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Modeling Fuels and Fire Effects in 3D with FuelManager and STANDFIRE

François Pimont*
INRA URFM, Avignon, France, francois.pimont@avignon.inra.fr

Russell Parsons
USFS RMRS, Missoula, Montana, USA, rparsons@fs.fed.us

Eric Rigolot
INRA URFM, Avignon, France, eric.rigolot@avignon.inra.fr

Jean-Luc Dupuy
INRA URFM, Avignon, France, jean-luc.dupuy@avignon.inra.fr

François de Coligny
INRA AMAP, Montpellier, France, coligny@cirad.fr

Rodman Linn
LANL EES, Los Alamos, New Mexico, USA, rrl@lanl.gov

Introduction

Scientists and managers need robust ways to assess how fuel treatments alter fire behavior, yet few tools currently exist for this purpose. In recent years, the physics-based fire models FIRETEC (Linn and Cunningham 2005, Pimont *et al.* 2009, Dupuy *et al.* 2011) and WFDS (Mell *et al.* 2007) have shown promise in this context since they explicitly account for 3D fuel structure (Pimont *et al.* 2011). However, there remains a need for tools which facilitate getting fuel data into these models as well as for assessments of how fuel changes affect fire behavior, both immediately and over time. Here, we introduce two spatially-explicit-fuel-modeling systems designed to interact with these models, called FuelManager (Pimont *et al.* 2016, Rigolot *et al.* 2010) and STANDFIRE. Both systems are modules in, and build upon, the common architecture of the CAPSIS (Computed Aided Projection of Strategies in Silviculture) platform[1] (Dufour-Kowalski *et al.* 2012), an integrated modeling framework for forestry research, and enable fuel data from various sources to be used as inputs to physics-based fire models. Both modules rely on the *Fire* library, that also enables simulation of fuel treatments and fire effects.

Model Description

The Fire library – for more information see http://capsis.cirad.fr/capsis/help_en/firelib

The *Fire* library is a computer code library which represents wildland fuels as spatially-explicit 3D objects in a CAPSIS scene (Fig. 1). Different kinds of vegetation are represented in either as *Plants* (with specific coordinates and dimensions) or as collections of plants called

* INRA, UR629, Domaine de Saint Paul, Agroparc F-84914 Avignon Cedex 9, France.
[1] http://www.inra.fr/capsis

LayerSets. Both approaches include descriptions of multiple fuel *Particle* types (leaves, needles and twigs of various sizes, either live or dead), characterized by their mass to volume ratio, surface area to volume ratio and moisture content. Each *Plant* has a position, a diameter at breast height, crown dimensions and geometry. Each particle type associated with a given *Plant* has a mass and a vertical distribution within the crown, typically computed using DBH and H allometries. A *LayerSet* is a flexible approach for representing groups of plants when it is impractical to describe them as individual plants. Within a *LayerSet*, various fuel components can be mixed together and assigned different characteristics. A *LayerSet* occupies a volume of space within a *Scene* and is represented as a right prism with a polygonal base face parallel to the ground.

The *Fire* library enables the computation of fuel properties, such as loads and cover fractions in a given strata, or to visualize the scene in 3D. The *Fire* library also provides a number of ways to apply fuel treatments, such as thinning, either to the whole scene or to specific areas within a scene. The primary purpose of this library, however, is to enable the export of a fuel scene as inputs to FIRETEC or WFDS to simulate fire behavior. Because these fire models capture key interactions between the fuels, fire and atmosphere, they provide unique capabilities for assessing how fuel changes affect fire behavior. Additionally, fire model outputs such as local fire intensities and residence times provide useful data to estimate fire effects to trees, using empirical models of damage and mortality, such as Van Wagner (1973) and Peterson and Ryan (1986).

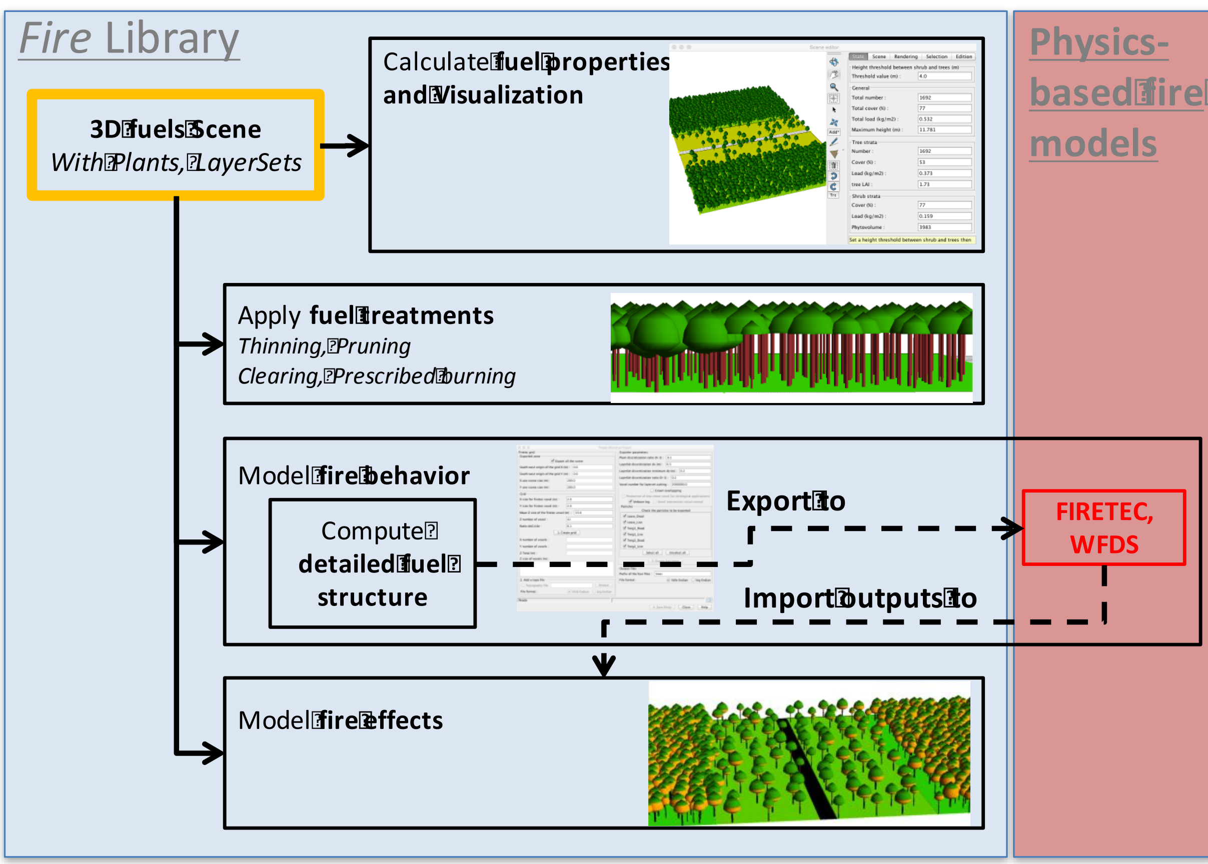

Figure 1: Features available in the *Fire* library (used by FuelManager and STANDFIRE).

STANDFIRE – for more information see: http://capsis.cirad.fr/capsis/help_en/standfire

In the US, FFE-FVS (Crookston and Nixon 2005) is the primary tool used to assess how fuel treatments affect fire at stand scales. STANDFIRE extends FFE-FVS' capabilities by connecting it to physics-based fire models, while continuing to use FVS to model growth over time. The core of the module relies on the *Fire* library described above, but STANDFIRE also includes additional components to import data from FFE-FVS and to read additional files required to build the scene, which describe fuel particle characteristics and tree crown geometry (Fig. 2). STANDFIRE also includes post processors for the WFDS model. In most cases, when users do not have spatially explicit data, STANDFIRE uses the Stand Visualization System (SVS) file, which has tree coordinates, to model trees in 3D. This one-acre square can be extended with STANDFIRE to cover larger extents by sampling from the tree data in the SVS file. Default values are available for fuel properties when those values or equations are unknown. To date, this is the first system to link FVS-FFE and physics-based models.

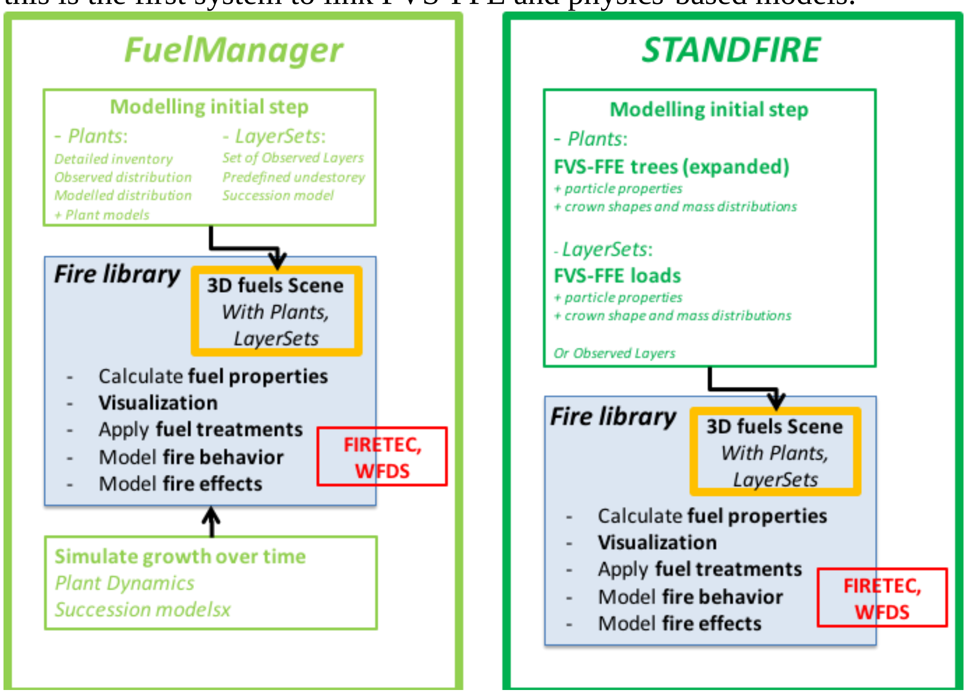

Figure 2: Architecture of FuelManager and STANDFIRE modules

FuelManager (for more information see: http://capsis.cirad.fr/capsis/help/fireparadox)

FuelManager was developed as a stand-alone module to build input data for physics-based models (Pimont *et al.* 2016). The core of the module is again the *Fire* library, but FuelManager includes its own models for *Plant* distributions, based on either detailed inventories (stem map), observed distributions of stem (by DBH classes) or modeled distributions. FuelManager includes some growth models for *Plants* and a succession model for *LayerSets* to simulate growth over time.

Example applications

Building FIRETEC input data for the International Crown Fire Modeling Experiment (ICFME). The ICFME crown fire experiment is a key dataset for physics-based model evaluation. Field data (Alexander et al. 2004) were used to parameterize individual *Plant models* in FuelManager. Three dimensional fuel scenes were then generated for use as input for FIRETEC for the full extent of the experiments by sampling from observed tree stem distributions. Data for four plots were used to compare predictions of fire behavior and radiant fluxes with experimental values (Pimont *et al.* 2014) (Fig. 3).

a) b)

Figure 3: Comparison between (a) Photograph of ICFME experiment and (b) modeled aerial view using FuelManager

Investigating fuel management scenarios (Pimont et al. 2016)

FuelManager and STANDFIRE both benefit from the CAPSIS architecture for modeling vegetation changes over time and with fuel treatments. This allows comparison of alternative states resulting from various sequences of events.

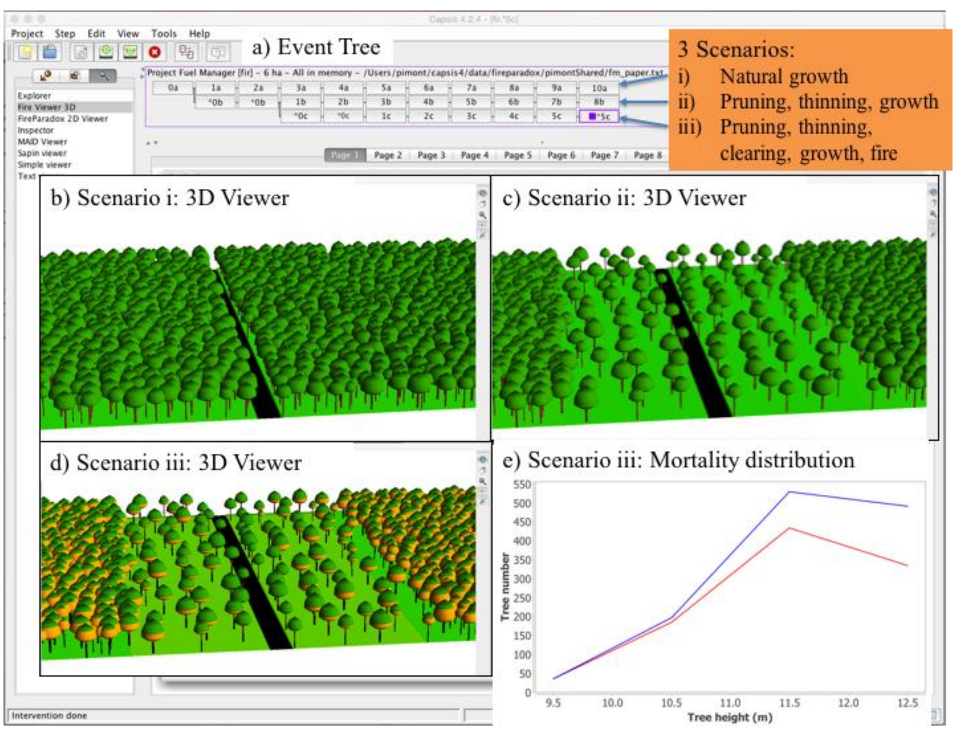

Figure 4: Views of FuelManager GUI illustrating Aleppo pine stands following three sequences of events: a) Event tree b) Initial stand with road passing through forest c) Crown spacing-based thinning to specified distance

from road d) Visualization of modeled crown scorch from prescribed fire, and e) Comparison of the distribution of modeled killed trees (in red) to the pre-fire distribution (in blue).

Comparison of crown space thinning fuel treatments with STANDFIRE

Using fuels data measured at the Tenderfoot Experimental Forest in central Montana, we used STANDFIRE and WFDS to examine the potential changes in fire behavior that might arise with different thinning treatments. Figures 5a and b shows 3D fuels and fire behavior at the same point in time for four different simulations with different crown space thinning, and three associated change metrics for each of those simulations.

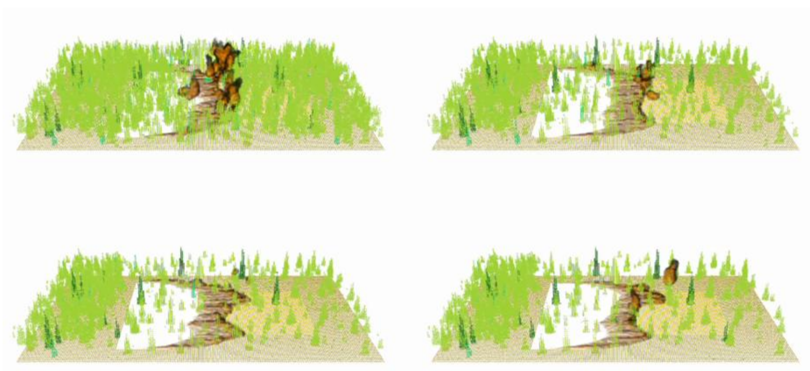

Figure 5a. 3D fuels and fire behavior at the same point in time for four different simulations with different crown space thinning: (upper left: no thinning; upper right, 5’ crown spacing; lower left, 10’ crown spacing; and lower right, 15’ crown spacing.

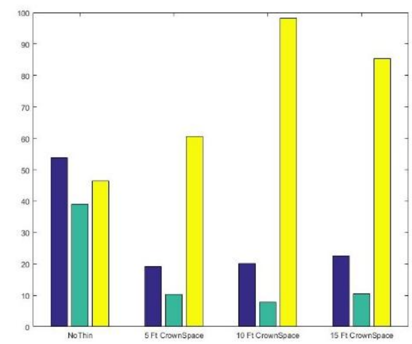

Figure 5b. 3 metrics of change for each simulation shown at left: 1) canopy fuel mass loss (%, blue bars), predicted mortality (%, green bars) and surface fire rate of spread (m min^{-1}, yellow bars).

Discussion and conclusion

FuelManager and STANDFIRE provide detailed fuel inputs for physics-based fire models, FIRETEC and WFDS, and can be used to explore how fuel management efforts may affect fire behavior. They integrate a wide range of fuel modeling capabilities, numerous recent fire-effect research results and recent technologies for visualization and *Scene* manipulation to provide a suite of capabilities relevant to examinations of fuel management scenarios.

FuelManager has shown to be a powerful and flexible tool in the context of fuel modeling, offering various applications (Pimont *et al.* 2016). STANDFIRE is in active development but more documentation is forthcoming. Both modules increase our capabilities to examine relationships between fuels, fire behavior and fire effects. They also increase the robustness of fire modeling studies using FIRETEC and/or WFDS, since input data are built in a transparent and reproducible manner.

At present, only thirteen species (mostly European fire prone species) are represented in FuelManager, but users can easily incorporate simple *Plant* models for other species without additional coding, since pre-defined equations and parameters can be defined in a separate text file (*speciesFile*[2]). Equations for crown dimension and biomass are often available in literature. Vertical distributions are less often available, but the user can rely on those already available in

[2] http://capsis.cirad.fr/capsis/help_en/firelib/speciesfile

the *speciesFile*. STANDFIRE will ultimately apply to a much larger set of species and ecosystems, since it builds connections to the US system FFE-FVS, which is widely used to facilitate fuel modeling throughout the United States.

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