ANALYSIS OF RIPARIAN VEGETATION AGE STRUCTURE AMONG THE FOREST LAND OWNERS OF THE CENTRAL OREGON CASCADES

by

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Abstract.

Vegetation along the banks of mountain streams in the western Oregon Cascades comprises the transition zone between land and water based ecosystems, and as such, is a vitally important and unique natural resource. Forestry is a major land use in this region, and harvesting riparian vegetation has serious and well documented impacts on natural ecological and hydrological processes. In order to protect riparian vegetation, "buffer strips" are often required by the presiding management agency. However, buffer strip management regulations and enforcement varies substantially among the many owners of forest land in the region. Given the substantial differences in forest management practices among owners that result in part from differing forest practice regulations that apply, it was unclear what the general ecological condition of riparian vegetation was. This study examined the forest stand structure and age characteristics, as identified from Landsat Thematic Mapper imagery, among five different land ownership classes. The study also examined the pattern of change in the occurrence of old-growth conifers that occurred with increasing lateral distance from the stream, across various land ownership classes. It was found that there was typically a predominance of younger mixed open canopy riparian conditions on low elevation private industrial and interspersed federal lands. In contrast, older conifers tended dominate riparian vegetation on higher elevation federal lands. Furthermore, it was found that change from an older to younger seral stage with increasing lateral distance from the stream tended to occur more rapidly on low elevation private industrial and interspersed federal lands.

This study provides insight about how the condition of riparian vegetation correlated to the corresponding ownership or management regime. Vegetation inventories across large regions such as the study area have only recently become feasible with advances in remote sensing technology, digital image processing techniques, and geographic information systems. The employment of these new technologies has introduced a scale of investigation which enables landscape scale patterns, processes, and human influences on riparian systems to be better understood.

I. *Introduction*.

Ecological and hydrological considerations.

Research exploring the functions and dynamics of riparian areas has developed substantially in recent years. Riparian areas are especially diverse and important elements of the landscape, which serve many crucial functions, both locally, and downstream. The vegetation composition within riparian areas is unique: streamside phreatophytic plant communities and hardwoods such as red alder *(Alnus rubra)* are typically interspersed with overstory conifers. This complex and unique structural pattern of the vegetation provides species habitat which "...ranks near the most productive of all habitat types in the western Cascades" (Harris, 1984, p. 142). Riparian zones also form "corridors" which permit the movement and interaction across the landscape of biotic entities at a number of trophic levels (ibid.).

Comprising the transitional zone between terrestrial and aquatic ecosystems (Gregory *et. al* 1991), riparian vegetation serves a number of unique ecological and hydrological functions. For example, trees which collapse and fall in to the stream create large in-stream pools (Sedell et al. 1988, Swanson et al. 1982). These pools serve as important habitat for many species of fish and amphibians (Sullivan et. al 1987). Litter which falls from streamside vegetation such as leaves, branches, and decaying bark, supplies food for macroinvertebrate and benthic communities, which in turn comprise an important component of the food chain for fish and amphibians (Vannote et al. 1980). Riparian vegetation also provides shade to the stream, which maintains cool temperatures necessary for the health of downstream fish populations (Beschta et al. 1987).

Hydrologically, the presence of large woody debris alters the way water flows through a stream channel. Large woody debris in streams creates riffles and falls which increases the dissolved oxygen content of the water, and subsequently provides better fish habitat (ibid.). The presence of large woody debris will also decrease the rate of flow, and thereby decrease the erosive capability of the stream. Removing riparian vegetation destroys the root systems, which are an important component of bank stability (Sedell and Beschta, 1991). Bank instability in turn causes increased bank erosion and sediment deposition into the stream channel. Increases in sediment deposition from the bank may also occur after removing riparian vegetation because vegetation interception mitigates the potential erosive force of rainfall (Brooks et al. 1991). Removing vegetation will increase the rainfall erosivity factor on a site, and thereby increase sediment deposition into the stream channel. Increased sediment deposits contribute to an increase in stream temperature, and also lead to the depletion of in-stream habitat pools from sediment influx (Sullivan et al. 1987). These are some of the primary ecological and hydrological functions of riparian vegetation that are often disturbed when timber harvest takes place in riparian areas.

Economic and legal considerations.

Large conifers tend to grow well given typical riparian conditions, and such species are sought for their commercial timber value. Hardwoods such as red alder also have a forest products commodity value, and in the central Oregon Cascades, these hydrophilic species grow almost exclusively within riparian zones. The riparian soil is often nutrient-rich and well supplied with water, which combines to create conditions ideal for timber production. However, the consequences of disturbing riparian vegetation, particularly for downstream fish populations, have led to the enactment of riparian protection measures at various levels of management. Oregon's Forest Practices Act (ORS 629-24-546, 1988) identifies minimum forest practices guidelines, known as "Best Management Practices," which must be met on privately owned industrial forest lands in Oregon. The guidelines designate vegetation along the banks of class 1 (fish bearing) streams as "riparian management areas," and identify silvicultural practices and conditions that must be met within riparian management areas (appendix A). For example, the guidelines stipulate that an average of nine conifers, comprising at least 10 square feet basal area, per acre, or 7.43 square meters per hectare, must be left within a 25 foot (7.6 meter) riparian buffer strip. In contrast, old-growth riparian forests within the region encompassed by the study area might typically contain between 50 and 120 square meters basal area per riparian hectare (Acker, 1994). In other words, private riparian management guidelines permit the harvest of between 85% and 94% of the live conifers within even the most highly protected class of riparian zone. Riparian vegetation along smaller or intermittent streams receives no protection under the current Oregon statutes, in spite of the fact that the condition of vegetation along these streams substantially influences downstream water quality and other riparian-related processes. Furthermore, the Forest Practices Act relies on "good faith" for compliance with the guidelines:

> "A forest operator conducting, or in *good faith* proposing to conduct, operations in accordance with Best Management Practices currently in effect shall not be considered in violation of any [water quality] standards."
> (OAR 629-24-527.770)

It is clear that the Oregon Department of Forestry (the state agency in charge of monitoring compliance with the Best Management Practices) must rely on so-called "good faith compliance;" it would be virtually impossible to comprehensively monitor Forest Practices Act compliance throughout the privately owned lands in Oregon. It was unclear how well "good faith compliance" had worked across the landscape. It was therefore unknown whether certain land owners or geographical (elevational) regions were more likely than others to have managed forest lands in accordance with (or perhaps surpassing) Best Management Practices minimum standards.

Federal lands within Oregon are, at a minimum, subject to Oregon's Forest Practices Rules, and they are usually managed under more stringent riparian protection guidelines. For example, the U.S. Forest Service's (USFS) 1990 Willamette National Forest Land and Resource Management Plan (USFS, 1990) identified various riparian "conditions" in terms of relative impact, presumably from human disturbance such as timber harvest. The plan then spells out the appropriate "riparian management" restoration measures that are designed to meet criteria based on riparian functions, such as sediment content. The Bureau of Land Management (BLM) also maintains riparian management guidelines that are outlined in a resource management plan. The BLM riparian management guidelines outlined in the Land and Resource Management Plan from May 1983 varied significantly from USFS riparian management guidelines. The BLM also published an Environmental Impact Statement from the same time period that attempted to inventory riparian vegetation on BLM lands within the Eugene management district (BLM, 1983; appendix B). The results of the inventory are only an approximation based on riparian management guidelines; there was no other accurate and efficient means to undertake such an inventory at the time. The difficulty of inventorying riparian vegetation across a large area pertains not only to BLM lands, but the landscape as whole.

There appears to be a trend towards the adoption of more stringent riparian management guidelines at both the state and the federal levels of forest management. At the state level, the Oregon Forest Practices Act is currently being reworked, as it is every few years, and the forthcoming version will most likely include more protective riparian protection measures (Gregory, pers. comm., 1994). On federal lands, the Federal Ecosystem Management Assessment Team's (FEMAT, 1993) report, which is currently in the process of being implemented by federal agencies, recommended riparian management guidelines that tend to be very protective of riparian vegetation relative to past federal or state riparian management measures. Under the guidelines specified by FEMAT, for example, vegetation adjacent to fish-bearing streams will be protected by no-harvest buffer strips as wide as three hundred feet (92 meters) or two site potential trees, whichever is greatest (appendix C).

It is clear that the importance of riparian protection is well established, and that future riparian management legislation and guidelines will call for significantly more protective measures on both private and federal lands. However, the current, or 'baseline,' condition of riparian vegetation, and how it changes with ownership, is still unclear and must be better understood for several reasons. First, the legislation that governed riparian management on Oregon forests in 1988 (the year from which the vegetation data was obtained) fluctuated substantially, from very minimal riparian protection measures on private lands, to perhaps more stringent but less spelled out riparian management guidelines on federal lands. Secondly, although it may be obvious that private lands will contain more evidence of timber harvest simply because the riparian protection measures are less strict, the magnitude of differences are unclear. Third, state and federal riparian protection measures will still vary in the future, and patterns of forest ownership will therefore continue to create distinct patterns of riparian vegetation composition. Fourth, the structural characteristics of riparian vegetation within a given ownership boundary may spur from the respective management practices and may affect on site conditions, but the downstream effects are cumulative, and the landscape must be examined as a whole. In other words, riparian vegetation inventories such as the BLM's are needed, but they are needed with accurate and consistent reliability across the landscape. Comparing riparian management practices, then, can only take place after the general condition of riparian vegetation is analyzed, both structurally and spatially.

In short, scientists have identified a broad range of important ecological and hydrological processes at all scales that are in some way affected by the condition of riparian vegetation. However, the general condition of riparian vegetation is much less clear. An inventory of riparian vegetation condition has never taken place across the western slope of the central Oregon Cascades in the past. Traditional techniques for obtaining vegetation inventories such as field surveys essentially preclude a comprehensive and accurate inventory of riparian vegetation condition. The integration of new technologies, such as satellites which provide high resolution remotely sensed imagery, increasingly sophisticated digital image processing techniques, geographic information systems, and powerful computing facilities have provided the means to conduct an inventory of riparian condition across the central Cascades. Clearly, the results of past inventory efforts such as the BLM inventory accentuate the need for improved accuracy and consistency of such inventories. Furthermore, water quality problems, degradation of fish and wildlife habitat, forest fragmentation, and other riparian related concerns are exacerbated by the lack of consistent management, which results in part from the lack of reliable information. This study provides the first reliable and consistently accurate inventory of riparian vegetation across the biologically diverse and economically valuable central Oregon Cascades.. This study provides a 'baseline' indication of riparian vegetation condition; future inventories will portray trends. The study also identifies only one of many largely unexplored ways that land ownership patterns across the landscape can have profound ecological and hydrological implications, both locally, and cumulatively.

II. *Objectives*.

This study is designed to investigate the poorly understood and undocumented implications of multiple land owners, differing riparian protection measures, and perhaps differing levels of enforcement, across the commercially valuable and ecologically diverse western slope of the central Oregon Cascades. Specifically, the study used stand age and stand structure characteristics of the riparian zone as measures of relative riparian ecological and hydrological condition, and compared these measures among different ownership/management regimes. Secondly, the study examined patterns of change in the stand age and structure with increasing lateral distance from the stream. Investigation of lateral change provided an insight about harvest patterns across the landscape, and how they have been affected, if at all, by riparian protection measures. For example, high contrast edge effects within a regular predictable distance from a stream's edge that result from riparian buffer strips may have unforeseen ecological or hydrological implications.

This study will provide a better understanding about the landscape patterns that have resulted from human activities that have taken place in the region. The information obtained will provide crucially needed information for ecologists and natural resource managers who need to understand processes taking place, how humans are shaping or altering those processes, and plan accordingly in the future.

III. *Approach*.

Given the wide range of riparian protection measures afforded streams throughout western Oregon, coupled with the fact that comprehensive inventory and enforcement of the guidelines is problematic, it was clear that the general ecological condition of riparian zones throughout western Oregon is essentially unknown. Advances in remote sensing technology and subsequent digital image processing techniques have made it feasible to identify a variety of riparian vegetation characteristics across large areas. Given these technological advances, it was possible to undertake the previously impractical or impossible task of conducting vegetation inventories over large regions. The resolution of Landsat

Thematic Mapper (TM) satellite imagery is ideal for examining the general condition of riparian zones across the Oregon Cascades. Forest stand characteristics such as age, canopy closure, and the predominance of deciduous or coniferous species can be determined with considerable accuracy from TM data (Cohen and Spies, 1992, Cohen et al., in press). These forest stand attributes change as vegetation matures, and are therefore reliable indicators relative seral stage, which in turn provides insight into the general ecological condition of the stand. Relative age and stand structure also change predictably after forest harvest. Therefore, analyzing age and stand structure of riparian vegetation provided an indication of the degree to which riparian zones have been altered, presumably by forest harvest. When this information was stratified by ownership, the effect of differing riparian protection measures and silvicultural treatment manifested itself in the distribution of relative average stand age of riparian vegetation.

IV. *Study Area*.

The study area encompassed approximately 1,200,000 hectares on the western slope of the Oregon Cascades from the Willamette valley to the crest of the Cascades (map 1). Specifically, the study area includes the portions of Linn and Lane counties that were imaged by Landsat TM wrs 46/29 on 31 August 1988. This was an ideal study area because it encompassed a broad cross section of the Cascades which is ecologically diverse and has traditionally been one of the most productive and actively harvested regions of timber production in the world (Harris, 1984). Furthermore, the study area included a variety of different land owners, which varied from vast expanses of Congressionally designated Wilderness to small intensively managed parcels at lower elevations.

V. *Methods*.

Compiling riparian vegetation information.

Riparian vegetation cover across the landscape was determined from remotely sensed imagery (map 1). The results presented here are based on the use of a vegetation classification which was previously developed by Cohen and Spies (1992) and Cohen et al. (in press). Briefly, TM data was used to identify six vegetation cover classes. The in order to compress the quantity of the TM data the six spectral TM bands (band six, the thermal band, was not used) were first transformed into the "greenness," "brightness," and "wetness" indices of the TM Tassled Cap (Crist et al., 1986). The thirty meter pixels of the original TM data were then resampled using a "nearest neighbor" resampling scheme to provide twenty-five meter resolution, primarily for the sake of convenience in subsequent rectification and registration to other layers in a geographic information system. The brightness, greenness, and wetness indices were used in conjunction to conduct an unsupervised classification. This classification separated stands based on canopy closure and whether a given stand was either conifer dominated or included a mixture of coniferous and deciduous vegetation. This classification identified four vegetation classes: "open mixed" (mixed conifers and hardwoods; less than 30% canopy closure), "semi-open mixed" (30-85% canopy cover), "closed mixed" (greater than 85% canopy cover, and closed-conifer dominated. The wetness index was then used by itself to differentiate between closed canopy conifer stands of different ages. Three different age classes could be identified: "young" (less than 80 years old), "mature" (80-200 years), and "old" (greater than 200 years old). The final result was a map with three mixed conifer-hardwood and three closed canopy conifer classes. Extensive ground truthing was undertaken based on 106 reference points located throughout the study area, and interpretation 1:60,000 color infrared aerial photographs of the region. Cohen et al. (in press) determined the final vegetation data layer contained an overall 82% rate of accuracy, with most of the error resulting from difficulty in distinguishing between "mature" and "old" conifers.

Riparian zones were extracted from the vegetation data layer using drainage information obtained from the U.S. Geological Survey's 1992 "River Reach Files," which were digitized from USGS 1:100,000 topographic maps. These reach files were procured as Arc/Info vector line coverages using latitude-longitude coordinates of reference. The drainage coverage was converted into raster form, transformed into Universal Transverse Mercator (UTM) coordinates, and transported into ERDAS, the geographic information system that was used for subsequent analysis. Data layers were resampled to create fifty meter cells; this allowed analysis within a twenty-five meter buffer of each side of the stream, assuming the stream had no spatial dimension. This assumption was legitimate because, except in very rare cases where the stream reaches were wide enough to dominate a given cell's reflectance characteristics, the riparian vegetation, rather than the water, dominated the spectral reflection of the pixel containing the stream (figure one). The vegetation that coincided spatially with the stream pixels were then extracted and used to create a new data layer which represented the vegetation within a twenty-five meter "buffer" adjacent to streams. The vegetation layer, which originated from satellite imagery registered well with the streams data layer, which was originally digitized in vector format from topographic maps. the precise registration was evident, because there were rare cases where the stream was wide enough to dominate the spectral reflection of the riparian pixel on the vegetation data layer, resulting in a classification label of "water." The fifty meter-wide riparian data layer, which was created from the USGS streams data layer, contained these stream-dominated pixels consistently across the study area, which indicated that registration was at least as accurate as the resolution of the data (figure one).

Ownership information.

A data layer containing ownership information was created from federal land boundary records, Oregon Department of Forestry private ownership records, and county taxation assessment information. Private holdings were stratified by land-use; Willamette valley agricultural, urban, or residential parcels were removed from the study area. Privately owned industrial forest lands were then separated into two classes: "small industrial" and "large industrial." The distinction represents a natural break that tended to occur in the average area owned; ownership of less than 1000 hectares (approximately 2470 acres) constituted a "small industrial" private landowner. Private holdings of more than 1000 hectares were labeled "large industrial." Federal lands were classified into "BLM," "USFS," and "[USFS] Wilderness." Other land owners, such as state, municipal, or Department of Transportation holdings, comprised less than 3% of the study area, and were excluded.

The riparian vegetation data layer was then overlaid with the five class ownership map, and the vegetation composition within riparian areas of each ownership class was quantified. The composition of vegetation was determined separately as a portion of 100% for each ownership class, which allowed a direct comparison of riparian age and structural composition between ownership classes. This was necessary because the quantity of land that was owned varied among ownership classes.

Elevation Bands.

In order to control for spatial or elevational concurrence of either ownership or natural patterns of vegetation which would have biased the results, analysis was separated into five elevational bands. Figures two and three portray the percentages of land within each ownership class, and the land within each vegetation cover type, respectively, by elevation. A digital elevation model of the study area was procured, and the vegetation-by-ownership analysis was repeated within each of the five bands, in an effort to isolate forest management differences from actual differences in natural vegetation composition across the landscape. The boundaries of the five elevation bands ran basically north to south, and were identified based on general taxonomic zones as identified by Franklin and Dyrness (1988). The elevational band below 315 meters was selected because Cohen et al. used this elevation to differentiate between agriculture and forestry land-uses that could not be distinguished based solely on spectral reflectance. The 315 meter elevational band was also used in this study to distinguish between small private agriculture operations and small private industrial forestry. The elevational band between 315 and 500 meters encompasses substantial downstream portions of the Santiam and MacKenzie river valleys, as well as the peripheral regions of the Willamette valley. Like the zone below 315 meters, this elevational band was also characterized by particularly intensive land-use patterns, due to its proximity and accessibility from the Willamette valley. The elevational band between 500 and 1000 meters was dominated by western hemlock *(Tsuga heterophylla)*. This region contained the majority of Douglas fir *(Pseudotsuga meniesii)* stands, and commercial timber land in general, within the study area. The fourth elevation band, lying between 1000 and 1500 meters, represents the approximate region of subalpine forest, including silver fir*(Abies amabilis)*, subalpine fir*(Abies lasiocarpa)*, and mountain hemlock *(Tsuga mertsentsia)*, and also contains large tracts of land managed for commercial timber production. The final elevational band, encompassing regions above 1500 meters, contains the approximate timberline and distinct high altitude vegetation communities. Ownership within this final band is entirely either USFS or USFS Wilderness. After elevational bands were delineated, analysis of riparian vegetation composition by ownership was repeated within each zone, as was done for the whole image.

Patterns of change observed with increasing distance from the stream.

In order to further examine ownership differences in the management of riparian zones, changes were quantified in the abundance of the oldest class of conifer forest with increasing distance from the stream. In the absence of disturbance, riparian zones in the central Oregon Cascades are usually dominated by old conifer forests (Gregory et al., 1991). Hardwoods often dominate riparian systems within the first several meters, but older riparian forests that tend to include overstory conifers that will dominate the spectral reflectance as imaged by TM's 30 meter resolution sensors. Therefore, dominance of mixed hardwood or young coniferous vegetation was indicative of disturbance. Although the data did not allow discrimination between natural and anthropogenic disturbances, it was assumed that natural disturbance would alter riparian age and stand structure characteristics fairly equally across ownership classes within a given elevation band, and therefore, variations in age/stand structure could be attributed primarily to anthropogenic disturbance such as timber harvest. The study area was restricted to the elevational band between 500 and 1500 meters in an effort to isolate land used for timber production from other regions containing particularly unique vegetation and ownership patterns, such as those found above timberline. The region below 500 meters was not included because land-use was dominated by private agriculture, and the riparian vegetation distinctly reflected the difference in land-uses.

For each ownership class, the percentage of area within the 50 meter wide riparian zone (25 meters on each side of the stream) that was dominated by old growth conifer forests was recorded. The abundance of the old growth conifer class was then expressed as a percentage of the abundance of the old conifer class in the 50 meter wide riparian zone for three sequentially distant buffer strips: 26-75 meters, 76-125 meters, and 126-175 meters.

VI. *Results*.

Figure four shows the composition of riparian vegetation across the study area as a whole, found within the 50 meter buffer (25 meters on each side of the stream) within each ownership class. The graph is essentially comprised of five separate ownership graphs, each totaling 100%, aligned along the x-axis. The total area within each ownership class varied substantially (figure 1); the total amount of area in each ownership and each vegetation age class is listed in table 1. Because aerial extent varied substantially between ownership classes, the distribution of vegetation among the six age/structural classes was recorded separately for each ownership class. This allows the different distributions occurring within different ownership classes to be compared with one another. For example, figure 3 indicates that old growth conifers comprised a larger percentage of total riparian vegetation on Wilderness lands (45.9%) than on private lands (15.2%). This does not necessarily mean, however, that there was more old growth forest within Wilderness; it only means that old growth conifers comprised a larger portion of the total riparian vegetation found in Wilderness areas. These patterns are evident from map 2, which portrays the 175 meter riparian vegetation by ownership class for several selected portions of the study area.

Ownership classes are arranged along the x-axis from "Wilderness" to "Small "Industrial" in order of descending occurrence of older conifers, and ascending occurrence of open or semi-open mixed riparian vegetation, as a proportion of total vegetation. The order of ownership classes might also represent a continuum of "less intensively" to "more intensively" managed lands. The histogram of vegetation occurrence for a given ownership class is visible along the z-axis of the graph. Orienting the ownership classes adjacent to one another on the graph facilitates comparison of riparian vegetation composition between ownerships. The decrease in the prevalence of older age classes from less intensively managed lands such as Wilderness and USFS lands, to more intensively managed private industrial lands, is readily apparent on the graph. Likewise, a concurrent increase of younger mixed open canopy vegetation occurs from less to more intensively managed lands.

The graph also contains differences in riparian vegetation composition that may occur naturally. For example, the considerable occurrence of "semi-open mixed" vegetation in Wilderness (18.9%) probably represents the natural vegetation communities which are found at high elevations. Such vegetation is characteristically sparse and open, reflecting the less favorable growing conditions found at higher altitudes. Similar natural patterns in the vegetation no doubt occur throughout the landscape. Given that natural patterns are largely determined by elevation (the latitudinal band, from approximately 44 to 45 degrees north latitude, is narrow enough such that its effects may be discounted at the scale of the investigation), the map was divided into five elevation bands. It was therefore easier to isolate management-induced differences from natural changes in vegetation. Theoretically, management differences should result in changes within elevation bands (among ownership classes); natural changes in riparian vegetation should result in changes across elevation bands.

Figure five portrays the composition of riparian vegetation within a 50 meter stream buffer, by ownership, below 315 meters. It is important to note that more than 90% of the land within in this elevation band was used for private agriculture. Forestry-specific riparian management comparisons within this elevational ban, therefore, apply to only a very small percentage of the area with in the elevation band.

There was no USFS Wilderness within this elevational zone. Furthermore, it is evident that the total vegetation within the "small industrial" category totaled only 49.8%. That was because the majority of "small industrial" land below 315 meters was agricultural land, and were excluded from the graph. The "large industrial" category totals 100%, however, because only large commercial forestry corporations were classified as "large industrial" on the ownership data layer.

Figure six portrays the composition of riparian vegetation by ownership between 315 and 500 meters. Patterns of change in vegetation composition are visible that resembles that pattern seen across the landscape as a whole. However, several patterns unique to the elevational band are visible in the graph. For example, USFS and BLM lands have vegetation distribution histograms that look very similar to the private industrial histograms. It is clear from the graph that timber harvest has been a primary land use on BLM and Forest Service lands within the 315-500 meter elevation band. Ease of accessibility, including developed road networks, are no doubt attributable to the indications of increased forest harvest activity at these lower elevations.

Figure seven portrays the composition of riparian vegetation by ownership between 501 and 1000 meters. The pattern observable at lower elevations is also present in the 501-1000 meter elevation band. The composition of riparian vegetation in Wilderness areas is almost entirely conifer dominated (87.9%). Conifers, especially young conifers, comprise a larger portion of the total riparian vegetation in all ownership classes than was seen at lower elevations. However, the general trend is still visible, where riparian vegetation composition is comprised of increasingly older species on less intensively managed lands such as Wilderness and Forest Service lands.

Figure eight portrays the composition of riparian vegetation by ownership between 1001 and 1500 meters. The general relationship between riparian vegetation composition and ownership, and the contrast between the more and less intensively managed lands, is strikingly apparent on the graph. For example, private large industrial lands were comprised of 58% semi-open mixed vegetation, but only 7.6% old-growth conifers. In contrast, riparian vegetation found within Wilderness areas was comprised of 15.6% semi-open mixed vegetation and 51.3% old-growth conifers. Riparian areas in general on private industrial lands were comprised primarily of open and semi-open mixed stands (65-75%). Wilderness and Forest Service riparian vegetation tends to be dominated by old-growth conifers (42-51%).

Figure nine portrays the composition of riparian vegetation by ownership above 1500 meters. There is no private land above this elevation; the entire region is either Wilderness or USFS forest. The composition of riparian vegetation above 1500 meters is almost entirely "old-growth conifer" or "semi-open mixed (USFS: 86.2%, Wilderness: 98.5%)." The "semi-open mixed" class indicates high-altitude scrub, brush, and sparsely distributed conifers that is characteristic of vegetation communities near timberline.

Patterns of change at increasing distances from the stream.

Figure 10 shows the decline in abundance of old-growth conifers at increasing distances from the stream between 500 and 1500 meters in elevation. Old-growth conifers were assumed to be characteristic of undisturbed riparian areas. The abundance of this class was used to represent the condition of the riparian vegetation as a whole. The only variable graphed was lateral change in vegetation from the stream, because the first point (representing the 0-25 meter buffer strip) in all five cases was adjusted to equal 100%. Subsequent points represent change in abundance of old-growth conifers relative to the quantity found within 25 meters of the stream.

It is clear from the graph that the decline in abundance of old-growth conifers was especially dramatic on "large industrial" private lands (34% over 150 meters). Rates of decline on USFS, BLM, and small industrial private lands were similar (between 22 and 25 % over 150 meters), and the rate of decline observed within Wilderness areas was significantly more gradual (14.8% over 150 meters). The rate of decline for all ownership classes fell rapidly for approximately 75-100 meters, and then leveled off. This pattern was especially evident within the large industrial class. The described patterns are discernable in several instances on map 2.

VII. *Discussion*.

It was apparent from analysis of the data that a distinct and predictable change in the composition of riparian vegetation occurred across ownership classes within the study area. Younger seral stages tended to comprise a larger portion of riparian vegetation at lower elevations and where intensive forest management, i.e. timber harvest is more prevalent. In contrast, older seral stages tend to comprise the majority of riparian vegetation at higher elevations where USFS and Wilderness areas prevail.

Figure four portrays these trends for the study area as a whole. However, It was unclear how much of the variation in figure four represented natural changes in riparian vegetation across the landscape, and how much represented anthropogenic change. As pointed out earlier, the study area was divided into five elevational bands to control for natural change in vegetation that occurs with elevation. The results were then re-examined within each band. It was also possible to isolate several unique attributes of the data that pertained to particular elevation bands. For instance, figure five, portraying the region below 315 meters, was almost entirely comprised of private agricultural lands. There was no Wilderness, and very few USFS holdings. The distribution of riparian vegetation shows relatively small portions of open canopy/mixed conditions. That is because it was all classified as "agricultural" when combined with the ownership map, and was thus excluded from the analysis. In other words, there was a very small quantity of industrial forest land below 315 meters. The total area graphed was only six percent of the total within the elevational band. For these reasons, it is probably inappropriate to examine the effects of forest management with data taken from the region below 315 meters. Nonetheless, it was important to isolate this region because the land use patterns were so clearly unique.

Figure six, which displays riparian vegetation composition by ownership for the elevation band between 315 and 500 meters, is also unique from other regions of the study area. Unlike the region below 315 meters, commercial forestry was the primary land use between 315 and 500 meters. The riparian vegetation on all ownership classes in this elevation band tends towards relatively young seral stages (with the exception of the small portion of Wilderness). Within this elevation band, two patterns were evident. Riparian vegetation tended to be comprised of younger seral stages on private industrial lands than on federal lands. Secondly, riparian vegetation provided more indication of forest harvest activity within all ownership classes (except Wilderness) in the lower elevational bands of the study area. The riparian age composition of USFS holdings in particular tended to mimic the patterns found on adjacent lands. For example, the riparian vegetation on USFS lands were more comprised of younger vegetation at lower elevations, where adjacent lands were often privately held. In contrast, USFS riparian vegetation composition looked similar to the composition of Wilderness areas at higher elevations (figure seven).

Figure seven, representing riparian vegetation composition by ownership for the elevation band between 501 and 1000 meters, indicates that large portions of riparian vegetation were comprised of young conifers. Wilderness in particular displays a curious distribution of riparian vegetation characteristics. Because the trend is apparent across ownership classes, the occurrence of young conifers is perhaps an indication that natural disturbances such as fires are more prevalent within this elevation band. The distribution of conifers across a wider range of age classes as is seen on Wilderness land between 501 and 1000 meters also suggests that the land that was Congressionally designated as Wilderness produces lower quality timber from a forest products standpoint. Canopy closure, for example, may take longer to develop given less ideal growing conditions. In other words, a given patch of forest on lesser quality lands typical of Wilderness areas might exhibit spectral reflectance characteristics similar to that of younger stands on more productive [lower elevation] lands.

Figure eight (1001-1500 meters) portrays radical differences in riparian vegetation composition between federal and private holdings. Riparian buffers within USFS and Wilderness lands were dominated by old growth conifers. In contrast, private industrial riparian zones were dominated by semi-open mixed canopy vegetative cover. The similarity in the USFS and Wilderness histograms probably stemmed from the fact that the majority of forest harvest on USFS lands took place within the lower elevation holdings. The semi-open mixed vegetation that occurred within USFS and Wilderness holdings includes high altitude scrub and discretely distributed conifers, which characterize vegetation communities above the timberline (Franklin and Dyrness, 1988). Another explanation for the prevalence of the semi-open mixed category on USFS lands in figure eight stems from the fact that timber harvest began at this higher altitude more recently than lower altitudes. Harris (1984, Appendix 3) points out that in the Willamette National Forest at elevations below 2000 feet (609 meters), the quantity of harvested acreage doubled between the decade starting in 1940 and the decade starting in 1970. In contrast, the harvested acreage increased more than 1800% at elevations above 4000 feet (above

1220 meters) over the same time period. In other words, there are considerable quantities of recently harvested and regenerating USFS lands at higher elevations, and their spectral reflection characteristics may be similar to that of natural vegetation communities found at higher altitudes in Wilderness areas, resulting in the same classification. This pattern is particularly evident in figure nine. Figure nine, which portrays riparian vegetation composition by ownership for the elevation band above 1500 meters, contains no privately owned or BLM lands. Although some of the semi-open mixed vegetation on USFS lands above 1500 meters may represent recently harvested regenerating vegetation, it is likely that the USFS and Wilderness riparian vegetation which is seen at the highest elevations portrays a natural compositional structure, rather than a compositional structure which has been extensively altered by forest management or harvesting activity. Forest harvest on USFS holdings is most likely restricted to lower elevations; it appears that the USFS holdings within this highest elevation band are essentially managed as 'de facto' wilderness. Therefore, the slight differences in vegetation composition between USFS lands and Wilderness may be explained by patterns of change in vegetation with altitude (figure three).

Figure 10 suggests that more intensively managed landscapes exhibit the pattern of rapid decline in the occurrence of late successional vegetation with increasing distance from the stream. Intensive management appears to result in a reduction in the width and integrity of the riparian zone vegetation. Buffer strips are the most likely explanation of rapid lateral change in vegetation composition, because in terms of regulation, buffer strips are typically characterized by a no-harvest or reduced-harvest strip parallel to the stream. The Oregon Forest Practices Act does not explicitly specify how lands adjacent to riparian zones must be managed (with respect to any interactions with the riparian zone). The result is an edge effect, and the effect is more prevalent on more intensively managed lands (figure 10). It is evident that up-slope disturbances, both human and naturally induced, have the potential to alter in-stream nutrient content, sediment load, and other processes (Naiman et al., 1988). It follows therefore, that the condition of the border between riparian and up-slope vegetation will alter the rate and magnitude of change at which these processes take place. Clearly, the creation of an edge markedly alters the nature of the natural transition zone between riparian and up-slope vegetation. Terrestrial ecological responses of edge effects are well documented for a number of processes, such as predator-prey balances or fragmentation of habitat (Saunders et al. 1991). Abrupt edges may also be more susceptible to disturbances such as windthrow (DeWalle, 1983) and forest fire ignition (Franklin and Forman, 1987). In-stream biotic resources may also be impacted by particular patterns of forest harvest adjacent to riparian areas. For example, surface water runoff may deposit increased quantities of sediment into the stream channel without a more gradual edge to decrease surface flow and block sediment runoff. The dynamics between specific ecological and hydrological processes, riparian edges, and ownership differences across the landscape which result in different edge patterns, is largely uninvestigated. The relevance of the observations presented here will only become clear after further study examines the specific effects of such landscape patterns.

The decay pattern observed on Wilderness areas in figure 10 is probably explainable by natural disturbance regimes. The rate of decline in the abundance of old growth conifers that was seen in the data is probably attributable to past patterns of disturbance. For example, perhaps drier upland conditions will be more susceptible to fire than moisture-saturated riparian vegetation. Therefore, the fire return interval will be longer in riparian areas, resulting in vegetation that is burned less frequently and is subsequently older.

Data Limitations.

There are several limitations to the data which limit conclusions that may be drawn from the results. With respect to ownership information, the five classes were not distributed evenly across the landscape, and the area covered by each ownership class varied substantially. For instance, the private small industrial class covered only 8.1% of the landscape, while 50.4% of the study area was in USFS holdings. It is possible that smaller ownership classes were dominated by a primary naturally occurring vegetative type, which would clearly bias the results. The study was broken into elevation bands to control for the strong geographic correlation between either vegetation or ownership, and elevation. Nonetheless, both ownership and vegetation were still unevenly distributed within elevation bands, albeit to substantially lesser degrees than the study area in aggregate (figures two and three).

The resolution of TM data prevents conclusions being drawn from the data at very large, site-specific scales. The unclassified digital data was obtained at TM's thirty meter resolution. In contrast, many riparian processes take place at significantly finer degrees of resolution. Riparian zones contain a notoriously complex variety of interdependent faunal and floral species at all scales. For example, woody debris from conifers which enters the stream channel is broken down by lotic invertebrates more slowly than woody debris from deciduous species (Sullivan et al., 1987) Furthermore, conifers are larger, hence a fallen conifer contributes more organic nutrients to the in-stream food chain than does a fallen hardwood. However, land-based species such as the white footed vole *(Arborimus albipes)* often depend on riparian hardwood species to fulfill habitat requirements (Harris, 1984). In order to understand these and other riparian ecological processes, the exact composition of individual trees and their on-site spatial distribution with respect to the stream channel must be examined. The resolution provided by TM data prohibits investigations such as these to be undertaken.

The resolution provided by TM data also precludes investigation of compliance with riparian protection measures such as buffer strip-leave requirements. Compliance with the various riparian protection measures that apply throughout the study area must be determined on site. Measurements which are accurate to the meter, exact counts of standing trees or basal area, and measures of water turbidity are all examples of characteristics which might be scrutinized to determine whether or not riparian protection measures have been met on a given stream reach. Clearly, 30 meter resolution capabilities prevent the application of TM data for the investigation of compliance with such measures; the scale of information which must be used to investigate compliance with riparian protection laws is much finer than the scale of information that is obtainable from TM imagery.

Nevertheless, the data provided by TM imagery do provide a valuable summary of the relative condition of riparian vegetation throughout the region. The results have a number of important implications and potential applications for future research.

Future research directions.

This study has provided a important inventory of the general condition of riparian vegetation, and how various conditions relate to ownership patterns, throughout the central Oregon Cascades. However, the usefulness of the data collected, and TM satellite imagery in general, is not limited to general inventories across the landscape. While it is important to understand the ground resolution limitations inherent with TM data, the results can certainly be extrapolated to finer degrees of resolution in several different manners.

The data contained herein could be used in the future to design a ground-based stratified sampling network across a study area. For instance, several sample locations representative of the six cover types portrayed on the vegetation data layer could be further investigated. The findings from the samples (and the variance that those results contained) could be used to extrapolate the results throughout the extent of the TM vegetation data layer. Such an investigation might help identify particular patterns in the information extracted from satellite imagery that tend to indicate particularly severe cumulative riparian impacts. For example, high contrast edge effects might correlate with sites that were determined from field observations to be the sources of large quantities of sediment deposition.

Relationships between satellite imagery and finer resolution data, such as site-collected data or aerial photography, are complex and need to be further explored in order to extrapolate on-site observations reliably throughout the landscape. The application of mixture models (Smith, 1990) will enable estimates to be made about the vegetation composition within a given pixel. Such models may have particular relevance for riparian areas, because the vegetation composition is naturally very complex at fine spatial scales, and its structure must be noted in order to fully understand related ecological and hydrological processes. Using the sediment deposition example again, perhaps certain patterns of vegetation age and structure as identified from high resolution aerial photography tend to correlate well with site-obtained sediment deposition data. If the relationship between the particular vegetational composition seen in the air photos can be identified with a unique spectral reflectance in the satellite imagery, then the results can be extrapolated throughout a large region (or at least a subsequent stratified sampling network can be devised from the "high-potential" sediment deposition sites).

TM imagery also provides adequate resolution for riparian species habitat distribution mapping on a number of scales. For example, Corn and Bury (1989) examined the correlation between general up-stream riparian vegetation condition (eg. clear-cut, second growth-mature, late successional), and the occurrence of salamanders and several other amphibians that inhabit riparian zones. Although they did not use remotely sensed data in their analyses, the scale at which they measured up-slope vegetation conditions (10 square meter parcels) was almost as coarse as the resolution provided by TM data. TM imagery, and certainly the data obtained from other finer resolution commercially available satellite remote sensing platforms such as the French SPOT system (up to 10 meter resolution), have many potential applications at the scale of Corn and Bury's investigation. Future innovations in earth-resource satellite technology will no doubt provide data collection at even finer resolutions, which will permit even more site-specific and species-level riparian dynamics to be investigated.

Ecological dynamics involving riparian zones take place at much broader scales as well;.the use of TM imagery across expansive regions such as the study area is not only appropriate in terms of data resolution, it is virtually the only way in which riparian vegetation condition in general can be determined over large areas. The ways in which the forested landscape is being altered by human activities, the patterns that are being created, and the ecological implications of ownership patterns that have developed, is crucial to understand for a variety of reasons. For example, it is clear from this investigation that lower elevation riparian zones are much more susceptible to human disturbance than are higher elevation riparian zones. Species which are dependent on riparian conditions found at lower altitudes may therefore be much more susceptible to extirpation than species associated with higher elevation riparian zones.

This study has shown that ownership patterns markedly influence riparian compositional characteristics, which in turn may alter the manner in which riparian vegetation functions as corridors of biotic movement across the landscape.

As the landscape becomes more fragmented, regions of biotic diversity such as wilderness areas, national parks, and wildlife reserves, become more isolated from each other. Subsequently, the ecological reliance on riparian strips increases; they are often the primary corridors of movement between various conservation areas (Harris, 1984). This study has provided insight as to how riparian vegetation is altered by patterns of ownership, which, at larger scales, alters natural conduits of dispersion across the landscape. "Fragmentation" is somewhat relative; isolated conservation areas that are connected by intact riparian strips will obviously provide more extensive species habitat than will the same fragmented parcels that lack corridors of movement between them. Further understanding of the ways in which riparian vegetation functions as natural corridors will permit improved planning in the future to create a regional network of "connected" conservation areas.

VIII. Conclusions.

This study provides the first comprehensive, systematic inventory and comparison of the relative condition of riparian vegetation across five ownership classes for 1.2 million hectares of land on the western slope of the central Oregon Cascades. The data shows patterns and trends that have developed across the landscape, such as the generally younger seral stage of riparian vegetation on private lands, and at lower altitudes. This information will be valuable to a wide array of future ecological and hydrological investigations, as well as to the creation of future riparian management policy. Furthermore, the methodology and the technologies that were employed in this study typifies the rapidly approaching new era of digital and electronic natural resource management. This study has shown how accurate information pertaining to complex riparian dynamics can be efficiently compiled from satellite imagery and rapidly processed in a geographic information system. Riparian vegetational characteristics must be periodically monitored in the future in order to understand the way in which humans are altering the landscape, and digital-electronic technologies permit efficient, accurate, and standardized future surveys to be undertaken.

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Appendix A: Major riparian management requirements as listed in the Oregon Forest Practices Act, 1987.

(Note: the information presented below was extracted from Oregon's Forest Practices Rules. The definitions do not necessarily apply to the research presented herein.)

Riparian Management Area: "This is the area the Board of Forestry has decided must be managed for protection of riparian values along Class I (fish bearing) waters. Its width on each side of a stream shall average three (3) times the stream width, but shall not average less than twenty-five (25) feet or average more than one hundred (100) feet. A riparian management area occurs on each side of a stream and usually includes a riparian area and a riparian area of influence. The width may vary with terrain and circumstances, The measurement is the average width over the length of stream where the operation occurs."

The riparian management area is defined by three distinct zones:

1. The aquatic area. This is the water area of a stream measured at high water level.
2. The riparian area. Riparian areas are the wet soil areas next to streams. These areas have high water tables and soils which exhibit characteristics of wetness. Water-loving plants are often associated with these areas.
3. The riparian zone of influence. This is a transition area between the riparian area and upland vegetation. It forms the outer edge of the riparian management area. It contains trees which may provide shade or contribute fine or large woody material or terrestrial insects to a stream. It also may contain trees that provide habitat for wildlife associated with the riparian management area.

Five major "leave" requirements for riparian management areas:

1. Leave 50% of the pre-operation tree canopy. Required only within the riparian area inside the limits of the riparian management area.

2. Leave live conifer trees equaling at least an average of 9 trees per acre and at least 10 square feet of basal area per acre. Required within half of the RMA closest to the stream or within 25 feet, whichever is greater.

3. Leave ALL downed and unmerchantable wood. Required in the aquatic area and in the riparian area of the riparian management area.

4. Leave 75% of the pre-operation shade over the aquatic area. Required throughout the riparian management area.

5. Leave all snags which are not a safety or fire hazard. Required throughout the riparian management area.

<u>*Appendix B: Results of the Bureau of Land Management's Inventory of Streamside Riparian/Habitat Zones for the Eugene BLM District, 1979*</u> (BLM, 1983, p. 29).

(Taken directly from the text) "An inventory of streamside riparian habitat/zones was conducted on the Eugene District in 1979. The objective of the inventory was to estimate the extent of this vegetative type within the land base. Results of this inventory are summarized in Tables 2-5A and 2-5B."

Table 2-5A Average Riparian Widths [1] Eugene District

Siuslaw

Stream Order	Riparian Zone [2]	One-Half Transition Zone	Riparian Habitat [2]
1	40	20	60
2	60	20	80
3	90	30	120
4	140	40	180
5	200	40	240
6	270	40	310

Upper Willamette

Stream Order	Riparian Zone [2]	One-Half Transition Zone	Riparian Habitat [2]
1	50	20	70
2	50	20	70
3	60	20	80
4	90	30	120
5	120	30	150
6	140	30	170

[1] Distances rounded to nearest 10' each side of stream.
[2] See Glossary for definitions.

Table 2-5B Miles of BLM Streams by Stream Order

SYU	Stream Order 1	2	3	4	5
Siuslaw	957	323	153	75	21
Upper Willamette	862	305	140	60	14
District	1,819	628	293	135	35

Appendix C: Riparian Management Guidelines from FEMAT's "Option 9" (p. V-37, 1993)

Minimum Widths of Riparian Reserves expressed as whichever slope distance is greatest. In addition, Riparian Reserves must include the 100 year floodplain, inner gorge, unstable and potentially stable areas.

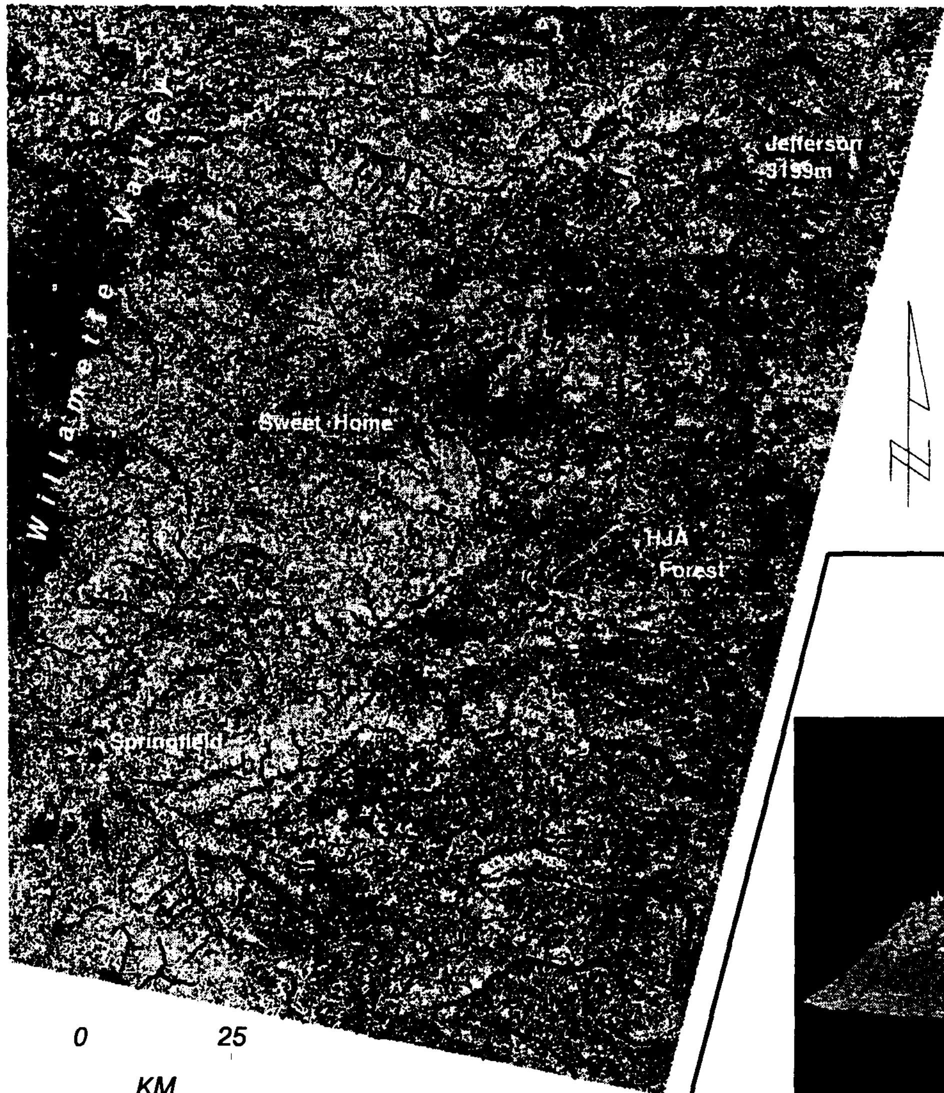
Stream Class	Tier 1 (Key watershed)	Other watersheds
Fish Bearing Streams	Average height of two site-potential trees or 300 feet	[same]
Permanently flowing non-fishbearing streams	Average height of one site-potential tree or 150 feet	[same]
Intermittent streams	Average height of one site-potential tree or 100 feet.	Average height of one-half site-potential tree or 50 feet.

Riparian reserves are identified in the FEMAT report as "designated riparian areas found outside [late-successional] reserves."

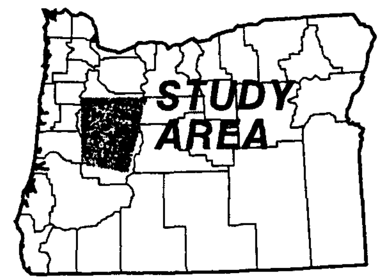
The FEMAT report defines *riparian area* as: "A geographic area containing an aquatic ecosystem and adjacent upland areas that directly affect it. This includes the floodplain, woodlands, and all areas within a horizontal distance of approximately 100 feet from the normal line of high water of a stream channel or from the shoreline of a standing body of water."

Map 1: STUDY AREA

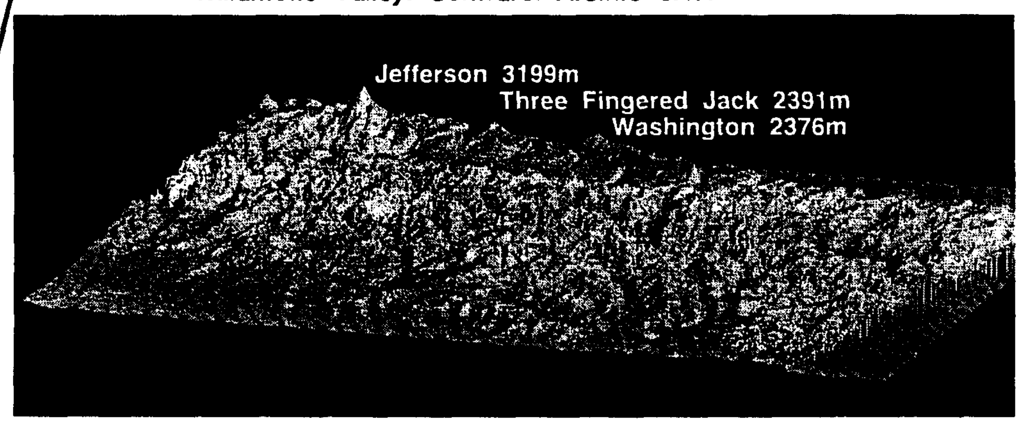
Vegetation and Drainage



- Water
- Snow/Ice
- Open Mixed
- Semi-open Mixed
- Closed Mixed
- Conifer, <80 yrs.
- Conifer, 80-200 yrs.
- Conifer, >200 yrs.

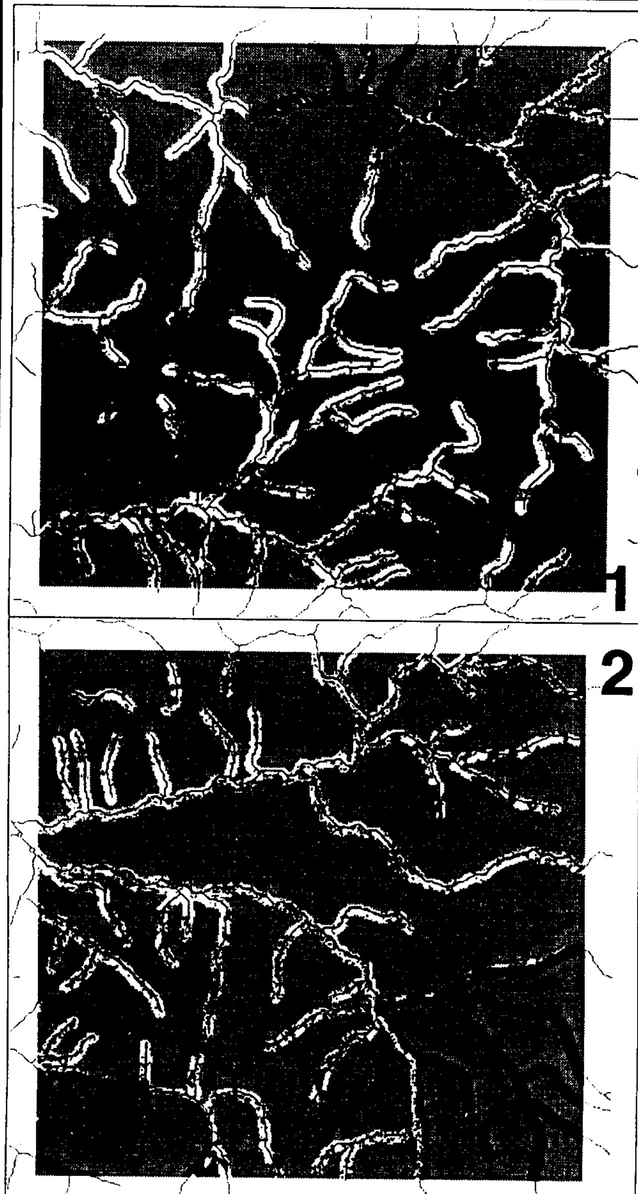


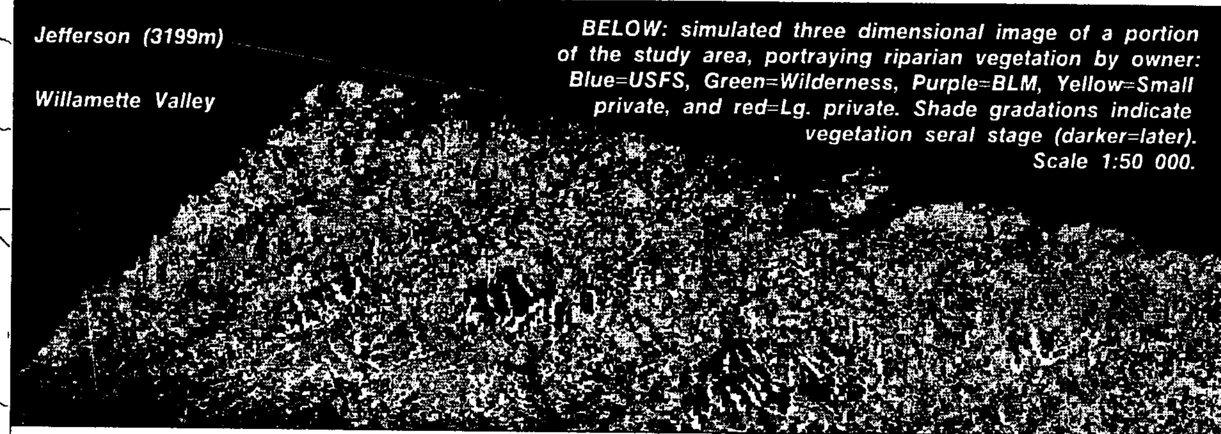
Below: Simulated three dimensional image of the study area. This scene was generated using a 50 meter digital elevation model. Surface exaggeration: 55x. Simulated observer elevation: approx. 3km above ground level; 2500 km west of the Willamette Valley. Software: ArcInfo 6.1.1

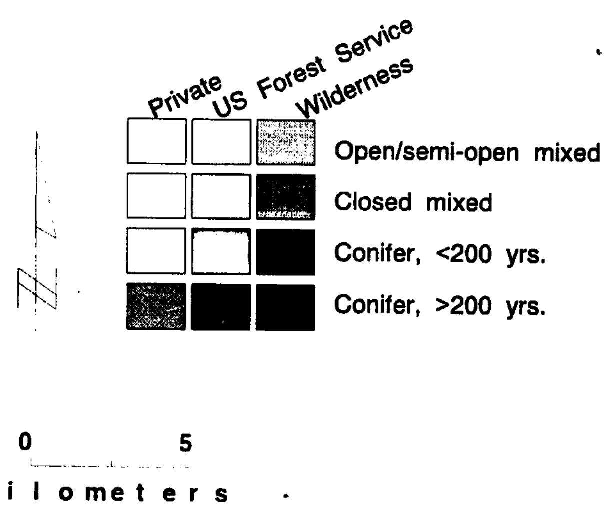


Oregon State University 1994 **Cartography: Chris Purnell**

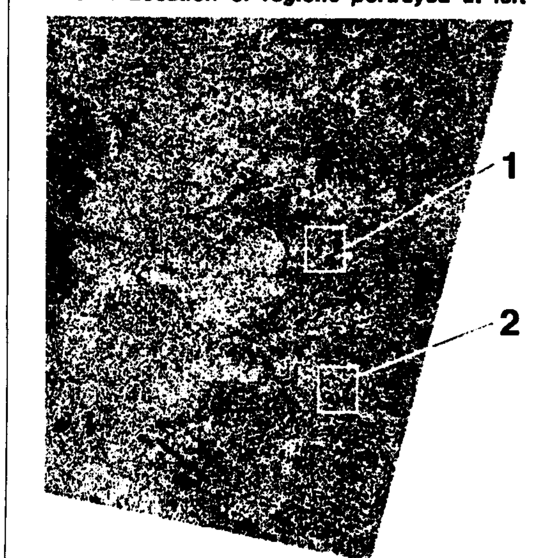
Map 2: Riparian Age/Structure and Land Ownership occuring 175 meters from Streams







BELOW: Location of regions portrayed at left



Oregon State University 1994 Cartography: Chris Purnell

Figure One: Relation between typical riparian stand characteristics and the resulting classification using the classification of Cohen and Spies (1992) and Cohen et al. (in press). The grid represents 50 meter pixels at which analysis was done. A representation of the USGS River Reach files is portrayed by the dashed line. The diagram on the left portrays a typical (hypothetical) riparian reach. The diagram on the right portrays how the reach would appear in the classified vegetation data layer. Note that in the central pixel, the stream dominates the pixel, and therefore results in a classification of water. This shows how the registration between the USGS River Reach files (vector format; digitized in ArcInfo) and the vegetation data layer (raster format; classified in ERDAS) was determined to be accurate to within twenty-five meters (see text).

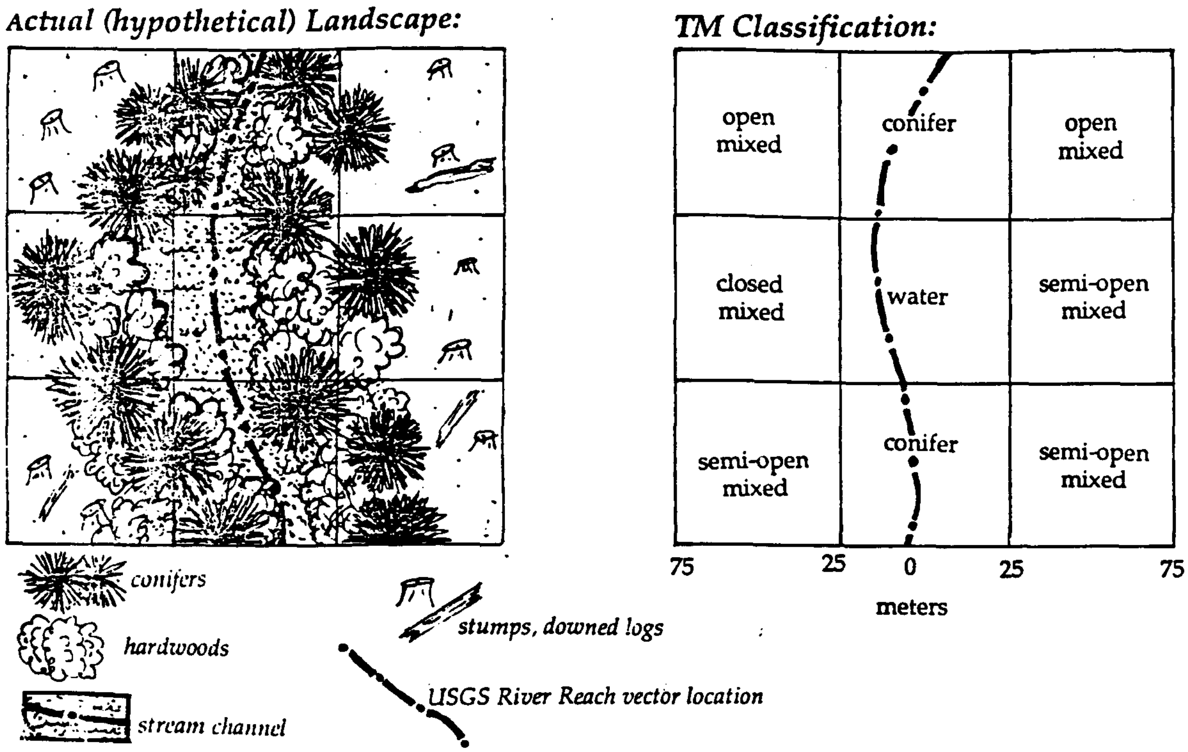


Figure two: Percentage of each ownership class within each of the five elevational bands.

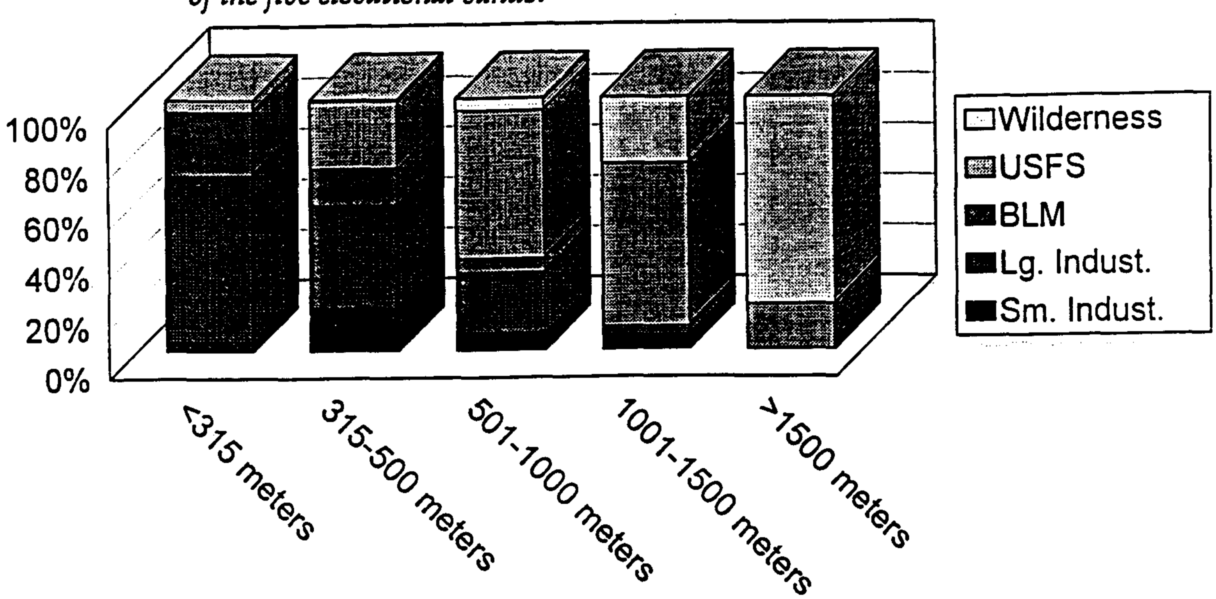
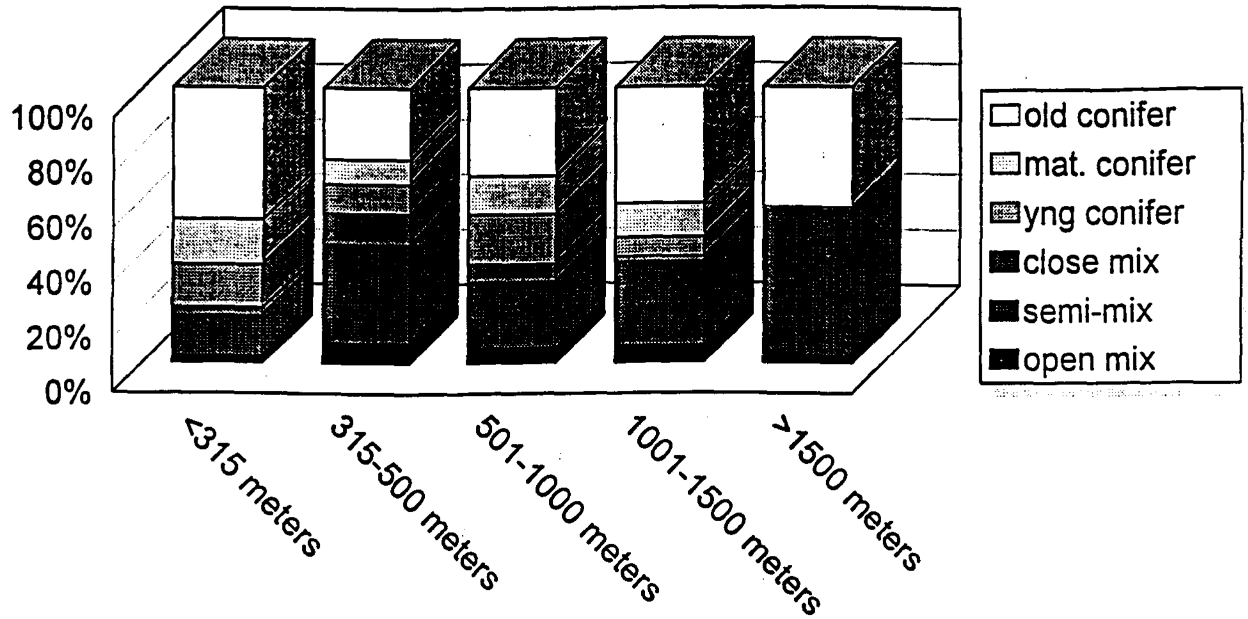


Figure three: Percentage of each vegetation cover type within each of the five elevational bands.



Note: Agricultural land has been excluded below 315 meters; the graph is only portraying private industrial forest or federal lands.

Figure four: Riparian age class/structure by ownership for the entire study area.

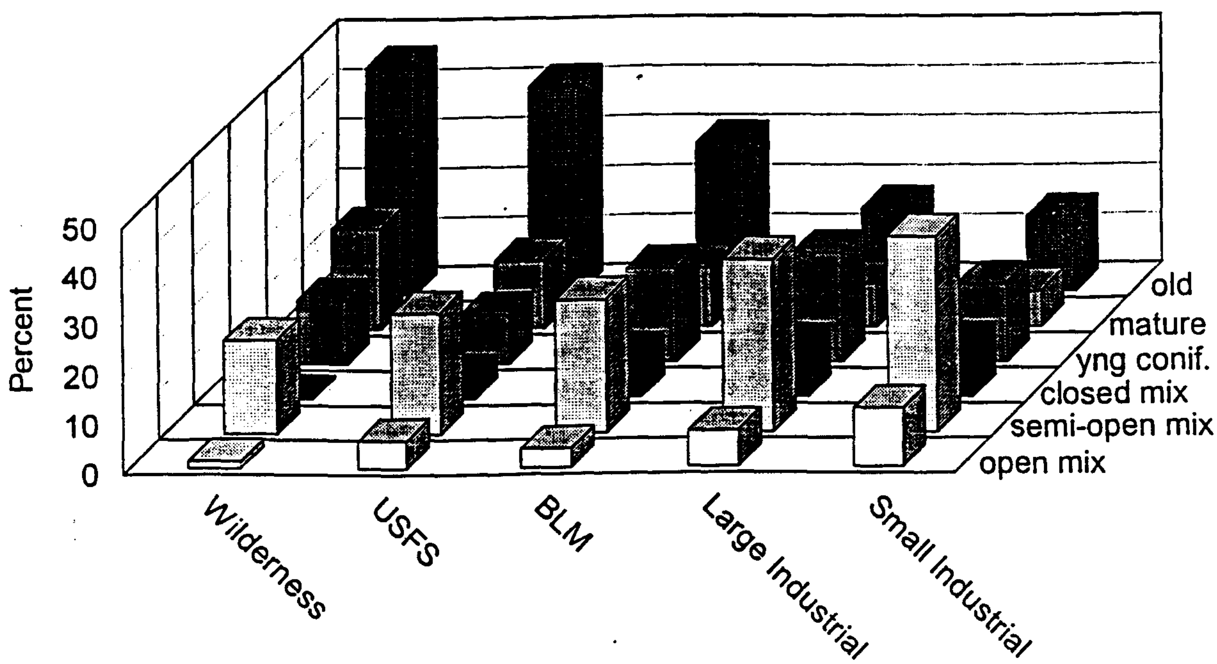
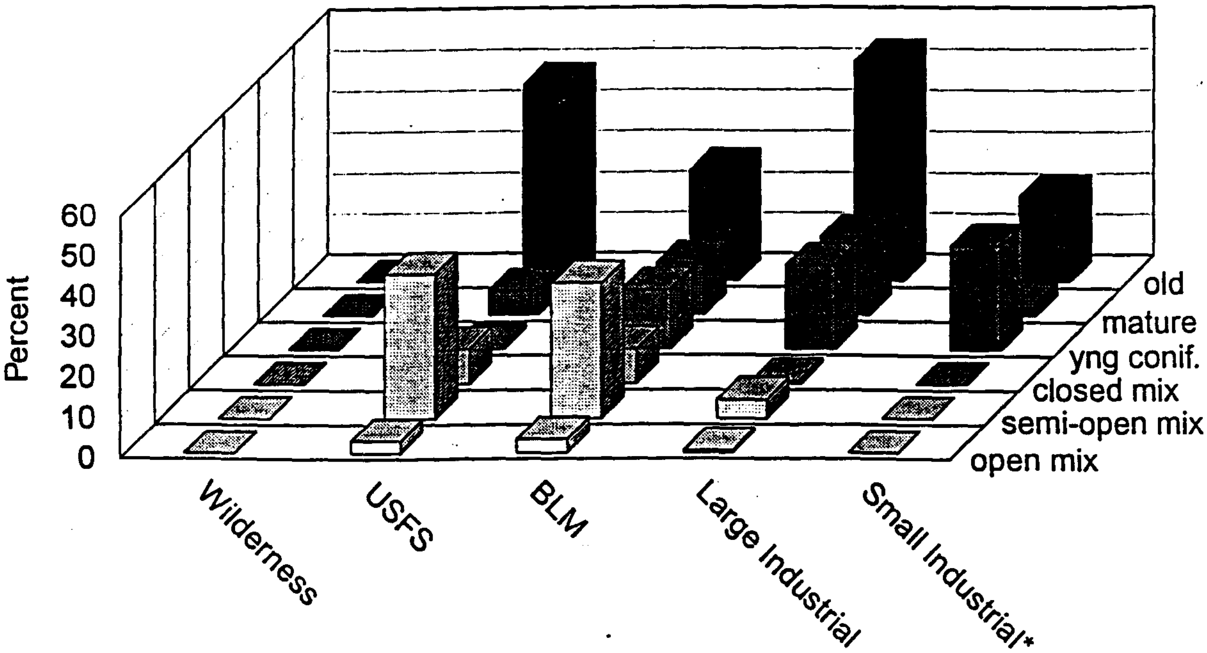


Figure five: Riparian age class/structure by ownership: Below 315 meters.



Note: Small Industrial class does not total 100%. See text.

Figure six: Riparian age class/structure by ownership: 315-500 meters.

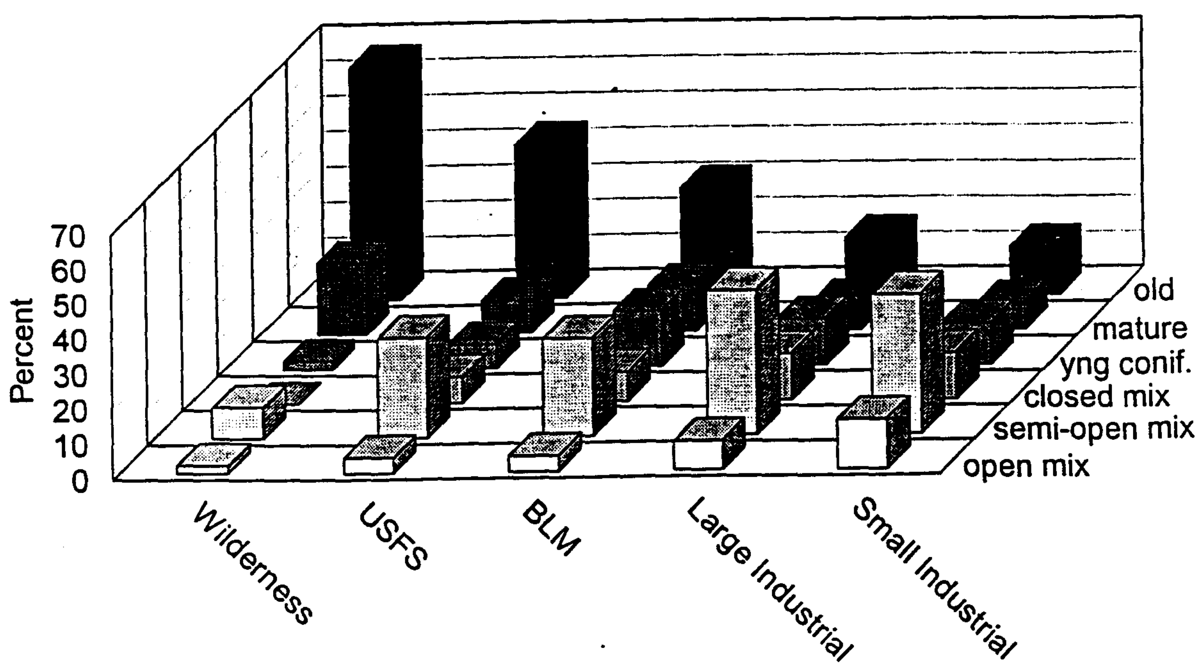


Figure seven: Riparian age class/structure by ownership: 501-1000 meters.

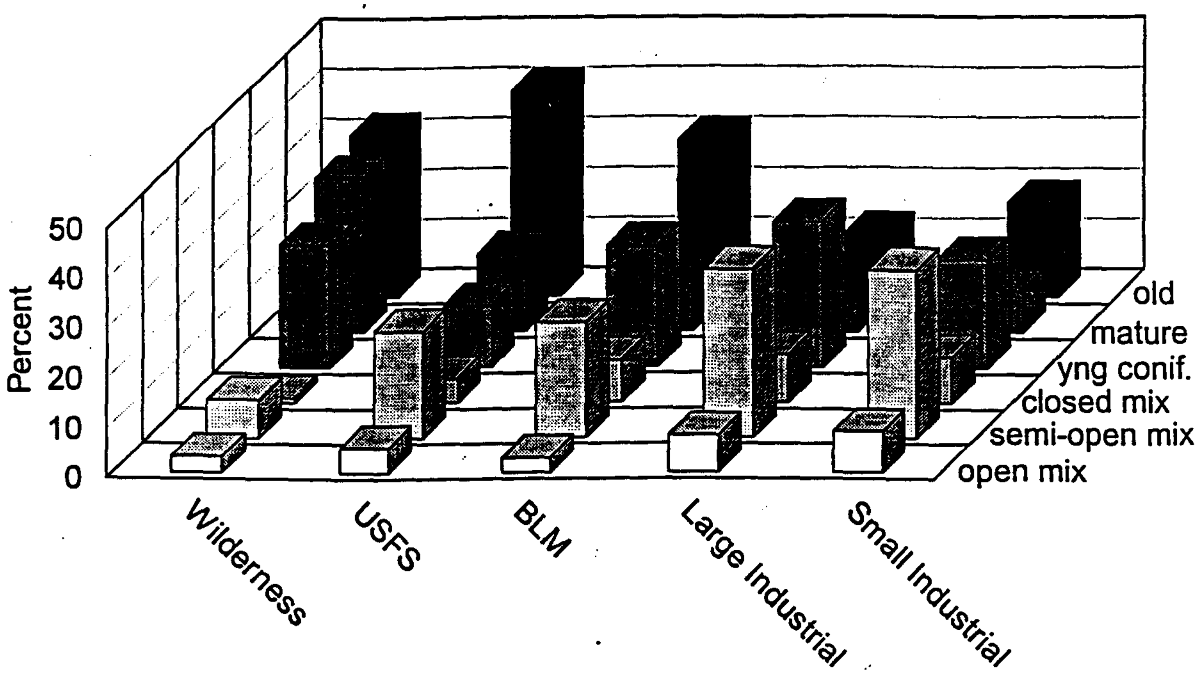


Figure eight: Riparian age class/structure by ownership: 1001-1500 meters.

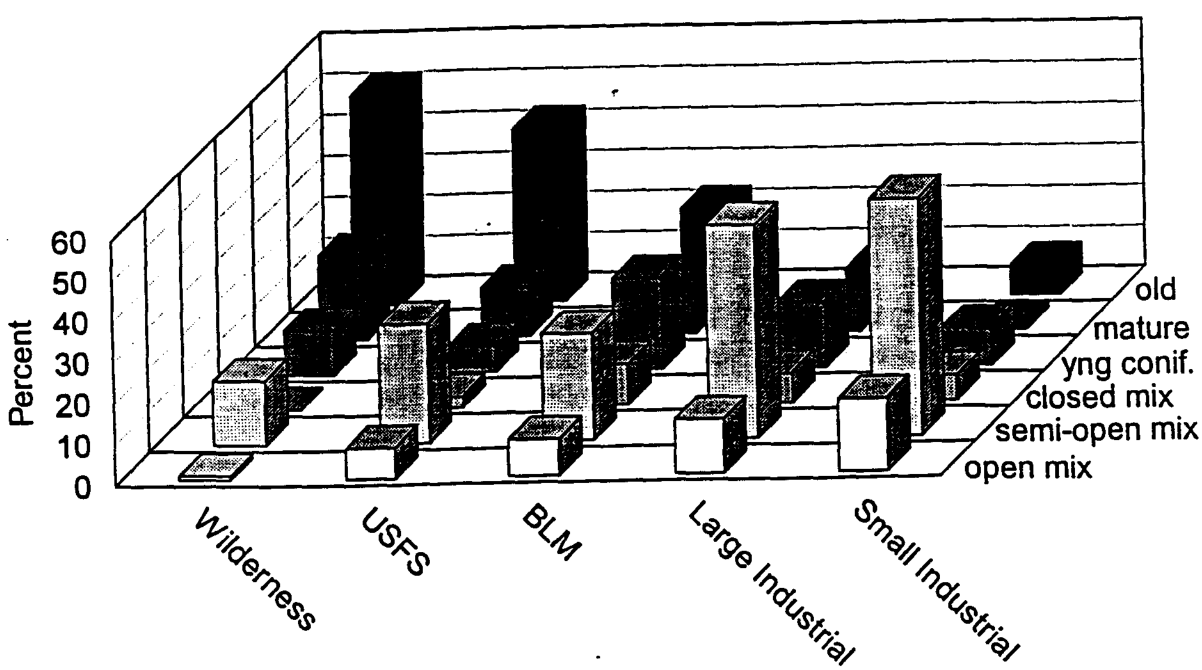


Figure nine: Riparian age class/structure by ownership: Above 1500 meters.

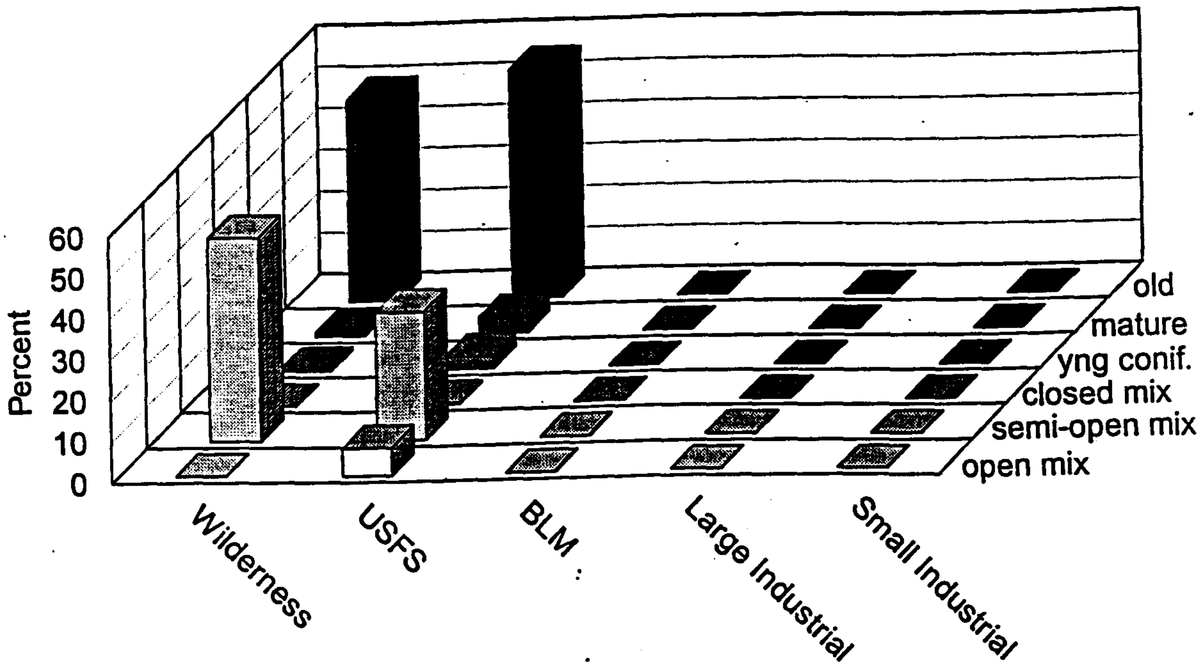


Figure ten: Decline in the abundance of old-growth conifers at increasing distances from the stream: Points used to construct the graph represent old-growth conifers found within the respective buffer zone (x-axis) as a percent-age of the quantity of old-growth conifers found within the streamside buffer.