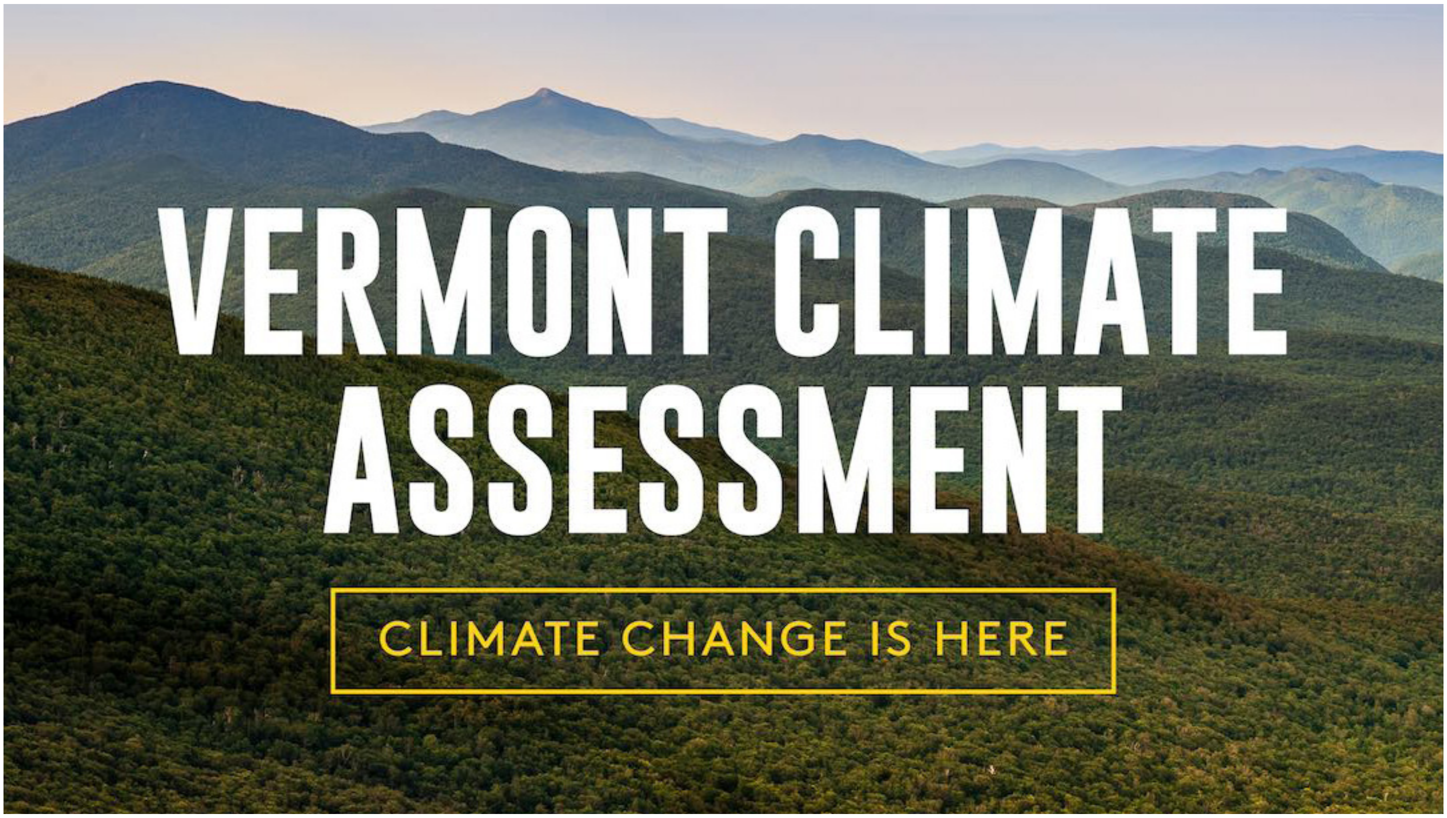

EXECUTIVE SUMMARY

RECOMMENDED CITATION

Galford, G.L., Faulkner, J., Dupigny-Giroux, L.-A., Posner, S. and Edling, L. (eds.) (2021). The Vermont Climate Assessment 2020. Gund Institute of Environment, University of Vermont, Burlington, VT. DOI: 10.18125/kowgvg. Accessed online at vtclimate.org

> **"The impacts of climate change are already being felt in communities across the country."**
>
> -Fourth National Climate Assessment, U.S. Global Change Research Program, 2018

The Earth's climate is changing. Data for the past several decades show long-term shifts in temperature, precipitation, and the risks of certain types of severe weather. As climate change unfolds, it is important to understand the impacts globally and locally here in Vermont.

The Vermont Climate Assessment 2021 (VCA) assesses the science of climate change and its impacts across Vermont. The VCA examines what climate change means for different sectors in Vermont and summarizes what we know about possible climate futures. It represents our current best understanding of climate change in Vermont.

This executive summary is a high-level overview of the underlying report. The VCA highlights the following main findings.

CLIMATE CHANGE IS HERE.

There is strong evidence that Vermont's climate is changing. Vermont is becoming warmer (average annual temperature is about 2°F warmer since 1900), and Vermont's winters are becoming warmer more quickly (winter temperatures have warmed 2.5x more quickly than average annual temperature since 1960). Vermont is also becoming wetter (average annual precipitation has increased by 21% or 7.5 inches since 1900). However, Vermont still experiences prolonged droughts because of shifts in the water cycle, and different regions of Vermont can experience different climate impacts. The data for Vermont mirror trends at the regional, national, and global scale.

CLIMATE CHANGE IS IMPACTING COMMUNITIES ACROSS VERMONT. PEOPLE ARE RESPONDING.

Climate change is transforming people's lives in Vermont, now and in the future. This report and others like it are increasingly documenting climate risks and vulnerabilities. For example, rivers overflowing from more rain increases risks of flooding that can damage homes, roads, bridges, and farm fields. Heavier rainstorms impact farm and forestry operations. Climate change affects people's recreation year-round: Vermont's ski season is shorter, spring activities are disrupted by more rain than in the past, and summer recreation faces increased risk of harmful algal blooms in lakes. And climate-related health impacts – greater risk of heat exposure, water and air quality issues, and natural disasters – threaten some parts of the population more than others, highlighting the unequal burden of climate impacts for people who are over 65, of low socioeconomic status, or have previous health issues. People are responding, for example by resizing culverts, riding snowmobiles less, storing piles of snow in attempts to extend the Nordic ski season, and managing water differently in farm fields. In planning for climate impacts, communities cannot assume that future climate conditions will resemble the past.

THERE ARE INTERACTIONS AMONG CLIMATE IMPACTS.

Multiple stressors can stack up to have an outsized effect on people and nature. Continuing to study these issues will help us understand how multiple, interacting factors will affect strategies designed to lessen climate impacts. For example, drought plus the spread of invasive pests could interact to stress trees and diminish the ability of forests to capture and store carbon from the atmosphere. We can anticipate some interactions among climate impacts; we will be surprised by other interactions that are difficult to predict. Interactions could push natural systems past tipping points, or limits in long-balanced ecosystems after which drastic changes lead to completely different systems. The long-term, persistent, and complex nature of climate change can also intensify other stresses on society, such as managing public health crises or confronting social inequities.

THE VCA 2021 UPDATES – AND IS LARGELY CONSISTENT WITH – THE ORIGINAL VCA 2014 STUDY.

The 2021 report builds from pioneering work completed in VCA 2014, the first state-level climate assessment in the U.S. Conclusions between the 2014 and 2021 reports are consistent. With additional data and new tools for visualizing climate change, the VCA 2021 finds:

- Vermont's average annual temperature increase since 1960 is 1.47°F compared to the previous estimate of 1.3°F.
- Vermont's average annual precipitation increase since 1960 is 6.71 inches compared to the previous estimate of 5.9 inches.

The VCA 2021 features new data that provide further evidence of warming in Vermont, including plots that show fewer cold days (max temperature less than or equal to 0°F) and more warm winter days (max temperature greater than or equal to 50°F during winter months). VCA 2021 incorporates new data to show how Vermont is experiencing 2.4 more days of heavy precipitation since 1960 (days with precipitation greater than or equal to 1 inch).

INFORMATION ABOUT CLIMATE IMPACTS IS VALUABLE FOR VERMONT DECISION MAKERS.

Planning for climate change requires sound scientific evidence. The VCA provides information on climate change and its impacts at scales relevant to policy and decision making. The information in this report can inform many decision makers in Vermont, from individual farmers to town highway departments to regional planning councils to state agencies. Bringing global and national climate assessment techniques to the state-level equips local stakeholders to make decisions based on scientific data. For example, the Vermont Climate Council is responding to concerns about Vermont's changing climate. Without action and investment, climate-related impacts and risks will continue to grow for current and future generations.

THE FOLLOWING KEY MESSAGES SUMMARIZE THE EVIDENCE AND MAIN FINDINGS FROM THE VCA 2021 REPORT.

1 CLIMATE CHANGE IN VERMONT

1.1 Vermont's annual average temperature has increased by almost 2°F (1.11°C) since 1900. Winter temperatures have increased 2.5 times faster than annual temperatures over the past sixty years, and the number of very cold nights has decreased by over seven days in the same time period.

1.2 Average annual precipitation in Vermont has increased by 21% since 1900 and has become more variable in the last decade. Annual snowfall has been decreasing since the 1960s, yet winter precipitation has increased, suggesting that more winter precipitation is falling as rain.

1.3 Vermont's freeze-free period has lengthened by three weeks since 1960; the trend has accelerated to an increase of nine days per decade since 1991.

1.4 On average, lakes and ponds across Vermont are icing-out one to three days earlier per decade since the 1970s and 1980s.

1.5 Extreme weather events such as droughts and floods are expected to continue to increase with climate change. Vermont experiences 2.4 more days of heavy precipitation than in the 1960s, most often in summer.

2 CLIMATE CHANGE IN FORESTS

2.1 Climate change is beginning to shift growing conditions for forests in Vermont, with greater changes expected to come, becoming more favorable for southern-adapted tree species and less favorable for currently adapted tree species. Species that will benefit from this change include northern red oak, shagbark hickory, and black cherry, while species including sugar maple, balsam fir, yellow birch, and black ash will be negatively impacted. While growing conditions will be significantly different by 2100, actual change in forest makeup will follow a delay as older trees die and are replaced by young ones.

2.2 Forest productivity, an important indicator of forest health and carbon storage, is amplified by a longer growing season and greater atmospheric carbon dioxide (CO2) and is expected to increase in Vermont in the next 50–100 years. However, productivity will be highly variable by species and will likely begin to decrease by the end of the century as high summer temperatures, drought, and soil nutrient loss outweigh benefits.

2.3 Climate change is expected to continue exacerbating the threats that invasive plants, insects, and diseases already pose to the health of Vermont's forests. These threats are compounded by other climate-related factors, such as worsening storms and increasingly irregular precipitation.

2.4 Warmer winters and wetter summers already limit active forest management by shortening the time frames that forest operations can take place. These negative climate impacts are projected to strengthen in the future, potentially leading to cascading negative effects on rural economies, forest product markets, and management for forest health and climate adaptation.

2.5 Land use change and parcelization, most commonly conversion of forests to residential or commercial use, is a persistent trend in Vermont, a major threat to forest health and productivity, and a contributor to climate change.

2.6 As climate change impacts forest ecosystem function, there is a need for management to increase forest adaptive capacity. Current methods to achieve increased adaptive capacity at the ecosystem level (retaining ecosystem function despite threats to individual tree species or forest types) include increasing forest structural complexity and enhancing compositional and functional diversity and redundancy.

2.7 Climate change impacts will be more severe for urban trees because of the effects of the built environment on temperature and water cycling, as well as additional stressors associated with urbanized areas like soil compaction, soil fertility, and pollution.

2.8 Urban trees will be increasingly important to humans because of the services they provide. While urbanized areas in Vermont make up less than 2% of the state's land area, they are home to nearly 243,000 people, 39% of the Vermont population. Because of the high population density and lower tree cover in urbanized areas, per-tree ecosystem services can be higher than in a forest setting. In addition to critical climate and ecosystem benefits provided by trees everywhere, urban trees mitigate the urban heat island effect through cooling and shading and reduce stormwater runoff from extreme rainfall events

3 WATER RESOURCES

3.1 Due to extreme variation in precipitation with our changing climate, periods of prolonged dry-spells and drought, coupled with higher water usage in snowmaking and agriculture could exacerbate low water availability.

3.2 Increases in overall precipitation, and extreme precipitation, have caused streamflows to rise since 1960. Climate change will further this pattern, although the overall increase in streamflow comes with disruptions in seasonal flows cycles.

3.3 Increases in heavy precipitation jeopardize water quality in Vermont. Storms produce large runoff events that contribute to erosion and nutrient loading. Combined with warm temperatures, this creates favorable conditions for cyanobacteria blooms.
3.4 Increased occurrence of high streamflows increase the risk of flooding that causes damages to many roads and crossing structures. Risk reduction requires addressing outdated and unfit structures.
3.5 Nature-based solutions are an effective, low-cost approach to climate change adaptation. River corridor, floodplain, and wetland protection dampen flood impacts and improve water quality along with green infrastructure.

4 FISH AND WILDLIFE IN VERMONT

4.1 As climate change worsens, 92 bird species of Vermont, including the iconic common loon and hermit thrush, are expected to disappear from the landscape within the next 25 years.
4.2 Increasing warming trends are expected to result in an increase in white-tailed deer population and a mirrored decrease in moose population, which may have long-term impacts on Vermont's forest composition. Managing social systems (e.g. hunting) to account for changing public tolerance and demand for deer may provide one avenue to minimize this risk if undertaken proactively.
4.3 As warming trends reduce the severity of winters, the subsequent warming waters will have adverse effects on lake and river systems, including increased risk for harmful algal blooms (HABs) and reduced overall biodiversity and health in lake ecosystems.

5 AGRICULTURE AND FOOD SYSTEMS

5.1 Vermont's climate is already changing in ways that benefit its agricultural system, including longer growing periods (freeze-free periods lengthened twenty-one days since early 1900s) and milder temperatures (annual average temperature increase of 2°F (1.1°C) since the 1990s), allowing farmers to experiment with new crops or practices not previously viable in Vermont.
5.2 The changing climate also brings agricultural setbacks, such as negative impacts on fruit-bearing species like apple trees that require a sufficient over-wintering period for success in the next growing season. The maple syrup industry is also at risk due to variations in winter temperatures.
5.3 Climate models predict tougher growing conditions due to greater variability in temperature and precipitation, including heavy precipitation and dry spells.
5.4 Vermont's average annual precipitation has increased 6.7 inches since the 1960s. Summer precipitation has increased most (additional 2.6 inches since 1960s) and is characterized by more heavy precipitation events (defined as more than one inch of precipitation in one day) (additional 1.0 day/year), although spring precipitation has also increased notably (additional 2.11 inches/year since

1960s, and 0.8 days/year with heavy precipitation). Spring precipitation accumulates in the soil and can make farm operations difficult. While precipitation during the growing season is trending upward, precipitation falls in fewer, more extreme events and is coupled with longer periods of no rain at times when crop water requirements are still high; thus, irrigation may become increasingly important.

5.5 At the Earth's surface, increasing concentrations of carbon dioxide may benefit yields in crops that utilize the C3 photosynthetic pathway (i.e., many of Vermont's forages) if conditions are otherwise ideal. Conversely, an increase in surface-level ozone concentrations may reduce crop productivity.

5.6 Extreme events are expected to increase. More periods of flooding and drought will lead to more crop damage or failure. Stormwater and irrigation infrastructure will be crucial in mitigating these effects.

5.7 Agriculture and food systems may play an important role in mitigating climate change, if mitigation provides financial opportunities, are distributed fairly and accurately, and are implemented with careful monitoring, reporting, and verification. Urban and suburban areas in Vermont have the potential to improve adaptation and mitigation of climate change by growing food closer to where it is consumed.

6 ENERGY

6.1 Vermont drivers have the highest average miles traveled per capita in the Northeast United States. Transportation is the largest source of greenhouse gas emissions in Vermont. Thermal energy use is a close second to the largest source of greenhouse gas emissions in Vermont, and the largest use of energy. Reducing energy use in these sectors by choosing more efficient vehicles, selecting heat sources with less emissions, and weatherizing homes will help Vermont meet its energy goals.

6.2 The electricity in Vermont has the lowest carbon intensity in the country. Electrifying transportation and thermal energy use will significantly reduce Vermont's carbon footprint.

6.3 In the short term, there is extra power line capacity to serve significantly more load in Vermont; however, some areas of Vermont have limited capacity to support further renewable energy generation. Areas where there is limited generation hosting capacity could be prioritized to shift local energy use to electricity to reduce congestion on local transmission lines. The priority in areas with extra generation hosting capacity can be two-fold: building new renewable generation and electrifying local energy use.

6.4 The storms that cause the most frequent power outages are expected to become more intense in the future, increasing the frequency of power outages, particularly in winter. Vermont can increase its energy resilience with distributed solar and storage, secondary heating systems (e.g., wood), and community buildings with resilient heating solutions.

7 RECREATION AND TOURISM

Winter

7.1 Downhill skiing, with the help of snowmaking, will likely remain largely viable in Vermont up until approximately 2050. By 2080, the Vermont ski season will be shortened by two weeks (under a low emissions scenario) or by a whole month (under a high emissions scenario), and some ski areas will remain viable.

7.2 Winter temperatures are increasing in Vermont, reducing the length of season for most snow sports.

7.3 February Median Flow, a measurement used by ski areas to collect water for snowmaking, has steadily increased across Vermont.

Summer

7.4 Summer recreation activities in Vermont will continue to be popular, with water-based activities likely to increase in interest as air temperatures rise. However, water quality issues will also become more prevalent.

7.5 Vermont may see an increase in summer “seasonal climate refugees” as the rise in temperatures nationwide draws visitors looking to escape extreme heat.

7.6 Vermont has the potential to increase tourism revenue via gastrotourism and agritourism as the growing seasons lengthen.

Fall/Spring

7.7 Transition seasons are becoming more important for tourism and recreation as Vermont is already experiencing warmer temperatures in fall and spring.

7.8 Trees, particularly sugar maples, are an important aspect of many fall/spring recreation activities (leaf peeping, maple syrup, apple picking), but may be negatively affected by warmer temperatures.

7.9 Fall and spring seasons offer new opportunities for lower-cost recreation and tourism opportunities that attract a wider range of potential visitors.

8 HUMAN HEALTH

8.1 Climate change affects human health by exacerbating existing health problems and amplifying conditions for new health problems.

8.2 Individuals who are children, over 65 years of age, of low socioeconomic status, Indigenous, or have previous health issues are more vulnerable to the health effects of climate change.

8.3 Warmer and more moist temperatures in Vermont are likely to create more habitat for disease-carrying ticks and mosquitoes.
8.4 Increases in the number and severity of natural disasters in Vermont will likely increase the risk of injury, illness, and death.
8.5 Climate change could affect the quality and safety of food and water, which could lead to increases in food and water-borne illnesses.
8.6 Decreases in air quality will exacerbate existing chronic diseases and decrease water quality.
8.7 Mental health is inextricably linked with environmental health. Impacts from climate change could contribute to mental health challenges.

9 COMMUNITY DEVELOPMENT

9.1 Flooding is the most likely natural disaster to occur in Vermont and should be accounted for in all community development and planning efforts in the state; however, extremes will become more common, so community development and planning efforts should also account for chronic hazards, such as drought.
9.2 Systems interconnections are essential to consider in community development and planning of future climate change scenarios, particularly in the context of disasters.
9.3 Vermont is expected to continue to have a favorable climate under future climate change projections, however, there is very little information to predict if the state will face an influx of climate migration.
9.4 Engaging in planning is essential for Vermont communities to access federal funding and to prepare for current and future climate change impacts, including population growth, flooding, and droughts.
9.5 Climate change will not impact all communities equally; the needs and capacity of vulnerable populations should be considered with all community planning efforts.

10 SPECIAL TOPIC: CARBON SEQUESTRATION IN AGRICULTURAL SOILS

10.1 The soil carbon sequestration potential of agricultural management practices in Vermont is uncertain and likely mediated by site-specific factors such as soil type, geography, land use history, and weather. Climate change mitigation benefits are possible but not guaranteed from the use of common practices implemented to sequester carbon (such as cover cropping, conservation tillage, no-till, and rotational grazing) on Vermont agricultural lands. There is evidence, however, that these practices can improve soil health and increase farm resilience to climate change.
10.2 Assigning carbon offsets or payments for climate mitigation services provided by Vermont agricultural lands based on practice adoption alone currently lacks a strong scientific foundation. Further investigation and monitoring is needed to improve understanding of management practices and soil

carbon sequestration, including field studies and modeling. Well-calibrated models, validated for application in Vermont, have potential for identifying relationships between management change(s) and carbon dynamics. Participatory research that engages the expertise and needs of farmers is necessary to assess the local impacts of best management practices and make projections into the future.

10.3 Whole-system accounting is required to assess potential trade-offs and to determine net climate change mitigation benefits of soil management strategies. Changes in soil carbon stocks at a given location are only one piece in climate mitigation accounting. In all cases where offsite carbon sources are being used to boost soil organic carbon, a broader life cycle assessment extending beyond the farm gate is needed that considers offsite carbon source removal, transport, and processing; alternative end uses of the carbon source; interactions with other soil GHG-producing processes; and synergies between the soil amendments and the input of in situ plant-derived carbon. It is critical to keep in mind the primary objective: increase the net transfer of CO2-equivalents from atmosphere to land – only strategies achieving this primary objective should be considered climate mitigation. Failing to account for other fluxes of carbon and greenhouse gases could result in unintended consequences due to trade-offs.