

Assessing Pathogen and Insect Succession Functions in Forest Ecosystems

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Abstract.—The pilot test of a method to assess the ecological function of pathogens and insects in forests is reported. The analysis is a practical application of current ecosystem management theory. The influences of pathogens and insects on forest succession are measured by relating successional transition rates and types to conditions for pathogen and insect activities which are expected to lead to transitions. Results of this analysis provide means to better understand historic and current functions of pathogens and insects. They also provide a basis for predictions of future trends of pathogen and insect activities with respect to specific ecological functions. Like controlled burning, the predictable actions of pathogens and insects may, in the future, be used as tools for ecosystem management.

INTRODUCTION

Understanding the ways in which forest pathogens and insects influence the ecological health of forests is a key to ecosystem management. Pathogens and insects are the primary disturbance agents in most natural forests. These agents recycle far more biomass over the course of stand development than is typically consumed in fires in even the most fire-intensive ecosystems. Epidemics of diseases and insect herbivory have occurred throughout history. Veblen and others (1991) described a series of spruce beetle outbreaks in subalpine forests in Colorado which altered the species composition of forests as far back as 1810. Similar history has been described for western spruce budworm outbreaks (Swetnam and Lynch 1989). Root disease epidemics have been common and enduring in large areas of the western United States (Filip and Goheen 1984, Hagle and Byler 1993, Hagle and others 1994).

Less extensive and intensive activity by pathogens and insects occur on every hectare of forest, every year and form much of the character of forests (Williams and others 1992). Both epidemic and endemic types of activities are characteristic of the forests in which most of our native species evolved or to which they have adapted (Amman 1977). In this context, it is not appropriate to view them as stresses (O'Laughlin and others 1993). In fact, they may be important mechanisms by which native biodiversity is maintained.

The ways in which pathogens and insects influence succession are among their most important functions in forests ecosystems. The succession functions of pathogens and insects also may be among the most predictable of the disturbances in forests (Amman 1977, Veblen and others 1991, Goheen and Hansen 1993).

Future forest plans will almost certainly be based in part on landscape-level analyses which use successional modelling as their primary prediction tools (Salwasser and Pfister 1994). To assure full consideration of the important successional functions of pathogens and insects in future plans, predictable effects of pathogens and insects must be integrated into developing succession models. Types of successional transition, and time required for transitions to take place, are the primary driv-

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ers of the dominant successional models under development in the Northwest (Kurz and others 1994).

In 1991 we undertook an analysis to identify and characterize important successional functions of forest pathogens and insects in Montana and northern Idaho (USDA—Forest Service Northern Region) (Hagle 1992, Hagle and Williams 1995). These efforts are aimed at describing how pathogens and insects affect spatial and temporal patterns of succession, describing current and historic pathogen and insect regimes (the spatial and temporal patterns of pathogen and insect actions), and predicting future successional trends that reflect the role of pathogens and insects.

Only those pathogens and insects which have significant successional functions at a Regional scale were analyzed (Table 1). For each of these agents the actions and the functions have been defined. The "actions" on the part of the pathogen or insect, in conjunction with the physical conditions of the polygons, determine the most likely functions of the pathogen or insect. These include, the potential vegetation type, cover type, structural stage, elevation, and so on. By focusing only on functions which are expected to be significant at this broad scale, many of the actions of pathogens and insects were eliminated from consideration. When applying this analysis system to other spatial scales, it may be necessary to add other pathogen or insect functions of the analysis and leave out others to better reflect local conditions or influences.

ANALYSIS STRUCTURE

The analysis consists of three general phases. In the first phase we:

- 1) selected a stratified random sample to represent a broad range of conditions on each Forest,
- 2) identified significant pathogen and insect succession functions associated with the represented forest types,
- 3) identified actions which lead to the significant functions and the conditions under which they occur,
- 4) analyzed the data from 1975 surveys to assign

Table 1.—Pathogens and insects included in the analysis.

Category	Primary causes
Root diseases	<i>Armillaria ostoyae</i> <i>Inonotus sulphurascens</i> (<i>Phellinus weirii</i> , Douglas-fir form) <i>Heterobasidion annosum</i> (s-type)
Bark beetles	<i>Dendroctonus ponderosae</i> <i>Dendroctonus pseudotsugae</i>
Dwarf mistletoe	<i>Arceuthobium douglasii</i> <i>A. laricis</i> <i>A. americanum</i>
Stem rust	<i>Cronartium ribicola</i>
Stem decay	<i>Echinodontium tinctorium</i> <i>Phellinus pini</i> <i>Phaeolus schweinitzii</i> and ecologically similar spp.
Defoliator	<i>Choristoneura occidentalis</i>

probability index values for each identified action,

- 5) characterized polygon classes according to their average, range and frequency distributions of pathogen and insect action indices.

In the second phase we:

- 1) analyzed successional changes from 1935 to 1975 in polygons covered in surveys from both years.
- 2) assign pathogen and insect action probability indices to polygons based on their 1935 classes,
- 3) compared 1935 and 1975 pathogen and insect action probability indices,
- 4) analyzed successional stage changes from 1935 to 1975,
- 5) calibrated FVS and pest models to reflect actual successional transitions according to polygon classes and pathogen and insect action probability indices.

In the third phase we will:

- 1) use actual transitions for well-represented classes and calibrated FVS simulations for poorly-represented classes to produce factors for types and rates of successional transitions,
- 2) enter the factors into transition matrices as appropriate for two landscape successional models which are currently under development.

In this paper we present an overview of the process in the context of the pilot test on the Nez Perce National Forest, Idaho. This set of sample areas was chosen because there were relatively few polygons in the sample and few with both 1975 and 1935 surveys. The small dataset was efficient for developing and testing the process for analysis of the large sample that represents the Northern Region. The methods were discussed in greater detail in a recent paper (Hagle and Williams 1995) so we will concentrate on greater discussion of results of the test on the Nez Perce.

ASSIGNING THE ACTION PROBABILITY INDEX (API):

The primary action of root pathogens is killing Douglas-fir (*Pseudotsuga menziesii*) and true firs of all ages. Root disease in stands was evaluated using aerial photography. The photographs were interpreted to assign a severity index value on a scale of 0–9 to reflect the relative degree of effect observable in the stand. A rating of “0” implies no visible effect from root diseases and “9” indicates root diseases have so severely affected the polygon that there are no remaining live overstory trees. All other values are relative to these minimum and maximum effects. Color aerial photographs at 1:24,500 were interpreted stereoscopically using the methods of Hagle (1992).

Actions generally have patterns such as the “weeding” action of Douglas-fir beetle (*Dendroctonus pseudotsugae*) in which single Douglas-fir trees or small groups are killed. Douglas-fir beetles also have a “outbreak” action in which large parts of a stand or multiple stands can be greatly altered in composition by the death of mature Douglas-fir trees. The two types of action on the part of Douglas-fir beetle are likely to have very different successional functions. The queries designed to detect the conditions under which the two types of Douglas-fir beetle actions may occur are distinct and independent.

The results of the action queries contribute both to the determination of probable function and to the initial assignment of probability of transition from one successional state to another. The function queries utilize the information produced by

the action queries along with site and stand composition information contained in the Regional database to determine the most probable types of functions. These function queries designate the successional transition associated with a particular insect or pathogen action.

Douglas Fir Beetle Action Indices for Outbreak Probability

The outbreak query was based on a hazard rating system developed by Weatherby and Their for southern Idaho (Weatherby and Their 1992). This system was based on a report by Furniss (1981). That hazard rating system is based on stand basal area, proportion of the stand basal area which is Douglas-fir, the average stand age, and average diameter of Douglas-fir sawtimber. The query sorts stands by age class, diameter, percent basal area in Douglas-fir and total basal area of the stand. Low hazard attributes were not included because the probability of group mortality was low. Under these conditions the actions of Douglas-fir beetle are better captured by the “weeding” action index. The outbreak probability index values were assigned as in Table 2.

Table 2.—Structure of query for Douglas-fir beetle outbreak probability index.

Average DBH of Douglas-fir which are >5" DBH	% of stand BA =DF	Stand BA	Age	Code
10–13.9	25–49	80–119	80–119	M
			120+	M
			80–119	M
		120–249	120+	H
			80–119	M
			120+	H
50+	25–49	80–119	80–119	M
			120+	H
			80–119	H
		120–249	80–119	H
			120+	H
			80–119	H
14+	25–49	80–119	120+	H
			80–119	M
			120+	H
50+	25–49	80+	80+	H
			80+	H

Table 3.—Structure of query for the Mountain Pine Beetle probability Index.

Age class of Lodgepole pine component	Mean DBH of Lodgepole pine component	Code
<60		L(low)
60–79	<7"	L
	>=7"	M(moderate)
>=80	7–8	M
>=80	>8"	H(high)

Mountain Pine Beetle

Mountain pine beetle (*Dendroctonus ponderosae*) can have three relevant actions depending on the composition of the forest in which it is active. They are: killing mature lodgepole pine (*Pinus contorta*), killing large-diameter western white pine (*Pinus monticola*), or killing immature ponderosa pine (*Pinus ponderosa*). Logic to assess the possible extent and probability of mountain pine beetle killing lodgepole pine in a stand was derived from a hazard rating system developed by Amman and others (1977) and, like the Douglas-fir beetle query, condensed to represent the significant classes with respect successional functions (Table 3). Stands with less than 10% lodgepole pine are assigned the value "0" since they are unlikely to experience successional transitions caused by mountain pine beetle even if all of the lodgepole pine is killed. All of the sample polygons on the Nez Perce National Forest received the "high" elevation/latitude factor (Amman and others 1977).

SAMPLE POLYGON CLASSES IN 1935 AND 1975

There had been very little tree harvest activity in the sample polygons before 1975, probably less than about 7% of hectares overall (Hagle and Byler 1993). Fire exclusion probably did affect some of the area, however; particularly on the drier, more fire-prone sites. For the most part, however, the changes seen on sites can be attributed to natural succession, including the actions of pathogens and insects. Polygons with evidence of harvest activity were excluded from this phase of the analysis because there were too few to provide a viable

sample. As greater numbers of harvested polygons are encountered in the analyses of the rest of Idaho and Montana, we will look for opportunities to examine the successional influences of management as well.

Habitat Type Groups

Habitat type groups, in descending order of importance in the sample, were; grand fir (*Abies grandis*), subalpine fir (*Abies lasiocarpa*), Douglas-fir, and western redcedar (*Thuja plicata*). Grand fir habitat types comprised 39 percent of the sample area. These are productive site types on which ponderosa pine, Douglas-fir and lodgepole pine are the primary seral species. Both mixed severity and stand replacement fire regimes are common on these habitat types. Grand fir cover type was found on 40 percent of these habitat types. Ponderosa pine, Douglas-fir and lodgepole pine cover types were about evenly split on these habitat types and, combined, made up another 40 percent of the area.

Subalpine fir habitats were divided into three groups. The most common of the three was the moderately dry type group, typified by the subalpine fir/beargrass (*Xerophyllum tenax*) habitat type. Second in importance was the moist group typified by subalpine fir/Menziesia (*Menziesia ferruginia*) habitat type. Lodgepole pine is the most important seral species found in either of these habitat type groups. The high elevation types which are potentially important habitat for whitebark pine (*Pinus albicaulis*) were found in 175 hectares of the sample area (5%). Here, both lodgepole pine and whitebark pine have the potential to be important seral species. Seral cover types dominated the subalpine fir habitat type sites, comprising 64% of the areas.

Douglas-fir and western redcedar habitat types covered (17%) and (14%) of the sample area respectively.

Cover Types

Douglas-fir cover type covered 29% of the overall sample area in 1975. Grand fir and lodgepole pine cover types comprised 19% and 17%, respectively, of the area. A mixture composed of at

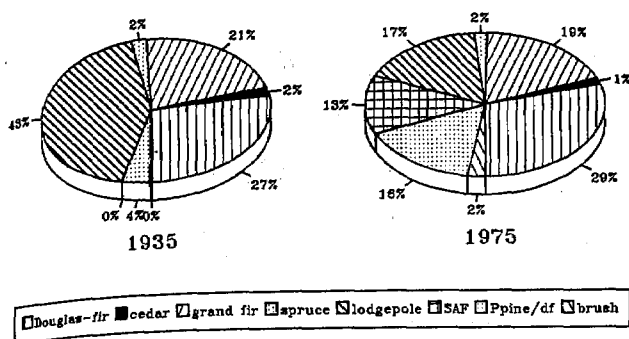


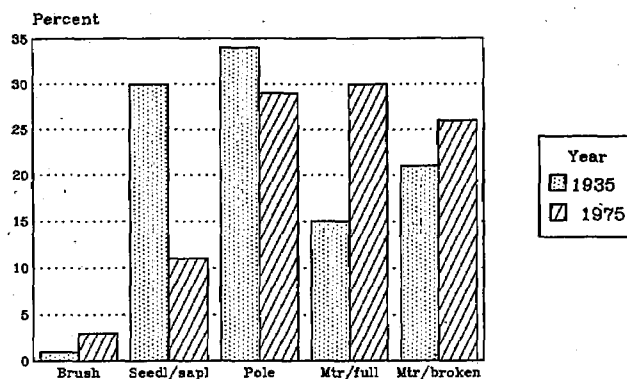
Figure 1.—Cover types of sample polygons.

least 25% ponderosa pine, called the pine/fir type covered 16% of the area. Subalpine fir and Douglas-fir was the only other common cover type (13%), although there were small amounts of Engelmann spruce (*Picea engelmannii*), western redcedar and brush types (fig. 1).

Structural stages were based on the combination of the size and density of trees on the site. The 1935 survey data contained information about the cover type, size class, stocking density, age class and, generally, the percent composition of stands by tree species. These data are sufficient to assign the cover type and structural stage of stands, the combination of which represent the successional stage. Cover types and structural stages for the 1975 survey data were assigned using the criteria used in the 1935 survey to provide the greatest comparability. Although the query designed to assign these attributes is quite lengthy, the general criteria for assigning structural stages are provided in Table 4.

Structural Stages

Mature structural stages (3 and 4) dominated the area, covering 67 percent of the grand fir habitat type. About half of the area covered by mature structural stages was closed canopied and well stocked as indicated by structural stage 3. The other half of the area with mature structural stages had open canopy, multi-storied structures (structural stage 4) often associated with the outcome of root disease and bark beetle activities.



Structural stages: brush = <25 trees per acre, Seedl/sapl = seedling/sapling, Pole = pole size/ submature, Mtr/full = mature/well stocked (>2 MBf/A) Mtr/broken = mature/ poorly stocked (2 MBf/A).

Figure 2.—Structural stages of sample polygons.

Table 4.—General criteria used to class polygons for structural stage from both 1935 and 1995 survey data.

Criteria	Structural Stage
≥4000* bdf/acre total AND >50% of CFV in trees ≥ 13*** dbh ≥20,000 bdf/A total stand volume 4–20,000 bdf/A total stand volume	4
<4000* bdf/A total AND <50% of CFV in trees >13*** dbh AND >25 tpa of trees ≥ 6" dbh	3
<4000* bdf/A AND >50% of CFV in trees >13*** dbh AND <25 tpa of trees ≥ 6" dbh AND >25 tpa total	2
<25 tpa total and <4000 bdf/A total	1
	0

*3000 bdf/A for ponderosa pine, lodgepole pine, subalpine fir, mountain hemlock or whitebark pine cover types.

**11" dbh for western redcedar and western white pine

The area was dominated by mature structural stages. Stages 3 and 4 combined comprised 56% of the area (fig. 2). Young, regenerating stands were only 11 percent of the sample area, the vast majority occurring in the highest elevation subalpine fir/whitebark pine types.

Results from queries designed to assign the polygon class (habitat type, cover type, structural stage) and pathogen and insect action probability

Table 5.—Action array table for selected polygon classes.

CT SS	RRSV 0-9*	dfb 0-H	mpblp 0-H	mpbpp 0-H	dmdf 0-6	dmwl 0-6	dmlp 0-6	et 0-11	pini 0-3	oth 0-3	wsbw 0-9
Habitat type group = western redcedar											
DF 1	8	0	0	0	4	0	0	0	0	1	0
	8	0	0	0	4	0	0	0	0	1	3
	6	0	0	0	4	0	1	0	0	1	0
2	8	0	0	L	4	0	0	0	0	1	0
	4	0	0	0	4	0	0	0	0	1	3
3	4	H	0	H	4	0	0	0	0	1	3
4	8	0	0	L	4	0	0	0	0	1	0
	4	0	0	0	4	0	0	0	0	1	0
	3	0	0	0	4	0	0	0	0	1	3
Habitat type group = Douglas-fir											
DF 4	6	0	0	0	5	0	0	0	0	3	0
	5	H	0	0	5	0	0	0	0	1	0
	5	0	0	M	4	0	0	0	0	1	7
	5	0	0	0	5	0	0	0	0	1	0
	5	0	0	H	4	0	0	0	0	1	0
	2	H	0	0	6	0	0	0	0	2	0
	1	0	0	0	5	0	0	0	0	2	0
Habitat type group = moderately dry subalpine fir											
LP 2	3	0	L	0	1	0	4	0	1	0	0
	8	0	0	L	4	0	0	0	0	1	0
	4	0	0	0	4	0	0	0	0	1	0
	3	0	0	0	4	0	0	0	0	1	0

CT = cover type, SS = structural stage, RRSV = root disease severity, DFB = Douglas-fir beetle outbreak, MPBlp = mountain pine beetle in lodgepole pine, MPBpp = mountain pine beetle in ponderosa pine, DMDf = Dwarf mistletoe in Douglas-fir, DMWL = dwarf mistletoe in western larch, DMLP = dwarf mistletoe in lodgepole pine, ET = stem decay caused by *Echinodontium tinctorium*, PINI = stem decay caused by *Phellinus pini*, OTH = stem decay caused by *Phaeolus schweinitzii* and ecologically similar fungi, WSBW = western spruce budworm, DF = Douglas-fir, LP = Lodgepole pine.

*Ranges of possible action probability index values. 0 = no probability; higher values imply higher probability of the action occurring.

indices (API), are stored in an Oracle data table called the "Action array table" (Table 5). From this table, further analyses were designed to discover relationships between polygon classes and the API's.

DISEASE AND INSECT ACTION INDICES IN THE SAMPLE AREA

The action indices indicate the relative probability of a particular type of action occurring in a polygon. The average root disease severity for polygons in 1975 ranged 0-8. The overall average for the samples was 4.2. Cedar habitat type group had the highest average root severity (5.7), moderately dry subalpine fir group was second with the average 4.5, and grand fir was a close third with 4.3 (fig. 3). The average root disease severity in seedling and sapling stands with Douglas-fir and grand

fir cover types was particularly high on cedar habitat types (7.5) and considerably lower on grand fir habitat types (4.4). Byler and others (1982) reported a similar relationship with habitat type on the Lolo National Forest in Montana. The probably of mortality from root disease was significantly higher on cedar and hemlock habitat types with Douglas-fir or grand fir forest types than on other habitat types or cover types.

Douglas-fir beetle outbreak probability tended to be either high (14.2 percent of hectares) or none (85.8 percent of hectares). Both Douglas-fir beetle and the major root pathogens on the Nez Perce have a strong host preference for Douglas-fir. The relationship of root disease severity and Douglas-fir beetle outbreak probability index is indicative of their relative effects on the forest composition. At the high end of root disease severity, there are few large trees remaining alive so there is little prob-

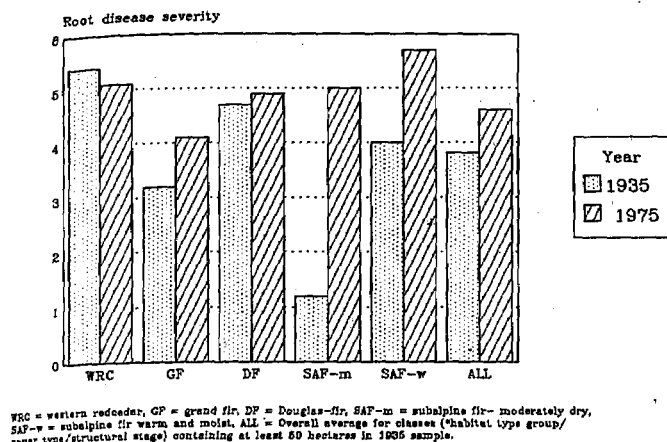


Figure 3.—Average root disease severity comparison 1935–1975 for polygon classes* with at least 50 hectares.

ability of a Douglas-fir beetle outbreak. In the mid-range of disease severity, the probability of Douglas-fir beetle outbreak reaches it's maximum (fig. 4).

High and moderate probability indices for mountain pine beetle in lodgepole pine were obtained for 2% and 10%, respectively, of the sample area. Low probability index was assigned to 16 percent of the hectares. Although the frequency is low, as we'll show later, polygons with high probability indices did undergo dramatic changes between 1935 and 1975.

Comparison of Historic and Current Probability Indices

Coverage in the 1935 survey was inconsistent on the Nez Perce National Forest. We were able to locate 1935 photo coverage for only 7 of the 22 sample subcompartments. This is far less than the 73–100% coverage we obtained for the sample subcompartments for the other National Forests of northern Idaho and western Montana. They did, however, provide useful insight and experience in the operational aspects of the GIS analysis. They also demonstrated the usefulness of the comparing the 1975 and 1935 surveys even though it represents only a 40-yr interval. In that 40 years, 76% of 97 polygons surveyed in both years, transitioned from one successional stage to another. Cover type

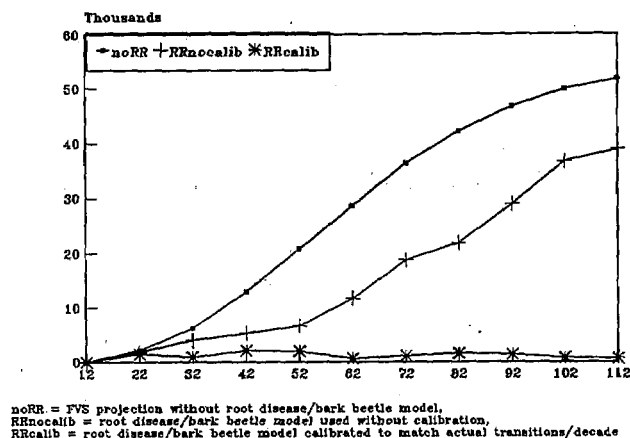


Figure 4.—FVS and root disease/bark beetle model projections calibrated and uncalibrated root disease/bark beetle models.

changed in 59% of those which transitioned (44% of all sample polygons represented in the 1935 survey). In the remaining 41% the cover type was the same in both 1935 and 1975, but the structural stage had changed. Typically, the structural stages had changed to later successional structures.

As polygons changed from one cover type or structural stage to another, their associated API's changed as well. Some habitat type groups were more prone to dramatic changes in cover or structure than others. For example, the moderately dry subalpine fir habitat type group which mostly had lodgepole pine cover types in 1935 (98%) converted to a significant proportion of subalpine fir cover type by 1975 (31%). Although the 1975 root disease severity rating (RRSV) was fairly high (5), the cover types and structural stages in 1935 suggest an expected average RRSV of only 1.2 (fig. 3). The opposite changes were seen in mountain pine beetle API's. The frequency of moderate to high MPB API's dropped from the expected 48% in 1935 to 31% in 1975. Mountain pine beetle was probably largely responsible for the changes in cover type within this class.

Tracking Transitions

A single polygon class often transitioned to a number of other successional stages (Table 6). For

Table 6.—Transitions in selected cover types and structural stages occurring in western redcedar, Douglas-fir and moderately dry subalpine fir habitat type groups in the Nez Perce pilot test.

Habitat type group	1935 Survey		1975 Survey		Frequency
	Cover type	Str.* stage	Cover type	Str. stage	
Cedar	Douglas-fir	1	Douglas-fir	1	.15
			Douglas-fir	2	.07
			Douglas-fir	4	.63
			Grand fir	1	.15
Douglas-fir	Douglas-fir	4	Ponderosa	3	.44
			Ponderosa	4	.08
			Douglas-fir	4	.48
			Lodgepole	1	.06
Subalpine fir, moderately dry	Lodgepole	1	Lodgepole	2	.65
			Subalpine fir	2	.29
		2	Lodgepole	2	.69
			subalpine fir	2	.31

*Structural stage

example, on sites in the cedar habitat type group (C HT), with Douglas-fir cover type (DF CT), and seedling/sapling structural stage (SS 1), there were 5 types of transitions which occurred, all of which appeared to be heavily influenced by root diseases. In one transition type the tree density had dropped below 25 trees per acre. This placed the polygon cover type in class 19 which designates a non-tree cover class on a stockable site (referred to as "brush").

Another transition type was to "pole" size trees (structural stage 2) with Douglas-fir cover type the stocking was only moderately dense in stands which had made this transition, less than 200 trees per acre. A third transition type was to structural stage 4 with Douglas-fir cover type. This indicates that some trees did grow large but the stocking density was moderate to poor (less than 20,000 bdf/t/A at maturity). The fourth transition type was to structural stage 4 as well but with a ponderosa pine/Douglas-fir cover type. The final transition found was from seedling/sapling Douglas-fir to seedling/sapling grand fir and western redcedar. The remaining polygons indicated no transition occurred. It would seem unreasonable to find seedling/sapling Douglas-fir stands that remained so 40 years later. In fact the average root disease severity assigned to these polygons in the aerial photography interpretation was "eight" out of a possible nine. This was the most severe root disease rating assigned in the pilot study area.

SUCCESSIONAL FUNCTIONS

The influence of pathogens and insects was evident in most of the transitions observed in the polygons from 1935 to 1975. For example, in the polygon class with western redcedar habitat type (C HT), Douglas-fir cover type (DF CT) and seedling/sapling structural stage (SS1) 25% of the hectares were still in the seedling/sapling stage 40 years later. Root disease severity on those sites averaged 7.6 in 1975. This is an indication that the root pathogens have functioned on these sites to "stall" succession. The root pathogens on these sites will chronically kill trees, effectively preventing most of the trees from growing into pole size classes. The result is that the stands have not transitioned to pole or mature structural stages. Regeneration in openings created by mortality is dominated by Douglas-fir or grand fir as evidence by the sites remaining in Douglas-fir and grand fir cover types. The frequency with which this function should be applied to successional models for the class CHT, DF CT, SS1 on the Nez Perce National Forest is estimated to be .25/ 40 yrs, according to these data. One third of polygons beginning in this class should remain in the class over a 40-yr projection.

Interaction of root diseases and Douglas-fir beetle is evident in polygons in class; Douglas-fir habitat type group (DF HT), Douglas-fir cover type (DF CT), structural stage mature, low density (SS4) in 1935. The root disease severity average expected

for the polygons in 1935 is 4.7 and the disease severity assigned to the same sites in 1975 averaged 4.9. According to the Douglas-fir beetle API's for this class, 17% of the stands in this class are dense enough to support a Douglas-fir beetle outbreak and all of the stands in the class are prone to Douglas-fir beetle single or small-group killing action. One half of the hectares had converted to ponderosa pine cover type over the 40 year period. Without the influence of root diseases and Douglas-fir beetle, these sites would have been expected to remain Douglas-fir cover types and in the absence of ground fire, they would be expected to increase in Douglas-fir density. Ponderosa pine is a shade-intolerant seral species in this habitat type group. Root diseases and Douglas-fir beetle are both expected to function to maintain seral species such as ponderosa pine, where they are present in the stands. Root diseases will selectively kill Douglas-fir of any age from such a species mix and Douglas-fir beetle will selectively kill mature Douglas-fir. Together they can be expected to enhance the survival of the pines by reducing the lateral competition. This function appears to have been strongly expressed in these polygons.

The other half of the hectares in the DF HT/ DF CT/ SS4 polygon class, remained in the same class after 40 years. The density did not increase, as may have been expected in the absence of ground fire. The 1975 root disease severity average of 4.9 and indicates that some mortality of Douglas-fir has probably occurred which may be the reason the stand has not increased stocking to more than 20,000 bdf/t/A, poor mature-stand stocking for this site quality.

Mountain pine beetle API's for lodgepole pine cover types, structural stages 2 and 3 (regardless of habitat type), were 13% = high, 41% = moderate, 39% = low and 0% = 0. This distribution of expected API's is associated with 38% of the hectares in these classes converting to other cover types (primarily grand fir or subalpine fir) or to structural stages indicating that the largest trees had been killed (such as from SS4 to SS2).

Forest Vegetation Simulator Calibration

To account for transitions not well represented in the sample polygons with both 1935 and 1975

surveys, Forest Vegetation Simulator (FVS) (Wykoff and others 1982) was calibrated to reflect the pathogen and insect functions appropriate for each polygon class. This was accomplished using a model produced by combining the annosum root disease model and western root disease model (Stage and others 1990). This model is an update which combines the capabilities of both models in a single model. This was used with the dwarf mistletoe damage model both of which operate in conjunction with FVS. The combined root disease model allows simulation of various types of bark beetle actions as well.

The root disease/bark beetle and dwarf mistletoe model parameters were adjusted according to both the probable action of the pathogens and insects, bases on the API values and the actual transitions which occurred in sample polygons over a 40-yr period. The calibrated models match closely the actual transitions in species composition and structural class of each polygon class for which they were calibrated. Transitions for the remaining polygon classes were derived from making FVS, root disease/barkbeetle, dwarf mistletoe model runs (based again on API and most similar polygon classes).

The calibrated models produced greatly different projections compared to the uncalibrated models runs or the FVS without root disease/barkbeetle models. For example, figure 4 illustrates an FVS simulation, an FVS with uncalibrated pest extensions simulation, and a calibrated simulation. In this simulation we were interested in representing the 25% of stands on cedar habitat types with Douglas-fir cover types and beginning in successional stage 1 (seedling/sapling) which remain in that structural class for at least the 40 years covered by this study. Without calibration the FVS and root disease model extension projected a transition to a well-stocked mature structural stage within 40 years. By calibrating the root disease model, we produced projections in which the stands remained in the Douglas-fir cover type and seedling/sapling structural stage through root disease-caused mortality and predominantly Douglas-fir regeneration. Using these calibration factors and slightly lowering the initial root disease inoculum at model initialization produced projections in which the stands changed to structural stage 4, mature with

poor relative stocking. This transition was represented in 63% of the sample area which was in the C HT, DF CT, SS1 in 1935.

Since FVS and pest extensions are sensitive to tree species composition, it is not necessary to calibrate for each forest type except as bark beetle parameters need to be adjusted to respond to relative purity of host. This significantly lessens the task of calibration, making the use of FVS simulations a useful link between stand-level assessments such as producing the API values, the landscape level projections.

Tables of transitions and 40-year probabilities of transition are being constructed through this analysis. These transition matrices will be the basis for landscape model calibration in the final phase of this project.

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