The role of functional traits of plant species in tundra soil carbon turnover

J. Hans C. Cornelissen

Systems Ecology
Dept. of Ecological Science,
VU University Amsterdam
The Netherlands

j.h.c.cornelissen@vu.nl
This talk from head to tail

1. Tundra warming and vegetation change

2. Vegetation change and ecosystem C release: ‘afterlife’ effects of plant traits on decomposition

3. Comparing different tundra plant types for litter decomposability: a Meeting of Litters

4. The Plant Economics Spectrum of litter decomposition

5. What next?
Global climate models predict strong warming in the Arctic this century
Vegetation change in response to experimental tundra warming

Peat bog in N-Sweden

Measuring species abundances
Meta-analysis of arctic/alpine ecosystem warming experiments (up to 20 yr duration)

Sweden

Japan
Abundance in tundra warming *versus* control plots across the globe

Canopy height in tundra warming versus control plots across the globe

Meta-analysis of arctic/alpine ecosystem warming experiments

- Increase in productivity (≤ 20 yr)
- Shrub expansion
- Decline of the small: mosses, lichens

But these experiments have artefacts, so:

Do we see these overall plant responses also in monitoring plots?
Meta-analysis of tundra plant responses (up to 30 yr) in monitoring plots

Caucasus, SW Russia

Elmendorf et al. 2012, *Nature Climate Change*
Meta-analysis of tundra plant responses (≤ 30 yr) in monitoring plots

Elmendorf et al. 2012, Nature Climate Change
Summary of vegetation response to tundra warming worldwide

• Both experimental and monitoring studies show overall ‘shrubification’ and decline of ‘the small ones’ (esp. mosses) worldwide

• Corresponds with greening spotted by satellites¹

¹Bhatt et al 2010 *Earth Int.*, Pouliot et al. 2009 *Int. J. Remote Sensing*
Tundra warming, vegetation change and ecosystem C release: ‘afterlife’ effects of plant traits on decomposition rates

Litter traits are inherited from the functional traits that help the species to make a living in terms of growth versus protection
DECOMPOSITION

Climate (Change)

1. direct

Microbial activity
Litter Quality

LITTER DECOMPOSITION RATE

Climate (Change)

1. direct

Nutrient availability

Plant quality (traits)

2. indirect

Site characteristics (topography, geology, soil)

Trait ‘afterlife effects’
Indirect global change effects on leaf litter decomposition: ‘afterlife’ effects of changing leaf traits in response to global changes:

a. changing leaf traits of given species
2a Chemical traits of plants of given species

Climate (Change)

1. direct

LITTER DECOMPOSITION RATE

2. indirect

Nutrient availability

Site characteristics (topography, geology, soil)
**Indirect** global change effects on leaf litter decomposition: ‘afterlife’ effects of changing leaf quality in response to global changes:

a. changing leaf quality of given species

b. changes in traits through changing species makeup (e.g. [lignin], [tannins], [N])
Climate Change

2a Chemical quality of plants of given species

AND

2b Plant species or functional type composition

Nutrient availability

Site characteristics (topography, geology, soil)

LITTER DECOMPOSITION RATE

1. direct

2. indirect
Nobody had quantified the contributions of these direct and indirect global change effects on litter decomposition rates across cold northern biomes until ….
Meeting of Litters project
Leaf litter collecting from multiple global change experiments
Meeting of Litters map: origin of leaf litter samples

33 Arctic and Alpine Field Experiments in the Meeting of Litters:

1. Ny Ålesund, Svalbard, Norway (F,I)
2. Adventdalen, Svalbard (2 exp.; UV,W)
3. Thingvellir, Iceland (W)
4. Audkuluheld, Iceland (W)
5. Caucasus, Russia (F,I)
6. Medicine Bow, USA (2 exp.; W)
7. Ruby Range, Canada (W,F)
8. Toolik Lake, Alaska, USA (W,F,SH)
9. Tateyama, Japan (W)
10. Qinghai, China (4 exp., W)
11. M. Follinao, Italy (2 exp., F)
12. Finse, Norway (2 exp.; W,F)
13. Lajjyjärvi, Sweden (3 exp.; W,F)
14. Abisko, Sweden (4 exp.; W,F,CO₂,UV)
15. Paddus, Sweden (2 exp.; W,F,SH)
16. Stättajäkka (Abisko), Sweden (W,F,SH)
17. Stordalen, Sweden (2 exp.; W,CO₂,F)
18. Kilpisjärvi, Finland (2 exp.; W,F)

Treatments: W, warming; F, fertilising; I, irrigation; CO₂, elevated CO₂ concentration; UV, elevated UVB irradiance; SH, shading
Each litter sample provided:

1 subsample for initial chemical analyses

2 subsamples, i.e. 1 litterbag for each incubation site
Litter mass loss over 2 years of *in situ* incubation in two contrasting litter beds in N-Sweden. The difference in climate could represent a long-term warming scenario.

Abisko, alt. 350 m

Latnjajaure, alt. 1000m
Abisko litter incubation bed, alt. 350 m
Latnjajaure litter incubation bed, alt. 1000 m
Analysis of variance (4-way ANOVA)

- **Dependent variable:** 2-yr litter mass loss % after transformation: arcsine{sqrt(x/100)}

- **Independent variables:**
  - Litter incubation site (altitude: climate / life zone)
  - Litter origin (collecting) site (soil, climate)
  - Litter type quality (between growth forms)
  - Litter quality within species (litter quality response to global change treatments)
  - *Interactions*
4-way ANOVA on 2-yr litter mass loss % (total df=1824)

- Litter Incubation Climate (LIC): P<0.001, df=1
- Growth Form (GF): P<0.001, df=5
- Site of Litter Origin (SLO): P<0.001, df=34
- SLO * GF: P<0.001, df=36
- GF * LIC: P<0.001, df=5
- Global Change Treatment (GCT): P=0.002, df=9
- SLO * GCT: P<0.001, df=60
- GF * GCT: P=0.006, df=29
- SLO * LIC: P=0.017, df=32
- GCT * LIC: P=0.27, df=9

Cornelissen et al., Ecology Letters 2007
Shrub litter decomposed more slowly than herbaceous litter from many cold sites worldwide.

Cornelissen et al., Ecology Letters 2007
Summary of main results:

The main contributors to variance in leaf litter decomposition rates were
– direct climate effects;
– variation in leaf litter decomposability among plant growth forms: shrubs and mosses are recalcitrant
Screening moss and lichen species for traits and litter decomposability

Decomposability of bryophytes, lichens and vascular plants

So far, these multi-species comparisons of decomposability have focused on the photosynthetic parts.
Hypothesis

Plant traits (e.g. [lignin], [tannins], dry matter content, [N]) are coordinated between organs when compared across diverse species.

**AFTERLIFE EFFECTS:**

Each species will fit on an axis ranging from producing generally fast-decomposing to generally slow-decomposing leaf, stem *and* root litter.
Hypotheses tested in subarctic Abisko (Lapland), N Sweden
Litter sampling in dry birch woodland, wet (riparian) birch-willow woodland, streams and ponds
**Method:** collecting fresh litter of leaves, stems and roots in a subarctic flora (N Sweden) representing aquatic, riparian and terrestrial environments

**PLANT TYPES**
- woody evergreens (4)
- woody deciduous (12)
- fern allies (3)
- club mosses (1)
- graminoids (4)
- terrestrial forbs (12)
- aquatic forbs (4)
Incubate pre-weighed litterbags in litterbed, for 1-2 years
Collect litterbags, dry, re-weigh: % mass loss
Calculate time to 50 % mass loss ($t_{1/2}$)
Strong correspondence of relationship between initial lignin content and decomposition rate of different plant organs

Freschet et al. 2012, Functional Ecology
Interspecific differences in wood decay rates: insights from a new short-term method to study long-term wood decomposition

Grégoire T. Freschet*,†, James T. Weedon, Rien Aerts, Jurgen R. van Hal and Johannes H. C. Cornelissen

Department of Systems Ecology, Faculty of Earth and Life Sciences, Institute of Ecological Science, VU University, de Boelelaan 1085, 1081 HV Amsterdam, The Netherlands
Strong correspondence of trait PCA axis 1 representing Plant Economics Spectrum and decomposition rate of different plant organs

Coarse stems
Fine roots,
Fine stems
Leaves

Axis 1 based on [lignin], [N], dry matter content, etc.
Litter decomposabilities are coordinated between subarctic plant organs across species.

Freschet et al. 2012, *Functional Ecology*
So:

Yes, our results support the hypothesis; in the Subarctic there is:
Take-home messages

• Tundra warming enhances shrub productivity and reduces moss abundance

• Shifts in species and plant type composition will affect decomposition rates through afterlife effects of plant traits

• As there is coordination of traits between plant organs, these afterlife effects operate at the whole plant level.
What next?

• Find out how general or special the plant economics spectrum of litter decomposability is.

• Find out how its effects are influenced by total litter input of each organ of each species in a real field setting.

• Translate interspecific variation in decomposition rates from litterbed values to realistic values in a field setting: interactions with (a-)biotic factors.
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Data analysis procedure

(a) Woody debris ‘1’
   (newly dead)

   (1a) (1b) (1c) (1d)

   ↓ ↓ ↓ ↓
   RD₁ RD₁ RD₁ RD₁

   (2-year incubation)

   RD’₁a RD’₁b RD’₁c RD’₁d

   RD’₁

   ‘n’ vectors
   RDᵢ – RD’ᵢ

   Woody debris ‘2’
   (partly decayed)

   (2a) (2b) (2c) (2d)

   ↓ ↓ ↓ ↓
   RD₂ RD₂ RD₂ RD₂

   (2-year incubation)

   RD’₂a RD’₂b RD’₂c RD’₂d

   RD’₂

   Woody debris ‘n’
   (partly decayed)

   (na) (nb) (nc) (nd)

   ↓ ↓ ↓ ↓
   RDₙ RDₙ RDₙ RDₙ

   (2-year incubation)

   RD’ₙa RD’ₙb RD’ₙc RD’ₙd

   RD’ₙ
(b) Starting 'time' values

Average slope of all 'n' vectors

RD (%)

0  20  40  60  80  100

Time (years)

0  5  10  15

(c) Iterative procedure

Best-fit exponential model

Best-fit linear model

Best-fit sigmoid model

RD (%)

RD (%)

(d) Best model selection

Model with the lowest \(\sigma\)

RD (%)

Time (years)

Time (years)
(6) Optimization procedure (R modelling) for best fit of all 2-year mass loss vectors following (a) linear, (b) exponential and (c) sigmoid model
(7) Compare best-fit curves and t1/2 for coarse stems or roots of each species