

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

Contents

<i>Methods Overview and Terminology</i>	1
<i>Condition Indicators</i>	4
<i>Services Indicators</i>	11
<i>Stressors Indicators</i>	14
<i>Structure Indicators</i>	20



The Forest Indicators Dashboard (FID) 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 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 this dashboard are dynamic, meaning that they are updated with new monitoring 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 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 and services that forested ecosystems provide. Forests provide timber, maple syrup, and recreational and hunting opportunities. Thus forest contribute greatly to the economy. Some of the indicators used here are timber and maple syrup production, hunting tags, and carbon storage among others.

Stressors

Stressors are naturally occurring event 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, minimum and maximum temperature, and precipitation.

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.

Below are 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.

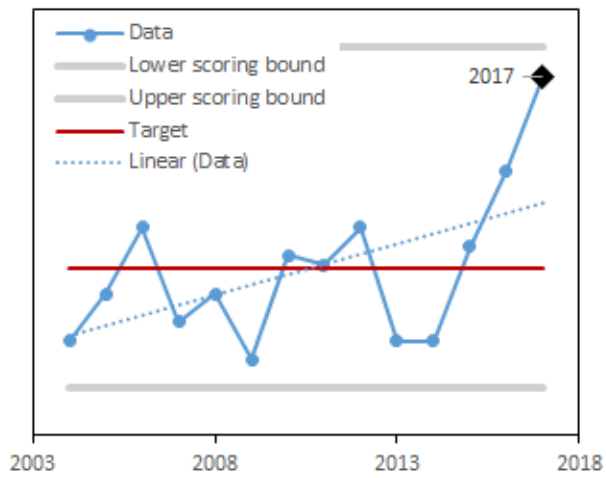
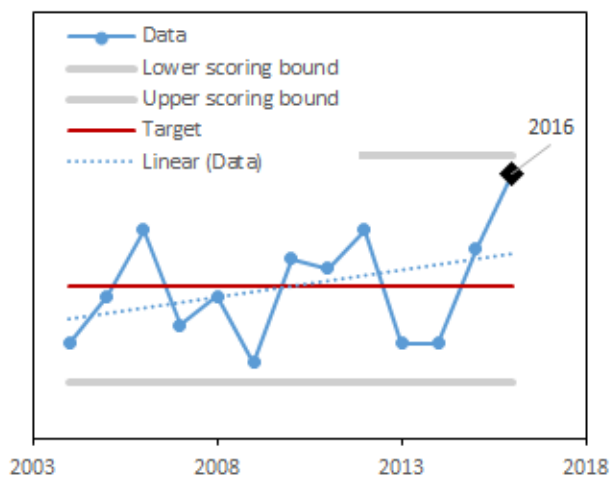
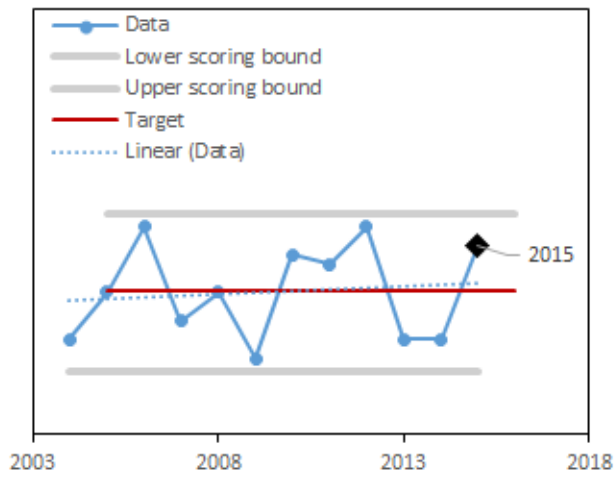
Terminology

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 annual 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

Tree Growth

Data on tree growth were extracted from the USFS Forest Inventory and Analysis Program Access database¹. We used a FIA-established query (“T025_Net growth of all live on forestland-cuftPerYr”) for net growth of live trees >5 inch DBH on sampled P1 plots. Annual data began in 2006. We relied on FIAs statistical models for computing this value over time. We set the target for this dataset as the long-term mean. The score was then computed as the deviation from the target, scaled to be between 0-1. When values were above the target, a score of 1 corresponds to the target and a score of 0 corresponds to the upper scoring bounds (data maximum plus 10% of the range). When values were below the target, a score of 1 corresponds to the target and a score of 0 corresponds to the lower scoring bounds(data minimum plus 10% of the range).

Citation:

¹ USDA Forest Service. 2017. FIA Data Mart. Available at: <https://apps.fs.usda.gov/fia/datamart/datamart.html>

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 Monitoring¹ (FHM, a collaboration between FEMC and VT FPR) and North American Maple Project (NAMP) plots² 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. 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 that had more than one tree of a non-maple species. 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. From this, we computed the mean crown dieback for all species across all sampled plots in both the FHM and NAMP datasets. For crown dieback, the target was set as the long-term mean. We computed the current year score was the distance between the target and the upper scoring bounds (maximum value in the dataset plus 10% of the range), scaled to be between 0-1. Values below the target were scored as 1.

Citation:

¹ Pontius J., S. Wilmot. 2017. Forest Health Monitoring. FEMC. Available at:

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

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

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¹ Pontius J., S. Wilmot. 2017. Forest Health Monitoring. FEMC. Available at:

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² 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 events¹. 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 0-1.

Citation:

¹ USDA Forest Service. Forest Health Protection.

<https://www.fs.fed.us/foresthealth/applied-sciences/mapping-reporting/gis-spatial-analysis/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 mortality¹. 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 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 0-1.

Citation:

¹ USDA Forest Service. Forest Health Protection.

<https://www.fs.fed.us/foresthealth/applied-sciences/mapping-reporting/gis-spatial-analysis/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 season¹. Available TIN images began in 2001. We first excluded all pixels with a value of either 0 or 255. 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 also computed the long-term mean over record. We set the target for this dataset as the maximum value plus 10% of the range. The current year score was computed as the difference between the lower scoring bounds (minimum value in the dataset minus 10% of the range) and the target, scored to be between 0-1.

Citation:

¹ MODIS Phenology Metrics. 2018. Available at: <https://earthexplorer.usgs.gov>

Tree Mortality

Data on tree growth were extracted from the USFS Forest Inventory and Analysis Program Access database¹. We used FIA-established queries (“T032_Mortality of all live trees on forestland-treesPerYr” and “T004_Number of all live trees on forestland”) to compute the mortality rate percentage for trees >5 inch DBH on sampled plots. Annual data began in 2006. We relied on FIAs statistical models for computing this value over time. We set the target for this dataset as the long-term mean. The score was then computed as the deviation from the target, scaled to be between 0-1. When values were above the target, a score of 1 corresponds to the target and a score of 0 corresponds to the upper scoring bounds (data maximum plus 10% of the range). When values were below the target, a score of 1 corresponds to the target and a score of 0 corresponds to the lower scoring bounds(data minimum plus 10% of the range).

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¹ USDA Forest Service. 2017. FIA Data Mart. Available at: <https://apps.fs.usda.gov/fia/datamart/datamart.html>

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Citation:

¹ USDA Forest Service. 2017. FIA Data Mart. Available at: <https://apps.fs.usda.gov/fia/datamart/datamart.html>

Damage and Decay

Data on the proportion of trees in Vermont’s forest considered non-growing stock were extracted from the USFS Forest Inventory and Analysis Program Access database¹. We used a FIA-established queries (“T005_Number of growing-stock trees on forestland” and “T004_Number of all live trees on forestland”) to compute the ratio. We took the inverse of this ratio to obtain the percentage of live trees not classified as growing stock. FIA defines a “growing stock tree” as a live tree >5.0 inches (12.7 cm) DBH that meet (now or prospectively) regional merchantability requirements in terms of saw-log length, grade, and cull deductions,

and excludes rough and rotten cull trees². Annual data began in 1997. We relied on FIAs statistical models for computing this value over time. We set the target for this dataset as the long-term mean. The score was then computed as the deviation from the target, scaled to be between 0-1. When values were above the target, a score of 1 corresponds to the target and a score of 0 corresponds to the upper scoring bounds (data maximum plus 10% of the range). When values were below the target, a score of 1 corresponds to the target and a score of 0 corresponds to the lower scoring bounds(data minimum plus 10% of the range).

Citation:

¹ USDA Forest Service. 2017. FIA Data Mart. Available at: <https://apps.fs.usda.gov/fia/datamart/datamart.html>

¹ 2USDA Forest Service. 2018. Forest Inventory and Analysis Glossary. Available at:

<https://www.nrs.fs.fed.us/fia/data-tools/state-reports/glossary/default.asp>

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¹ USDA Forest Service. 2017. FIA Data Mart. Available at: <https://apps.fs.usda.gov/fia/datamart/datamart.html>

¹ 2USDA Forest Service. 2018. Forest Inventory and Analysis Glossary. Available at:

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Citation:

¹ USDA Forest Service. 2017. FIA Data Mart. Available at: <https://apps.fs.usda.gov/fia/datamart/datamart.html>

¹ 2USDA Forest Service. 2018. Forest Inventory and Analysis Glossary. Available at: <https://www.nrs.fs.fed.us/fia/data-tools/state-reports/glossary/default.asp>

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Citation:

¹ USDA Forest Service. 2017. FIA Data Mart. Available at: <https://apps.fs.usda.gov/fia/datamart/datamart.html>

¹ 2USDA Forest Service. 2018. Forest Inventory and Analysis Glossary. Available at: <https://www.nrs.fs.fed.us/fia/data-tools/state-reports/glossary/default.asp>

SERVICES

Timber Harvest

Using data collected in the Vermont Forest Resource Harvest Report¹, 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. This difference was scaled 0-1.

Citation:

¹ Vermont Agency of Natural Resources, Department of Forest, Parks and Recreation. Vermont Forest Resource Harvest Reports. Available at:

http://fpr.vermont.gov/forest/forest_business/forest_statistics/harvest_reports

Stream Indicator Species

Species richness was collected from Vermont Integrated Watershed Information System¹. 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 authors². 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. This difference was then scaled from 0-1.

Citation:

¹ VTDEC-Watershed Management Division. 2018. Integrated Watershed Information System (IWIS). Available at: <https://anrweb.vt.gov/DEC/IWIS/>

² Vermont Agency of Natural Resources, Department of Environmental Conservation, Water Quality Division. 2012. Water Quality Field Methods. Available at:

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 Wildlife¹. 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 0-1.

Citation:

¹ Darling, S. (2017) 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>

Carbon Storage

Using a query set by the Forest Inventory and Analysis program ('IPCC carbon total: all 5 pools on forestland') access via the FIA Data Mart¹. 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 (minimum value in the data minus 10% of the range) and the target. This difference was then scaled between 0-1.

Citation:

¹ USDA Forest Service. 2017. FIA Data Mart. Available at: <https://apps.fs.usda.gov/fia/datamart/datamart.html>

Maple Syrup Production

We used the total annual maple syrup revenue (in dollars) reported by the USDA National Agriculture Statistics Service¹. 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 the lower scoring bounds (either the minimum value in the data minus 10% of range or 0, whichever was greater) and the target. This difference was then scaled 0-1.

Citation:

¹ USDA National Agriculture Statistics Service. 2018. Available at: <https://quickstats.nass.usda.gov/>

Recreation Rates

Data on camping and day use visitation counts per state park in Vermont were accessed from Vermont Department of Forest Parks and Recreation¹. 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 parcel² in the FPR dataset by the percent of forest cover using the National Land Cover Dataset³. Data spanned from 1936-2016. A total of 144 parks were include in 2016, but further back in time, fewer parks are represented. Thus, we select the years 1970-2016 to have >129 parks per year. 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 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 this group of parks were summed per year. 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. This difference was then scaled from 0-1.

Citation:

¹Savage, J. 2017. Recreational Rates at Vermont State Parks.

² vtanrgis. 2017. ANR Land Dataset. Available at:

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

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

Forest Bird Diversity

Data on forest bird counts by species were collected by Vermont Center for Ecostudies¹ at forested locations throughout Vermont between 1989-2017. From these data, we computed a Living Planet Index (LPI) ². We used a beta package for R, rlp³, to compute the LPI for all species and birds. We used equal weighting among species and no sub-groupings. Only those Forest Bird Monitoring sites with a complete record were included: Cornwall Swamp, Dorset Bat Cave, Moose Bog, Roy Mt WMA, Shaw Mt, Sugar Hollow, The Cape,

and Underhill State Park.

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:

¹Faccio, S. Vermont Center for Ecostudies. 2018. Forest Bird Monitoring Program.

²MacDonald, G.M. 2003. Biogeography: space, time and life.

STRESSORS

Precipitation Acidity

Data on the pH of precipitation were accessed from the National Atmospheric Deposition Program (NADP)¹. Data were collected from the Underhill, Vermont. We set a target for precipitation acidity of 5.6, based on a previously established value². 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 0-1. Values above the target receive a 1.

Citation:

¹ National Atmospheric Deposition Program. 2017. Available at: <http://nadp.slh.wisc.edu/ntn/>

² Vermont Department of Environmental Conservation. 2018. Available at: <http://dec.vermont.gov/watershed/map/monitor/acid-rain>

Growing Season Length

Using MODIS remotely sensed phenology products, we selected Time Integrated Normalized Difference Vegetation Index (NDVI)¹ as an assessment of the total length of the functional growing season. We used ArcDesktop (version 10.4) to clip images to the state of Vermont boundary², 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 Dataset³. 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 and computed the annual score as the difference from this target. This difference was then scaled from 0-1.

Citation:

¹ MODIS Phenology Metrics. 2018. Available at: <https://earthexplorer.usgs.gov/>

² US Census. 2016. US Boundaries. Available at:

https://www.census.gov/geo/maps-data/data/cbf/cbf_state.html

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

Ozone Exposure

Daily ozone data (ppm-hour) was accessed from the National Atmospheric Deposition Network (NADP) sites at Underhill (Proctor Maple Research Forest) and Bennington (Morse Airport), Vermont¹. To compute an ozone exposure index, we selected the W126 standard² 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 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-hour³. 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). This difference was scaled from 0-1.

Citation:

¹ Environmental Protection Agency. 2018. Available at: <https://www.epa.gov/outdoor-air-quality-data>

² 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

² 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>

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¹ Environmental Protection Agency. 2018. Available at: <https://www.epa.gov/outdoor-air-quality-data>

² 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

³ 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>

Mercury Deposition

Data on mercury deposition ($\mu\text{g}/\text{m}^2$) were accessed from the National Atmospheric Deposition Program (NADP) Mercury Deposition Network (MDN) for sites at Underhill, Vermont¹. Annual values are compute from weekly samples collected at the site. We set the target for mercury deposition to zero². The annual score was computed as the difference between the target concentration of 0 $\mu\text{g}/\text{m}^2$ and upper scoring bounds

(maximum value in the data plus 10% of the range). This difference was then scaled between 0-1.

Citation:

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

Minimum Temperature

Data of mean minimum annual temperature (?) for Vermont were gathered from NOAA National Centers for Environmental Information¹. We set the target for the dataset as the mean minimum temperature from 1961-1990 based on the baseline set by the IPCC. Annual scores were computed as the deviation from the data target, scaled from 0-1.

Citation:

¹ NOAA National Centers for Environmental Information. 2018.

Maximum Temperature

Data of mean maximum annual temperature (?) for Vermont were gathered from NOAA National Centers for Environmental Information¹. We set the target for the dataset as the mean maximum temperature from 1961-1990 based on the baseline set by the IPCC. Annual scores were computed as the deviation from the data target, scaled from 0-1.

Citation:

¹ NOAA National Centers for Environmental Information. 2018.

Precipitation

Data of annual total precipitation (inches) for Vermont were collected from NOAA National Centers for Environmental Information¹. We set the target for the dataset as the total precipitation from 1961-1990 based on the baseline set by the IPCC. Annual scores were computed as the deviation from the data target, scaled from 0-1.

Citation:

¹ NOAA National Centers for Environmental Information. 2018.

Snow Cover

The total annual number of days with snow cover >1 inch in Vermont were collected from NOAA National Centers for Environmental Information¹. We set the target for the dataset as the mean duration of snow cover from 1961-1990 based on the baseline set by the IPCC. Annual scores were computed as the deviation from the data target, scaled from 0-1.

Citation:

¹ NOAA National Centers for Environmental Information. 2018.

Climate Extremes

NOAA National Centers for Environmental Information (NCEI) provides a robust Climate Extremes Index for the northeastern US¹. 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 same¹. We set the target for the dataset as the long-term mean. Annual scores were computed as the deviation from the data target, scaled from 0-1.

Citation:

¹ NOAA National Centers for Environmental Information. 2018. Climate Extremes Index. Available at:

<https://www.ncdc.noaa.gov/extremes/cei/graph/ne/cei/01-12>

Drought

Drought was assessed through the Standardized Precipitation Evapotranspiration Index (SPEI) for Vermont¹. 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 mean duration of snow cover from 1961-1990 based on the baseline set by the IPCC. Annual

scores were computed as the deviation from the data target, scaled from 0-1.

Citation:

¹ 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>

² Vicente-Serrano S.M., Beguería S., López-Moreno J.I., Angulo M., El Kenawy A. (2010) A global 0.5° gridded dataset (1901-2006) of a multiscale drought index considering the joint effects of precipitation and temperature. *Journal of Hydrometeorology* 11(4), 1033-1043, DOI: 10.1175/2010JHM1224.1.-- Available at: <http://digital.csic.es/handle/10261/23906>

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 disturbance¹. Here, we summed the total area mapped by pests that we could determine as invasive to Vermont. The current year is scored as the difference between the minimum and maximum (+10%) values in the record. Annual scores were computed as the deviation from the data target, scaled from 0-1.

Citation:

¹ USDA Forest Service. Forest Health Protection. Available at:

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

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Citation:

¹ USDA Forest Service. Forest Health Protection. Available at:

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

STRUCTURE

Forest Cover

We used forest cover estimates generated by Forest Inventory and Analysis program accessed via the FIA Datamart Access Database¹. We relied on the query and methods set by FIA to compute these estimates. 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 annual score was computed as a deviation from the target, scaled to be between 0-1. When values were above the target, a score of 1 corresponds to the target and a score of 0 corresponds to the upper scoring bounds (maximum plus 10% of the range). When values were below the target, a score of 1 corresponds to the target and a score of 0 corresponds to the data lower scoring bounds (minimum minus 10% of the range).

Citation:

¹ USDA Forest Service. 2017. FIA Data Mart. Available at: <https://apps.fs.usda.gov/fia/datamart/datamart.html>

Hardwood Regeneration

We collected counts of sugar maple (*Acer saccharum*) seedlings per subplot in the Forest Inventory and Analysis Phase 2 plots via the FIA Datamart Access Database¹. The first year of available data is 2003. A hardwood seedling is classified as a small tree less than 1" in diameter and greater than 12" in height². We averaged seedling counts over all sampled subplots per year and scaled this number to the acreage of a subplot (0.25 ac.) to compute a density value (seedlings per acre). Per FIA protocol, plots are reassessed every 5 years until 2014, and every 7 years after that. To compute the annual score, we used 5-year leading edge moving window (i.e., data reported for 2007 used 2003, 2004, 2005, 2006 and 2007) until 2014 when we switched to a 7-year leading edge moving window per FIA protocol². The target for this dataset was set to the maximum value plus 10% of the range. The score was then computed as the difference between the lower scoring bound of 0 and the target, scaled to be between 0-1.

Citation:

¹ USDA Forest Service. 2017. FIA Data Mart. Available at: <https://apps.fs.usda.gov/fia/datamart/datamart.html>

² 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

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Citation:

¹ USDA Forest Service. 2017. FIA Data Mart. Available at: <https://apps.fs.usda.gov/fia/datamart/datamart.html>

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Citation:

¹ USDA Forest Service. 2017. FIA Data Mart. Available at: <https://apps.fs.usda.gov/fia/datamart/datamart.html>

² 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

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Softwood Regeneration

We collected counts of red spruce (*Picea rubens*) seedlings per subplot in the Forest Inventory and Analysis Phase 2 plots via the FIA Datamart Access Database¹. The first year of available data is 2003. A softwood seedling is classified as a small tree less than 1" in diameter and greater than 6" in height². We averaged seedling counts over all sampled subplots per year and scaled this number to the acreage of a subplot (0.25 ac.) to compute a density value (seedlings per acre). Per FIA protocol, plots are reassessed every 5 years until 2014, and every 7 years after that. To compute the annual score, we used 5-year leading edge moving window (i.e., data reported for 2007 used 2003, 2004, 2005, 2006 and 2007) until 2014 when we switched to a 7-year leading edge moving window per FIA protocol². The target for this dataset was set to the maximum value plus 10% of the range. The score was then computed as the difference between 0 and the target,

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Citation:

¹ USDA Forest Service. 2017. FIA Data Mart. Available at: <https://apps.fs.usda.gov/fia/datamart/datamart.html>

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Mean Forest Patch Size

From the Forest Cover images we generated (see details under that metric above), we used FragStats¹ to compute the mean size of forest patches. While the first available year of data was 1992, we excluded this year from our analysis as NLCD methodology changed between 1992 and 2006. We used the 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 annual score was computed as the

difference between the minimum (minimum value minus 10% of the range) and the target when values are below the target, or the upper scoring bounds (maximum value plus 10% of the range) and the target when values are above the target, scaled to be between 0-1.

Citation:

¹ 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 Connectivity

From the Forest Cover images we generated (see details under that metric above), we used FragStats¹ to compute the mean forest connectivity between forest blocks. While the first available year of data was 1992, we excluded this year from our analysis as NLCD methodology changed between 1992 and 2006. We used the the 8 cell neighborhood rule with a 'no sampling' strategy. We selected 'Contagion' as the Landscape Aggregation metric to compute. We set the target for this dataset to be the long-term mean. The annual score was computed as the difference between the lower scoring bounds (minimum value minus 10% of the range) and the target when values are below the target, or the upper scoring bounds (maximum value plus 10% of the range) and the target when values are above the target, scaled to be between 0-1.

Citation:

¹ 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>

Tree Species Diversity

Using Forest Inventory and Analysis data on Phase 1 plots via the FIA Datamart Access Database¹, we tallied the number of trees (>5 in diameter) per species to compute a Shannon-Weiner Diversity Index (H') (see equation below). The first year of available data was 1997. To compute the annual score, we used 5-year moving windows centered on the target year (i.e., data reported for 2005 used 2003, 2004, 2005, 2006 and 2007). This 5-year moving window was selected because FIA data is collected on a 5-year rotation. However, when the target year occurred at the beginning or end of the time period, we used a smaller window. For instance, target year 2003 uses 2003, 2004, 2005, and target year 2004 uses 2003, 2004, 2005, 2006. This

pattern is similar on the upper end of the data time period. The one exception is the 1997 data, which represented a full inventory, so no moving window was used to calculate values for this year. We set the target for this dataset at 3.5 according to established research². The current year is scored as the distance between the acceptable species diversity thresholds of 1.5 and 3.5², scaled to be between 0 and 1.

Shannon-Weiner Index (H')

Citation:

¹ USDA Forest Service. 2017. FIA Data Mart. Available at: <https://apps.fs.usda.gov/fia/datamart/datamart.html>

² MacDonald, G.M. 2003. Biogeography: space, time and life."

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¹ USDA Forest Service. 2017. FIA Data Mart. Available at: <https://apps.fs.usda.gov/fia/datamart/datamart.html>

² MacDonald, G.M. 2003. Biogeography: space, time and life."

Stand Complexity

Using Forest Inventory and Analysis data on Phase 1 plots accessed via the FIA Datamart Access Database¹, 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 5-year moving windows centered on the target year (i.e., data reported for 2005 used 2003, 2004, 2005, 2006 and 2007). This 5-year moving window was selected because FIA data is collected on a 5-year rotation. However, when the target year occurred at the beginning or end of the time period, we used a smaller window. For instance, target year 2003 uses 2003, 2004, 2005, and target year 2004 uses 2003, 2004, 2005, 2006. This pattern is similar on the upper end of the data time period. The one exception is the 1997 data, which represented a full inventory, so no moving window was used to calculate values for this year. The target for this dataset was set as the maximum value plus 10% of the range. The annual score was then calculated as a deviation between the target and the lower scoring bounds (minimum value in the dataset minus 10% of the range), scaled to be between 0-1.

Shannon-Weiner Index (H')

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Stand Age Diversity

Data on the annual acreage occupied by forests divided into 20 year age classes were extracted from the the Forest Inventory and Analysis EVALIDator¹. The first year of available data was 2011. We re-categorized stand ages into 40 year buckets (0-40, 40-80, and 80+ years) and created a ratio per each age class per year based on the estimated forestland. Per FIA protocol, plots are reassessed every 5 years until 2014, and every 7 years after that. 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 0-1.

Citation:

¹ USDA Forest Service. 2018. FIA EVALIDator. Available at: <https://apps.fs.usda.gov/Evalidator/evalidator.jsp>



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