Use of FVS for a Forest-Wide Inventory on the Spokane Indian Reservation

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Abstract—The Forest Vegetation Simulator (FVS) was used with Continuous Forest Inventory (CFI) data on the Spokane Indian Reservation to provide predicted yields over a 100-year period for 994 1/5 acre plots. The plots were grouped into five strata based on habitat type groupings, projected separately, and the stratum results were combined after processing. Results from the projections provided information which was useful in management planning. Problems with the unbalanced age-class distribution of the forest were shown to be largely compensated for by differing rates of the development among the different strata. Although stocking levels and harvest yields within most strata fluctuated over time, the variations of forest-wide averages were considerably smoother. The results also predicted which components of the forest would likely suffer the highest rates of mortality in the near-term, and should receive more management attention. At the outset, this study also sought to test several differing options for management, such as precommercial thinning, regeneration density, and type of regeneration. However, FVS only demonstrated a difference in yields in the last case.

Introduction

The Spokane Indian Reservation has a system of Continuous Forest Inventory (CFI) plots which are used to monitor forest growth, mortality, and health problems. The system has been in place since 1957, and periodic measurements are used to calculate an annual allowable cut for the reservation.

In the most recent inventory (1998), data were projected in the Forest Vegetation Simulator (FVS) model (Wykoff and others 1982) to provide a comparison with more conventional analysis tools used in the past. To accomplish this, 1/5-acre plot data were expanded to a per-acre basis, converted to FVS-ready files, and projected in FVS. Plots were projected individually; however, five groupings were used for applying base parameters such as habitat type, calibration factors, and management options. The results were compiled for each of the five groups in FVSSTAND and then the groups were combined in a spreadsheet to present forest-wide results.

Three methods were used in the inventory analysis; FVS a semi-distance-independent growth and yield model, the Australian formula (Recknagel 1913), a method based on growing stock and increment, and the area-volume check, a stand analysis method based on area and increment by age class (Davis 1987). These methods were evaluated to determine the most accurate and efficient method or combination of methods to set an allowable cut.

Objectives for the Analysis

In analyzing the 1998 CFI data, two objectives were set forth for the task of computing an annual allowable cut (AAC). The first was to duplicate as nearly as possible the chief methods used with the previous (1985) inventory, for comparison purposes. The second was to also employ a newer method that might have some advantages over those used formerly.

The Austrian formula and the area-volume check methods were used in the 1985 Inventory Analysis, and were replicated in the 1998 analysis. For a third method of analysis, growth was projected on inventory data using the Inland Empire variant of the Forest Vegetation Simulator (FVS) model. Projections also included natural mortality factors, timber harvests, precommercial thinning and regeneration. However, unlike the more conventional analysis methods, FVS projections did not produce an AAC in the usual sense, but provided projected yields from timber harvests over time for a given management regime. A long term average of the yields projected by FVS was compared with the Austrian formula and the area-volume check methods.

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Extending CFI Utility Using FVS

Using conventional CFI data analysis tools, we are only able to analyze in detail stand development over the most recent measurement period. Looking backwards beyond that point, conclusions can only be very broadly drawn, and 41 years into the past is as far as the Spokane Reservation CFI system goes. The most recent 13-year growth period is just a snapshot compared to the long-term perspective needed to evaluate progress in forest regulation. The FVS model provides the capability of projecting development of inventory plots into the future for a longer period of time to obtain a long-range picture of stand dynamics.

Growth

Under traditional AAC calculation methods, measured growth rates for the last growth period are used in order to determine the cut for the future. The problem, however, is that growth rates may increase or decrease in the future based on changes in stand conditions, weather conditions and other factors. Growth rates in FVS do vary according to stand density and development, and this hopefully will indicate imminent changes in the forest.

Mortality

Mortality is an important component of the AAC calculation. If insects and diseases take a larger share of the potential volume in the future, we must harvest less. However, none of the other methods offer any way of predicting if mortality in the next period will follow suit with the previous period, increase or decrease. A review of mortality measured in previous inventories indicates that it is the least stable parameter tracked. FVS does simulate mortality in projections, as "background" mortality, mortality based on stand density, and from a variety of specific agents.

Harvest Yields

One crucial issue in this analysis was the effect that the unbalanced age-class distribution of the forest might have in determining a level of yield from the forest which could be sustained indefinitely without fluctuation or decline. The FVS model provides the opportunity to grow plots forward in time, independently, starting at their current point of development. Growth and mortality rates can be adjusted, based on that which has been measured. Current silvicultural regimes (as well as alternatives) were applied to each plot independently. The yields from all plots were then combined, cycle by cycle, to project the effects of the existing age-class distribution on long-term harvest yields.

Calibration

The FVS model has built-in functions for the various growth components as well as mortality; these are based on site factors (such as habitat type, slope, aspect, elevation) and stand conditions (density, overstory effects). It also uses measured growth, if available, to calibrate growth. In addition, there are user-controlled keywords that can be invoked to bring model growth and mortality projections more in line with the rates observed in our inventory.

How FVS Was Used in This Analysis

The overall approach in this analysis was to provide the tribal decision-makers with the range of solutions that resulted from each of these methods, and allow them to select an AAC that the data could support and that meets tribal objectives as a whole.

Mindful of the strengths and weaknesses of the FVS model, we proposed to use projections to provide some perspective on future trends, especially in areas where the other methods fall short. In particular, the following questions were addressed.

- What yields will current management practices produce over the next 40 to 50 years?
- Does FVS forecast an increase in mortality that might impact yields?
- Will the current age-class distribution of the forest result in a future down-cycle in harvest yields?
- Can FVS be used to identify the more vulnerable components of the forest as a means to focus harvest in the coming decade?
- Can yields be improved using alternatives to current management on a long-term basis?

Data Conversion

The Bureau of Indian Affairs Northwest Regional Office provided the CFI-to-Suppose program that converted CFI plot data into formatted FVS-ready files. The plot header data for each plot was read by the program to create one line of data for the FVS stand list files (*.slf). The program also read CFI tree data to create an FVS tree file (*.fvs) for each plot. FVS allows for up to two different plot sizes for each plot, whereas the Spokane CFI uses four plot sizes. Sawtimber is measured on a 1/5-acre plot; poletimber on a 1/20-acre minor plot; saplings on 1/80-acre minor plot; and seedlings on 1/240-acre. As an additional step, the program expands pole data by four to a 1/5-acre plot basis, and the seedling data by three to a 1/80-acre basis.

Stratification

The FVS model is designed to use stand exam data. This type of inventory differs from a CFI in many ways. It would typically be run in aggregation, with many plots making up a single data set run as a unit. CFI data is extensive; the plots are widely scattered, have widely varying attributes and are not designed to give stand level information. Projecting CFI plots in aggregate would give misleading results. So for the purposes of these projections, each plot was projected separately as a unit and the results were aggregated at the end.

Although CFI plots are not spatially related to each other, many share similar site features. These can be a basis for grouping plots for the purposes of calibration, regeneration input, growth simulation and management activities. In this analysis, the plots were grouped into four strata based on habitat type (Cooper and others 1991; Zamora 1983). The model did not support all habitat types recognized in the CFI, so type codes that were supported by FVS had to be substituted in some cases. These are listed in table 1 with data relevant to the groups.

Dry Pine Stratum

This grouping represents the driest sites on the reservation, all ponderosa pine (*Pinus ponderosa*) climax. It presents a challenge for the Inland Empire variant of the model, since only one of the four habitat types in the group (Pipo/Agsp) is supported by the model. To match measured increment, it was necessary to dampen growth in FVS considerably using model calibration.

Pine-Fir Stratum

This stratum represents the largest acreage and the most plots of the four, including wet ponderosa pine and dry Douglas-fir sites. One or both of these two species dominate the stands in this stratum. Western larch (*Larix occidentalis)* and lodgepole pine (*Pinus contorta)* are also present as small fractions on some of the plots. All three habitat types of this stratum are supported by FVS.

Ninebark Stratum

This represents both Douglas-fir/ninebark (*Pseudotsuga menziesii* / *Physocarpus malvaceus)* and grand fir/ninebark (*Abies grandis* / *Physocarpus malvaceus)* types found in the inventory. It was a problem that FVS does not recognize the grand fir/ninebark

Table 1— Habitat type codes used for FVS runs, 1998 Spokane CFI.[a]

Stratum name	Habitat types	FVS habitat types Code	FVS habitat types Name	Number of plots	Estimated acres
Dry pine	Pipo/Stco	130	Pipo/Agsp	227	24,045
	Pipo/Agsp	130	Pipo/Agsp		
	Pipo/Feid	130	Pipo/Agsp		
	Pipo/Putr	130	Pipo/Agsp		
Pine-fir	Pipo/Syal	170	Pipo/Syal	388	41,311
	Psme/Syal	310	Psme/Syal		
	Psme/Caru	320	Psme/Caru		
Ninebark	Psme/Phma	260	Psme/Phma	217	22,986
	Abgr/Phma	260	Psme/Phma		
Wet grand fir	Psme/Vaca	250	Psme/Vaca	159	16,948
	Abgr/Libo	520	Abgr/Clun		
	Abgr/Clun	520	Abgr/Clun		
	Thpl/Clun	530	Thpl/Clun		

[a] Zamora 1983; Cooper and others 1991.

habitat type. This became a significant issue in the input of regeneration—the plots that were on Douglas-fir habitat types could not be expected to produce grand fir seedlings; the grand fir types would. This was resolved by calculating a count of the grand fir trees on the plot in each cycle. If the count was greater than zero and regeneration input was prescribed, then natural regeneration called into the routine would include grand fir, as well as greater numbers of the other species. Two different management simulations were tried, one which allowed for the prospect of planting western larch and ponderosa pine, and one which confined regeneration inputs to natural seeding, dominated by the more shade tolerant species.

Wet Grand Fir Stratum

These are the wettest sites on the reservation, and the most complex in terms of species mixes. Although this group has the smallest number of plots, it was further subdivided into two substrata to enable different treatments for plots with lodgepole pine as opposed to those without. This would allow more realistic inputs of regeneration as well as varying the other treatments to better reflect actual management practices. Unlike the method used for the ninebark stratum, these groups were run as separate strata; the set without lodgepole pine included 92 plots, the set with lodgepole pine, 68 plots. These two strata also were tried with different regeneration options, one with planted ponderosa pine and western larch and the other with only natural seeding.

Model Calibration, Adjustments, and Inputs

The Inland Empire variant was built with little data that included sites as dry as the Spokane Reservation, and ponderosa pine growth functions are particularly weak (William Wykoff, personal communication, September 1999). So that projections would better reflect current local conditions, growth and mortality functions were calibrated using data from the CFI in the latest measurement period. It should be noted that calibration was not determined and applied on a plot-by-plot basis, but rather stratum by stratum.

Large Tree Diameter Growth

Each stratum was run through the model for a single cycle using the CALBSTAT keyword, to obtain an overall average for the stratum of the scaling factors computed for individual plots. These averages were used as permanent scaling factors for each stratum with the READCORD keyword and no further scaling or attenuation was allowed (NOCALB).

Large Tree Height Growth

There is no scaling factor calculated for this component and no simple way to compare height development with inventory data. However, preliminary runs appeared to attain unrealistic standing volumes of timber, even with diameter growth calibrated, so height growth seemed suspect. To look at how heights developed in the model, some bare-ground runs were generated, and top-40 heights were tracked and graphed. For a real-world comparison, some CFI plots were selected to graph as an age-height scatterplot. Plots were selected which had a simple even-aged structure, included a range of stand ages, were measured in both 1985 and 1998, showed a reasonable and predictable diameter increase from 1985 to 1998, did not have a significant harvest in that period, and had at least 40 trees per acre in 1998.

These plots were graphed and compared to the age-height curve of the bare-ground FVS runs. This was done for two strata, pine-fir and ninebark. In both cases, FVS heights developed more rapidly and attained greater heights than the comparison plots. Early growth rates, up to about 50 years of age, were most strikingly different. To scale back FVS growth rates, the FIXHTG keyword was used, applying it only to trees 0.1” to 7.5” DBH. After several trials, it was found that a multiplier of 0.60 lowered the projected height curve into the range of the CFI plot observations for the two strata considered. This adjustment was used for all species in all strata.

Regeneration Inputs

The FVS model is capable of automatic natural regeneration inputs, controlled by factors such as stand density and habitat typing (Ferguson and others 1991). Initial runs were made allowing this input. However, this option seemed to multiply the complexity of the runs beyond what was either beneficial or desirable given the objectives at hand. Instead, the automatic inputs were suppressed (NOAUTOES) and whenever density was reduced to a given level, either by natural conditions or harvest, regeneration was invoked using the PLANT or NATURAL keywords. The questions of how much and what species of regeneration would be invoked were resolved by running each stratum through the Spokane CFI program to generate a regeneration summary. This provided an average count of seedlings per acre by species from the seedling subplot. These runs were limited to plots that had a seedling/sapling understory. The results yielded some rough guidelines as to how much regeneration and what species should be invoked.

This approach has some shortcomings. By limiting the Spokane CFI program sample runs to those plots with a seedling/sapling understory, it may have effectively eliminated open areas where natural regeneration had failed. Also, using an average for all plots might tend to obscure the negative aspects of having some areas with excessive stocking and others that are marginally stocked. An ideal solution might be to use a randomized input, where regeneration falls within a normal range of distribution around a specified mean. However, this was not attempted.

On most sites on the reservation, natural regeneration does not seem to be a problem when an opening is created. This generalization is most true on the kinds of sites represented in the pine-fir stratum and the wet grand fir stratum. In these strata, the approach of invoking an average stocking for reproduction when stocking fell below a given level seems reasonable. For the other two strata, this approach probably led to some underestimation of the growth losses resulting from incomplete or patchy regeneration patterns.

Mortality Functions—Maximum Basal Area

In reviewing the preliminary runs, it was apparent that inventory trees fared better inside the model than out in the woods. Mortality in projections seemed consistently lower than what was seen in the last growth period of the CFI. The 1998 inventory registered rates of mortality which, although higher than those from the 1985 inventory, were in line with earlier measurements. So it appeared reasonable to calibrate the model to approximate current mortality, at least into the first growth cycle or two.

The first function that was looked at was maximum basal area. This varies with habitat type and controls background mortality in the model. The closer the stand is to the maximum, the more trees die. Given the fact that there are still plenty of stands in the forest that have not yet been thinned, one might compare the highest basal area

CFI plots for each habitat type with those used in the model. This was done, and in all cases was found to be lower for the inventory data. To adjust this, the BAMAX keyword was used, with the appropriate level specified for each stratum.

Mortality Functions—Mortmult

The BAMAX keyword increased mortality slightly, but still fell short of approximating mortality for some species in some strata. Next, mortality rates, expressed as a ratio of cubic-foot mortality to cubic-foot stocking (by species) were compared between the 1985–1998 measurement and the first cycle projection in FVS (1999–2008). In the two strata where root disease is prevalent, only non-diseased plots were used for the comparison, since root disease mortality could be adjusted separately in the Western Root Disease Model extension. From these comparisons, multipliers were calculated for each species in each stratum. These were fed into the model using the MORTMULT keyword.

Mortality Functions—Western Root Disease Model

The Western Root Disease Model extension was invoked on plots where root disease had been diagnosed in 1998 inventory. For these plots, even with both BAMAX and MORTMULT adjustments in the run-stream, it was noted that (compared to 1998 CFI results) mortality for Douglas-fir was underestimated in the wet grand fir stratum, while mortality for grand fir was underestimated in the ninebark stratum. Using the root disease model, mortality was further adjusted using both the TTDMULT and INFMULT keywords. It took several trial iterations varying the multipliers to arrive at mortality rates for all species that approximated in the first projection period what had been measured in the latest CFI growth period.

The FVS Run-Streams

The first step in building the FVS run-streams was to create the basic set of keywords for each stratum to control program outputs, volume equations, growth and mortality functions, etc. These keywords were read into a base *.kcp file for each stratum to streamline the process of building other runs.

The Management Regime

A set of keywords was assembled for each stratum that was designed to simulate the full management regime that a stand (or in this case, a plot) might undergo over a 100-year period. Using condition statements, the model would recognize the particular state of development and condition at which a plot entered the simulation; simulate a management activity based on that condition; grow the plot forward for 10 years; again assess the plot conditions; simulate a new management activity based on the new set of conditions (if called for); and repeat this process for ten 10-year projection cycles. During the full 100 years of projections, most plots would go through a similar cycle of stand development and stand treatments, including precommercial thinning, one or more commercial thinnings, a regeneration harvest (with regeneration added), and an overstory removal to reduce stocking of residual trees. What differed between plots was the stage of development at which they entered the sequence.

The Event Monitor Function

Since each plot entered the model separately and at its own particular stage of development, the management options were invoked through the Event Monitor function of the model (Crookston 1990). This function allows the application of a particular treatment to be made contingent on the stand meeting a given set of parameters at the beginning of each cycle.

The condition statements were designed to recognize the stand conditions that would typically initiate a particular treatment in actual management under current regimes. They were also designed (for the most part) to be mutually exclusive: for example, if a plot met the conditions for a commercial thinning, it could not, in the same cycle, meet the conditions for a regeneration cut or any other management option. Condition statements variously used the following parameters for timing treatments.

- Stand age
- Total basal area per acre
- Sawtimber basal area per acre
- Total number of trees per acre
- Number of trees per acre of saplings and/or pole sizes
- Ratio of cubic-foot mortality to cubic-foot stocking
- Stand mistletoe rating
- Quadratic mean diameter

Stand age was one of the plot attributes read into FVS in the data conversion, and it had an important role in conditioning and ordering management activities. When a regeneration harvest was invoked, the stand age of the plot was reset to reflect the age of new regeneration.

Management Activities

Simulated treatments were developed through repeated trial runs and examination of outputs to determine if treatments were invoked when desired and whether the application of the treatments matched what might be expected in actual management. The range of treatments that made up the management regime for each stratum were essentially the same, except that the conditions required to invoke them, the residual densities, regeneration specifications, and so on, were varied as appropriate for the stratum. Following is a description of each type of treatment included in the management regime for each stratum.

Initial Input of Regeneration—This was invoked to provide an input of regeneration into the model on plots that began simulations with a light or scattered overstory and an unstocked or understocked understory, This was only applied in cycle 1 and was designed to provide regeneration for plots that had been subjected to a recent overstory reduction and where regeneration had not yet come into the plot.

Overstory Removal—This was applied to plots with a stand age less than 31, a light to scattered overstory and a well-stocked understory. Overstory was reduced to a few reserve trees**.**

Precommercial Thinning, Alternative 1—The condition statement recognizes plots with greater than 500 trees per acre from seedling to 5” dbh and invokes a precommercial thinning. This may occur in the same cycle as a commercial harvest.

Precommercial Thinning, Alternative 2—This was formulated because the first precommercial thinning alternative failed to thin older stands that had dense conditions in pole-size trees but fewer than 500 trees per acre in smaller sizes. This is often the case in stands on the reservation that have never been thinned and have stagnated before reaching commercial size.

First Commercial Thinning, Alternative 1—This treatment was applied to stands reaching merchantable size for the first time (usually 50 to 80 years old) to reduce stocking in overly dense stands and to harvest volume.

First Commercial Thinning, Alternative 2—The previously described first commercial thinning occasionally missed stands with an age less than 50 that nonetheless had considerable basal area in sawtimber. These are most likely plots with multiple age/size classes, in which the selected stand age call applied to the younger group rather than the older group. Plots were thinned to the same target as alternative 1.

Second Commercial Thinning—This thinning was applied to slightly older stands, usually occurring about 20 years after a first commercial thinning, and leaving a slightly higher basal area.

Regeneration Cut, Light Stocking—This regeneration harvest was applied to plots with stand age greater than 100 (or 80 in the lodgepole stratum) with a low basal area. The stand is harvested, leaving some residuals, regeneration is invoked and stand age is reset.

Regeneration Cut, High Mortality—A regeneration cut was applied to older stands when the mortality in cubic-foot volume for a cycle exceeded 30 percent of total stocking. The stand is harvested, leaving some residuals, regeneration is invoked and stand age is reset.

Regeneration Cut, Mistletoe—A regeneration cut was applied to older stands with a stand mistletoe rating that exceeded 1.8. The stand is harvested, leaving some residuals, regeneration is invoked and stand age is reset.

Mature Stand Maintenance Thin—This is a light commercial thin for older stands that have continued to build basal area after the second commercial thin, but thus far not met any conditions for a regeneration cut.

Other Program Control Functions

Some additional constraints were placed on the stand treatments as they were invoked. First of all, treatments that removed harvestable volume could not be invoked until at least 20 years after the last harvest. This was designed to imitate the 20-year management cycle in use on the reservation. Second, each treatment had a particular repeat delay set for it. For example, regeneration cuts were permitted at a minimum interval of 80 years; precommercial thinnings were on a 40-year interval. Many of the condition statements that controlled the management options were based partly on stand age. This also had the effect of limiting the possibility that a particular management activity be repeated.

Management Options

As noted above, one of the objectives for using FVS was to test different management options. This was only attempted in a fairly limited way, since an encyclopedic testing of management regimes for each of the five plot strata was well beyond the scope of an inventory analysis. But it seemed worthwhile to test the sensitivity of the results to some simple variations in management, particularly those that addressed changes currently under consideration. Some of the options that were considered are outlined below. In some cases, it was concluded that FVS was not suited to analyze the option in a comparative way.

Regeneration Unit Size (Uneven-Aged vs. Even-Aged)

This was suggested as an appropriate option to test using FVS simulations, since the use of even-aged management and specifically even-aged regeneration cuts is currently under review for the upcoming management plan. So the comparison would basically be between regeneration by group selection vs. regeneration by clearcut with residuals.

However, given the fact that the FVS simulations were based on projecting individual fifth-acre plots, it seemed impossible to make any distinction between the group selection cut and a larger even-aged regeneration cut. As applied on the reservation, both are done leaving some residual stocking, and both are carried out over areas larger than 1/5-acre. So this comparison was mooted.

Regeneration Type, Natural vs. Planted

For types represented by the two drier inventory strata, natural regeneration has been effective on the reservation, and no alternative to that has been seriously considered. On wetter types, however, both natural and planted regeneration methods have been used, and are the subject of some debate and controversy. In fact, this is an aspect of even-aged vs. uneven-aged management that could be tested. Up to the present, planting has been considered a viable option only in even-aged management on the reservation.

In this comparison, the key distinction at the plot level is the species and amount of regeneration that is introduced in a planted treatment, versus that which is obtained by natural seeding. Natural regeneration inputs (tried as “option 1”) were determined for each stratum by analyzing the CFI data as previously described. These runs were compared to “option 2,” which simulated planting of ponderosa pine and western larch in the numbers usually prescribed for planting treatments on the Spokane Reservation.

Option 2 also included natural regeneration in reduced numbers from option 1, as based on stocking surveys from areas which have been planted on the Spokane Reservation.

Regeneration Density

As noted earlier, some concerns were raised over the use of average figures across the board for natural regeneration input. To test the effects of higher versus lower densities, some initial runs were tried at varying densities and results were compared. Surprisingly, varying the density of natural regeneration inputs into the model had very little effect on long-term volume yields.

Precommercial Thinning

Another aspect of management that was considered for testing was the relative efficacy of precommercial thinning. The use of these treatments is not controversial or considered for revision. However, precommercial thinning is not uniformly implemented on all stands that need treatment. So it seemed worthwhile to try a set of runs without precommercial thinning and to compare that to runs with the treatment. If this showed a large difference in yields, it might indicate the need to discount yields in accordance with the percentage of stands that might not receive the treatment as needed.

Precommercial thinning was found to have practically no effect on overall yields. Although stand mean diameters were affected, overall yields on a board-foot per acre were nearly identical. The results from these last two tests provoked some skepticism concerning performance of the model.

FVS Projection Results and Discussion

The output from the runs was post-processed using the FVSSTAND module. This module combined all the plot outputs (which were each projected separately) into summary tables for an entire stratum. These stratum summaries in turn were combined into an "all strata" summary table, which weighted each stratum by the proportion of the mapped acres it represented. Charts were produced from these summary tables.

The charts show how FVS-projected stocking, harvest yields and mortality change over time. Data are displayed for each stratum and for all five strata combined. For the wetter sites, which include the ninebark, grand fir, and lodgepole strata, charts show trends for two different management options. Option 1 represents current management treatments, with input of only natural regeneration when regeneration cuts are made. Option 2 (applied only to the wetter sites and not the dry pine and pine-fir strata) uses all the same treatments, except that regeneration cuts are accompanied by an input of planted ponderosa pine and western larch, as well as natural regeneration in reduced numbers.

Stocking Projections

Figures 1 through 6 show board-foot stocking for each stratum and for the combined data weighted by plot proportion. Note the scale of the y-axis differs from chart to chart when comparing overall stocking levels.

One thing evident in each stratum is that while stocking varies up to the year 2048, after 2048 stocking climbs steadily. This may indicate a tendency in the model to build unrealistic volumes, which becomes most pronounced in later projections as real measured tree data is gradually replaced by trees that have entered projections as regeneration inputs. For this reason, projected volume levels after 2048 may be suspect, although the relative difference between option 1 and option 2 are of interest.

Stocking changes over time vary greatly depending on the stratum. The pine-fir stratum (fig. 3) shows the most even stocking levels up to 2048, staying between 9,000 and 10,000 board-feet per acre for that entire period. This might indicate that the pine-fir stratum currently has the most diverse age-class distribution. The dry pine stratum (fig. 2) alone climbs continuously in volume, which may indicate a greater proportion of plots in younger age classes. In fact, this stratum has 26 percent of its plots with a stand age less than, 60, more than any other stratum.

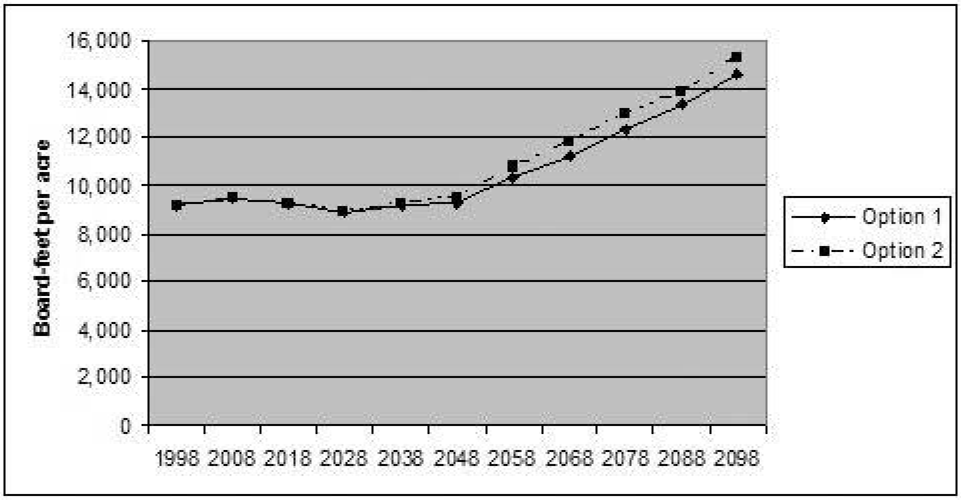


Figure 1—Board-foot stocking projections from FVS, all strata combined.

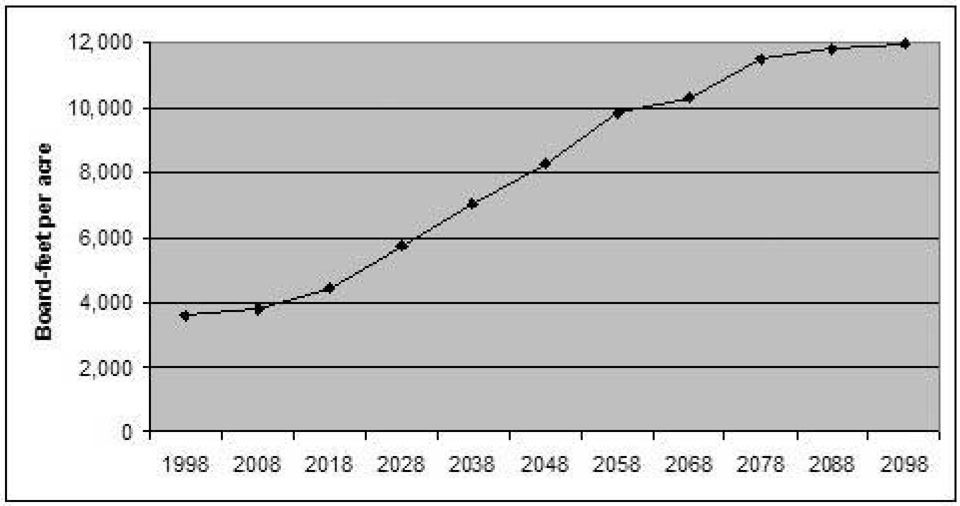


Figure 2—Board-foot stocking projections from FVS, dry pine stratum.

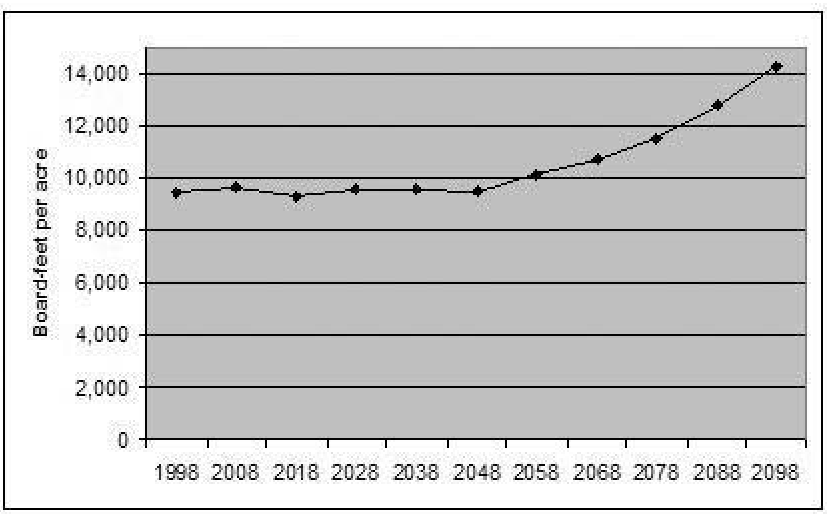


Figure 3—Board-foot stocking projections from FVS, pine-fir stratum.

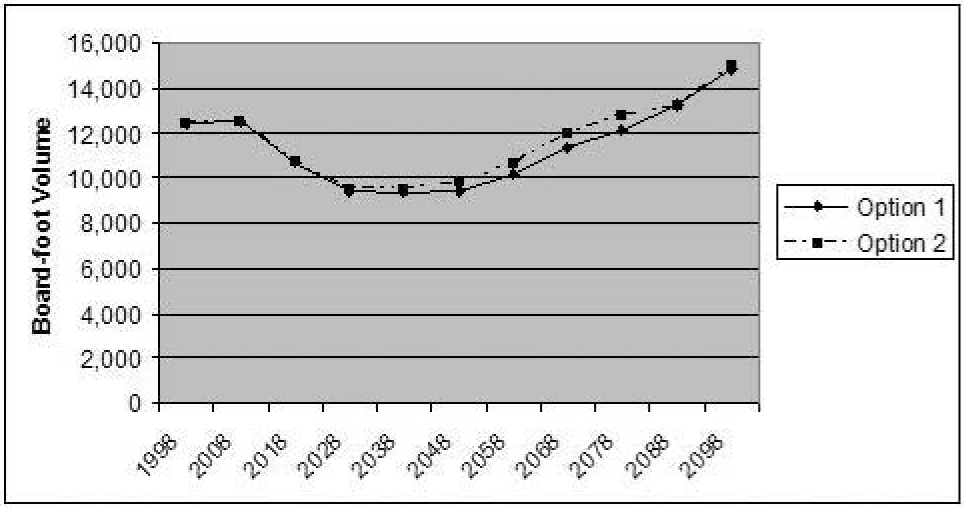


Figure 4—Board-foot stocking projections from FVS, ninebark stratum.

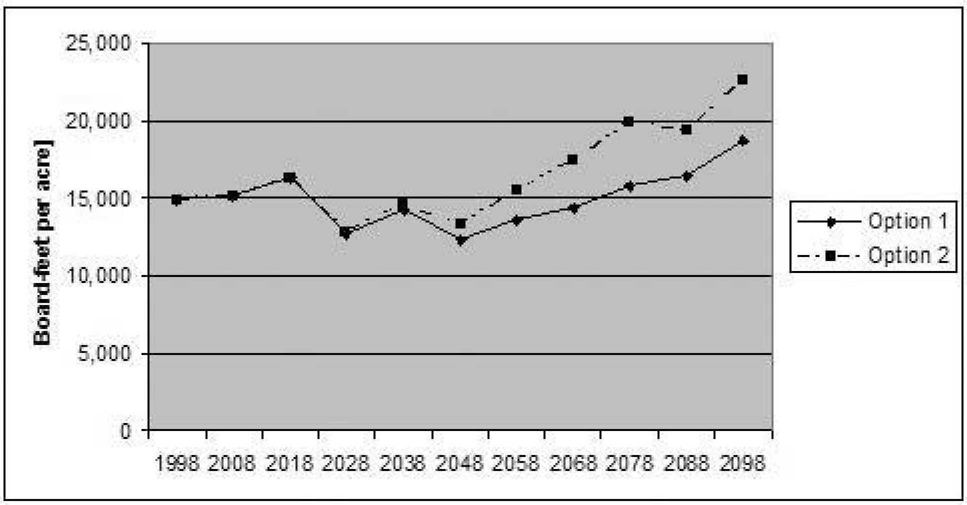


Figure 5—Board-foot stocking projections from FVS, grand fir stratum.

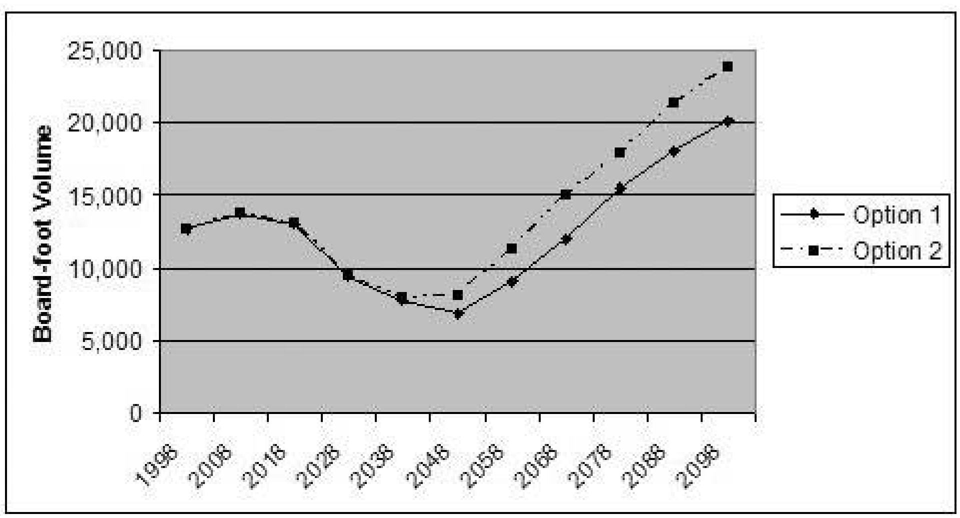


Figure 6—Board-foot stocking projections from FVS, lodgepole stratum.

The ninebark, grand fir and lodgepole strata (figs. 4, 5 and 6) all decline in volume during the first 50 years of projection: ninebark bottoms out at around 2028; the other two, 10 to 20 years later. These indicate the period in which mature stands are being gradually replaced by younger stands, which produce no measurable board-foot volume for 30 to 50 years. The all strata chart (fig. 1) shows that when viewed on a forest-wide basis, the various cyclical trends of the individual strata are mutually compensating and so the dip in stocking about 30 years in the future is relatively slight.

Option 2 in the three strata in which it was tried shows slightly higher volumes overall in the last 50 years of projections, and these differences are noticeably higher in the wet grand fir and lodgepole strata. It is logical that these differences are not seen until 50 years into the future, because it would take that long for the differing regeneration inputs to finally be expressed in board-foot volume. The improved volumes from option 2 are probably attributable to two causes. First, natural regeneration inputs on wetter types are more dominated by root disease susceptible species, and the Western Root Disease Model component of FVS should be reducing volumes of these species accordingly. Also, in the lodgepole stratum, ponderosa pine and larch stocking replaces lodgepole pine in option 2, and over time these species do attain greater standing volumes per acre than lodgepole pine because of greater height and diameter growth potential.

Harvest Yield Projections

The harvest yield projections shown in figures 7 through 12 are expanded from a per acre basis to total annual volumes in thousand-board-feet units (MBF). Expansion factors are based on the current commercial forest acreage estimated for each of the strata. Deduction for defect is included. The harvest yield projections made in the FVS model are based on simulated management treatments in the model that, as much as possible, imitate current practices. These are not designed to show the greatest yields possible in either the short- or long-term, but merely reflect what might be expected given continuing management. No attempt was made to optimize yields or create a non-declining and even yield pattern.

The harvest charts show an erratically fluctuating yield. This is probably an artifact of condition statements for harvest that specify that (a) when given conditions are met for any plot, a regeneration cut shall be done immediately, and (b) a plot may not be harvested in two consecutive cycles. Most likely, a large percentage of plots are simultaneously meeting conditions for regeneration and a large harvest (many plots aggregated) occurs in one cycle. Ten years later relatively few plots are eligible for harvest because of the number of plots harvested in the previous cycle. One more cycle later, plots regenerated 20 years earlier are eligible for overstory removal, as well as numerous plots available for a second commercial thinning. In reality, all plots theoretically eligible for harvest would not be cut in one decade as it takes about 20 years to move through the whole reservation. A more realistic harvest level would plot a midpoint through the see-sawing levels seen in these charts.

In viewing the harvest volumes associated with each stratum, note that since these are expanded by stratum acreages, the magnitude of the total volumes reflect the geographic size of the stratum (shown in table 1), as well as volumes per acre. The all strata chart (fig. 7) provides an indicator of what the reservation-wide annual harvest might be.

The yield patterns shown for the individual strata fluctuate more widely than the stocking charts in the previous section. The ninebark stratum (fig. 10) peaks earliest at around 2018; lodgepole (fig.12) peaks in 2028; and grand fir (fig. 11) between 2028 and 2048 (taking the midpoint between peaks). The drier strata fluctuate far less, with pine-fir (fig. 9) peaking in 2048 and dry pine (fig. 8) in 2058 or later. When the yields are averaged together for all strata (fig. 6), the overall picture appears more stable.

This provides a hopeful sign that, although the age-class distribution is not at all balanced in this forest, the current management scheme for prioritizing harvests and the rate at which stands on different sites develop might nonetheless provide a yield flow from the forests which is does not vary greatly. This is especially true if we chart a midpoint between the more widely fluctuating consecutive cycles. Still, overall annual yields for the first 50 years of projections average about 2 million board-feet more than the average for the second 50 years. This is most likely due to the current distribution of age classes on the reservation forests.

The 100-year average of harvest yields simulated under option 1 is about 16.8 million board-feet per year. Is that realistic? First of all, consider that yields after 2048 are quite

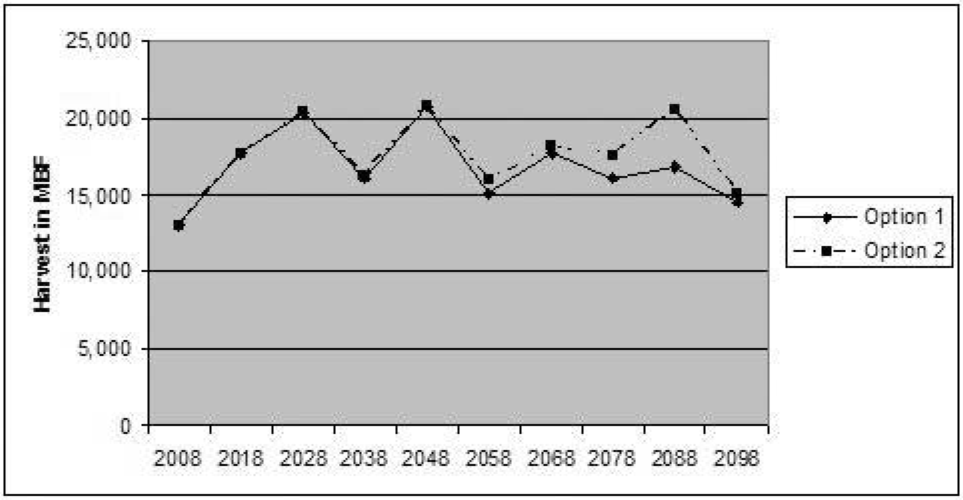


Figure 7—Harvest yield projections from FVS, all strata combined.

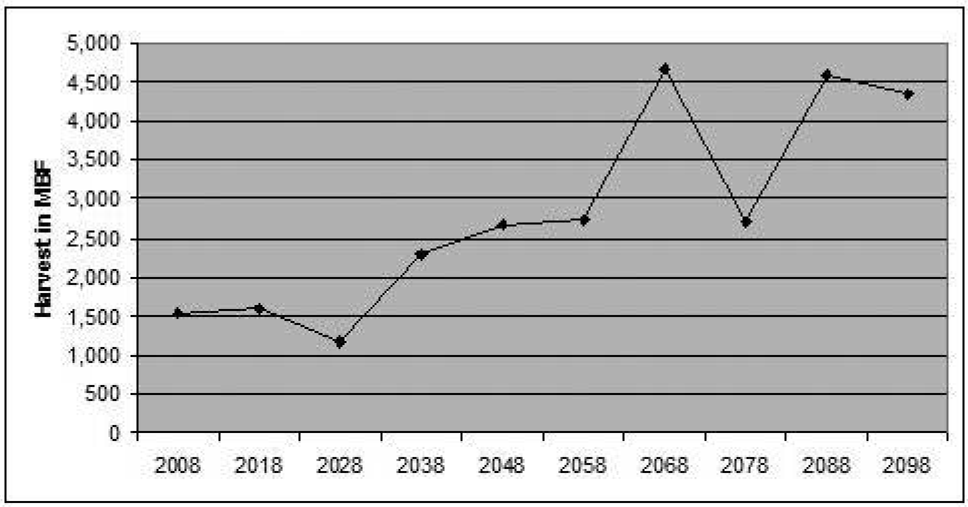


Figure 8—Harvest yield projections from FVS, dry pine stratum.

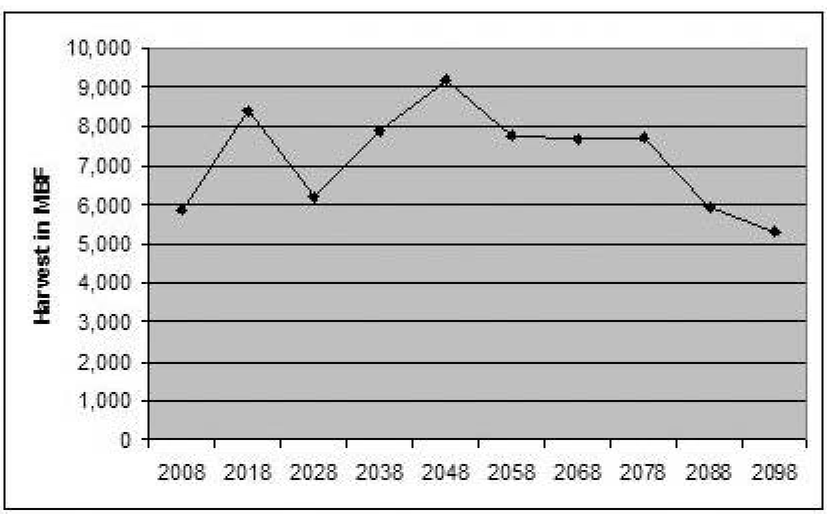


Figure 9—Harvest yield projections from FVS, pine-fir stratum.

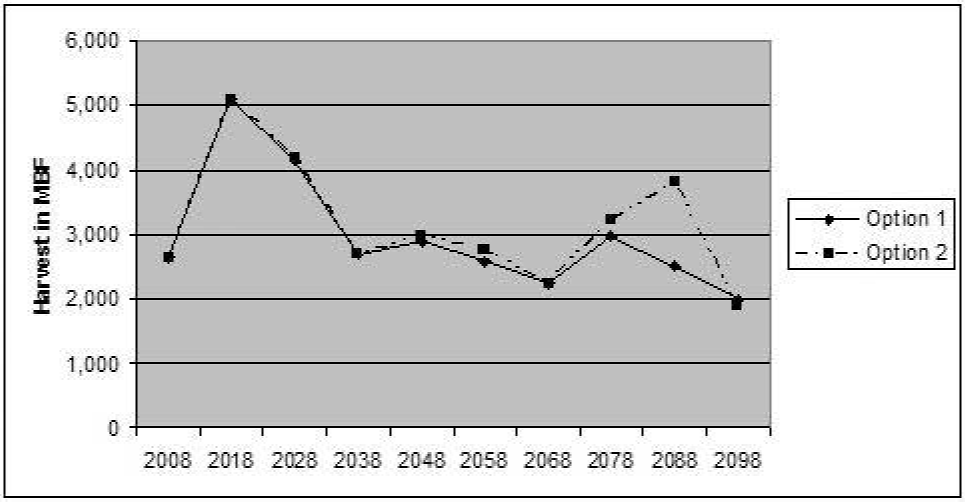


Figure 10—Harvest yield projections from FVS, ninebark stratum.

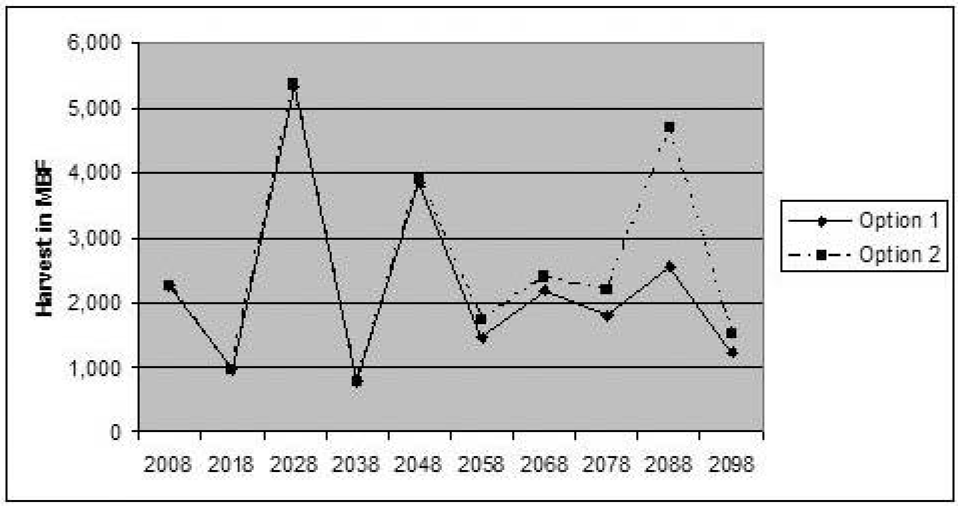


Figure 11—Harvest yield projections from FVS, grand fir stratum.

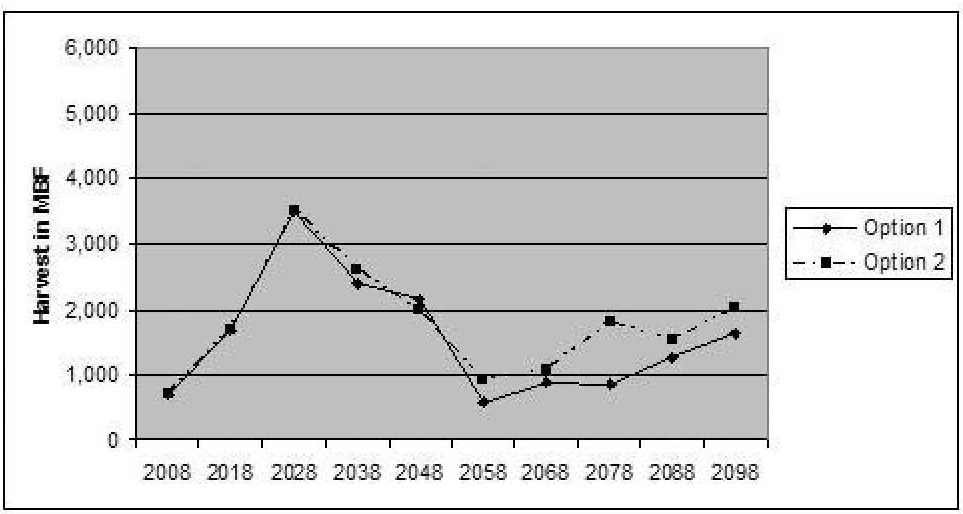


Figure 12—Harvest yield projections from FVS, lodgepole stratum.

dependent on model-generated trees. If growth rates for these are overblown, then yield could fall off even more than indicated in the second 50 years of the projection period. Secondly, the ability to maintain fairly high, even yields for the first 50 years is very dependent on mortality trends. Dramatic increases in mortality in the next 20 years beyond levels foreseen by FVS could present a choice between accelerating harvest for the first 25 years at the expense of the second 25 years, or allowing a diminished level of harvest overall for the first 50-year period.

On the wetter sites, option 2 shows higher harvest yields than option 1, with the lodgepole stratum showing the greatest differential over time. These distinctions do not appear until fairly late in the projections, which is what would one expect given the time it would take for the model-generated regeneration to reach mature sizes. If the differences shown are realistic, they would most likely persist beyond the 100-year projection period as long as these regeneration practices are continued.

If we look at the second 50 years of projections alone (since the first 50 years will not reflect different harvest yields between options 1 and 2), yields from option 2 are noticeably higher than option 1. For the ninebark stratum, option 2 yields over the last 50 years of projection are 13 percent higher; wet grand fir option 2 yields are 37 percent higher; lodgepole option 2 yields are 41 percent higher.

Mortality Projections

Volume loss due to natural mortality is highly dependent on stocking volume for a particular stratum or time period. So in order to provide a uniform basis for comparing the mortality between strata and between cycles, cubic-foot mortality was converted to percent of cubic-foot stocking.

To evaluate how FVS mortality projections compare to the rates recently measured in the 1998 CFI, annual cubic-foot mortality for that growth measurement period (generated from CFI program output) was expanded for a 10-year period and converted to a percent of cubic-foot stocking. These are listed as follows for the four main strata and for all strata combined. (The wet grand fir mortality percentage includes the plot sets for both the grand fir stratum and lodgepole stratum from the FVS projections.)

- Dry pine: 4.1 percent
- Pine-fir: 6.0 percent
- Ninebark: 5.5 percent
- Wet grand fir: 6.1 percent
- All strata combined: 5.8 percent

In reviewing these comparisons, we find that despite measures to calibrate the model to reflect mortality levels measured in 1998 CFI, FVS rates (figs. 13 through 18) are still mostly lower than measured rates for the period. The grand fir and lodgepole strata (figs. 17 and 18, respectively) are the only exception to this. This might indicate a need to discount yield projections posted by FVS in the event that mortality continues at or increases from 1985–1998 rates.

FVS projects that average mortality for all strata (fig. 13) would peak at around 2018, subside slightly, and finally return to that level again about 50 years later. The wetter types drive this peaking in the near term; the dry pine (fig. 14) and pine-fir strata (fig. 15) do not show this trend. The lodgepole stratum (fig. 18) shows the highest mortality rate in terms of percent of volume lost, peaking at over 9% in 2018; the grand fir stratum (fig. 17) has the second highest level, over 7%. Lodgepole also shows the most widely varying trend over the period projected.

The comparison between options 1 and 2 on the wetter strata yields some interesting results. It appears that mortality for option 2 rises above that of option 1 at about 2058 and then drops to about the same level 30 years later. Actual cubic-foot mortality volumes are pretty steady for option 2 after 2058. However, as seen in figures 4 through 6, stocking is steadily rising throughout that period, and so mortality expressed as a percent of stocking falls in comparison.

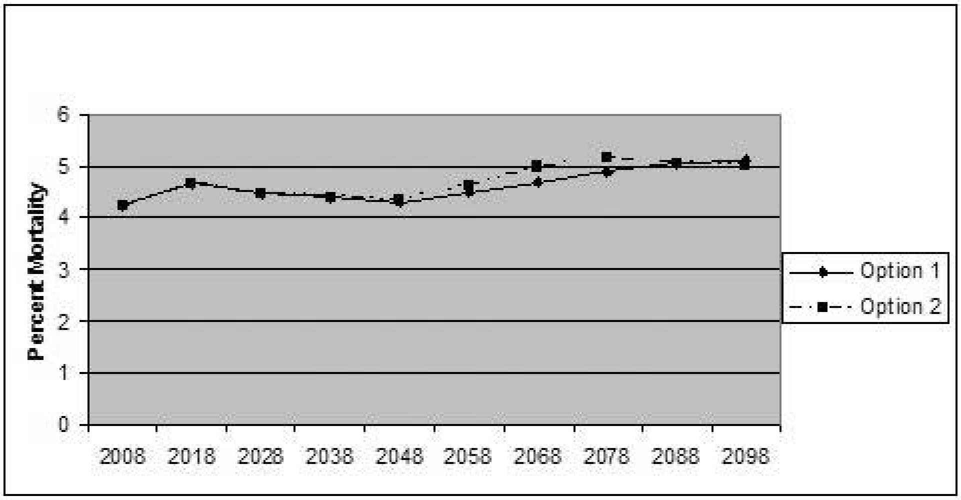
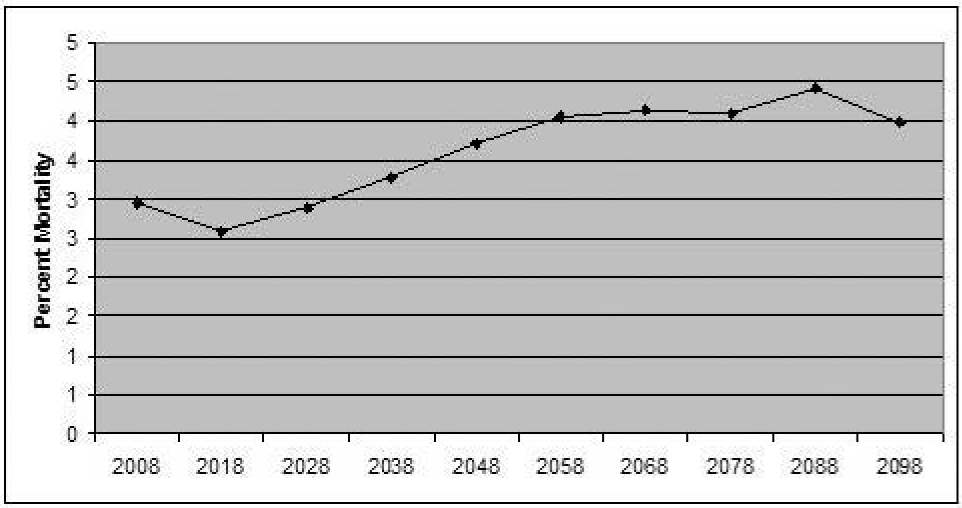


Figure 13—Mortality as percent of stocking from FVS, all strata combined.

Figure 14—Mortality as percent of stocking from FVS, dry pine stratum.



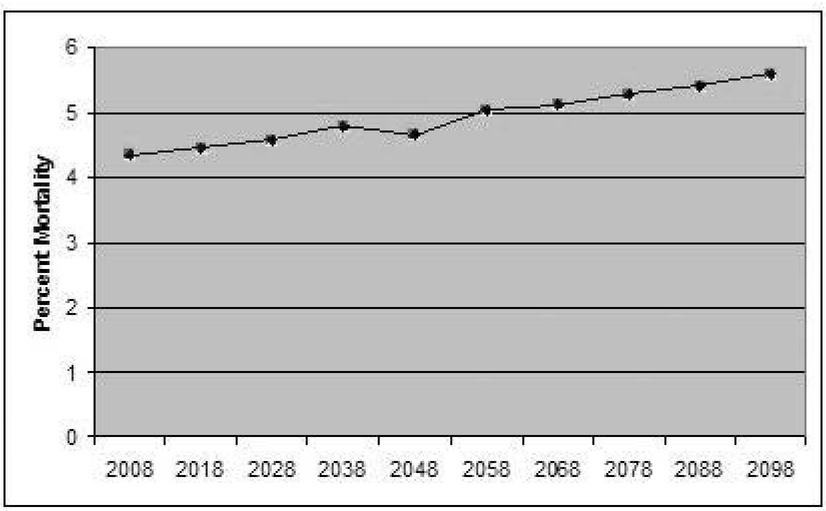


Figure 15—Mortality as percent of stocking from FVS, pine-fir stratum.

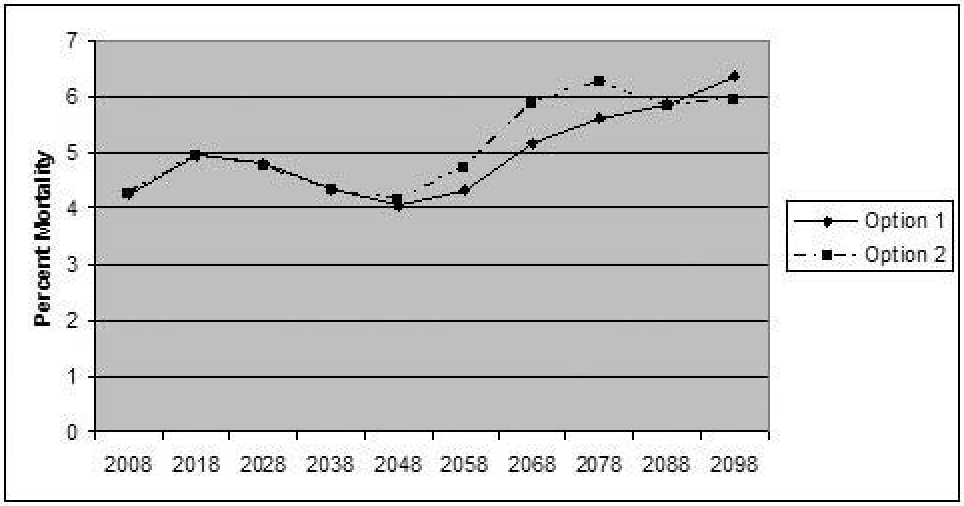


Figure 16—Mortality as percent of stocking from FVS, ninebark stratum.

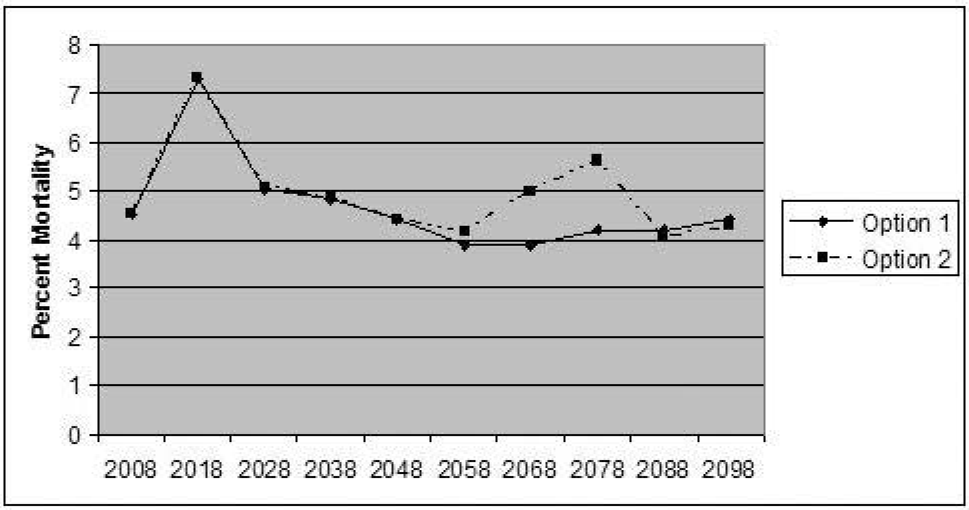


Figure 17—Mortality as percent of stocking from FVS, grand fir stratum.

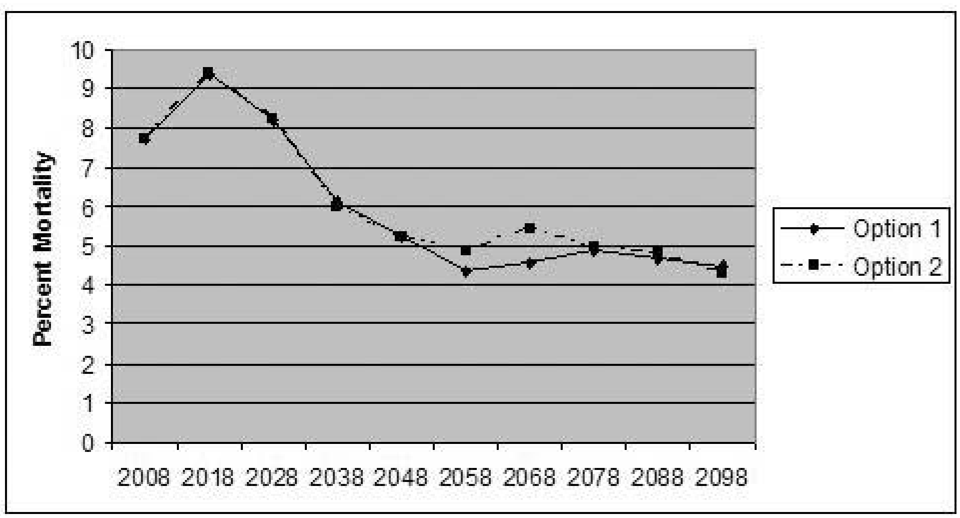


Figure 18—Mortality as percent of stocking from FVS, lodgepole stratum.

Conclusions

In general, FVS was a useful supplement to the traditional annual allowable cut computation methods for this CFI analysis. The harvest yields projected by FVS for the first 20 years were in line with other AAC computation methods. Long-term FVS harvests were considerably higher, however, and may reflect overestimation of growth by the model that was not completely corrected by calibration.

The question of how the current age-class distribution of the forest might affect harvest yields in the future seemed to be one for which the model was particularly well-suited. FVS results projected a great deal of fluctuation in harvest yields for the individual strata. However, the combined yields indicated that the dynamic trends of the individual strata may balance one another during the transition period to a regulated forest.

Some of the FVS results could be useful for guiding silvicultural treatments in the future. In viewing mortality projections, it appears that wetter sites (particularly with lodgepole stands) are prone to increased mortality in the next two decades. This would support a strategy that makes these areas a high priority for regeneration harvests in the near future. Also, the results indicate that planting ponderosa pine and western larch vs. natural regeneration on disease prone sites will lead to higher yields.

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