Using FVS and Its Fire and Fuels Extension in the Context of Uncertain Climate

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Abstract—While the prospect of a static climate is no longer tenable, the direction of change for particular localities is not yet clear. Modelling vulnerability of silvicultural options to various scenarios of climate change requires a modelling system that can represent major processes affected by climatic variability. The Forest Vegetation Simulator (FVS), through its Keywords and Event Monitor commands modifying the underlying model, can be used for such analyses. In this report, we document an FVS-based analysis of four scenarios of climate change: warmer-dryer, warmer-wetter, cooler-dryer, and cooler-wetter. Regeneration rates and species composition of regeneration and rates of mortality and accretion are expected to respond differently under the four scenarios. Development of forest stands in the example locales (northwestern Montana and central Washington) is strongly influenced by fire, and conversely, fire behavior is influenced by stand structure. We describe how analyses illustrating the interplay of these hypotheses were formulated using FVS and its Fire and Fuels Extension (FFE). Our hypotheses of how processes might change in response to varying climate are qualitatively consistent with our understanding of the ecosystem represented. Furthermore, the present range of weather variability is sufficient to test each of the component hypotheses independently by monitoring how their rates change in response to weather variation.

Application of the Forest Vegetation Simulator for evaluating the effects of hypothesized changes in climate has been described by Stage and others (2001). In that report, we evaluated four possible scenarios: warmer-dryer, warmer-wetter, cooler-dryer, and cooler-wetter. This report provides more detail on how FVS and its Fire and Fuels Extension (FFE) (Beukema and others 1997) were used in the analysis. Critical for the analysis were the capabilities of the Event Monitor (Crookston 1990) to define variables and the use of computed functions of those variables to modify the processes represented by the underlying FVS model.

The essence of the scenarios for stand development was represented by differences in mean and variance of seasonal moisture stress and length of growing season (table 1) (Zahner and Stage 1966; Rehfeldt and others 1999).

These parameters of climate were hypothesized to affect rates and species composition of regeneration, rates of mortality and accretion, probability of wildfire, and rates of fuel accumulation. Management options included thinning, pruning, and prescribed burning. Separate keyword files were prepared for each combination of climatic scenario and management alternative. Within the keyword file, management alternatives were defined by separate ADDFILES for each alternative.

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Table 1—Scenarios of moisture stress. Present MS = 9.2 ± 3.0 inches.

	Warmer	Cooler
Wetter	8 ± 3	5 ± 2
Dryer	13 ± 4	10 ± 4

Several of the processes being modelled have large stochastic variation in addition to the variation in the climatic parameters. These include wildfire frequency, regeneration, and accretion. Therefore, the outcomes of each scenario were represented by the mean and standard deviation of 40 replications of each simulation, initiated by reseeding the random number generator.

Temporal Change in Climatic Effects

Four variables define the temporal progression from present conditions to the conditions represented by the four climatic scenarios: MS, the scenario mean moisture stress; SIGMS, its annual standard deviation; STRESS, the stochastic realization of scenario stress applicable to the current cycle in the projection; and STR, the departure from current stress including the 50–year transition from present to future mean conditions. NYEAR is the length of each cycle. Although usually 10 years, it was calculated to make the conversion from annual to periodic rates explicit. Keywords implementing temporal change follow:

```
COMPUTE
   DEV = BOUND (–2., NORMAL(0., 1.),+2)
   NYEAR = CENDYEAR + 1. –YEAR
   STRESS = MS + SIGMS*DEV/SQRT(NYEAR)
   STR= (STRESS–9.2)*DECADE(0.1, 0.3, 0.5, 0.7, 0.9, 1.0)
END
```

FVS Processes Responding to Scenarios

All three of the principal processes represented by FVS, mortality, accretion, and regeneration were modified by the moisture stress variables. In addition, the height increment component of accretion was reduced for the cooler scenarios to account for increased frost-damage to terminals.

Mortality

Response of mortality rates to the interaction of moisture stress and stand stocking was derived from a thinning study on the Flathead Reservation (Khatouri and Moore 1993; Cheng and Moore 1996). Those data, however, were not sufficiently comprehensive for a completely new fitting of the logistic mortality submodel. Therefore, the analysis used the present northern Idaho variant (Hamilton 1986; Wykoff and others 1982) as the null model. Then two new terms modifying the argument of the exponential function were added: a multiplicative term (P6= RIPMLT), and an additive term (P7= RIPAD). P7 varied by moisture stress and species.

Ham = linear function in NI variant

$$\text{Mort} = \frac{1}{1+\exp(-P_6 * HAM - P_7)}$$

$P_6 = 1.6482$
$P_7 = -0.4683 * \text{STR} - 2.0882$ for Pondersa pine
$P_7 = -0.4683 * (\text{STR} + 1) - 2.088$ for Douglas-fir
$P_7 = -0.4683 * (\text{STR} + 2) - 2.088$ for Grand fir

Entering these two new parameters required modifying FVS to add two additional fields to the MORTMULT keyword and to use the new parameters in the calculation of the probability of mortality. Modifying the argument of the exponential function in the probability of mortality submodel permitted analysis of the mortality data in the same format as the original analysis. Furthermore, the modified rates are still bounded by zero and unity. Therefore, this approach was considered a better solution than simply multiplying the mortality rate, which was the original function of MORTMULT.

Therefore, the keywords modifying mortality for ponderosa pine, Douglas-fir and grand fir were:

```
COMPUTE
  RIPMLT = 1.648163
  RIPAD = –0.468393*STR – 2.088163
  RIPAD3 = RIPAD – 0.468393
  RIPAD4 = RIPAD – 0.468393*2.
END
  MORTMULT     0.     PARMS(10,1.0,0.0,99.0,1.0,
                      RIPMLT,RIPAD)
  MORTMULT     0.     PARMS(3,1.0,0.0,99.0,1.0,
                      RIPMLT,RIPAD3)
  MORTMULT     0.     PARMS(4,1.0,0.0,99.0,1.0,
                      RIPMLT,RIPAD4)
```

Accretion

Basal area increment of large trees was assumed to change by 5 percent for each inch of departure from mean moisture stress (Zahner and Stage 1966). In the norhtern Idaho variant, the submodel for height increment of large trees includes diameter increment as a driving variable. Therefore, no further modification for moisture stress was required. However, predicted increment was reduced by an additional 4 percent for normal top damage. Height increment of small trees, however, must be changed in concert with the effects on height increment of the large trees. In the logarithmic large-tree height increment model, the coefficient of logarithm of diameter increment is approximately 0.5. Therefore, a multiplier that is the square root of the diameter multiplier is appropriate. The necessary keywords are:

```
COMPUTE
  GSTR=1.– (STR/20)
END
  BAIMULT      0.     PARMS(0., GSTR)
  HTGMULT      0.     0.     0.96
  REGHMULT     0.     PARMS(0., SQRT(GSTR)*0.96))
```

Regeneration

Disturbances trigger the addition of regeneration to the list of trees in the stand. In these analyses, there are three kinds of disturbances: wildfire, prescribed fire, and thinning with slash burning. The combinations of management actions and climatic scenarios were hypothesized to affect the rates of stocking, the species composition, and the extent of site preparation (proportion burned in these analyses). Stocking rate is made quite sensitive to moisture stress (Mika 2000). Then, conditional on the small regeneration plot (1/300 acre) being stocked, the relative proportions of drought-tolerant species are increased if moisture stress is above present average, and conversely, decreased if moisture stress is below present average. The SPECMULTs are shown for ponderosa pine (10), Douglas-fir (3), and grand fir (4). Ponderosa pine was sparsely represented in the regeneration model for the northern Idaho variant. Therefore, its presence was increased manyfold by the arbitrary 70, multiplying the stress effect.

```
ESTAB
  STOCKADJ     0.     PARMS(GSTR**2)
  SPECMULT     0.     PARMS(10, 70.0*EXP(STR*0.5))
  SPECMULT     0.     PARMS(3, EXP(STR*0.3))
  SPECMULT     0.     PARMS(4, EXP(STR*0.2))
END
```

Event Timing

Wildfire frequency (FIRFREQ) was calculated as a function of moisture stress using an approximation of the return intervals shown in table 2 with a further increase of 40 percent to represent effects of suppression (Agee 1993). The suite of management options also included prescribed fire at intervals of 30 years. However, in the event of a wildfire, the next prescribed fire would be rescheduled for 30 years after the wildfire (NXTFRYR2). If the wildfire event is triggered for a cycle, then a particular year for the fire to occur (FIRYEAR) is chosen at random within the

Table 2—Fire return intervals for four scenarios.

	Warmer	Cooler
Wetter	150 years	300 years
Dryer	20 years	40 years

cycle. This date is used in the regeneration keywords as the date of disturbance. Site preparation for the regeneration model is set to 100 percent for wildfire disturbances. Here are the keywords:

```
COMPUTE
        FIRFREQ = 1.4*EXP (7.39 – 0.34*(STR + 9.2) )
        PFIRE= 1. – (1.– 1./FIRFREQ)**NYEAR
        FIRYEAR = YEAR +INT( RANN*NYEAR )
        RNDM = RANN
END
IF
        PFIRE GE RNDM
THEN
        COMPUTE       0.0
                NXTFRYR2 = FIRYEAR + 29.9
        END
        ESTAB
                TALLY        9.0   PARMS(FIRYEAR)
                BURNPREP     9.0   100.
        END
ENDIF
```

Prescribed fire keywords were filed in an ADDFILE along with the silvicultural options. If a run was to consider prescribed fire, it was invoked with the following keywords:

```
IF
   (PFIRE LT RNDM) AND (YEAR GE NXTFRYR2)
THEN
        FMIN
                FIRETYPE     1.0    2.
                FIRECOND     1.0    3.     4.     70.     1.
        END
        COMPUTE      2.0
                NXTFRYR2 = YEAR + 30.
        END
        ESTAB
                TALLY        9.0   PARMS(YEAR+1.)
                BURNPREP     9.0   50.
        END
ENDIF
```

Fire and Fuels

Duff and woody debris loading was initialized with default loadings applicable to the habitat type. Ideally, the fuels inventory should be obtained directly from the subject stand.

Modelled fuels are augmented by detritus from the growing stand using parameters in the Fuels extension. Then they decay at rates specified by the FUELDCAY keyword (table 3). In the runs reported earlier, fuel decay rates were held constant at values specified in table 3 throughout the span of simulated time. Hence, there is a discrepancy with the trends in moisture stress, which followed a linear trend over the 50–year transient between present mean and the climate-scenario mean. A more realistic assumption would use the moisture stress (STRESS) applicable to the current cycle to interpolate among the values in table 3.

Model Execution in Suppose

The Suppose user interface for FVS was a critical adjunct to the analysis beyond the obvious assistance with entering routine keywords. The first step, “Select Simulation Stands,” involved searching the inventory database for suitable stands to be used as examples. The 40 replicates were created by successively doubling the list of replications of the selected stand. Then the “Edit Simulation File” operation was used to open and append the keyword files for the particular combination of climatic scenario and management options. “Run Simulation” produced the output files, including those requested by keyword. Finally, “Generate Report” was used to parse the output for the variables to be displayed, averaged over the 40 replications, and transmit summary statistics to a spreadsheet for further display.

Recommendations for Model Modifications

FVS

- Provide two added parameters to Keywords modifying probabilities as additions to, and multipliers of, the argument in the exponential term in logistic function: for example, MORTMULT, STOCKADJ, SPECMULT, and so forth.
- Incorporate within-stand variability of stocking into accretion and mortality models (Regeneration Establishment already has it) (Stage and Wykoff 1998).
- Update specifications for inventory design. FVS could not accommodate Yakama Nation inventory without revision. For example, use Byrne and Stage (1988) protocols.

FFE

- Incorporate within-stand variability of stocking into fire behavior model.
- Improve linkage between stand attributes and fire behavior.

Table 3—Dead and downed fuel decay rates (proportion of weight loss per year) by fuel size.

Scenario	Litter	Duff	0-0.25”	0.25–1”	1–3”	>3”
Warm-wet	1.000	0.0040	0.200	0.120	0.120	0.060
Warm-dry	0.650	0.0026	0.130	0.078	0.078	0.039
Cool-wet	0.350	0.0014	0.070	0.042	0.042	0.021
Cool-dry	0.250	0.0010	0.050	0.030	0.030	0.015

Suppose

- Provide capability to routinely replicate stands. (Needed to address concerns of Hamilton (1991) that FVS users do not recognize the implications of random variation.)
- Augment computation of means over multiple stands with computation of their standard deviations.

Conclusion

These analyses describe how FVS was used to evaluate silvicultural alternatives in the context of changing climate in forests where fire is a significant process in stand dynamics. We reduce the problem of predicting future weather variables such as daily temperature, humidity, and precipitation to the more accessible problem of predicting a few key parameters—seasonal moisture stress and growing season length. Response to changes in these parameters can and should be estimated from direct observation of existing forests. Furthermore, quantifying these responses to weather variations would be useful in evaluating current model biases.

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