponds more closely to rules established for non-federal forest lands in the state of Oregon. The streamside retention buffer delineation provides a treatment that potentially accelerates the development of large trees near the stream while providing some of the physical functions of bank stability and stream shading, but in theory less moderation of microclimate changes along the stream.

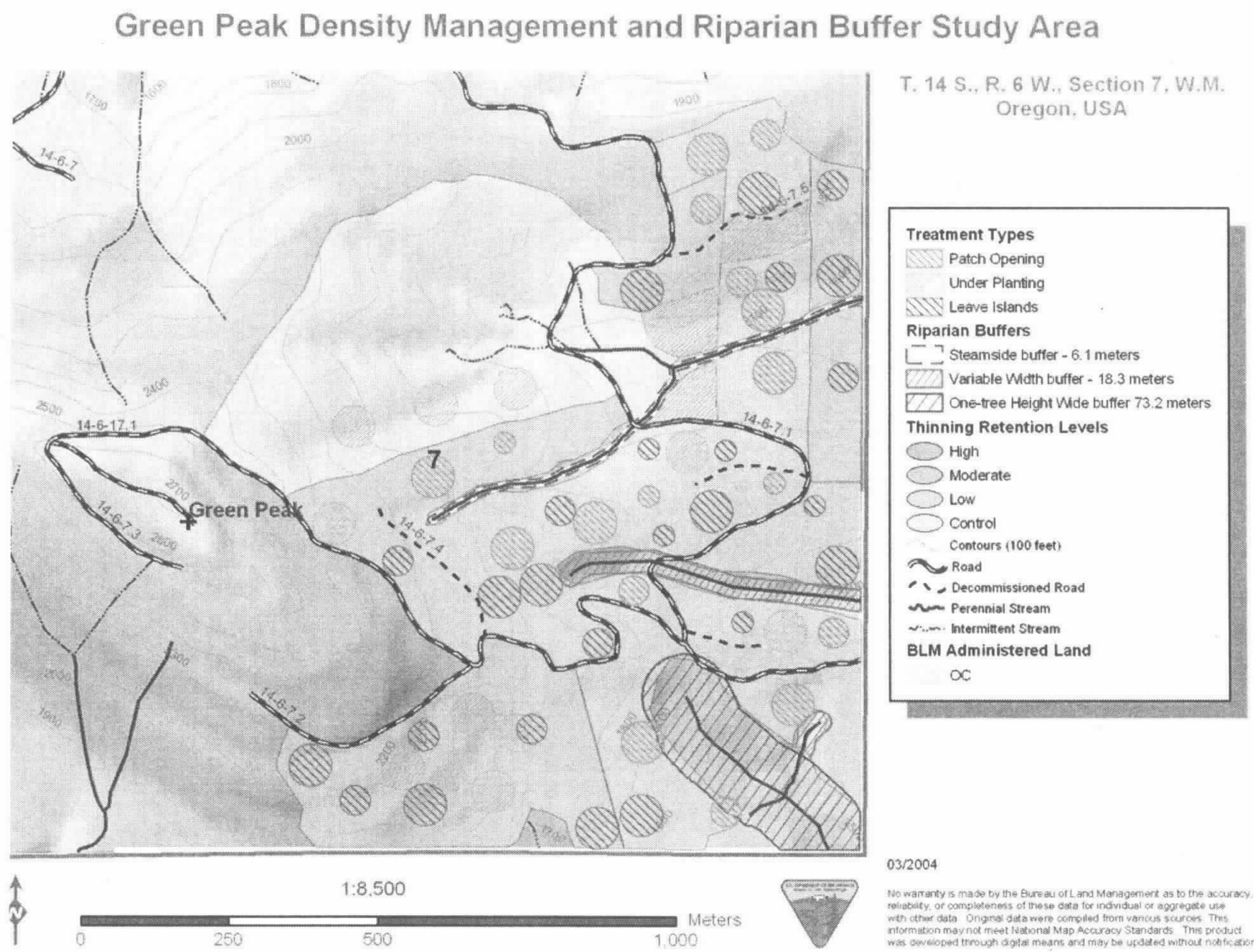


Fig. 3. Map of a density management study site (Green Peak in western Oregon) showing the complex of density management and riparian buffer treatments.

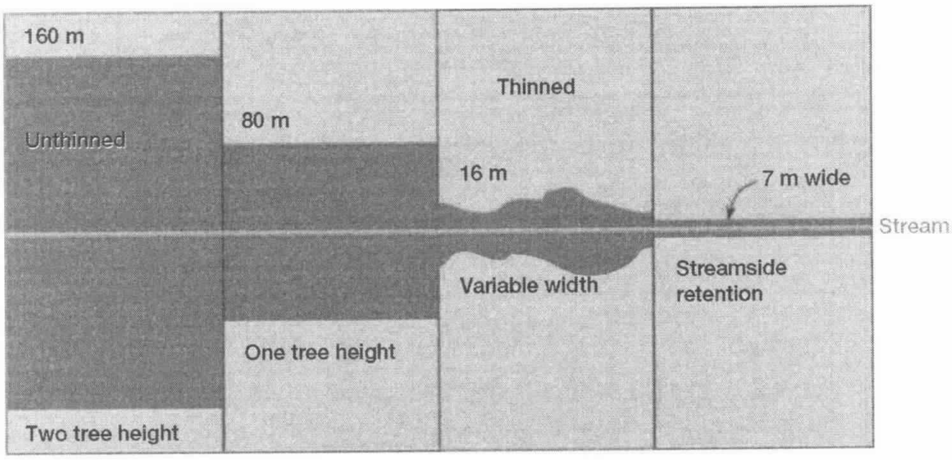


Fig. 4. The four unthinned buffer widths under investigation on the joint Density Management and Riparian Buffer studies. Buffer widths are approximated and based on the height of a site potential tree (USDA and USDI 1994), a tree that has attained the average maximum height possible given "site" conditions where it occurs. Schematic only. The array of buffer treatments varies between sites.

2.3 Response variables

Various metrics of stand development, microclimate, understory vegetation, aquatic ecology, invertebrates, lichens, and bryophytes, are being evaluated with respect to overstory thinning and the establishment of riparian buffers. Due to limited knowledge of ecosystem processes in relation to thinning in headwater forests, the initial scope of the riparian buffer companion studies is exploratory and is confined to describing the microhabitat, microclimate, and spatial and temporal characteristics of aquatic invertebrate and vertebrate abundance. Empirical findings from these studies will likely generate refined mechanistic hypotheses on ecosystem processes and functions in riparian buffers as well as density management influences on individual species of flora and fauna.

2.4 Study implementation

Although complex, with four upland density management regimes and four riparian buffer delineations, the Density Management Study was designed to be representative of a commercially viable project as administered and implemented by BLM managers. The BLM and researchers collaborated to design and lay out alternative thinning regimes to be applied to large treatment units at sites characteristic of 40-to-70 year-old forests on BLM lands throughout western Oregon. The BLM assumed responsibility for basic monitoring of vegetation responses in the large thinning treatments under the guidance of researchers. Data collection, analyses, and reporting responsibilities for companion studies were assumed by various investigators from collaborating research institutions. Implementing the study on 12 sites across 4 BLM districts was facilitated by strong support and direction from the BLM's Oregon State Office and acceptance by field office managers.

Balancing concerns for multiple resource objectives on a site specific basis was critical to the implementation of the study. Economic, engineering, and ecological concerns had to be evaluated and resolved before the treatments could be implemented at a site. Economic concerns focused on whether the costs of sale layout and administration were recovered in proceeds from the timber sale. Engineering concerns included road construction, stream crossings and harvesting design. The occurrence of protected species (rare or threatened species) of flora posed ecological constraints to study implementation. Most of these ecological constraints were resolved by subjective placement of unthinned leave islands and varying the width of buffers. Resolution of engineering and ecological conflicts compromised the randomization of treatments on every study site. Economic concerns were minor and often overcome by grouping sales to increase the economies of scale (OLSON *et al.* 2002).

3 Early study findings

The scope of this paper does not permit a detailed summary and discussion of early findings from all the DMS studies conducted to date. Rather, we present a summary of early findings on canopy, light, and microclimate responses associated with differing density management and riparian buffer treatments.

These studies reflect some of the multiple resource values of concern on forested sites in western Oregon. Not all studies are implemented on every site:

Hydrology of headwater streams (M. Reiter, Weyerhauser Co.)
- Most perennial headwater systems are spring fed.
- New methods for measuring small, low flow streams are being tested.

In-stream periphyton and invertebrates (R. Danehy, Weyerhauser Co.)
- Recently initiated study.
- New techniques for small stream invertebrate and periphyton sampling being developed.

Riparian macroinvertebrates (A. Moldenke, Oregon State University & R. Progar, USDA Forest Service) PROGAR and MOLDENKE (2002).
- Terrestrial floor of headwaters riparian zones are hot spots of arthropod diversity.
- Soil-associated arthropod diversity near 2nd-order streams is twice that of 1st-order streams.
- Most arthropod species on upland forest floor occur in equal or greater abundance near stream.
- 50 percent of species in riparian zone are restricted to 1–3 m wide terrestrial margin near stream.
- Moderate thinning increases species richness. Heavy thinning and large gaps increase species richness of both forest and introduced species.
- Thinning increases soil microbial activity as indicated by increased soil respiration.
- Forest riparian buffers 30 m wide serve as refuge for both forest-upland and forest-riparian species.
- Most truly aquatic headwater insect taxa occur in both clearcut and forested situations although relative density differs.
- Headwater streams with interrupted/intermittent flow produce higher densities of flighted adult insects.

Aquatic vertebrates (D. Olson, USDA Forest Service)
- Most aquatic vertebrate assemblages found close to stream.
- Assemblages vary longitudinally with stream flow and laterally from stream center.
- Sensitive species occur in headwater riparian zones.
- At least one species is associated with discontinuous flow.
- Thinning has minimal effect on most species.
- One species responded to the most intensive thinning.

Leave-island fauna (S. Wessel, USDA Forest Service)
- Leave islands provide refugia only for amphibians.

Lichens and bryophytes (P. Muir, Oregon State University & C. McCune, Oregon State University)
- Diversity and abundance are associated with canopy gaps, hardwood trees and shrubs, and remnant large trees.
- Key species associated with legacy features.
- Dense stands with little or no understory make poor habitat.

Microclimate of riparian and upland forest (S. Chan, USDA Forest Service & S. Wessel, USDA Forest Service)
- Strongest gradient in microclimate from stream to upland occurs within 15 m of stream channel.
- Detectable changes in upland microclimate with thinning occurred during warmest and driest part of day.
- Changes in riparian microclimate with thinning were slight or undetectable.
- Upland thinning and gaps alter microclimate but effects on species as yet undetermined.
- Light availability is patchy and low in unthinned stands.
- Heavy thinning resulted in light levels that were less than 40% of full sunlight.

Understory development (S. Chan, USDA Forest Service & S. Wessel, USDA Forest Service)
- Riparian areas support diverse flora, possibly in association with heterogeneous microsites.
- Upland vascular plant diversity increased with lower stand densities and larger gaps.

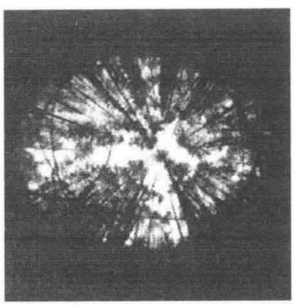
Canopy development (S. Chan, USDA Forest Service)
- Canopy expansion and closure evident five-years following thinning.

Stand development and vegetation dynamics (K. Puettman, Oregon State University)
- Basic monitoring of the BLM Density Management Study.
- Pre- and post-treatment data collected and being analyzed.
- Revised sampling design in place to study 5th year responses and effects of edges and gap size.

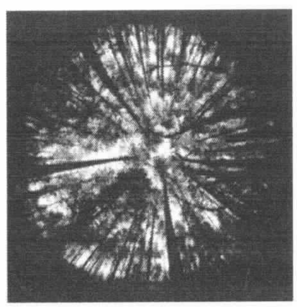
3.1 Variability and influence of thinning on a riparian buffer

The continuum of stand conditions along a transect oriented perpendicular to the stream center, and extending through the riparian buffer and into the thinned upland is illustrated in Figure 5. Thinning to 200 tph decreased stand density by up to 70%, but only increased available light from 13–19% in the unthinned buffer to about 29% in the thinning. The increase in light (~10% absolute increase) associated with heavy thinning to 200 tph is small relative to the number of trees removed and proves to be insufficient to stimulate substantial understory development (MAILEY and KIMMINS 1997; DREVER and LERTZMAN 2001).

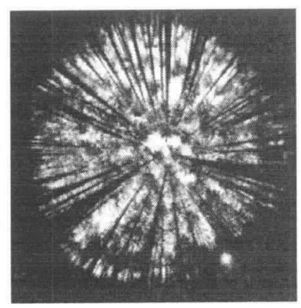
Light values derived from the hemispherical canopy images presented in Figure 5, indicate that upland thinning to 200 tph increases available light within the first 20 m of the adjacent riparian buffer. This pattern of light penetration from a harvested edge into an unthinned forest is similar to that reported in CHEN (1991) and generalized in Figure 1, indicating that an untreated buffer moderates increased radiation from an adjacent clearcut into an un-harvested old growth stand. Douglas-fir/western hemlock canopies respond quickly to thinning by arresting self-pruning of lower branches, expanding branch length and growing longer and denser crowns. Thus, thinning may result in some significant but transitory changes in stand light and microclimate conditions. Questions remain as to how long increased light levels and modified microclimates will persist, and what long-term impacts these modifications may have on stand development and biota.



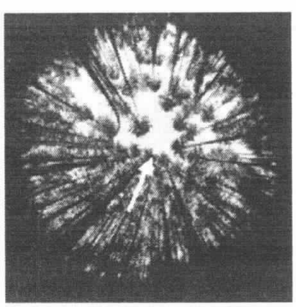
Stream center 19% sky



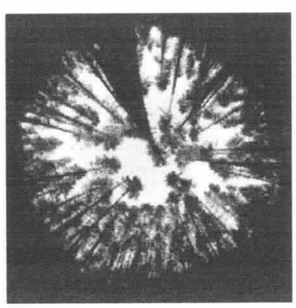
30 m, 13% sky (stream buffer)



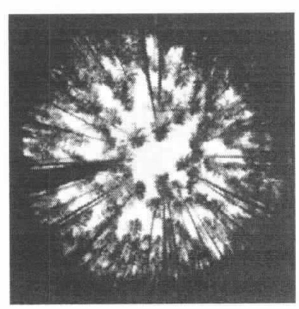
50 m, 15% sky (stream buffer)



70 m, 19% sky (edge of buffer/ thinning)



90 m, 29% sky (thinned)



110 m, 29% sky (thinned)

Fig. 5. Hemispherical images showing the overstory canopy of a 50–55 year old Douglas-fir dominated density management and riparian buffer site. The images initiate from the stream center, upland through an unthinned 70 m wide riparian buffer (1 site potential tree height wide) and into a stand thinned to 200 trees per hectare (tph). The % sky readings relate to the percent of open sky. The edge between the unthinned buffer and the upland thinning is shown at 70 m.

3.2 Microclimate patterns in riparian areas

Maintaining typical microclimate conditions with riparian buffers, specifically relative humidity, was a primary guide for delineation of 1 and 2 SPTH Riparian Reserve widths in the NWFP (Fig. 1; FEMAT 1993; USDA and USDI 1994). Patterns of relative humidity measured between 1 to 1.5 m above ground during the summer as a function of distance from the stream are depicted in Figure 6. The FEMAT (1993) plot, based on extrapolation of data from an upland, mid-slope (non-riparian) old growth stand and adjacent clearcut (CHEN 1991), suggests that relative humidity should decrease linearly with distance upland from the stream. Chen's work suggested that alterations of relative humidity may extend from a clearcut up to three site-potential tree-heights into an intact forest. Subsequent work by BROSOFSKE *et al.* (1997) in riparian buffers, uncut managed forests and adjacent clearcuts suggested that riparian relative humidity patterns could be maintained with buffers of only 45 m minimum width. The BROSOFSKE *et al.* (1997) recommendation is based on the assumptions that gradients in microclimate in untreated stands stabilize within 30 meters of the stream and that upslope edge effects extend no more than 15 m into the buffer. Current work from the riparian buffer component of the BLM density management study reveals that under warm and dry summer conditions, the largest change in relatively humidity from streamside to the upland typically occurs within 15 m of the stream channel and begins to stabilize at approximately 25 meters from the stream (Fig. 6). This pattern is consistent for both unthinned and thinned stream reaches having riparian buffers of various widths.

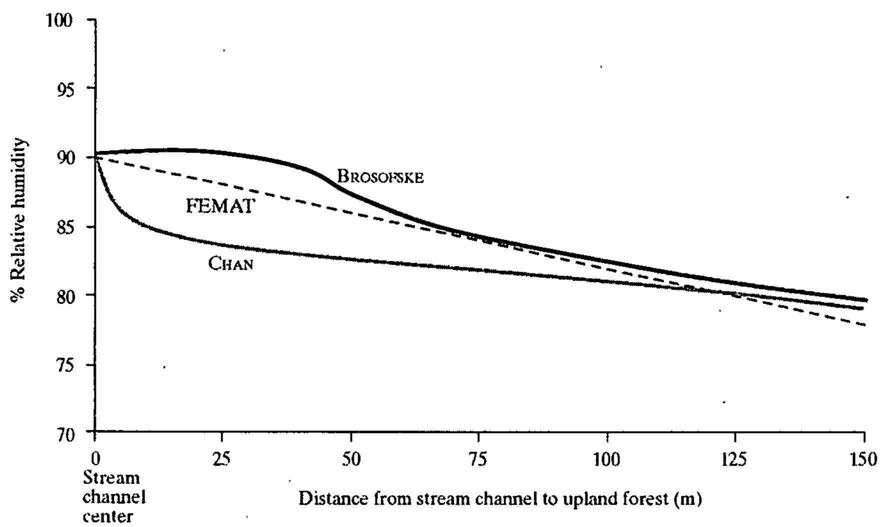


Fig. 6. Generalized patterns of relative humidity associated with distance from the stream channel, streamside forests and upland forests in western Oregon. The three lines show a progression of knowledge on riparian microclimate. Dotted, adapted from FEMAT 1993, suggests buffers of at least 2 site potential trees wide (> 160 m) based on an upland study adjacent to a clearcut by CHEN (1991). Solid line is generalized from BROSOFSKE *et al.* (1997) suggesting minimum buffer widths of 45 m to maintain streamside microclimate from adjacent clearcuts. Grey line, based on Chan's work in progress (OLSON *et al.* 2000, 2002) suggests that the majority of the inherent higher relative humidity characteristics of riparian areas are detected within the first 15 meters of a stream.

3.3 Emerging patterns from early findings of the riparian buffer component of the Density Management Study

Early results from the DMS suggest that differing residual thinning densities and different buffer widths result in relatively small changes in the riparian environment, and that these changes are not associated with detectable decreases in riparian-dependent organisms (Table 1). A consistent pattern emerging from early results suggests that the most suitable habitat for many species of riparian-dependent fauna is found within 5 m of the stream. These initial observations on gradients in microclimate and surveys of macro-invertebrates and amphibians showing relationships with distance from stream support our interest in developing silvicultural systems that explicitly account for the unique riparian zone features within headwater forest ecosystems.

4 Are disturbances from the various riparian buffer width and density management treatments sufficiently large to detectably alter habitat?

As with any silvicultural system, the intent of vegetation manipulation is to alter the amount, quality, and distribution of environmental resources in ways expected to affect specific forest conditions. The study looks at a suite of variables that, taken together, encompass vegetation structure and composition ranging from herbaceous ground cover, through woody shrubs, to the coniferous fir overstory. This consideration of vegetation complexity is coupled with measures of light, temperature, and relative humidity to relate manipulation and development of the vegetation to microclimatic factors that are postulated to be important elements of riparian habitat.

A concern with large-scale ecological studies is that as treatment area, geographic scope of inference, and complexity of experimental design and response variables increase, it becomes difficult to resolve research questions. The fiscal and logistical costs of large plots are often great. Typically, there is a decrease in the amount of treatment replication as plot size and treatment complexity increases. Further, as size of treatment units and geographic extent of inference increases, there is likely to be increased heterogeneity, both within and among individual treatment units and dispersed research sites. Also, as studies incorporate more ecological features, there will be a need to monitor a broader range of response variables that may differ greatly in relevant spatial and temporal scales. All of these issues lead to a concern about the power of large-scale operational studies to statistically test specific experimental hypotheses.

A question we had with the riparian buffer component of the Density Management Study is whether the range of buffer widths created would be diverse enough to generate measurable treatment differences given the heterogeneity within and among treatment units and sites. Given the basic conceptual model of the silvicultural study linking overstory manipulation and buffer width to understory vegetation and microclimate, it is relevant to determine if we can detect statistical differences in overstory vegetation structure and some measures of microclimate.

In Table 1, variances associated with blocks (sites), treatments (buffer widhts), and sampling (transects and plots within transects) are summarized for vegetation characteristics of leaf area index (LAI), percent canopy light transmittance, and percent cover of shrubs and herbs sampled within five buffer widhts at six sites the first year following treatment. Conceptually, manipulation of the overstory will be reflected structurally by LAI. Structural differences in LAI will be reflected in differences in light transmittance. Understory vegetation will respond either directly to manipulation of the buffer canopy (harvest disturbance) or indirectly to the altered canopy environment. For each of these variables, the variability in site, buffer widht, and sampling is reflected by mean sums-of-squares. The largest amount of variance in LAI, light, and herbaceous cover was usually accounted for by the buffer treatments, leading to significant differences. Similarly, site contributes a significant source of variation in LAI, shrub cover, and herb cover. It is interesting to note that although there was a significant site effect on LAI, the measured light levels were not sufficiently different relative to the error variance (variation among transects within sites) to be significant. It should also be noted that in terms of sampling variance for LAI, shrub cover, and herb cover, the amount of variation among sub-plots was substantially greater than that among transects. In contrast, for light transmittance, there is less variation among sub-plots than among transects. This illustrates the importance of sampling design in studies that encompass phenomena that operate at different spatial scales. LAI, shrub cover, and herbaceous cover represent relatively static structural features at a given sampling event and therefore spatial variability exists at a fine scale and in some proportion to the size and density of individuals with crowns that overlap a location. In contrast, measured light levels through a forest canopy include a fraction due to direct solar radiation (which is a very local feature determined by the position of the vegetation and topography) and also a fraction of diffuse radiation (which is determined by canopy and topographic features at a broader spatial scale). Thus, for total light, there could conceivably be less variation within transects (among sub-plots) than was observed for parameters indicative of vegetation structure.

Table 1. Variance characteristics and significance of site and buffer width effects for canopy leaf area index (LAI), percent light transmittance, percent shrub cover and percent herbaceous vegetation cover measured the year following treatment. MS refers to mean squares as estimates of variance. Significance refers to the probability of no differences existing among sites or among buffer treatments, fixed effects in the mixed-model analysis. Variance among transects, a random effect, served as the error term for testing site and buffer treatment effects. Mean square for sub-plots (a random effect) are shown to illustrate relative contributions of transects and sub-plots as sources of sampling variation.

	Overstory Characteristics					Understory Characteristics				
		LAI (m^2/m^2)		Light Transmittance (%)			Shrub Cover (%)		Herb Cover (%)	
Source	# of Units	MS	Signif.	MS	Signif.	# of Units	MS	Signif.	MS	Signif.
Site	6	0.85	0.0269	30	n.s.	6	571	0.0085	2061	<0.0001
Buffer width	5	4.42	<0.0001	578	<0.0001	5	235	n.s.	551	0.0073
Whole Plot (transects)	70	0.31	n.s.	69	n.s.	64	165	n.s.	141	n.s.
Sub-plots within transects	384	0.37	n.s.	37	–	291	740	–	458	–

The issue of statistical power can be restated as: "How large of a difference must exist to be statistically significant?" The degree to which we determine a treatment influence is based on the chance of detecting the difference with the experiment design and the methods (HAYES 1987). In studies where knowledge of potential responses is very limited, setting a lower threshold for making a Type II error (failure to identify true treatment differences) might be a reasonable approach for generating more refined hypotheses based on empirical observations. Table 3 illustrates the magnitude of differences required to meet significance criteria of α = 0.05, 0.1, and 0.2 (the probability of incorrectly rejecting the null hypotheses) while holding the probability of failing to identify a treatment effect to β = 0.2) for LAI, percent light, shrub cover, and herb cover. In the context of large-scale operational studies with limited opportunity for replication, it may be more important to determine magnitudes of differences that are ecologically meaningful and use those criteria as a measure of successful implementation. Table 2 illustrates that if one were willing to accept higher alpha levels of 0.1 or 0.2 (greater risk of incorrectly stating a significant effect), significant differences could be detected by sampling 10% and 25% fewer transects, respectively. As indicated by MONSERUD (2002), it may be reasonable to consider higher α-levels in complex studies, if the differences observed are considered meaningful and the fiscal or logistical costs of experimental replication are high.

Given the analyses presented in Tables 1 and 2, based on first-year post treatment data, we have demonstrated significant treatment effects on a range of parameters representing both structural and process elements of the ecosystem under study. It is our preliminary conclusion that the study design is sufficiently robust to address our objectives for the riparian buffer component of the Density Management Study. It remains to be determined if the design will be robust to long-term temporal trends in vegetation and microclimate, or to synthesis with other attributes from companion studies focusing on macroinvertebrates, amphibians or aquatic-dependent fauna.

Table 2. The minimum difference among means for detecting site or buffer treatment effects with significance at the α = 0.05, 0.10 or 0.2 levels with a power of 0.8 (a probability of β = 0.2 for making a type II error) for four parameters measured in the year following treatment.

	Minimum difference among means for significance at alpha			
	Overstory characteristics		Understory characteristics	
Alpha (Prob. H_0: $\mu_1 = \mu_2$)	LAI	Light transmission (%)	Shrub cover (%)	Herb cover (%)
Prob. < 0.05	0.260	3.88	6.28	5.81
Prob. < 0.10	0.234	3.49	5.64	5.22
Prob. < 0.20	0.200	2.98	4.81	4.45

5 Inferences and applications

5.1 Post-hoc synthesis versus integrated design and hypothesis testing

Although companion studies address several resource values in addition to the basic vegetation responses being monitored by the BLM (see Chapter 3), the ability to integrate results across multiple values is limited. Companion studies were initiated and implemented with relative independence. In some cases, such as the microclimate evaluations of Chan, the aquatic vertebrate work of Olson and the riparian invertebrate studies of Moldenke, these companion studies share some sites and stream reaches within sites (Chapter 3). However, sampling designs and timing often differ among studies, thus limiting our ability for joint analysis of the data. Although explicitly integrated analyses among component studies is generally not possible, complimentary efforts can lead to development of more focused hypotheses for testing functional linkages between the stream, riparian area and upland; between invertebrates, aquatic-dependent vertebrates and flora.

5.2 Utility and timing of information generation and delivery

When the NWFP was being developed; a lack of information directly relevant to riparian ecology and management led to the adoption of conservative guidelines for buffer delineation in Riparian Reserves. Only recently, with studies such as ours, has information on structure, dynamics, and function of riparian forests in a density management context become available to land managers. Ongoing DMS research on microclimate, density management and riparian buffers is providing managers with information to better identify riparian areas in critical need of protection, to assess the potential short-term impacts of density management and riparian buffer design, and to more accurately assess risks and benefits of active management within Riparian Reserves. With DMS sites dispersed across management districts in western Oregon, the BLM is providing managers with opportunities to gain first-hand knowledge on the outcomes of density management through study implementation and monitoring.

5.3 Pitfalls and opportunities

The resource investment required for establishment of large, operational-scale studies can be very large and there is risk that periodic or permanent short-falls in funding and/or changes in personnel might compromise the study. Large-scale studies often have the disadvantage of requiring several years to fully implement; initial harvest of the 12 DMS sites took nearly five years to complete. This extended period of implementation stretches the measurement cycle, forces compromises in sampling, and delays our ability to derive and comprehensively report results across all sites. Furthermore, a broad geographic scope often results in substantial variation among sites, making it difficult: to achieve consistent treatment implementation; to hold variables constant; and to test narrowly focused hypotheses. To address these limitations in the DMS, researchers have evaluated some hypotheses using subsets of experimental sites; have reported on subsets of data; have partitioned work among multiple projects and funding pools; and have used workshops, symposiums and field tours to convey interim results.

In contrast to the pitfalls mentioned above, large-scale experiments provide many unique opportunities. The principal advantages they provide are the opportunities for integrated or complimentary multidisciplinary research, and integration of research and management. Operational-scale studies can facilitate cooperation between managers and researchers and afford more opportunities for researchers and managers to identify issues of common concern. Observations and early findings from DMS have demonstrated to managers that alternative treatments are feasible to implement. Managers have been willing to accept some risk associated with adopting interim DMS findings and have begun to operationally implement density management treatments. This has resulted in a wider distribution of treatment options across landscapes and additional monitoring opportunities. As studies such as DMS improve our knowledge of stand-level density management, there will likely be future efforts to evaluate these treatments at the small watershed scale to improve our understanding of linkages between riparian and upland forests and for assessing silvicultural systems at larger spatial scales.

6 Collaboration between research and management facilitates the development of large scale experiments

Taking an ecosystem approach to riparian management is often not possible without cooperation between researchers and managers (CAREY *et al.* 1999b). Knowledge of the complexity of land management issues has increased, while resources available for addressing these issues have decreased for most public agencies in the USA. Partnerships between land managers and researchers, such as the DMS study, are an effective mechanism for leveraging increasingly scare resources and expertise to focus on important issues.

6.1 Unanswered questions and unquestioned answers

The process of questioning previously unquestioned answers can yield important advances in knowledge and its applications (CAHN 2000). For example, the ecological value of large downed wood is now recognized as a critical component of in-stream and riparian habitat (GREGORY *et al.* 1991; MASER and SEDELL 1994; GOMI *et al.* 2002). However, wood removal from Pacific Northwest streams and rivers went largely unquestioned for over two decades between the 1950's and 1970's (MASER and SEDELL 1994). During this period, trees were often cut along stream banks to prevent them from falling into streams. The logic behind clearing wood from streams was that wood in streams restricted fish passage and supplied material for debris jams that caused channels to scour during floods and created hazards to engineered structures and navigation (MASER and SEDELL 1994). It is possible that the stocks of wild anadromous fish, such as salmon and steelhead, would be even more depleted if the unintentional degradation of fish habitat, resulting from wood removal from streams were left unquestioned.

The Density Management Study provide many current examples of unanswered questions and unquestioned answers. Our understanding of headwater riparian systems and their linkages with management practices in upland forests is limited (GOMI *et al.* 2002). Yet, until the implementation of the Northwest Forest Plan in 1994, many of the forests associated with headwater streams and intermittent streams were managed as part of the upland forest. The wide interim Riparian Reserves and the Late Successional Reserves dictated under the Northwest Forest Plan were based in part on limited knowledge of functions, processes and management of these systems. Thus, it is essential that managers, scientists and policy makers facilitate testing of assumptions used to formulate the NWFP (USDA and USDI 1994) and be open to evaluating new knowledge.

Questioning is not meant to cast doubt on previous achievements, but provides a process to critically assess assumptions used to generate policies. CAHN (2000) cites Groucho Marx as stating that "the problem with prediction is that it is about the future and we do not know the future". He emphasizes that "to understand the cause of things is the best way to overcome Murphy's Law". With intuition and critical thinking, we develop hypotheses on what is not known and what we ought to know. The difficulty may be in prioritizing our efforts to study a problem.

6.2 Successful research and management partnerships

The scale of knowledge provided through research should be compatible with the scale of the issue perceived as important by management. For land managers, this relevant scale is often determined by logistics of management planning or operational implementation. Researchers should strive to provide information that is useful to the development of tools and guidelines for land managers by formulating hypotheses that meet management needs and by employing research designs in which treatments or experimental units are of operational scale.

A researcher's role is to apply scientific methods to develop information that leads to better solutions to management issues. This typically consists of the researcher conducting a problem analysis; translating issues into testable hypotheses; developing an appropriate experimental design consistent with site constraints, management concerns, and resource limitations; guiding or conducting acquisition and analysis of data; and generating and reporting objective, defensible inferences. In the case of large, operational-scale research, scientists responsibilities may also include assisting managers in identifying potential methods for incorporating results into operational practice, and to facilitate adaptive learning by involving managers throughout all phases of the study from planning through interpretation.

The role of land managers in research projects has typically been to identify issues; to provide professional, expert insight for developing hypotheses; to work with researchers and stakeholders to implement projects; and to alert researchers to potential problems that may affect implementation. Managers work to understand a study, appreciate its value and make suggestions for improvement. BLM personnel were integrally involved in planning and implementing the study design and methods. Thus, they were aware of the concepts of randomization, replication and procedures that may lead to bias, and understand the need to consistantly apply monitoring procedures.

To test hypotheses, researchers may propose activities that may be at odds with current best management practices (e.g., thinning without buffers adjacent to streams or randomly placing occasional intensive treatments in areas visible to the public). Likewise, manager's expert opinion regarding best management practices may have to be challenged to gain insight on the effectiveness of a practice. Thus, a successful partnership may require that managers and researchers operate within contexts that may be atypical for their respective positions as resource professionals and scientists.

A common issue cited by managers is that researchers are often not familiar with the operational details and constraints on practices imposed by environmental laws and agency regulations and policies; the role of public participation in project planning; the logistics of project scheduling; and agency priorities for allocating fiscal and personnel resources. In the majority of cases, research must comply with the laws, procedures and regulations facing managers. In DMS, managers guided researchers through the process for implementing study plans consistent with procedural standards and guidelines of the Northwest Forest Plan and the BLM.

Successful partnerships require a commitment at both policy and implementation levels. Both the State Office of the Oregon/Washington BLM and the USDA Forest Service are strongly committed to the Density Management Study. Designation by the BLM of an overall DMS coordinator and individual site coordinators provides leadership in communicating management and administrative needs, facilitates acquisition of needed resources, encourages peer review of scientific procedures and outputs, maintains consistency between replications, and assures that the educational potential of the study is realized. The DMS coordinator also works with researchers and site coordinators to insure that plots and transects are permanently marked in the field and recorded in GIS layers to protect field investments. They also facilitate data management and secure storage of information from research and monitoring that includes metadata standards, data quality assurance and access to datasets. The BLM has established a website for the Density Management Study that provides an interface for accessing general descriptions of the projects, progress summaries, technology transfer activities, publications and GIS information.

To encourage adaptive learning, BLM managers and specialists have participated not only in planning and implementing DMS study, but also have participated in measuring the responses. Collaboration among managers and researchers in the DMS study has improved the ability of each to meet their respective missions, and contributed greatly to an improved understanding of the trade-off involved with young stand management.

Acknowledgements

The authors wish to thank Dr. Peter Brang and Dr. Andrew Moldenke who graciously provided valuable review and comments on drafts of this manuscript that led to substantial improvements. We sincerely thank Mr. Mark S. Koski, Geographer with the USDI BLM, Salem District for the numerous hours he devoted to customizing the map for this paper. This study and paper were facilitated by the dedication of the BLM site coordinators and USDA Forest Service staff members including Emmalie Goodwin, Valerie Banner, David Larson, Daniel Mikowski and Jon Sewell. Much thanks to Kelly Redwine with the Oregon State University Extension Service for her contributions in editing this paper.

7 References

AGEE, J.K., 1988: Successional dynamics in riparian forests. In: RAEDKE, K.J. (ed) Streamside management: Riparian wildlife and forestry Interactions. University of Washington, College of Forest Resources, Contribution 59: 31–43.

BAILEY, J.D.; TAPPEINER, J.C., 1998: Effects of thinning on structural development in 40–100 year-old Douglas-fir stands in western Oregon. For. Ecol. Manage. 108: 99–113.

BEACH, E.W.; HALPERN, C.B., 2001: Controls on conifer regeneration in managed riparian forests: Effects of seed source, substrate, and vegetation. Can. J. For. Res. 31: 471–482.

BROSOFSKE, K.D.; CHEN, J.; NAIMAN, R.J.; FRANKLIN, J.F. 1997: Harvesting effects on microclimate gradients from small streams to uplands in western Washington. Ecol. Appl. 7: 1188–1200.

BUNNELL, F.L., 1999: What habitat is an island? In: ROCHELLE, J.A.; LEHMANN, L.A.; WISNIEWSKI, J. (eds) Brill, Leiden, Netherlands, Forest Fragmentation: Wildlife and Management Implications. 1–31.

CAHN, R.W., 2000: The Science of Things: Unanswered Scientific Questions and Unquestioned Scientific Answers in Materials Research and Development. Mater. Res. Soc. Bull., September 25: 59–62.

CAREY, A.B., 1995: Sciurids in Pacific Northwest managed and old growth forests. Ecol. Appl. 5: 648–661.

CAREY, A.B.; LIPKE, B.R.; SESSIONS, J., 1999a: Intentional systems management: Managing forests for biodiversity. J. Sustanainable For. 9: 83–125.

CAREY, A.; CALHOUN, J.M.; DICK, B.; JENNINGS, D.; YOUNG, L.S.; BIGLEY, R.E.; CHAN, S.S.; HARRINGTON, C.A.; HAYES, J.P.; MARZLUFF, J., 1999b: Reverse technology transfer: obtaining feedback from managers". West. J. Appl. For. 14: 153–163.

CHEN, J., 1991: Edge effects: microclimatic pattern and biological responses in old-growth Douglas-fir forests. Ph.D. dissertation. Seattle, Washington, University of Washington. 174 pp.

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.A.; 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. Portland, OR: USDA-Forest Service, Pacific Northwest Research Station, PNW-GTR-422.

CURTIS, R.O., 1997: The role of extended rotations. In: KOLM, K.A.; FRANKLIN, J.F. (eds) Creating a Forestry for the 21st Century: The science of Ecosystem Management. Washington D.C, Island Press. 165–170.

DANEHY, R.J.; KIRPES, B.J., 2000: Relative Humidity Gradients Across Riparian Areas in Eastern Oregon and Washington Forests. Northwest Sci. 74: 224–233.

DEBELL, D.S.; CURTIS, R.O.; HARRINGTON, C.A., 1997: Shaping stand development through silvicultural practices. In: KOLM, K.A.; FRANKLIN, J.F. (eds) Creating a Forestry for the 21st Century: The science of Ecosystem Management. Washington D.C, Island Press. 141–149.

DEFERRARI, C.M., 1993: Exotic Plant Invasions Across Landscape Patch Types on the Olympic Peninsula. M.S. Thesis. Seattle, Washington, University of Washington.

DEMAYNADIER, P.G.; HUNTER JR, M.L., 1995: The relationship between forest management and amphibian ecology: a review of the North American literature. Environ. Rev. 3: 230–261.

DIAZ, N.; MELLEN, K.T., 1996: Riparian Ecological Types, Gifford Pinchot and Mt. Hood National Forests, Columbia River Gorge National Scenic Area, USDA Forest Service, Pacific Northwest Region, Spring, 1996.

DIAZ, N.M., 1996: Landscape Metrics: a New Tool for Forest Ecologists. J. For. 94: 12–16.

DREVER, C.R.; LERTZMAN, K.P., 2001: Light-growth responses of coastal Douglas-fir and western red cedar saplings under different regimes of soil moisture and nutrients. Can. J. For. Res. 31: 2124–2133.

FEMAT, 1993: Forest Ecosystem Management: An ecological economic and social assessment. Report of the Forest Ecosystem Management Assessment Team (FEMAT). 1993-793-071. Washington DC. GPO.

FETHERSTON, K.L.; NAIMAN, R.J.; BILBY, R., 1995: Large woody debris, physical process, and riparian forest development in montane river networks. Geomorphology 13: 133–144.

FRANKLIN, J.F.; BERG, D.R.; THORNBURGH, D.A.; TAPPEINER, J.C., 1997: Alternative Silvicultural Approaches to Timber Harvesting. In: KOLM, K.A.; FRANKLIN, J.F. (eds) Creating a forestry for the 21st Century: The science of Ecosystem Management. Washington D.C., Island Press, 111–140.

GOMI, T.; SIDLE, R.C.; RICHARDSON, J.S., 2002: Understanding Processes and Downstream Linkages of Headwater Systems. BioScience 52: 905–915.

GREGORY, S.V.; SWANSON, F.J.; MCKEE, W.A.; CUMMINS, K.W. 1991: An ecosystem. Harris, perspective of riparian zones. BioScience 41: 540–551.

HANN, D.W., 1995: A key to the literature presenting site-index and dominant-height-growth curves and equations for species in the Pacific Northwest and California. Res. Contrib. 7. Corvallis, OR: Oregon State University, Forest Research Laboratory. 26 pp.

HAYES, J.P, 1987: The positive approach to negative results in toxicology studies. Ecotoxicol. Environ. Saf. 14: 73–7.

HAYES, J.P.; CHAN, S.S.; EMMINGHAM, W.H.; TAPPEINER, J.C.; KELLOG, L.D.; BAILEY, J.F., 1997: Wildlife responses to thinning in young forests in the Pacific Northwest. J. For. 95: 28–33.

LINDERMAYER, D.B.; FRANKLIN, J.F., 2002: Conserving forest biodiversity: a comprehensive multiscaled approach. Washington, Covelo and London, Island Press. 351 pp.

MAILY, D.; KIMMINS, J.P., 1997: Growth of *Pseudotsuga menziesii* and *Tsuga heterophylla* seeds along a light gradient: resource allocation and morphological acclimation. Can. J. Bot. 75: 1424–1435.

MASER, C.; SEDELL, J.R., 1994: From the Forest to the Sea: The ecology of Wood in Streams, Rivers, Estuaries and Oceans. Delray, Florida, St Lucie Press. 200 pp.

MCARDLE, R.E.; MEYER, W.H.; BRUCE, D., 1961: The yield of Douglas fir in the Pacific Northwest. 2nd rev. Tech. Bull. 201. Washington, DC: U.S. Department of Agriculture. 65 pp.

MCCOMB, W.C.; SPIES, T.A.; EMMINGHAM, W.H., 1993: Douglas-fir Forests: Managing for Timber and Mature-Forest Habitat. J. For. 91: 31–42.

MEYER, J.L.; WALLACE, J.B., 2001: Lost linkages and lotic ecology: Rediscovering small streams. In: PRESS, M.C.; HUNTLY N.J.; LEVIN, S. (eds) Ecology: Achievement and Challenge. Oxford U.K. Blackwell Scientific. 295–317.
MONSERUD, R.A., 2002: Large-scale management experiments in the moist maritime forests of the Pacific Northwest. Landsc. Urban Plan. 59: 159–180.
NAIMAN, R.J.; DECAMPS, H.; POLLOCK, M., 1993: The role of riparian corridors in maintaining regional biodiversity. Ecol. Appl. 3: 209–212.
NILSSON, C.; EKBLAD, A.; DYNESIUS, M., BACKE, S.; GARDFJELL, M.; CARLBERG, B.; HELLQVIST, S.; JANSSON, R., 1994: A comparison of species richness and traits of riparian plants between a main river channel and its tributaries. J. Ecol. 82: 281–295.
OLIVER, C.D.; LARSON, B.C., 1996: Forest stand dynamics. New York, John Wiley and Sons. 520 pp.
OLSON, D.H.; CHAN, S.S.; THOMPSON, C.R., 2002: Riparian Buffers and Thinning Design in Western Oregon Headwaters Accomplish Multiple Resource Objectives. In: JOHNSON, A.C.; HAYNES, R.W.; MONSERUD, R.A. (eds) Congruent Management of Multiple Resources: Proceedings From the Wood Compatibility Initiative Workshop. USDA Forest Service Pacific Northwest Research Station General Technical Report PNW-GTR-563. 81–91.
OLSON, D.H.; CHAN, S.S.; WEAVER, G.; CUNNINGHAM, P.; MOLDENKE, A.; PROGAR, R.; MUIR, P.S.; MCCUNE, B.; ROSSO, A.; PETERSON, E.B., 2000: Characterizing Stream, Riparian, Upslope Habitats and Species in Oregon Managed Headwater Forests. In: International Conference on Riparian Ecology and Management in Multi-Land Use Watersheds. American Water Resources Association. 83–88.
POLLOCK, M.M.; NAIMAN, R.J.; HANLEY, T.A., 1998: Plant species richness in riparian wetlands: A test of biodiversity theory. Ecology 79: 94–105.
PROGAR, R.A.; MOLDENKE, A.R., 2002: Insect production from temporary and perennially flowing headwater streams. J. Freshwater Ecol. 17: 391–407.
SALO, E.O.; CUNDY, T.W. (eds) 1987: Streamside management: Forestry and fishery interactions. Seattle, Washington, University of Washington, College of Forest Resources.
THOMPSON, C.; OLSON, D.; CHAN, S.S.; MAAS-HEBNER, K.; TAPPEINER, J.C., 2001: The Density Management and Riparian Buffer Studies of Western Oregon. USDI Bureau of Land Management Poster BLM/WA/OR/G-01/031-4800.
THOMPSON, C.R.; LARSEN, L., 2003: Density management studies status report. Portland, Oregon, Oregon/Washington USDI Bureau of Land Management.
USDA, Forest Service; USDI, Bureau of Land Management, 1994: Final Supplemental Environmental Impact Statement on Management of Habitat for Late-Successional and Old-Growth Forest Related Species within the Range of the Northern Spotted Owl, Appendix A, Forest Ecosystem Management: An Ecological, Economic, and Social Assessment. Portland, OR.
WILEY, K.N., 1978: Site index tables for western hemlock in the Pacific Northwest. Weyerhaeuser For. Pap.17. Centralia, WA: Weyerhaeuser Company, Western Forestry Research Center. 28 pp.

Accepted April 9, 2004