

Supplementary Information

Asymmetric impacts of climate change on thermal habitat suitability for inland lake fishes

Xu et al.

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Supplementary Discussion
Supplementary Figures 1-25

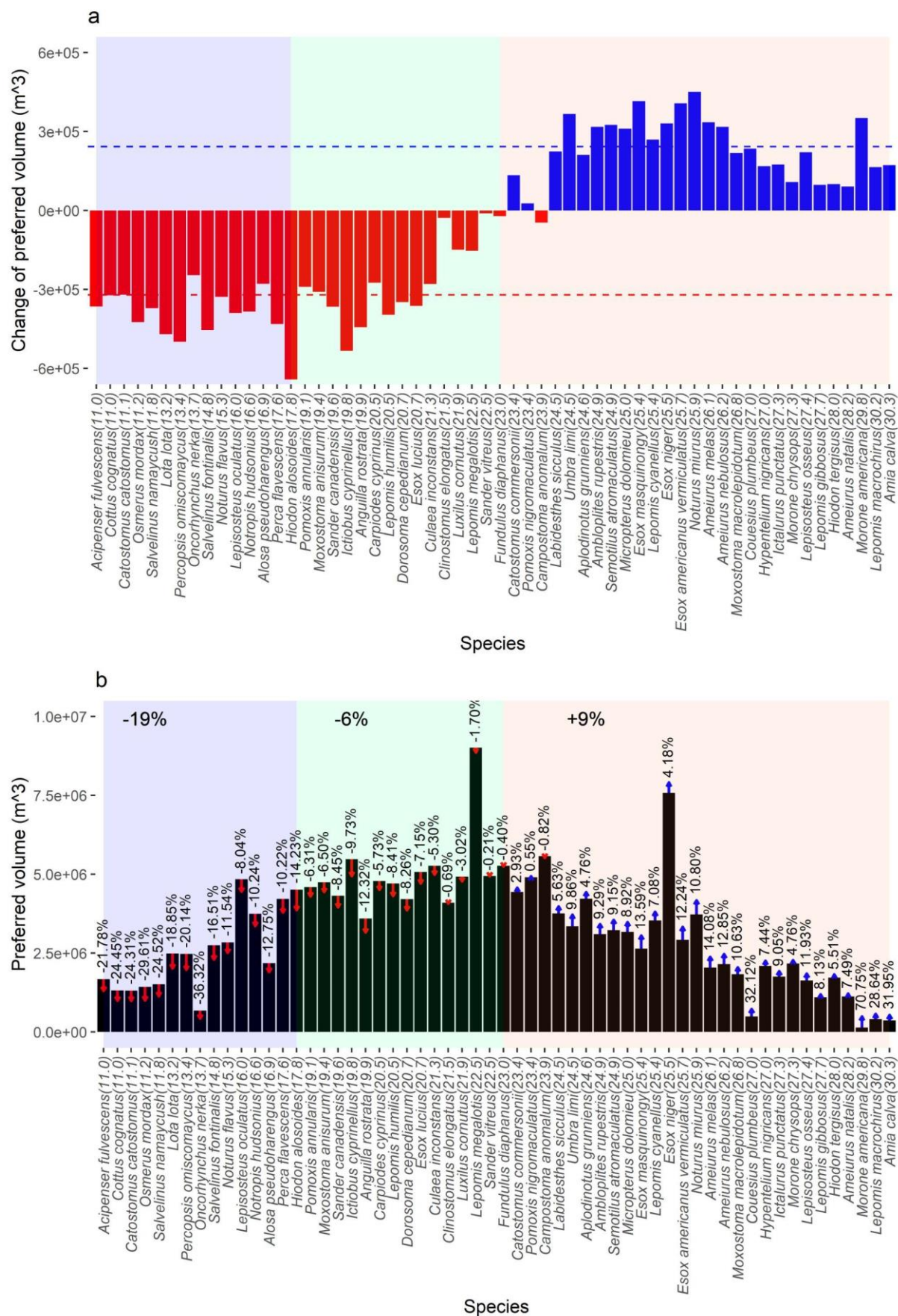
Supplementary Discussion:

Hypsometry data are available for 4,462 of the 12,688 study lakes (approximately 35%). We have conducted the analysis comparing changes in preferred habitat volume with changes in preferred habitat days for these lakes. Similar to the preferred days, the decrease in preferred volumes for species experiencing a decline was more pronounced than the increase for those experiencing a rise. However, as anticipated, the disparity in the change of preferred volumes between warmer- and cooler-water species was more subdued, featuring an average decrease of 320,292 m³ versus an average increase of 242,553 m³—a 1.3 times difference (Supplementary Figure 1a). This contrasted with the change in preferred days with an average reduction of 5.5 days versus an average increase of 2.9 days—a 1.9 times difference (Supplementary Figure 2a). This outcome aligns with expectations, as warmer-water species typically occupy shallower and thus broader areas.

Additionally, we found that for some cool-water species, while preferred days increased, preferred volumes decreased. This occurs because warming shifts these species' preferred temperatures deeper, leading to a decrease in volume despite an increase in days.

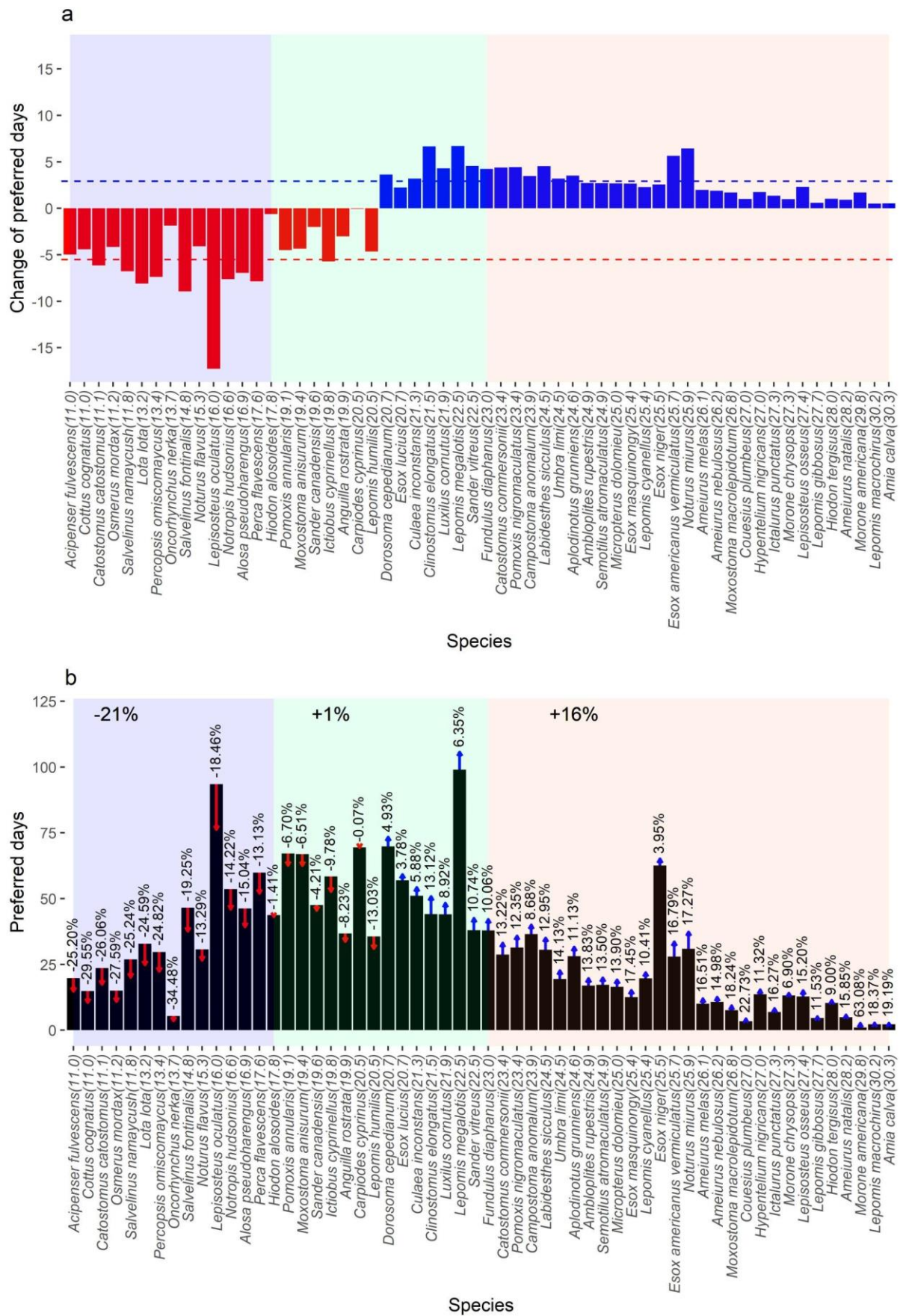
In this region, cool-water species generally have a greater amount of preferred habitat compared to cold- and warm-water species, whether measured by volume or days (Supplementary Figures 1b, 2b and 3). Cold-water species experienced a proportionally larger habitat loss than the habitat gains observed for warm-water species (Supplementary Figures 1b, 2b and 3).

Supplementary Figures:

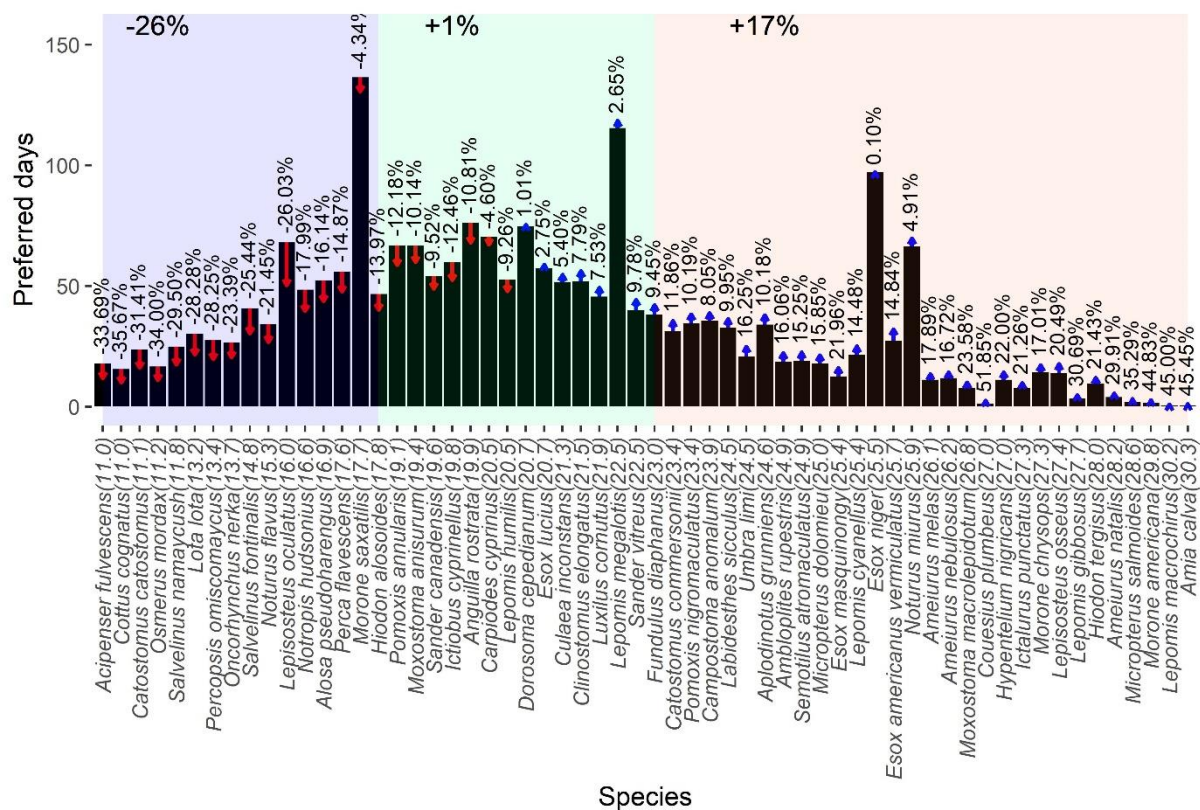


Supplementary Figure 1: Change of species' averaged preferred volumes for lakes with hypsography information between 1980-2000 and 2001-2021. The numbers in parentheses on the

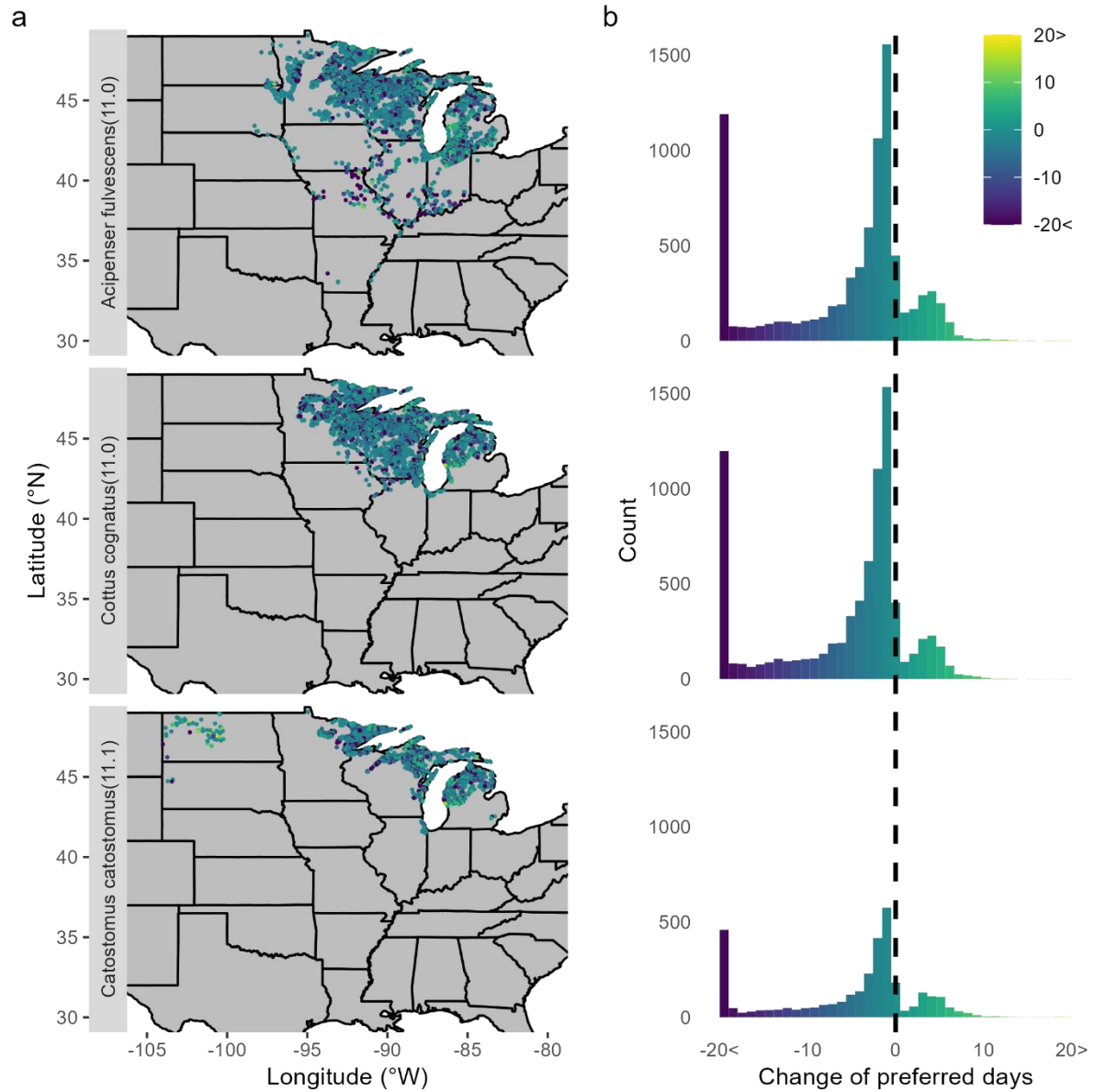
x-axis indicate the final temperature preferendum of the corresponding species. Species are categorized by final temperature preferendum, with those below 19°C classified as cold (blue shaded background), between 19°C and 23°C as cool (spring-green shaded background), and above 23°C as warm (pink-orange shaded background). (a) The dashed lines signify the average change for species that gained or lost days, respectively, with the blue line indicating the mean increase and the red line indicating the mean decrease in preferred volume among species that gained or lost preferred habitat volume, respectively. (b) The black bars represent the average annual preferred volume for each species in 1980-2000. The red and blue arrows represent the change of preferred volume in year 2001-2021 compared to 1980-2000. The percentages above each bar show the proportion of change, while the percentages in the upper-left corner of each shaded area reflect the average change among species within the corresponding thermal guild.



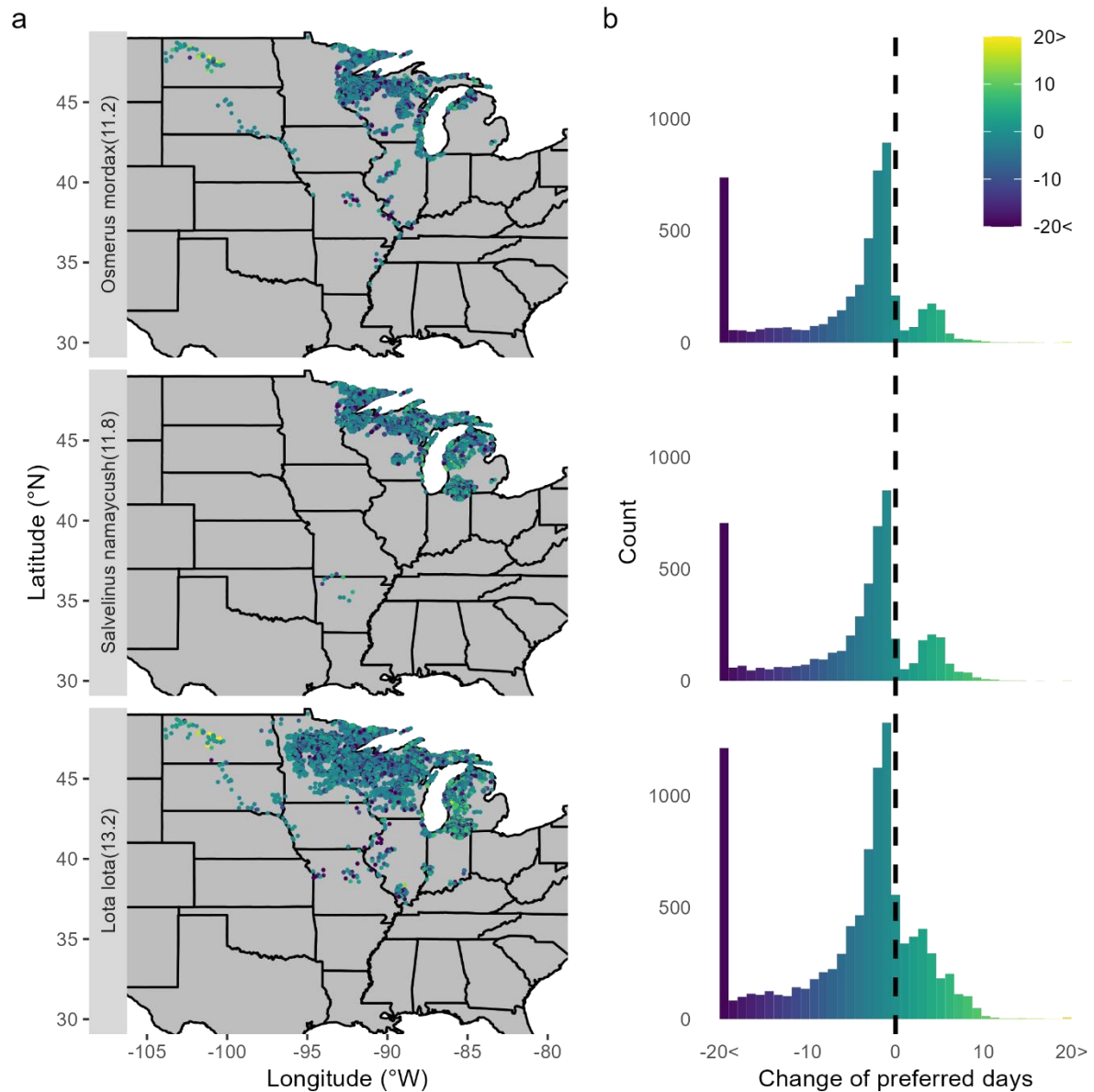
temperature preferendum, with those below 19°C classified as cold (blue shaded background), between 19°C and 23°C as cool (spring-green shaded background), and above 23°C as warm (pink-orange shaded background). (a) The dashed lines signify the average change for species that gained or lost days, respectively, with the blue line indicating the mean increase and the red line indicating the mean decrease in preferred days among species that gained or lost preferred days, respectively. (b) The black bars represent the average annual preferred days for each species in 1980-2000. The red and blue arrows represent the change of preferred days in year 2001-2021 compared to 1980-2000. The percentages above each bar show the proportion of change, while the percentages in the upper-left corner of each shaded area reflect the average change among species within the corresponding thermal guild.



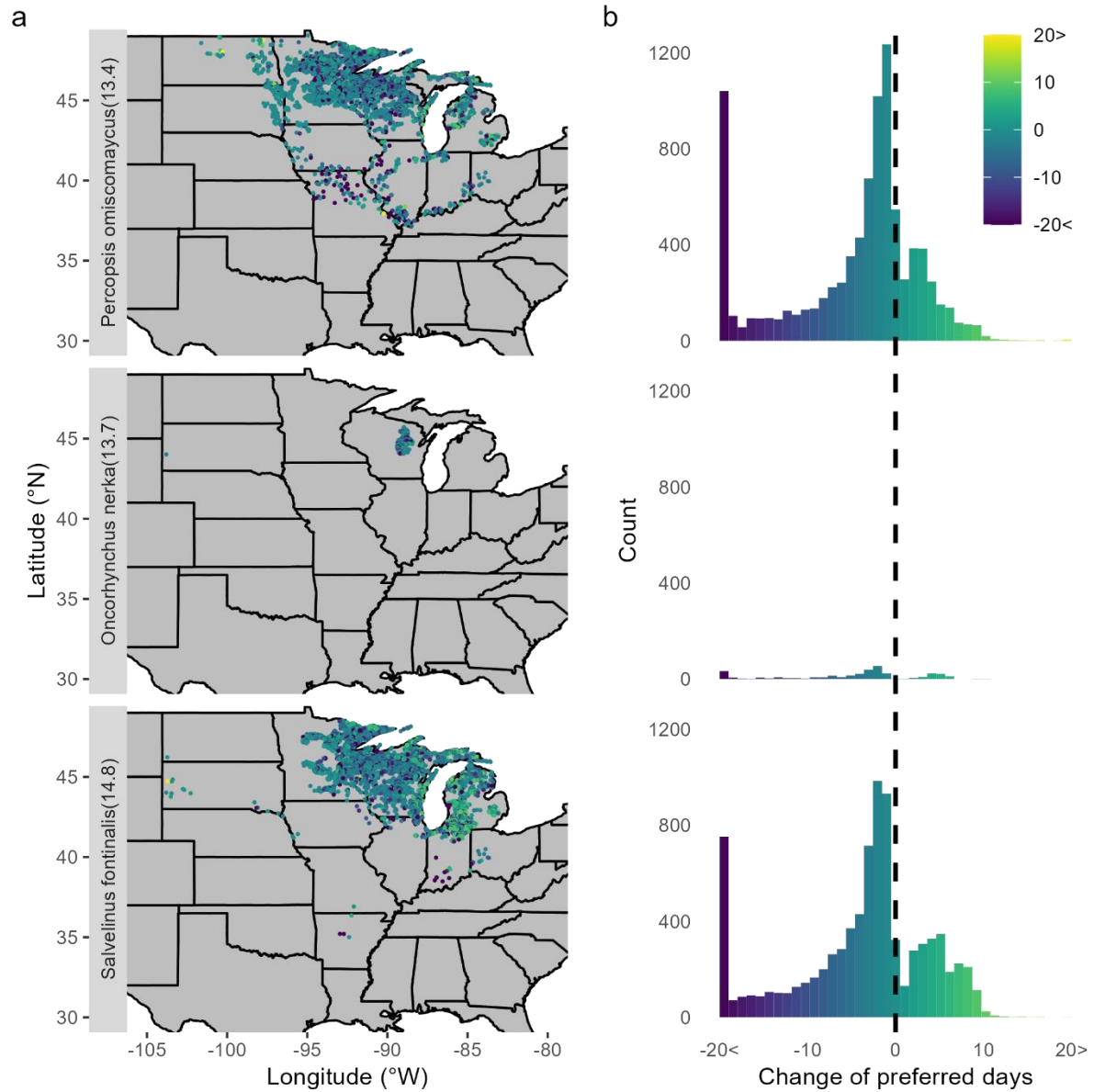
Supplementary Figure 3: **Change of species' averaged preferred days for all lakes between 1980-2000 and 2001-2021.** The numbers in parentheses on the x-axis indicate the final temperature preferendum of the corresponding species. Species are categorized by final temperature preferendum, with those below 19°C classified as cold (blue shaded background), between 19°C and 23°C as cool (spring-green shaded background), and above 23°C as warm (pink-orange shaded background). The black bars represent the average annual preferred volume for each species in 1980-2000. The red and blue arrows represent the change of preferred volume in year 2001-2021 compared to 1980-2000. The percentages above each bar show the proportion of change, while the percentages in the upper-left corner of each shaded area reflect the average change among species within the corresponding thermal guild.



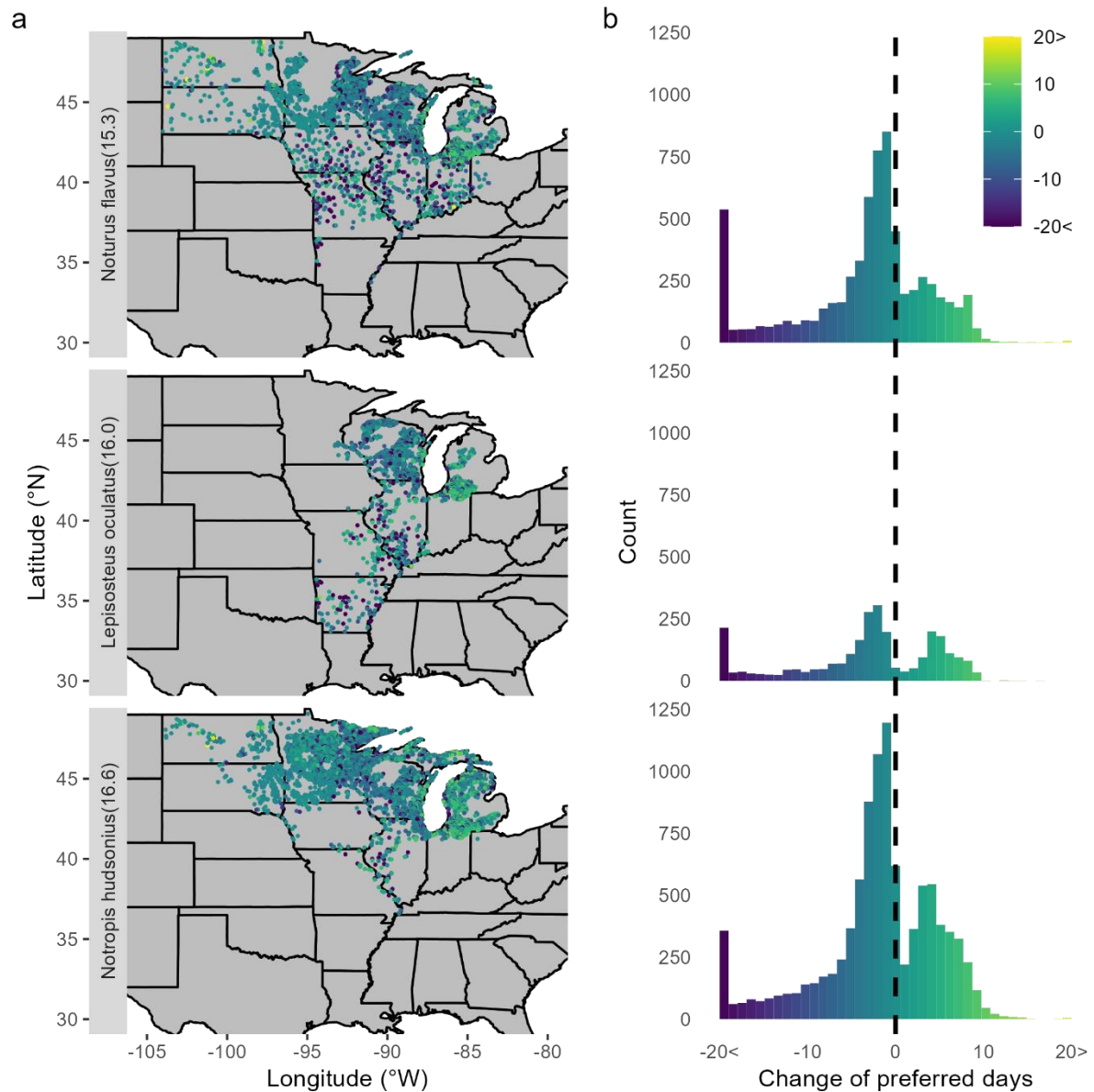
Supplementary Figure 4: **Spatial and frequency distribution of the change in preferred days for *Acipenser fulvescens*, *Cottus cognatus* and *Catostomus catostomus*.** Panel (a) presents maps of the geographic distribution of changes in preferred days for each species from 1980–2000 to 2001–2021. Panel (b) displays histograms for each species, with each bar representing the count of lakes experiencing a specified change in preferred days. The color of the points in panel (a) and bars in panel (b) corresponds to the changes in preferred days as indicated by the color palette legend.



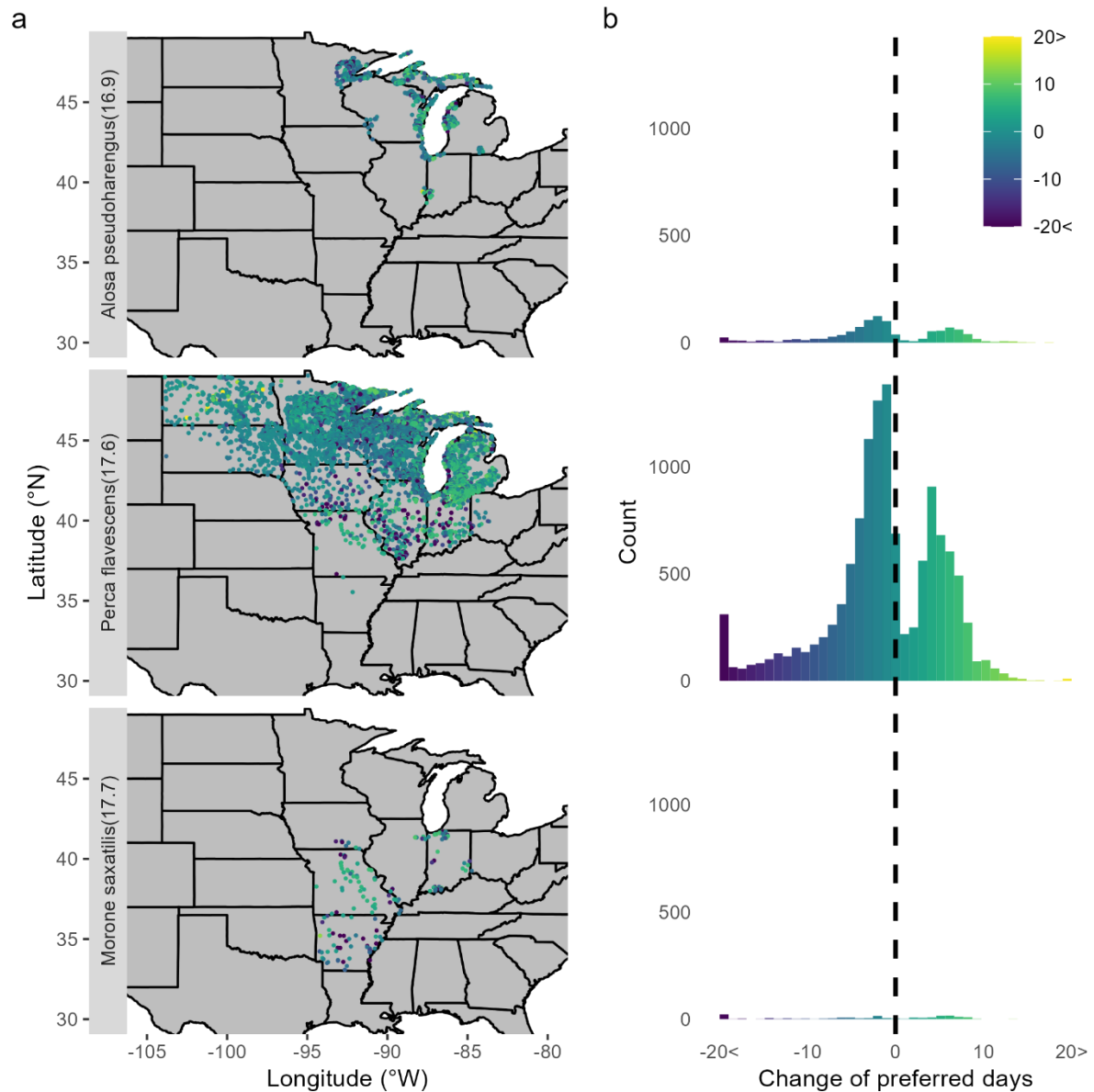
Supplementary Figure 5: **Spatial and frequency distribution of the change in preferred days for *Osmerus mordax*, *Salvelinus namaycush* and *Lota lota*.** Panel (a) presents maps of the geographic distribution of changes in preferred days for each species from 1980–2000 to 2001–2021. Panel (b) displays histograms for each species, with each bar representing the count of lakes experiencing a specified change in preferred days. The color of the points in panel (a) and bars in panel (b) corresponds to the changes in preferred days as indicated by the color palette legend.



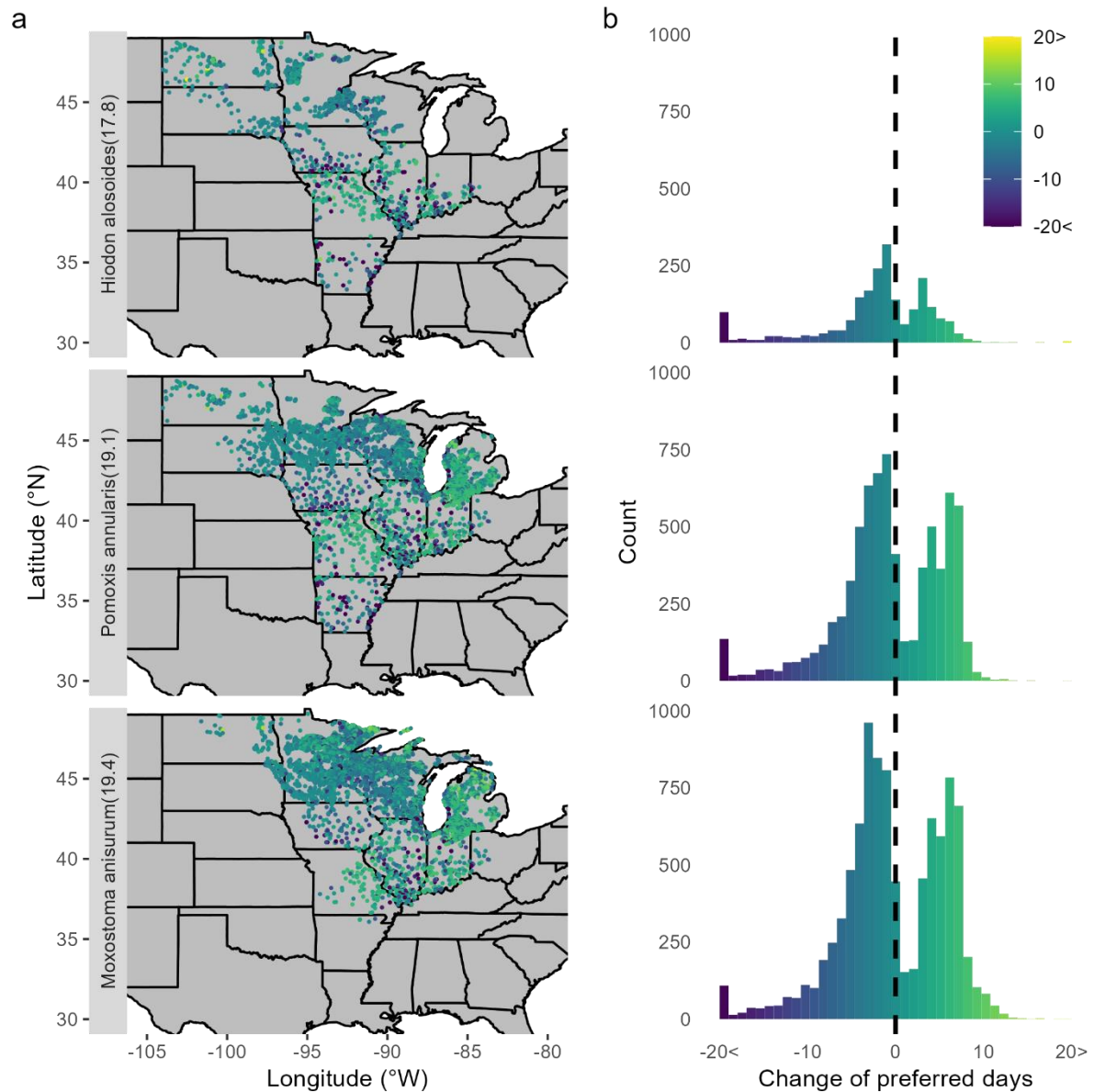
Supplementary Figure 6: **Spatial and frequency distribution of the change in preferred days for *Percopsis omiscomaycus*, *Oncorhynchus nerka* and *Salvelinus fontinalis*.** Panel (a) presents maps of the geographic distribution of changes in preferred days for each species from 1980–2000 to 2001–2021. Panel (b) displays histograms for each species, with each bar representing the count of lakes experiencing a specified change in preferred days. The color of the points in panel (a) and bars in panel (b) corresponds to the changes in preferred days as indicated by the color palette legend.



Supplementary Figure 7: **Spatial and frequency distribution of the change in preferred days for *Noturus flavus*, *Lepisosteus oculatus* and *Notropis hudsonius*.** Panel (a) presents maps of the geographic distribution of changes in preferred days for each species from 1980–2000 to 2001–2021. Panel (b) displays histograms for each species, with each bar representing the count of lakes experiencing a specified change in preferred days. The color of the points in panel (a) and bars in panel (b) corresponds to the changes in preferred days as indicated by the color palette legend.

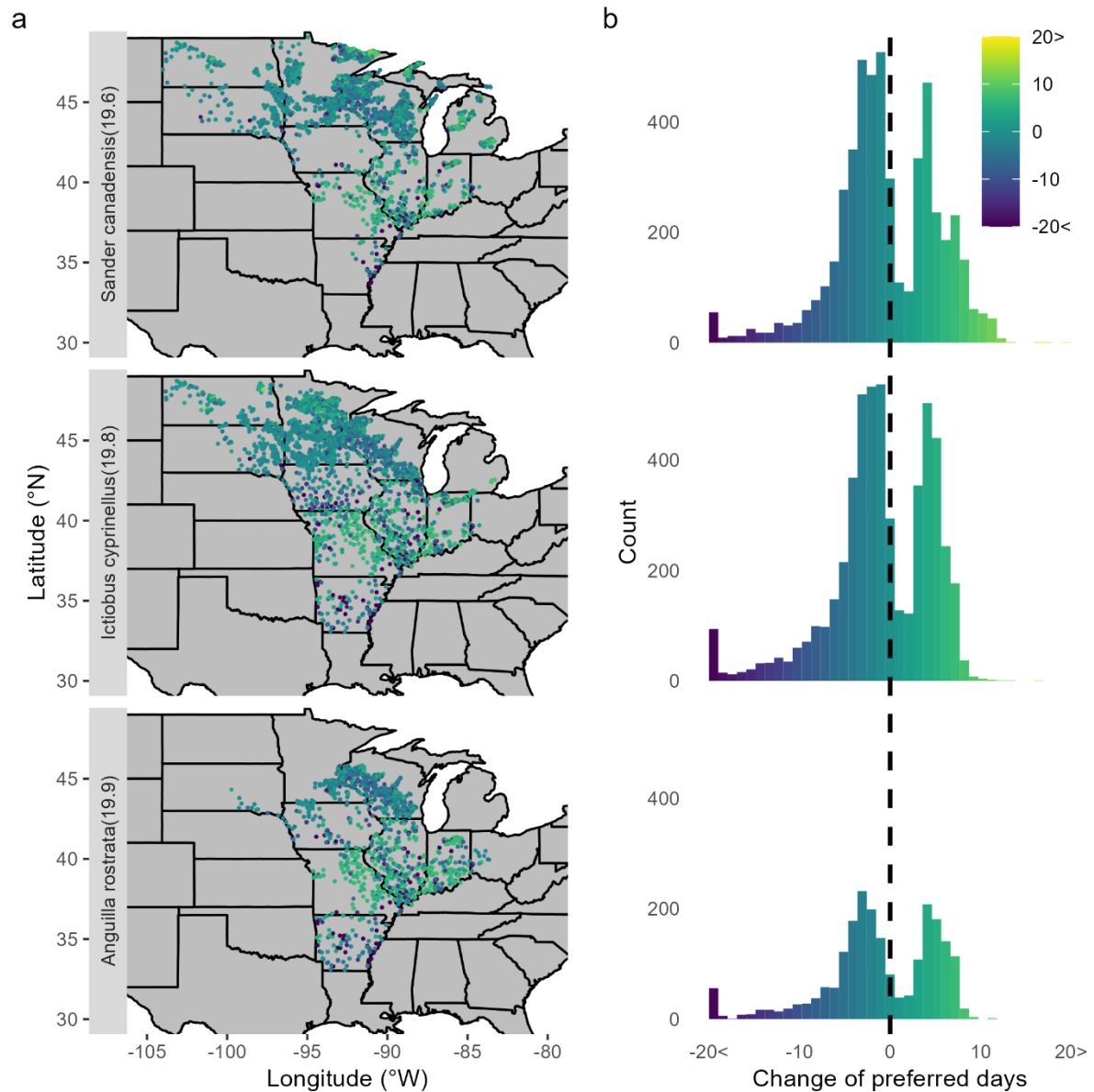


Supplementary Figure 8: **Spatial and frequency distribution of the change in preferred days for *Alosa pseudoharengus*, *Perca flavescens* and *Morone saxatilis*.** Panel (a) presents maps of the geographic distribution of changes in preferred days for each species from 1980–2000 to 2001–2021. Panel (b) displays histograms for each species, with each bar representing the count of lakes experiencing a specified change in preferred days. The color of the points in panel (a) and bars in panel (b) corresponds to the changes in preferred days as indicated by the color palette legend.



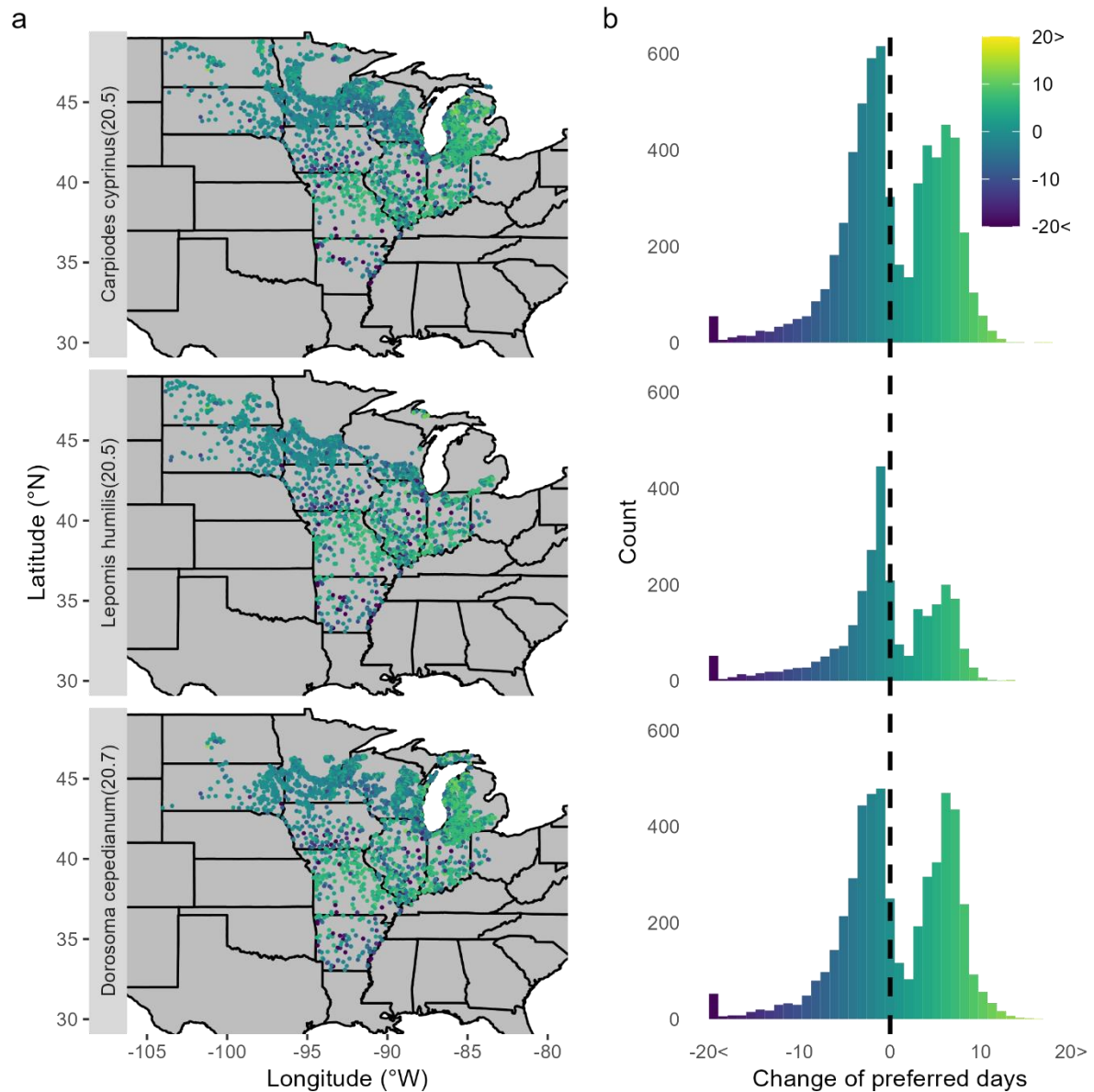
Supplementary Figure 9: **Spatial and frequency distribution of the change in preferred days for *Hiodon alosoides*, *Pomoxis annularis* and *Moxostoma anisurum*.** Panel (a) presents maps of the geographic distribution of changes in preferred days for each species from 1980–2000 to 2001–2021.

Panel (b) displays histograms for each species, with each bar representing the count of lakes experiencing a specified change in preferred days. The color of the points in panel (a) and bars in panel (b) corresponds to the changes in preferred days as indicated by the color palette legend.



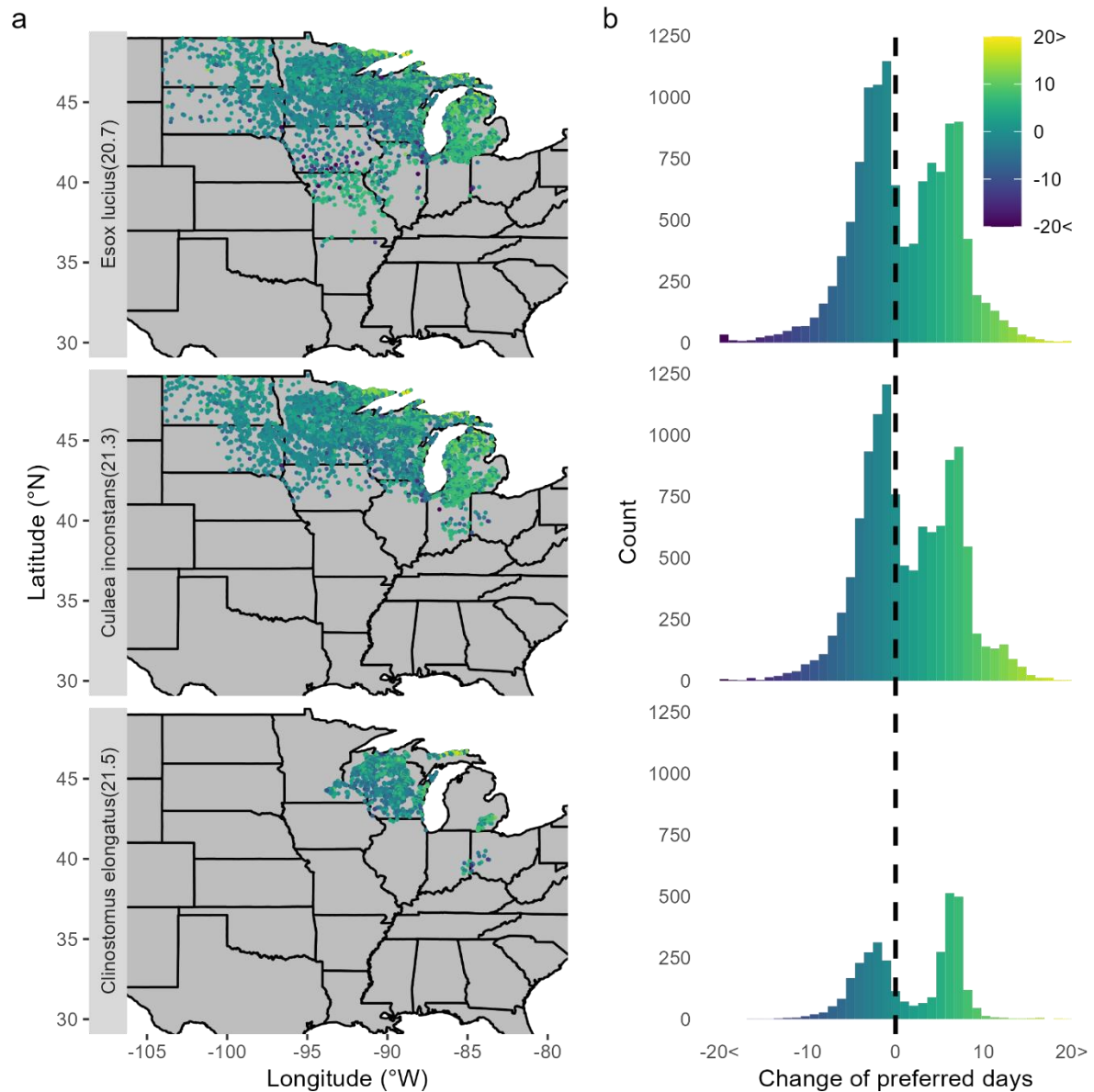
Supplementary Figure 10: **Spatial and frequency distribution of the change in preferred days for *Sander canadensis*, *Ictiobus cyprinellus* and *Anguilla rostrata*.** Panel (a) presents maps of the geographic distribution of changes in preferred days for each species from 1980–2000 to 2001–2021.

Panel (b) displays histograms for each species, with each bar representing the count of lakes experiencing a specified change in preferred days. The color of the points in panel (a) and bars in panel (b) corresponds to the changes in preferred days as indicated by the color palette legend.

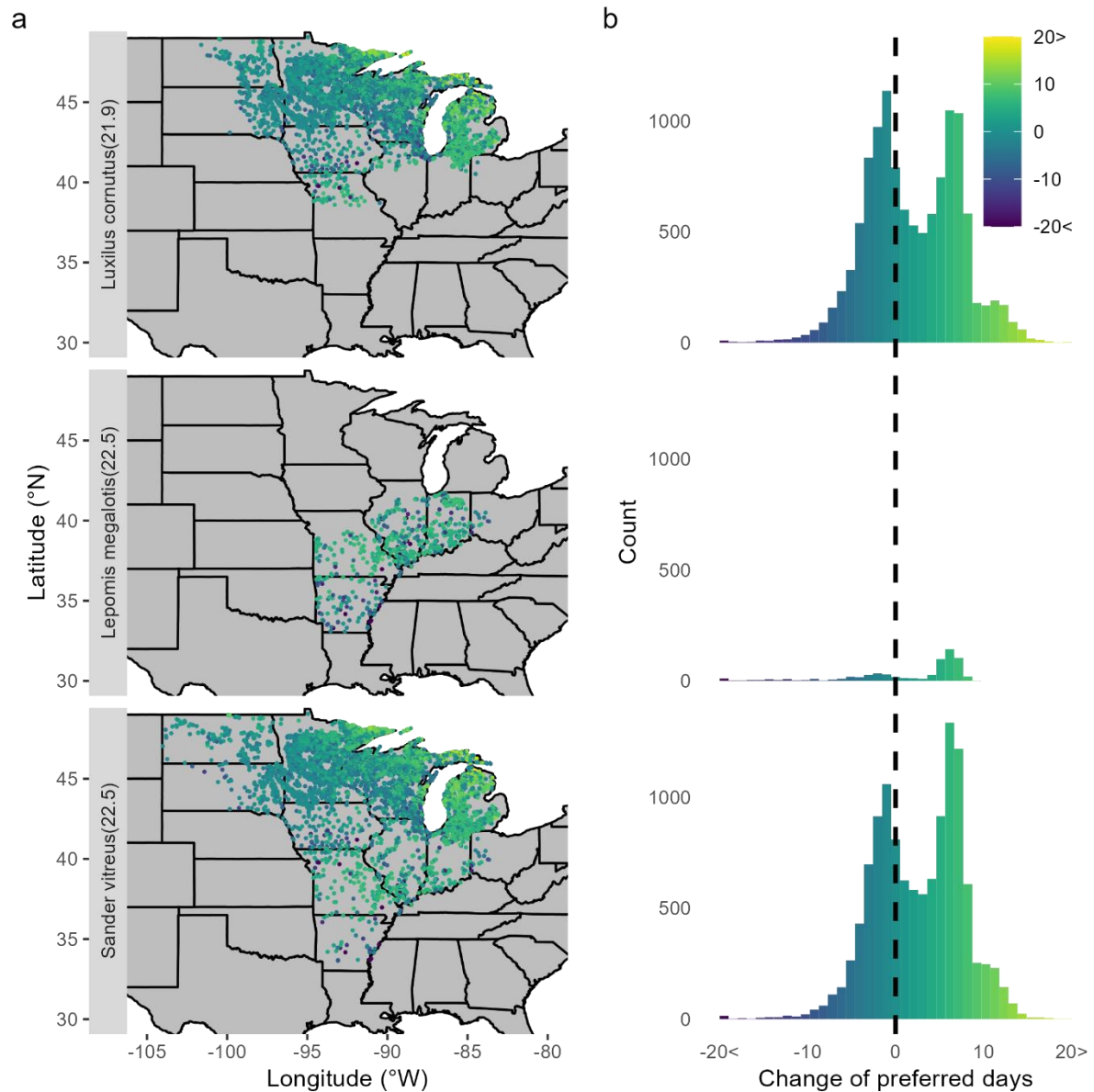


Supplementary Figure 11: **Spatial and frequency distribution of the change in preferred days for *Carpiodes cyprinus*, *Lepomis humilis* and *Dorosoma cepedianum*.** Panel (a) presents maps of the geographic distribution of changes in preferred days for each species from 1980–2000 to 2001–2021.

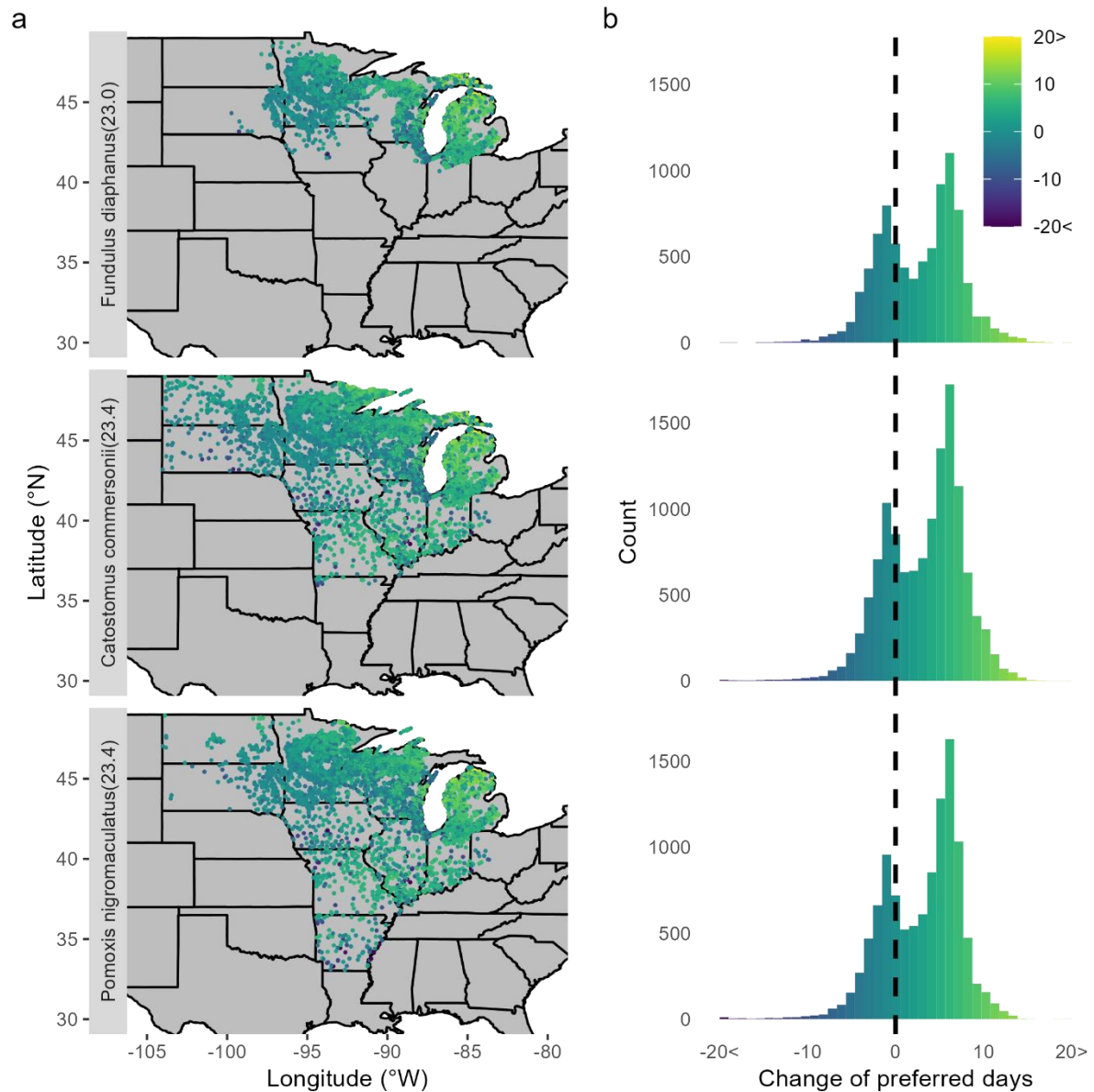
Panel (b) displays histograms for each species, with each bar representing the count of lakes experiencing a specified change in preferred days. The color of the points in panel (a) and bars in panel (b) corresponds to the changes in preferred days as indicated by the color palette legend.



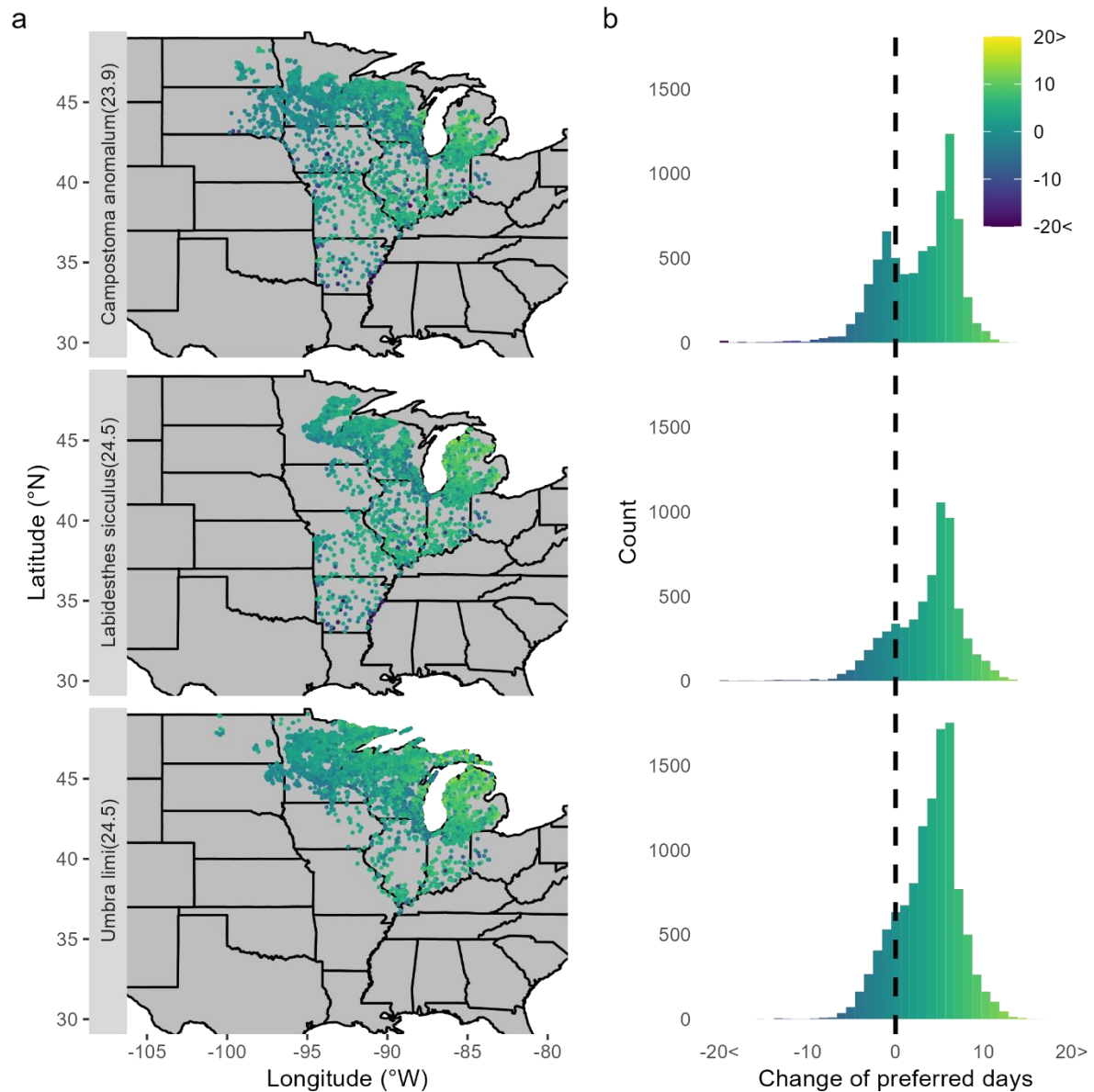
Supplementary Figure 12: **Spatial and frequency distribution of the change in preferred days for *Esox lucius*, *Culaea inconstans* and *Clinostomus elongatus*.** Panel (a) presents maps of the geographic distribution of changes in preferred days for each species from 1980–2000 to 2001–2021. Panel (b) displays histograms for each species, with each bar representing the count of lakes experiencing a specified change in preferred days. The color of the points in panel (a) and bars in panel (b) corresponds to the changes in preferred days as indicated by the color palette legend.



Supplementary Figure 13: **Spatial and frequency distribution of the change in preferred days for *Luxilus cornutus*, *Lepomis megalotis* and *Sander vitreus*.** Panel (a) presents maps of the geographic distribution of changes in preferred days for each species from 1980–2000 to 2001–2021. Panel (b) displays histograms for each species, with each bar representing the count of lakes experiencing a specified change in preferred days. The color of the points in panel (a) and bars in panel (b) corresponds to the changes in preferred days as indicated by the color palette legend.

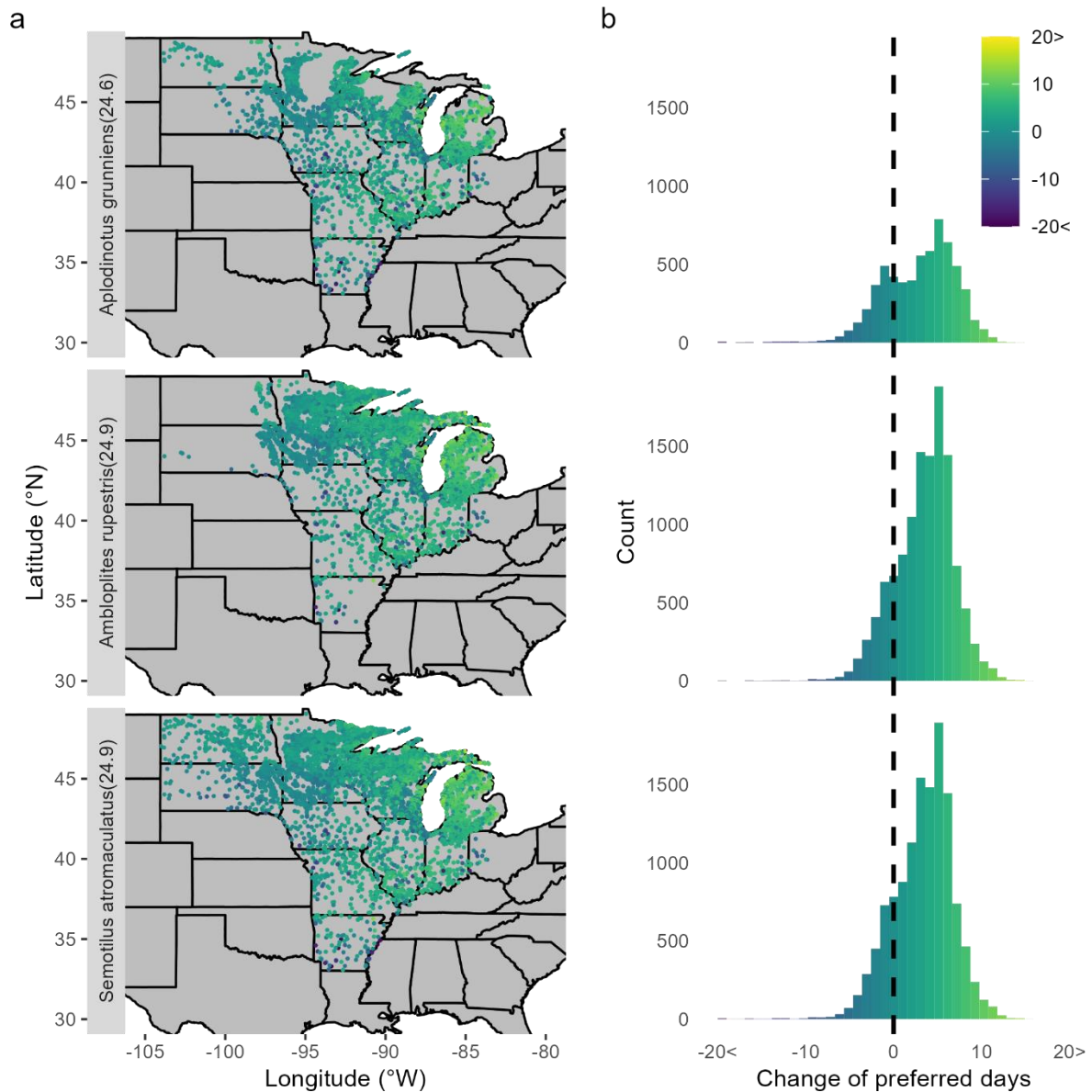


Supplementary Figure 14: **Spatial and frequency distribution of the change in preferred days for *Fundulus diaphanus*, *Pomoxis nigromaculatus* and *Catostomus commersonii*.** Panel (a) presents maps of the geographic distribution of changes in preferred days for each species from 1980–2000 to 2001–2021. Panel (b) displays histograms for each species, with each bar representing the count of lakes experiencing a specified change in preferred days. The color of the points in panel (a) and bars in panel (b) corresponds to the changes in preferred days as indicated by the color palette legend.

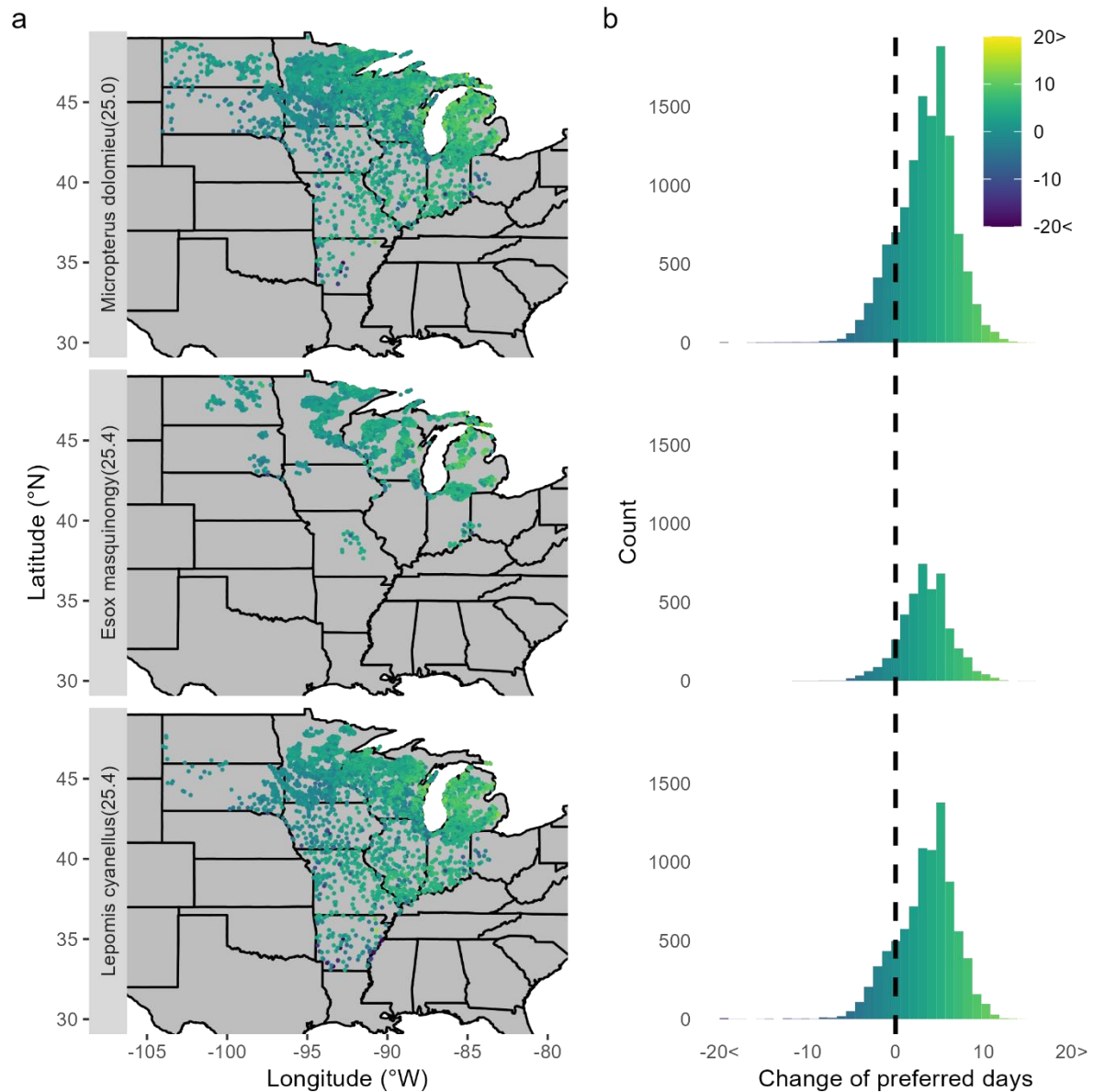


Supplementary Figure 15: **Spatial and frequency distribution of the change in preferred days for *Campostoma anomalum*, *Labidesthes sicculus* and *Umbra limi*.** Panel (a) presents maps of the geographic distribution of changes in preferred days for each species from 1980–2000 to 2001–2021.

Panel (b) displays histograms for each species, with each bar representing the count of lakes experiencing a specified change in preferred days. The color of the points in panel (a) and bars in panel (b) corresponds to the changes in preferred days as indicated by the color palette legend.

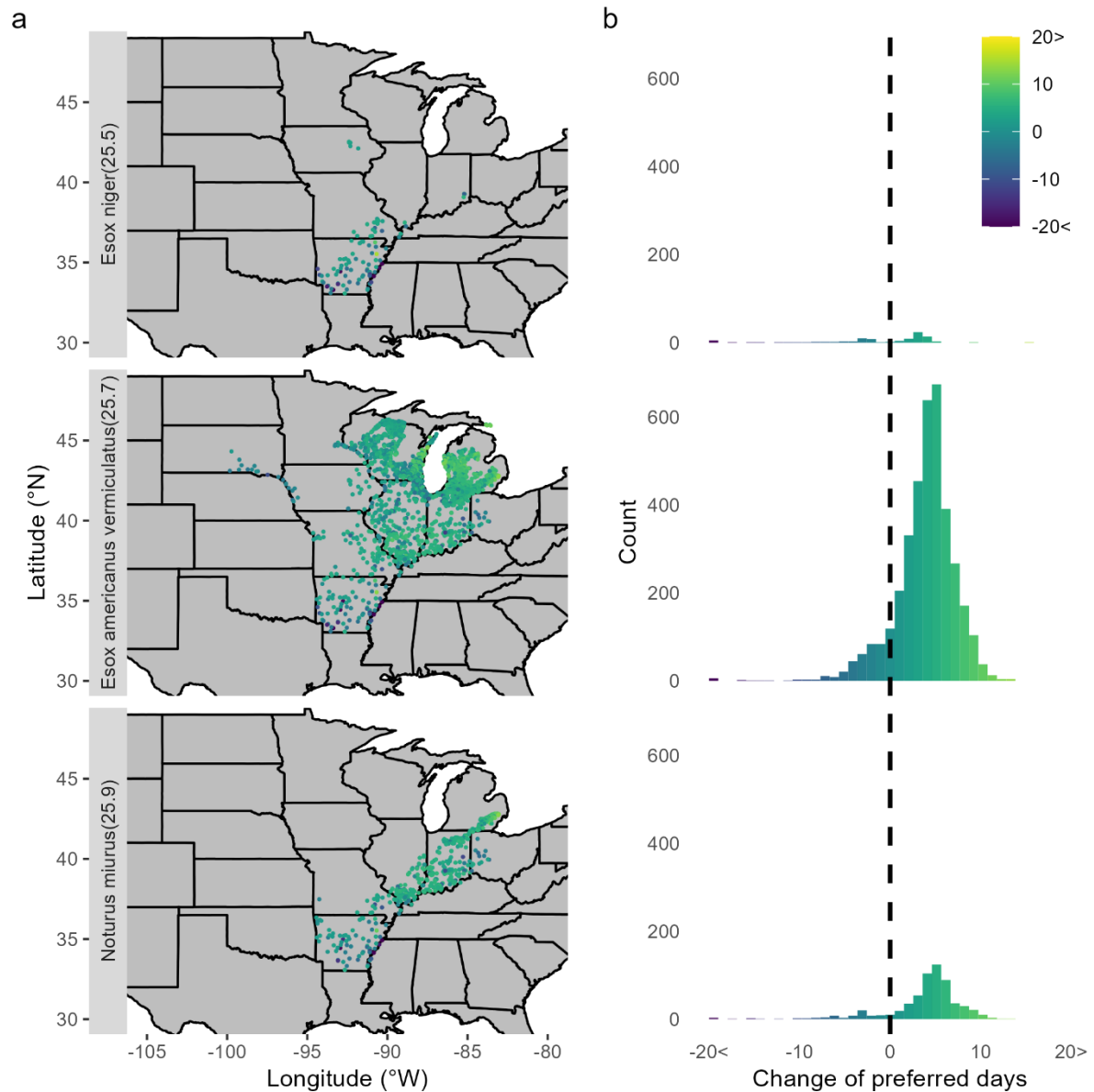


Supplementary Figure 16: **Spatial and frequency distribution of the change in preferred days for *Aplothinotus grunniens*, *Ambloplites rupestris* and *Semotilus atromaculatus*.** Panel (a) presents maps of the geographic distribution of changes in preferred days for each species from 1980–2000 to 2001–2021. Panel (b) displays histograms for each species, with each bar representing the count of lakes experiencing a specified change in preferred days. The color of the points in panel (a) and bars in panel (b) corresponds to the changes in preferred days as indicated by the color palette legend.



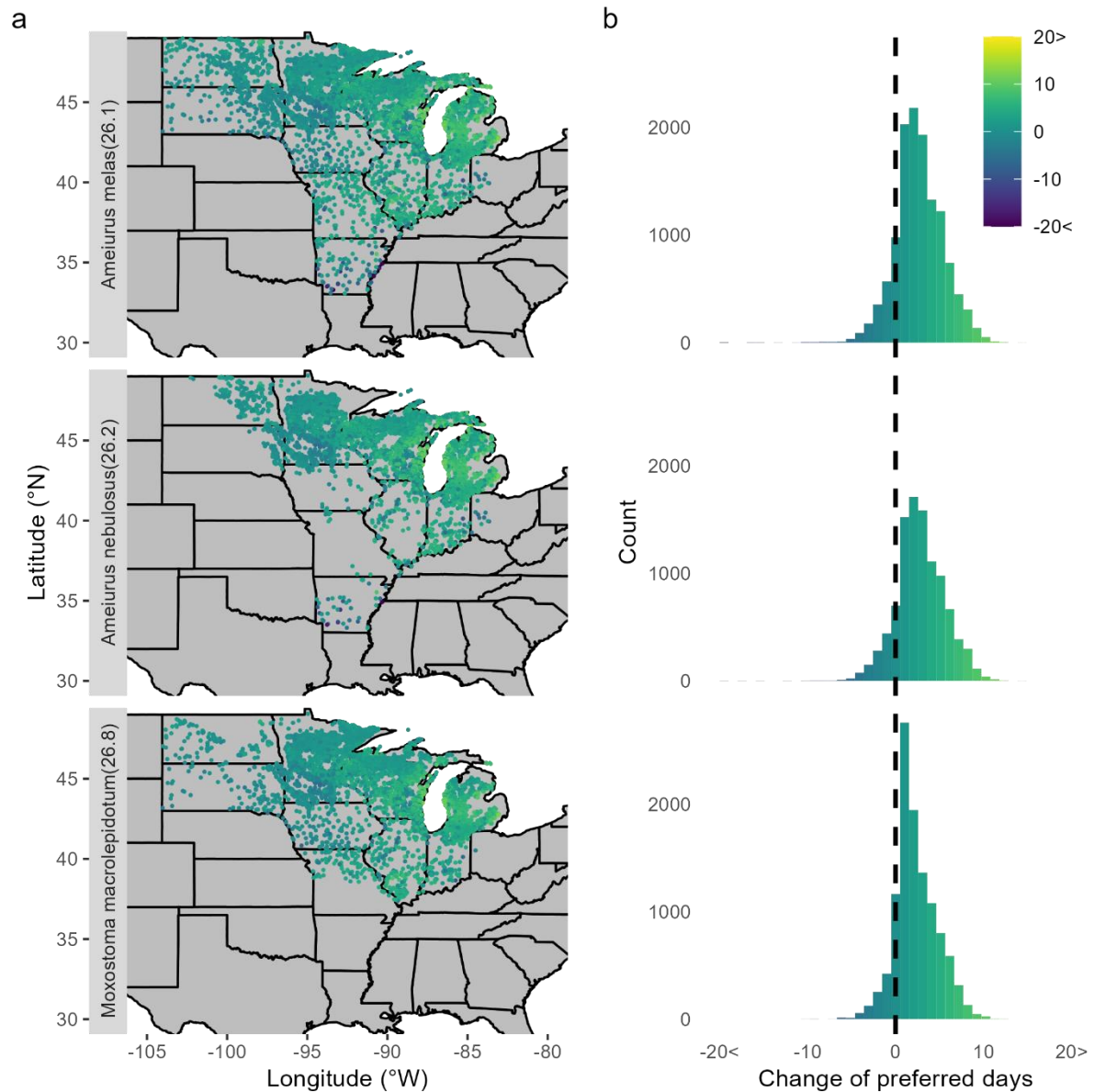
Supplementary Figure 17: **Spatial and frequency distribution of the change in preferred days for *Micropterus dolomieu*, *Esox masquinongy* and *Lepomis cyanellus*.** Panel (a) presents maps of the geographic distribution of changes in preferred days for each species from 1980–2000 to 2001–2021.

Panel (b) displays histograms for each species, with each bar representing the count of lakes experiencing a specified change in preferred days. The color of the points in panel (a) and bars in panel (b) corresponds to the changes in preferred days as indicated by the color palette legend.

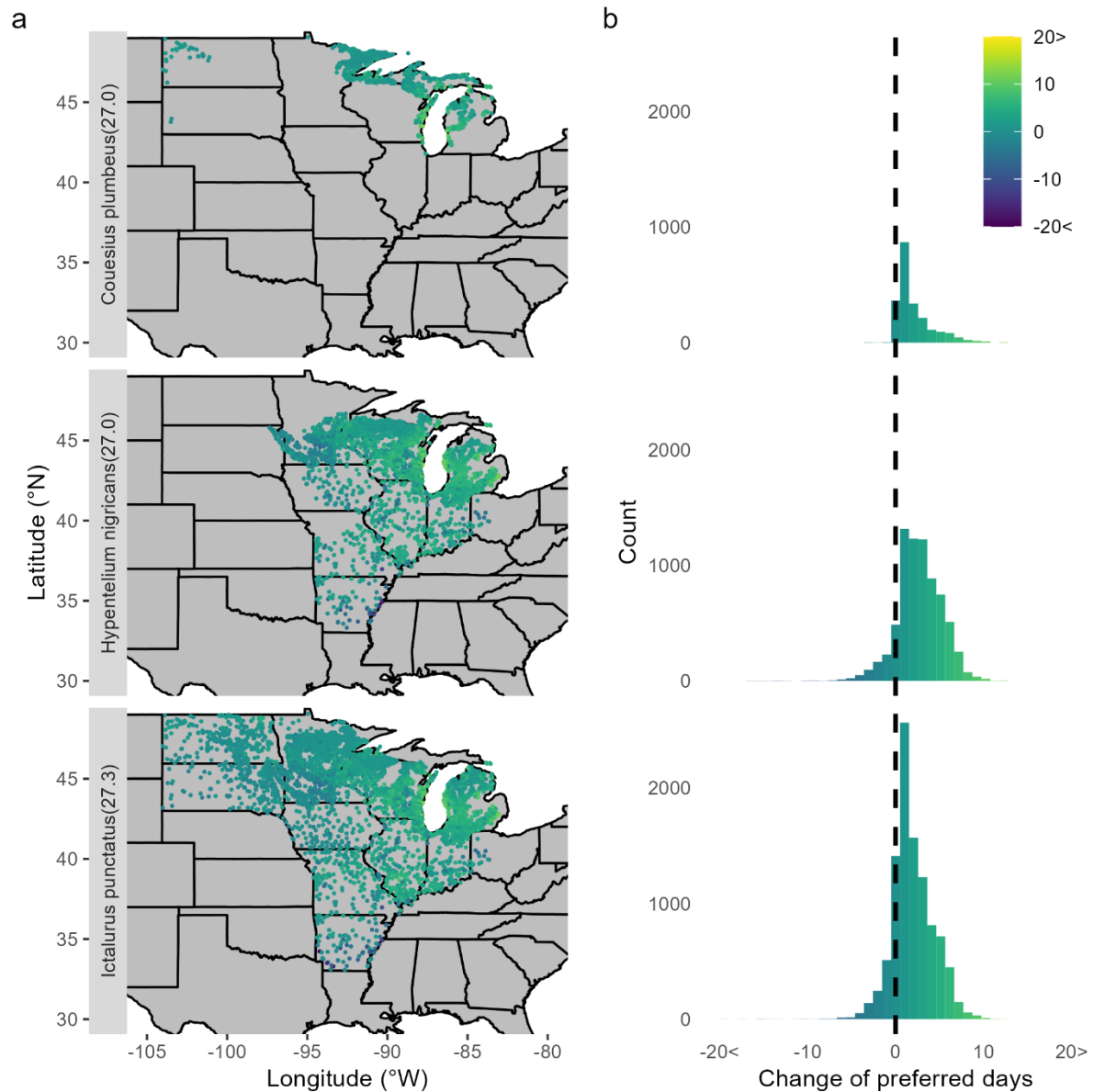


Supplementary Figure 18: **Spatial and frequency distribution of the change in preferred days for *Esox niger*, *Esox americanus vermiculatus* and *Noturus miurus*.** Panel (a) presents maps of the geographic distribution of changes in preferred days for each species from 1980–2000 to 2001–2021.

Panel (b) displays histograms for each species, with each bar representing the count of lakes experiencing a specified change in preferred days. The color of the points in panel (a) and bars in panel (b) corresponds to the changes in preferred days as indicated by the color palette legend.

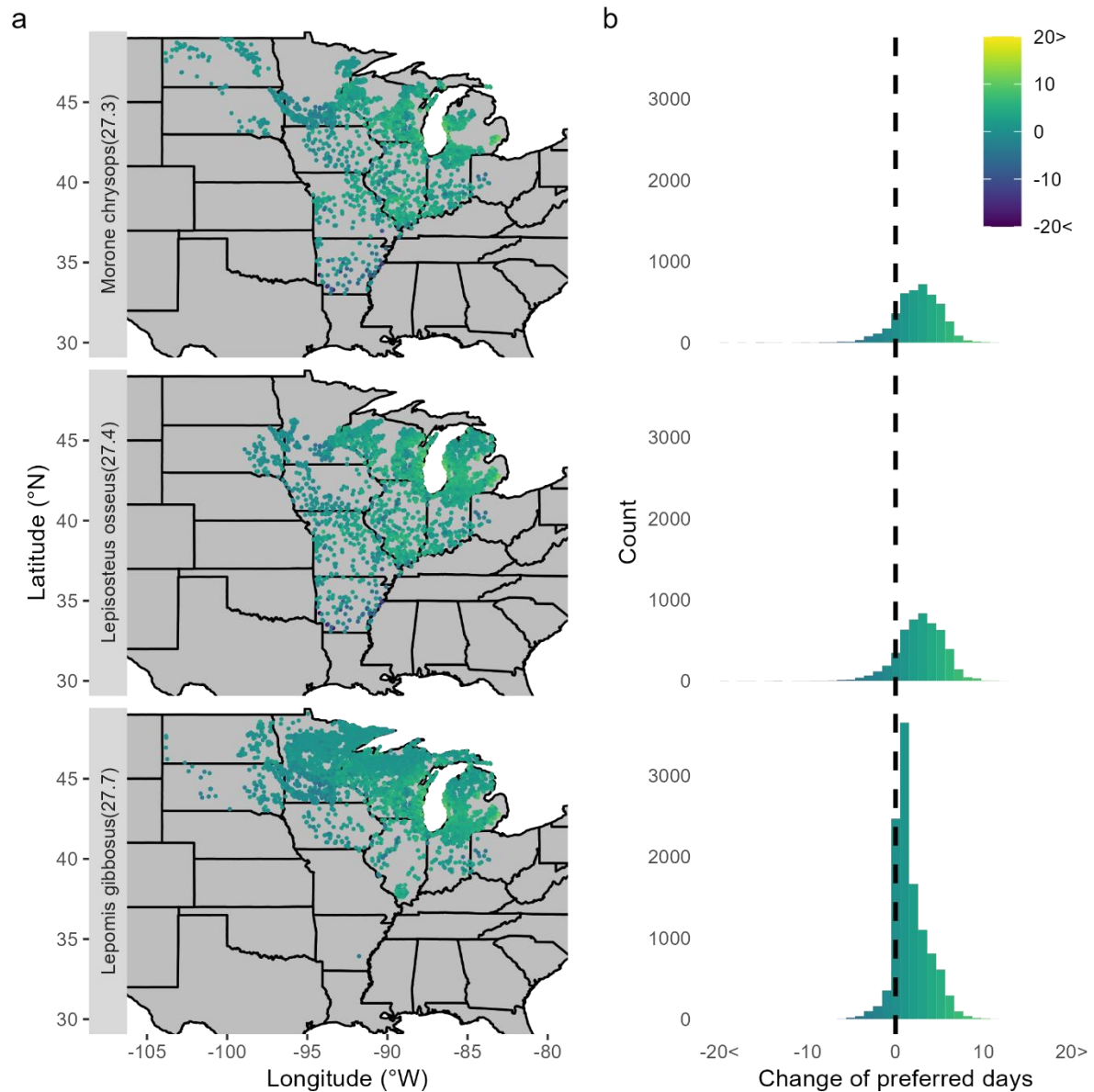


Supplementary Figure 19: **Spatial and frequency distribution of the change in preferred days for *Ameiurus melas*, *Ameiurus nebulosus* and *Moxostoma macrolepidotum*.** Panel (a) presents maps of the geographic distribution of changes in preferred days for each species from 1980–2000 to 2001–2021. Panel (b) displays histograms for each species, with each bar representing the count of lakes experiencing a specified change in preferred days. The color of the points in panel (a) and bars in panel (b) corresponds to the changes in preferred days as indicated by the color palette legend.

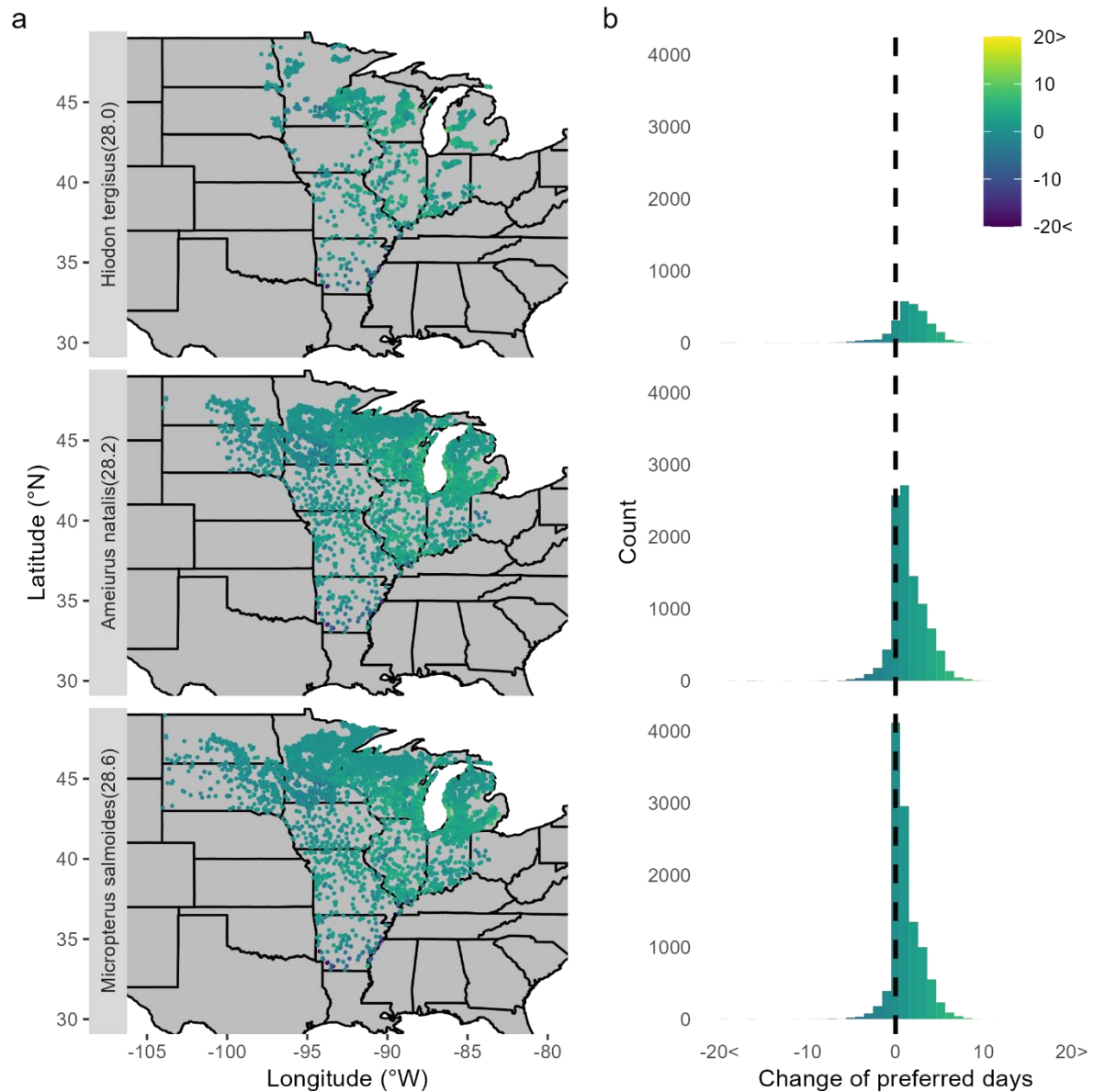


Supplementary Figure 20: **Spatial and frequency distribution of the change in preferred days for *Couesius plumbeus*, *Hypentelium nigricans* and *Ictalurus punctatus*.** Panel (a) presents maps of the geographic distribution of changes in preferred days for each species from 1980–2000 to 2001–2021.

Panel (b) displays histograms for each species, with each bar representing the count of lakes experiencing a specified change in preferred days. The color of the points in panel (a) and bars in panel (b) corresponds to the changes in preferred days as indicated by the color palette legend.

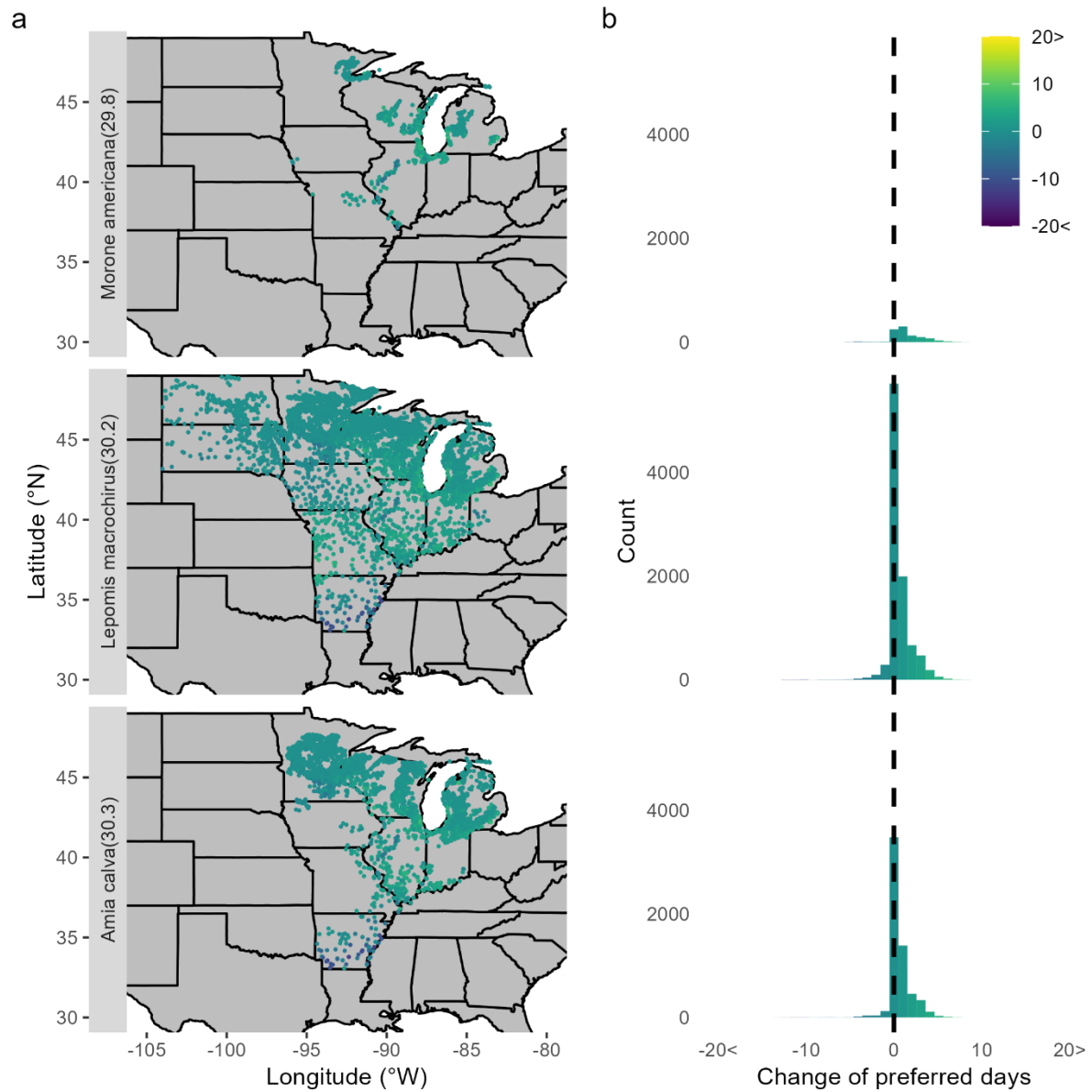


Supplementary Figure 21: **Spatial and frequency distribution of the change in preferred days for *Morone chrysops*, *Lepisosteus osseus* and *Lepomis gibbosus*.** Panel (a) presents maps of the geographic distribution of changes in preferred days for each species from 1980–2000 to 2001–2021. Panel (b) displays histograms for each species, with each bar representing the count of lakes experiencing a specified change in preferred days. The color of the points in panel (a) and bars in panel (b) corresponds to the changes in preferred days as indicated by the color palette legend.

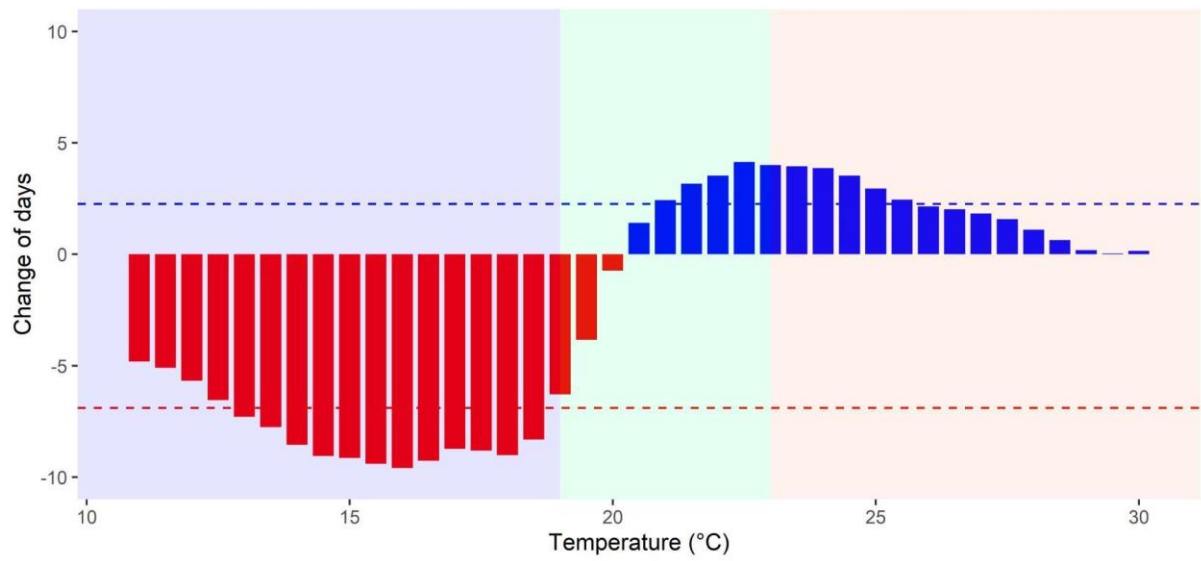


Supplementary Figure 22: **Spatial and frequency distribution of the change in preferred days for *Hiodon tergisus*, *Ameiurus natalis* and *Micropterus salmoides*.** Panel (a) presents maps of the geographic distribution of changes in preferred days for each species from 1980–2000 to 2001–2021.

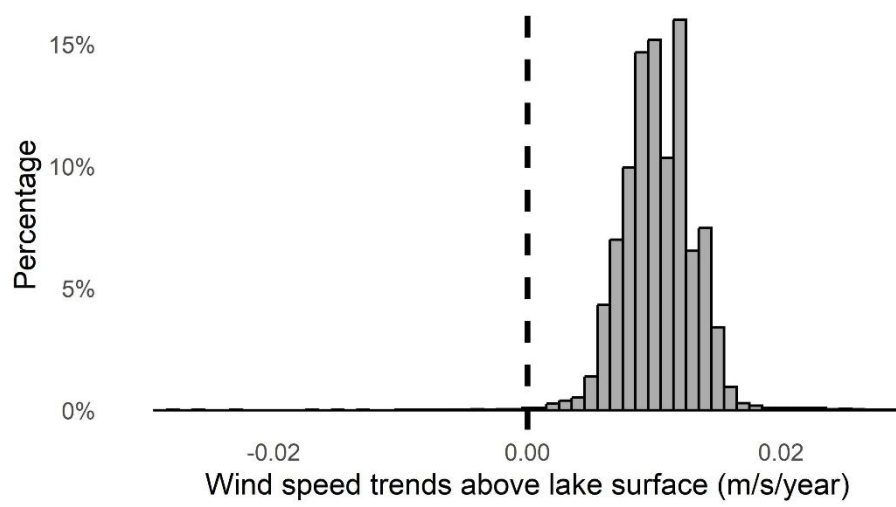
Panel (b) displays histograms for each species, with each bar representing the count of lakes experiencing a specified change in preferred days. The color of the points in panel (a) and bars in panel (b) corresponds to the changes in preferred days as indicated by the color palette legend.



Supplementary Figure 23: **Spatial and frequency distribution of the change in preferred days for *Morone americana*, *Lepomis macrochirus* and *Amia calva*.** Panel (a) presents maps of the geographic distribution of changes in preferred days for each species from 1980–2000 to 2001–2021. Panel (b) displays histograms for each species, with each bar representing the count of lakes experiencing a specified change in preferred days. The color of the points in panel (a) and bars in panel (b) corresponds to the changes in preferred days as indicated by the color palette legend.



Supplementary Figure 24: **Difference of average days the lake in the studied area contains certain temperature between 1980-2000 and 2001-2021.** Species are segregated by final temperature preferendum, with those below 19°C classified as cold (blue shaded background), between 19°C and 23°C as cool (spring-green shaded background), and above 23°C as warm (pink-orange shaded background). The dashed lines signify the average change for gained or lost days, respectively, with the blue line indicating the mean increase and the red line indicating the mean decrease in days.



Supplementary Figure 25: **Histogram of wind speed trends above lake surface**