HOW DOES SNOW GUM DIEBACK INFLUENCE SOIL PROCESSES?

SNOWY MOUNTAIN FORESTED HILLSLOPE SOIL CHARACTERISATION, SOIL HYDROLOGICAL PROPERTIES AND SOIL GEOCHEMISTRY PROGRAM

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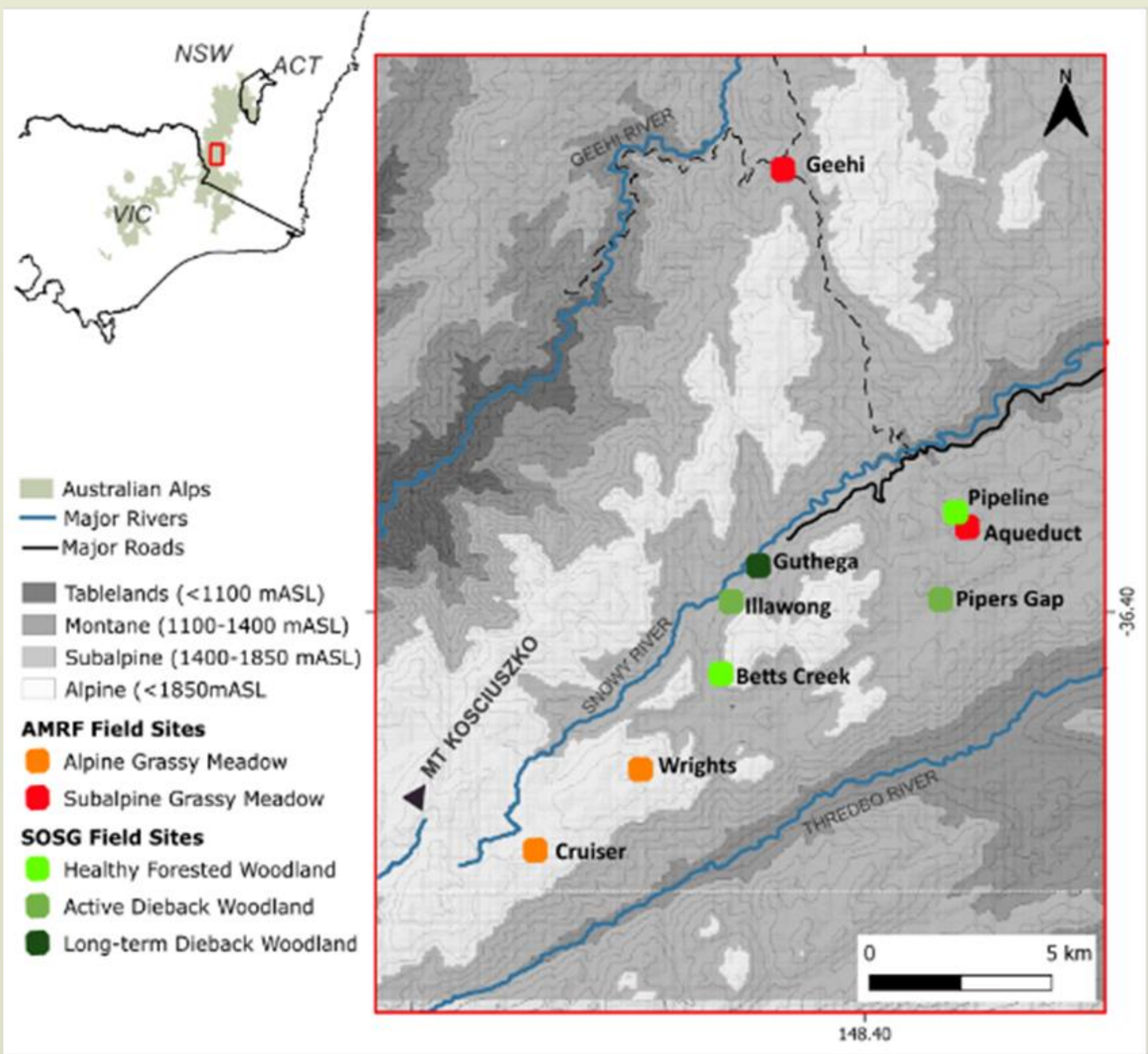
Upland soils research history

- In the 1950's Costin mapped soils, mostly in the Monaro area but also described Alpine Humus Soils (AHS) across the region
- Soil conservation efforts in alpine areas were implemented in parallel with the Snowy Scheme, and again through NSW Soil Conservation, when alpine grazing ceased (throughout the late 1960s, into the 1970s and again in the 1990s)
- Local regolith characterisation took place as part of the research of the CRC LEME in the 1990/2000s – mostly in montane areas
- Ivanah Oliver (now UNE), working with NSW DPIE in the early 2020s, characterised an array of soils at alpine and subalpine sites in the NSW Snowy Mountains – revising the AHS classification based on soil configuration and landscape location Celine Anderson (UC) conducted subsequent work characterising regolith profiles at AMRF grassy hillslope sites, encompassing the soils work of Nat Walkom and Alice Kelly (both ANU).

SOSG SOIL CHARACTERISATION WILL AUGMENT OUR UNDERSTANDING OF UPLAND SOILS BY INTEGRATING KNOWLEDGE OF FORESTED SYSTEMS

STUDY OF SOILS IN AREAS WITH A CONTINUUM OF DIEBACK WILL HELP US UNDERSTAND HOW SNOW GUM DIEBACK INFLUENCES SOIL PROCESSES



SOSG SOIL CHARACTERISATION AT FORESTED SITES COMPLEMENTS EARLIER WORK AT AMRF GRASSY HILLSLOPE SITES

Upland soils

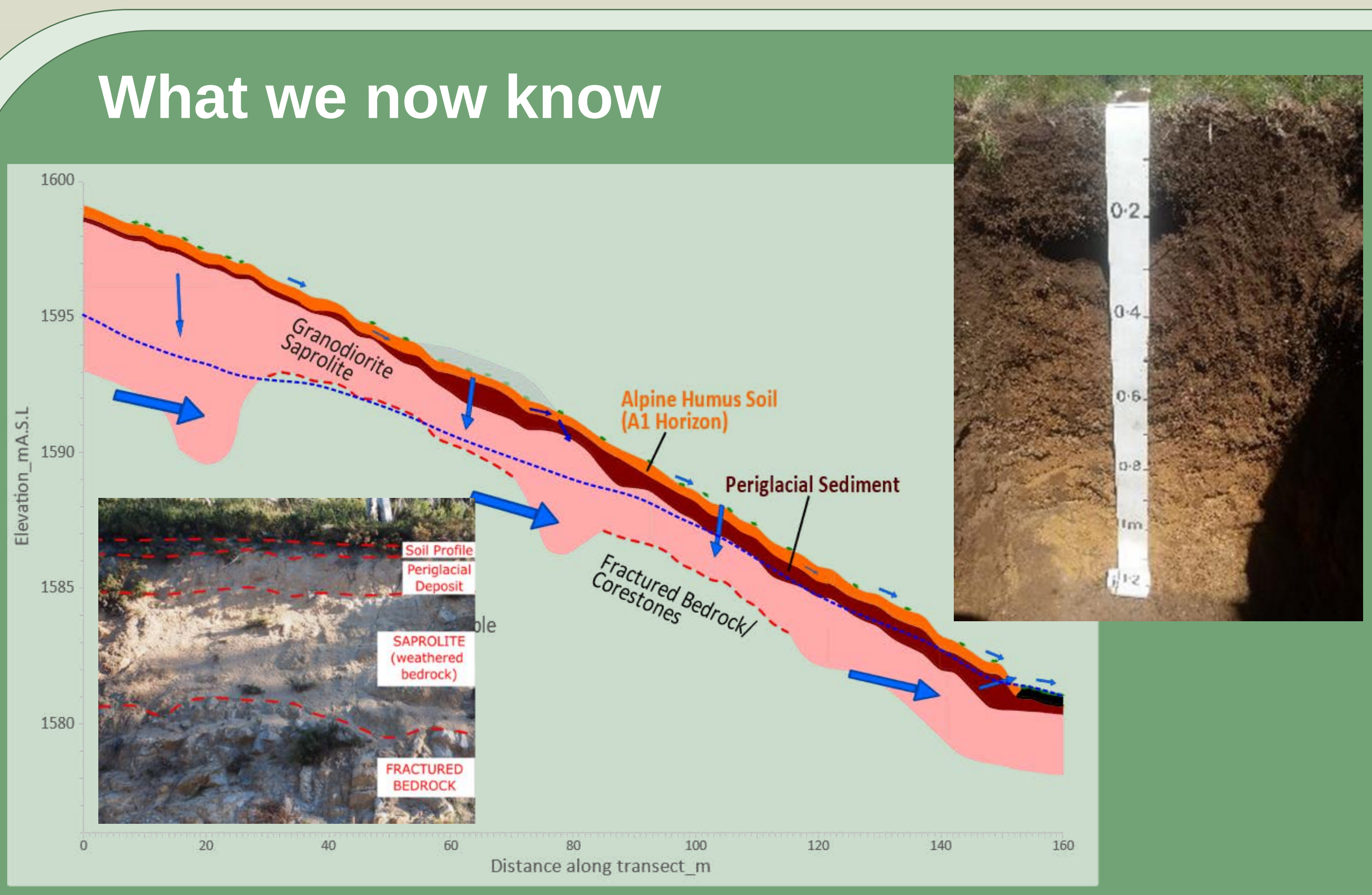
Complex substrates and seasonally extreme climatic conditions create unique soil landscapes not found elsewhere in Australia

Soil landscapes dominated by organic soils

- Chernic-Leptic Tenosols
- Chernic-Regolithic Tenosols

formed from decomposing alpine vegetation (organic material) underlain by periglacial and colluvial hillslope gravels overlying a weathered granodiorite substrate

What we now know



These organic soils are spatially extensive and volumetrically form: second largest store of carbon in the upland landscape after the tissue in Snow Gums

Precipitation capture and infiltration is one of the principle hydrological ecosystem services provided by alpine soil

Infiltration patterns change depending on antecedent conditions

Infiltration varies by orders of magnitude

vertically - with changes in substrate

downslope - with regolith configuration

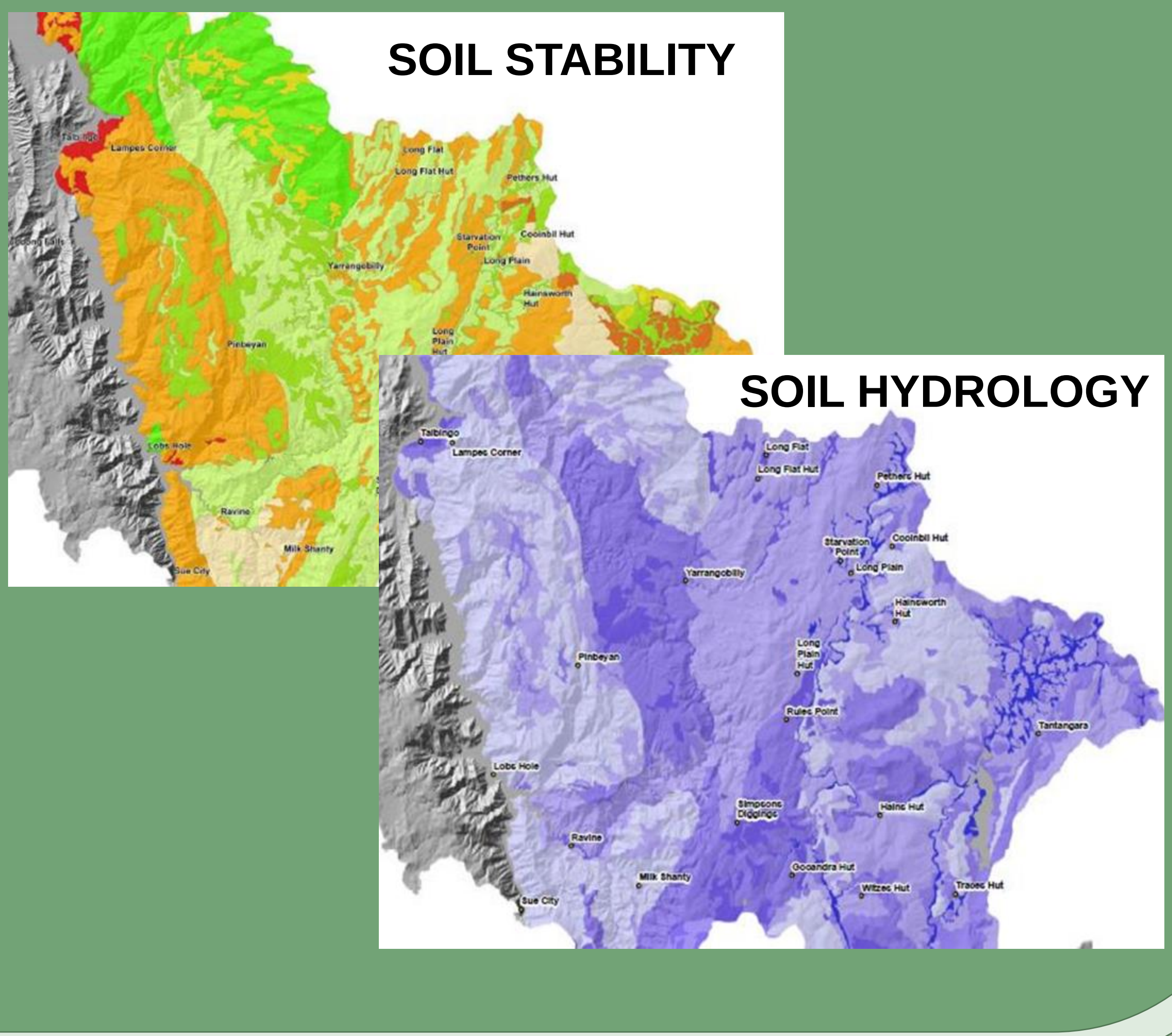
These organic soils form part of a contiguous shallow regolith-hosted aquifer system that provides a slow-release year-round water supply to: the Murray, Murrumbidgee, and Snowy headwaters, protected alpine bogs and fens, and the Snowy scheme

Our SOSG Work:

1. Acquire comprehensive soil property information across ~15 SOSG holes (~3 minimum at each of Pipeline, Betts Creek, Pipers Gap, Guthega and Illawong) to inform this and other SOSG studies
2. Accurate calibration of the SOSG soil moisture sensors to be deployed Spring 2024/Autumn 2025 (10cm, 20cm, 40cm, 60cm, 1m and regolith). This work is complemented by characterisation of the regolith materials extracted from the piezometer holes at these sites
3. Use push-tube soil samples in the laboratory-based hydraulic conductivity rig (2 x Engineering interns on this from February 2025) to calculate the hydraulic conductivity and aligned properties of soils/regolith materials
4. Conduct full soil chemistry analyses across all 5 catena and down all 15 holes to understand the patterns we see across the landscape and across the Snow Gum Dieback continuum - this includes comprehensive C analyses for integration into broader C-cycle modelling
5. Tie these soil-related findings into SOSG and aligned projects e.g. evaluation of Snow Gum dieback impact on soil function; modelling of C cycle processes; patterns in vegetation distribution - and potential change; climate related impact on Snow Gum soil systems
6. Value-add to, and benefit from, aligned upland soils initiatives e.g. NSW DCCEEW Soil landscape mapping

INFORM ADAPTIVE MANAGEMENT DECISION-MAKING

Parallel Work: NSW DCCEEW SNOWY MOUNTAIN SOIL LANDSCAPES



A hydrogeologic examination of Snow Gum Woodland hillslopes and water recharge in the Snowy Mountains, NSW.

Celine Anderson[1] and Leah Moore[1,2]

[1] Fenner School of Environment and Society, The Australian National University
2 Centre for Applied Water Science, University of Canberra

Research Aims and Objectives

These alpine landscapes provide a year-round supply of water to the headwaters of the Snowy, Murray and Murrumbidgee river systems. The perenniality and patterns of streamflow from alpine and subalpine areas is more similar to temperate snow-impacted areas globally than Australia rivers in lower lying areas. There is a current lack of understanding about, and misconceptions regarding, subsurface hydrological processes influencing alpine hillslopes hydrological response patterns contributing to streamflow generation.

This research explores the effect of vegetation cover type and condition on controlling water infiltration, recharge, and aquifer storage in the Snowy Mountains

Questions

1. How does water move through the hillslopes hydrological system?
2. Is there a difference in hydrological response between forested and grassy meadow hillslopes? How does this influence snow gum dieback?
3. How are alpine hillslope hydrological response patterns likely to change as a result of predicted climate change?

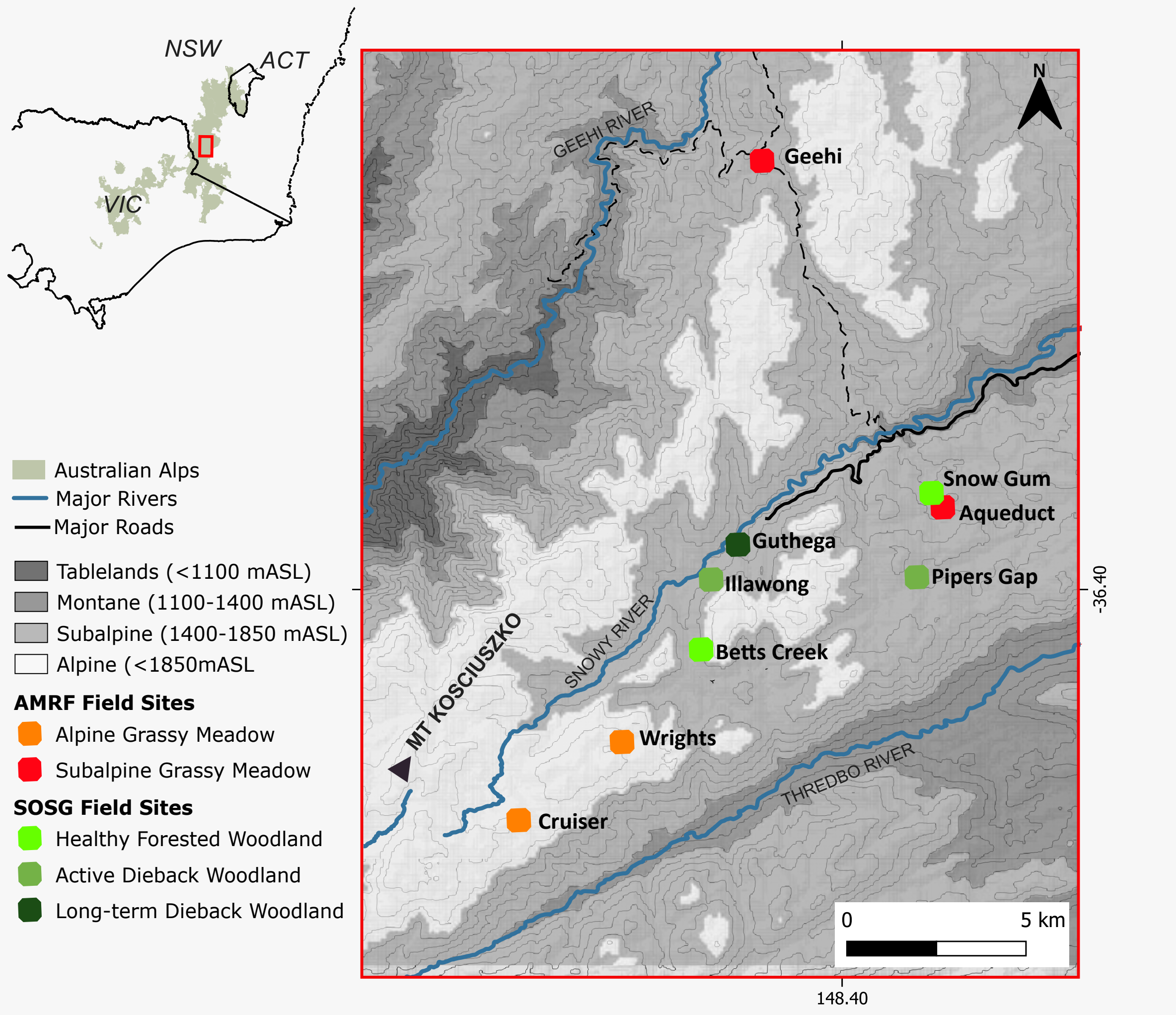


Figure 1 - Location map of Save our Snow Gums (SOSG) and Australian Mountain Research Facility (AMRF) study sites in Snowy Mountains, NSW,


Snow River near Illawong (left) and Guthega (right) during snowmelt

Hydrological Monitoring Array

Hydrological monitoring arrays are installed across five hillslope catenas with varying severities of dieback as part of the Save our Snow Gum project. Set-up mirrors a similar array installed at the Australian Mountain Research Facility (AMRF) sites.

The purpose of the infrastructure is to measure spatial and temporal variability in hydrological responses patterns.

Site Infrastructure

4x Multi-profile soil moisture probes (w/ temp)
(loggers at 10, 20, 40, 60, and 100cm)
3x Groundwater piezometers (monitoring bores)
(depths between 4.5 - 9.0 m below ground)
1x Rainwater sampler (at select sites)

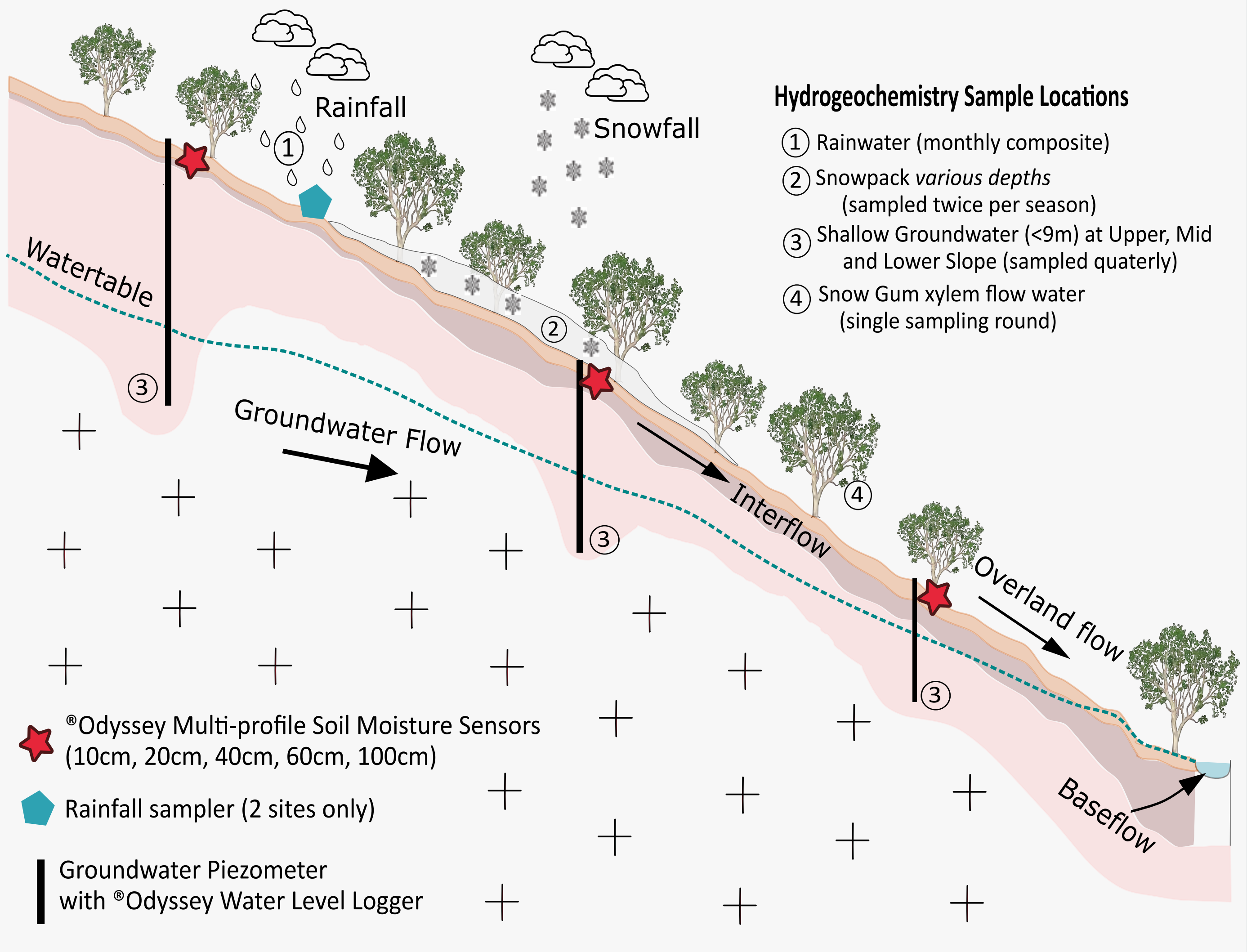


Figure 2 - Location of Hydro Array Infrastructure and hydrogeochemistry sampling locations at Save our Snow Gums (SOSG) study sites in Snowy Mountains, NSW,

Reserach Methods

1. Regolith materials characterisation: determining regolith stratigraphy, soil structure, texture and fabric
2. Hydrological properties of materials (porosity, hydraulic conductivity (K_{sat}), permeability): infiltrometer surveys and laboratory hydraulic conductivity testing
3. Hydrological Monitoring Array Infrastructure: water level and soil moisture logging at 15 minute intervals, quarterly data download and QA/QC
4. Isotope and Hydrogeochemistry: quarterly sampling for physicochemistry, major ions (including carbon flux), and stable isotopes
5. Xylem Flow experiment: sampling xylem water for comparison with groundwater and surface water isotopes to trace sources of plant water used (testing whether GDE)

Preliminary Findings from AMRF Sites

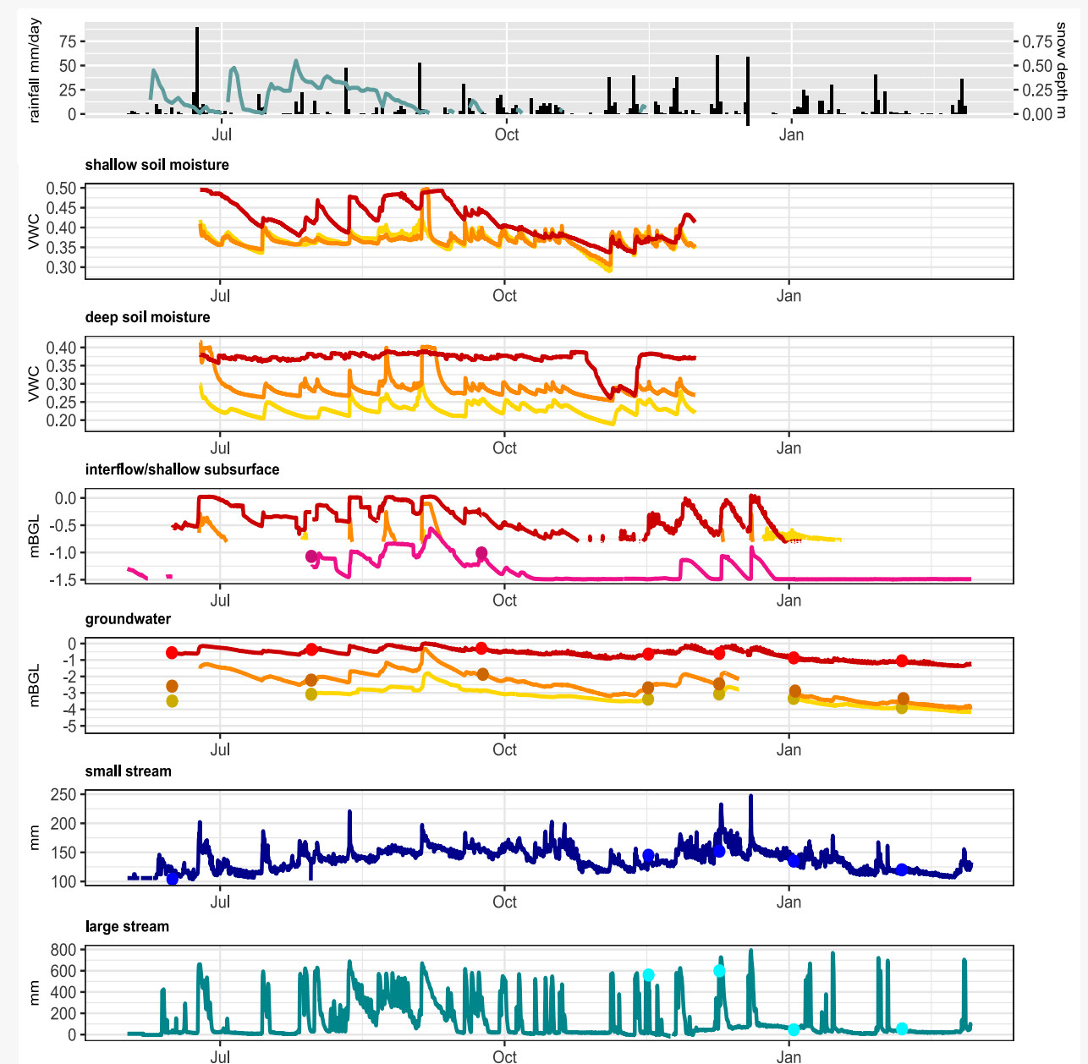


Figure 3 - Example of hydrological monitoring array output from AMRF Aqueduct site. Similar temporal data outputs to be generated from the SOSG hydrological array sensors

High infiltration rates into the alpine humus soils (AHS) (K_{sat} = 3 x10^{-4} to 1 x10^{-5} m.s^{-1}), and strong vertical connectivity to saprolite regolith-hosted aquifer allows for significant rates of groundwater recharge.

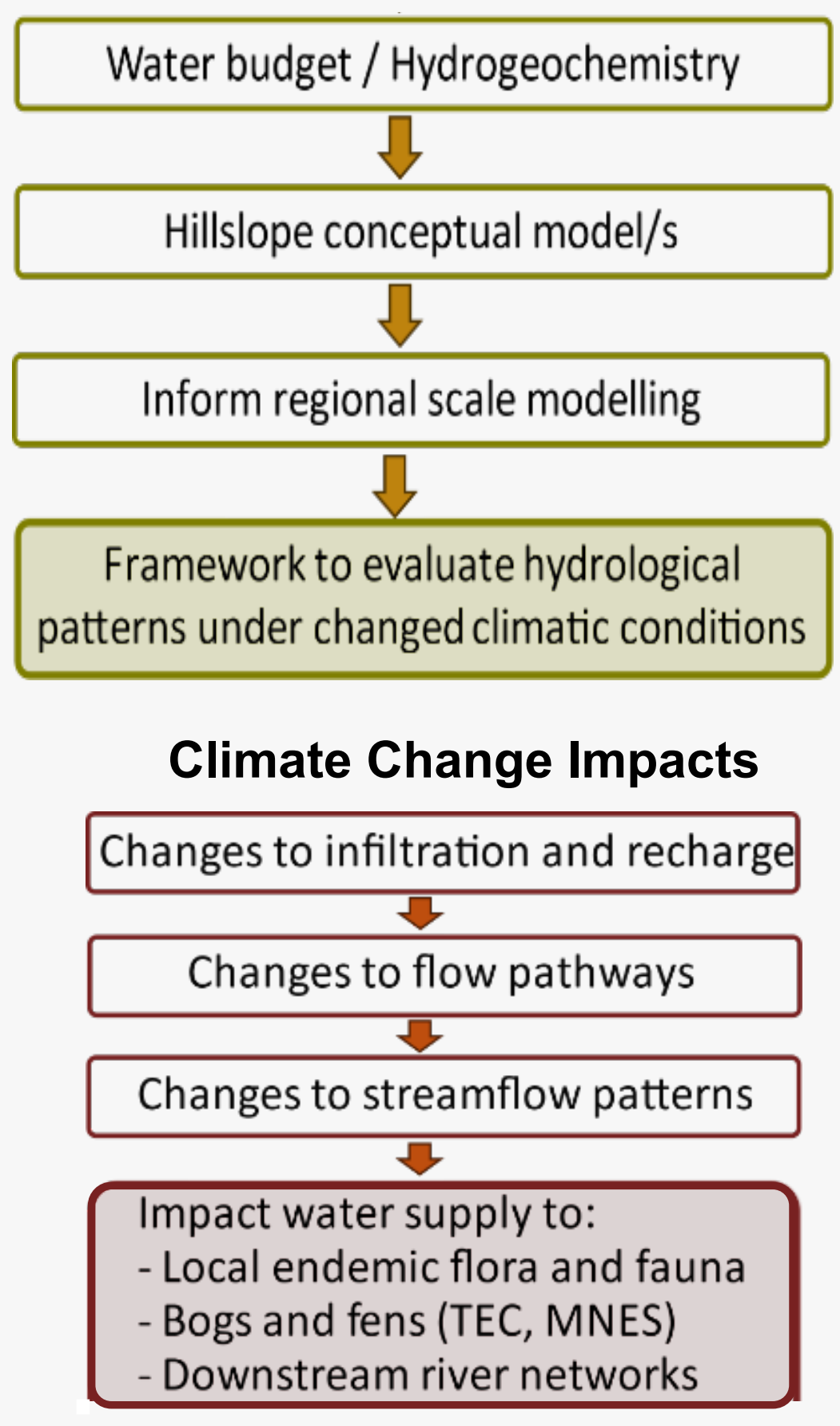
Groundwater baseflow dominates lateral flow pathways. Irregular interflow through AHS occurs periodically under intense precipitation conditions.

High recharge rates during wet winter periods from periodic snowmelt and rain on snow events and extended hillslope residence time (weeks to months) contribute to sustained streamflow during dry periods.

Research Implications

Combination of data from SOSG and AMRF sites will provide spatial variability across different vegetation cover types/conditions.

This will allow for more robust conceptual modelling of regional hydrogeological response patterns, improving our understanding of climate change impacts on water storage and streamflow generation. Identify potential influence of hydro on snow gum dieback



Water budget / Hydrogeochemistry
Hillslope conceptual model/s
Inform regional scale modelling
Framework to evaluate hydrological patterns under changed climatic conditions

Climate Change Impacts

Changes to infiltration and recharge
Changes to flow pathways
Changes to streamflow patterns
Impact water supply to:
- Local endemic flora and fauna
- Bogs and fens (TEC, MNES)
- Downstream river networks

Borehole Piezometer Installation at Perisher

Contact: *celine.anderson@anu.edu.au or leah.moore@anu.edu.au*

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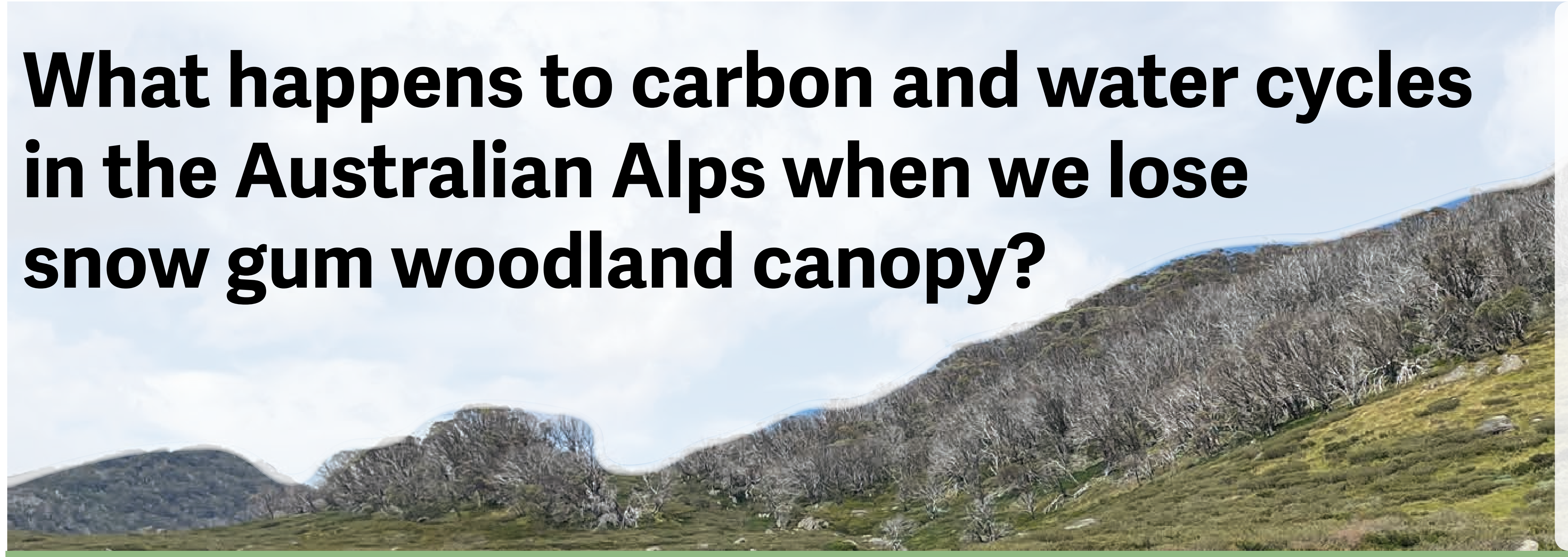


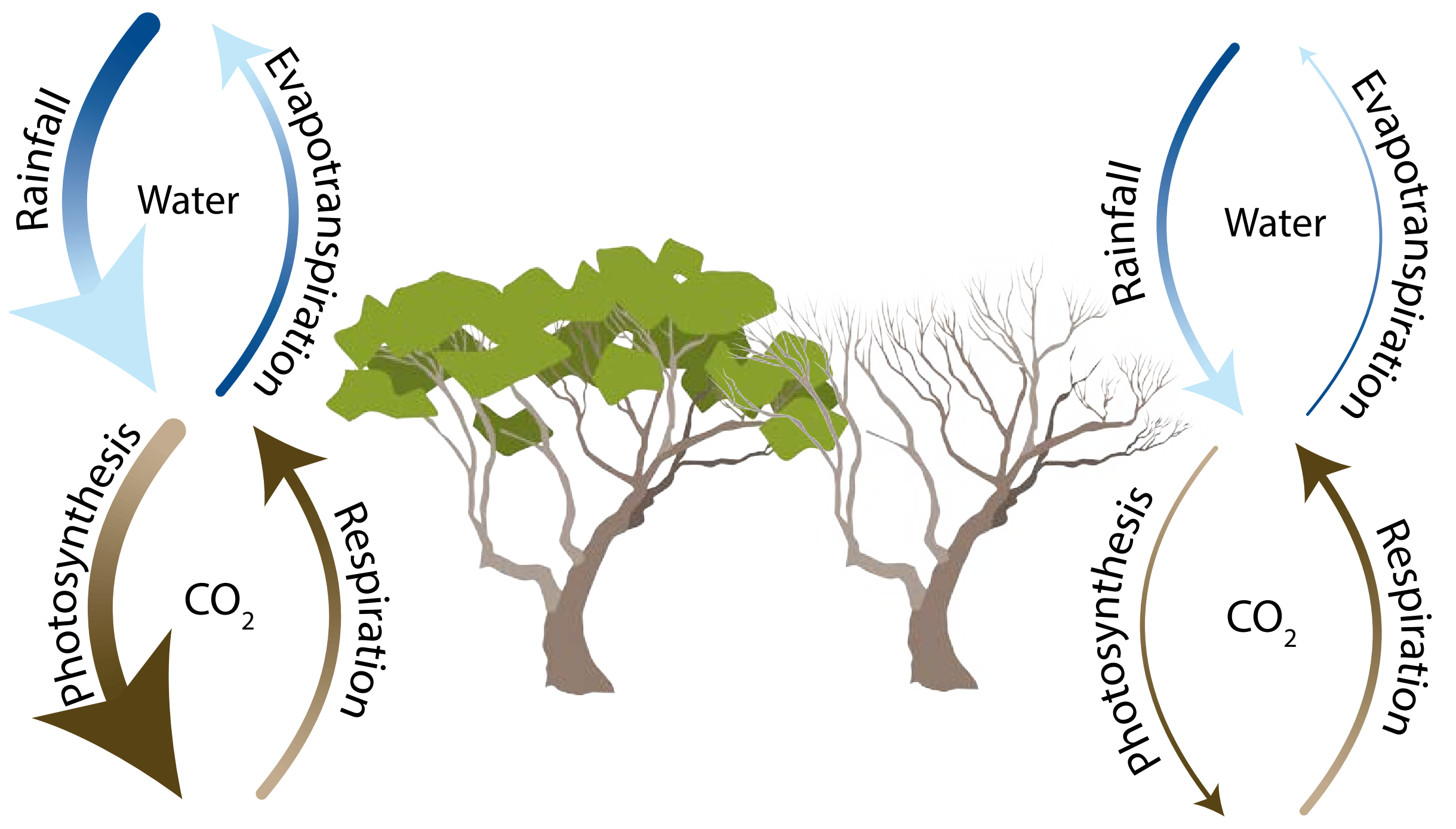
What happens to carbon and water cycles in the Australian Alps when we lose snow gum woodland canopy?

Hilary Rose Dawson
Postdoc in the Nicotra Lab

Leo Lovesy
Honours student
Supervised by Adrienne Nicotra, Hilary Rose Dawson, Zachary Brown

Summary

Snow gum woodlands are key components of carbon and water cycling in subalpine landscapes. Plants remove carbon dioxide from the atmosphere through photosynthesis and store it in wood and roots. Both plants and soil microbes respire, releasing carbon dioxide back into the atmosphere. Snow gums intercept rainfall and fog, potentially increasing soil moisture. However, they also release water back to the atmosphere through evapotranspiration. We predict snow gum dieback will alter these cycles and we are measuring this effect several ways.



Snow gum illustrations by Weerach Charerntantanakul

How we measure carbon and water

Eddy covariance fluxes

Gas analyser mounted on 14m tall tower that continuously measures carbon, water, and energy going into and coming out of a healthy snow gum woodland.

Soil respiration

Collars inserted into the ground that we repeatedly visit and use a gas analyser to measure how much carbon dioxide is released by roots and microbes in the soil.

Net ecosystem exchange

Collars inserted into the ground that we repeatedly visit and attach a sealed gas analyser chamber to measure carbon dioxide and water changes from understory vegetation.

Biomass accumulation

Metal dendrometer bands under tension that expand as the tree grows to measure how quickly biomass (and thus carbon) accumulates in snow gums.

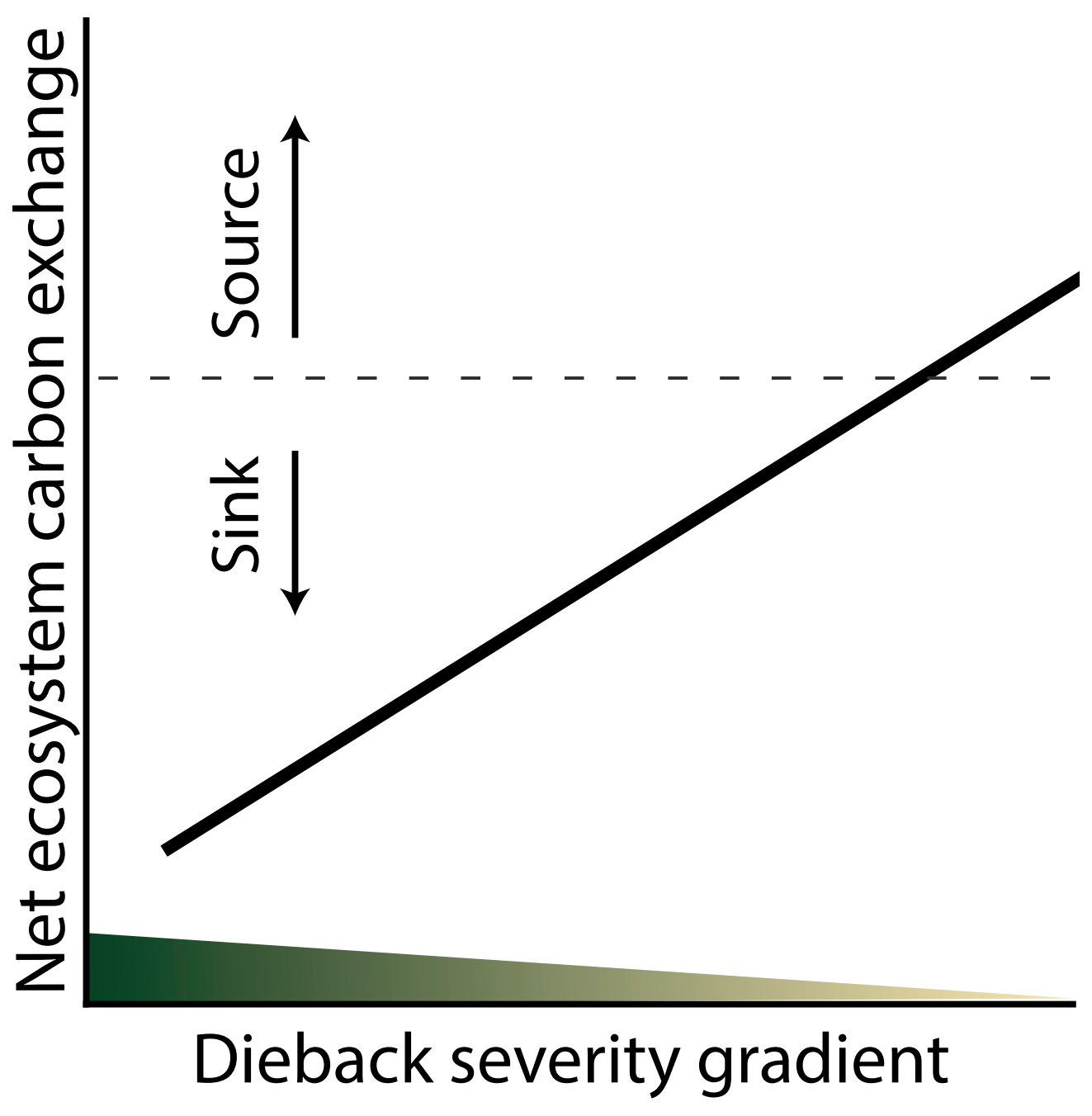
Soil moisture

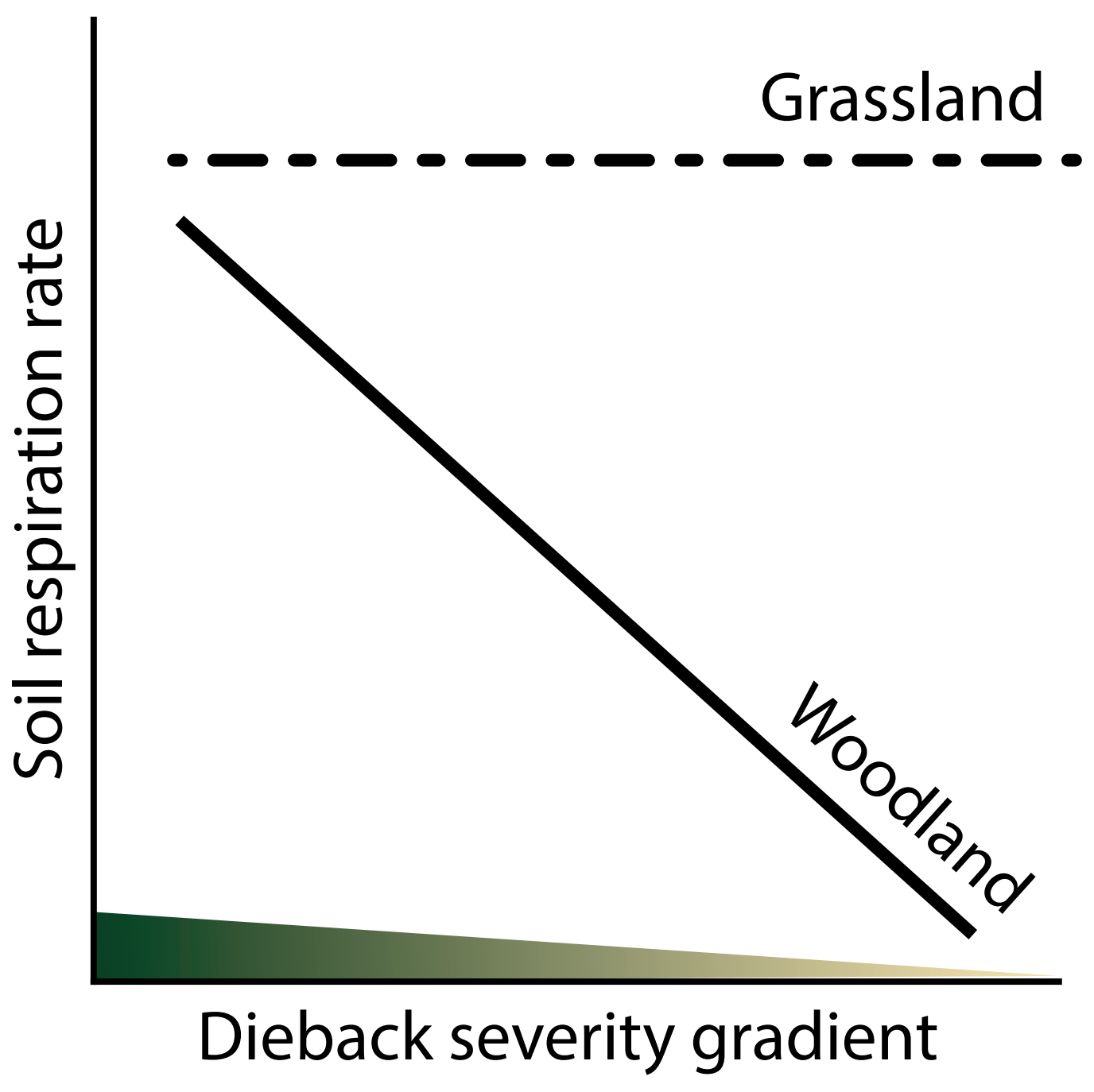
Underground sensors to measure how much water is in the soil under snow gums compared to open areas.

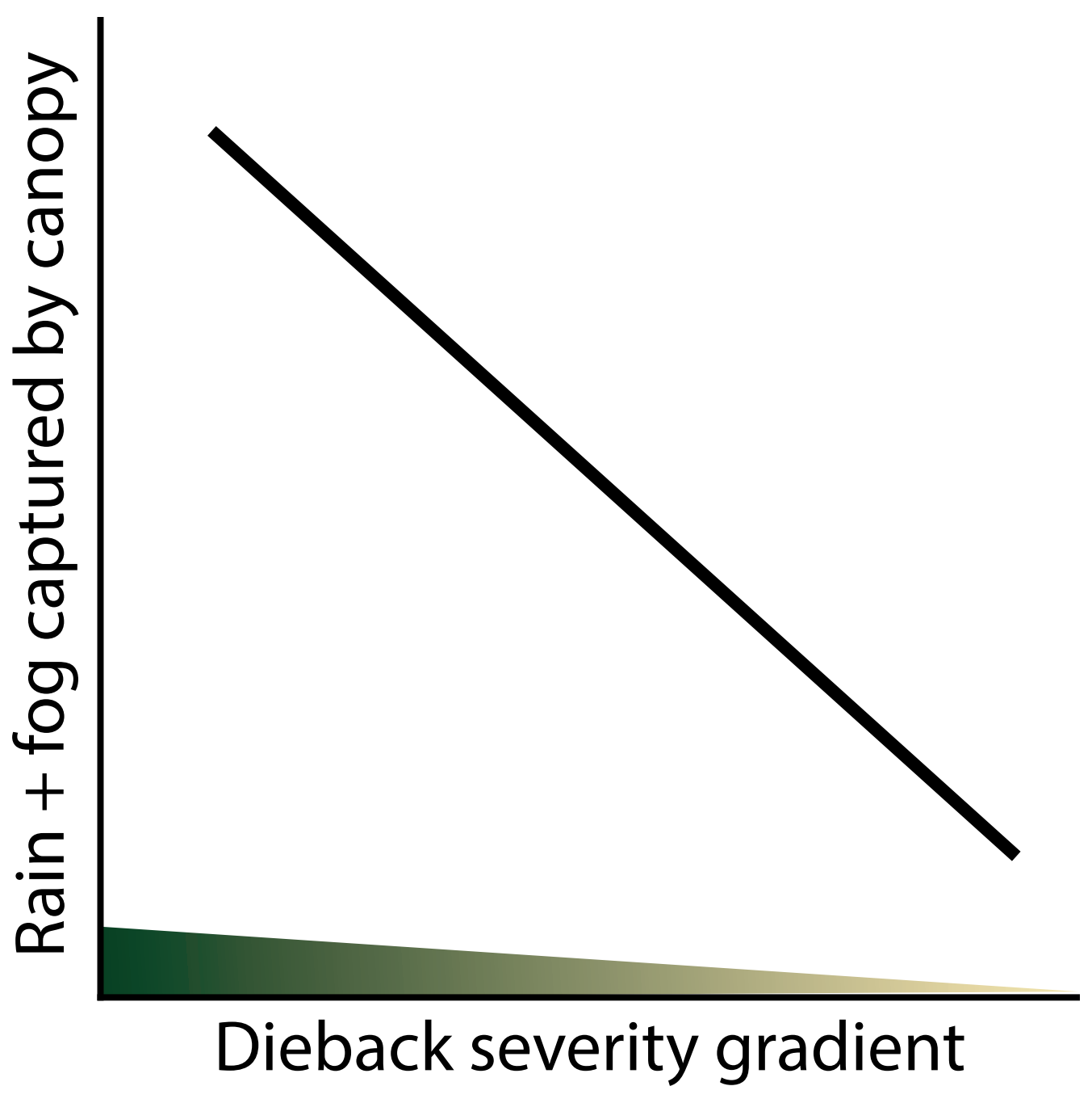
Photo from Odyssey Data Recording

What we predict

1. Under dieback, snow gum woodlands will switch from accumulating carbon through photosynthesis to releasing more carbon than they take up.
2. Carbon released from the soil is primarily driven by living trees and will decrease under dieback.
3. Canopy dieback will reduce the water snow gum leaves capture from fog and rain.







Why it matters

- Canopy loss could switch snow gum woodlands from a significant carbon sink to a source that emits more carbon than is sequestered through photosynthesis.
- Available water could be reduced by the canopy loss. Alternatively, less tree cover may leave subalpine areas vulnerable to extreme runoff events that erode soil and increase the chance of flooding.

Assessing variation in seedling freeze tolerance among snow-gum provenances

Lucy Zarew, Honours Student, Australian National University
Supervised by: Cal Bryant and Adrienne Nicotra

Background

- Dieback is isolated to the high-elevation snow-gum subspecies
- Subsp. *pauciflora* (found in lower elevations) may be more resistant to borer infestation and fire
- The current snow-gum subspecies are distinguished based on morphological differences seen in the field
- Are the subspecies genetically different or a product of differing growth environments? (Figure 1)

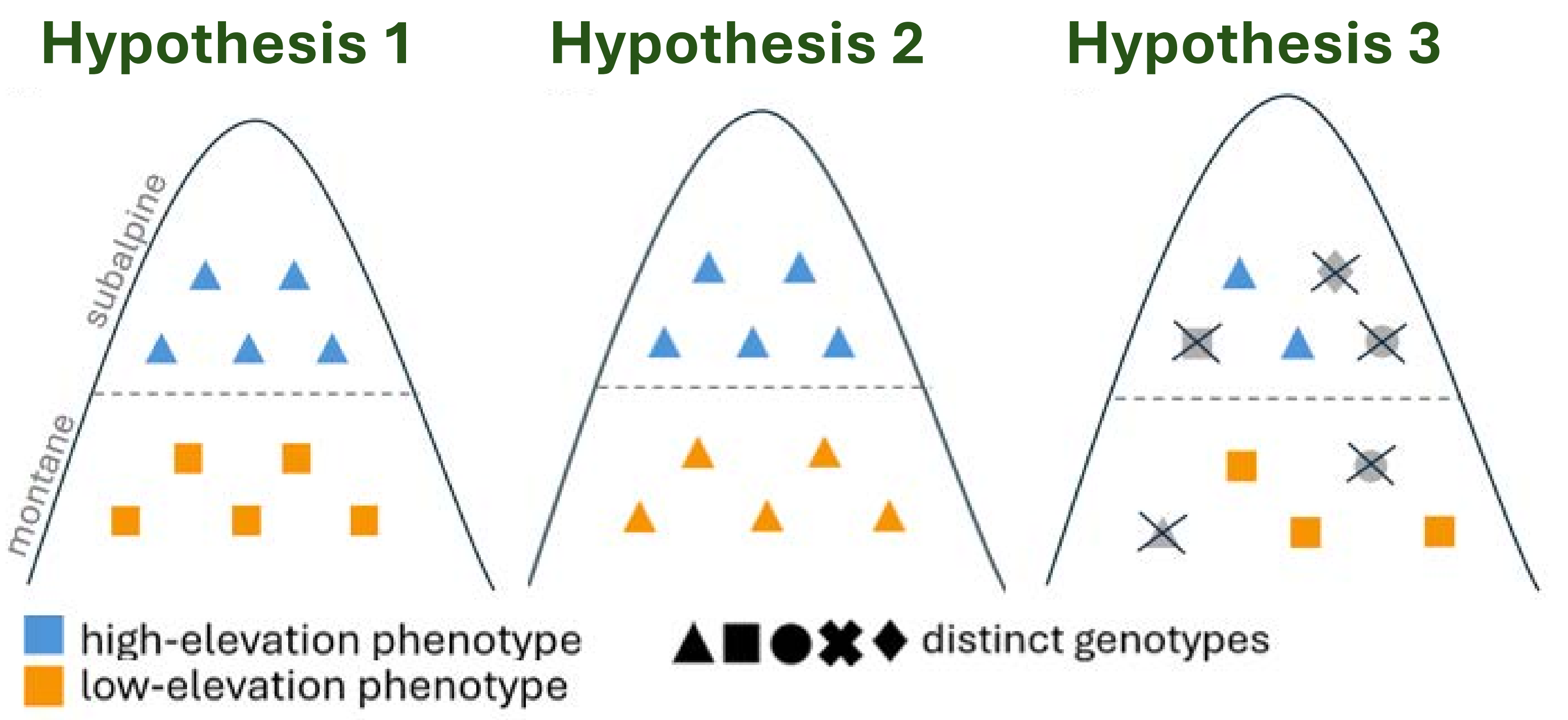


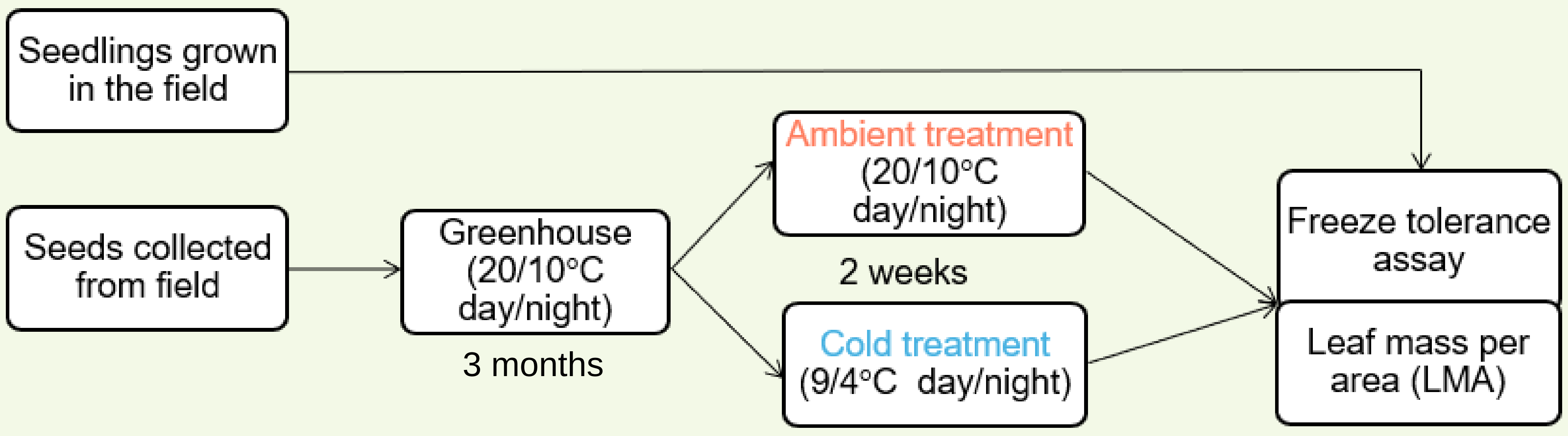
Figure 1. Three possible explanations for differences in phenotype (e.g. freeze tolerance) that are seen in field grown plants. **Hypothesis 1:** genotypic differences drive phenotypic differences seen in the field. **Hypothesis 2:** Growth environment induces phenotypic plasticity seen in field seedlings. **Hypothesis 3:** Environment filters genetic variation resulting in some phenotypes surviving.

The project:

Since freezing temperatures are a likely limit to the distribution of subsp. *pauciflora*, **we investigated what is causing variation in snow-gum seedling freeze tolerance, cold acclimation and leaf structure.**

Methods

- A common-garden experiment with 826 seedlings, with seed collected across 9 regions, 6 subspecies and 117 mother trees
- Half of the greenhouse-grown seedlings were exposed to a cold treatment to test acclimation
- Freeze tolerance of leaves were measured using chlorophyll fluorescence methods: using T_{crit} as a proxy for leaf tissue damage



Seedlings grown in the field

Seeds collected from field

Greenhouse (20/10°C day/night)

3 months

Ambient treatment (20/10°C day/night)

2 weeks

Cold treatment (9/4°C day/night)

Freeze tolerance assay

Leaf mass per area (LMA)

Results

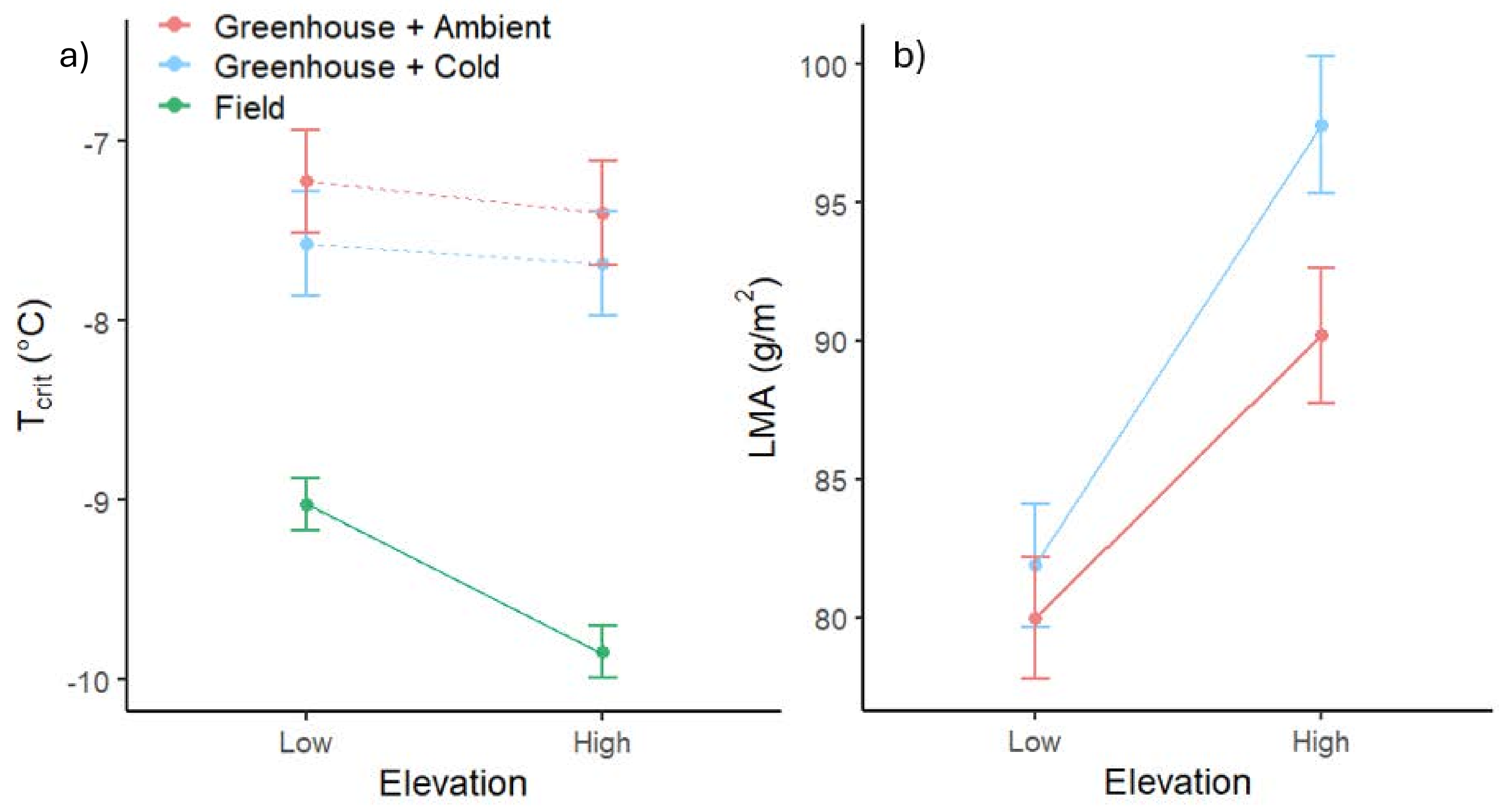


Figure 2. Comparing low and high-elevation seed sources in **a)** Freeze tolerance (T_{crit}) and **b)** Leaf mass per area (LMA).

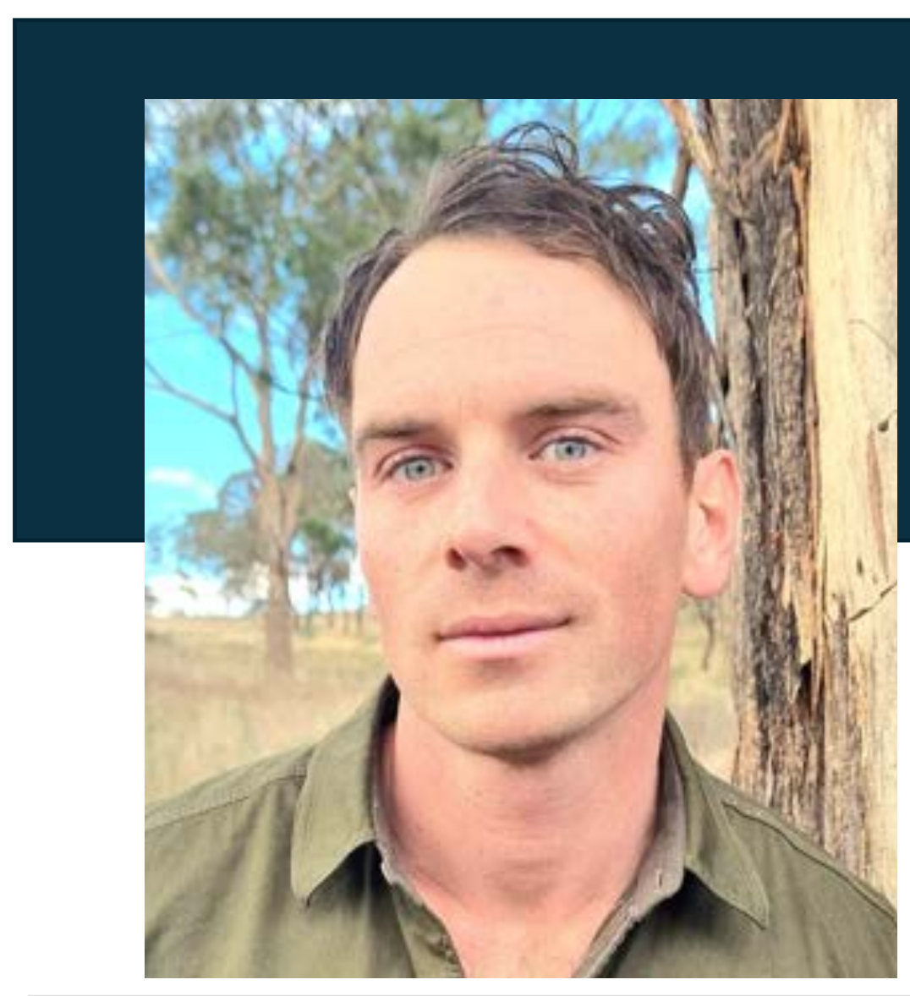
- Leaf freeze tolerance converged under common conditions (Figure 2a)
- High-elevation subspecies seed sources did not have better cold acclimation ability
- No significant differences in freeze tolerance across regions, elevation or mother trees
- Leaf structural differences were maintained in common conditions (Figure 2b)

Conclusions

- Leaf freeze tolerance is plastic and can adjust to seedling growth environment → distribution of subsp. *pauciflora* might not be limited by leaf tissue freeze tolerance
- After pairing further common garden phenotyping with genetic data, we will have a better understanding of the potential of subsp. *pauciflora* to be a resilient seed source that could successfully be used to reforest dieback affected areas

WHICH SNOW GUM WHERE?

Unpacking the snow-gum subspecies complex to inform dieback responses



CAL BRYANT
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BACKGROUND

When a species experiences a large-scale dieback, some of the first questions asked are:

- Are there any stands/ trees that might be more resilient to future dieback events?
- What might we replant with?

Unfortunately, these questions butt up against the limits of the current resolution of the snow-gum subspecies complex.

This project combines field surveys, phenotyping, and genotyping to resolve the Genotype × Environment × Phenotype associations **(Figure 1)** that may underpin differential dieback vulnerability observed among snow-gum subspecies **(Figure 2).**

METHODS

1. **Field surveys, collections, mature tree phenotyping** of all snow-gum subspecies across distributions.
2. **Genotyping**: whole-genome sequencing
3. **Assessment** of
    1. Neutral genomic variation among subspecies (local clustering/ adaptation)
    2. Geneflow by geographic distance **(Figure 3)**
    3. Common-garden phenotypes **(Figure 4)**
4. **Translation** to dieback management guidelines.

OUTCOMES

Understanding population structure and the origins of dieback resistance among snow gums is central to informed dieback management actions:.

1. Identification of borer-resistant seed sources within populations (if they exist).
2. Assessment of the genomic basis of snow-gum subspecies. Do the subspecies exist?
3. Characterisation of heat, drought and cold-tolerance differences among subspecies.
4. Assessment of value/ risk of management interventions:
    1. Assisted-gene flow between populations?
    2. Are there provenances within the population that might be more suitable for revegetation?
    3. Is there any value in assisted species migration?

ACKNOWLEDGEMENTS

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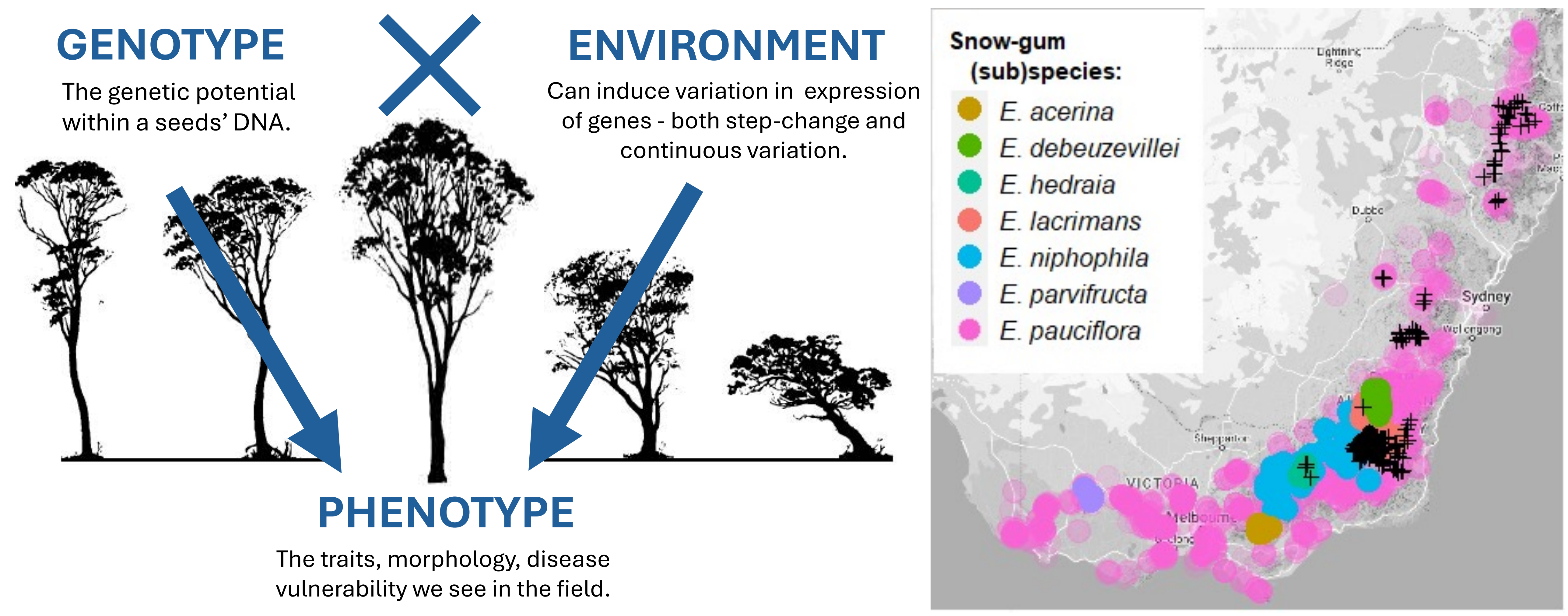


GENOTYPE × **ENVIRONMENT**

The genetic potential within a seeds' DNA.

Can induce variation in expression of genes - both step-change and continuous variation.

PHENOTYPE

The traits, morphology, disease vulnerability we see in the field.

Figure 1. Understanding the species we are managing. **(Left)** A trees' phenotype arises from interactions between its genotype and the environment. **(Right)** Snow-gum subspecies are currently distinguished by differences in phenotype (leaf, bud, seed morphology) and geographic distributions. This project will extend surveys of genomic variation in *E. pauciflora,* shown by + on the map, to the entire subspecies complex.

Vulnerability varies with elevation and among subspecies

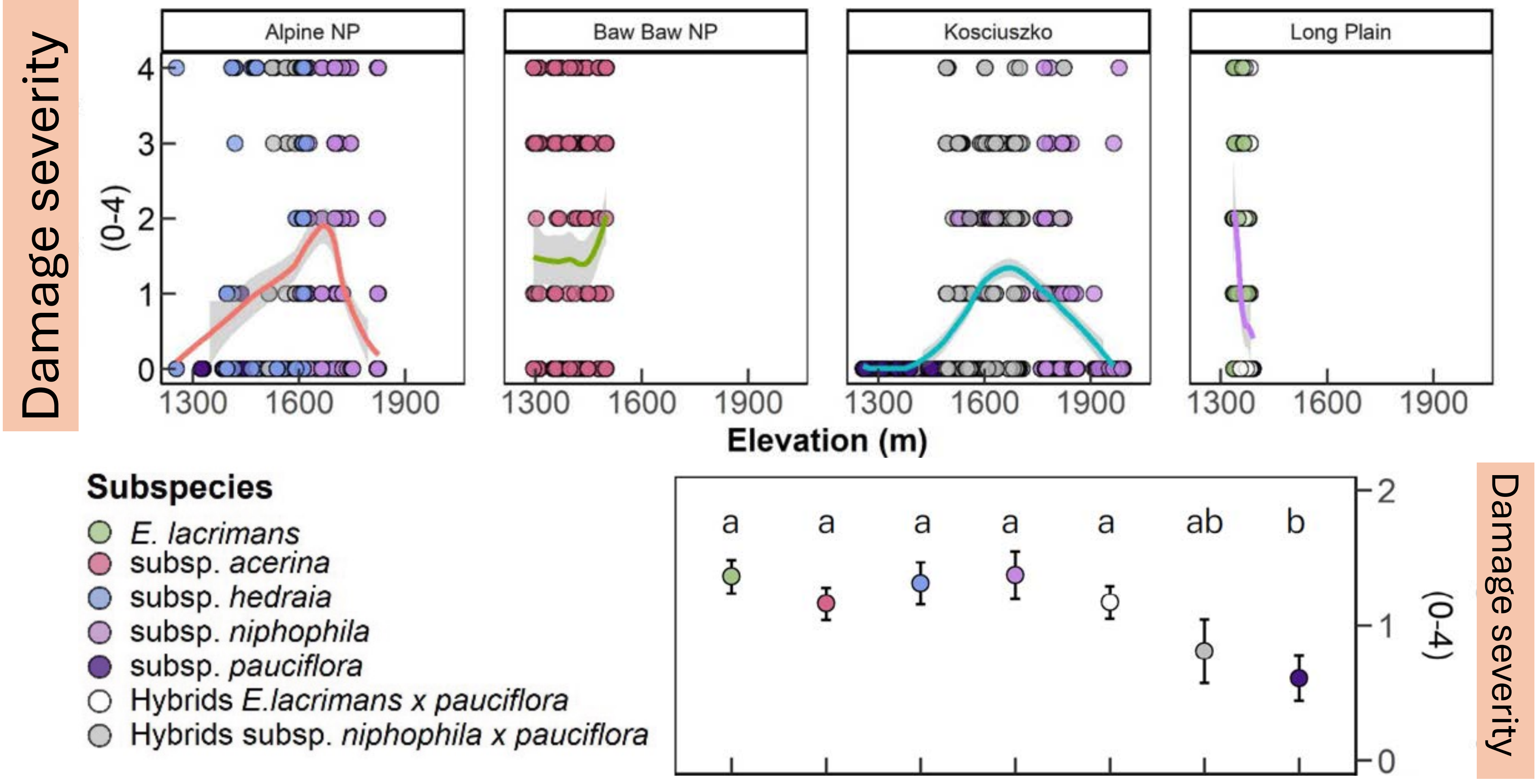


Figure 2. Preliminary surveys suggest consistent borer vulnerability across all cold specialist/subalpine snow-gum subspecies, and consistent resilience within montane *E. pauciflora subsp. pauciflora*. However, it remains unclear which snow-gum subspecies' phenotypes arise from genetically distinct genotypes, which are induced by differences in environment, and which are being filtered by the environment. *Note:* hybrids designated when morphology unclear.

Estimating gene flow across distributions

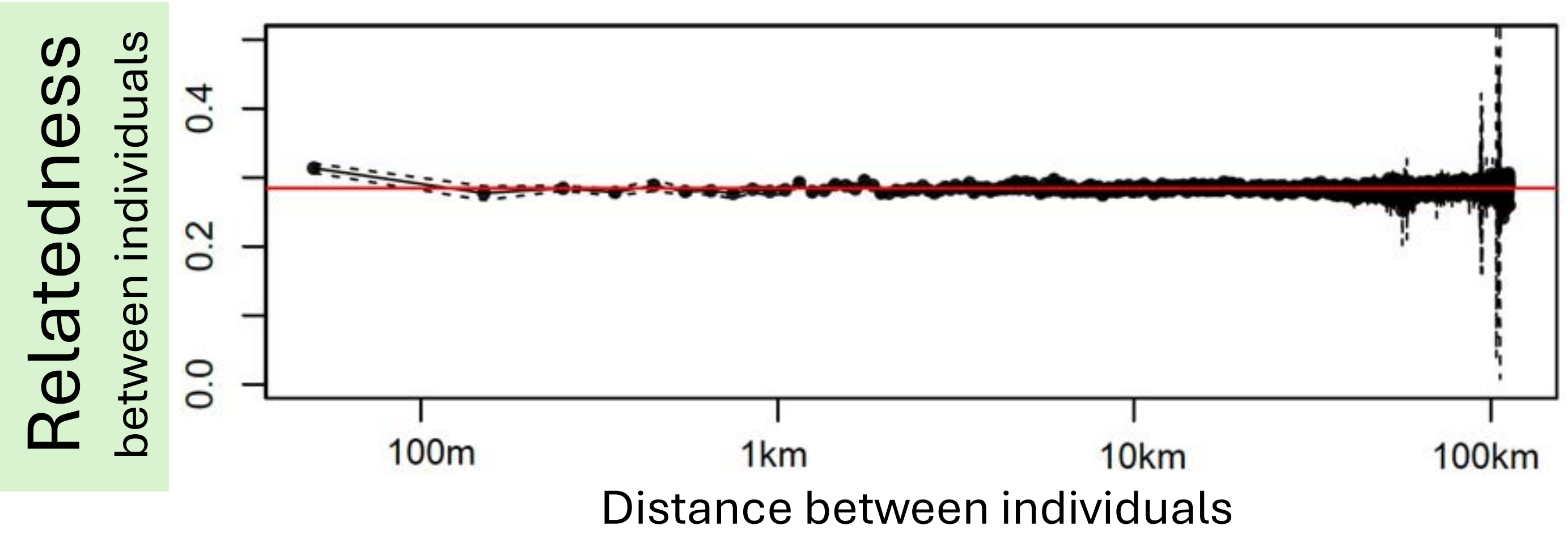


Figure 3. We can infer the extent of gene flow across the snow gum populations by characterising the spatial distribution of neutral genetic diversity . This plot shows that relatedness between ***E. pauciflora subspecies pauciflora*** trees is highest within the first 100m, suggesting this is how far seeds typically move from maternal trees. At distances greater than 100m relatedness is no different between trees up to 100km away, suggesting low but consistent levels of long-distance pollen dispersal. Given these levels of gene flow, geographic/ environmental clines may not exist at this distance. Next, we will estimate geneflow *among* snow-gum subspecies & populations.

Comparing subspecies' phenotypes in common conditions

Shadehouse | Greenhouse | Future-climate field trials | Provenance field trials

Figure 4. Characterising adaptive phenotypes/traits among snow-gum subspecies grown under common environments is necessary to distinguish the genetic or environmental basis of variation physiological tolerances. Vulnerability to borer-mediated dieback appears to interact with subspecies' differences in tolerance to cold, heat, drought, as well as other growth and tissue characteristics. By growing subspecies and neighboring montane species in a variety of "common gardens" we can distinguish environmental and genetic drivers of these differences. We've conducted the first of two controlled environment trials in the ANU greenhouses, the second will take place in 2025. Next, we will plant into Australian Mountain Research Facility's *FutureClim* infrastructure to explore seedling survival and performance under simulated future climates of elevated soil temperatures and elevated drought stress. Finally, phenotypes will be assessed in a variety of short-term reciprocal transplant experiments or "provenance trials", to be codesigned with willing partners.

Mapping dieback in subalpine woodlands with satellite imagery

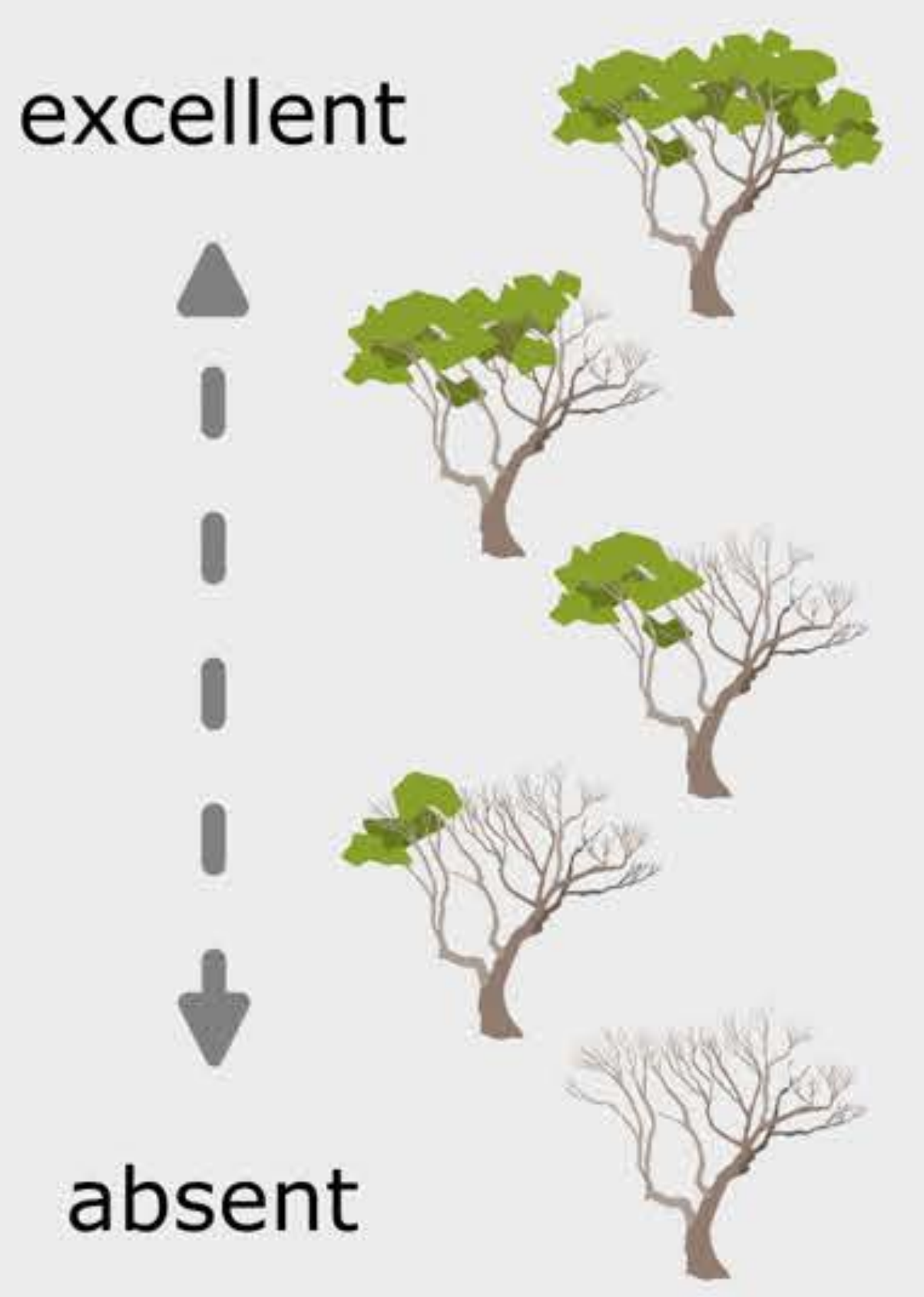
Weerach Charerntantanakul (weerach.charerntantanakul@anu.edu.au)
Matthew T. Brookhouse, Saul Cunningham, Hilary R. Dawson, Adrienne Nicotra, Marta Yebra

Australian National University

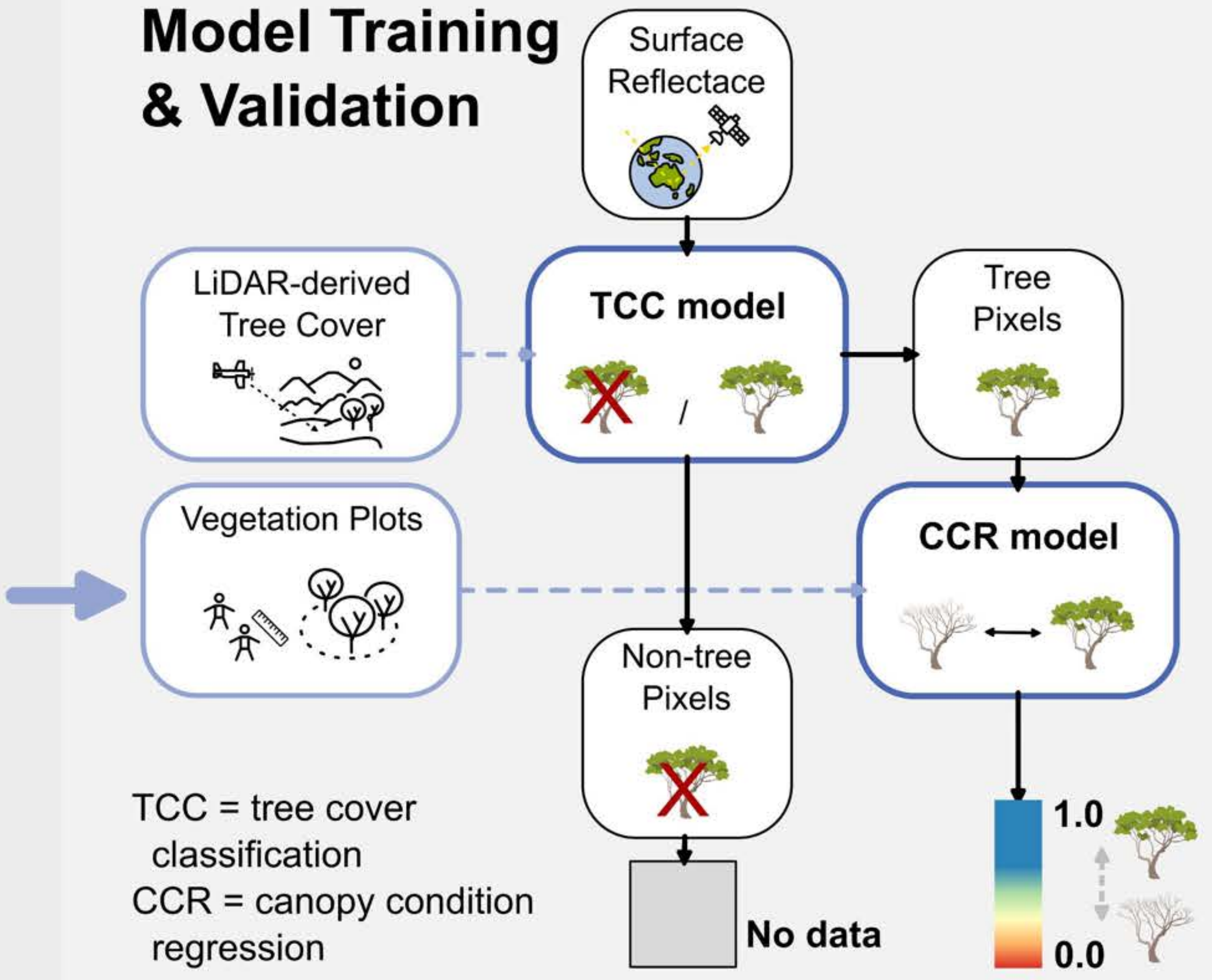
We used data from aerial LiDAR and vegetation plots to train and test machine learning models to automatically identify tree cover and assess its canopy condition within satellite images. This method can effectively map canopy condition over a large area annually.

Vegetation Plots

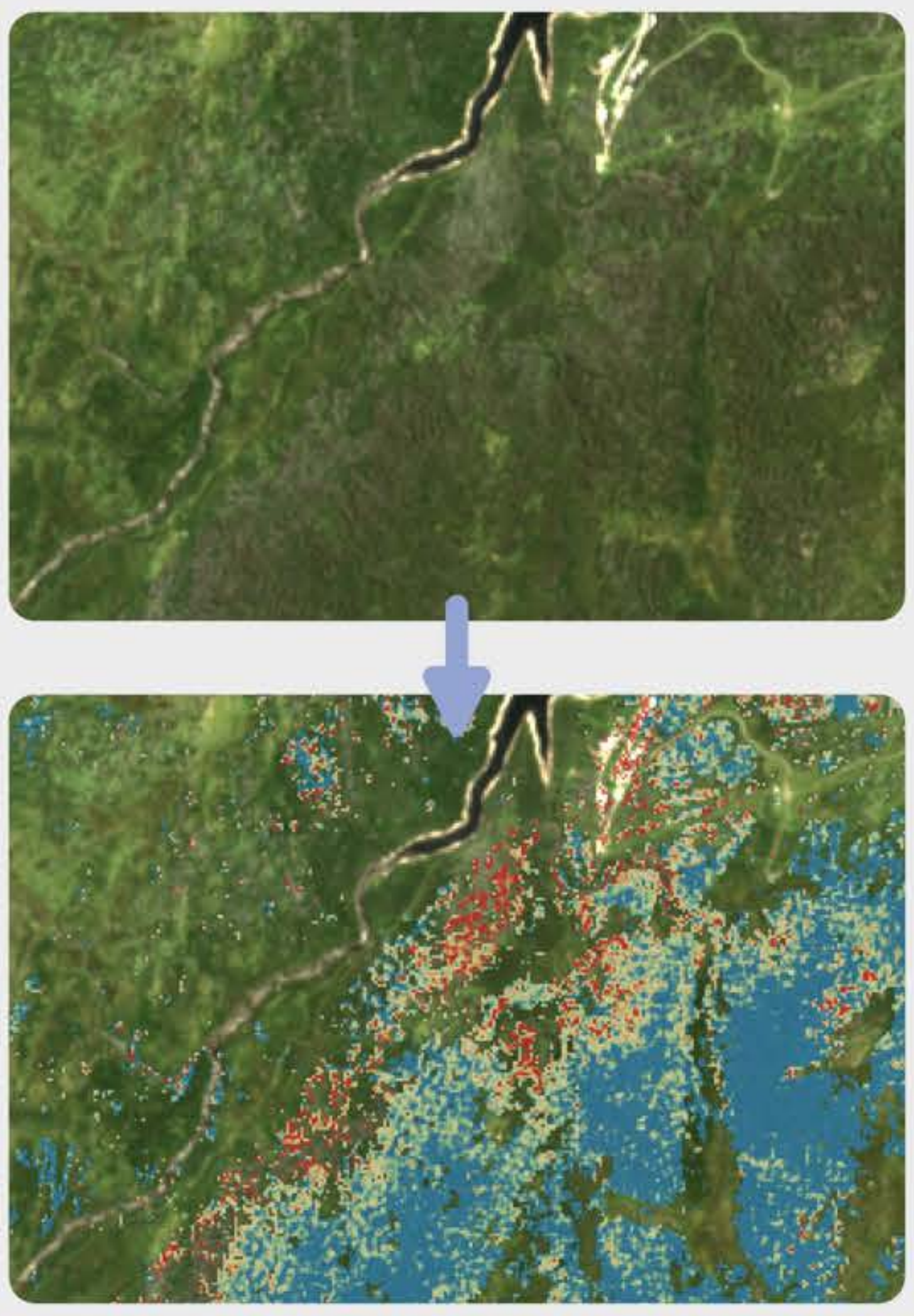
Field-based assessment of canopy condition



Model Training & Validation

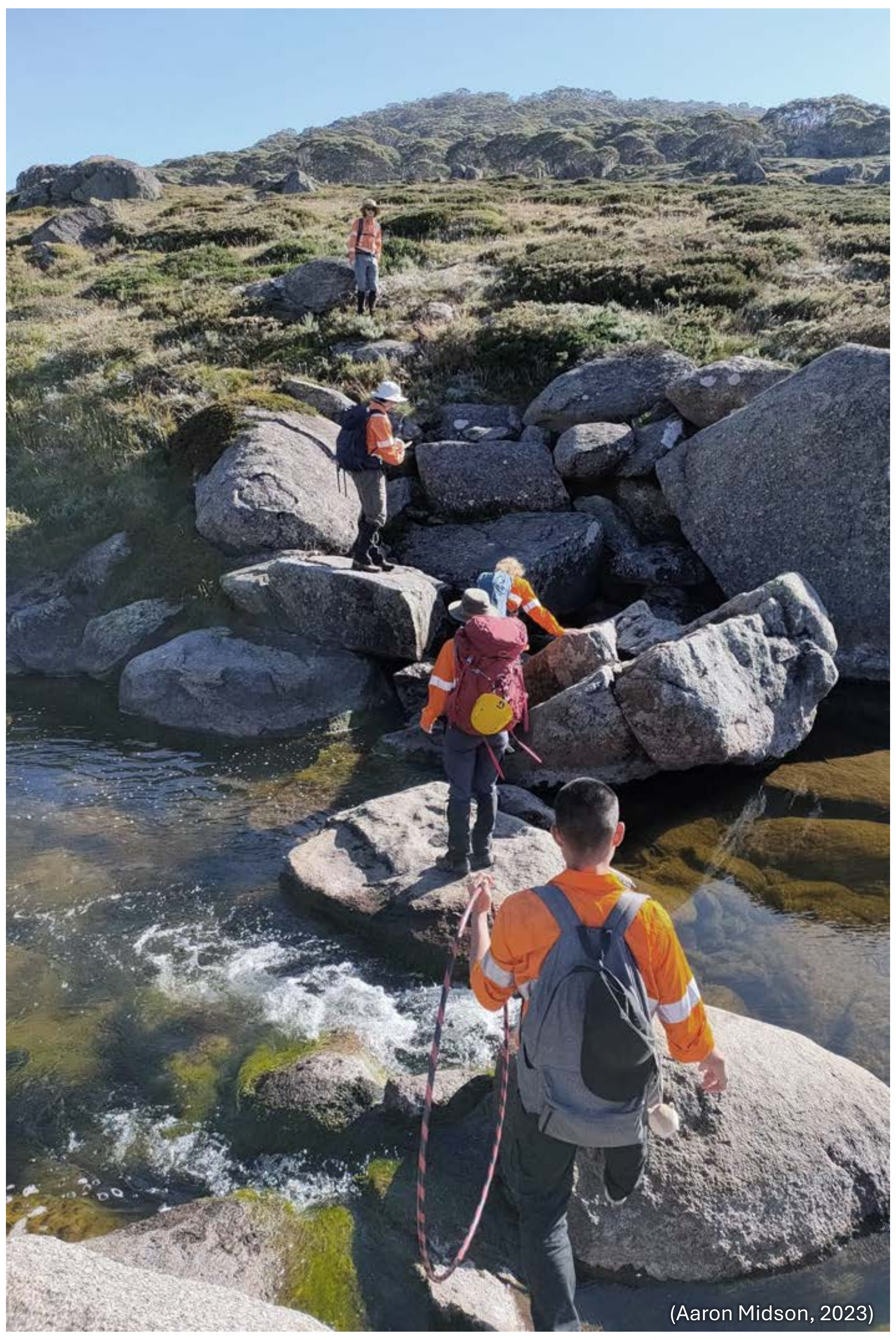


TCC = tree cover classification
CCR = canopy condition regression



Background

- Large-scale dieback in high-elevation snow gums
- Lack of complete mapping
  - spatial coverage
  - temporal resolution
- Field-based survey is very labour-intensive
- Remote sensing can be a cost-effective solution



(Aaron Midson, 2023)

Datasets

Input

- Opensource satellite images: Sentinel-2 / Landsat
  (USGS, ESA, Geoscience Australia)

Training data

- Aerial LiDAR data (NSW Govt.)
  → tree cover
- Vegetation plot surveys
  - 85 plots across KosciuszkoNP
  → canopy condition

Methods

- Pixel-based supervised classification and regression
- Tested different machine-learning algorithms and model configurations for the best mapping accuracies
  - Random forest
  - Support-vector machine
  - Multiple linear regression

(Aaron Midson, 2023)

Results

- Tree Cover
  - Support-vector machine
  - All 10 spectral bands
  - Overall accuracy = 85%
- Canopy Condition
  - Multiple linear regression
  - blue, red-edge 1–2, NIR
  - R2 = 0.73

View map:
tinyurl.com/sosg-01

This can be applied for:

- Monitoring areas which are difficult to access
- Checking for affected areas before visiting the sites
- Analysis of when and where dieback happened in the past, which can be useful for understanding the underlying factors

Acknowledgements: All fieldwork volunteers & contributors, Dr Josh Dorrough, Dr Linda Henderson, Dr Zach Brown, Mel Schroder, NSW National Parks and Wildlife, Perisher Ski Resort
Fundings: NSW Environmental Trust Grant (2020/RD/02) & ARC Linkage Project (LP210300506)

Stable Isotopes in Snow Gums

Introducing new techniques to uncover the world of stable isotope dendrochronology in *Eucalyptus pauciflora spp. niphophila*

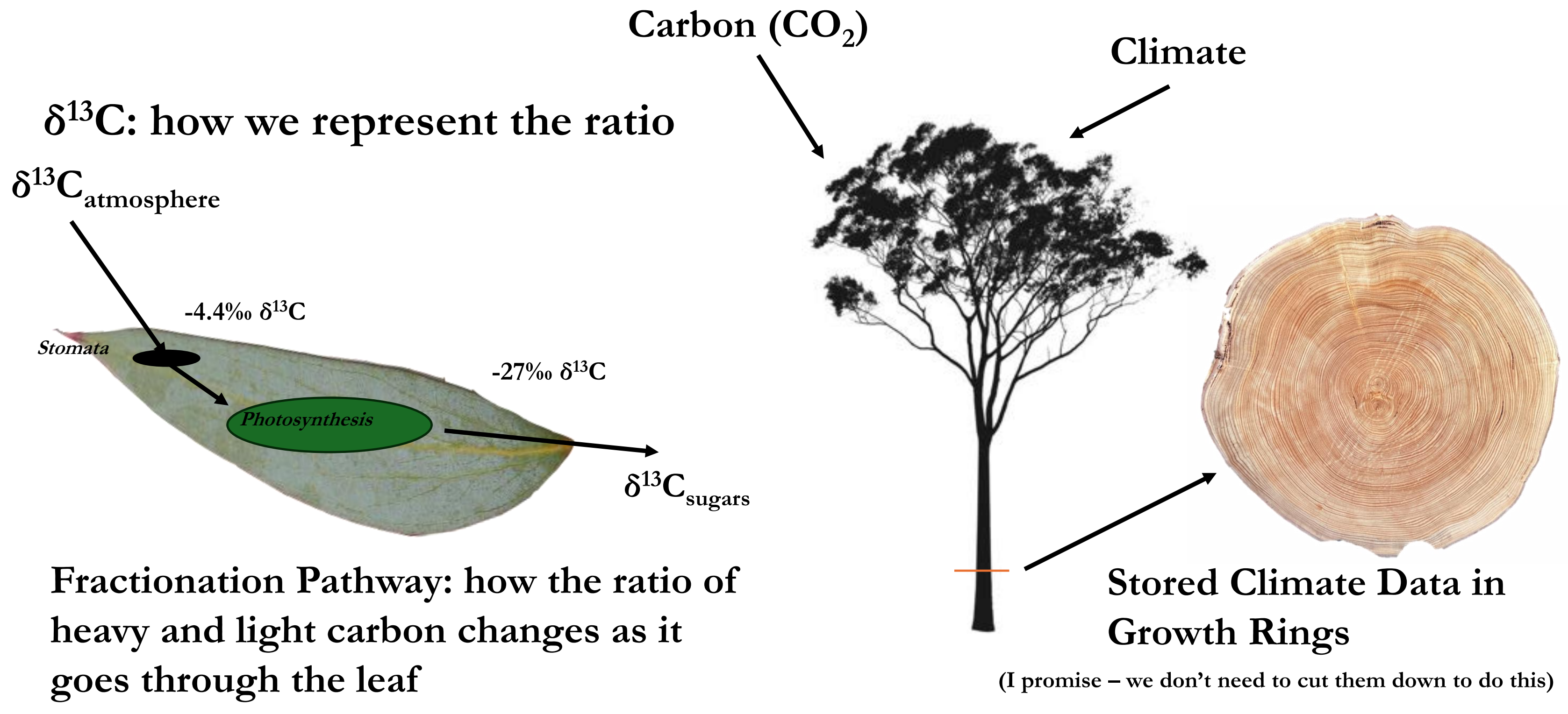
Oliver M. Medd – Ph.D. Candidate – Australian National University
First Supervisor – Prof. Stewart Fallon (RSES, ANU), Second Supervisor – Dr. Matthew Brookhouse (FSES, ANU)

What is Stable Isotope Dendrochronology?

Dendrochronology – the study of tree rings – allows one to look back in time at the growth of the tree, by the widths and characteristics of the rings it has produced.
Stable Isotopes are isotopes of elements which do not decay (lose their extra neutrons). Heavily utilised stable isotopes are Carbon-13 and Oxygen-18, in a ratio with their common (C-12, O-16) counterparts.

Stable Isotope Dendrochronology utilises the incorporation of stable isotopes (heavy and light) in a ratio into the wood of the tree rings. This ratio is represented in permille (‰) and is determined by plant health and climate. The heavy and light isotope ratio is changed at different parts of the plant, but most change occurs at the leaf.

Stable isotope dendrochronology can be used to reconstruct the climate of the past, once we know the relationship between the isotopes and the experienced conditions of the tree.



Fractionation Pathway: how the ratio of heavy and light carbon changes as it goes through the leaf

Stored Climate Data in Growth Rings

(I promise – we don't need to cut them down to do this)

What can it tell us about Snow Gums and Dieback?

Snow Gums are some of the best Australian trees to perform dendrochronology on. Therefore, they are a great base to attempt stable isotope analysis. If successful, we should be able to relate the stable isotope signature held within the rings of Snow Gums to a climatic force.

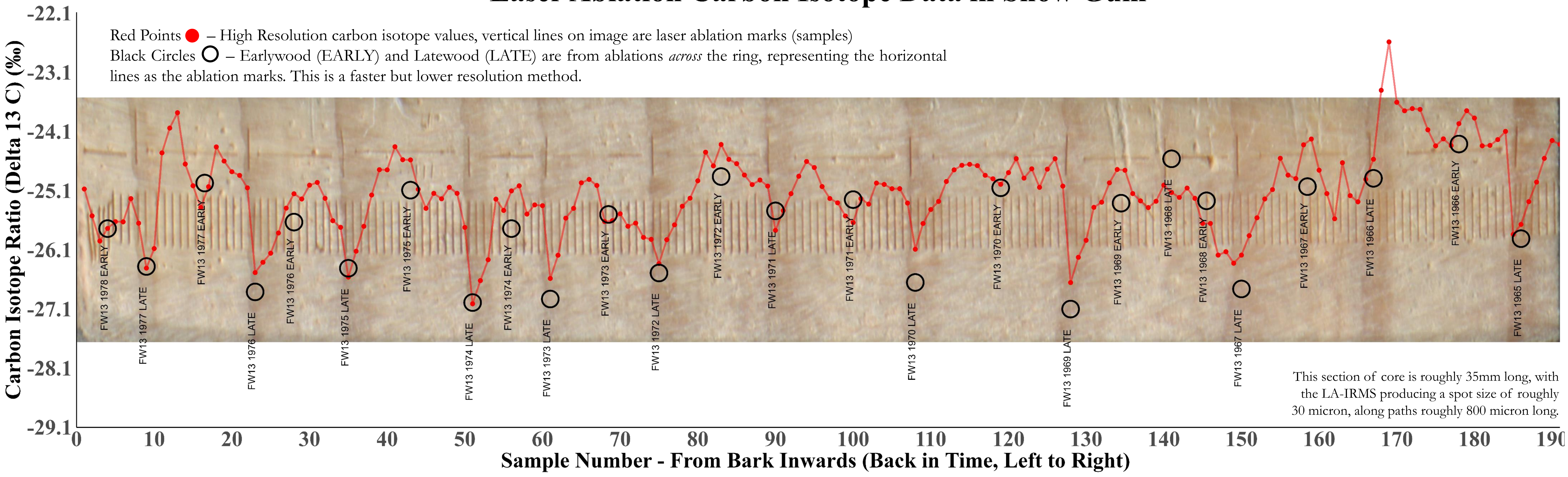
Snow gums are responsive to changing conditions due to the unforgiving weather of the Australian Alps, producing sensitive ring series in the chronology (sensitive = well correlated to the conditions).

Stable isotope ratios could provide significant and accurate information about the conditions faced by specific stands of Snow Gum, so that historical dieback events can be related to potential climatic influences, such as drought.

This technique can potentially inform predictions on the effect that climate change has on the Snow Gum population.

Work So Far – Methods, Analysis and Preliminary Results of Snow Gum Stable Isotopes

Laser Ablation Carbon Isotope Data in Snow Gum



Red Points ● – High Resolution carbon isotope values, vertical lines on image are laser ablation marks (samples)
Black Circles ○ – Earlywood (EARLY) and Latewood (LATE) are from ablations *across* the ring, representing the horizontal lines as the ablation marks. This is a faster but lower resolution method.

This section of core is roughly 35mm long, with the LA-IRMS producing a spot size of roughly 30 micron, along paths roughly 800 micron long.

A short but ultra-high-resolution chronology from John Banks' Funnel Web site has been analysed to assess the variability of $\delta^{13}C$ within and between tree rings.

Once more supporting preliminary results have been produced, gridded climate data will be used to determine which is potentially influencing carbon isotopes in the ring material.

So What?

By continuing to support this research and the development of Stable Isotope Dendrochronology in Australia, more can be understood about the potential for Snow Gum to survive into the future, strongly supporting conservation efforts and management.

I would like to acknowledge and thank the **NSW Environmental Trust** for their support of my Ph.D. research, as well as many other projects here at the ANU.

! Please contact me with any questions at oliver.medd@anu.edu.au !

The role of futures thinking and the “Resist, Accept, Direct” (RAD) framework in assisting managers respond to ecological transformation

Ruby Olsson: PhD scholar – commenced Feb 2024

Supervisors: Carina Wyborn, Paul Wyrwoll, Jamie Pittock, Josh Dorrough, and Laurie Yung

Background

Anthropogenic climate change is driving ecological transformation, defined as the dramatic and potentially irreversible shift in multiple ecological characteristics of an ecosystem. Western society’s current conservation paradigm seeks to maintain or restore ecosystems to “historically defined conditions”, a goal that may no longer be possible in the context of a rapidly changing climate. The Resist-Accept-Direct (RAD) framework emerged from the United States as an assessment tool to assist natural resource managers respond to ecological transformation, however it is yet to be formally adopted in Australia. This research examines RAD’s utility as it moves from theory to practice, using a comparative case study of ecological transformation in the Australian Alps (snow gum decline) and in North America (white bark pine dieback). This research seeks to answer:

1. How are managers responding to ecological transformation?
2. What is the utility of the Resit-Accept-Direct (RAD) framework in assisting with this response?
3. How do peoples’ conception of RAD differ and what are the implications of these different understandings?
4. What enables and constrains managers to undertake a RAD process?
5. How might RAD be useful for engaging with internal and external stakeholders in responding to ecological transformation?

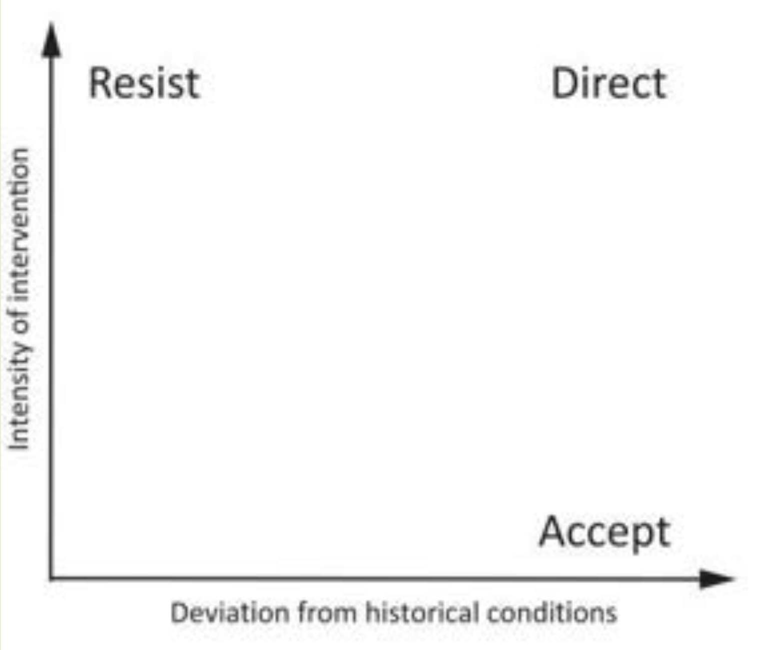


Figure 1: 1) resisting change to maintain current or historically defined conditions (resist); 2) accepting change with no or little intervention to prevent or direct it (accept); and 3) shaping management pathways to achieve desired conditions (direct). Figure adapted from Schuurman et al. 2023

Figure 2: Resist-Accept-Direct options for a sailboat. 1) use intensive resources (motor) to fight the direction of change (resist); 2) allow the boat to move with the wind (accept); 3) use the wind via sail and rudder to steer the boat to a new, desired destination (direct). Schuurman et al. 2022

Resist-Accept-Direct (RAD)

RAD provides a continuum of adaptation actions outlined in figure 1 and visualised in Figure 2. The premise for RAD is that social and ecological systems (SES) may need to transform in the context of climate change and considering plausible futures is critical to make RAD decisions.

There is emerging work on the social, cultural, and institutional contexts in which RAD decisions are made (e.g. Clifford et al. 2022), although to date literature has mostly been conceptual.

This research seeks to explore the values, rules, and knowledge that enable or constrain RAD decisions using empirical qualitative data from two comparative case studies grounded in participants’ experiences using RAD.

Methodology

This qualitative research employs an interpretivist methodology and adaptive theory approach. Primary methods include:

1. Semi-structured interviews with natural resource managers in Australia and North America (Australia mid-2025, North America Feb-Mar 2025)
2. Co-produced RAD workshops with Australian managers and researchers (this workshop! And 2025-2026, pending interest)

Different conceptions of RAD

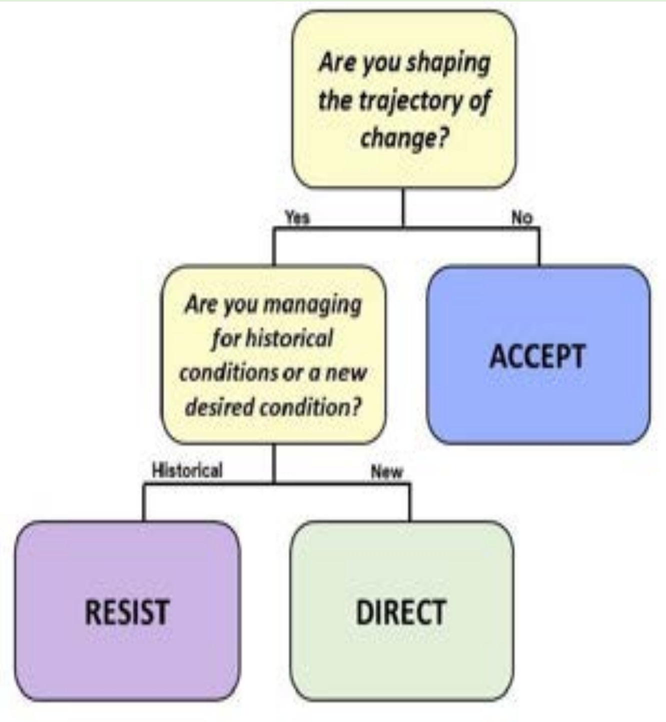


Figure 3: Schuurman et al. 2020. Decision tree depicting the three possible management responses to the trajectory of change

Figure 4: Cal Bryant 2024, adapted from Lynch 2022. Top: feasibility of RAD interventions against forest variability and time/transformation. Bottom: RAD coupled with an adaptive management cycle.

There are often a wide range of understandings as new frameworks move from theory to practice. As we see RAD start to be adopted by managers in Australia and the US, the application is clearly more complex than indicated by Fig. 3. Figure 4. illustrates just one example of how RAD can be incorporated in an adaptive management cycle and one way of using RAD across time. Examining different understanding and their implications as RAD moves from theory to practice will help shape the framework’s implementation to achieve desirable outcomes and avoid maladaptation.

Thought experiments

1. Wildlife corridors:

A series of wildlife corridors are constructed to allow species to move to new habitats that are more suitable in a changing climate. Is this response:

a) Direct: Active intervention in the landscape to achieve a desired outcome where species are located in new, climate-adapted habitats
b) Accept: Enables species to move of their own accord to new habitats as the result of climate change and other drivers

Q 1: What intensity of intervention moves an accept response to a direct response?

2. Establishing an ex-situ colony:

An ex-situ colony is established to ensure the survival of the species despite rapid, climate-change driven habitat loss. Is this response:

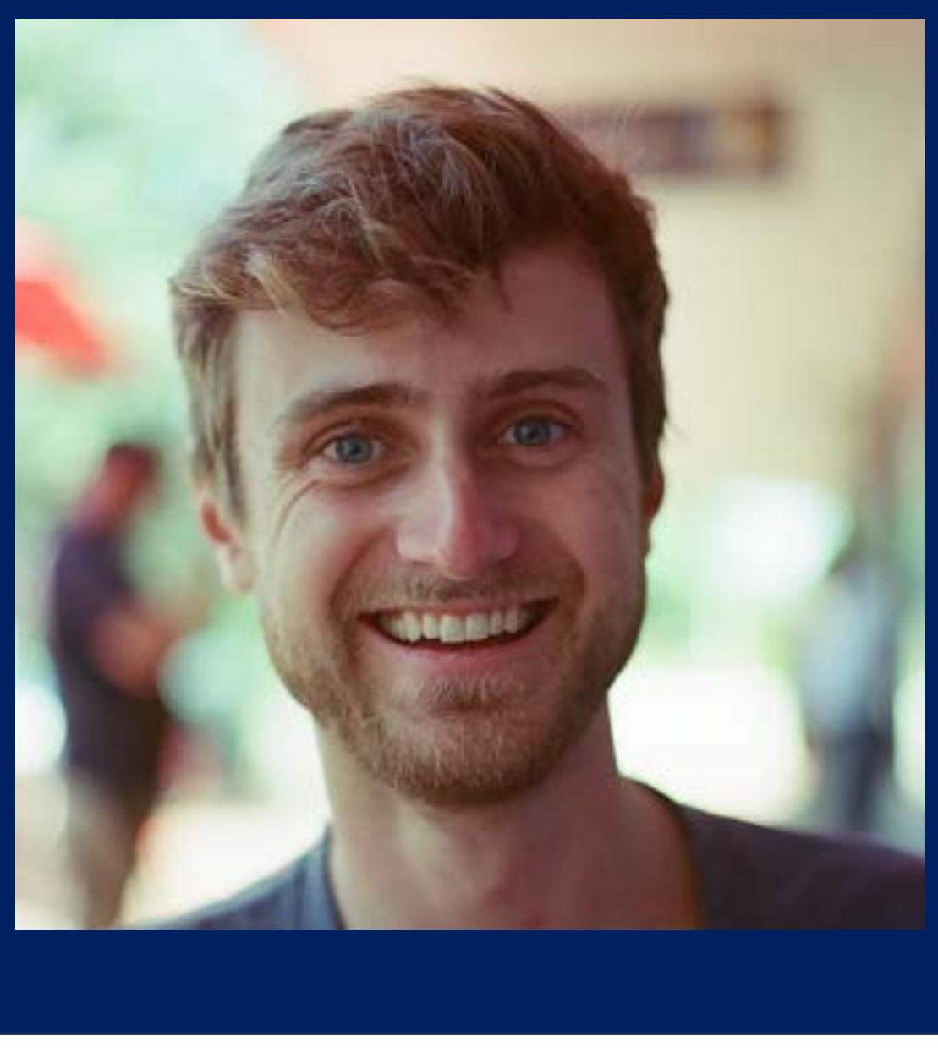
a) Resist: Active intervention to maintain the existence of a species
b) Accept: Allowing the landscape to change rather than actively intervening to maintain the existence of the species in-situ

Q 2.1: Does the scale (e.g., species-level vs landscape level) determine whether an action is resist, accept or direct?

Q 2.2.: If there is no clear “purpose” for the ex-situ colony (e.g., the intention to re-introduce the species in the future to the same habitat [resist] or a new habitat [direct]) then do these kind of “insurance” strategies fall outside the RAD framework at certain scales (in this case the species-level?).

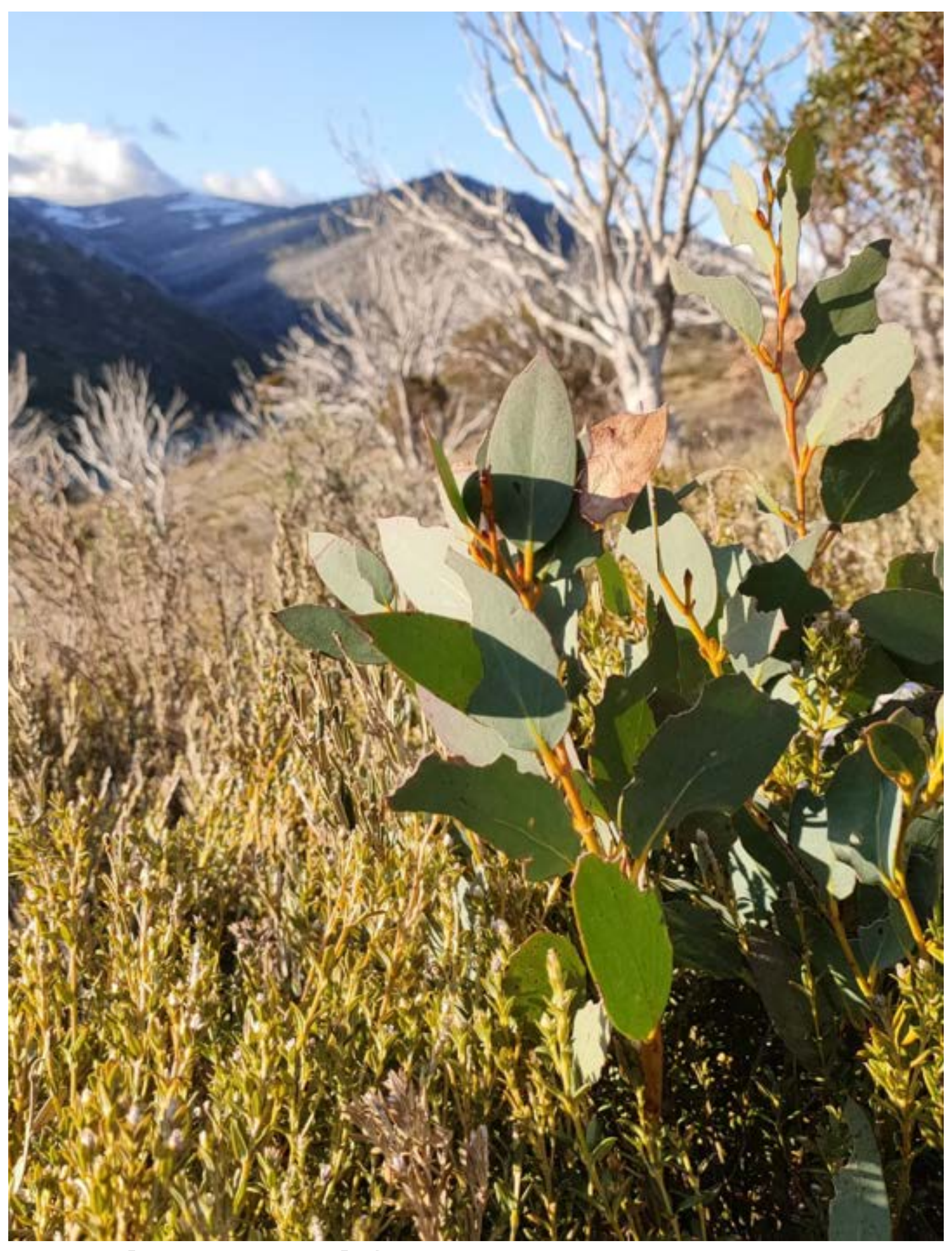
Modelling climate-related snow gum dieback, management and recovery

Aaron Midson (a.midson@westernsydney.edu.au)
Prof. Benjamin Smith, Dr. Zachary Brown, Dr. Paul Miller, Dist. Prof. Belinda Medlyn



1. Problem and approach

- **Climate change and disturbance events threaten the persistence of subalpine snow gums and their conservation values**
- **Could woodlands recover by themselves?**
- **Can management interventions change the trajectory of snow gum woodlands?**
- **This work will run 100-year simulations of snow gum woodlands under future scenarios (climate, management, disturbance scenarios) to produce management tools**



ARC LP210300506: Understanding snow gum dieback for effective and integrated management (Save Our Snow Gums).

2. Research questions and timeline

Work in 2024-2025:

1. Mechanistic vegetation model for subalpine woodlands

1.1 *To what extent do model simulations replicate historically observed data?*
1.2 *Over the past century, how has carbon cycling within subalpine woodlands responded to multiple drivers of change?*

Work planned for 2025:

2. Future risks for subalpine woodland conservation

2.1 *What are the implications of snow gum dieback, climate change, and* $[CO_2]$ *on future wildfire risk and carbon fluxes in subalpine woodlands?*

Work planned for 2026:

3. Management opportunities for landscape restoration

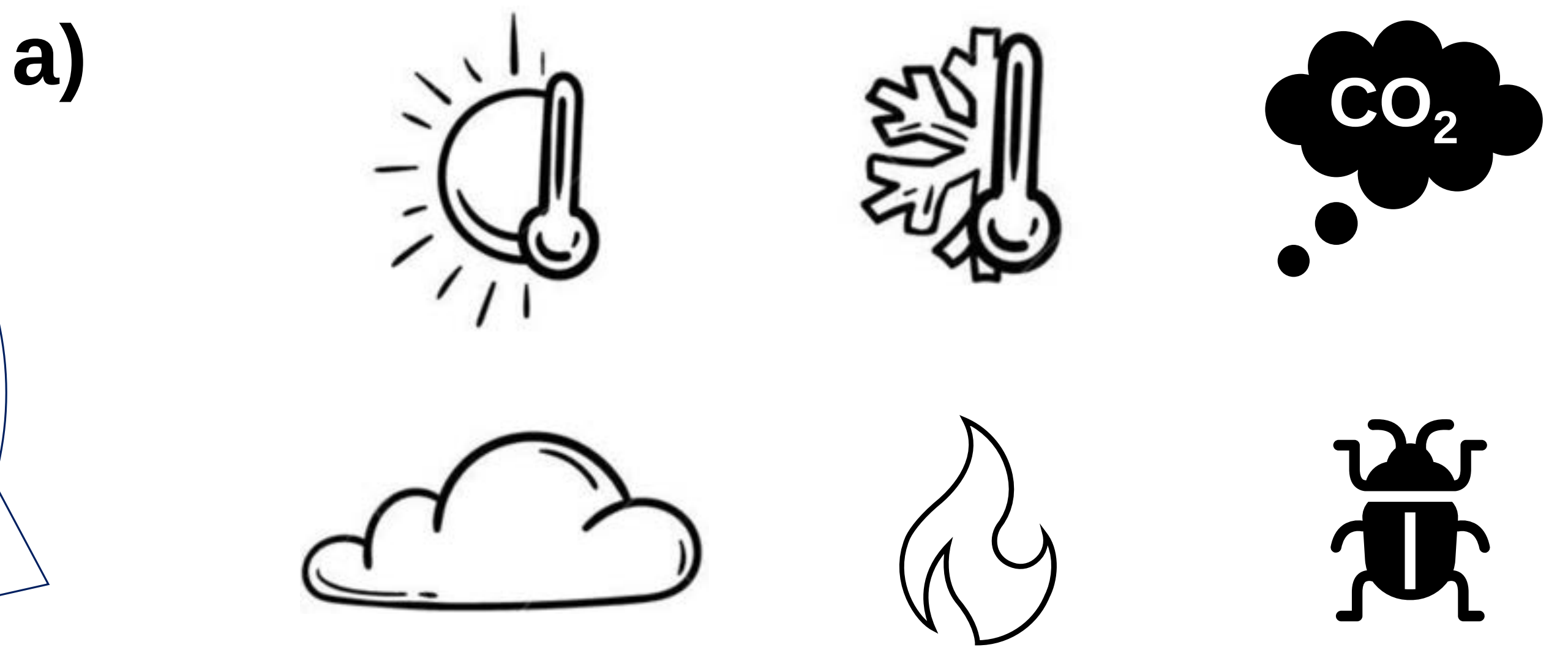
3.1 *To what extent may snow gum woodland structure and function recover following stand-level mortality?*
3.2 *What management strategies are most effective in countering dieback and securing valuable ecosystem services of subalpine woodlands in future climate scenarios?*

Thanks to ANU, UTas, and SOSG colleagues for extensive data collection over years and ongoing that contribute to this modelling effort

I acknowledge the Traditional Owners of the lands on which this research is engaged; the Gunaikurnai, Taungurung, Ngunnawal, Yuin Nation, Walgalu, and Ngarigo peoples, and other nations with a connection to the land

3. Background

Snow gums are resilient, but they're vulnerable to compounding pressures such as drought, fire, and wood-borer attack



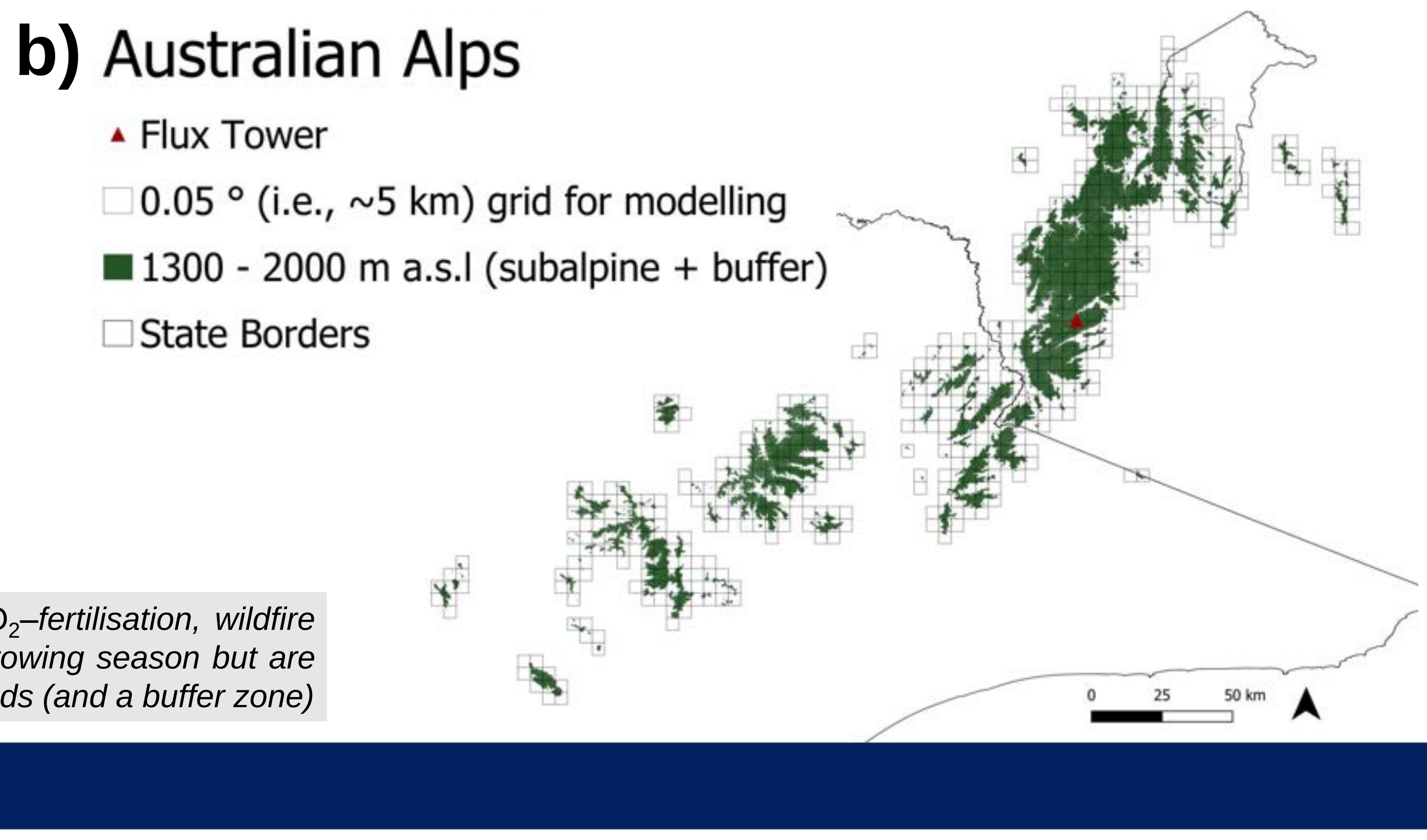
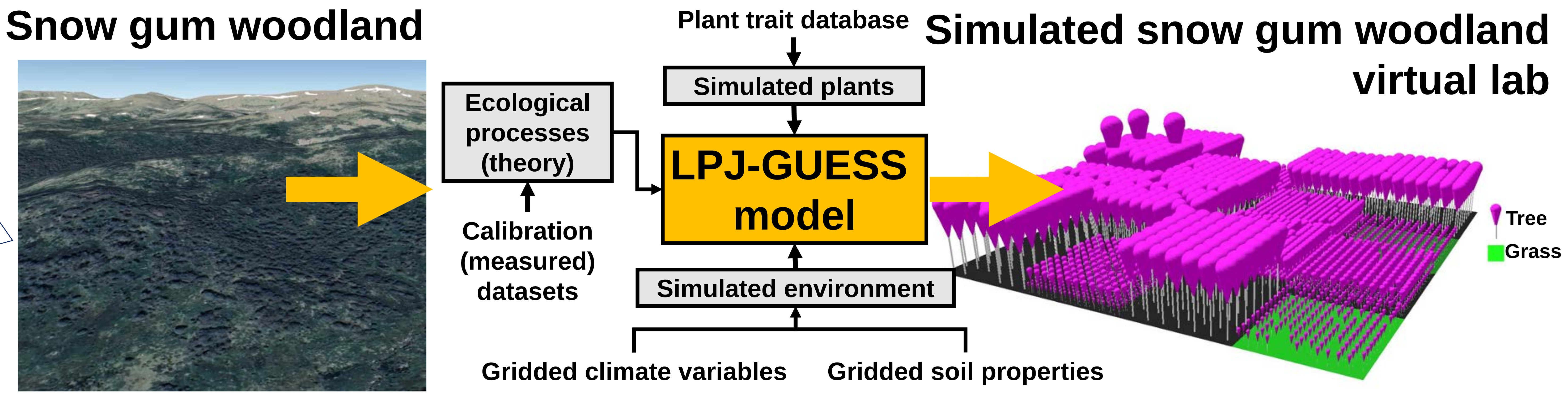


Figure 1. *a) multiple drivers of change are impacting subalpine snow gum woodlands: increasing temperatures,* CO_2*–fertilisation, wildfire frequency, and wood-borers, reduced snow cover, and altered precipitation. Snow gums may benefit from a longer growing season but are vulnerable to compounding disturbance events, b) this work studies these drivers within ~5 km blocks, covering woodlands (and a buffer zone)*

3. Methods

A dynamic vegetation model will simulate snow gum woodlands and wood-borer dieback. The model acts as a virtual lab



Snow gum woodland

Plant trait database

Simulated plants

Ecological processes (theory)

LPJ-GUESS model

Calibration (measured) datasets

Simulated environment

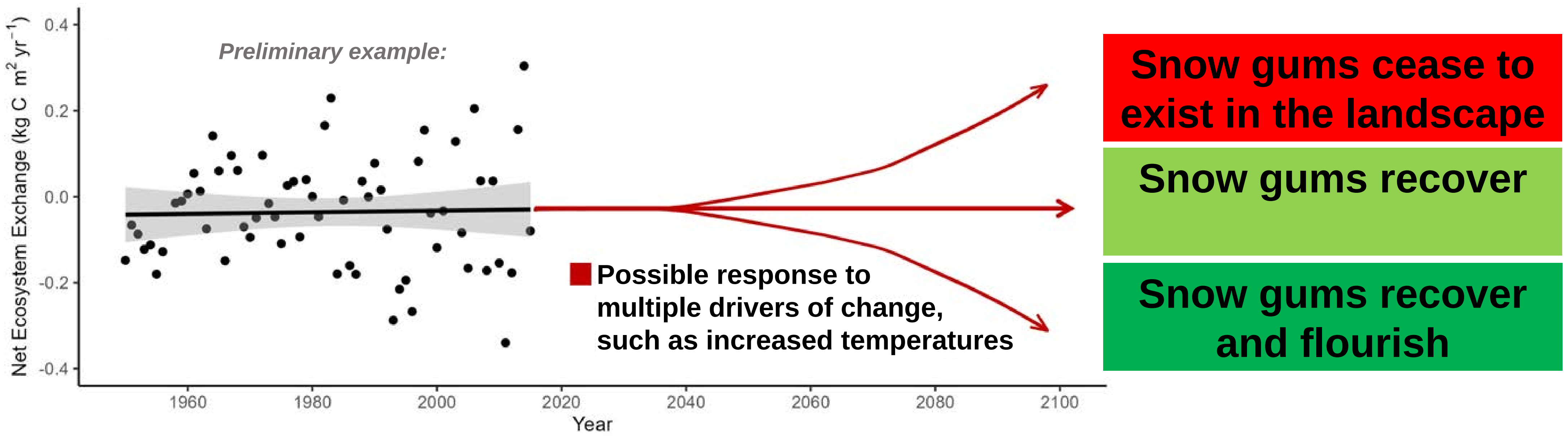
Gridded climate variables

Gridded soil properties

Simulated snow gum woodland virtual lab

4. Expected results

The model will forecast impacts of dieback on persistence of snow gums in the subalpine landscape, and test management interventions



🟥 Possible response to multiple drivers of change, such as increased temperatures

Snow gums cease to exist in the landscape

Snow gums recover

Snow gums recover and flourish

Figure 5. *Carbon is a key currency of ecosystem structure and function. The trajectory of net carbon exchange between the atmosphere and vegetation/soil (Net Ecosystem Exchange; NEE) is uncertain given interactions between multiple drivers of change. Values less than 0 indicate a net uptake by vegetation/soil. Changes in NEE may depend on increased productivity due to longer growing seasons/*CO_2*-fertilisation, effects of temperature, soil moisture, and vegetation on respiration, and changes in community composition following disturbance events*

5. So what?

If stand mortality from dieback prevents resprouting, recovery will rely on recruitment and/or management intervention to maintain ecosystem services. By simulating management options in future climate scenarios, this work will provide evidence to support management planning