Disentangling the drivers of coarse woody debris behavior and carbon gas emissions during fire

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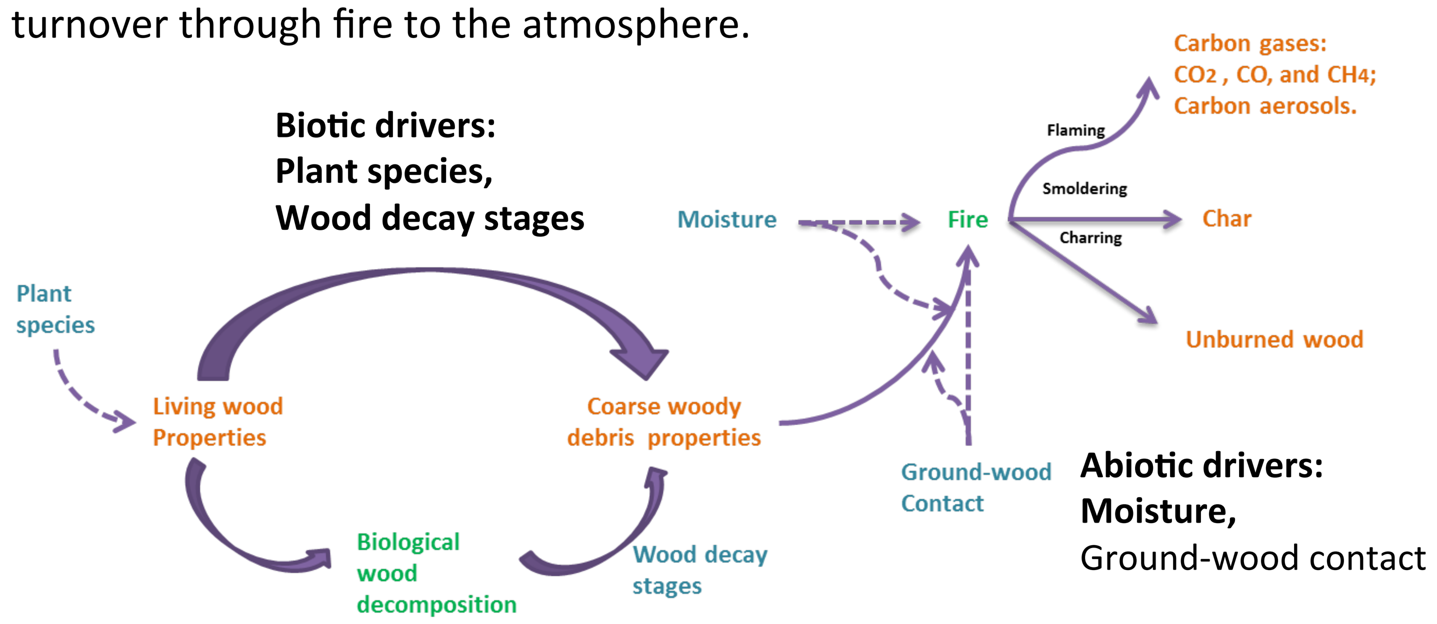
Introduction

Coarse woody debris (CWD) is an important carbon pool which is both big in size and relatively stable. 10~20% of the world's forest biomass carbon is in forms of CWD, and slow decaying coarse wood usually has relatively long residence time in Nature. So CWD turnover is fundamental in global carbon cycling.

Biological decomposition and fire are two main pathways of CWD turnover. Abiotic factors (climate), biotic wood properties, and their interactions determine the fate: decomposed gradually or burned immediately. **Our understanding of the magnitude of those drivers' effects are poor especially for fire.**

Aim and Research Questions

We try disentangle the biotic and abiotic drivers of CWD carbon turnover through fire to the atmosphere.



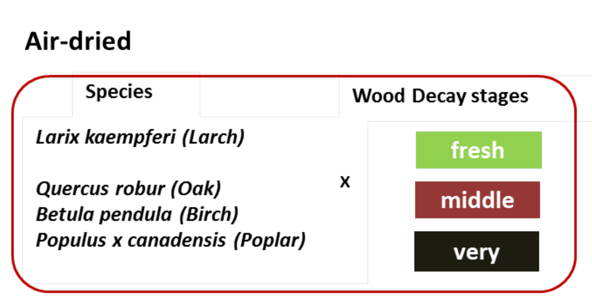
We asked:

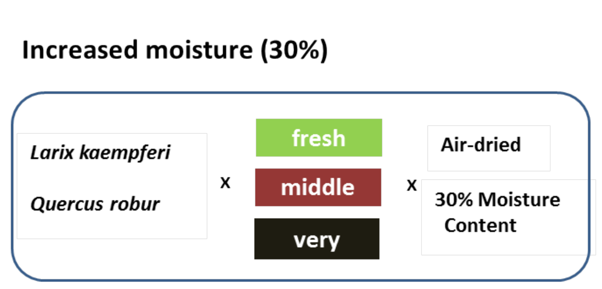
(1) Air dried: how do **plant species** and **wood decay stage** influence coarse wood behavior and C gas emissions (CO_2 and CO) during fire? Is there interaction between these biotic drivers?

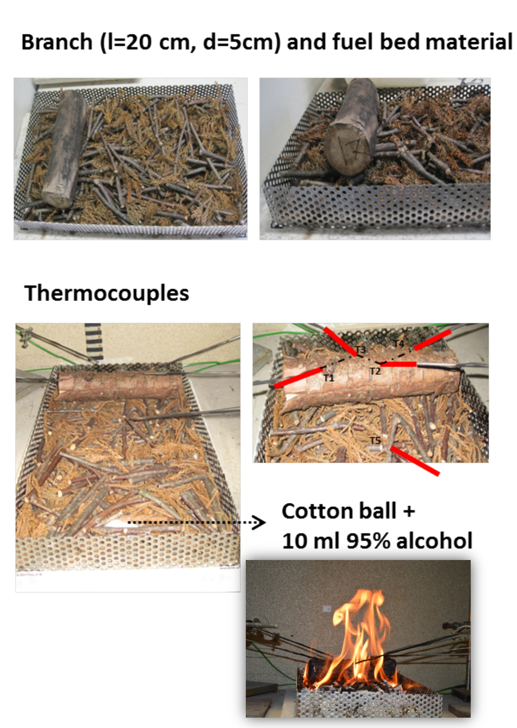
(2) Increased moisture (30%): does it inhibit wood flammability and its associated C gas emissions for coarse wood at various decay stages of different plant species? Is there interaction between moisture, plant species, and wood decay?

Experiment design and Set up

FLARE
Fire Lab Amsterdam for Research in Ecology







Flammability:
Ignitability: time until ignition;
Sustainability: flaming duration, smoldering duration;
Combustibility: max. temperature, sum of heat release;
Consumability: percentage mass loss.

Carbon gas emissions:
CO_2 and CO in grams.

Results

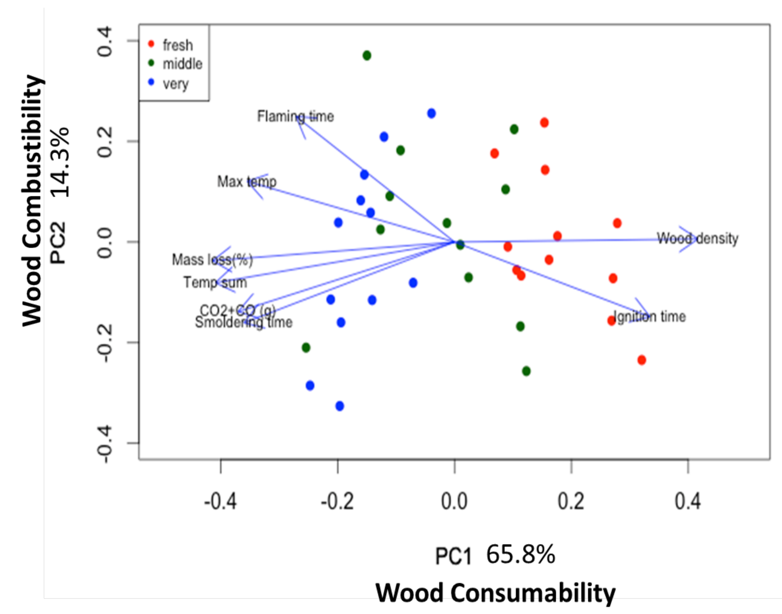
Air-dried

(1) Differences between Plant species and between Wood decay stages (two way ANCOVA)

	Plant Species	Wood Decay	Diameter	Wood Decay × Plant Species
Flammability				
lg(time until ignition (s))	1.77	14.8***	0.987	2.15
Flaming duration (s)	1.98	8.14***	5.15*	3.43*
Smoldering duration (s)	2.47	17.3***	7.75*	1.51
Max. temperature (°C)	2.76	18.5***	0.243	1.88
Sum of heat release (°C*s)	5.53**	37.0***	2.65	1.65
Mass loss (%)	31.8***	198.2***	0.394	10.8***
Carbon gas emissions				
CO_2 emission (g)	0.84	13.4***	4.66*	0.49
CO emission (g)	1.06	6.36***	5.31*	1.11

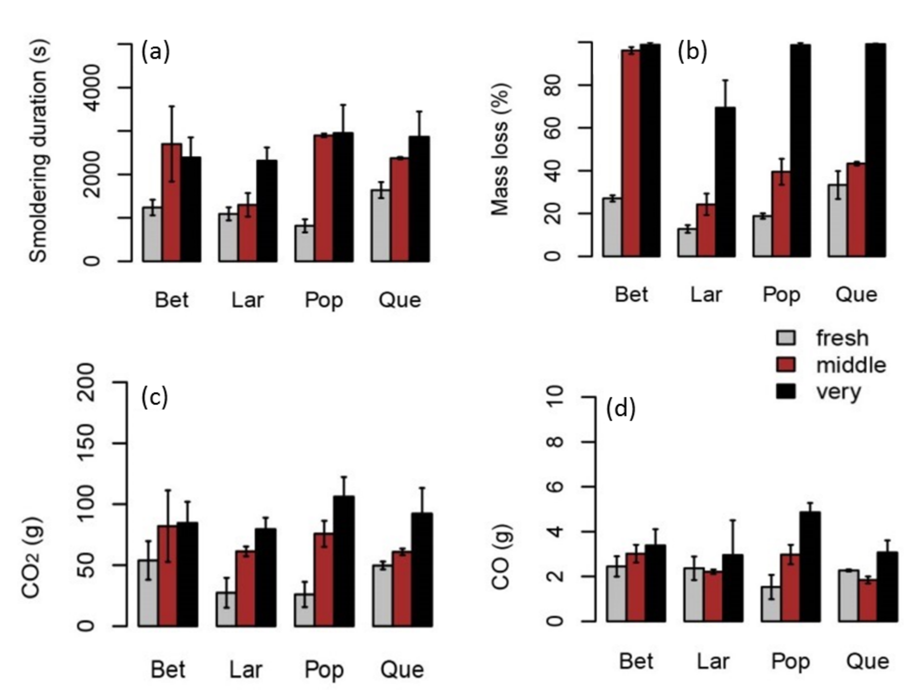
Significance code: $^{***}p< 0.001$, $^{**}p< 0.01$, $^{*}p< 0.05$.

(2) Wood Flammability Dimensions (air-dry wood)



The first dimension wood consumability (mass loss(%)) was strongly controlled by wood density. Mass loss(%) and CO_2 and CO emissions were closely correlated to smoldering combustion. **Key parameters are Smoldering time, Mass loss (%), CO_2 and CO emissions.**

(3) Across plant species, wood decay stage was a positive driver



Across plant species, more decomposed wood smoldered longer, lost more mass, and released more CO_2 and CO during fire.

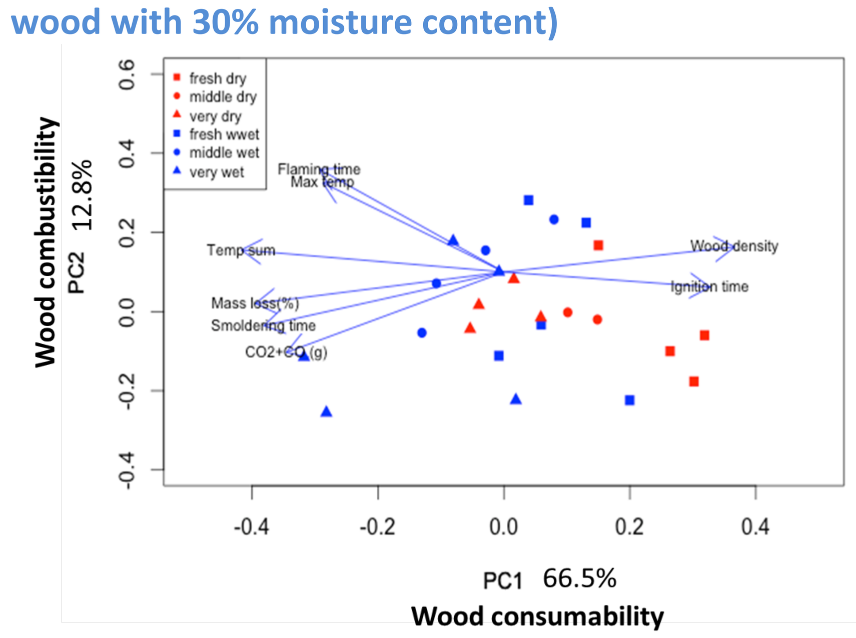
Increased moisture (30%)

(1) Across moisture levels, differences between Plant species and between Wood decay stages (three way ANCOVA)

	Moisture	Wood Decay	Plant Species	Diameter	Moisture × Wood Decay	Moisture × Plant Species
Flammability						
lg(time until ignition (s))	6.26*	15.5***	4.79*	0.273	0.459	0.038
lg(flaming duration (s))	28.9***	7.96**	6.84*	0.12	7.68**	8.05*
lg(smoldering duration (s))	5.6*	11.2***	19.7***	0.015	1.07	5.66*
Max. temperature (°C)	2.8	3.85*	0.926	1.02	2.64	0.486
Sum of branch heat release (°C*s)	19.3***	11.6***	17.7***	0.064	2.82	2.11
Mass loss (%)	57.5***	60.8***	75.3***	3.17	0.429	5.13*
Carbon gas emissions						
CO_2 (g)	0.723	8.67**	5.73*	1.02	1.72	0.024
CO (g)	0.523	9.84***	5.79*	6.71*	1.841	0.412

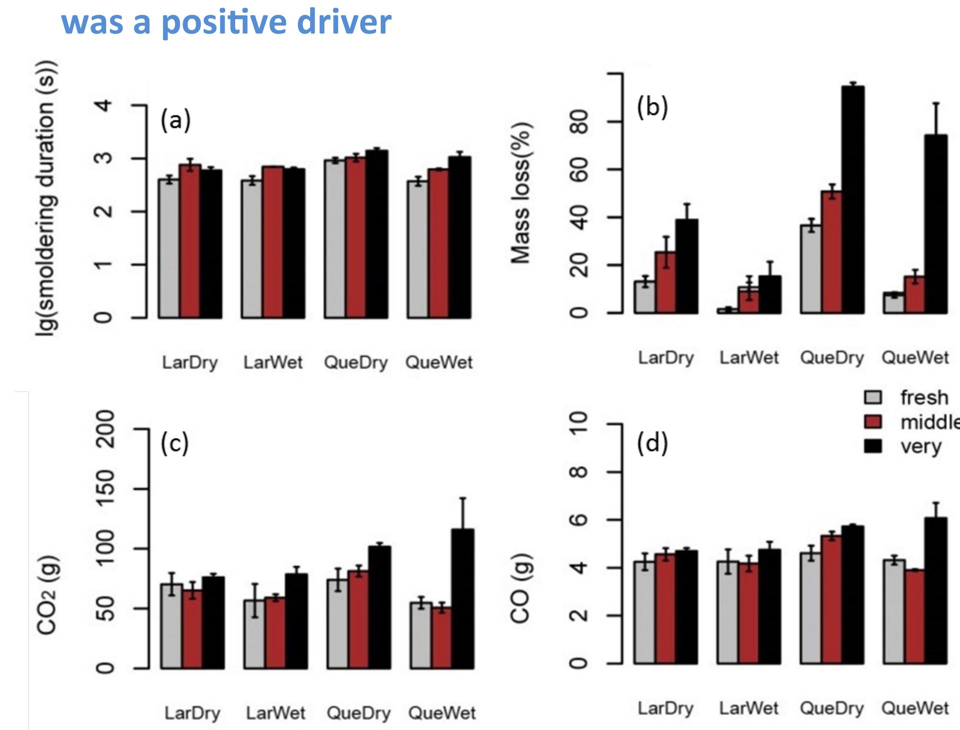
Significance code: $^{***}p< 0.001$, $^{**}p< 0.01$, $^{*}p< 0.05$.

(2) Wood Flammability Dimensions (air-dry wood and wood with 30% moisture content)



Across moisture levels, the first dimension wood consumability was strongly controlled by wood density. Mass loss (%) and CO_2 and CO emissions were closely correlated to smoldering combustion. **Key parameters are Smoldering time, Mass loss (%), CO_2 and CO emissions.**

(3) Across moisture levels, wood decay stage was a positive driver

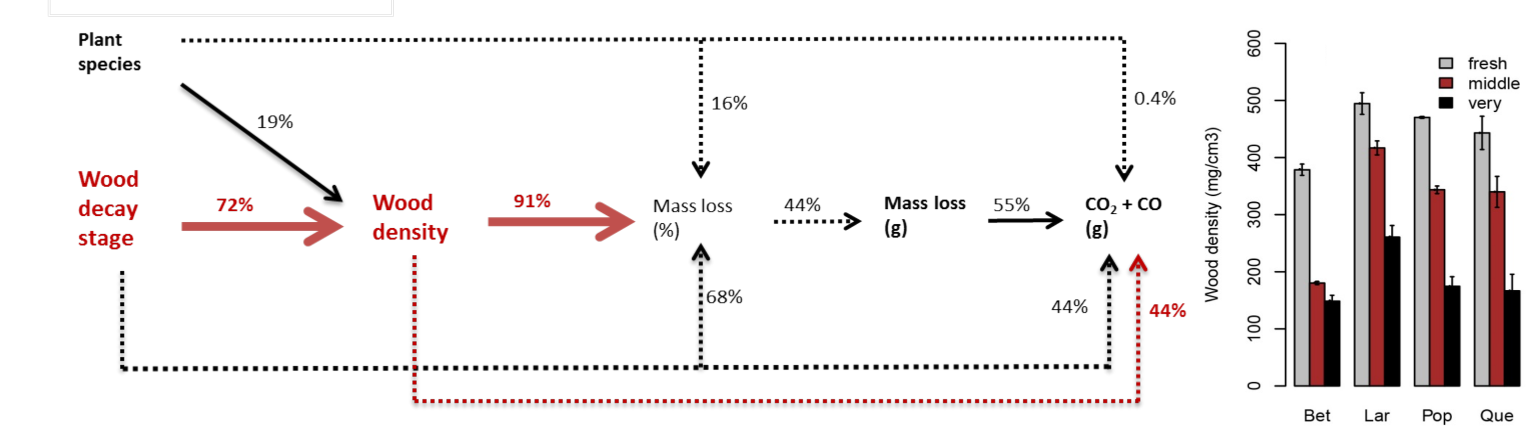


Branch with 30% moisture content smoldered shorter and lost less mass compared to air-dried ones. Across moisture levels and plant species, wood decay stages still act as a positive driver. A trend that the difference between wood decay stages was amplified by increased moisture.

Discussion

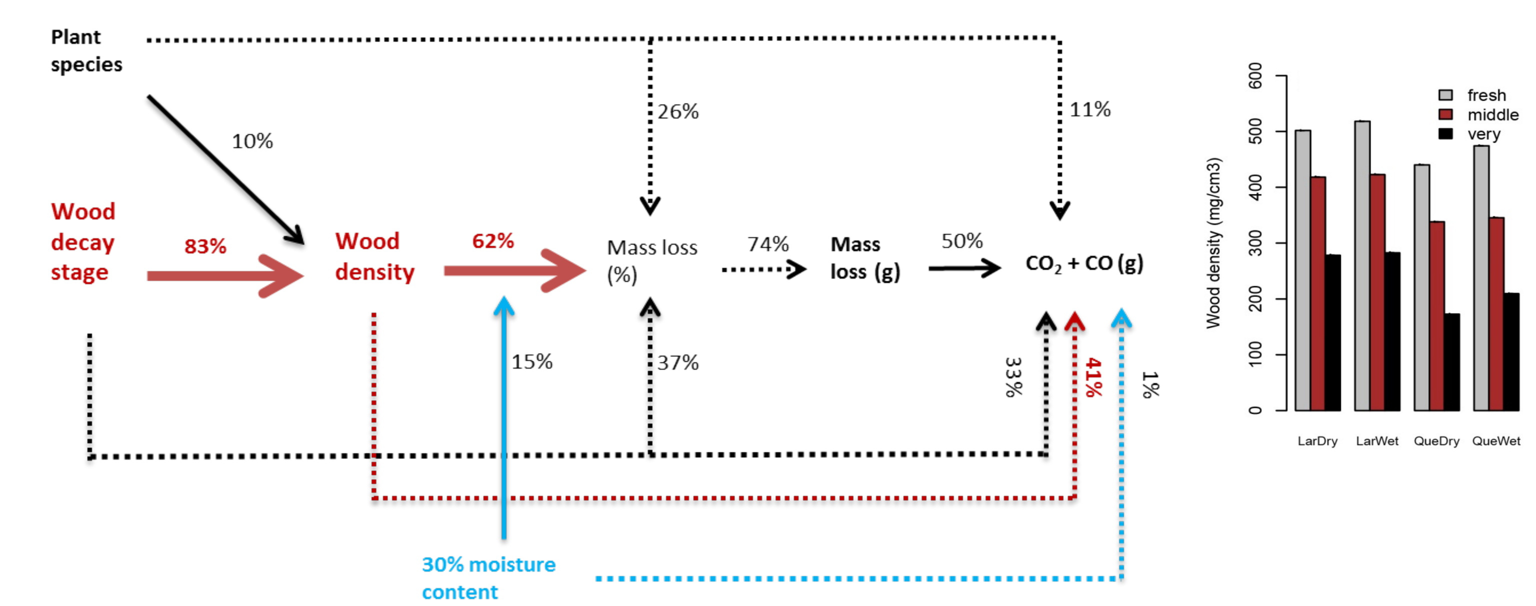
(1) When air-dried, wood density is the key underlying trait, and wood decay stage is the main driver of CWD carbon turnover through fire.

CWD Air-dried

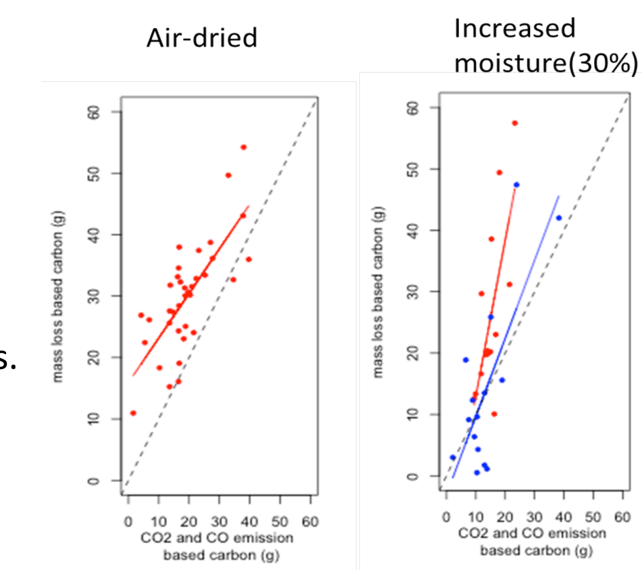


(2) Under increased moisture condition, wood density is still the key underlying trait and wood decay stage is still the main driver.

CWD at 30% moisture content



(3) There is mismatch between mass loss predicted and gas emission measured carbon, which is predicted values are larger than measured ones. This might be explained by the charring process which transfers organic C to solid char.

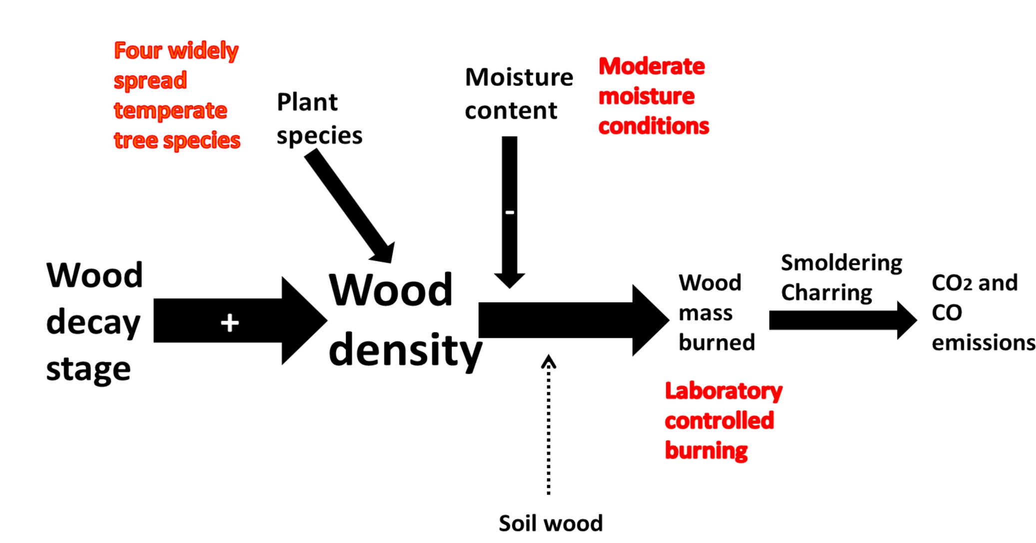


$$(CH_2O)n + O_2 \xrightarrow{\text{Flaming}} CO_2 + H_2O$$

$$(CH_2O)n + O_{2(\text{limited})} \xrightarrow{\text{Smoldering}} CO_2 + CO + CH_4 + H_2O$$

$$(CH_2O)n \xrightarrow{\text{Charring}} (C)n + H_2O$$

Conclusions



Wood density was the key underlying trait for predicting coarse wood carbon turnover through fire to the atmosphere.

Wood decay stage was the main positive driver of wood density variation and therefore coarse wood carbon turnover.