

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 V5.0

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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 for decision-makers, educators, researchers, and the general public that summarizes the condition of Vermont's forest ecosystem and places recent observations in a long-term context. Following this initial working group meeting, FEMC staff worked with collaborators within the FEMC network to identify datasets, establish indicator definitions, and develop scoring criteria for the Dashboard.

The Forest Indicators Dashboard has four indicator categories: **Structure**, **Condition**, **Services**, and **Stressors**. Within each category, multiple indicator datasets were selected to represent complementary dimensions of forest ecosystem status. Selected datasets characterize forest ecosystems in objectively measurable ways, come from high-quality long-term sources, are updated on a regular basis when possible, and are supported by data programs expected to persist over time. Indicator values are transformed to a common 1-to-5 scale and combined using stakeholder-defined relative weights to produce category scores and an Overall Score, where 1 represents impaired status and 5 represents optimum status under the scoring definition for that indicator.

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 contain a diversity of species, ages, and sizes and retain sufficiently large and connected forest patches. Indicators include regeneration, species diversity, forest cover, stand age diversity, stand complexity, patch size, and connectivity.

Condition

Condition is the overall health and growth of trees and canopies. Forests must persist into the future while responding to current environmental conditions. Metrics include tree growth, crown dieback, tree damage and mortality, aerially detected forest injury, and canopy greenness.

Services

Services are the goods and functions that forested ecosystems provide, including timber, maple syrup, recreational and hunting opportunities, biodiversity support, water-related ecological functions, and carbon storage.

Stressors

Stressors are forces or processes that can harm forests or move environmental conditions away from those to which forests are adapted. Indicators include drought, climate extremes, snow cover, growing season length, temperature and precipitation, atmospheric deposition, ozone exposure, and invasive pests.

Metrics included in the Forest Indicators Dashboard were selected through an expert working group and subsequent technical review, together with considerations of ecological relevance, data availability, data quality, temporal continuity, and repeatability. The Dashboard is intentionally based on a suite of measurements rather than a single measure of forest health.

For each indicator, the underlying observations are processed into an annual value, such as annual tree mortality rate, forest cover, or total precipitation. These annual values are transformed to a common score (1-5 scale) so indicators measured in different units can be interpreted together. The score is an ecological interpretation of the annual value, not a probability, percentile, or statistical significance test. A score of 5 represents the most favorable condition defined by that indicator's scoring method, while a score of 1 represents the least favorable condition on the adopted scale.

Dashboard Scoring (V5.0)

Starting with Version 5.0 (V5.0) of the Dashboard, all indicators are scored on a common scale. The scoring separates three ecological questions: whether direction itself is favorable, whether consistency with a historical reference is favorable, or whether published science provides an external target. Scores are calculated internally on a 0-to-1 scale and displayed on the Dashboard as $1 + 4 \times \text{internal score}$.

Category 1: Direction Matters. For directional indicators, higher or lower raw values are consistently interpreted as better. The annual record defines padded scoring bounds. Let R be the observed range, lower = $\max(0, \text{minimum} - 0.1R)$, and upper = $\text{maximum} + 0.1R$. For higher-is-better indicators:

$$\text{Score} = 1 + 4 \times (\text{value} - \text{lower}) / (\text{upper} - \text{lower})$$

For lower-is-better indicators the direction is reversed:

$$\text{Score} = 5 - 4 \times (\text{value} - \text{lower}) / (\text{upper} - \text{lower})$$

Scores are bounded to the 1-to-5 display range. Directional scoring is used where the ecological interpretation is monotonic, including forest cover, connectivity, regeneration, carbon storage, canopy density, forest damage, forest mortality, and invasive-pest damage.

Category 2: Consistency With a Fixed Reference Matters. For indicators where departures from a historical reference are the concern, the score uses a fixed baseline rather than a mean that changes whenever new observations are added. Climate indicators with sufficiently long records use the 1961-1990

reference period. Shorter records use a fixed mean and standard deviation calculated from the first N valid years of the series. For a two-sided indicator:

$$z = (\text{value} - \text{baseline mean}) / \text{baseline standard deviation}$$

$$\text{Score} = 5 - 4 \times |z| / (|z| + 2)$$

This smooth-decay function gives a score of 5 at the baseline, a score of 3 at a departure of two standard deviations, and approaches 1 for increasingly large departures. Climate Extremes are one-sided: years calmer than the reference are not penalized, while increasing extremeness lowers the score. Its highest score is anchored one standard deviation below the 1961-1990 mean so unusually calm years receive full credit and the long-term increase in extremes remains visible.

Category 3: External Science Defines the Target. Some indicators are scored against published scientific or regulatory reference values rather than against the Dashboard record itself. These include precipitation acidity, mercury deposition, ozone exposure, tree species diversity, and stand complexity. The exact target or reference bounds are described in the indicator-specific sections below. Forest Bird Diversity is also directional but uses a fixed external index scale rather than data-derived bounds.

Trend Assessment

V5.0 replaces ordinary least-squares trend fitting with a more statistically rigorous Theil-Sen slope and a Mann-Kendall rank-based trend test¹. The dotted trend line displayed with an indicator is the Theil-Sen line, which is less sensitive than ordinary least squares to a single unusual year. Trend direction is determined from the indicator score, so an upward arrow always means improving ecological condition, and a downward arrow means declining condition, even when lower raw values are desirable. Whether an arrow is displayed is evaluated on the underlying data: the trend must pass the Mann-Kendall significance gate (one-sided p-value of 0.10 or less) and show a relative change of at least 5%. Category and Overall Score arrows pass the same significance and magnitude gates; because those rows contain score-only series, the magnitude is evaluated relative to the series mean.

Uncertainty and Variability

V5.0 adds typed uncertainty information where the source and statistical design support it. The Dashboard distinguishes uncertainty about an estimate from spatial variability in the landscape and from map-classification uncertainty^{2,6}. It intentionally shows no band where a statistical interval would be misleading.

Confidence interval: A sampling-based measure of how precisely the annual value is estimated². FIA indicators generally carry FIA design-based sampling error³; other sampled indicators use field-sample standard errors or bootstrap intervals⁴.

Map-classification band: A distinct band for a metric derived from a classified land-cover map. Forest Cover uses a National Land Cover Database (NLCD) accuracy-based standard error⁵. Mean Forest Patch Size and Forest Connectivity reserve this uncertainty type but do not display a band in V5.0 because the current simulation approach is not considered sufficiently reliable.

Spatial-variability range: A description of how much the underlying quantity varies across the landscape, not a confidence interval on the statewide mean². Canopy Density and Growing Season Length use the middle 50% (interquartile range) of forest-pixel values.

No band: Used for complete administrative counts, mapped totals, constructed indices, or regional climate values for which a sampling interval is not appropriate.

Annual Variability: An optional stability badge based on the von Neumann ratio $V = \text{MSSD} / \text{population variance}$, where MSSD is the mean successive squared difference of adjacent-year values⁷. V below 1 is Low variability, V above 2 is High, and values in between are Medium. At least eight valid adjacent-year pairs and non-zero variance are required.

Important Notes

The Dashboard is versioned. When authoritative sources publish new observations, the updated data are added to the FEMC data archive as new dataset versions, and a new Dashboard version is built from them. Each Dashboard version is therefore tied to specific versions of its source datasets, keeping a complete record of the data behind every published result. Historical raw values may change between versions when an upstream source revises its record or when FEMC corrects a documented processing error, and historical scores may change when a methodology is intentionally revised. Such changes are documented, and published Dashboard versions remain available for reference rather than being overwritten.

The availability of annual values differs among data sources, so the most recent year shown for an indicator may differ from other indicators. The V5.0 data refresh uses the latest source year available at release time; many indicators extend through 2025, while others remain at 2024 or 2022 because newer source data are not yet available.

Terminology

Upper scoring bound	The upper endpoint used to scale a directional or threshold-based score. Depending on the indicator it may be data-derived (for example, maximum plus 10% of the observed range) or fixed from external science.
Lower scoring bound	The lower endpoint used to scale a directional or threshold-based score. Depending on the indicator it may be data-derived or a fixed scientific reference.
Target / reference	A fixed ecological benchmark used by reference- or threshold-based indicators. Category 2 baselines include both a mean and standard deviation; Category 3 targets come from external science.
Baseline period	The fixed period used to calculate the mean and standard deviation for Category 2 scoring. Climate indicators generally use 1961-1990; shorter records use their first defined set of valid years.
Minimum / Maximum	The minimum and maximum observed values in the indicator record. For directional indicators these values are used to construct padded scoring bounds.
Uncertainty band	A labeled range shown around an annual value when supported by the data. It may be a confidence interval, map-classification band, or spatial-variability range; these have different interpretations.
Trend direction	The long-term direction of ecological condition based on the score series, with display gated by the significance and magnitude of the underlying data trend.

How Scores Can Change Over Time

Scores within a published Dashboard version do not change. When new data are added, a new version is created using the same methodology, and scores in that new version can differ from the previous version. Fixed-reference (Category 2) scores do not redefine their baseline when a new year is appended. Directional (Category 1) scores can be rescaled if a new observation extends the observed minimum or maximum, because their bounds are based on the full record with 10% padding; this is intentional and differs from the

former V4 approach, in which many reference means drifted as new years were added. A documented source revision, processing correction, or methodology change can also cause historical values or scores to be recomputed in a new version. FEMC preserves prior Dashboard versions so previously published results remain traceable.

Reading a chart

The coloured line is the score and the grey line is the underlying measured value. If the two move together, the scoring is representing the data faithfully; that agreement is the check the V5.0 methodology review was built around.

Methodology document

The methodology for this version of the dashboard is available as a PDF: [download the current methodology](#). Methodology documents for prior versions of the dashboard are available from the Download methodology menu at the top of this tab.

References

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- ³ Bechtold, W.A., and Patterson, P.L., eds. 2005. The Enhanced Forest Inventory and Analysis Program—National Sampling Design and Estimation Procedures. General Technical Report SRS-80. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 85 p. <https://doi.org/10.2737/SRS-GTR-80>
- ⁴ Efron, B., and Tibshirani, R. 1986. Bootstrap methods for standard errors, confidence intervals, and other measures of statistical accuracy. *Statistical Science* 1(1): 54-75. <https://doi.org/10.1214/ss/1177013815>
- ⁵ Olofsson, P., Foody, G.M., Herold, M., Stehman, S.V., Woodcock, C.E., and Wulder, M.A. 2014. Good practices for estimating area and assessing accuracy of land change. *Remote Sensing of Environment* 148: 42-57. <https://doi.org/10.1016/j.rse.2014.02.015>
- ⁶ Regan, H.M., Colyvan, M., and Burgman, M.A. 2002. A taxonomy and treatment of uncertainty for ecology and conservation biology. *Ecological Applications* 12(2): 618-628. [https://doi.org/10.1890/1051-0761\(2002\)012\[0618:ATATOU\]2.0.CO;2](https://doi.org/10.1890/1051-0761(2002)012[0618:ATATOU]2.0.CO;2)
- ⁷ Von Neumann, J. 1941. Distribution of the ratio of the mean square successive difference to the variance. *The Annals of Mathematical Statistics* 12(4): 367-395. <https://doi.org/10.1214/aoms/1177731677>

CONDITION

Tree Growth

Data on tree growth are obtained from the USDA Forest Service FIA program through automated FIADB-API/EVALIDator queries. The metric is average annual net growth of sound bole volume of live trees at least 5 inches d.b.h. on forest land. The first usable annual panel is 2008, and FIA population-estimation methods are used to represent statewide conditions.

V5.0 treats Tree Growth as a stability indicator because both unusually low growth and unusually high growth can indicate conditions outside the historical regime. The fixed baseline is the mean and standard deviation of the first five valid years (2008-2012). Annual scores use the two-sided smooth-departure function. FIA design-based sampling error is passed through as a confidence interval.

Citation:

¹ USDA Forest Service. Forest Inventory and Analysis Program, EVALIDator and FIADB-API.

Crown Dieback

Crown dieback is a visual assessment of the percentage of a tree crown showing recent fine-twig mortality. Vermont values are derived from long-running Forest Health Monitoring (FHM) and North American Maple Project (NAMP) plots. FHM data are now retrieved directly from the FEMC FHM database through a reproducible export that includes an authoritative state field. FHM plots have been assessed since 1994; during the 2008-2013 rotating-panel period, missing annual values are represented using the surrounding three-year pooled measurements, consistent with the historical series. NAMP plots have been assessed annually beginning in 1988. To reduce the influence of sugar-maple-dominated NAMP plots, only plots where dominant and codominant trees are less than 80% sugar maple are used. Dieback is first averaged within species and plot before the annual program-level averages are combined.

V5.0 scores crown dieback as two-sided stability around a fixed baseline from the first 10 valid years of record (approximately 1992-2001), rather than as a simple lower-is-better measure. Uncertainty is calculated from the spread among plot means and displayed as a symmetric confidence interval.

Citation:

¹ Pontius, J. and S. Wilmot. 2017. Forest Health Monitoring. Forest Ecosystem Monitoring Cooperative.

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

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

Forest Damage

Insect and Disease Surveys (IDS; aerial detection surveys) are conducted annually by the State of Vermont and the USDA Forest Service to map visible forest disturbance caused by insects, diseases, weather events, and other agents. The digitally available record used by the Dashboard begins in 1995. For V5.0, aerial-survey processing is explicitly restricted to Vermont before annual totals are calculated. Forest Damage is the sum of forest area mapped with visible current-year damage, excluding polygons classified as current-year mortality.

Forest Damage is a directional lower-is-better indicator. The lower and upper scoring bounds are the observed minimum minus 10% of the range (not below zero) and the observed maximum plus 10% of the range. Lower damaged area receives a higher score. Because this is a mapped total of detected polygons rather than a sample estimate, no confidence interval is shown; variation in survey effort and detectability is a data-quality limitation rather than sampling error.

Citation:

¹ USDA Forest Service, Forest Health Protection. Aerial Detection Surveys / Insect and Disease Surveys. Available at:
<https://www.fs.usda.gov/foresthealth/applied-sciences/mapping-reporting/detection-surveys.shtml>

Forest Mortality

Forest Mortality uses the same annual aerial detection survey program as Forest Damage but sums the area mapped as current-year tree mortality. The digitally available Vermont record begins in 1995. V5.0 processing uses the Vermont-only subset before annual acres of visible mortality are totaled.

This is a directional lower-is-better indicator. Annual mortality area is scored across the padded observed range, with lower mortality area receiving higher scores. As a mapped polygon total rather than a sampled estimate, no uncertainty band is shown.

Citation:

¹ USDA Forest Service, Forest Health Protection. Aerial Detection Surveys / Insect and Disease Surveys.

Canopy Density

Canopy Density is based on USGS Remote Sensing Phenology products and uses time-integrated Normalized Difference Vegetation Index (TIN NDVI) as a measure of growing-season canopy greenness. Annual raster values are clipped to the Vermont boundary and restricted to forest using National Land Cover Database forest classes. Invalid or no-data pixels are excluded before the annual statewide mean is calculated. The phenology series includes a sensor/platform transition in 2021 from eMODIS to eVIIRS, which should be considered when interpreting changes around that year.

V5.0 scores Canopy Density as a directional higher-is-better indicator using the padded observed-range formula. The dashboard also reports the interquartile range of forest-pixel TIN values as a spatial-variability band. This band describes how canopy greenness varies across Vermont; it is not a confidence interval on the statewide mean.

Citation:

¹ USGS Remote Sensing Phenology products. Available through the U.S. Geological Survey.

² US Geological Survey. Annual National Land Cover Database. Available at: <https://www.mrlc.gov/>

Damage and Decay

Damage and Decay is derived from USDA Forest Service FIA data obtained through automated FIADB-API/EVALIDator queries. The metric is based on live trees at least 5 inches d.b.h. with a recorded damage agent and is expressed as a statewide FIA ratio estimate. The automated V5.0 pull preserves the archive fields required by the Dashboard and uses the current FIA evaluation.

The V5.0 score is a two-sided stability score around a fixed baseline from the first five valid years of the current series (2013-2017). Values near that baseline score highest, while departures in either direction score lower. FIA design-based sampling error is displayed as a confidence interval.

Citation:

¹ USDA Forest Service. Forest Inventory and Analysis Program, EVALIDator and FIADB-API.

² USDA Forest Service. Forest Inventory and Analysis Glossary.

Tree Mortality

Data on annual tree mortality are obtained from the USDA Forest Service Forest Inventory and Analysis (FIA)

program through automated FIADB-API/EVALIDator queries. The annual metric is the ratio of average annual mortality of sound bole volume of trees at least 5 inches d.b.h. to the sound bole volume of live trees at least 5 inches d.b.h. on forest land. The usable annual series begins in 2008 and relies on FIA population-estimation methods to represent statewide forest conditions.

Version 5.0 treats Tree Mortality as a stability indicator rather than assuming that progressively lower mortality is always better. The reference is the mean and standard deviation of the first 10 valid years of the record (2008-2017), held fixed thereafter. Annual scores use the two-sided smooth-departure formula described above, so values close to the reference score highest and unusually high or unusually low mortality rates score lower. FIA design-based sampling error is carried through as a confidence interval.

Citation:

¹ USDA Forest Service. Forest Inventory and Analysis Program, EVALIDator and FIADB-API. Available at: <https://apps.fs.usda.gov/Evalidator/>

SERVICES

Carbon Storage

Total forest carbon is obtained from the USDA Forest Service FIA program through automated FIADB-API/EVALIDator queries. The metric uses FIA forest carbon total across all five carbon pools on forest land, reported in metric tonnes. FIA population estimates are used to represent total statewide carbon storage.

Carbon Storage is a directional higher-is-better indicator and is scored across the padded observed range. FIA design-based sampling error is carried through as a confidence interval; because statewide carbon is a large, well-sampled total, this interval is generally proportionally tight.

Citation:

¹ USDA Forest Service. Forest Inventory and Analysis Program, EVALIDator and FIADB-API.

Forest Bird Diversity

Forest bird abundance data are collected by the Vermont Center for Ecostudies Forest Bird Monitoring

Program at long-running forested sites across Vermont. The Dashboard uses the Living Planet Index (LPI) to summarize change across monitored forest bird species, with equal species weighting and no subgrouping. Only sites meeting the long-term record requirements are included. V5.0 processing constrains the LPI output to the last year represented in the source observations so the model cannot generate a projected value for a future, unsampled year.

The LPI is scored directionally on a fixed external index scale from 0 to 2, with higher values receiving higher scores and an index value of 1 representing the reference level. The LPI method produces a bootstrap interval by resampling the monitoring data; V5.0 carries the explicit lower and upper bounds through to the dashboard as an asymmetric confidence interval.

Citation:

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

² Collen, B., J. Loh, S. Whitmee, L. McRae, R. Amin and J.E.M. Baillie. 2009. Monitoring change in vertebrate abundance: the Living Planet Index. *Conservation Biology* 23(2):317-327.

³ Indicators and Assessments Research Unit, Zoological Society of London. Living Planet Index tools.

Timber Harvest

Timber Harvest uses the annual quantity of timber harvested in Vermont reported in the Vermont Forest Resource Harvest Report, expressed in cords of wood. The indicator represents the production of a major forest commodity and is updated when the state harvest summary is released.

Timber Harvest is a directional higher-is-better indicator. V5.0 scores the annual value across the full padded observed range and corrected the historical minimum-tracking logic used in this family. The harvest total is an administrative total rather than a statistical sample, so no uncertainty band is shown.

Citation:

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

Recreation Rates

Data on camping and day-use visitation to Vermont state parks are provided by the Vermont Department of Forests, Parks and Recreation. These data do not represent all public-land visitation in Vermont. To focus the

indicator on parks where forests are a predominant resource, park parcels are classified by forest cover using NLCD deciduous, evergreen, and mixed-forest classes. Parks with more than 60% forest cover are retained; wooded wetland is not included in this screening because it can overstate forest cover for parks dominated by water-oriented settings. Total camping and day-use visits are averaged by the number of qualifying parks reporting data in each year.

Recreation Rates is a directional higher-is-better indicator. Annual values are scored across the padded observed range, with higher visitation receiving higher scores. Because the metric is based on administrative visit counts rather than a statistical sample, no uncertainty band is shown.

Citation:

¹ Savage, J. Recreational Rates at Vermont State Parks. Vermont Department of Forests, Parks and Recreation.

² US Geological Survey. Annual National Land Cover Database. Available at: <https://www.mrlc.gov/>

Stream Indicator Species

Species richness data are obtained from the Vermont Integrated Watershed Information System for Ranch Brook in Underhill, Vermont (site 502032), the site with a sufficiently long and annually resolved record for the Dashboard. The indicator is EPT richness: the number of unique taxa belonging to Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies). When multiple samples occur in a year, the annual value is their mean.

Stream Indicator Species is a directional higher-is-better indicator and is scored across the padded observed range. V5.0 replaces the older compressed maximum-based score with the standard directional formula. When more than one sample contributes to an annual mean, the Dashboard calculates the standard error of that mean as a confidence interval; a year with only one sample has no interval.

Citation:

¹ VTDEC Watershed Management Division. 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 Field Methods.

Hunting Harvests

The Dashboard uses the annual number of meals represented by harvests of major game species, including white-tailed deer, black bear, moose, and wild turkey, as reported by the Vermont Department of Fish and Wildlife. The annual statewide total provides a standardized representation of this forest-related provisioning service.

Hunting Harvests is a directional higher-is-better indicator. V5.0 uses the full padded observed range, including the true observed minimum, rather than the older compressed value-to-maximum formulation. Reported harvest is treated as an administrative statewide total, so no sampling uncertainty band is shown.

Citation:

¹ Darling, S. Vermont Big Game Meals. Vermont Department of Fish and Wildlife. Available through the Forest Ecosystem Monitoring Cooperative data archive.

Maple Syrup Production

The Dashboard uses total annual maple syrup revenue reported by the USDA National Agricultural Statistics Service. The series represents an economic forest product service and is updated when the annual NASS values become available.

Maple Syrup Production is scored as a directional higher-is-better indicator using the full padded observed range. V5.0 corrected the minimum-tracking logic so the true observed minimum is used rather than an implicit zero, allowing the annual scores to span the intended 1-to-5 scale. The source series does not provide a coefficient of variation suitable for the Dashboard, so no uncertainty band is shown.

Citation:

¹ USDA National Agricultural Statistics Service. Quick Stats. Available at: <https://quickstats.nass.usda.gov/>

STRESSORS

Drought

Drought is assessed using the Standardized Precipitation Evapotranspiration Index (SPEI), which combines precipitation supply with atmospheric water demand through evapotranspiration. The Dashboard uses a six-month SPEI spanning April through September to represent moisture conditions during the functional

growing season.

V5.0 scores drought as two-sided consistency with the fixed 1961-1990 reference period. The baseline mean and standard deviation are held fixed and annual scores use the smooth-departure function; both unusually dry and unusually wet growing seasons therefore represent departures from the historical climate regime. SPEI is a deterministic constructed index rather than a sampled mean, so no uncertainty band is shown.

Citation:

¹ Vicente-Serrano, S.M., S. Beguería and J.I. López-Moreno. 2010. A multi-scalar drought index sensitive to global warming: the Standardized Precipitation Evapotranspiration Index. *Journal of Climate* 23(7):1696-1718.

Ozone Exposure

Daily ozone observations are obtained for Vermont air-quality monitoring sites and converted to the vegetation-focused W126 exposure metric. The monitoring season is April 1 through September 30 and the relevant daytime hours are 8:00 a.m. to 8:00 p.m. Hourly ozone concentrations are weighted using the W126 transformation, summed to daily and monthly values, and used to construct the annual seasonal exposure metric according to the established W126 procedure.

The protective target is 7 ppm-hours W126. Values at or below 7 receive the highest score; values above the target decline linearly toward an upper scoring bound equal to the observed maximum plus 10% of the observed range. V5.0 corrects the implementation to use this data-derived upper bound rather than the former hardcoded 17 ppm-hour ceiling, which had produced overly lenient historical scores. W126 is a deterministic cumulative index, so no sampling uncertainty band is shown.

Citation:

¹ U.S. Environmental Protection Agency. Outdoor Air Quality Data.

² U.S. Environmental Protection Agency. W126 ozone exposure calculation guidance.

³ U.S. Environmental Protection Agency. National Ambient Air Quality Standards for Ozone.

Precipitation Acidity

Precipitation acidity is based on pH measurements from the National Atmospheric Deposition Program National Trends Network in Vermont. V5.0 processing calculates the annual mean pH directly from valid monitoring readings.

The ecological target is pH 5.6, representing clean rain in equilibrium with atmospheric carbon dioxide. Scores increase toward this fixed external target, and values at or above the target receive the highest score. The lower scoring reference is fixed in the V5.0 implementation rather than being redefined from the current record. Because the annual value is a mean of monitoring readings, the standard error of that mean is displayed as a confidence interval.

Citation:

¹ National Atmospheric Deposition Program. National Trends Network. Available at: <https://nadp.slh.wisc.edu/networks/national-trends-network/>

² Vermont Department of Environmental Conservation. Acid rain monitoring information.

Growing Season Length

Growing Season Length is derived from USGS Remote Sensing Phenology duration (DUR) products. Annual phenology rasters are clipped to the Vermont polygon and restricted to forest pixels using NLCD forest classes. V5.0 corrects a processing fault in which pixels outside the Vermont polygon but inside its bounding box could enter the duration sample as zero-day growing seasons. The corrected workflow uses the polygon mask itself to exclude out-of-state pixels and also treats zero-day duration as invalid. Historical values are rebuilt under this corrected method. The underlying phenology series transitions from eMODIS to eVIIRS in 2021.

Growing Season Length is a two-sided Category 2 indicator with a fixed baseline from the first 10 valid years of the record (2001-2010). Annual values are scored by standardized departure from that baseline using the smooth-decay function. The dashboard reports the interquartile range of forest-pixel growing-season duration as a spatial-variability band, describing geographic variation across Vermont rather than uncertainty in the mean.

Citation:

¹ USGS Remote Sensing Phenology products.

² US Geological Survey. Annual National Land Cover Database.

Mercury Deposition

Mercury deposition data are obtained from the National Atmospheric Deposition Program Mercury Deposition Network for Vermont monitoring locations. Annual deposition is a precipitation-weighted quantity derived from repeated wet-deposition measurements.

V5.0 retains an externally defined target of zero mercury deposition because mercury is a bioaccumulative neurotoxin. Higher deposition receives a lower score, and scores are clamped to the 1-to-5 display range. A simple sampling confidence interval is not shown because the annual value is precipitation-weighted and generally based on a small monitoring network; such an interval would overstate what is known.

Citation:

¹ National Atmospheric Deposition Program. Mercury Deposition Network. Available at: <https://nadp.slh.wisc.edu/networks/mercury-deposition-network/>

Minimum Temperature

Mean annual minimum temperature for Vermont is obtained from NOAA National Centers for Environmental Information. V5.0 processing uses the Vermont-only source subset and the current minimum-temperature field.

The annual value is scored against the fixed 1961-1990 mean and standard deviation using the two-sided smooth-departure function. Both unusually warm and unusually cool annual minimum temperatures are departures from the historical climate reference. No sampling uncertainty band is shown because the source provides a single regional/state climate value per year.

Citation:

¹ NOAA National Centers for Environmental Information. Climate at a Glance / climate divisional data.

Maximum Temperature

Mean annual maximum temperature for Vermont is obtained from NOAA National Centers for Environmental Information. V5.0 processing uses the Vermont-only source subset and the current maximum-temperature field.

The annual value is scored against the fixed 1961-1990 mean and standard deviation using the two-sided smooth-departure function. Both unusually warm and unusually cool annual maximum temperatures are departures from the historical climate reference. No sampling uncertainty band is shown because the source provides a single regional/state climate value per year.

Citation:

¹ NOAA National Centers for Environmental Information. Climate at a Glance / climate divisional data.

Snow Cover

Snow Cover is the number of days with snow depth of at least 1 inch, from NOAA Global Historical Climatology Network Daily (GHCN-D) records at long-running Vermont weather stations¹. For each station, the monthly day counts are summed over the snow year (October through the following May); a station-year missing any of those eight months is excluded. Stations differ considerably in their typical snow-cover duration because of elevation, latitude, and local climate (Vermont station averages range from roughly 80 to 200 snow-days), and the set of stations reporting changes from year to year, so a simple average of raw totals partly tracks which stations reported rather than the snow itself.

V5.0 therefore averages station departures². Each station-year total is expressed as a departure from that station's own long-term average, the departures are averaged across the stations reporting that year, and a single fixed constant (the mean of the included stations' long-term averages) is added back so the indicator still reads in snow-days. V5.0 also expanded the Vermont station list from two to twelve long-running stations; a station needs at least 15 complete snow-years to establish its long-term average, so eleven are used. Stations with shorter records have long-term averages drawn from more recent winters, so their departures can understate part of the long-term decline; the approach is therefore conservative.

The score uses a fixed 1961-1990 baseline mean and standard deviation, calculated from the departure-based series, and the two-sided smooth-departure formula. This replaces the former moving long-term mean, so the reference does not shift as newer winters are added. Because the annual value is an average of station departures, the dashboard displays the standard error of that mean departure as a confidence interval; years with more reporting stations generally have tighter intervals.

Citation:

¹ NOAA National Centers for Environmental Information, Global Historical Climatology Network Daily (GHCN-D).

² Brown, R., Derksen, C., & Wang, L. 2010. A multi-data set analysis of variability and change in Arctic spring snow cover extent, 1967–2008. *Journal of Geophysical Research: Atmospheres* 115, D16111. <https://doi.org/10.1029/2010JD013975>

Climate Extremes

The NOAA National Centers for Environmental Information Climate Extremes Index (CEI) measures the fraction of the Northeast region experiencing unusually extreme temperature, precipitation, and drought conditions in a given year. V5.0 automates retrieval of the Northeast annual all-steps CEI record directly from NCEI and rebuilds the full historical series each update.

Climate Extremes uses a fixed 1961-1990 baseline but is scored one-sided because fewer climate extremes than the historical normal are not considered a stressor. The top score is anchored one standard deviation below the baseline mean. Values at or below that calm-year anchor receive the highest score, while increasing extremeness above the anchor lowers the score using the smooth-decay form; a year at the baseline mean scores approximately 3.7 of 5. Because CEI is a constructed index, no sampling uncertainty band is shown.

Citation:

¹ NOAA National Centers for Environmental Information. U.S. Climate Extremes Index. Available at: <https://www.ncei.noaa.gov/access/monitoring/cei/>

Damage by Invasive Pests

Damage by Invasive Pests is derived from the annual aerial detection survey record. FEMC identifies aerial-survey polygons associated with insects and diseases considered invasive in Vermont and sums their mapped affected area for each year. V5.0 processing explicitly restricts the source data to Vermont before the annual total is calculated.

This is a directional lower-is-better indicator. Annual invasive-pest damage is scored across the padded observed range, with smaller affected area receiving a higher score. The mapped area is a detected polygon total rather than a sample estimate, so no confidence interval is shown.

Citation:

¹ USDA Forest Service, Forest Health Protection. Aerial Detection Surveys / Insect and Disease Surveys.

Precipitation

Annual total precipitation for Vermont is obtained from NOAA National Centers for Environmental Information. V5.0 processing uses the Vermont-only climate subset and the current precipitation field.

Precipitation is scored as two-sided consistency with the fixed 1961-1990 mean and standard deviation. Departures toward either unusually wet or unusually dry annual conditions lower the score using the smooth-decay function. The source is a single NOAA regional/state climate value for each year rather than a station sample maintained by FEMC, so no sampling uncertainty band is shown.

Citation:

¹ NOAA National Centers for Environmental Information. Climate at a Glance / climate divisional data. Available at: <https://www.ncei.noaa.gov/access/monitoring/climate-at-a-glance/>

STRUCTURE

Softwood Regeneration

Softwood Regeneration uses red spruce (*Picea rubens*) seedling density in spruce-fir forest types estimated from USDA Forest Service FIA Phase 2 plots. V5.0 obtains the seedling population estimates through automated FIADB-API/EVALIDator queries using the FIA seedling estimate and red-spruce species code, grouped to the applicable forest-type group. FIA panel estimates represent the spruce-fir forest resource rather than raw plot counts.

Softwood Regeneration is a directional higher-is-better indicator. V5.0 replaces the former value-to-maximum formulation with the standard padded observed-range score so the full 1-to-5 scale is used consistently. FIA design-based sampling error is displayed as a confidence interval.

Citation:

¹ USDA Forest Service. Forest Inventory and Analysis Program, EVALIDator and FIADB-API.

² USDA Forest Service. Forest Inventory and Analysis National Core Field Guide.

Mean Forest Patch Size

Mean Forest Patch Size is calculated from Annual NLCD land cover¹. Forest includes Deciduous Forest, Evergreen Forest, Mixed Forest, and Woody Wetlands. Forest pixels are grouped into patches using an eight-cell neighborhood rule. Most patches in the classified map are slivers of only a few pixels, so the plain mean and the median patch size mainly describe those slivers rather than the forest landscape; Vermont's median patch size takes only two values, 0.27 and 0.36 hectares, across the whole record. V5.0 therefore uses the area-weighted mean patch size (FRAGSTATS AREA_AM)^{2,3}: each patch is weighted by its own area, so the value is the expected size of the contiguous forest patch containing a randomly chosen hectare of forest. It is calculated as the sum of squared patch areas divided by total forest area and is reported in hectares.

This change raises reported values from roughly 75 hectares (plain mean) to roughly 35,000 hectares and

changes the direction of Vermont's trend: the plain mean declined as small edge fragments multiplied, while the area-weighted mean increases as the large core forest patches have consolidated.

The indicator is scored as directional higher-is-better using the padded observed range, because larger contiguous patches generally provide more interior habitat and reduce fragmentation. A map-classification uncertainty type is reserved for this metric, but V5.0 does not display a band because the available pixel-perturbation simulation over-fragments the landscape and is not considered sufficiently reliable.

Citation:

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

² McGarigal, K., S.A. Cushman and E. Ene. FRAGSTATS v4: Spatial Pattern Analysis Program for Categorical and Continuous Maps.

³ Jaeger, J.A.G. 2000. Landscape division, splitting index, and effective mesh size: new measures of landscape fragmentation. *Landscape Ecology* 15: 115-130.

Forest Cover

Version 5.0 derives Forest Cover from Annual NLCD land cover rather than from FIA survey estimates. Forest is defined as the area classified as Deciduous Forest, Evergreen Forest, Mixed Forest, or Woody Wetlands, and the annual value is the percentage of Vermont land represented by those forest classes. Using NLCD aligns this structural indicator with the land-cover products used for patch size and connectivity and provides annual mapped coverage through the latest available NLCD year.

Forest Cover is a directional higher-is-better indicator and is scored across the padded observed range. V5.0 therefore removes the former distance-from-long-term-mean scoring, which could invert the ecological interpretation of declining forest extent. The dashboard displays a map-classification band derived from the published Annual NLCD accuracy assessment using an Olofsson-style design-based standard error. The band reflects uncertainty in the land-cover classification, not sampling error from field plots.

Citation:

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

² US Geological Survey. Annual NLCD Collection 1.0 validation and accuracy assessment (DOI 10.5066/P94UXNTS).

Hardwood Regeneration

Hardwood Regeneration uses sugar maple (*Acer saccharum*) seedling density in maple-beech-birch forest types estimated from USDA Forest Service FIA Phase 2 plots. V5.0 retrieves the FIA seedling estimate through automated FIADB-API/EVALIDator queries using the sugar-maple species code and applicable forest-type grouping. FIA population-estimation methods scale the sampled seedling observations to the statewide forest resource.

Hardwood Regeneration is a directional higher-is-better indicator. V5.0 replaces the former value-to-maximum score with the standard padded observed-range method, allowing low-regeneration years to use the lower portion of the 1-to-5 scale. FIA design-based sampling error is displayed as a confidence interval.

Citation:

¹ USDA Forest Service. Forest Inventory and Analysis Program, EVALIDator and FIADB-API.

² USDA Forest Service. Forest Inventory and Analysis National Core Field Guide.

Stand Age Diversity

Stand Age Diversity is derived from USDA Forest Service FIA population estimates of forest area by 20-year stand-age class, obtained through automated FIADB-API/EVALIDator queries. The age classes are combined into broader 40-year groupings used by the Dashboard, and their relative forest-area distribution is summarized with a Shannon-based diversity/evenness measure.

V5.0 confirms Stand Age Diversity as a directional higher-is-better indicator rather than a distance-from-mean indicator. It is scored across the padded observed range. The scoring implementation also corrects minimum tracking so the true observed minimum is used, allowing the long-term decline in the underlying diversity measure to be represented across the full scoring scale. Sampling errors for the underlying FIA age-class estimates are combined with a delta-method diversity-index standard error and displayed as a confidence interval.

Citation:

¹ USDA Forest Service. Forest Inventory and Analysis Program, EVALIDator and FIADB-API.

² USDA Forest Service. Forest Inventory and Analysis National Core Field Guide.

Tree Species Diversity

Tree Species Diversity is derived from USDA Forest Service FIA live-tree population estimates by species, obtained in V5.0 through automated FIADB-API/EVALIDator queries rather than manual raw-table exports.

The proportional abundance of tree species is summarized with a Shannon-Wiener diversity index.

The indicator is scored against fixed external thresholds: a Shannon diversity index of 1.5 is the lower reference and 3.5 is the upper reference, with higher diversity receiving higher scores. V5.0 corrects the implementation so these thresholds remain fixed throughout the calculation rather than being inadvertently altered inside the scoring loop. FIA sampling errors for species estimates are combined using a delta-method diversity-index standard error and displayed as a confidence interval.

Citation:

¹ USDA Forest Service. Forest Inventory and Analysis Program, EVALIDator and FIADB-API.

² MacDonald, G.M. 2003. Biogeography: Space, Time and Life.

Forest Connectivity

Forest Connectivity is calculated from Annual NLCD land cover after classifying Deciduous Forest, Evergreen Forest, Mixed Forest, and Woody Wetlands as forest. The forest map is analyzed using the same eight-cell neighborhood convention used for the landscape metrics, and the Dashboard uses the FRAGSTATS Contagion landscape-aggregation metric as its connectivity measure.

V5.0 scores Forest Connectivity as directional higher-is-better across the padded observed range. This replaces the former distance-from-long-term-mean approach, which could invert or flatten an ecologically meaningful loss of connectivity. Because connectivity is derived from a classified map, its natural uncertainty is map-classification error; however, the current forward-simulation method produces unrealistic fragmentation, so V5.0 does not display an uncertainty band for this indicator and explicitly defers that band pending a better error model.

Citation:

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

² McGarigal, K., S.A. Cushman and E. Ene. FRAGSTATS v4: Spatial Pattern Analysis Program for Categorical and Continuous Maps.

Stand Complexity

Version 5.0 replaces the former Shannon-Wiener index of 5-inch diameter classes with a Gini coefficient of tree basal area derived from USDA Forest Service FIA data. The Gini is calculated from the pooled statewide live-tree basal-area distribution using 2-inch diameter classes and trees at least 1 inch d.b.h. This measure

preserves the ordering and magnitude of tree sizes and is better aligned with the reverse-J diameter structure characteristic of uneven-aged, structurally diverse forests than a Shannon index that is maximized by equal abundance among arbitrary diameter classes.

The Gini is scored against fixed literature-based reference bounds rather than Vermont's observed range. A Gini of 0.50 is the lower reference and 0.75 is the upper reference; values are linearly scaled between those bounds to the 1-to-5 Dashboard scale and clamped at the endpoints. The production metric is the pooled statewide 2-inch-class Gini, which is the basis on which these bounds were calibrated. A design-based stratified plot bootstrap is used to quantify uncertainty: FIA plots are resampled within design strata, the pooled Gini is recomputed for each replicate, and the 2.5th and 97.5th percentiles form the displayed confidence interval.

The Gini captures the spread of basal area across stems but is not a complete description of diameter-distribution shape; different distributions can occasionally produce similar Gini values. The pooled statewide metric also should not be interpreted as the average stand-level Gini. These limitations are considered alongside the separate regeneration, age-diversity, and species-diversity indicators.

Citation:

¹ Lexerod, N.L. and T. Eid. 2006. An evaluation of different diameter diversity indices based on criteria related to forest management planning. *Forest Ecology and Management* 222:17-28.

² Sterba, J.H. and H. Sterba. 2018. The semi-logarithmic stem number distribution and the Gini-index: structural diversity in balanced dbh-distributions. *Austrian Journal of Forest Science* 135(1).

³ USDA Forest Service. Forest Inventory and Analysis Program and FIA DataMart.



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Providing the information needed to understand, manage, and protect the region's forested ecosystems in a changing global environment

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