Analyst Hazards When Assessing Fire, Insect, and Disease Hazard in Montana Using FIA Data with FVS: Or Alligators We Didn't See Coming

David Atkins
Renee Lundberg

Abstract—The Forest Vegetation Simulator (FVS), with the Fuels and Fire Effects and Insect and Pathogen Extensions, was used to characterize forest health hazards in Montana. Forest Inventory Analysis (FIA) data were processed through FVS to characterize current and future hazards related to fire, insect, and disease. While conducting this Statewide analysis, several weaknesses in the base model and extensions were discovered. The paper presents problems encountered, how they were resolved, recommendations for future FVS development, and research needs.

The potential for wildfires to put lives, property, and environmental values at risk is a much discussed and debated topic in recent years. It is important for managers, policy makers, and the public to understand potential wildfire behavior and effects, along with the potential for insect and disease activities and their potential interaction with fire. Describing changes that may occur across an entire State requires a consistent dataset across ownerships and the tools to analyze these data. Using the Forest Inventory and Analysis (FIA) Database and the Forest Vegetation Simulator Model (FVS) program provides this opportunity. Atkins and Lundberg (in preparation) used FIA plot data processed through FVS (Wykoff and others 1982; FMSC 2001) to predict current and future hazards related to fire, insect, and disease. In the process of conducting this Statewide analysis, several weaknesses in the base model and extensions were observed. The objectives of this presentation are:

- To provide FVS users with an overview of our results.
- To share the problems we encountered and how we dealt with them.
- To submit recommendations for future system development and research needs.

In: Crookston, Nicholas L.; Havis, Robert N., comps. 2002. Second Forest Vegetation Simulator Conference; 2002 February 12–14; Fort Collins, CO. Proc. RMRS-P-25. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

David Atkins is a Forest Ecologist with the USDA Forest Service Northern Region in Missoula, MT. During this project, his primary responsibilities were Forest Health Monitoring Coordinator for the Northern and Intermountain Regions. Renee Lundberg is a Silviculturist/Ecologist with the Forest Service Northern Region in Missoula, MT. Her primary responsibility for this project was data analysis.

Overview of Results

The original work had two objectives: (1) to develop methods to use FIA data and FVS, incorporating its Fuels and Fire Effects (FFE) (Beukema and others 2000) and the Insect and Pathogen (I&P) (FHTET 2001) Extensions, to characterize current and simulated future forest conditions; and (2) to use the methods developed to describe the conditions of Montana forests now and in 50 years.

Methods

We used FIA data for the State of Montana (USDA 2000; Conner and others 1993; O'Brien and Conner 1991; USDA 1988) for this analysis. There are a total of 3,721 forested plots from all ownerships, with the exception of National Park Service lands that have not yet been inventoried. The 2,343 National Forest System (NFS) plots were inventoried between 1993 and 1998. There are 1,378 plots on private and other public lands, which were inventoried in 1988 and 1989. For purposes of display, all plots were modeled with 2000 as the inventory year. Our results do not reflect changes in the forest condition from fires, insect, disease, or management activities that may have occurred between the inventory year and 2000.

Fire, insect, and disease potential are affected by a variety of variables that describe and influence how much and where hazardous conditions exist. We used these variables to stratify the data:

- Forest type
- Potential vegetation groups
- Stand structure
  - o Size class
  - o Stand layering
- Ecoregions (fig.1)

The Eastern Montana (EM) and North Idaho (NI) variants of FVS were used in modeling the FIA plots. The FVS model was modified to allow both FFE and I&P extensions to model fire, and insects and diseases simultaneously. This was important because insect and disease processes directly affect fuel loadings and subsequent fire behavior. Insect and diseases behave somewhat differently in varying environmental settings (Hagle and others 2000). To account for these variations we used the action probability indices (APIs) from the results of Hagle and others (2000) to create

Figure 1— Ecoregions in Montana.

the FVS keyword files by habitat type groups for east and west of the Continental Divide.

The FVS Fuels and Fire Effects Extension provides indicators of fire effects including tree mortality, exposed mineral soil, and fuel consumption. We chose fire type and crown index as our measures of fire hazard. Mortality is influenced by the intensity of the fire, species of trees in the stand, and their size, both diameter and height. We show fire type, forest type, and basal area loss to illustrate potential fire mortality. The I&P extensions simulate mortality from various agents, including root disease, bark beetles, and mistletoe, as FVS projects the forest through time. We show bark beetle hazard as an example.

Fire behavior and effects vary considerably with short-term weather and longer term climatic conditions (drought) through time. Although these variables occur along a continuum, we chose to simulate two conditions. One represents the average summer day weather and average climatic conditions. The second represents extreme fire weather conditions and very dry climatic conditions. They are displayed in table 1.

Down woody debris data were available on 88 percent of the NFS plots. These measured fuel loadings were used in the FVS simulations. For the plots without measured fuel data, the default values from the FFE model were used. Fuel loadings directly affect flame lengths, fire intensity, and fire effects. By incorporating actual fuel loadings, the simulations better reflect the variation that exists in Montana forests.

After the plots were processed by FVS, the output was run through a custom program to extract specified report fields and then loaded into an Access database, which facilitated summarization and analysis.

Table 1—Weather conditions used in FVS to represent average and extreme fire scenarios.

Weather conditions	Average fire	Extreme fire
20 foot wind speed	15	40
Temperature	75	90
Fuel Moistures:		
1 hour (0-1/4")	6%	4%
10 hour (1/4-1")	8%	6%
100 hour (1-3")	10%	7%
1000 hour (3"+)	15%	12%
duff	100%	65%
live	90%	60%

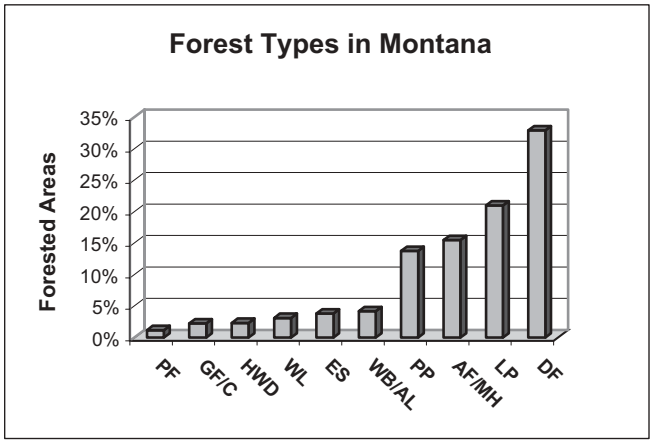
Results

In order to understand and display the potential for fires, insects and disease and their possible effects, we first summarized the inventoried conditions, forest type, structure, layering, size class, and hazard rating for bark beetles. Then we related these characteristics to FFE outputs: fire type, crown index, and mortality. The results also included some 50-year projections.

Figure 2 shows that Douglas-fir *(Pseudotsuga menziesii)*, lodgepole pine *(Pinus contorta),* subalpine fir *(Abies lasiocarpa),* and ponderosa pine *(Pinus ponderosa)* forests are dominant types across the State. Douglas-fir and lodgepole pine compose over half of the forest types, and these four types represent 83 percent of the forests in Montana.

Figure 3 shows that medium two storied stands are the most common condition in the State. Figure 3 also illustrates that two-storied and multistoried stands (layered stands with fuel ladders) are abundant, representing approximately 12.3 million acres.

Figure 4 shows the relative abundance of the four size classes. The medium size class is most abundant. The pole class is next in abundance with the seedling/sapling and large size classes present in lesser amounts. This size class distribution is reflective of fire suppression and the logging history. This distribution of size classes has important ramifications for fire, insect, and disease hazard.



PF–limber pine, GF/C-grand fir & cedar, HWD-hardwood, WL-western Larch, ES-Englemann spruce, WB/AL-whitebark pine & subalpine larch, PP-ponderosa pine, AF/MH- subalpine fir and mountain hemlock, LP-lodgepole pine, DF- Douglas-fir

Figure 2—Percent of forested area in Montana by forest type.

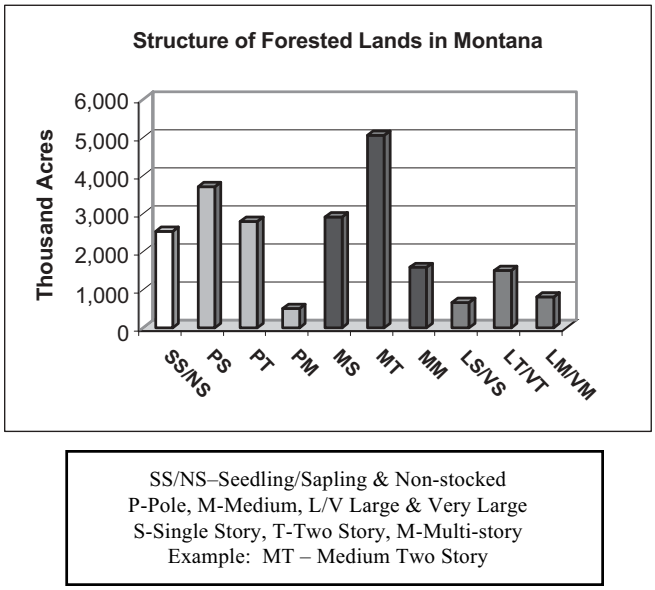


Figure 3—Number of acres by structure group for forested lands in Montana.

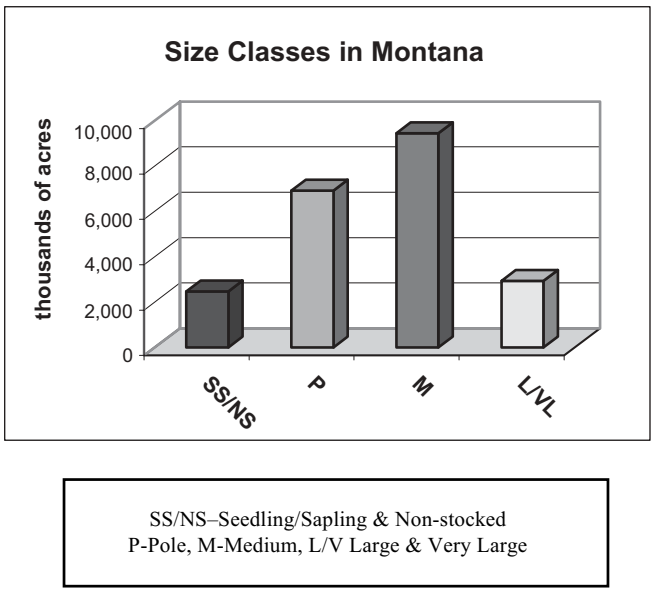


Figure 4—Number of acres by size class in Montana.

Insects, particularly bark beetles, can have a substantial effect on fuel loading and stand structure over time. Figure 5 illustrates that approximately 8.6 million acres are in moderate and high hazard conditions from bark beetles. These figures indicate stand conditions that could support an outbreak given the right combination of conditions. Some of these acres have been, or are currently being, attacked since the plot data were collected in the

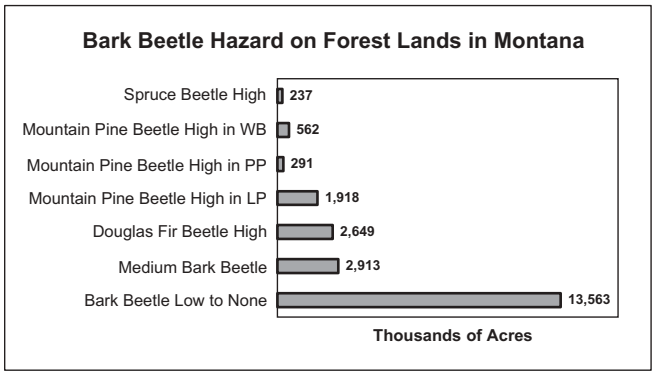


Figure 5—Number of acres by bark beetle hazard rating for forested lands in Montana. Note host species are indicated where hazard rated as high (WB - whitebark pine, PP - ponderosa pine, LP - lodgepole pine). Medium and low hazard area include all host species forest types.

late 1980s to the late 1990s. It can be seen that lodgepole pine and Douglas-fir forest types have the greatest amount of hazard. This is partly a reflection of the size class distribution illustrated earlier in figure 4.

The FFE simulates wildfire type based on the conditions *within* the particular stand that is modeled. The FFE classifies fires behavior into three types:

- **Surface fire:** The fire burns on the ground through the dead and down material, and crowns do not burn.
- **Passive fire:** The fire burns on the ground, and some crowns will burn as individual trees or groups of trees torch, but fire is not sustained in the crown.
- **Active fire:** The fire is a running through the crowns burning all crowns, thus killing all trees.

The potential for fire is a function of weather, fuel conditions, and topography, and the interplay of these variables. We modeled two weather conditions to provide a sense of how weather influences fire behavior and effects. Figures 6a and 6b display the percent of area by fire type for the inventoried conditions, given average and extreme weather parameters. With the extreme conditions, the amount of active fires increased eight-fold, while the passive and surface fires decreased.

Stand layering has two somewhat contrary effects on fire behavior. One is to add ladder fuels that facilitate flames reaching into the canopy of the forest resulting in passive or active fires. The second effect is to reduce the within-stand wind speed on the fire, which can reduce the potential for the flames to reach the forest canopy, thus reducing the amount of passive and active fire. The FFE model accounts for this interaction by using crown base height and canopy closure calculations to determine if fire can get into the crown. If the crown canopy is within reach of predicted flame lengths and there are adequate ladder fuels, then torching and crowning fires will result. The model uses percent canopy cover to calculate mid-flame wind speed, thus incorporating density effects on within-stand wind speed.

Figures 7a and 7b show the percentage of fire types for average and extreme weather conditions. The amount of

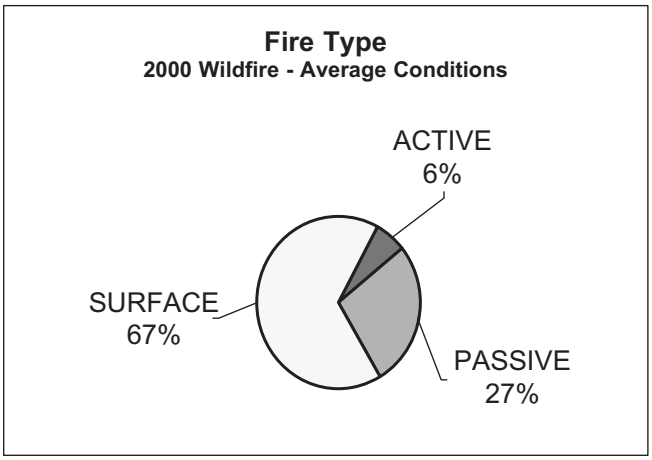


Figure 6a—Percent of forested area in the three FVS simulated fire types, using average fire conditions and current/inventoried plot data.

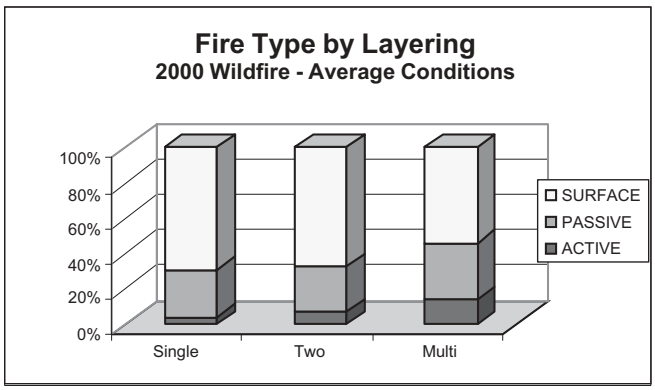


Figure 7a—Percent of forested area in the three FVS simulated fire types, for single story, two story and multi-story conditions, using average fire conditions and current/inventoried plot data.

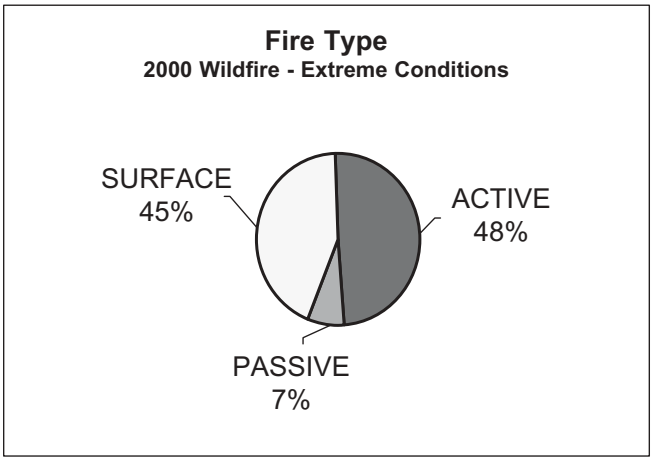


Figure 6b—Percent of forested area in three FVS simulated fire types, using extreme fire conditions and current/inventoried plot data.

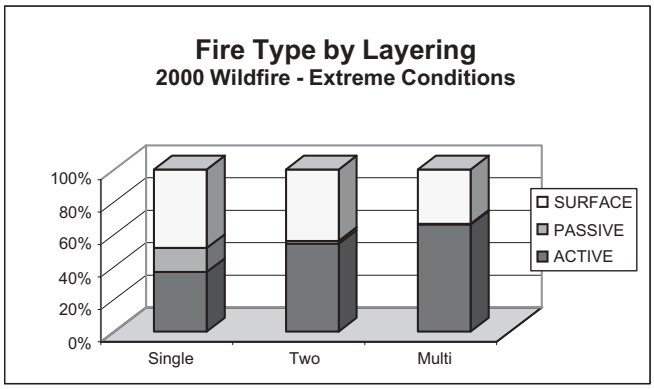


Figure 7b—Percent of forested area in the three FVS simulated fire types, for single story, two story and multi-story conditions, using extreme fire conditions and current/inventoried plot data.

passive fire behavior in average conditions increases from 4 percent for single-storied stands to 14 percent for multistoried stands. With extreme fire conditions, the active fire increases from 37 to 66 percent as layering increases from single to multistoried stands. The fire intensity increases with the number of layers, regardless of weather conditions.

The simulated fire type reflects fire behavior *based on the fire originating in that stand*. It does not reveal how a fire might spread into the stand from an adjacent stand. This is an important point when interpreting the results. Fires that burn hundreds to tens of thousands of acres are primarily a function of fire spread from stand to stand.

Two fire indices are produced by the FFE model: crowning index and torching index. The interplay of these indices, with the specified weather and fuel loadings, results in a fire type being assigned (Beukema and others 2000). The torching index indicates the wind speed needed to move the flames burning in the ground fuels into the tree crowns. Crown base height is an important variable in computing this index.

The crowning index indicates the wind speed needed to sustain a crown fire. This is largely a function of crown bulk density. The denser the canopy and the steeper the slope, the less wind is needed to sustain a crown fire. Crowning index gives an indication of the potential for fire to spread from stand to stand, the behavior that drives medium to large fires.

Figure 8 shows the percentage of forested area in three crowning index classes. If a stand is in class 1, winds of 15 mph or less will sustain a running crown fire; in class 2, winds of greater than 15 to 40 mph will sustain a crown fire. This index is important because a stand classified as surface-fire type may have a low crowning index, which means it lacks ladder fuels to help fire get into the crown. But once

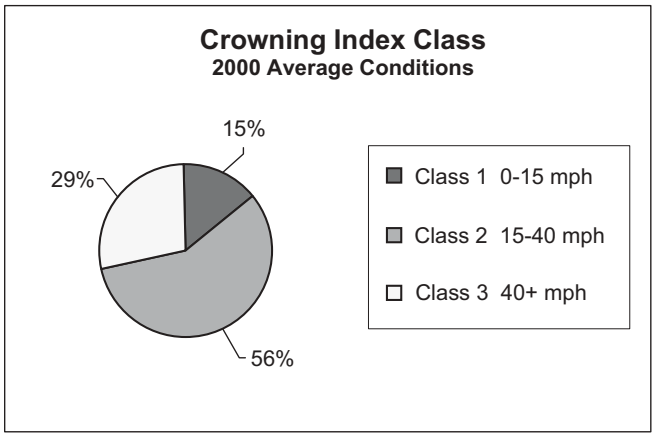


Figure 8—Percent of area in three crown index classes, using average fire conditions and current/inventoried plot data.

in the crown, fire is easily sustained. Figure 9 shows the acres in three crowning index classes by fire type for average conditions. Note that 7.8 million acres of surface-fire type would sustain a crown fire, spreading from another stand, if winds were greater than 15 to 40 mph. An additional 1.8 million acres of crown-fire type could be sustained with wind speeds less than 15 mph winds. Over 4.6 million acres of passive-fire type would sustain a crown fire with winds between 15 to 40 mph. In total over 15.7 million acres have crown indices in the 0 to 40 mph wind classes, which indicates 71 percent of Montana's forests are at risk of crown fire, even though modeled weather conditions relegated them to the surface- or passive-fire type categories.

It is important to consider fire hazard using both fire type and crown index. The fire type indicates the potential for fire moving vertically within a stand, and the crown index shows the potential for fire moving horizontally across the landscape as an active fire. Both aspects are important when determining how to reduce fire hazard.

Figure 10 shows the basal area mortality for Montana's forest types by fire type. The variation in mortality illustrates that forest types dominated by species resistant to fire have substantially less mortality. For example, a surface fire in the lodgepole type results in an average of 67 percent mortality, while the average is 32 percent in the ponderosa pine type. For passive fires, there is less variation in the mortality between forest types, but the trend between types is similar.

Figure 11 illustrates that there is little difference in mortality related to layering, which indicates that a similar type of fire produces similar mortality regardless of layering. However, as illustrated in figure 7, layering does affect the amount of fire type, with single layer stands having the

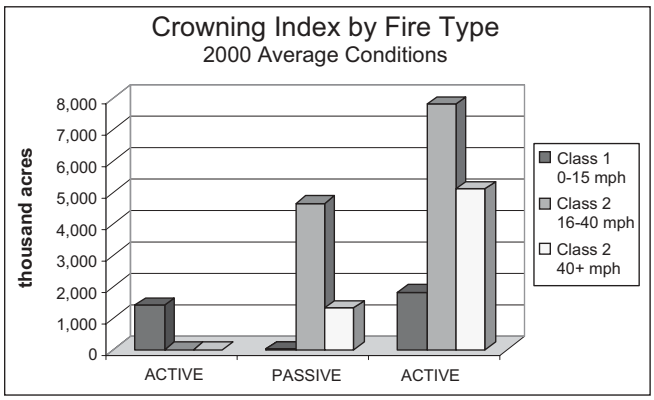
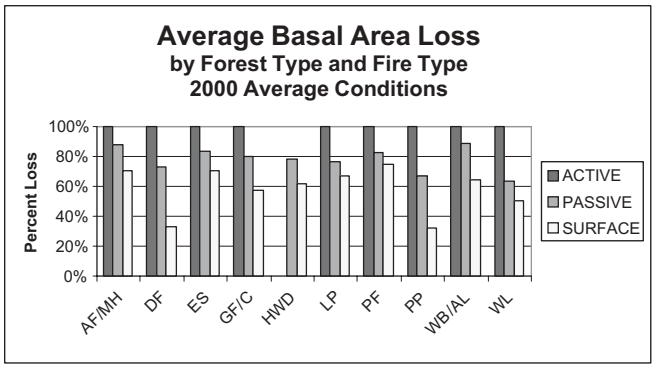


Figure 9—Acres by crown index class for the three FVS simulated fire types, using average fire conditions and current/inventoried plot data.



PF–limber pine, GF/C-grand fir & cedar, HWD-hardwood, WL-western Larch, ES-Englemann spruce, WB/AL-whitebark pine & subalpine larch, PP-ponderosa pine, AF/MH- subalpine fir and mountain hemlock, LP-lodgepole pine, DF- Douglas-fir

Figure 10—Average percent basal area loss by forest type, for the three FVS simulated fire types; using average fire conditions and current/inventoried plot data.

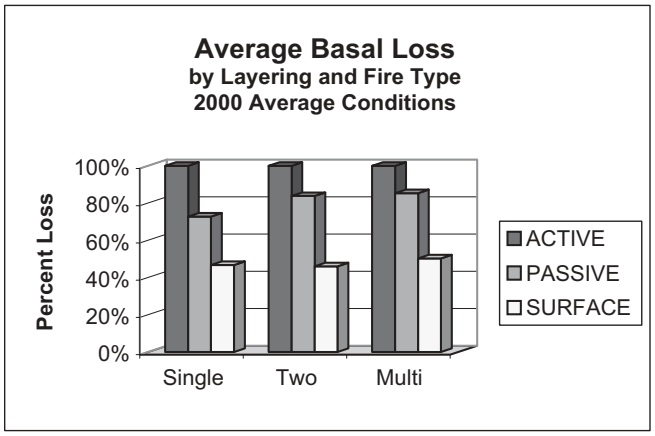


Figure 11—Average percent basal area loss in single story, two story and multi-story areas, for the three FVS simulated fire types, using average fire conditions and current/inventoried plot data.

least and multilayer stands the greatest distribution of active and passive fire. Therefore, mortality is affected by layering because it affects the type of fire simulated. Mortality does vary by size class as shown in figure 12. For surface fires, mortality decreases from 66 percent in seeding/saplings to 34 percent in the large/very large class. The implication is that forests composed of fire resistant species and larger size classes suffer less mortality given the same fire type.

Analysis Problems/Challenges

In this section we describe the challenges we encountered, how we calibrated the model, and suggest system developments that would improve and streamline analysis. We also highlight research needed to improve model behavior.

Model Calibration and Improvements

During the analysis we encountered several problems with default values and made adjustments, described below. Other limitations were identified, and recommendations for future improvements are presented.

Ingrowth and small tree mortality—Model runs with default parameters resulted in outputs inconsistent with our knowledge and that of others with considerable experience in Montana. The NI variant projected a 70 to 90 percent decrease in understory trees per acre over 50 years. Experience and fire history studies (Smith and Arno 1999) indicate an increase of small trees when fire has been excluded.

We used Flathead National Forest permanent growth plot data (Northern Region, unpublished) to provide a basis for adjusting model performance. Analysis of the data revealed the base FVS model was killing too many tolerant species, such as subalpine fir, and not enough of the intolerant species, such as western larch. Also the permanent growth plots indicated a substantially greater number of tolerant species becoming established through time. We adjusted the model using the MortMult and Estab keywords.

Our adjustments used only the Flathead growth plots because they were the only data set available at the time. A more thorough analysis of all the permanent growth plot data is needed and consideration given to calibration of the NI and EM variants of FVS based on this analysis.

Fuel load initialization—Actual fuel loading data were available on most of the NFS plots. We used the FuelInit keyword to initialize fuel loading for these plots. For plots without data, default values were used. We compared the average measured fuels to the default fuels and found the default loadings were lower. As a result, the flame lengths and subsequent fire behavior are most likely underestimated for the plots modeled with default values.

FIA fuel transect data could be used to refine the default fuel loadings. Analysts are encouraged to use field measurements where available.

Decay rates—The decay rates of woody debris in the version of the model that we used seemed high. We expected to see an increase in fuel loading over time. The average fuel loading during our 50-year projections remained about same, even though no burning or harvesting activities occurred. However, we would have expected fuel loadings to increase due to ongoing insect, disease, and suppression mortality. As a result, we feel fire behavior is underestimated for the 50-year projections.

Another concern is the same decay rate applies to all habitat types. Decay rates are a function of moisture and temperature, so we would expect variation by habitat type. Since our work was completed, the model has been adjusted. However, the knowledge of decay rates is limited, indicating an area needing further research.

"Other" species—FVS uses OT (other) for less common species such as whitebark pine, alpine larch, and hardwoods. FVS's definition of OT species depends on the variant. We need to be able to model and display all species. It is becoming more important to be able to quantify and predict the effects of fire, insect, and diseases for all species. This may mean additional research in a number of areas including fire response, crown bulk densities, growth and regeneration, or others.

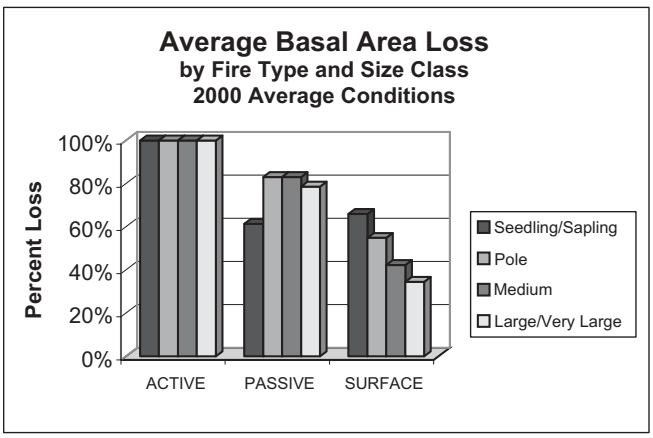


Figure 12—Average percent basal area loss by size class, for the three FVS simulated fire types using average fire conditions and current/inventoried plot data. Seedling/Sapling class includes seedling, sapling and non-stocked areas.

Programming Needs

Several improvements in data processing are needed to make this type of analysis more efficient. Our project required substantial assistance from a several data managers and programmers. The following is a list and discussion of improvements that would streamline analysis.

Software that migrates FIA data into FSVEG—When we started our project, FIA data were not available in FVS format. The USDA Forest Service's FSVEG database has the capability to do this. However, the FIA data have not been loaded into FSVEG at this time. All users need to be able to access FVS-formatted FIA data for both NFS plots and non-NFS plots.

Adding attributes to data sets—A programmer modified the FVS files by attaching attributes such as action

probability indices (for insect and diseases), inventoried fuel conditions, and habitat type groups. This step greatly simplified running the model. There is a need to develop more automated tools that would give users the ability to modify or supplement the FVS data without getting specialized help from programmers.

FVS output/reports—We used a custom program to extract selected report fields. This program only works for the output data fields we chose. This "extract" program enabled us to load selected report fields into an Access database, and to analyze and graphically display results. There is a need for an FVS postprocessor that would put user-defined fields in a flat-file format, so that large data sets could be easily moved into other software applications. This would greatly facilitate postmodeling analysis.

Postprocessing analysis—We wanted to quantify how insects, diseases, growth, and mortality change forest types and fire conditions, but we were unable to compare inventoried, FIA forest type with the simulated stand forest type after 50 years. A postprocessor routine that reclassifies forest type is needed for this type of analysis. This application is under development.

Mortality source identification—We were not able to distinguish the cause of mortality between bark beetles, root disease, or suppression. With current reports it is impossible to discern the influence of insect and disease activity on fire type, fuel models, and stand conditions. The way the I&P extensions operate, more than one agent can kill the same tree. To assess the impacts of insect and pathogens, and determine the source of fuels, a methodology to track mortality by agent for each cycle would be useful.

Non-NFS plots do not have a National Forest—Some FVS variants use National Forest (NF) in growth calibrations. The default for the NI variant is St. Joe NF, and the EM variant uses the Custer NF. This was unsatisfactory for our analysis since the plots were from across the whole State. We solved this by assigning a National Forest based on ecosection and county. This was added to the Montana FVS stand list files. It is desirable to have a preprocessing option available to allow all users to add National Forest.

Additional Research Needs

- It is apparent that permanent growth plot data and FIA data, used separately and in conjunction with each other, could be used to calibrate and improve FVS predictions.
- Research on ingrowth, small tree mortality, fuel loading, decay rates, and crown dynamics is needed and should be incorporated into FVS as information becomes available.
- Because crown bulk density is a critical factor in predicting and managing fire behavior, but not easily measured, research is needed to find a readily applicable field technique to characterize it.
- There is a need to develop a better overall measure of fire hazard that integrates fire type with crown index and torch index.

Conclusions

Our project demonstrates the utility of using FIA data in combination with the FVS model, and its extensions, for examining fire, insect, and disease hazard for large geographic areas, such as the State of Montana or subregions of the State. Where data are available, they can also be applied to a multi-State level. The flexibility of the model allows it to be parameterized for a variety of different environmental conditions. Our conclusion is the model and data provide a powerful tool to help land managers and policymakers assess conditions and provide a basis for making decisions.

The model was useful in describing specific indicators, which allowed us to depict current conditions related to fire, insect, and disease hazard. The results lead us to the following conclusions:

- An abundance of medium and pole sized forests exist, and the fire hazard is not just a small tree problem. There are too many medium sized trees as well.
- An abundance of forests with two or more layers exist, which provide fuel ladders for fire.
- An abundance of forests exist with crowning index ratings that indicate high potential for crown (active) fires, which leads to the highest mortality.
- The extreme weather conditions resulted in much higher amounts of active fire, and subsequently the mortality and effects are greater than with average conditions.
- It is important for decisionmakers to consider both fire type and crowning index when assessing the overall fire hazard.
- Stand structure and composition that favor fire resistant species, larger diameter trees, lower crown bulk densities (the major factor in crown index), and less stand layering reduce fire intensity and mortality predicted when fires do occur. This gives managers options for taking action to change hazard level, where desired.
- An abundance of forests are rated as moderate to high hazard for bark beetle attack.

A number of caveats and limitations need to be recognized by analysts and decisionmakers when using these tools and data:

- Small tree mortality and ingrowth should be adjusted for the forest conditions being modeled because they can substantially change the results.
- On the non-NFS plots (37 percent of the plots), all of the 0 to 5 inch diameter trees may not have been recorded because survey methodology was to determine which plots were "stocked." Therefore ladder fuels are underestimated, resulting in less active and passive fire types.
- The default fuel loads appear to be underestimated, which leads to underestimating fire type intensity.
- The decay rates appear to be too high, which reduces the fuel load, which would tend to underestimate the intensity of the fire type.
- The use of only Flathead NF permanent growth plots for calibrating the small tree mortality and ingrowth may have resulted in overestimating ladder fuels for some areas, which would tend to overestimate the intensity of the fire type.

Future analyses could be made more efficient by:

- Making model improvements, such as adding tree species and recalculating growth and mortality functions, thereby producing more realistic results.
- Adding improved data input/output options to streamline data analysis, and reducing the number of helpers needed to format and manipulate data.

Remember what George E. P. Box said, "All models are wrong but some are useful!" Models are simplified abstractions of reality. We believe the results of this analysis are useful for showing overall trends in hazards and the factors that contribute to hazards. The model also provides information as to the potential effects that may occur. Therefore, even though we know these simulations cannot predict reality, they are useful for indicating patterns of likely outcomes and options for managers to alter fire effects.

Acknowledgments

The authors acknowledge the many individuals who contributed their knowledge and abilities to this project, each playing a critical role in making this project possible: David Browder, Renate Bush, Jimmie Chew, Glenn Christensen, Nicholas Crookston, Lance David, Gary Dixon, Denny Edward, Susan Hagle, Robert Havis, Jeff Jones, Janet Krivacek, George Lightner, Blakey Lockman, Elizabeth Reinhardt, Don Vandendriesche, and Sharon Woudenberg. We extend our thanks to the numerous others for their review and advice. The Forest Health Monitoring Program, FIA Program, and the Northern Region Fire Program provided funding for this project.

References

Beukema, S. J.; Reinhardt, E.; Greenough, J. A.; Kurz, W.A.; Crookston, N.; Robinson, D.C.E. 2000. Fire and fuels extension: model description. Prepared by ESSA Technologies Ltd., Vancouver, BC for USDA Forest Service, Rocky Mountain Research Station. Moscow, ID. 80 p.

Conner, Roger C.; O'Brien, Renee A. 1993. Montana's forest resources. Res. Bull. INT-81. Ogden, UT: USDA Forest Service, Intermountain Research Station 96 p.

Forest Health Technology Enterprise Team (FHTET). 2001. Forest Vegetation Simulator, North Idaho and Eastern Montana variants with multiple insect and pathogen extensions (available from FHTET). USDA Forest Service, FHTET, Fort Collins, CO.

Forest Management Service Center (FMSC). 2001. Forest Vegetation Simulator (FVS) available from FMSC @ www.fs.fed.us/fmsc/fvs. USDA Forest Service, FMSC, Fort Collins, CO.

Hagle, Susan K.; Johnson, Terri L.; Stipe, Lawrence E.; Schwandt, John W.; Byler, James W.; Kegley, Sandra J.; Bell-Randall, Carol S.; Taylor, Jane E.; Lockman, I. Blakey; Sturdevant, Nancy J. 2000. Succession functions of pathogens and insects; ecoregion sections M332a and M333d in North Idaho and Western Montana – Volume 1: analysis methods. USDA Forest Service, Cooperative Forestry-Forest Health Protection, Northern Region. FHP Report No. 00-10.

O'Brien, Renee A.; Conner, Roger C. 1991. Forest statistics for land outside National Forests in eastern Montana, 1989. Res. Bull. INT-71, Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 45 p.

Smith, Helen Y.; Arno, Stephen F., eds. 1999. Eighty-eight years of change in a managed ponderosa pine forest. Gen. Tech. Rep. RMRS-GTR-23. Ogden, UT: U.S. Department of Agriculture, Rocky Mountain Research Station. 55 p. plus 14 foldout photopoint pages, one poster.

USDA Forest Service. 1988. Montana forest survey field procedures. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station, Forest Survey. 111 p.

USDA Forest Service. 2000. IWRIME inventory documentation and terminology for Region 1 Montana National Forests.

Wykoff, William R.; Crookston, Nicholas L.; Stage, Albert R. 1982. User's guide to the stand prognosis model. Gen. Tech. Rep. INT-133. Ogden, UT. U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 112 p.