Assessing the potential impacts of weather changes on pest activities and establishment

Brittany Barker, Maxine Cruz, and Isabella Meibauer

Last modified: November 16, 2026

Abstract

Early detection of invasive plant pests helps Plant Protection and Quarantine (PPQ) carry out its mission to safeguard agriculture and facilitate safe trade by assuring that our response to incursions is rapid and efficient, minimizing the costs of a response. The goal of this project was to develop a web app that delivers maps and other products that communicate the potential influence of recent (1981−2025) weather changes on the seasonal activities (phenology) and establishment of 18 major invasive insects for the contiguous United States. Project deliverables will inform strategic planning by PPQ and state agencies in terms of both when and where to conduct pest surveillance. For example, a trend towards the earlier appearance of adult insects may indicate that monitoring traps should be installed earlier in the season, whereas areas that are becoming increasingly suitable for pest establishment should be prioritized for surveillance.

Background

Recent weather trends may be promoting overwintering survival and increasing developmental rates of invasive insects, potentially allowing them to expand their range, emerge earlier, and attain higher densities over a longer growing season. The primary purpose of this project was to deliver predictions of the impacts of weather changes on the seasonal activities (phenology) and establishment risk of 18 major invasive insects that threaten agriculture in the United States to aid in early detection efforts. This project used a proven modeling system known as the Degree-Day, establishment Risk, and Phenological event mapping system (DDRP) to assess the potential impacts of recent weather trends (1981−2025) on the timing of pest activities (phenology) such as emergence, number of generations, and establishment for 18 major invasive species for the contiguous United States (CONUS; Table 1). We expected that a trend toward earlier phenological events and increasing climatic suitability would be most prevalent in the northeastern and midwestern U.S. owing to particularly large increases (3 to $>$ 5°F) in winter and spring temperatures in these regions since 1981 (Vose et al. 2017, Marvel et al. 2023).

Goal and Objectives

Our goal was to develop a web app that delivers maps and other products that communicate the potential influence of recent (1981−2025) weather changes on the phenology and establishment of 18 major invasive insects for the CONUS. The project addressed the following three objectives:

1. Evaluate trends in predictions of selected phenological events (adult emergence and egg hatch) and climatic suitability over the full 44-year period (1981–2025) and a more recent 24-year period (2001–2025).

2. Identify areas in the CONUS where trends are consistent across the 18 species, including earlier predicted pest activities, decreasing cold stress, increasing heat stress, and increasing climatic suitability.

3. Deliver and promote interactive maps in a range of user-friendly, readily accessible formats via a web app at USPest.org (https://uspest.org/wea/), and through Extension programming and end user training.

Table 1. Invasive insect species with completed DDRP models. As of 2026, five are present in the CONUS, 12 are designated as National Priority Pests, six were formerly on the list, and two are Federal Program Pests. Links to real-time forecasts, spreadsheet analyses, technical reports, and peer-reviewed publications associated with each species model are available at https://uspest.org/DDRP.

Species	Common name	Present in CONUS	National Priority Pest	Federal Program Pest
Anoplophora glabripennis	Asian longhorned beetle	Yes	Yes	Yes
Chilo suppressalis	Asiatic rice borer	No	Yes	No
Cryptoblabes gnidiella	Christmas berry webworm	No	Yes	No
Spodoptera litura	Common or Cotton cutworm	No	Yes	No
Agrilus planipennis	Emerald ash borer	Yes	No	No
Spodoptera littoralis	Egyptian cottonworm	No	No	No
Thaumatotibia leucotreta	False codling moth	No	Yes	No
Popillia japonica	Japanese beetle	Yes	No	Yes
Monochamus alternatus	Japanese pine sawyer beetle	No	No	No
Epiphyas postvittana	Light brown apple moth	Yes	No	No
Platypus quercivorus	Oak ambrosia beetle	No	Yes	No
Helicoverpa armigera	Old world bollworm	No	Yes	Yes
Dendrolimus pini	Pine-tree lappet moth	No	Yes	No
Autographa gamma	Silver Y moth	No	Yes	No
Neoleucinodes elegantalis	Small tomato borer	No	Yes	No
Lycorma delicatula	Spotted lanternfly	Yes	Yes	Yes
Eurygaster integriceps	Sunn pest	No	Yes	No
Phthorimaea absoluta	Tomato leaf miner	No	Yes	No

Methods

All analyses and modeling were conducted using R versions 4.4 or 4.5 (R Development Core Team 2025). Raster data processing and calculations were performed using the R package *terra* v. 4.5 (Hijmans 2025). All plots were produced using the R package *ggplot2* v. 3.5.2 (Wickham 2016).

i. Overview of DDRP

The mechanics of DDRP are detailed in Barker et al. (2020). Briefly, DDRP uses a process-based modeling approach in which degree-days and climate stress are calculated daily and accumulate over time to model phenology and climatic suitability, respectively (Figure 1 A). Required inputs include gridded daily minimum and maximum temperature data for a time frame of interest and a species parameter file. Models include four separate life stages (egg, larva, pupa, and adult) plus a separately parameterized overwintering stage. Phenology models often incorporate variation in phenology using a user-defined number of time-distributed cohorts that reflect the distribution of times in which the overwintering stage completes development.

DDRP uses annual accumulated climate stress units to identify two levels of temperature-based exclusion: moderate and severe. Similar to degree-days, which accumulate temperatures above a developmental threshold, climate stress units accumulate when temperatures exceed specified stress thresholds for heat or fall below thresholds for cold. The greater the accumulated stress units, the greater the potential for temperature-related

exclusion. Locations not excluded by either level of stress are considered part of the potential distribution and have the highest potential for establishment based on temperature alone. Moderate stress may limit long-term establishment, although short-term establishment may still occur during favorable years. Severe stress is expected to prevent even short-term establishment, defined as survival for one complete year. Because the model considers temperature alone, it does not account for host availability or other environmental factors that may influence pest distributions.

Over the daily time-step, DDRP produces outputs that include maps of the potential distribution, number of generations, life stages present, and dates of phenological events. Additionally, it integrates maps produced by the phenology and climatic suitability model to provide insight into phenology (i.e., life stage present or the date of specific event) only in areas at risk of establishment.

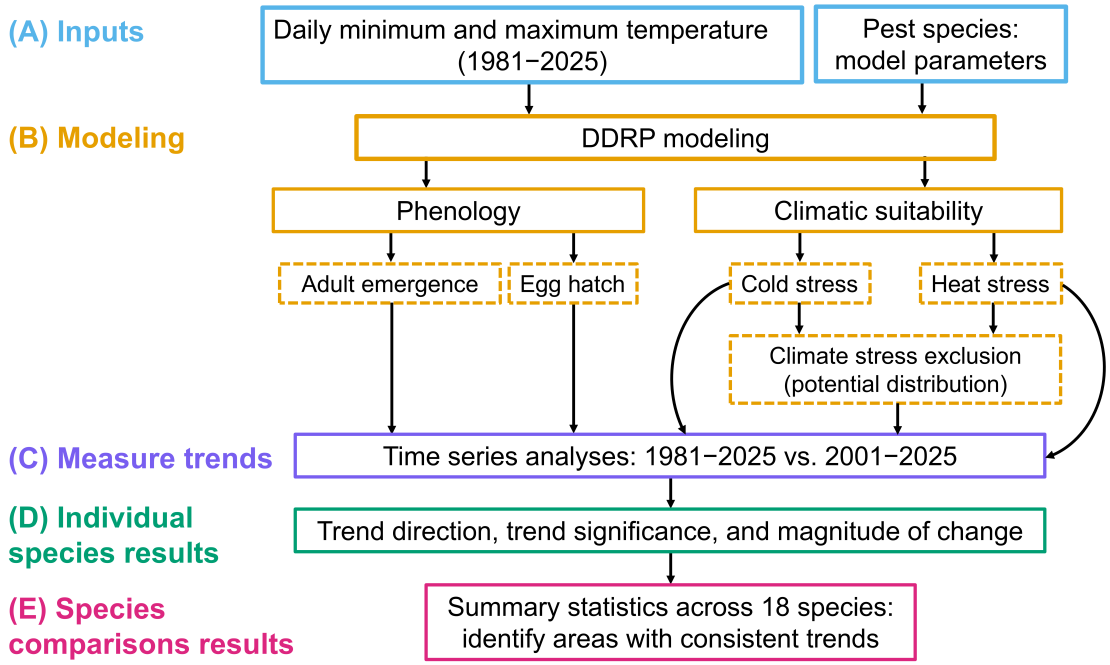

Figure 1. Workflow for producing maps for the DDRP Pest Trends web application. (A) Daily minimum and maximum temperatures (1981–2025) and species-specific model parameters served as inputs to the Degree-Days, Risk, and Phenological Event Mapping (DDRP) system. (B) DDRP models estimate pest phenology, including adult emergence and egg hatch, and climatic suitability based on cold and heat stress, which together inform potential distribution. (C) Time series analyses compare trends over the full 1981–2025 period and the more recent 2001–2025 period. (D) Individual-species outputs characterize trend direction, statistical significance, and magnitude of change. (E) Summary statistics across 18 invasive pest species identify geographic areas with consistent trends in phenology and climatic suitability.

ii. Trend analyses for individual species

Five types of predictions produced by DDRP were retained for trend analyses for this study: (1) dates (day of year) of first adult emergence, (2) dates of first egg hatch, (3) cold stress accumulation, (4) heat stress accumulation, and (5) the potential distribution, as measured by areas not excluded by cold and heat stresses

(Figure 1 B). Modeling in DDRP used daily minimum and maximum temperature data for 1981 to 2025 at 4-km^2 resolution from the PRISM (Parameter-elevation Relationships on Independent Slopes Model) (Daly et al. 1994, 2008) database.

We evaluated the direction and magnitude of changes in predictions over two periods: 1981–2025 (the full 44-year period) and 2001–2025 (the recent 25-year period; Figure 1 C). Analyzing both periods allowed us to characterize long-term trends and determine whether more recent changes in predicted phenology and climatic suitability differed from patterns observed over the longer period. Trends were assessed using the Mann–Kendall test and Theil–Sen regression, two rank-based, non-parametric methods widely used for analyzing environmental and remotely sensed time series (Goossens and Berger 1986). These methods do not require normally distributed data and are therefore suitable for environmental variables that may depart from a normal distribution. The Mann–Kendall test identifies whether an increasing or decreasing trend exists and assesses its statistical significance (Mann 1945, Kendall 1975, Gilbert 1987). Kendall's tau quantifies the direction and strength of the trend, ranging from -1 (strong negative trend) to $+1$ (strong positive trend). Trends were considered statistically significant at $P < 0.10$, a threshold often used in spatial analyses of environmental and remotely sensed time series to identify potentially meaningful trends while accounting for variability in climatic data (Wang et al. 2020).

Theil–Sen regression estimates the rate of change over time as the median slope across all pairs of observations. Slopes are expressed in the relevant units per year: days per year for phenological events and cumulative climate stress units per year for cold and heat stress. For phenology, negative slopes indicate that developmental events are occurring earlier, whereas positive slopes indicate later timing. These shifts may affect seasonal activity, survival, reproduction, and establishment potential, depending on the species and its life history. Changes in annual climate stress units indicate whether temperature stress is increasing or decreasing over time. Decreasing cold stress may increase climatic suitability as accumulated units fall below moderate or severe exclusion limits, whereas increasing cold stress may reduce suitability as these limits are exceeded. The opposite applies to heat stress: increasing heat stress may reduce suitability as accumulated units exceed exclusion limits, whereas decreasing heat stress may improve suitability. Decreasing cold stress may improve winter survival and allow range expansion into previously unsuitable areas, whereas increasing heat stress may reduce summer survival and limit establishment.

The Mann-Kendall and Theil-Sen analyses were implemented in the R package `modifiedmk` v. 1.6 (Patakamuri 2021) and used predictions that were corrected for serial correlation (autocorrelation) using the approach of von Storch (1995) and Kulkarni and von Storch (1995). This correction for autocorrelation, also known as "prewhitening," is often applied to avoid violating the Mann-Kendall test's assumption of no autocorrelation in the time series, which may increase the likelihood of type 1 error (rejecting the null hypothesis when it might be true) (Kulkarni and von Storch 1995, Yue et al. 2002, Zhang and Zwiers 2004). The accumulation of degree-days and climate stresses in our models exhibits a seasonal cycle driven by temperature, which would increase autocorrelation in the time series (Coen et al. 2020).

A cumulative link model (CLM) was used to assess temporal changes in predicted climate suitability for establishment, represented by three ordinal categories of climate-stress exclusion: no exclusion, moderate exclusion, and severe exclusion (Barker et al. 2020). The model estimates temporal trends in the probability of a location falling into each suitability category. Positive trends indicate a shift toward no exclusion, consistent with decreasing temperature-related stress and potentially more favorable conditions for establishment. Conversely, negative trends indicate a shift toward moderate or severe exclusion, consistent with increasing temperature-related stress and potentially less favorable conditions for establishment. The CLM was fitted in R using the ordinal package (v. 2023.12-4) (Christensen 2025), with a logit link function and the proportional odds assumption. Model coefficients ( ) were used to assess the direction and magnitude of temporal trends, and corresponding P-values were used to evaluate statistical significance. Positive coefficients indicate a shift toward lower climate stress and greater potential for establishment, whereas negative coefficients indicate a shift toward

greater climate stress and lower potential for establishment. Coefficients are expressed on the log-odds scale and are not restricted to a fixed range.

iii. Comparative analyses

Outputs from trend analyses for the 18 species (Figure 1 D) were combined to identify areas where pests consistently exhibited earlier first adult emergence and first egg hatch, decreasing cold stress, and increasing heat stress (Figure 1 E). Spatial descriptive statistics were calculated across species, including the mean and variance in the magnitude of change and the frequency of statistically significant increasing versus decreasing trends. Analyses were conducted separately for 1981–2025 and 2001–2025 to characterize spatial patterns in long-term trends and determine whether more recent trends differed from those observed over the longer period.

References

Barker, B. S., L. Coop, T. Wepprich, F. S. Grevstad, and G. Cook. 2020. DDRP: real-time phenology and climatic suitability modeling of invasive insects. PloS ONE 15:e0244005.

Christensen, R. H. B. 2025. ordinal—regression models for ordinal data. R package version 2025.12-29, https://CRAN.R-project.org/package=ordinal.

Coen, M. C., E. Andrews, A. Bigi, G. Martucci, G. Romanens, F. P. A. Vogt, and L. Vuilleumier. 2020. Effects of the prewhitening method, the time granularity, and the time segmentation on the Mann-Kendall trend detection and the associated Sen' s slope. Atmospheric Measurement Techniques 13:6945–6964.

Daly, C., H. Halbleib, J. I. Smith, W. P. Gibson, M. K. Doggett, G. H. Taylor, J. Curtis, and P. P. Pasteris. 2008. Physiographically sensitive mapping of climatological temperature and precipitation across the conterminous United States. International Journal of Climatology 28:2031–2064.

Daly, C., R. P. Neilson, and D. L. Phillips. 1994. A statistical-topographic model for mapping climatological precipitation over mountainous terrain. Journal of Applied Meteorology 33:140–158.

Gilbert, R. O. 1987. Statistical methods for environmental pollution monitoring. John Wiley & Sons, Richland, WA.

Goossens, C., and A. Berger. 1986. Annual and seasonal climatic variations over the northern hemisphere and Europe during the last century. Annales Geophysicae 4:385–400.

Hijmans, R. J. 2025. Package "terra": spatial data analysis. R package version 1.8, https://cran.r-project.org/web/packages/terra/index.html.

Kendall, M. G. 1975. Rank Correlation Methods. Charles Griffin, London, UK.

Kulkarni, A., and H. von Storch. 1995. Monte Carlo experiments on the effect of serial correlation on the Mann-Kendall test of trend. Meteorologische Zeitschrift N.F 4:82–85.

Mann, H. B. 1945. Nonparametric tests against trend. Econometrica 13:245–259.

Marvel, K., W. Su, R. Delgado, S. Aarons, A. Chatterjee, M. E. Garcia, Z. Hausfather, K. Hayhoe, D. A. Hence, E. B. Jewett, A. Robel, D. Singh, A. Tripati, and R. S. Vose. 2023. Chapter 2: Climate trends. *In* A. R. Crimmins, C. W. Avery, D. R. Easterling, K. E. Kunkel, B. C. Stewart, & T. K. Maycock (Eds.), Fifth National Climate Assessment. U.S. Global Change Research Program.

Patakamuri, S. K. 2021. Package "modifiedmk": Modified versions of Mann Kendall and Spearman's Rho trend tests. R package version 1.6, https://cran.r-project.org/web/packages/modifiedmk/index.html.

von Storch, H. 1995. Misuses of statistical analysis in climate research. Pages 11–26 *in* H. von Storch and A. Navarra, editors. Analysis of Climate Variability: Applications of Statistical Techniques. Springer-Verlag, Berlin, Heidelberg.

Vose, R. S., D. R. Easterling, K. E. Kunkel, A. N. LeGrande, M. F. Wehner. 2017. Temperature changes in the United States. *In* D. J. Wuebbles, D. W. Fahey, K. A. Hibbard, D. J. Dokken, B. C. Stewart, and T. K. Maycock (Eds.), Climate Science Special Report: Fourth National Climate Assessment, Volume I

(pp. 185–206). U.S. Global Change Research Program.
Wang, F., W. Shao, H. Yu, G. Kan, X. He, D. Zhang, M. Ren, and G. Wang. 2020. Re-evaluation of the power of the Mann-Kendall test for detecting monotonic trends in hydrometeorological time series. Frontiers in Earth Science 8:14.
Wickham, H. 2016. ggplot2: Elegant Graphics for Data Analysis. Springer-Verlag, New York, NY.
Yue, S., P. Pilon, B. Phinney, and G. Cavadias. 2002. The influence of autocorrelation on the ability to detect trend in hydrological series. Hydrological Processes 1829:1807–1829.
Zhang, X., and F. W. Zwiers. 2004. Comment on "Applicability of prewhitening to eliminate the influence of serial correlation on the Mann-Kendall test" by Sheng Yue and Chun Yuan Wang. Water Resources Research 40:W0385.

Pest reports

Select a species to jump to its Results, or download its individual report as a PDF.

1. Asian longhorned beetle
2. Asiatic rice borer
3. Honeydew moth
4. Emerald ash borer
5. Egyptian cottonworm
6. False codling moth
7. Japanese beetle
8. Japanese pine sawyer beetle
9. Light brown apple moth
10. Oak ambrosia beetle
11. Old world bollworm
12. Pine tree lappet moth
13. Spotted lanternfly
14. Cotton cutworm
15. Silver Y moth
16. Small tomato borer
17. Sunn pest
18. Tomato leafminer

1. Asian longhorned beetle

1A. Introduction

The Asian longhorned beetle (ALB), *Anoplophora glabripennis* Motschulsky (Coleoptera: Cerambycidae), is a wood-eating pest native to the Korean peninsula and eastern China. In the United States, the beetle was first discovered on Long Island, NY, in 1996, where it likely arrived via wood packaging from China (Haack and Hoebeke 1996). The pest spread to several sites in the eastern United States and Canada but has since been eradicated in Illinois, New Jersey, New York City, Boston, and Canada (Coyle et al. 2021, EPPO 2019). However, infestations currently persist in central Long Island, NY; Worcester County, MA; Clermont County, OH; and Charleston County, SC (Coyle et al. 2021, USDA-APHIS 2025). ALB is a major threat to the maple hardwood lumber and sugar maple syrup industries, as well as tourism associated with fall colors in maple trees (Smith and Wu 2008). The cost of a complete infestation of all urban areas in the United States has been estimated at $669 billion (Nowak et al. 2001).

An estimated 30-35% of trees in the eastern United States are species commonly attacked by ALB (Nowak et al. 2001, Smith and Wu 2008). The pest can complete its lifecycle on *Acer*, *Aesculus*, *Albizia julibrissin*, *Betula*,

Cercidiphyllum, *Elaeagnus angustifolia*, *Fraxinus*, *Platanus*, *Populus*, *Salix*, *Sorbus aucuparia* and *Ulmus* species (van der Gaag and Loomans 2014). However, preferred genera in North America are *Acer* and *Ulmus*, compared to *Populus* and *Salix* in China (Hu et al. 2009, van der Gaag and Loomans 2014). Following oviposition under the bark of host trees, larvae feed in the cambial region before burrowing into the inner xylem and heartwood (Haack and Hoebeke 1996, Haack 2006). ALB may overwinter as an egg, larva, or pupa, though typically as an egg or larva, before emerging from round exit holes as adults (Haack and Hoebeke 1996, Haack 2006, Herard et al. 2009, Faccoli et al. 2015, Trotter and Keena 2016). Diapause termination requires a chilling period, and larvae may be freeze tolerant (Roden et al. 2008, Torson et al. 2021).

A model for ALB developed for the Degree-Day, establishment Risk, and Phenological event mapping system (DDRP) is operationalized to produce near real-time forecasts for the contiguous United States (CONUS) at https://uspest.org/DDRP. The full set of model parameters for ALB, including developmental temperature thresholds, degree-day requirements for individual life stages, and climate stress thresholds and limits, are available at USPest.org (Coop 2018).

1B. Results

i. Phenology

Entire period: 1981–2025

Significant trends in predicted first adult emergence and egg hatch for ALB over the entire 44-year period (1981–2025) were predominantly negative, indicating that these phenological events shifted earlier over time (Figure 2, Figure 3). Significant advances were concentrated across large portions of the eastern United States, with additional localized areas along the Pacific coast, in the South, and at higher elevations of the interior West. In these regions, predicted adult emergence and egg hatch decreased by approximately 0.01–0.8 days per year, with some of the largest declines occurring at higher elevations in the West.

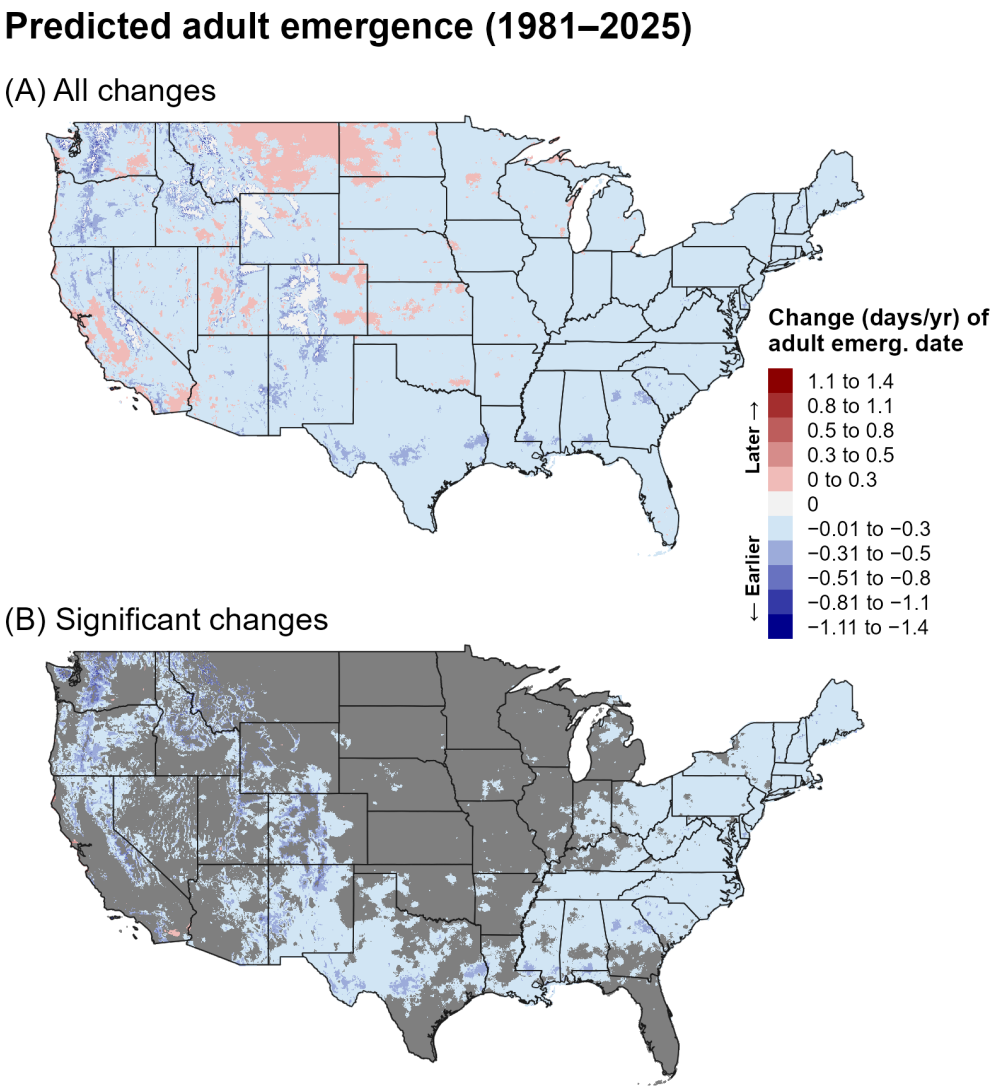

Figure 2. Changes (days/year) in predicted dates of first adult emergence for ALB across the CONUS over the entire 44-year period (1981–2025). Maps show (A) all changes and (B) statistically significant changes ($P < 0.1$); areas shown in gray are not statistically significant.

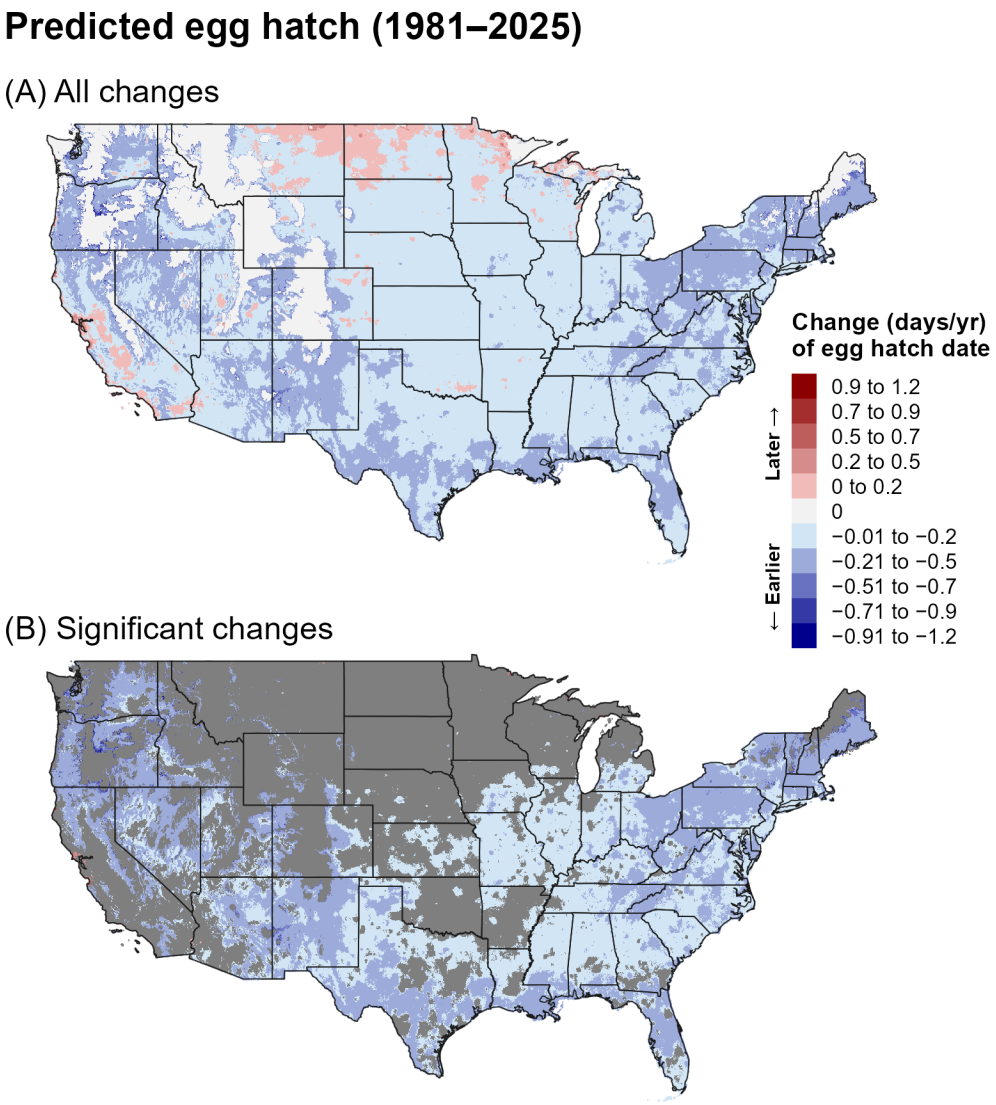

Figure 3. Changes (days/year) in predicted dates of first egg hatch for ALB across the CONUS over the entire 44-year period (1981–2025). Maps show (A) all changes and (B) statistically significant changes ($P < 0.1$); areas shown in gray are not statistically significant.

Recent period: 2001–2025

Trends in predictions of first adult emergence and egg hatch for ALB during the recent 24-year period (2001–2025) were generally consistent with those observed over the 44-year period, although changes were smaller in magnitude and less spatially extensive (Figure 4, Figure 5). For example, significantly earlier adult emergence and egg hatch were predicted primarily in parts of the eastern United States, with only isolated areas of significant change elsewhere in the CONUS.

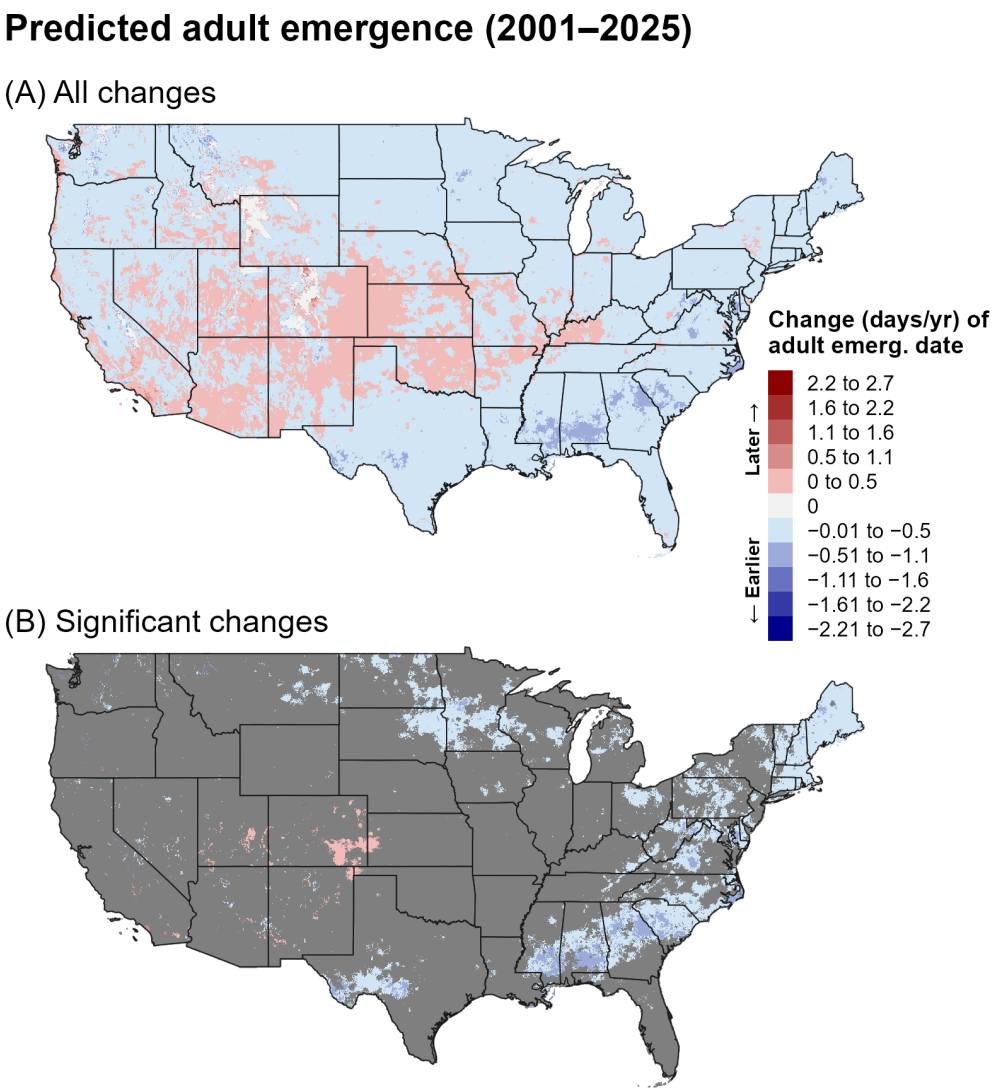

Figure 4. Changes (days/year) in predicted dates of first adult emergence for ALB across the CONUS over the recent 24-year period (2001–2025). Maps show (A) all changes and (B) statistically significant changes ($P < 0.1$); areas shown in gray are not statistically significant.

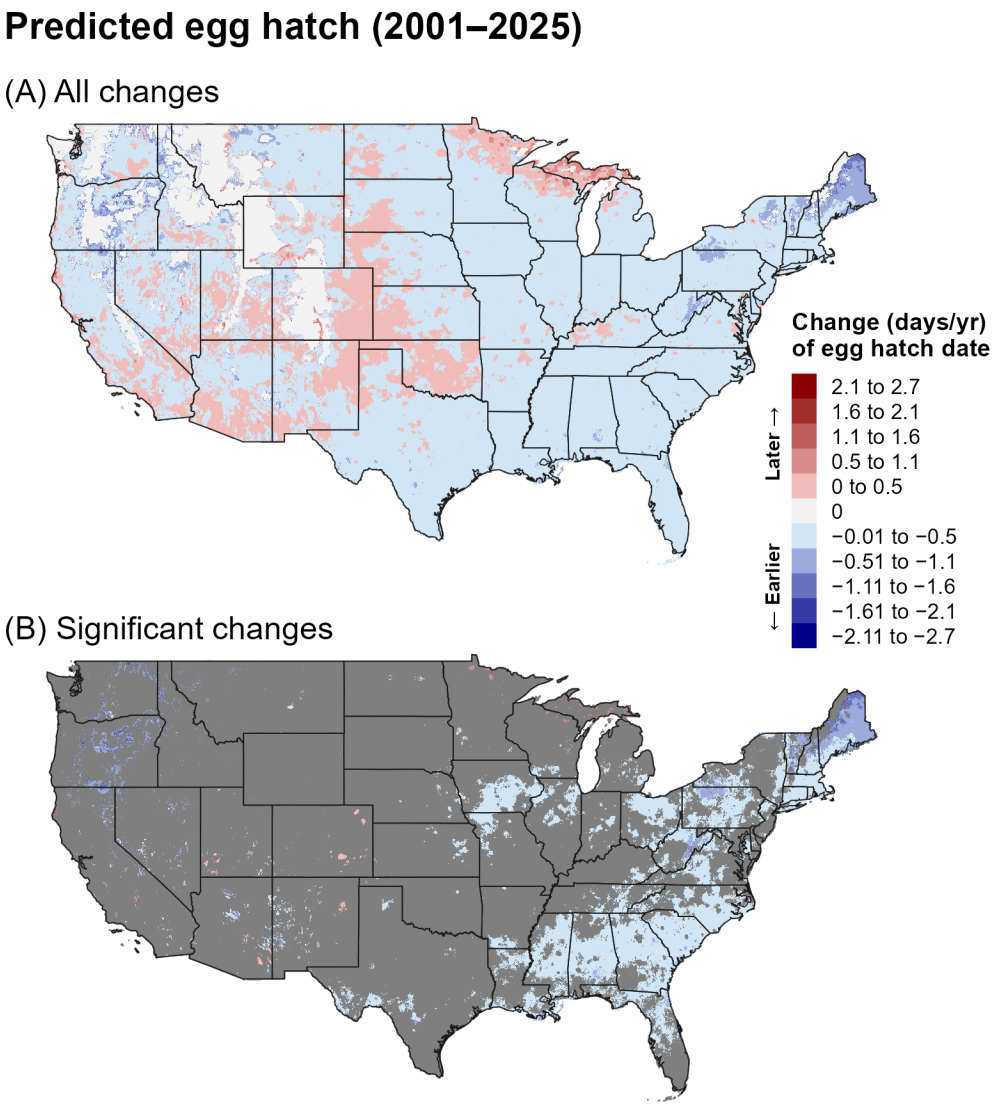

Figure 5. Changes (days/year) in predicted dates of first egg hatch for ALB across the CONUS over the recent 24-year period (2001–2025). Maps show (A) all changes and (B) statistically significant changes ($P < 0.1$); areas shown in gray are not statistically significant.

ii. Climatic suitability

Entire period: 1981–2025

Significant trends in predicted cold stress for ALB over the full 44-year period (1981–2025) were predominantly negative (Figure 6), indicating a general decrease in cold stress over time. In contrast, significant trends in heat stress were largely positive across portions of the Southwest, indicating increasing heat stress (Figure 7). When annual accumulated stress units exceed limits specified in DDRP models, climatic suitability may change. Consistent with these trends, suitability for ALB increased in parts of the Midwest, including Minnesota and North Dakota, but decreased in southern California and adjacent desert regions (Figure 8). However, only some of these changes were statistically significant, suggesting that shifts in climatic suitability were spatially limited.

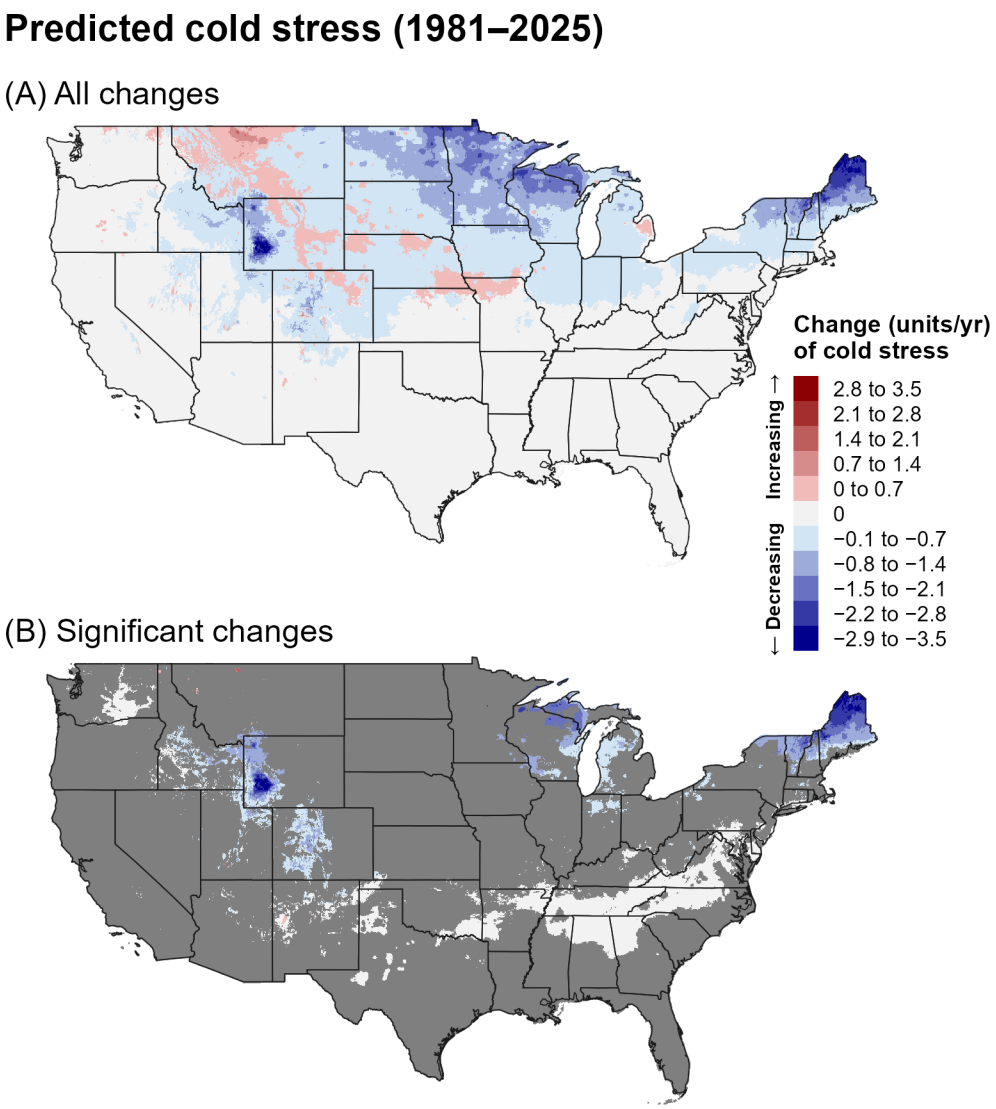

Figure 6. Changes (units/year) in predicted cold stress for ALB across the CONUS over the entire 44-year period (1981–2025). Maps show (A) all changes and (B) statistically significant changes ($P < 0.1$); areas shown in gray are not statistically significant. Areas shown as 0 in (B) had significant trends but very small changes.

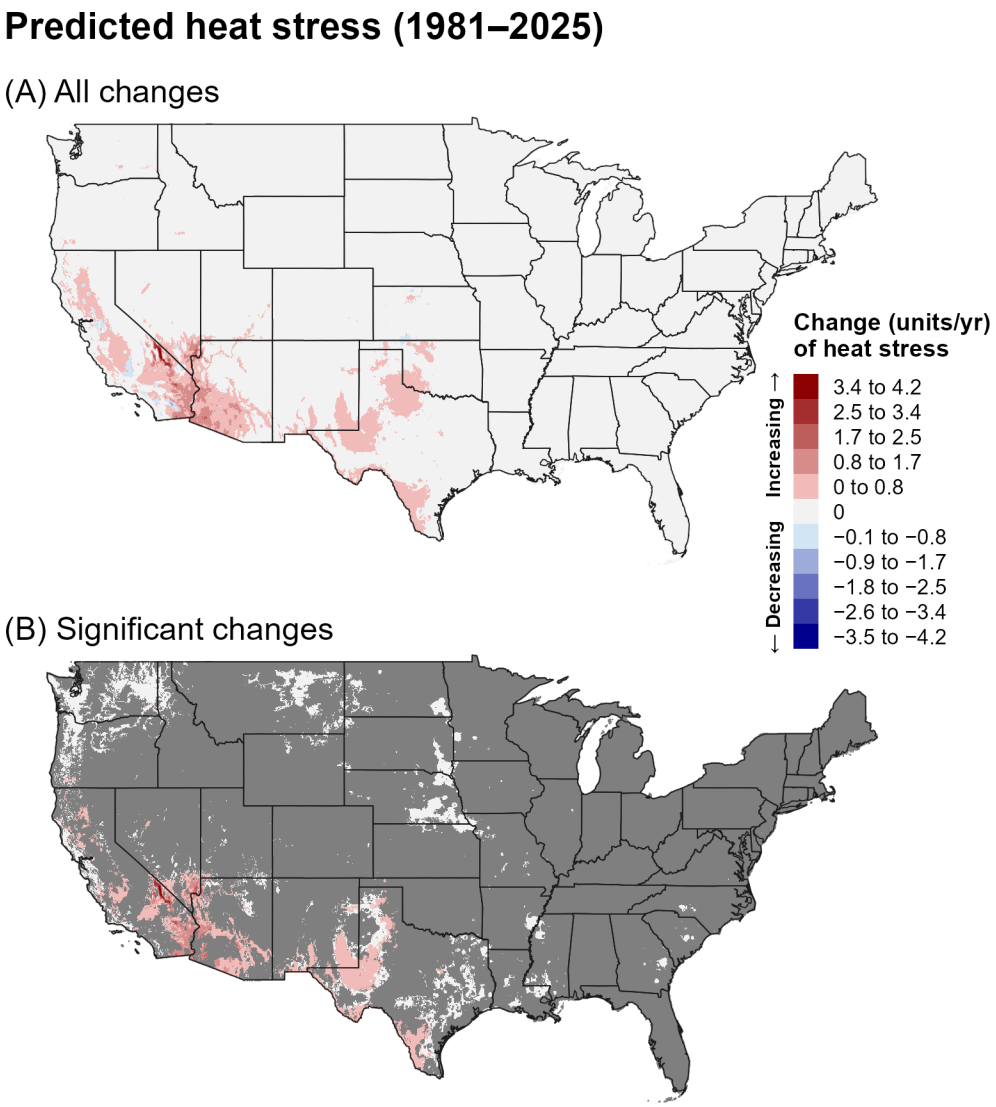

Figure 7. Changes (units/year) in predicted heat stress for ALB across the CONUS over the entire 44-year period (1981–2025). Maps show (A) all changes and (B) statistically significant changes ($P < 0.1$); areas shown in gray are not statistically significant. Areas shown as 0 in (B) had significant trends but very small changes.

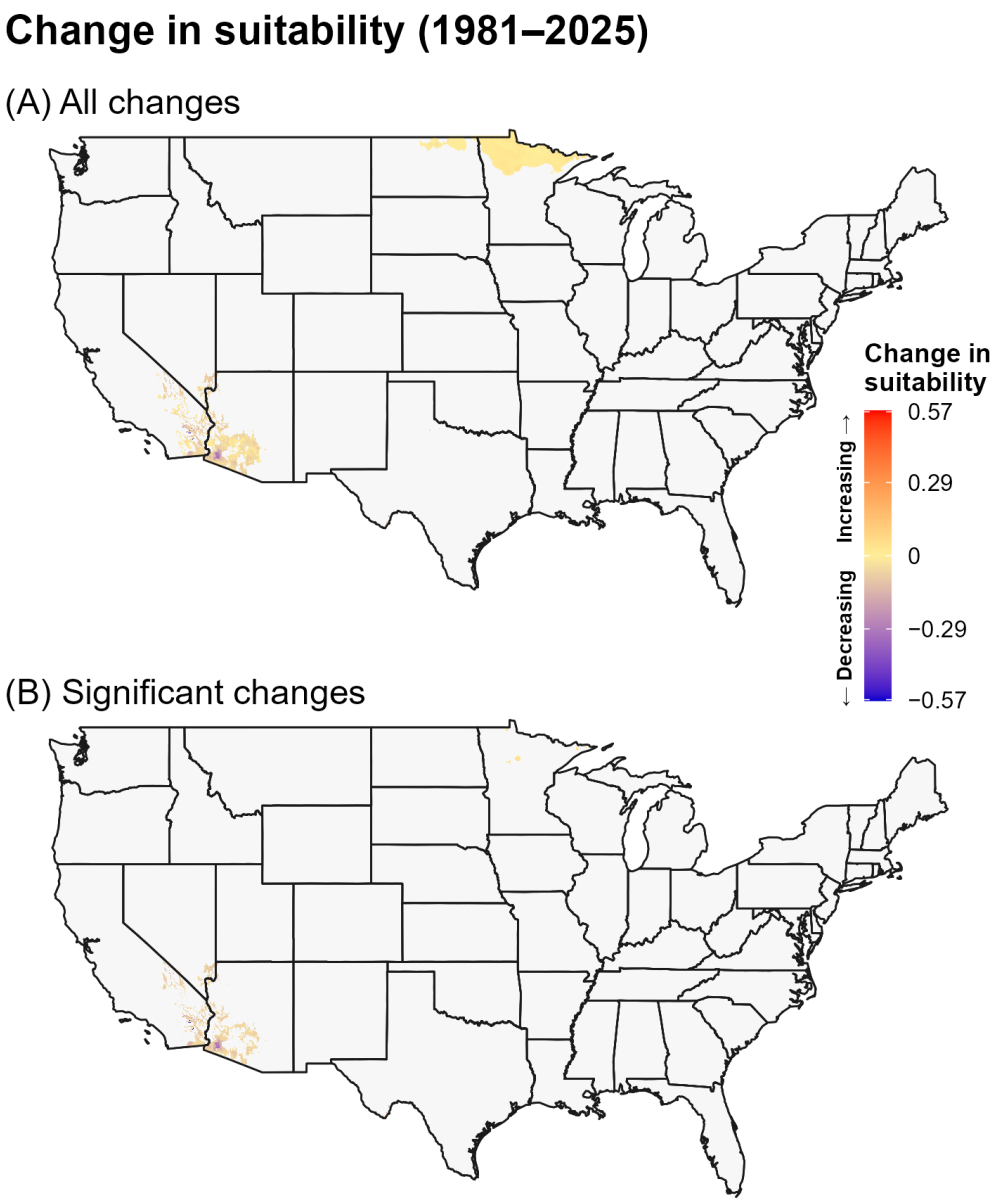

Figure 8. Changes in predicted climatic suitability for ALB across the CONUS over the 44-year period (1981–2025). Suitability is defined as areas not excluded by cold and heat stress. Positive changes (warmer colors) indicate an increased likelihood of establishment, whereas negative changes (cooler colors) indicate a decreased likelihood of establishment.

Recent period: 2001–2025

Statistically significant trends in predicted heat and cold stress for ALB over the recent 24-year period (2001–2025) were more spatially limited than those observed over the entire 1981–2025 period (Figure 9, Figure 10). Areas with significant increases in heat stress were generally consistent with those identified for the entire period, whereas several areas with significant decreases in cold stress over 1981–2025 showed no significant trend during 2001–2025. Additionally, parts of the Midwest and Rocky Mountains exhibited significant increases in cold stress, although the magnitude of these changes was small. Consistent with these patterns, fewer areas with significant changes in climatic suitability were identified, indicating that the predicted likelihood of establishment was

relatively stable during the recent recent period (Figure 11).

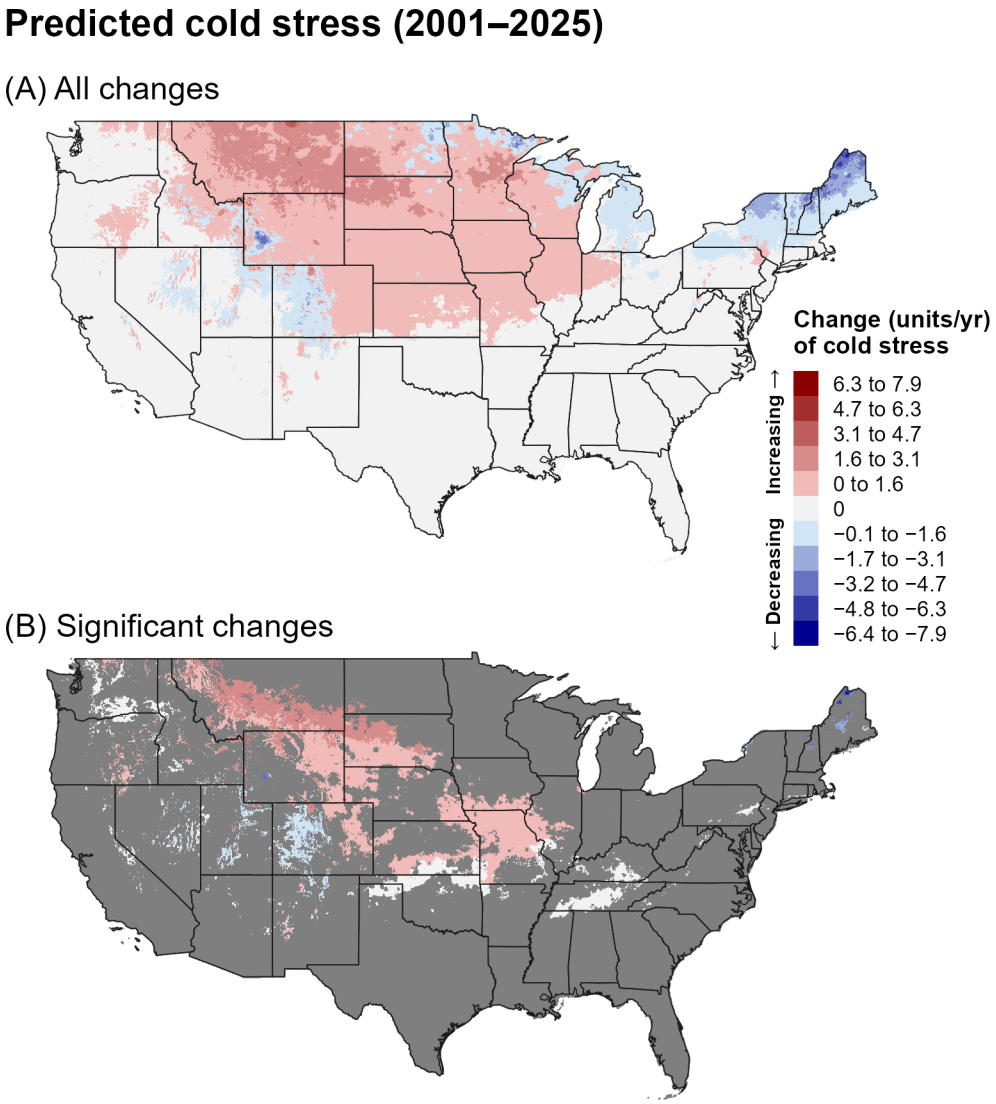

Figure 9. Changes (units/year) in predicted cold stress for ALB across the CONUS over the recent 24-year period (2001–2025). Maps show (A) all changes and (B) statistically significant changes ($P < 0.1$); areas shown in gray are not statistically significant. Areas shown as 0 in (B) had significant trends but very small changes.

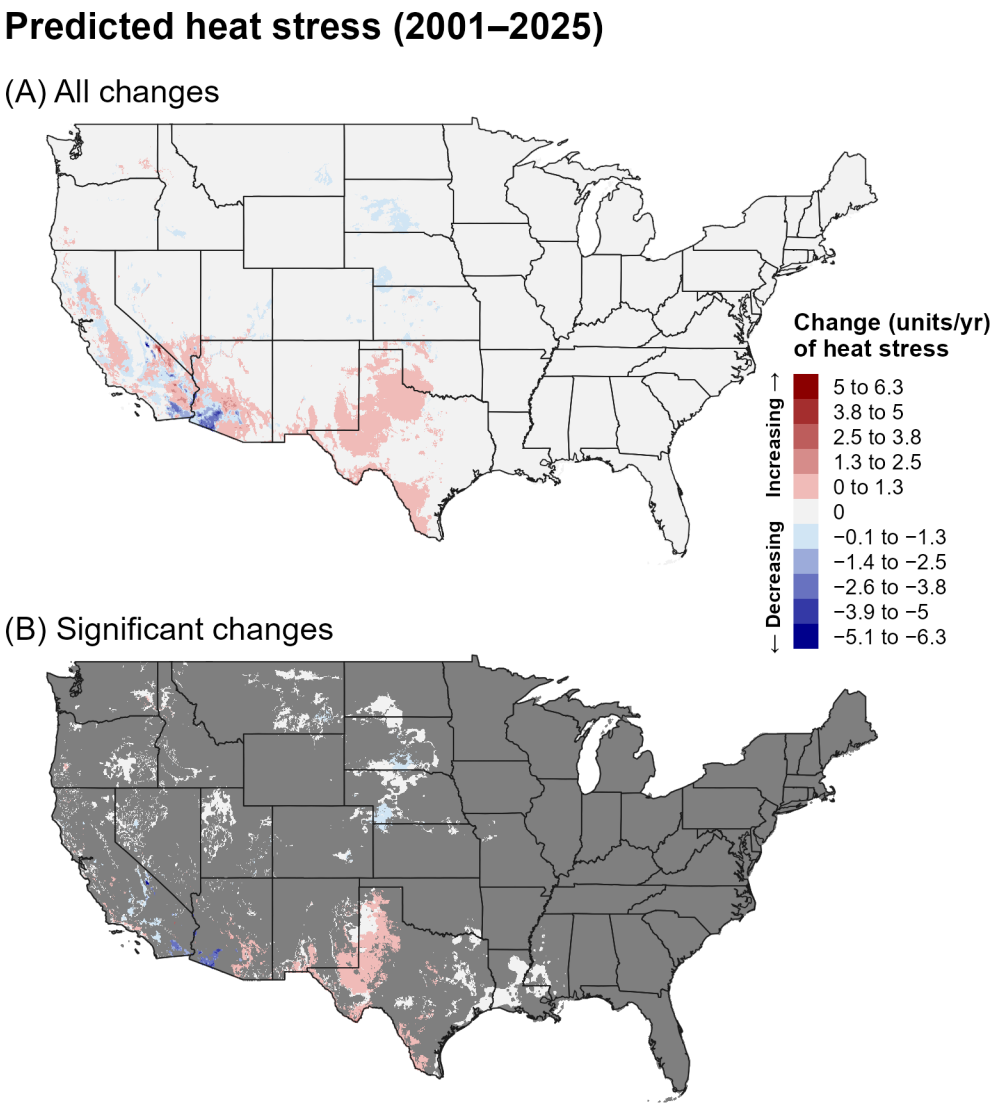

Figure 10. Changes (units/year) in predicted heat stress for ALB across the CONUS over the recent 24-year period (2001–2025). Maps show (A) all changes and (B) statistically significant changes ($P < 0.1$); areas shown in gray are not statistically significant. Areas shown as 0 in (B) had significant trends but very small changes.

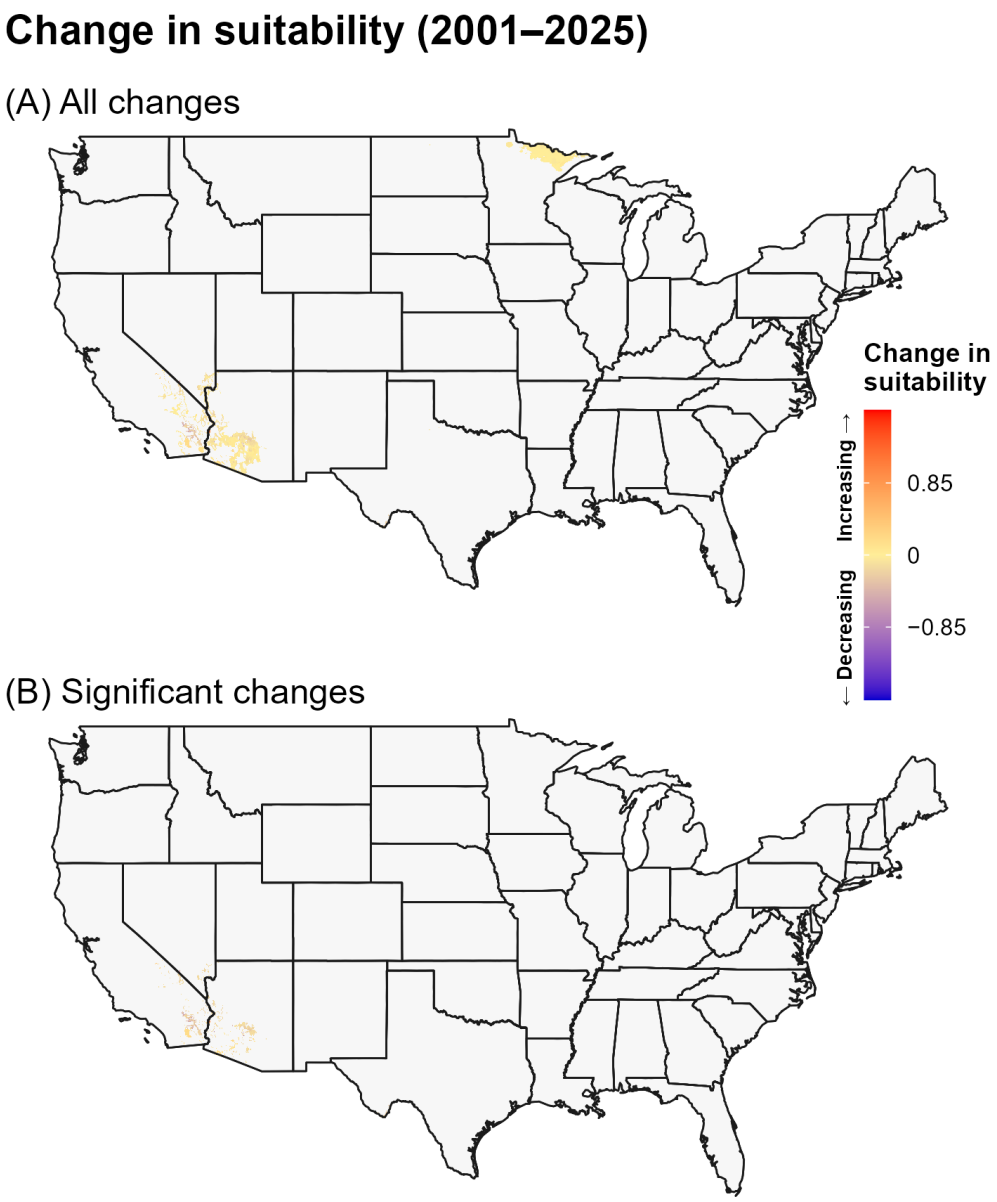

Figure 11. Changes in predicted climatic suitability for ALB across CONUS over the recent 24-year period (2001–2025). Suitability is defined as areas not excluded by cold and heat stress. Positive changes (warmer colors) indicate an increased likelihood of establishment, whereas negative changes (cooler colors) indicate a decreased likelihood of establishment.

1C. Discussion

Predictions of phenology and climatic suitability for ALB show clear, directional changes, with the strongest and most spatially extensive signals emerging over the entire 44-year period (1981–2025). Predicted adult emergence and egg hatch occurred progressively earlier across large portions of CONUS, averaging 0.01–0.5 days earlier per year, which suggests that surveyors and other management staff in these areas may want to ensure that materials are prepared earlier in the season. Faster development under warmer conditions could also enable ALB to achieve more rapid population growth, increase its damage potential, and shorten or eliminate the pupal hold period, potentially increasing the likelihood of multiple generations per year (Schmitt et al. 2025a,b).

Declines in predicted cold stress across northern and high-elevation regions—including parts of the Northeast and Midwest—may indicate increasing potential for overwinter survival in ALB. These regions may be especially vulnerable because of the high abundance of preferred host species for ALB, particularly maple (Smith and Wu 2008; Berland and Elliot 2014). Thus, surveyors and managers may want to increase the prioritization of areas such as northern New England and Michigan. Although significant increases in heat stress—and corresponding reductions in establishment risk—are predicted for the hottest parts of the Southwest, risk in this region is likely already constrained by the relatively low density of hardwood forests.

The stronger and more significant trends in predicted phenology and climate stress over the entire 44-year period may reflect both the larger sample size, which can reduce noise and improve detection of directional patterns, and differences in the underlying climate trends between the two time periods. In particular, the recent 24-year period may capture climate variability or regional trends that differ from those observed over the longer 44-year period. For example, increases in predicted cold stress in parts of the north-central United States may reflect this region's departure from the broader warming pattern during the more recent period, with some areas experiencing cooler conditions relative to the preceding years (NCEI 2021).

1D. References

Berland, A., and G. P. Elliott. 2014. Unexpected connections between residential urban forest diversity and vulnerability to two invasive beetles. Landscape Ecology 29:141–152.

Coop, L. 2018. IPPC model analysis summary: Asian longhorned beetle phenology (degree-day) model. Developed for Animal and Plant Health Inspection Service (APHIS) – Plant Protection and Quarantine (PPQ) – Cooperative Agricultural Pest Survey (CAPS) – Center for Plant Health Science and Technology (CPHST). Vs. 1.1 (12/17/2018). Available online: https://uspest.org/wea/ALB_model_v11.pdf (accessed 17 March 2026).

Coyle, D. R., R. T. Trotter, M. S. Bean, and S. E. Pfister. 2021. First recorded Asian longhorned beetle (Coleoptera: Cerambycidae) infestation in the southern United States. Journal of Integrated Pest Management 12:10.

Ding, W., H. Li, C. Wen, and J. Wen. 2025. The ecological niche of two invasive species, Asian longhorned beetle and its host Russian olive, has been affected by invasion and climate change. Entomologia Generalis 45:105–116.

EPPO. 2019. *Anoplophora glabripennis*. EPPO datasheets on pests recommended for regulation. Available online: https://gd.eppo.int/ (accessed 10 December 2025).

Faccoli, M., R. Favaro, M. T. Smith, and J. Wu. 2015. Life history of the Asian longhorn beetle *Anoplophora glabripennis* (Coleoptera Cerambycidae) in southern Europe. Agricultural and Forest Entomology 17:188–196.

van der Gaag, D. J., and A. J. M. Loomans. 2014. Host plants of *Anoplophora glabripennis*, a review. EPPO Bulletin 44:518–528.

Haack, R. A. 2006. Exotic bark-and wood-boring Coleoptera in the United States: recent establishments and interceptions. Canadian Journal of Forest Research 36:269–288.

Haack, R., and E. R. Hoebeke. 1996. *Anoplophora glabripennis*: A new tree infesting exotic cerambycid invades New York. Newsletter of the Michigan Entomological Society 41:411–413.

Herard, F., M. Maspero, N. Ramualde, C. Jucker, M. Colombo, M. Ciampitti, and B. Cavagna. 2009. *Anoplophora glabripennis*-Eradication programme in Italy (April 2009). EPPO.

Hu, J., S. Angeli, S. Schuetz, Y. Luo, and A. E. Hajek. 2009. Ecology and management of exotic and endemic Asian longhorned beetle *Anoplophora glabripennis*. Agricultural and Forest Entomology 11:359–375.

Huang, J., X. Lu, H. Liu, and S. Zong. 2021. The driving forces of *Anoplophora glabripennis* have spatial spillover effects. Forests 12:1678.

Li W, and C. Wu. 1993. Species, distributions, and host plants of the longhorned beetles injuring poplars. Chapter 2 in Integrated management of longhorned beetles damaging poplar trees. China Forest Press, Beijing, China (in Standard Chinese).

Kappel, A. P., R. T. Trotter, M. A. Keena, J. Rogan, and C. A. Williams. 2017. Mapping of the Asian longhorned beetle's time to maturity and risk to invasion at contiguous United States extent. Biological Invasions 19:1999–2013.

National Centers for Environmental Information (NCEI). 2021. U.S. Climate Normals. National Oceanic and Atmospheric Administration, National Centers for Environmental Information. Available online: https://www.ncei.noaa.gov/products/land-based-station/us-climate-normals (accessed 7 October 2026).

Nowak, D. J., J. E. Pasek, R. A. Sequeira, D. E. Crane, and V. C. Mastro. 2001. Potential effect of *Anoplophora glabripennis* (Coleoptera: Cerambycidae) on urban trees in the United States. Journal of Economic Entomology 94:116–122.

Roden, D. B., R. A. Haack, M. A. Keena, D. W. McKenney, F. D. Beall, and P. M. Roden. 2008. Potential Northern Distribution of Asian Longhorned Beetle in North America. Pages 65–67 *in* K. McManus and K. Gottschalk, editors. 2008 USDA Research Forum on Invasive Species, General Technical Report NRS-P-36. U.S. Department of Agriculture, Forest Service, Northern Research Station, Newtown Square, PA.

Schmitt, L. R., R. T. Trotter III, and D. R. Coyle. 2025a. Validating a variable-instar, climate-based phenology model for the Asian longhorned beetle (Coleoptera: Cerambycidae) using field data from South Carolina. Environmental Entomology 54:710–717.

Schmitt, L. R., R. T. Trotter III, C. J. Bishop, K. E. Crout, S. E. Pfister, and D. R. Coyle. 2025b. Phenology and voltinism of the Asian longhorned beetle (Coleoptera: Cerambycidae) in South Carolina, United States. Environmental Entomology 54:367–377.

Smith, M., and J. Wu. 2008. Asian longhorned beetle: renewed threat to northeastern USA and implications worldwide. International Pest Control 50:311–316.

Torson, A. S., M. Lei Zhang, A. J. Smith, L. Mohammad, K. Ong, D. Doucet, A. D. Roe, and B. J. Sinclair. 2021. Dormancy in laboratory-reared Asian longhorned beetles, *Anoplophora glabripennis*. Journal of Insect Physiology 130:104179.

Trotter, R. T., and M. A. Keena. 2016. A variable-instar climate-driven individual beetle-based phenology model for the invasive Asian longhorned beetle (Coleoptera: Cerambycidae). Environmental Entomology 45:1360–1370.

USDA-APIHS. 2025, July 10. Asian Longhorned Beetle. U.S. Department of Agriculture, Animal and Plant Health Inspection Service. Available online: https://www.aphis.usda.gov/plant-pests-diseases/alb (accessed 10 December 2025).

Wang, Y., D. O. Hessen, H. Samset, and F. Stordal. 2022. Remote sensing of environment evaluating global and regional land warming trends in the past decades with both MODIS and ERA5-Land land surface temperature data. Remote Sensing of Environment 280:113181.

2. Asiatic rice borer

2A. Introduction

The Asiatic rice borer (ASRB), *Chilo suppressalis* Walker (Lepidoptera: Crambidae), is a stem borer and major pest of rice and other grasses, including water oat, sorghum, millet, and corn, throughout Asia, Oceania, the Middle East, and Europe (CAPS 2025, Meng et al. 2008). ASRB larvae cause major damage to rice crops by severing panicles or the vascular system of tillers, leading to white earheads and dead hearts (Kiritani and Iwao 1967, Muralidharan and Pasalu 2006, Chen et al. 2014, EPPO 2019). Larvae can cause substantial economic losses, with reports of 20% yield loss under some conditions (Rahman et al. 2004). The pest is present in Hawaii

and is frequently intercepted at United States ports of entry (Solis 2006). With the United States rice industry valued at over USD 6 billion in 2025 (Childs 2025), yield reductions resulting from ASRB could cause significant economic damage to rice-producing regions.

A model for ASRB developed for the Degree-Day, establishment Risk, and Phenological event mapping system (DDRP) is operationalized to produce near real-time forecasts for the contiguous United States (CONUS) at https://uspest.org/DDRP. The full set of model parameters for ASRB, including developmental temperature thresholds, degree-day requirements for individual life stages, and climate stress thresholds and limits, are available at USPest.org (Coop and Barker 2020).

2B. Results

i. Phenology

Entire period: 1981–2025

Trends in predicted first adult emergence and egg hatch for ASRB over the 44-year period (1981–2025) were predominantly negative, indicating that both phenological events shifted earlier over time. Earlier phenology was spatially extensive, occurring across much of the CONUS, although trends toward later phenology occurred in portions of the northern interior and western United States (Figure 12, Figure 13). Statistically significant trends were more spatially restricted, occurring primarily in the East, the South, and higher elevations of the West. Within these regions, predicted adult emergence and egg hatch shifted earlier by approximately 0.01–0.5 days per year, with some of the largest shifts occurring at higher elevations in the West. Only a few small, isolated areas exhibited significant trends towards later phenology.

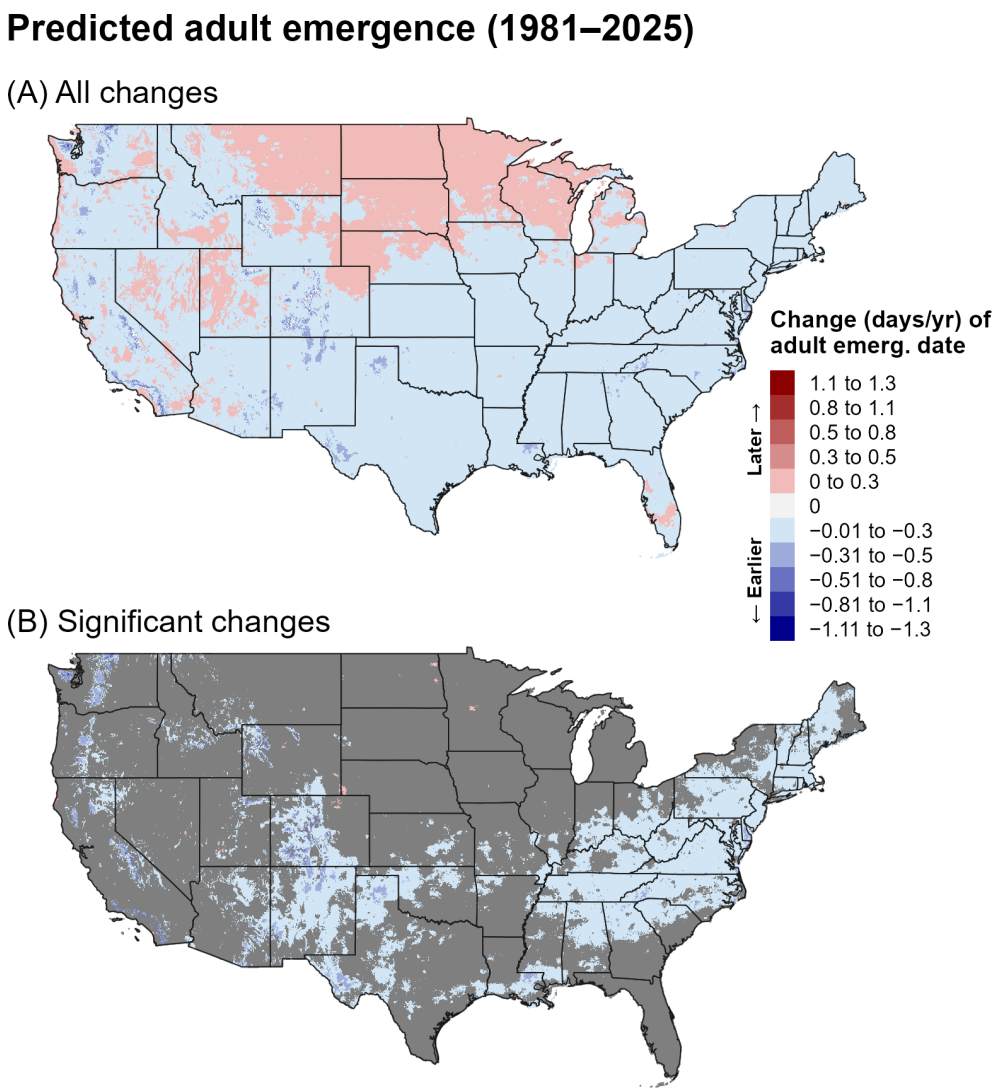

Figure 12. Changes (days/year) in predicted dates of first adult emergence for ASRB across the CONUS over the entire 44-year period (1981–2025). Maps show (A) all changes and (B) statistically significant changes ($P < 0.1$); areas shown in gray are not statistically significant.

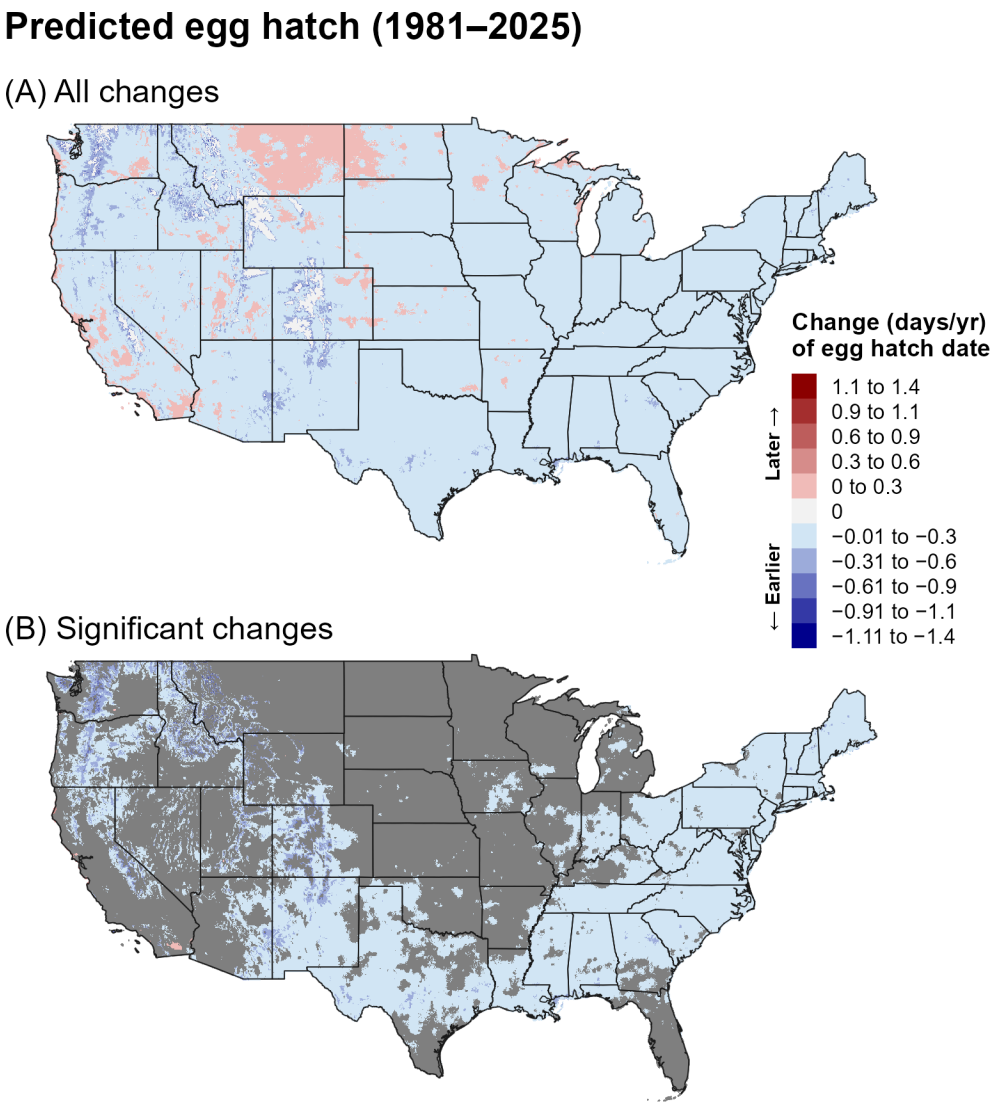

Figure 13. Changes (days/year) in predicted dates of first egg hatch for ASRB across the CONUS over the entire 44-year period (1981–2025). Maps show (A) all changes and (B) statistically significant changes ($P < 0.1$); areas shown in gray are not statistically significant.

Recent period: 2001–2025

Trends in predictions of first adult emergence and egg hatch for ASRB over the recent 24-year period (2001–2025) were partially consistent with those observed over the 1981–2025 period. In the eastern United States, significant trends towards earlier phenology were larger in magnitude but less spatially extensive (Figure 14, Figure 15), whereas most trends in the West were not significant. In contrast to the longer-term trends, isolated areas of the interior West, primarily in the southern Intermountain West, showed trends toward later phenological events.

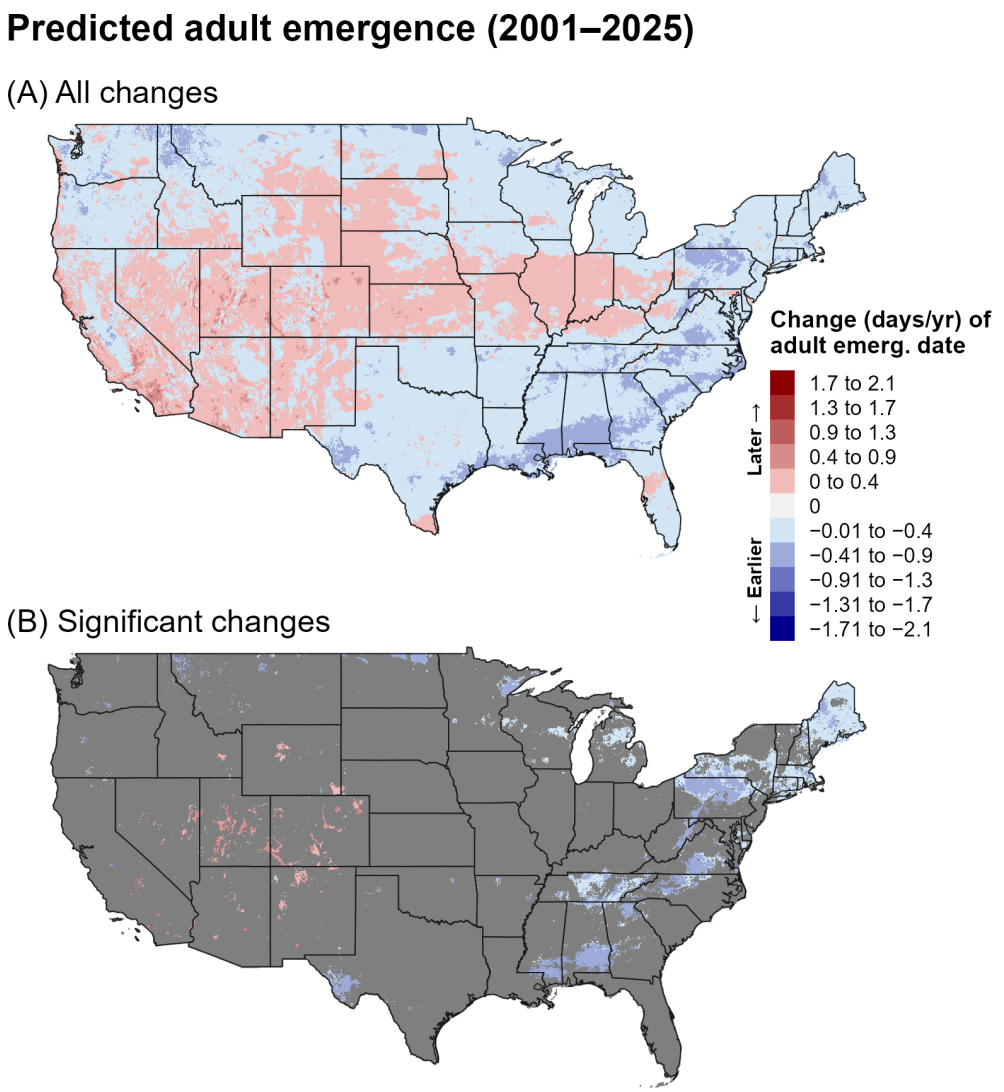

Figure 14. Changes (days/year) in predicted dates of first adult emergence for ASRB across the CONUS over the recent 24-year period (2001–2025). Maps show (A) all changes and (B) statistically significant changes ($P < 0.1$); areas shown in gray are not statistically significant.

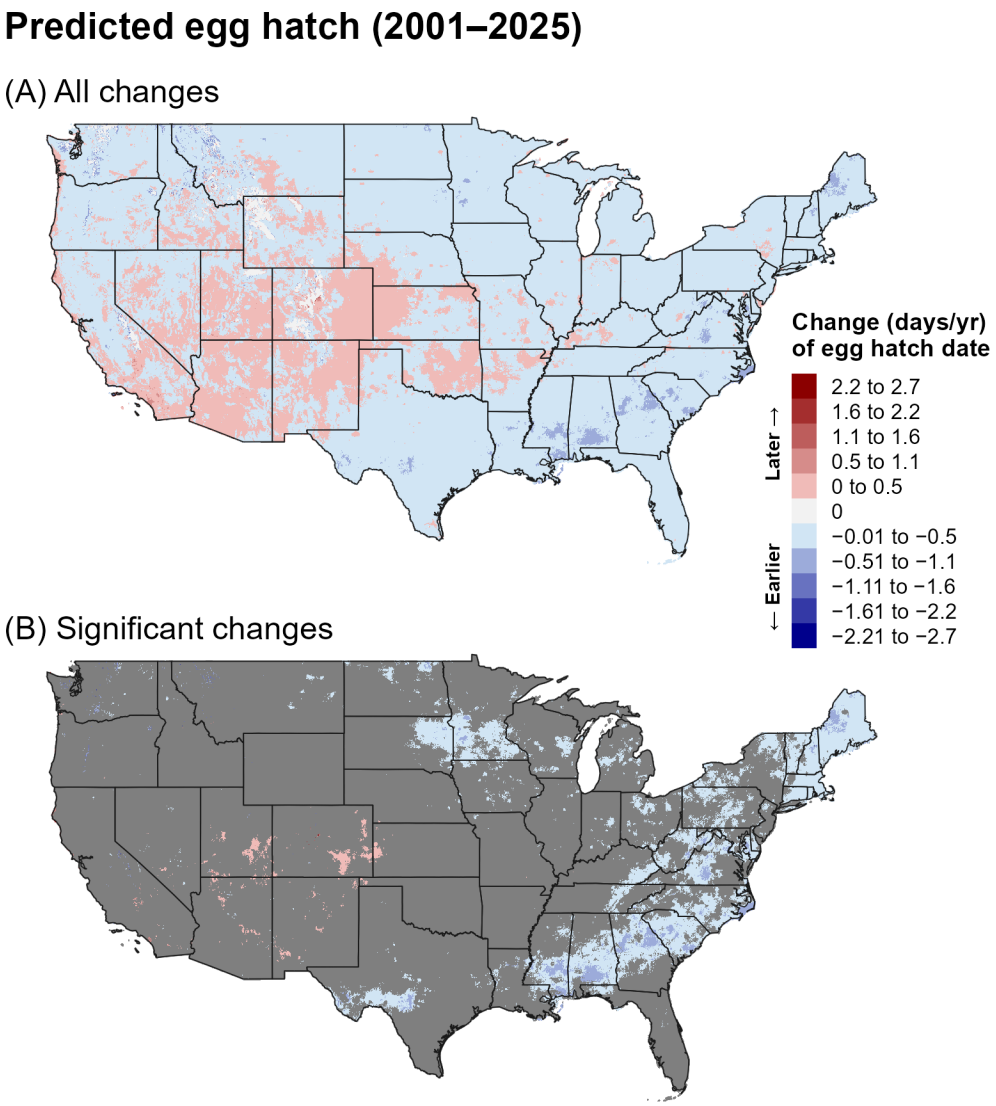

Figure 15. Changes (days/year) in predicted dates of first egg hatch for ASRB across the CONUS over the recent 24-year period (2001–2025). Maps show (A) all changes and (B) statistically significant changes ($P < 0.1$); areas shown in gray are not statistically significant.

ii. Climatic suitability

Entire period: 1981–2025

Over the entire 44-year period (1981–2025), predicted cold stress for ASRB decreased significantly across the northern United States, including portions of the Great Lakes region and northeastern United States, as well as parts of the Rocky Mountains (Figure 16). When annual accumulated stress units exceed limits specified in DDRP models, climatic suitability may change. However, changes in stress units for ASRB did not correspond to widespread shifts in suitability; only a small area of Arizona showed a significant decrease in predicted suitability (Figure 18).

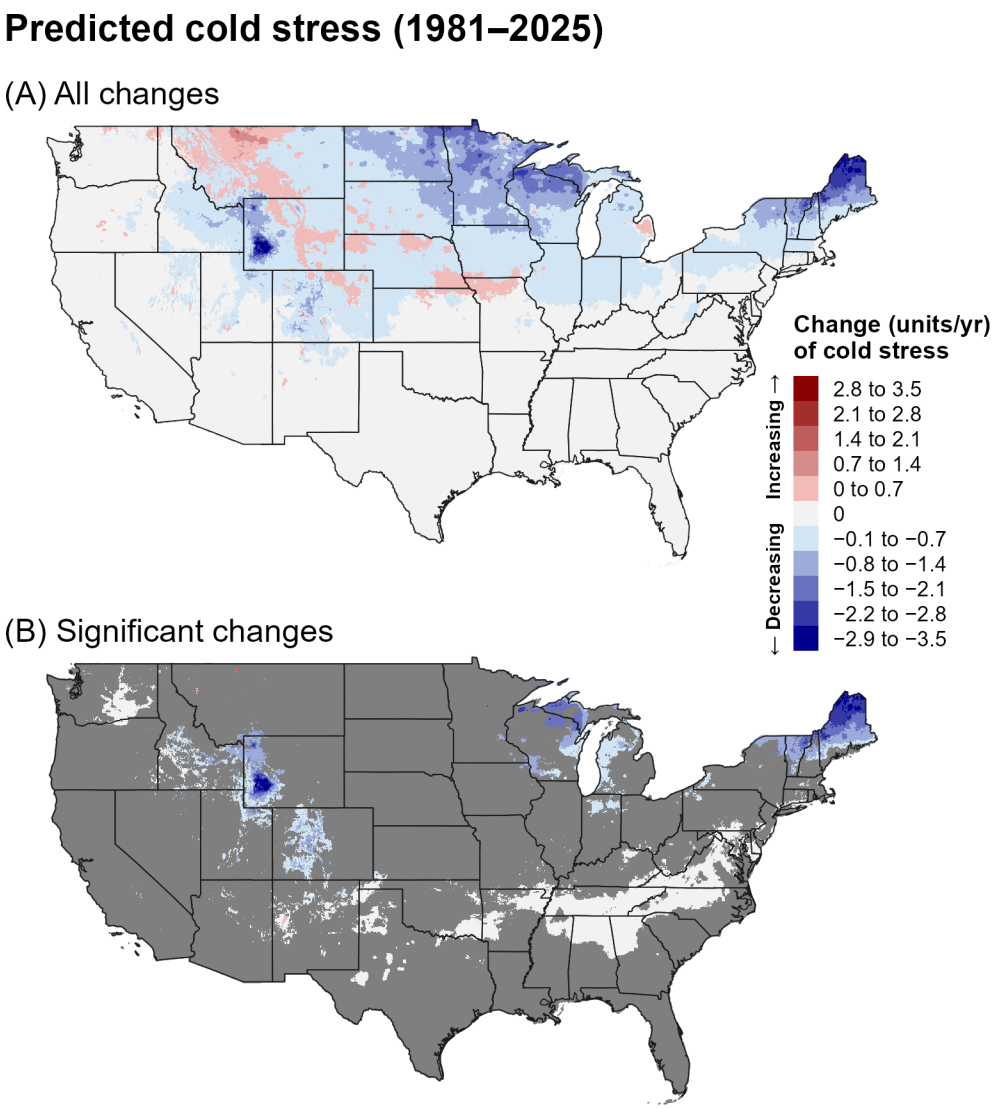

Figure 16. Changes (units/year) in predicted cold stress for ASRB across the CONUS over the entire 44-year period (1981–2025). Maps show (A) all changes and (B) statistically significant changes ($P < 0.1$); areas shown in gray are not statistically significant. Areas shown as 0 in (B) had significant trends but very small changes.

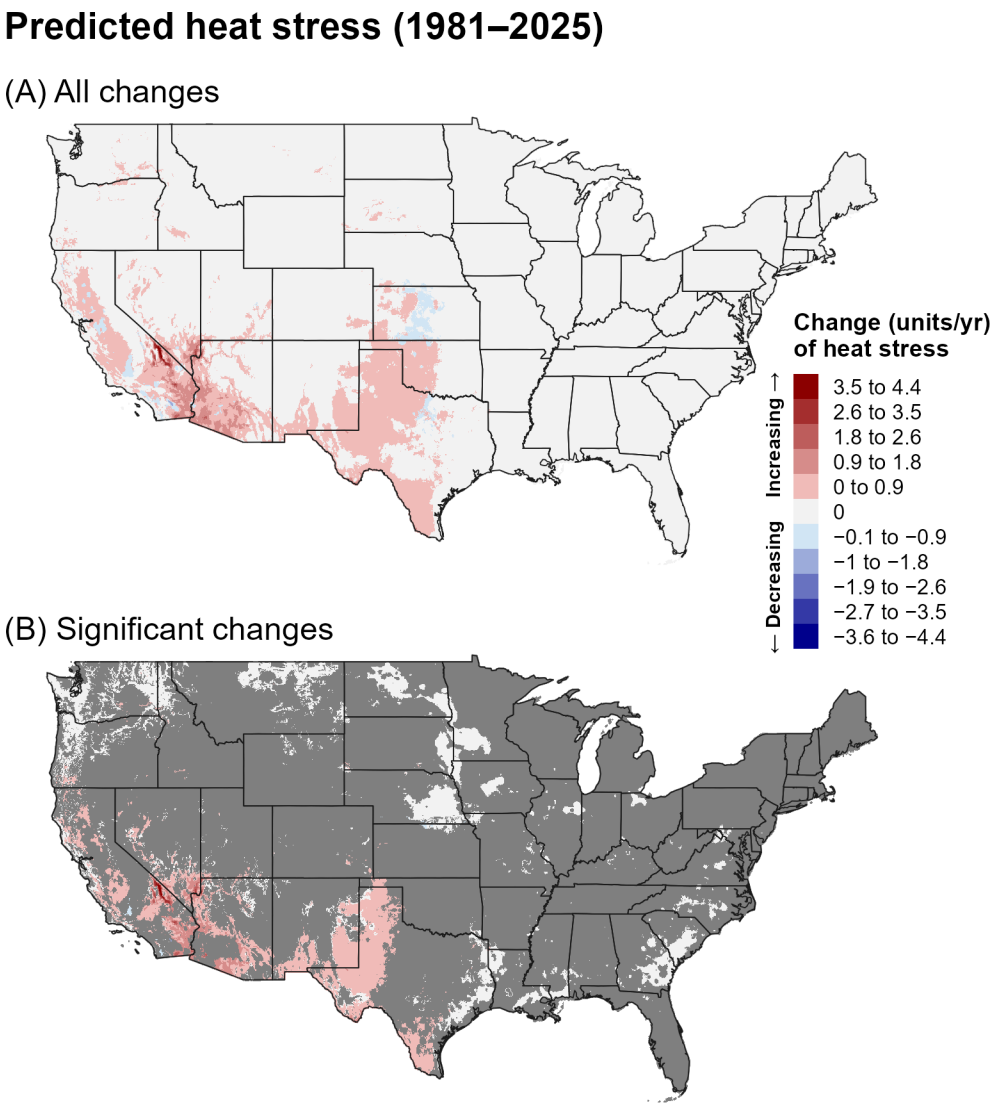

Figure 17. Changes (units/year) in predicted heat stress for ASRB across the CONUS over the entire 44-year period (1981–2025). Maps show (A) all changes and (B) statistically significant changes ($P < 0.1$); areas shown in gray are not statistically significant. Areas shown as 0 in (B) had significant trends but very small changes.

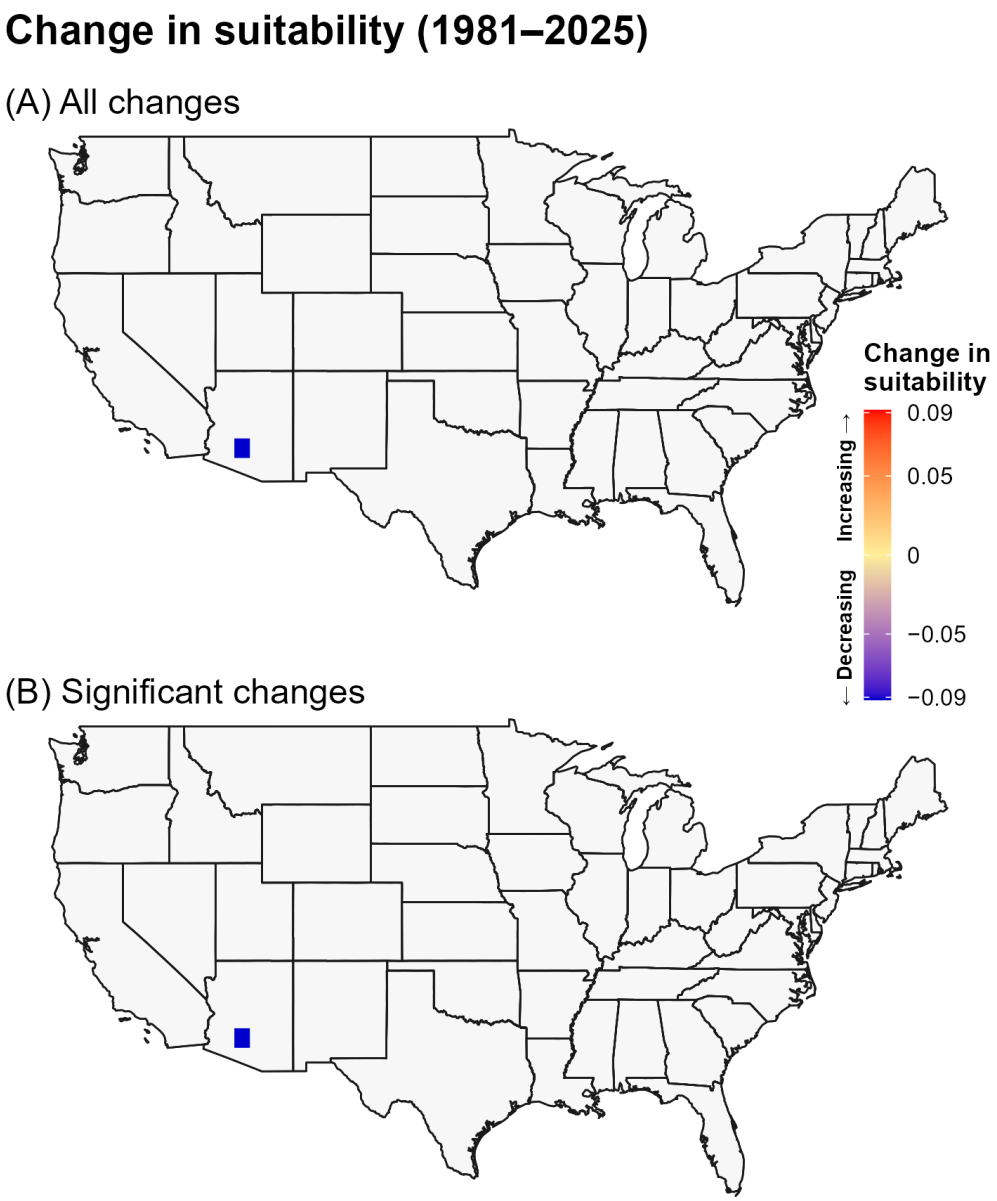

Figure 18. Changes in predicted climatic suitability for ASRB across the CONUS over the 44-year period (1981–2025). Suitability is defined as areas not excluded by cold and heat stress. Positive changes (warmer colors) indicate an increased likelihood of establishment, whereas negative changes (cooler colors) indicate a decreased likelihood of establishment.

Recent period: 2001–2025

Many areas that exhibited significant decreases in cold stress for ASRB over 1981–2025 no longer showed significant trends during the recent period, while significant increases in predicted cold stress emerged across portions of the northern and central Great Plains (Figure 19). Significant increases in heat stress were more localized to the Southwest, whereas parts of California showed significant decreases (Figure 20). As in the 1981–2025 analysis, significant changes in climatic suitability were limited to a small area of Arizona (Figure 21), indicating that predicted establishment suitability remained relatively stable across most of the CONUS.

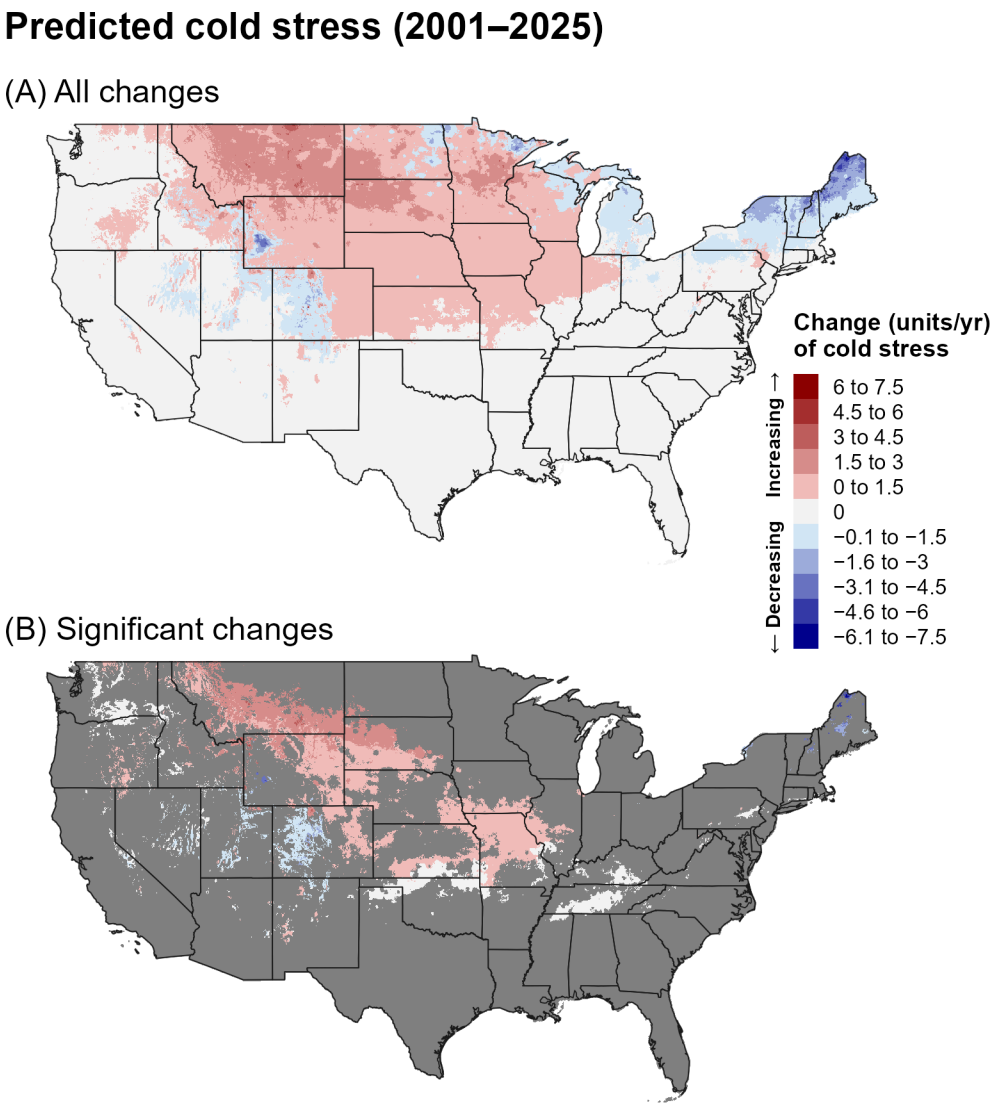

Figure 19. Changes (units/year) in predicted cold stress for ASRB across the CONUS over the recent 24-year period (2001–2025). Maps show (A) all changes and (B) statistically significant changes ($P < 0.1$); areas shown in gray are not statistically significant. Areas shown as 0 in (B) had significant trends but very small changes.

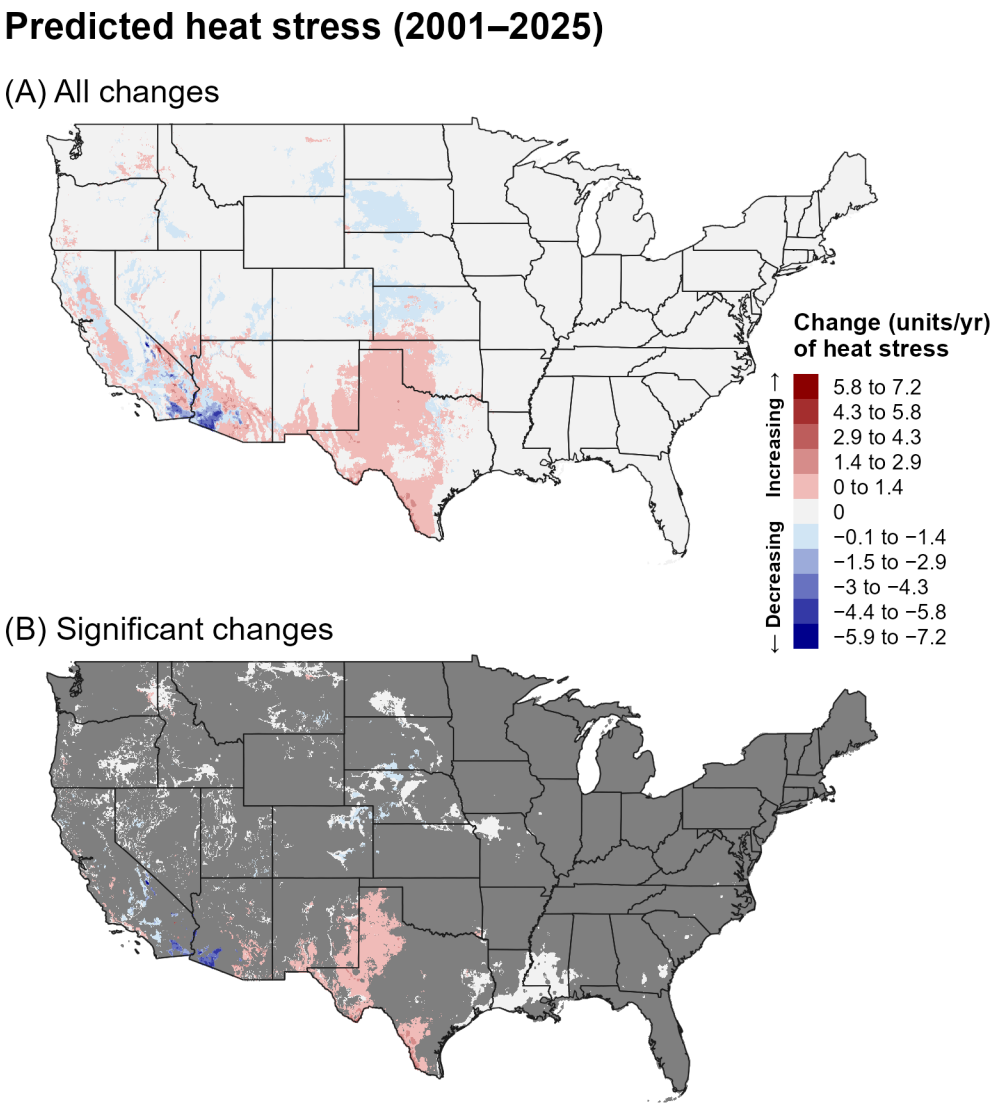

Figure 20. Changes (units/year) in predicted heat stress for ASRB across the CONUS over the recent 24-year period (2001–2025). Maps show (A) all changes and (B) statistically significant changes ($P < 0.1$); areas shown in gray are not statistically significant. Areas shown as 0 in (B) had significant trends but very small changes.

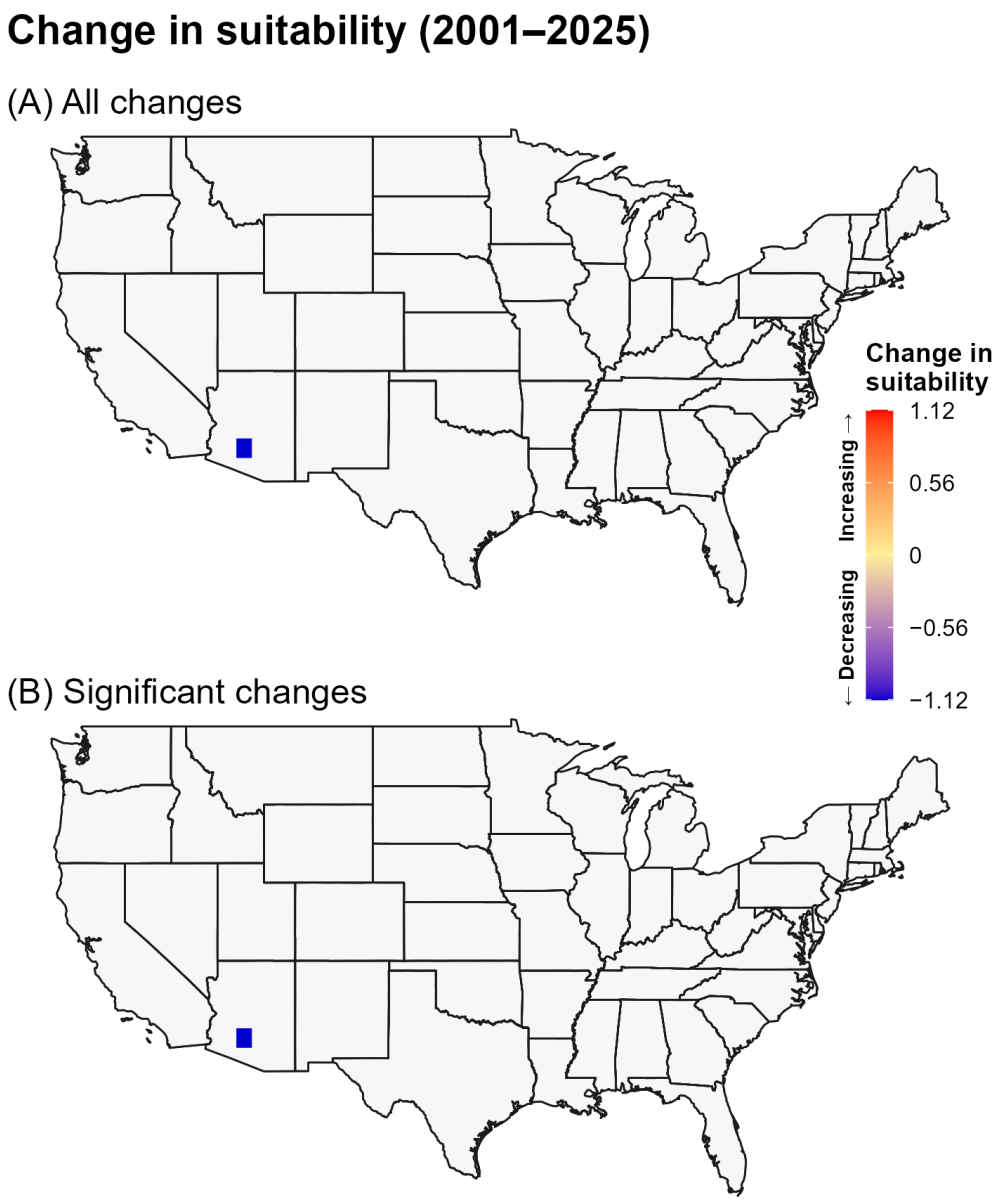

Figure 21. Changes in predicted climatic suitability for ASRB across the CONUS over the recent 24-year period (2001–2025). Suitability is defined as areas not excluded by cold and heat stress. Positive changes (warmer colors) indicate an increased likelihood of establishment, whereas negative changes (cooler colors) indicate a decreased likelihood of establishment.

2C. Discussion

Although ASRB is not established in the CONUS, understanding predicted changes in phenology can inform surveillance planning. In areas with earlier phenological events, predicted dates shifted earlier by approximately 0.01–0.5 days per year, suggesting that surveillance materials may need to be deployed earlier in the season. The southern United States warrants particular attention because it includes major rice-producing states, such as Louisiana, Texas, and Arkansas, where surveillance could help detect potential introductions into areas with suitable host crops.

Although warmer growing-season temperatures can advance ASRB emergence and increase voltinism,

temperature effects on development and overwintering are context dependent. ASRB is univoltine in cooler parts of its native range, such as northern Japan, where shortening day lengths serve as the primary environmental cue for larvae to enter winter diapause. In contrast, populations in warmer regions, including Taiwan, can complete 5–6 generations annually and typically lack diapause (Kiritani and Iwao 1967, Ramoneda and Roig 1993, Tsumuki et al. 1994). Genetic differentiation among ASRB populations in China is also associated with geographic variation in voltinism (Meng et al. 2008). Warmer growing-season temperatures have been linked to earlier emergence and spring flight, increased voltinism (Lee 2014), and greater pupal weight and fecundity (Fu et al. 2016, Huang et al. 2018). However, experimental studies found that warmer winter temperatures (10 °C versus 1 and 5 °C) reduced pupation rates, pupal weight, and post-diapause reproductive potential (Xiao et al. 2017). Collectively, these findings suggest that the effects of temperature on ASRB development and population dynamics depend on seasonal conditions and geographic context, underscoring the importance of considering both phenological shifts and climatic suitability when prioritizing surveillance.

The climate-stress maps showed regional changes in both cold and heat stress, but these changes produced little statistically significant change in predicted climatic suitability. This distinction is important because changes in individual stress variables do not necessarily translate into changes in establishment likelihood when the modeled conditions remain within the suitable range. Decreasing cold stress in portions of the northern United States and could reduce a temperature-related limitation on establishment, whereas increasing heat stress in parts of the Southwest and California could impose greater climatic constraints. However, because the climatic-suitability maps showed very few significant changes, these stress trends did not translate into widespread changes in predicted establishment likelihood.

The stronger and more spatially extensive trends in predicted phenology and climate stress over the entire 44-year period likely reflect both the greater number of years included, which may reduce interannual variability and improve the detection of directional trends, and differences in the underlying climatic trends between the two study periods. In particular, the recent 24-year period may capture climate variability or regional trends that differ from those observed over the longer 44-year period. Thus, differences between the two periods should be interpreted as reflecting both long-term climate trends and shorter-term regional variability.

2D. References

Chen, R. Z., M. G. Klein, C. F. Sheng, Q. Y. Li, Y. Li, L. B. Li, and X. Hung. 2014. Mating disruption or mass trapping, compared with chemical insecticides, for suppression of *Chilo suppressalis* (Lepidoptera: Crambidae) in Northeastern China. Journal of Economic Entomology 107:1828–1838.

Childs, N. 2025. Rice Outlook: August 2025. United States Department of Agriculture, Economic Research Service, RCS-25G. August 14, 2025. Available at: https://www.ers.usda.gov/media/10743/rcs-25g.pdf?v=71521 (accessed 3 September 2026).

Coop, L., and B. S. Barker. 2020. Phenology/degree-day model analysis: Asiatic rice borer (). Prepared for Animal and Plant Health Inspection Service (APHIS) – Plant Protection and Quarantine (PPQ). Available at: https://uspest.org/wea/Chilo_suppressalis_model.pdf (accessed 21 July 2025).

Cooperative Agricultural Pest Survey (CAPS). 2025. CPHST Pest Datasheet for *Chilo suppressalis*. USDA-APHIS-PPQ-CPHST. Available at: https://caps.ceris.purdue.edu/wp-content/uploads/2025/07/Chilo-suppressalis_v1.pdf (accessed 21 July 2025).

EPPO. 2019. *Chilo suppressalis*. EPPO datasheets on pests recommended for regulation. Available at: https://gd.eppo.int/ (accessed 21 July 2025).

Fu, D. M., H. M. He, C. Zou, H. J. Xiao, and F. Sen Xue. 2016. Life-history responses of the rice stem borer *Chilo suppressalis* to temperature change: Breaking the temperature–size rule. Journal of Thermal Biology 61:115–118.

Kiritani, K., and S. Iwao. 1967. The Biology and Life Cycle of *Chilo suppressalis* (Walker) and *Tryporyza* (Schoenobius) *incertulas* (Walker) in temperate-climate areas. Pages 45–101 in The Major Insect Pests

of the Rice Plant, Proceedings of a Symposium at The International Rice Research Institute, September, 1964. John Hopkins Press, Baltimore, Maryland.
Lee, H. 2014. Prediction of phenological changes of *Chilo suppressalis* (Walker) (Lepidoptera: Pyralidae) under global warming. Masters thesis, Seoul National University, Seoul, South Korea.
Meng, X. F., M. Shi, and X. X. Chen. 2008. Population genetic structure of *Chilo suppressalis* (Walker) (Lepidoptera: Crambidae): Strong subdivision in China inferred from microsatellite markers and mtDNA gene sequences. Molecular Ecology 17:2880–2897.
Muralidharan, K., and I. C. Pasalu. 2006. Assessments of crop losses in rice ecosystems due to stem borer damage (Lepidoptera: Pyralidae). Crop Protection 25:409–417.
Rahman, M. T., M. Khalequzzaman, and M. A. R. Khan. 2004. Assessment of infestation and yield loss by stem borers on variety of rice. Journal of Asia-Pacific Entomology 7:89–95.
Ramoneda, J., and J. Roig. 1993. Characteristics of the larval development of the rice stem borer, *Chilo suppressalis* Walker (Lepidoptera: Crambidae) in the Ebro Delta (Northeastern Spain). Applied Entomology and Zoology 28:267–273.
Tsumuki, H., T. Take, K. Kanehisa, T. Saito, and Y. Chu. 1994. Effect of temperature on the development and voltinism of the rice stem borer, *Chilo suppressalis*. European Journal of Entomology 91:447–479.
Xiao, H., J. Chen, L. Chen, C. Chen, and S. Wu. 2017. Exposure to mild temperatures decreases overwintering larval survival and post-diapause reproductive potential in the rice stem borer *Chilo suppressalis*. Journal of Pest Science 90:117–125.
Huang, X., L. Xiao, H. He, and F. Xue. 2018. Effect of rearing conditions on the correlation between larval development time and pupal weight of the rice stem borer, *Chilo suppressalis*. Ecology and Evolution 8:12694–12701.
Solis, M. A. 2006. Key to Selected Pyraloidea (Lepidoptera) Larvae Intercepted at United States Ports of Entry: Revision of Pyraloidea in "Keys to Some Frequently Intercepted Lepidopterous Larvae" by Weisman 1986. Agricultural Research Service, United States Department of Agriculture.

3. Honeydew moth

3A. Introduction

Native to the Mediterranean region, the honeydew moth, *Cryptoblabes gnidiella* (CGN) (Lepidoptera: Pyralidae), can act as both a primary and secondary pest of numerous economically important crops, including avocado, citrus, corn, cotton, grape, loquat, pomegranate, rice, and wheat throughout Asia, Oceania, the Middle East, and Europe (Silva and Mexia 1999, Molet 2013). It is commonly associated with coccoids and pseudococcids, which produce honeydew that serves as a food source for its larvae, although it can also directly damage the fruit of certain host plants (Avidov and Gothilf 1960, Yehuda et al. 1991, Silva and Mexia 1999, Molet 2013). The species has spread widely across southern Europe, parts of Africa, and several regions worldwide, including Brazil, Fiji, India, Malaysia, New Zealand, Uruguay, and Hawaii in the United States (EPPO 2025, Molet 2013). Although it has not become established in the contiguous United States (CONUS), it is frequently intercepted at ports of entry, often originating from countries where its establishment has not been documented (Molet 2013, Velez-Gavilan 2023).

A model for CGN developed for the Degree-Day, establishment Risk, and Phenological event mapping system (DDRP) is operationalized to produce near real-time forecasts for the CONUS at https://uspest.org/DDRP. The full set of model parameters for CGN, including developmental temperature thresholds, degree-day requirements for individual life stages, and climate stress thresholds and limits, are available at USPest.org (Barker and Coop 2019).

3B. Results

i. Phenology

Entire period: 1981–2025

Trends in predicted first adult emergence and egg hatch for CGN over the 44-year period (1981–2025) were predominantly negative, indicating that both phenological events shifted earlier over time. Earlier phenology was spatially extensive, occurring across most of the CONUS (Figure 22, Figure 23). Statistically significant trends were more spatially restricted, occurring primarily in portions of the southern and eastern United States and in scattered areas of the West. Within these regions, predicted adult emergence and egg hatch shifted earlier by approximately 0.01–0.8 days per year, with some of the largest shifts occurring at higher elevations in the West. Trends toward later phenology occurred in a some isolated areas of the West but most were not statistically significant.

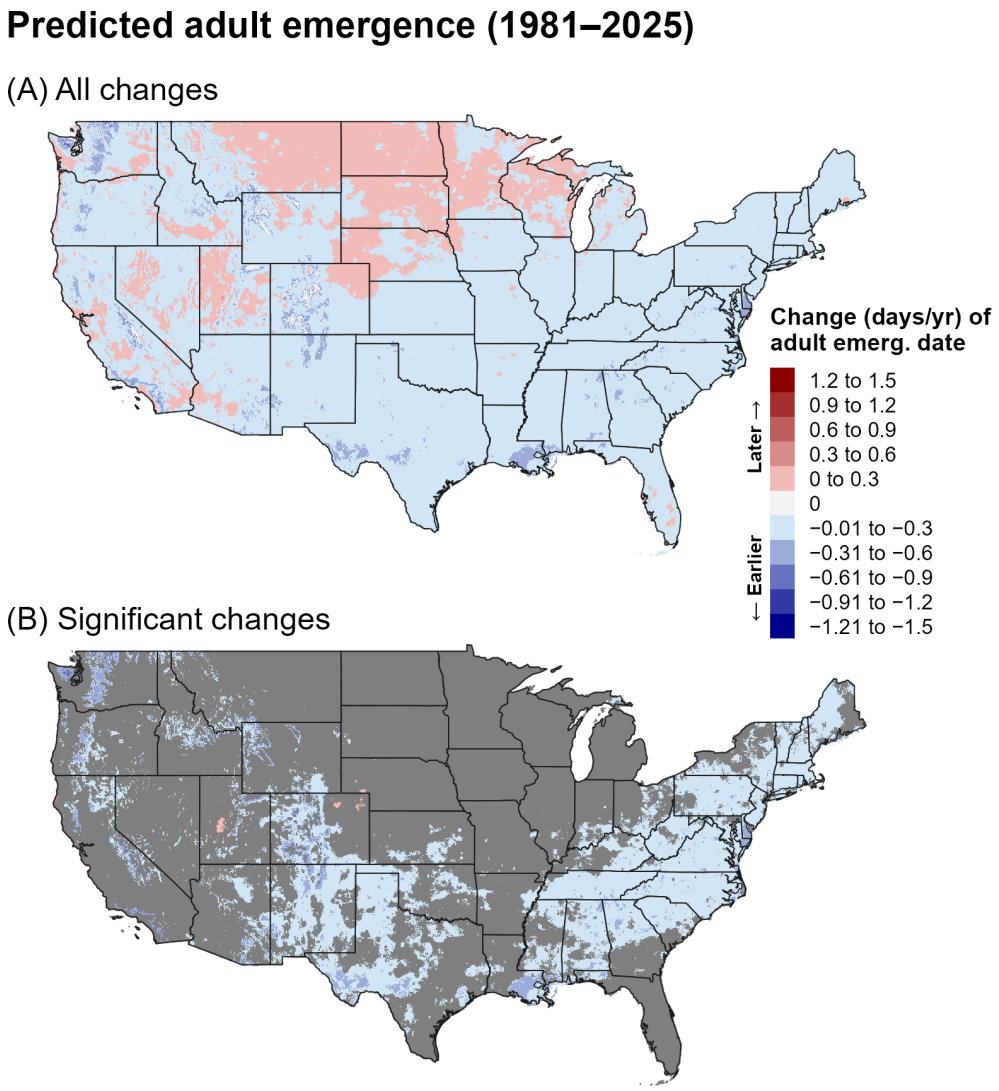

Figure 22. Changes (days/year) in predicted dates of first adult emergence for CGN across the CONUS over the entire 44-year period (1981–2025). Maps show (A) all changes and (B) statistically significant changes ($P < 0.1$); areas shown in gray are not statistically significant.

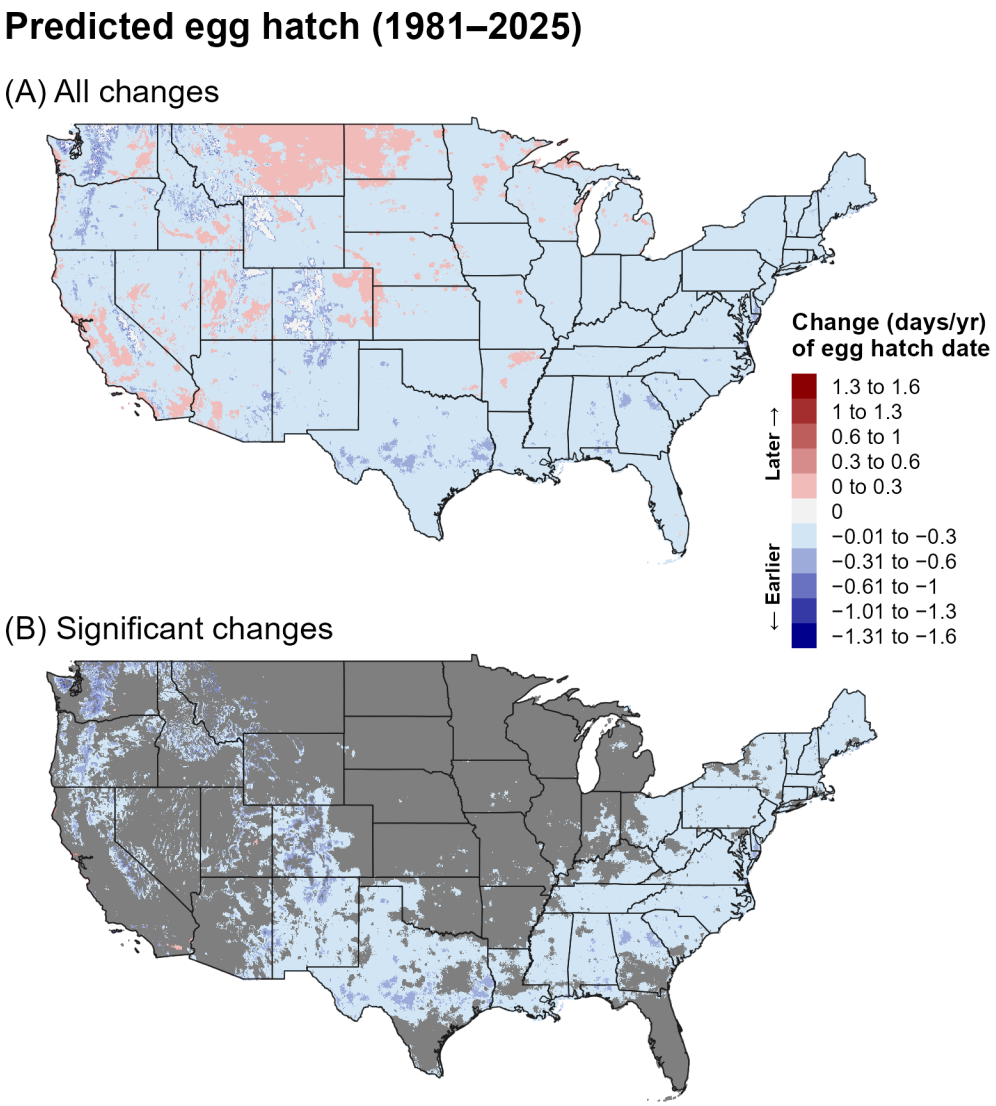

Figure 23. Changes (days/year) in predicted dates of first egg hatch for CGN across the CONUS over the entire 44-year period (1981–2025). Maps show (A) all changes and (B) statistically significant changes ($P < 0.1$); areas shown in gray are not statistically significant.

Recent period: 2001–2025

Trends in predictions of first adult emergence and egg hatch for CGN over the recent 24-year period (2001–2025) were partially consistent with those observed over the 1981–2025 period. Significant trends towards earlier phenology were similar in magnitude but less spatially extensive, occurring predominantly in parts of the upper Midwest, Northeast, and Southeast (Figure 24, Figure 25). In contrast, areas exhibiting trends toward later phenological events were somewhat larger and more spatially extensive across the West.

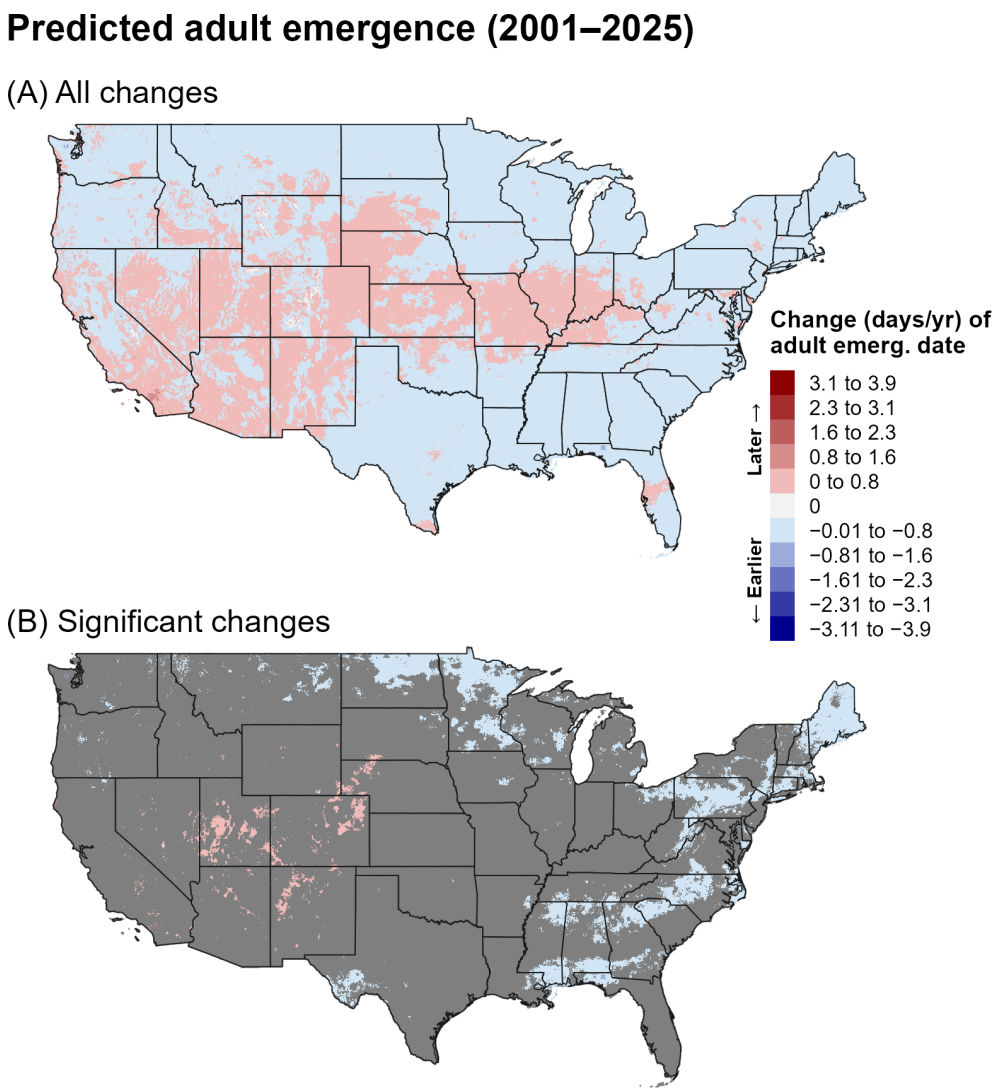

Figure 24. Changes (days/year) in predicted dates of first adult emergence for CGN across the CONUS over the recent 24-year period (2001–2025). Maps show (A) all changes and (B) statistically significant changes ($P < 0.1$); areas shown in gray are not statistically significant.

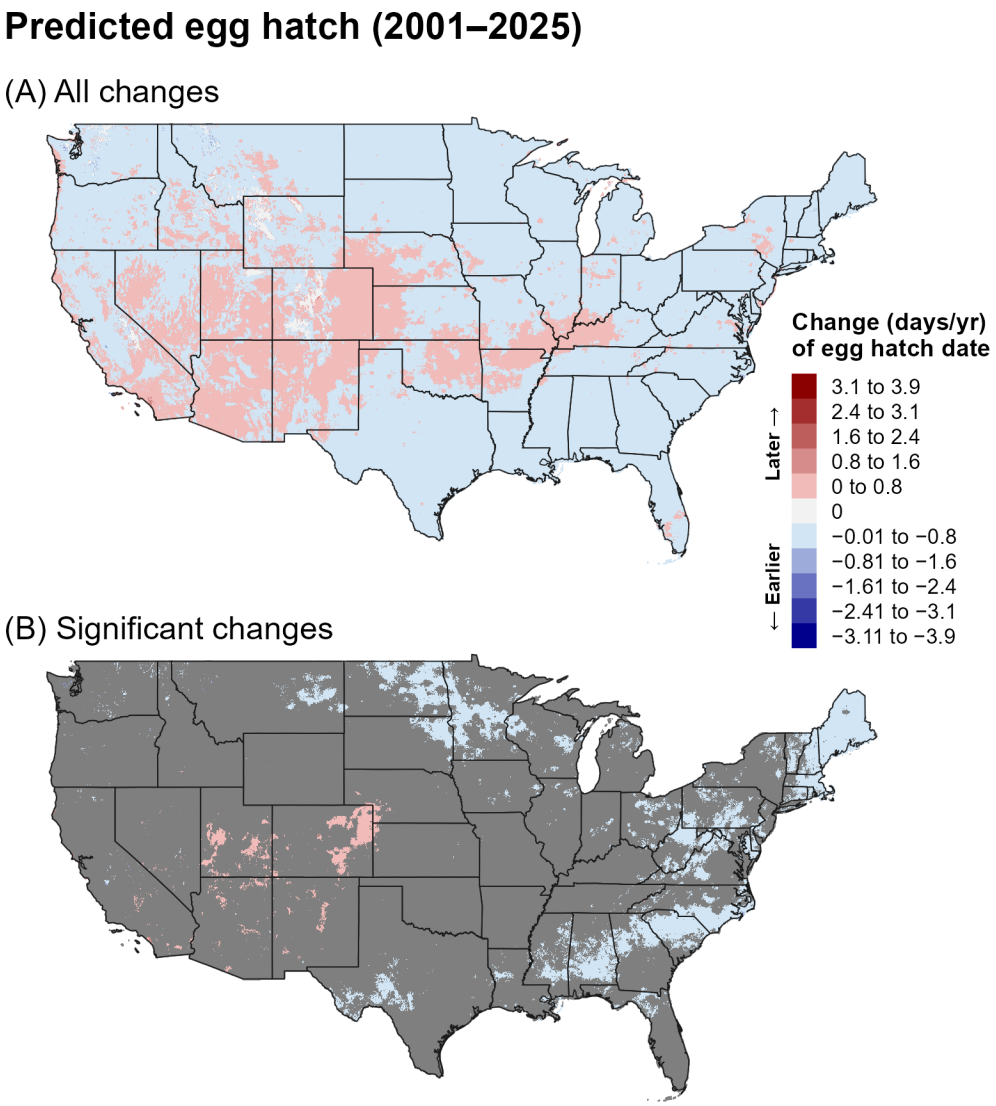

Figure 25. Changes (days/year) in predicted dates of first egg hatch for CGN across the CONUS over the recent 24-year period (2001–2025). Maps show (A) all changes and (B) statistically significant changes ($P < 0.1$); areas shown in gray are not statistically significant.

ii. Climatic suitability

Entire period: 1981–2025

Over the entire 44-year period (1981–2025), predicted cold stress for CGN decreased across broad portions of the CONUS, with the strongest changes occurring in the Northeast, upper Midwest, and Intermountain West (Figure 26). However, trends across the Great Plains and South were generally smaller and mostly nonsignificant. Predicted heat stress increased across much of the West, southern Great Plains, and parts of the Southeast, although significant trends were concentrated primarily in the West (Figure 27). However, changes in stress units for CGN did not correspond to significant shifts in climatic suitability across the CONUS (Figure 28), indicating that accumulated stress generally remained within the limits defining CGN's climatic suitability.

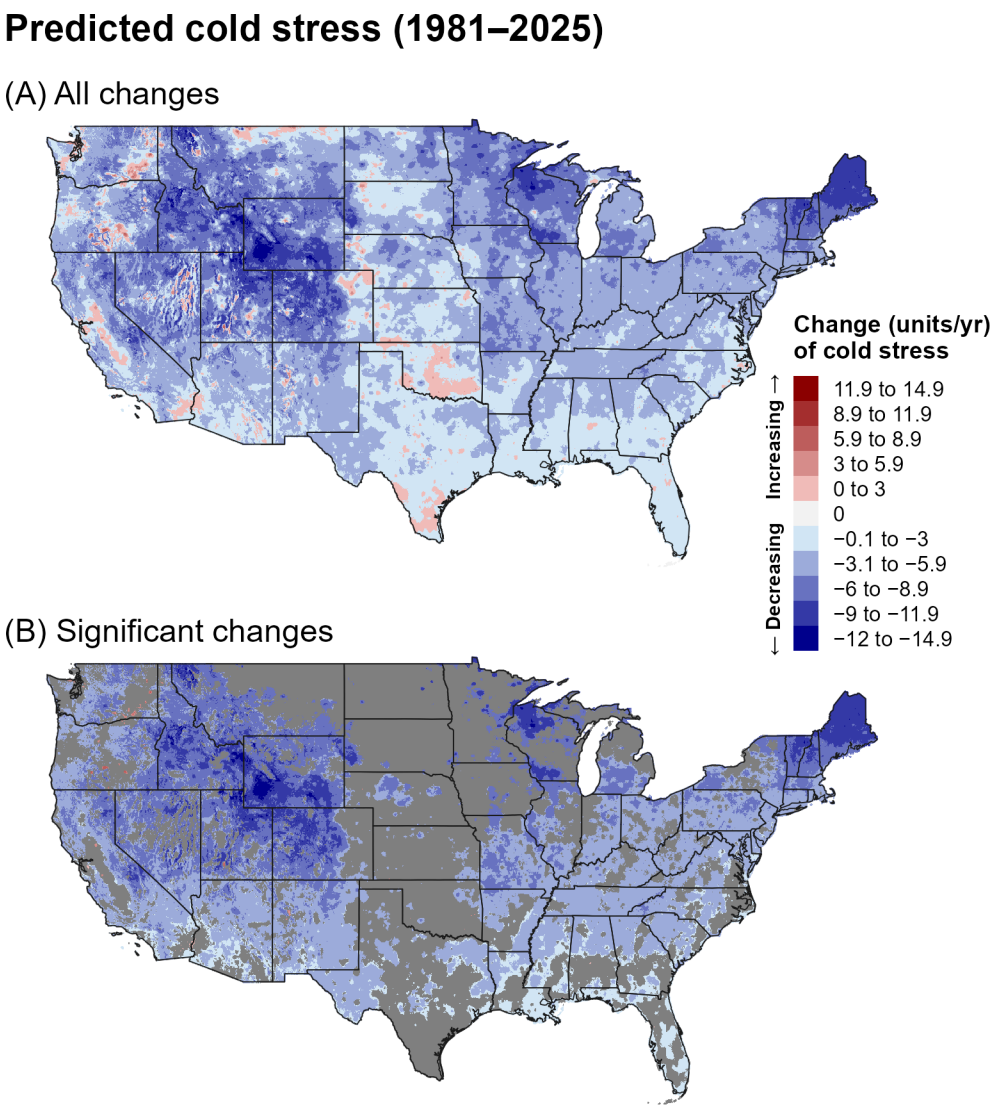

Figure 26. Changes (units/year) in predicted cold stress for CGN across the CONUS over the entire 44-year period (1981–2025). Maps show (A) all changes and (B) statistically significant changes ($P < 0.1$); areas shown in gray are not statistically significant. Areas shown as 0 in (B) had significant trends but very small changes.

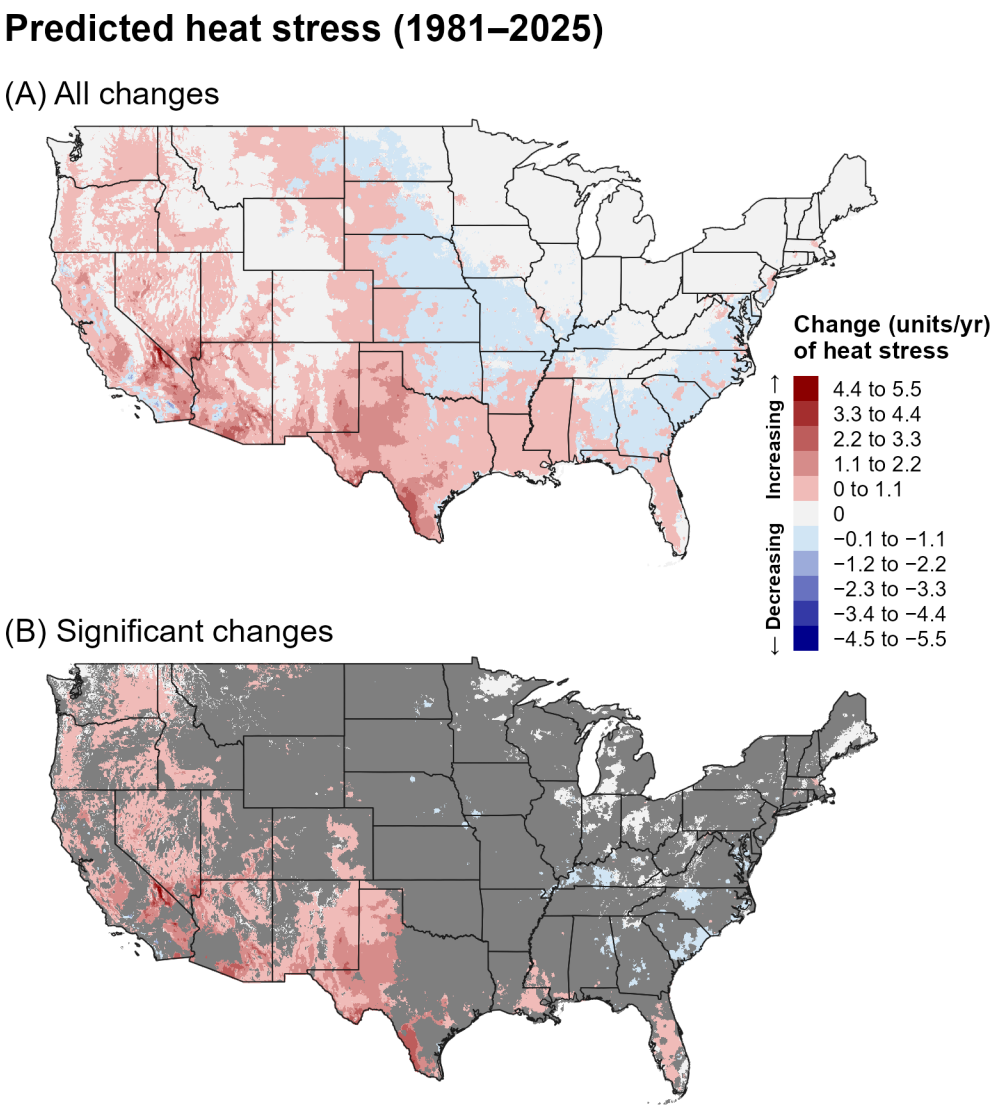

Figure 27. Changes (units/year) in predicted heat stress for CGN across the CONUS over the entire 44-year period (1981–2025). Maps show (A) all changes and (B) statistically significant changes ($P < 0.1$); areas shown in gray are not statistically significant. Areas shown as 0 in (B) had significant trends but very small changes.

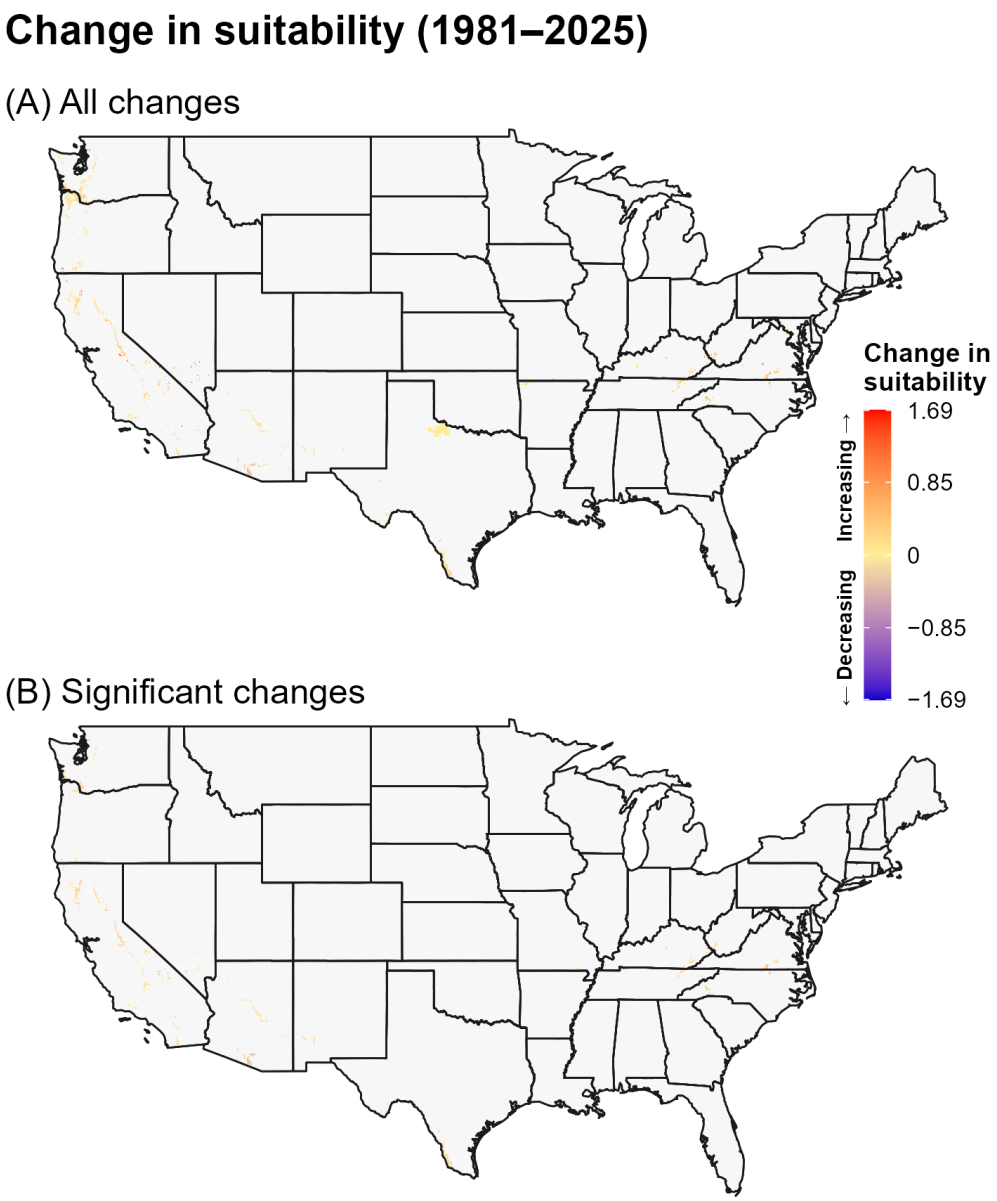

Figure 28. Changes in predicted climatic suitability for CGN across the CONUS over the 44-year period (1981–2025). Suitability is defined as areas not excluded by cold and heat stress. Positive changes (warmer colors) indicate an increased likelihood of establishment, whereas negative changes (cooler colors) indicate a decreased likelihood of establishment.

Recent period: 2001–2025

Many areas that exhibited significant decreases in cold stress for CGN over 1981–2025 no longer showed significant trends during the recent period. These areas were concentrated in scattered patches across the East and South and at higher elevations in the West (Figure 29). Significant increases in predicted cold stress occurred in a few small, isolated areas of the West. Significant increases in heat stress were concentrated in the South, particularly Texas, whereas parts of California showed significant decreases (Figure 30). As in the 1981–2025 analysis, changes in cold and heat stress did not produce significant changes in climatic suitability (Figure 31).

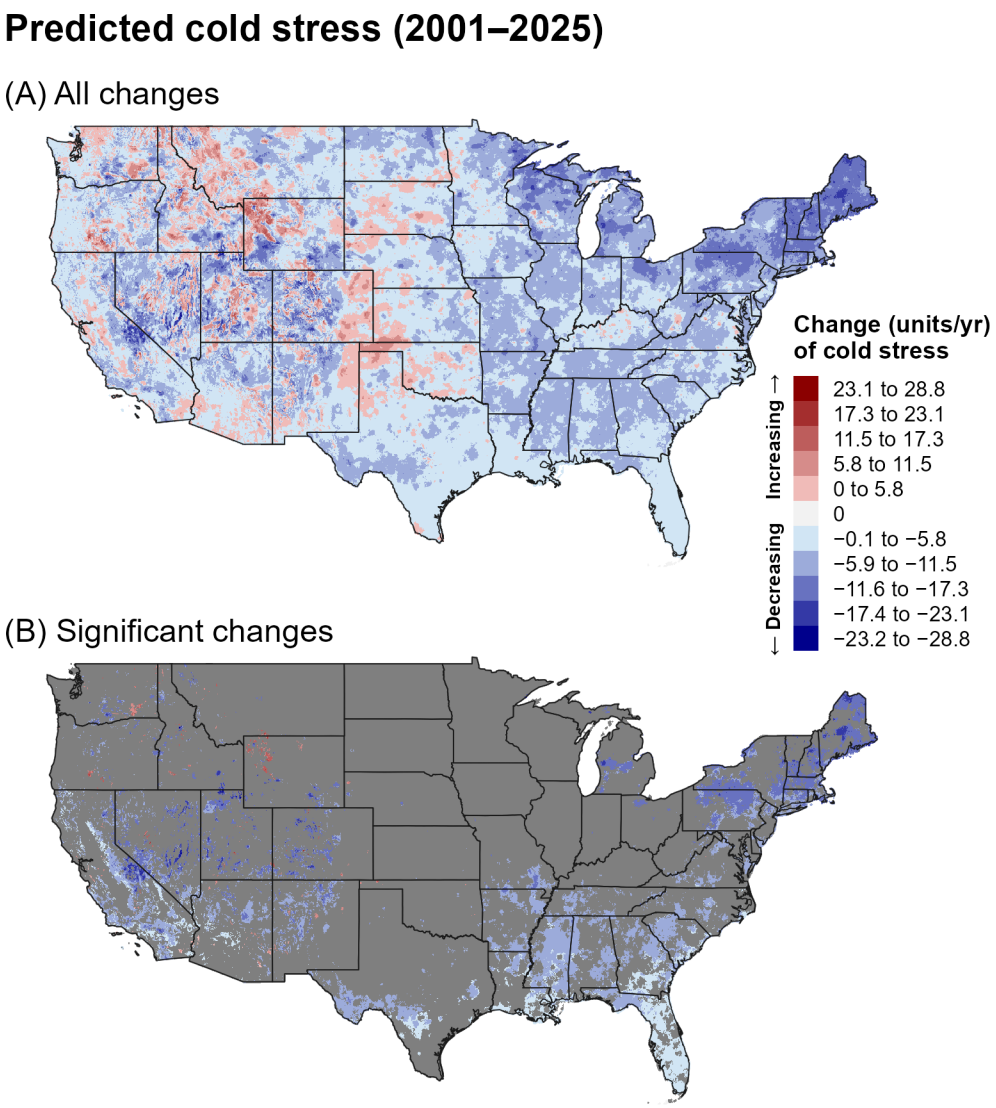

Figure 29. Changes (units/year) in predicted cold stress for CGN across the CONUS over the recent 24-year period (2001–2025). Maps show (A) all changes and (B) statistically significant changes ($P < 0.1$); areas shown in gray are not statistically significant. Areas shown as 0 in (B) had significant trends but very small changes.

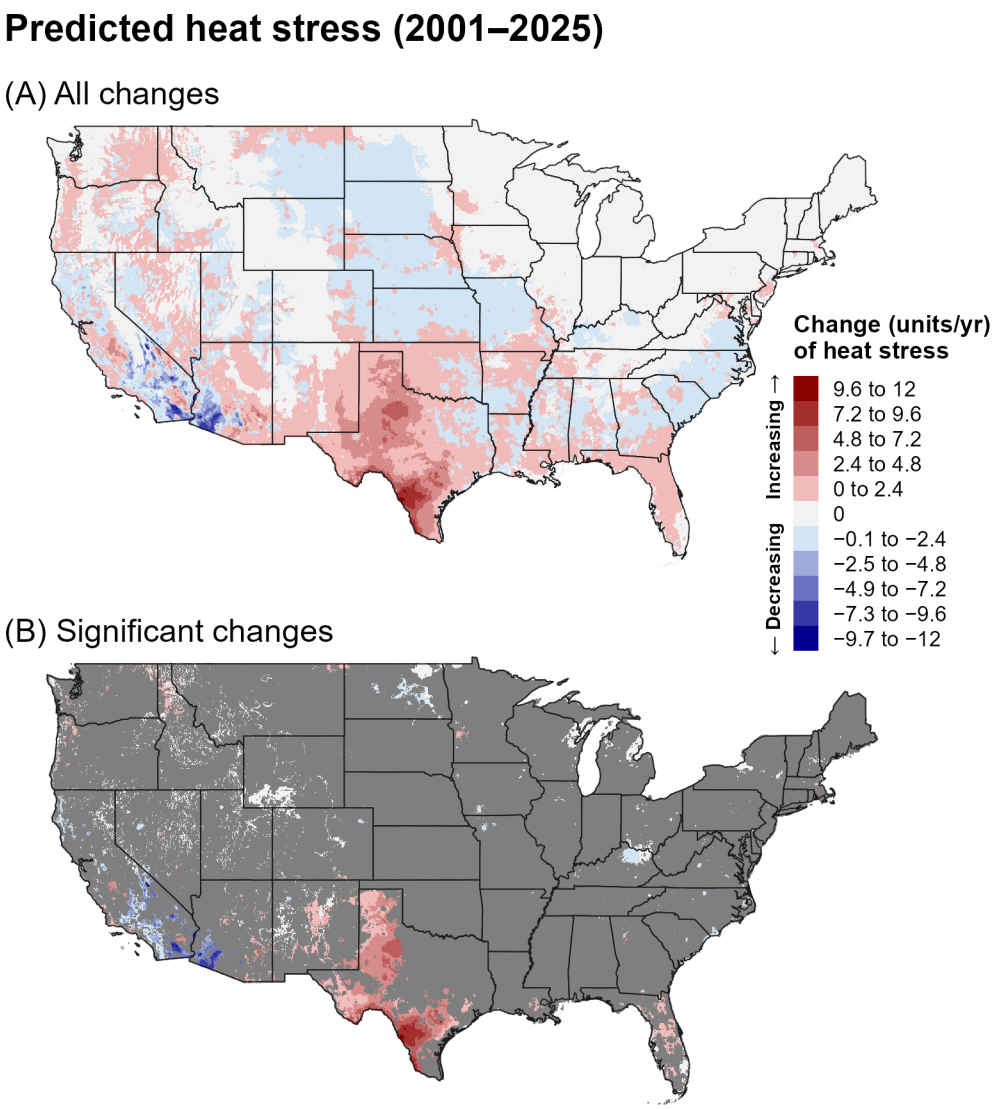

Figure 30. Changes (units/year) in predicted heat stress for CGN across the CONUS over the recent 24-year period (2001–2025). Maps show (A) all changes and (B) statistically significant changes ($P < 0.1$); areas shown in gray are not statistically significant. Areas shown as 0 in (B) had significant trends but very small changes.

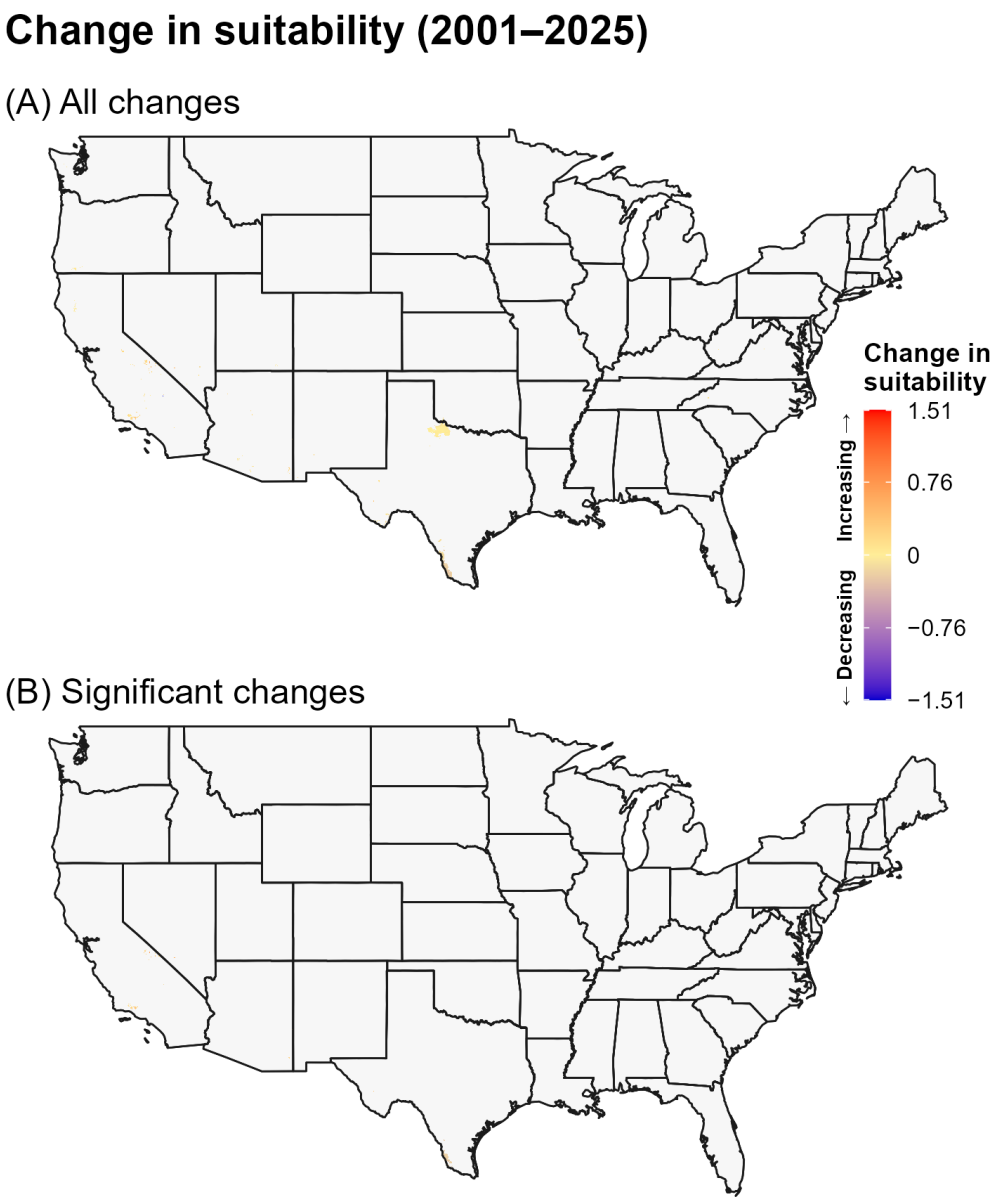

Figure 31. Changes in predicted climatic suitability for CGN across the CONUS over the recent 24-year period (2001–2025). Suitability is defined as areas not excluded by cold and heat stress. Positive changes (warmer colors) indicate an increased likelihood of establishment, whereas negative changes (cooler colors) indicate a decreased likelihood of establishment.

3C. Discussion

Although CGN is not established in the CONUS, understanding predicted changes in phenology can inform surveillance planning. In areas exhibiting significant trends toward earlier phenology, predicted dates shifted earlier by approximately 0.01–0.8 days per year, suggesting that surveillance materials may need to be deployed earlier in the season. Surveillance efforts may be particularly important where these trends overlap with major host-fruit production areas, including those supporting intensive cultivation of grapes, citrus, pomegranates, and avocados. Such areas include parts of the West and South, particularly California and Texas, as well as portions of the Gulf Coast.

Earlier adult emergence and egg hatch could potentially allow CGN to complete more generations per year, increasing pest pressure and associated crop damage. CGN lacks a true winter diapause and can complete multiple generations under warm conditions (Avidov and Gothilf 1960, Molet 2013, Lucchi et al. 2019). The number of generations completed annually therefore depends partly on whether local environmental conditions permit continued development throughout the growing season. CGN can complete as many as nine generations annually in the warmest parts of its range, such as northeastern Brazil (Ringenberg et al. 2005, Ioriatti et al. 2012, Molet 2013, Öztürk 2018, Lucchi et al. 2019, Corbetta et al. 2025). DDRP predictions indicate that CGN may complete at least one generation annually and up to eight generations in the South within climatically suitable areas (Barker and Coop 2019). These findings underscore the importance of interpreting regional trends in predicted phenology alongside climatic suitability and the potential for multiple generations, which together determine the timing and duration of seasonal CGN activity.

The climate-stress trend maps showed broad changes in both cold and heat stress, but these changes translated into statistically significant shifts in predicted climatic suitability for ECW in only a few isolated areas of California and the Southwest. The contrast between widespread climate-stress trends and limited suitability changes suggests that the modeled climatic limits remain sufficiently broad that changes in individual stress variables do not necessarily alter establishment potential. Previous modeling studies for CGN identified suitable environments for the pest throughout the South and Midwest, as well as along the West Coast, whereas cold temperatures would likely exclude the pest from colder regions, including the Intermountain West and latitudes north of *ca.* 41° N in the East (Barker and Coop 2019, Zumbado-Ulate et al. 2023). The results of this study suggest that these areas have remained suitable for CGN establishment over the study periods. However, a recent modeling study predicted increasing climatic suitability for CGN in the Mediterranean region, with suitable conditions shifting northward along the region's northern margins. These findings highlight the need for further investigation into potential shifts in CGN establishment risk across the CONUS (Rossi et al. 2026).

The stronger and more spatially extensive trends in predicted phenology and climate stress over the entire 44-year period may reflect both the larger sample size, which can reduce noise and improve detection of directional patterns, and differences in the underlying climate trends between the two time periods. In particular, the recent 24-year period may capture climate variability or regional trends that differ from those observed over the longer 44-year period. Thus, differences between the two periods should be interpreted as reflecting both long-term climate trends and shorter-term regional variability.

3D. References

Avidov, Z., and S. Gothilf. 1960. Observations on the honeydew moth (*Cryptoblabes gnidiella* Milliere) in Israel. Ktavim: Records of the Agricultural Research Station 10:109–124.

Barker, B. S., and L. Coop. 2019. Honeydew moth, *Cryptoblabes gnidiella*. Phenology/degree-day and climate suitability model analysis for USPEST.ORG. Prepared for Animal and Plant Health Inspection Service (APHIS) – Plant Protection and Quarantine (PPQ). Vs. 1.0 (12/9/2019). Available online: https://uspest.org/CAPS/Cryptoblabes_gnidiella_white_paper.pdf (accessed 21 July 2025).

Corbetta, M., G. Benelli, R. Ricciardi, V. Rossi, and A. Lucchi. 2025. Adaptation of a physiologically based demographic model for predicting the phenology of *Cryptoblabes gnidiella* with validation in Italian vineyards. Journal of Pest Science:1–14.

EPPO. 2025. *Cryptoblabes gnidiella*. EPPO datasheets on pests recommended for regulation. Available online: https://gd.eppo.int/ (accessed 11 August 2025).

Ioriatti, C., A. Lucchi, and L. G. Varela. 2012. Grape Berry Moths in Western European Vineyards and Their Recent Movement into the New World. Pages 339–359 in N. J. Bostanian, C. Vincent, and R. Isaacs, editors. Arthropod Management in Vineyards: Pests, Approaches, and Future Directions. Springer, Dordrecht.

Lucchi, A., R. Ricciardi, G. Benelli, and B. Bagnoli. 2019. What do we really know on the harmfulness of

Cryptoblabes gnidiella (Millière) to grapevine? From ecology to pest management. Phytoparasitica:1–15.
Molet, T. 2013. CPHST Pest Datasheet for *Cryptoblabes gnidiella*. USDA-APHIS-PPQ-CPHST (updated 29 July 2016). Available online: https://caps.ceris.purdue.edu/wp-content/uploads/2025/07/Cryptoblabes-gnidiella_CPHST-Pest-Datasheet_2014.pdf (accessed 4 August 2025).
Öztürk, N. 2018. Creating a degree-day model of honeydew moth [*Cryptoblabes gnidiella* (Mill., 1867) (Lepidoptera: Pyralidae)] in pomegranate orchards. Turkish Journal of Entomology 42:53–62.
Ringenberg, R., M. Botton, M. S. Garcia, and A. Nondillo. 2005. Biologia comparada e exigências térmicas de *Cryptoblabes gnidiella* em dieta artificial. Pesquisa Agropecuária Brasileira 40:1059–1065.
Rossi J, Streito J, Ipekdal K, Constant N. 2026. Climate change reshapes suitable areas for the honeydew moth *Cryptoblabes gnidiella* in the Mediterranean. Climate Change Ecology 12:100121.
Silva, E. B., and A. Mexia. 1999. The pest complex *Cryptoblabes gnidiella* (Milliére) (Lepidoptera: Pyralidae) and Planococcus citri (Risso) (Homoptera: Pseudococcidae) on sweet orange groves (Citrus sinensis (L.) Osbeck) in Portugal: Interspecific association. Boletín de sanidad vegetal 25:89–98.
Velez-Gavilan, J. 2023. *Cryptoblabes gnidiella* (honeydew moth). CABI Compendium. Available online: https://doi.org/10.1079/cabicompendium.16381 (accessed 11 August 2025).
Yehuda, S. Ben, M. Wyoski, and D. Rosen. 1991. Phenology of the honeydew moth, *Cryptoblabes gnidiella* (Milliere) (Lepidoptera: Pyralidae), on avocado in Israel. Israel Journal of Entomology XXV–XXVI:149–160.
Zumbado-Ulate H, Schartel TE, Simmons GS, Daugherty MP. 2023. Assessing the risk of invasion by a vineyard moth pest guild. NeoBiota 86:169–191.

4. Emerald ash borer

4A. Introduction

The emerald ash borer (EAB), *Agrilus planipennis* Fairmaire (Coleoptera: Buprestidae), is a flat-headed, wood-boring beetle native to eastern Asia that relies almost exclusively on ash trees (*Fraxinus* species) to complete its life cycle (Poland et al. 2015, USDA-APHIS 2025). It was first detected in North America in 2002 in Michigan and Ontario, although it likely arrived in Michigan during the early to mid-1990s (Siegert et al. 2014). EAB is now present in 37 U.S. states and six Canadian provinces (EPPO 2025, USDA-APHIS 2025). Adult beetles lay eggs in bark crevices, and upon hatching, larvae burrow into the tree to feed on the inner phloem, outer xylem, and cambium. They overwinter as larvae or pre-pupae within characteristic serpentine galleries beneath the bark (Tluczek et al. 2011, Poland et al. 2015). This feeding disrupts the tree's ability to transport water and nutrients, typically leading to tree death within several years (Knight et al. 2013). EAB's cryptic nature, in which all life stages except for the adult beetle are inside of trees, makes early detection of this pest extremely difficult (Haack et al. 2002, USDA-APHIS 2025).

Previous modeling studies indicated broad climatic suitability for EAB across North America that overlapped with the ranges of native *Fraxinus* species (DeSantis et al. 2013, Sobek-Swant et al. 2012, Liang & Fei 2014, Cuddington et al. (2018), Barker et al. 2023). All North American ash species are vulnerable to EAB, though blue ash (*F. quadrangulata* Michaux) appears to be less preferred (Poland et al. 2015). In its native range, the beetle primarily infests stressed or weakened trees, whereas in North America it readily attacks both healthy and stressed individuals, with stressed trees often supporting higher beetle densities (Poland and McCullough 2006, Tluczek et al. 2011). Other members of the olive family, such as white fringetree (*Chionanthus virginicus* L.) and olive (*Olea europaea* L.), may also serve as hosts, though survival rates on these species appear to be lower (Rutledge and Arango-Velez 2017, Peterson and Cipollini 2020). The economic impact of EAB in the United States has reached billions of dollars, and the widespread loss of ash trees has led to reduced biodiversity and the degradation of important ecosystem services (Kovacs et al. 2010, Aukema et al. 2011, Schrader et al. 2021).

A model for EAB developed for the Degree-Day, establishment Risk, and Phenological event mapping system

(DDRP) is operationalized to produce near real-time forecasts for the contiguous United States (CONUS) at https://uspest.org/DDRP. The full set of model parameters for EAB, including developmental temperature thresholds, degree-day requirements for individual life stages, and climate stress thresholds and limits, are available at USPest.org (Barker et al. 2023).

4B. Results

i. Phenology

Entire period: 1981–2025

Predicted adult emergence and egg hatch for JPB shifted significantly earlier across large portions of CONUS over the entire period (1981–2025), including most East Coast states and parts of the South and Intermountain West (Figure 32, Figure 33). In these regions, predicted adult emergence and egg hatch decreased by approximately 0.01–0.9 days per year, with some of the largest declines occurring at higher elevations in the Intermountain West. Significant changes were more spatially extensive for predicted egg hatch, encompassing much of the central United States.

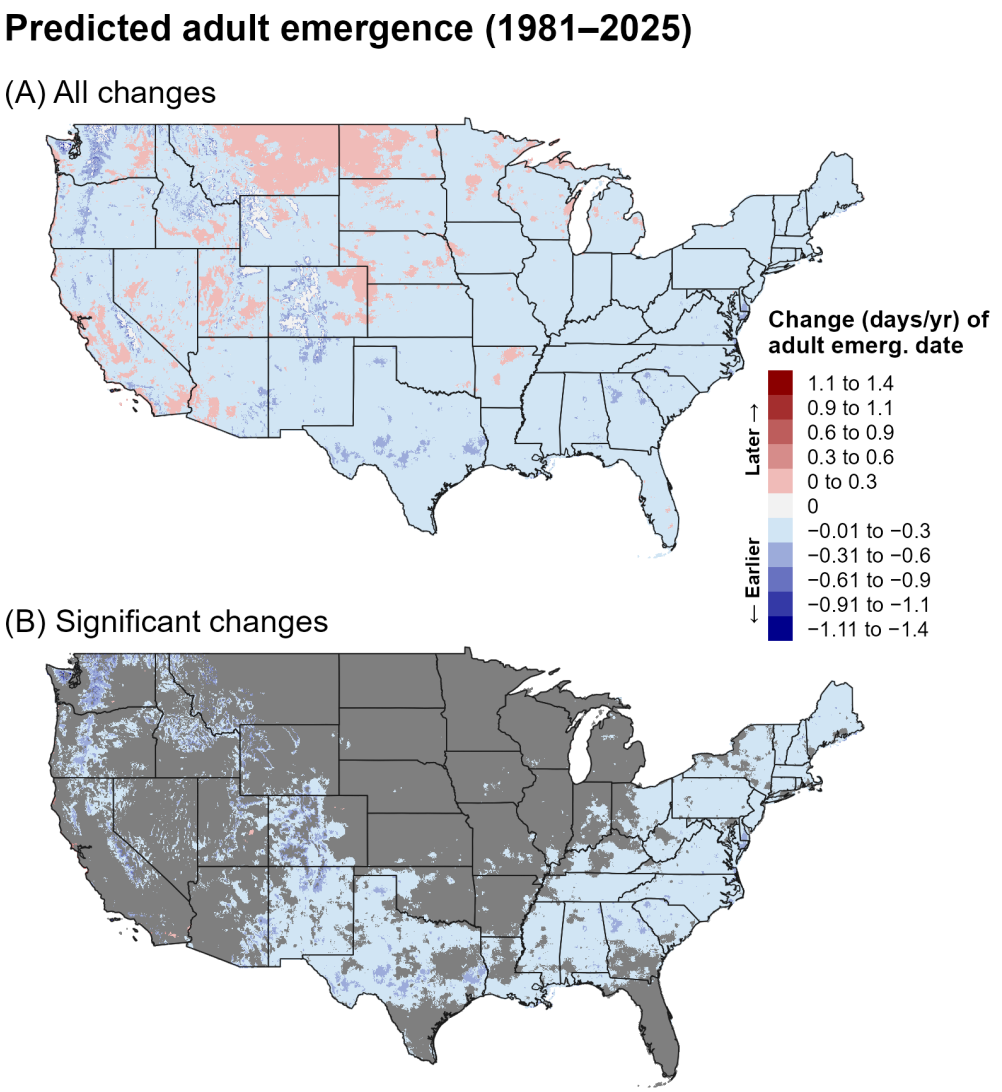

Figure 32. Changes (days/year) in predicted dates of first adult emergence for EAB across the CONUS over the entire 44-year period (1981–2025). Maps show (A) all changes and (B) statistically significant changes ($P < 0.1$); areas shown in gray are not statistically significant.

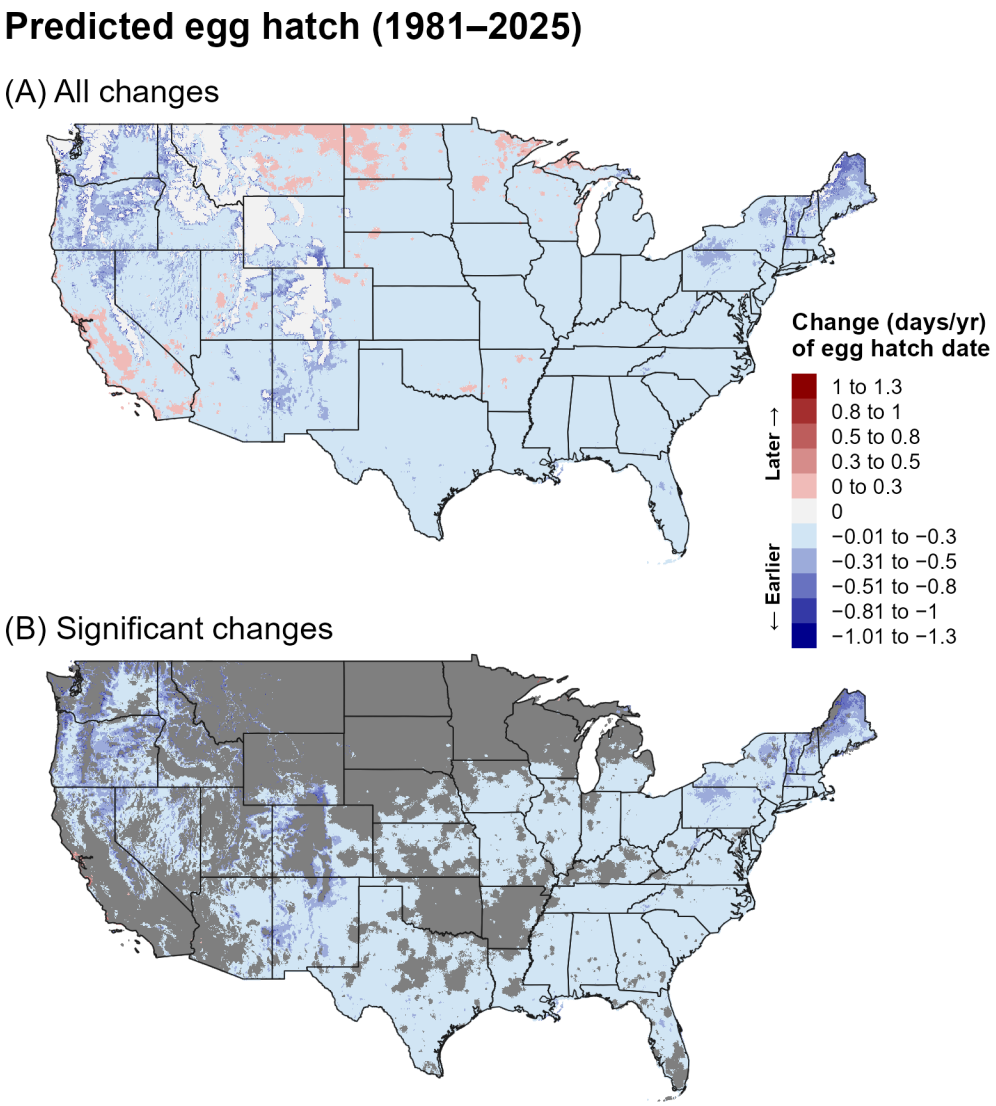

Figure 33. Changes (days/year) in predicted dates of first egg hatch for EAB across the CONUS over the entire 44-year period (1981–2025). Maps show (A) all changes and (B) statistically significant changes ($P < 0.1$); areas shown in gray are not statistically significant.

Recent period: 2001–2025

Trends in predictions of first adult emergence and egg hatch for EAB over the recent 24-year period (2001–2025) were partially consistent with those observed over the 1981–2025 period. In the East, significant trends were similar in magnitude but less spatially extensive (Figure 34, Figure 35), whereas most trends in the West were not significant. In contrast to the longer-term trends, parts of the northern Great Plains showed significant shifts toward earlier adult emergence, whereas isolated areas of the interior West, primarily in the southern Intermountain West, exhibited significant trends toward later phenological events.

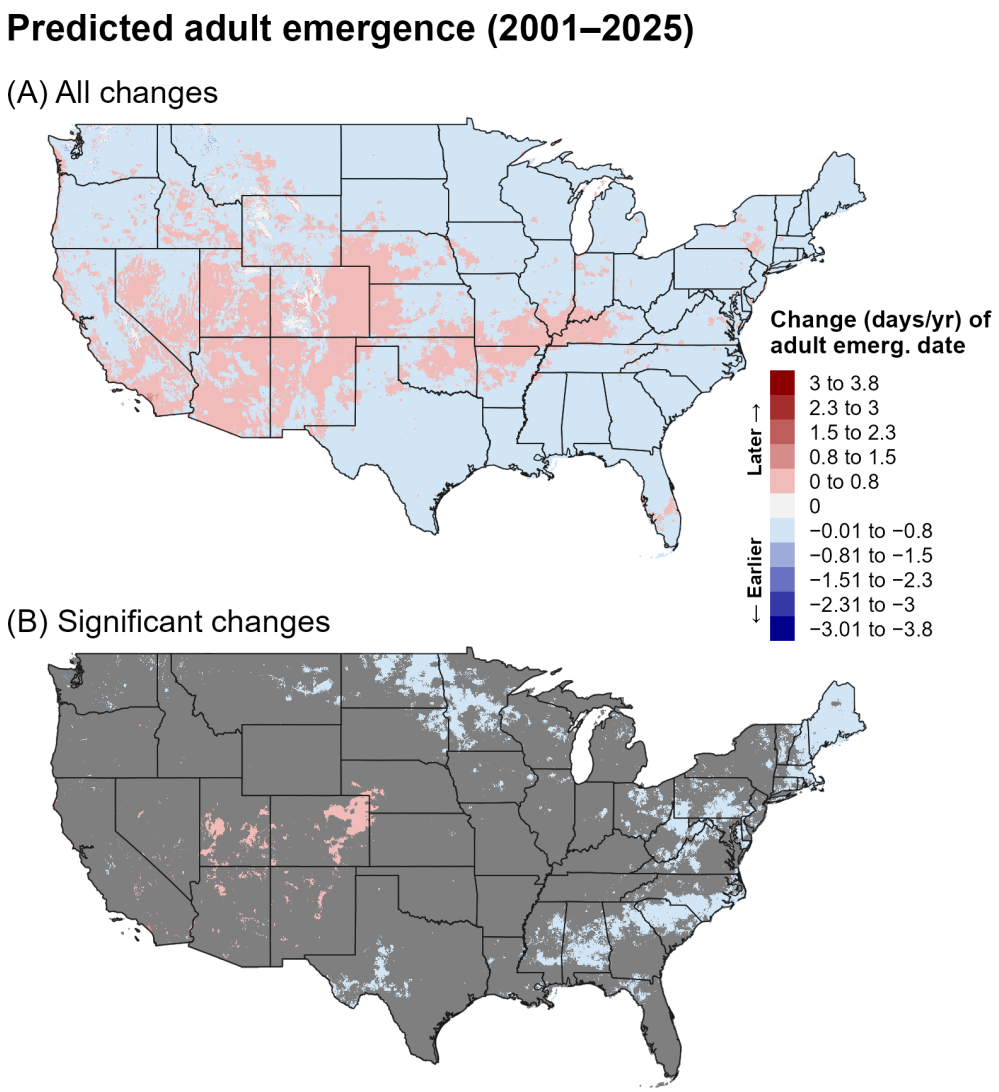

Figure 34. Changes (days/year) in predicted dates of first adult emergence for EAB across the CONUS over the recent 24-year period (2001–2025). Maps show (A) all changes and (B) statistically significant changes ($P < 0.1$); areas shown in gray are not statistically significant.

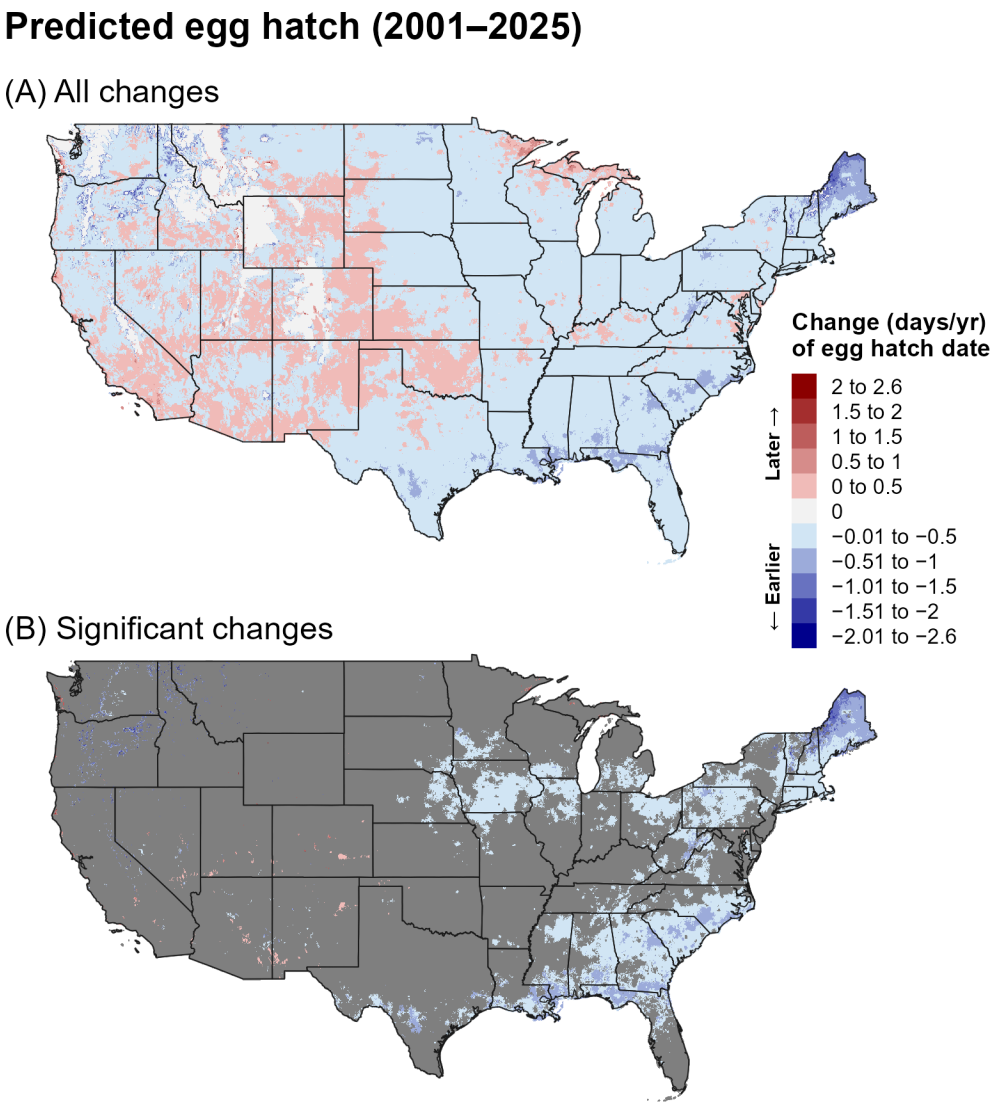

Figure 35. Changes (days/year) in predicted dates of first egg hatch for EAB across the CONUS over the recent 24-year period (2001–2025). Maps show (A) all changes and (B) statistically significant changes ($P < 0.1$); areas shown in gray are not statistically significant.

ii. Climatic suitability

Entire period: 1981–2025

Over the entire 44-year period (1981–2025), predicted cold stress for EAB decreased significantly across portions of the northern United States, particularly the Upper Midwest, although localized increases occurred in parts of Montana (Figure 36). During the same period, predicted heat stress increased significantly across parts of the South and West (Figure 37). When annual accumulated stress units exceed limits specified in DDRP models, climatic suitability may change. Significant shifts in climatic suitability for EAB were relatively limited, indicating that accumulated stress generally remained within the limits defining suitability. Increases in suitability were concentrated in portions of the Southwest (Figure 38).

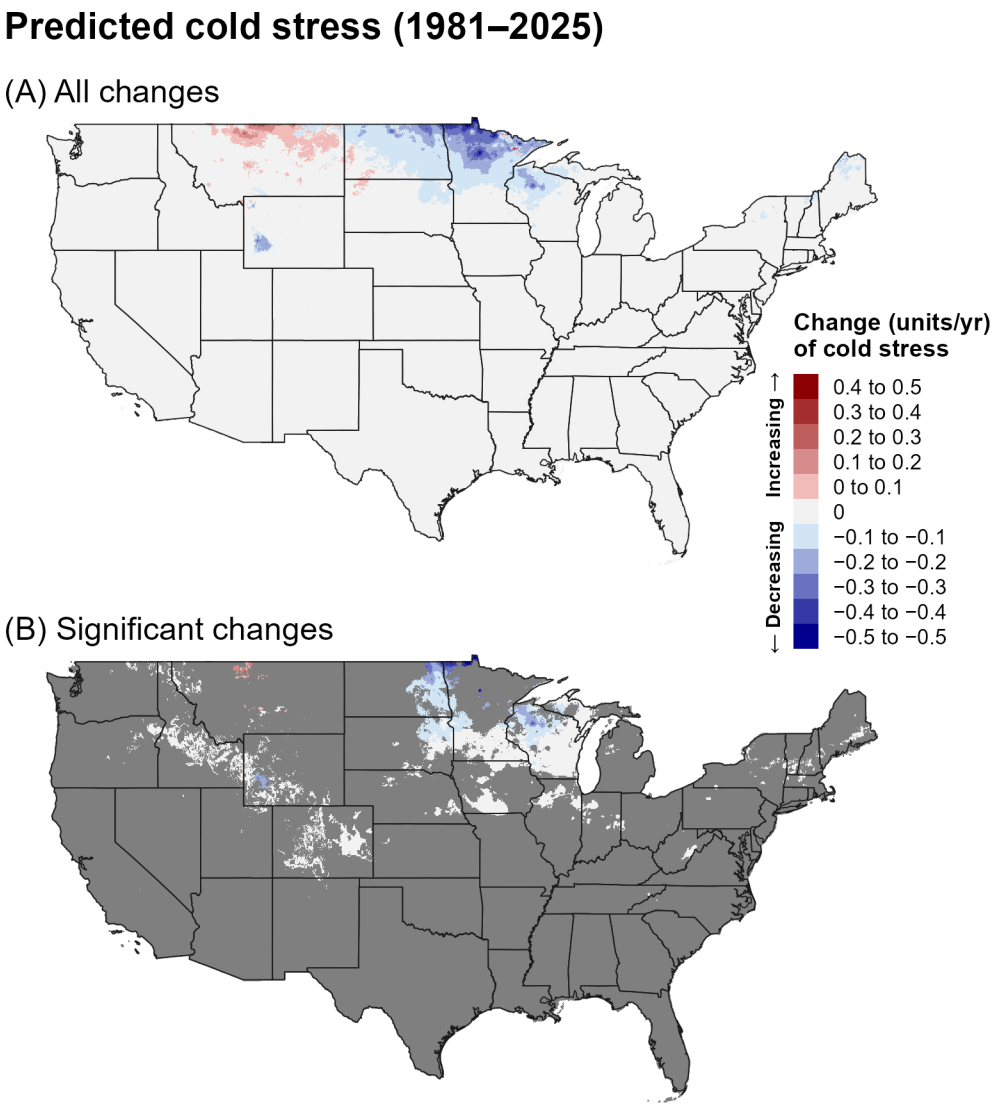

Figure 36. Changes (units/year) in predicted cold stress for EAB across the CONUS over the entire 44-year period (1981–2025). Maps show (A) all changes and (B) statistically significant changes ($P < 0.1$); areas shown in gray are not statistically significant. Areas shown as 0 in (B) had significant trends but very small changes.

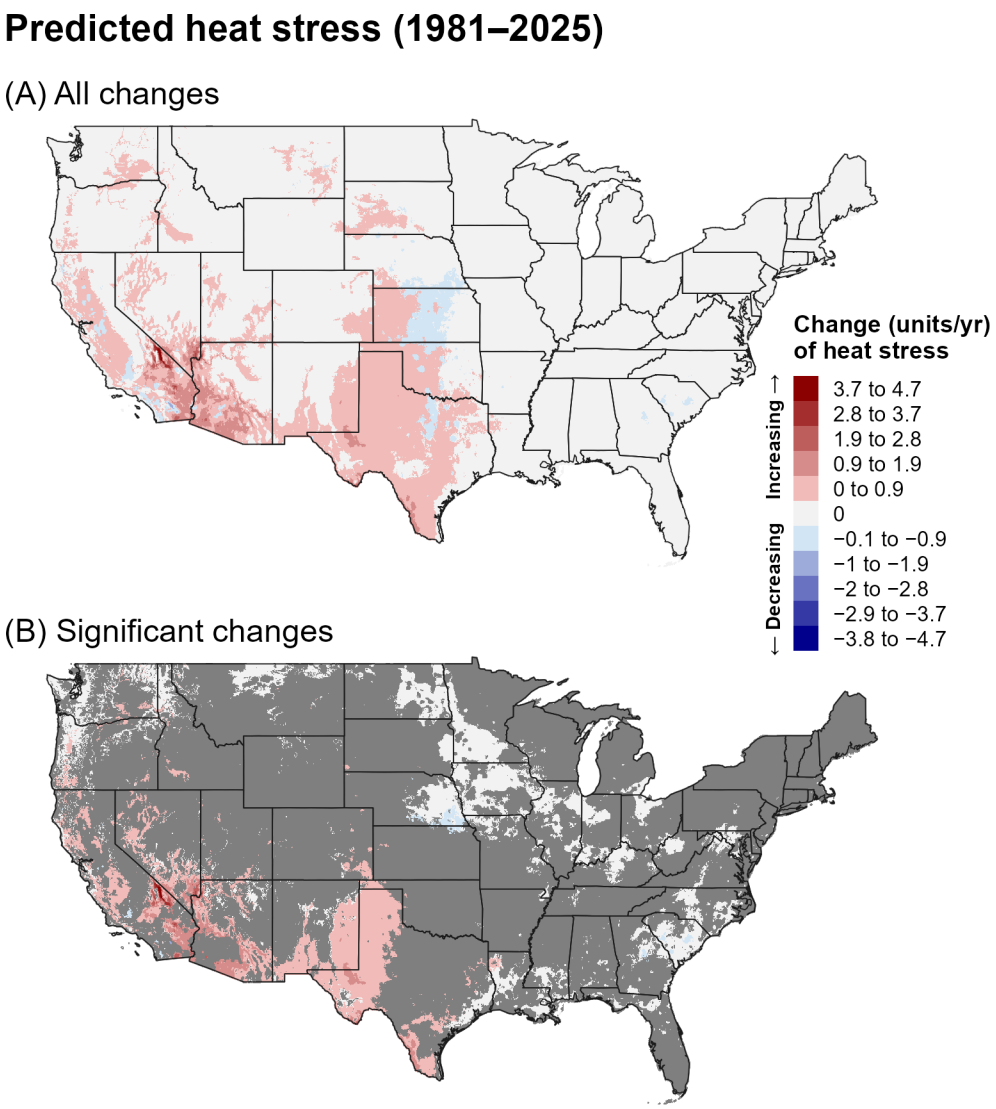

Figure 37. Changes (units/year) in predicted heat stress for EAB across the CONUS over the entire 44-year period (1981–2025). Maps show (A) all changes and (B) statistically significant changes ($P < 0.1$); areas shown in gray are not statistically significant. Areas shown as 0 in (B) had significant trends but very small changes.

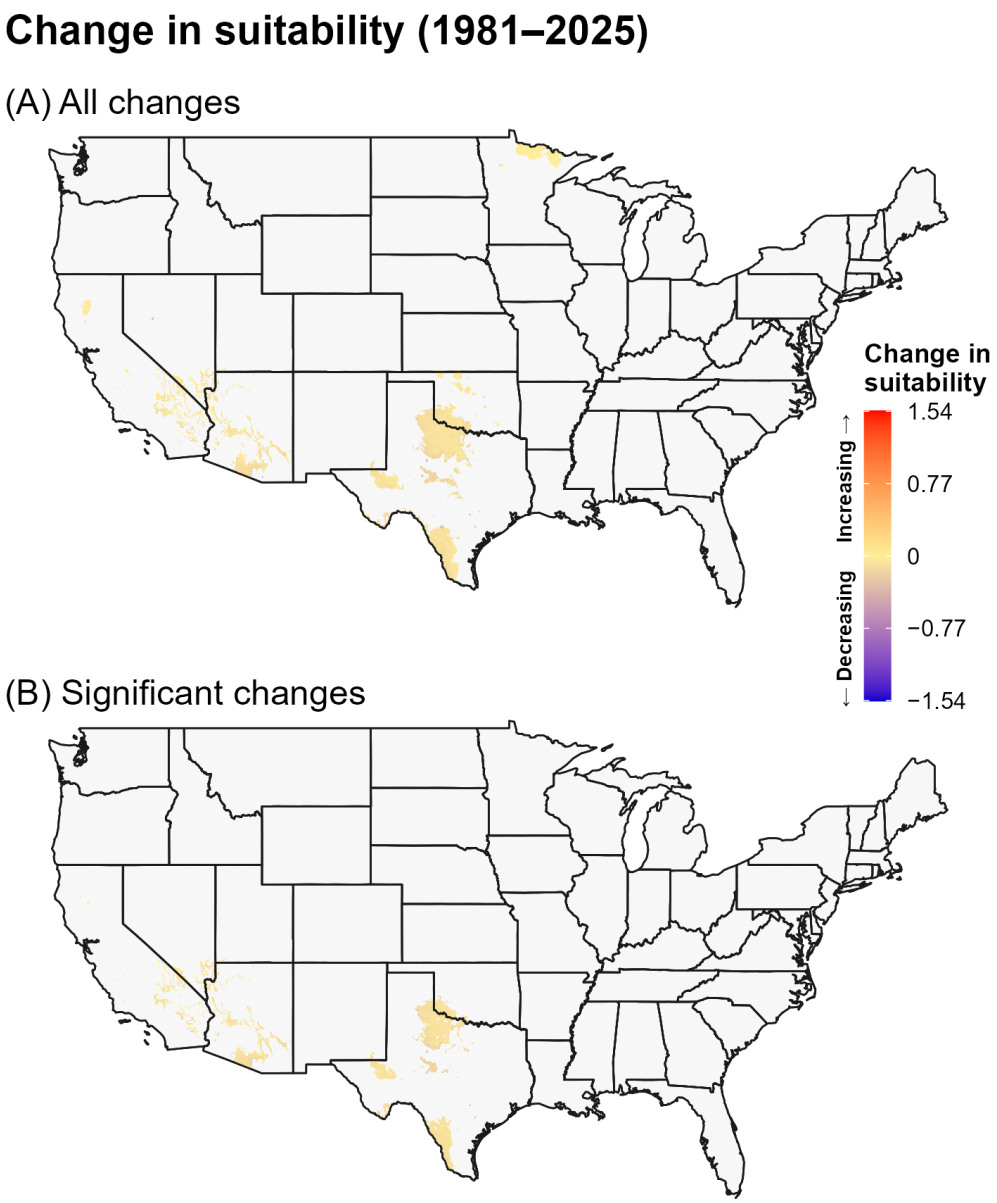

Figure 38. Changes in predicted climatic suitability for EAB across the CONUS over the 44-year period (1981–2025). Suitability is defined as areas not excluded by cold and heat stress. Positive changes (warmer colors) indicate an increased likelihood of establishment, whereas negative changes (cooler colors) indicate a decreased likelihood of establishment.

Recent period: 2001–2025

Trends in climate stress for EAB over the recent 24-year period (2001–2025) differed in several respects. Predicted cold stress increased across portions of the Upper Midwest, with few areas showing significant decreases (Figure 39), contrasting with the widespread decreases observed over the longer period. Heat stress continued to increase across the Southwest and Lower Midwest but decreased in parts of the interior West, southern California, and Arizona (Figure 40). As during the longer period, changes in climatic suitability remained spatially localized, suggesting that recent shifts in cold and heat stress translated into relatively limited changes in predicted establishment suitability (Figure 41).

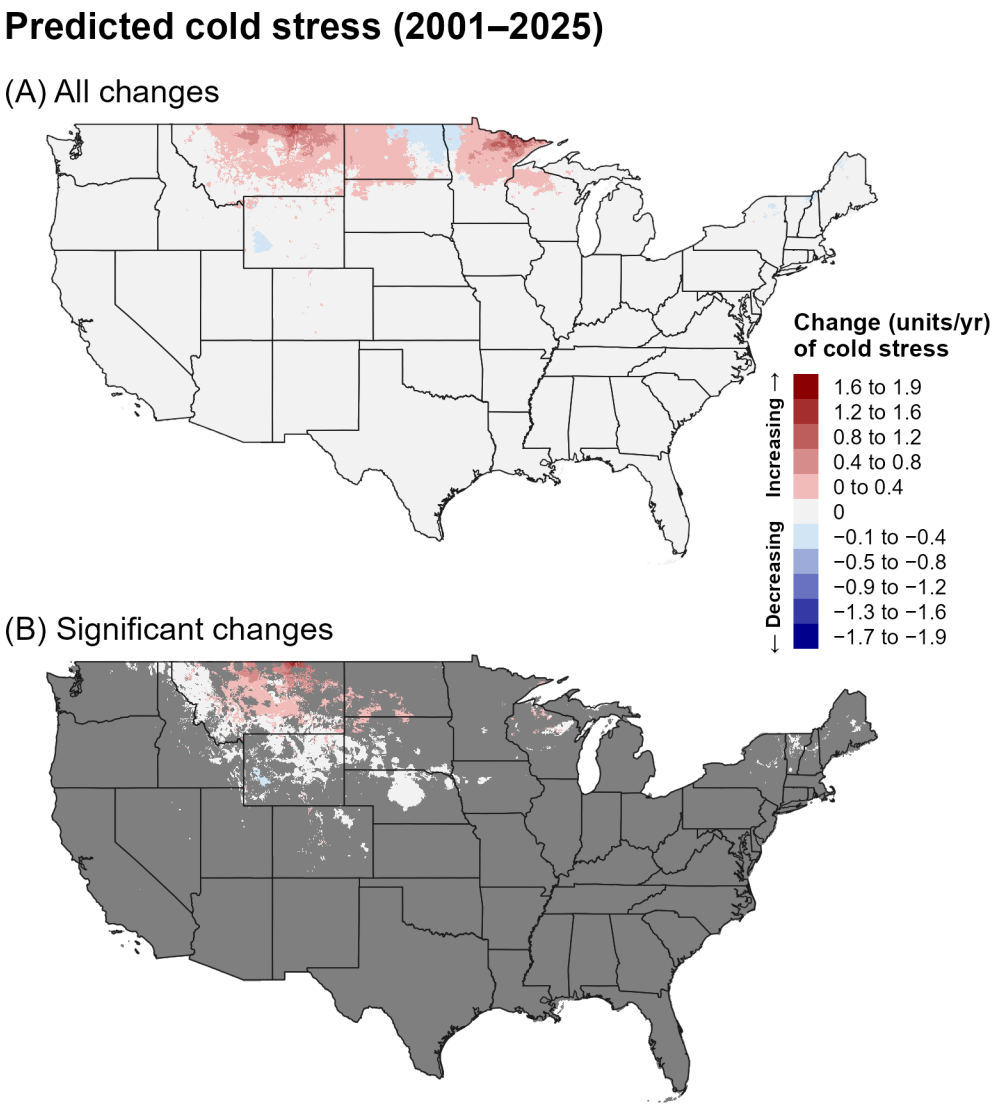

Figure 39. Changes (units/year) in predicted cold stress for EAB across the CONUS over the recent 24-year period (2001–2025). Maps show (A) all changes and (B) statistically significant changes ($P < 0.1$); areas shown in gray are not statistically significant. Areas shown as 0 in (B) had significant trends but very small changes.

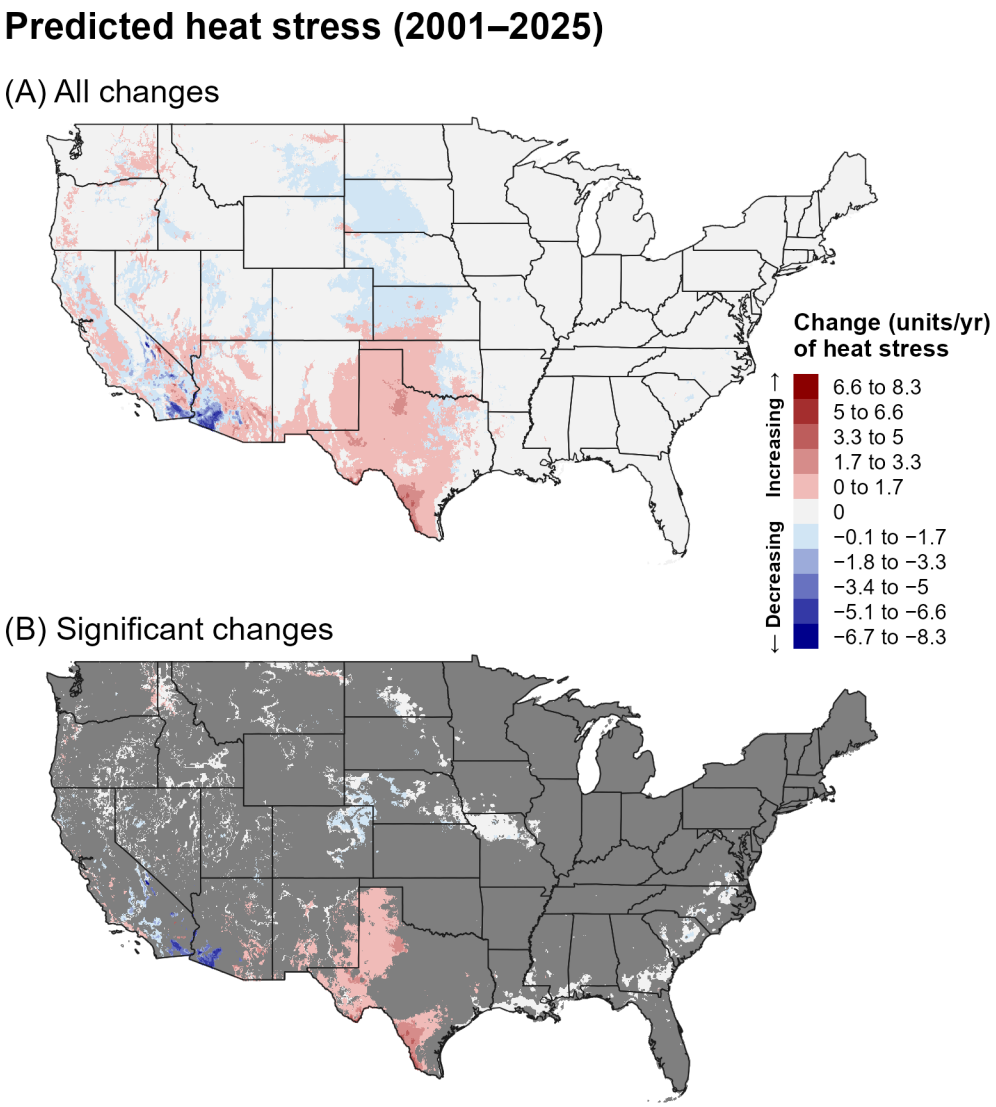

Figure 40. Changes (units/year) in predicted heat stress for EAB across the CONUS over the recent 24-year period (2001–2025). Maps show (A) all changes and (B) statistically significant changes ($P < 0.1$); areas shown in gray are not statistically significant. Areas shown as 0 in (B) had significant trends but very small changes.

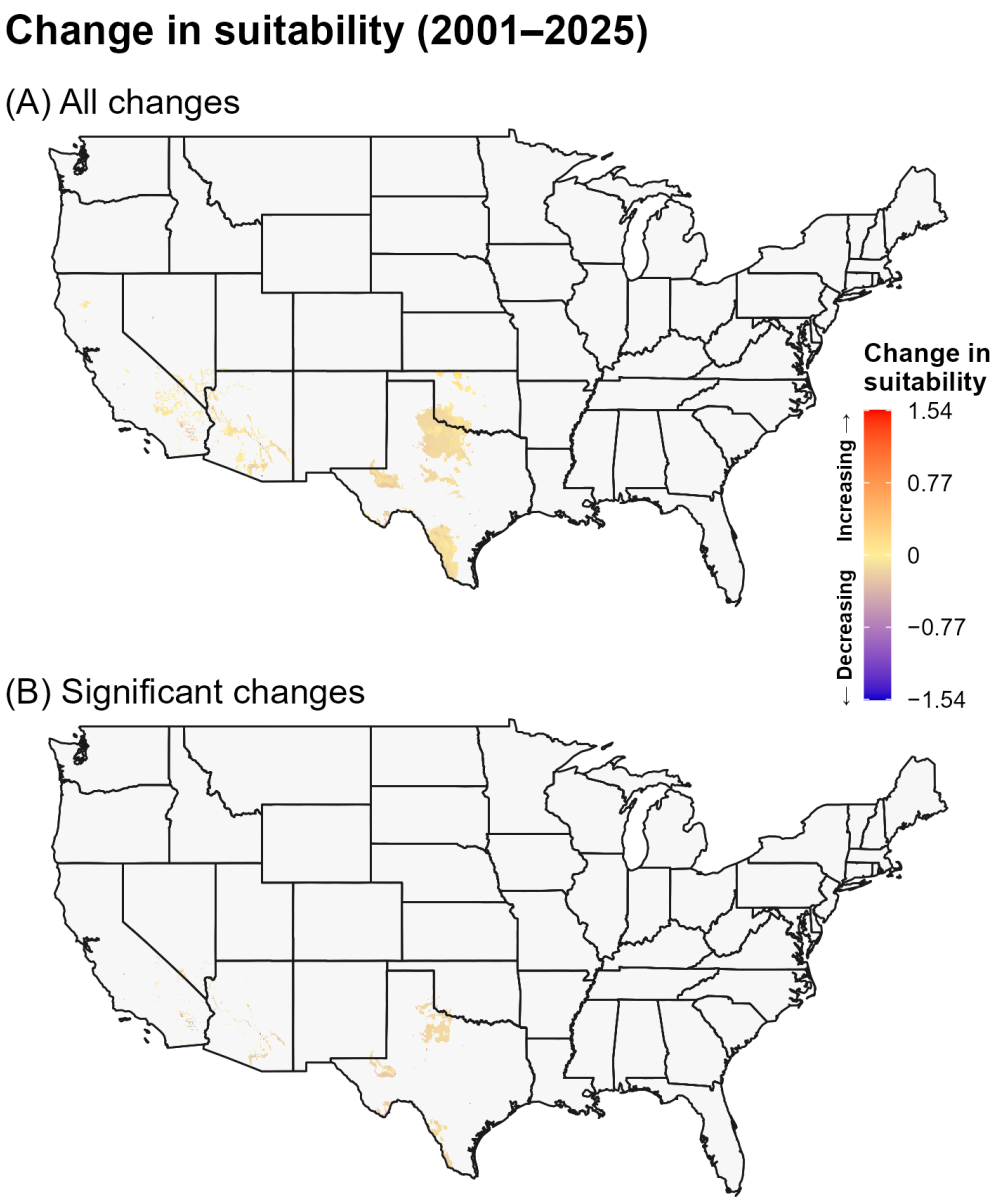

Figure 41. Changes in predicted climatic suitability for EAB across the CONUS over the recent 24-year period (2001–2025). Suitability is defined as areas not excluded by cold and heat stress. Positive changes (warmer colors) indicate an increased likelihood of establishment, whereas negative changes (cooler colors) indicate a decreased likelihood of establishment.

4C. Discussion

Predicted EAB phenology generally shifted toward earlier seasonal events, with the strongest and most spatially extensive trends occurring over the entire 44-year period (1981–2025). Predicted adult emergence and egg hatch occurred progressively earlier across portions of the East during both study periods, at rates of approximately 0.01–0.9 days per year. Because EAB is widely established across much of this region, these shifts have practical implications for monitoring and management. Pest managers may need to adjust the timing of seasonal activities to maintain their effectiveness. For example, traps targeting adult beetles may need to be deployed earlier in spring to improve early detection of new infestations, while release schedules for biological control agents,

including the larval parasitoids *Spathius agrili* and *S. galinae*, may need to be adjusted to account for changes in host availability.

In contrast, significant trends toward later adult emergence and egg hatch occurred in parts of the Intermountain West during 2001–2025. These localized patterns may reflect regional differences in temperature trends and seasonal warming, which have not been spatially or seasonally uniform across the United States (NCEI 2021). However, further analysis of temperature trends during the study period is needed to determine whether these differences explain the predicted delays.

Trends in EAB's phenology should be interpreted in light of some current limitations of the phenology model. First, the model predicts adult emergence solely from degree-day accumulation and does not account for the chilling requirements of overwintering J-larvae, which must receive sufficient winter chilling to terminate obligatory diapause before metamorphosis can begin (Duan et al. 2021, Duan et al. 2026). Because warmer chilling temperatures may delay adult emergence (Duan et al. 2026), the model may overestimate advances in emergence in warmer regions of the United States, including the South. Second, the model assumes a univoltine life cycle, whereas EAB can exhibit a semivoltine life cycle in cooler regions, overwintering as early instars and requiring a second summer of feeding before reaching the J-larval stage (Jones et al. 2019, Bohannon et al. 2022). This extended development may alter the timing and distribution of adult emergence relative to model predictions. Incorporating chilling requirements and regional variation in voltinism could therefore improve the accuracy of predicted phenological trends and their application to monitoring and biological control.

The limited changes in predicted climatic suitability across both time periods indicate that trends in cold and heat stress have not produced broad changes in predicted EAB establishment potential across the CONUS. Although decreasing cold stress across portions of the Upper Midwest could potentially enhance overwintering survival in EAB, it did not substantially increase predicted establishment potential in these regions. Conversely, increasing heat stress in the Southwest may constrain establishment in already warm regions, particularly where it overlaps with the ranges of native *Fraxinus* species. The lack of substantial increases in predicted suitability in the Upper Midwest is consistent with previous findings that only sufficiently extreme cold, such as that experienced in parts of northern Canada, is likely to limit EAB establishment through overwintering mortality (Venette et al. 2014, Barker et al. 2023). From a management perspective, these findings support continuing EAB surveillance across the CONUS rather than substantially narrowing surveillance efforts based on the observed trends in climatic suitability.

Our findings were broadly consistent with Barker et al. (2023), who reported geographically restricted trends toward earlier predicted first adult emergence of EAB over 2002–2021, including in parts of the Southeast, New England, and Upper Midwest. Our analysis also identified significant trends toward later adult emergence in parts of the interior West over 2001–2025. Both studies identified isolated areas of decreasing climatic suitability in the southwestern United States, consistent with increasing heat stress. Differences between the studies may partly reflect methodological differences, particularly our use of pre-whitening to account for temporal autocorrelation in the Mann–Kendall analysis. Pre-whitening reduces temporal autocorrelation to better satisfy the test's assumption of independence among observations and can affect the magnitude and spatial extent of statistically significant trends (Kulkarni and von Storch 1995).

The stronger and more spatially extensive trends in predicted phenology and climate stress over the entire 44-year period may reflect both the larger sample size, which can reduce noise and improve detection of directional patterns, and differences in the underlying climate trends between the two time periods. In particular, the recent 24-year period may capture climate variability or regional trends that differ from those observed over the longer 44-year period. Thus, differences between the two periods should be interpreted as reflecting both long-term climate trends and shorter-term regional variability.

4D. References

Aukema, J. E., B. Leung, K. Kovacs, C. Chivers, K. O. Britton, J. Englin, S. J. Frankel, R. G. Haight, T. P.

Holmes, A. M. Liebhold, D. G. McCullough, and B. von Holle. 2011. Economic impacts of non-native forest insects in the continental United States. PLoS ONE 6:e24587.

Barker, B. S., L. Coop, J. J. Duan, and T. R. Petrice. 2023. An integrative phenology and climatic suitability model for emerald ash borer. Frontiers in Insect Science 3:1239173.

Bohannon, G. R., C. L. Johnson, R. M. Jetton, and K. L. F. Oten. 2022. Phenology and voltinism of emerald ash borer (Coleoptera: Buprestidae) in Central North Carolina. Environmental Entomology 51:1077–1085.

DeSantis, R. D., Moser, W. K., Gormanson, D. D., Bartlett, M. G., & Vermunt, B. (2013). Effects of climate on emerald ash borer mortality and the potential for ash survival in North America. Agricultural and Forest Meteorology, 178–179, 120–128.

Duan, J. J., J. M. Schmude, and K. M. Larson. 2021. Effects of low temperature exposure on diapause, development, and reproductive fitness of the emerald ash borer (Coleoptera: Buprestidae): implications for voltinism and laboratory rearing. Journal of Economic Entomology 114:201–208.

Duan, J. J., T. R. Petrice, J. M. Schmude, and T. Hagerty. 2026. Temperature-dependent response of diapause termination in the emerald ash borer (Coleoptera: Buprestidae): implications for its geographic distribution. Journal of Economic Entomology 19:3111–3116.

EPPO. 2025. *Agrilus planipennis*. EPPO datasheets on pests recommended for regulation. Available online: https://gd.eppo.int (accessed 7 July 2025).

Haack, R., E. Jendek, H. Liu, K. Marchant, T. Petrice, T. Poland, and H. Ye. 2002. The emerald ash borer: a new exotic pest in North America. Newsletter of the Michigan Entomological Society 47:1–5.

Jones, M. I., J. R. Gould, H. J. Mahon, M. K. Fierke, and B. Sullivan. 2019. Phenology of emerald ash borer (Coleoptera: Buprestidae) and its introduced larval parasitoids in the northeastern United States. Journal of Economic Entomology 113:622–632.

Knight, K. S., J. P. Brown, and R. P. Long. 2013. Factors affecting the survival of ash (*Fraxinus* spp.) trees infested by emerald ash borer (*Agrilus planipennis*). Biological Invasions 15:371–383.

Kovacs, K. F., R. G. Haight, D. G. McCullough, R. J. Mercader, N. W. Siegert, and A. M. Liebhold. 2010. Cost of potential emerald ash borer damage in United States communities, 2009-2019. Ecological Economics 69:569–578.

Kulkarni, A., and H. von Storch. 1995. Monte Carlo experiments on the effect of serial correlation on the Mann-Kendall test of trend. Meteorologische Zeitschrift N.F 4:82–85.

Liang, L., and S. Fei. 2014. Divergence of the potential invasion range of emerald ash borer and its host distribution in North America under climate change. Climatic Change 122:735–746.

MacDonald, B., R. Baydack, A. R. Westwood, and D. Walker. 2022. Predicting emerald ash borer adult emergence and peak flight activity in Winnipeg, Manitoba, Canada. Frontiers in Ecology and Evolution 10:846144.

National Centers for Environmental Information (NCEI). 2021. U.S. Climate Normals. National Oceanic and Atmospheric Administration, National Centers for Environmental Information. Available online: https://www.ncei.noaa.gov/products/land-based-station/us-climate-normals (accessed 7 October 2026).

Peterson, D. L., and D. Cipollini. 2020. Larval performance of a major forest pest on novel hosts and the effect of stressors. Environmental Entomology 49:482–488.

Poland, T. M., Y. Chen, J. Koch, and D. Pureswaran. 2015. Review of the emerald ash borer (Coleoptera: Buprestidae), life history, mating behaviours, host plant selection, and host resistance. Canadian Entomologist 147:252–262.

Poland, T. M., and D. G. McCullough. 2006. Emerald ash borer: invasion of the urban forest and the threat to North America's ash resource. Journal of Forestry 104:118–124.

Rutledge, C. E., and A. Arango-Velez. 2017. Larval survival and growth of emerald ash borer (Coleoptera: Buprestidae) on white ash and white fringetree saplings under well-watered and water-deficit conditions. Environmental Entomology 46:243–250.

Schrader, G., R. Baker, Y. Baranchikov, L. Dumouchel, K. S. Knight, D. G. McCullough, M. J. Orlova-Bienkowskaja, S. Pasquali, and G. Gilioli. 2021. How does the emerald ash borer (*Agrilus planipennis*) affect ecosystem services and biodiversity components in invaded areas? EPPO Bulletin 51:216–228.

Siegert, N. W., D. G. Mccullough, A. M. Liebhold, and F. W. Telewski. 2014. Dendrochronological reconstruction of the epicenter and early spread of emerald ash borer in North America. Diversity and Distributions 20:847–858.

Sobek-Swant, S., D. A. Kluza, K. Cuddington, and D. B. Lyons. 2012. Potential distribution of emerald ash borer: What can we learn from ecological niche models using Maxent and GARP? Forest Ecology and Management 281:23–31.

Tluczek, A. R., D. G. McCullough, and T. M. Poland. 2011. Influence of host stress on emerald ash borer (Coleoptera: Buprestidae) adult density, development, and distribution in *Fraxinus pennsylvanica* trees. Environmental Entomology 40:357–366.

USDA-APHIS. 2025. Emerald ash borer. United States Department of Agriculture, Animal and Plant Health Inspection Service, Washington D.C. Available online: https://www.aphis.usda.gov/plant-pests-diseases/eab (accessed on 5 December 2025).

Venette, R., L. Christianson, and M. Abrahamson. 2014. Cold snap is no snow day for emerald ash borer management. In Biological and Environmental Influences on Forest Health and Productivity. 6. Delaware, OH: United States Department of Agriculture, Forest Service, Northern Research Station.

5. Egyptian cottonworm

5A. Introduction

The Egyptian cottonworm (ECW), *Spodoptera littoralis* Boisduval (Lepidoptera: Noctuidae), is a highly destructive and polyphagous moth distributed across southern Europe, the Mediterranean Basin, the Middle East, Africa, China, and India (EPPO 2025). With a host range spanning more than 80 plant species in over 40 families, it is a major pest of crops such as cotton, maize, potato, sugarcane, soybeans, vegetables, and wheat (CABI 2022). The larval stage, which consists of six instars, causes significant damage through extensive defoliation, as well as by attacking growing points and mining or cutting stems (Baker and Miller 1974, EFSA 2015, CABI 2022). Although ECW is not established in the United States, it has been intercepted multiple times at United States ports of entry (Ellis 2004).

A model for ECW developed for the Degree-Day, establishment Risk, and Phenological event mapping system (DDRP) is operationalized to produce near real-time forecasts for the contiguous United States (CONUS) at https://uspest.org/DDRP. The full set of model parameters for EDW, including developmental temperature thresholds, degree-day requirements for individual life stages, and climate stress thresholds and limits, are available at USPest.org (Barker and Coop 2021).

5B. Results

i. Phenology

Entire period: 1981–2025

Trends in predicted first adult emergence and egg hatch for ECW over the 44-year period (1981–2025) were predominantly negative, indicating that both phenological events shifted earlier over time (Figure 42, Figure 43). Earlier phenology was predicted across much of the East and South, as well as higher-elevation areas of the West. Statistically significant trends were more spatially restricted, occurring primarily in portions of the East and scattered areas of the Intermountain West. Within these regions, predicted adult emergence and egg hatch shifted earlier by approximately 0.01–0.6 days per year, with some of the largest shifts occurring at higher elevations in the Intermountain West. Trends toward later phenology occurred in a some isolated areas of the

West but most were not statistically significant.

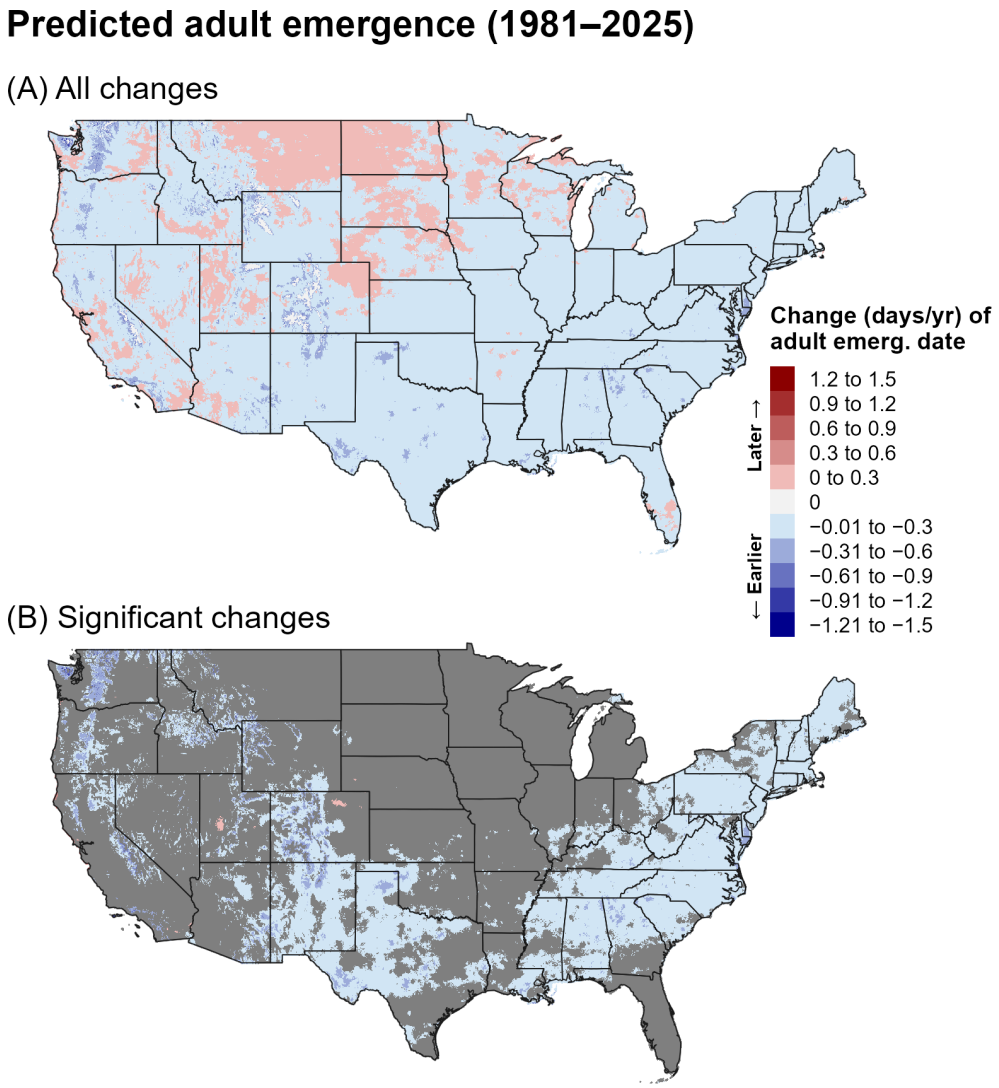

Figure 42. Changes (days/year) in predicted dates of first adult emergence for ECW across the CONUS over the entire 44-year period (1981–2025). Maps show (A) all changes and (B) statistically significant changes ($P < 0.1$); areas shown in gray are not statistically significant.

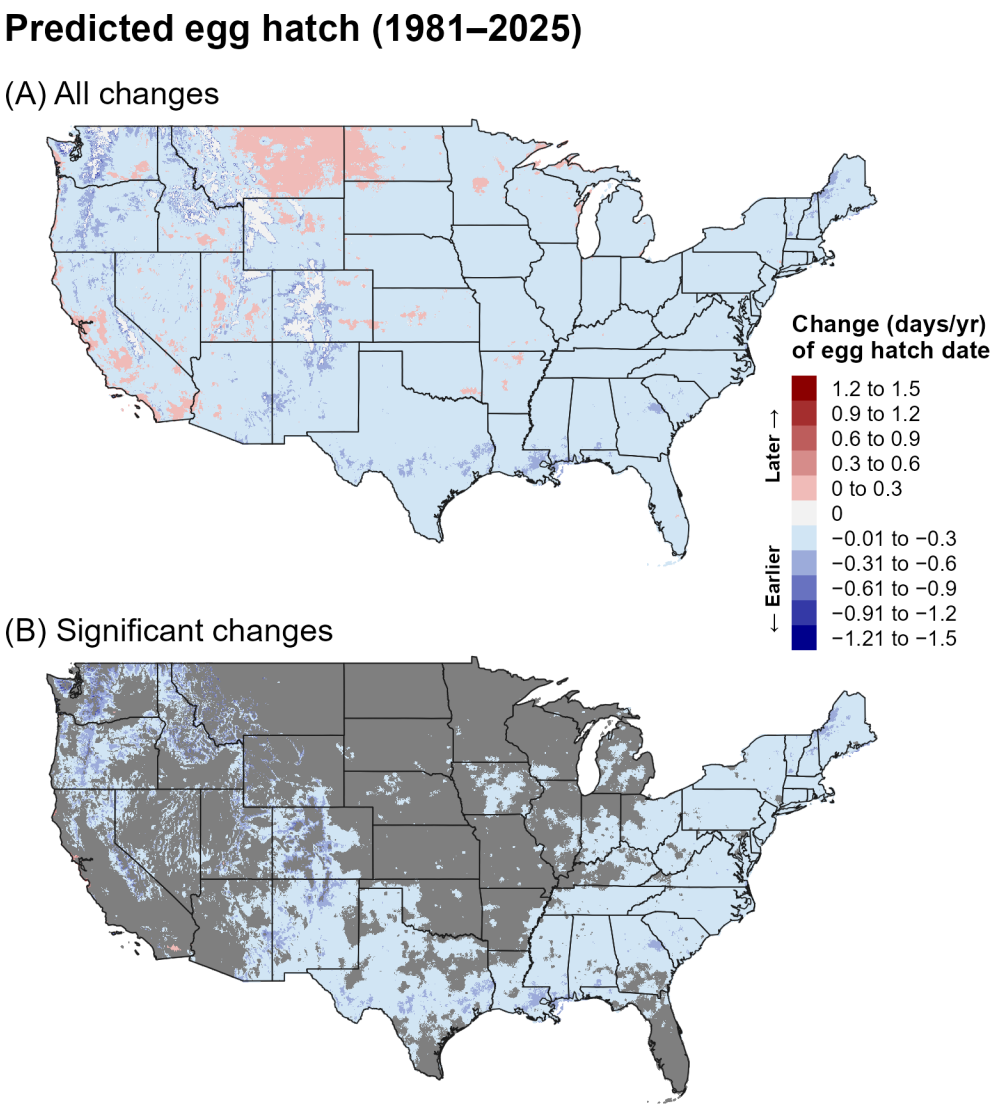

Figure 43. Changes (days/year) in predicted dates of first egg hatch for ECW across the CONUS over the entire 44-year period (1981–2025). Maps show (A) all changes and (B) statistically significant changes ($P < 0.1$); areas shown in gray are not statistically significant.

Recent period: 2001–2025

Trends in predictions of first adult emergence and egg hatch for ECW over the recent 24-year period (2001–2025) were partially consistent with those observed over the 1981–2025 period. Significant trends towards earlier phenology were similar in magnitude but less spatially extensive, occurring predominantly in parts of the East and Upper Midwest (Figure 44, Figure 45). In contrast, areas exhibiting trends toward later phenological events were somewhat larger and more spatially extensive across the West.

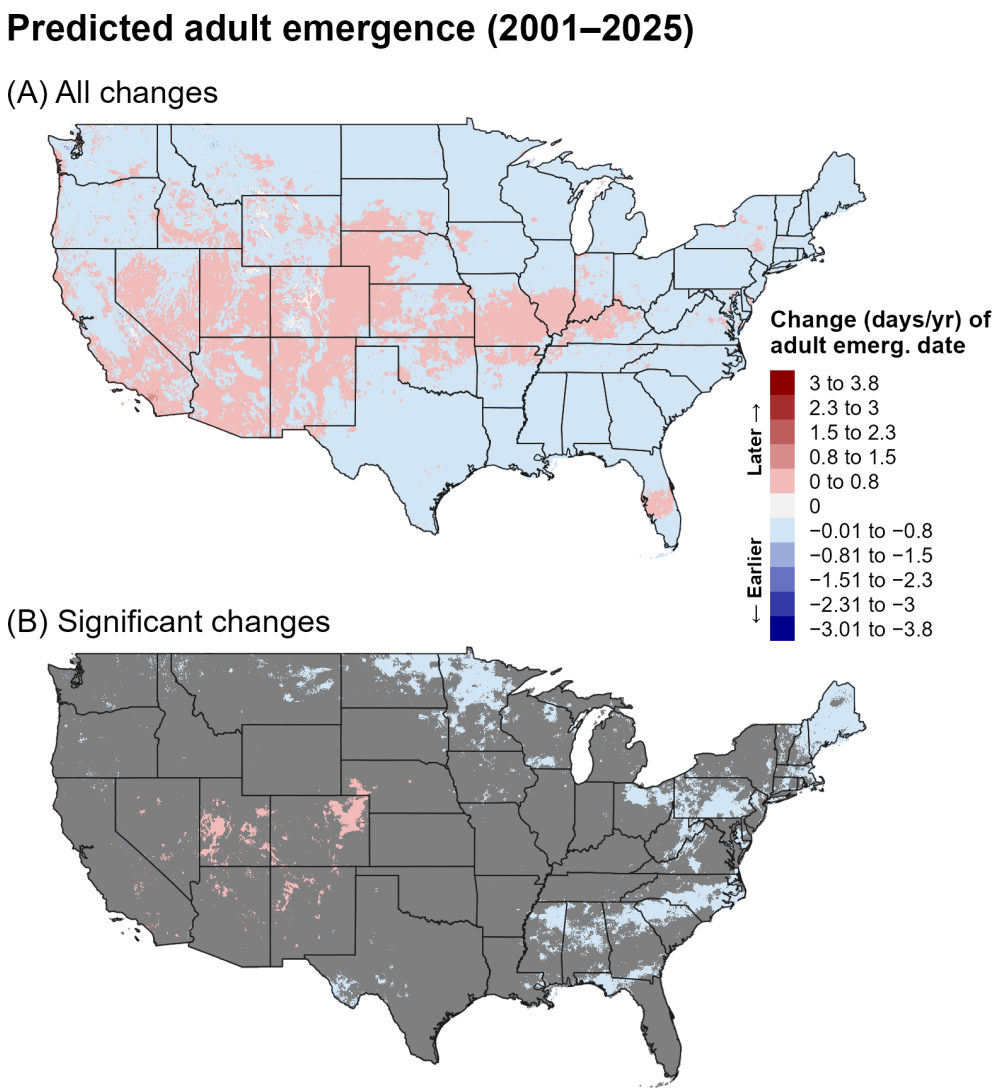

Figure 44. Changes (days/year) in predicted dates of first adult emergence for ECW across the CONUS over the recent 24-year period (2001–2025). Maps show (A) all changes and (B) statistically significant changes ($P < 0.1$); areas shown in gray are not statistically significant.

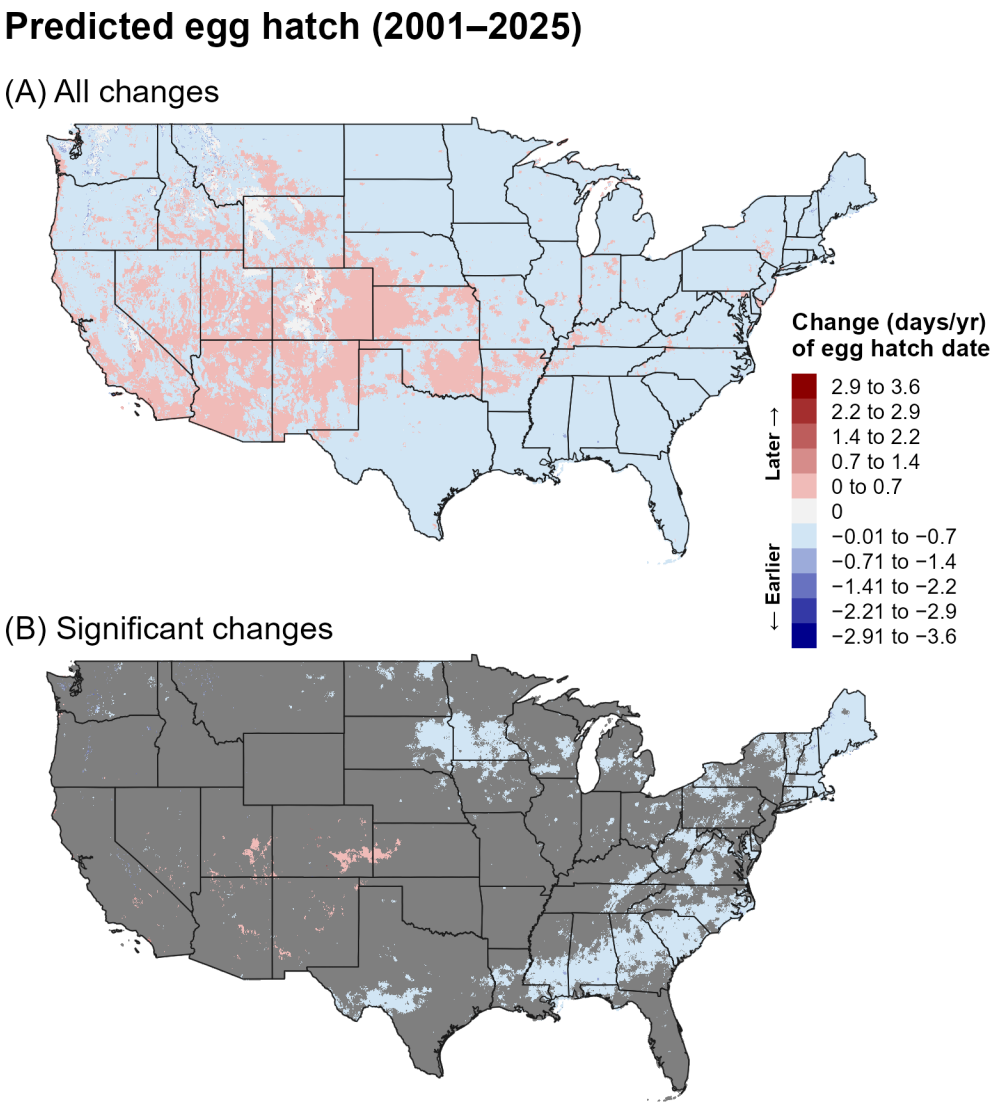

Figure 45. Changes (days/year) in predicted dates of first egg hatch for ECW across the CONUS over the recent 24-year period (2001–2025). Maps show (A) all changes and (B) statistically significant changes ($P < 0.1$); areas shown in gray are not statistically significant.

ii. Climatic suitability

Entire period: 1981–2025

Over the entire 44-year period (1981–2025), predicted cold stress for ECW decreased across broad portions of the CONUS, with the strongest changes occurring in the Northeast, Upper Midwest, and Intermountain West (Figure 46). However, trends across the Midwest and South were generally smaller and mostly nonsignificant. Predicted heat stress increased across much of the West and Great Plains, although significant trends were concentrated primarily in the West (Figure 47). When annual accumulated stress units exceed limits specified in DDRP models, climatic suitability may change. However, changes in stress units for ECW did not correspond to widespread shifts in suitability; only a few small areas in California showed significant decreases in predicted suitability (Figure 48).

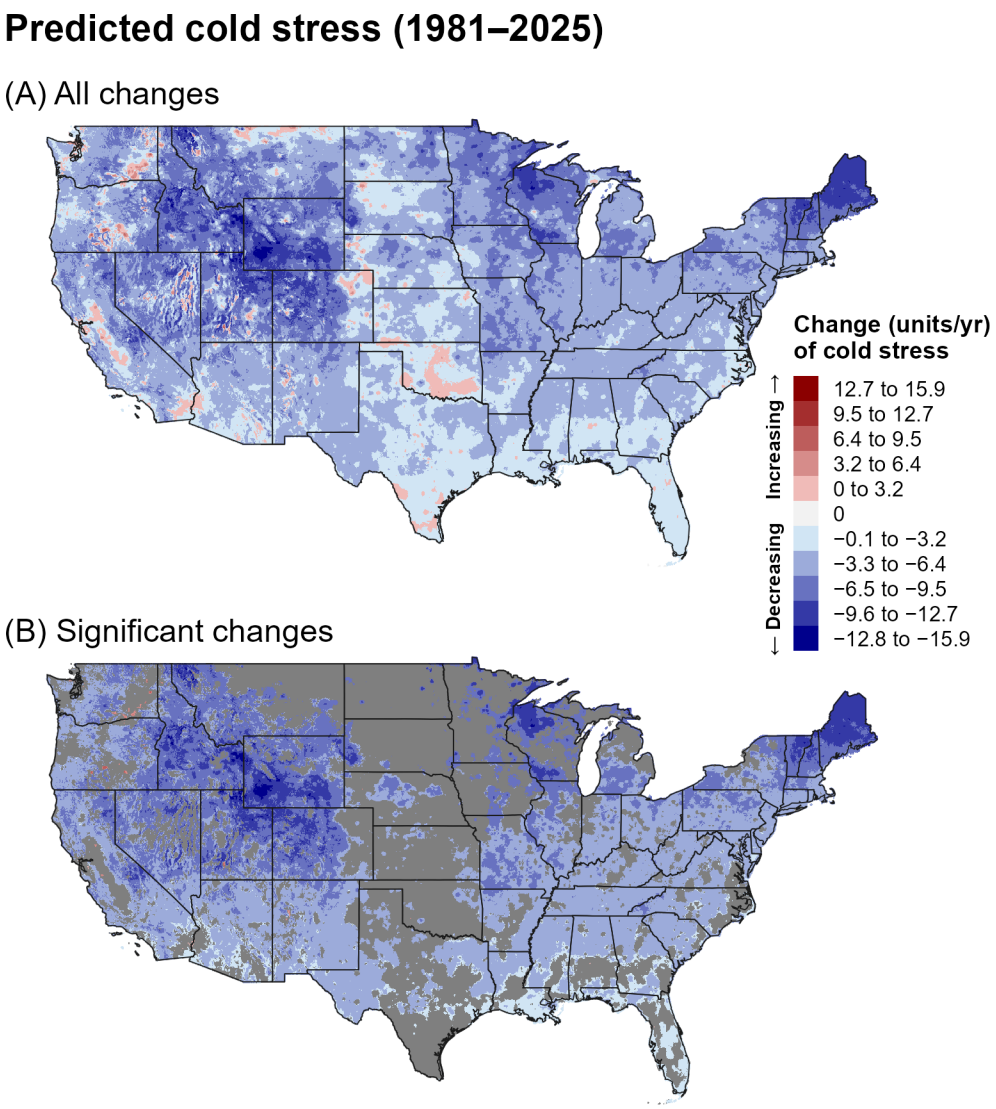

Figure 46. Changes (units/year) in predicted cold stress for ECW across the CONUS over the entire 44-year period (1981–2025). Maps show (A) all changes and (B) statistically significant changes ($P < 0.1$); areas shown in gray are not statistically significant. Areas shown as 0 in (B) had significant trends but very small changes.

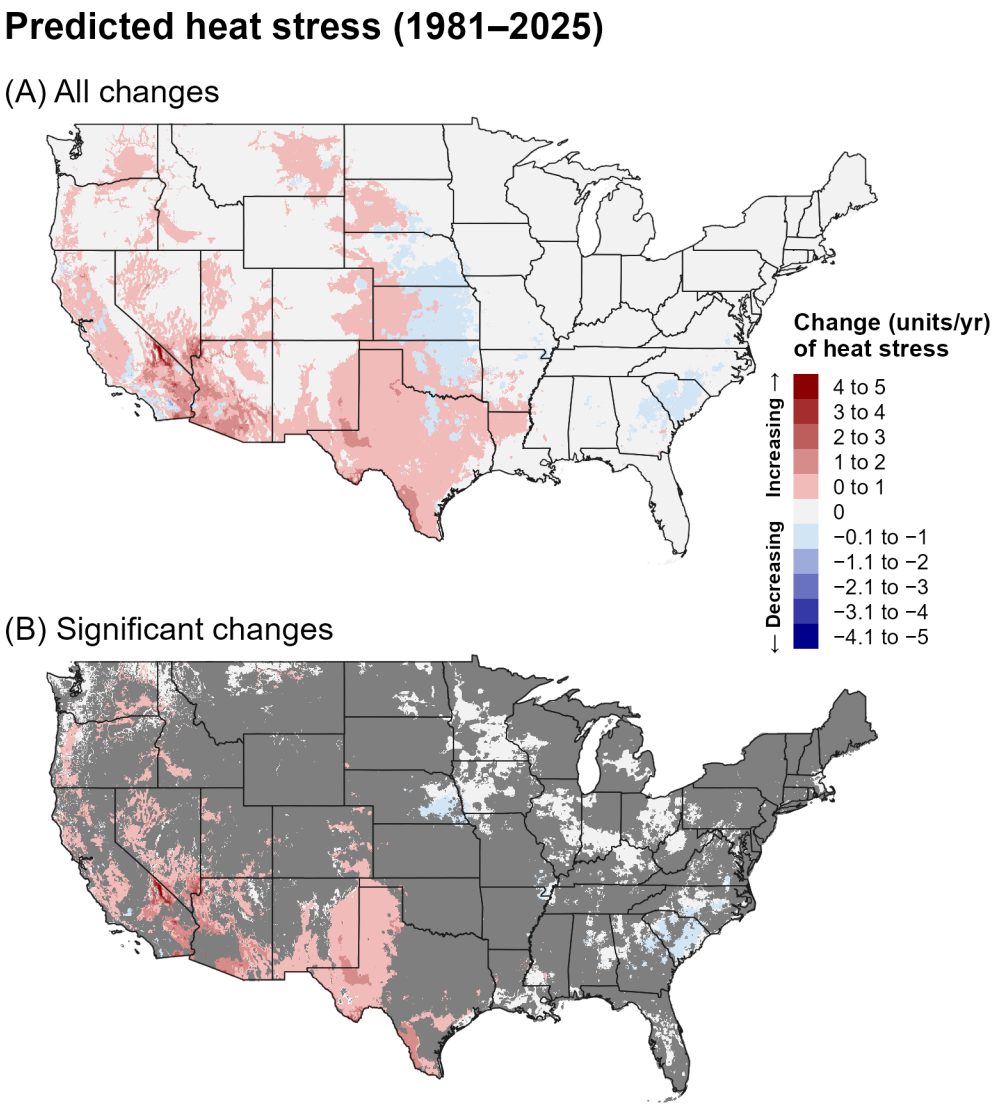

Figure 47. Changes (units/year) in predicted heat stress for ECW across the CONUS over the entire 44-year period (1981–2025). Maps show (A) all changes and (B) statistically significant changes ($P < 0.1$); areas shown in gray are not statistically significant. Areas shown as 0 in (B) had significant trends but very small changes.

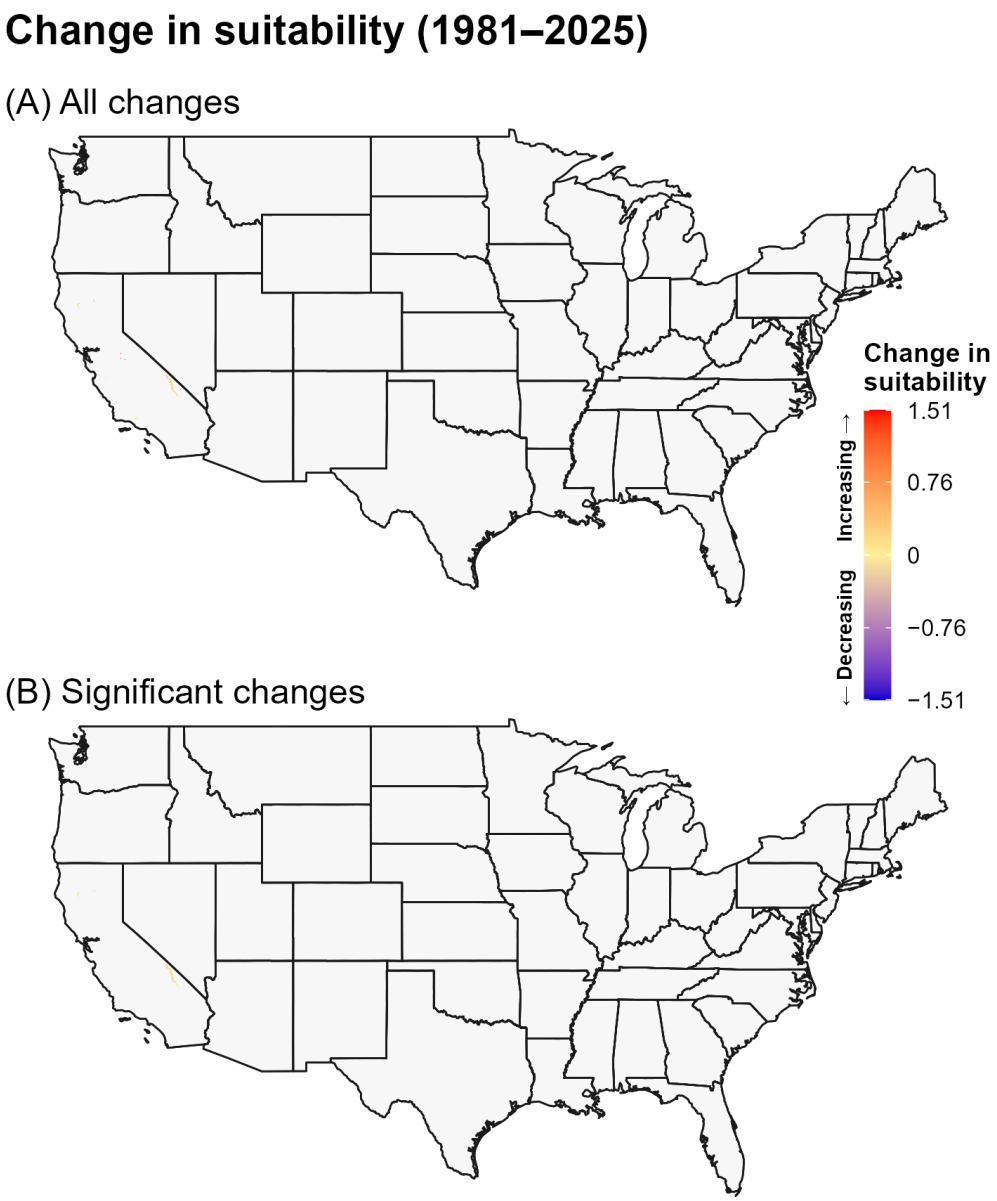

Figure 48. Changes in predicted climatic suitability for ECW across the CONUS over the 44-year period (1981–2025). Suitability is defined as areas not excluded by cold and heat stress. Positive changes (warmer colors) indicate an increased likelihood of establishment, whereas negative changes (cooler colors) indicate a decreased likelihood of establishment.

Recent period: 2001–2025

Many areas that exhibited significant decreases in cold stress for ECW over 1981–2025 no longer showed significant trends during the recent period. These areas were concentrated in scattered patches across the East and South and at higher elevations in the West (Figure 49). Significant increases in predicted cold stress occurred in a few small, isolated areas of the West. Significant increases in heat stress were concentrated in the South, particularly Texas, whereas parts of California showed significant decreases (Figure 50). As in the 1981–2025 analysis, changes in cold and heat stress produced very few significant changes in climatic suitability (Figure 51).

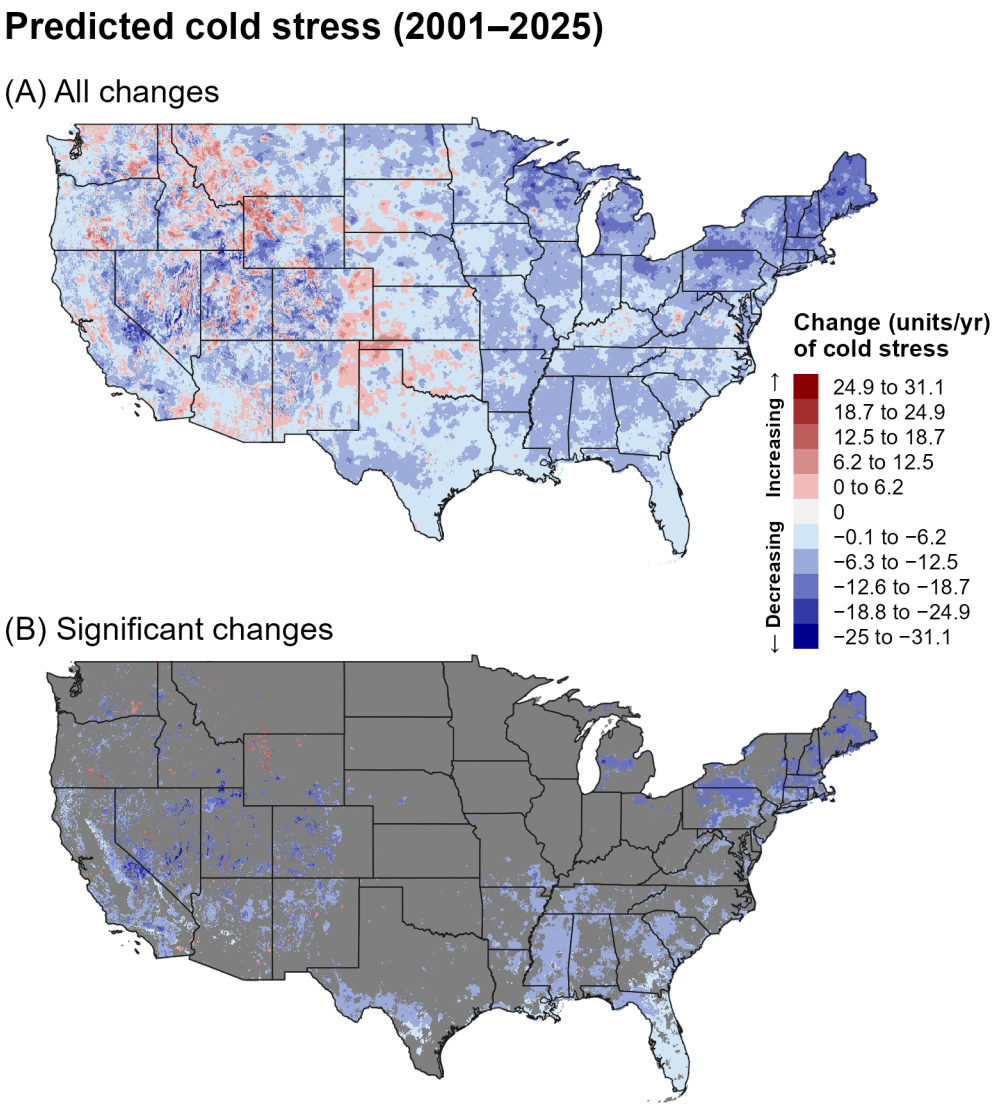

Figure 49. Changes (units/year) in predicted cold stress for ECW across the CONUS over the recent 24-year period (2001–2025). Maps show (A) all changes and (B) statistically significant changes ($P < 0.1$); areas shown in gray are not statistically significant. Areas shown as 0 in (B) had significant trends but very small changes.

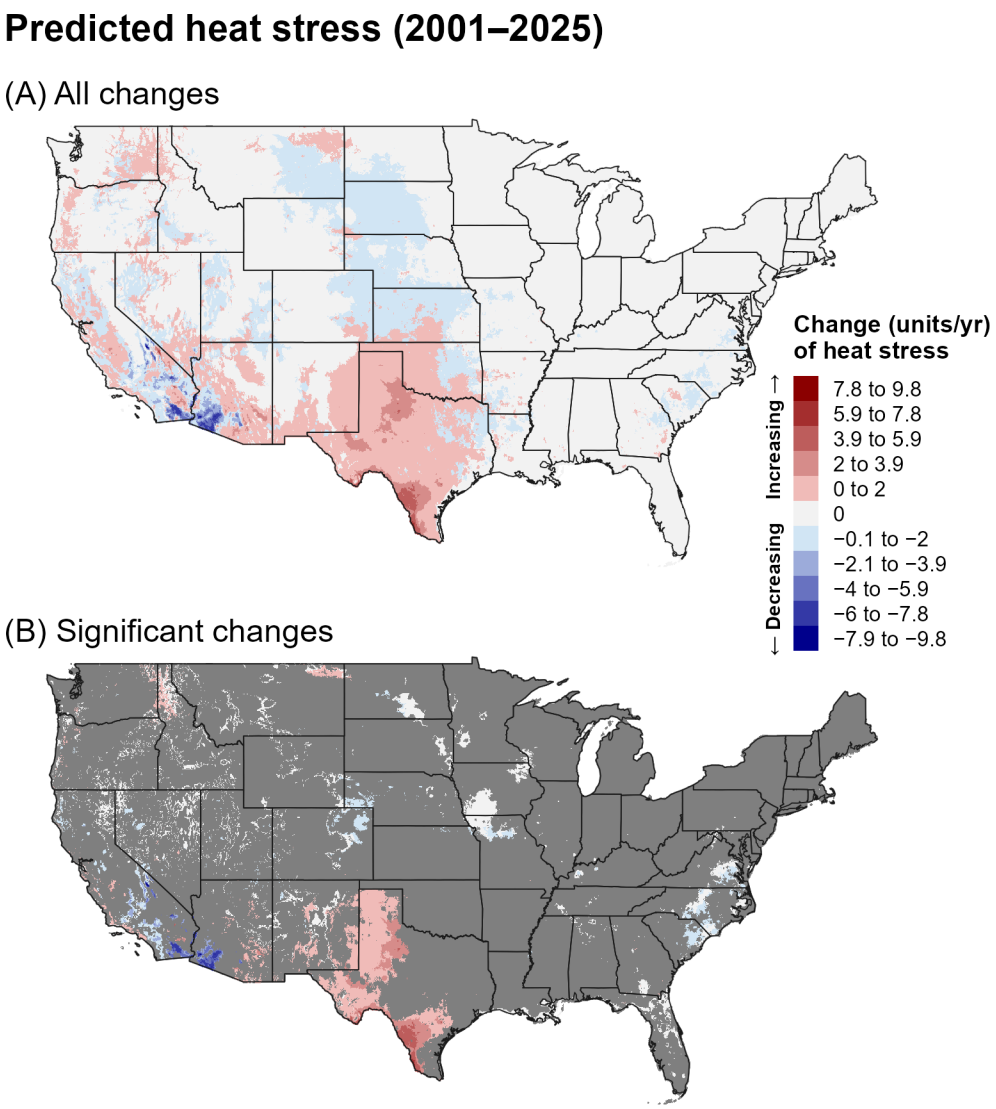

Figure 50. Changes (units/year) in predicted heat stress for ECW across the CONUS over the recent 24-year period (2001–2025). Maps show (A) all changes and (B) statistically significant changes ($P < 0.1$); areas shown in gray are not statistically significant. Areas shown as 0 in (B) had significant trends but very small changes.

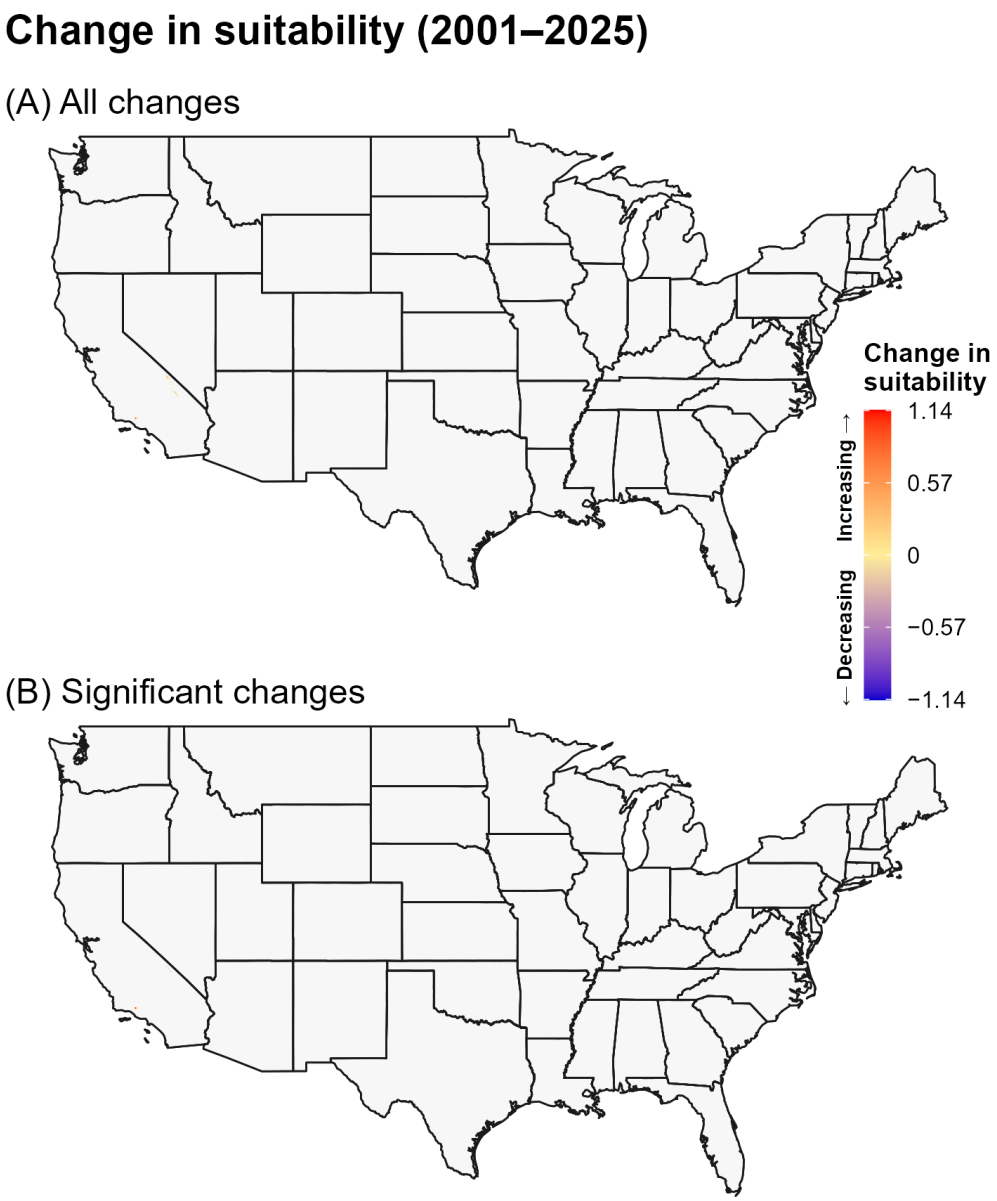

Figure 51. Changes in predicted climatic suitability for ECW across the CONUS over the recent 24-year period (2001–2025). Suitability is defined as areas not excluded by cold and heat stress. Positive changes (warmer colors) indicate an increased likelihood of establishment, whereas negative changes (cooler colors) indicate a decreased likelihood of establishment.

5C. Discussion

Although ECW is not established in the CONUS, understanding predicted changes in phenology can inform surveillance planning. In areas exhibiting significant trends toward earlier phenology, predicted dates shifted earlier by approximately 0.01–0.6 days per year, suggesting that surveillance materials may need to be deployed earlier in the season. Surveillance may be particularly important where these trends overlap with major host production areas, including extensive commercial cotton acreage and intensive fruit and vegetable production across the South and along the West Coast (Sullivan 2014. However, considering trends in more northern areas is also important because migratory moths may be capable of periodic spread into northern regions later in the

season (EFSA PLH 2015).

Earlier adult emergence and egg hatch could potentially allow ECW to complete more generations per year, increasing pest pressure and associated crop damage. ECW lacks a true winter diapause and can complete multiple generations under warm conditions (Yathom 1971, Ellis 2004, Miller 1977, Barker and Coop 2021). ECW may complete 3–9 generations depending on climate and host plant (Ellis 2004), with 1–11 generations predicted in environmentally suitable areas in the CONUS (Barker and Coop 2021). Photoperiod may also influence ECW's response to temperature across different latitudes (Hegazi et al. 2021). A laboratory study revealed interactive effects of temperature and photoperiod on ECW development, with longer photoperiods slowing larval development rates and reducing the number of larval instars (Hegazi et al. 2021). Its development rate may also vary across host plant species (Salama et al. 1971, Shoman et al. 2025). Higher temperatures could increase ECW reproductive rates and affect insecticide effectiveness (Massot et al. 2021).

The climate-stress trend maps showed broad changes in both cold and heat stress, but these changes did not translate into statistically significant shifts in predicted climatic suitability for ECW in only a few isolated areas of California (Death Valley). The contrast between widespread climate-stress trends and limited suitability changes suggests that the modeled climatic limits remain sufficiently broad that changes in individual stress variables do not necessarily alter establishment potential. Previous modeling studies reported suitable environments for ECW throughout the South and Midwest, as well as along the West Coast, whereas cold temperatures would likely exclude the pest from colder regions, including the Intermountain West and latitudes north of *ca.* 41° N in the East (Barker and Coop 2021, ElShahed et al. 2023).

The stronger and more spatially extensive trends in predicted phenology and climate stress over the entire 44-year period may reflect both the larger sample size, which can reduce noise and improve detection of directional patterns, and differences in the underlying climate trends between the two time periods. In particular, the recent 24-year period may capture climate variability or regional trends that differ from those observed over the longer 44-year period. Thus, differences between the two periods should be interpreted as reflecting both long-term climate trends and shorter-term regional variability.

5D. References

Baker, C. R. B., and G. W. Miller. 1974. Some effects of temperature and larval food on the development of *Spodoptera littoralis* (Boisd.) (Lep., Noctuidae). Bulletin of Entomological Research 63:495–511.

Barker, B. S., and L. Coop. 2021. Egyptian cottonworm, *Spodoptera littoralis*. Phenology/degree-day and climate suitability model white paper for USPEST.ORG. Prepared for United States Department of Agriculture (USDA) – Animal and Plant Health Inspection Service (APHIS) – Plant Protection and Quarantine (PPQ). Vs. 1.0 (1/8/2021). Available online: https://uspest.org/CAPS/Spodoptera_littoralis_white_paper.pdf (accessed 8 September 2025).

CABI. 2022. *Spodoptera littoralis* (cotton leafworm). CABI Compendium. Available online: https://doi.org/10.1079/cabicompendium.51070 (accessed 31 October 2025).

Coop, L., and B. S. Barker. 2021. Phenology/degree-day model analysis: Egyptian cottonworm (*Spodoptera littoralis*). Prepared for USPEST.org at Oregon State University, Oregon IPM Center. Available online: https://uspest.org/wea/Spodoptera_littoralis_model.pdf (accessed 8 September 2025).

EFSA Panel on Plant Health (PLH). 2015. Scientific opinion on the pest categorisation of *Spodoptera littoralis*. 2015. EFSA Journal 13:3987.

Ellis, S. E. 2004. New Pest Response Guidelines: *Spodoptera*. USDA/APHIS/PPQ/PDMP. Animal and Plant Health Inspection Service, Plant Protection and Quarantine. Available online: https://assets.ippc.int/static/media/uploads/resources/new_pest_response_guidelines_spodoptera.pdf (accessed 9 September 2025).

ElShahed, S. M., Z. K. Mostafa, M. H. Radwan, and E. M. Hosni. 2023. Modeling the potential global distribution of the Egyptian cotton leafworm, *Spodoptera littoralis* under climate change. Scientific

Reports 13:1–10.
EPPO. 2025. *Spodoptera littoralis*. EPPO datasheets on pests recommended for regulation. Available online: https://gd.eppo.int/ (accessed 11 August 2025).
European Food Safety Authority (EFSA). 2015. Scientific opinion on the pest categorisation of *Spodoptera littoralis*. EFSA Journal 13:1–26.
Hegazi, E. M., W. E. Khafagi, and E. Agamy. 2021. Do non-diapausing insects respond to different photoperiods: *Spodoptera littoralis*? Journal of Entomology and Nematology 13:26–34.
Massot, M., T. Bagni, A. Maria, P. Couzi, T. Drozdz, A. Malbert-Colas, M. Maïbèche, and D. Siaussat. 2021. Combined influences of transgenerational effects, temperature and insecticide on the moth *Spodoptera littoralis*. Environmental Pollution 289:117889.
Miller, G. W. 1977. Mortality of *Spodoptera littoralis* (Bolsduval) (Lepidoptera; Noctuidae) at non-freezing temperatures. Bulletin of Entomological Research 67:143–152.
Salama, H. S., N. Z. Dimetry, and S. A. Salem. 1971. On the host preference and biology of the cotton leaf worm *Spodoptera littoralis*. Zeitschrift für Angewandte Entomologie 67:261–266.
Shoman, S. A., N. M. Ghanim, N. H. Harraz, and W. Z. Aziz. 2025. Effect of four host plants on biological characteristics of *Spodoptera frugiperda* and *Spodoptera littoralis* (both Lepidoptera: Noctuidae). International Journal of Tropical Insect Science:1909–1919.
Sullivan, M. 2014. CPHST Pest Datasheet for *Spodoptera littoralis*. USDA-APHIS-PPQCPHST. Revised March 2014. Available online: https://caps.ceris.purdue.edu/wp-content/uploads/2025/07/Spodoptera-littoralis_CPHST-Datasheet_2014-version.pdf (accessed 22 October 2026).
Yathom, S. 1971. Distribution and flight period of Heliothidinae species in Israel in 1959-1969. Israel Journal of Agricultural Research 21:51–61.

6. False codling moth

6A. Introduction

Native to sub-Saharan Africa, the false codling moth (FCM), *Thaumatotibia leucotreta* Meyrick (Lepidoptera: Tortricidae), is a highly polyphagous pest distributed throughout much of Africa and parts of the Middle East, including Israel (Carstens and Moore 2020). Its economically important hosts include avocado, *Citrus* spp., corn, cotton, eggplant, grapes, stone fruits, peppers, and cut roses (EPPO 2025). FCM undergoes five larval instars, during which larvae bore into and feed within plant tissues, particularly fruit, causing direct damage before exiting the host to form cocoons in the soil (NAPPFAST 2003, Gilligan et al. 2011). Although not established in the United States, FCM has been repeatedly intercepted at U.S. ports of entry in cargo and passenger baggage (Venette et al. 2003, Stibick 2006). The only confirmed domestic detection occurred in 2008, when a single adult male was found in Ventura County, California. Subsequent extensive trapping detected no additional individuals, and the introduction was successfully eradicated (Gilligan et al. 2011). The establishment of FCM in the United States could result in substantial economic losses, potentially reaching billions of dollars (Venette et al. 2003, Stibick 2006).

A model for FCM developed for the Degree-Day, establishment Risk, and Phenological event mapping system (DDRP) is operationalized to produce near real-time forecasts for the contiguous United States (CONUS) at https://uspest.org/DDRP. The full set of model parameters for FCM, including developmental temperature thresholds, degree-day requirements for individual life stages, and climate stress thresholds and limits, are available at USPest.org (Barker and Coop 2019).

6B. Results

i. Phenology

Entire period: 1981–2025

Trends in predicted first adult emergence and egg hatch for FCM over the 44-year period (1981–2025) were predominantly negative, indicating that both phenological events shifted earlier over time (Figure 52, Figure 53). Earlier phenology was predicted across much of the eastern, south-central, and western United States. Statistically significant trends were more spatially restricted, occurring primarily in portions of the East and Southwest and scattered areas of the Intermountain West. Within these regions, predicted adult emergence and egg hatch shifted earlier by approximately 0.01–0.6 days per year, with some of the largest shifts occurring in southern latitudes. Trends toward later phenology occurred in a some isolated areas of the Great Plains and Intermountain West but most were not statistically significant.

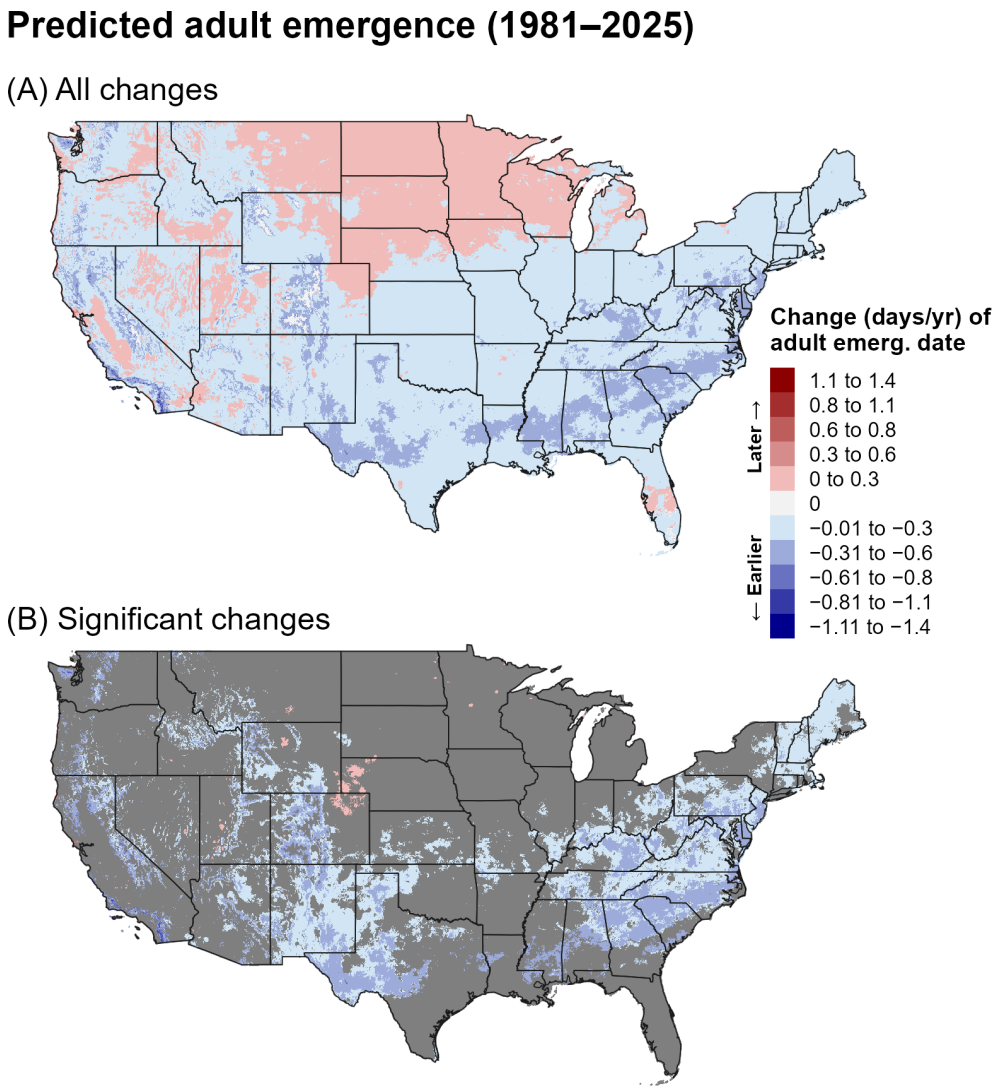

Figure 52. Changes (days/year) in predicted dates of first adult emergence for FCM across the CONUS over the entire 44-year period (1981–2025). Maps show (A) all changes and (B) statistically significant changes ($P < 0.1$); areas shown in gray are not statistically significant.

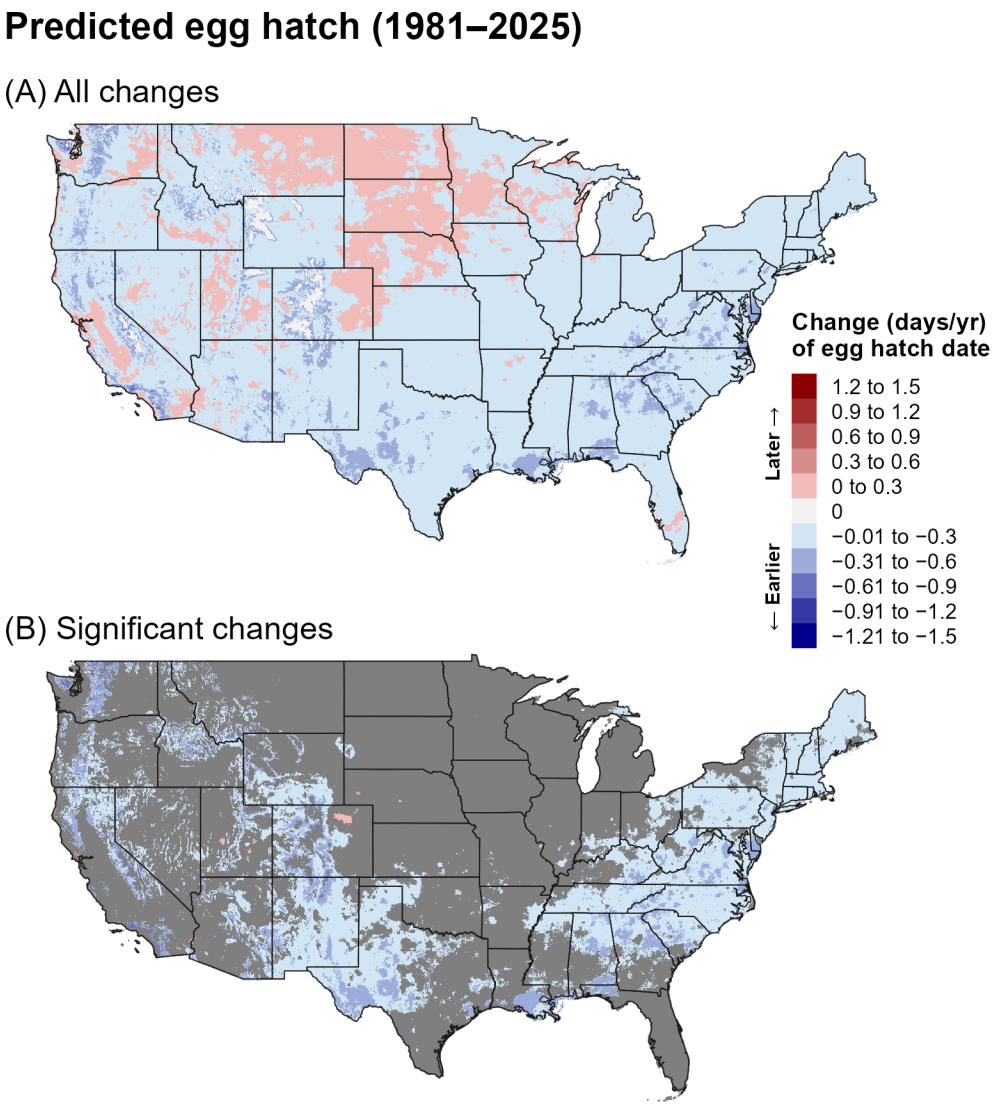

Figure 53. Changes (days/year) in predicted dates of first egg hatch for FCM across the CONUS over the entire 44-year period (1981–2025). Maps show (A) all changes and (B) statistically significant changes ($P < 0.1$); areas shown in gray are not statistically significant.

Recent period: 2001–2025

Trends in predictions of first adult emergence and egg hatch for FCM over the recent 24-year period (2001–2025) were partially consistent with those observed over the 1981–2025 period. Trends were more spatially heterogeneous, with significantly later predicted events across portions of the central and northern United States and earlier events in parts of the Southeast and West (Figure 54, Figure 55). Significant changes were relatively localized, particularly in the central and eastern United States.

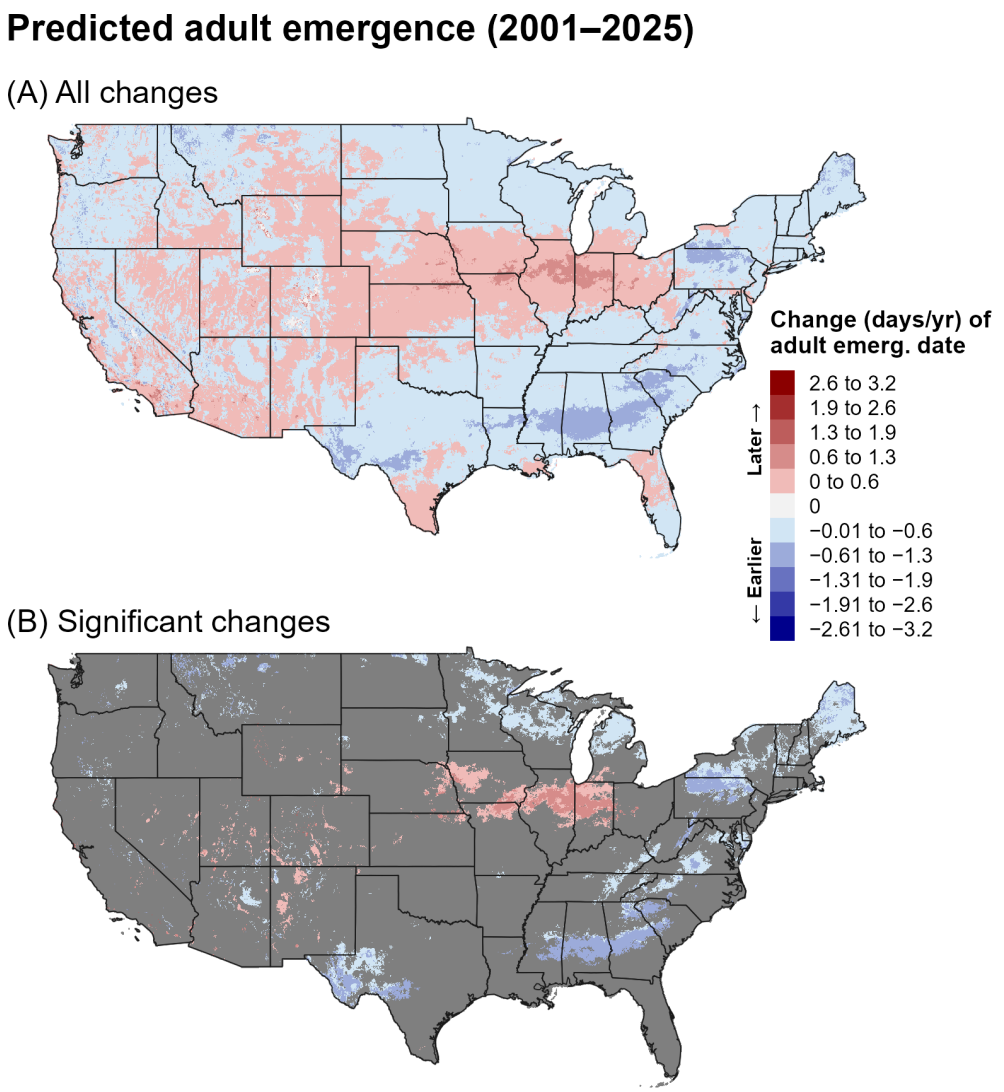

Figure 54. Changes (days/year) in predicted dates of first adult emergence for FCM across the CONUS over the recent 24-year period (2001–2025). Maps show (A) all changes and (B) statistically significant changes ($P < 0.1$); areas shown in gray are not statistically significant.

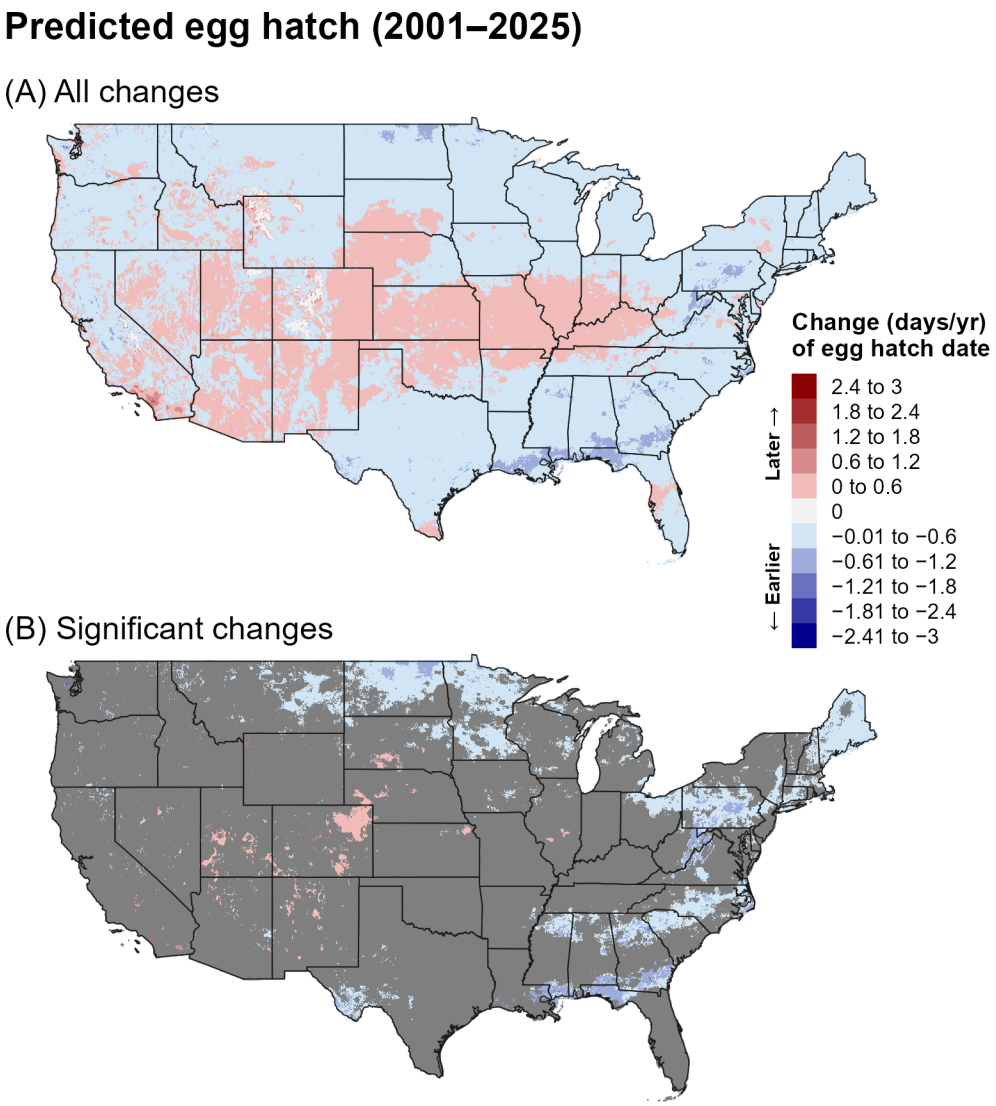

Figure 55. Changes (days/year) in predicted dates of first egg hatch for FCM across the CONUS over the recent 24-year period (2001–2025). Maps show (A) all changes and (B) statistically significant changes ($P < 0.1$); areas shown in gray are not statistically significant.

ii. Climatic suitability

Entire period: 1981–2025

Over the entire 44-year period (1981–2025), predicted cold stress for FCM decreased across much of the northern and western United States, with significant decreases especially evident in the Upper Midwest, Northeast, and the Intermountain West (Figure 56). However, decreases across the Southeast, Great Plains, northern interior, and Pacific Coast were generally smaller and significant in only some areas. Predicted heat stress significantly increased in isolated parts of the Southwest and California (Figure 57). Climatic suitability increased significantly in parts of California and the southern United States, particularly along the Gulf Coast, although these trends were spatially limited (Figure 58). Decreases in suitability owing to heat stress were predicted in parts of the Sonoran Desert region of the Southwest.

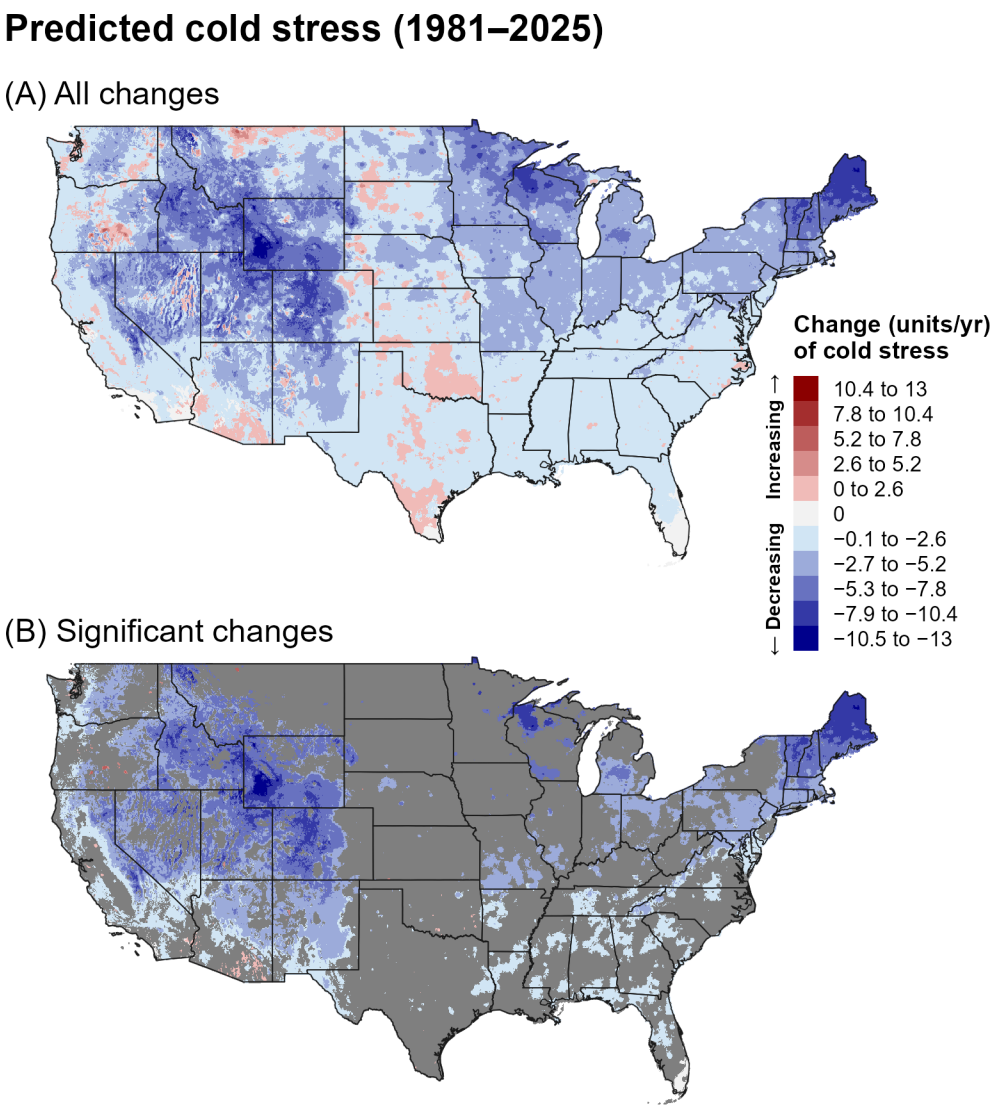

Figure 56. Changes (units/year) in predicted cold stress for FCM across the CONUS over the entire 44-year period (1981–2025). Maps show (A) all changes and (B) statistically significant changes ($P < 0.1$); areas shown in gray are not statistically significant. Areas shown as 0 in (B) had significant trends but very small changes.

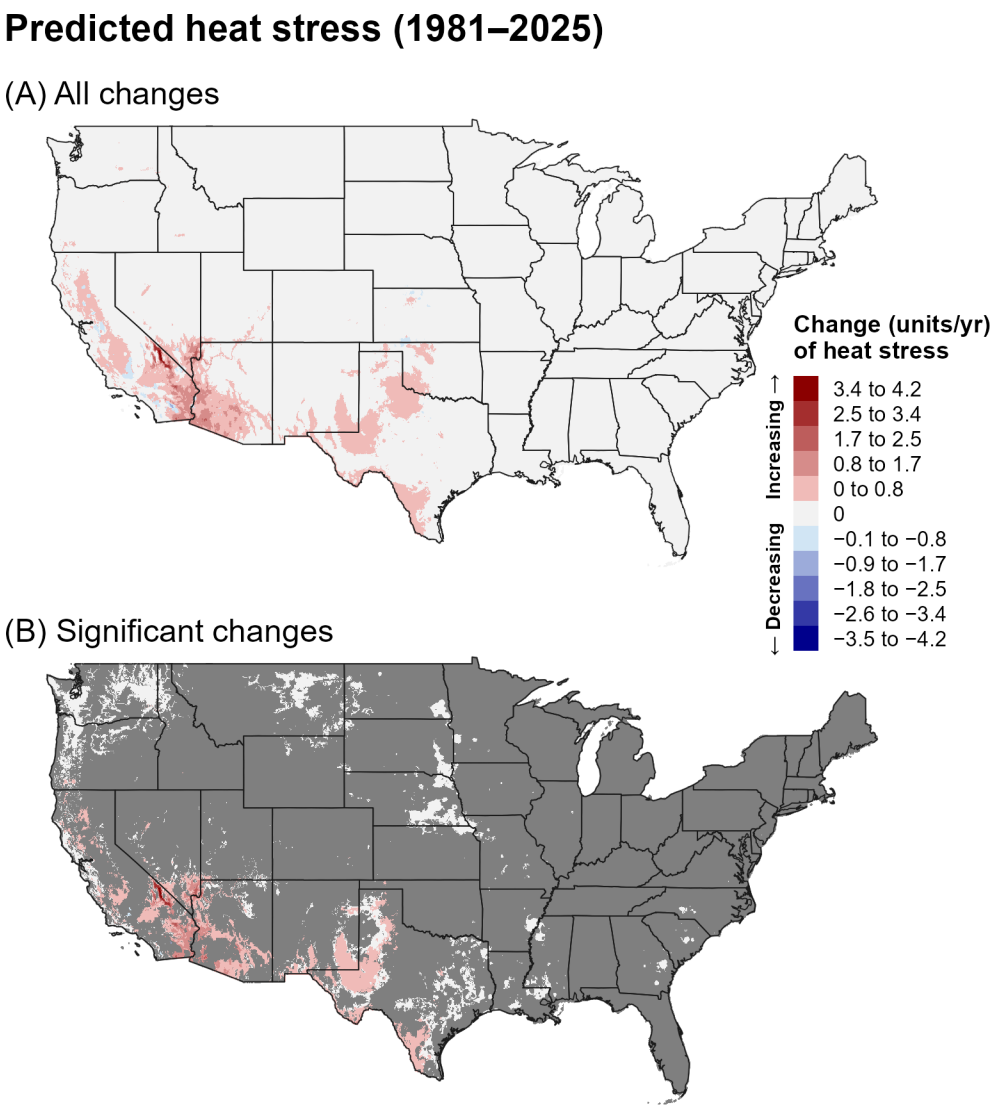

Figure 57. Changes (units/year) in predicted heat stress for FCM across the CONUS over the entire 44-year period (1981–2025). Maps show (A) all changes and (B) statistically significant changes ($P < 0.1$); areas shown in gray are not statistically significant. Areas shown as 0 in (B) had significant trends but very small changes.

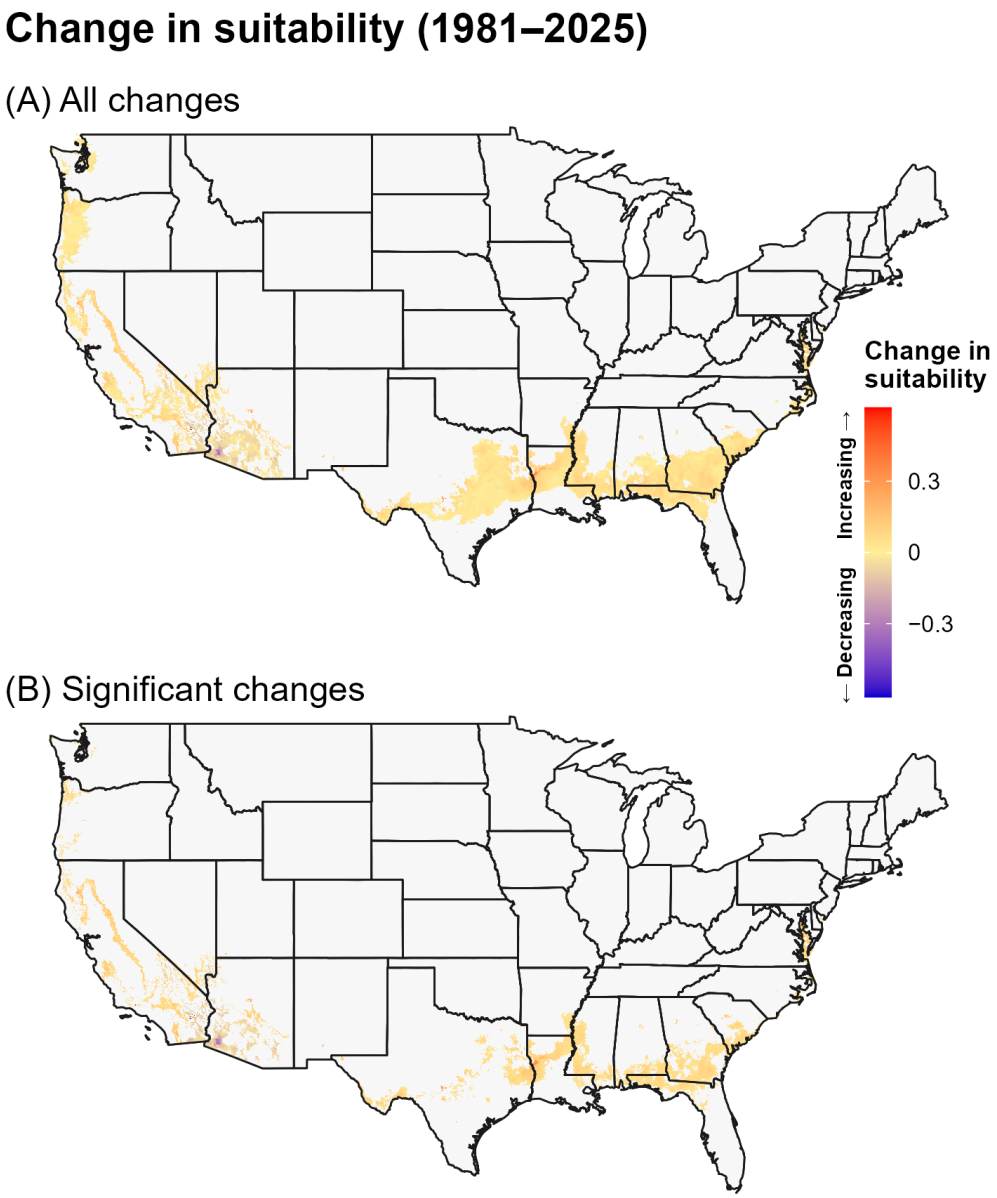

Figure 58. Changes in predicted climatic suitability for FCM across the CONUS over the 44-year period (1981–2025). Suitability is defined as areas not excluded by climate stress. Positive changes (warmer colors) indicate an increased likelihood of establishment, whereas negative changes (cooler colors) indicate a decreased likelihood of establishment.

Recent period: 2001–2025

Many areas that exhibited significant decreases in cold stress for FCM over 1981–2025 no longer showed significant trends during the recent period. These areas were concentrated in scattered patches across the Northeast, Southeast, and California (Figure 59). Significant increases in predicted cold stress occurred in a few small, isolated areas of the Northwest. Areas with increasing heat stress were concentrated in the Southwest, particularly Texas, whereas parts of California showed significant decreases (Figure 60). The climatic-suitability map showed relatively limited significant change, although increases remained evident in small portions of the South (Figure 61).

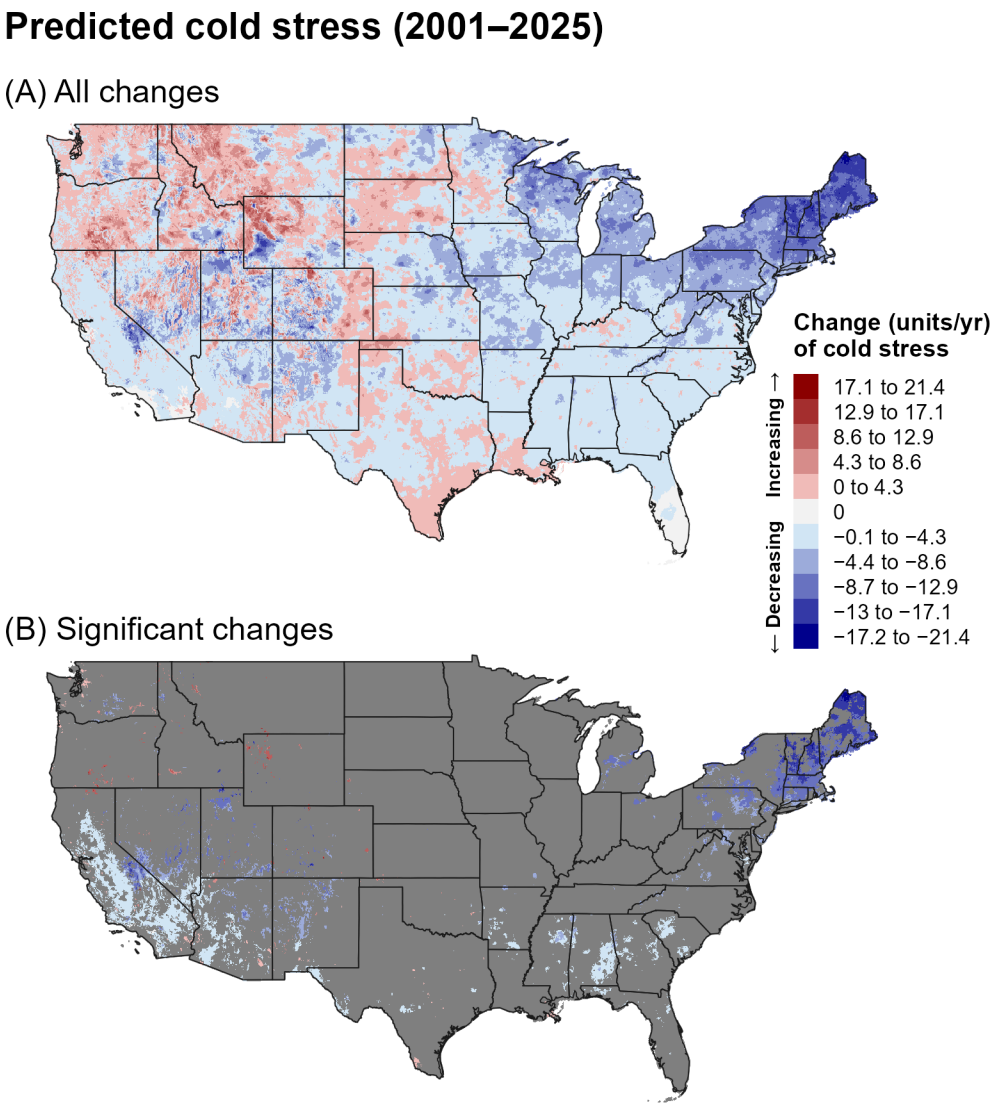

Figure 59. Changes (units/year) in predicted cold stress for FCM across the CONUS over the recent 24-year period (2001–2025). Maps show (A) all changes and (B) statistically significant changes ($P < 0.1$); areas shown in gray are not statistically significant. Areas shown as 0 in (B) had significant trends but very small changes.

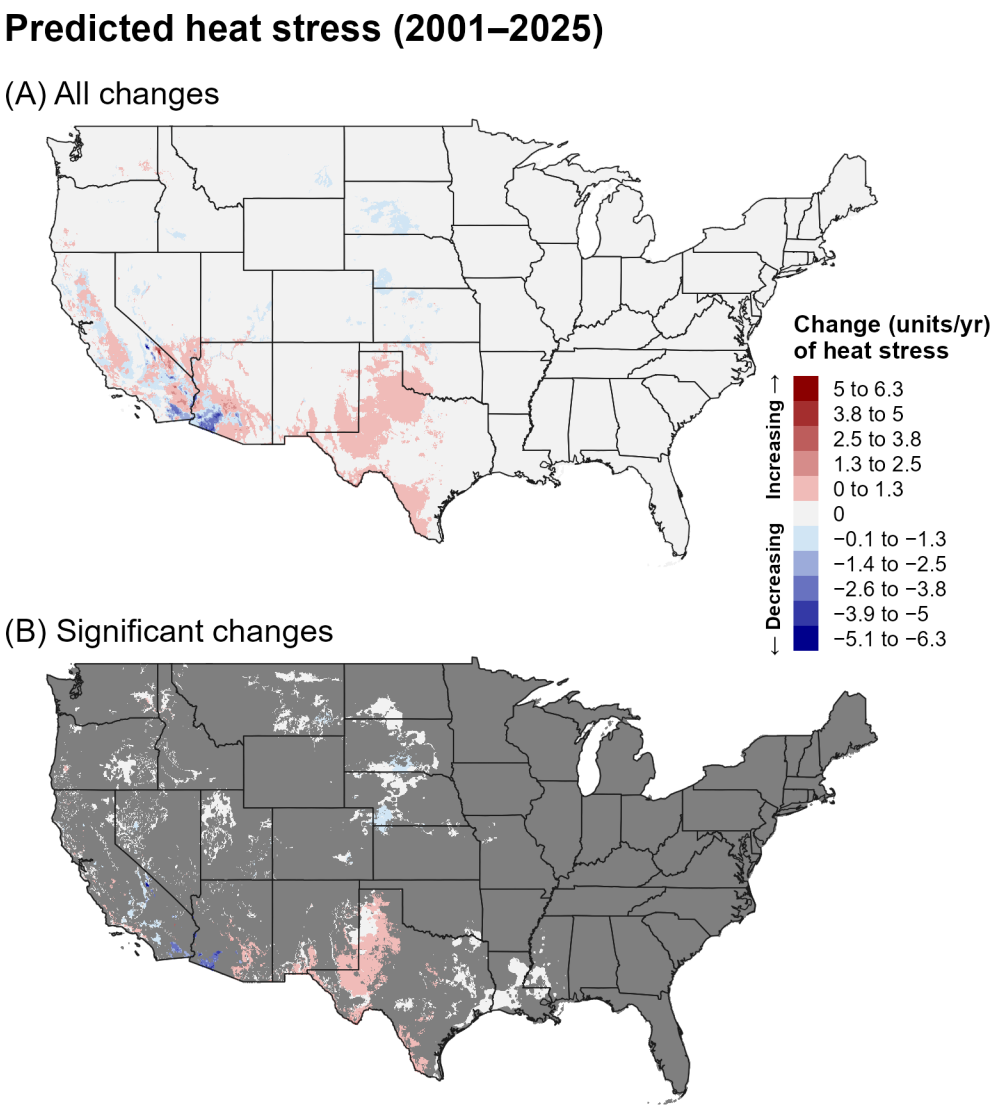

Figure 60. Changes (units/year) in predicted heat stress for FCM across the CONUS over the recent 24-year period (2001–2025). Maps show (A) all changes and (B) statistically significant changes ($P < 0.1$); areas shown in gray are not statistically significant. Areas shown as 0 in (B) had significant trends but very small changes.

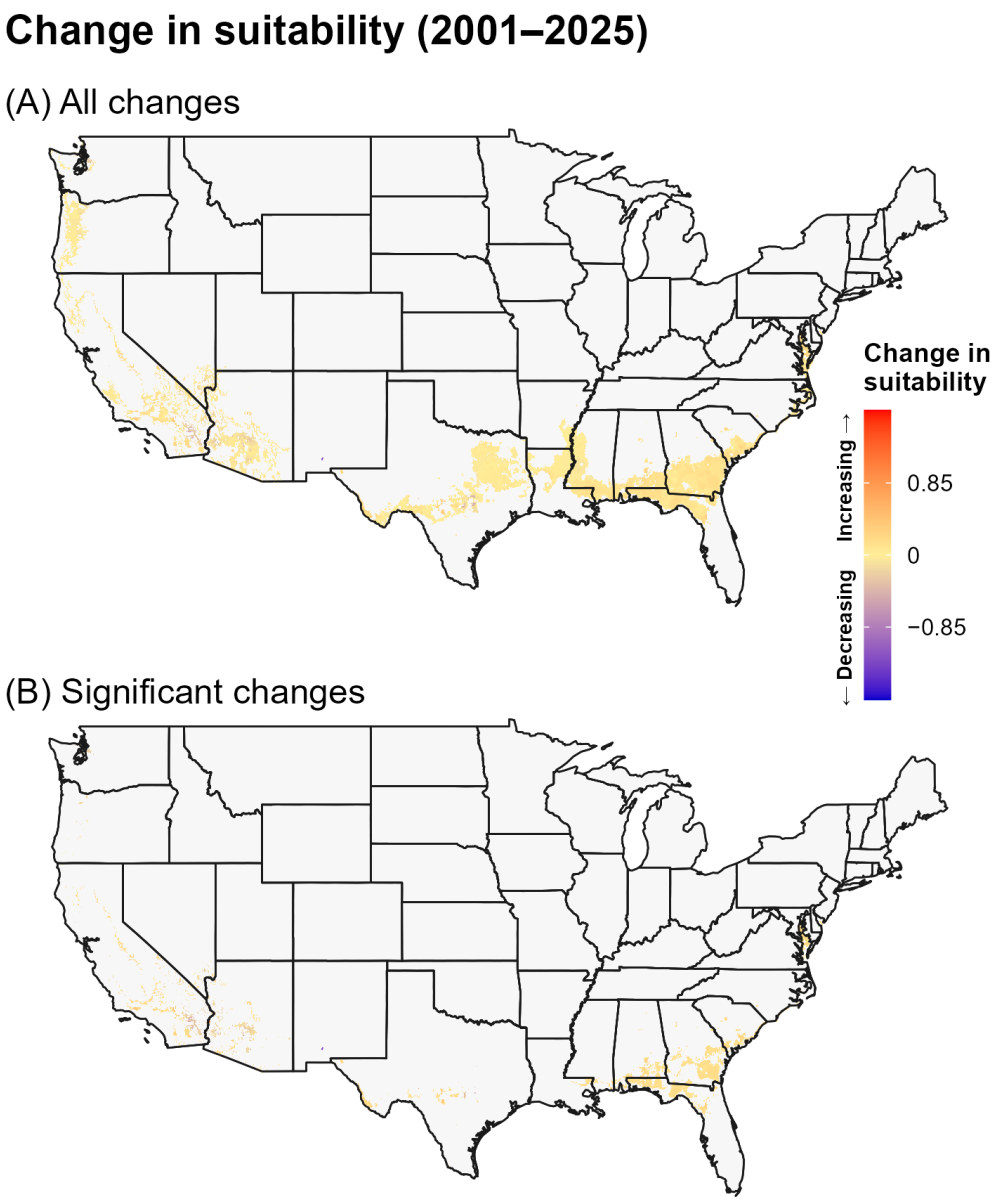

Figure 61. Changes in predicted climatic suitability for FCM across the CONUS over the recent 24-year period (2001–2025). Suitability is defined as areas not excluded by climate stress. Positive changes (warmer colors) indicate an increased likelihood of establishment, whereas negative changes (cooler colors) indicate a decreased likelihood of establishment.

6C. Discussion

Although FCM is not established in the CONUS, understanding potential changes in phenology can inform surveillance planning. In areas exhibiting significant trends toward earlier phenology, predicted dates shifted earlier by approximately 0.01–0.6 days per year, suggesting that surveillance materials may need to be deployed earlier in the season. These trends may be particularly relevant where they overlap with major host-fruit production areas, including regions supporting intensive cultivation of citrus and other susceptible crops, such as avocados, peaches, and cotton. Such areas include parts of Florida, the Gulf Coast, and California (NAPPFAST 2003).

Earlier adult emergence and egg hatch could potentially allow FCM to complete more generations per year, increasing pest pressure and associated crop damage. FCM can complete 2–10 generations annually, with developmental rates and voltinism influenced by temperature, food availability and quality, photoperiod, and humidity (Venette et al. 2003, Gilligan et al. 2011). In areas predicted to be environmentally suitable in the CONUS, FCM may complete 1–9 generations (Barker and Coop 2019). Moisture conditions may further modify development and host use: drought can affect host-plant availability and quality (Gilligan et al. 2011), and experimental studies have demonstrated effects of moisture stress on FCM development and tomato infestation (Patrick et al. 2021).

Decreases in predicted cold stress across parts of the CONUS, particularly in southern regions with substantial host-fruit production, suggest that low temperatures have become less limiting to FCM establishment in these areas. A biome-based risk assessment identified parts of Florida and the western United States, excluding the Pacific Coast, as suitable for FCM establishment (Venette et al. 2003), while subsequent modeling predicted suitable conditions in California and other parts of the Pacific Coast, as well as portions of the South (Barker and Coop 2019). These findings highlight the importance of continued surveillance, particularly in regions where susceptible crop hosts overlap with increasingly favorable climatic conditions.

In contrast, predicted heat stress increased significantly in the hottest parts of the Southwest, particularly the Sonoran Desert region, corresponding to declines in establishment suitability. Thus, despite the availability of suitable crop hosts, increasing thermal stress may make some areas less favorable for FCM establishment. However, these patterns should be interpreted cautiously because DDRP models assume equivalent climatic tolerances across life stages, which may not reflect FCM thermal biology. Larvae tolerate a broader range of temperatures than adults, while adults exhibit a heat-hardening response (Stotter and Terblanche 2009, Terblanche et al. 2017). Consequently, predicted climate-stress trends provide an indication of changing thermal constraints but should not be interpreted as a definitive measure of establishment potential.

The stronger and more spatially extensive trends in predicted phenology and climate stress over the entire 44-year period likely reflect both the greater number of years included, which may reduce interannual variability and improve the detection of directional trends, and differences in the underlying climatic trends between the two study periods. In particular, the recent 24-year period may capture climate variability or regional trends that differ from those observed over the longer 44-year period. Thus, differences between the two periods should be interpreted as reflecting both long-term climate trends and shorter-term regional variability.

6D. References

Barker, B. S., and L. Coop. 2019. False codling moth, *Thaumatotibia leucotreta*. Phenology/degree-day and climate suitability model analysis for USPEST.ORG. Prepared for United States Department of Agriculture (USDA) – Animal and Plant Health Inspection Service (APHIS) – Plant Protection and Quarantine (PPQ). Vs. 1.0 (12/2/2019). Online at: https://uspest.org/CAPS/Thaumatotibia_leucotreta_white_paper.pdf (accessed 8 September 2025).

Carstens, E., and S. Moore. 2020. *Thaumatotibia leucotreta* (false codling moth (FCM)). CABI Compendium. Available online: https://doi.org/10.1079/cabicompendium.6904 (accessed 25 August 2025).

EPPO. 2025. *Thaumatotibia leucotreta*. EPPO datasheets on pests recommended for regulation. Online at: https://gd.eppo.int/ (accessed 25 August 2025).

Gilligan, T. M., M. E. Epstein, and K. M. Hoffman. 2011. Discovery of false codling moth, *Thaumatotibia leucotreta* (Meyrick), in California (Lepidoptera: Tortricidae). Proceedings of the Entomological Society of Washington 113:426–435.

NAPPFAST. 2003. Pest assessment: False codling moth, *Cryptophlebia leucotreta* (Meyrick), (Lepidoptera: Tortricidae). USDA-APHIS-PPQ-CPHST-PERAL/NCSU.

Patrick, E. M., I. Koomen, S. Ndlela, and J. M. Wesonga. 2021. Effect of moisture stress on the development of false codling moth *Thaumatotibia leucotreta* (Lepidoptera: Tortricidae) on two tomato varieties.

Neotropical Entomology 50:828–834.
Stotter, R. L., and J. S. Terblanche. 2009. Low-temperature tolerance of false codling moth *Thaumatotibia leucotreta* (Meyrick) (Lepidoptera: Tortricidae) in South Africa. Journal of Thermal Biology 34:320–325.
Terblanche, J. S., K. A. Mitchell, W. Uys, C. Short, and L. Boardman. 2017. Thermal limits to survival and activity in two life stages of false codling moth *Thaumatotibia leucotreta* (Lepidoptera, Tortricidae). Physiological Entomology 42:379–388.
Stibick, J. 2006. New pest response guidelines: false codling moth *Thaumatotibia leucotreta*. USDA-APHIS-PPQ-Emergency and Domestic Programs, Riverdale, Maryland. Online at: https://www.cdfa.ca.gov/plant/fcm/pdfs/publications/Stibick_2006-FCM_NPRG.pdf (accessed 3 April 2026).
Venette, R. C., E. E. Davis, M. Dacosta, H. Heisler, and M. Larson. 2003. Mini risk assessment False codling moth, *Thaumatotibia* (=*Cryptophlebia*) *leucotreta* (Meyrick) [Lepidoptera: Tortricidae]. CAPS PRA, St. Paul, Minnesota.

7. Japanese beetle

7A. Introduction

Native to Japan, the Japanese beetle (JPB), *Popillia japonica* Newman (Coleoptera: Scarabaeidae), is a highly polyphagous pest with a host range exceeding 400 plant species, including food crops, fruit trees, turfgrass, and ornamental plant (Fleming 1972, EPPO 2025, Tayeh et al. 2023). Since its initial detection in the United States in 1916 in New Jersey, JPB has spread widely across the eastern and central regions of the country, as well as parts of eastern Canada (Dickerson and Weiss 1918, Fleming 1972, EPPO 2025, Althoff and Rice 2022). Although isolated infestations have been successfully eradicated in several western states, including Nevada and California, the beetle persists in localized areas of the Pacific Northwest, including parts of Colorado, British Columbia, Washington, and Oregon (Althoff and Rice 2022, EPPO 2025, Stoven et al. 2021). Total associated costs of JPB in the United States are estimated at $460 million annually, with $234 million a year spent on control and turf replacement costs (Fleming 1972, USDA-APHIS 2015).

A model for JPB developed for the Degree-Day, establishment Risk, and Phenological event mapping system (DDRP) is operationalized to produce near real-time forecasts for the contiguous United States (CONUS) at https://uspest.org/DDRP. The full set of model parameters for JPB, including developmental temperature thresholds, degree-day requirements for individual life stages, and climate stress thresholds and limits, are available at USPest.org (Barker and Coop 2024).

7B. Results

i. Phenology

Entire period: 1981–2025

Predicted adult emergence and egg hatch for JPB shifted significantly earlier across large portions of CONUS over the entire period (1981–2025), including most East Coast states, parts of the South and Midwest, and the Intermountain West (Figure 62, Figure 63). In these regions, predicted adult emergence and egg hatch decreased by approximately 0.01–0.5 days per year, with some of the largest declines occurring at higher elevations in the northeastern and western United States.

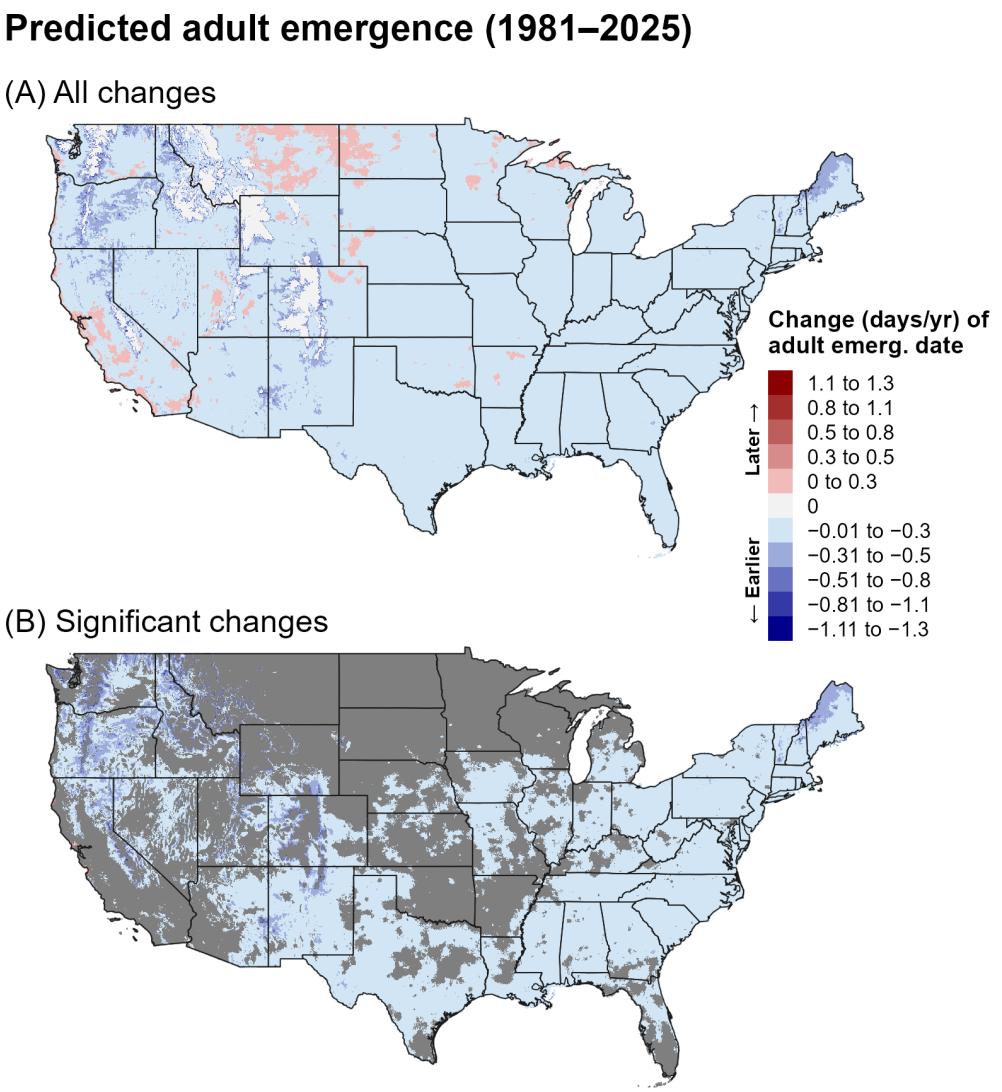

Figure 62. Changes (days/year) in predicted dates of first adult emergence for JPB across the CONUS over the entire 44-year period (1981–2025). Maps show (A) all changes and (B) statistically significant changes ($P < 0.1$); areas shown in gray are not statistically significant.

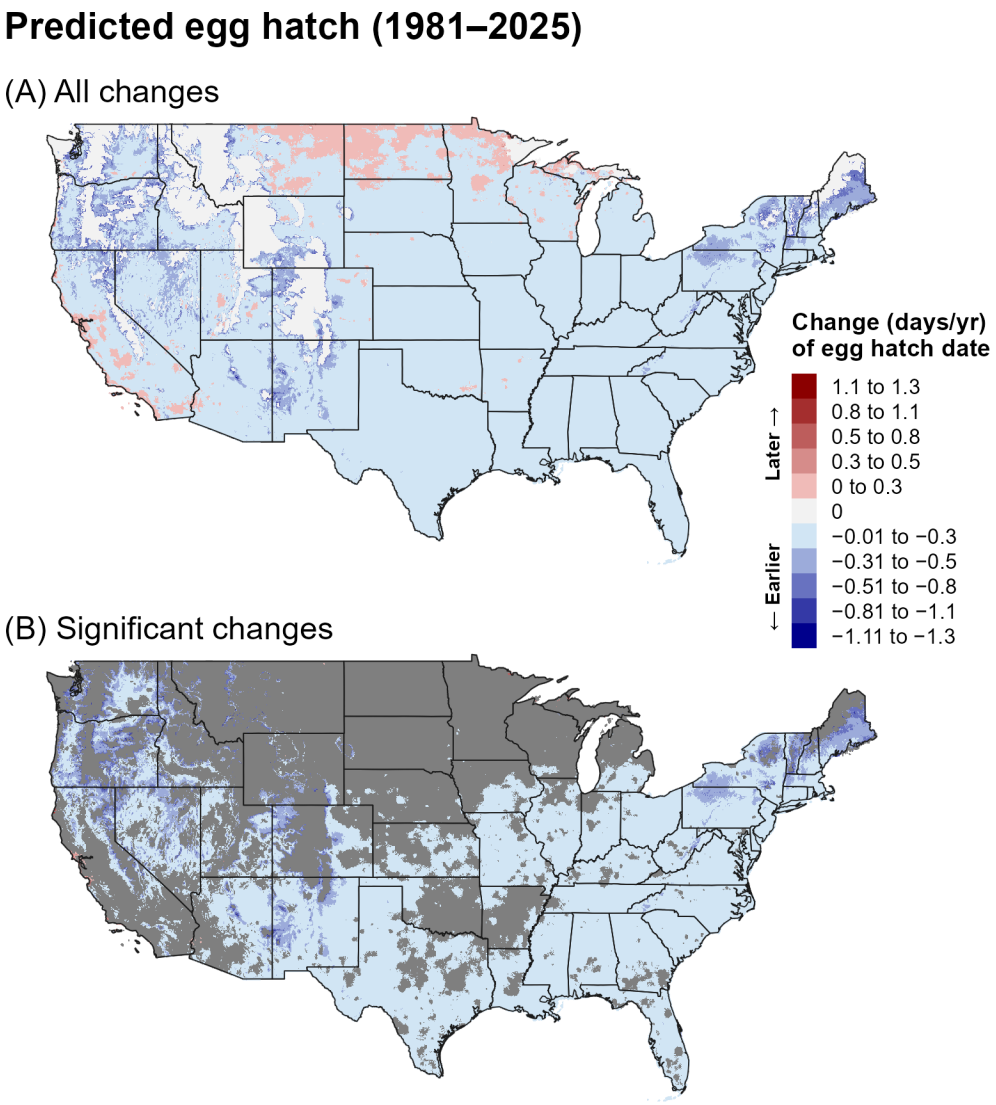

Figure 63. Changes (days/year) in predicted dates of first egg hatch for JPB across the CONUS over the entire 44-year period (1981–2025). Maps show (A) all changes and (B) statistically significant changes ($P < 0.1$); areas shown in gray are not statistically significant.

Recent period: 2001–2025

Trends in predictions of first adult emergence and egg hatch for JPB over the recent 24-year period (2001–2025) were partially consistent with those observed over the 1981–2025 period. In the eastern United States, significant trends were similar in magnitude but less spatially extensive (Figure 64, Figure 65), occurring mostly in East coast states and certain parts of the northern Midwest. Most trends in the western United States were not were not significant. In contrast to the longer-term trends, some isolated areas of the interior West, primarily in the southern Intermountain West, exhibited significant trends toward later phenological events.

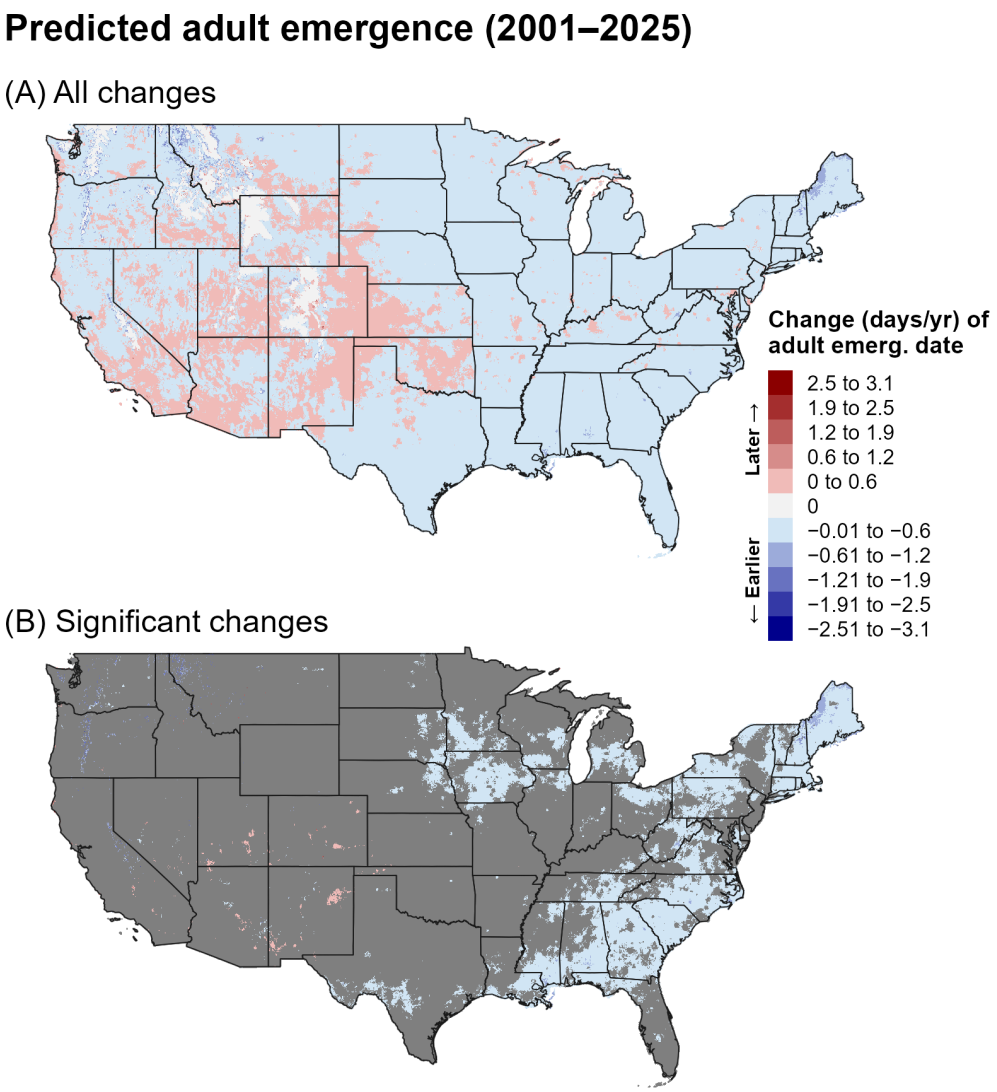

Figure 64. Changes (days/year) in predicted dates of first adult emergence for JPB across the CONUS over the recent 24-year period (2001–2025). Maps show (A) all changes and (B) statistically significant changes ($P < 0.1$); areas shown in gray are not statistically significant.

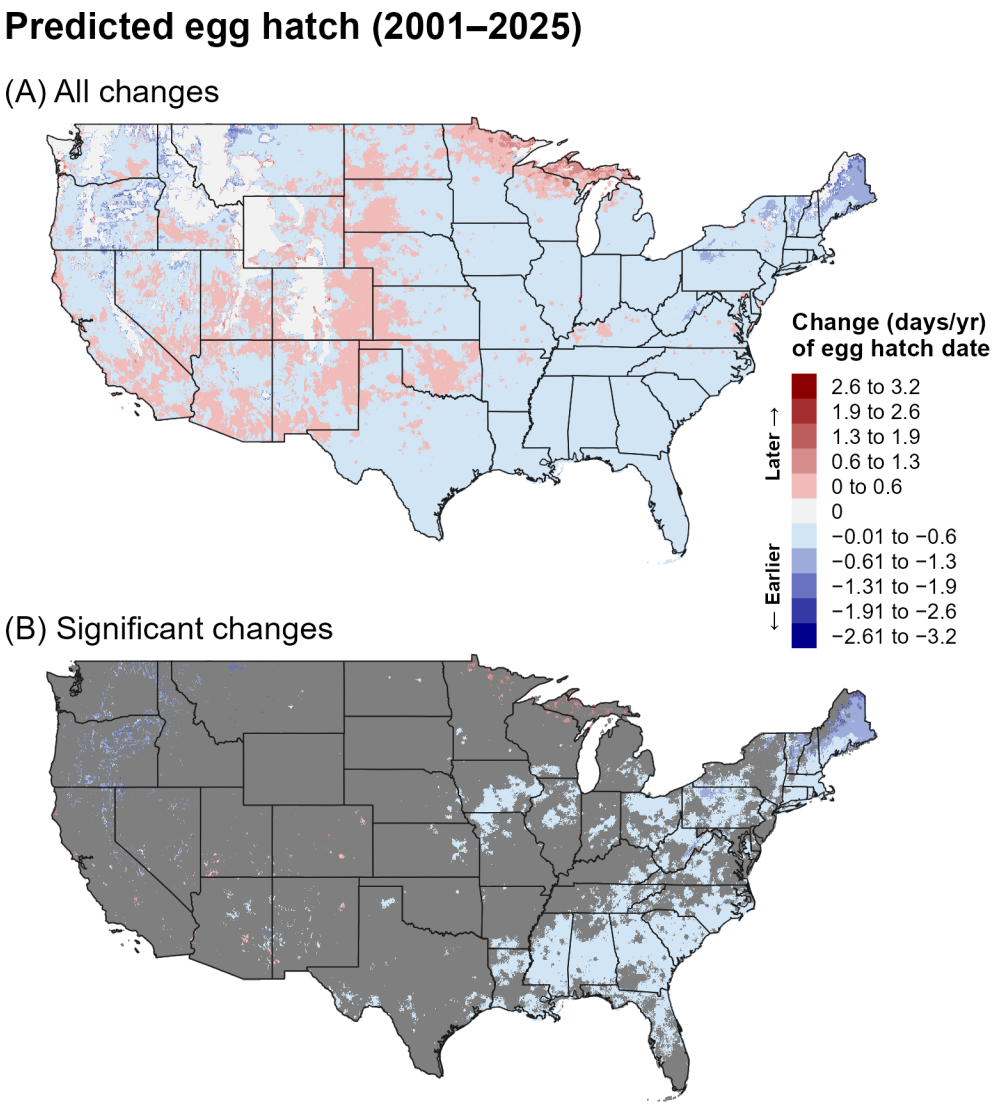

Figure 65. Changes (days/year) in predicted dates of first egg hatch for JPB across the CONUS over the recent 24-year period (2001–2025). Maps show (A) all changes and (B) statistically significant changes ($P < 0.1$); areas shown in gray are not statistically significant.

ii. Climatic suitability

Entire period: 1981–2025

Significant trends in predicted cold stress for JPB over the entire 44-year period (1981–2025) were predominantly negative (Figure 66), indicating a general decrease in cold stress over time. In contrast, significant trends in heat stress were largely positive across portions of the South and West, indicating increasing heat stress (Figure 67). When annual accumulated stress units exceed limits specified in DDRP models, climatic suitability may change. Consistent with these trends, suitability for JPB increased in Minnesota, but decreased in portions of the Southwest (Figure 68). However, these changes were statistically significant only in parts the Southwest and California, suggesting that changes in predicted heat stress may reduce the likelihood of JPB establishment in these areas.

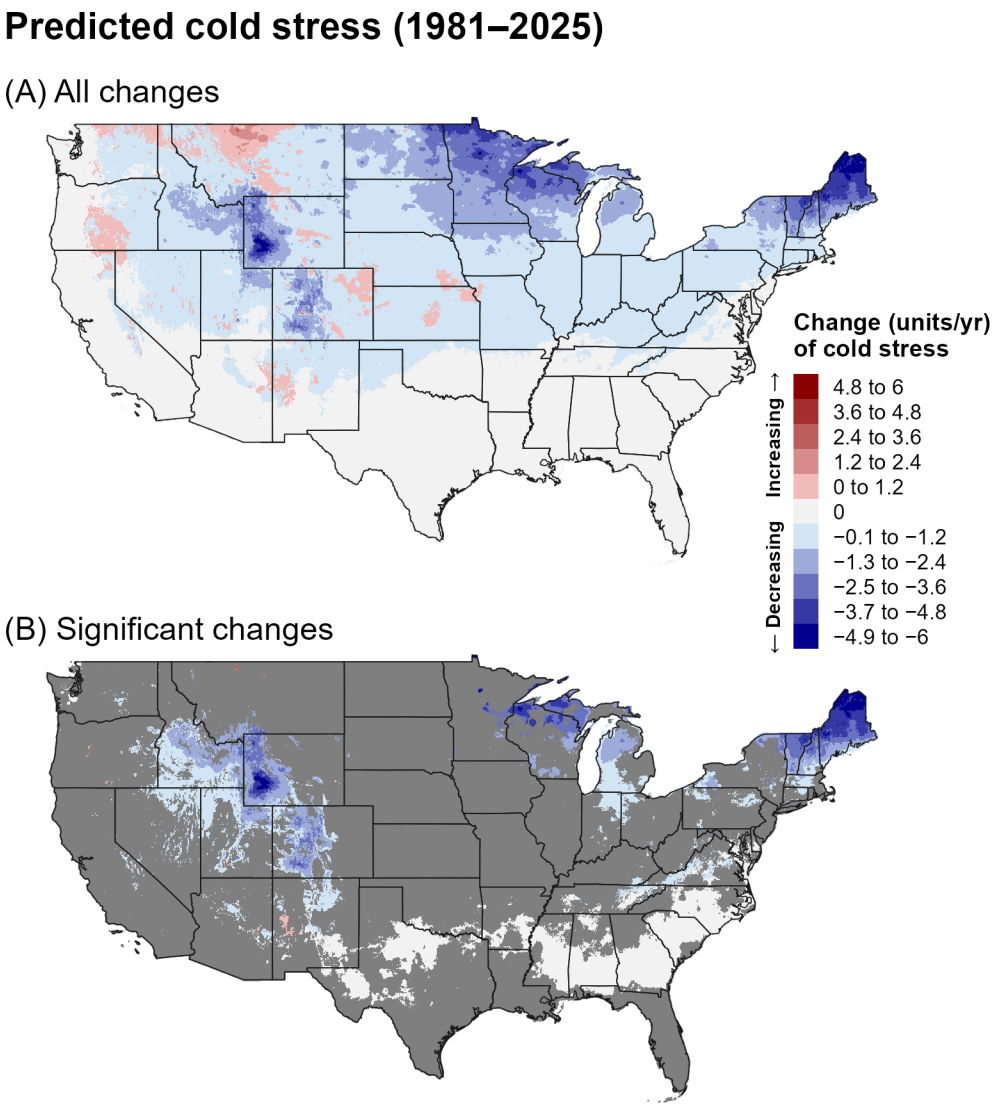

Figure 66. Changes (units/year) in predicted cold stress for JPB across the CONUS over the entire 44-year period (1981–2025). Maps show (A) all changes and (B) statistically significant changes ($P < 0.1$); areas shown in gray are not statistically significant. Areas shown as 0 in (B) had significant trends but very small changes.

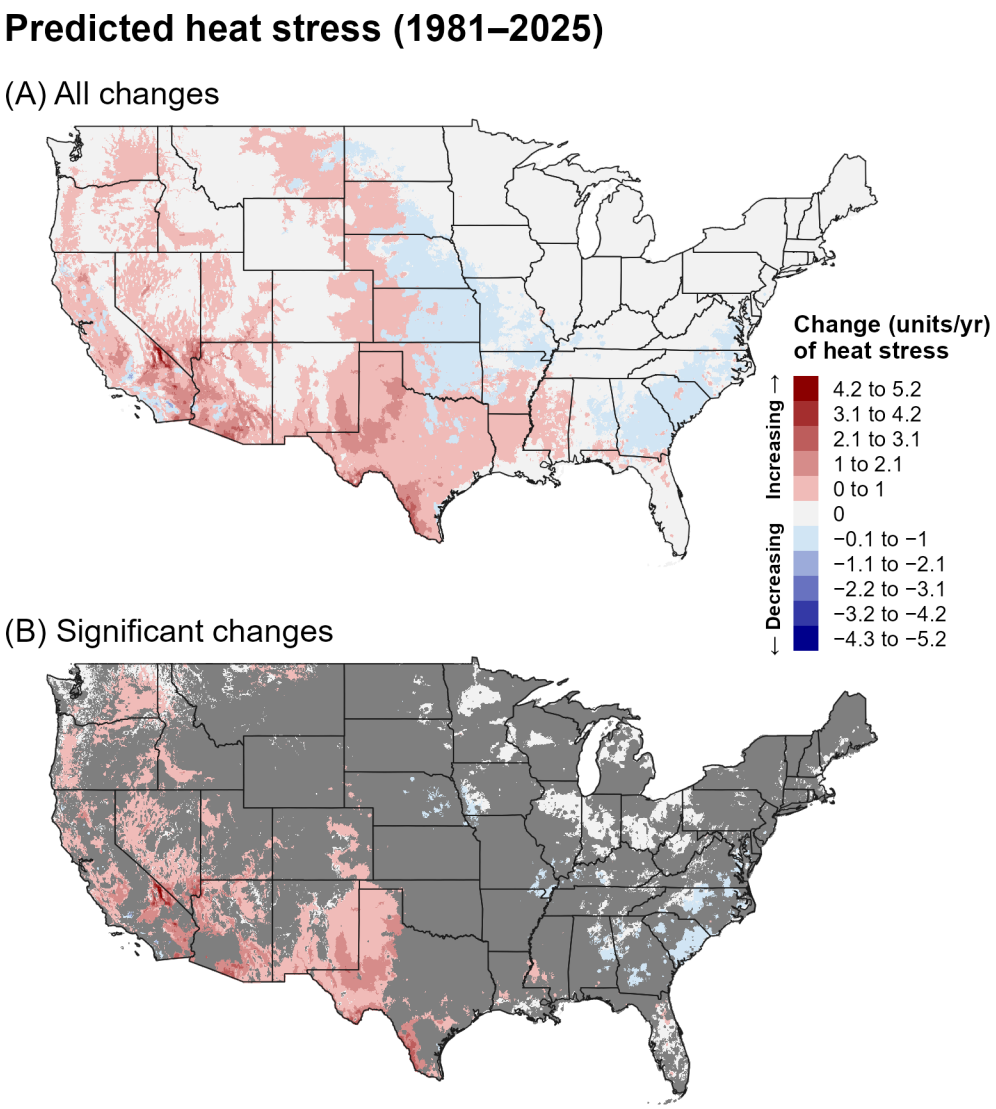

Figure 67. Changes (units/year) in predicted heat stress for JPB across the CONUS over the entire 44-year period (1981–2025). Maps show (A) all changes and (B) statistically significant changes ($P < 0.1$); areas shown in gray are not statistically significant. Areas shown as 0 in (B) had significant trends but very small changes.

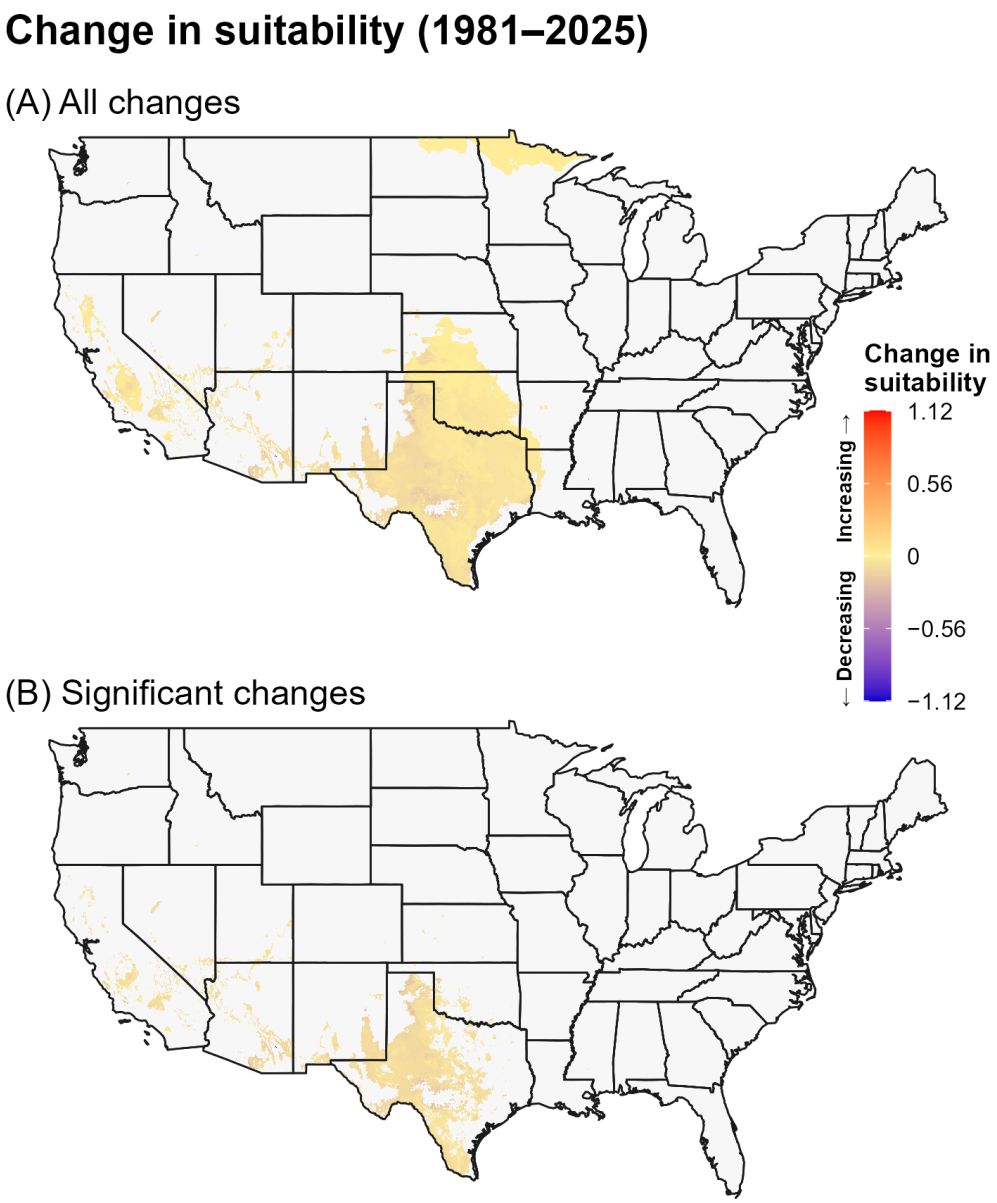

Figure 68. Changes in predicted climatic suitability for JPB across the CONUS over the 44-year period (1981–2025). Suitability is defined as areas not excluded by climate stress. Positive changes (warmer colors) indicate an increased likelihood of establishment, whereas negative changes (cooler colors) indicate a decreased likelihood of establishment.

Recent period: 2001–2025

Statistically significant trends in predicted heat and cold stress for JPB during the recent period (2001–2025) were more spatially limited than those observed over the entire period (1981–2025) (Figure 69, Figure 70). Areas with significant increases in heat stress were generally consistent between the two periods, whereas several areas that exhibited significant decreases in cold stress over the entire period, including the Great Lakes region, no longer showed significant trends. Conversely, parts of the Great Plains and Rocky Mountains exhibited significant increases in cold stress during the recent period. Trends in predicted climatic suitability were broadly consistent with those observed over the entire period but were less spatially extensive, with significant decreases

in suitability confined to isolated areas of the Southwest and California, where heat stress increased (Figure 71).

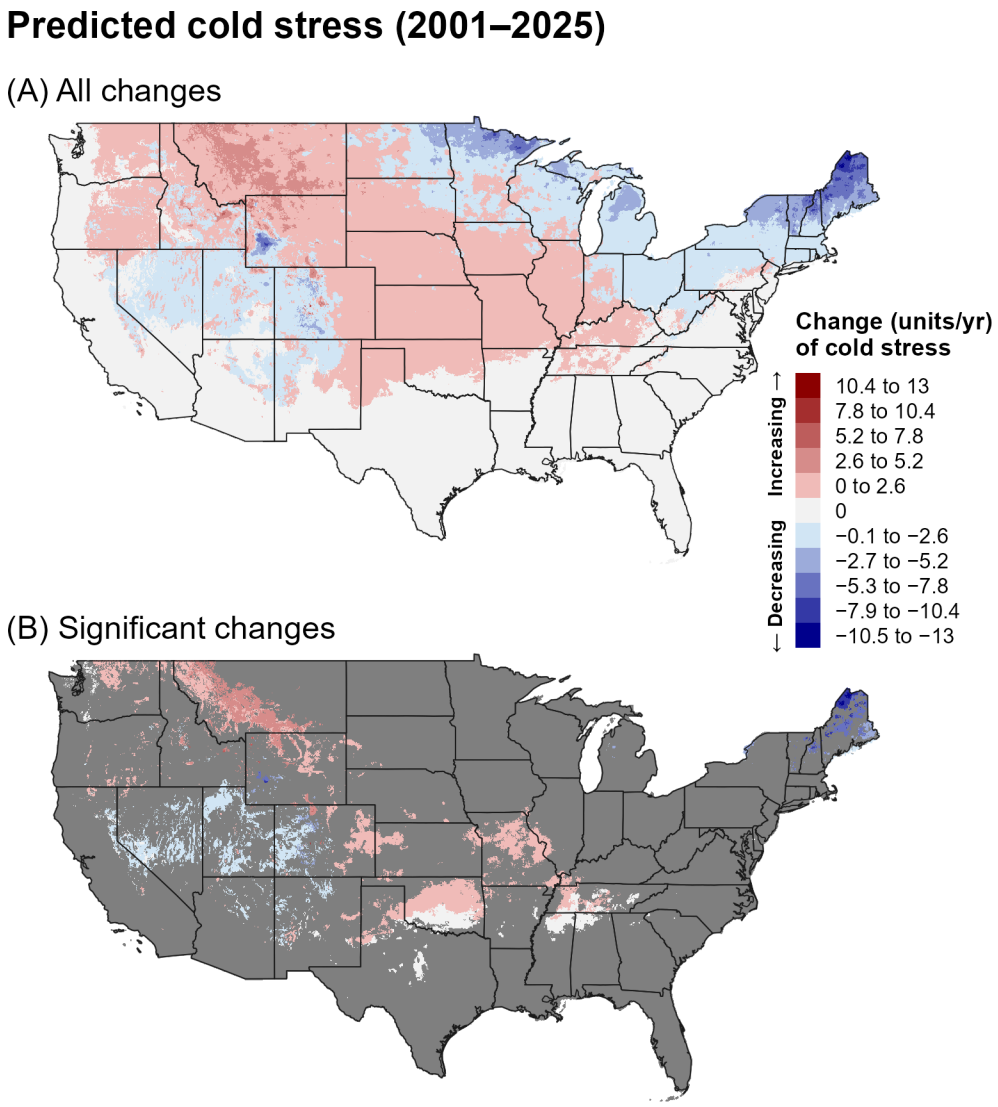

Figure 69. Changes (units/year) in predicted cold stress for JPB across the CONUS over the recent 24-year period (2001–2025). Maps show (A) all changes and (B) statistically significant changes ($P < 0.1$); areas shown in gray are not statistically significant. Areas shown as 0 in (B) had significant trends but very small changes.

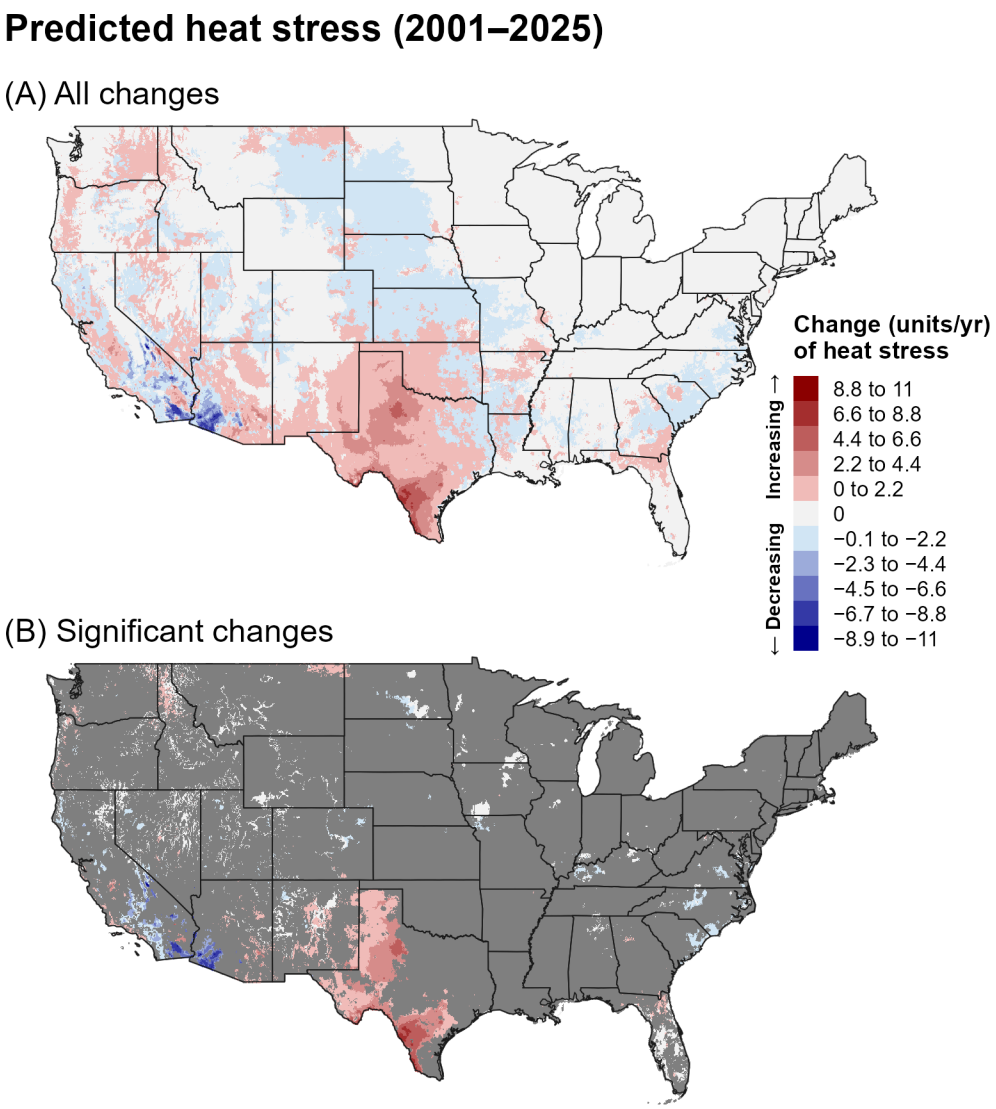

Figure 70. Changes (units/year) in predicted heat stress for JPB across the CONUS over the recent 24-year period (2001–2025). Maps show (A) all changes and (B) statistically significant changes ($P < 0.1$); areas shown in gray are not statistically significant. Areas shown as 0 in (B) had significant trends but very small changes.

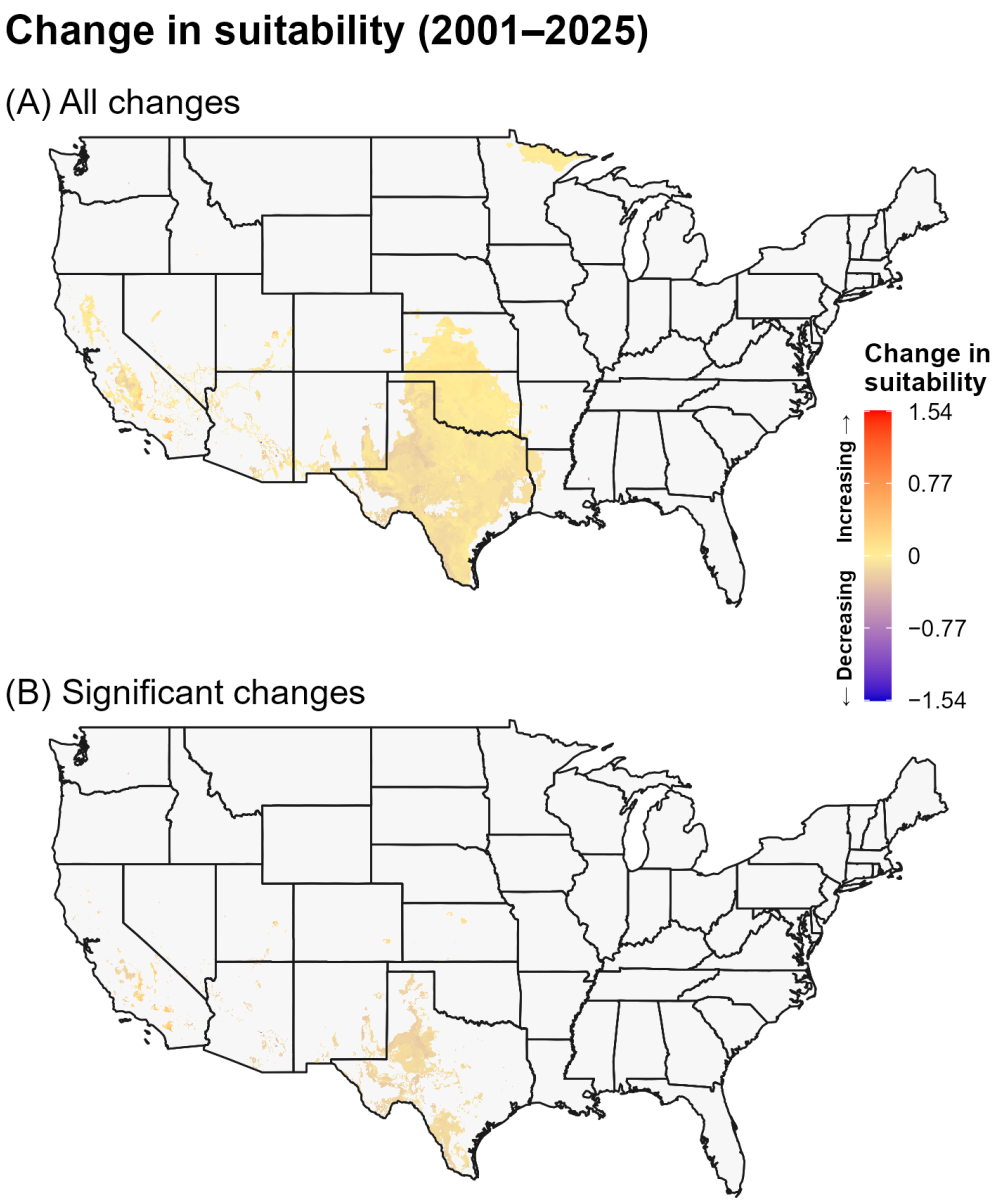

Figure 71. Changes in predicted climatic suitability for JPB across the CONUS over the recent 24-year period (2001–2025). Suitability is defined as areas not excluded by climate stress. Positive changes (warmer colors) indicate an increased likelihood of establishment, whereas negative changes (cooler colors) indicate a decreased likelihood of establishment.

7C. Discussion

Because JPB is widely established across much of the East and Midwest, trends toward earlier predicted adult emergence and egg hatch could have practical implications for monitoring and management. Pest managers may need to adjust the timing of seasonal activities to maintain their effectiveness. For example, traps targeting adult beetles may need to be deployed earlier to improve early detection of new infestations, while insecticide treatments targeting larvae may need to be applied earlier because first- and second-instar larvae are more susceptible to insecticides than older larvae. Similarly, releases of larval parasitoids, such as *Tiphia vernalis* (Rohwer), may need to be timed to coincide with earlier larval development.

A trend toward earlier phenological events could increase the likelihood of univoltinism in cooler regions. Although JPB is generally univoltine in the United States, semivoltinism has been reported in colder areas, such as New England, where larvae overwinter a second winter as second or third instars in the soil, typically beneath managed turfgrass (Fleming 1972, Vittum 1986). Consistent with field observations, a CLIMEX model predicted univoltinism across most of the beetle's current North American range, but semivoltinism in the Northeast and along the United States–Canada border (Kistner-Thomas 2019).

Although cold stress declined for JPB in northern and high-elevation regions of the CONUS, these changes did not translate into significant shifts in predicted establishment risk. However, previous research linked JPB occurrence at its expanding range edge in the Midwest and Great Plains to minimum temperatures and long-term weather trends (Kucherov et al. 2025), suggesting that changes in cold stress could influence its distribution over time. Declining cold stress may also reduce the effectiveness of *Ovavesicula popilliae*, a microsporidian biocontrol agent that increases JPB larval mortality under cold overwintering conditions (Smitley et al. 2026). In contrast, Kucherov *et al.* (2025) found negative associations between JPB occurrence and maximum temperature, consistent with our finding of significant declines in predicted climatic suitability across the Southwest and California, where heat stress increased over both the entire (1981–2025) and recent (2001–2025) periods. These declines also align with evidence that JPB survival is low under hot, dry conditions (Fleming 1972, Vittum 1986, Allsopp 1996).

The stronger and more spatially extensive trends in predicted phenology and climate stress over the entire 44-year period may reflect both the larger sample size, which can reduce noise and improve detection of directional patterns, and differences in the underlying climate trends between the two time periods. In particular, the recent 24-year period may capture climate variability or regional trends that differ from those observed over the longer 44-year period. Thus, differences between the two periods should be interpreted as reflecting both long-term climate trends and shorter-term regional variability.

7D. References

Allsopp, P. G. 1996. Japanese beetle, *Popillia japonica* Newman (Coleoptera: Scarabaeidae): rate of movement and potential distribution of an immigrant species. The Coleopterists Bulletin 50:81–95.

Althoff, E. R., and K. B. Rice. 2022. Japanese beetle (Coleoptera: Scarabaeidae) invasion of North America: history, ecology, and management. Journal of Integrated Pest Management 13:1–11.

Barker, B. S., and L. Coop. 2024. Japanese beetle, *Popillia japonica*. Phenology/degree-day and climate suitability model analysis for USPEST.ORG. Prepared for National Institute of Food and Agriculture, Agriculture and Food Research Initiative, and Tactical Sciences for Agricultural Biosecurity. Vs. 1.0 (11/22/24). Available online: https://uspest.org/CAPS/Popillia_japonica_white_paper.pdf (accessed 29 May 2025).

Della Rocca, F., and P. Milanesi. 2022. The new dominator of the world: modeling the global distribution of the Japanese beetle under land use and climate change scenarios. Land 11:567.

Dickerson, E.L. and Weiss H.B. (1918). *Popillia japonica* Newman, a recently introduced Japanese pest. Canadian Entomologist 50:217–221.

EPPO. 2025. *Popillia japonica*. EPPO datasheets on pests recommended for regulation. Available online: https://gd.eppo.int (accessed 5 August 2025).

Fleming, W. E. 1972. Biology of the Japanese Beetle. Technical Bulletin No. 1149. United States Department of Agriculture, Agricultural Research Service, Washington D.C. Available online: http://dx.doi.org/10.22004/ag.econ.171890 (accessed 5 August 2025).

Gilioli, G., G. Sperandio, A. Simonetto, M. Colturato, A. Battisti, N. Mori, M. Ciampitti, B. Cavagna, A. Bianchi, and P. Gervasio. 2022. Modelling diapause termination and phenology of the Japanese beetle, *Popillia japonica*. Journal of Pest Science 95:869–880.

Kistner-Thomas, E. J. 2019. The potential global distribution and voltinism of the Japanese beetle (Coleoptera:

Scarabaeidae) under current and future climates. Journal of Insect Science 19:6.
Kucherov NB, Hefley T, Kim TN. 2025. Climate and human-modified landscapes influence spread of invasive agricultural pest *Popillia japonica* Newman in American Midwest and Great Plains. Scientific Reports 15:33013.
Petty, B. M., D. T. Johnson, and D. C. Steinkraus. 2015. Changes in abundance of larvae and adults of *Popillia japonica* (Coleoptera: Scarabaeidae: Rutelinae) and other white grub species in Northwest Arkansas and their relation to regional temperatures. Florida Entomologist 98:1006–1008.
Pulighe, G., F. Lupia, and V. Manente. 2025. Climate-driven invasion risks of Japanese beetle (*Popillia japonica* Newman) in Europe predicted through species distribution modelling. Agriculture 15:684.
Smitley D, Krischik V, Lewis P, Nomura Y, Cranshaw W, Deans C, Parkanzky E, Guédot C, Hajek AE. 2026. Biological and microbial control: increasing prevalence of *Ovavesicula popilliae* (Microsporidia), a pathogen of Japanese beetle (Coleoptera: Scarabaeidae), in the Midwest and North-central United States from 1999 to 2025. Journal of Economic Entomology:toag249.
Stoven, H., J. Rendon, and G. Langellotto-Rhodaback. 2021. Japanese Beetles in Oregon. Oregon State University Extension Service. Available online: https://extension.oregonstate.edu/sites/extd8/files/documents/em9158.pdf (accessed 16 December 2025).
Tayeh, C., C. Poggi, N. Desneuex, H. Jactel, and F. Verheggen. 2023. Host plants of *Popillia japonica*: a review. Data INRAE. Available online: https://doi.org/10.57745/SXZNQF (accessed 29 May 2025).
USDA-APHIS. 2015. Managing the Japanese beetle: A homeowner's handbook. APHIS Publication 81-25-003. United States Department of Agriculture, Animal and Plant Health Inspection Service, Washington D.C. Available online: https://www.aphis.usda.gov/sites/default/files/JBhandbook.pdf (accessed 5 Feb 2025).
Vittum, P. J. 1986. Biology of the Japanese beetle (Coleoptera: Scarabaeidae) in eastern Massachusetts. Journal of Economic Entomology 79:387–391.

8. Japanese pine sawyer beetle

8A. Introduction

The Japanese pine sawyer beetle (JPSB), *Monochamus alternatus* Hope (Coleoptera: Cerambycidae), is a major vector of nematodes that cause pine wilt disease, primarily *Bursaphelenchus xylophilus*, commonly known as the pine wilt nematode or pinewood nematode (Vicente et al. 2012, EPPO 2024). Native to East Asia, including mainland China, Taiwan, Laos, Korea, and Japan, JPSB has expanded its range to other parts of Asia, including Vietnam (Kobayashi et al. 1984, EPPO 2024). The pest primarily attacks conifers, particularly *Pinus*, *Abies*, *Picea*, *Larix*, and *Cedrus*, although some hardwood genera, such as *Malus* and *Acer*, may also serve as occasional hosts (Kobayashi et al. 1984, EPPO 2024). Pine wilt disease has caused extensive tree mortality and substantial economic losses where it has been introduced, particularly in Asia and Europe (Vicente et al. 2012, An et al. 2019). JPSB is not known to be established in the United States. Although it was detected in Mississippi in 2020, the introduced population was subsequently eradicated. Historically, most U.S. interceptions of *Monochamus* species have occurred in general cargo associated with wood, crating, and dunnage (Haack and Cavey 2000). Live adults were also discovered in infested crating at a warehouse in western New York in 1998 (CAPS 2013). More recently, a study conducted by U.S. Customs and Border Protection and APHIS at 11 U.S. ports documented eight interceptions of live JPSB in pine wood packaging material originating from China between 2012 and 2018 (Krishnankutty 2020).

Adult JPSB acquire and transmit nematodes while feeding on healthy pine trees, with infection disrupting xylem function and causing wilt and, in susceptible trees, death within weeks (Kobayashi et al. 1984, Vicente et al. 2012). Females primarily oviposit in weakened or diseased trees, where larvae develop beneath the bark and in the sapwood. Nematodes subsequently associate with newly emerging adults, completing the transmission

cycle (Kobayashi et al. 1984, An et al. 2019). Although *B. xylophilus* is native to North America and generally causes little damage in its native range, JPSB may also serve as a vector for other nematode species not currently present in North America (CAPS 2013, An et al. 2019). Recorded hosts for *B. xylophilus* include several pine species native to the eastern United States, including loblolly pine (*Pinus taeda*), longleaf pine (*P. palustris*), and eastern white pine (*P. strobus*) (CAPS 2013). Several introduced species commonly planted in the United States, including Scots pine (*P. sylvestris*), Austrian pine (*P. nigra*), and Japanese black pine (*P. thunbergii*), are also susceptible to pine wilt disease ((CAPS 2013, Donald et al. 2016). Drought stress may further increase host vulnerability to nematode-induced hydraulic dysfunction and mortality (Suzuki and Kiyohara 1978).

A model for JPSB developed for the Degree-Day, establishment Risk, and Phenological event mapping system (DDRP) is operationalized to produce near real-time forecasts for the contiguous United States (CONUS) at https://uspest.org/DDRP. The full set of model parameters for FCM, including developmental temperature thresholds, degree-day requirements for individual life stages, and climate stress thresholds and limits, are available at USPest.org (Barker and Coop 2020).

8B. Results

i. Phenology

Entire period: 1981–2025

Predicted adult emergence and egg hatch for JPSB shifted significantly ($P < 0.01$) earlier across large portions of CONUS over the entire period (1981–2025), including most East Coast states, parts of the South and Midwest, and the Intermountain West (Figure 72, Figure 73). In these regions, predicted adult emergence and egg hatch decreased by approximately 0.01–0.5 days per year, with some of the largest declines occurring at higher elevations in the Northeast and Intermountain West.

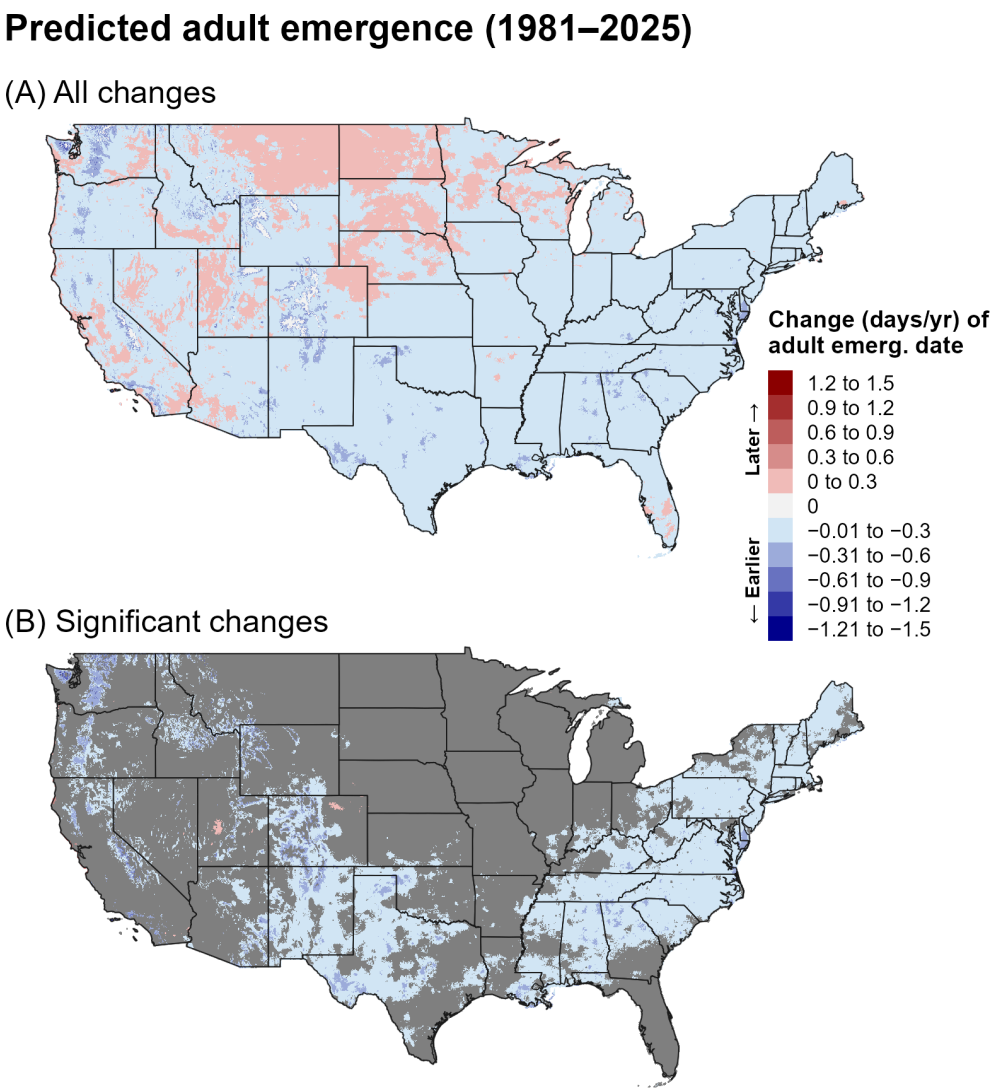

Figure 72. Changes (days/year) in predicted dates of first adult emergence for JPSB across the CONUS over the entire 44-year period (1981–2025). Maps show (A) all changes and (B) statistically significant changes ($P < 0.1$); areas shown in gray are not statistically significant.

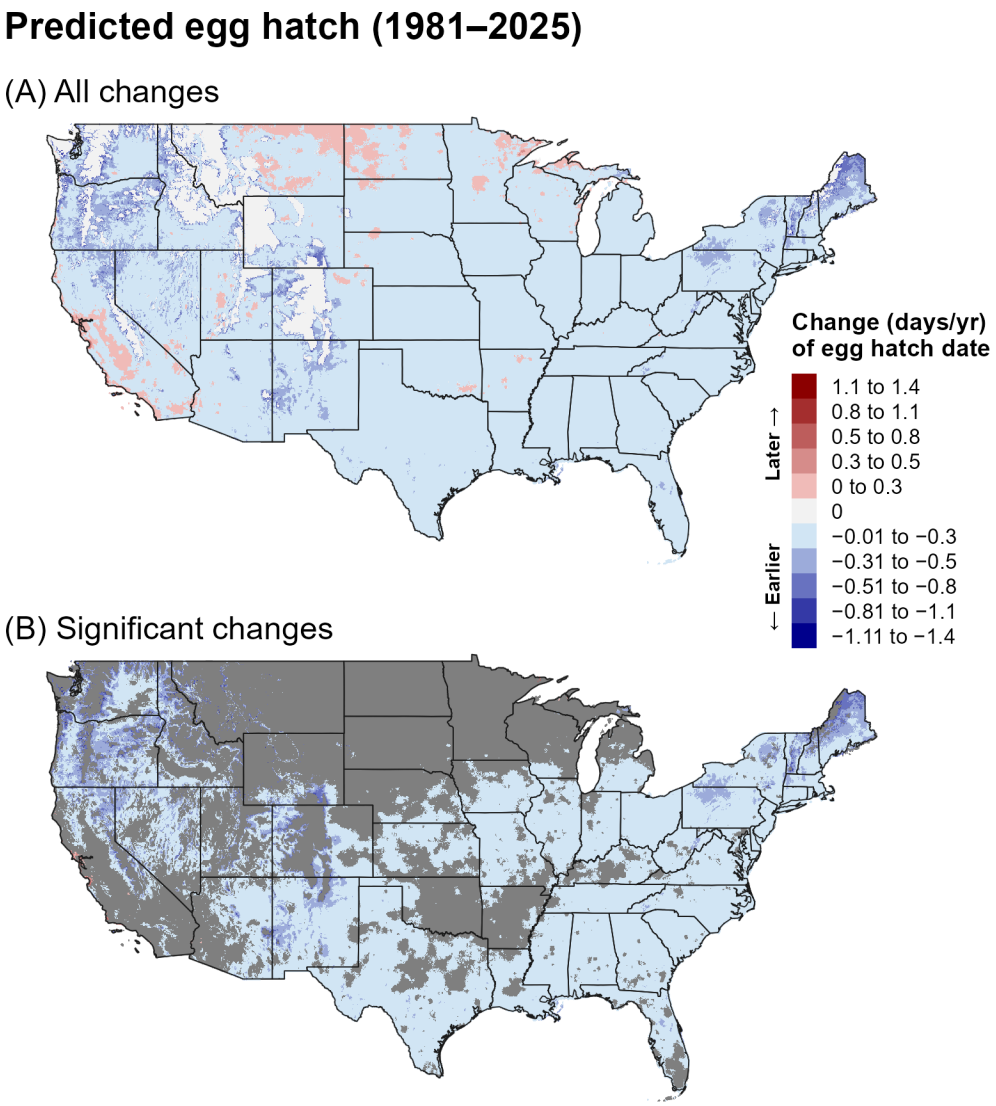

Figure 73. Changes (days/year) in predicted dates of first egg hatch for JPSB across the CONUS over the entire 44-year period (1981–2025). Maps show (A) all changes and (B) statistically significant changes ($P < 0.1$); areas shown in gray are not statistically significant.

Recent period: 2001–2025

Trends in predictions of first adult emergence and egg hatch for JPSB over the recent 24-year period (2001–2025) were partially consistent with those observed over the 1981–2025 period. In the eastern United States, significant trends were similar in magnitude but less spatially extensive (Figure 74, Figure 75), occurring mostly in East Coast states and the Upper Midwest. Most trends in the West were not significant. In contrast to the longer-term trends, some isolated areas of the interior West, primarily in the southern Intermountain West, exhibited significant trends toward later phenological events.

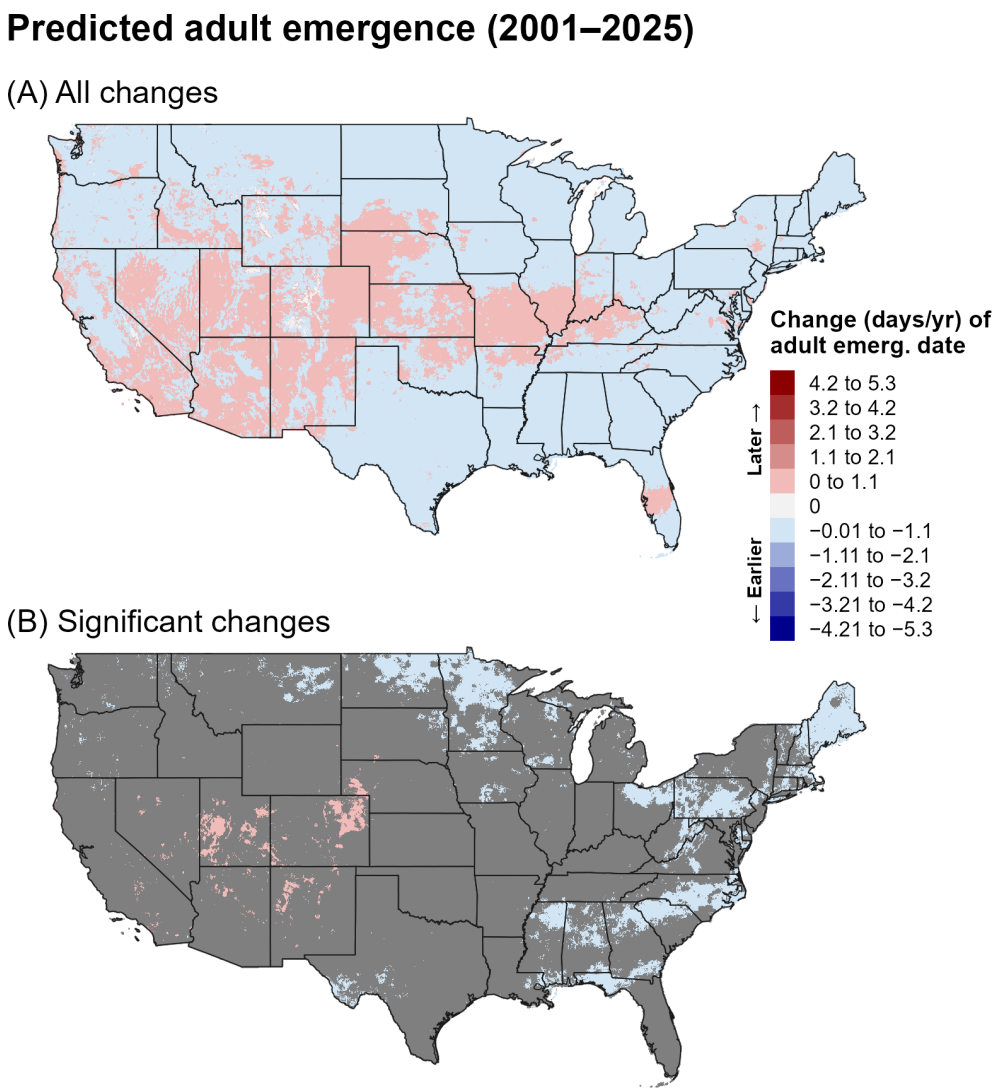

Figure 74. Changes (days/year) in predicted dates of first adult emergence for JPSB across the CONUS over the recent 24-year period (2001–2025). Maps show (A) all changes and (B) statistically significant changes ($P < 0.1$); areas shown in gray are not statistically significant.

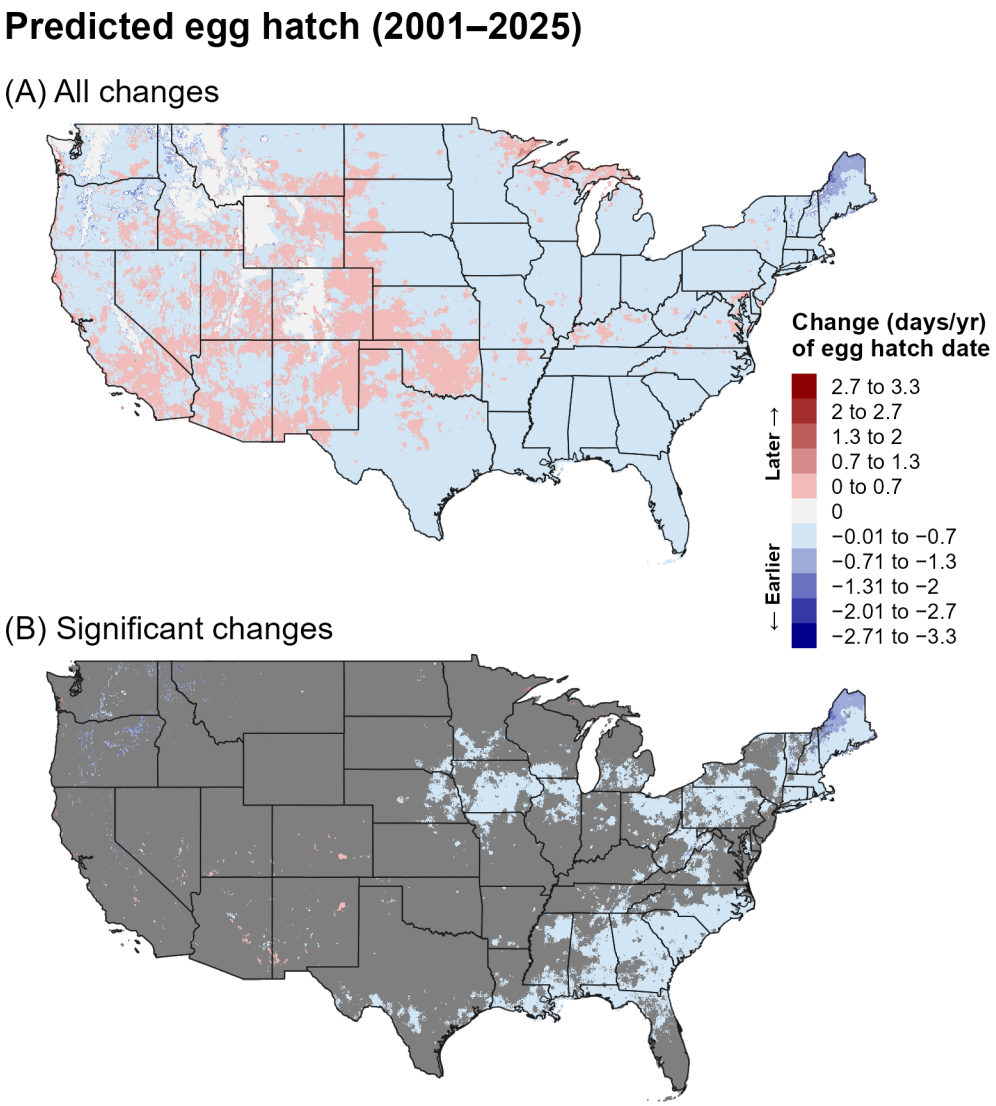

Figure 75. Changes (days/year) in predicted dates of first egg hatch for JPSB across the CONUS over the recent 24-year period (2001–2025). Maps show (A) all changes and (B) statistically significant changes ($P < 0.1$); areas shown in gray are not statistically significant.

ii. Climatic suitability

Entire period: 1981–2025

Significant trends in predicted cold stress for JPSB over the entire 44-year period (1981–2025) were predominantly negative (Figure 76), indicating a general decrease in cold stress over time. In contrast, significant trends in heat stress were largely positive across portions of the South and West, indicating increasing heat stress (Figure 77). When annual accumulated stress units exceed limits specified in DDRP models, climatic suitability may change. Consistent with these trends, suitability for JPSB increased in parts of the Northeast, Midwest, and Intermountain West (Figure 78), although these changes were statistically significant only in some areas.

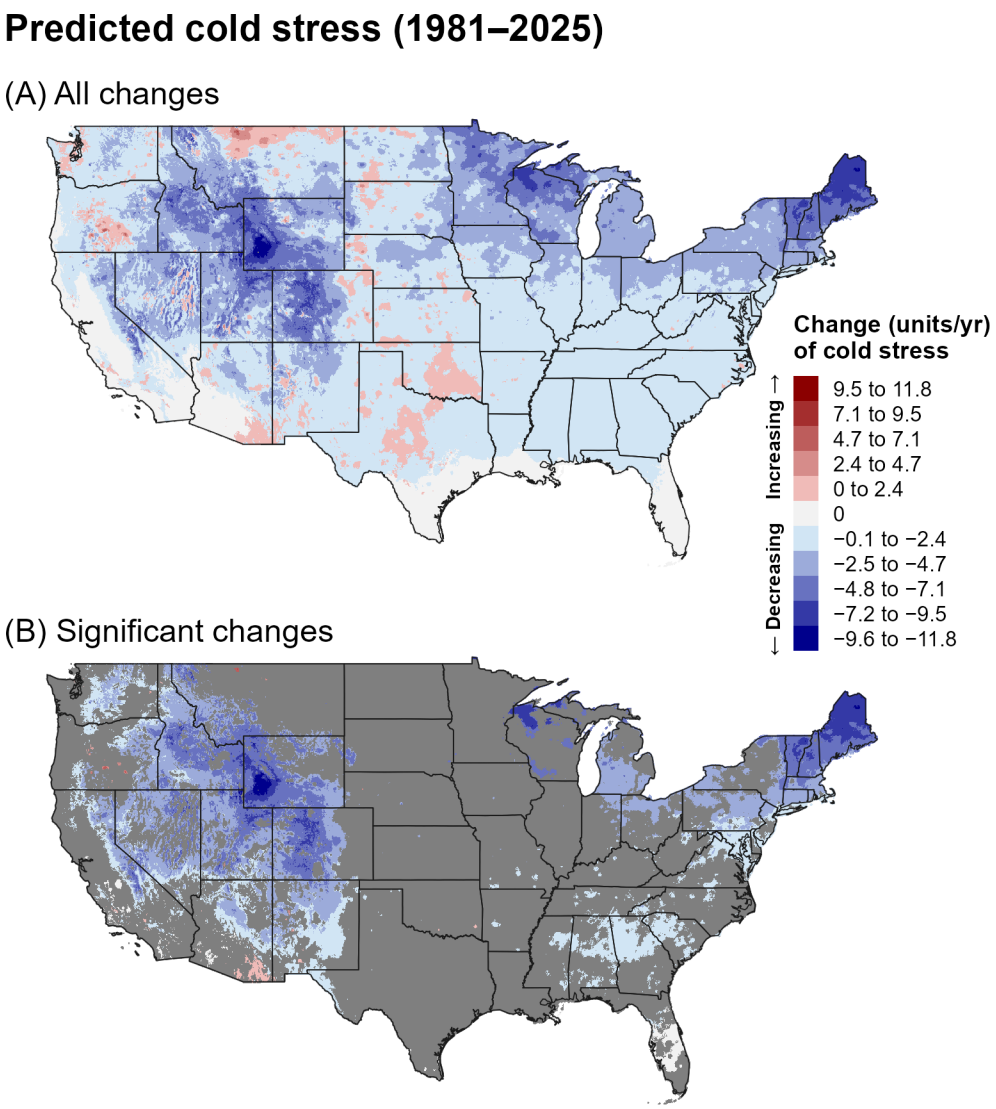

Figure 76. Changes (units/year) in predicted cold stress for JPSB across the CONUS over the entire 44-year period (1981–2025). Maps show (A) all changes and (B) statistically significant changes ($P < 0.1$); areas shown in gray are not statistically significant. Areas shown as 0 in (B) had significant trends but very small changes.

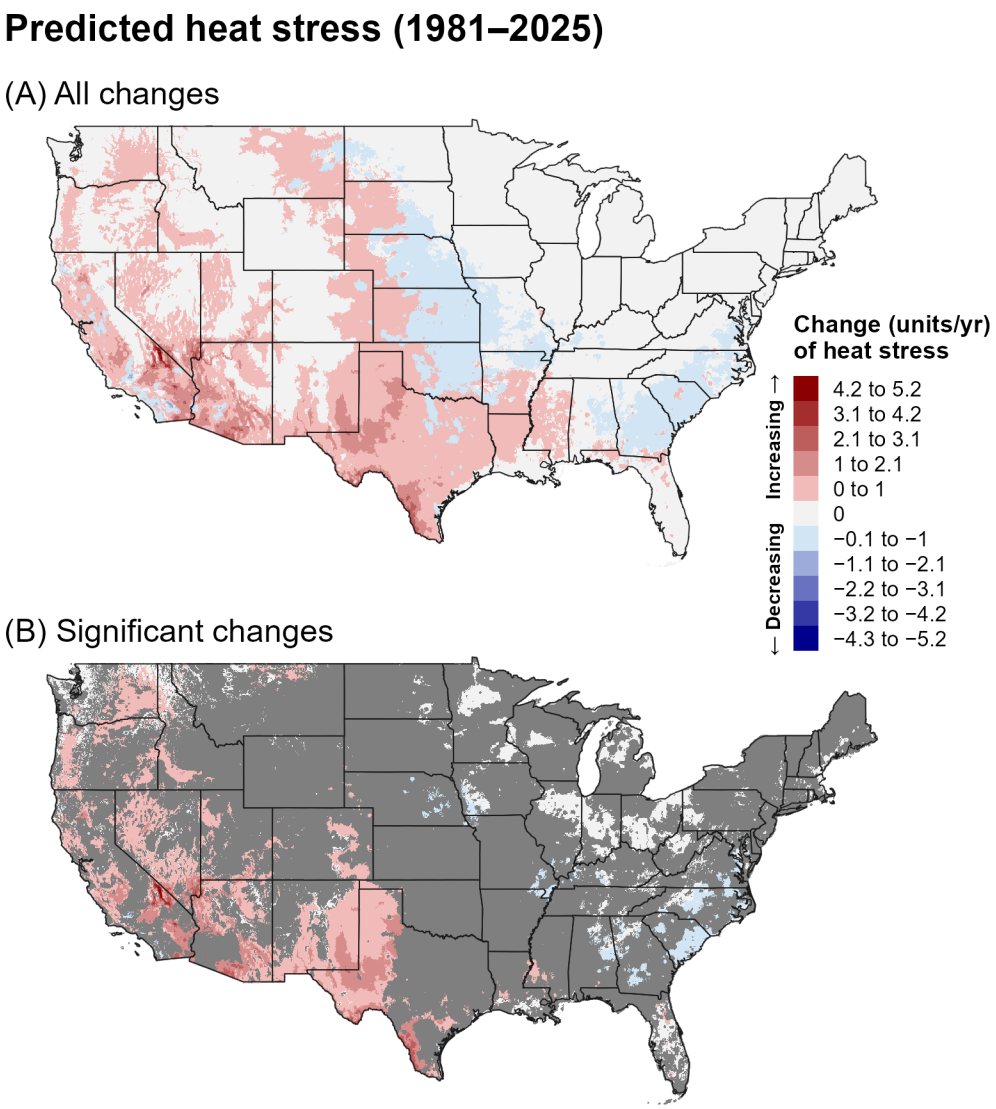

Figure 77. Changes (units/year) in predicted heat stress for JPSB across the CONUS over the entire 44-year period (1981–2025). Maps show (A) all changes and (B) statistically significant changes ($P < 0.1$); areas shown in gray are not statistically significant. Areas shown as 0 in (B) had significant trends but very small changes.

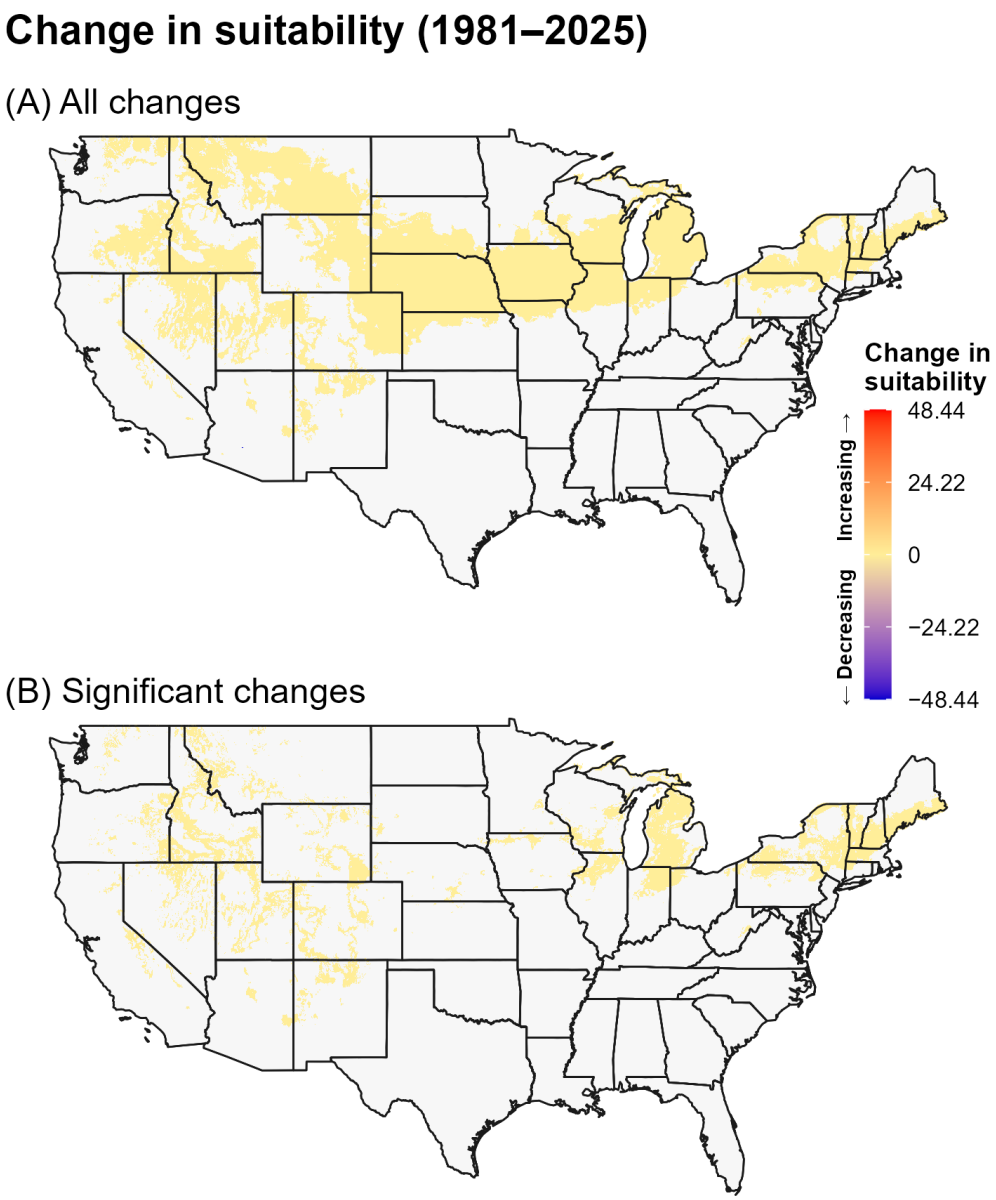

Figure 78. Changes in predicted climatic suitability for JPSB across the CONUS over the entire 44-year period (1981–2025). Suitability is defined as areas not excluded by climate stress. Positive changes (warmer colors) indicate an increased likelihood of establishment, whereas negative changes (cooler colors) indicate a decreased likelihood of establishment.

Recent period: 2001–2025

Many areas that exhibited significant decreases in cold stress for JPSB over 1981–2025 no longer showed significant trends during the recent period. These areas were concentrated in scattered patches across the Northeast and higher-elevation parts of the Southwest (Figure 79). Significant increases in predicted cold stress occurred in a few small, isolated areas of the South and Northwest. Areas with increasing heat stress were concentrated in the Southwest, particularly Texas, whereas parts of California showed significant decreases (Figure 80). The climatic-suitability map showed relatively limited significant change, although increases remained evident in isolated areas of the Northeast, Midwest, and Intermountain West (Figure 81).

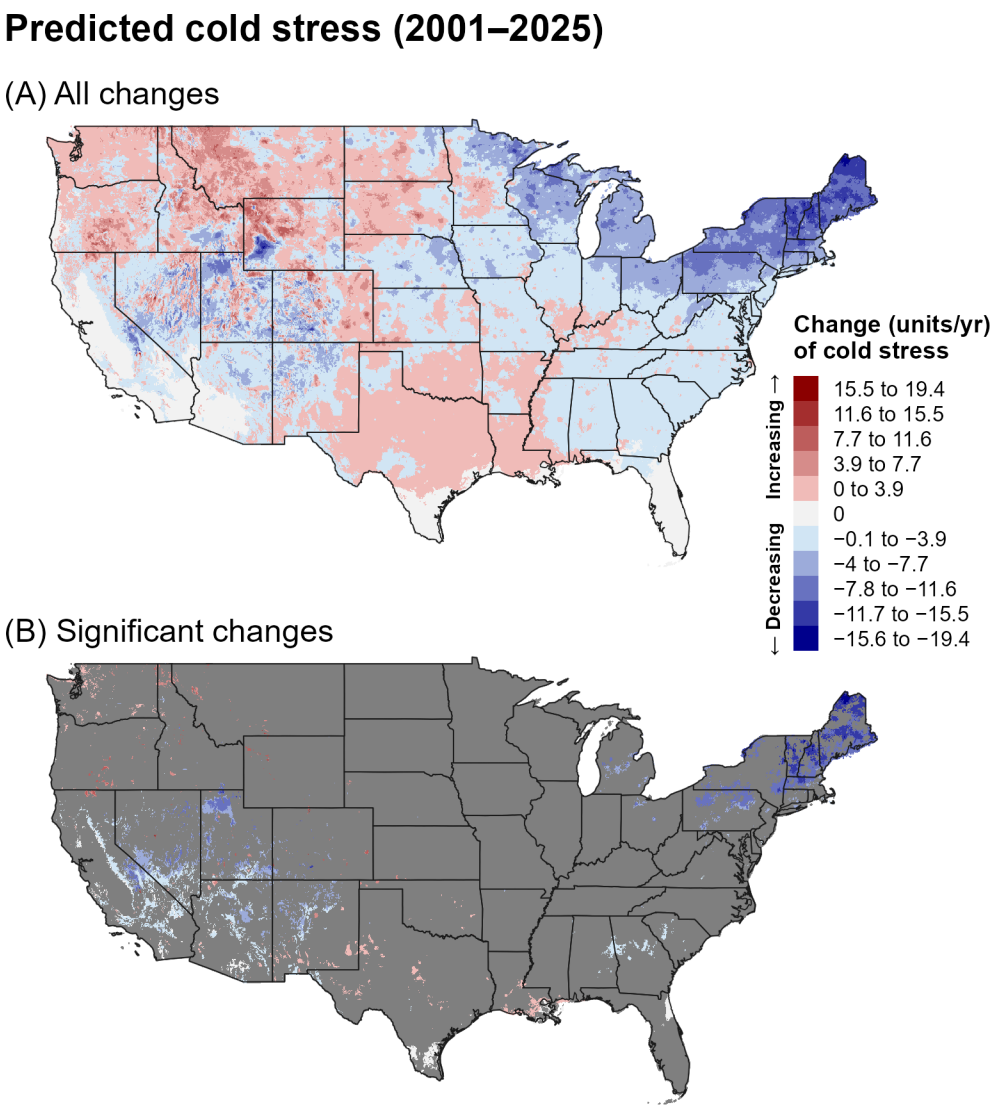

Figure 79. Changes (units/year) in predicted cold stress for JPSB across the CONUS over the recent 24-year period (2001–2025). Maps show (A) all changes and (B) statistically significant changes ($P < 0.1$); areas shown in gray are not statistically significant. Areas shown as 0 in (B) had significant trends but very small changes.

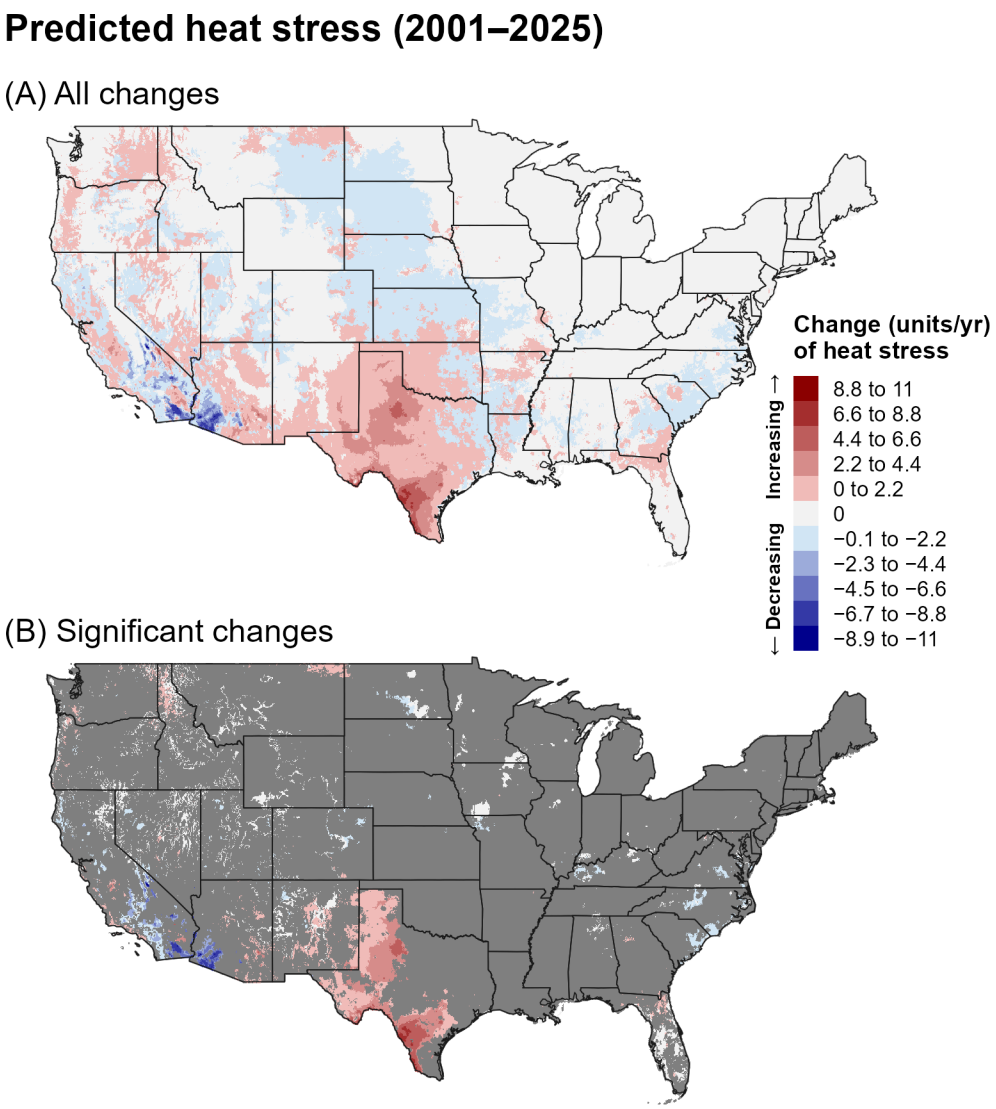

Figure 80. Changes (units/year) in predicted heat stress for JPSB across the CONUS over the recent 24-year period (2001–2025). Maps show (A) all changes and (B) statistically significant changes ($P < 0.1$); areas shown in gray are not statistically significant. Areas shown as 0 in (B) had significant trends but very small changes.

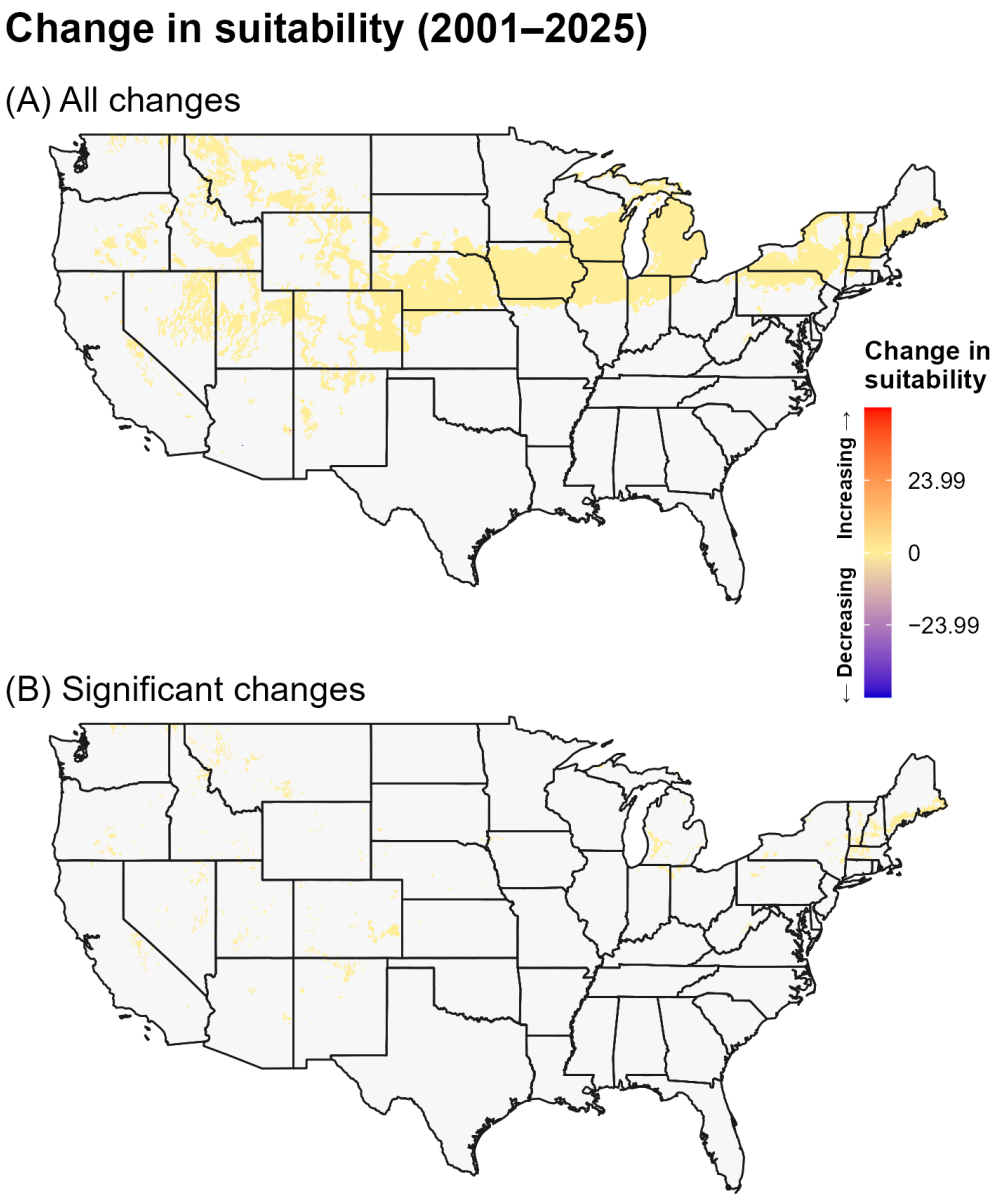

Figure 81. Changes in predicted climatic suitability for JPSB across the CONUS over the recent 24-year period (2001–2025). Suitability is defined as areas not excluded by climate stress. Positive changes (warmer colors) indicate an increased likelihood of establishment, whereas negative changes (cooler colors) indicate a decreased likelihood of establishment.

8C. Discussion

Although JPSB is not established in the CONUS, understanding potential changes in phenology can inform surveillance planning. In areas exhibiting significant trends toward earlier phenology, predicted dates shifted earlier by approximately 0.01–0.5 days per year, suggesting that surveillance materials may need to be deployed earlier in the season. These trends may be particularly relevant in the Southeast and Midwest, where extensive pine forests and plantations include introduced species such as *P. sylvestris*, *P. nigra*, and *P. thunbergii* that are susceptible to infection by *B. xylophilus* (Wingfield et al. 1986, CAPS 2013, Donald et al. 2016).

JPSB undergoes winter diapause primarily during the final larval instar, with diapause termination dependent

on winter chilling requirements and subsequent temperature-driven development (Togashi 1995, Go et al. 2026). Climate-driven changes in winter and spring temperatures could therefore alter the timing of diapause termination and first adult emergence, while warmer growing-season temperatures could accelerate development and increase the potential for additional generations. The number of generations completed annually by JPSB varies geographically, ranging from univoltine or semivoltine development in colder parts of its native range to 2–3 generations in warmer regions of subtropical and tropical China (Togashi 1989, CAPS 2013, Togashi and Sugimoto 2024). Within environmentally suitable areas of the CONUS, JPSB is predicted to complete at least one generation annually, with up to four generations in the South (Barker and Coop 2020). Earlier emergence and increased voltinism could have important epidemiological implications by creating additional opportunities for *B. xylophilus* transmission, increasing the number of nematode-carrying adults emerging from infested trees, and potentially accelerating pine wilt disease spread and increasing tree mortality in susceptible pine populations (Togashi and Sugimoto 2024).

Declining cold stress and associated increases in climatic suitability for JPSB across portions of the Northeast, Midwest, and Intermountain West suggest that these regions may be becoming increasingly conducive to establishment. Previous modeling studies identified suitable climates for JPSB across much of the South and Midwest, while low temperatures were predicted to constrain establishment in colder regions, including the Northeast and high-elevation areas of the Intermountain West (Song and Xu 2006, Barker and Coop 2020, Gao et al. 2023). Our findings suggest that these climatic constraints may be relaxing, potentially increasing establishment potential in regions previously considered less suitable. This is particularly concerning in the Midwest, where the presence of susceptible pine hosts could increase the consequences of JPSB establishment and subsequent pinewood nematode transmission. Although previous models also identified climatically suitable areas along the West Coast, including much of California (Song and Xu 2006, Barker and Coop 2020), we detected few significant temporal trends in suitability across this state.

The stronger and more spatially extensive trends in predicted phenology and climate stress over the entire 44-year period likely reflect both the greater number of years included, which may reduce interannual variability and improve the detection of directional trends, and differences in the underlying climatic trends between the two study periods. In particular, the recent 24-year period may capture climate variability or regional trends that differ from those observed over the longer 44-year period. Thus, differences between the two periods should be interpreted as reflecting both long-term climate trends and shorter-term regional variability.

8D. References

An, H., S. Lee, and S. J. Cho. 2019. The effects of climate change on pine wilt disease in South Korea: Challenges and prospects. Forests 10:486.

Barker, B. S., and L. Coop. 2020. Japanese pine sawyer beetle, *Monochamus alternatus*. Phenology/degree-day and climate suitability white paper for USPEST.ORG. Prepared for United States Department of Agriculture (USDA) – Animal and Plant Health Inspection Service (APHIS) – Plant Protection and Quarantine (PPQ). Vs. 1.0 (2/26/2020). Available online: https://uspest.org/CAPS/Monochamus_alternatus_white_paper.pdf (accessed 13 September 2025).

Cooperative Agricultural Pest Survey (CAPS). 2013. Exotic Wood Borer/Bark Beetle Survey Reference, *Monochamus alternatus* (Hope). USDA-APHIS-PPQ-CPHST (updated 29 July 2016). Available online: https://caps.ceris.purdue.edu/wp-content/uploads/2025/07/Monochamus-alternatus_EWBB_2015.pdf (accessed 18 September 2025).

Donald, P. A., W. T. Stamps, M. J. Linit, and T. C. Todd. 2016. Pine wilt. The Plant Health Instructor. Online at: https://doi.org/10.1094/PHI-I-2003-0130-01 (accessed 16 November 2026).

EPPO. 2024. *Monochamus alternatus*. EPPO datasheets on pests recommended for regulation. Online at: https://gd.eppo.int/ (accessed 13 September 2025).

Gao, R., L. Liu, L. Zhao, and S. Cui. 2023. Potentially suitable geographical area for *Monochamus alternatus*

under current and future climatic scenarios based on optimized MaxEnt model. Insects 14:182.
Go, M. S., S. H. Kwon, and D. S. Kim. 2026. A conceptual model for the diapause intensity curve and termination in overwintering Japanese pine sawyer larvae, *Monochamus alternatus* (Coleoptera: Cerambycidae). Physiological Entomology 51:226–236.
Haack, R. A., and J. F. Cavey. 2000. Insects intercepted on solid wood packing materials at United States ports-of-entry: 1985–1998. In Proceedings of the International Conference on Quarantine Pests for the Forestry Sector and Their Effects on Foreign Trade (27–28 June 2000, Concepción, Chile). CORMA. 16 pp.
Kobayashi, F., A. Yamane, and T. Ikeda. 1984. The Japanese pine sawyer beetle as the vector of pine wilt disease. Annual Review of Entomology 29:115–135.
Krishnankutty, S., H. Nadel, A. M. Taylor, M. C. Wiemann, Y. Wu, S. W. Lingafelter, S. W. Myers, and A. M. Ray. 2020. Identification of tree genera used in the construction of solid wood-packaging materials that arrived at U.S. ports infested with live wood-boring insects. Journal of Economic Entomology 113:1183-1194.
Song, H.-M., and R.-M. Xu. 2006. Global potential geographical distribution of *Monochamus alternatus*. Chinese Bulletin of Entomology 43:535–539.
Suzuki, K., and T. Kiyohara. 1978. Influence of water stress on development of pine wilting disease caused by *Bursaphelenchus lignicolus*. European Journal of Forest Pathology 8:97-107.
Togashi, K. 1989. Development of *Monochamus alternatus* Hope (Coleoptera: Cerambycidae) in relation to oviposition time. Japanese Journal of Applied Entomology and Zoology 33:1–8.
Togashi, K. 1995. Interacting effects of temperature and photoperiod on diapause in larvae of *Monochamus alternatus* (Coleoptera: Cerambycidae). Japanese Journal of Entomology 63:243–252.
Togashi, K., and Sugimoto, H. 2024. Copulation duration and sperm precedence with reference to larval diapause induction in *Monochamus alternatus* Hope (Coleoptera: Cerambycidae). Insects 15:255.
Wingfield, M. J., P. J. Bedker, and R. A. Blanchette. 1986. Pathogenicity of *Bursaphelenchus xylophilus* on pines in Minnesota and Wisconsin. Journal of Nematology 18:44–49.
Vicente, C., M. Espada, P. Vieira, and M. Mota. 2012. Pine wilt disease: a threat to European forestry. European Journal of Plant Pathology 133:89–99.

9. Light brown apple moth

In progress - check back soon

10. Oak ambrosia beetle

In progress - check back soon

11. Old world bollworm

In progress - check back soon

12. Pine tree lappet moth

In progress - check back soon

13. Spotted lanternfly

13A. Introduction

The spotted lanternfly (SLF), *Lycorma delicatula* (White) (Hemiptera: Fulgoridae), is a highly polyphagous planthopper that feeds on a broad range of agricultural and non-agricultural plants, including grapevines, fruit

and nut trees, and ornamental species (Chu 1930, Barringer and Ciafré 2020, EPPO 2025). Adults cause direct damage by feeding on plant sap, while the accumulation of honeydew promotes the growth of sooty mold, which can inhibit photosynthesis and attract additional pests (Dara et al. 2015, Urban and Leach 2023). Native to China, SLF was first detected in the United States in 2014 in Pennsylvania and has since spread to at least 22 eastern states (Urban and Leach 2023, Cornell Integrated Pest Management 2026). The widespread presence of its preferred host, tree-of-heaven [*Ailanthus altissima* (Mill.) Swingle], has facilitated its rapid expansion (Barringer and Ciafré 2020). In suburban and urban environments, SLF can become a significant nuisance, with large aggregations of adults often swarming on trees (Urban and Leach 2023). The species has already caused substantial economic impacts in the United States, including estimated annual losses of $8.8 million to New York's grape industry alone (Pinto et al. 2025).

A model for SLF developed for the Degree-Day, establishment Risk, and Phenological event mapping system (DDRP) is operationalized to produce near real-time forecasts for the contiguous United States (CONUS) at https://uspest.org/DDRP. The full set of model parameters for SLF, including developmental temperature thresholds, degree-day requirements for individual life stages, and climate stress thresholds and limits, are available at USPest.org (Barker et al. 2025).

13B. Results

i. Phenology

Entire period: 1981–2025

Trends in predicted first adult emergence and egg hatch for SLF over the 44-year period (1981–2025) were predominantly negative, indicating that both phenological events shifted earlier over time. These earlier phenological events were spatially extensive, occurring across much of the CONUS, although trends toward later phenology were evident in portions of the northern interior and western United States (Figure 82, Figure 83). Statistically significant trends were more spatially restricted, particularly for egg hatch, and occurred primarily in the East, South, and portions of the West. Within these regions, predicted adult emergence and egg hatch shifted earlier by approximately 0.01–0.5 days per year, with some of the largest shifts occurring in the Northeast and at higher elevations in the West. Only a few small, isolated areas exhibited significant trends toward later phenology.

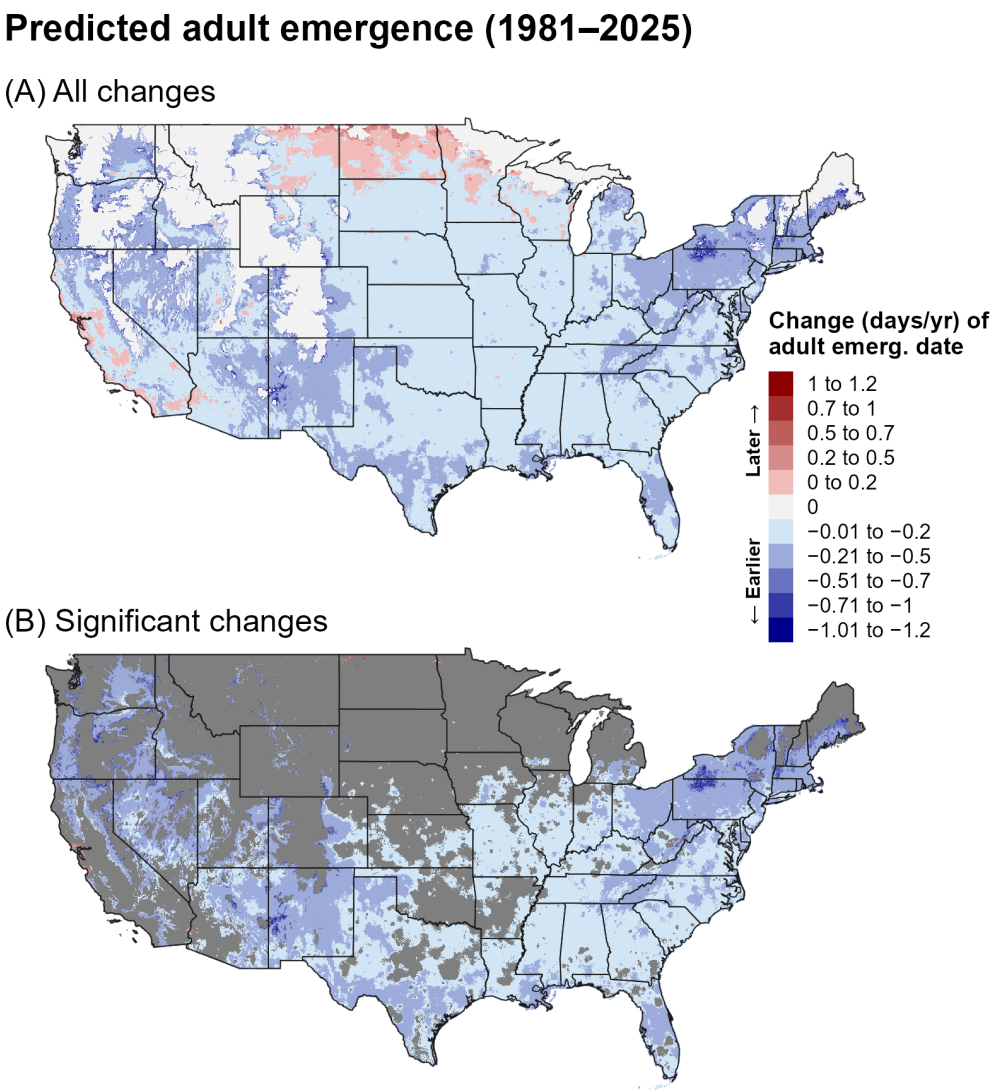

Figure 82. Changes (days/year) in predicted dates of first adult emergence for SLF across the CONUS over the entire 44-year period (1981–2025). Maps show (A) all changes and (B) statistically significant changes ($P < 0.1$); areas shown in gray are not statistically significant.

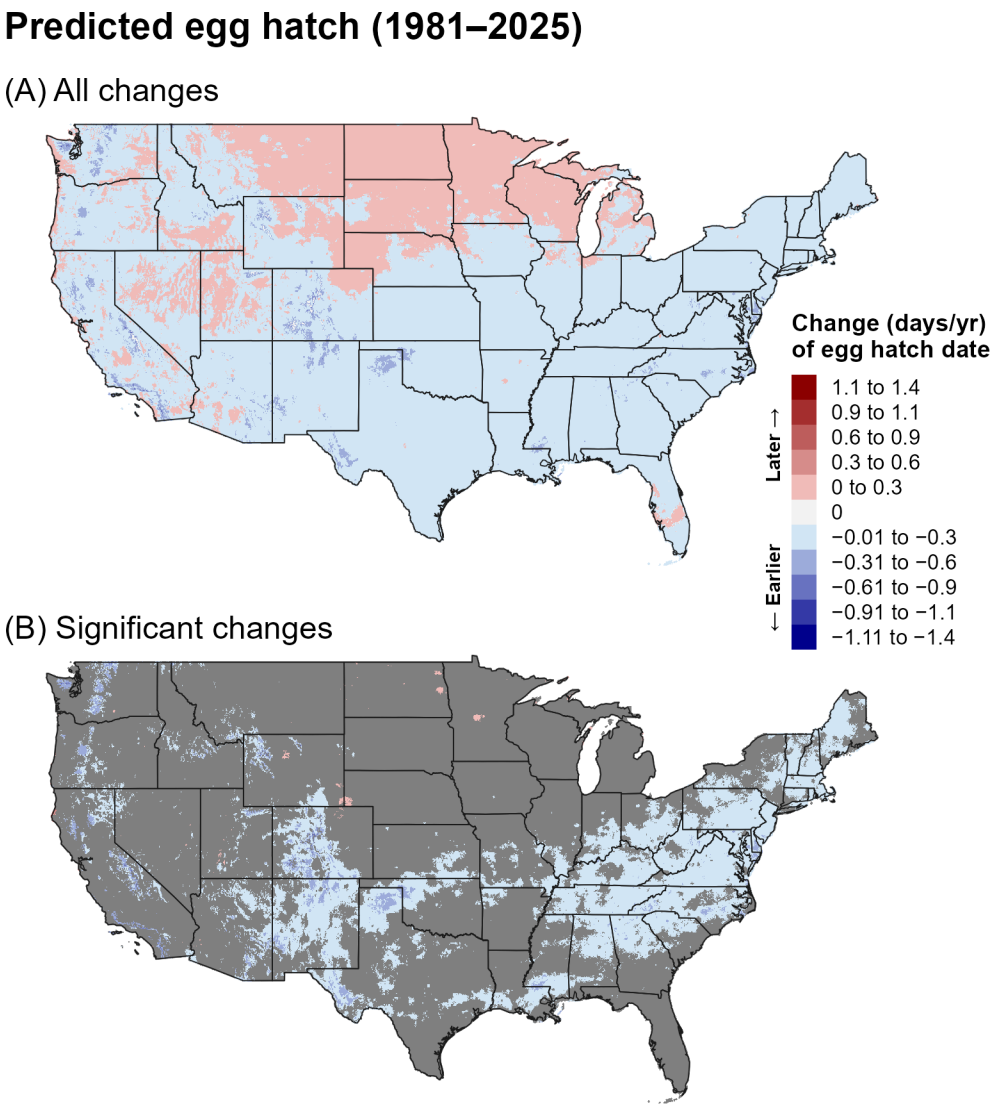

Figure 83. Changes (days/year) in predicted dates of first egg hatch for SLF across the CONUS over the entire 44-year period (1981–2025). Maps show (A) all changes and (B) statistically significant changes ($P < 0.1$); areas shown in gray are not statistically significant.

Recent period: 2001–2025

Trends in predictions of first adult emergence and egg hatch for SLF over the recent 24-year period (2001–2025) were partially consistent with those observed over the 1981–2025 period. Significant trends towards earlier phenology were similar in magnitude but less spatially extensive (Figure 84, Figure 85), occurring primarily in the Northeast and Southeast. In contrast to the longer-term trends, several isolated areas of the Upper Midwest and Intermountain West showed significant trends toward later phenological events.

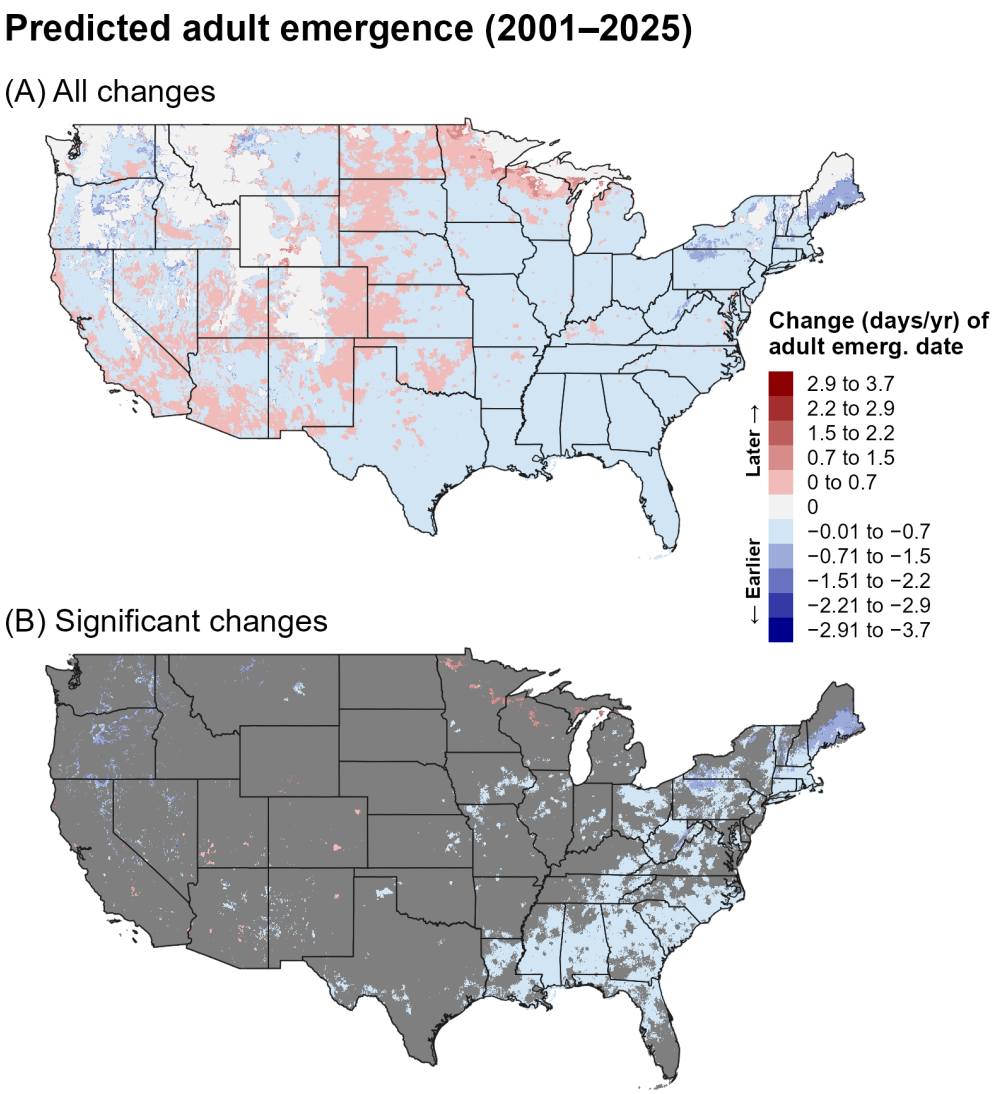

Figure 84. Changes (days/year) in predicted dates of first adult emergence for SLF across the CONUS over the recent 24-year period (2001–2025). Maps show (A) all changes and (B) statistically significant changes ($P < 0.1$); areas shown in gray are not statistically significant.

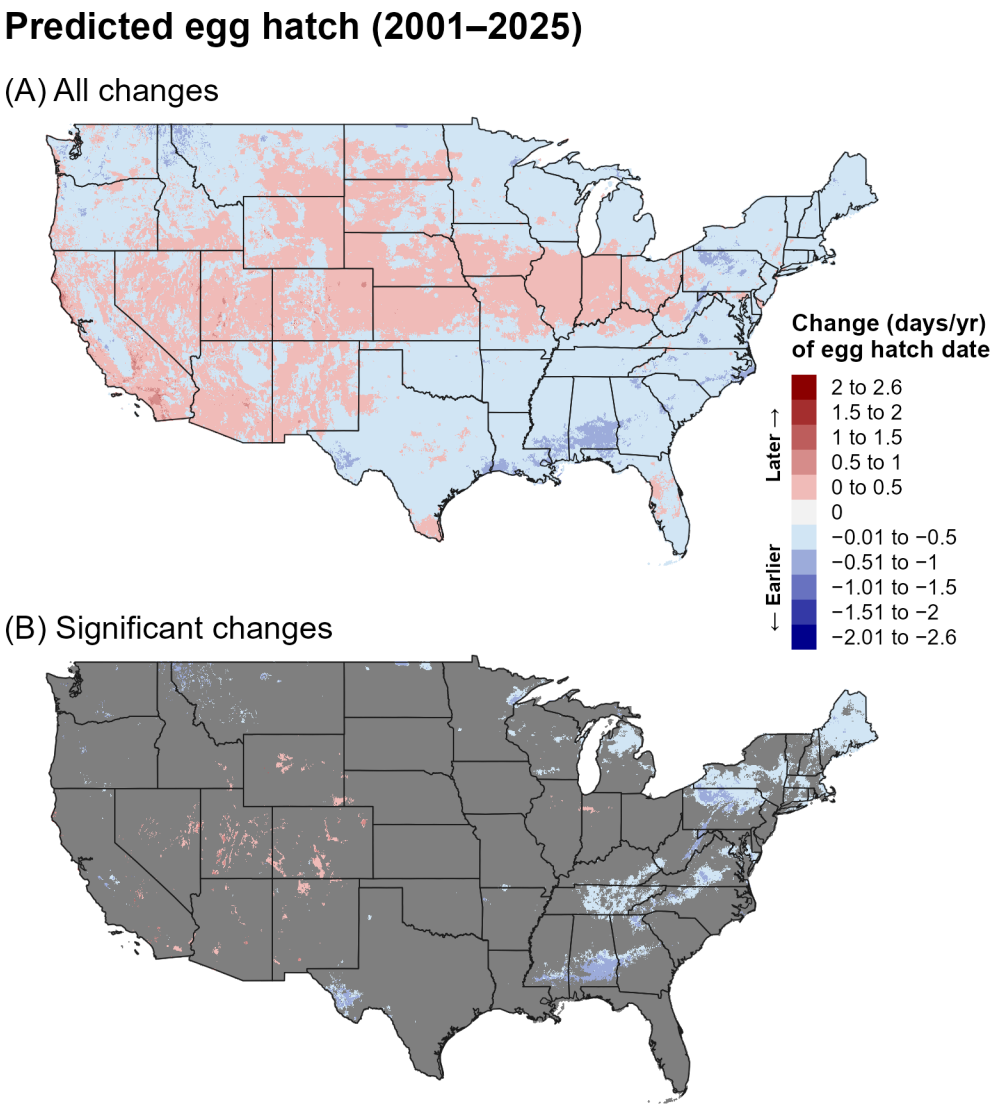

Figure 85. Changes (days/year) in predicted dates of first egg hatch for SLF across the CONUS over the recent 24-year period (2001–2025). Maps show (A) all changes and (B) statistically significant changes ($P < 0.1$); areas shown in gray are not statistically significant.

ii. Climatic suitability

Entire period: 1981–2025

Trends in predicted cold stress for SLF over the full 44-year period (1981–2025) were predominantly negative (Figure 86), indicating an overall decline in cold stress, with statistically significant decreases occurring in portions of the northern United States, including New England and the Upper Midwest. In contrast, trends in heat stress were significantly positive across parts of the Southwest and Pacific coast, indicating increasing heat stress in these regions (Figure 87). When annual accumulated stress units exceed limits specified in DDRP models, climatic suitability may change. Consistent with these trends, predicted climatic suitability for SLF increased in parts of the northern United States but decreased in portions of the Southwest, including Texas (Figure 88). Many of these changes were statistically significant, although significant changes in the Midwest were concentrated primarily in the Great Lakes region.

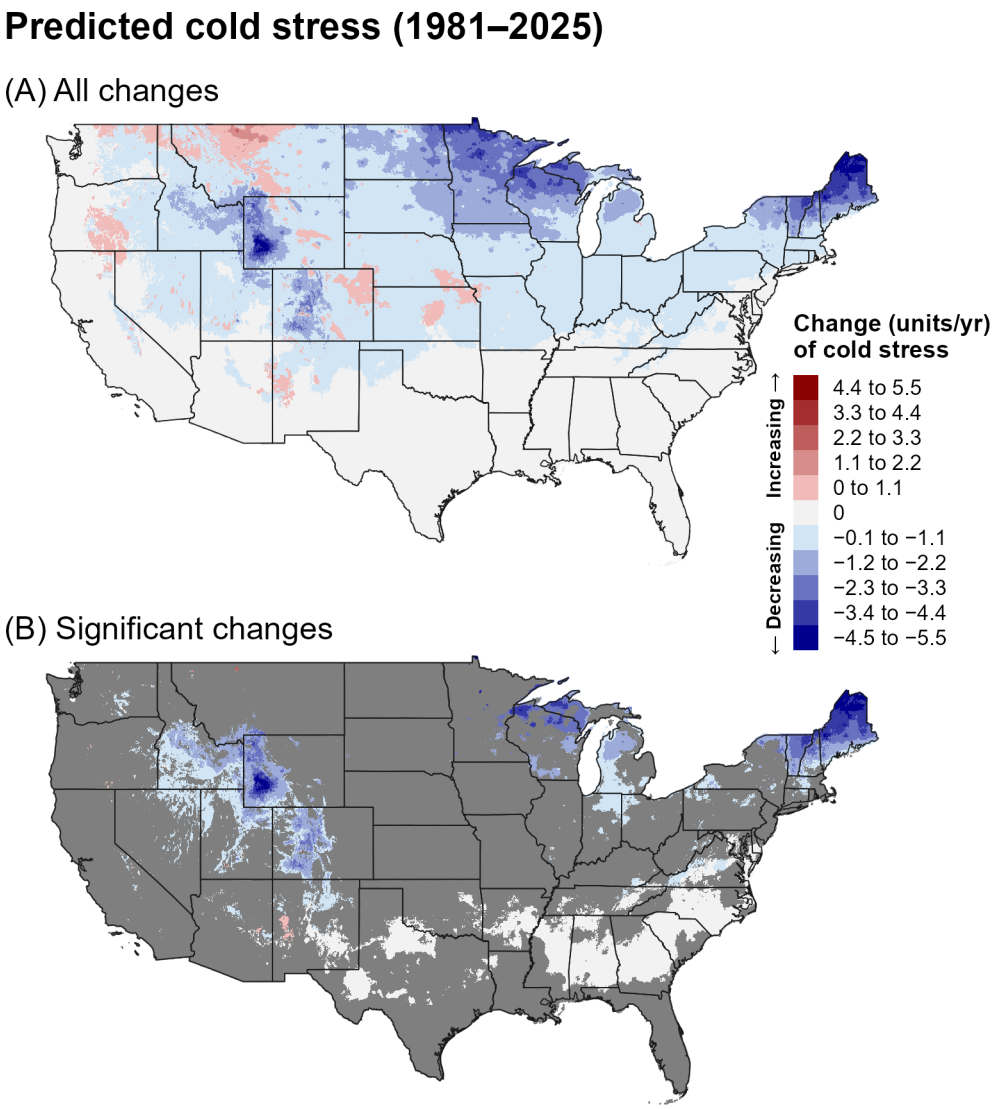

Figure 86. Changes (units/year) in predicted cold stress for SLF across the CONUS over the entire 44-year period (1981–2025). Maps show (A) all changes and (B) statistically significant changes ($P < 0.1$); areas shown in gray are not statistically significant. Areas shown as 0 in (B) had significant trends but very small changes.

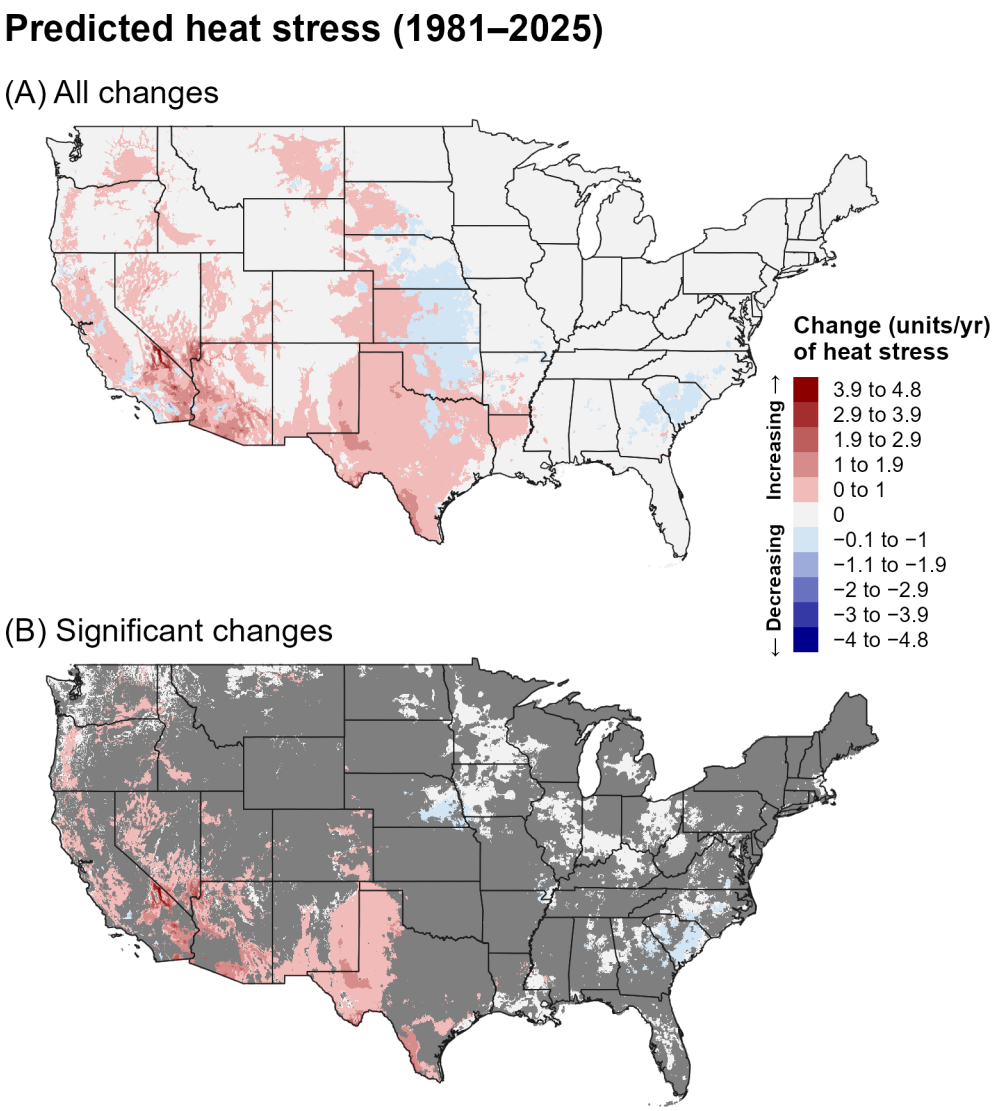

Figure 87. Changes (units/year) in predicted heat stress for SLF across the CONUS over the entire 44-year period (1981–2025). Maps show (A) all changes and (B) statistically significant changes ($P < 0.1$); areas shown in gray are not statistically significant. Areas shown as 0 in (B) had significant trends but very small changes.

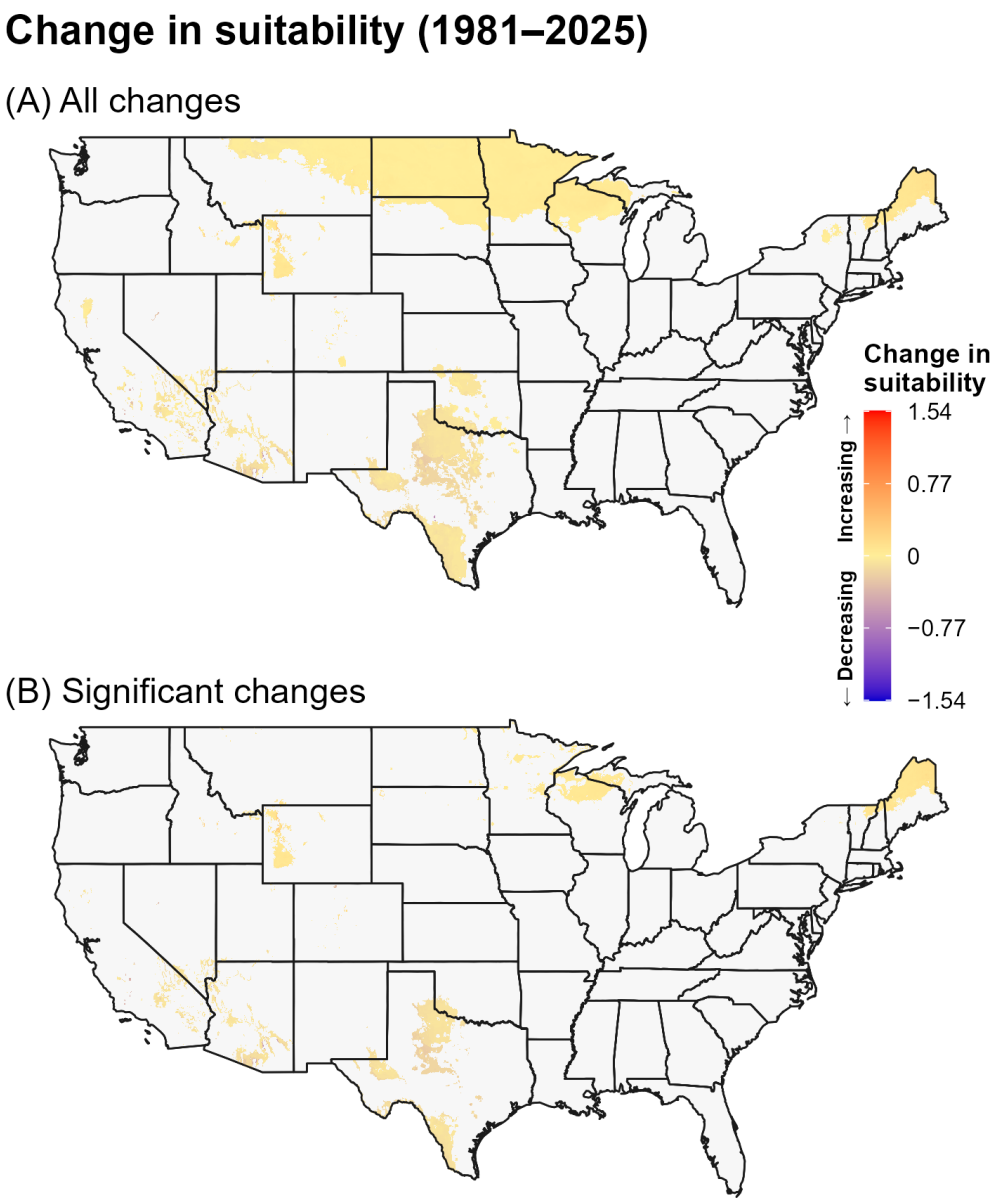

Figure 88. Changes in predicted climatic suitability for SLF across the CONUS over the 44-year period (1981–2025). Suitability is defined as areas not excluded by climate stress. Positive changes (warmer colors) indicate an increased likelihood of establishment, whereas negative changes (cooler colors) indicate a decreased likelihood of establishment.

Recent period: 2001–2025

Over the recent 24-year period (2001–2025), statistically significant trends in predicted heat and cold stress for SLF were less spatially extensive than those observed over the full 44-year period (1981–2025) (Figure 89, Figure 90). Significant increases in heat stress generally occurred in the same regions identified over the full period, although significant decreases were also predicted in parts of southern California and Arizona. In contrast, several areas that exhibited significant decreases in cold stress over 1981–2025 showed no significant trends over 2001–2025. Additionally, parts of the Midwest and Intermountain West exhibited significant increases in cold stress over the more recent period. Consistent with these patterns, significant changes in climatic suitability

were less extensive, with predicted increases largely restricted to parts of northern New England (Figure 91).

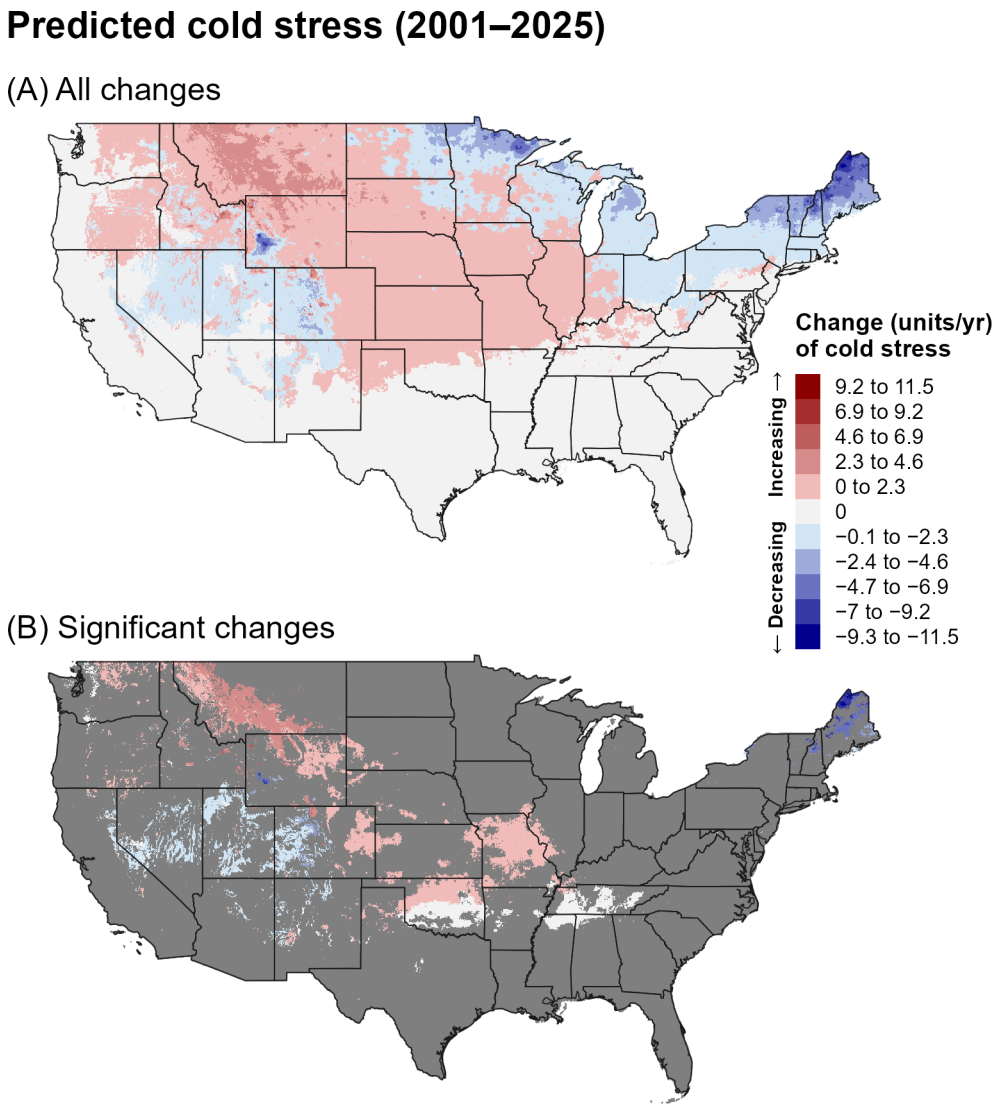

Figure 89. Changes (units/year) in predicted cold stress for SLF across the CONUS over the recent 24-year period (2001–2025). Maps show (A) all changes and (B) statistically significant changes ($P < 0.1$); areas shown in gray are not statistically significant. Areas shown as 0 in (B) had significant trends but very small changes.

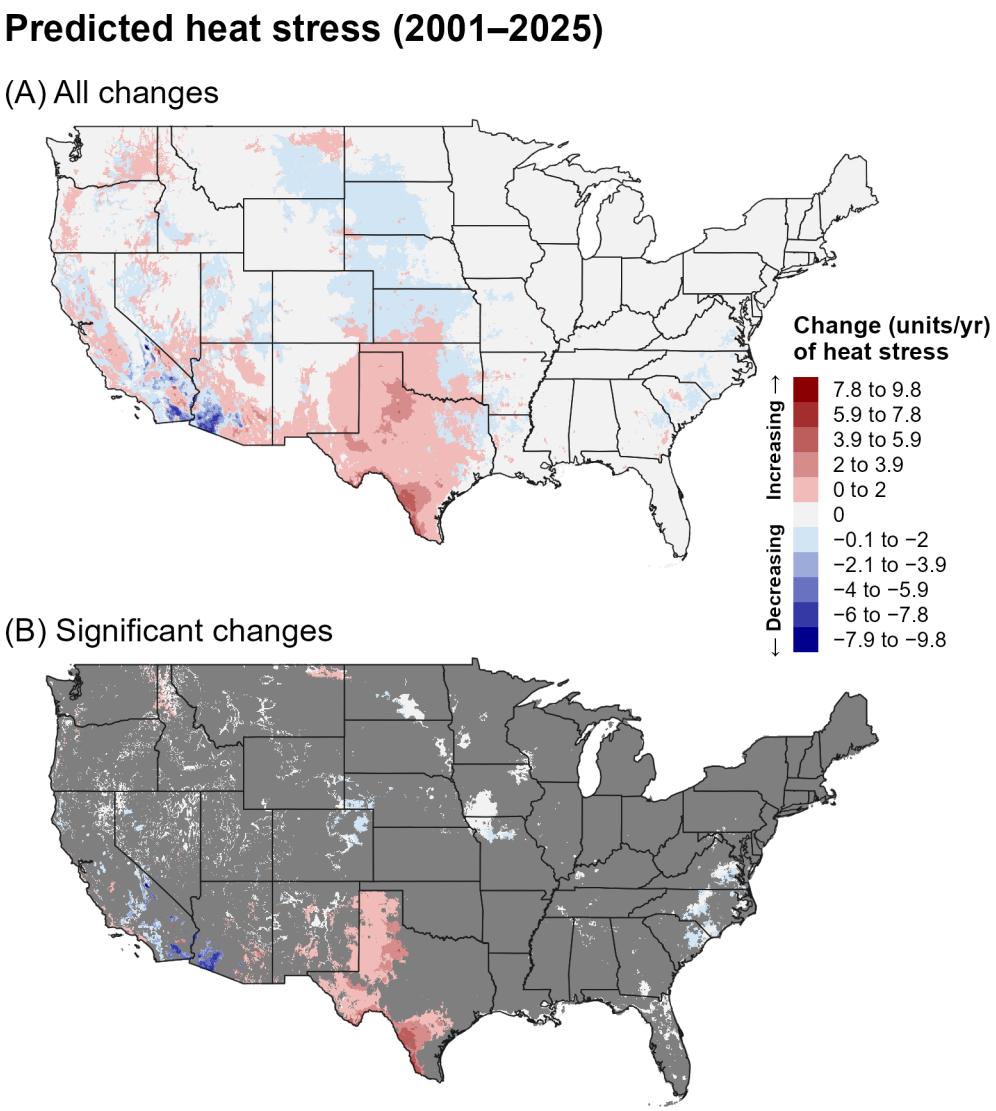

Figure 90. Changes (units/year) in predicted heat stress for SLF across the CONUS over the recent 24-year period (2001–2025). Maps show (A) all changes and (B) statistically significant changes ($P < 0.1$); areas shown in gray are not statistically significant. Areas shown as 0 in (B) had significant trends but very small changes.

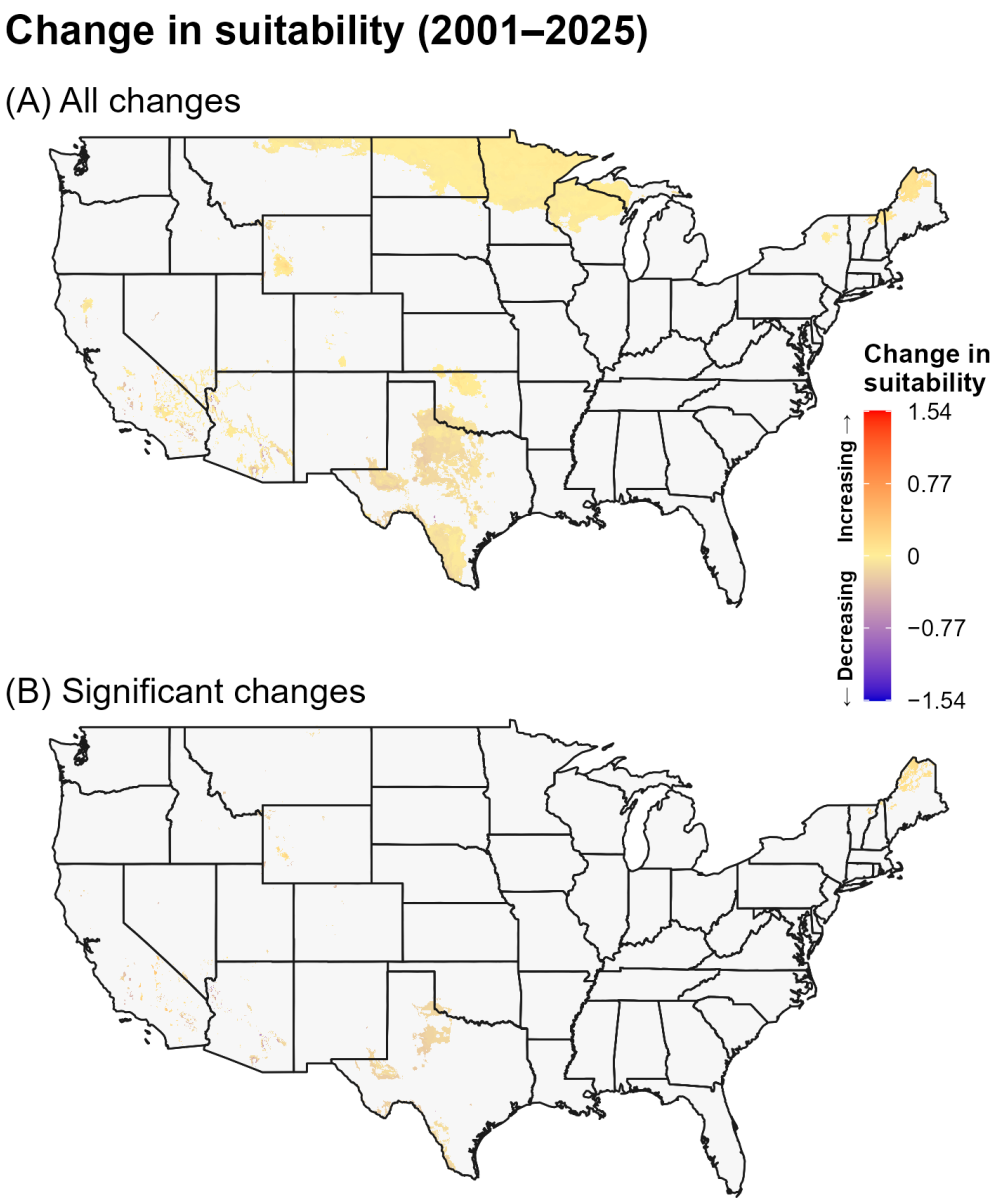

Figure 91. Changes in predicted climatic suitability for SLF across the CONUS over the recent 24-year period (2001–2025). Suitability is defined as areas not excluded by climate stress. Positive changes (warmer colors) indicate an increased likelihood of establishment, whereas negative changes (cooler colors) indicate a decreased likelihood of establishment.

13C. Discussion

Significant trends toward earlier egg hatch and adult emergence of SLF in the Northeast are consistent with an analysis of citizen science observations from 2014 to 2022 that documented earlier adult emergence as SLF expanded its range in this region (Owen et al. 2024). Because SLF is now widely established across much of the Northeast, these shifts toward earlier predicted phenological events have important implications for seasonal surveillance and management. Pest managers may need to adjust the timing of monitoring, control activities, and biological control releases to maintain their effectiveness. For example, earlier egg hatch may necessitate earlier releases of the nymphal parasitoid, *Dryinus sinicus* Olmi, 1987 (Hymenoptera: Dryinidae), which is most

effective against first-instar SLF (Zhuang et al. 2025). Similarly, earlier adult emergence could lead to earlier egg laying, potentially shifting the optimal timing for releasing of egg parasitoids, such as *Anastatus orientalis* Yang and Choi, 2015 (Hymenoptera: Eupelmidae) (Gould et al. 2024).

Declining cold stress and associated increases in climatic suitability for SLF across portions of the northern United States, including parts of New England and the Great Lakes region, suggest that these areas may be becoming increasingly conducive to SLF establishment. Previous modeling studies indicate that SLF does not yet occupy its full fundamental climatic niche in the CONUS, with suitable conditions extending across much of the Pacific Coast and eastern United States (Jones et al. 2022, Wakie et al. 2019, Barker et al. 2025). However, portions of the Midwest and Northeast, among the coldest regions of the CONUS, have historically been predicted to be less suitable for SLF establishment (Wakie et al. 2019, Barker et al. 2025). Our findings of declining cold stress and increasing climatic suitability in portions of these regions suggest that their potential for SLF establishment may be greater than previously recognized. Furthermore, urban heat island effects could create localized microclimates that further facilitate establishment in colder regions beyond the currently predicted suitable range (Owen et al. 2024).

Although the model captures important temperature-driven patterns in SLF phenology, uncertainty in how environmental cues interact to regulate diapause and development may influence predictions of phenological trends under changing climate conditions. The effects of temperature, photoperiod, and other environmental factors on egg diapause and developmental rates remain incompletely understood, making it difficult to fully predict how SLF may respond to changing weather patterns (Keena and Nielsen 2021, Calvin et al. 2023). Diapause may buffer populations against weather variability by enhancing overwintering egg survival and accelerating development and fecundity during summer and fall heat waves (Lewkiewicz et al. 2024). Although SLF is currently considered univoltine, even in warmer regions of China, whether it can complete multiple generations annually in warmer areas of the United States remains uncertain (Keena and Nielsen 2021, Calvin et al. 2023).

The stronger and more spatially extensive trends in predicted phenology and climate stress over the full 44-year period may reflect both the larger sample size, which can reduce noise and improve detection of directional patterns, and differences in the underlying climate trends between the two time periods. In particular, the recent 24-year period may capture climate variability or regional trends that differ from those observed over the longer 44-year period. Thus, differences between the two periods should be interpreted as reflecting both long-term climate trends and shorter-term regional variability.

13D. References

Barker, B. S., J. Beyer, and L. Coop. 2025. Real-time integrative mapping of the phenology and climatic suitability for the spotted lanternfly, *Lycorma delicatula*. Insects 16:790.

Barringer, L., and C. M. Ciafré. 2020. Worldwide feeding host plants of spotted lanternfly, with significant additions from North America. Environmental Entomology 49:999–1011.

Calvin, D. D., J. Rost, J. Keller, S. Crawford, B. Walsh, M. Bosold, and J. Urban. 2023. Seasonal activity of spotted lanternfly (Hemiptera: Fulgoridae), in Southeast Pennsylvania. Environmental Entomology 52:1108–1125.

Chu, H. J. 1930. Notes on the life-history of *Lycorma delicatula* White in Nanking. Peking Natural History Bulletin 5:33–35.

Cornell Integrated Pest Management. 2026. Spotted lanternfly status map (version 1.0.0, dataset v2026.10.0). Cornell University College of Agriculture and Life Sciences. Online at: https://maps.cornell-ipm.org/spotted-lanternfly (accessed 3 November 2026).

Dara, S., L. Barringer, and S. Arthurs. 2015. *Lycorma delicatula* (Hemiptera: Fulgoridae): A new invasive pest in the United States. Journal of Integrated Pest Management 6:20.

EPPO. 2025. Lycorma delicatula. EPPO datasheets on pests recommended for regulation. Online at: https:

//gd.eppo.int (accessed 29 May 2025).
Gould, J. R., C. Losch, L. Sullivan, Y. Wu, X. Y. Wang, L. M. Cao, and H. J. Bradley. 2024. Lifecycle of *Anastatus orientalis* (Hymenoptera: Eupelmidae) and synchrony with its host, the spotted lanternfly, *Lycorma delicatula* (Hemiptera: Fulgoridae). Environmental Entomology 53:954-965.
Jones, C., M. M. Skrip, B. J. Seliger, S. Jones, T. Wakie, Y. Takeuchi, V. Petras, A. Petrasova, and R. K. Meentemeyer. 2022. Spotted lanternfly predicted to establish in California by 2033 without preventative management. Communications Biology 5:558.
Keena, M. A., and A. L. Nielsen. 2021. Comparison of the hatch of newly laid *Lycorma delicatula* (Hemiptera: Fulgoridae) eggs from the United States after exposure to different temperatures and durations of low temperature. Environmental Entomology 50:410–417.
Lewkiewicz, S. M., B. Seibold, and M. R. Helmus. 2024. Quantifying population resistance to climatic variability: The invasive spotted lanternfly grape pest is buffered against temperature extremes in California. Ecological Modelling 497:110841.
Owen HL, Meng F, Winchell KM. 2024. Urbanization and environmental variation drive phenological changes in the spotted lanternfly, *Lycorma delicatula* (Hemiptera: Fulgoridae). Biological Journal of the Linnean Society 143:blae099.
Park, M. 2015. Overwintering ecology and population genetics of *Lycorma delicatula* (Hemiptera: Fulgoridae) in Korea. Ph.D. thesis. Seoul, South Korea: Seoul National University.
Pinto, A. F., B. C. Eshenaur, F. E. Acevedo, A. A. Calixto, M. Centinari, and M. I. Gómez. 2025. Assessing the potential economic impacts of spotted lanternfly (Hemiptera: Fulgoridae) infestations on grape production in New York State. Journal of Integrated Pest Management 16:2.
Urban, J. M., and H. Leach. 2023. Biology and management of the spotted lanternfly, *Lycorma delicatula* (Hemiptera: Fulgoridae), in the United States. Annual Review of Entomology:157–167.
Wakie, T. T., L. G. Neven, W. L. Yee, and Z. Lu. 2019. The establishment risk of *Lycorma delicatula* (Hemiptera: Fulgoridae) in the United States and globally. Journal of Economic Entomology 113:306–314.
Zhuang, Y., K. Bao, and X. Wang. 2025. Functional response of the native natural enemy of *Dryinus sinicus* (Hymenoptera: Dryinidae) to different instars of spotted lanternfly (*Lycorma delicatula*, Hemiptera: Fulgoridae). Journal of Economic Entomology 118:1320-1327.

14. Cotton cutworm

In progress - check back soon

15. Silver Y moth

In progress - check back soon

16. Small tomato borer

In progress - check back soon

17. Sunn pest

In progress - check back soon

18. Tomato leafminer

In progress - check back soon