Overview of Climate Trends and Projections for Natural Lands Preserves

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Bear Creek Preserve
Photo by Nicholas A. Tonelli

Eastern Hemlock and Red Spruce
Photo by Nicholas A. Tonelli (Public Domain)

ChesLen Preserve
Photo by Simone Collins

Recommended Citation

EcoAdapt. 2022. Overview of Climate Trends and Projections for Natural Lands Preserves. Version 1.0. EcoAdapt, Bainbridge Island, WA.

Further information on the Natural Lands Climate Adaptation Project is available on the project website at https://ecoadapt.org/goto/Natural-Lands.

Introduction

This document provides an overview of historical climate trends and future projections for Natural Lands preserves, with particular focus on the Bear Creek and ChesLen preserves located in Luzerne and Chester Counties of Pennsylvania (Figure 1).

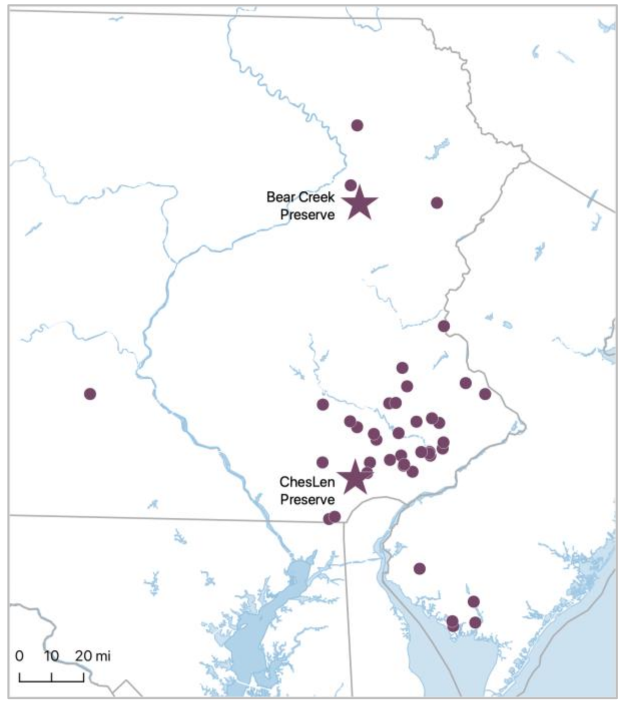

Figure 1. The location of all Natural Lands preserves (Bear Creek and ChesLen preserves are identified by stars).

Most of the trends and projections presented here are based on data from the Pennsylvania 2021 Climate Impacts Assessment (ICF 2021) and the U.S. Climate Resilience Toolkit Climate Explorer (USFG 2021). We used these resources to examine changes in air temperature, precipitation, snowfall and snowpack, extreme weather events, and soil moisture as well as factors such as drought and wildfire. Wherever possible, we present historical trends compared to mid- and end-of-century time frames for the state of Pennsylvania as well as for Luzerne and Chester Counties (see Appendix A for projected changes in all other counties where Natural Lands manages a preserve).[1] We also used the Northern Institute of Applied Climate Science (NIACS) climate change projections for individual tree species in Pennsylvania to identify species that are projected to have the highest and lowest adaptability and capability to cope or persist in a rapidly changing climate (NIACS 2021a, 2021b). These results can be found in Appendix B.

Throughout this document, most projections given are for the RCP 8.5 (high emissions) scenario, which is the commonly-used scenario that most closely matches the current global trajectory. Appendix A also presents county projections under RCP 4.5 (moderate-emissions scenario). RCP 4.5 likely underestimates the amount of change that will occur, and for this reason is not recommended as the primary scenario for consideration within management planning. However, it does represent an additional set of possibilities if global efforts to reduce greenhouse gas emissions are significantly increased from their current levels.[2]

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[1] The trends and projections presented here provide the foundation for ranking the climate exposure component of ecosystem vulnerability assessments for Bear Creek and Cheslen Preserves, together with additional literature that provided habitat- and species-specific information related to exposure.

[2] See this resource from CoastAdapt "What are the RCPs?" (https://coastadapt.com.au/infographics/what-are-rcps) for more introductory information about the different emissions scenarios.

The following table summarizes the trend direction and projected future changes of important climate and climate-driven factors, which are discussed in greater detail in the remaining sections of this report (Table 1).

Table 1. Summary of trend direction and projected future changes for climate and climate-driven factors, extreme events, and major natural disturbance regimes within Pennsylvania, with a focus on Chester and Luzerne Counties. A summary of trends for all counties where Natural Lands preserves are located can be found in Appendix A.

Variable	Trend	Projected Future Changes
Climate and climate-driven factors		
Air temperature	⬆	**Pennsylvania** • 5.9°F (3.3°C) increase in average annual temperature statewide by mid-century; 9.4°F (4.6°C) increase by end-of-century **Chester County** • 5.7°F increase in average annual temperature by mid-century; 9.1°F increase by end-of-century **Luzerne County** • 6.1°F increase by mid-century; 9.6°F increase by end-of-century
Precipitation	⬆	**Pennsylvania** • 8% increase in average annual precipitation (to 47 in [120 cm]) by mid-century; 12% increase in average annual precipitation (to 49 in [123 cm]) by end-of-century • Most increases will occur in winter (+19%) and spring (+12%) rainfall, with little to no change from historical patterns in the summer and fall **Chester County** • 5% increase in average annual precipitation (to 48.4 in [123 cm]) by mid-century; 12% increase (to 5.62 in [14 cm]) by end-of-century **Luzerne County** • 5% increase in average annual precipitation (to 46.5 in [118 cm]) by mid-century; 12% increase (to 5.52 in [14 cm]) by end-of-century
Soil moisture	⬆ ⬇	**Pennsylvania** • Increased frequency of short- and medium-term soil moisture droughts • Increased spring soil moisture due to more winter precipitation and earlier snowmelt
Snowpack & Snowmelt	⬇	**Pennsylvania** • Decrease in the number of days per year when snowfall occurs • 88% decrease in state annual average snowfall by end-of-century

Variable	Trend	Projected Future Changes
Extreme events and natural disturbance regimes		
Extreme heat & heat waves	⬆	**Pennsylvania** • Increase from 5.1 to 37 days per year with high temperatures over 90°F by mid-century (+625%), and to 65.5 days per year by 2100 (+1,184%) **Chester County** • Increase from 11.2 to 45.4 days per year with high temperatures over 90°F by mid-century (+305%), and to 91.6 days per year by 2100 (+718%) **Luzerne County** • Increase from 2.3 to 22.5 days per year with high temperatures over 90°F by mid-century (+878%), and to 64.1 days per year by 2100 (+2,687%)
Extreme precipitation, storms & flooding	⬆	**Pennsylvania** • Increase in magnitude, frequency, and intensity of extreme precipitation events and associated flooding **Chester County** • Increase from 0.8 to 1.2 days per year with >2" precipitation by 2100 (+50%) **Luzerne County** • Increase from 0.5 to 0.9 days per year with >2" precipitation by 2100 (+80%)
Drought	⬆	**Pennsylvania** • Likely increases in drought frequency and severity due to higher temperatures that increase evaporative demand and plant transpiration • 11% increase in annual maximum of consecutive dry days by 2100 **Chester County** • Insignificant decrease (0.5%) in annual average dry days by 2100 **Luzerne County** • Insignificant decrease (0.8%) in annual average dry days by 2100
Wildfire	⬆	**Pennsylvania** • Likely increased risk of wildfire due to hotter summer temperatures and moisture deficits

Trends and Projections for Climate and Climate-Driven Factors

Air Temperature

Annual average air temperatures increased in Pennsylvania over the 20th century and are projected to continue increasing through 2100. From 2000-2020, the annual average air temperature across the state rose by approximately 1.2°F (0.67°C). By the end of the century (2070–2099), annual mean air temperatures in Pennsylvania are projected to increase by +9.4°F (4.6°C) compared to historical temperatures from 1971 to 2000 (Figure 2; ICF 2021). Warming is expected to be greater in the southeastern part of the state compared to other regions, with annual average temperatures between 56 (13.3°C) and 65°F (18.3°C; Figure 2). Across the state, the highest rates of warming are also expected to occur in the summer months (ICF 2021).

Both Chester and Luzerne counties will see an increase in annual average temperatures. Table 2 details the historical trends for air temperature and projected changes for these counties.

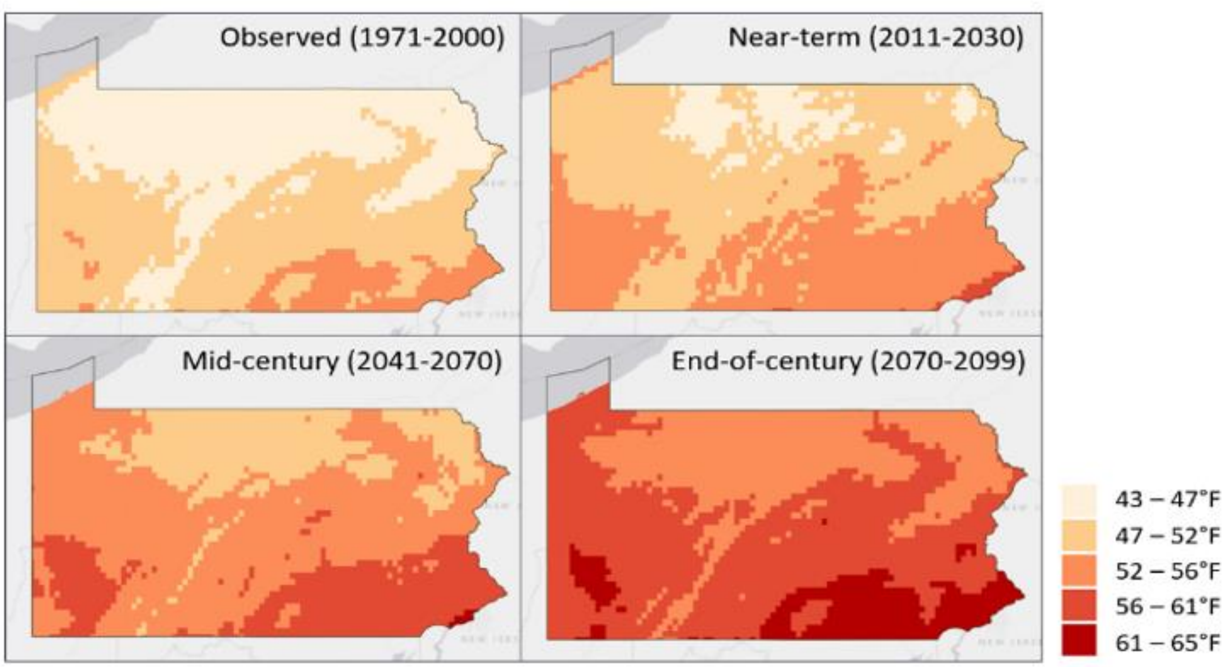

Figure 2. Observed and projected annual average temperature in Pennsylvania, based on the 50th percentile of 32 climate models representing potential future climate conditions, generated using a high-emissions scenario (RCP 8.5). *Source: Pennsylvania Climate Impacts Assessment 2021 (ICF 2021).*

Table 2. Projected change in average annual air temperature for mid-century (2041-2070) and end-of-century (2070–2099) timeframes compared to a 1971-2000 baseline. These projections were generated using a high-emissions scenario (RCP 8.5), and the value reported is the median of 32 climate models representing potential future climate conditions (ICF 2021).

Location	Historical	Projected (mid-century)	Projected (end-of-century)
Pennsylvania	48.3°F (9.06°C)	54.1°F (12.3°C) Change from historical: +5.8°F (3.2°C)	57.6°F (14.2°C) Change from historical: +9.3°F (5.2°C)
Chester County	52.1°F (11.2°C)	57.8°F (14.3°C) Change from historical: +5.7°F (+3.1°C)	61.2°F (16.2 °C) Change from historical: +9.1°F (+5°C)
Luzerne County	47.2°F (8.4°C)	53.3°F (11.8 °C) Change from historical: +6.1°F (+3.4°C)	56.8°F (13.8 °C) Change from historical: +9.6°F (+5.4°C)

High confidence in direction of projected trends, high confidence in magnitude of change.

Precipitation

Between 2000-2020, the mean annual precipitation in Pennsylvania increased by 117 mm (~4.6 in), and models suggest that increases are likely to continue in the future. By mid-century, average annual precipitation is projected to increase by 8% compared to the 1971-2000 baseline of 43.5 in (110.5 cm), and precipitation is likely to increase by 12% by 2100 (ICF 2021). The greatest increase in average annual precipitation for the state of Pennsylvania is projected to occur in winter (+19%) and spring (12%) precipitation, with precipitation during summer and fall seasons remaining similar to observed trends (ICF 2021; Figure 3).

Both Chester and Luzerne counties will see an increase in annual average precipitation. Table 3 details the projected changes for these counties.

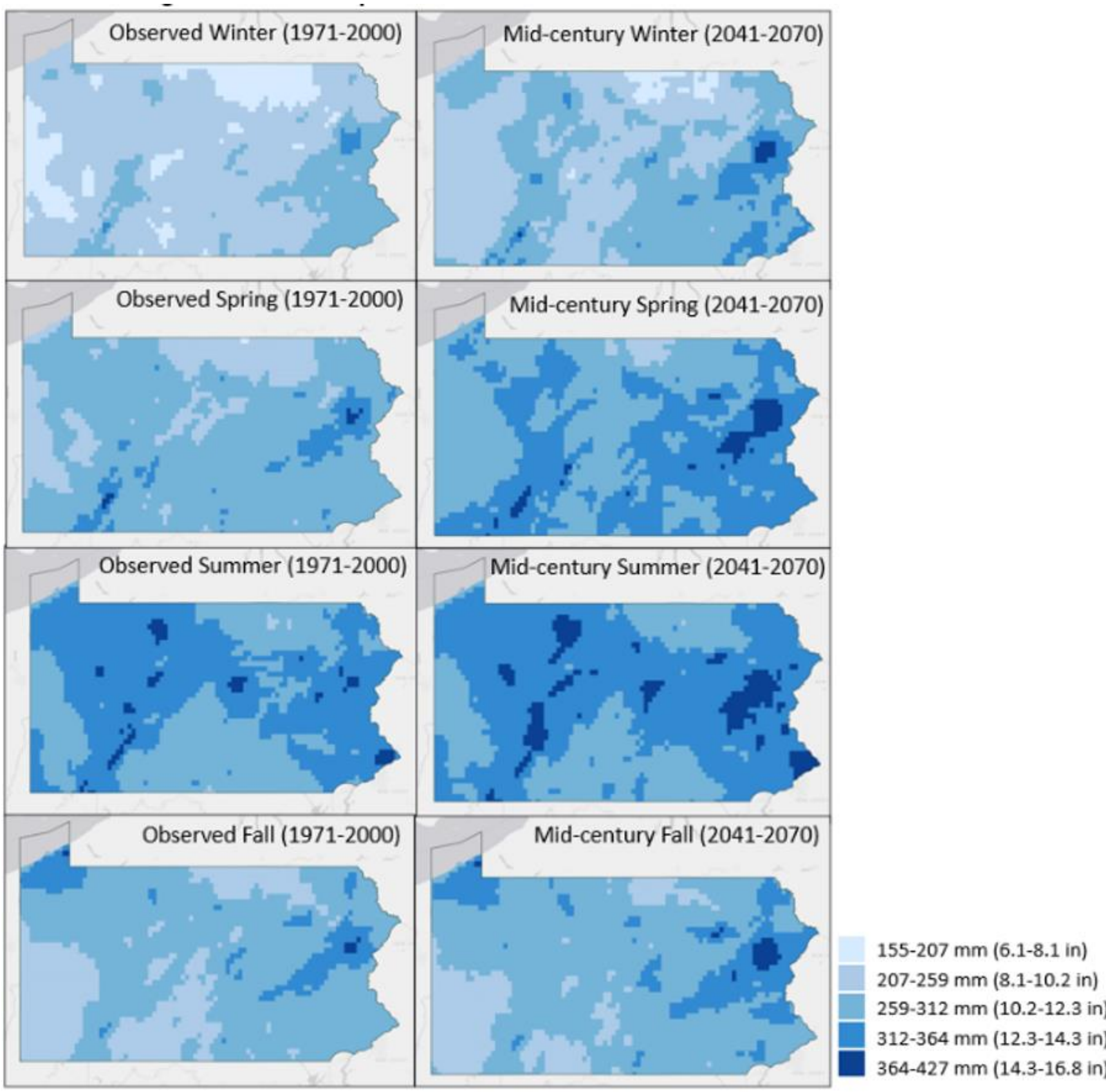

Figure 3. Observed and projected seasonal cumulative precipitation, based on the 50th percentile of 32 climate models representing potential future climate conditions, generated using a high-emissions scenario (RCP 8.5). *Source: Pennsylvania Climate Impacts Assessment 2021 (ICF 2021).*

Table 3. Projected change in average annual precipitation for the state of Pennsylvania is provided for mid-century (2041-2070) and end-of-century (2070-2099) compared to a 1971-2000 baseline (ICF 2021). Projections were generated using a high-emissions scenario (RCP 8.5) and the values reported represent the median as well as the 10th and 90th percentile of 32 climate models representing potential future climate conditions. For Chester and Luzerne Counties, the baseline for historic observations is 1961-1990, and the mean and model range for projections are provided for mid-century (2040-2049) and end-of-century (2090–2099; USFG 2021).

Location	Historical	Projected (mid-century)	Projected (end-of-century)
Pennsylvania	43.5 in (110.5 cm)	47.1 in (119.7 cm) (44.2–49.7 in; 112.3–126.2 cm) Change from historical: +3.6 in (9.1 cm), +8.4%	48.5 in (123.2 cm) (44.7–51.4 in; 113.6–130.6 cm) Change from historical: +5.0 in (12.7 cm), +11.5%
Chester County	46.1 in (117.2 cm)	48.4 in (122.8 cm) (33.4–65.1 in; 84.8–165.3 cm) Change from historical: +2.22 in (5.6 cm), +4.8%	51.8 in (131.4 cm) (34.3–69.9 in; 87.2–177.5 cm) Change from historical: +5.62 in (14.3 cm), +12%
Luzerne County	44.4 in (112.8 cm)	46.5 in (118.1 cm) (32.0–63.1 in; 81.2–160.2 cm) Change from historical: +2.1 in (5.3 cm), +4.7%	49.9 in (126.8 cm) (33.8–67.7 in; 85.8–171.9 cm) Change from historical: +5.5 (14.0 cm), +12%

Moderate to high confidence in direction of projected trends; moderate confidence in magnitude of change.

Soil Moisture

For Pennsylvania, soil moisture is projected to increase in the spring and decrease during summer and fall months, with an overall trend toward decreasing moisture (PSU 2013). The southeastern region of Pennsylvania is projected to have between 0-3.2% decline in soil moisture by mid-century under medium-high emission scenarios (A2), compared to state-wide declines averaging between 0-6% (Figure 4).

Rising annual average air temperatures, increased frequency of extreme heat events, and precipitation declines during summer months increase the likelihood of forest mortality events due to heat-related stressors such as drier soil moisture and increased evapotranspiration (ICF 2021; PSU 2013).

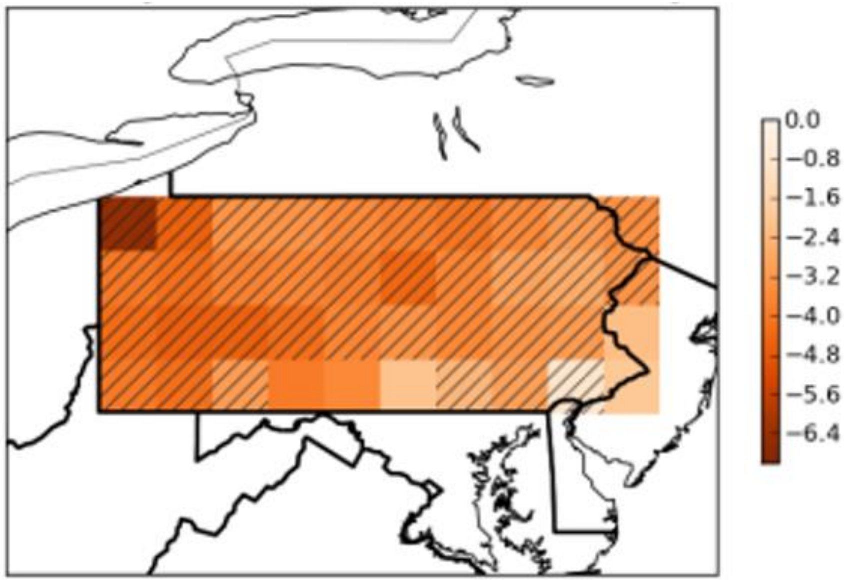

Figure 4. Changes in summer average soil moisture in Pennsylvania, presented as the average of regional climate models representing potential future climate conditions and generated for the 2041-2070 (mid-century) time frame using a medium-high emissions scenario (A2). Hatching indicates where at least eight of the nine models agree on the sign of change. *Source: 2013 Pennsylvania Climate Impacts Assessment Update (PSU 2013).*

Moderate confidence in direction of projected trends; low confidence in magnitude of change.

Snowfall, Snowmelt, and Snowpack

Between 1965 and 2005, the number of snow-covered days in the Northeastern United States (including Pennsylvania and New Jersey) declined by 1.5 days/decade for January and 1.0 days/decade for February (PSU 2015, Burakowski et al. 2008). State-wide, average annual snowfall is expected to decline by roughly 60–70% by mid-century and 100% by the end of the century; the same patterns are projected for both Chester and Luzerne Counties (Alder & Hostetler 2013).

While winter precipitation is expected to increase in Pennsylvania, the proportion that falls as snow will likely continue to decline. Additionally, the number of days per year where snowfall could occur is projected to decrease and there will be a significant decrease in snow cover extent and duration (Figure 5; ICF 2021). Heavier precipitation and higher temperatures will cause earlier snowmelt in the year, leading to increased flood risk. More rain than snow in the winter could also lead to higher streamflow in winter and spring and an increased risk of winter floods.

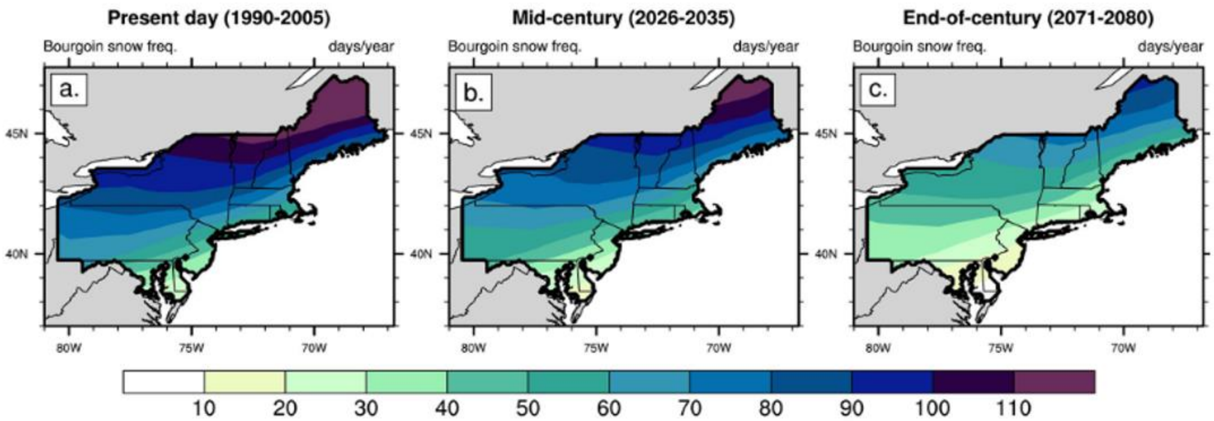

Figure 5. Average number of days per year where snowfall could occur for present-day (1990-2005), mid-century (2026-2035), and end-of-century (2071-2080). *Source: Zarzycki 2018 via the Pennsylvania Climate Impacts Assessment 2021 (ICF 2021).*

High confidence in direction of projected trends; moderate confidence in magnitude of change.

Trends and Projections for Extreme Events and Natural Disturbance Regimes

Extreme Heat and Heat Waves

In Pennsylvania, a 625% increase is projected in the number of days over 90°F per year by mid-century (2041–2070), to 37 days/year from a historical average of 5.1 (1971–2000). By the end of the century (2070–2099), that is expected to increase further to 65.5 days/year (+1,184%; ICF 2021). The southeastern portion of the state is projected to experience an even greater number of extreme heat days, with 82–103 days over 90°F by the end of the century (Figure 6).

In Chester and Luzerne Counties, an increase to 91.6 (+718%) and 64.1 days (+2,687%) over 90°F is projected, respectively (USFG 2021). Table 4 details the projected changes for these counties.

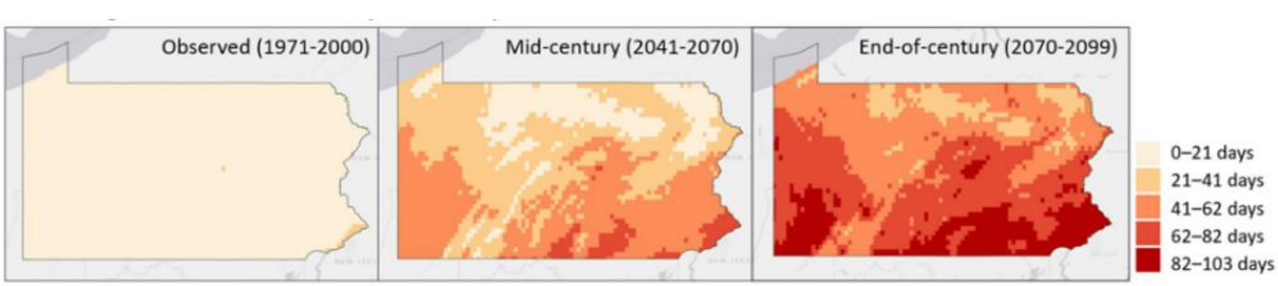

Figure 6. Observed and projected annual days with temperatures above 90°F, based on the 50th percentile of 32 climate models representing potential future climate conditions, generated using a high-emissions scenario (RCP 8.5). *Source: Pennsylvania Climate Impacts Assessment 2021 (ICF 2021).*

Table 4. Projected change in annual days with maximum temperatures above 90°F for the state of Pennsylvania is provided for mid-century (2041-2070) and end-of-century (2070-2099) compared to a 1971-2000 baseline (ICF 2021). Projections were generated using a high-emissions scenario (RCP 8.5), and the values reported are the median as well as the 10th and 90th percentile of 32 climate models representing potential future climate conditions. For Chester and Luzerne Counties, the baseline for historic observations is 1961-1990, and the mean and model range for projections using a high-emissions scenario (RCP 8.5) are provided for mid-century (2040-2049) and end-of-century (2090–2099; USFG 2021).

Location	Historical	Projected (mid-century)	Projected (end-of-century)
Pennsylvania	5.1 days	37 days (22–51.2 days) Change from historical: +31.9 days; +625%	65.5 days (35.8–89 days) Change from historical: +60.4 days; +1,184%
Chester County	11.2 days	45.4 days (14.1–75 days) Change from historical: +34.2 days; +305%	91.6 days (41.4–129.1 days) Change from historical: +80.4 days; +718%
Luzerne County	2.3 days	22.5 days (3.3–48.9 days) Change from historical: +20.2 days; +878%	64.1 days (15.3–108.9 days) Change from historical: +61.8 days; +2,687%

High confidence in direction of projected trends and magnitude of change.

Extreme Precipitation, Storms, and Flooding

Overall, extreme precipitation events are projected to increase in frequency and intensity (e.g., amount) in Pennsylvania, leading to associated increases in flooding. State-wide, a 42% increase is projected in the number of days with extremely heavy precipitation (events that currently occur less than 1% of the time) by mid-century (2041–2070), to 3.5 days/year from a historical average of 2.5 days from 1971–2000. By the end of the century (2070–2099), that is expected to increase further to 4.2 days/year (+69%; ICF 2021). The amount of precipitation that falls on these days is also projected to increase, from a historical average of 1.2 inches to 1.2 inches by mid-century (+13%) and 1.4 inches by the end of the century (+20%).

The southeastern portion of the state is projected to experience a more significant increase in the number of extreme precipitation events, with projections suggesting the region may experience between 17-35 days of "very heavy" precipitation (events that currently occur less than 5% of the time) per year by 2100 (Figure 7). The number of days per year with >2" precipitation will also increase for Luzerne and Chester counties by the end of the century (Table 5).

Extreme weather events such as extratropical cyclones (e.g., winter storms or Nor'easters) are expected to grow more frequent in the region, increasing the potential for damaging thunderstorms, blizzards, tornadoes, and flooding (ICF 2021).

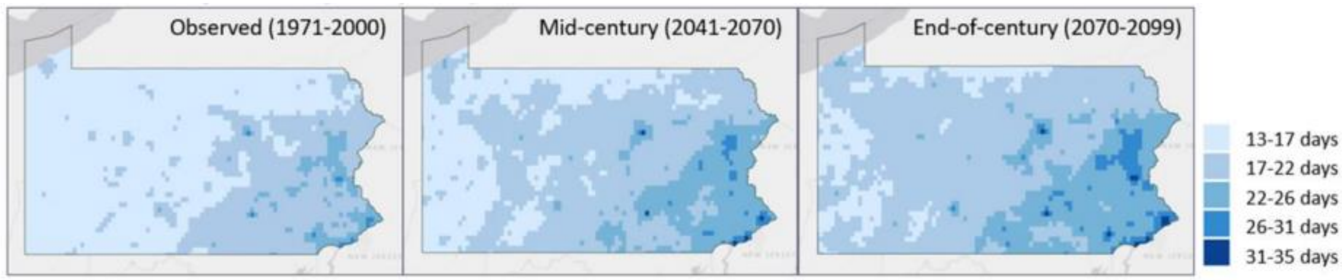

Figure 7. Observed and projected annual days with "very heavy" precipitation (events that currently occur less than 5% of the time), based on the 50th percentile of 32 climate models representing potential future climate conditions, generated using a high-emissions scenario (RCP 8.5). *Source: Pennsylvania Climate Impacts Assessment 2021 (ICF 2021).*

Table 5. Projected days per year with >2" precipitation for mid-century (2040-2049) and end-of-century (2090-2099) compared to 1961-1990 in Chester and Luzerne counties. Projections were generated using a high-emissions scenario (RCP 8.5) and the values reported represent the mean and range of 32 climate models representing potential future climate conditions (USFG 2021).

Location	Historical	Projected (mid-century)	Projected (end-of-century)
Chester County	0.8 days	0.8 days (0-3.4 days) Change from historical: +0 days; 0%	1.2 days (0-4.5 days) Change from historical: +0.4 days; +50%
Luzerne County	0.5 days	0.6 days (0-2.9 days) Change from historical: +0.1 days; +20%	0.9 days (0-4.1 days) Change from historical: +0.4 days; +80%

High confidence in direction of projected trends; low confidence in magnitude of change.

Drought

Although drought conditions in Pennsylvania have decreased in recent decades, they are projected to occur more frequently in the future (ICF 2021). Despite projected increases in annual precipitation, warmer temperatures increase evaporative demand and plant transpiration, reducing overall water availability. By the end of the century, the state's annual consecutive dry days (days when precipitation is less than 0.01 in, 0.254 mm) are projected to increase by 11%, with the most consecutive dry days likely occurring between September and November (Figure 8; ICF 2021).

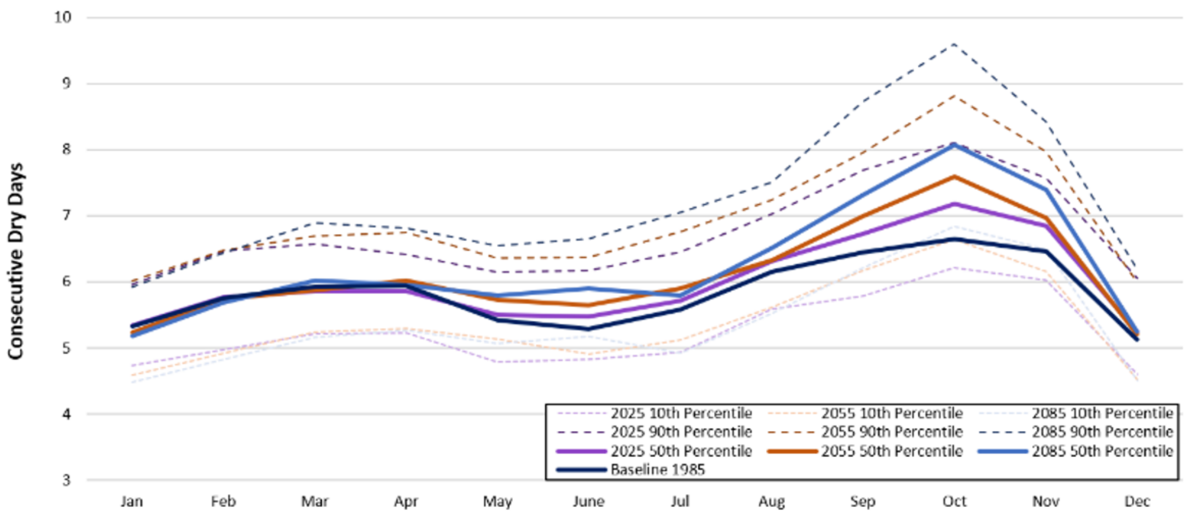

Figure 8. Statewide observed and projected average monthly consecutive dry days, generated for 32 climate models using a high-emissions scenario (RCP 8.5). Values for 2025 represent all years 2011-2040, values for 2055 represent all years 2041-2070, and values for 2085 represent all years 2070-2099. *Source: Pennsylvania Climate Impacts Assessment 2021 (ICF 2021).*

Moderate confidence in direction of projected trends and magnitude of change.

Wildfire

Increasing temperatures and extreme heat events paired with soil moisture deficits are likely to increase the risk of wildfires in Pennsylvania (PADCNR 2018). However, it is still uncertain how exactly climate change will impact the fire regimes of the state. Currently, populated areas in Pennsylvania have greater average risk of wildfire than 14% of states in the U.S. By the end of the century, there is a projected average increase of 0.2% area burned/year in the state of Pennsylvania under a high emissions scenario (RCP 8.5), compared to the historical average (1971-2000) of 0.6% of area burned/year (Figure 9; Hegewisch et al. 2022).

Within the state, populated areas in Chester County currently have a greater risk of wildfire than 82% of the other counties in Pennsylvania, while Luzerne County has a greater risk of wildfire than 55% of counties (USDA 2022). However, both Chester and Luzerne counties are at a minor risk of wildfire into mid-century.

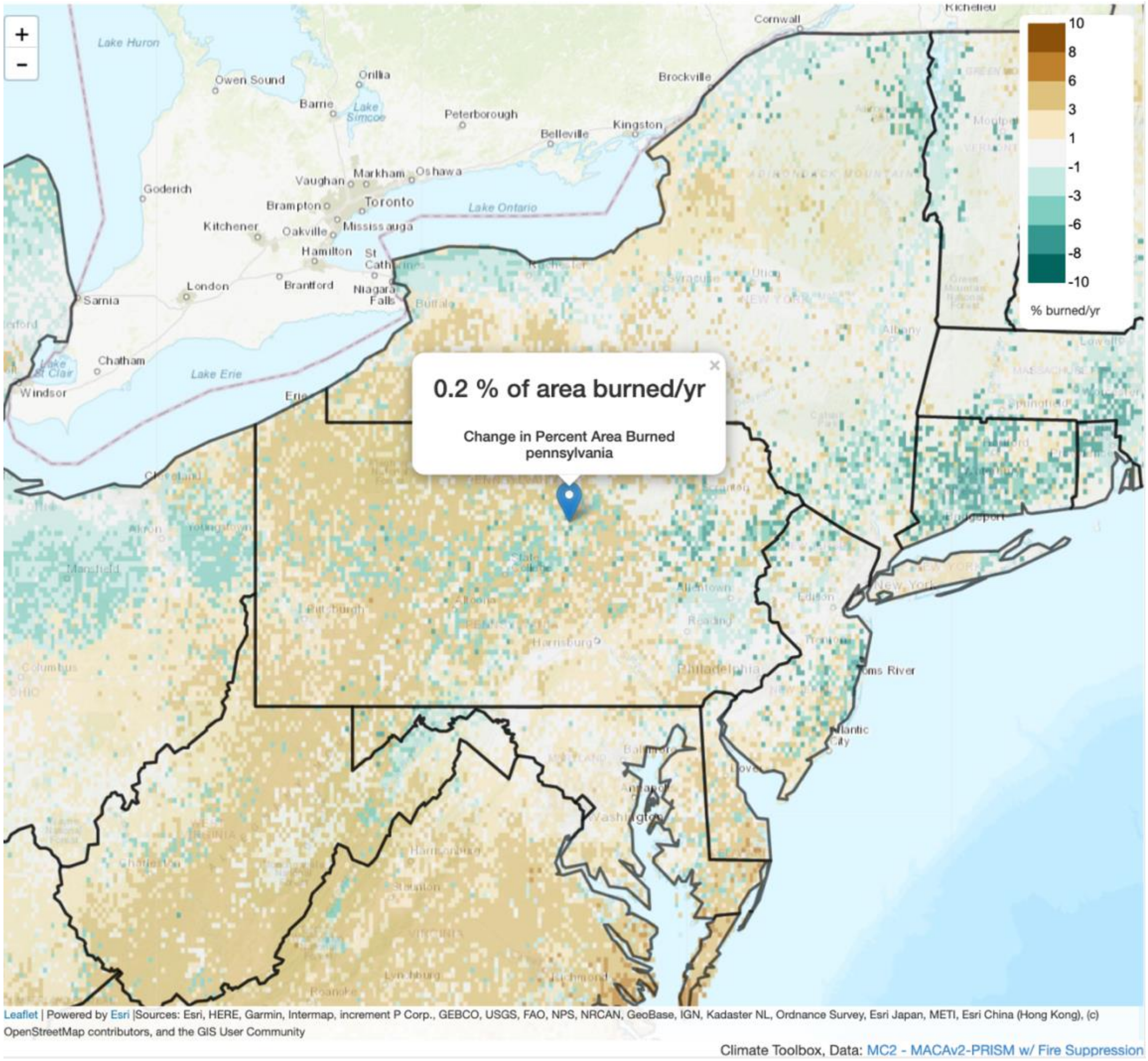

Figure 9. Projected mean change in percent area burned in the state of Pennsylvania, generated using a high-emissions scenario (RCP 8.5) for 2070–2099 compared to 1971–2000. Values depicted represent the mean of 20 climate models. *Source: Climate Mapper (Hegewisch et al. 2022).*

Moderate confidence in direction of projected trends and magnitude of change.

Appendix A: Summary of Climate Trends for All Counties with Natural Lands Preserves

Air Temperature

Table A1. Projected change in average annual air temperature and change from historical conditions was sourced from Alder & Hostetler 2013 for mid-century (2050-2071) and end-of-century (2075-2099) timeframes compared to a 1981-2010 baseline. Counties listed include all those where Natural Lands manages preserves.

County	Historical	Emissions Scenario	Projected (Mid-Century)	Projected (End-of-century)
Berks, PA	52.17°F (11.21°C)	*RCP 8.5*	+6.13°F (+3.41°C)	+ 9.02°F (+5.01°C)
		RCP 4.5	+4.17°F (+2.32°C)	+4.85°F (+2.69°C)
Bucks, PA	53.3°F (11.83°C)	*RCP 8.5*	+6.01°F (+3.34°C)	+8.83°F (+4.9°C)
		RCP 4.5	+4.08°F (+2.27°C)	+4.75°F (+2.64°C)
Chester, PA	53.35°F (11.86°C)	*RCP 8.5*	+5.99°F (+3.33°C)	+8.8°F (+4.89°C)
		RCP 4.5	+4.07°F (+2.26°C)	+4.73°F (+2.63°C)
Cumberland, NJ	53.8°F (12.1°C)	*RCP 8.5*	+7.4°F (+4.1°C)	+10.1°F (+5.6°C)
		RCP 4.5	+3.83°F (+2.13°C)	+4.48°F (+2.49°C)
Delaware, PA	55.32°F (12.96°C)	*RCP 8.5*	+5.92°F (+3.29°C)	+8.7°F (+4.83°C)
		RCP 4.5	+4.02°F (+2.23°C)	+4.68°F (+2.6°C)
Lackawanna, PA	47.46°F (8.59°C)	*RCP 8.5*	+6.36°F (+3.54°C)	+9.39°F (+5.22°C)
		RCP 4.5	+4.33°F (+2.4°C)	+5.04°F (+2.8°C)
Luzerne, PA	48.58°F (9.21°C)	*RCP 8.5*	+6.31°F (+3.51°C)	+9.3°F (+5.17°C)
		RCP 4.5	+4.29°F (+2.39°C)	+5°F (+2.78°C)
Monroe, PA	48.08°F (8.93°C)	*RCP 8.5*	+6.25°F (+3.47°C)	+9.2°F (+5.11°C)
		RCP 4.5	+4.25°F (+2.36°C)	+4.94°F (+2.74°C)
Montgomery, PA	53.96°F (12.2°C)	*RCP 8.5*	+6.01°F (+3.34°C)	+8.83°F (+4.9°C)
		RCP 4.5	+4.08°F (+2.27°C)	+4.75°F (+2.64°C)
Northampton, PA	51.23°F (10.68°C)	*RCP 8.5*	+6.17°F (+3.43°C)	+9.07°F (+5.04°C)
		RCP 4.5	+4.19°F (+2.33°C)	+4.87°F (+2.71°C)
Perry, PA	51.66°F (10.92°C)	*RCP 8.5*	+6.18°F (+3.44°C)	+9.13°F (+5.07°C)
		RCP 4.5	+4.21 °F (+2.34°C)	+4.9°F (+2.72°C)
Philadelphia, PA	56.03°F (13.35°C)	*RCP 8.5*	+5.91°F (+3.28°C)	+8.65°F (+4.81°C)
		RCP 4.5	+4.01°F (+2.23°C)	+4.66°F (+2.59°C)
Salem, NJ	52.2°F (11.2°C)	*RCP 8.5*	+9.52°F (+5.3°C)	+12.27°F (+6.84°C)
		RCP 4.5	+3.93°F (+2.19°C)	+4.59°F (+2.55°C)

Extreme Heat

Table A2. Historic and projected change in annual days with temperature above 90°F and change from historical conditions for mid-century (2040-2049) and end-of-century (2090–2099) compared to a 1961-1990 baseline (USFG 2021). Counties listed include all those where Natural Lands manages preserves.

County	Historical	Emissions Scenario	Projected (Mid-Century)	Projected (End-of-century)
Berks, PA	9.1 days	*RCP 8.5*	37.9 days (+317%)	82.6 days (+808%)
		RCP 4.5	31.1 days (+242%)	44 days (+384%)
Bucks, PA	13.3 days	*RCP 8.5*	47.1 days (+254%)	92.1 days (+593%)
		RCP 4.5	40.3 days (+203%)	53.8 days (+305%)
Chester, PA	11.2 days	*RCP 8.5*	45.4 days (+305%)	91.6 days (+718%)
		RCP 4.5	38.3 days (+242%)	52 days (+364%)
Cumberland, NJ	16.1 days	*RCP 8.5*	51.5 days (+220%)	96.5 days (+499%)
		RCP 4.5	45.2 days (+181%)	59 days (+267%)
Delaware, PA	15.7 days	*RCP 8.5*	49.5 days (+215%)	93.8 days (+498%)
		RCP 4.5	43 days (+174%)	55.8 days (+255%)
Lackawanna, PA	1.8 days	*RCP 8.5*	16.7 days (+828%)	56.4 days (+3,033%)
		RCP 4.5	13.2 days (+633%)	20.9 days (+1,061%)
Luzerne, PA	2.3 days	*RCP 8.5*	22.5 days (+878%)	64.1 days (+2,687%)
		RCP 4.5	18 days (+683%)	27.3 days (+1,087%)
Monroe, PA	3.9 days	*RCP 8.5*	25.4 days (+551%)	67.9 days (+1,641%)
		RCP 4.5	20.4 days (+423%)	30.8 days (+690%)
Montgomery, PA	12.8 days	*RCP 8.5*	49.1 days (+284%)	94.2 days (+636%)
		RCP 4.5	42.2 days (+230%)	56 days (+338%)
Northampton, PA	8.3 days	*RCP 8.5*	39.6 days (+377%)	84.3 days (+916%)
		RCP 4.5	33.3 days (+301%)	45.6 days (+449%)
Perry, PA	9.5 days	*RCP 8.5*	38.7 days (+307%)	84.3 days (+787%)
		RCP 4.5	31.4 days (+231%)	45.2 days (+376%)
Philadelphia, PA	18.8 days	*RCP 8.5*	58.3 days (+210%)	101.3 days (+439%)
		RCP 4.5	51.8 days (+176%)	65.3 days (+247%)
Salem, NJ	17.6 days	*RCP 8.5*	52.9 days (+201%)	97.9 days (+456%)
		RCP 4.5	46 days (+161%)	60.1 days (+242%)

Precipitation

Table A3. Projected change in average annual precipitation and change from historical conditions for mid-century (2040-2049) and end-of-century (2090–2099) compared to a 1961-1990 baseline (USFG 2021). Counties listed include all those where Natural Lands manages preserves.

County	Historical	Emissions Scenario	Projected (Mid-Century)	Projected (End-of-century)
Berks, PA	45.1 in (114.6 cm)	*RCP 8.5*	+4.8%	+12.9%
		RCP 4.5	+4.7%	+8%
Bucks, PA	46.7 in (118.7 cm)	*RCP 8.5*	+4.3%	+11.2%
		RCP 4.5	+4.1%	+6.9%
Chester, PA	46.1 in (117.2 cm)	*RCP 8.5*	+4.9%	+12.3%
		RCP 4.5	+5%	+7.6%
Cumberland, NJ	43.2 in (109.7. cm)	*RCP 8.5*	+4.1%	+11%
		RCP 4.5	+4.4%	+6.7%
Delaware, PA	45.8 in (116.4 cm)	*RCP 8.5*	+5%	+13%
		RCP 4.5	+5.3%	+8%
Lackawanna, PA	44.6 in (113.3 cm)	*RCP 8.5*	+5.5%	+13.5%
		RCP 4.5	+4.7%	+8.2%
Luzerne, PA	44.4 in (112.8 cm)	*RCP 8.5*	+4.7%	+12.4%
		RCP 4.5	+4.7%	+7.7%
Monroe, PA	51.3 in (130.3 cm)	*RCP 8.5*	+6.2%	+15.1%
		RCP 4.5	+5.4%	+9.8%
Montgomery, PA	45.9 in (116.6 cm)	*RCP 8.5*	+4.4%	+11.5%
		RCP 4.5	+4.4%	+7.3%
Northampton, PA	46.6 (118.4 cm)	*RCP 8.5*	+5.5%	+14.1%
		RCP 4.5	+4.7%	+9%
Perry, PA	42.8 in (108.8 cm)	*RCP 8.5*	+5.5%	+13.4%
		RCP 4.5	+5%	+7.6%
Philadelphia, PA	46.4 in (117.9 cm)	*RCP 8.5*	+5.1%	+12.7%
		RCP 4.5	+5.4%	+8.1%
Salem, NJ	42.9 in (108.9 cm)	*RCP 8.5*	+4.5%	+12.2%
		RCP 4.5	+4.7%	+7.5%

Extreme Precipitation

Table A4. Projected days per year with >2" precipitation and change from historical conditions for mid-century (2040-2049) and end-of-century (2090–2099) compared to a 1961-1990 baseline (USFG 2021). Counties listed include all those where Natural Lands manages preserves.

County	Historical	Emissions Scenario	Projected (Mid-Century)	Projected (End-of-century)
Berks, PA	0.6 days	*RCP 8.5*	0.6 days (+0%)	0.9 days (+50%)
		RCP 4.5	0.6 days (+0%)	0.7 days (+17%)
Bucks, PA	0.9 days	*RCP 8.5*	1 day (+11%)	1.4 days (+56%)
		RCP 4.5	1 day (+ 11%)	1.4 days (+56%)
Chester, PA	0.8 days	*RCP 8.5*	0.8 days (+0%)	1.2 days (+50%)
		RCP 4.5	0.8 days (+0%)	0.9 days (+13%)
Cumberland, NJ	0.8 days	*RCP 8.5*	0.7 days (-13%)	1.3 days (+63%)
		RCP 4.5	0.8 days (+0%)	0.9 days (+13%)
Delaware, PA	0.9 days	*RCP 8.5*	1.1 days (+22%)	1.5 days (+67%)
		RCP 4.5	1.2 days (+33%)	1.3 days (+44%)
Lackawanna, PA	0.6 days	*RCP 8.5*	0.7 days (+17%)	1.1 days (+83%)
		RCP 4.5	0.7 days (+17%)	0.9 days (+50%)
Luzerne, PA	0.5 days	*RCP 8.5*	0.6 days (+20%)	0.9 days (+80%)
		RCP 4.5	0.6 days (+20%)	0.7 days (+40%)
Monroe, PA	1 day	*RCP 8.5*	1.2 days (+20%)	1.8 days (+80%)
		RCP 4.5	1.1 days (+10%)	1.4 days (+40%)
Montgomery, PA	0.7 days	*RCP 8.5*	0.7 days (+0%)	1 day (+43%)
		RCP 4.5	0.7 days (+0%)	0.8 days (+14%)
Northampton, PA	0.9 days	*RCP 8.5*	1 day (+11%)	1.4 days (+56%)
		RCP 4.5	1 day (+11%)	1.2 days (+33%)
Perry, PA	0.5 days	*RCP 8.5*	0.6 days (+20%)	0.9 days (+80%)
		RCP 4.5	0.6 days (+20%)	0.6 days (+20%)
Philadelphia, PA	1.1 days	*RCP 8.5*	1.5 days (+36%)	1.9 days (+73%)
		RCP 4.5	1.5 days (+36%)	1.7 days (+55%)
Salem, NJ	0.7 days	*RCP 8.5*	0.8 days (+14%)	1.2 days (+71%)
		RCP 4.5	0.8 days (14 %)	0.9 days (+29%)

Appendix B: Climate Change Projections for Individual Tree Species

The information below has been adapted from the Northern Institute of Applied Climate Science's (NIACS) Climate Change Projections for Individual Tree Species in Pennsylvania handouts for the Ridge and Valley (subregion 4) and Piedmont (subregion 5) physiographic regions of Pennsylvania (NIACS 2021a, 2021b; Figure B1). The preserves managed by Natural Lands are located within these two subregions.

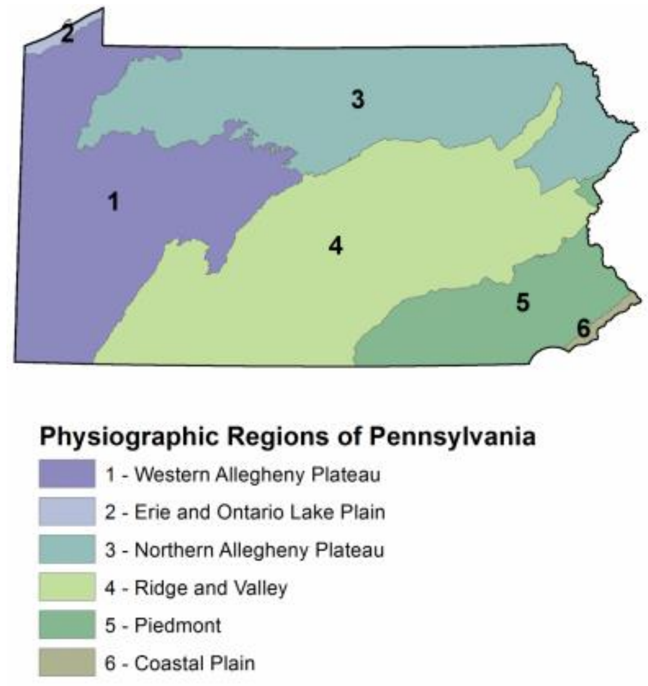

Figure B1. Physiographic Regions of Pennsylvania. *Source: NIACS Climate Change Projections for Individual Tree Species in Pennsylvania (NIACS 2022).*

Within each subregion, tree species are ranked based on four factors utilized by the [USDA Climate Change Tree Atlas]: adaptability, habitat change, abundance, and capability (Figure B2). Each subregion includes a breakdown of how the individual tree species rank using the four factors under lower and higher emissions scenarios (RCP 4.5 and RCP 8.5, respectively; Figures B3 and B4), as well as a table summarizing the species according to their capability ranking, which describes the overall ability of the species to cope or persist under future climate conditions (Tables B1 and B2).

Table B1. Summary of ranking definitions and categories for adaptability, abundance, habitat change, and capability, used to evaluate tree species in Pennsylvania. *Source: NIACS Climate Change Projections for Individual Tree Species in Pennsylvania (NIACS 2021a, 2021b).*

Adaptability		Abundance	
Life-history factors, such as the ability to respond favorably to disturbance, that are not included in the Tree Atlas model and may make a species more or less able to adapt		Based on Forest Inventory Analysis summed Importance Value data, calibrated to a standard geographic area	
+	**High** species may perform better than modeled	+	**Abundant**
–	**Low** species may perform worse than modeled	–	**Rare**
o	**Medium**	o	**Common**
Habitat Change		**Capability**	
Projected change in suitable habitat between current and potential future conditions		An overall rating that describes a species' ability to cope or persist with climate change based on suitable habitat change class, adaptability, and abundance within this region	
▲	**Increase:** projected increase of >20% by 2100	△	**Good:** increasing suitable habitat, medium or high adaptability, and common or abundant
▼	**Decrease:** projected decrease of >20% by 2100	○	**Fair:** mixed combinations, such as a rare species with increasing suitable habitat and medium adaptability
●	**No change:** little change (<20%) by 2100	▽	**Poor:** decreasing suitable habitat, medium or low adaptability, and uncommon or rare
★	**New habitat:** Tree Atlas projects new habitat for species not currently present		

Subregion 4: Ridge and Valley

SPECIES	ADAPT	ABUN	LOW CLIMATE CHANGE (RCP 4.5) HABITAT CHANGE	LOW CLIMATE CHANGE (RCP 4.5) CAPABILITY	HIGH CLIMATE CHANGE (RCP 8.5) HABITAT CHANGE	HIGH CLIMATE CHANGE (RCP 8.5) CAPABILITY
American basswood	•	•	▲	△	▲	△
American beech	•	•	▲	△	▲	△
American elm	•	–	▲	○	▲	△
American hornbeam*	•	–	▼	▽	●	▽
Balsam poplar	•	–	▼	▽	▼	▽
Bigtooth aspen	•	•	▼	▽	▼	▽
Bitternut hickory*	+	–	●	○	●	○
Black ash	–	–	▼	▽	▼	▽
Black cherry	–	+	●	○	▼	○
Black locust*	•	•	▲	△	▲	△
Black oak	•	•	▲	△	▲	△
Black walnut*	•	•	●	○	▲	△
Blackgum	+	•	▲	△	▲	△
Blackjack oak	+		★		★	
Boxelder*	+	–	●	○	●	○
Bur oak	+	–	▼	▽	▼	▽
Cherrybark oak	•		★		★	
Chestnut oak	+	+	●	△	●	△
Cucumbertree*	•	–	▼	▽	▼	▽
Eastern hemlock	–	•	▼	▽	▼	▽
Eastern hophornbeam*	+	–	▲	△	▲	△
Eastern redcedar	•	–	▲	△	▲	△
Eastern white pine	–	•	▼	▽	▼	▽
Flowering dogwood	•	–	▲	○	▲	△
Gray birch*	•	–	▼	▽	▼	▽
Hackberry	+	–	▼	▽	●	○
Jack pine	+	–	▼	▽	▼	▽
Loblolly pine	•	–	▲	△	▲	△
Mockernut hickory	+	•	▲	△	▲	△
Northern pin oak	+	–	▼	▽	▼	s
Northern red oak	+	+	●	△	●	△
Osage-orange	+	–	▼	▽	▲	△
Paper birch	•	–	▼	▽	▼	▽
Pignut hickory	•	•	▲	△	▲	△
Pin cherry*	•	–	▼	▽	▼	▽
Pitch pine	•	•	▼	▽	▼	▽
Post oak	+		★		★	
Quaking aspen	•	–	▼	▽	▼	▽
Red maple	+	+	▼	△	▼	△
Red pine	–	–	▼	▽	▼	▽
Red spruce	–	–	▼	▽	▼	▽
Sassafras*	•	•	▲	△	▲	△
Scarlet oak	•	•	▲	△	▲	△
Serviceberry*	•	–	▼	▽	▼	▽
Shagbark hickory	•	•	▲	△	▲	△
Shortleaf pine	•		★		★	
Silver maple*	+	–	▼	▽	●	○
Slippery elm*	•	–	●	▽	●	▽
Southern red oak	+		★		★	
Striped maple	•	–	▼	▽	▼	▽
Sugar maple	+	•	●	△	●	△
Sweet birch	–	+	▼	▽	▼	▽
Sweetgum	•		★		★	
Sycamore*	•	–	▲	○	▲	△
Tamarack (native)	–	–	▼	▽	▼	▽
Virginia pine	•	•	▲	△	▲	△
Water oak	•		★		★	
White ash	–	•	●	▽	●	▽
White oak	+	•	▲	△	▲	△
White spruce	•	–	▼	▽	▼	▽
Willow oak*	•		★		★	
Winged elm	•		★		★	
Yellow birch	•	–	▼	▽	▼	▽
Yellow-poplar	+	•	▲	△	▲	△

Figure B2. Table summarizing adaptability, abundance, habitat change, and capability rankings under low (RCP 4.5) and high (RCP 8.5) climate change scenarios for tree species in Pennsylvania subregion 4. Species marked with an asterisk (*) have low model reliability. *Source: NIACS Climate Change Projections for Individual Tree Species in Pennsylvania: Ridge and Valley (Pennsylvania Subregion 4; NIACS 2021a).*

The species in Subregion 4 with low adaptability, rare abundance, decreasing suitable habitat between current and future conditions, and poor capability to cope or persist with climate change (under both RCP 4.5 and 8.5) include black ash (*Fraxinus nigra*), eastern hemlock (*Tsuga canadensis*), eastern white pine (*Pinus strobus*), red pine (*Pinus resinosa*), red spruce (*Picea rubens*), serviceberry (*Amelanchier laevia*), sweet birch (*Betula lenta*), and tamarack (*Larix laricina*).

The species in Subregion 4 (under both RCP 4.5 and 8.5) with high adaptability, good abundance, increasing suitable habitat, and a good capability of coping or persisting with climate change include blackgum (*Nyssa sylvatica*), mockernut hickory (*Carya tomentosa*), eastern hophornbeam (*Ostrya virginiana*), yellow-poplar (*Liriodendron tulipifera*).

Table B2. Summary of likely species overall ability of the species to cope or persist under future climate conditions, based on NIACS rankings of capability for species in Pennsylvania subregion 4.

CLIMATE CHANGE CAPABILITY		
Poor Capability		
American hornbeam	Cucumbertree	Pine, jack
Ash, black	Cherry, Pin	Pine, pitch
Ash, white	Elm, slippery	Pine, red
Aspen, bigtooth	Fir, balsam	Serviceberry
Aspen, quaking	Hemlock, eastern	Spruce, red
Birch, gray	Maple, striped	Spruce, white
Birch, paper	Oak, bur	Tamarack (native)
Birch, sweet	Oak, northern pin	
Birch, yellow	Pine, eastern white	
Fair Capability		
Boxelder	Cherry, black	Hickory, bitternut
Good Capability		
Basswood, American	Hickory, shagbark	Oak, scarlet
Beech, American	Hophornbeam, eastern	Oak, white
Blackgum	Locust, black	Pine, loblolly
Ceder, eastern red	Maple, red	Pine, Virginia
Dogwood, flowering	Maple, sugar	Poplar, yellow
Elm, American	Oak, black	Sassafras
Hickory, mockernut	Oak, chestnut	Sycamore
Hickory, pignut	Oak, northern red	Walnut, black
New Habitat with Migration Potential		
Elm, winged	Oak, post	Oak, water
Oak, blackjack	Pine, shortleaf	Oak, willow
Oak, cherrybark	Oak, southern red	Sweetgum

Subregion 5: Piedmont

Species	Adapt	Abun	Low Climate Change (RCP 4.5) Habitat Change	Low Climate Change (RCP 4.5) Capability	High Climate Change (RCP 8.5) Habitat Change	High Climate Change (RCP 8.5) Capability
American basswood	•	–	▲	△	▲	△
American beech	•	–	▲	△	▲	△
American elm	•	–	▲	○	▲	△
American hornbeam*	•	–	●	▽	▲	○
Bald cypress	•		★		★	
Bigtooth aspen	•	–	▼	▽	▼	▽
Bitternut hickory*	+	–	▲	△	▲	△
Black cherry	–	•	●	▽	▼	▽
Black locust*	•	•	●	○	▲	△
Black oak	•	•	▲	△	▲	△
Black walnut*	•	•	▼	▽	▼	▽
Black willow*	–	–	▼	▽	●	▽
Blackgum	+	•	▲	△	▲	△
Blackjack oak	+		★		★	
Boxelder*	+	•	●	△	▲	△
Cherrybark oak	•		★		★	
Chestnut oak	+	•	●	△	▼	○
Common persimmon*	+	–	●	○	▲	△
Eastern hemlock	–	–	▼	▽	▼	▽
Eastern redcedar	•	•	▲	△	▲	△
Eastern white pine	–	•	▼	▽	▼	▽
Flowering dogwood	•	–	▲	△	▲	△
Green ash*	•	•	●	○	▲	△
Hackberry	+	–	▼	▽	●	○
Jack pine	+	–	▼	▽	▼	▽
Loblolly pine	•	–	▲	△	▲	△
Mockernut hickory	+	•	▲	△	▲	△
Northern red oak	+	•	▲	△	●	△
Osage-orange	+	–	▼	▽	▼	▽
Pignut hickory	•	•	▲	△	▲	△
Pin oak*	–	–	▲	▽	▲	▽
Pitch pine	•	–	▼	▽	▼	▽
Post oak	+		★		★	
Quaking aspen	•	–	▼	▽	▼	▽
Red maple	+	+	●	△	▼	△
Red mulberry*	•	–	▼	▽	▼	▽
Redbay*	+		★		★	
Sassafras*	•	•	▲	△	▲	△
Scarlet oak	•	•	▲	△	▲	△
Shagbark hickory	•	•	▲	△	●	○
Shortleaf pine	•		★		★	
Silver maple*	+	–	●	○	▲	△
Sugar maple	+	•	▲	△	▲	△
Swamp tupelo	–		★		★	
Swamp white oak*	•	–	▼	▽	▼	▽
Sweet birch	–	•	▼	▽	▼	▽
Sweetbay	•		★		★	
Sweetgum	•	•	▲	△	▲	△
Virginia pine	•	–	▲	△	▲	△
Water oak	•		★		★	
Water tupelo	–		★		★	
White ash	–	•	▼	▽	▼	▽
White oak	+	•	▲	△	▲	△
White spruce	•	–	▼	▽	▼	▽
Winged elm	•		★		★	
Yellow birch	•	–	●	▽	●	▽
Yellow-poplar	+	•	●	△	▼	○

Figure B3. Table summarizing adaptability, abundance, habitat change, and capability rankings under low (RCP 4.5) and high (RCP 8.5) climate change scenarios for tree species in Pennsylvania subregion 5. Species marked with an asterisk (*) have low model reliability. *Source: NIACS Climate Change Projections for Individual Tree Species in Pennsylvania: Piedmont (Pennsylvania Subregion 5; NIACS 2021b).*

The species in Subregion 5 (under both RCP 4.5 and 8.5) with low adaptability, rare abundance, decreasing suitable habitat between current and future conditions, and poor capability to cope or persist with climate change include bigtooth aspen (*Populus grandidentata*), eastern hemlock (*Tsuga canadensis*), eastern white pine (*Pinus strobus*), sweet birch (*Betula lenta*), and white ash (*Fraxinus americana*).

The species in Subregion 5 (under both RCP 4.5 and 8.5) with high adaptability, good abundance, increasing suitable habitat, and a good capability of coping or persisting with climate change include bitternut hickory (*Carya cordiformis*), blackgum (*Nyssa sylvatica*), mockernut hickory (*Carya tomentosa*), white oak (*Quercus alba*).

Table B3. Summary of likely species overall ability of the species to cope or persist under future climate conditions, based on NIACS rankings of capability for species in Pennsylvania subregion 5.

Climate Change Capability		
	Poor Capability	
Ash, white	Hemlock, eastern	Pine, pitch
Aspen, bigtooth	Pine, jack	Spruce, white
Aspen, quaking	Mulberry, red	Walnut, black
Birch, sweet	Oak, pin	Willow, black
Birch, yellow	Oak, swamp white	
Cherry, black	Osage-orange	
	Mixed Results	
Hackberry	Hornbeam, American	Poplar, yellow
Hickory, shagbark	Oak, chestnut	
	Good Capability	
Ash, Green	Elm, American	Oak, black
Basswood, American	Hickory, bitternut	Oak, northern red
Beech, American	Hickory, mockernut	Oak, scarlet
Blackgum	Hickory, pignut	Oak, white
Boxelder	Locust, Black	Pine, loblolly
Cedar, eastern red	Maple, red	Pine, Virginia
Common persimmon	Maple, silver	Sassafras
Dogwood, flowering	Maple, sugar	Sweetgum
	New Habitat with Migration Potential	
Cypress, bald	Oak, post	Sweetbay
Elm, winged	Oak, water	Tupelo, swamp
Oak, blackjack	Pine, shortleaf	Tupelo, water
Oak, cherrybark	Redbay	

Appendix C: Climate Change Impacts on Plant Hardiness Zones

Plant hardiness zones (PHZ) show the extent of overwintering stress due to cold temperatures that plants experience in a particular region. As winter temperatures continue to rise, PHZ will shift. Historically (1980-2009), southeastern Pennsylvania and the state of New Jersey have been in PHZ 7 with an annual minimum winter temperature range of -17.7 to -12.2°C (0 to 10°F; Figure C1). Mid-century (2040-2069) projections under a moderate emissions scenario (RCP 4.5) show that most of southeastern Pennsylvania will remain in PHZ 7 with parts of Delaware and Philadelphia counties in Pennsylvania and Salem County in New Jersey changing to PHZ 8 (Figure C2). Under a high-emissions scenario (RCP 8.5), southeastern Pennsylvania and most of the state of New Jersey will shift into PHZ 8 (annual minimum winter temperature range of -12.1 to -6.7°C / 10 to 20°F) by mid-century. However, Luzerne, Lackawanna, and Monroe counties will remain in PHZ 7 (Figure C2).

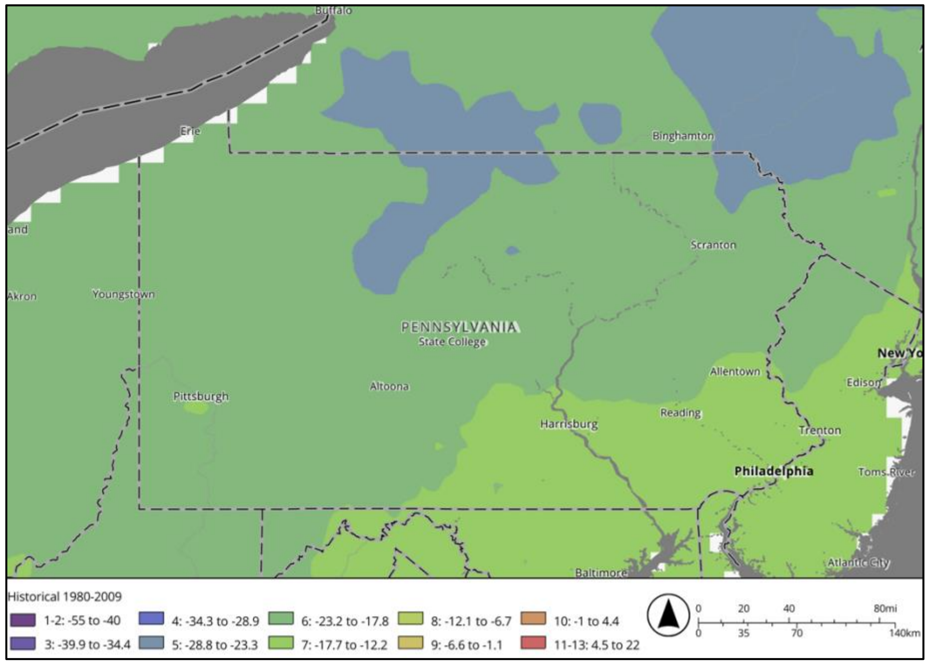

Figure C1: Historical (1980-2009) plant hardiness zones for the state of Pennsylvania. Next to each zone number is a temperature range in degrees Celsius that indicate the range of annual minimum winter temperatures for that zone. *Source: Assessing Potential Climate Change Pressures across the Conterminous United States: Mapping Plant Hardiness Zones, Heat Zones, Growing Degree Days, and Cumulative Drought Severity throughout this Century (Matthews et al. 2018)*

End-of-century projections (2070-2099) for RCP 4.5 show a change to PHZ 8 from PHZ 7 for parts of Chester, Delaware, Philadelphia, and Bucks counties in Pennsylvania as well as for Salem and Cumberland counties in New Jersey. Under RCP 8.5, all of southeastern Pennsylvania will change to PHZ 8 with parts of Chester, Delaware, and Philadelphia counties in Pennsylvania and Salem and Cumberland counties in New Jersey changing to PHZ 9 (annual minimum winter temperature range of -6.6 to -1.1°C / 20 to 30°F) by the end of the century (Figure C2).

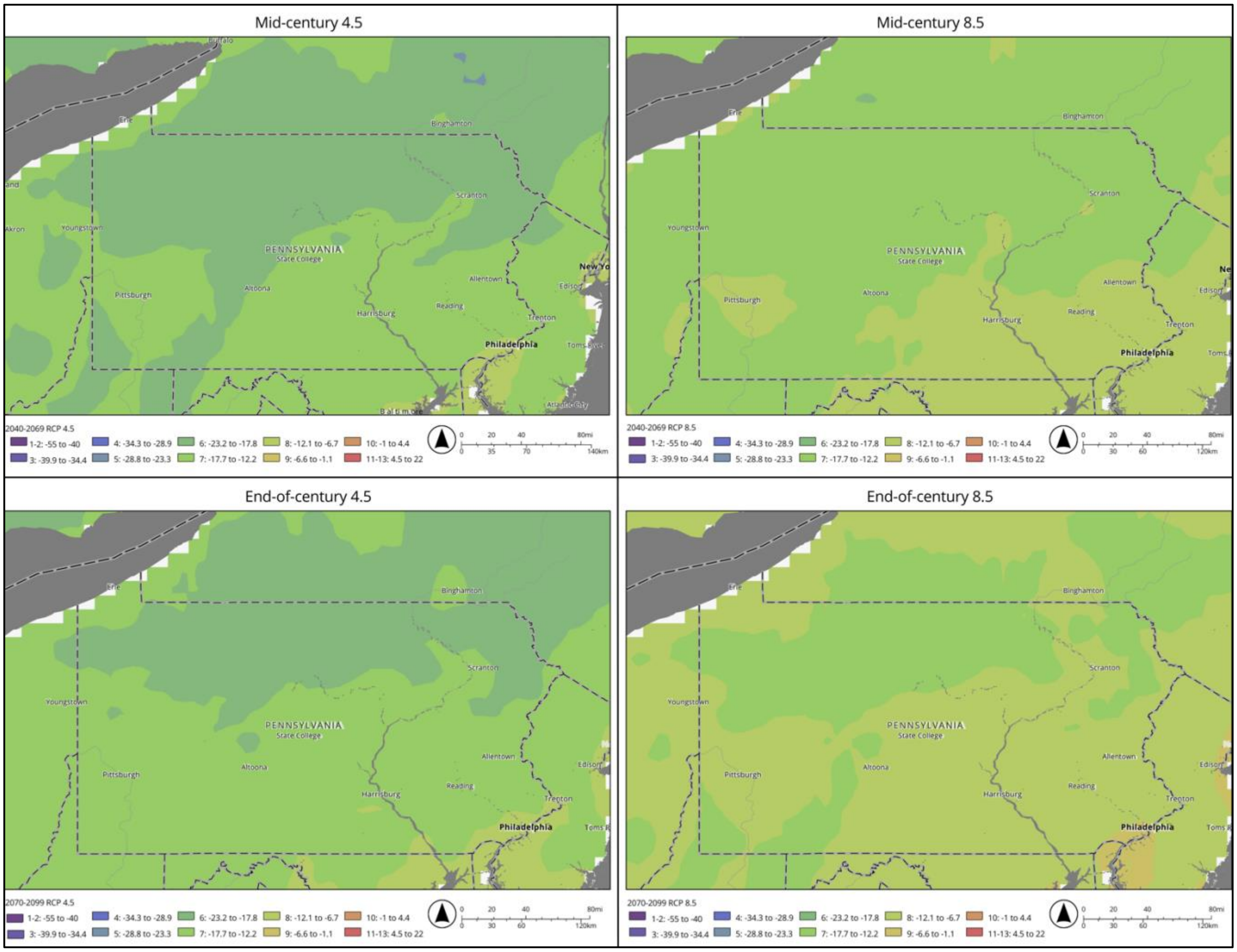

Figure C2: Projections of change in plant hardiness zones for the state of Pennsylvania for mid-century (2040-2069) and end-of-century (2070-2099) under RCP 4.5 and RCP 8.5 scenarios. Next to each zone number is a temperature range in degrees Celsius that indicates the annual minimum winter temperatures range for that zone. *Source: Assessing Potential Climate Change Pressures across the Conterminous United States: Mapping Plant Hardiness Zones, Heat Zones, Growing Degree Days, and Cumulative Drought Severity throughout this Century (Matthews et al. 2018).*

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