2.2 Fuels

How can we define and characterize wildland fuels?




Fuel is:

"the combustible material that provides the source of chemical bond energy to sustain the combustion chain reaction."

Some key properties of fuel:

1. Mass
2. Shape
3. Spatial configuration or arrangement
4. Heat content
5. Moisture
6. Type
7. Position

Together these create a **FUEL MODEL**

1. Fuel mass

- How much combustible biomass exists to sustain the reaction?
- Typically measured in kg
- In a wildland setting, this is measured as fuel load (kg ha^{-1}), where:
  - 1 kg ≈ 2.2 lbs
  - 1 ha (hectare) = 10,000 m^2 = a square 100 m on a side

- Fuel loads are often broken out by fuel type and size class
- Higher fuel loads increase reaction intensity but may also reduce rate of spread (why?)

Reaction intensity = (ignition velocity) x (fuel mass) x (moisture damping coefficient) x (heat content)

So for any given fuel type, reaction intensity $\propto$ fuel mass

But recall that rate of spread (m min^{-1}) =

$$\left(\frac{\text{heat source}}{\text{heat sink}} \right)$$

"Heat sink" of biomass because it takes more energy to initiate combustion process (tends to absorb energy)

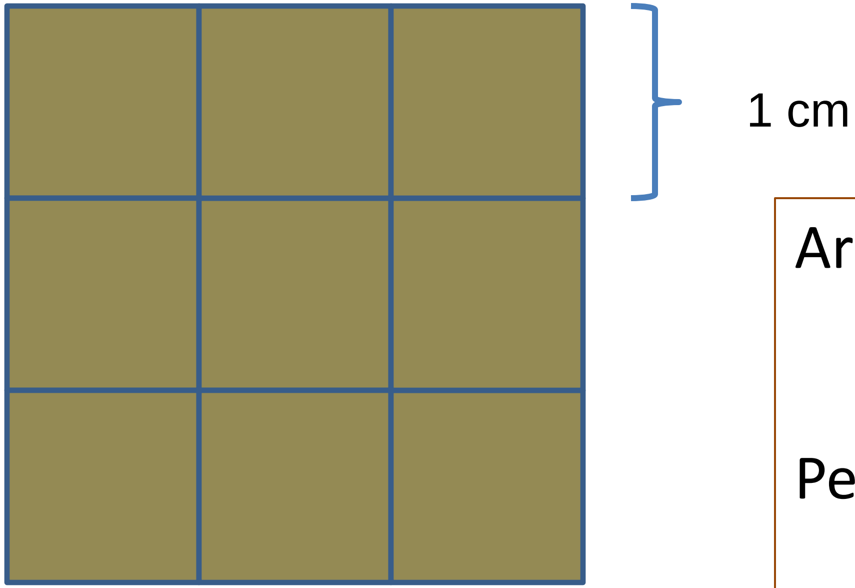
Depending on the fuel, the "heat sink" effect may slow down the combustion process, even though over time a lot more heat will be produced

2. Fuel shape

- Why would shape matter?

  BIG influence on how heat transfer mechanisms bring energy to the fuel and commence the combustion reaction – think of the physics of energy transfer

A thought experiment

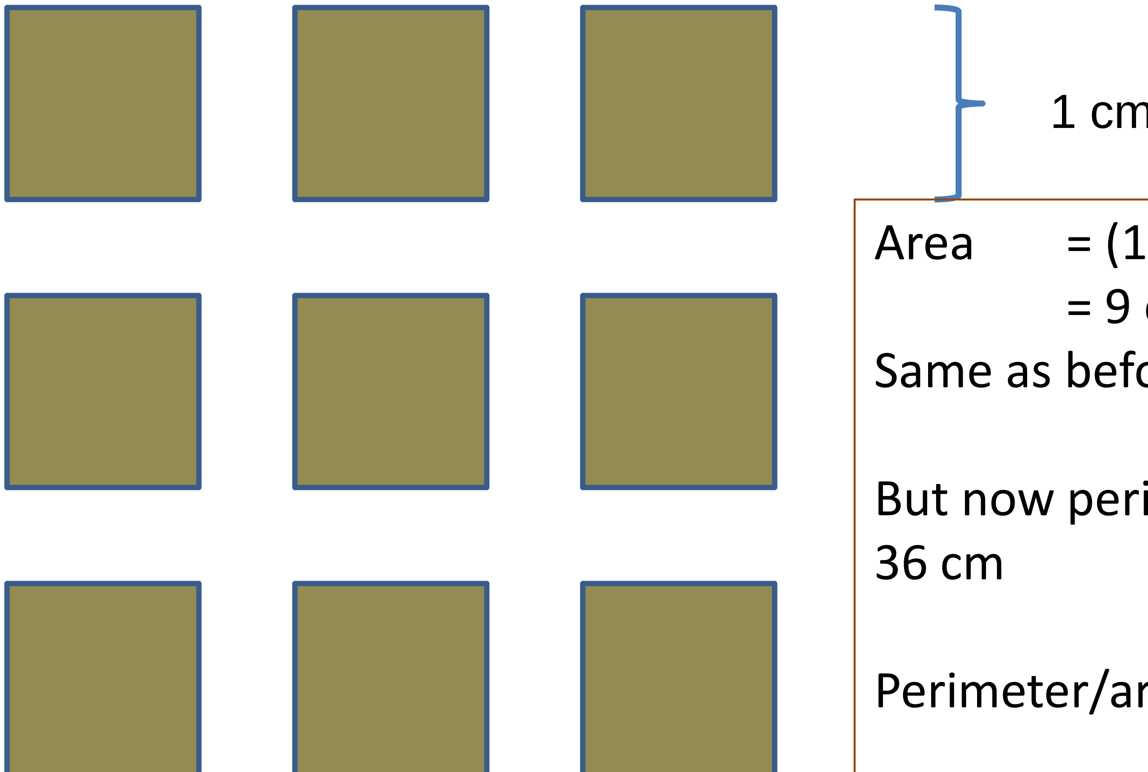


Area = $(3\ cm)^2$
= $9\ cm^2$

Perimeter = 12 cm

Perimeter/area ratio
= 12/9 = 1.33

Now just do this:



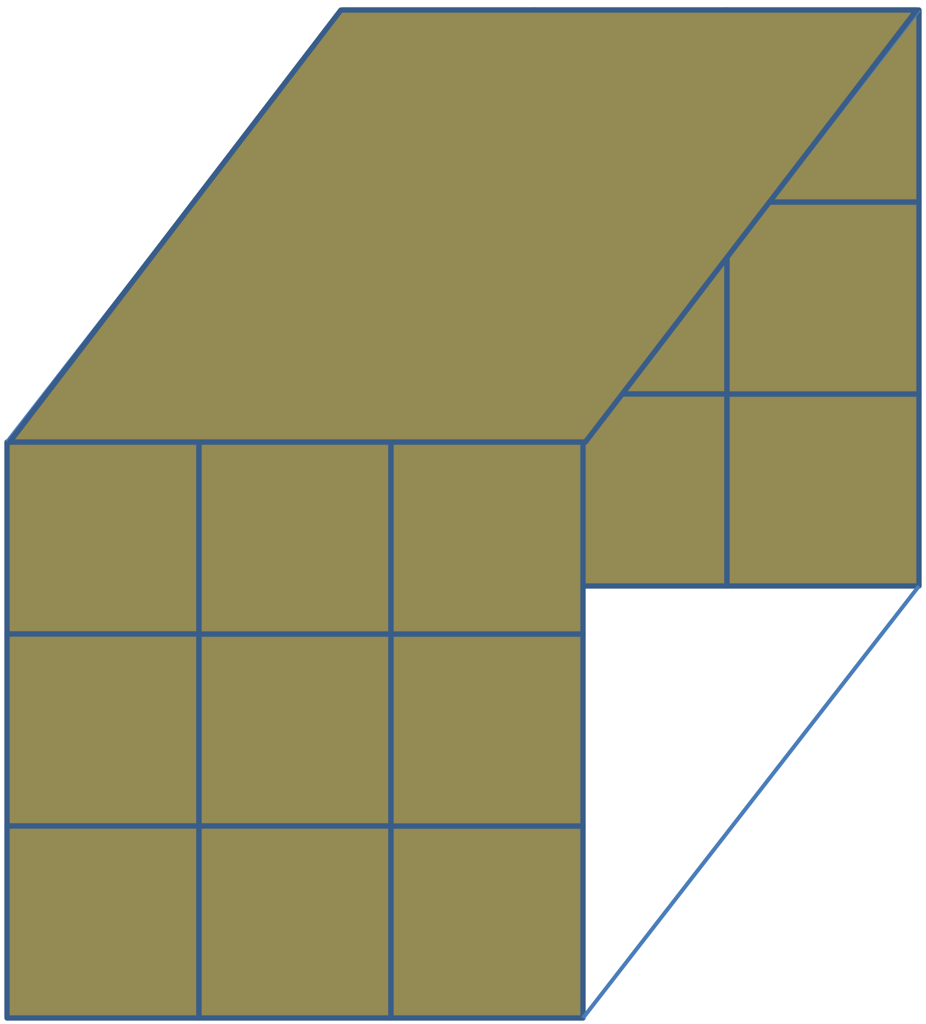
Area $= (1\ \text{cm})^2 \times 9$
$= 9\ \text{cm}^2$
Same as before

But now perimeter = (4 cm) x 9 = 36 cm

Perimeter/area ratio = 36/9 = 4

(ratio increased ≈ 300%)

Now let this be a rectangular solid 10 cm long:

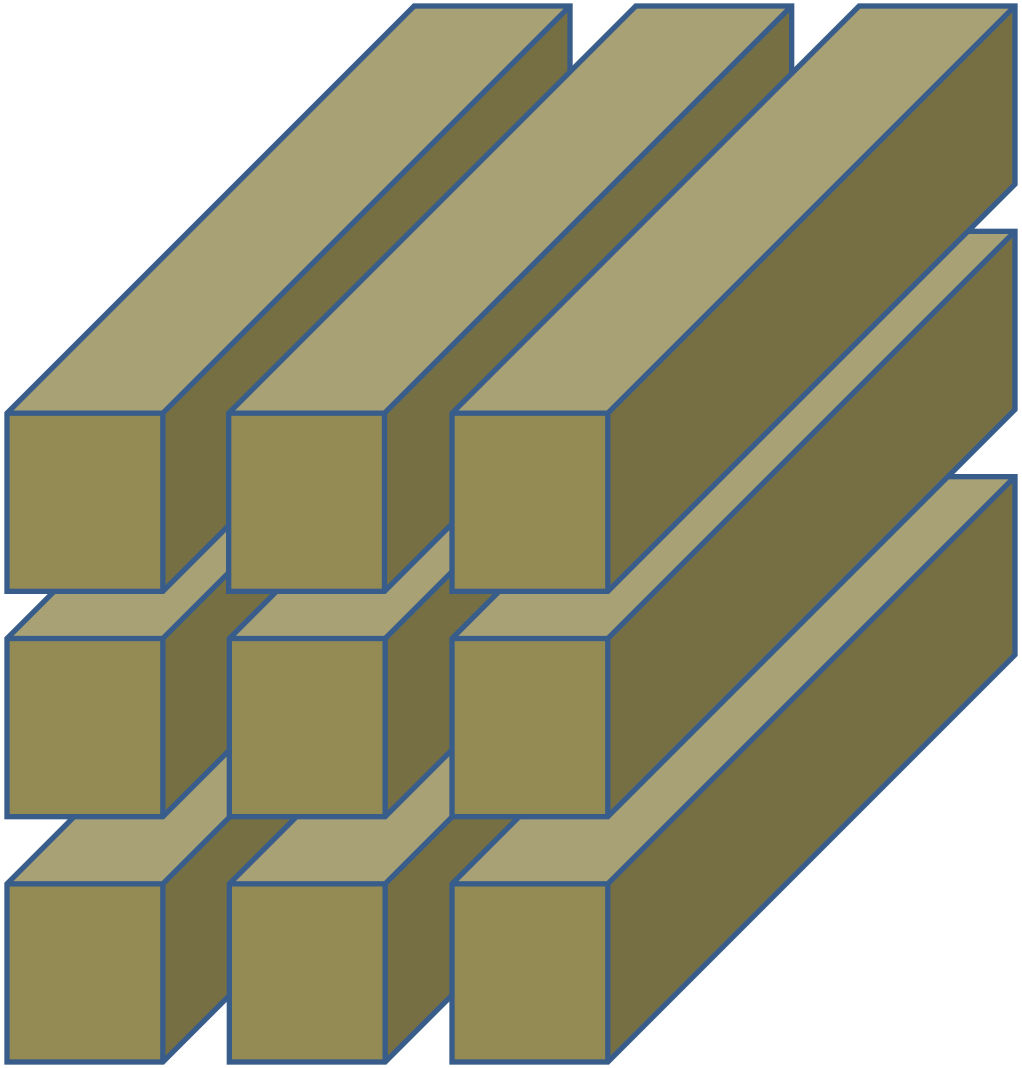


Volume
= area of base x length
= 9 cm^2 x 10 cm
= 90 cm^3

Surface area
= (area of base x 2) + (area of sides x 4)
= (9 x 2) + (30 x 4)
= 138 cm^2

Surface/volume ratio = 138/90 ≈ 1.53

…and now break it into pieces again:



Volume
= area of base x length
= $(1\ cm^2 \times 10\ cm) \times 9$
= $90\ cm^3$ (unchanged)

Surface area
= (area of base x 2) + (area of sides x 4)
= [(1 x 1 x 2) + (1 x 10 x 4)] x 9
= $378\ cm^2$

Surface/volume ratio = 12/9 = 378/90 ≈ 4.2

Increased 4.2/1.5 = 275%

Why would this matter?

Greater surface area per unit volume provides:

1. more rapid equilibration with ambient temperature and humidity
2. more area for absorbing heat during pre-heating phase by radiation and convection
3. more surface area for evaporation (drying) of fuels in Phases I and II (pyrolysis)
4. smaller volume allows greater conductive heat penetration into fuel particle

Fuel load and packing can be estimated visually

0.10 kg m^{-2}

0.25 kg m^{-2}

0.40 kg m^{-2}

Keane, Robert E.; Dickinson, Laura J. 2007. Development and evaluation of the photoload sampling technique. Research Paper RMRS-RP-61CD. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 29 p.

3. Spatial configuration of fuels

- How compact is the fuel bed?
  - Determines air penetration among fuel particles, which is essential to sustain the combustion chain reaction
  - Also determines how easily heat energy passes from one part of the fuel complex to another by radiation and convection (if separate) or conduction (if touching)

Packing ratio

A Common metric is the *packing ratio*:

$$\left(\frac{\text{volume of fuel alone}}{\text{volume of "fuel bed" (fuel and air)}} \right)$$

- In other words, the proportion of the fuel array volume that is occupied by fuel
- Tells you whether the fuel is tightly or loosely packed

Two sample packing ratio calculations

1. Fuel bed volume = 100 cm^3

Total volume of fuel = 90 m^3

Packing ratio = 0.9

Most of the volume is fuel; small amount of oxygen may limit combustion

2. Fuel bed volume = 500 cm^3

Total volume of fuel = 90 cm^3

Packing ratio = 0.18

Most of the volume is air – fuel mass may be limiting

Try it!

1. What is the packing ratio for 120 cm^3 of fuel in a cubic space 4 x 3 x 10 cm?

2. What if you put the same fuel into a cubic space 4 x 6 x 10 cm?

1. 4 x 3 x 10 = 120 cm^3

   120/120 = 1.0 (solid material)

2. 4 x 6 x 10 = 240 cm^3

   120/240 = 0.5

Put size, shape, arrangement together:

4. Heat content

- Units of MJ kg^{-1}
  - that is: energy output per unit mass
- Woody *vs.* herbaceous fuels (which is higher?)
- Characteristic of different species
- Heat content also affected by those highly combustible *volatiles*

5. Fuel moisture

- Over time, fuels would reach equilibrium with surrounding air
- Live fuels (living plants) have physiological processes to maintain moisture differential (part of being alive)
  - These are measured as live foliar moisture content
  - Calculated as percent of dry weight

How exactly does moisture affect combustion?

- Water has high *latent heat potential*
  - this means that it can absorb a lot of energy before changing state (e.g., from liquid to gas)
  - so water absorbs energy that could otherwise go into pre-heating combustible material (Phase I)
- Water also displaces air in interstitial spaces
  - Interstice, the spaces between solids; from L. *intersistere*, "to stand between"
- *Thus, water tends to inhibit the combustion reactions*

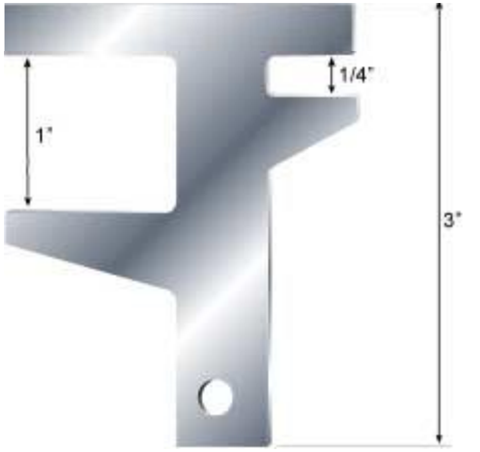
Fuel time-lag classes

- *Timelag* is the amount of time for a particle of fuel to reach 63% of equilibrium moisture for a given temperature and humidity
- Shorter timelag fuels equilibrate faster
- What kinds of fuels would be in short timelag classes?
    - very small diameters (actually, smallest dimension)

Woody fuel timelag classes

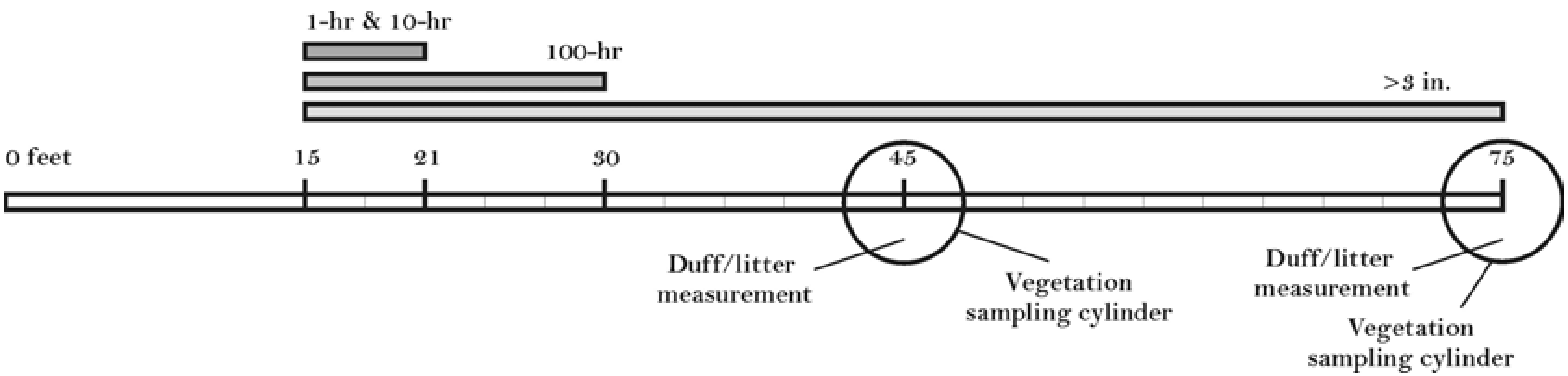
Time lag	Smallest dimension (cm)	Smallest dimension (in)
< 1 hr	Grass, fine litter	
1 hr	< .6 cm	< ¼ in
10 hr	.6 – 2.5 cm	¼ - 1 in
100 hr	2.5 – 7.5 cm	1 -3 in
1000 hr	> 7.5 cm	> 3 in

“Go/no-go fuel gauge”



Fuel abundance by size class often assessed along transects

Standard practice: “Brown’s transect” ~ 22.8 m (75 ft)



US Forest Service. *Fuel Load (FL) Sampling Methods. FIREMON,* v2.0, 2002.
National Park Service, *Fire Monitoring Handbook.* 2004.

The Fuel Characteristics Classification System (FCCS)

http://www.fs.fed.us/pnw/fera/products/tutorials/fccs/fccs_tutorial_html/02_Part1.htm

6. Fuel types

- Fuels are vegetation (plants)!
- Two basic categories:
  - Live vs. dead fuels
  - Herbaceous vs. foliar vs. woody
- So:
  - Live foliar = tree or shrub canopies
  - Dead foliar or herbaceous = litter or cured grasses
  - Etc.


CAMELBAK

7. Fuel position

- Three basic positions or locations:
  1. Ground fuels
  2. Surface fuels
  3. Canopy fuels (shrub and tree fuels sometimes distinguished)

Questions

- Why does the size of fuel we can burn in a campfire increase over time?
- Packing ratio example
- Influences on behavior (heat sources/heat sinks)
- How exactly does fuel moisture affect combustion?