THE FUEL TREATMENT EVALUATOR - A SILVICULTURAL APPROACH TO REDUCING FIRE HAZARD

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Abstract

The Fuel Treatment Evaluator (FTE 3.0) is a web-based tool that can be used to explore the impacts of alternative thinning intensities for any forest area in the United States. This paper will explain the Stand Density Index-based prescription engine used in uneven-aged scenarios in the FTE 3.0 program and present examples of uneven-aged fuels treatment activity prescriptions that can be developed.

Introduction

Over the past few years land managers and the public have become aware that the conditions of some forests in the United States have been slowly changing and that many forests are subject to more intense wildfire behavior than what occurred in the past. The magnitude of the problem requires the development of strategic planning tools to estimate the fuel conditions at a spectrum of scales and evaluate alternate treatment scenarios. Factors that hamper efforts to do so include the lack of consistent and comparable inventory databases, and the inability to estimate fire risk, evaluate treatment alternatives, estimate biomass removal quantities and estimate costs for a spectrum of forest types at landscape and larger scales.

The Fuel Treatment Evaluator (FTE 3.0) (Miles and others, 2004, 2005) is a web-based tool that has been developed to meet these needs. It can be used to select specific forest types in a geo-political region, estimate wildfire risk parameters for specified conditions, and explore the impacts and economics of alternative treatment strategies in reducing wildfire risk. It is primarily a strategic and planning tool intended to analyze the impacts of alternative thinning treatments on stands having similar characteristics such as forest type, topography, productivity and presence in a wildland urban interface (WUI). Using the USFS Forest Inventory and Analysis (FIA) Resources Planning Act (RPA) 2002 database, the Fuel Treatment Evaluator can estimate biomass yields from a suite of fuels treatment prescriptions that reduce stocking by diameter class under even- or uneven-aged management scenarios. The goal of these treatments is to reduce both the Crowning Index (CI),or wind speed at which a forest is likely to sustain a crown fire and Torching Index (TI), the wind speed that individual tree crowns are likely to be consumed.

The reader is referred to Miles and others (2005) for specific explanations of the logic behind treatment scenarios available in the FTE 3.0 program. The purpose of this paper is to present a detailed explanation of the prescription engine that uses Stand Density Index (SDI) as a stocking guide to drive the uneven-aged fuels treatment scenarios in the FTE 3.0 program.

A Brief Review of Stand Density Index

SDI was conceived by Reineke (1933) to describe the empirical relationship between quadratic mean stand diameter (D_q) and stem density (N) in even-aged forests. He noticed that a consistent pattern existed between average tree size and average stand density when data from numerous stands were plotted on a log/log scale (Fig. 1). A thorough and comprehensive review of the history of SDI and an evaluation of the various ways of calculating it was presented by Ducey and Larson (2003) and will not be repeated here.

However, Reineke originally chose to express the tree size/density relationship mathematically and derived the following equation to estimate Stand Density Index:

$$SDI = N(D_q/10)^{1.605}$$

Where: N = stems ac^{-1}
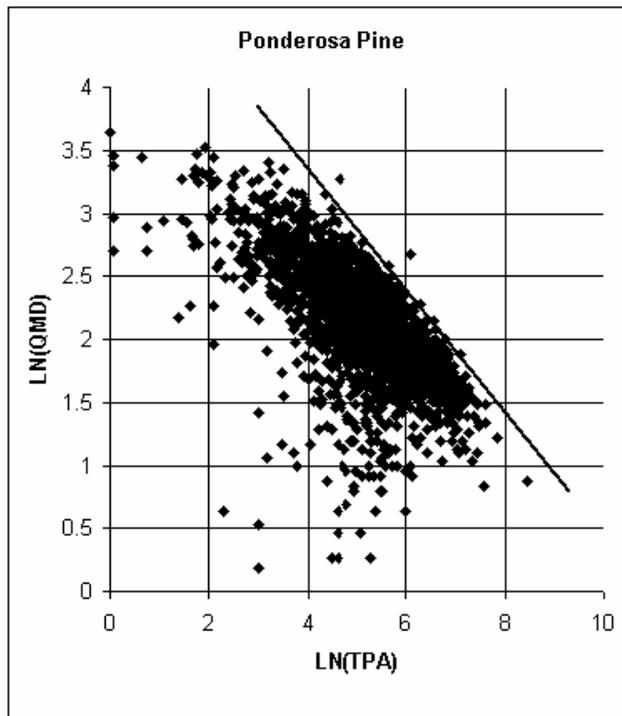And D_q = quadratic mean stand diameter in inches

Figure 1. Stem density (TPA) versus quadratic stand diameter (QMD) for ponderosa pine in Colorado, plotted on log normal scales with SDImax = 450 line (from FIA data).

Obviously, if D_q = 10 inches, then SDI = N. Since D_q can be other than 10 inches, SDI is really a unitless index most of the time, but it can be thought of as being equivalent to the number of 10-inch trees that might occur in a forest of a given basal area. Reineke considered SDI to be a universal index because the slope of the pattern shown in Fig. 1 occurred among all species that he investigated, although the height of the data swarm varied by species due to differences in shade tolerance and canopy architecture. This means that while the same SDI equation can be used universally among tree species, each species will have a unique maximum SDI value. The use of a 10 inch size standard in the SDI equation allows the maximum SDI value for a tree species to be estimated by dividing the maximum stand basal area found in the population by the basal area of a 10-inch tree (0.5454 ft^2):

$$SDI_{max} = (BA_{max} \text{ ft}^2/0.5454 \text{ ft}^2)$$

Stocking in any given stand can therefore be expressed as a percentage of SDI_{max}, which provides a handy benchmark for comparing existing stocking against a known maximum possible density for a given population. It should be noted that a population should encompass either the entire geographic distribution of a species or an eco-region defined by unique growing conditions or genetic variation.

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Modifying SDI for use in Uneven-Aged Management

Long and Daniel (1990) presented a modification of SDI for use in uneven-aged forests. They proposed calculating a partial SDI for each diameter class, and then summing the values to obtain an overall stand SDI in the following manner:

$$SDI = \sum N_i \, (D_i/10)^{1.605}$$

Where: N_i = stems ac^{-1} in diameter class i
And D_i = mid-point (in inches) of diameter class $_i$

This equation can be utilized to proportion desired post-harvest target stocking evenly among diameter classes by calculating a target stocking density for each diameter class (D_i) in the stand. First, a target SDI (SDI_t) is estimated by dividing the percentage of maximum SDI desired for the residual stand by the number of dbh classes in the stand. SDI_t is then substituted for SDI in the above equation and solved for N_i giving:

$$N_i = SDI_t/(D_i/10)^{1.605}$$

This procedure results in stem ac^{-1} stocking values across diameter classes that typify the "reverse J" target stocking curve associated with uneven-aged forests. In this case, each dbh class contains an equal proportion of the overall desired percentage of maximum SDI for the stand. While this procedure allows the overall target stocking to be adjusted to any percent of maximum SDI, the even apportionment of SDI over all diameter classes does not provide the ability to adjust the slope of the resulting stocking curve, as could be done by changing the Q value in BDQ stocking control. The result is a high number of small trees being retained regardless of the percentage of maximum SDI prescribed. This shortcoming hinders the flexibility and usefulness of the Long and Daniel approach, especially when open understories are needed (e.g. prescribing uneven-aged treatments to reduce crown fire risk).

> **Comment [m1]:** Could a reference to BDQ be added here?

The SDI-FLEX Procedure used in the Fuels Treatment Evaluator

The alternative method used in the FTE 3.0 program to calculate residual stocking for uneven-aged fuels treatment options is a modification of the Long and Daniel (1990) approach. Called SDI-FLEX, the technique proportionally reduces the amount of stocking assigned to successively smaller dbh classes, allowing the shape of the SDI target stocking curve to be changed as well as its height (Fig. 2). This permits the user to specify an infinite variety of uneven-aged stocking distributions and estimate the potential effect that thinning to these stockings would have on fire behavior in stands selected from the RPA database. Stand characteristics can be altered to meet multiple resource needs while still reducing wildfire risk for selected stands. For example, denser understories can be provided to stimulate the development of good stem form, provide hiding cover, or discourage the development of undesirable shrubs.
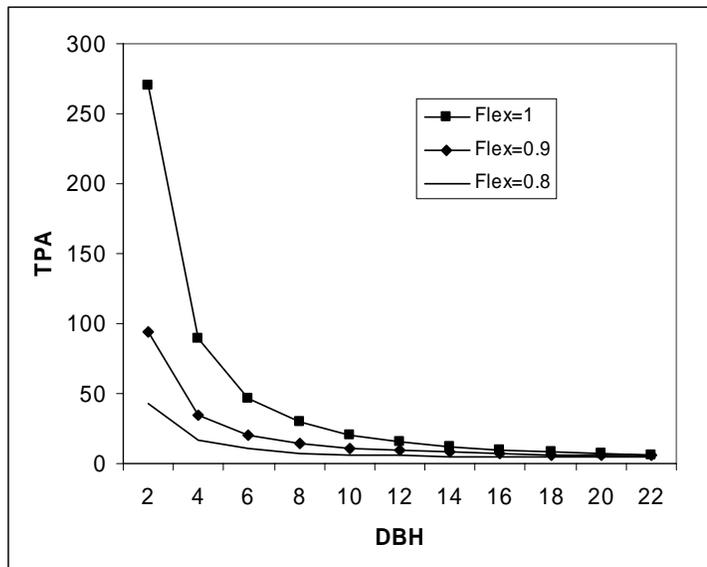
Figure 2. Flexing the distribution of SDI allows both the height and shape of a desired stocking curve to be changed.

Or, conversely, sparse, open understories can be created to favor forage growth or reduce live ladder fuels where crown fire risk is a concern. Figure 3 illustrates the dramatic effect that flexing SDI can have on the appearance of a forest. The only limitation that should be placed on the development of uneven-aged stocking curves derived in the FTE program is that sufficient numbers of trees should be retained in smaller diameter classes to grow into and replace trees in larger classes (e.g. the stocking curve should always slope slightly downward to the right to retain the "reverse J" shape).

Two user-specified parameters control the shape of the target stocking curve in the FTE 3.0 program, the seed and the flex factor. The seed controls the overall level of stocking within the target stand. The flex factor varies from 0.844 to 1.0 and controls the shape of the stocking curve by proportionally reducing partial SDI values in successively smaller dbh classes. Setting the flex factor to 1.0 results in an even apportionment of SDI over all dbh classes, as with the Long and Daniel (1990) procedure. Using a value less than 1.0 flattens the stocking curve, reducing the number of trees in smaller dbh classes. A lower limit of 0.844 for the flex factor is recommended so that smaller dbh classes always have more stems than larger classes. This is a hallmark of any actuarial table for an uneven-aged population – younger individuals must always outnumber older ones to account for age-dependent mortality through time.
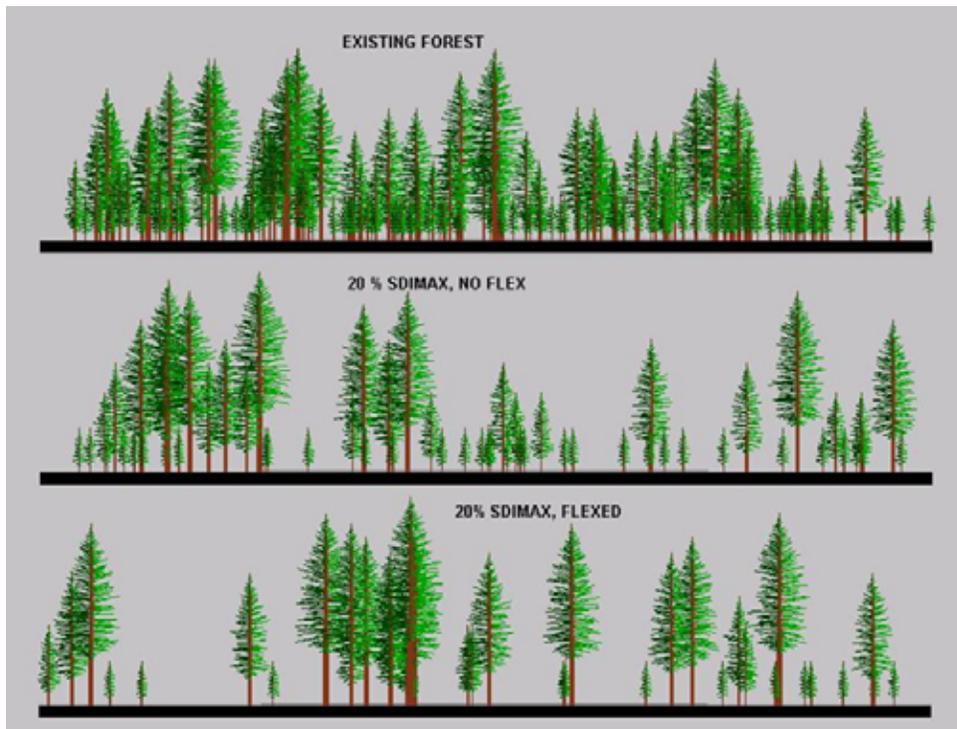
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Figure 3. The stand at the top was thinned to 20% SDImax using an even apportionment of SDI to all diameter classes (center) and a Flexed apportionment that kept overall stocking at 20% SDImax, but reduced stocking in smaller diameter classes (lower).

The seed parameter is a decimal value less than 1.0 and is used to adjust overall stocking to a desired percentage of maximum SDI. It will be equivalent to the percent of SDI_{max} desired for the target stand if all diameter classes are fully stocked and the flex factor is set to 1.0. However, if the flex factor is set at a value less than 1.0 the seed is no longer equivalent to SDI_{max} due to the sequential reduction of SDI assigned to smaller dbh classes. Therefore in practice, the user must iteratively manipulate both the seed and flex until the desired percentage of SDI_{max} is reached, or the desired fire risk reduction is achieved.

Actual stocking distributions often don't follow such idealized population distribution curves as those specified by the seed and flex parameters. Some age classes may be overstocked and others understocked with respect to the curve. Therefore, we have designed the FTE 3.0 program to account for such differences by calculating the actual stocking that would exist in a stand after treatment under the specified parameters. This means that predicted stocking levels after treatment may be less that that specified by the SDI-FLEX parameters.

Using the Fuel Treatment Evaluator

The FTE 3.0 program is a web-based application that can be accessed at:
http://www.ncrs2.fs.fed.us/4801/fiadb/FTE_TEST/FTE_TESTWC.ASP

Once there, the user will be asked to specify the following criteria :
- Select State/County, or specify polygon, or circle defined by Lat/Long.
- Select criteria to specify data selection
  - Drought characteristics
  - Crowning Index (CI) and Torching (TI) treatment criteria
  - CI and TI retrieval criteria
  - Fire condition class
  - Wildland Urban Interface (WUI) class
  - Minimum harvest level
  - Ownership class/National Forest
  - Stand age to be treated
  - Slope to treat
  - Forest type
  - Stand origin (natural/artifical)
  - Site productivity class
  - Physiographic class
- Specify economic valuation criteria (Prices per unit for softwoods and hardwoods)
- Choose Forest Vegetation Simulator (FVS) ready output if desired and specify FVS variant
- Enter a Project name
- Select one of the Silviculture Treatment Scenarios listed below:
  - Scenario 1A - Unevenaged - leaving high structural (dbh) diversity
  - Scenario 2A - Unevenaged - leaving limited structural (dbh) diversity
  - Scenario 3A - Evenaged - thin from below up to 50% of initial basal area
  - Scenario 4A - Evenaged - thin from below up to 25% of initial basal area
  - Scenario 1B - Scenario that takes out the most large trees
  - Scenario 2B - Scenario that takes out the most small trees
  - Scenario 3B - Thin from below to a maximum of 50% of initial basal area
  - Scenario 4B - Thin from below to take out 25% of initial basal area
  - Scenario 5 - User defined FlexFactor and MaxSDI Seed (Enter Flex Factor and SDI_{max} Seed if selected)
- Submit

The goal of all treatment scenarios except Scenario 5 is to attain (TI) and (CI) values of 25 miles per hour or greater (one value may initially be above 25 mph). Under the uneven-aged scenarios the FTE 3.0 program sets flex and seed parameters in an iterative fashion to seek the TI and CI solutions. To achieve the goal of retaining as many small trees as possible, the Flex is set to 1.0 in Scenarios 1A and 1B and the seed iteratively lowered from 1.0 until a solution is found. However, removals in Scenario 1A are limited to 50% of existing BA and the CI solution capped at 40 mph to avoid removing all large trees. Conversely, in Scenarios 2A and 2B Flex is set to 0.844 to remove as many small trees as possible as the Seed is iteratively lowered from 1.0 to seek a solution. The same limitations are applied to Scenario 2A as in 1A to avoid drastic reductions in stocking while trying to seek TI and CI solutions. These limitations were imposed to allow users to compare uneven-aged solutions that reduce fire risk at all cost (1B and 2B) against alternatives that retain the some of the original structural integrity of the forest (1A and 2A).

FTE 3.0 Uneven-aged Prescription Examples

To illustrate the differences between alternative uneven-aged scenarios used in FTE 3.0 we performed two FTE runs utilizing the following data selection criteria:

- All Colorado counties
- Fire Condition Class 3 only
- WUI only
- National Forest land only
- No minimum harvest
- All ages and slopes
- Ponderosa pine forest type
- All stand origin, site productivity, and physiographic classes

We selected Scenario 1A (Flex = 1.0, floating seed, 50% BA removal limit, and 40 mph CI cap) for the first run and Scenario 2B (Flex = 0.844, floating seed, no limitation on removals until TI and CI goals are met) for the second run. The first run tried to retain as many small trees as possible for maximum structural diversity (Fig. 4). The second run allowed greater removals of small trees to meet CI and TI goals while retaining future replacement trees for the resulting uneven-aged forest (Fig. 5). While the differences between these two scenarios appear subtle, the effect on crown fire behavior is more dramatic. Considerably fewer acres of ponderosa pine forest on National Forest System lands in Colorado could be moved to higher Crowning Indices under the Scenario 1A prescription (Fig. 6) than under the Scenario 2B prescription (Fig. 7).

The FTE program produces numerous other tabular and graphic summaries of predicted treatment effects for the selected data in addition to the data shown in Figs 1-4. In particular interest to economists and planners is a link to the Forest Inventory Mapmaker program that allows map projections of treatments to be generated, such as the projected ponderosa pine biomass yield county in Colorado that would occur under Scenario 1A modeled above (Fig. 8).

Discussion

The SDI-FLEX procedure used in the Fuels Treatment Evaluator program provides an easy to use and highly effective means of estimating potential biomass yields under uneven-aged silviculture prescriptions that might be applied to a particular forest type over large areas. The procedure is based on a long-accepted empirically-derived stocking guide that is unique to each tree species. Residual stocking can be adjusted to meet a variety of management needs, while retaining an expectation of the forests potential for future production and growth.
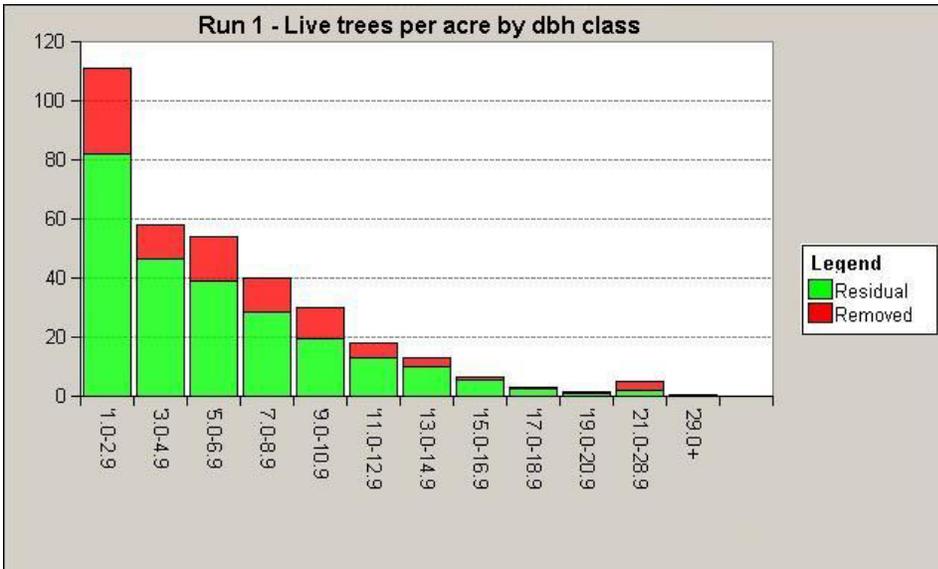
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Figure 4. Results from first of two Fuels Treatment Evaluator runs using an SDI-based uneven-aged fuels treatment prescription applied to ponderosa pine on national forests in Colorado. The goal was to raise crowning and torching indices above 25 mph while emphasizing retention of trees in smaller diameter classes.
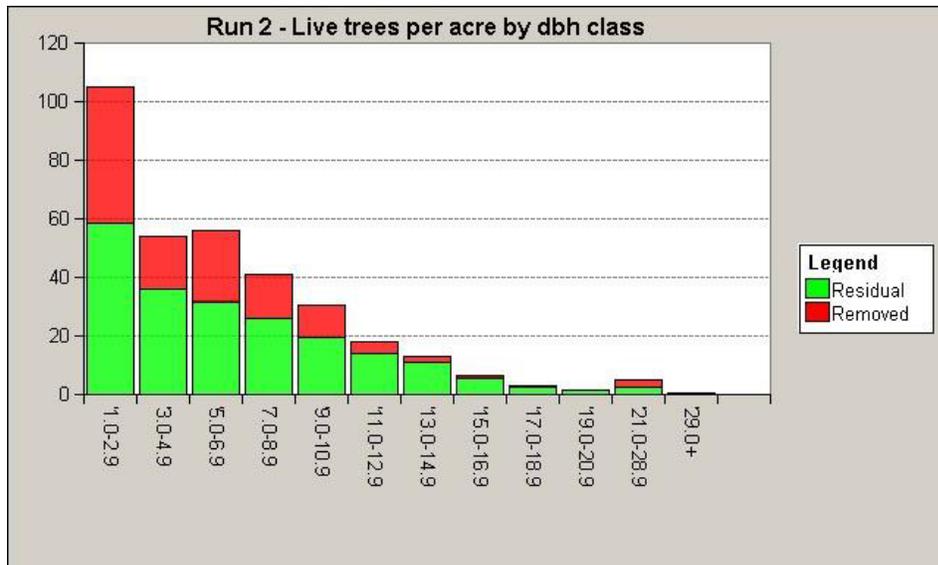

Figure 5. Results from second of two Fuels Treatment Evaluator runs using an SDI-based uneven-aged fuels treatment prescription applied to ponderosa pine on national
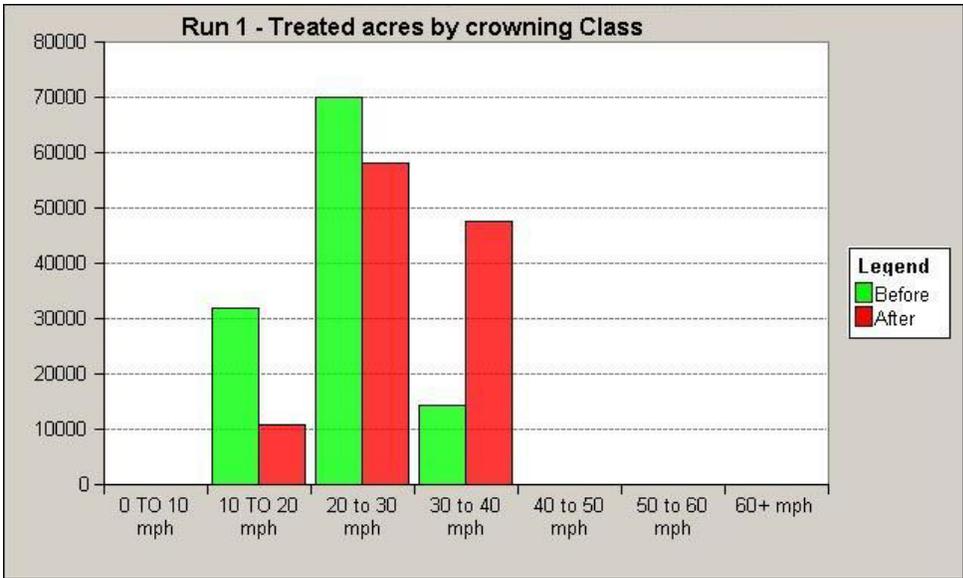
Figure 6. Distribution of ponderosa pine acres on national forests in Colorado by crowning index class, before and after the SDI-based treatment scenario in Figure 4 (flex = 1.0, floating seed, 50% BA removal limit, 40 mph CI cap).
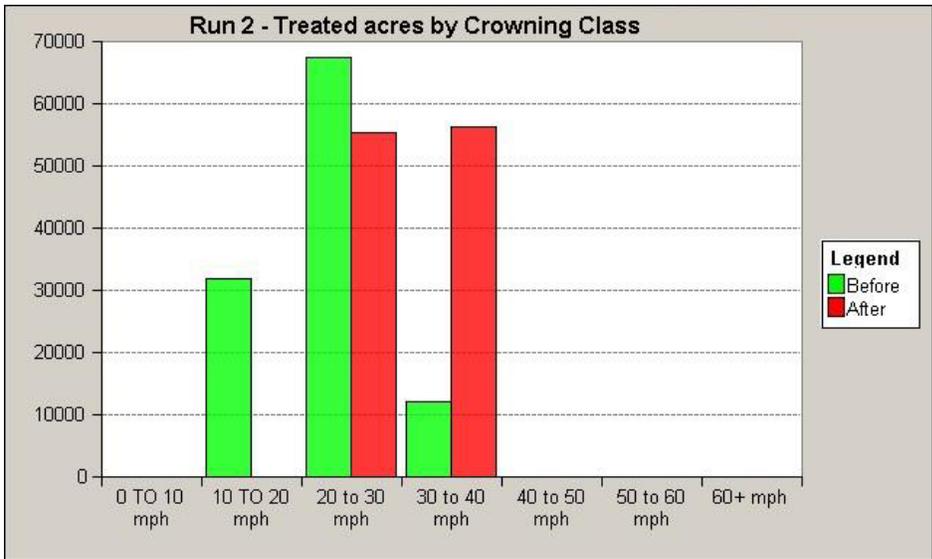

Figure 7. Distribution of ponderosa pine acres on national forests in Colorado by crowning index class, before and after the SDI-based treatment scenario in Figure 5 (flex = 0.844, floating seed, no removal limits until TI and CI goals met).
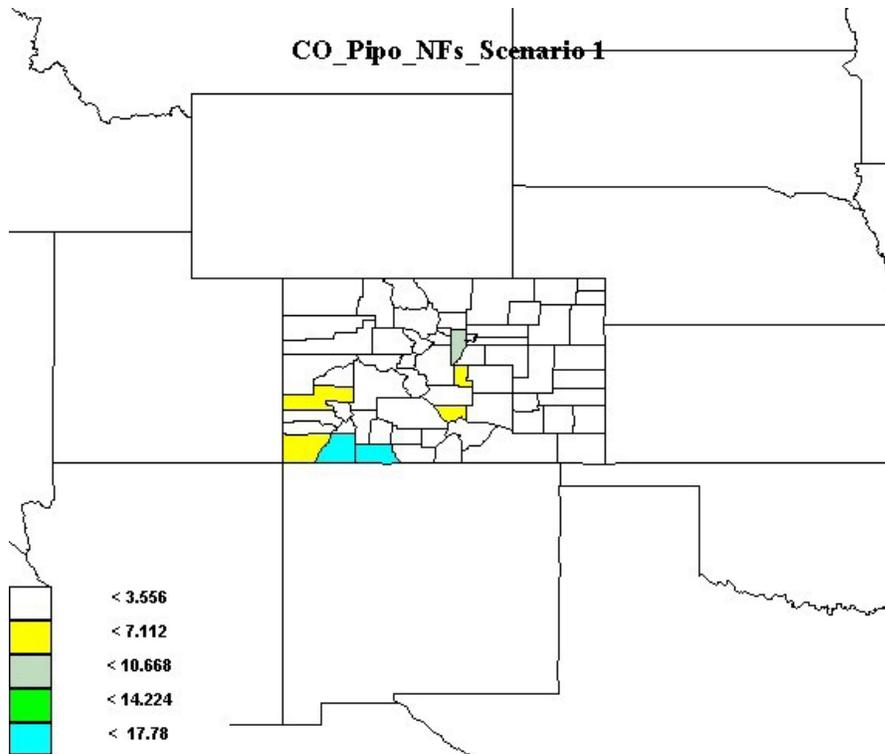
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Figure 8. Map of ponderosa pine biomass yields by Colorado county under the SDI-based treatment scenario shown in Figures 4 and 6. Yield classes are cubic feet per acre (all live cubic foot volume removed divided by the total area of land in each County).

Utilizing uneven-aged management for fuels treatment activities is justified and in fact necessary when the management objective is to maintain a particular forest condition on site through time, or to continually retain a component of large old trees in the forest. Since such attributes are often desired, or even required in urban interface forests, uneven-aged management is a logical management choice in these situations. The goal was to raise crowning and torching indices above 25 mph, but allow greater removal of small trees while still retaining an uneven-aged diameter distribution.

However, users must be aware that trade-offs exist between optimizing the productive capabilities of a forest and reducing fire risk. For example, a forest stocked at levels below 15 – 20 % maximum SDI is probably stocked at less than full occupancy, and not producing optimal yields. It also may contain open-grown trees that are limby and of poor form. Higher overall residual stocking levels will tend to favor regeneration of shade tolerant species while lower stocking will favor intolerant species. Similarly, "steep" stocking curves with numerous small trees in the understory will favor growth of shade tolerant species, while "shallow" curves will favor intolerant species. Low SDI values in residual stands will generally encourage abundant natural regeneration as well as development of associated understory species. This could be

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desirable in vegetation associations that have low biomass and corresponding low fire intensity when burned. However, stimulation of understory development may be undesirable if aggressive shrubby species that burn at high fire intensities are present.

When developing prescriptions for reducing crown fire risk, even a few low-crowned residual trees will affect average crown height and thus result in a low torching index. Adverse effects can be avoided in these cases by managing for grouped or clumped regeneration, or applying the prescription to isolate low-crowned trees from larger trees. Even so, managers must accept that tree removal alone cannot change fire behavior in all cases. Mechanical pruning or prescribed burning under safe conditions may be needed to raise crown base heights and reduce torching potential.

Finally, the user is reminded that as with all models, a certain degree of uncertainty is inherent in FTE biomass estimates. Sources of potential error include the universal applicability of the SDI equation form used in FTE (Ducey and Larson 2003), the statistical reliability of the RPA inventory plot data associated with a given query, and error associated with imbedded models that estimate tree volumes, potential fire behavior, and other summary results. Estimating the reliability of a given query is impossible, given the infinite combinations of queries that are possible in FTE. Nevertheless, we feel that the FTE program produces consistent and comparable results that are useful in strategic planning of fuels treatments.

In conclusion, the SDI-based procedures used in the FTE 3.0 program provide a quick and easy method of evaluating and planning both even and uneven-aged fuels treatment scenarios at landscape and larger scales. The procedure uses a well-established scientifically-based, stocking guideline that can be adjusted to specific tree species and local growing conditions. The program allows easy estimation of residual stocking, biomass yields, and fire behavior metrics. The SDIFlex procedure used in the uneven-aged scenarios allows easy development of a wide variety of possible uneven-aged fuels treatment prescriptions that could be applied to maintain desired forest conditions continuously through time.

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