# I. Title Page

Modeling the influence of management actions on fire risk and spread under future climatic conditions

Theme: Climate Change
Sub Theme: Climate Change and Application of Predictive Models

Principle Investigators:
Matthew Hurteau
Northern Arizona University, Box 6077, Flagstaff, AZ 86011, phone (928) 523-0497, fax (928) 523-0565, Matthew.Hurteau@nau.edu
George Koch
Department of Biological Sciences, Northern Arizona University, Flagstaff, AZ 86011, phone (928) 523-7150, George.Koch@nau.edu
Malcolm North
USFS Pacific Southwest Research Station, Sierra Nevada Research Center, 1731 Research Park Dr. , Davis, CA 95618, phone (530) 754-7398, mnorth@fs.fed.us

Grants Contact Person:
Cindy Judge
Phone: (928) 523-6917, fax: (928) 523-1075, Cindy.Judge@nau.edu

Total Funding Requested
$157,820
Total Value of in-kind and financial contributions
$237,963

## II. Proposal Narrative

### Justification

Western forests increasingly experience larger and more severe fires than occurred historically. In many areas this has lead to an increase in fuels reduction treatments that rely on prescribed fire. In the Lake Tahoe Basin, however, where there is a high density of development, managers are limited in their options for reducing forest fuels using prescribed fire. Compounding this management challenge is the expectation that changes in climate resulting from increasing greenhouse gas levels will exacerbate the threat of catastrophic fire. We believe that successful forest management for the 21st century requires increasing forest resistance to high severity fire, drought and greater precipitation variation that are likely to occur with global climate change. In the face of climate change, how can Basin forests be best managed to increase their resistance to drought and high-intensity fire? We believe that answering this complex question requires calibrating a set of forest growth and process-based models for Basin conditions and dynamically linking these models in a decision support system. We propose to update the Forest Vegetation Simulator (FVS) using a process-based model (3-PG) to predict species-specific tree growth rates under future climate scenarios. With this foundation we will then examine management treatment impacts on changing Basin forest conditions using the spatially-explicit landscape model, SIMPPLLE (Simulating Patterns and Processes at Landscape Scales). These tools will enable us to work with managers to identify which forest treatments can be practically implemented and how these treatments will influence the risk and spread of stand-replacing fire.

### Background and Problem Statement

High density competition is a significant influence on how Sierran mixed-conifer trees respond to changing climate conditions (Hurteau et al. 2007). In Yosemite National Park, Guarin and Taylor (2005) generally found a negative correlation between April snowpack and tree mortality, but they also identified high tree density, a result of fire suppression, as a factor limiting stand resilience to drought. Working in Jeffrey pine forests of the Tahoe basin, Taylor and Beaty (2005) found that historically, fire years were associated with drought and that drought intensity influenced the extent of fires. The fires identified in these studies occurred during a relatively cool and wet climatic period (Millar and Woolfenden 1999). Recent increases in wildfire severity and extent have been linked to warmer spring and summer temperatures and earlier spring snowmelt (Westerling et al. 2006). With predicted overall drying (Brown et al. 2004), earlier snowmelt, and warmer temperatures , western U.S. forests may experience increases in seasonal severity rating (Flannigan et al. 2000), fire size and frequency (Fagre et al. 2003), and land area experiencing high to extreme fire danger (Stocks et al. 1998). Given this set of future conditions, a key management question becomes: *What treatments will help reduce drought stress and fuel conditions that facilitate crown fire, and produce stand conditions making trees more resilient to warming temperatures and changing precipitation patterns?*

We have previously used FVS to model a century of carbon storage and release in Sierran mixed conifer with and without wildfire following different fuels treatments (Hurteau and North *In review*). The simulations suggest that reducing the number of trees per hectare and retaining larger fire-tolerant pines increases carbon sequestration and reduces the risk of catastrophic tree loss under extreme wildfire conditions. This modeling worked on a fairly simple assumption that under current climate conditions, thinning to reduce stand competition would shift resources and significantly increase growth rates of large, leave-tree pines. The model did not account for how different tree species may respond to changing climate conditions, nor did it examine how best to treat stands typical of the Tahoe Basin, stands having few large individuals of fires-sensitive, shade tolerant species such as white fir and incense cedar.

The FVS is a growth and yield model that uses location-specific, measured growth rates to predict tree growth under varying stand conditions (Crookston and Dixon 2005). It relies on an assumption of uniformitarianism, namely that tree growth response to climate will be the same in the future as it was during the measurement period. While this has been a valid assumption for estimating growth response to climate during periods of climate stability, some recent studies have identified changes in growth response to warming temperatures at higher latitudes (Briffa et al. 1998, Wilmking et al. 2004). As climate shifts continue to occur, tree growth will likely respond differently than it has in the past, making growth and yield models less reliable (Constable and Friend 2000).

To predict how forest stands will respond to management actions under future climatic conditions, we must first identify how individual species' growth rates will change as the climate changes. Process-based models (e.g. 3-PG, Landsberg and Waring 1997) use data inputs ranging from climate variables and soil variables to stand age to calculate the amount of carbon converted to biomass. By using climate data to determine growth rates, process-based models do not rely on the uniformitarian assumption. This type of adaptive structure makes process-based models useful for determining the influence of changing climatic patterns on tree growth (Lindner 2000). There is precedent for this approach. Matala et al. (2005) successfully used the growth-climate relationships provided by a process-based model to parameterize a statistically based growth and yield model, and this in turn was used to identify forest stand response to management actions under predicted climate changes.

The process model is most accurate when it is calibrated with field sampled growth data for a specific location. We will develop growth-climate equations for each of the major tree species in the Tahoe Basin using the process model. These locally-derived equations will be used to revise FVS, re-calibrating its model of stand dynamics for Basin conditions under changing climatic conditions. We will use this revised version of FVS to determine stand-level response to different fuels treatments under changing climatic conditions. This improved forecasting of stand dynamics will more accurately predict the risk of stand replacing fire when integrated in a model of landscape dynamics such as SIMPPLLE. Managers will be able to compare different treatment scenarios to assess best management practices for Tahoe Basin forest communities.

## Goals, Objectives, Hypotheses to be tested

The goals of this study are to 1) determine how forests of the Tahoe basin will respond to changing climatic conditions and 2) identify which suite of management actions will maintain forest processes while minimizing stand replacing fire risk. To achieve these goals, we will complete the following tasks:

1. Parameterize and validate a process-based model to the specific growing conditions of the Tahoe Basin.
2. Use the process-based model and predicted changes in climate under business-as-usual, Kyoto targets, and carbon neutral $CO_2$ scenarios to parameterize species specific tree growth relationships in FVS and model structural treatment effects on stand growth.

3. Model fire risk and fire spread for current stand conditions and the structural treatments under the three $CO_2$ scenarios to determine which fuels treatment alternatives reduce the risk of catastrophic fire and best meets location specific goals for each management unit and forest type in the Tahoe Basin.

## Approach, Methodology, and Location

A recent classification of Basin conditions, the Terrestrial Ecosystem Unit Inventory (TEUI), identified 18 conifer-dominated communities that comprise approximately 65,880 ha within the Lake Tahoe Basin (Slaton et al. 2006). This study will focus on the conifer-dominated communities that occur at or below the red fir (*Abies magnifica*) community type in elevation. These communities are dominated, white fir (*Abies concolor*), incense cedar (*Calocedrus decurrens*), sugar pine (*Pinus lambertiana*) and Jeffrey pine (*Pinus jeffreyi*) and have received the primary focus of past management actions.

### Plot Data

This study will use a combination of data sources. We will work with managers to obtain stand inventory data for forest communities that occur within the scope of this study. To augment this data source, we will randomly install ten 28.2 m fixed radius plots (0.25 ha), stratified across the 8 forest community types that occupy the majority of this elevation range in the Basin, for a total of 80 plots. Diameter at breast height, tree height, and height to live crown will be measured for each tree. To capture the current spatial variability, we will map (using a criterion laser total station) all trees located within the plot boundary. We will also measure fuels using Browns' (1974) methods and core trees to gather growth data. The tree cores will be used to determine stand age and used in conjunction with stand demography data determined from the plots and allometric biomass equations from the literature for parameterizing and validating the tree growth component of the process-based model.

### Climate Data

We will use PRISM climate data in conjunction with local weather stations to provide climate data for parameterizing the process-based model for Basin specific conditions. Future climate data will be gathered from Cayan et al. (2006), which used a medium-high emissions scenario and a low emissions scenario from the IPCC fourth climate assessment to simulate climate changes for California. Additionally we will use current climatic conditions as a baseline for comparison of stand dynamics under the two forecasted scenarios.

### Process-Based Model

Growth and yield models, such as FVS, make the assumption that future environmental conditions will be the same as the measurement period; whereas process-based models are driven by climatic variables and edaphic factors (Garcia-Gonzalo et al. 2007). This makes process-based models more robust for dealing with shifts in climate. We will parameterize and validate a process-based model (3-PG) for Basin specific conditions (Figure 1). 3-PG calculates gross primary production by correcting canopy absorbed photosynthetically active radiation for the effects of stand age, soil drought, and vapor pressure deficits (Lansberg and Waring 1997). To parameterize the model, we will use a subset of the plot data gathered from this project in conjunction with TEUI stand, soils and climate data. The tree attribute data gathered from the plots will be used to supplement TEUI data and develop growth-climate equations for each dominant tree species. Model validation will be carried out using the remaining plot and TEUI stand data.

**Revising FVS**

Once validated, we will use the process-based model to predict species specific growth relationships under medium-high emissions, low emissions, and current climate conditions. These revised growth relationship will be used to inform the Western Sierra variant of FVS by correcting the species specific growth relationships within FVS for the three future climate scenarios. FVS uses log-linear regression equations to calculate diameter growth (Wykoff 1986). Where:

10-year $\Delta$ $dbh^2$ = *f*(habitat type, location, aspect, slope, elevation, competition, crown ratio, basal area/ac)

Using 3-PG and predicted climatic changes, we will develop a candidate set of linear models that include the current model parameters, as well as climatically influenced parameters, such as photosynthetically active radiation use efficiency. We will rank these models using the Akaike Information Criterion to select the best models for both large and small tree growth in an information theoretic framework (Burnham and Anderson 2002). The selected models will then be used to replace the current tree growth models in FVS.

After FVS has been re-calibrated, we will work with forest managers to identify the suite of possible management alternatives for each forest type and planning unit. These manager defined forest structural treatments will be applied in FVS with the species specific growth-climate parameters determined from the process-based model to determine how each overstory species within the TEUI forest community types will respond under the three $CO_2$ scenarios.

**Testing Landscape Treatment Scenarios with SIMPPLLE**

The re-parameterized FVS will be used to make growth predictions that will be input into the spatially explicit landscape model, SIMPPLLE (Figure 2). SIMPPLLE was developed as a planning tool for identifying disturbance prone areas and management actions that can influence these disturbance processes (Chew et al. 2004). It is an effective tool for evaluating fire risk and spread under different management alternatives and climate scenarios (Figure 2). We will initiate fire events based on probabilities developed from 1990-2007 and probabilities developed for the medium-high and low emissions scenarios used to model climate change in California (Westerling and Bryant 2006).

SIMPPLLE has been used in Yosemite National Park to recreate system processes beginning from 1930's (Chew et al. Draft Report). The findings of this particular study indicate that 'fine-tuning' the model is necessary to accurately assess site specific processes. To accomplish this, Chew et al. (Draft Report) recommend that significant local knowledge is necessary. To minimize error inherent in any modeling exercise, we will work with local land managers to gather site and forest type specific variation to incorporate in 'fine-tuning' the SIMPPLLE model.

## Strategy for Engaging with Managers

We have selected FVS as the growth and yield model for this project because it is used extensively by managers to inform project planning and SIMPPLEE because it was developed specifically as a management decision support system and is currently being integrated into management planning. To ensure that the re-parameterized version of FVS is available for Basin forest managers we will develop a website that will provide access to the model, as well as links to all data necessary to drive the model and all documentation. Additionally we will develop and hold a series of workshops for managers in the Basin. These workshops will allow managers the opportunity to bring a forest inventory data set and a set of potential management actions to simulate stand level response under predicted climate scenarios.

## Deliverables/products

We will provide local managers with the re-parameterized climate scenario specific version of FVS. All modeled future tree-growth relationships and data necessary to conduct further simulations will be made freely available. All simulation outputs of forest response to the selected suite of management actions under the three atmospheric $CO_2$ concentration scenarios will be supplied to managers in the Basin.

A series of workshops will be developed that will inform Basin managers as to model results of each treatment-climate simulation and identify other possible management alternatives. We will also provide advanced model training for individuals whom would like to hold continued planning workshops.

Publications: the findings of this study will be presented in peer-reviewed publications and at scientific meetings. We anticipate 2 peer-reviewed publications and several presentations at regional and national meetings.

## Schedule of Deliverables

| Deliverable | Description | Delivery Dates(s) |
|---|---|---|
| Quarterly Reports | Update on project accomplishments and invoices | September, December, March, and June 2008-2010 |
| Identification of TEUI sites | Site selection using GIS and site visits | Fall 2008 |
| Data Aggregation | Work with Basin Managers to gather TEUI data. | Fall 2008 |
| Data Collection | Field data collection in Lake Tahoe Basin | Summer 2009 |
| Process-based model parameterization and validation | Parameterize model using 2009 field data and validate using 2010 field data | Winter 2008 and Fall 2009 |
| Manager Meetings | Meet with Basin managers to identify forest treatment options | Summer 2008 |
| Modeling | FVS simulations incorporated into SIMPPLLE | Winter 2010 |
| Workshop series | Manager workshops to present results and identify any additional treatment options | Spring 2010 |
| Results | Presentation of results at regional and national conferences | Summer/Fall 2010 |
| Articles | Peer-reviewed scientific articles (2) | Fall 2010 |

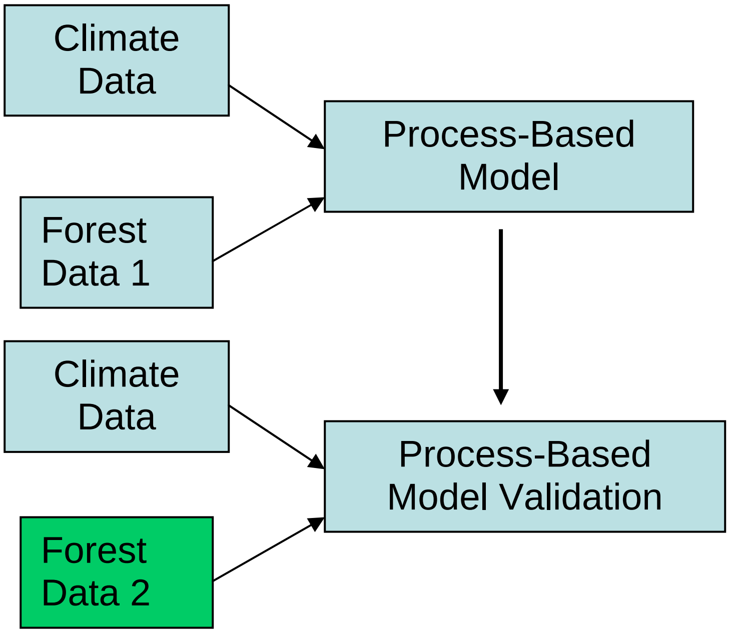


Figure 1: Process-based model parameterization and validation methodology.

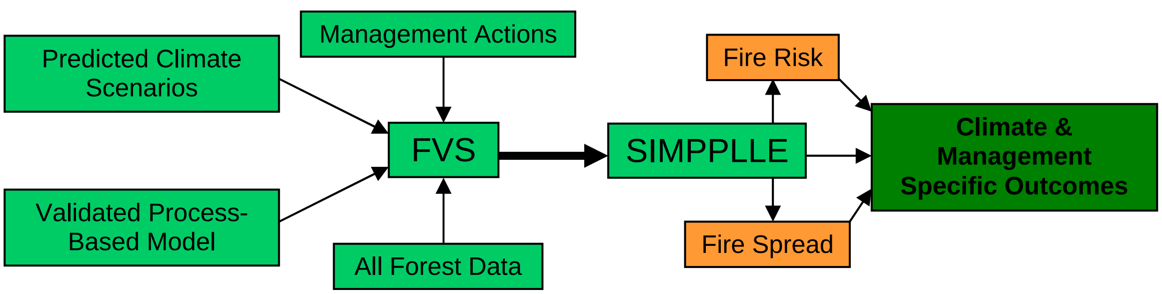


Figure 2: Modeling process incorporating the validated process-based model, predicted climate scenarios, FVS, and SIMPPLLE used to produce an assessment of fire risk and spread under manager selected treatment alternatives.

## Literature Cited


Briffa, K.R. F.H. Schweingruber, P.D. Jones, T.J. Osborn, S.G. Shiyatov, and E.A. Vaganov. 1998. Reduced sensitivity of recent tree-growth to temperature at high northern latitudes. Nature 391:678-682.

Brown, J.K. 1974. Handbook for inventorying downed woody material. USDA Forest Service General Technical Report GTR-INT-16 26pp.

Brown, T.J., B.L. Hall, and A.L. Westerling. 2004. The impact of twenty-first century climate change on wildland fire danger in the western United States: an applications perspective. Climatic Change 62:365-388.

Burnham, K.P. and D.R. Anderson. 2002. *Model selection and multimodel inference: A practical information-theoretic approach* 2nd ed. Springer, New York, NY. 488pp.

Cayan, D., E. Maurer, M. Dettinger, M. Tyree, K. Hayhoe, C. Bonfils, P. Duffy, and B. Santer. 2006. Climate scenarios for California. California Climate Change Center.

Chew, J.D., C. Stalling, and K. Moeller. 2004. Integrating knowledge for simulating vegetation change at landscape scales. Western Journal of Applied Forestry 19:102-108.

Chew, J.D., E. Bella, K. Moeller, and C. Stalling. Draft Report. Yosemite retrospective analysis using SIMPPLLE. USFS, RMRS, Forstry Sciences Lab, Missoula, MT.

Constable, J.H.V. and A.L. Friend. 2000. Suitability of process-based tree growth models for addressing tree response to climate change. Environmental Pollution 110:47-59.

Crookston, N.L. and G.E. Dixon. 2005. The forest vegetation simulator: a review of its structure, content, and applications. Computers and Electronics in Agriculture 49:60-80.

ESSA Technologies Ltd. 2007. Development of a climate-driven forest vegetation simulator: the Priest River Experimental Forest workshop results. Prepared by ESSA Technologies Ltd., for Rocky Mountain Research Station, USDA Forest Service, Moscow, Idaho and the Forest Management Service Center, USDA Forest Sercive, Fort Collins, CO. 14pp.

Fagre, D.B., D.L. Peterson, and A.E. Hessl. 2003. Taking the pulse of the mountains: ecosystem response to climatic variability. Climatic Change 59:263-282.

Flannigan, M.D., B.J. Stocks, and B.M. Wotton. 2000. Climate change and forest fires. The Science of the Total Environment 262:221-229.

Garcia-Gonzalo, J., H. Peltola, E. Ericeno-Elizondo, S. Kellomaki. 2007. Changed thinning regimes may increase carbon stock under climate change: A case study from a Finnish boreal forest. Climatic Change 81:431-454.

Guarin, A. and A.H. Taylor. 2005. Drought triggered tree mortality in mixed conifer forests in Yosemite National Park, California, USA. Forest Ecology and Management 218:229-244.

Hurteau, M. and M. North. *In review*. Fuel Treatment Affects on Forest Carbon Storage and Emissions under Modeled Wildfire Scenarios. *Frontiers in Ecology and the Environment.*

Hurteau, M., H. Zald, and M. North. 2007. Species-specific response to climate reconstruction in upper-elevation mixed-conifer forests of the western Sierra Nevada, California. Canadian Journal of Forest Management 37:1681-1691.

Landsberg, J.J. and R.H. Waring. 1997. A generalised model of forest productivity using simplified concepts of radiation-use efficiency, carbon balance and partitioning. Forest Ecology and Management 95:209-228.

Lindner, M. 2000. Developing adaptive forest management strategies to cope with climate. Tree Physiology 20:299-307.
Mäkelä, A., J. Landsberg, A.R. Ek, T.E. Burk, M. Ter-Mikaelian, G.I. Agren, C.D. Oliver, and P. Puttonen. 2000. Process-based models for forest ecosystem management: current state of the art challenges for practical implementation. Tree Physiology 20:289-298.
Matala, J., R. Ojansuu, H. Peltola, R. Sievanen, and S. Kellomaki. 2005. Introducing effects of temperature and $CO_2$ elevation on tree growth into a statistical growth and yield model. Ecological Modelling 181:173-190.
Millar, C.I. and W.B. Woolfenden. 1999. The role of climate change in interpreting historical variability. Ecological Applications 9:1207-1216.
Milner, K.S., D.W. Coble, A.J. McMahan, and E.L. Smith. 2003. FVSBGC: a hybrid of the physiological model STAND-BGC and the forest vegetation simulator. Canadian Journal of Forest Research 33:466-479.
Slaton, M.R., A.J. Gallegos, H.D. Safford, and D. Downie. 2006. Lake Tahoe Basin Management Unite landtype association ecological unit inventory USFS R5 pilot study. USDA Forest Service, Pacific Southwest Region, Ecology Program. 333pp.
Stocks, B.J., M.A. Fosberg, T.J. Lynham, L. Mearns, B.M. Wotton, Q. Yang, J-Z. Jin, K. Lawrence, G.R.Hartley, J.A. Mason, and D.W. McKenney. Climate change and forest fire potential in Russian and Canadian boreal forests. Climatic Change 38:1-13.
Taylor, A.H. and R.M. Beaty. 2005. Climatic influences on fire regimes in the northern Sierra Nevada mountains, Lake Tahoe Basin, Nevada, USA. Journal of Biogeography 32:425-438.
Westerling, A.L., H.G. Hidalgo, D.R. Cayan, and T.W. Swetnam. 2006. Warming and earlier spring increase western U.S. forest wildfire activity. Science 313:940-943.
Westerling, A.L. and B. Bryant. 2006. Climate change and wildfire in and around California: fire modeling and loss modeling. California Climate Change Center.
Wilmking, M., G.P. Juday, V.A. Barber, and H.S.J. Zald. 2004. Recent climate warming forces contrasting growth responses of white spruce at treeline in Alaska through temperature thresholds. Global Change Biology 10:1724-1736.
Wykoff, W.R. 1986. Supplement to the user's guide for the stand Prognosis model version 5.0. GTR-INT-208. Intermountain Forest and Range Experiment Station, Ogden, Utah. 36pp.