INFLUENCE OF HEAT WAVE DURATION AND TIMING ON ALPINE GRASSLAND PLANT COMMUNITIES: AN UPSCALING PERSPECTIVE

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INTRODUCTION

The Alps are warming at nearly twice the global average rate, leading to more frequent and intense heat waves characterized by high temperatures and water stress. These events threaten alpine ecosystems, which are highly vulnerable due to their short growing season and strong climatic constraints. Among them, **alpine grasslands** are key reservoirs of biodiversity and providers of essential ecosystem services, yet their responses to heat waves remain poorly understood. In particular, the effects of **event duration**, **seasonal timing**, and **substrate type** (siliceous vs. calcareous) require further investigation. A comprehensive understanding demands both observational and experimental approaches, integrating multiple plant traits across ecological scales. **Remote sensing** offers a valuable, non-invasive means to monitor vegetation responses in this context.

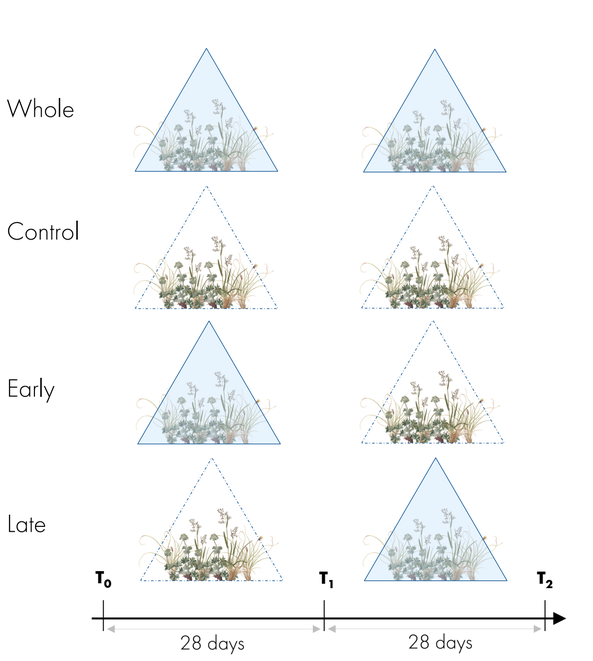
MATERIAL & METHODS

STUDY AREA

Gavia Pass: 2600 m a.s.l., Siliceous grassland

Sappada: 2000 m a.s.l. Calcareous substrate

EXPERIMENTAL DESIGN

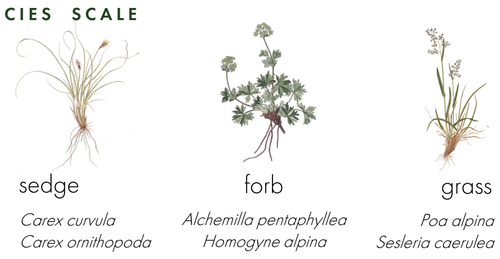


Sheltered plot
Precipitation excluded
Increased air temperature

Not sheltered plot
Natural conditions

DATA COLLECTION

@ SPECIES SCALE



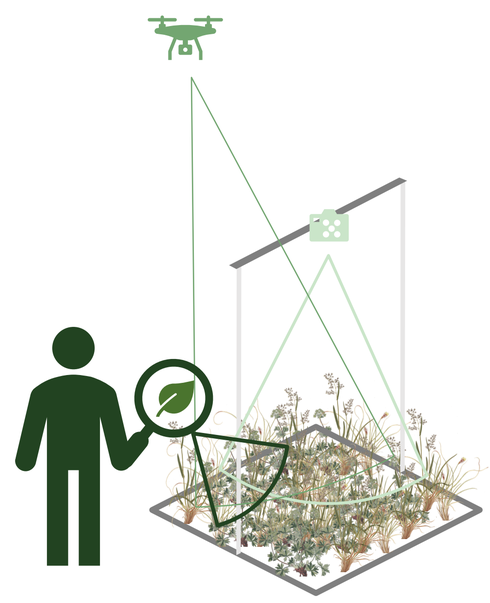
sedge	forb	grass
Carex curvula *Carex ornithopoda*	*Alchemilla pentaphyllea* *Homogyne alpina*	*Poa alpina* *Sesleria caerulea*

- pigment concentration (chlorophyll, carotenoid) @ T_1 & T_2
- flavonoid concentration @ T_1 & T_2
- morphological and anatomical traits @ T_2
  (Specific Leaf Area, Dry Matter Content, stomata density)

@ COMMUNITY SCALE

- multispectral survey (UAV + close range) @T1 & T2
- CO_2 fluxes @ T_1 & T_2
- biomass collection (necromass, biomass) @ T_2
- intercept point vegetation survey @ T_2

UPSCALING FRAMEWORK



STATISTICAL ANALYSIS

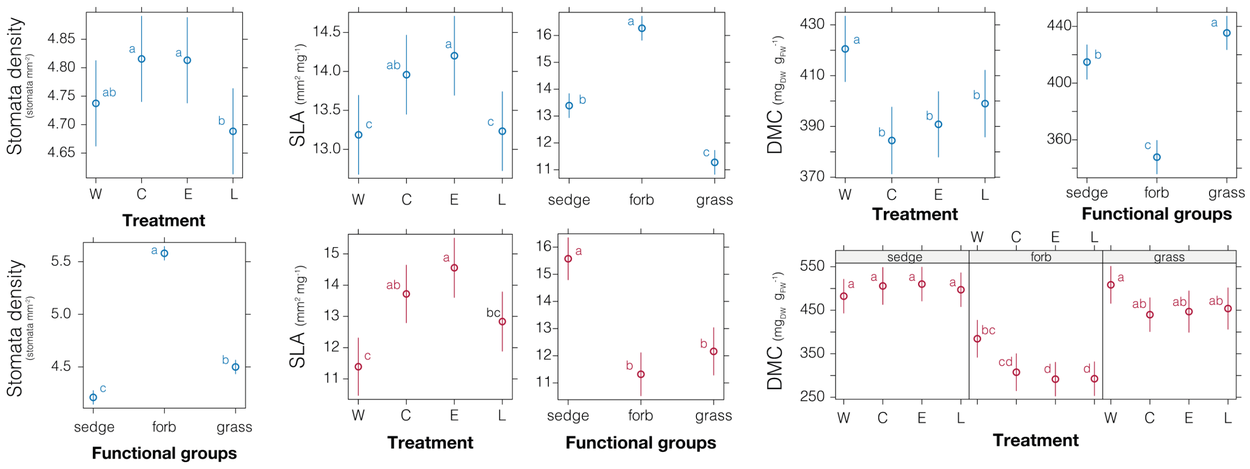
Two datasets **Siliceous grassland** & **Calcareous grassland**

Linear mixed models

morphological traits ~ Treatment * Functional groups
Community biomass ~ Treatment
Multispectral indices ~ Treatment*Time

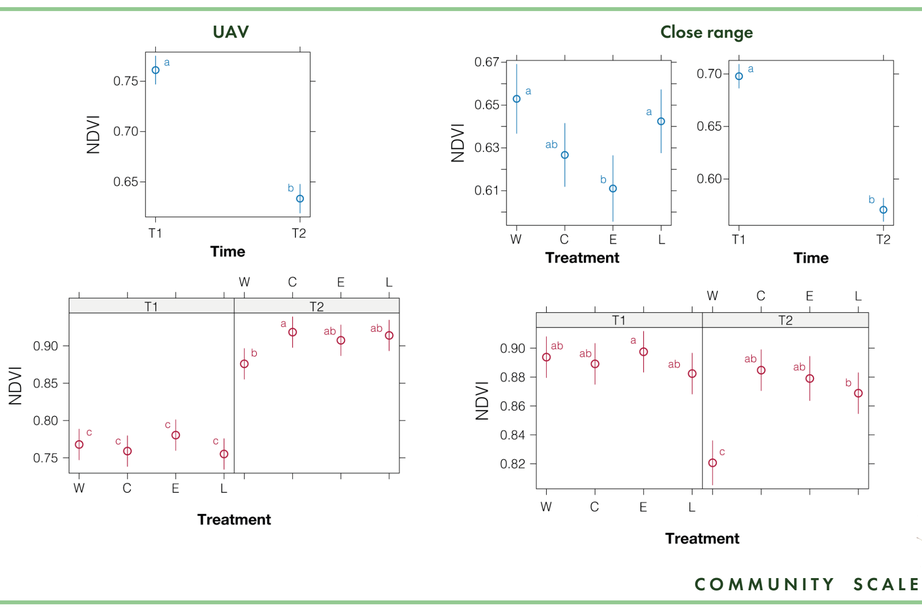
RESULTS

Dependent Variable	Site	Factor	P-value	
SLA	**Siliceous**	Treatment	< 0.001	***
		Species	< 0.001	***
	Calcareous	Treatment	0.004	***
		Species	< 0.001	***
DMC	**Siliceous**	Treatment	< 0.001	***
		Species	< 0.001	***
	Calcareous	Treatment	0.756	
		Species	< 0.001	***
		Treat. * Sp.	0.041	*
Stomata density	**Siliceous**	Treatment	0.043	*
		Species	< 0.001	***
	Calcareous	Treatment	0.527	
		Species	< 0.001	***



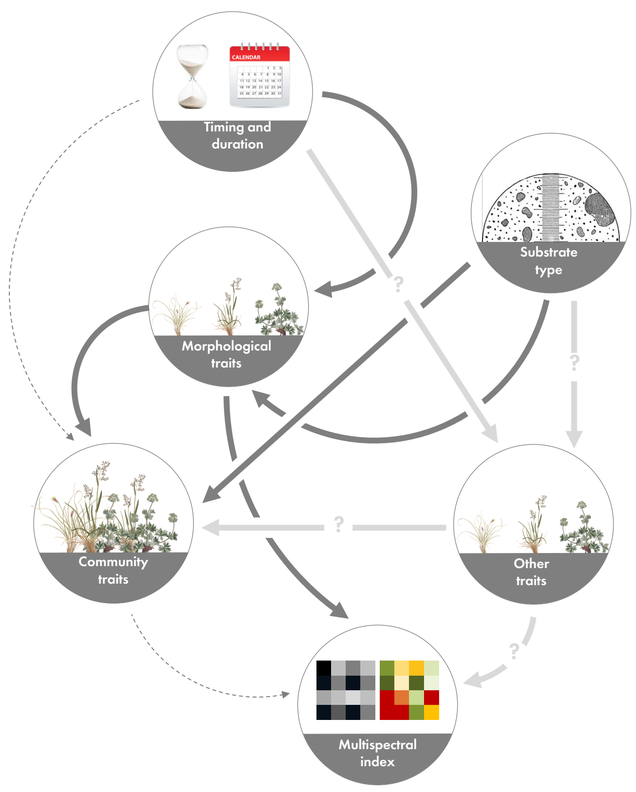
SPECIES SCALE

Dependent Variable	Site	Factor	P-value	
Necromass	**Siliceous**	Treatment	0.637	
	Calcareous	Treatment	< 0.048	*
Biomass	**Siliceous**	Treatment	0.225	
	Calcareous	Treatment	0.332	
NDVI UAV	**Siliceous**	Time	< 0.001	***
		Treatment	0.318	
	Calcareous	Time	0.221	
		Treatment	< 0.001	***
		Time*Treat.	0.011	*
NDVI close range	**Siliceous**	Time	< 0.001	***
		Treatment	< 0.001	***
	Calcareous	Time	0.235	
		Treatment	< 0.001	***
		Time*Treat.	< 0.001	***



COMMUNITY SCALE

CONCLUSION



Alpine grasslands show **complex, scale-dependent responses** to heat waves. At the species level, morphological traits reveal clear stress signals, while community-level dynamics are less predictable. Overall, the most severe impacts occurred during prolonged (W) or late-season (L) heat waves. Multispectral data mainly reflected **structural rather than biomass** changes, highlighting its usefulness for monitoring plant responses. Differences between sites suggest that additional, yet unexplored factors also shape ecosystem resilience.

2nd International Symposium on Biodiversity and Ecosystem Functions under Global Change
12 – 14 November 2025
Alghero (Sardinia – Italy)