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Commentary

Need for False Spring Research in the Northern Great Plains, USA

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Core Ideas

- Late spring frosts (false springs) may increase in northern latitudes of the USA.
- Researchers need to determine how false springs will affect plants and wildlife.
- Special attention is required in vulnerable areas such as the northern Great Plains.

Abstract: Global climate change is typically characterized by warming average temperatures and more frequent extreme weather events. An understudied component of climate change is the occurrence of false springs, where warm temperatures in early spring prematurely release plants from dormancy, only to be harmed by a late spring frost event. Only limited research has investigated the nature, extent, and impacts of false springs, despite their potential for extreme environmental and economic consequences. More resources should be devoted to false spring research because they are predicted to increase in several regions, especially the northern Great Plains. We review the existing literature on false springs and identify knowledge gaps in both cropland and natural systems. Further, we propose avenues of research, focusing on ecosystems of the northern Great Plains. This research will be crucial in creating strategies that allow land managers to adapt to changing conditions caused by more frequent false springs.

Global climate change associated with increasing greenhouse gas levels is broadly characterized by warming average temperatures and more extreme weather events, with specific effects differing by region (IPCC, 2013). For example, in northern regions of the United States, increasing temperatures and more precipitation may have positive effects on vegetation production and carbon sequestration via an extended growing season (Peterson and Abatzoglou, 2014), while the southwestern United States may be exposed to more severe droughts (Martinuzzi et al., 2016). In addition to varying by region, the intensity of climate change effects is also temporally discrete, such as extreme hail events during the growing season (Brimelow et al., 2017) or volatile early-season temperature shifts that create a false spring (Gu et al., 2008). Research is limited on such events, despite their potential for extreme environmental and economic consequences.

False springs are a weather event whereby warmer than average temperatures in late winter or early spring cause plants to break their winter dormancy prematurely (Fig. 1; Ault et al., 2013). Plants released from dormancy too early may reach a phenological stage at which they are unable to withstand a frost event (Gu et al., 2008). False springs represent a paradox (Ball et al., 2012) because warming temperatures would be expected to decrease frost damage. Indeed, research is divided over whether these events are likely to increase (Augspurger, 2013) or decrease (Peterson and Abatzoglou, 2014) overall across the United States. However, predictions for regional trends are more consistent, with the intermountain West, the Great Plains, and the upper Midwest identified as vulnerable regions that will have more frequent false springs (Allstadt et al., 2015; Peterson and Abatzoglou 2014).

Damage to plants from false springs can result in significant monetary losses (Kistner et al., 2018). The 2007 false spring in the southeastern United States

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Abbreviations: NGP, northern Great Plains.

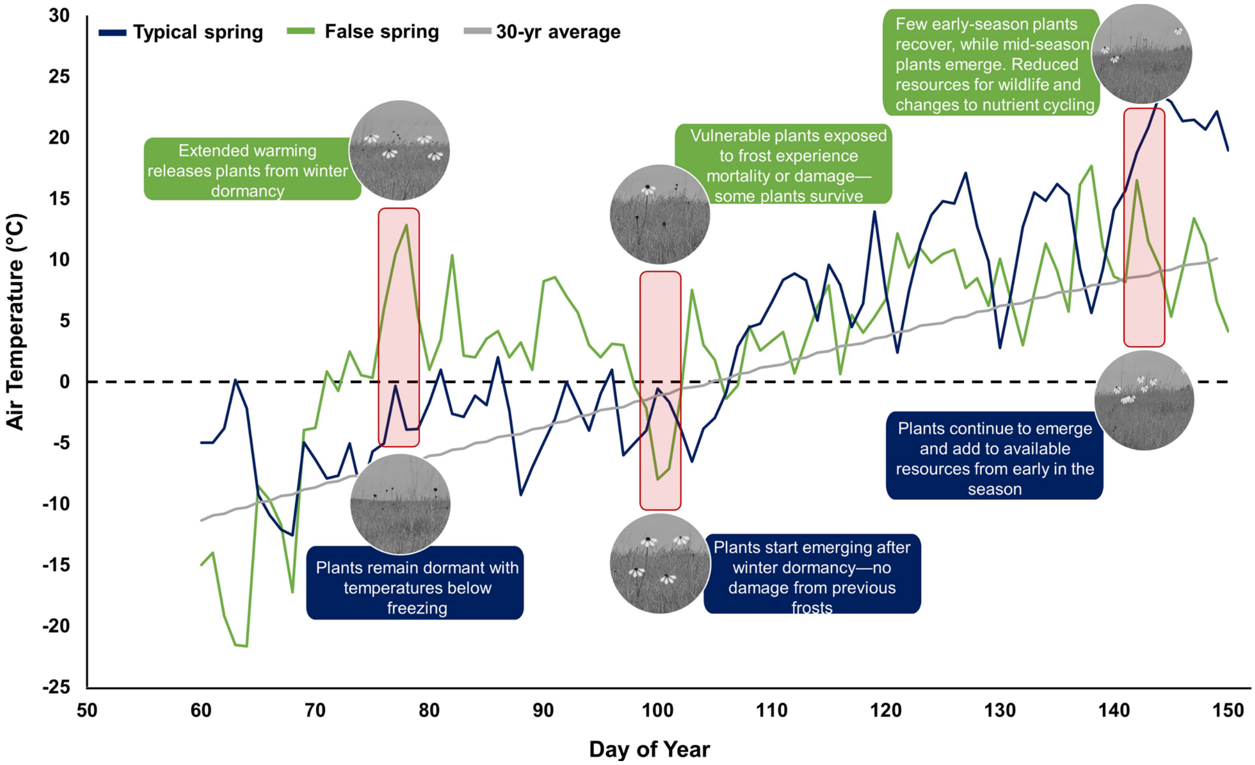

Fig. 1. Depiction of a false spring (green line) compared with a typical spring (blue line) in terms of air temperature and day of the year. The 30-yr average temperature (gray line) is included for a reference point, along with potential direct and indirect responses to each type of spring. Data from NDAWN (https://ndawn.ndsu.nodak.edu/) were manipulated by the authors to create conceptual figure.

caused an estimated $2 billion of yield reductions for crops such as winter wheat (*Triticum aestivum* L.), corn (*Zea mays* L.), and forage legumes due to frost burn and plant mortality (Lawrimore et al., 2008). The 2012 false spring in the upper Midwest resulted in over $200 million of damage to fruit trees in Michigan alone (Knudson, 2012). These events primarily damaged blossoms and developing fruit trees or specialty crops that could not be replanted. Despite the economic and environmental impacts of false springs, research documenting the occurrence, immediate effects, and long-term consequences of false springs is relatively sparse. Moreover, much of it may not be applicable to additional vulnerable regions. Like other affects of global climate change, false springs are spatially dependent, so future research needs are region specific.

We focus here on the northern Great Plains (NGP), a region vulnerable to increased false springs, because it offers an intersection between row crop and perennial grasslands. Within the context of the NGP, our objectives are (i) to briefly review existing literature, (ii) to direct future research into possible direct and indirect effects on grassland and cropland vegetation, wildlife, and soils, and (iii) to propose areas for future research that guide management strategies to help mitigate harmful effects of false springs.

Existing Literature

Research investigating false springs may be classified into three categories: (i) identifying its previous extent and predicting future occurrences, (ii) investigating direct effects to vegetation, and (iii) describing indirect effects on ecosystems.

Broadly, false springs are expected to increase in northern, inland regions (i.e., continental climates; Allstadt et al., 2015; Martinuzzi et al., 2016), while they are expected to decrease in southern and coastal regions (Peterson and Abatzoglou, 2014). In northern latitudes of the NGP, these trends typically reflect an earlier onset of spring rather than a later date for last frost (Cutforth et al., 1999). Despite these general trends, predicting location and timing of false springs is especially difficult, as climatic and vegetative variability can cause findings to change based on the scale of research area (Allstadt et al., 2015; Marino et al., 2011).

Most research documenting the direct effects of false springs has focused on agricultural crops (Kistner et al., 2018; Lawrimore et al., 2008; Molitor et al., 2014) because of their economic importance. However, perennial vegetation in grasslands is also susceptible to frost damage (Inouye, 2008). For both crop and grassland vegetation, plants may experience above- and belowground damage (Inouye, 2008), with severity dictated by the level of phenological development (Augspurger, 2013). Severely damaged crops may be completely lost, while less severely affected crops have reduced yields (Lawrimore et al., 2008). Grassland plants that survive the frost event are expected to experience reduced seedling recruitment (Inouye 2008), reduced growth rates, and changes in morphological development (Pardee et al., 2018; Rodrigo, 2000), including reduced flower (Pardee et al., 2018) or nectar production (Akšić et al., 2015). Further, damaged plants that do survive the frost will be less likely to successfully handle additional stressors, such as additional frosts, biomass removal, or drought (Allstadt et al., 2015; Guiden et al., 2018).

The research community has started to unravel the cascading effects of false springs on wildlife, including pollinators (Boggs and Inouye, 2012; Pardee et al., 2018), birds (Senner et al., 2015), squirrels (Nixon and McClain, 1969), and bears (Honda, 2013). Resource availability for plant-dependent wildlife can be altered by changes in plant community composition (Allstadt et al., 2015) due to a competitive advantage of plants that are frost sensitive and avoid emerging early (Hufkens et al., 2012). Delayed development of plants creates phenological mismatches between plants and animals where specific plants are not available during the time of year when animals are active (Allstadt et al., 2015). Additionally, pollinators may have reduced fecundity when false springs reduce the quantity of floral resources for nectar and pollen (Fig. 1; Boggs and Inouye, 2012; Ogilvie et al., 2017).

Knowledge Gaps—Direct and Indirect Effects

We propose building off previous research to guide investigations into direct and indirect effects of false springs in the NGP. Researchers have investigated the effects on other regionally important plants, such as deciduous trees in Illinois (Augspurger, 2013), viticulture in European winegrowing regions (Molitor et al., 2014), and montane meadows in Colorado (Inouye, 2008). These studies highlight some areas for research, such as frost mortality rates or reduced reproductive potential. However, research must be extended to important vegetation in the NGP because different plant species tend to respond differently to frost damage (Guiden et al., 2018; Pardee et al., 2018).

One focus may be quantifying individual plant species responses of common NGP species (both cropland and grassland) to false springs. Specific possible lines of investigation for regionally important plants may include the following: how repeated frosts affect plant resistance and resiliency (Príncipe et al., 2017), how plants express frost damage (e.g., internally or externally; Rodrigo, 2000), how landscape position affects frost damage (Augspurger, 2013), and whether additional differences exist between native and exotic plant responses to frost (Wilsey et al., 2011).

Notably, a major knowledge gap is understanding the direct effects of false springs on different species of plant-dependent arthropods and soil fauna, including both pests and beneficial insects. While many species in the NGP will be adapted to freeze–thaw cycles, newly adapted species to the region may be more affected. For example, corn–soybean [*Glycine max* (L.) Merr.] rotations are becoming more common in the NGP (Auch et al., 2018), so the effects of false springs should be investigated on their associated species, especially corn rootworms (*Diabrotica* spp.) and soybean aphid (*Aphis glycines* Matsumra). Some exotic earthworms can benefit agriculture but may experience mortality when emerging during a false spring (Görres et al., 2018). Therefore, we should evaluate what soil conditions promote or decrease soil buffering capacities to protect soil fauna. Similarly, direct effects on pollinators must be explored since larvae may be vulnerable to frost (Boggs and Inouye, 2012) and the region provides important forage and habitat for native pollinators (Kral et al., 2018).

Changes in vegetation survival and resource production will have cascading effects on the entire ecosystem (e.g., pollinator response, soil nutrient cycling, ecosystem resilience), the extent of which has not yet been addressed in the NGP. For example, in cropland systems, crop loss may leave bare ground that can exacerbate the increases of greenhouse gas emissions associated with freeze–thaw cycles (Gao et al., 2018), as well as redistribute nutrients into surface and groundwater because of reduced plant uptake and increased erosion (Cheng et al., 2018). Quantifying these nutrient losses, as well as possible impacts on the C budget (Matzner and Borken, 2008), are valuable lines of inquiry in the NGP. In addition to these abiotic ecosystem components, the indirect effects on plant-dependent wildlife have not been examined. For example, investigations into pollinators interacting with false spring-damaged vegetation may be especially impactful because of their economic and environmental importance. Similarly, damage caused by false springs may reduce resource availability for other wildlife, including waterfowl that depend on the Prairie Pothole Region within the NGP (Niemuth et al., 2006).

Guiding Future Management Strategies

Upon identifying the direct and indirect effects of false springs, researchers and land managers can focus on providing management strategies. However, management strategies with a sole focus on dealing with false springs may not be feasible to test or impose, so it may be fruitful to link strategies that may increase frost tolerance with additional benefits. For example, many farmers in the NGP manipulate the soil microclimate with different tillage practices, cover crops, or residue management, with the goal of increasing water use efficiency, retaining soil organic matter, and reducing erosion (Hatfield et al., 2001; Wegner et al., 2015). These practices also moderate soil temperature extremes (Hatfield et al., 2001), such that they may offer some protection against volatile temperature shifts associated with false spring events. Additionally, land under no-till is typically planted later in the spring, which may indirectly reduce risk of exposure to false springs. However, farmers in the NGP may often try to plant early (i) to utilize spring moisture (Cutforth et al., 1999) and (ii) because they are planting more crops that require a longer growing season (i.e., corn). Coupling existing research into these management techniques with investigations regarding frost tolerance would be a feasible and easily implemented approach in cropland systems. Further, researchers may explore developing crop varieties able to withstand harsher frosts, although frost hardiness likely comes at the expense of drought tolerance (Vitasse and Rebetez, 2018), which is of critical importance in the NGP.

Grasslands, even those managed for intensive grazing, are manipulated much less than croplands, and fewer strategies may be temporally available to cope with false springs. The best preventative strategies in grasslands may be to encourage biodiversity. Highly diverse plant communities may contain species with a range of frost tolerances (e.g., Inouye, 2008), such that not all species would be damaged. Similarly, grasslands with high diversity likely contain species with a range of phenological development schedules, enabling the availability of at least some resources following a false spring. Furthermore, managers need to consider how false springs may affect planned strategies, such as grazing or prescribed fire, because these additional disturbances may compound the effects of the false spring event (Allstadt et al., 2015; Guiden et al., 2018). However, management could theoretically be used prior to a false spring to reset phenology (e.g., prescribed fire; Baum and Sharber, 2012). Plants could then avoid frost damage during more vulnerable life stages. Grassland research in the NGP should focus on how different plant communities respond to false springs and how management strategies can be used to offset direct and indirect effects of false springs.

Conclusions

False springs are an understudied aspect of global climate change that can have major economic and environmental consequences in both croplands and natural systems. Under the changing climate, false springs are increasing in northern, continental climates, such as the NGP. Vegetation in the NGP may be especially susceptible to the effects of false springs as plants with historically limited growing seasons will try to take advantage of warming temperatures. The existing scientific literature does not adequately explain the effects of false springs in the NGP, nor does it offer guidance for management strategies to cope with the changing conditions. We propose that region-specific research be undertaken in vulnerable regions (e.g., the NGP) to explore direct and indirect effects of false springs on vegetation, insects and wildlife, and abiotic processes. This research then needs to be applied to identify useful management strategies that allow producers and managers to adapt to changing conditions.

Conflict of Interest

The authors have no conflict of interest.

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