A model of tree resprout biomass allocation in a fire-prone savanna

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Fire in savanna

• Wet savannas ( >650 mm yearly rainfall) are maintained by fire and/or herbivory (Sankaran et al. 2005)
• ~50% of African savannas (Sankaran et al. 2005)
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• ~50% of African savannas (Sankaran et al. 2005)
• Young trees are trapped in the flame zone by repeated topkill = the ‘fire trap’ (Bond and Keely 2005)
• In Lamto savanna (Ivory Coast with 1200 mm rainfall) fire occurs yearly
Fire in savanna

Paradise

Hell

2m

Paradise

By Gignoux Jacques
Fire in savanna

Last year stem

This year stem

By Gignoux Jacques

Piliostigma thonningii
Fire in savanna

But how can <2m trees:
- Survive such repeated extreme stress?
- Escape the fire trap?

Last year stem

This year stem

Piliostigma thonningii

By Gignoux Jacques
About my model

Dry season + fire

Wet season
About my model

- Above ground biomass is lost through topkill
- How to regrow with no leaves?
- How to quickly grow >2m in 1 year?
• Above ground production is lost through topkill
• How to regrow with no leaves?
• How to quickly grow >2m in 1 year?

• How to allocate photosynthesis to reserves, leaves, stem and roots? (carbon and biomass allocation problem)
• Modelling to assess which allocation strategies enable tree resprouts to survive and reach 2m.
Questions

- What is the **impact** of **fire** on **allocation strategies**?
- Can we **predict** stem/leaf **allocation** from plant **architecture**?
- Is the effect of fire on allocation strategies different from the effect of just the dry season?
The best part

4 Variables + 12 parameters = 4 ODE
Dynamic of reserve biomass:
\[ \frac{dB_p}{dt} = p \ p_{\text{lim}} (aB_l + bP) - b \ B_p \] where \( p_{\text{lim}} = 1-P/(p_{\text{max}}R) \)

Dynamic of roots biomass:
\[ \frac{dB_r}{dt} = r \alpha G - q \ B_r = r \ (1- \ p \ p_{\text{lim}})/(1-p) \ G - q \ B_r \]

Dynamic of leafs biomass:
\[ \frac{dB_l}{dt} = G_L = \left( \frac{\beta^3}{(\beta^3+3L^2)} \right) s \ (1- \ p \ p_{\text{lim}})(aB_l + b \ B_p)/(1-p) \]

Dynamic of stem biomass allocation:
\[ \frac{dB_s}{dt} = G_S - qS = \left( \frac{3L^2}{(\beta^3+3L^2)} \right) s \ (1- \ p \ p_{\text{lim}})(aB_l + b \ B_p)/(1-p) - q \ B_s \]
After fire

Roots

Reserves ($B_p$)
Rainy season

Aerial parts

Roots

Aerial parts allocation (s)

Reserve allocation (p)

Reserves \( (B_p) \)

Roots allocation (r)
Rainy season

Photosynthesis (a)

Aerial parts allocation (s)

Reserve allocation (p)

Reserves ($B_p$)

Respiration cost (q)

Aerial parts

Roots allocation (r)

Respiration cost (q)

Roots
Dry season

Aerial parts

- Reserve allocation (p)
- Aerial parts allocation (s)
- Photosynthesis (a)
- Respiration cost (q)

Roots

- Roots allocation (r)
- Respiration cost (q)

Reserves ($B_p$)
Dry season

Aerial parts

Roots

Reserves ($B_p$)

Roots allocation ($r$)

Respiration cost ($q$)

When fire occurs
After fire

Roots

Reserves \((B_p)\)
Many allocation models are unconstrained (by lack of information)
Allocation models

- Many allocation models are unconstrained (by lack of information)

- Except mass conservation

\[ s + r + l + p = 1 \]

- But there are others ubiquitous constraints

Cat flying
Source: Google photo
Allocation model constraints

- **Reserve** compartment is physically **limited** by the size of stem and roots
Allocation model constraints

- Leaf biomass is limited by stem biomass
Allocation to aerial parts (s+l)
An illustration of results

Allocation to roots ($r$)

Allocation to aerial parts ($s+l$)
An illustration of results
An illustration of results

 Allocation to aerial parts (s+l) = success ( >2m after 50 years)
 Others = failed ( <2m after 50 years)
What is the impact of fire on allocation strategies?

Allocation to aerial parts (s+l)
What is the impact of fire on allocation strategies?

- Fire reduces set of successful strategies
- Better strategies have low allocation to roots
What is the impact of fire on allocation strategies?

- Fire reduces set of successful strategies
- **Better strategies** have **low allocation to roots**
Can we predict stem/leaf allocation from plant architecture?

Dominate species of Lamto

Bridelia ferruginea

Piliostigma thonningii

Crossopteryx febrifuga
Can we predict stem/leaf allocation from plant architecture?

Dominate species of Lamto

Bridelia ferruginea

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Allocation to aerial parts (r+l)
Can we predict stem/leaf allocation from plant architecture?

- There are differences between species (even relatively similar).
- Crosso has n=2 leaves per node.

### Allocation to aerial parts (r+l) vs. Allocation to roots (r)

**Bridelia ferruginea**

**Piliostigma thonningii**

**Crossopteryx febrifuga**

**Dominate species of Lamto**
Fire Vs Dry season

Rainy season
Fire Vs Dry season

Rainy season

Dry
Fire Vs Dry season

Rainy season

Dry

Fire
Fire Vs Dry season

Rainy season has more 🌟

Dry

Fire
Dry season and fire decrease the area of ★
In a similar way
Take home messages

1.
Leaves are more important than roots to survive fire.
Take home messages

1. Leaves are more important than roots to survive fire.

2. Fire is just a severe dry season.
Take home messages

1. Leaves are more important than roots to survive fire.

2. Fire is just a severe dry season

3. Architecture differs: leafiness matters
1. Leaves are more important than roots to survive fire.

2. Fire is just a severe dry season

3. Architecture differs: leafiness matters

4. Savanna tree model must take allocation into account

5. I’m available for collaboration
Our architectural effect is very crude: stems do branch!

A multi stemmed resprouts
Our architectural effect is very crude: stems do branch!
A multi stemmed resprouts

Our fire mortality is very crude (0/1): stem mortality depends on size (detailed mortality model in Gignoux et al 1997)
The next steps

1. Our architectural effect is very crude: stems do branch!
   A multi stemmed resprouts

2. Our fire mortality is very crude (0/1): stem mortality depends on size (detailed mortality model in Gignoux et al 1997)

3. Integration in a savanna ecosystem models
Thank you!
Take home messages

1. Leaves are more important than roots to survive fire.

2. Fire is just a severe dry season

3. Architecture differs:
   leafiness matters

4. Savanna tree model must take allocation into account