Decomposition of wetland plants: a traits-based hierarchical Bayesian approach

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Introduction

- Wetlands mediate the global carbon cycle through their role in sequestering carbon in the soil. Permanence of this stock depends upon how readily plant material decompose.
- Research shows that the quality of dead and decaying plant material is a strong predictor of decomposition rate. Functional traits can be used to approximate litter quality by quantifying nutrients or carbon forms.
- While there is a good basis for the role of plant traits in mediating litter decay dynamics, most studies employ the relatively simplistic negative exponential model of decay to explain dynamics, which assumes a constant decay over time.
- This study seeks to address these issues using non-linear traits-based hierarchical modelling of experimentally decomposed wetland species.

Main Objectives

This study asks the following key questions using wetland plant litter decay data from a greenhouse decomposition experiment:

1. How do wetland species characterised by diverse biomass compounds decay over time?
2. How do functional traits of these species affect rate of decay over time?
3. Do different traits affect different characteristics of decay?

Materials and Methods

0.1 Mesocosms

- 29 species were included: 9 forbs, 15 graminoids, 5 woody, and 1 non-vascular.
- Litterbags filled with 4 g of litter were placed on a 2:1 ratio of organic soil and washed sand. Drip taps suspended over tubs simulated 'flooding' once per week (Figure 1).
- Six litterbags of a species were placed in each of three replicate tubs: one bag was removed at two weeks, four weeks, six weeks, three months, six months, and finally at nine months.
- Upon removal, litter was dried for three days at 60 C and weighed.

Figure 1: Mesocosm experimental set-up

0.2 Traits

Ten robust individuals of each species were collected for trait measurement (Table 1). These traits were selected to encompass a range of both leaf and biomass characteristics (Figure 2).

Trait	Units	Method
Specific Leaf Area	m^2/g	Fresh one-sided area / dry weight
Leaf Dry Matter Content	mg/g	Fresh weight / dry weight
Leaf Nitrogen Content	mg/g	LECO Elemental Analyser
Leaf Carbon Content	mg/g	LECO Elemental Analyser
Leaf Hemicellulose Content	mg/g	TGA and mixture modelling
Leaf Cellulose Content	mg/g	TGA and mixture modelling
Leaf Lignin Content	mg/g	TGA and mixture modelling

Table 1: Selected traits and measurement methods

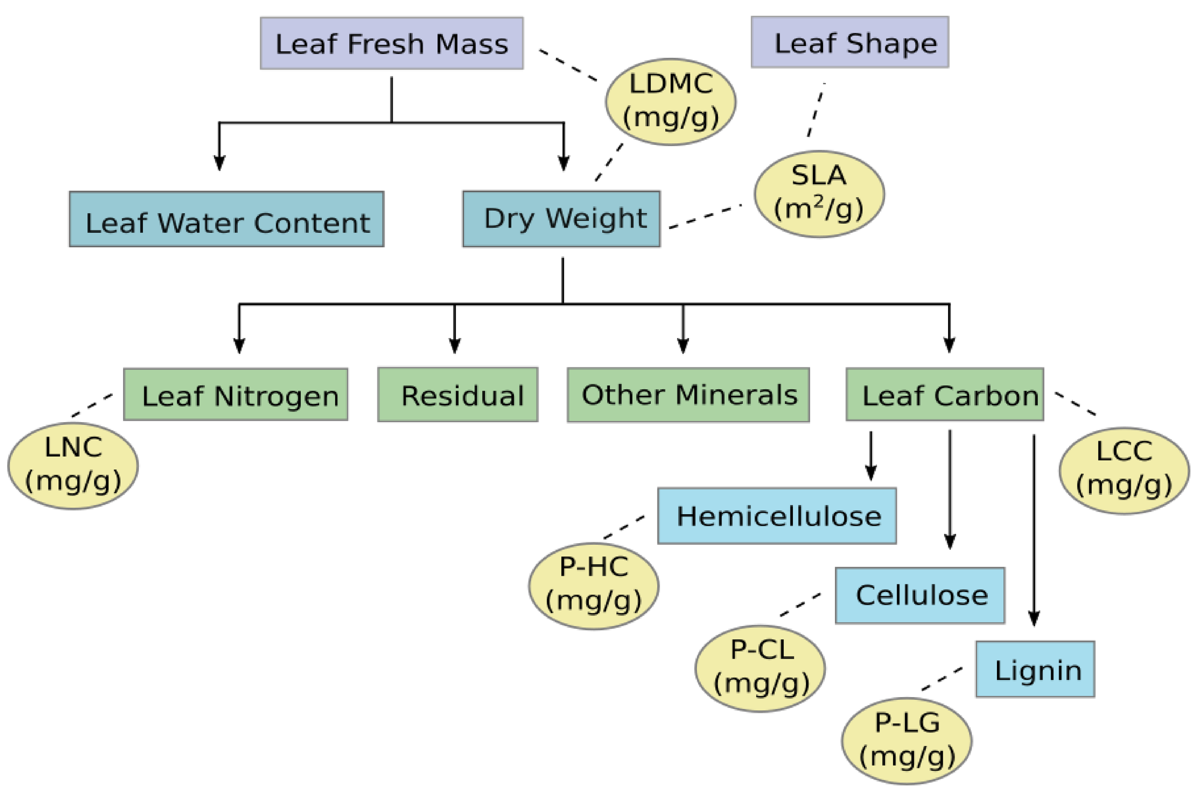

Figure 2: Flowchart of carbon types and traits measured

0.3 Analysis

- We compared the negative exponential model (1) to the 2-parameter Weibull decay function (2).

$$M_t = M_0 e^{-kt} \quad (1)$$

$$M_t = M_0 e^{-t/\beta^{\alpha}} \quad (2)$$

Where M_t is mass at time t, M_0 is initial mass, and k is the negative exponential decay parameter, which is replaced in the Weibull by α and β (Figure 3). When $\alpha = 1$, the two models are equivalent, since in that case $\beta = 1/k$.

- In order to evaluate the effect of traits on the decay parameters, we selected two traits, leaf dry matter content and leaf lignin content, based on correlation and principal components analysis.
- We tested all combinations of these two traits on both α and β (3-6) (16 models total). Analyses were conducted using Stan for MCMC sampling.
- Because our aim was to understand how well traits alone could predict species' decay, we used cross-validation by species to evaluate model predictive performance.

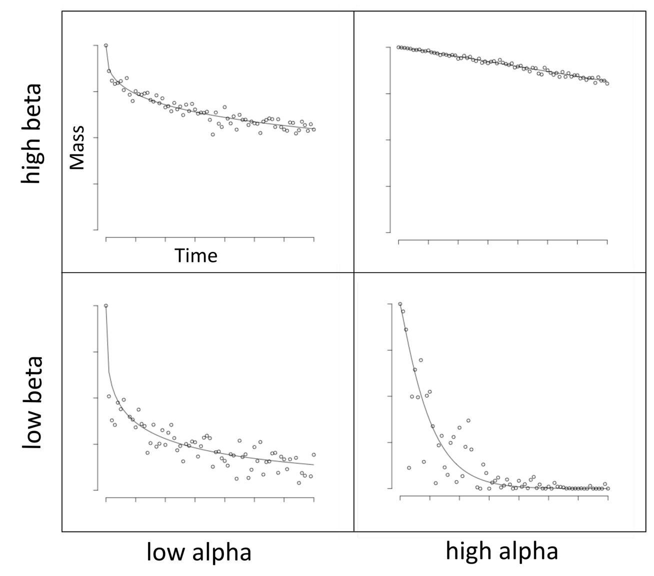

Figure 3: Simulated Weibull decay data

$$ln(M_t)_{ij} \sim Normal(\mu_{ij}, \sigma^2) \quad (3)$$

$$\mu_{ij} = ln(M_0)_{ij} - \left(\frac{t_{ij}}{\beta_j}\right)^{\alpha_j} \quad (4)$$

$$\beta_j = e^{1+species_j+traits_j} \quad (5)$$

$$\alpha_j = e^{1+species_j+traits_j} \quad (6)$$

Where $species_j$ refers to a random intercept effect for species $1:j$ and $traits_j$ refers to a fixed effect matrix of one or more traits.

Selected results

1. For all 29 species, the credible interval for α did not include 1. This suggests that the negative exponential model would not be a suitable model for decay in this case (Figure 4).
2. Based on log-likelihood calculations for the 16 models, the model with the lowest deviance included a fixed effect for leaf lignin content on both the α and β parameters. This was also the only model with lower deviance than the model with only random-intercept effects on both parameters.

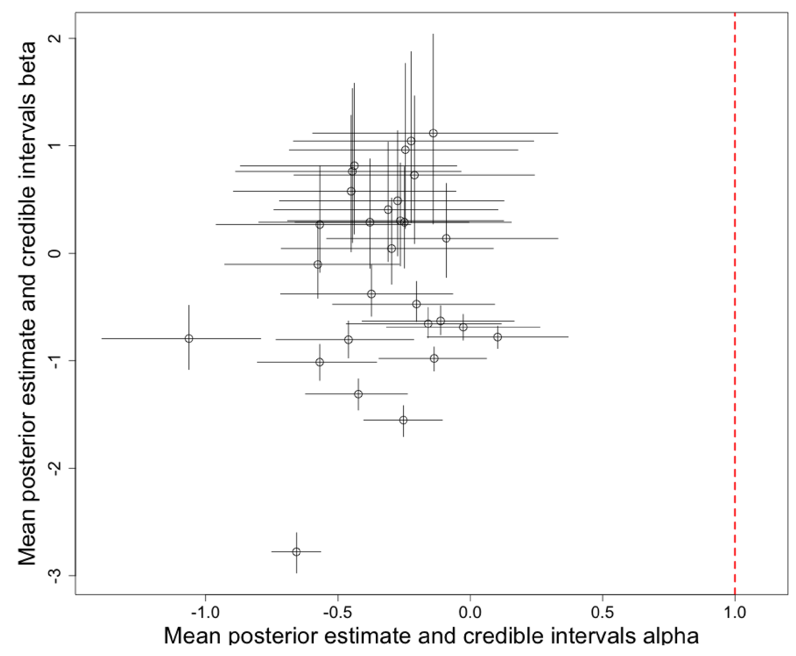

Figure 4: Mean posterior estimates and credible intervals of α and β for each of 29 species. Red dotted line indicates $\alpha = 1$, where the Weibull function is equivalent to the negative exponential.

Fixed effects α	Fixed effects β	Deviance
$P.LG_j$	$P.LG_j$	75.705
none	none	121.591
none	$P.LG_j$	125.065
$LDMC_j$	none	127.378

Table 2: Fixed effects (for species $1:j$) of four top-performing models, where 'P.LG' is leaf lignin content (mg/g) and 'LDMC' is leaf dry matter content (mg/g).

Conclusions

While this analysis is still underway, several important inferences can be drawn.

- In many contexts, the simple negative exponential model may be insufficient for predicting decay rate, and for accurately characterising change in rate over time.
- It is clear from the random intercepts model alone that species' litter decays in consistent patterns. Biomass traits such as leaf lignin content appear to improve on the random effect model. This is also a promising confirmation of the method employed in this study for measuring lignin in leaf tissue.
- While we expected leaf traits associated with resource acquisition to have a greater impact on initial decay rate (α), and carbon complexity to have a greater impact on mass remaining (β), initial results suggest that leaf lignin has a strong effect on both of these decay characteristics.

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