

# VERMONT FOREST INDICATORS DASHBOARD

Combining dozens of key datasets into a snapshot of the overall status of Vermont's forests



## Forest Indicators Dashboard Detailed Methods

Vermont Forest Indicators Dashboard V3.3

November 27, 2023



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## Preferred Dashboard Citation

Forest Ecosystem Monitoring Cooperative. 2323. Vermont Forest Indicators Dashboard. [Available at: <https://dev.vmc.w3.uvm.edu/nancy/indicators/vt?version=1701068609>]

## Preferred Methods Documentation Citation

Forest Ecosystem Monitoring Cooperative. 2323. Forest Indicators Dashboard: Detailed Methods. Vermont Forest Indicators Dashboard. [Available at: [https://dev.vmc.w3.uvm.edu/nancy/apps/indicators\\_dashboard/media/vermont\\_forest\\_indicators\\_dashboard\\_methods\\_1701068609.pdf](https://dev.vmc.w3.uvm.edu/nancy/apps/indicators_dashboard/media/vermont_forest_indicators_dashboard_methods_1701068609.pdf)]

The Forest Indicators Dashboard grew from a working group coordinated by Dr. Jennifer Pontius (University of Vermont, Forest Ecosystem Monitoring Cooperative) at the [2015 Annual Conference of the Vermont Monitoring Cooperative](#) (now Forest Ecosystem Monitoring Cooperative, FEMC). The aim was to develop a tool to be used by decision-makers, educators, and the general public to capture the condition of Vermont's forest ecosystem as well as provide a long-term context for those changes. Following this initial working group meeting, FEMC staff worked with collaborators within the FEMC network to identify datasets and establish criteria for scoring to be used in the Dashboard.

The Forest Indicators Dashboard has four indicator categories: Structure, Condition, Services, and Stressors. Within each of these categories, there are multiple indicator datasets that have been selected to best represent the category. The datasets selected characterize the forested ecosystem in objectively measurable ways and come from high quality, long-term sources. They are easily measured and available on a regular basis (preferably annual), and further, must come from sources with stable funding to ensure ongoing collection. The datasets that drive the Dashboard are dynamic, meaning that they are updated with new observations on a regular basis. The datasets within each of the four indicator categories are averaged based on a stakeholder-defined weighting, producing an Overall Score with a scale of 1 (impaired status) to 5 (optimum status).

#### *Structure*

Forest Structure is the horizontal and vertical arrangement of trees in a forest, as well as the pattern of forest cover on the landscape. Healthy forests have a diversity of species at all different stages of growth. Some of the indicators used are regeneration, species diversity, forest cover, and stand complexity.

#### *Condition*

Condition is the overall health and growth rate of the trees. The forest needs to persist into the future while responding to current environmental conditions. Metrics used to assess forest condition include tree growth, crown dieback, tree damage and mortality, and canopy greenness.

#### *Services*

Services are the goods that forested ecosystems provide such as timber, maple syrup, and recreational and hunting opportunities, and the functions that they perform such as supporting bird diversity and storing carbon.

#### *Stressors*

Stressors are forces or processes like changes in temperature or air pollution that can harm forests. Among the indicators contributing to this score are precipitation acidity, length of the growing season, ozone exposure, and invasive pests.

## *Overview and Terminology*

Metrics included in the Forest Indicators Dashboard were selected through an expert working group, as well as based on data availability and quality. We sought to include a limited number of datasets per category, while providing a robust assessment of forest health based on a suite of measurements.

Periodic values for each metric produce a current condition value for the most recent year of the data, such as the current forest growth rate or total annual precipitation. These values are translated into scores on a 1 to 5 scale to provide an estimate of whether things are getting 'better' or 'worse'. To generate the current year's score, this value is compared to a target value. For example, for Hardwood Regeneration, the current-year value is scored based on where it falls between the minimum and maximum hardwood regeneration values in the entire dataset, and the target is higher regeneration. Higher hardwood regeneration density in any year thus receives a higher score. Conversely, for maximum annual temperature, the current-year score is computed as the distance away from the long-term mean, as deviations away from historical patterns can negatively affect forests. The closer the value for a given year is to the long-term mean, the higher the score will be. More specific details on the target, maximum, and minimum values, as well as computational notes are included with each metric. For more information, refer to our [comprehensive methodology](#).

## *Important Notes*

**For many metrics, the computation of annual scores is dynamic.** This means that as new data becomes available and is added to the FID, previously calculated annual scores may change. If the annual scores are computed relative to the long-term mean, this addition of a new year of data could change the long-term mean and thus, the resultant annual scores. Because the scores could change from year to year, we offer snapshots of the dashboard over time, allowing you to [revisit previous versions of the dashboard](#).

**Computation of annual scores is often limited by data availability.** For some datasets, we may alter annual score computation to be more ecologically relevant. For example, we may change the annual score computation from a deviation from the long-term mean to a deviation from a baseline.

**We did not assess non-linear trends.** The significance of each long-term trend was tested using linear regression and a p-value threshold of 0.05.

The dropdown menu at the top of this tab provides detailed descriptions of our methodology used to process and analyze the datasets included in FID. For each, we describe the **data source**, the **data processing**, the

## target value, and computation of the annual score.

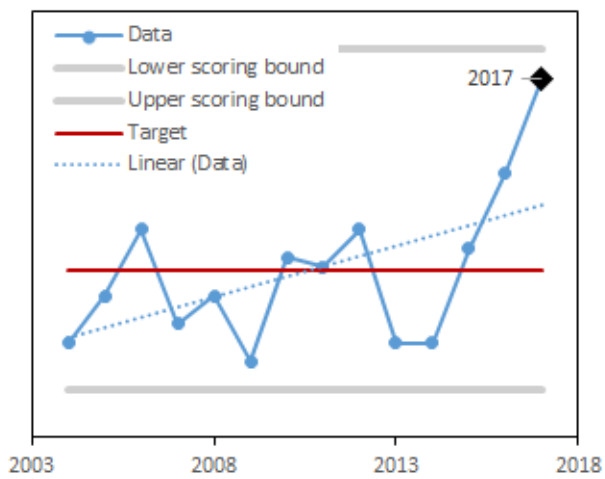
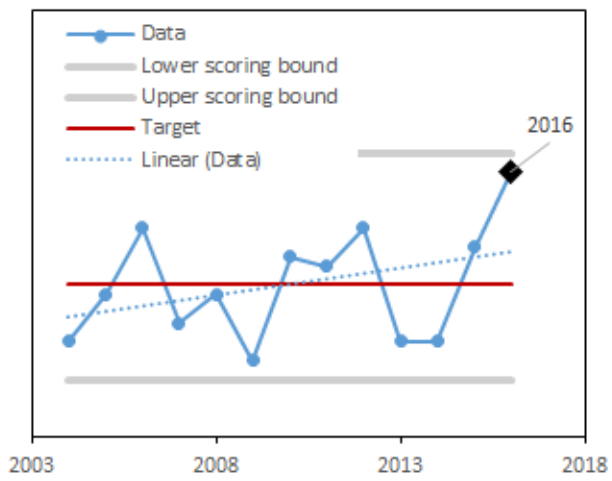
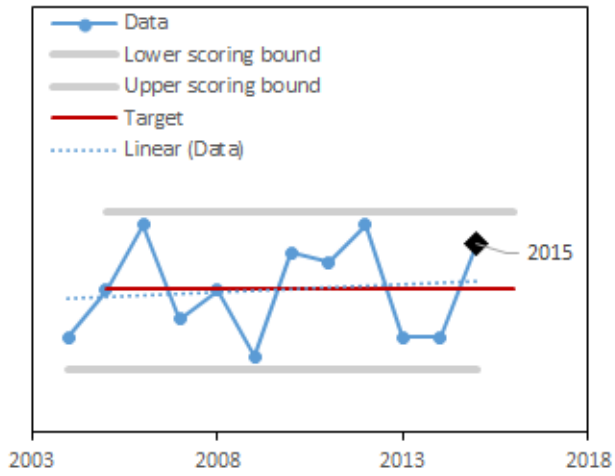
### *Terminology*

|                      |   |
|----------------------|---|
| Upper scoring bounds | The maximum value used for computing the annual score based on background knowledge and expert input. For some datasets, the upper scoring boards aligns with a predefined target or value (e.g., Shannon-Weiner Diversity Index of 3.5), while for other datasets, it is a bounding value based on the data range (e.g., maximum value plus 10% of the range). See example below for more information. |
| Lower scoring bounds | The minimum value used for computing the annuals score based on background knowledge and expert input. For some datasets, the lower scoring boards aligns with a predefined target or value (e.g., ozone exposure of 0 ppm-hour), while for other datasets, it is a bounding value based on the data range (e.g., minimum value minus 10% of the range). See example below for more information.        |
| Target               | The target value for the dataset is based on background knowledge and expert input. For some datasets, it can be the same as the upper or lower scoring bounds, while for other datasets, it is the long-term mean value. See example below for more information.   |
| Minimum              | The minimum value in the dataset  |
| Maximum              | The maximum value in the dataset  |

### *How Scores Can Change Over Time*

In the example below, we present graphs of data (blue solid line) and the trend of these data (blue dotted line) for three different time periods (2004-2015, 2004-2016, and 2004-2017). For these data, the target was set to be the long-term mean (red line). Notice that as new data are added each year (moving from 2015-2017 in the figures below), the target dynamically changes. The upper and lower scoring bounds (grey lines) were set to be the minimum value in the dataset -10% of the range and the maximum value in the dataset +10% of the range, respectively. Like for the target, as new data are included each year, these bounding values also change. In the example below, values for 2016 and 2017 are higher than in the rest of the dataset, so that the

upper scoring bound increases as these years of data are added.



## CONDITION

### **Crown Dieback**

Crown dieback is a visual assessment of the percentage of the tree's crown that has recent fine twig mortality. Crown dieback has been assessed annually on Vermont Forest Health Monitoring<sup>1</sup> (FHM, a collaboration between FEMC and VT FPR) and North American Maple Project (NAMP) plots<sup>2</sup>. For the FHM program, plots have been assessed annually since 1994, but between 2008 and 2013, plots were assessed on a 3-year rotation. To generate values for the missing years of 2009 and 2012, we used the average dieback from 2008-2010 and 2011-2013, respectively. FHM dieback scores were averaged per plot per year of survey data for dominant and codominant trees of all species. NAMP plots have assessed on an annual basis, beginning in 1988. While maple species are the focus of the NAMP project, co-occurring species have also been assessed. To approach the unequal species composition on NAMP plots, we selected only those plots where dominant and codominant trees were less than 80% sugar maple. We averaged dieback within species in a plot prior to averaging across plots. We then computed the mean crown dieback for all species across all plots per year in NAMP. From these two data sources, we computed an overall mean crown dieback for all species for each year by taking the mean of the NAMP and FHM yearly dieback averages. For crown dieback, the target was set as the long-term mean. We computed the current year score as the distance between the target and the upper scoring bounds (maximum value in the dataset plus 10% of the range), scaled to be between 1 and 5. Values below the target were scored as 5.

#### Citation:

<sup>1</sup> Pontius J., S. Wilmot. 2017. Forest Health Monitoring. FEMC. Available at:

<https://www.uvm.edu/femc/data/archive/project/forest-health-monitoring>

<sup>2</sup> Wilmot, S., Halman, J. 2018. North American Maple Project. Vermont Department of Forest Parks and Recreation.

### **Forest Damage**

Insect and Disease Surveys (IDS) are annual aerial surveys of forests conducted by the State of Vermont and the USDA Forest Service to map forest disturbance, including damage caused by insects, diseases, fire, and weather events<sup>1</sup>. While the program has been conducted for many decades in Vermont, the first year of digitally available data was 1995. This metric is computed as a sum of forest area identified with visible damage in a given year (excluding any areas identified as current-year mortality) that has occurred since the previous survey. We set the target for this dataset to be the minimum value in the dataset minus 10% of the

range. The current year is scored as the difference between the target and the upper scoring bounds (maximum value in the dataset plus 10% of the range), scaled to be between 1 and 5.

Citation:

<sup>1</sup> USDA Forest Service. Forest Health Protection.

<https://www.fs.fed.us/foresthealth/applied-sciences/mapping-reporting/detection-surveys.shtml>

## **Forest Mortality**

Insect and Disease Surveys (IDS) are annual aerial surveys of forests conducted by the state of Vermont and the USDA Forest Service to map areas of tree mortality<sup>1</sup>. While the program has been conducted for many decades in Vermont, the first year of digitally available data is 1995. This metric is computed as a sum of total area mapped with visible mortality in a given year that has occurred since the previous survey. We set the target for this dataset to be lowest possible acreage (either the minimum value in the data minus 10% of range or 0, whichever was greater). The current year is scored as the difference between the target and the upper scoring bounds (maximum value in the dataset plus 10% of the range), scaled to be between 1 and 5.

Citation:

<sup>1</sup> USDA Forest Service. Forest Health Protection.

<https://www.fs.fed.us/foresthealth/applied-sciences/mapping-reporting/detection-surveys.shtml>

## **Canopy Density**

Using MODIS phenology remote sensing products, we selected the Time Integrated (TIN) Normalized Difference Vegetation Index (NDVI) to quantify maximum canopy greenness over a growing season<sup>1</sup>. Available TIN images began in 2001. We first excluded all pixels with a value of either 0 where no chlorophyll was detected throughout the growing season, or 255 for water or areas of no data. Using National Land Cover Dataset (2011), we created a forest cover layer by masking out all non-forest pixels (i.e. those not identified as forest/woody wetlands [values 41, 42, 43, 90]). We used this forest mask to compute the mean TIN and standard deviation of the mean TIN across all forest-cover pixels per year. We set the target for this dataset as the maximum value. The current year was scored based on where it falls between zero and the target, scaled to be between 1 and 5.

Citation:

<sup>1</sup> MODIS Phenology Metrics. 2019. <https://modis.gsfc.nasa.gov/>. Imagery available at:

<https://earthexplorer.usgs.gov>



## Damage and Decay

Data on tree damage and decay were extracted from the USFS Forest Inventory and Analysis (FIA) Program EVALIDator<sup>1</sup>. We used an FIA-established query to retrieve the number of live trees (“0004 Number of live trees (at least 1 inch d.b.h./d.r.c.), in trees, on forest land”) filtered by trees 5 inch DBH (“and DIA>=5”). We computed tree damage and decay as any living tree 5 inch DBH with a recorded damage agent (“and DAMAGE\_AGENT\_CD1>0”) <sup>2</sup>. We set the target for this dataset as the long-term mean. The current year is scored for where it falls between the target and the upper scoring bounds (maximum value in the dataset plus 10% of the range) or the lower scoring bounds (minimum value in the dataset minus 10% of the range), scaled to be between 1 and 5.

### Citation:

<sup>1</sup> USDA Forest Service. 2019. FIA EVALIDator. Available at: <https://apps.fs.usda.gov/Evalidator/evalidator.jsp>

<sup>2</sup> USDA Forest Service. 2018. Forest Inventory and Analysis Glossary. Available at: <https://www.nrs.fs.fed.us/fia/data-tools/state-reports/glossary/default.asp>

## Tree Growth

Data on tree growth were extracted from the USFS Forest Inventory and Analysis Program EVALIDator<sup>1</sup>. We used an FIA-established query (“Average annual net growth of sound bole volume of trees (at least 5 inches d.b.h./d.r.c.), in cubic feet, on forest land”) for net growth of live trees 5 inch DBH on sampled P1 plots. The first usable panel is for the year 2008. We relied on FIA’s statistical models for computing this value over time. We set the target for this dataset as the long-term mean. The current year is scored for where it falls between the target and the upper scoring bounds (maximum value in the dataset plus 10% of the range) or the lower scoring bounds (minimum value in the dataset minus 10% of the range), scaled to be between 1 and 5.

### Citation:

<sup>1</sup> USDA Forest Service. 2019. FIA EVALIDator. Version 1.8.0.01. Available at: <https://apps.fs.usda.gov/Evalidator/evalidator.jsp>

## Tree Mortality

Data on annual tree mortality were extracted from the USFS Forest Inventory and Analysis Program EVALIDator<sup>1</sup>. We used FIA-established queries to retrieve volume estimates for tree mortality (“0213 Average annual mortality of sound bole volume of trees (at least 5 inches d.b.h./d.r.c.), in cubic feet, on forest land”) and live trees (“0024 Sound bole volume of live trees (at least 5 inches d.b.h./d.r.c.), in cubic feet, on forest

land”) filtered by trees 5 inch DBH (“and tree.DIA>=5”). We computed tree mortality as the ratio of the annual mortality tree volume relative to the volume of all live trees 5 inch DBH on sampled plots. Annual data began in 2008 with a more complete inventory in 2010. We relied on FIA’s statistical models for computing this value over time. We set the target for this dataset as the long-term mean. The current year is scored for where it falls between the target and the upper scoring bounds (maximum value in the dataset plus 10% of the range) or the lower scoring bounds (minimum value in the dataset minus 10% of the range), scaled to be between 1 and 5.

Citation:

<sup>1</sup> USDA Forest Service. 2019. FIA EVALIDator. Version 1.8.0.01. Available at:

<https://apps.fs.usda.gov/Evalidator/evalidator.jsp>

## SERVICES

### **Maple Syrup Production**

We used the total annual maple syrup revenue (in dollars) reported by the USDA National Agriculture Statistics Service<sup>1</sup>. We set the dataset target as the maximum value in the dataset plus 10% of range. The annual score was then computed as the distance between the lower scoring bounds (either the minimum value in the data minus 10% of range or 0, whichever was greater) and the target, scaled between 1 and 5.

Citation:

<sup>1</sup> USDA National Agriculture Statistics Service. 2019. Available at: <https://quickstats.nass.usda.gov/>

### **Forest Bird Diversity**

Data on forest bird counts by species were collected by Vermont Center for Ecostudies<sup>1</sup> at forested locations throughout Vermont beginning in 1989, with a more complete survey of the selected sites in 1990. From these data, we computed a Living Planet Index (LPI)<sup>2</sup>. We used a beta package for R, rlp<sup>3</sup>, to compute the LPI for all bird species. We used equal weighting among species and no sub-groupings. Only those Forest Bird Monitoring sites with a complete record were included: Bear Swamp, Concord Woods, Dorset Bat Cave, Galick Preserve, Maypond, Moosebog, Pease Mountain, Roy Mt WMA, Sandbar WMA, Sugar Hollow, The Cape, and Underhill State Park. Living Planet Index ranges from zero to two. We computed the index and set the target to 1, and the current year is scored as the difference between the target and the current year value,

scaled to be between 1 and 5.

Citation:

<sup>1</sup>Faccio, S. Vermont Center for Ecostudies. 2019. Forest Bird Monitoring Program. Available at: <https://vtecostudies.org/projects/forests/vermont-forest-bird-monitoring-program/>

<sup>2</sup>Collen, B., Loh, J., Whitmee, S., McRAE, L, Amin, R. and Baillie, J.E., 2009. Monitoring change in vertebrate abundance: the Living Planet Index. Conservation Biology, 23(2), pp.317-327.

<sup>3</sup>Indicators and Assessments Research Unit, Institute of Zoology, Zoological Society of London. Available at: <https://github.com/Zoological-Society-of-London/rtpi>

## **Recreation Rates**

Data on camping and day use visitation counts for state park in Vermont were accessed from the Vermont Department of Forest Parks and Recreation<sup>1</sup>. Note that these data do not contain all Vermont public lands visitation counts; for example, Camel's Hump State Park is managed by the Green Mountain Club and those data are not collected by the state of Vermont. To process these data, we first classified each park parcel<sup>2</sup> in the FPR dataset by the percent of forest cover using the National Land Cover Dataset<sup>3</sup>. The goal of this step was to subset state parks where forests were a predominant reason visitors came to the park, as opposed to water bodies or other types of non-forested natural resources. We classified parks based on the percent of Deciduous, Evergreen, and Mixed Forest Cover according to the NLCD (codes 41, 42, 43). We did not include Woody Wetland cover (code 90) because many parks that are adjacent to water bodies were classified as having a high amount of forest cover when this land cover type was included. Based on our familiarity with many of the state parks, we selected 60% forest cover as the threshold for a park considered forested. We subsetted all park visitation data to include only those parks with >60% forest cover as determined by NLCD. Total visitation counts (both camping and day use) of the 41 forested state parks were averaged by the number of parks with data per year beginning in 1970. We set the dataset target as the maximum value in the dataset plus 10% of the range. The annual score was computed as the difference between the lower scoring bounds (minimum value in the data minus 10% of the range) and the target, scaled between 1 and 5.

Citation:

<sup>1</sup>Savage, J. 2019. Recreational Rates at Vermont State Parks.

<sup>2</sup>vtanrgis. 2017. ANR Land Dataset. Available at:

<http://geodata.vermont.gov/datasets/VTANR::anr-land-dataset-unit>

<sup>3</sup>US Geological Survey. 2019. National Land Cover Database. Available at: <https://www.mrlc.gov/data>

## Hunting Harvests

We used data on the annual number of meals procured from harvesting big game animals (white-tailed deer, black bear, moose, and wild turkey), as reported by the Vermont Department of Fish and Wildlife<sup>1</sup>. We set the data target as the data maximum plus 10% of the range. The annual score was computed as the difference between the lower scoring bound of 0 (indicating that no hunting harvests were reported) and the target, scaled to be between 1 and 5.

### Citation:

<sup>1</sup> Darling, S. 2019. Vermont Big Game Meals. Vermont Department of Fish and Wildlife. Available online at: <https://www.uvm.edu/femc/data/archive/project/annualharvest/dataset/vermont-big-game-meals>

## Stream Indicator Species

Species richness was collected from the Vermont Integrated Watershed Information System<sup>1</sup>. We selected one location, Ranch Brook (site #502032) in Underhill VT, where species richness metrics were computed for macroinvertebrates. Data from other locations in the state did not have annually-resolved data with a sufficient long-term record to warrant inclusion. We used the EPT richness score as computed by the dataset authors<sup>2</sup>. EPT richness is a count of the unique number of taxa identified in the sample that belong to a trio of particularly sensitive macroinvertebrate orders - Ephemeroptera (mayflies), Plecoptera (stoneflies), and Tricoptera (caddisflies). In cases where a specimen could not be identified to the species level, it was only counted as unique taxon if no other specimens were identified to that level or below. In some cases, there were multiple samples in a single year. In these cases, we took the mean of the EPT richness scores as the value for the year. The target for these data was set to be the maximum value plus 10% of the range. The annual score was computed as the difference between the lower scoring bound of 0 (indicating no EPT taxa were identified) and the target, scaled between 1 and 5.

### Citation:

<sup>1</sup> VTDEC-Watershed Management Division. 2019. Integrated Watershed Information System &#40;IWIS&#41;. Available at: <https://anrweb.vt.gov/DEC/IWIS/>

<sup>2</sup> Vermont Agency of Natural Resources, Department of Environmental Conservation, Water Quality Division. 2012. Water Quality Field Methods. Available at: [http://dec.vermont.gov/sites/dec/files/wsm/mapp/docs/bs\\_fieldmethodsmanual.pdf](http://dec.vermont.gov/sites/dec/files/wsm/mapp/docs/bs_fieldmethodsmanual.pdf)

## Timber Harvest

Using data collected in the Vermont Forest Resource Harvest Report<sup>1</sup>, we presented the total quantity of timber harvested in Vermont per year, which is reported as cords of wood. We set the target for these data as the maximum value in the dataset plus 10% of the range. The annual score was computed as the difference between the lower scoring bounds (either the minimum value in the data minus 10% of the range or 0, whichever was greater) and the target, was scaled between 1 and 5.

Citation:

<sup>1</sup> Vermont Agency of Natural Resources, Department of Forest, Parks and Recreation. 2019. Vermont Forest Resource Harvest Reports. Available at: <https://fpr.vermont.gov/harvest-reports>

## **Carbon Storage**

Data on carbon storage were extracted from the USFS Forest Inventory and Analysis Program EVALIDator<sup>1</sup>. We used an FIA-established query (“0103 Forest carbon total: all 5 pools, in metric tonnes, on forest land”) accessed by the FIA EVALIDator<sup>1</sup>. This query computed the total carbon storage (in MgT) on FIA plots across all carbon pools. The first available year of data was 1997. The data target was set at the maximum value in the dataset plus 10% of the range. The annual score was computed as the difference between the lower scoring bounds (either the minimum value in the data minus 10% of range or 0, whichever was greater) and the target, scaled between 1 and 5.

Citation:

<sup>1</sup>USDA Forest Service. 2019. FIA EVALIDator. Available at: <https://apps.fs.usda.gov/Evalidator/evalidator.jsp>

# STRESSORS

## **Minimum Temperature**

Data of mean minimum annual temperature for Vermont were gathered from NOAA National Centers for Environmental Information<sup>1</sup>. We set the target for the dataset as the mean minimum temperature from 1961-1990 which is used as the baseline normal for climate comparisons by the Intergovernmental Panel on Climate Change (IPCC). The current year is scored for where it falls between the target and the upper scoring bounds (maximum value in the dataset) or the lower scoring bounds (minimum value in the dataset), scaled to be between 1 and 5.

Citation:

<sup>1</sup> NOAA National Centers for Environmental Information. 2019. Available at: <https://www.ncdc.noaa.gov/cag/>

## **Damage by Invasive Pests**

To quantify the damage caused by invasive insects and diseases, we use Insect and Disease Surveys (IDS), which are annual aerial surveys of forests conducted by the State of Vermont and the USDA Forest Service to map forest disturbance<sup>1</sup>. Here, we summed the total area mapped by pests that we could determine as invasive to Vermont. The target was set as the lowest possible acreage (either the minimum value in the data minus 10% of range or 0, whichever was greater), and the current year is scored for where it falls between the target and the upper scoring bounds (maximum value in the dataset plus 10% of the range), scaled to be between 1 and 5.

Citation:

<sup>1</sup>USDA Forest Service. Forest Health Protection. Available at:

<https://www.fs.fed.us/foresthealth/applied-sciences/mapping-reporting/detection-surveys.shtml>

## **Drought**

Drought was assessed through the Standardized Precipitation Evapotranspiration Index (SPEI) for Vermont<sup>1</sup>. The SPEI more fully captures the effect of drought on plants than the Palmer Drought Severity Index, as the former includes the loss of water through evapotranspiration. We selected a six month SPEI value which spans from April-September to capture drought in the functional growing season. We set the target for the dataset as the long-term mean from 1961-1990 based on the baseline set by the Intergovernmental Panel on Climate Change (IPCC). The current year is scored for where it falls between the target and the upper scoring bounds (maximum value in the dataset plus 10% of the range) or the lower scoring bounds (minimum value in the dataset minus 10% of the range), scaled to be between 1 and 5.

Citation:

<sup>1</sup> Vicente-Serrano S.M., Beguería S., López-Moreno J.I., 2010. A Multi-scalar drought index sensitive to global warming: The Standardized Precipitation Evapotranspiration Index – SPEI. *Journal of Climate* 23(7), 1696-1718, DOI: 10.1175/2009JCLI2909.1. Available at: <http://digital.csic.es/handle/10261/22405>

## **Climate Extremes**

NOAA National Centers for Environmental Information (NCEI) provides a robust Climate Extremes Index for the northeastern US<sup>1</sup>. NCEI computes the regional CEI based on a set of climate extreme indicators: (1) monthly maximum and minimum temperature, (2) daily precipitation, and (3) monthly Palmer Drought Severity Index (PDSI). The CEI is a combination of the proportion of the year and the area in the region that has experienced an extreme event for these three indices. NCEI has defined extremes as those CEI values that fall in the upper (or lower) tenth percentile of the local period of record. Please refer to NCEI documentation for more details on calculations. Accordingly, a value of 0% for the CEI indicates that no portion of the year was subject to any of the extremes considered in the index. In contrast, a value of 100% indicates that the entire northeast region had extreme conditions throughout the year for each of the indicators. The long-term variation or change in the CEI represents the tendency for extremes of climate to either decrease, increase, or remain the same<sup>1</sup>. We set the target for the dataset as the long-term mean. The current year is scored for where it falls between the target and the upper scoring bounds (maximum value in the dataset) or the lower scoring bounds (minimum value in the dataset), scaled to be between 1 and 5.

Citation:

<sup>1</sup> NOAA National Centers for Environmental Information. 2018. Climate Extremes Index. Available at: <https://www.ncdc.noaa.gov/extremes/cei/graph/ne/cei/01-12>

## **Ozone Exposure**

Daily ozone data (ppm-hour) was accessed from the air quality monitoring sites at Underhill (Proctor Maple Research Forest) and Bennington (Morse Airport), Vermont<sup>1</sup>. To compute an ozone exposure index, we selected the W126 standard<sup>2</sup> because it is thought to be better representation of ozone injury to plants. Under this, Vermont's ozone monitoring season runs April 1 to September 30 and growing hours are 8:00 am to 8:00 pm. We determined the minimum detection limit per site (here 0.005 for both sites over the entire record). We backfilled missing values with the minimum value observed per year, restricted to the established monitoring season and growing hours. All months must have >75% completeness in daily records to be utilized. Data were transform following the equation:  $OZ*(1/(1+4403*EXP((OZ*(-126))))))$ . A daily index value was calculated by summing the transformed values per day; these were then summed per month to compute a monthly index value. These monthly indices were multiplied by the ratio of collected and backfilled samples to total possible samples within the month. For each month, we computed a three-month maximum -- the current month plus the two preceding months (i.e., the 3-month maximum for June is the maximum of June, May and April). In Vermont, this results in 3-month maximum values for June, July, August and September. To compute the annual W126, we took the mean of the largest 3-month maximum over the current year and the previous two years. We set the target for ozone exposure at 7 ppm-hour<sup>3</sup>. The annual score was computed as a difference between 7 and the upper scoring bounds (maximum value in the dataset plus 10% of the range), scaled between 1 and 5. Values below 7 were given a score of 5.

Citation:

<sup>1</sup> Environmental Protection Agency. 2019. Available at: <https://www.epa.gov/outdoor-air-quality-data>

<sup>2</sup> Environmental Protection Agency. 2015. W126 Standard. Available at: [https://www.epa.gov/sites/production/files/2015-09/documents/w126\\_steps\\_to\\_calculate\\_revised\\_feb19.pdf](https://www.epa.gov/sites/production/files/2015-09/documents/w126_steps_to_calculate_revised_feb19.pdf)

<sup>3</sup> Environmental Protection Agency. 2015. National Ambient Air Quality Standards (NAAQS) for Ozone. Available at: <https://www.epa.gov/ozone-pollution/2015-national-ambient-air-quality-standards-naaqs-ozone>

## **Snow Cover**

The total annual number of days with snow cover >1 inch in Vermont were collected from NOAA National Centers for Environmental Information<sup>1</sup>. We set the target for the dataset as the mean duration of snow cover from 1961-1990 which is used as the baseline normal for climate comparisons by the Intergovernmental Panel on Climate Change (IPCC). The current year is scored for where it falls between the target and the upper scoring bounds (maximum value in the dataset) or the lower scoring bounds (minimum value in the dataset), scaled to be between 1 and 5.

Citation:

<sup>1</sup> NOAA National Centers for Environmental Information. 2019. Available at: <https://www.ncdc.noaa.gov/cag/>

## **Precipitation**

Data of annual total precipitation (inches) for Vermont were collected from NOAA National Centers for Environmental Information<sup>1</sup>. We set the target for the dataset as the total precipitation from 1961-1990 which is used as the baseline normal for climate comparisons by the Intergovernmental Panel on Climate Change (IPCC). The current year is scored for where it falls between the target and the upper scoring bounds (maximum value in the dataset) or the lower scoring bounds (minimum value in the dataset), scaled to be between 1 and 5.

Citation:

<sup>1</sup> NOAA National Centers for Environmental Information. 2019. Available at: <https://www.ncdc.noaa.gov/cag/>

## **Maximum Temperature**

Data of mean maximum annual temperature for Vermont were gathered from NOAA National Centers for Environmental Information<sup>1</sup>. We set the target for the dataset as the mean maximum temperature



from 1961-1990 which is used as the baseline normal for climate comparisons by the Intergovernmental Panel on Climate Change (IPCC). The current year is scored for where it falls between the target and the upper scoring bounds (maximum value in the dataset) or the lower scoring bounds (minimum value in the dataset), scaled to be between 1 and 5.

Citation:

<sup>1</sup> NOAA National Centers for Environmental Information. 2019. Available at: <https://www.ncdc.noaa.gov/cag/>

## **Mercury Deposition**

Data on mercury deposition ( $\text{g/m}^2$ ) were accessed from the National Atmospheric Deposition Program (NADP) Mercury Deposition Network (MDN) for sites at Underhill, Vermont<sup>1</sup>. Annual values are computed from weekly samples collected at the site. We set the target for mercury deposition to zero<sup>2</sup>. The annual score was computed as the difference between the target concentration of  $0 \text{ g/m}^2$  and upper scoring bounds (maximum value in the data plus 10% of the range), scaled between 1 and 5.

Citation:

<sup>1</sup> National Atmospheric Deposition Program. 2017. Mercury Deposition Network Available at: <http://nadp.slh.wisc.edu/mdn/>

## **Growing Season Length**

Using MODIS remotely sensed phenology products, we selected the Growing Season Duration (DUR) dataset as an assessment of the total length of the functional growing season<sup>1</sup>. We clipped imagery to the state of Vermont boundary<sup>2</sup>, and masked to limit only those pixels identified as forested (Deciduous (41), Evergreen (42), and Mixed (43), and Woody Wetlands (90) cover pixels), according to 2011 National Land Cover Dataset<sup>3</sup>. In each MODIS image, we excluded values of -1000 (unknown) and 1000 (water), then calculated the mean pixel value per image. We also computed the mean for each pixel over all image years and then computed the mean across pixels to establish the long-term mean of the dataset. We set the data target as the long-term mean. The current year is scored for where it falls between the target and the upper scoring bounds (maximum value in the dataset plus 10% of the range) or the lower scoring bounds (minimum value in the dataset minus 10% of the range), scaled to be between 1 and 5.

Citation:

<sup>1</sup>MODIS Phenology Metrics. 2018. <https://modis.gsfc.nasa.gov/>. Imagery available at: <https://earthexplorer.usgs.gov/>

<sup>2</sup> US Census. 2016. US Boundaries. Available at:

[https://www.census.gov/geo/maps-data/data/cbf/cbf\\_state.html](https://www.census.gov/geo/maps-data/data/cbf/cbf_state.html)

<sup>3</sup> US Geological Society. 2018. National Land Cover Dataset. Available at: <https://www.mrlc.gov/finddata.php>

## **Precipitation Acidity**

Data on the pH of precipitation were accessed from the National Atmospheric Deposition Program (NADP)<sup>1</sup>. Data were collected from the Underhill, Vermont, station. We set a target for precipitation acidity of 5.6, based on a previously established value<sup>2</sup>. The annual score was computed as the difference between the lower scoring bounds (minimum value in the data minus 10% of the range) and the target value (5.6). This difference was then scaled between 1 and 5. Values above the target receive a 5.

### Citation:

<sup>1</sup> National Atmospheric Deposition Program. 2019. Available at: <http://nadp.slh.wisc.edu/ntn/>

<sup>2</sup> Vermont Department of Environmental Conservation. 2018. Available at:

<http://dec.vermont.gov/watershed/map/monitor/acid-rain>

# STRUCTURE

## **Mean Forest Patch Size**

Using the National Land Cover Database (NLCD)<sup>1</sup>, we mapped forest cover (41 Deciduous Forest, 42 Evergreen Forest, 43 Mixed Forest, and 90 Woody Wetlands) at 30 meter resolution. The NLCD begins in 2001 from the reprocessed release in 2019. We used FragStats<sup>2</sup> to compute the mean size of forest patches. We used the 8 cell neighborhood rule with a 'no sampling' strategy. We selected all Area-Edge Class metrics for computation. We set the target for this dataset to be the long-term mean. The current year is scored for where it falls between target and either the lower scoring bounds (dataset minimum minus 10% of the range) or the upper scoring bounds (dataset maximum plus 10% of the range) and the target when values are above the target, scaled to be between 1 and 5.

### Citation:

<sup>1</sup>US Geological Survey. 2019. National Land Cover Database. Available at: <https://www.mrlc.gov/data>

<sup>2</sup> McGarigal, K., SA Cushman, and E Ene. 2012. FRAGSTATS v4: Spatial Pattern Analysis Program for Categorical and Continuous Maps. Computer software program produced by the authors at the University of

Massachusetts, Amherst. Available at the following web site:

<http://www.umass.edu/landeco/research/fragstats/fragstats.html>

## Forest Cover

We used forest cover estimates generated by the USFS Forest Inventory and Analysis Program EVALIDator<sup>1</sup> (“0079 Area of sampled land and water, in acres”). We relied on the query and methods set by FIA to compute these estimates (Accessible forest as defined by FIA)/(Total land– (Noncensus Water + Census Water)) x 100%). We then converted them to a percentage of the state of Vermont using the total area of the state. The target was set as the long-term mean value. The current year is scored for where it falls between the target and the upper scoring bounds (maximum value in the dataset +10% of the range) or the lower scoring bounds (minimum value in the dataset -10% of the range), scaled to be between 1 and 5.

### Citation:

<sup>1</sup> USDA Forest Service. 2019. FIA EVALIDator. Available at: <https://apps.fs.usda.gov/Evalidator/evalidator.jsp>

## Softwood Regeneration

We used red spruce (*Picea rubens*) seedling counts per acre in spruce-fir forests estimated from USFS Forest Inventory and Analysis (FIA) Program Phase 2 subplots. Seedling data were collected using an FIA-established query in EVALIDator<sup>1</sup> (“0045 Number of live seedlings (less than 1 inch d.b.h./d.r.c.), in seedlings, on forest land”) filtered by red spruce (“and seedling.spcd = 97”) and grouped by forest type. Per FIA protocol, plots were reassessed every 5 years until 2014 (i.e. data reported for 2007 used 2003, 2004, 2005, 2006 and 2007), and then every 7 years after that<sup>2</sup>. Estimates are calculated by scaling the seedling data to represent the spruce-fir forests of Vermont. The target for this dataset was set to the maximum value plus 10% of the range. The current year is scored for where it falls between zero and the target, scaled to be between 1 and 5.

### Citation:

<sup>1</sup> USDA Forest Service. 2019. FIA EVALIDator. Version1.8.0.01. Available at:

<https://apps.fs.usda.gov/Evalidator/evalidator.jsp>

<sup>2</sup> USDA Forest Service. 2017. Forest Inventory and Analysis National Core Field Guide, Volume 1: Field Data Collection Procedures for Phase 2 plots. Version 7.2. Available at:

[https://www.fia.fs.fed.us/library/field-guides-methods-proc/docs/2017/core\\_ver7-2\\_10\\_2017\\_final.pdf](https://www.fia.fs.fed.us/library/field-guides-methods-proc/docs/2017/core_ver7-2_10_2017_final.pdf)

## Hardwood Regeneration

We used sugar maple (*Acer saccharum*) seedling counts per acre in maple-beech-birch forests estimated from USFS Forest Inventory and Analysis (FIA) Program Phase 2 subplots. Seedling data were collected using an FIA-established query in EVALIDator;<sup>1</sup> (“0045 Number of live seedlings (less than 1 inch d.b.h./d.r.c.), in seedlings, on forest land”) filtered by sugar maple (“and seedling.spcd = 318”) and grouped by forest type. Per FIA protocol, plots were reassessed every 5 years until 2014 (i.e. data reported for 2007 used 2003, 2004, 2005, 2006 and 2007), and then every 7 years after that;<sup>2</sup>. Estimates are calculated by scaling the seedling data to represent the maple-beech-birch forests of Vermont. The target for this dataset was set to the maximum value plus 10% of the range. The current year is scored for where it falls between zero and the target, scaled to be between 1 and 5.

### Citation:

<sup>1</sup> USDA Forest Service. 2019. FIA EVALIDator. Version 1.8.0.01. Available at:

<https://apps.fs.usda.gov/Evalidator/evalidator.jsp>

<sup>2</sup> USDA Forest Service. 2017. Forest Inventory and Analysis National Core Field Guide, Volume 1: Field Data Collection Procedures for Phase 2 plots. Version 7.2. Available at:

[https://www.fia.fs.fed.us/library/field-guides-methods-proc/docs/2017/core\\_ver7-2\\_10\\_2017\\_final.pdf](https://www.fia.fs.fed.us/library/field-guides-methods-proc/docs/2017/core_ver7-2_10_2017_final.pdf)

## Stand Age Diversity

Using the USFS Forest Inventory and Analysis Program data accessed via the FIA EVALIDator<sup>1</sup>, we extracted the acreage of forest for every 20 year age class. We re-categorized stand ages into 40 year buckets (0-40, 41-80, and 81-140 years) and computed age class diversity using a Shannon-Weiner Diversity Index calculation (see equation below). Per FIA protocol, plots were reassessed every 5 years until 2014 (i.e. data reported for 2007 used 2003, 2004, 2005, 2006 and 2007), and then every 7 years after that<sup>2</sup>. The target for this dataset was set to the long-term mean, and the score was then computed as the deviation from this target, scaled to be between 1 and 5.

Shannon-Weiner Index ( $H'$ )

$$H' = - \sum_{i=1}^n p_i \ln p_i$$

Where  $p_i$  is the proportion of trees in the  $i$ th size class

Citation:

<sup>1</sup> USDA Forest Service. 2019. FIA EVALIDator. Available at: <https://apps.fs.usda.gov/Evalidator/evalidator.jsp>

<sup>2</sup> USDA Forest Service. 2017. Forest Inventory and Analysis National Core Field Guide, Volume 1: Field Data Collection Procedures for Phase 2 plots. Version 7.2. Available at: [https://www.fia.fs.fed.us/library/field-guides-methods-proc/docs/2017/core\\_ver7-2\\_10\\_2017\\_final.pdf](https://www.fia.fs.fed.us/library/field-guides-methods-proc/docs/2017/core_ver7-2_10_2017_final.pdf)

## **Stand Complexity**

Using the USFS Forest Inventory and Analysis Program population estimate data on Phase 2 plots accessed via the FIA Datamart<sup>1</sup>, we computed tree size class diversity using a Shannon-Weiner Diversity Index calculation (see equation below). The first available data year was 1997. We divided all sampled trees into 5 inch classes and tallied the total proportion of each size class measured in the plots. To compute the annual score, we used FIA's plot evaluation group panels to create population estimates for each year. The target for this dataset was set as the maximum value plus 10% of the range. The target was set as the upper scoring bounds (dataset maximum plus 10% of the range), and the current year is scored for where it falls between the lower scoring bounds (dataset minimum minus 10% of the range) and the target, scaled to be between 1 and 5.

Shannon-Weiner Index ( $H'$ )

$$H' = - \sum_{i=1}^n p_i \ln p_i$$

Where  $p_i$  is the proportion of trees in the  $i$ th size class

Citation:

<sup>1</sup> USDA Forest Service. 2019. FIA Data Mart. Available at: <https://apps.fs.usda.gov/fia/datamart/datamart.html>

## **Forest Connectivity**

Using the National Land Cover Database (NLCD)<sup>1</sup> we mapped forest cover (41 Deciduous Forest, 42 Evergreen Forest, 43 Mixed Forest, and 90 Woody Wetlands) at 30 meter resolution. The 2019 reprocessed release of the NLCD begins in 2001. We used FragStats<sup>2</sup> to compute forest connectivity. We used the 8 cell neighborhood rule with a 'no sampling' strategy. We selected 'Contagion' as the Landscape Aggregation

metric for computation. We set the target for this dataset to be the long-term mean. The current year is scored for where it falls between target and either the lower scoring bounds (dataset minimum minus 10% of the range) or the upper scoring bounds (dataset maximum plus 10% of the range) and the target when values are above the target, scaled to be between 1 and 5.

Citation:

<sup>1</sup>US Geological Survey. 2019. National Land Cover Database. Available at: <https://www.mrlc.gov/data>

<sup>2</sup> McGarigal, K., SA Cushman, and E Ene. 2012. FRAGSTATS v4: Spatial Pattern Analysis Program for Categorical and Continuous Maps. Computer software program produced by the authors at the University of Massachusetts, Amherst. Available at the following web site:

<http://www.umass.edu/landeco/research/fragstats/fragstats.html>



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