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Initial Development of Surface Fuel Models for The Netherlands

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Abstract

Estimating the spread of wildland fire is growing concern in the Netherlands, where fire events at the wildland urban interface is a growing concern with a changing climate. A multi-year project was initiated in 2012 to obtain field-based fuel measurements to be used to estimate wildland fire spread for surface fire. The overall objective was to develop either custom fuel models or utilize existing Northern American fuel models to fuel conditions in some of the hazardous vegetation in the Netherlands. Over a four-year period, 96 plots were established, a wide variety of fuel parameters measured, and ANOVA ($p \leq 0.1$) and Duncan's MRT used to place these into 56 different vegetation communities. Following multiple permutations in Behaveplus, the 56 communities were consolidated into 28 different fuel models. It was then attempted to use these fuel models as input variables in a Dutch-developed wildland fire spread model. Some fuel models produced similar fire spread, and since they were within relatively similar communities, were combined, resulting in 21 working fuel models. The results of this project will provide land managers, fire brigades and landowners more accurate wildland fire spread estimations, improving safety of the public in this densely populated country. The results of this project will contribute to more accurate and detailed calculations of the NBVM (Dutch wildfire spreadmodel). The NBVM will provide necessary information, to be able to reduce the risk on uncontrollable wildfires, via wildfire prevention measurements and during an incident, to support decision making.

Keywords: Wildland fire; Fire behavior; Spread model

Introduction

While the Netherlands is known for their efforts to prevent flooding, it is not known as a country where wildfires occur. Wildfires do happen every year in the Netherlands, but on a much smaller scale (e.g., a wildfire at the National Park Hoge Value in 2014 was 350 hectares) than in South Europe, Australia, Canada and United States; these wildfires still have major local impact and had the attention of the politicians, the public and the press. In the Netherlands, there is a great interrelationship between nature/wildland, infrastructure, houses, recreation, commonly known as wildland urban interface. So even a relative small wildfire can cause great risk, and have an impact on both the environment and the public.

For many years a standard rule has been used in the Netherlands during a wildfire. However, this generic estimate was rarely accurate, nor did it take into account the various fuel conditions found around the country. The Institute Fysieke Veiligheid (Institute for Safety, IFV) started the development of a more accurate Dutch wildfire spreadmodel by command of the Ministry of Safety and Justice in 2009.

A literature review was initiated to find a computer model to estimate the spread (speed and direction) of a wildfire that can be adapted to the Dutch situation [1]. The possibilities, usability and the wishes from the fire departments were obtained through a variety of interviews to find the right model structure to adapt for use in the Netherlands. The literature review and the interviews combined identified the North American wildfire model FARSITE the best choice. The mathematical part of this program was used to construct the Dutch Wildfire Spread model (NBVM).

The initial decision was made to make the NBVM calculations with four very basic fuel models. Each fuel model contains information about the fuel bed characteristics, and is therefore different per vegetation type. A basic map of the Netherlands, called TOP10NL was used for the NBVM; this map contains five legend units that could be linked with an existing fuel model used in the United States. Broadleaf forest was linked with TL6 [2], mixed forest with TU2, coniferous forest to TU3 and heather to an adapted grassland model [3]. The initial choice of these fuels models was based on the description of the vegetation [4]. This adaptation was necessary since there were no specific fuel models for heather fields. Validation during wildfires and prescribed burning was used for the adaptation of this grassland model [3]. These fuel models contained information about the biomass, amount of burnable material in a specific vegetation type, and used for mapping high risk areas [5].

To improve the linkage between fuel models and vegetation types in the Netherlands, field fuel research was initiated in 2012. Using input from wildland managers, we began with a basic fuel model classification of four common nature types in the Netherlands: dry heather, dune area, peat and undergrowth forest.

The overall goal of this study was the development of custom fuel models or to link of vegetation types found in the Netherlands with existing Northern American fuel models. The specific objectives were to identify: 1) which American fuel models be used for the Dutch vegetation types, and, if so, which; and 2) which vegetation types require custom fuel models.

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Adding fuel models, based on the data of the fuel research, to the NBVM, further develops and allows for more accurate simulations of the potential spread of a wildfire.

Material and Methods

Fuel research

Field fuel research was conducted between 2012 and 2015 by IFV, in cooperation with Stephen F. Austin State University (SFA) in Texas and the University of Applied Sciences van Hall Larenstein (VHL) Velp, the Netherlands. Each year, fieldwork was conducted supervised on-site by IFV, and data analysis was conducted at SFA. The vegetation classification of SNL (a Dutch uniform subsidy system) was followed. This vegetation index is used nationwide in the Netherlands by all major wildland/nature organizations and is therefore the most suitable index (www.bij12.nl). Within this index priorities were identified for the vegetation types that form a potential risk on the occurrence and the spread of a wildfire [6]. For each vegetation type, a goal was a minimum six different plots to capture differences in biomass, age and composition of the vegetation to obtain a range of conditions.

The first research season took place on dry sandy sites supporting heather fields, and the undergrowth under scots pine, Douglas-fir and beech, as well as two exploratory plots performed in grasslands. Measurements in 2013 were in various dune types: open dune, dune grassland, dune heather, dune valley and dune shrub. The first four were investigated on Texel Island (Northern part of the Netherlands), and sites near Harlem and Amsterdam for dune shrub.

Peat areas were measured in 2014 in Northumberland (North England) for peat grasslands, heather fields, shrub and forests since north England has a large area of peat that access was easily obtained. Northumberland is comparable to sites in the Netherlands as they are in the same climate zone. In the Netherlands peat areas are smaller and are considered vulnerable to any disturbance, which made research in the Netherlands nearly impossible. In addition to the research in the UK a small scale comparable research was performed in Aamsveen (eastern part of the Netherlands).

In 2015 measurements were conducted in the undergrowth of different forest types. Plots that were utilized in 2012 and 2014 were utilized, as were new plots in areas such as peat forests. Plots were also performed in dune forest, conifer, broadleaf and mixed forests. The fieldwork took place in Aamsveen (peat forest), National Park duinen van Texel (dune forest), National Park Loonse and Drunense duinen and New Forest in England (conifer, broadleaf and mixed).

Fieldwork

The field protocol initially developed by Ottmar [7] was modified for this research (Figure 1). The following measurements were taken: 50 litter and duff measurements, 31 transects (15.4 m) for herbaceous cover, 12 circular plots (3 m radius) crown densities and shrubs and trees, and 25 plots (1 m^2) for the herbaceous species. Each plot was given a site/plot code, and pictures of each site taken. A fish-eye lens on a camera was also utilized to characterize forest canopy conditions. GPS coordinates, slope, aspect and dominant vegetation were recorded. In addition, five samples are taken of the litter and duff layer to determine the bulk density at S1, L2S7, S13, L9, S19 and S25. Samples were weighed, dried in an oven at 90°C for 48 hours and weighed again. Crown density is measured at all the 'L' points in four cardinal directions with a densitometer, and a mean canopy cover calculated.

The transects were initiated at 'S' and 'L' points. The direction of each transect was randomly determined, but had to fall within the outside lines as shown in Figure 1. Along each transect, percent cover by species, litter, mineral soil, downed woody material, etc. was recorded. For the downed woody material, the size class was also recorded [8,9].

The three-meter radius plots were located at the 'L' points. All trees and shrubs within the plot were recorded by species, the DBH (diameter breast height) and the diameter of the base of the tree measured with a D-tape the total height, height of the first dead branch and the height of the live crown were measured with a clinometer for each tree within the plot. The size of the crown was estimated, widest dimension and then perpendicular. For shrubs the total height, ground diameter and crown width was also measured, and seedlings recorded by species.

Each 1 m^2 plots were located at the 'S' points, and the herbaceous and grass species recorded, per species the cover percentage estimated, and mean height of the herbaceous and grass species calculated.

Statistical analysis

All data was entered into Excel and an Analysis of Variance (ANOVA) using SAS 9.0 was performed on fuel parameters (downed woody material by size, total herbaceous, including cover and height, litter, humus depth, over story, shrub) for biomass on an Mg ha^{-1} basis to identify significant differences ($p \leq 0.1$) in fuel loadings per site and within vegetation types.

Total fuel load was used as the initial parameter to identify significant differences across and within major types, and then the measured parameters that drive fire behavior within that type (e.g., SAV for grasslands, downed woody material in Coniferous forests) were used to father identify if significant differences occurred within the various types. Duncan's' Multiple Range Test was then performed to identify which sites were statistically different. Similar sites were then grouped together within each community type.

These results were then compared to existing fuel models from the United States, and if consistent in fuel loads, were given an existing model code (e.g., TL3). When the conditions did not fit an existing model, a custom model was then developed. Depending whether in the

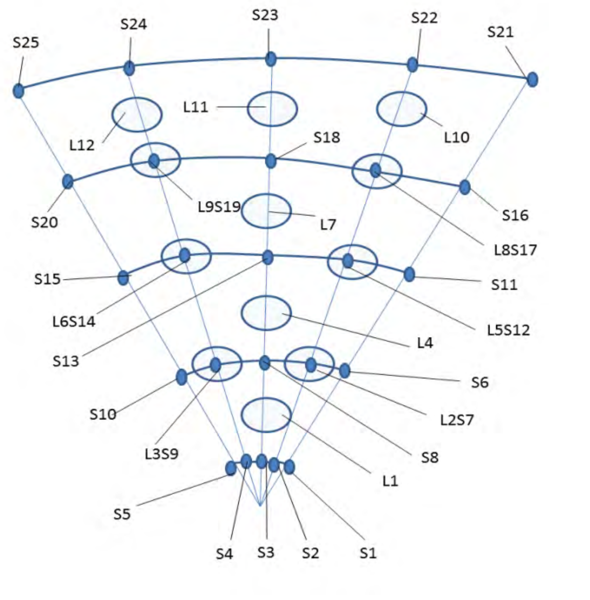

Figure 1: Design plot lay-out.

concerned vegetation type herbaceous species are present or not a fuel model was determined to be dynamic (herbaceous layer present) or static (no herbaceous species).

The range of fuel conditions for each site type and fuel model were then run 100 times through Behave Plus, a computer program which can be used to predict potential fire behavior [10]. Slight changes in fuel parameters and/or weather conditions were made for each run, and potential fire behavior outputs (rate of spread (km hr^{-1}), mean or maximum intensity (kW m^{-1}), and mean flame height (m) determined, a fire behavior class label given, and for custom models, a new model code given.

Results

Between 2012 and 2015, 93 different plots were established and utilized for this study. These plots were then given a Site Label to provide a short description of the site, resulting in 56 different labeled communities (Table 1, Initial Site Label). Using Analysis of Variance and Duncan's MRT, distinct statistical differences ($p \leq 0.1$) were found between all of the community types and between some of the plots within each type. Fuel data was then compared to existing US fuel models to provide an initial starting point for estimating potential wildfire spread utilizing BehavePlus, reducing the 96 plots to 28 initial fuel models (Table 1, Initial Fuel Model), each statistically different than the others.

Each of these initial fuel models for each site were then utilized in BehavePlus, slightly changing the appropriate input variables for that model 100 times and results compiled. The results were then compared to Behaveplus outputs for US models, and if they fell within one Standard Deviation of the means provided for the US model, they were left in that model. If the resulting parameters exceeded 1 Standard Deviation, they were evaluated to see if they fell within another existing US model, or should be placed in a custom model. If the later, they were then again run 100 times in a custom model scenario, and the results recorded. The resulting outputs were then given 23 revised site labels to simplify descriptions of the sites based on similar estimated fire behaviors (e.g., the 6 different Beech communities from 2012 were given the same label (Broadleaf Forest no understory) since they all modelled the same regardless of our initial observations (Table 1, Revised Site Label).

The next step was to see whether all these models could be used in the Dutch wildfire spreadmodel. A number of proposed models were found not to work within the parameters within the spreadmodel; as a result, a selection was made by data out of fieldwork. This data was combined and used to create new fuel models (Table 1, Fire Spread Model Code). This process was based on the vegetation classification of SNL with a translation to a logic classification for the NBVM (biomass), since biomass has a great influence on the fire behavior. Also, this selection was made in comparison with the data of several wildfires and prescribed burns, so the most relevant fuel models were selected.

Discussion

Developing accurate estimates of wildfire spread in new environments where wildfire fire has had limited attention was challenging. Rather than working in historically fire-prone conditions as found in North America, Australia and the Mediterranean region, the Netherlands we were working in environments where fire has had little historic presence, and where fire's role as an ecological agent may be minimal. It is because of this that it is the government agencies responsible for emergency preparedness and safety such a IFV that are taking the lead on this issue, rather than the natural resource managers as found in the United States.

The reduction of the number of types of fuel conditions from the fieldwork without losing valuable data was not surprising, since we didn't have any idea what fuel conditions would result in significant difference in potential wildland fire spread. When you consider that the initial fuel models developed in the United States for Behave in the 1970's reduced potential conditions down to 11 or 13 [2,11], we found that our reduction to 21 is actually less conservative, and may avoid future needs to expand the number of models as now are acknowledged [4], in addition to the custom model option in Behaveplus.

What was especially challenging was when all fuel parameters fit into an existing fuel model, but then would not work in the spreadmodel. Even using dryer-than-normal weather conditions for the Netherlands did not result in an accurate fire spread, or no fire spread at all. The highly fragmented landscape found in the Netherlands compared that found in the western United States and Canada may have contributed to some models not producing fire spread characteristics that were observed at wildfires. It is possible that landscape scale might be a variable that should be incorporated into the Dutch spread model as they continue to improve its accuracy.

The results of this study did add 21 fuel models to the NBVM contributing to more accurate calculations. This is of great value in a small-scale country like the Netherlands, with a great interrelationship of land use, infrastructure and population density. By adding fuel models to the NBVM, a more specific calculation can be made which can contribute to scenarios to indicate high risk areas. This is useful information for wildfire prevention measures. In addition, a more detailed calculation of the NBVM contributes also to the support of the fire brigade by making decisions during a wildfire.

To be able to add the 21 fuel models to the NBVM a more detailed map was necessary. Therefore, a project was started to create detailed and up-to-date vegetation maps with satellite data. The potential usage of the firespread models is high. Any user of the NBVM can via the TOP10NL map and/or coordinates, identify the location of the start of a wildfire. It is also possible to make a calculation based on an existing fire front. Besides the location, the user also needs to enter meteorological data of seven days previous of the wildfire: temperature (minimum and maximum), relative humidity (minimum and maximum) and precipitation. For the day of the wildfire the wind speed, in meters per second, and the wind direction is entered. Via meteorological data and fuel models, the NBVM produces a calculation of the spread of a wildfire for the next six hours. In addition, potential firelines can be drawn in the model to be able to see the effect, and multiple fires can be calculated at the same time.

The results of this research and fuel models needs to be further validated for the Netherlands. This can also be done in countries with a same climate zone, like the UK and Germany. Wildfires and prescribed burnings can be used to validate all of the selected fuel models. For the vegetation types that need custom fuel models, for example heather, additional research on the SAV ratio's (surface area volume) is necessary, and was initiated in 2016 and 2017, as well as research in calculating canopy fuels to estimate crown fire spread and spot fire probabilities. In addition, satellite data shall be used to create 'fuelmaps', consisting of different vegetation types to which the fuel models are linked. The goal of the fuel map is more details but also more up-to-date (once a year an update of the vegetation and twice a year an update of the biomass).

Initial Site Label	Initial Fuel Model (or Farsite fuel model)	Revised Site Label	Fire Spread Model Code (Dutch)
2012			
Beech	TL9	Broadleaf Forest no understory	L1
Upland Beech	TL9	Broadleaf Forest no understory	L1
Beech-Mixed Hardwood	TL9	Broadleaf Forest no understory	L1
Beech closed Canopy	TL9	Broadleaf Forest no understory	L1
Dense Beech 1	TL9	Broadleaf Forest no understory	L1
Dense Beech 2	TL9	Broadleaf Forest no understory	L1
Thick Grass	GR9	Grassland	GR3
Moderate Grass	GR8	Grassland	GR2
Thinned DF (2plots)	TL3	Coniferous Forest-shrub undergrowth	N4
Regenerating DF	TU5	Coniferous Forest-shrub undergrowth	N3
Thin DF	TU5	Coniferous Forest-shrub undergrowth	N3
Dense DF	TL3	Coniferous Forest-no understory	N4
Mature DF	TL3	Coniferous Forest-shrub undergrowth	N4
Stripped O Horizon	H1	Heather (dry sandy ground)	H1
Grazed	H1	Heather (dry sandy ground)	H1
Heather 2	H2	Heather (dry sandy ground)	H1
Heather-Grass	H3	Heather (dry sandy ground)	H2
Heather-Grass	H3	Heather (dry sandy ground)	H2
Heather-Scattered Pine	H3	Heather (dry sandy ground)	H2
Scots Pine 1	SP1	Conifer forest	N2
Scots Pine -Hardwood seedlings	SP1	Conifer forest	N2
Thinned Scots Pine	SP2	Conifer forest	N2
Scots Pine-Shrubs	SP3	Conifer forest	N3
Scots Pine-Birch	SP3	Conifer forest	N3
Dense Scots Pine-Shrubs	SP3	Conifer forest	N3
2013			
Dune Grassland 1	GR7	Dune grassland	OD2
Dune Grassland 2	GR3	Dune grassland	OD1
Grazed Dune Grassland 1	GR5	Dune grassland	DG1
Mod. Thick Dune Heather	H4	Dune heather	H3
Dune Heather 1	H5	Dune heather	H3
Dune Heather2	H5	Dune heather	H3
Thick Dune Heather	H5	Dune heather	H3
Grazed Dune Heather	H4	Dune heather	H3
Mowed Dune Heather	H1	Dune heather	H1
Dune Valley Grassland-Shrub	GS4	Dune valley	ST1
Dune Valley Shrub	SH6	Dune valley	ST2
Thick Dune Valley Shrub	SH9	Dune valley	ST2
Mowed Dune Valley	GS3	Dune valley	ST1
Sparse Load Open Dune Grass	ODG1	Grassland-open dune	OD1
Very Low Load Open Dune Grass	ODG2	Grassland-open dune	DG1
Low Load Open Dune Grass	ODG3	Grassland-open dune	DG1
Low Load Open Dune Grass	ODG3	Grassland-open dune	OD1
High Load Open Dune Grass	ODG4	Grassland-open dune	OD2
Dune Grassland-Shrub	GS 4	Dune grassland-shrub	ST1
Dune Grassland-Shrub	GS 4	Dune grassland-shrub	ST1
Dune Grassland-Shrub	GS 3	Dune grassland-shrub	ST1
Dune Shrub-Grass 1	SH8	Dune grassland-shrub	ST2
Dune Shrub-Grass 2	SH9	Dune grassland-shrub	ST2
Open Dune Shrub-Grass	GS4	Dune grassland-shrub	ST1
Coastal Dune Shrub	ODGS1	Dune shrub	ST2
2014			
Peatland Bog (2 plots)	GR3	Peatland bog	GR4
Peatland Bog (6 plots)	GR6/8	Peatland bog	GR5
Peatland Heather (3 plots)	SH6	Peat heather	H4
Peatland Heather (4 plots)	SH8	Peat heather	H4
2015			
Dune Forest (*Pinus nigra*) (2 plots)	TL1	Dune forest	N4
Dune Forest (*Pinus nigra*)	TL3	Dune forest	N4

Dune Forest (*Pinus nigra*)	TU3	Dune forest	N2
Dune Forest (*Pinus nigra*) (2 plots)	SH8	Dune forest	N3
Peat Forest 3 plots	TU3/TU5/SH3	Peat forest	V1
New Forest-Conifer	GR6	Conifer forest	N1
New Forest-Conifer	TL1	Conifer forest	N4
New Forest-Conifer	TU3	Conifer forest	N2
New Forest-Conifer	TL3	Conifer forest	N4
New Forest-Conifer	TL4	Conifer forest	N4
New Forest-Conifer	TL1	Conifer forest	N4
New Forest- Mixed	TU1	Mixed forest	N2
New Forest- Mixed	TL9	Mixed forest	TL9
New Forest- Mixed	TL4	Mixed forest	N4
New Forest- Mixed	TU3	Mixed forest	N2
New Forest- Mixed	TU1	Mixed forest	N2
New Forest- Mixed	TL9	Mixed forest	TL9
New Forest- Mixed	TL9	Mixed forest	TL9
New Forest-Broadleaf 4 plots	TL9	Broadleaf Forest no understory	TL9
Drunense duinen 2 plots	GR8	Conifer forest	N1
Drunense duinen 2 plots	GR9	Conifer forest	N1
Drunense duinen 1 plot	TL3	Conifer forest	N4
Drunense duinen 2 plots	TL4	Conifer forest	N4

Revised Site Label	Revised Model Code	Fire Spread Model Code	Description
Broadleaf Forest no understory	TL9	L1	Broadleaf forest, no undergrowth
Grassland	GR9	GR3	Grass higher than 1 meter, mostly *Molinia caerulea*, dry sandy area
grassland (dry) 2	GR8	GR2	Grass lower than 1 meter, mostly *Molinia caerulea*, dry sand area
Conifer Forest 2/Conifer Forest 4	TU3	N4	Dense conifer forest, no undergrowth
Coniferous Forest-shrub undergrowth	TU3	N2	Open conifer forest with dense shrub
Coniferous Forest-no understory	TL3	N4	Dense conifer forest, no undergrowth
Heather 1	H1	H1	Young heather smaller than 30 cm
Heather 2	H2	H1	Young heather smaller than 30 cm
Heather 3	H3	H2	Heather mixed with grass
Conifer Forest 2	SP1	N2	Open conifer forest with low shrub
Conifer Forest 3	SP3	N3	Open conifer forest with dense shrub
Open Dune 2	GR7	OD2	Typical white dune vegetation, with mainly *Ammophila arenaria*
Open Dune 1	GR3	OD1	Open vegetation, typical white dune habitat with species like *Ammophila arenaria* and *Elytrigia juncea*
Dune Grassland 1	DG1?	DG1	Dune grassland, grey dune habitat
Heather 3	H4?	H3	Old heather, higher than 30 cm
Dune Heather	H1	H1	Young heather smaller than 30 cm
Shrub 2	SH 6	ST2	(Dune) shrub
Shrub 1	GS3/4	ST1	Low (dune) shrub
Grassland-open dune	ODG1/3	OD1	Open vegetation, typical white dune habitat with species like *Ammophila arenaria* and *Elytrigia juncea*
Dune Grassland 1	DG1?	DG1	Dune grassland, grey dune habitat
Open Dune 1/Dune grassland 1	DG1?	OD1/DG1	Open vegetation, typical white dune habitat with species like *Ammophila arenaria* and *Elytrigia juncea*/dune grassland, grey dune habitat
Grassland-open dune	GR7/ODG4	OD2	Typical white dune vegetation, with mainly *Ammophila arenaria*
Shrub 1	GS 3	ST1	Low (dune) shrub
Peatland Bog	GR 3	GR4	Grassland (wet)
Peatland Bog	GR 6/8	GR5	Grassland (wet)
Peat Heather	SH6/8	H4	Peat heather, wet areas
Peat Shrub		ST1	Low (dune) shrub
Peat Forest	x	V1	Peat forest

Table 1: Site labels and fuel models for plots used to quantify fuel loads for the development of the Dutch Wildland Spreadmodel.

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References

1. Duyvis MG, Stalenhoef-Willemsen E (2009) Modellenonderzoek natuurbrandverspreiding. Simulatiemodel voor Nederland, NIFV, Arnhem.

2. Rothermel RC (1972) A Mathematical model for predicting fire spread in wildland fuels. Res. Pap. INT-115. US Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station, Ogden, USA, p: 40.

3. Lemaire AD, Mierlo RJM (2011) Rekenmodel uitbreidingssnelheid heidebrand: ontwikkeling en achtergronden. Rijswijk, Efectis Nederland BV.

4. Scott JH, Burgan RE (2005) Standard fire behavior fuel models; a comprehensive set for use with Rothermel's surface fire spread model. Rocky Mountain Research Station, USA.

5. Ager A, Finney M, McMahan A (2006) A wildfire risk modeling system for evaluating landscape fuel treatment strategies. USDA Forest Service, USA.

6. Bobbink RM, Weijters M, Nijssen M, Vogels J, Haveman R, et al. (2009) Branden als EGM – maatregel. Ministerie van landbouw, Natuur en voedselkwaliteit, Ede.

7. Ottmar R (2000) Stereo photo series for quantifying natural fuels. Pacific Wildland Fire Sciences Laboratory, Seattle, USA.

8. Deeming JE, Lancaster JW, Fosberg MA, Furman RW, Schroeder MJ (1972) National Fire Danger Rating Systems. USDA Forest Service Rocky Mountain Forest and Range Experiment Station Res Pap RM-84, Fort Collins Colo, p: 165.

9. Brown JK, Oberheu RT, Johnston CM (1982) Handbook for inventorying surface fuels and biomass in the Interior West. USDA For Serv, Intermountain Forest and Range Experiment Station. INT-129. Ogden, USA, p: 48.

10. Andrews PL (2013) Current status and future needs of the BehavePlus fire modeling system. International Journal of Wildland Fire, USDA Forest Service, USA.

11. Albini FA (1976) Estimating wildland fire behavior and effects. Gen Tech Rep INT-30. US Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station, Ogden, USA, p: 40.

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