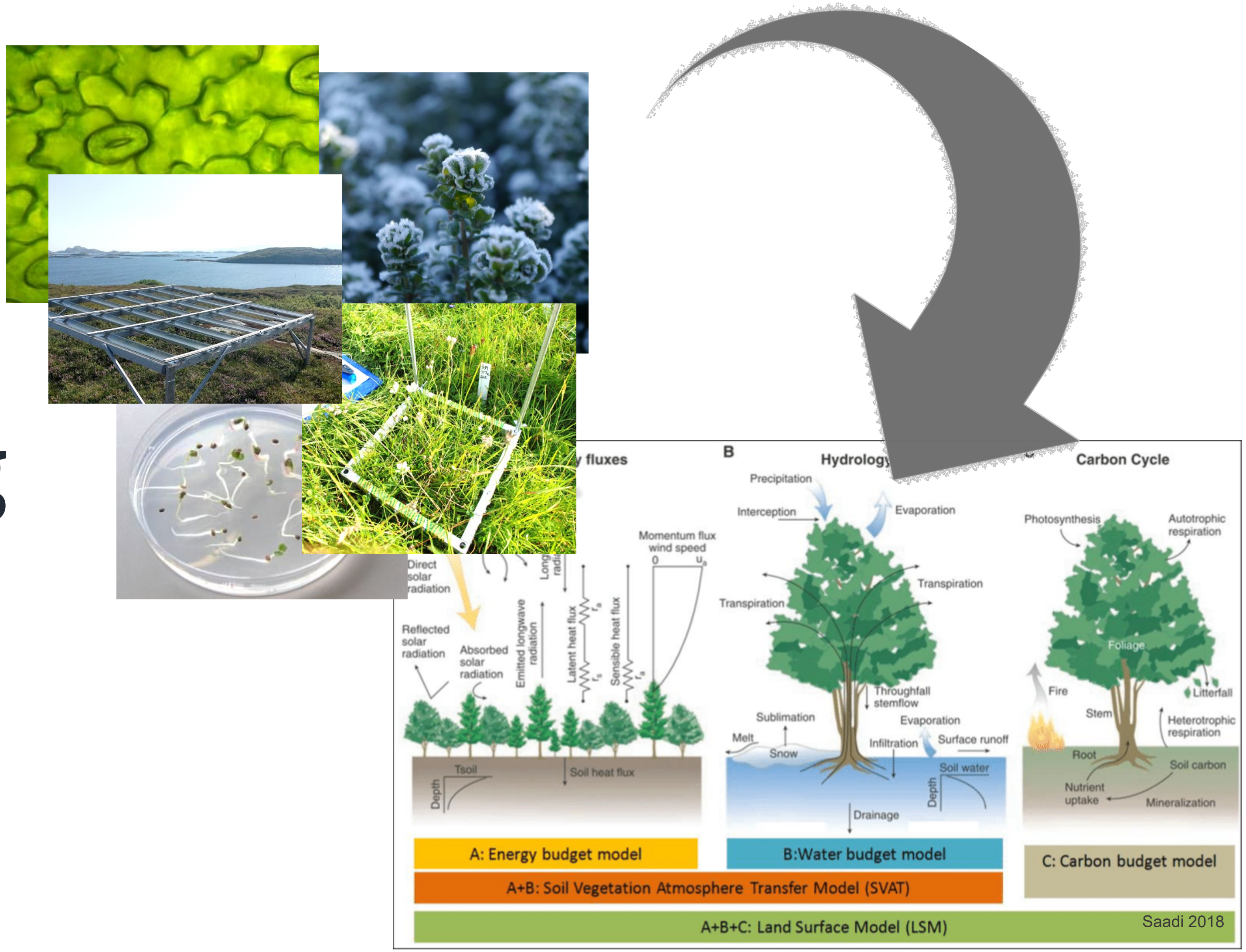
Challenges in linking ecological data to vegetation models

EMERALD Webinar Series 10-6-2020



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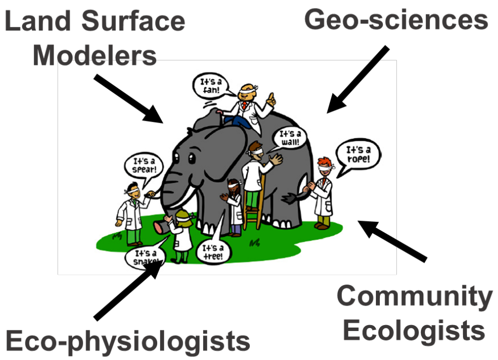
A perspectives piece on ‘Addressing the challenges of interdisciplinarity’

Scientific synthesis and the development of state-of-the-art terrestrial ecosystem models means now, more than ever, communication and collaboration between on-the-ground ecologists and modelers is critical



EMERALD is a microcosm of broader interdisciplinary collaboration between vegetation ecologists, geoscientists and modelers

Each discipline brings a unique perspective on:

- which vegetation processes are important to include
- the challenges of incorporating vegetation data into land surface models
- insights into how future collaborations could be improved

Proposal: An opinion piece integrating EMERALD perspectives, the current literature, and a global survey of the research fields on ‘Improving communication and collaboration between ecologists and terrestrial ecosystem modelers'

A global survey of LSM's and Vegetation Scientists

Land Surface Modelers

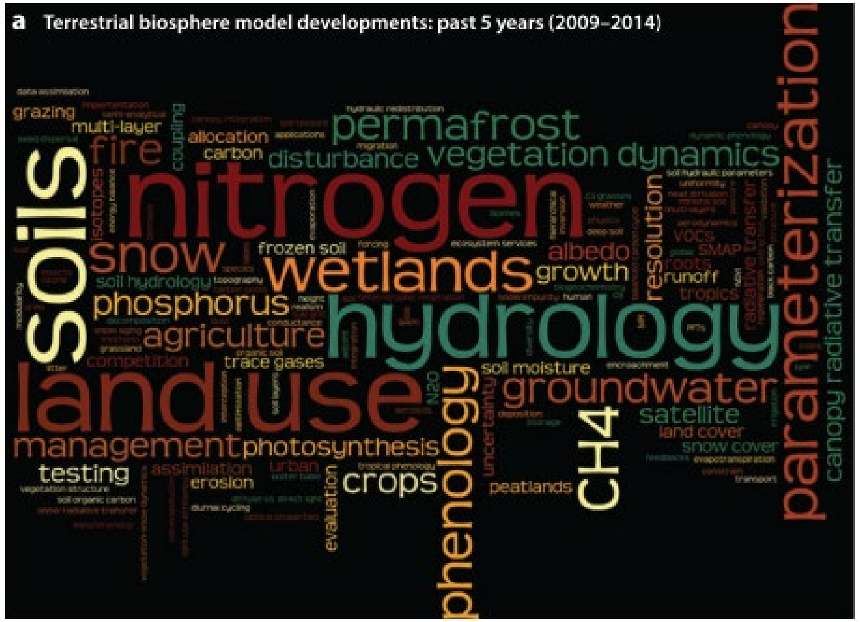
Ecologists

Collating perspectives on..

- Do the different research fields agree on research priorities regarding vegetation processes and patterns and climate change?
- Do we need a common language between research fields?
- How well do the fields understand data collection or modelling limitations?
- How do we approach scaling from individual traits to ecosystem responses, are there new methods?
- Is the Open Science movement i.e. data accessibility, going to improve links between the research fields? How can we best facilitate this?

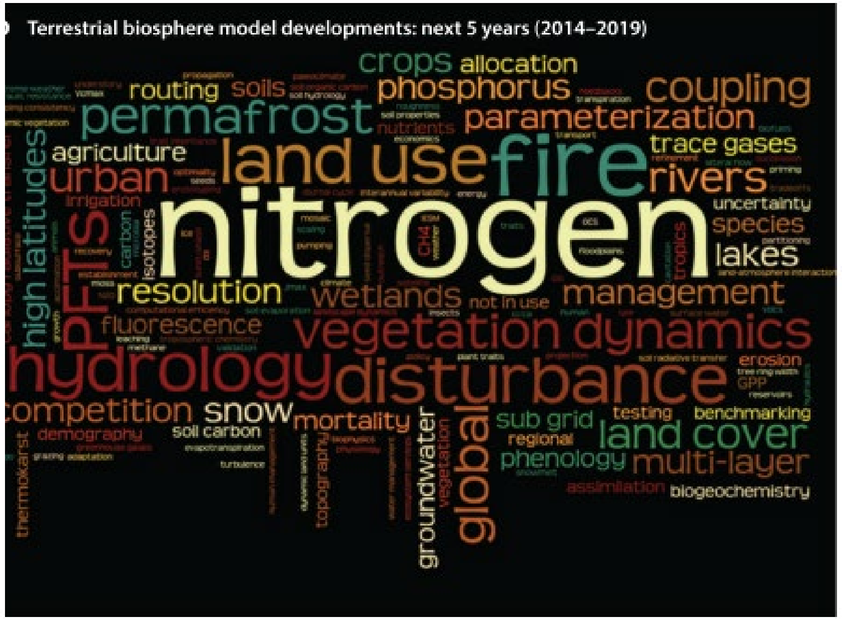
In the literature: What the modelers think?

LSM’s 2009 - 2014



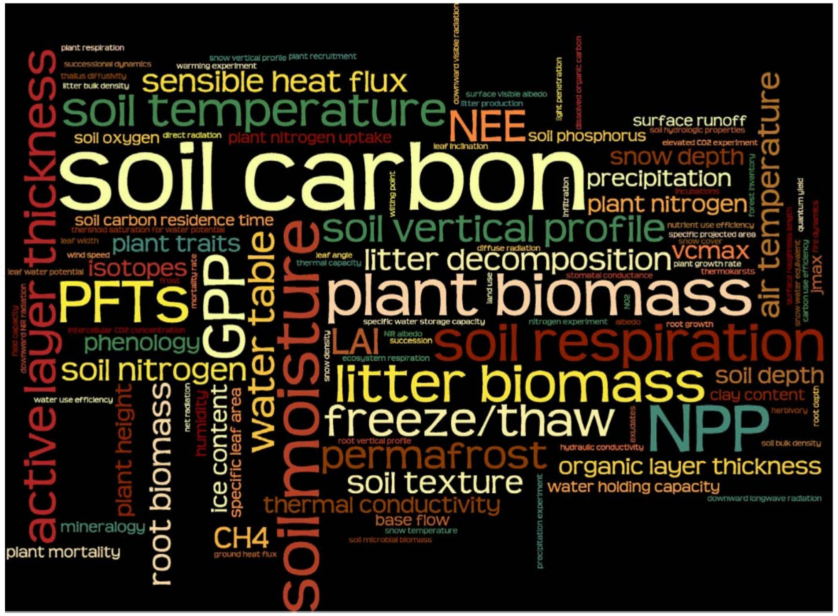
Nitrogen
Hydrology
Soil
Phenology

LSM’s predictions 2014-2019



Nitrogen
Hydrology
Fire
Vegetation dynamics
Disturbance

LSM’s 2019+ predictions



Soil carbon
Soil moisture
Plant / litter biomass
NPP
PFTs

Fisher et al. 2014; Fisher et al. 2018

In the literature: What the vegetation scientists think?

A lot of vegetation based parameters are collected on individuals, populations or species, not plant functional types

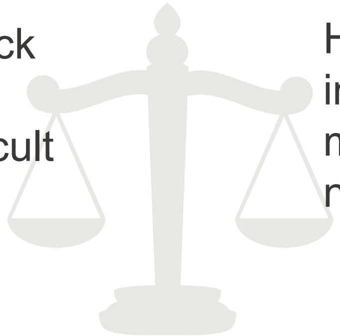
Ecologically - there is a focus on examining variation in trait expression, i.e. inter- & intraspecific variability, phenotypic plasticity

In modelling - the use of plant functional types tends to compress variation into a single mean, or a single representative value

Proposed approaches to facilitating collaboration and communication?

Core to connecting researchers and modelers is the accessibility and relevance of terrestrial ecosystem models

For some LSM's are a 'black box' where complicated, unrealistic models are difficult to engage with



However, when asked to provide insights into model development, many specialists provide more nuanced insights into processes

Dietze et al. (2013)

We need to develop a community based approach to data-model synthesis

Interlinking a top-down and bottom-up community may be best facilitated through the development of interactive resources that benefit both empiricists and modelers. The FATES downscaling platform is perhaps one such option?

Potential Action Items

Vegetation Scientists	Modelers
Open access data	Open, accessible parameterization
Standardized reporting / improved meta-data	Outline a 'handbook' on relevant plant functional traits (and units) for ecologists
Co-ordinated experimental designs	
Integrated Efforts	
Increased awareness of model processes and data requirements during undergraduate / postgraduate education	
Cross-disciplinary conference symposia, workshops	
Create inter-disciplinary , user friendly interfaces for exploring modelling concepts	

Proposal: An opinion piece integrating EMERALD perspectives, the current literature, and a global survey of the research fields on ‘Improving communication and collaboration between ecologists and terrestrial ecosystem modelers'

1. Identify what perspectives pieces are already in the literature?
   - Are they discipline specific
   - Technical nature, vs research goals and collaboration

2. Develop survey questions and target demographics
   - Research priorities for each discipline (do they align?)
   - How can we facilitate data sharing and integration
   - How do we deal with scaling between field research and modelling units
   - Identify areas where communication and collaboration could be improved

3. Outline interdisciplinary actions to promote communication and collaboration
   - Educational awareness, user-friendly interfaces, integrate Open Science

A new cross-cutting theme? Something to work on during the proposed Autumn retreat?

Australian National University | UTS University of Technology Sydney | Deakin University Australia

The thermal tolerance of photosynthetic tissues

A global systematic review

Review submitted to *New Phytologist*

Sonya Geange, Pieter Arnold, Alexandra Catling, Onoroide Coast, Alicia Cook, Kelli Gowland, Andrea Leigh, Rocco Notarnicola, Brad Posch, Susanna Venn, Lingling Zhu, Adrienne Nicotra

Plant thermal tolerance

Temperature is a key determinant of species adaptation & distribution

Past research focuses on:

- Crop development for food
- Fundamental ecological insights
- Predict individual species responses

BUT knowledge is scattered across research fields and interests

Plant thermal tolerance

High temperatures

- Frequency, intensity, and a-seasonality of heat waves are breaking records annually

Low temperatures

- Frequency of cold snaps is increasing for some regions
  - Directly – disruption of the polar vortex
  - Indirectly – warmer averages reducing snow cover and increasing frost risk

Temperature events cause shifts in resource allocation from growth and reproduction to protection from physiological stress

Understanding **BOTH** ends of the thermal spectrum is key

Plant thermal tolerance

The potential for extreme temperature events to become stressful, may depend on other factors:

- Water status
- Light conditions
- Preceding temperatures

What constitutes an 'extreme event' is likely to differ for a given species in a given biome

Specific growth and experimental conditions for assessing thermal tolerance diverge widely, influencing thermal responses

- Field studies
- Common garden
- Glasshouse / Growth chambers

Plant thermal tolerance

Methods for imposing thermal stress can vary immensely

Gradual stress is more representative of cold stress

- i.e. overnight frost risks

Rapid temperature transitions are more reflective of heat stress

- i.e. lulls in wind speed, passing sunflecks

Depending on the context, slower temperature changes may either enhance acclimation, or increase the accumulation of tissue damage

Effective comparison requires an appreciate of experimental design

Plant thermal tolerance

Many techniques are used to assess thermal stress

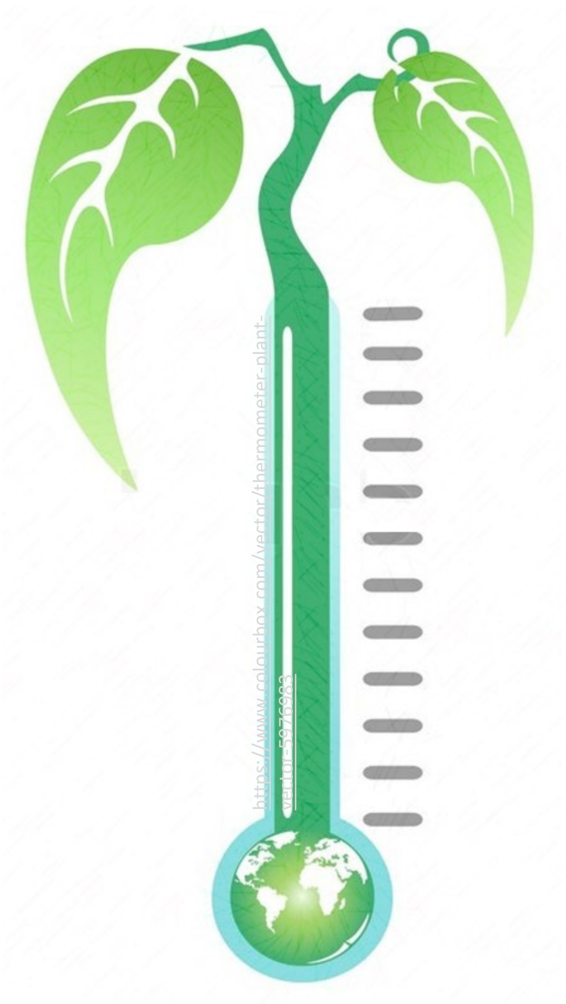
These vary from;

- *subjective* scores of tissue damage
- *qualitative* description of protein expression /biochemistry
- *quantitative* measures, i.e. gas exchange, chlorophyll fluorescence

Not all methods result in a thermal metric, or threshold temperature being described, which would enable comparisons of tolerance across species or environments

Even amongst those that do, considerable variation exists

Our Objectives

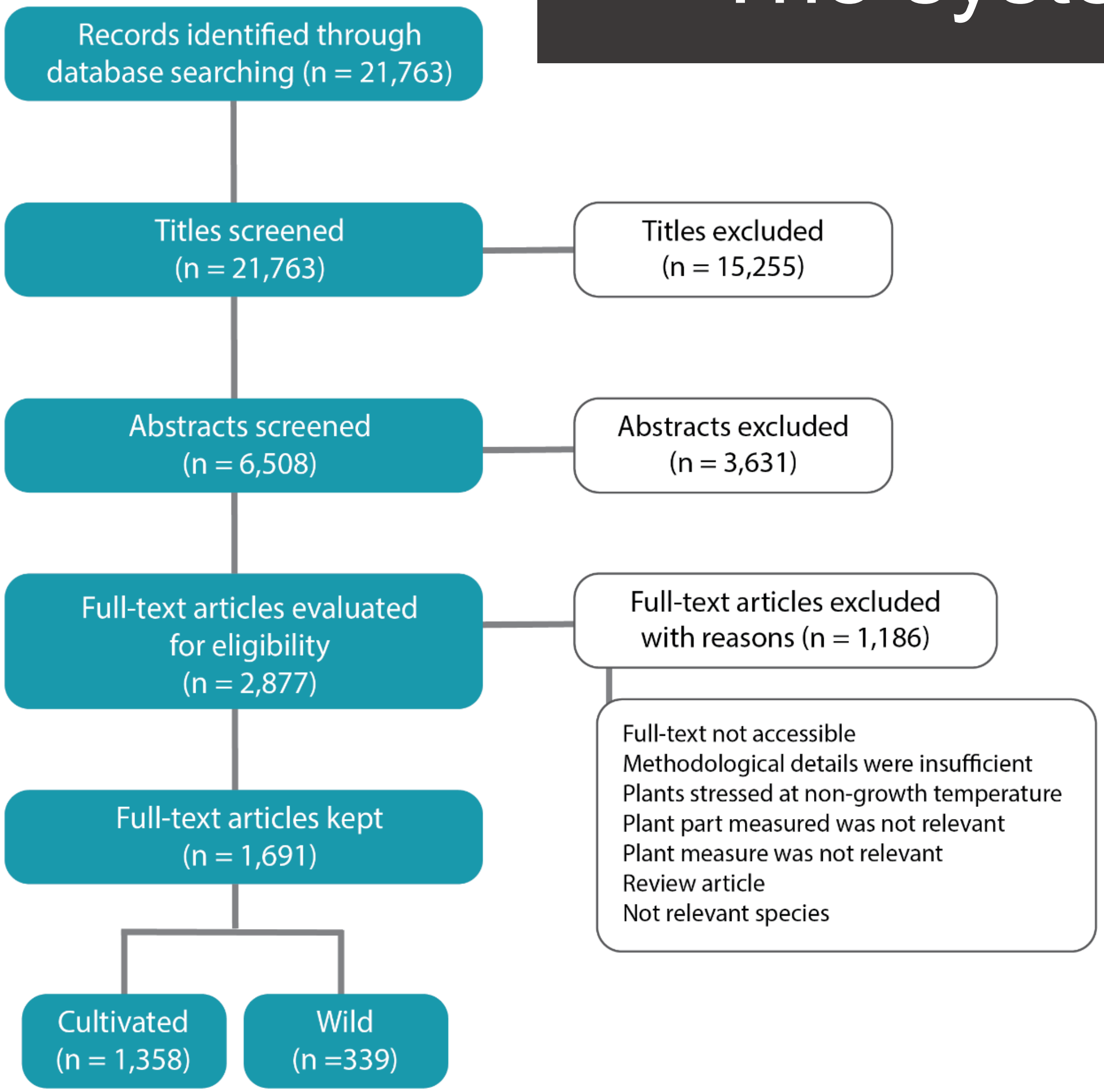


To determine the distribution of thermal tolerance studies **that measured the tolerance of photosynthetic tissues of land plants to extreme temperatures** for both cultivated and wild species across life forms, biomes and the globe.

To reveal knowledge gaps, ambiguities and commonalities in plant thermal tolerance research.

To identify emerging techniques and opportunities for addressing plant species persistence under increasing temperature extremes.

The systematic review process



Evidence synthesis is rapidly becoming a valuable research tool

Nakagawa et al. 2020

Systematic reviews use explicit search strategies, and criterion based selection procedures to provide an unbiased overview of a research field

Haddaway et al. 2015

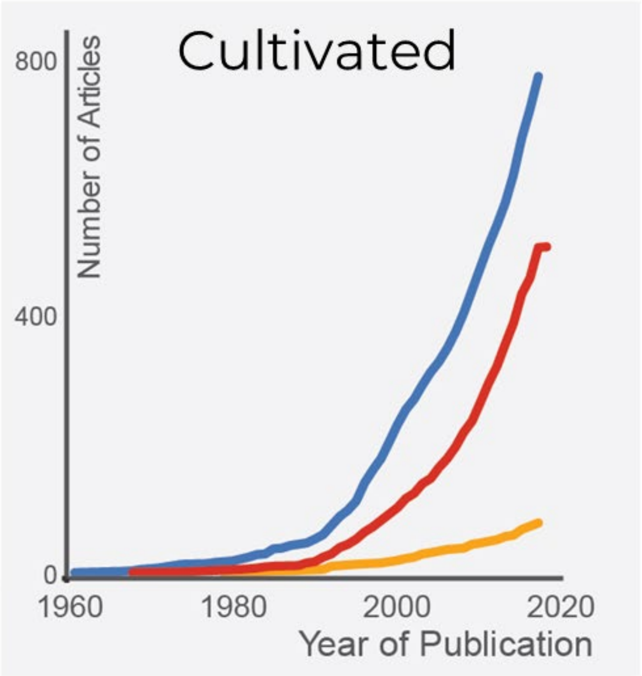
Our review process ultimately led to **1,691 unique studies** being included in the final analysis, comprising **3,743 records of thermal tolerance technique** use

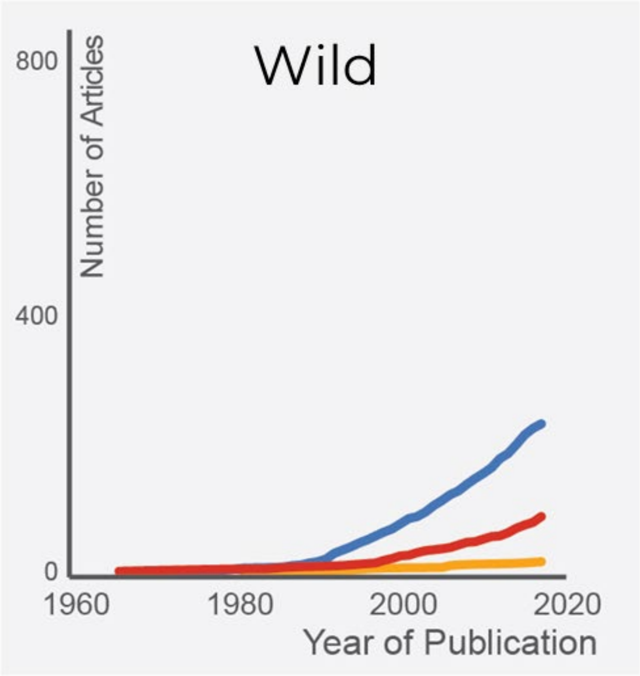
Assessment Criteria

1) Whether the article dealt with **cultivated or wild species**;
2) Whether the assay investigated **heat, cold, or both**;
3) The **diversity of the species** measured in the study;
4) For papers on cultivated species – the **type of cultivation**;
5) For wild species – the **biome** of origin;
6) The **life forms** of species;
7) The **thermal tolerance technique(s)** used;
8) The **nature of the thermal stress** applied in the experiment (manipulated or natural);
9) Whether **other experimental factors** (water, light, etc.) were considered;
10) Whether a **thermal metric was reported** for the technique(s);
11) Whether **stress temperature was gradually ramped, applied as a shock during thermal assay(s)**;
12) The **maximum duration** of the thermal assay;
13) Whether the thermal assay was **repeated**

Highlighted outcomes

Hot or cold tolerance?





Research into plant thermal tolerance is dominated by investigations in to cultivated species

It turns out that there are many more studies that consider cold tolerance than heat tolerance

But also notable is the paucity of studies that consider both heat and cold tolerance

These patterns are generally consistent across crop types or biomes

Plant growth forms and species diversity

Which plant growth forms are focused on?

Cultivated: mostly graminoids, herbs and vines

Wild: emphasis on trees, forbs and shrubs

Are we focusing on single species, intraspecific variation, or cross-species comparisons?

Cultivated: few cross-species comparisons

Wild: few focusing on intraspecific variation

The variety of thermal tolerance techniques

1. Quantified visual damage

Measures the percentage of damaged (discolored/brown) leaves or leaf area (e.g. proportion of cell death; leaf area).

2. Thermometry & Spectrometry

Used to identify temperature-induced changes in plant tissue and can indicate functional parameters (e.g. leaf ice nucleation point and its progression through the plant and indices of photochemical health).

3. Gas exchange

Determines the ability of a leaf to recover photosynthethic capacity, or change its rate of respiration, after exposure to stressful temperature through examination of the time stability of rate of CO_2 uptake or O_2 evolution.

4. Electrolyte leakage / Membrane stability

Measures electrical conductivity to determine cell membrane damage/ leakiness in response to stress.

5. Chlorophyll fluorescence

Refers to light re-emitted from chlorophyll and provides a sensitive indicator of temperature stress.

6. Other biochemistry

Techniques can be used to assess thermal tolerance by the presence or absence of certain biochemicals.

7. (Epi)genetics and 'omics

Broadly, 'omics refers to the fields of molecular biology that are specifically associated with whole-genome detection of: genes (genomics), gene expression (transcriptomics), proteins (proteomics), and metabolites (metabolomics). Epigenomics specifically refers to the molecular mechanisms that alter gene expression and function without changes in DNA sequence (e.g. through chemical modification of DNA (methylation) and histones, incorporation of histone variants and long or small non-coding RNAs).

8. Heat Shock Proteins (HSPs)

Rapidly induced in response to abiotic stresses and alleviates damage. HSPs function as molecular chaperones, assist in protein folding, maintain signal transduction and prevent protein aggregation.

9. Reactive Oxygen Species (ROS)/ Antioxidants

ROS are oxygen radicals and non-radical oxidizing agents that can be converted into radicals. They are by-products of a plant's metabolic processes which can impact upon a plant's growth, signalling, development, cell cycle, programmed cell death, abiotic stress responses and pathogen defence and can increase rapidly in response to temperature stress. Antioxidants mitigate the cellular damage that ROS cause.

10. Water potential

Quantifies the potential for water to move between one area of a plant to another through osmosis, gravity, mechanical pressure or matrix effects such as capillary action.

Researchers of cultivated species were consistently earlier adopters of emerging techniques

The most widely used techniques since 2000, have been chlorophyll fluorescence, electrolyte leakage and other biochemical assays.

Rapidly developing techniques are (epi)genetics and 'omics, ROS and antioxidants, and other biochemistry

Little bias appeared based off cultivation types, biome or life form.

Metrics of thermal tolerance

10 main techniques reported

6 report a metric of damage

- Quantified visual damage
- Thermometry and spectrometry
- Gas exchange
- Electrolyte leakage / membrane stability
- Chlorophyll fluorescence
- Other biochemistry

(Epi)genetics and 'omics

Heat Shock Proteins (HSPs)

Reactive Oxygen Species (ROS) / Antioxidants

Water potential

Thermal tolerance metric:

Quantifying a temperature at which some level of damage occurs to the tissue

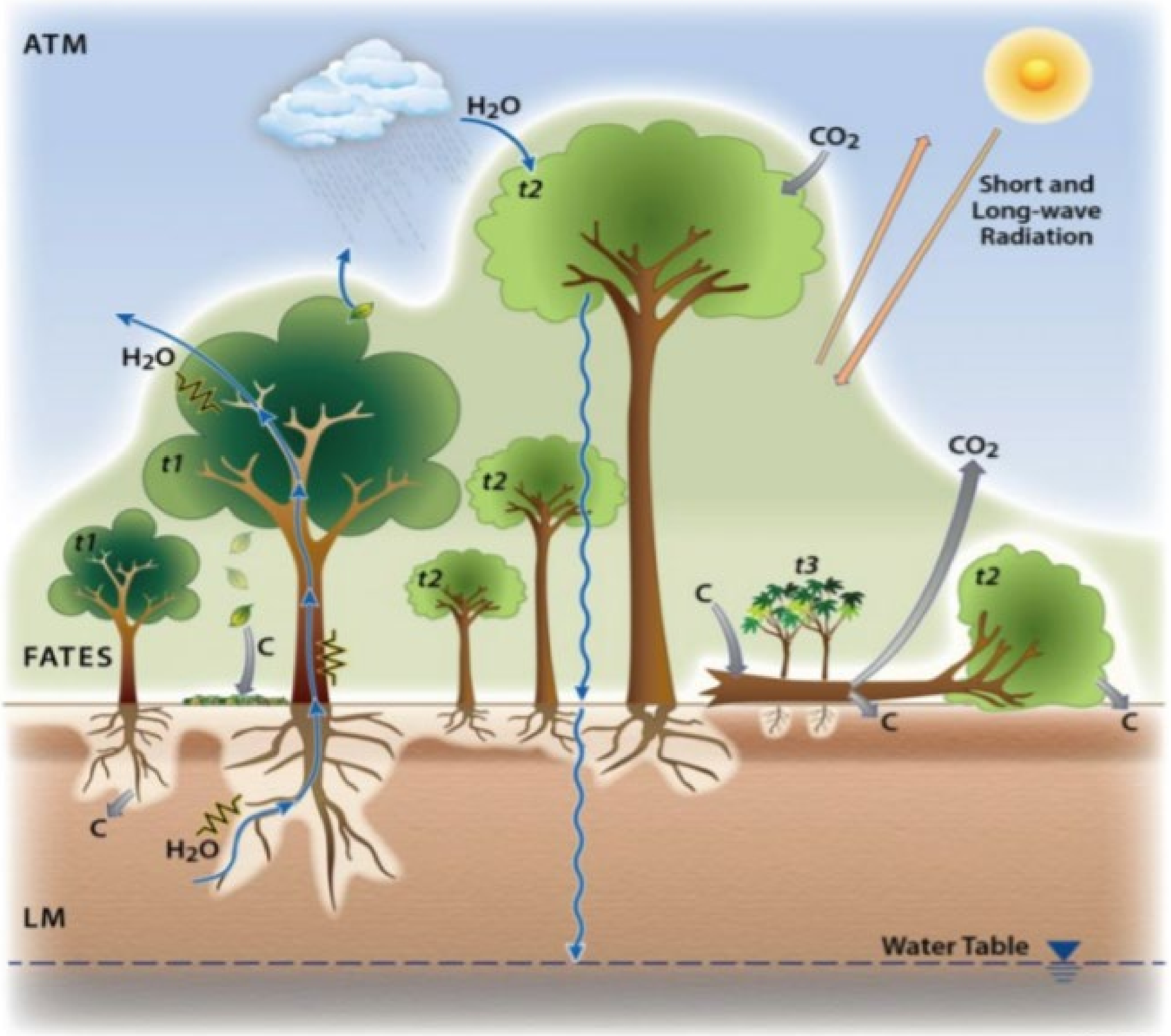
Metrics only reported by 23% of studies

Wild studies reported more often

Even within techniques, many different approaches are taken

Critically, we have little knowledge on how these metrics of thermal tolerance compare - an important step for scaling, and developing generalized insights

FATES: Functionally Assembled Terrestrial Ecosystem Simulator



Fisher et al. 2015.

Simulates plant physiology, competition processes and ecosystem assembly along with distribution patterns for vegetation

Needs plant trait parameters to be integrated, robust and ecologically sound

But elements such as thermal tolerance are yet to be fully integrated – how should this concept be parameterized given the diversity in research approaches highlighted by this review?

How can we best integrate our thermal tolerance knowledge into these dynamic vegetation models?

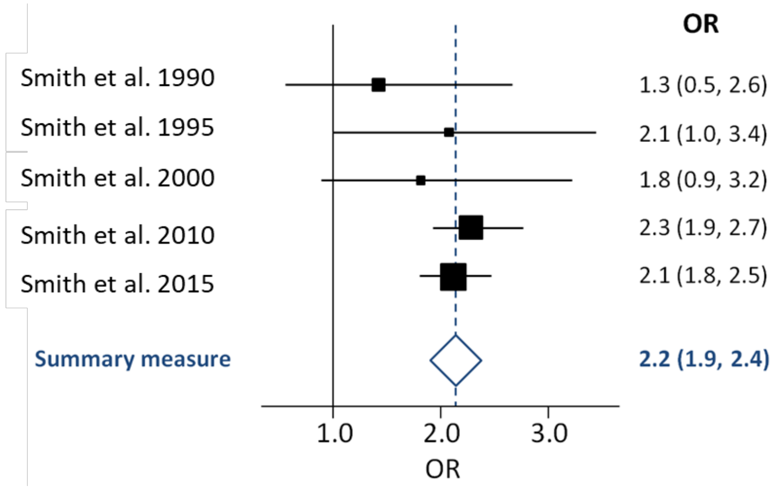
Meta-analysis approaches:

Using the methodologies that can provide thermal metrics, we can ask:

Do the different methodological approaches provide comparable parameters than can be incorporated into land surface models?

What role do experimental factors such as gradual vs rapid exposure to stress play?

What patterns could we find for thermal tolerance as a result of life form, biome, plant functional traits etc.



Plant Thermal Tolerance Synthesis

Greater consideration of the **breadth of thermal tolerance**

Increased **understanding of how a diverse array of methodological approaches can be compared**, in order to create metrics for inclusion in modelling platforms

Integration into Land Surface Models

Challenges in linking ecological data to vegetation models

'Addressing the challenges of interdisciplinarity'

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Identify knowledge gaps for future prioritization either in the field, or evidence synthesis

For example underrepresented PFT's, or novel processes, i.e. thermal tolerance

Publication

Interdisciplinary perspectives piece focusing on:

- Which traits and processes are important
- Strategies for better communication and sharing between disciplines
- How the open science movement can facilitate model development

The importance of plant thermal tolerance

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Insights into which metrics could be used to parameterize thermal tolerance at the leaf level

Integration of thermal tolerance with other key processes, i.e. hydrology, photosynthesis

Publications

1. Systematic review on thermal tolerance methods to date in ecology and agriculture
2. Meta-analysis / perspectives on how common thermal metrics compare to one another
3. How do thermal metrics compare to plant functional traits, biomes and other properties
4. Integrate thermal tolerance into FATES

Challenges in linking ecological data to vegetation models

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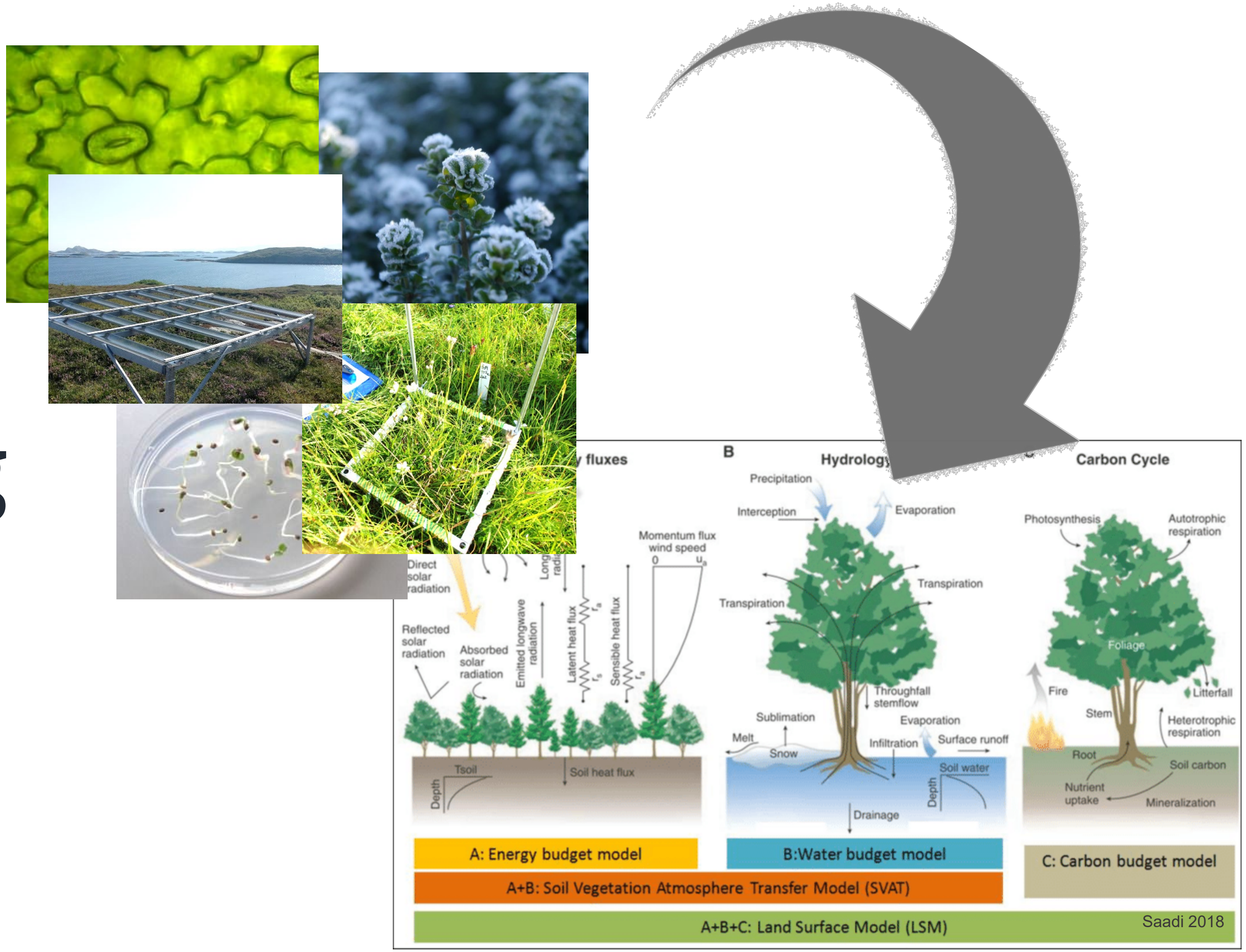

Thanks to all those within EMERALD for insightful discussions and to the co-authors of the thermal tolerance systematic review