Regional Risk Outline

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1 Introduction

1. Temperate tree and shrub species are at risk of damage from late spring freezing events, also known as false springs.

2. However, the extent of damage and the frequency and intensity of false spring events is still largely unknown.

3. Individuals that initiate budburst before the last spring freeze are at risk of leaf tissue loss, damage to the xylem, and slowed canopy development (Gu *et al.*, 2008; Hufkens *et al.*, 2012).

4. Temperate plants are exposed to freezing temperatures numerous times throughout the year, however, individuals are most at risk to damage from stochastic spring frosts, when frost tolerance is lowest (Sakai & Larcher, 1987).

5. False spring events can result in photosynthetic tissue loss, which could potentially impact multiple years of growth and, with the growing season extending, individuals could be exposed to more frosts in the future (Liu *et al.*, 2018).

6. For these reasons, episodic frosts are one of the largest limiting factors in species range limits (Kollas *et al.*, 2014).

1. Plant phenology – which is defined as the timing of recurring life-history events such as budburst – strongly tracks shifts in climate (Wolkovich *et al.*, 2012).

2. Trees and shrubs in temperate regions optimize growth by using three cues to initiate budburst: low winter temperatures, warm spring temperatures, and increasing spring daylengths.

3. With climate change advancing, this interaction of cues may shift spring phenologies both across and within species.

4. Due to the changing climate, spring onset is advancing and many temperate tree and shrub species are initiating leafout 4-6 days earlier per °C of warming (Wolkovich *et al.*, 2012; Polgar *et al.*, 2014).

5. The North Atlantic Ossilation (NAO) index is often used to describe winter and spring circulation across Europe.

6. More positive NAO phases tend to result in higher than average winter and early spring temperatures, and with climate change, great NAO indices has correlated to earlier budburst dates (Chmielewski & Rötzer, 2001).

7. However, last spring freeze dates are not predicted to advance at the same rate as spring onset in some regions of the world (Inouye, 2008; Martin *et al.*, 2010; Labe *et al.*, 2016; Sgubin *et al.*, 2018), potentially amplifying the effects of false spring events in these regions.

8. Temperate plants have evolved to minimize false spring damage through a myriad of strategies, with the most effective being avoidance: plants must exhibit flexible spring phenologies in order to maximize growth and minimize frost risk by timing budburst effectively (Polgar & Primack, 2011; Basler & Korner, 2014).

9. Thus, there is a trade-off between growing season length and frost risk.

10. Individuals that initiate budburst earlier in the season are more frost resistant (Körner *et al.*, 2016), however, as climate change advances, less frost resistant individuals may start initiating budburst before the last freeze date.

11. Individuals from more Northern provenances tend to be more susceptible to spring frost damage, whereas more Southern individuals are more sensitive to fall frosts (Montwé *et al.*, 2018).

12. The growing season is lengthening across many regions in the northern hemisphere (Chen *et al.*, 2005; Liu *et al.*, 2006; Kukal & Irmak, 2018), but false spring events still pose a threat in many of these regions (Wypych *et al.*, 2016)

13. Plants growing in forest systems tend to exhibit staggered days of budburst.

14. Lower canopy species typically initiate budburst earlier in the season in order to utilize available resources such as light, whereas larger canopy species usually initiate budburst later in the season.

15. Frost tolerance greatly diminishes once individuals exit the dormancy phase (i.e. processes leading to budburst) through full leaf expansion (Vitasse *et al.*, 2014).

1. False spring incidence has declined in many regions (i.e. across parts of North America and Asia), however the prevalence of spring frosts has increasing across Europe since 1982 (Liu *et al.*, 2018).
2. Major false spring events that impacted entire forests have been recorded in recent years (Gu *et al.*, 2008; Augspurger, 2009, 2013; Menzel *et al.*, 2015).
3. After such false spring events, it can take 16-38 days for trees to refoliate, which can detrimentally affect processes such as photosynthesis and respiration, carbon updake, and nutrient cycling (Hufkens *et al.*, 2012; Richardson *et al.*, 2013; Klosterman *et al.*, 2018).
4. There is large debate over whether or not spring freeze damage will increase (Hänninen, 1991; Augspurger, 2013; Labe *et al.*, 2016), remain the same (Scheifinger *et al.*, 2003) or even decrease (Kramer, 1994) with climate change.
5. (PUT QUESTIONS AROUND HERE)
6. Many studies have assessed the interplay between cue interactions and budburst dates by investigating potenital latitudinal effects (Partanen, 2004; Vihera-aarnio *et al.*, 2006; Caffarra & Donnelly, 2011; Zohner *et al.*, 2016; Gauzere *et al.*, 2017).
7. However, recent studies have demonstrated regional effects may be more closely related to false spring risk through shifts in elevation (Vitra *et al.*, 2017) and from distance to the coast (Wypych *et al.*, 2016).
8. By better understanding these regional climatic implications, we may be better able to determine which regions may be at risk currently and which regions may become more at risk over time.
9. (METHODS) I assessed the daily gridded climate data across Europe (E-OBS) from 1950-2016.
10. (METHODS) By simply using climate data, I compared the frequency of spring freeze events throughout Europe before and after anthropogenic climate change began (i.e. around 1980 (Barnett *et al.*, 2001)).
11. (METHODS) A spring freeze was considered if the the daily minimum temperature fell below -2°C (Schwartz, 1993) between March 1 and June 30.
12. (RESULTS) A few regions experienced increased exposure to spring freeze events, whereas most other regions experienced fewer or similar numbers of years with spring freezes (Figure 1).
13. (DISCUSSION) Understanding regional differences in spring freeze intensity and frequency is essential for predicting future habitat risk.

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Tables and Figures

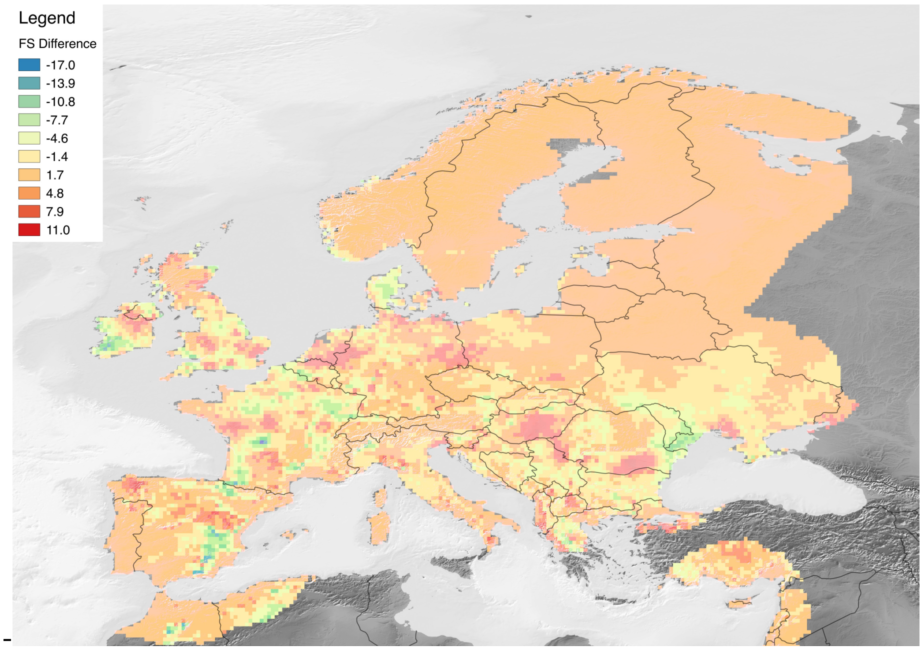

Figure 1: Number of years with freezing events that occured before anthropogenic climate change began (1951-1983) as compared to after anthropogenic climate change began (1984-2016). If temperatures fell below -2°C between March 1 and June 30, a year with a spring freeze was tallied. Some regions experienced more years with spring freezes after climate change began, whereas other years experienced the same number or even fewer years with spring freezes. Regions that had more years with spring freezes after climate change began are blue and regions that had fewer freezes are red.