Estimating Forest Fuels in the Southwest Using Forest Inventory Data[1]

Krista M. Gebert,[2] Ervin G. Schuster,[3] Sharon Woudenberg,[4] and Renee O'Brien[5]

Abstract

Catastrophic wildfires occurring over the last several years have led land management agencies to focus on reducing hazardous fuels. These wildland fuel reduction projects will likely be concentrated in shorter interval, fire-adapted ecosystems that have been moderately or significantly altered from their historical range. But where are these situations located? What are their fuel characteristics? Who owns them? Describing fuel characteristics on these lands is not simple, but Forest Inventory and Analysis (FIA) data may be helpful. One objective of this study was to demonstrate the linkages between forest inventory data and hazardous fuel characteristics and to identify information gaps and needed relationships. A second objective was to estimate and contrast overstory and understory biomass, especially in high fire-risk areas. Restricting analysis to Arizona, New Mexico, and Utah, we estimate that understory biomass accounts for 4 to 8 percent (20 to 42 million tons) of total forest biomass. Additionally, we estimate that around 57 percent (619 million tons) of the estimated 1.08 billion tons of biomass is found on high fire-risk forest lands. Of these 619 million tons, approximately 434 million tons is associated with larger diameter ($\geq$ 10 inches) overstory trees, both live and dead, and most is found on non-reserved forestlands (lands where tree utilization is not precluded by statute or administrative designation) administered by the USDA Forest Service. We found that FIA data provides useful data on 92-96 percent of biomass, but we did encounter problems with estimating understory biomass. Some of the problems we encountered included a lack of widely applicable understory biomass equations, no equations for estimating tree seedling biomass using percent cover, and many biomass equations for shrubs that use diameter, a measurement that is not collected by FIA.

Introduction

Years of fire suppression have led to forest densification and unnatural buildups of forest vegetation. Consequently, a major focus of the National Fire Plan (USDA Forest Service and U.S. Department of Interior 2000) is to reduce hazardous fuels. According to the Cohesive Strategy (USDA Forest Service 2000), wildland fuel reduction projects will be concentrated in shorter interval, fire-adapted ecosystems that have been moderately or significantly altered from their historical range of fire frequency, severity, and density of understory vegetation. But where are these hazardous situations located? What are their fuel characteristics? Who owns them? This information is needed for broadscale assessments and fuel treatment planning.

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[2] Economist, Rocky Mountain Research Station, USDA Forest Service, 800 E. Beckwith, Missoula, MT 59807 (e-mail: kgebert@fs.fed.us).
[3] Research forester (retired), Rocky Mountain Research Station, USDA Forest Service, 800 E. Beckwith, Missoula, MT 59807.
[4] Supervisory forester, Rocky Mountain Research Station, USDA Forest Service, 507 25th St., Ogden, UT 84401 (e-mail: swoudenberg@fs.fed.us).
[5] Lead ecologist, Rocky Mountain Research Station, USDA Forest Service, 507 25th St., Ogden, UT 84401 (e-mail: robrien@fs.fed.us).

Describing fuel characteristics on these lands is not simple, but forest inventory data may be helpful. The USDA Forest Service's Forest Inventory and Analysis (FIA) program is administered through five regional centers (Southern, Northeastern, North Central, Pacific Coast, and Interior West), each of which conducts resource inventories on all forested land within their geographical area. This system of inventory allows for a consistent set of data that can be used to produce a wide array of forest measurements, such as acres of forest and timber land, growing stock volume, and biomass, along with a wide range of resource characteristics (ownership, species, size, etc.). Consistency in data collection allows for nationwide comparisons of forest attributes. If one wishes to estimate, for example, the volume of small-diameter timber for various states, differences found between states can be attributed to actual, physical differences, not to inconsistencies in what data are available or how those data are collected or measured. Additionally, FIA data include forest inventory information on all ownerships, allowing comparisons among agencies or between Federal and private lands.

Our main objective was to assess the extent to which FIA data could be used to describe forest fuels on a broad scale, especially fuels associated with high-risk forest situations. Forest fuel, measured as tons of biomass, will be described for both forest overstory and understory vegetation. The overstory contains large and small diameter trees. Understory vegetation focuses on three layers. The lowest layer, from ground to the knee, contains grasses, forbs, and low shrubs. The next layer, between the knee and eye level, contains forbs and medium shrubs. The highest layer includes plants above eye level, usually seedlings, saplings, and tall shrubs only. Information gaps and needed relationships are identified.

Methods

We wanted to use FIA data to describe forest fuels, not only in the overstory, but also in the understory. To do this, we needed to determine the types of information collected by FIA and how that information could be used to describe forest fuels. We decided upon biomass as a measure that could be used to estimate amounts of forest fuel and allow us to compare the overstory and understory. Analysis was restricted to Arizona, New Mexico, and Utah, the three southwestern states for which we could obtain relatively recent and complete FIA data, but the same process could be applied to other FIA regions. A major focus was on forest lands with a high potential for catastrophic wildfires.

Data Compilation

We began data compilation by investigating the types of FIA data available. FIA collects and estimates a large variety of information on the forest overstory (trees greater than 1" diameter) including biomass for both live and dead trees. The term diameter in this publications refers to the diameter of the tree at the point of measurement, which is either breast height or root collar depending upon species. (For more information about IWFIA, see http://www.fs.fed.us/rm/ogden/). However, the only widely-available understory information is percent cover by vegetation layer (0-1.5 feet, 1.6-6 feet, and 6.1 feet or greater) and life form (trees, shrubs, grasses, forbs), and this information is collected for live vegetation only. Within the last several years, information on down woody debris has begun to be collected, but the collection of this information is in its infancy and, therefore, was not available for any State in its entirety. This information is collected on what are called "P3" or Phase 3 plots, which are a by-product of the Forest Health Monitoring/FIA merger in 2000. Approximately one in 16 FIA plots is also sampled for P3 data using one to two additional field personnel to collect data items and samples, including information on down woody debris (Rogers, personal communication).

Once we determined availability of fuels information in the FIA data, we selected a metric of forest fuels that would allow us to compare fuels in the overstory to those in the understory. We decided on biomass for several reasons: (1) fuel loadings are often measured in terms of biomass, (2) biomass was already estimated for the overstory by FIA, (3) biomass is a useful measure of potential material for bio-based products, and (4) we knew of equations for computing biomass of forbs and grasses using percent cover. We then obtained overstory data from the Interior West Forest Inventory and Analysis (IWFIA) unit in Ogden, Utah. For the understory data, IWFIA calculated average percent cover by layer and life form for each inventory plot, averaged across all subplots on which information was collected. Understory data were then merged with overstory plot data.

We were particularly interested in assessing the amount of forest fuels on lands at risk for severe wildfires. The Cohesive Strategy states that its aim is to "reduce losses and damages from wildland fires by concentrating treatments where human communities, watersheds, and species are at risk" (USDA Forest Service 2000). To determine the location of these areas, we used a map of coarse-scale spatial data developed by Hardy and others (1999). These data designate both Historic Natural Fire Regime (historic fire frequency and severity) and Current Condition Class (an indication of the degree of departure from the historic fire regimes). This map was sent to IWFIA where it was overlaid with FIA plots, and each plot was assigned a Fire Regime/Condition Class depending upon where the plot fell on the map. We designated plots falling in Fire Regime I or II and Condition Class 2 or 3 as "high risk." According to Schmidt (2002), almost all of the lower elevation zones in the United States, which are the areas most affected by human intervention and where resources and communities are at highest risk, fall under Fire Regimes I and II. In addition, Condition Classes 2 and 3 have been moderately or significantly altered from their historical range and, therefore, are more at risk for severe wildland fires and generally require some degree of mechanical treatment before prescribed fires can be successfully used to control fuels (Schmidt and others 2002). It should be noted that FIA plot information could have been used directly to evaluate forest conditions and assess fire risk, but that was not feasible given the time frame and scope of this study; that procedure is more suitable to smaller land areas.

We encountered several problems during data compilation, including the lack of useable information on down woody debris and no dead understory vegetation information for the states analyzed. Additionally, several plots were missing understory vegetation information due to snow cover at the time the plot was field visited. For these plots, we used the average percent cover by layer and life form for the appropriate forest type.

Calculating Biomass

To calculate the biomass (in oven-dry tons) of live and dead overstory vegetation (trees $\geq$ 1" diameter), we used the algorithms designed by FIA for use with their data (Miles and others 2001); this was a straightforward process. However, for understory vegetation, we had to use equations relating biomass to percent cover. This turned out to be much more difficult than originally envisioned.

Several problems were encountered in converting FIA understory vegetation attributes of percent cover by layer and life form to biomass. First, we were unable to locate any equations for estimating the biomass of tree seedlings based on percent cover or the number of seedlings. This meant we were unable to estimate biomass of tree seedlings (trees < 1" diameter), thus leaving a gap in our analysis. Second, many of the equations for estimating biomass of shrubs or other woody plants used diameter as an estimation parameter (Alaback 1986, Reeves and Lenhart 1988). Shrub stem diameters were not collected by FIA. Third, most biomass equations for the understory were developed for very specific geographical areas and specific species (Alaback 1986, Alexander 1978, Means and others 1996, Reeves and Lenhart 1988). Little work has been done to develop more generally applicable equations or to validate them for estimating biomass of other species.

In the end, we used understory biomass equations that were based on a mix of species, rather than equations developed for one specific species. These mixed-species equations had been developed for other regions of the country and their applicability to the southwest is questionable; however, we felt these equations could be used for illustrative purposes and give some idea of the relative understory biomass of the three states. For grasses and forbs, we used equations developed by Mitchell and others (1997) for estimating biomass based on percent cover. For shrubs, we adapted an equation developed by Olson and Martin (1981) that used two parameters, percent cover and height (*table 1*). Although FIA does not specifically measure height of understory plants, percent cover by vegetation layer is recorded. We used the midpoints of the first two layers (0.75 feet, 3.8 feet) as an estimate of the height of the understory vegetation. For the third layer ($\geq$ 6.1 feet), we assumed that, on average, shrubs ranged from 6.1 feet to around 15 feet, so we used a midpoint of 10.5 feet.

Table 1— *Regression equations used for estimating biomass of forest land understory vegetation in Arizona, New Mexico, and Utah*

Life form	Parameters	Equation[1]	Source
Shrubs	% Cover (x_1) Height (x_2)	$g/0.5m^2$ = -.62689 + ($0.05778 * x_1 * x_2$)	Olson and Martin 1981
Forbs	% Cover (x_1)	kg/ha = $13.66 * x_1$	Mitchell and others 1987
Grasses	% Cover (x_1)	kg/ha = $8.17 * x_1$	Mitchell and others 1987

[1]Dependent variable (y) = oven-dry plant weight. Units varied, but all results were converted to pounds/acre.

We encountered an additional problem in the calculation of biomass for saplings --- inclusion of saplings in the FIA understory data varied by inventory year. Therefore, when saplings were included in the understory, we subtracted them out of the calculations of overstory biomass to prevent double counting.

Results

The results presented in this section are largely illustrative of the types of forest fuel information that can be extracted from FIA data. Estimates of area and overstory biomass are standard outputs from the FIA database. Understory estimates of biomass involve more extrapolation. We also provide information on the relative amounts of biomass found on lands at risk for severe wildland fires by merging the FIA data with current condition class and historic natural fire regime information.

There are 51.8 million acres of forest land in Arizona, New Mexico, and Utah (*fig. 1*). Forest land is land at least 10 percent stocked with trees. Forest land is made up (by IWFIA definitions) of timberland and woodland. The majority of the forest land in these three states (68 percent) is classified as woodland. Woodland is forest land where the majority of stocking is in woodland tree species---species such as pinyon and juniper that are not usually converted into industrial wood products. Only one-fourth of the forest land is classified as timberland. Timberland is forest land where the majority of stocking is in timber tree species---species such as ponderosa pine and Douglas-fir that are used for industrial wood products. Each of the three states have more than 10 million acres of woodland, with Arizona containing both the largest area of woodland and hence, the largest area of forest land. None of the states have more than 5 million acres of timberland. Only 8 percent of the forest land has been withdrawn from tree utilization through statute or administrative designation (reserved land). Reserved land could include either timberland or woodland--that distinction was not used in this paper.

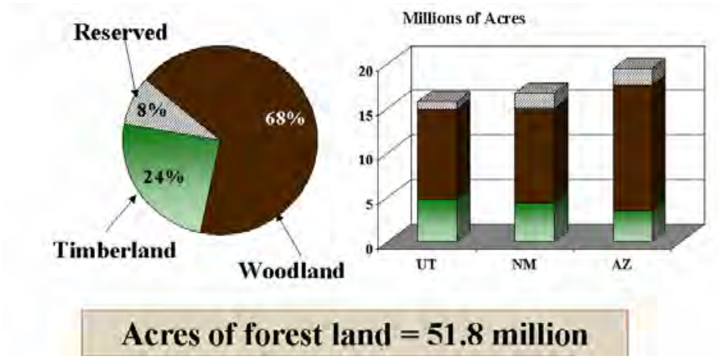


Figure 1—Acres of forest land in Arizona, New Mexico, and Utah

Total biomass found on forest land in these three states comes to an estimated 1.08 billion tons (not counting tree seedlings) (*fig. 2*). Most of this, 96 percent, is found in the overstory, and the majority of the overstory biomass comes from live trees. Interestingly, although Arizona contains the largest area of forest land (*fig. 1*), Utah contains the largest amount of total biomass, more than 390 million tons, and also contains the largest amount of understory biomass.

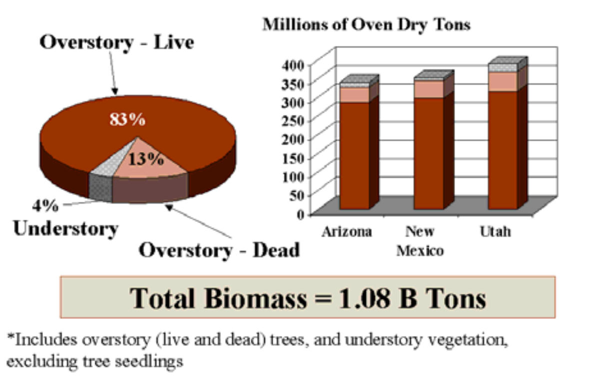


Figure 2—Estimated biomass of overstory and understory vegetation*on forest land in Arizona, New Mexico, and Utah

Estimates of understory biomass do not include tree seedlings (trees < 1" diameter) due to the lack of equations for estimating seedling biomass. Just how much did this likely affect our estimates? We found one reference that suggested that seedling biomass comprises anywhere from 5 to 50 percent of total understory biomass (Telfer 1971). To test how the missing seedling information affected our estimates, we recalculated our estimates by including tree seedlings as 5, 25, and 50 percent of total understory biomass (*table 2*). Assuming that tree seedlings account for 5 percent of understory biomass, there would be no noticeable affect on understory biomass estimates. If tree seedlings were 25 percent of understory biomass, the total understory percentage increased to 5 percent, as opposed to 4 percent with no tree seedlings included. When we assumed that tree seedlings make up 50 percent of understory biomass, the percentage of biomass accounted for by the understory increased to 8 percent. At this level, the importance of the understory began to vie with that of the dead overstory trees, and our overall biomass estimates increased from 1.08 billion tons to 1.13 billion tons.

Table 2— *Sensitivity of forest land understory biomass estimates to missing tree seedling information: Arizona, New Mexico, and Utah.*

Tree seedling assumption	Estimated understory biomass using tree seedling assumptions	
Pct. tree seedling biomass of total understory biomass	Total understory biomass	Understory biomass as a pct. of total biomass
	Millions of tons	Percent
w/o seedlings	20.8	4
5	21.9	4
25	27.8	5
50	41.7	8

A major focus in this study was forest lands at risk for catastrophic wildfires because these are the areas where fuel treatments are most likely to occur. Using the maps developed by Hardy and others (1999) to classify FIA plots according to historic natural fire regime and condition class, we estimated the amount of biomass on these lands. Results show that of the estimated 1.08 billion tons of forest land biomass, approximately 57 percent (619 million tons) is found on lands we classify as high risk (Fire Regime I or II, and Condition Class 2 or 3); 23 percent is found in the highest risk category (Condition Class 3) (*fig. 3*).

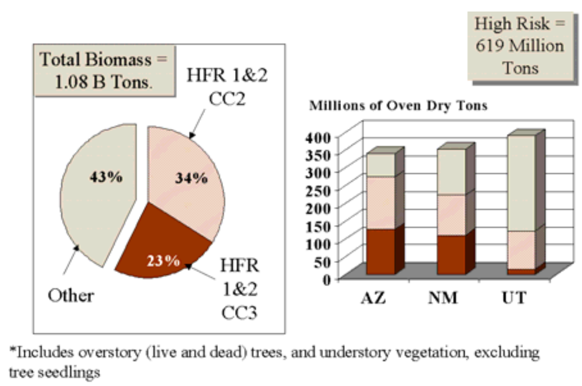


Figure 3— Estimated biomass of overstory and understory vegetation* on high fire risk forestland in Arizona, New Mexico, and Utah.

This is not surprising considering the amount of land falling in these categories (*fig. 4*). More than two-thirds of the forest land in Arizona and New Mexico falls into these high-risk categories. For Utah, the percentage is much smaller, with less than one-third of the forest land classified as high risk. In fact, the breakdown of biomass by state shows that Utah, although having the largest amount of forest land biomass, has only 30 percent of its biomass in these high-risk areas and only a very small percentage (less than 5 percent) in the highest risk category. Conversely, 81 percent of the forest land biomass in Arizona is found in these high-risk areas, with about an equal amount falling on Condition Class 2 and Condition Class 3 lands. In New Mexico, the biomass is about evenly split between the two fire risk categories and all other lands.

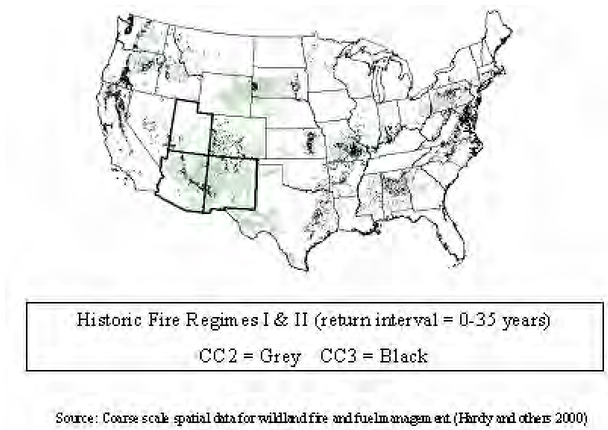


Figure 4— Historic Fire Regimes I & II, Condition Classes 2 & 3

Next, we looked in more detail at biomass in these high-risk areas, focusing on overstory versus understory, ownership, and reserved status. Looking first at vegetation layers (*fig. 5*), the majority of the biomass found on these high-risk lands is in the overstory (96 percent) with 84 percent coming from live overstory trees and 12 percent from dead trees. Of the 4 percent of understory biomass, half is found in Layer 2 (1.6 - 6 feet). However, it is important to note that because this estimate does not include tree seedlings, the distribution of biomass among layers is affected. Yet, when we looked at the plot data, more plots reported tree seedlings in Layer 2 than the other two layers, so the relative ranking may be correct.

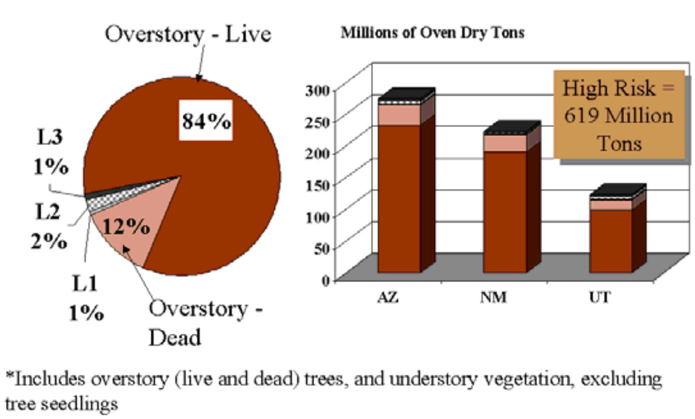
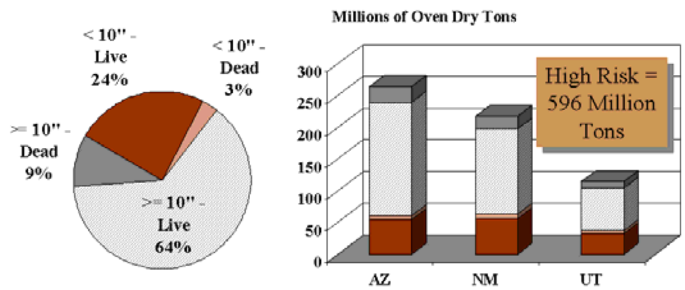


Figure 5— Estimated biomass of overstory and understory vegetation*on high fire risk forestland in Arizona, New Mexico, and Utah by vegetation layer

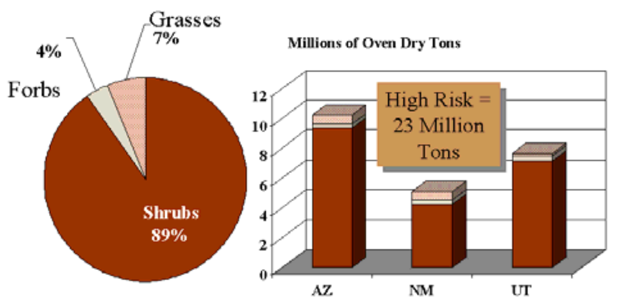
Looking at the overstory separately (*fig. 6*), there are at least two points of note. First, 73 percent of the overstory biomass is found in trees (both live and dead) 10 inches or greater in diameter. If stand density is a concern, it is difficult to reduce it by removing only small trees when such a large proportion of the biomass is in larger trees. Second, the relative percentage of dead to live trees does not change much with size. Twelve percent of the biomass of the larger trees comes from dead trees, while the percentage of dead tree biomass is 11 percent for the smaller trees. There is little difference in the distribution of the overstory in the three states.



*Includes overstory (live and dead) trees

Figure 6— Estimated biomass of overstory vegetation* on high fire risk forestland in Arizona, New Mexico, and Utah, by size

Turning to understory biomass, nearly 90 percent comes from shrubs, followed by grasses and then forbs (*fig. 7*). The breakdown by state shows, however, that the relative ranking of states has now changed. When looking at total biomass on these high-risk lands, or just overstory biomass (*fig. 5 and fig. 6*), the ranking from largest to smallest amount was Arizona, New Mexico, and Utah. When focusing on understory biomass only, Arizona still ranks first, but Utah overtakes New Mexico to rank second in terms of understory biomass on high-risk lands.



*Does not include tree seedlings

Figure 7— Estimated biomass of understory vegetation* on high fire risk forestland in Arizona, New Mexico, and Utah, by life form

Aside from the physical characteristics of forest fuels on high-risk lands, other important dimensions in the management of these lands are ownership and reserved status. Nearly 60 percent of the biomass occurs on lands administered by the Forest Service, with another 28 percent being found on private land (*fig. 8*). A comparison of states shows that Arizona has a larger percentage of this material occurring on lands administered by Federal agencies other than the Forest Service or the Bureau of Land Management (mainly the National Park Service) than the other two states. In Utah, a larger percentage of biomass is found on lands administered by the Bureau of Land Management than in either Arizona or New Mexico. Most of the biomass in these three states (88 percent) occurs on lands currently available for timber utilization (non-reserved lands) (*fig. 9*).

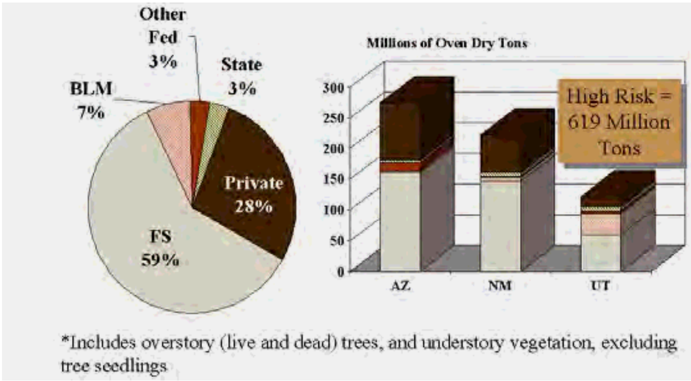


Figure 8— Estimated biomass of understory and overstory vegetation* on high fire risk forestland in Arizona, New Mexico, and Utah, by ownership

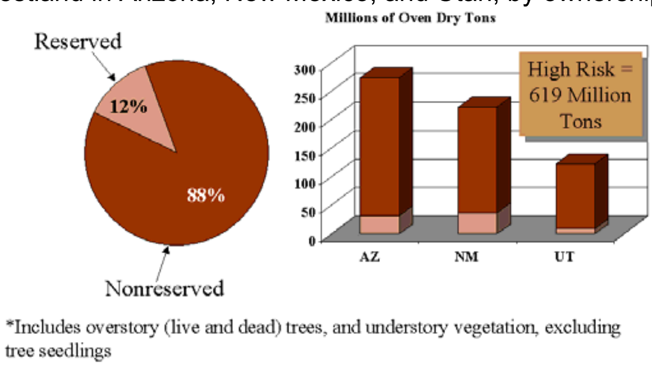


Figure 9— Estimated biomass of understory and overstory vegetation* on high fire risk forestland in Arizona, New Mexico, and Utah, by reserved status

Conclusion

Broadscale assessments of forest fuels would be useful for fuel treatment and bio-based product planning. The general conclusion of this study, however, is that more research is needed to accurately estimate biomass from FIA understory vegetation data. While overstory biomass can be adequately estimated using FIA data, the understory biomass estimates presented here are only illustrative, giving a general impression of the amount of understory biomass in Arizona, New Mexico, and Utah. These understory estimates are not completely satisfactory. They are based on equations developed for other areas of the country, for different species, and do not include tree seedling biomass. Biomass of dead understory plants is also not available.

Given the fact that the understory appears to be a fairly small component of total forest biomass, FIA data can be used to provide reasonable estimates of amounts and location of forest fuels for broadscale assessments. However, to develop more complete estimates of biomass, including the understory, research is needed to develop equations for estimating the biomass of tree seedlings based on percent cover or the number of seedlings. Additionally, there is a lack of equations for estimating the biomass of shrubs based on percent cover; many of the available equations for shrub biomass use other parameters, such as diameter, which is not a measurement collected by FIA. Finally, and perhaps most importantly, research is needed to test the applicability of species- and area-specific understory biomass equations to other species or areas and/or to develop more generally applicable understory biomass equations.

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