# Rethinking False Spring Risk

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## Tables and Figures

# 1 Determining Spring Onset

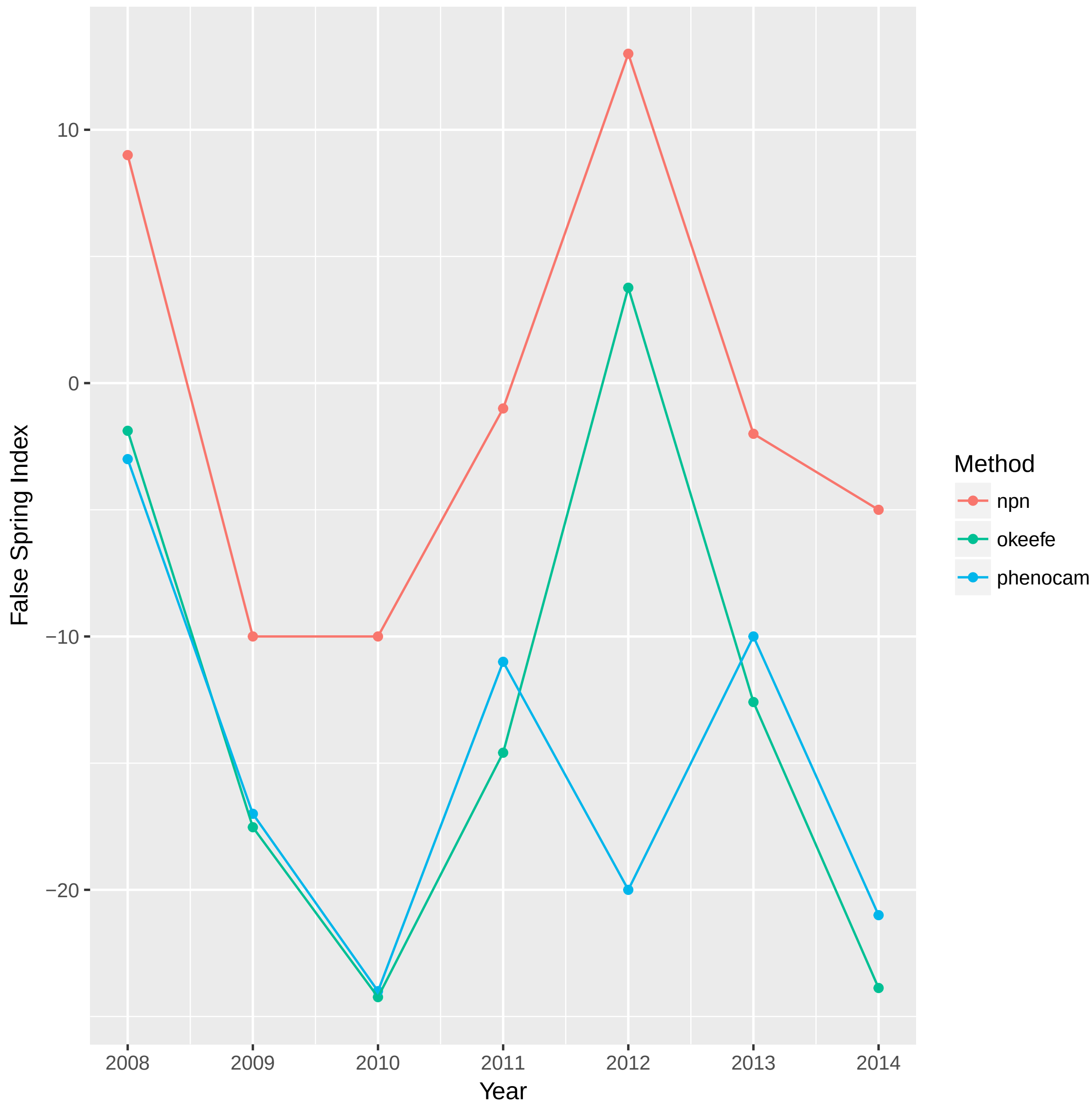
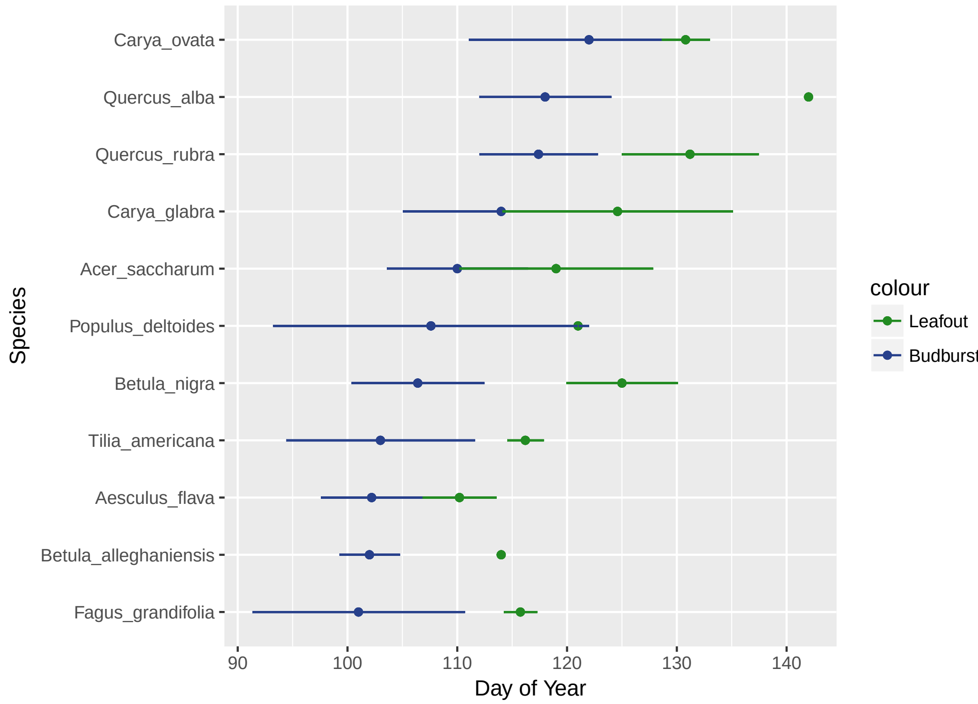



Figure 1: A scatterplot indicating FSI values from 2008 to 2014 for each methdology used in this study. PhenoCam FSI values are red, Observed FSI values are blue, and USA-NPN FSI values are green.

# Species Differences and Vegetative Risk

## Treespotters Data

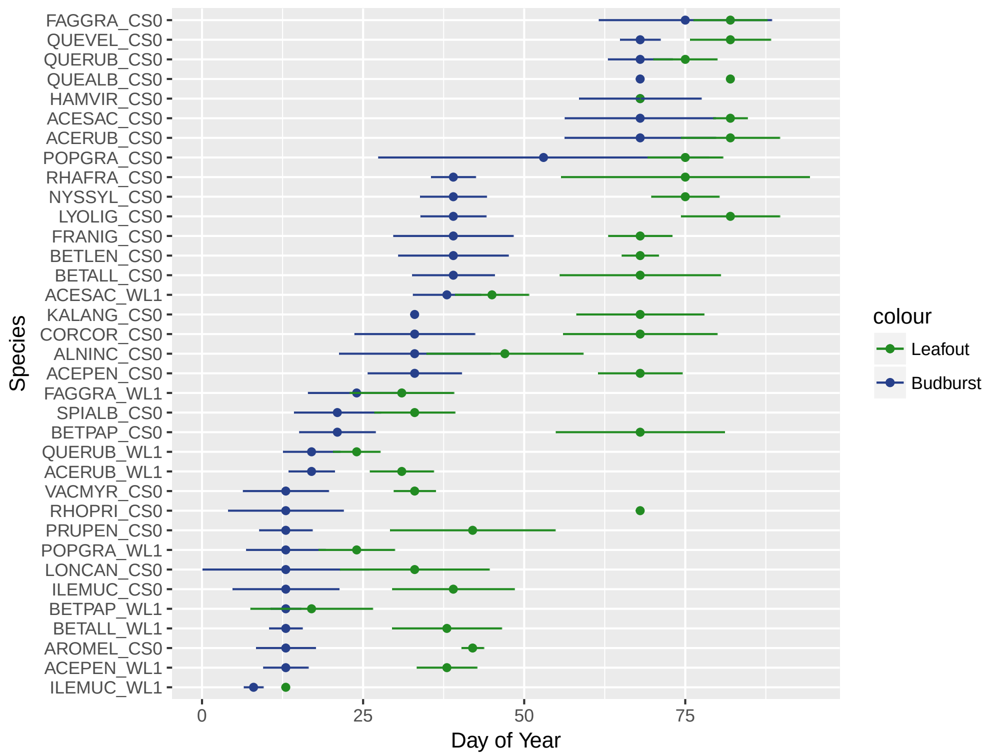
Figure 2: Day of budburst and the day of leaf out for native tree species in New England. Data was downloaded from the US-NPN data download tool (http://data.usanpn.org/observations/get-started) and observations were collected from the Arnold Aboretum - Tree Spotters program. The standard deviation is represented in coral for budburst and green for leaf out.




| | Estimate | Std. Error | t value | Pr(>\|t\|) |
|---|---|---|---|---|
| (Intercept) | 7.0456 | 9.4102 | 0.75 | 0.4575 |
| Budburst | 0.0549 | 0.0858 | 0.64 | 0.5250 |

## Dan's Data

Figure 3: Day of budburst and the day of leaf out for native tree species in New England. Data was collected from a growth chamber experiment using any combination of two photoperiod treatments, two forcing treatments, and three chilling treatments. The standard deviation is represented in blue for budburst and green for leaf out.




Anova Table (Type II tests)

Response: risk Sum Sq Df F value Pr(¿F) chilling 119.1 1 1.9246 0.1682 warm 4883.5 1 78.8970 1.602e-14 *** photo 1300.3 1 21.0076 1.235e-05 *** Residuals 6684.9 108 — Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1 Anova Table (Type II tests)

Response: risk Sum Sq Df F value Pr(¿F) chilling 0.6 1 0.0094 0.923076 warm 1742.3 1 26.3542 1.402e-06 *** photo 462.9 1 7.0015 0.009461 ** Residuals 6611.2 100 — Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1 Anova Table (Type II tests)

Response: risk Sum Sq Df F value Pr(¿F) chilling 15.5 1 0.2174 0.6426 warm 269.9 1 3.7758 0.0564 . photo 224.8 1 3.1453 0.0809 . Residuals 4574.7 64 — Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1 Anova Table (Type II tests)

Response: risk Sum Sq Df F value Pr(¿F) chilling 0 warm 1025.1 1 5.9585 0.01929 * photo 198.5 1 1.1541 0.28930 Residuals 6709.5 39 — Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1 Anova Table (Type II tests)

Response: risk Sum Sq Df F value Pr(¿F) chilling 0 warm 374.08 1 40.041 0.0001364 *** photo 126.75 1 13.567 0.0050493 ** Residuals 84.08 9 — Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1 Anova Table (Type II tests)

Response: risk Sum Sq Df F value Pr(¿F) chilling 287.1 1 5.3166 0.0226709 * warm 1464.4 1 27.1142 7.109e-07 *** photo 617.1 1 11.4266 0.0009506 *** Residuals 7183.3 133 — Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1 Anova Table (Type II tests)

Response: risk Sum Sq Df F value Pr(¿F) chilling 0 warm 1383.03 1 18.8814 0.0003139 *** photo 539.58 1 7.3665 0.0133581 * Residuals 1464.97 20 — Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1 Anova Table (Type II tests)

Response: risk Sum Sq Df F value Pr(¿F) chilling 4.6 1 0.0554 0.8142417 warm 1780.6 1 21.6850 7.928e-06 *** photo 1104.1 1 13.4457 0.0003587 *** Residuals 10510.5 128 — Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1 Anova Table (Type II tests)

Response: risk Sum Sq Df F value Pr(¿F) chilling 0 warm 941.67 1 14.261 0.0005059 *** photo 660.25 1 9.999 0.0029452 ** Residuals 2707.30 41 — Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1 Anova Table (Type II tests)

Response: risk Sum Sq Df F value Pr(¿F) chilling 60.29 1 1.3655 0.2467952 warm 722.34 1 16.3610 0.0001396 *** photo 2.08 1 0.0472 0.8287207 Residuals 2913.91 66 — Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1 Anova Table (Type II tests)

Response: risk Sum Sq Df F value Pr(¿F) chilling 0 warm 1094.34 1 23.115 2.416e-05 *** photo 519.11 1 10.965 0.002043 ** Residuals 1799.04 38 — Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1 Anova Table (Type II tests)

Response: risk Sum Sq Df F value Pr(¿F) chilling 0 warm 92.04 1 3.3681 0.08067 . photo 5.04 1 0.1845 0.67192 Residuals 573.88 21 — Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1 Anova Table (Type II tests)

Response: risk Sum Sq Df F value Pr(¿F) chilling 25.6 1 1.0452 0.3084 warm 2262.8 1 92.2793 ¡ 2.2e-16 *** photo 1036.2 1 42.2555 1.403e-09 *** Residuals 3334.9 136 — Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1 Anova Table (Type II tests)

Response: risk Sum Sq Df F value Pr(¿F) chilling 0 warm 1362.4 1 10.2219 0.01513 * photo 1145.8 1 8.5968

0.02196 * Residuals 933.0 7 — Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1 Anova Table (Type II tests)

Response: risk Sum Sq Df F value Pr(¿F) chilling 0 warm 264.73 1 9.722 0.003834 ** photo 506.70 1 18.608 0.000144 *** Residuals 871.35 32 — Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1 Anova Table (Type II tests)

Response: risk Sum Sq Df F value Pr(¿F) chilling 0 warm 2028.26 1 44.701 2.158e-06 *** photo 76.41 1 1.684 0.2099 Residuals 862.11 19 — Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1 Anova Table (Type II tests)

Response: risk Sum Sq Df F value Pr(¿F) chilling 0 warm 1269.62 1 31.3571 1.76e-05 *** photo 317.40 1 7.8393 0.01106 * Residuals 809.78 20 — Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1 Anova Table (Type II tests)

Response: risk Sum Sq Df F value Pr(¿F) chilling 37.7 1 0.5452 0.4620583 warm 2412.4 1 34.8806 5.066e-08 *** photo 1013.1 1 14.6486 0.0002282 *** Residuals 6777.9 98 — Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1 Anova Table (Type II tests)

Response: risk Sum Sq Df F value Pr(¿F) chilling 0 warm 1976.6 1 25.2187 8.971e-06 *** photo 402.8 1 5.1387 0.02836 * Residuals 3448.6 44 — Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1 Anova Table (Type II tests)

Response: risk Sum Sq Df F value Pr(¿F) chilling 0 warm 310.08 1 1.8102 0.2154 photo 56.37 1 0.3291 0.5820 Residuals 1370.35 8 Anova Table (Type II tests)

Response: risk Sum Sq Df F value Pr(¿F) chilling 9.4 1 0.2390 0.625773 warm 697.7 1 17.8189 4.591e-05 *** photo 370.1 1 9.4512 0.002584 ** Residuals 4972.5 127 — Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1 Anova Table (Type II tests)

Response: risk Sum Sq Df F value Pr(¿F) chilling 0 warm 0.66 1 0.0173 0.8971 photo 3.05 1 0.0793 0.7819 Residuals 615.94 16 Anova Table (Type II tests)

Response: risk Sum Sq Df F value Pr(¿F) chilling 0 warm 426.51 1 6.1587 0.02317 * photo 113.90 1 1.6447 0.21595 Residuals 1246.57 18 — Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1 Anova Table (Type II tests)

Response: risk Sum Sq Df F value Pr(¿F) chilling 0 warm 676.1 1 3.7283 0.06856 . photo 717.2 1 3.9548 0.06133 . Residuals 3445.5 19 — Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1 Anova Table (Type II tests)

Response: risk Sum Sq Df F value Pr(¿F) chilling 0 warm 54.14 1 1.2225 0.2783 photo 23.87 1 0.5390 0.4690 Residuals 1240.03 28 Anova Table (Type II tests)

Response: risk Sum Sq Df F value Pr(¿F) chilling 0 warm 549.82 1 15.5969 0.0002936 *** photo 62.38 1 1.7694 0.1906292 Residuals 1480.58 42 — Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1 Anova Table (Type II tests)

Response: risk Sum Sq Df F value Pr(¿F) chilling 94.2 1 3.6275 0.05915 . warm 50.9 1 1.9585 0.16417 photo 38.8 1 1.4947 0.22381 Residuals 3221.0 124 — Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1 Anova Table (Type II tests)

Response: risk Sum Sq Df F value Pr(¿F) chilling 5.38 1 1.0236 0.3140 warm 4.63 1 0.8804 0.3503 photo 9.20 1 1.7479 0.1890 Residuals 547.11 104

## Harvard Forest Data

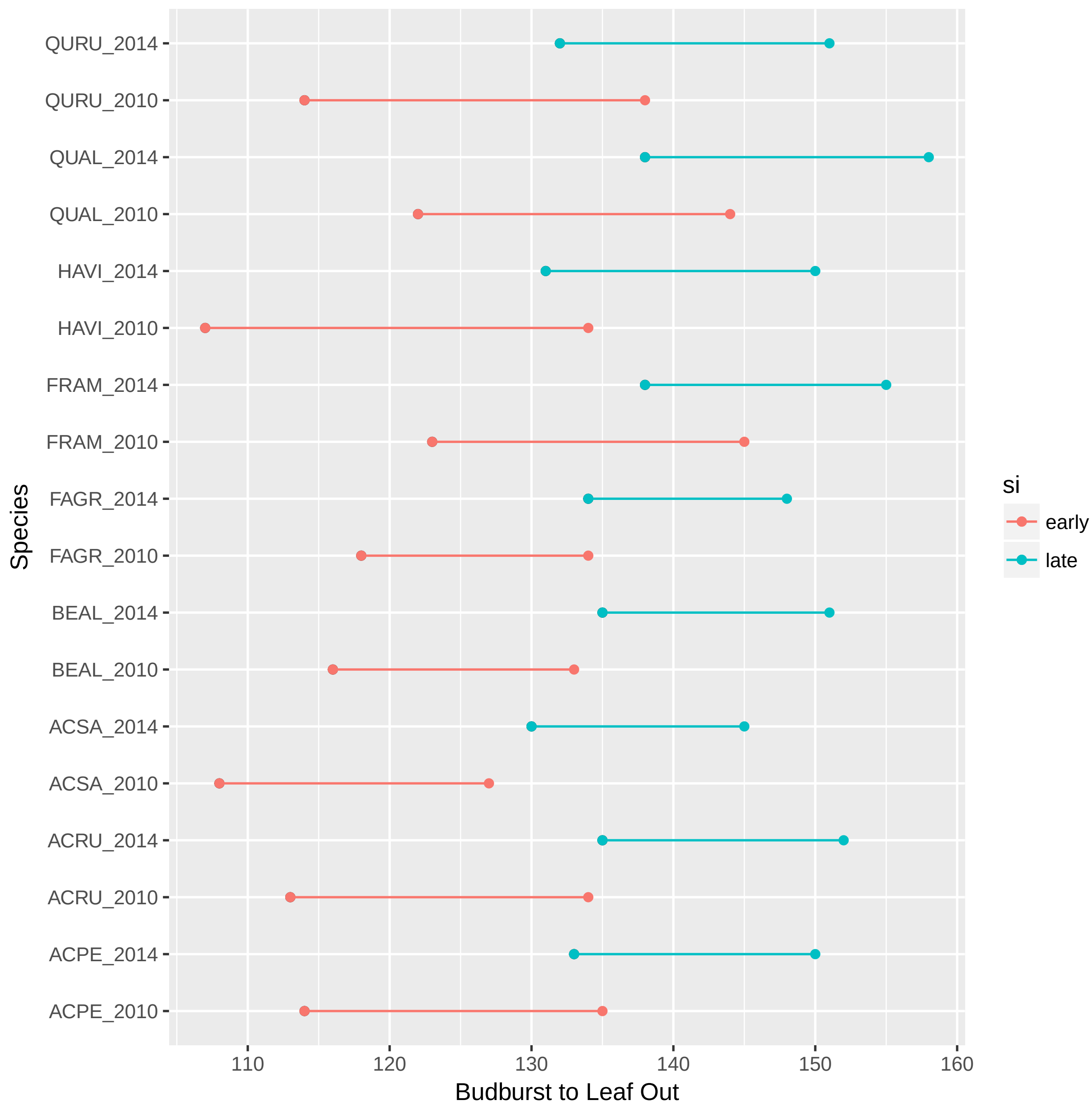
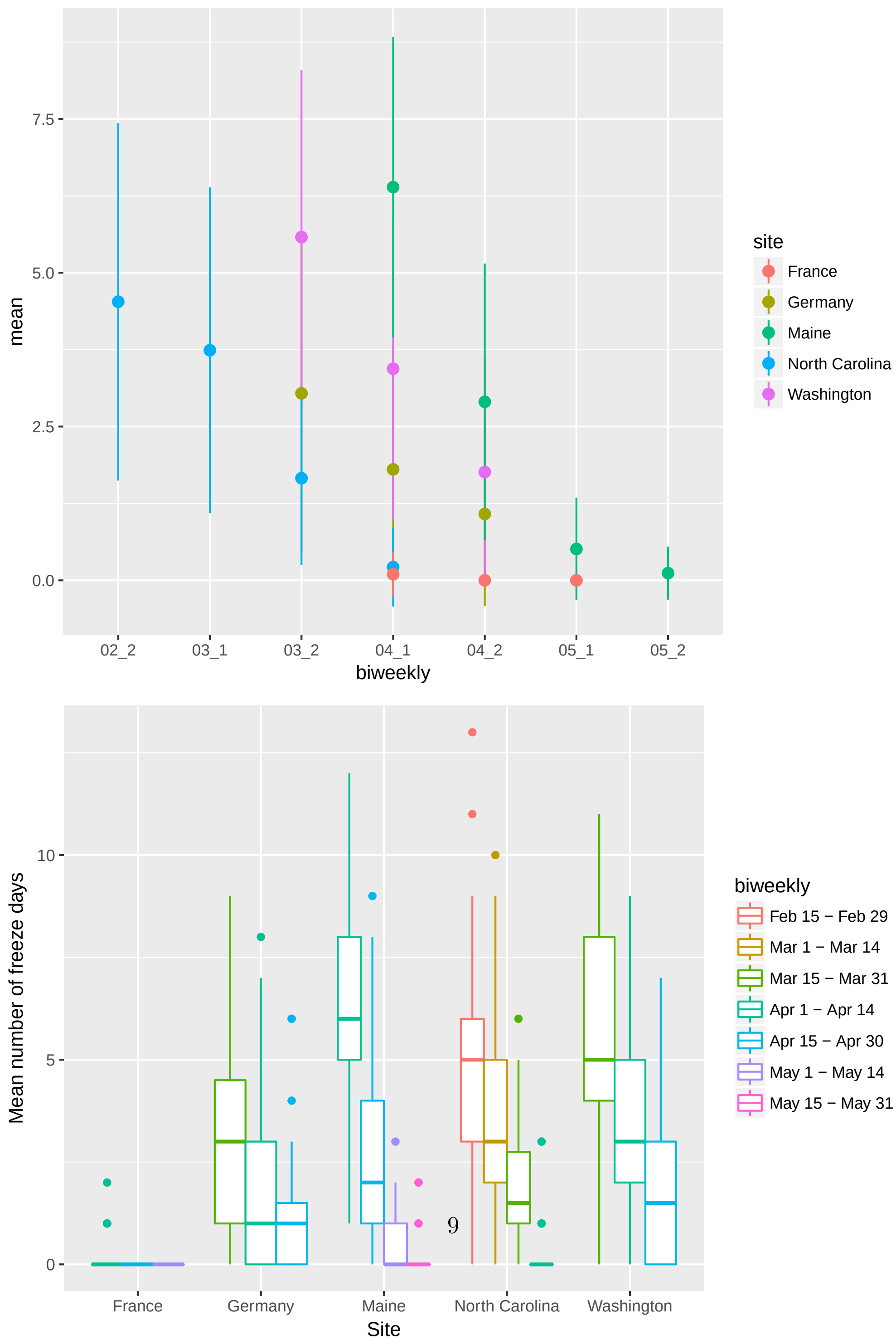



Figure 4: A timeline plot indicating the duration of vegetative risk for each species from collected from Harvard Forest.

# Regional Differences in Vegetative Risk?

Figure 5: Risk of a false spring event across five archetypal climate regions. The data was subsetted for each region based on earliest historical spring onset date to the latest historical leafout date and was divided into biweekly time periods (USA-NPN, 2016; Soudani *et al.*, 2012; Schaber & Badeck, 2005). We calculated the mean number of days that were -2.2°C (Ault *et al.*, 2015; Schwartz *et al.*, 2006; Schwartz, 1993) or below for each two week period that fell within the budburst to leafout timeframe in each region.



## Conclusion - Box

**Box 1: Key Indicators for Modeling False Spring Risk and Damage**

In order to properly evaluate the expected level of damage sustained from a false spring event key indicators should be included in the model.

I. Life Stage of the Individual(s) (Caffarra & Donnelly, 2011)

   (i) Seedlings and saplings will begin budburst earlier than adults

   (ii) The duration of vegetative risk may vary between life stages

   (iii) Long-term effects may vary

II. Location Within a Forest (Augspurger, 2013)

   (i) Individuals along the forest edge are more likely to experience a false spring

   (ii) Level of damage is likely to be higher at forest edges

III. Amount of Winter Chilling (Flynn & Wolkovich, 2017?)

   (i) Will affect the timing of budburst in the spring

   (ii) Will affect the duration of vegetative risk

IV. Proximity to Water

   (i) Large bodies of water are expected to act as a buffer to spring freezes

V. Precipitation Prior to Budburst (Anderegg *et al.*, 2013)

   (i) Will a drought increase cavitation and heighten damage from a false spring?

   (ii) Or will a drought decrease the risk of damage due to a lower chance of intracellular frost damage?

VI. Freeze Duration and Intensity

   (i) How should we define freezing temperatures?

   (ii) At what point is a freezing event severely damaging and xylem embolism occurs?

   (iii) How long must a false spring be to cause xylem embolism?

VII. Range of the Species

   (i) Species that have a more northern range may be more photoperiod than temperature sensitive

## References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Augspurger, C.K. (2013) Reconstructing patterns of temperature, phenology, and frost damage over 124 years: Spring damage risk is increasing. *Ecology* **94**, 41–50.

Ault, T.R., Zurita-Milla, R. & Schwartz, M.D. (2015) A Matlab{©} toolbox for calculating spring indices from daily meteorological data. *Computers {&} Geosciences* **83**, 46–53.

Caffarra, A. & Donnelly, A. (2011) The ecological significance of phenology in four different tree species: Effects of light and temperature on bud burst. *International Journal of Biometeorology* **55**, 711–721.

Schaber, J. & Badeck, F.W. (2005) Plant phenology in germany over the 20th century. *Regional Environmental Change* **5**, 37–46.

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Schwartz, M.D., Ahas, R. & Aasa, A. (2006) Onset of spring starting earlier across the Northern Hemisphere. *Global Change Biology* **12**, 343–351.

Soudani, K., Hmimina, G., Delpierre, N., Pontailler, J.Y., Aubinet, M., Bonal, D., Caquet, B., de Grandcourt, A., Burban, B., Flechard, C. & et al. (2012) Ground-based network of ndvi measurements for tracking temporal dynamics of canopy structure and vegetation phenology in different biomes. *Remote Sensing of Environment* **123**, 234–245.

USA-NPN (2016) USA National Phenology Network Data Visualizer Tool.

| | Sum Sq | Df | F value | Pr(>F) |
|---|---|---|---|---|
| chilling | 119.12 | 1 | 1.92 | 0.1682 |
| warm | 4883.47 | 1 | 78.90 | 0.0000 |
| photo | 1300.30 | 1 | 21.01 | 0.0000 |
| Residuals | 6684.85 | 108 | | |
| chilling1 | 0.62 | 1 | 0.01 | 0.9231 |
| warm1 | 1742.33 | 1 | 26.35 | 0.0000 |
| photo1 | 462.88 | 1 | 7.00 | 0.0095 |
| Residuals1 | 6611.18 | 100 | | |
| chilling2 | 15.54 | 1 | 0.22 | 0.6426 |
| warm2 | 269.90 | 1 | 3.78 | 0.0564 |
| photo2 | 224.83 | 1 | 3.15 | 0.0809 |
| Residuals2 | 4574.75 | 64 | | |
| chilling3 | | 0 | | |
| warm3 | 1025.10 | 1 | 5.96 | 0.0193 |
| photo3 | 198.55 | 1 | 1.15 | 0.2893 |
| Residuals3 | 6709.50 | 39 | | |
| chilling4 | | 0 | | |
| warm4 | 374.08 | 1 | 40.04 | 0.0001 |
| photo4 | 126.75 | 1 | 13.57 | 0.0050 |
| Residuals4 | 84.08 | 9 | | |
| chilling5 | 287.15 | 1 | 5.32 | 0.0227 |
| warm5 | 1464.43 | 1 | 27.11 | 0.0000 |
| photo5 | 617.15 | 1 | 11.43 | 0.0010 |
| Residuals5 | 7183.30 | 133 | | |
| chilling6 | | 0 | | |
| warm6 | 1383.03 | 1 | 18.88 | 0.0003 |
| photo6 | 539.58 | 1 | 7.37 | 0.0134 |
| Residuals6 | 1464.97 | 20 | | |
| chilling7 | 4.55 | 1 | 0.06 | 0.8142 |
| warm7 | 1780.62 | 1 | 21.68 | 0.0000 |
| photo7 | 1104.06 | 1 | 13.45 | 0.0004 |
| Residuals7 | 10510.45 | 128 | | |
| chilling8 | | 0 | | |
| warm8 | 941.67 | 1 | 14.26 | 0.0005 |
| photo8 | 660.25 | 1 | 10.00 | 0.0029 |
| Residuals8 | 2707.30 | 41 | | |
| chilling9 | 60.29 | 1 | 1.37 | 0.2468 |
| warm9 | 722.34 | 1 | 16.36 | 0.0001 |
| photo9 | 2.08 | 1 | 0.05 | 0.8287 |