

Package ‘firebehaviorR’

October 2, 2018

Title Prediction of Wildland Fire Behavior and Hazard

Version 0.1.0

Description Fire behavior prediction models, including the Rothermel Wildland Fire Modelling System (Scott & Reinhardt 2001; DOI:10.2737/RMRS-RP-29) and Alexander et al.'s (2006) Crown Fire Initiation & Spread model (DOI:10.1016/j.foreco.2006.08.174). Also contains sample datasets, estimation of fire behavior prediction model inputs (e.g., fuel moisture, canopy characteristics, wind adjustment factor), results visualization, and 15 methods to estimate fire weather hazard.

Depends R (>= 3.4.0)

Imports ggplot2, utils

License GPL-2

Encoding UTF-8

LazyData true

RoxygenNote 6.0.1.9000

Suggests knitr, rmarkdown, reshape2, truncnorm, xtable

VignetteBuilder knitr

R topics documented:

canFuel	2
cfis	3
coForest	4
ffm	5
fireChart	6
fireIndex	7
fireIndexKBDI	8
fuelModels	9
fuelMoisture	11
rothermel	11
rrRAWS	14
waf	15
Index	17

canFuel

*Canopy Fuel Stratum Characteristics Calculator***Description**

Canopy parameters estimated by Cruz, Alexander & Wakimoto (2003).

Usage

```
canFuel(ba, ht, tph, type)
```

Arguments

ba	a numeric vector of stand basal areas (m ² /ha)
ht	a numeric vector of average stand tree heights (m)
tph	a numeric vector of stand densities (trees/ha)
type	a character vector of forest cover types, either: "df" for Douglas-fir (<i>Pseudotsuga menziesii</i>); "pp" for ponderosa pine (<i>Pinus ponderosa</i>); "lp" for lodgepole pine (<i>Pinus contorta</i>); "mc" for mixed conifer

Value

a data frame with canopy base height (m), canopy fuel load (kg/m²), and canopy bulk density (kg/m³)

Author(s)

Justin P Ziegler, <justin.ziegler@colostate.edu>

References

Cruz M.G., Alexander M.E., Wakimoto R.H. 2003. Assessing canopy fuel stratum characteristics in crown fire prone fuel types of western North America. *International Journal of Wildland Fire*. **12**(1):39-50.

See Also

This function provides values for [rothermel](#) and [cfis](#) inputs.

Examples

```
#Two hypothetical forest stands
ba = c(10, 15)
ht = c(12, 20)
tph = c(100, 300)
type = c('df', 'lp')
canFuel(ba, ht, tph, type)
```

cfis

*Canopy Fire Initiation & Spread model***Description**

Prediction of crown fire probability, crown fire rate of spread and separation distance (Alexander and Cruz 2006). Separation distance is distance ahead of main fire front required for a spot fire to form, separate of a main fire.

Usage

```
cfis(fsg, u10, effm, sfc, cbd, id)
```

Arguments

fsg	a numeric vector of fuel stratum gaps (m)
u10	a numeric vector of 10-m open wind speeds (km/hr)
effm	a numeric vector of effective fine fuel moistures (%)
sfc	a numeric vector of surface fuel consumed (Mg/ha)
cbd	a numeric vector of canopy bulk densities (kg/m3)
id	a numeric vector of spot ignition delays, the time during which a given firebrand generates, is transported aloft, and ignites a receptive fuelbed (min)

Value

a data frame with type of fire, probability of crown fire occurrences (%), crown fire rate of spread (m/min), and critical spotting distance (m)

Author(s)

Justin P Ziegler, <justin.ziegler@colostate.edu>

References

Alexander M.E., Cruz M.G. 2006. Evaluating a model for predicting active crown fire rate of spread using wildfire observations. *Canadian Journal of Forest Research*. **36**:2015-3028.

Examples

```
data("coForest")
# show the data format:
head(coForest)
# Predict crown fire, using coForest
# measurements and assumed weather
# parameters
df.cfis = cfis(fsg = coForest$cbh_m, u10 = 20,
               effm = 6, sfc = coForest$sfl_kgm2*10, cbd = coForest$cbd_kgm3,
               id = 1)
print(df.cfis)

# Examine differences between treatment
```

```
# statuses
aggregate(x = df.cfis$cROS, by = list(treatmentStatus = coForest$status),
  FUN = mean)
# Now, examine the sensitivity of fire
# type designations to wind speed by
# treatment status
coForest = coForest[rep(seq_len(nrow(coForest)),
  11), ]
coForest$u10 = sort(rep(10:20, 14))
coForest$type = cfis(coForest$cbh_m, coForest$u10,
  6, coForest$sfl_kgm2*10, coForest$cbd_kgm3,
  1)$type
table(u10 = coForest$u10, coForest$type,
  coForest$status)
```

coForest

Colorado dry forest inventory summary.

Description

Fuels inventory summary of seven sampled forests in the southern Rocky Mountains and Colorado Plateau. Each forest was sampled before and after tree thinnings.

Usage

```
data("coForest")
```

Format

A data frame with 14 observations of 10 variables:

site name of forest location
status either before (pre) or after (post) forest thinning
trees_perha tree density (trees/ha)
basalArea_m2ha basal area (m²/ha)
qmd_cm quadratic mean diameter (cm)
height_m mean tree height (m)
sfl_kgm2 surface fuel load (kg/m²)
cbd_kgm3 canopy bulk density (kg/m³)
cbh_m canopy base height (m)
cfl_kgm2 canopy fuel load (kg/m²)

Source

Ziegler, J.P., Hoffman, C., Battaglia, M., Mell, W., 2017. Spatially explicit measurements of forest structure and fire behavior following restoration treatments in dry forests. *Forest Ecology & Management* **386**, 1–12. doi:10.1016/j.foreco.2016.12.002

ffm

*Estimate fine fuel moisture***Description**

Methods to estimate fine fuel moisture based on meteorological data.

Usage

```
ffm(method, rh, temp, month, hour, asp, slp, bla, shade)
```

Arguments

method	a character vector of specifying the method ("pech", "simard", "wagner", "anderson", "mcarthur", "fbo")
rh	a numeric vector of relative humidities (%)
temp	a numeric vector of dry bulb temperatures (deg. C)
month	a numeric vector of Gregorian month numbers (1-12)
hour	a numeric vector of hours (1-24)
asp	a character vector of aspects specified as cardinal directions, either "N", "S", "E", or "W"
slp	a numeric vector of topographic slopes (%)
bla	a character vector specifying the difference in elevation between the fine fuel's location and that of the meteorological data; either within 305 m ('l', the default), or the meteorological data are > 305m below ("b"), or above ("a") the fine fuel's location
shade	a character vector specifying whether fine fuels are shaded, "y" or "n"

Details

This function has six methods to estimate fine fuel moisture. If method = "fbo", all arguments must be specified, otherwise, only method, rh and temp are required.

Value

a data frame of litter, 1-hr, 10-hr, and 100-hr fuel moistures

Author(s)

Justin P Ziegler, <justin.ziegler@colostate.edu>

References

Viney, N.R. 1991. A review of fine fuel moisture modelling. *International Journal of Wildland Fire*. 1(4):215–234.

Examples

```
#Example using RAWS meteorological station data
data(rrRAWS)
wx = rrRAWS[2000:3000,]
ff = rbind(
  data.frame(ffm = ffm('simard',wx$rh, wx$temp_c)$fm1hr,method='simard'),
  data.frame(ffm = ffm('wagner',wx$rh, wx$temp_c)$fm1hr,method='wagner'),
  data.frame(ffm = ffm('anderson',wx$rh, wx$temp_c)$fm1hr,method='anderson')
)
ff$dateTime = rep(wx$dateTime,3)
par(mfrow=c(3,1))
hist(ff$ffm[ff$method=="simard"])
hist(ff$ffm[ff$method=="wagner"])
hist(ff$ffm[ff$method=="anderson"])

#The FBO method requires more inputs
rh = wx$rh
temp =wx$temp_c
month = as.numeric(format(strptime(wx$dateTime,"%m/%d/%Y %H:%M"),'%m'))
hour = as.numeric(format(strptime(wx$dateTime,"%m/%d/%Y %H:%M"),'%H'))
ffm(method = 'fbo', rh, temp, month, hour, asp = 'N', slp = 10, bla = 'l', shade = 'n')
```

fireChart	<i>Fire Characteristics Chart</i>
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Description

Visualization of predicted fire behavior using the Fire Characteristics Chart.

Usage

```
fireChart(name, hpua, ros)
```

Arguments

name	a character vector identifying names of predictions
hpua	a numeric vector of heat per unit area (kJ/m2)
ros	a numeric vector of rate of spread (m/min)

Value

an object of class ggplot

Author(s)

Justin P Ziegler, <justin.ziegler@colostate.edu>

References

Andrews, P.L. & Rothermel, R.C. 1982. Charts for interpreting wildland fire behavior characteristics. *INT-GTR-131*. USDA Forest Service Intermountain Forest & Range Experimental Station.

Examples

```
fc = fireChart('fire',hpua = 15000, ros = 50)
print(fc)
```

fireIndex

Fire weather indices based on static weather observations

Description

Methods to estimate fire weather indices using static weather observations.

Usage

```
fireIndex(temp, u, rh, fuel = 4.5, cure = 100)
```

Arguments

temp	a numeric vector of air temperatures (C)
u	a numeric vector of wind speeds (km/hr)
rh	a numeric vector of relative humidities (%)
fuel	a numeric vector of available fuel load (Mg/ha), defaults to 4.5
cure	a numeric vector for proportion of cured grass (%), defaults to 100

Details

This function computes seven methods to estimate static fire weather indices: the Angstrom Index, the Chandler Burning Index, the Hot Dry Windy Index, the Fuel Moisture Index, the Fosberg Fire Weather Index, the MacArthur Grassland Mark 4 Index, and the MacArthur Grassland Mark 5 Index. Each of these are static in that values are derived using a daily weather summary and do not consider weather during prior days. temp, rh and u are required for all methods. The latter two indices also use fuel, and the Grassland Mark 4 Index uses cure. Defaults for fuel and cure are provided, but can be specified by the user. Sharples (2009a, b) review all of the methods.

Value

a data frame of static fire weather index values

Author(s)

Justin P Ziegler, <justin.ziegler@colostate.edu>

References

Sharples, J.J., McRae, R.H.D., Weber, R.O. and Gill, A.M., 2009a. A simple index for assessing fuel moisture content. *Environmental Modelling & Software*, **24**(5):637-646.
Sharples, J.J., McRae, R.H.D., Weber, R.O. and Gill, A.M., 2009b. A simple index for assessing fire danger rating. *Environmental Modelling & Software*. **24**(6):764-774.

Examples

```
#Example using RAWS meteorological station data
data(rrRAWS)
rrRAWS.daily = rrRAWS[format(strptime(rrRAWS$dateTime, "%m/%d/%Y %H:%M"), "%H:%M")=="14:35",]
fireIndex(temp=rrRAWS.daily$temp_c, u= rrRAWS.daily$windSpeed_kmh, rh = rrRAWS.daily$rh)
```

fireIndexKBDI

Fire weather indices based on cumulative weather observations

Description

Methods to estimate daily fire weather indices using dynamic weather observations.

Usage

```
fireIndexKBDI(temp, precip, map, rh, u)
```

Arguments

temp	a numeric vector of daily air temperatures (C)
precip	a numeric vector of daily precipitations (mm)
map	a single numeric value of mean annual precipitation (mm)
rh	a numeric vector of relative humidities (%)
u	a numeric vector of daily wind speeds (km/hr)

Details

This function computes up to 8 methods to estimate dynamic fire weather indices. These methods are dynamic in that they take prior days' weather into consideration. Therefore the inputs must be ordered by day (i.e., weather observations for a given day are followed by weather observations for the next day.) The number of computed methods depends on the supplied arguments. If requisite arguments for specific methods are not supplied, fireIndexKBDI will not output results for those specific methods (i.e., there will be fewer than 8 columns). The requisite arguments for each method:

```
kbdi 'temp', 'precip', 'map'
drought factor 'temp', 'precip', 'map'
forestMark5 'temp', 'precip', 'map', 'u', 'rh'
fosbergKBDI 'temp', 'precip', 'map', 'u', 'rh'
fuelMoistureKBDI 'temp', 'precip', 'map', 'u', 'rh'
nesterov 'temp', 'precip', 'rh'
nesterovMod 'temp', 'precip', 'rh'
zdenko 'temp', 'precip', 'rh'
```

Value

a data frame of fire weather index values with a column for each valid method

Author(s)

Justin P Ziegler, <justin.ziegler@colostate.edu>

References

- Sharples, J.J., McRae, R.H.D., Weber, R.O. and Gill, A.M., 2009. A simple index for assessing fuel moisture content. *Environmental Modelling & Software*, **24**(5):637-646.
- Goodrick, S.L., 2002. Modification of the Fosberg fire weather index to include drought. *International Journal of Wildland Fire*, **11**(4), pp.205-211.
- Sharples, J.J., McRae, R.H.D., Weber, R.O. and Gill, A.M., 2009. A simple index for assessing fire danger rating. *Environmental Modelling & Software*. **24**(6):764-774.
- Keetch, J.J., Byram, G.M., 1968. A drought index for forest fire control. *RP-SE-68*, US Department of Agriculture, Forest Service, Southeastern Forest Experiment Station.
- Groisman, P.Y., Sherstyukov, B.G., Razuvaev, V.N., Knight, R.W., Enloe, J.G., Stroumentova, N.S., Whitfield, P.H., Førland, E., Hannsen-Bauer, I., Tuomenvirta, H. and Aleksandersson, H., 2007. Potential forest fire danger over Northern Eurasia: changes during the 20th century. *Global and Planetary Change*, **56**(3-4):371-386.
- Skvarenina, J., Mindas, J., Holec, J. and Tucek, J., 2003, May. Analysis of the natural and meteorological conditions during two largest forest fire events in the Slovak Paradise National Park. *In Proceedings of the International Scientific Workshop on Forest Fires in the Wildland–Urban Interface and Rural Areas in Europe: an integral planning and management challenge*.

Examples

```
#Example using RAWS meteorological station data
data(rrRAWS)
ff = rbind(
  data.frame(ffm = ffm('simard', rrRAWS$rh, rrRAWS$temp_c)$fm1hr, method = 'simard'),
  data.frame(ffm = ffm('wagner', rrRAWS$rh, rrRAWS$temp_c)$fm1hr, method = 'wagner'),
  data.frame(ffm = ffm('anderson', rrRAWS$rh, rrRAWS$temp_c)$fm1hr, method = 'anderson')
)
ff$dateTime = rep(rrRAWS$dateTime, 3)

#NOT RUN

#par(mfrow=c(3,1))
#hist(ff$ffm[ff$method=="simard"])
#hist(ff$ffm[ff$method=="wagner"])
#hist(ff$ffm[ff$method=="anderson"])
```

fuelModels

Surface fuel models.

Description

Fuel models developed by Anderson (1982), Scott (1999), and Scott & Burgan (2005) for prediction of surface fire behavior.

Usage

```
data("fuelModels")
```

Format

A data frame with 60 observations of 18 variables:

fuelModelType "S"tatic or "D"ynamic fuel load transfer

loadLitter load of litter fuel (Mg/ha)

load1hr load of 1-hr fuel (Mg/ha)

load10hr load of 10-hr fuel (Mg/ha)

load100hr load of 100-hr fuel (Mg/ha)

loadLiveHerb load of herbaceous fuel (Mg/ha)

loadLiveWoody load of woody fuel(Mg/ha)

savLitter surface area to volume ratio of litter fuel (m2/m3)

sav1hr surface area to volume ratio of 1-hr fuel (m2/m3)

sav10hr surface area to volume ratio of 10-hr fuel (m2/m3)

sav100hr surface area to volume ratio of 100-hr fuel (m2/m3)

savLiveHerb surface area to volume ratio of herbaceous fuel (m2/m3)

savLiveWoody surface area to volume ratio of woody fuel (m2/m3)

fuelBedDepth depth of woody fuel (cm)

mxDead dead fuel moisture of extinction (%)

heat heat content (J/g)

description fuel model description

source scientific source

References

- Anderson, H.E. 1982. Aids to determining fuel models for estimating fire behavior. *INT-GTR-122*. US Department of Agriculture, Forest Service, Intermountain Forest and Range Experimental Station.
- Scott, J.H. 1999. NEXUS: A system for assessing crown fire hazard. *Fire Management Notes* **59**(2):20 –24.
- Scott, J.H., & Burgan, R. E. 2005. A new set of standard fire behavior fuel models for use with Rothermel's surface fire spread model. *RMRS-GTR-153*. US Department of Agriculture, Forest Service, Rocky Mountain Research Station.

See Also

[rothermel](#)

fuelMoisture

Modified Scott & Burgan (2005) moisture scenarios.

Description

Moisture scenarios are a set of fuel moistures of surface fuels, on a dry-weight basis, for each of the surface fuel classes. Adapted from Scott & Burgan (2005), this dataset includes fuel moistures of litter.

Usage

```
data("fuelMoisture")
```

Format

A data frame with 16 observations of 7 variables:

fmLitter moisture of litter (%)

fm1hr moisture of 1-hr fuel (%)

fm10hr moisture of 10-hr fuel (%)

fm100hr moisture of 100-hr fuel (%)

fmLiveHerb moisture of herbaceous fuel (%)

fmLiveWoody moisture of woody fuel (%)

description scenario description

Source

Scott, J., & Burgan, R. E. 2005. A new set of standard fire behavior fuel models for use with Rothermel's surface fire spread model. *RMRS-GTR-153*. Fort Collins, CO: US Department of Agriculture, Forest Service, Rocky Mountain Research Station.

See Also

[rothermel](#)

rothermel

Rothermel Fire Behavior Modeling System

Description

Potential surface and crown fire behavior predicted by Scott and Reinhardt (2001).

Usage

```
rothermel(surfFuel, moisture, crownFuel, enviro, rosMult = 1,
  cfbForm = "f", folMoist = "y")
```

Arguments

surfFuel	<p>a data frame of surface fuel attributes. Variable names are not important but the order is important. The first variable is a character type whereas the rest are numeric</p> <ol style="list-style-type: none"> 1. the fuel model type, either 'S'tatic or D'ynamic herb load transfer 2. litter load (Mg/ha) 3. 1-hr load (Mg/ha) 4. 10-hr load (Mg/ha) 5. 100-hr load (Mg/ha) 6. herb load (Mg/ha) 7. woody load (Mg/ha) 8. litter SAV (m2/m3) 9. 1-hr SAV (m2/m3) 10. 10-hr SAV (m2/m3) 11. 100-hr SAV (m2/m3) 12. herb SAV (m2/m3) 13. woody SAV (m2/m3) 14. fuel bed depth (cm) 15. moisture of extinction (%) 16. heat content (J/g)
moisture	<p>a numeric-only data frame of surface fuel moistures on a dry-weight basis (%). Variable names are not important but the following order of surface fuel components is important: litter, 1-hr woody fuels, 10-hr woody fuels, 100-hr woody fuels, live herbaceous, and live woody vegetation (6 values or columns)</p>
crownFuel	<p>a vector or data frame with canopy fuel attributes, in order:</p> <ol style="list-style-type: none"> 1. canopy bulk density (kg/m3) 2. foliar moisture content (%) 3. canopy base height (m) 4. canopy fuel load (kg/m2)
enviro	<p>a numeric-only data frame with environmental attributes, in order:</p> <ol style="list-style-type: none"> 1. topographic slope (%) 2. open windspeed (km/hr) 3. wind direction, from uphill (deg.) 4. wind adjustment factor (0-1)
rosMult	<p>a numeric value for multiplying crown fire rate of spread, defaults to 1 (see details)</p>
cfbForm	<p>a character specifying how crown fraction burned is calculated. Options are "sr", "w", or "f" (default); see details.</p>
folMoist	<p>either "y" (default) or "n", specifying if foliar moisture effect is calculated (see details)</p>

Details

This is an R build of the Rothermel fire behavior modelling system (Scott & Reinhardt 2001) which links sub-models of surface fire rate of spread (Rothermel 1972), crown fire initiation (Van Wagner 1977), and Rothermel's (1991) crown fire rate of spread.

rosMult multiples the rate of spread for active or passive crown fires and is recommended a value of 1.7 when a user desires a maximum crown fire rate of spread (Rothermel 1991).

cfbForm selects the method to estimate crown fraction burned. This selection impacts estimates of passive crown fraction burned, fireline intensity, and heat per unit area. Use "sr" for Scott and Reinhardt (2001), "w" for van Wagner (1993), and "f" for Finney (1998).

folMoist, if invoked with a "y", calculates the foliar moisture effect to scale crown fire rate of spread (see Scott & Reinhardt 2001). If "n", no foliar moisture effect is determined.

Value

a list with 6 data frames

fireBehavior	a data frame with fire behavior estimates including fire type, crown fraction burned (%), rate of spread (m/min), heat per unit area (kJ/m ²), fireline intensity (kW/m), flame length (m), direction of max spread (deg), scorch height (m), torching index (km/hr), crowning index (km/hr), surfacing index (km/hr), effective midflame wind (km/hr), flame residence time (min)
detailSurface	a data frame with some intermediate variables of surface fire behavior including: potential ROS (m/min); no wind, no slope ROS (m/min); slope factor (-); wind factor (-); characteristic dead fuel moisture (%); characteristic live fuel moisture (%); characteristic SAV (m ² /m ³); bulk density (kg/m ³); packing ratio (-); relative packing ratio (-); reaction intensity (kW/m ²); heat source (kW/m ²); heat sink (kJ/m ³)
detailCrown	a data frame with some intermediate variables of crown fire behavior including: potential ROS (m/min); no wind, no slope ROS (m/min); slope factor (-); wind factor (-); characteristic dead fuel moisture (%); characteristic live fuel moisture (%); characteristic SAV (m ² /m ³); bulk density (kg/m ³); packing ratio (-); relative packing ratio (-); reaction intensity (kW/m ²); heat source (kW/m ²); heat sink (kJ/m ³)
critInit	a data frame of critical values for crown fire initiation including: fireline intensity (kW/m), flame length (m), surface ROS (m/min), Canopy base height (m)
critActive	a data frame of critical values for active crown fire including: canopy bulk density (kg/m ³), "ROS, crown (R'active) (m/min)
critCess	a data frame of critical values for cessation of crown fire including: canopy base height (m), O'cessation (km/hr)

Author(s)

Justin P Ziegler, <justin.ziegler@colostate.edu>

References

- Rothermel, R.C. 1972. A mathematical model for predicting fire spread in wildland fuels. *INT-RP-115*. USDA Forest Service Intermountain Forest & Range Experimental Station.
- Van Wagner, C.E. 1977. Conditions for the start and spread of crown fire. *Canadian Journal of Forest Research* **7**:23–34.
- Rothermel, R.C., 1991. Predicting behavior and size of crown fires in the northern Rocky Mountains. *INT-RP-438*. USDA Forest Service Intermountain Research Station.
- Van Wagner, C.E. 1993. Prediction of crown fire behavior in two stands of jack pine. *Canadian Journal of Forest Research* **23**:442–449.
- Finney, M.A. 1998. FARSITE: Fire area simulator — model development and evaluation. *RMRS-RP-47*. USDA Forest Service Rocky Mountain Research Station.

Scott, J.H., Reinhardt, E.D. 2001. Assessing crown fire potential by linking models of surface and crown fire behavior. *RMRS-RP-29*. USDA Forest Service Rocky Mountain Research Station.

Examples

```
data(fuelModels, fuelMoisture)
#fuelModels['A10',]
exampSurfFuel = fuelModels['A10',]

#fuelMoisture['D1L1',]
exampFuelMoisture = fuelMoisture['D1L1',]

exampCrownFuel = data.frame(
  CBD = coForest$cbd_kgm3[1],
  FMC = 100,
  CBH = coForest$cbh_m[1],
  CFL = coForest$cfl_kgm2[1]
)

exampEnviro = data.frame(
  slope = 10,
  windspeed = 40,
  direction = 0,
  waf = 0.2
)
rothermel(exampSurfFuel, exampFuelMoisture, exampCrownFuel, exampEnviro)
```

rrRAWS

Rampart Range RAWS meteorological data

Description

Hourly meteorological data from April 2017 through September 2017 from the Rampart Range Remote Automated Weather Station (RAWS; Station ID: RRAC2), maintained by the United States Forest Service.

Usage

```
data("rrRAWS")
```

Format

A data frame with 4392 observations of 4 variables:

dateTime date and time of individual observation formatted as "%m/%d/%Y %H:%M"

temp_c air temperature (deg. C)

rh relative humidity (%)

windSpeed_kmh wind speed (km/hr)

precip_mm precipitation (mm)

Source

RAWS USA Climate Archive <https://raws.dri.edu/>

waf	<i>Calculated wind adjustment factor</i>
-----	--

Description

Prediction of wind adjustment factor for sheltered and unsheltered fuels.

Usage

```
waf(fuelDepth, forestHt, cr, cc, sheltered = "n")
```

Arguments

fuelDepth	a numeric vector of surface fuel bed depths (cm)
forestHt	a numeric vector of average stand tree heights (m)
cr	a numeric vector of crown ratios (%)
cc	a numeric vector of canopy cover (%)
sheltered	a character vector of either "y" or "n" (default) to use sheltered or not (unsheltered) equations

Details

This calculates the wind adjustment factor (ratio of 20-ft open wind speed to wind speed at midflame height of a surface fire). One of two equations are used, depending on user input: by default, this function assumes the surface fuel bed is unsheltered. `fuelDepth` must be a positive value if the unsheltered variant is invoked.

There are two conditions to enable calculation for a sheltered fuelbed. One, the product of `cr` and `cc` must exceed 5%. Alternatively, if `cr` and `cc` are not supplied, the user may enter `"sheltered = y"`. The former method is recommended when `cr` and `cc` are known. In addition, either means of invoking the sheltered equation must also have `forestHt` provided.

Value

a vector of wind adjustment factors

Author(s)

Justin P Ziegler, <justin.ziegler@colostate.edu>

References

Andrews, P.L. 2012. Modeling wind adjustment factor and midflame wind speed for Rothermel's surface fire spread model. *RMRS-GTR-266*. USDA Forest Service Rocky Mountain Research Station.

Examples

```
#Sheltered fuelbed with a 10 m tall forest with unknown crown ratio and canopy cover
waf(forestHt = 10, sheltered = 'y')
#Sheltered fuelbed with known high crown ratio and canopy cover
waf(forestHt = 10, cr = 40, cc = 40)
#Sheltered fuelbed with known low crown ratio and canopy cover
waf(fuelDepth = 1, forestHt = 10, cr = 10, cc = 10)
#Because cr and cc are low, the previous solution is equivalent to an unsheltered fuelbed
waf(fuelDepth = 1)
```


Index

*Topic **datasets**

coForest, [4](#)

fuelModels, [9](#)

fuelMoisture, [11](#)

rrRAWS, [14](#)

canFuel, [2](#)

cfis, [2](#), [3](#)

coForest, [4](#)

ffm, [5](#)

fireChart, [6](#)

fireIndex, [7](#)

fireIndexKBDI, [8](#)

fuelModels, [9](#)

fuelMoisture, [11](#)

rothermel, [2](#), [10](#), [11](#), [11](#)

rrRAWS, [14](#)

waf, [15](#)