Wilting Wildflowers and Bummed-Out Bees: Climate Change Threatens U.S. State Symbols

Xuezhen Ge[a], Ya Zou[b], Heather A Hager[a], and Jonathan A Newman[a]

This manuscript was compiled on September 8, 2024

Species designated as state symbols in the United States carry cultural importance and embody historical heritage. However, they are threatened by climate change and even face the risk of local or global extinction. The responses of these species to climate change have received little attention. In this study, we examine the effects of climate change on state flowers and insects in the United States by employing correlative species distribution models (SDMs). We select a variety of commonly used SDM algorithms to construct an ensemble forecasting framework aimed at predicting the potential habitats for each species under both historical and future climate scenarios, and how these changes might influence the distributions of state flower and insect species. Our results show that more than half of the state flowers ($\sim$ 66%) and insects ($\sim$ 51%) are predicted to experience a substantial decrease in regions with favorable climates within the states they represent. Conversely, only a small number (Flowers: $\sim$ 2%; Insects: $\sim$ 10%) are projected to see an increase in habitat suitability in the future. Certain states may no longer possess suitable habitats for their state-designated species. Our findings indicate that cultural heritage might be at risk due to reduced habitat suitability and local extinctions driven by climate change. These findings can provide guidance regarding the protection or replacement of state species to preserve cultural heritage.

Geographic distribution | Species distribution models | State flowers | State insects | Climate change

Significance Statement

We have known for decades that climate change may lead to species' local or global extinction. However, the vast majority of such research has focused on species of ecological or economic importance. Only recently have researchers begun to seriously consider the impacts of climate change on our cultural heritage, and that research has mainly focused on tangible cultural assests such as buildings and anthropological sites. Here, we consider the impacts of climate change on species of cultural significance, namely U.S. state flowers and insects. We find that the majority of these species are threatened with local extinction from climate change, and the loss of these species will take with them important aspects of our history and culture.

American states have official flowers and insects (and often other flora and fauna; 1–3). Some states share the same official species, while others boast unique species exclusive to their region. Writing about state flowers and trees, Nord (1) says:

> "The history behind our nation's selection of its flowers and trees is rich with political intrigues, legends, deception, and humor, which makes each state's adoption a unique story." (p. xiii)

Presumably, the states feel these species are in some way particularly representative of their citizens' way of life—perhaps they are common (e.g., peach blossom*Prunus persica* in Delaware) or once were and are now endangered (e.g., Hawaiian hibiscus *Hibiscus brackenridgei* in Hawaii, rusty patched bumble bee *Bombus affinis* in Minnesota), or perhaps the majority of citizens just have a fondness for these species (e.g., black-eyed Susan *Rudbeckia hirta* in Maryland). Why they were chosen differs by state, but these species are in some way *culturally significant* to citizens of the state. Jackson and Perkins (4) write:

> "The diverse array of state flowers in the United States weaves a tapestry of natural beauty, cultural significance, and historical heritage. These floral emblems encapsulate the essence of each state, reflecting its unique landscapes, economic contributions, and regional identity."

These unique histories and contributions are threatened when state flora and fauna are endangered by climate change. Developed nations such as the United States often spend large sums to conserve their cultural and historical heritage. Research on climate change is not new, but the impact of climate change on cultural heritage has only recently emerged as a subject of research. This issue gained attention at the Conference of the Parties to the United Nations Convention on Climate Change in Madrid in 2019 (COP25) and continues to be a prominent topic of interest (5). Most commonly, researchers have considered *cultural heritage* in the form of the so-called "tangible cultural heritage", such as architecture or ancient anthropological sites. Nevertheless, intangible cultural heritage, including customs and Indigenous knowledge, also faces threats just as significant due to climate change (5).

Author affiliations: [a]Department of Biology, Wilfrid Laurier University, Waterloo, Canada, N2L 3C5; [b]Forestry College, Beijing Forestry University, Beijing, 100083, P.R. China

[1]XG conducted the modelling work and co-wrote the manuscript. YZ contributed to the data gathering and modelling work, and the preparation of some of the supplements. HH contributed to the data gathering, some writing, and manuscript editing. JN concieved of the project, provided funding, supervised the modelling work, and co-wrote the manuscript.

The authors have no competing interests.

[2]To whom correspondence should be addressed. E-mail: jonathannewman@wlu.ca

DRAFT

State species are chosen for a variety of reasons, but ecological importance is not usually one of them. In fact, it is worth noting that some state species are not even native to North America, let alone their state. For example, Delaware, in 1895, chose the Chinese-native peach blossom (*Prunus persica*) as its state flower, reflecting the state's significant economic impact as the leading peach producer in the United States at the time (https://bit.ly/4fel4O1). New Hampshire designated the purple lilac (*Syringa vulgaris*), native to the Balkan Peninsula (6), as its official state flower in 1919, as it "symbolizes the hardy character of the men and women of the Granite State" (https://bit.ly/4bXy2wH). The promotion and prioritization of non-native state species can disrupt the habitats of native species and may significantly affect ecosystems, especially for plant species. With global warming, non-native plant species tend to respond with earlier phenological development compared to native species. Thus, climate change may favor non-native over native species and also amplify the impacts of non-native species on native species (7, 8).

In this work, we investigate how climate change is reshaping the future of state species that hold cultural significance. We selected various commonly used correlative species distribution model (SDM) algorithms and constructed an ensemble forecasting framework to predict the potential distributions for each species under historical and future climate conditions and how climate change might alter the distributions of state flowers and insects. By classifying the effect of climate change on species' habitat suitability through both quantitative and qualitative lenses (i.e., change in median, spatial variation, and local extinction indicator; Tab. 1), we seek to determine whether these symbols of cultural heritage, officially adopted by their states, will continue to thrive and uphold their vital multifaceted roles.

Results

Climate impacts on state flowers. Thirty-three states had only a single type of official floral species, whereas 15 had both state flowers and state wildflowers. State floral species comprise a variety of forbs (31), as well as vines (2), shrubs (16), trees (11) (including one gymnosperm), orchids (2), cactus (1), and mistletoe (1), and include both native (54) and non-native (9) species*. Of the 64 floral species analyzed, seven (*Coreopsis* spp., *Cornus florida*, *Kalmia latifolia*, *Magnolia grandiflora*, *Malus domestica/pumila*, *Rosa arkansana*, *Solidago gigantea*) were designated by two states, and one (*Viola sororia*) was designated by four states. Nine states designate a genus rather than a specific species. Hawaii and New York were excluded from this analysis due to the lack of occurrence records for their state flowers.

We quantified the strength of climate change impacts on species' habitat suitability by calculating the difference in median habitat suitability values within their respective states under climate change. We then grouped these state flowers by their plant types (Fig. 1C), origin (Fig. 1D), and whether they are state wildflowers or not (Fig. 1E) to identify general patterns. For the analysis by plant type, we selected three types (i.e., forb, shrub, and tree) that each have more than three species. The figures reveal that climate change generally has a stronger negative effect on: shrubs than on forbs or trees (1C), on native than on non-native flowers (1D), and on non-wildflowers than designated wildflower species (1E).

We further classified these state flowers into six categories (Tab. 1) based on the magnitude (δ; Eq. 3), spatial heterogeneity (CV; Eq. 8) and likely outcome (θ; Eq. 9) of climate change impacts. As shown in Tab. 1, most state flowers will experience negative climate effects, reducing species habitat suitability and potentially leading to local extinction by the 2080s. Although, on average, some state flowers may barely be affected by climate change, these effects vary geographically within the states. The more detailed results are summarized below.

Climate change reduces habitat suitability. As shown in the difference plot and the density plots that include all state flowers (Figs. 1A,B), climate change will reduce the habitat suitability for most state flowers within their respective states. In total, 42 ($\sim$ 66%) state flowers will experience a negative climate effect (Tab. 1). Among these species, the median habitat suitability value will decrease by up to 0.83 due to climate change (Fig. 1 A). The negative effect of climate change may lead to local extinctions for nine ($\sim$ 14%) state flowers (Tab. S5), such as the orchard apple (*Malus domestica*) in Arkansas (Fig. 1B, Fig. 2A) and the showy lady's slipper (*Cypripedium reginae*) in Minnesota (Fig. 1B).

Habitat suitability remains stable under climate change. Twenty-one ($\sim$ 33%) state flowers experience, on average, trivial effects due to climate change (Tab. 1), with their median habitat suitability remaining roughly stable under climate change. Nevertheless, the spatial variation in suitability changes differs among the species. Fifteen state flowers ($\sim$ 23%), such as the giant blue iris (*Iris giganticaerulea*), show more pronounced and obvious spatial variations in their response to change than do others (Fig. 2D). Notably, the American pasqueflower (*Pulsatilla hirsutissima*) has low suitability in South Carolina under both historical and future climate conditions (Fig. 1B).

Climate change increases habitat suitability. Only one ($<$ 2%) state flower – the marvel of Peru (*Mirabilis jalapa*) is projected to experience increased habitat suitability due to climate change (Tab. 1). Climate change effects on *M. jalapa* exhibit little spatial variation within Connecticut, and the species is expected to have greater habitat suitability in most areas within the state (Fig. 2E).

Climate change impacts on state insects. Thirty-three states had only a single type of official insect species, whereas 16 states had multiple types (e.g., state insect and state butterfly). State insect species come from a limited number of groups: butterflies (31), bees (21), lady beetles (6), fireflies (3), dragonflies (2), mantids (2), burying beetles (1), damselflies (1), and wasps (1). Of the 68 insect species analyzed, European honey bee (*Apis mellifera*), an non-native species, was designated by 20 states, monarch butterfly (*Danaus plexippus*) by seven states, eastern tiger swallowtail butterfly (*Papilio glaucus*) by six states, black swallowtail butterfly (*Papilio polyxenes*) by three states, and each of two lady beetles (*Coccinella novemnotata* and *Hippodamia*

*For Michigan, we interpret the apple blossom as representing *Malus coronaria* (a native species) and *Malus domestica* (a non-native species). Therefore, we excluded the Michigan state flower from the analysis comparing native and non-native species.

DRAFT

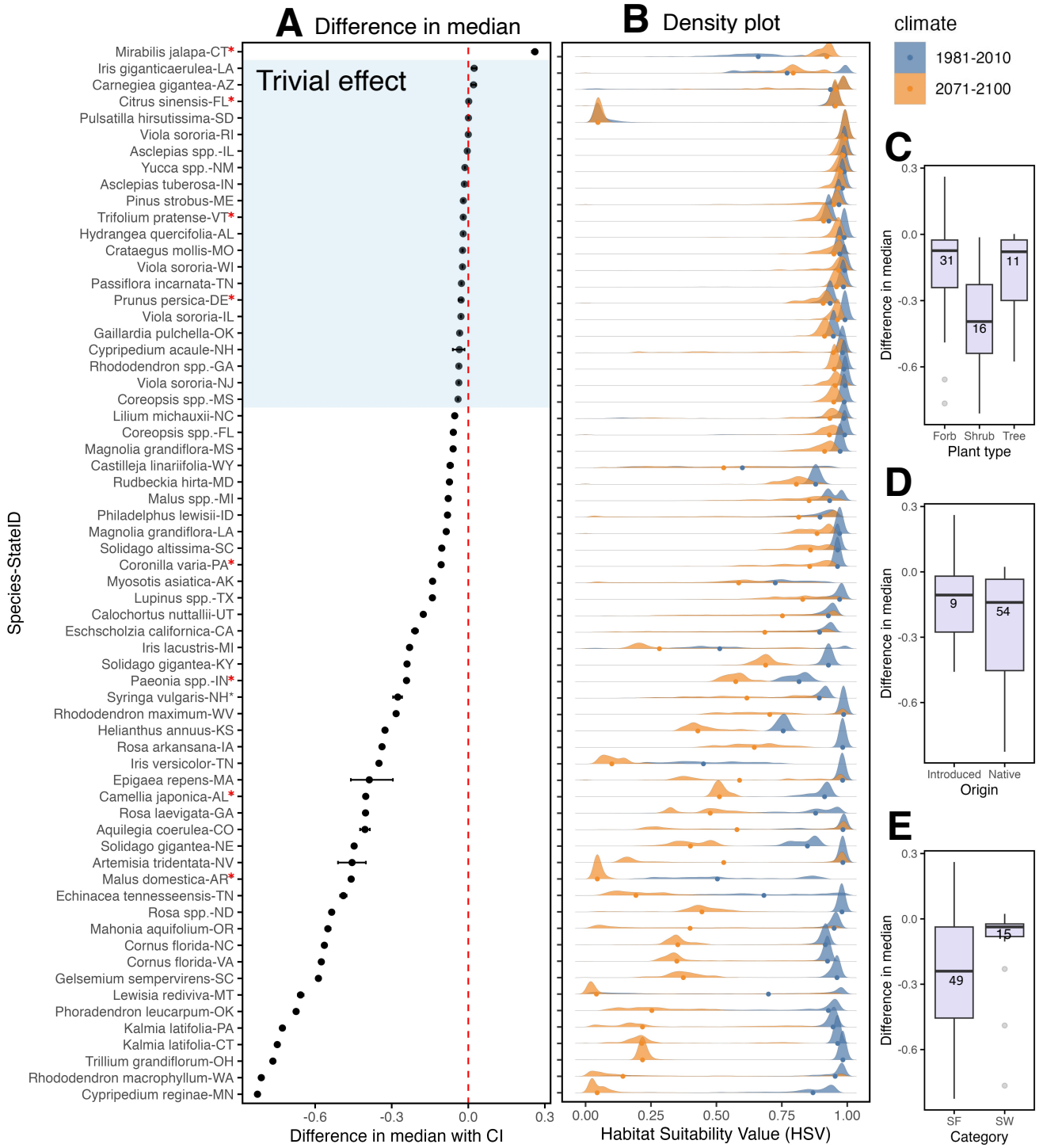

Fig. 1. State flowers: Changes in habitat suitability for 64 state flowers under climate change. Panel A shows the difference in the median habitat suitability value (HSV) between future and historical climate conditions (δ, Eqs. 2-3) for each state flower in its designated state. These state species are ranked by the δ value. Non-native species are indicated by red $\star$ in y-axis labels. Panel B plots the distribution of HSVs under historical (blue) and future (orange) climate conditions; blue and orange dots represent the median HSVs. Panels C-E show box plots of δ (Eq. 3) for all state flowers grouped by plant type (C), origin (D), and whether they are state wildflowers (SW) or not (SF) (E). The number below each median line is the sample size for each group. Large differences in sample size could affect the reliability of comparisons.

Table 1. Quantities and proportions of state flowers and state insects across various types of responses to climate change. δ represents the change in median habitat suitability between the two climate conditions (Eq. 3), CV represents the spatial variation of the changes in habitat suitability (Eqs. 5-8), θ is the local extinction indicator (Eq. 9).

Type	Criteria	State flowers		State insects	
		N	%	N	%
A. Negative overall effect causes local extinction	$\delta < -0.05, \theta = 1$	9	14.06	3	4.41
B. Negative overall effect reduces suitability	$\delta < -0.05, \theta = 0$	33	51.56	32	47.06
C. Trivial overall effect with small spatial variation	$-0.05 \leqslant \delta < 0.05, CV < 1$	6	9.36	7	10.29
D. Trivial overall effect with large spatial variation	$-0.05 \leqslant \delta \leqslant 0.05, CV \geqslant 1$	15	23.44	19	27.94
E. Positive overall effect with small spatial variation	$\delta > 0.05, CV < 1$	1	1.56	6	8.82
F. Positive overall effect with large spatial variation	$\delta > 0.05, CV \geqslant 1$	0	0.00	1	1.47
	Sum	64	100.00	68	100.00

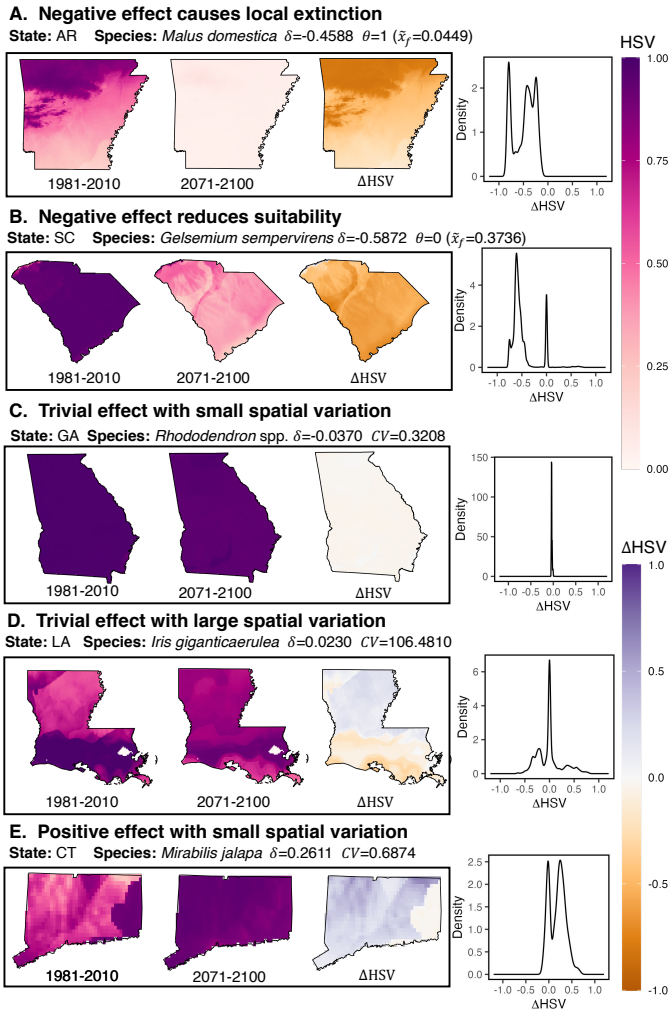

Fig. 2. State flowers: Geographical distribution of different types of climate change effects on the habitat suitabilities (HSV) for state flowers. We selected five representative state flowers to illustrate the geographical distribution of habitat suitability under historical (1981-2010, 1st column) and future (2071-2100, 2nd column) climate conditions. Additionally, we plotted the geographical distribution (3rd column) and probability density (4th column) of $\Delta\mathrm{HSV}$ to highlight the changes in habitat suitability due to climate change.

convergens) by two states. The difference plot and the density plots for each state insect are shown in Fig. 3.

Climate change is expected to reduce the habitat suitability of 35 ($\sim$ 51%) state insects (Fig. 3A and Tab. 1), but only three of them are likely to face future local extinction (Tab. S4). Seven ($\sim$ 10%) state insects will experience positive effects. The habitat suitability of 26 ($\sim$ 38%) state insects will remain roughly stable under climate change. Compared to its impact on state flowers, climate change generally results in fewer negative effects and more significant positive effects on climate suitability for state insects (Fig. 1A vs Fig. 3A). Fig. 4 shows the geographical distribution of habitat suitability for characteristic state insects within each response category, with the similar patterns observed in Fig. 2.

Among different species groups, climate change has a slightly stronger negative effect on butterflies than on bees or ladybugs (Fig. 3C). Earlier, we showed that native state flowers tend to be more vulnerable to the negative impacts of climate change than non-native state flowers (Fig. 1D). This situation is also the case for state insects (Fig. 3D).

Given that multiple states have chosen the same insects as their state symbols, we generated scatter plots for these species across their designated states (Fig. 5) to look for latitudinal patterns. The trend lines in Fig. 5 show that there is an observable latitudinal trend in the impacts of climate change on habitat suitability for these three insect species. Climate change mainly leads to a decrease in habitat suitability (negative effect), and its negative effect seems to be stronger at lower latitudes; however, its tendency varies among the species, which underscores the importance of studying species-specific responses in the context of climate change.

Discussion

Cultural loss. Figs. 1 and 3 clearly show that numerous state flowers and insects are expected to undergo a significant reduction in areas with favorable climate within their states, with some experiencing such severe declines that it may result in dire consequences. Although a number of these species are not indigenous to their states and may not hold much economic or ecological importance, their potential disappearance poses a threat to the cultural heritage of the states. It is challenging to quantify, let alone summarize, the cultural impacts of climate change due to the unique and diverse reasons behind the selection of each state species.

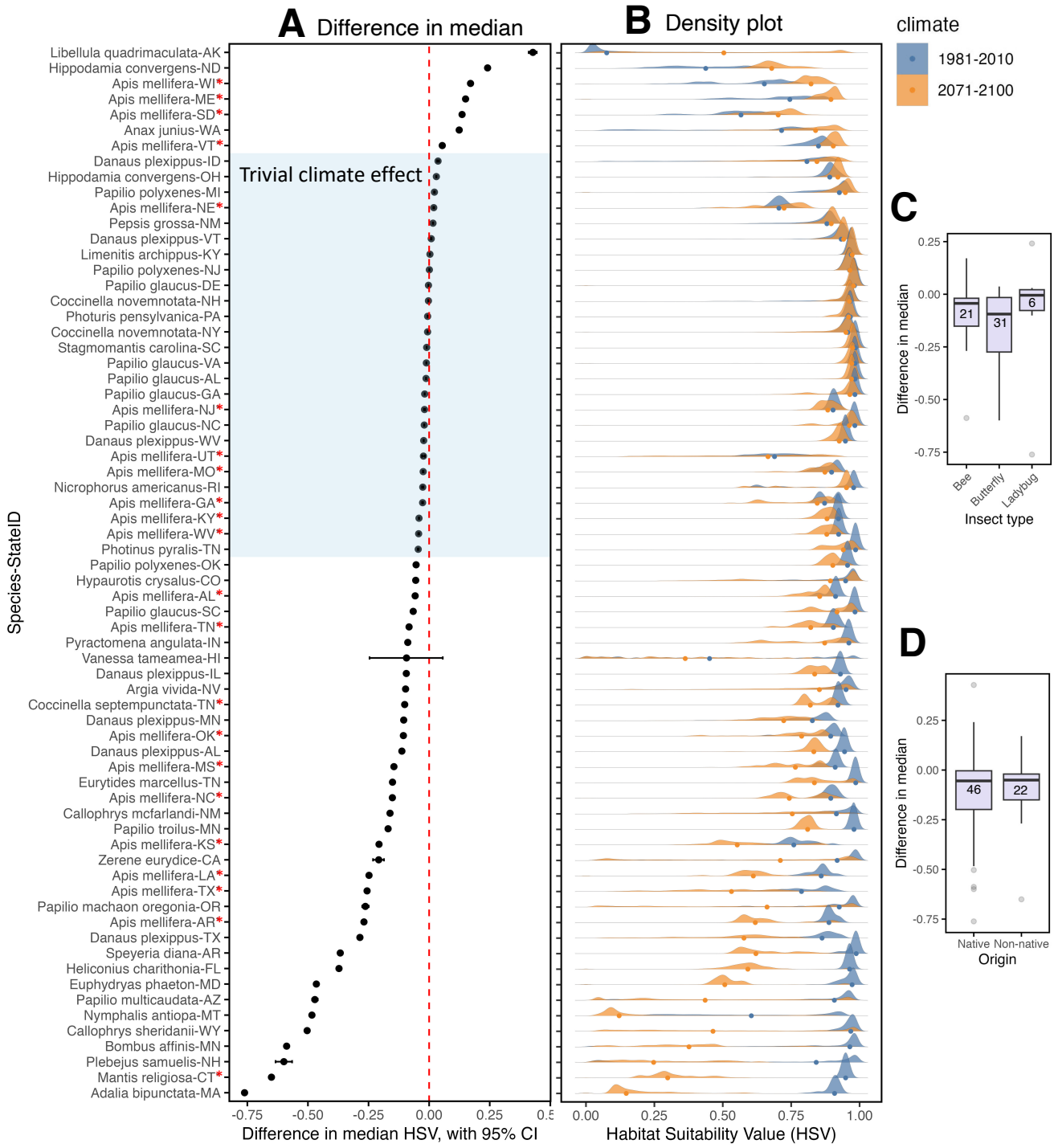

Fig. 3. State insects: Changes in habitat suitability for 68 state insects under climate change. Panel A shows the difference in median habitat suitability value (HSV) between future and historical climate conditions (δ, Eqs. 2-3) for each state insect in its designated state. Non-native species are indicated by red $\star$ in y-axis labels. Panel B shows the distribution of HSVs under historical (blue) and future (orange) climate conditions; blue and orange dots represent the median HSVs. Panels C-E show box plots of δ (Eq. 3) grouped by insects type (C) and origin (D). The number below each median line is the sample size for each group. Large differences in sample size could affect the reliability of comparisons.

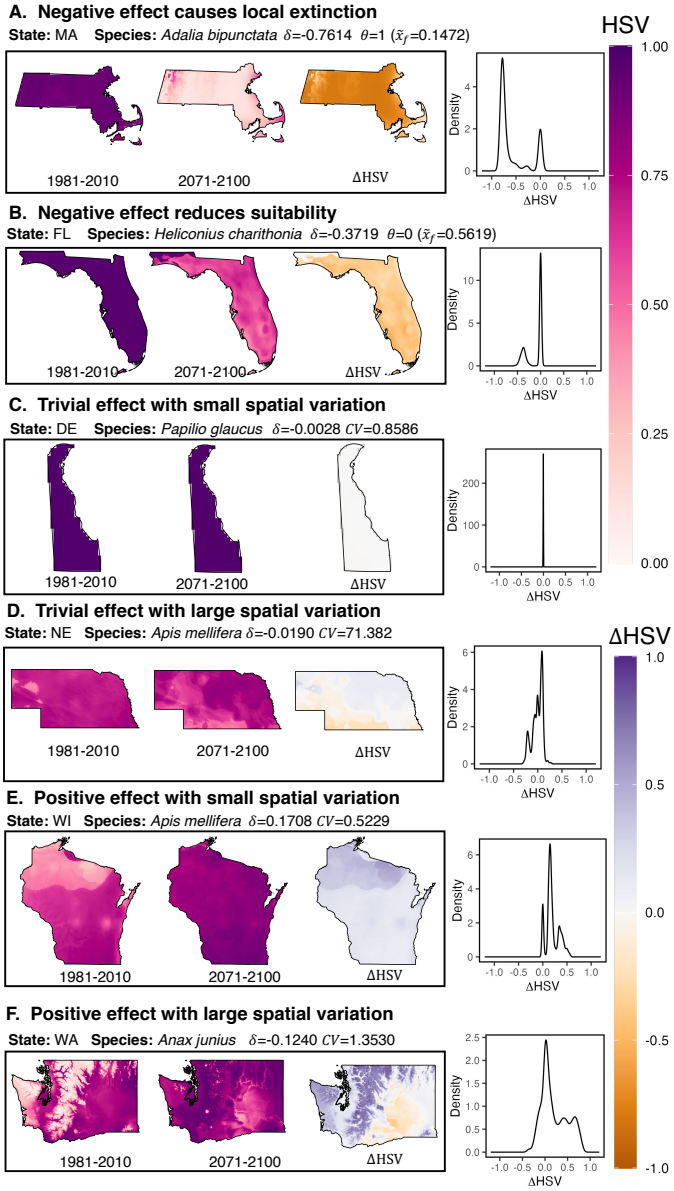

Fig. 4. State insects: Geographical distribution of different types of climate change effects on the habitat suitabilities (HSVs) for state insects. We selected six representative state insects to illustrate the geographical distribution of habitat suitability under historical (1981-2010, 1st column) and future (2071-2100, 2nd column) climate conditions. Additionally, we plotted the geographical distribution (3rd column) and probability density (4th column) of Δ HSV to highlight the changes in habitat suitability due to climate change.

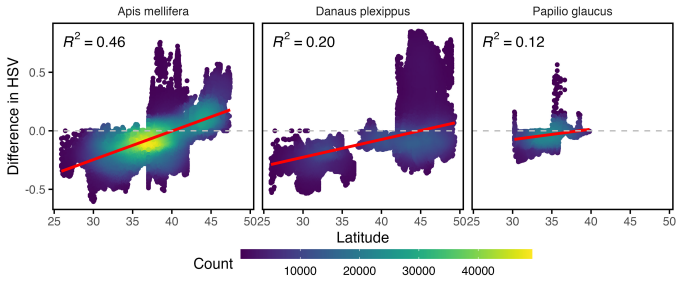

Fig. 5. State insects: Correlation between change in habitat suitability and latitude of each grid cell. Each plot only includes all grid cells within states that designated the same focal insect species. The color depth indicates the point density. The red lines in each plot are trend lines fitted through the data.

However, a few anecdotes can help illustrate some of the significant cultural losses at stake.

Minnesota's state flower, the showy lady's slipper (*Cypripedium reginae*), is projected to go from a very high median HSV of about 0.87 currently to a median value close to zero (~ 0.04 by the 2080s), and will thus be at high risk of local extinction. This flower has been featured on the state flag since 1893 and was commemorated with the Minnesota Wildflower Route, designating 130 km of State Highway 11 in its honor, where it is estimated that $> 800,000$ of these flowers can be found today (9). Our analysis suggests that this area will be climatically unsuitable for this species by the 2080s. Washington's state flower, the rhododendron (*Rhododendron macrophyllum*), also faces a serious risk of local extinction. It was chosen through an 1893 vote, which was only open to women, 17 years before women were legally allowed to vote in elections (1).

Similarly, Oklahoma's state flower, the mistletoe (*Phoradendron leucarpum*), was selected 14 years *before* statehood and is the oldest of the state's symbols. Legend has it that the ability of the plant to withstand harsh winters symbolized the mettle of Oklahoma's early pioneers (1). Ironically, it may be warming winters that lead to the plant's downfall and the state's loss of its cultural heritage.

Montana's bitterroot (*Lewisia rediviva*) is also endangered by climate change. The genus name honors Captain Meriwether Lewis of the Lewis and Clark Expedition. This historical journey holds significant cultural importance for the state (https://bit.ly/3yiu2co). The Bitterroot Mountains, Bitterroot Valley and Bitterroot River owe their names to this state flower. Mary Long Anderson, who organized the referendum that selected the bitterroot in 1894, long before the state allowed women to vote, went on to become the state's first congresswoman in 1916 (1).

These examples highlight the diverse and difficult-to-quantify cultural losses that may result from local extinctions caused by climate change. Similar to losing an important work of art, local loss of these species can have impacts that extend far beyond their ecological or economic effects (10).

Technical details. Only eleven ($\sim 10\%$) of the flowers and five ($\sim 15\%$) of the insects previously had their potential distributions modelled in the United States (Tabs. S5 and S6). Most of these studies used MaxEnt as the primary model algorithm and rarely employed other algorithms. Unlike previous studies, we used an ensemble model framework

comprising multiple correlative SDM algorithms to predict how climate change might alter the distributions of state flowers and insects. For an individual species, the differences in our predictions can be attributed to the use of alternative climate data, different General Circulation Models (GCMs), emission scenarios, and modelling algorithms/approaches.

Most state species were originally chosen for their popularity, had high habitat suitability, and were widely distributed within their states. However, our results predict that 11 state species (nine flowers and three insects) may be at risk of local extinction by the 2080s. It should be noted that the threshold for the local extinction indicator (θ; Eq. 9) is somewhat arbitrary and does not definitively mean that the species will go extinct in the future. To be precise, $\theta = 1$ indicates that the species' predicted habitat suitability is relatively low. Nevertheless, it indicates that the climate within a state is unlikely to support the local persistence of these species by the 2080s.

Non-native versus native species. Several states have designated non-native species as their state species. It is well documented that non-native species pose significant threats to local biodiversity, ecosystem services, environmental quality, and human health (11). While not all non-native species are harmful to the environment, and some provide ecological or economic benefits (12, 13), managing these species is a complicated and uncertain task due to their potential complex interactions with ecosystems. We also know that native and non-native species sometimes respond differently to climate change (14). Our results suggest that non-native species may be less vulnerable to climate change compared to native species. This warns us that, in the future, non-native species could potentially be predominant in ecosystems, leading to unpredictable ecological consequences and economic losses.

Some local state movements are dedicated to promoting the cultural identity of native species to align with a state's priorities of maintaining local ecosystem stability. They advocate for native species to replace exotic species as the designated state symbol. For example, Georgia's current state flower, the Cherokee rose (*Rosa laevigata*), is actually an invasive plant from South China. The Georgia Native Plant Society has proposed replacing it with sweetbay magnolia (*Magnolia virginiana*), which not only supports pollinators but also has a rich history in Georgia's botanical heritage and was cherished by Indigenous communities (15, 16). Georgia Senate Bill 518 (17) to amend the Georgia state code with sweetbay magnolia as state flower has already received unanimous approval from the Senate Committee on Economic Development and Tourism.

In Alabama, goldenrod (*Solidago* spp.) was originally designated as the state flower in 1927. Thirty years later, a group of camellia flower enthusiasts successfully lobbied to replace goldenrod with non-native *Camellia,* arguing (mistakenly) that goldenrod is a sneeze-inducing weed (ragweed, *Ambrosia artemisiifolia*, pollen usually causes seasonal allergies). Recognizing the importance of native species, professor Oneal Smitherman at Auburn University campaigned tirelessly until his death to have the Alabama azalea (*Rhododendron alabamense*) named state flower (18). More recently, Kyle Lybarger has started a petition advocating for goldenrod to reclaim its status due to its crucial ecosystem functions, medicinal uses, and rich species diversity of goldenrod species (19).

Although state governments must weigh multiple factors when selecting state species, the native versus non-native issue has garnered increasing attention. We recommend prioritizing native species to honor a state's ecology and natural history.

Management strategies. Our findings can provide guidance for protecting or replacing state species to ensure that cultural heritage is preserved. Any discussion of state species can also be used as an opportunity to educate the public about the importance of mitigating climate change, with most species expected to face reduced habitat suitability, and some even potential local or regional extinction. Alternative representative species may be selected to replace species that were chosen initially for their popularity but that may become locally extinct under climate change. Given that some groups such as shrubs and butterflies may be more vulnerable to climate change than other groups, it may be desirable to avoid selecting such species as emblems. On the other hand, the public may become more interested in mitigating climate change to avoid losing their beloved state species.

Some state species were originally selected for their rarity or endangered status, such as showy lady's slipper (*Cypripedium reginae*), Tennessee coneflower (*Echinacea tennesseensis*), and Karner blue butterfly (*Plebejus samuelis*), to raise public awareness and support for their protection. Climate change is expected to reduce the habitat suitability for all three of these species by varying degrees. Habitat loss is another important factor for many species. For showy lady's slipper, habitat loss is currently more crucial for its rarity than climate factors (with a historical median habitat suitability value of around 0.82 in Minnesota). Reconstructing its suitable alkaline habitats and designating conservation areas could be effective protective measures (20). However, habitat conservation alone may not be sufficient, given that the median habitat suitability value is projected to decline significantly to nearly zero. For the Karner blue butterfly, population decline and extinction have been closely linked to both harsh climatic conditions (2012 drought and heat) and habitat loss (21). Its median habitat suitability value in New Hampshire is projected to decrease from 0.85 to 0.25 with climate change. Conservationists and stakeholders will need to dedicate significant efforts to maintain the necessary habitat for Karner blue butterfly and to ensure the survival of its sole food source, the wild blue lupine (*Lupinus perennis*).

Supporting Information Appendix (SI). All the supporting text (Supplement 1-2), supplementary tables (Table S1-S6), and the codes related to this study are available at: https://github.com/xuezhenge/state_species.

SI Datasets. The model projection data (SI Dataset 1-4) for all state species will be provided after acceptance. The total file size is about 20 GB.

Materials and Methods

Species lists. We compiled lists of official state flower and insect species by consulting netstate.com and cross-referencing with associated state legislation and state websites (See Supplement 1 and 2). Flowers included 46 state flowers, 15 state wildflowers, 1 state floral emblem, 1 children's state flower, and 1 beautification

DRAFT

and conservation plant (total = 64; $\sim$ 83% native species; Tab. S1).

Four state flowers were excluded due to the lack of occurrence records: Hawaii's endemic endangered *Hibiscus brackenridgei*, New York's cultivated *Rosa* spp., Ohio's cultivated *Dianthus caryophyllus* (carnation), and Oklahoma's cultivated hybrid tea rose 'Oklahoma' (*Rosa* $\times$ *hybrida*). Of the 64 official flowers included, 9 were designated by genus alone or as multiple species (Florida, *Coreopsis* spp.; Georgia, native *Rhododendron* spp.; Illinois, *Asclepias* spp.; Indiana, cultivated *Paeonia* spp.; Michigan, *Malus coronaria* and *Malus domestica/pumila*; Mississippi, *Coreopsis* spp.; New Mexico, *Yucca* spp.; North Dakota, *Rosa arkansana* and *Rosa blanda*; Texas, *Lupinus* spp.). For genera, we determined all the species native to the state using the USDA Plants database (USDA, NRCS 2023) and included those with sufficient occurrence records for modelling (Tab. S2). For cultivated *Paeonia*, we included *P. lactiflora* and *P. officinalis*. After accounting for all species selected for states that did not designate a specific species name, we included 114 floral species and modelled their habitat suitability under climate change.

Insects included 41 state insects, 21 state butterflies, 3 state agricultural insects, 1 state bee, 1 state bug, and 1 state pollinator (total = 68; $\sim$ 68% native species; Tab. S3). Another state bug was excluded (Delaware, *Coccinella* spp.) because the genus was too broad. When only a common name or genus was specified in the legislation, we consulted other state materials to determine if there was an accepted representative species. Of the 68 insect species analyzed, many species are designated by multiple states, such as European honey bee (*Apis mellifera*) and monarch butterfly (*Danaus plexippus*). After accounting for the multiple uses of these species, we included 34 insect species and modeled their habitat suitability under climate change.

Species occurrence records. We used the `R` package, `rgbif`(22), to obtain global occurrence records for all species from the Global Biodiversity Information Facility (GBIF, http://www.gbif.org), updated up to December 2023. Following the methods of Ge et al. (23, p4), we removed duplicate records and those with spatial and temporal errors using the `R` package, `CoordinateCleaner`(24). We spatially thinned the raw occurrence data by randomly selecting a single presence point within each 10 $\times$ 10 km grid cell using the `R` package, `BiodiversityR`, to reduce sampling bias (25) ((See Tabs. S1-S3 for counts of occurrence records counts for data cleaning and thinning). Depending on the correlative model algorithm and the number of occurrence records (26), we used different strategies (Fig. S1) to generate the pseudo-absence data for each species using the `R` package, `biomod2` (27). Finally, we split the occurrence and pseudo-absence data sets into training sets for model fitting and test sets for model evaluation using the block cross-validation technique, implemented in the `R` package, `blockCV` (28). The processes used to generate pseudo-absence data and split the training and test data sets are listed in Fig. S2 of Ge et al.'s study(23).

Climate data. We downloaded 19 raster-based bioclimate variables from CHELSA V2.1 (Climatologies at High Resolution for the Earth's Land Surface Areas, https://chelsa-climate.org/, (29)) to represent the historical (1981–2010) and future (2071–2100) climates. The historical climate data included in CHELSA V2.1 were generated by downscaling temperature and precipitation estimates from the ERA-Interim climatic reanalysis to a high resolution of 30 arcseconds (29). CHELSA V2.1 also includes future bioclimate variables that were derived for five global climate models (GCMs: `GFDL-ESM4`, `IPSL-CM6A-LR`, `MPI-ESM1-2-HR`, `MRI-ESM2-0`, and `UKESM1-0-LL`) and three Shared Socioeconomic Pathways (SSPs: SSP1-2.6, SSP3-7.0, and SSP5-8.5) as well as three time periods (2011–2040, 2041–2070, 2071–2100). We selected the most extreme warming scenario (SSP5-8.5), as we are interested in the effect of climate change under the most extreme scenario. Historical (1981–2010) and future (2071–2100) global climate data are used here to demonstrate how species' habitat suitability changes over time. The multi-model ensemble can reduce the uncertainty that results from differences in the GCMs (30, 31), so we calculated the ensemble mean value of the five GCMs and used these values to generate future global projections with the SDMs. Given the global study area, we 'upscaled' each bioclimatic variable from 1 km to 10 km resolution.

Ensemble correlative SDM. Among numerous correlative SDM algorithms, we selected eight that are commonly used and provided by the `Biomod2` package: generalized linear models (GLM, 32), generalized additive models (GAM, 33), generalized boosted models (GBM, 34), multivariate adaptive regression splines (MARS, 35), classification tree analysis (CTA, 36), flexible discriminant analysis (FDA, 37), and maximum entropy (MaxEnt, 38).

Following the methods of Ge et al. (23, p4), for each species, we applied model-specific training and test data sets for presence and pseudo-absence data across various model algorithms for each species. For each presence training set and its corresponding historical climate data, we used the variance inflation factor (VIF) to assess the multicollinearity between the 19 bioclimate variables and the excluded variables with VIF > 4. The remaining variables were used to fit the model to historical data, and the fitted model, combined with future climate values, predicted future habitat ranges. We generated multiple training and test data sets for each algorithm, with each replicate representing a model simulation. Simulations were evaluated using a 10% omission rate, excluding those where more than 10% of the test data appeared in unsuitable habitat to prevent overfitting. We then averaged habitat suitability across all locations for both historical and future conditions. For future predictions (2071–2100, SSP5-8.5), we used validated models that met the omission rate criteria. The model projections (i.e., global projection data and state's projection maps)for each state species are included in SI Dataset 1-4.

Data analysis. We used the ensemble correlative SDM approach described above to predict habitat suitability values (HSV) of species within the United States under historical (1981–2010) and future (2071–2100) climate conditions. For the states that only designated a genus, we selected species with sufficient occurrence records for modelling from all the species native to the state using the USDA Plants database (USDA, NRCS 2023), and then determined the HSVs of the genus by calculating the maximum HSV among all the selected species ($[1, ..., n]$) in each grid cell (i) using:

$$x_i = \max_{j \in [1,\ldots,n]} (x_{i,j}), \qquad [1]$$

where x_i represents the habitat suitability value for the state species in grid cell i. We did the same calculation for the states with multiple species.

For the 64 state flowers, we obtained the habitat suitability value of each grid cell over two time periods within their respective states and compared the distributions of their habitat suitability values under climate change (Fig. 1B). Furthermore, we compared the effects of climate change on the habitat suitability of species within a state using the following three metrics:

1. Change in median (δ)

$$\delta_k = \tilde{x}_{f,k} - \tilde{x}_{h,k}, \qquad [2]$$

$$\delta = \frac{1}{10^4} \sum_{k=1}^{10^4} \delta_k. \qquad [3]$$

We applied the bootstrap method to calculate the difference in median values and the 95% confidence interval. The $\tilde{x}_{h,k}$ and $\tilde{x}_{f,k}$ are the medians of the kth ($k \in [1, ..., 10^4]$, repeat 10^4 times) bootstrap sample of all habitat suitability values under historical (h) and future (f) climate conditions, respectively. The δ_k is the difference in the median of the kth bootstrap sample under climate change; δ is the bootstrap estimate of the median difference between the two climate conditions.

Then,

$$\text{climate effect is} \begin{cases} \text{negative} & \text{if } \delta < 0.05, \\ \text{trivial} & \text{if } -0.05 \leqslant \delta \leqslant 0.05, \\ \text{positive} & \text{if } \delta > 0.05. \end{cases} \qquad [4]$$

DRAFT

2. Spatial variation (CV)

$$\Delta x_i = x_{f,i} - x_{h,i}, \quad [5]$$

$$\mu = \frac{1}{n}\sum_{i=1}^{n} \Delta x_i, \quad [6]$$

$$\sigma = \sqrt{\frac{1}{n}\sum(\Delta x_i - \mu)^2}, \quad [7]$$

$$CV = |\sigma/\mu|. \quad [8]$$

The coefficient of variation (CV) can quantify the extent of spatial variability in habitat suitability across the state. We estimated CV for each state species by calculating the difference in habtat suitability for each grid cell (Δx_i, Eq. 5), and the mean (μ, Eq. 6) and standard deviation (σ, Eq. 7) of these difference values. $CV < 1$ indicates small spatial variation, whereas $CV \geqslant 1$ denotes large spatial variation.

3. Local extinction indicator (θ)

$$\theta = \begin{cases} 1 & \tilde{x}_f \leqslant 0.25 \\ 0 & \tilde{x}_f > 0.25 \end{cases} \quad [9]$$

We define the local extinction indicator (θ) based on the median in habitat suitability values under future climate condition ($\tilde{x}_f$). If $\tilde{x}_f \leqslant 0.25$, we assume that the state flower is likely to face local extinction in this state.

Based on the values of δ, CV, and θ, we categorized the responses of the state species to climate change into six distinct types (Tab. 1):

- A. **Negative** overall effect causes local *extinction*.
- B. **Negative** overall effect *reduces* suitability.
- C. **Trivial** overall effect with *small* spatial variation.
- D. **Trivial** overall effect with *large* spatial variation.
- E. **Positive** overall effect with *small* spatial variation.
- F. **Positive** overall effect with *large* spatial variation.

ACKNOWLEDGMENTS. This research was conducted on the treaty lands and territory of the Six Nations of the Grand River. We recognize that today this gathering place is home to many First Nations, Inuit and Métis peoples. Acknowledging them reminds us of our collective responsibility to the land where we learn and work and to our on-going efforts for reconciliation. This research was funded by a grant from the Canadian Natural Sciences and Engineering Reseach Council (NSERC) to JAN. YZ was supported by a China Scholarship Council fellowship.

1. GJ Nord, *Official State Flowers and Trees.* (Trafford Publishing, Bloomington, Indiana), (2014).
2. List of U.S. state and territory flowers (https://en.wikipedia.org/wiki/List_of_U.S._state_and_territory_flowers) (2023) (Accessed 12/04/2023).
3. List of U.S. state insects (https://simple.wikipedia.org/wiki/List_of_U.S._state_insects) (2023) (Accessed 12/04/2023).
4. List of state flowers and how they were chosen (https://www.jacksonandperkins.com/state-flowers-list-history/a/state-flowers-list-history/#:~:text=The%20diverse%20array%20of%20state,economic%20contributions%2C%20and%20regional%20identity.) (2024) (Accessed on 07/23/2024).
5. M Pasikowska-Schnass, The impact of climate change on cultural heritage, (European Parliamentary Research Service), Technical report (2024).
6. Syringa vulgaris—wikipedia (https://en.wikipedia.org/wiki/Syringa_vulgaris#cite_note-rushforth-1) (2024) (Accessed on 07/25/2024).
7. JM Alexander, JM Levine, Earlier phenology of a nonnative plant increases impacts on native competitors. *Proc. Natl. Acad. Sci.* **116**, 6199–6204 (2019).
8. MA Zettlemoyer, EH Schultheis, JA Lau, Phenology in a warming world: differences between native and non-native plant species. *Ecol. letters* **22**, 1253–1263 (2019).
9. Scenic drives northern mn (https://visitwarroad.com/scenic-drives/#:~:text=The%20Wildflower%20Route%20on%20Highway,along%20the%2075%2Dmile%20stretch.) (2024) (Accessed on 07/24/2024).
10. JA Newman, G Varner, S Linquist, *Defending Biodiversity: Environmental Science and Ethics.* (Cambridge University Press), (2017).
11. PK Rai, J Singh, Invasive alien plant species: Their impact on environment, ecosystem services and human health. *Ecol. indicators* **111**, 106020 (2020).
12. L Wootton, et al., When invasive species have benefits as well as costs: managing carex kobomugi (asiatic sand sedge) in new jersey's coastal dunes. *Biol. Invasions* **7**, 1017–1027 (2005).
13. M Kourantidou, et al., Invasive alien species as simultaneous benefits and burdens: trends, stakeholder perceptions and management. *Biol. Invasions* **24**, 1905–1926 (2022).
14. HA Hager, GD Ryan, HM Kovacs, JA Newman, Effects of elevated co_2 on photosynthetic traits of native and invasive c3 and c4 grasses. *BMC ecology* **16**, 1–13 (2016).
15. Time to change the state flower from cherokee rose to a native plant (https://georgiarecorder.com/2024/02/26/time-to-change-the-state-flower-from-cherokee-rose-to-a-native-plant/) (2024) (Accessed on 07/30/2024).
16. Now is your chance to change the state flower of georgia to a native species! (https://www.nurturenativenature.com/post/now-is-your-chance-to-change-the-state-flower-of-georgia-to-a-native-species) (2024) (Accessed on 07/30/2024).
17. Georgia senate bill 518 (https://www.legis.ga.gov/legislation/67159) (2024) (Accessed on 07/30/2024).
18. Many official state flowers aren't native plants (https://www.csmonitor.com/The-Culture/Gardening/diggin-it/2011/0908/Many-official-state-flowers-aren-t-native-plants) (2024) (Accessed on 07/30/2024).
19. Goldenrod is the rightful alabama state flower (https://www.change.org/p/goldenrod-is-the-rightful-alabama-state-flower) (2024) (Accessed on 07/30/2024).
20. Cypripedium reginae (https://en.wikipedia.org/wiki/Cypripedium_reginae) (2024) (Accessed on 07/30/2024).
21. Karner blue (https://en.wikipedia.org/wiki/Karner_blue) (2024) (Accessed on 07/30/2024).
22. S Chamberlain, et al., *rgbif: Interface to the Global Biodiversity Information Facility API*, (2023) R package version 3.7.8.
23. X Ge, CK Griswold, JA Newman, Robust species distribution predictions of predator and prey responses to climate change. *J. Biogeogr.* (2024).
24. A Zizka, et al., Coordinatecleaner: Standardized cleaning of occurrence records from biological collection databases. *Methods Ecol. Evol.* **10**, 744–751 (2019).
25. R Kindt, R Coe, *Tree diversity analysis. A manual and software for common statistical methods for ecological and biodiversity studies* (World Agroforestry Centre (ICRAF)), (2005) ISBN 92-9059-179-X.
26. M Barbet-Massin, F Jiguet, CH Albert, W Thuiller, Selecting pseudo-absences for species distribution models: how, where and how many? *Methods Ecol. Evol.* **3**, 327–338 (2012).
27. W Thuiller, et al., *biomod2: Ensemble Platform for Species Distribution Modeling*, (2023) R package version 4.2-3.
28. R Valavi, J Elith, JJ Lahoz-Monfort, G Guillera-Arroita, blockCV: An R package for generating spatially or environmentally separated folds for k-fold cross-validation of species distribution models. *Methods Ecol. Evol.* **10**, 225–232 (2019).
29. DN Karger, et al., Climatologies at high resolution for the earth's land surface areas. *Sci. data* **4**, 1–20 (2017).
30. G Flato, et al., Evaluation of climate models in *Climate change 2013: the Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* (Cambridge University Press), pp. 741–866 (2014).
31. S Kamworapan, C Surussavadee, Evaluation of CMIP5 global climate models for simulating climatological temperature and precipitation for Southeast Asia. *Adv. Meteorol.* **2019**, 1–18 (2019).
32. P McCullagh, JA Nelder, *Generalized linear models.* (Chapman and Hall), 2 edition, (1989).
33. T Hastie, R Tibshirani, Generalized additive models. *Stat. Sci.* **1**, 297–310 (1986).
34. G Ridgeway, The state of boosting. *Comput. Sci. Stat.* pp. 172–181 (1999).
35. JH Friedman, Multivariate adaptive regression splines. *The Annals Stat.* **19**, 1–67 (1991).
36. L Breiman, *Classification and regression trees.* (Routledge, New York), 1 edition, (1984).
37. T Hastie, R Tibshirani, A Buja, Flexible discriminant analysis by optimal scoring. *J. Am. Stat. Assoc.* **89**, 1255–1270 (1994).
38. SJ Phillips, RP Anderson, RE Schapire, Maximum entropy modeling of species geographic distributions. *Ecol. Model.* **190**, 231–259 (2006).

DRAFT