CLIMATE CHANGE EXPOSURE MAPPING FOR NORTHEASTERN TREE SPECIES

Lukas Kopacki, Jennifer Pontius, Anthony D'Amato, & James Duncan

EXECUTIVE SUMMARY

The uncertainty around the impacts of changing climate poses a significant challenge to sustaining forest ecosystems in the Northeast. Important work has been done downscaling projected changes in climate conditions, modeling shifts in suitable habitat, and mapping disturbance patterns across the region, but no one effort has combined all these predictive tools into one cohesive dataset. The goal of this project is to aggregate these valuable but disparate spatial data sets to quantify a more comprehensive assessment of relative exposure to climate change impacts at the species, and community level.

Using the most current spatial data, this aggregate climate exposure map integrates data from four primary sources:

1. **Percent basal area**: Current distribution and abundance for key northeastern tree species from the Forest Ecosystem Monitoring Cooperative (FEMC) Species abundance project (Gudex-Cross, et al. 2017) weights exposure by species based on relative abundance across the landscape;
2. **Degree of Projected Climate Change**: differences in projected and historical norms for 5 downscaled climate metrics from TerraClimate (Abatzoglou, et al. 2018) were aggregated into a univariate spatial product that quantifies the overall degree of expected change in climate conditions across the Northeast;
3. **Projected Change in Suitable Habitat**: Species-level projected changes in relative importance index from the Climate Change Tree Atlas (Iverson, et al. 2008) integrated additional climate and site variables to model how the relative suitability for various species will change under various climate scenarios;
4. **Disturbance History**: Historical archives from the FEMC Northeastern Forest Health Atlas (Duncan, et al. 2018) that quantify the frequency of disturbance between 1997 and 2019 used to estimate a relative likelihood of ongoing climate related disturbance.

Aggregate climate exposure maps were quantified using normalized input from the 4 primary sources for 14 species under low and high emission scenarios. The resulting aggregate climate exposure maps provide insight into how projected changes in climate conditions vary across the landscape and how impacts of those changes may differ across species. Results indicate that at the stand level, highest overall exposure to climate, disturbance, and limitations in suitable habitat for current species distributions occurs in mountainous regions throughout the region and southeastern Maine.

Across the region, relative exposure across all species increases by 4 percent between low and high emission scenarios, although the differences between individual species varies widely.

Much of our current management is guided by the outcomes of decades of silviculture research, yet many of the conditions under which those results were generated are rapidly changing. These relative exposure maps can inform where climate adaptation management applications may be most successful over time and where various species may find refugia as climate change continues to change forest dynamics across the region.

Northeastern Forest Climate Change Exposure Mapping (NEFCCEM) Web Tool

Keywords*: Eastern United States, global change, geographic information systems, forest inventory and analysis, trees, landscape ecology, disturbance, climate change exposure*

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Cover art provided by Lukas Kopacki

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A special thanks to the USDA National Institute of Food and Agriculture McIntire- Stennis Cooperative Forestry Research Program for funding this project.

QUICK LINKS

Project information can be found on the FEMC website.

Project Overview video

Access to the interactive web mapping tool can be found here.

Climate Exposure Tool User’s Guide

DISCLAIMERS

Climate exposure is only one component of the overall risk of climate change to northeastern forests. The aggregate climate exposure maps quantify the degree of change in climate conditions and related impacts on the forest system. However, they do not include the sensitivity of individual species or their ability to resist or adapt to changes in climate conditions. As such, these aggregate climate exposure maps are one part of the broader information needed to understand forest vulnerability to climate change.

An absence of species abundance data layers meant that Connecticut and Rhode Island were excluded from the regional analyses.

The community-level exposure mapping scenarios include fourteen dominant tree species that inhabit the study area but does not represent a comprehensive list of existing species. As such, it should be considered a general representation of community level exposure to climate change, rather than a comprehensive assessment. Similarly, aggregate climate exposure maps should not be used as a source for opportunity mapping for species that are expected to increase in dominance under changing climate conditions. For example, southern sections of the region included in the study contain species such as Carya (hickory) species, tulip popular (*Liriodendron tulipifera*), and pitch pine (*Pinus rigida*) that are not a part of the analyses.

INTRODUCTION

Northeastern Forest Climate Change Exposure Mapping (NEFCCEM) is one piece of a larger effort set out to develop and test an interdisciplinary, collaborative approach to managing northern forests in the face of ongoing climate change. The broader **Adaptation and Restoration of Northern Forests** project combines restoration forestry, adaptive silviculture, geospatial decision support, and stakeholder engagement to inform the collaborative management of forests at risk. Although the potential impacts of climate change on forests may be considerable, few tools for assessing the current vulnerabilities of regional forests, or for managing forests to prosper despite these challenges, exist. Moreover, given the uncertainties and additional costs associated with proposed adaptation strategies, there is a need for tools that prioritize areas for these activities based on their relative exposure and sensitivity to climate change.

The goal of the **NEFCCEM** sub-project was to model the relative degree of climate change exposure across northeastern forests. Using a geospatial model with inputs from existing forest abundance, historical disturbance patterns, projected changes in habitat suitability for key species and deviations from climate norms for a suite of high-resolution climate metrics, the resulting spatial products can be used to inform where adaptive restoration techniques are most needed and likely to succeed. This included aggregating and normalizing spatial data from the USDA Forest Service's Forest Inventory and Analysis (FIA) program (Wilson, et al. 2013) and the Climate Change Tree Atlas (Iverson, et al. 2008), the TerraClimate research group (Abatzoglou, et al. 2018), the Forest Ecosystem Monitoring Cooperative (FEMC) Forest Health Atlas (Duncan, et al. 2018) and species abundance maps (Gudex - Cross, et al. 2017).

Outputs include 30 meter species-level aggregate climate exposure rasters for 14 of the region's most prominent tree species, as well as community-level rasters calculated as a percent-basal-area-weighted average of all species present at a given location. Each of these species- and community-level raster climate aggregate exposure maps was calculated for two climate scenarios (low and high emissions) as well as three possible disturbance scenarios (no disturbance, climate-related disturbances only, all disturbance). In addition to the production of raster layers, an online mapping tool was developed to facilitate access and visualization of aggregate climate exposure maps without the need to download storage-intensive raster files.

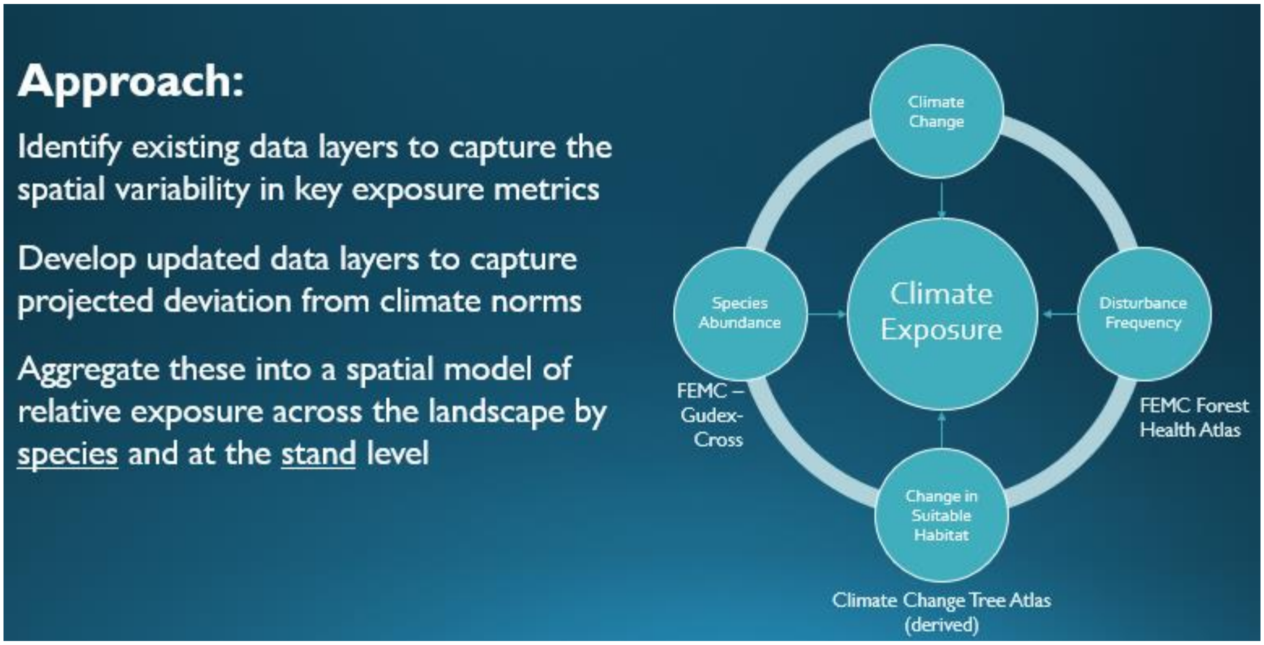
With this novel toolkit, we hope that forest land managers and practitioners across the northeastern United States will be able to make more informed decisions about forest management that include considerations of spatial variability in climate exposure. This information is critical to inform long-term management, policy, and planning decision support across the broader northern forest region.

APPROACH

SUMMARY

Mapping overall climate exposure began by identifying existing spatial data sets that could quantify the direct exposure to changing climate conditions, or indirect impacts of those changing conditions on habitat suitability and disturbance patterns. The spatial data inputs include:

- Disturbance-return frequency (DIST) derived from the FEMC's 'Northeastern Forest Health Atlas' (Duncan, et al. 2018),
- Species abundance (ABUND) from FEMC's percent basal area maps (Gudex- Cross, et al. 2017),
- Projected change in suitable habitat (PCSH) from the USFS's Climate Change Tree Atlas (Iverson, et al. 2008), and
- Climate variability (CLIM), a new spatial data set we created to quantify the projected deviation from historical climate norms as projected for a suite of monthly climate metrics obtained from the TerraClimate research group (Abatzoglou, et al. 2018).



Approach:

Identify existing data layers to capture the spatial variability in key exposure metrics

Develop updated data layers to capture projected deviation from climate norms

Aggregate these into a spatial model of relative exposure across the landscape by species and at the stand level

FIGURE 1. GENERAL APPROACH

Input spatial layers were normalized to a 0 to 100 scale representing no exposure to high exposure. The exception was projected suitable habitat, which is projected to become more favorable for some of the 14 target species (Table 1) under changing climate scenarios. For this input, relative importance values for each species were normalized to a -100 to 100 scale where negative values indicate where more favorable conditions are projected for any given species. Such normalization was calculated to assure that each input layer received equal weighting in the calculated exposure model. Once rescaled, we were able to add these rescaled datasets together into aggregate exposure models expressing the overall severity of exposure across disparate datasets.

$$ABUND + PCSH + DIST + CLIM = Exposure$$

FIGURE 2: CALCULATION OF EXPOSURE VALUES

Aggregate exposure models for each species represent the relative exposure to climate change with a possible range from -100 to 400 scale. This was replicated for low and high emission scenarios, as well as three disturbance scenarios (Table 2). The combination of these layers produced a total of six climate and disturbance scenarios for 14 of the Northeast's most abundant tree species, yielding a total of 84 species-specific climate exposure maps.

In addition to the species-specific maps, an aggregate of all 14 target species was developed to reflect relative climate exposure at the stand level. This community exposure layer was based on a basal area-weighted average of climate exposure values for each species present in each pixel. This yielded an additional six scenarios of community-level exposure maps.

TABLE 1. THE SPECIES OF INTEREST FOR CLIMATE EXPOSURE MODELING.

Common Name	Latin Name	Abbreviation
Balsam fir	*Abies balsamea*	ABBA
Red maple	*Acer rubrum*	ACRU
Sugar maple	*Acer saccharum*	ACSA
Yellow birch	*Betula alleghaniensis*	BEAL
Black birch	*Betula lenta*	BELE
Paper birch	*Betula papyrifera*	BEPA
American beech	*Fagus grandifolia*	FAGR
White ash	*Fraxinus americana*	FRAM
Red spruce	*Picea rubens*	PIRU
Eastern white pine	*Pinus strobus*	PIST
White oak	*Quercus alba*	QUAL
Chestnut oak	*Quercus prinus*	QUPR
Northern red oak	*Quercus rubra*	QURU
Eastern hemlock	*Tsuga canadensis*	TSCA

TABLE 2: COMBINATION OF LAYERS FOR THE SIX EMISSIONS/ DISTURBANCE SCENARIOS USED IN MODELING FOR EACH TARGET SPECIES.

Scenario Name	PCSH	ABND	DIST	CLIM
Low Emissions, No Disturbance	RCP 4.5	% Basal Area	None	2° Celsius Rise
High Emissions, No Disturbance	RCP 8.5	% Basal Area	None	4° Celsius Rise
Low Emissions, Climate Disturbance	RCP 4.5	% Basal Area	Climate -Specific Disturbance	2° Celsius Rise
High Emissions, Climate Disturbance	RCP 8.5	% Basal Area	Climate -Specific Disturbance	4° Celsius Rise
Low Emissions, All Disturbance	RCP 4.5	% Basal Area	All Disturbance	2° Celsius Rise

HIGH EMISSIONS, ALL DISTURBANCE	RCP 8.5	% BASAL AREA	ALL DISTURBANCE	4^{O} CELSIUS RISE

INPUT LAYERS: SPECIES ABUNDANCE (ABUND)

To capture species distribution and abundance across the region, 30m percent basal area layers were created from the FEMC's species percent basal area maps (Gudex-Cross, et al. 2017). The FEMC basal area products are derived from seasonally stacked Landsat 7 imagery and derived vegetation indices that capture seasonal differences in spectral signatures. Spectral unmixing techniques were used to model percent abundance at 30m resolution using field calibration sites across the region.

FIA percent basal area maps are derived from 250m MODIS imagery and raster data describing relevant environmental parameters with field calibration sites from across the region. K-nearest neighbor and canonical correspondence analysis were used to model basal area using a weighting of nearest neighbors based on proximity in a feature space and stratification derived from the 2001 National Land-Cover Database tree canopy cover layer (Wilson, et al. 2013).

Both Gudex-Cross and FIA species-level rasters were resampled and snapped to common 30m pixels using bilinear interpolation using ArcGIS Pro. Species-level percent basal area values were normalized to a 0 – 100 integer scale with 0 representing the complete absence of a species and 100 representing a pure stand dominated solely by that respective species. Because individual species percent basal area maps are created independently and may not sum to 1, we used a raster calculator to convert raw species values to a relative proportion based on the sum across all species present at each pixel. The resulting 0-100 relative percent basal area metric provides a high-resolution input of distribution and abundance for the 14 key northeastern species such as sugar maple (Figure 3).

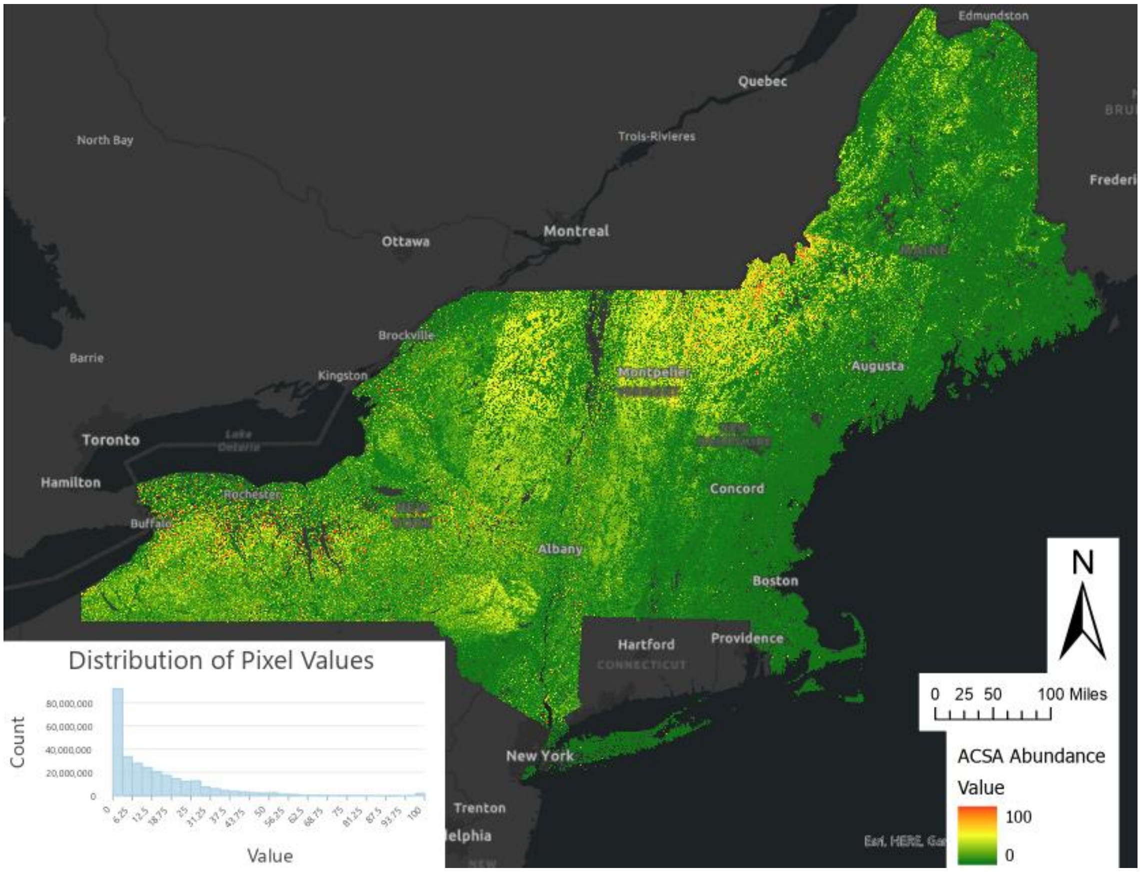


FIGURE 3: AN EXAMPLE OF THE SUGAR MAPLE (ACSA) ABUNDANCE LAYER. THE HIGHER THE VALUE, THE HIGHER THE PERCENTAGE OF BASAL AREA REPRESENTED BY THE SPECIES.

Input Layers: Projected Change in Suitable Habitat (PCSH)

The Climate Change Tree Atlas (Iverson et al. 2008) has produced spatial maps that represent current and projected suitable species habitat for low and high emissions scenarios based on species characteristics, life history and current species distributions. Climate inputs are limited to seven key metrics including: mean annual temperature (T), mean January and July T, mean growing season T, annual precipitation totals and mean difference between January and July T. The resulting current and projected suitable habitat maps are based on climate, elevation, soil characteristics and land use data to predict relative importance values for 134 tree species at 20km resolution across the eastern United States. Relative importance is a measure of abundance that accounts for both tree basal area and number of stems, ranging from 0 - 100.

Our focus on climate exposure led us to develop a new output layer that quantifies the degree of projected change in relative importance values for our 14 species of interest. The resulting habitat DIFF layers represent the difference in relative importance values between current and projected (year 2100) layers for both RCP 4.5 (low emissions) and RCP 8.5 (high emissions) climate scenarios. From the original input layers, cells valued at 200 (cells that were not modeled) and 300 (cells that weren't suitable under the current scenario) were removed and remaining values were normalized to a -100 to 100 scale where negative values represent areas with expected increases in relative importance value (improved habitat), while positive values indicate high climate exposure and projected decrease in relative importance value.

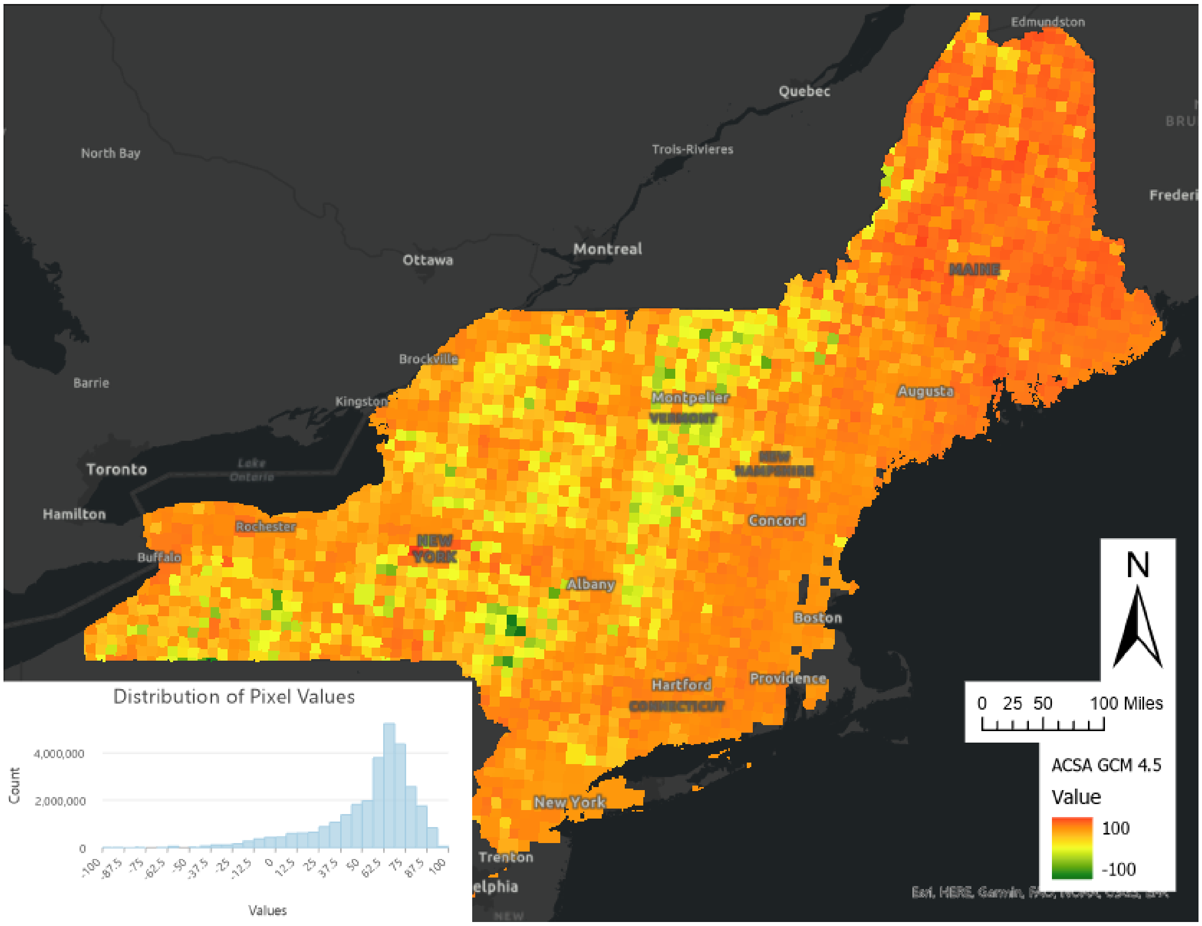


FIGURE 4: THE RCP 4.5 (LOW EMISSIONS) SUGAR MAPLE PROJECTED CHANGE IN SUITABLE HABITAT LAYER. AREAS CLOSER TO RED REPRESENT PROJECTED DECREASES IN SUITABLE HABITAT, WHEREAS GREEN AREAS REPRESENT PROJECTED IMPROVED HABITAT SUITABILITY.

INPUT LAYERS: DISTURBANCE RETURN FREQUENCY (DIST)

The Northeastern Forest Health Atlas (NEFHA) (Duncan, et al. 2018) is an online database aggregating decades of annual aerial surveys conducted by state and federal agencies to identify and map the locations of biotic and abiotic forest disturbances. The tools and data access mechanisms in NEFHA provide a novel and invaluable tool for quickly finding and mapping data on forest disturbance that can be filtered by damage agent and damage type across the northeastern US. Outputs include polygon-based frequency maps to highlight where various types of disturbance are most common.

We sourced data from the Northeastern Forest Health Atlas representing the frequency of occurrence of all disturbance types and damage agents across the Northeast from 1998 to 2019, as well as a climate-based disturbance layer that included only damage agents such as flooding/ high water, windthrow/ hurricane/ tornado, drought, frost damage, and snow/ ice. Raw frequency values were rescaled to a 0 to 100 scale using linear methods to ensure equal weighting with the other exposure input layers in the final aggregate model. A zero value represents a cell where no disturbance has occurred over the period of measurement, and 100 represents the cell with the highest possible return rate of disturbance in the 21-year period. The highest value (100) represents the maximum recorded disturbance climate-related frequency of 9 occurrences for a given pixel and 15 occurrences for all disturbances. Given the compounding effects of repeated disturbance on forest health, return values were squared prior the rescaling of the layers.

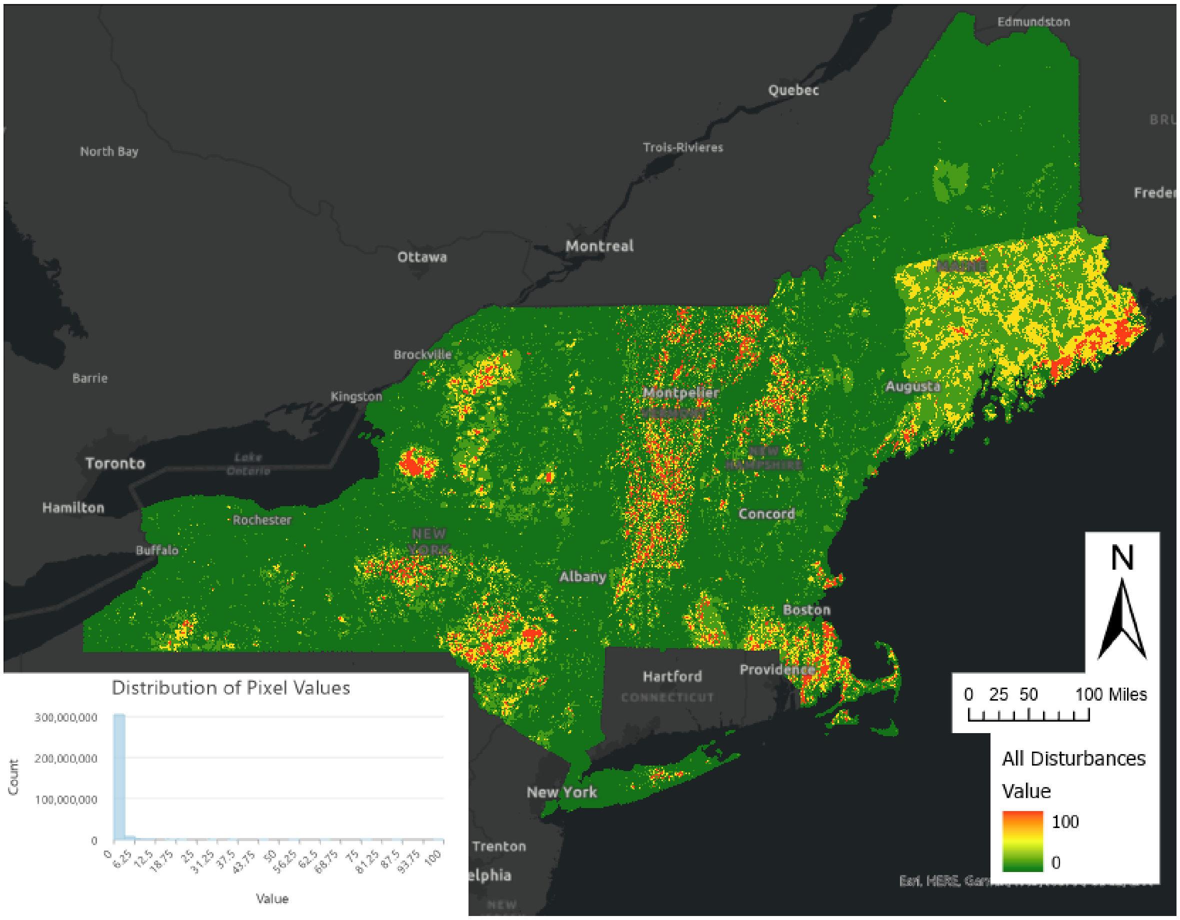


FIGURE 5: LAYER REPRESENTING ALL DISTURBANCES FOR THE REGION. SYMBOLOGY WAS CHANGED TO PERCENT CLIP OVER THE TRADITIONAL LINEAR STRETCH TO HIGHLIGHT REGIONS WITH HIGHER VALUES.

Input Layers: Climate Variability (CLIM)

TerraClimate (Abatzoglou, et al. 2018) is a dataset of monthly climate and hydrological measures for global terrestrial surfaces from 1958-2020. The same suite of climate metrics is available for two projected climate scenarios commensurate with global mean temperatures +2C and +4C above preindustrial levels. TerraClimate uses climatically aided interpolation, that combines high-spatial resolution climate normals from the WorldClim dataset, with coarser spatial resolution, but time-varying data from CRU Ts4.0 and the Japanese 55-year Reanalysis (JRA55). TerraClimate additionally produces monthly surface water balance datasets using a water balance model that incorporates reference evapotranspiration, precipitation, temperature, and interpolated plant extractable soil water capacity. The result is a broad temporal record for 92 unique climate and ecologically relevant interpolated variables at high spatial (4km) and temporal (monthly) resolution that reflect historical norms as well as +2C and +4C climate scenarios.

Our focus on climate exposure led us to develop a new set of output layers that quantify the degree of projected change in each of these 92 metrics as the difference between historical and projected values. To aggregate information across these 92 climate difference metrics, data reduction was achieved using a principal components analysis to develop a new aggregate climate variability metric that would reflect overall deviation in climate characteristics. This one climate variability metric captures 53% of the total variability in all climate variables across the region. The largest contributors to this climate variability metric include snow water equivalent (SWE), actual evapotranspiration (AET), predicted evapotranspiration (PET), soil moisture, and precipitation, with significant contributions from shoulder season months (spring and fall). Original values were on a 0 - 1 scale but were rescaled to 0- 100 to conform to other climate exposure model inputs. Lower values represent smaller changes from current climate conditions and higher values represent greater overall change in climate conditions.

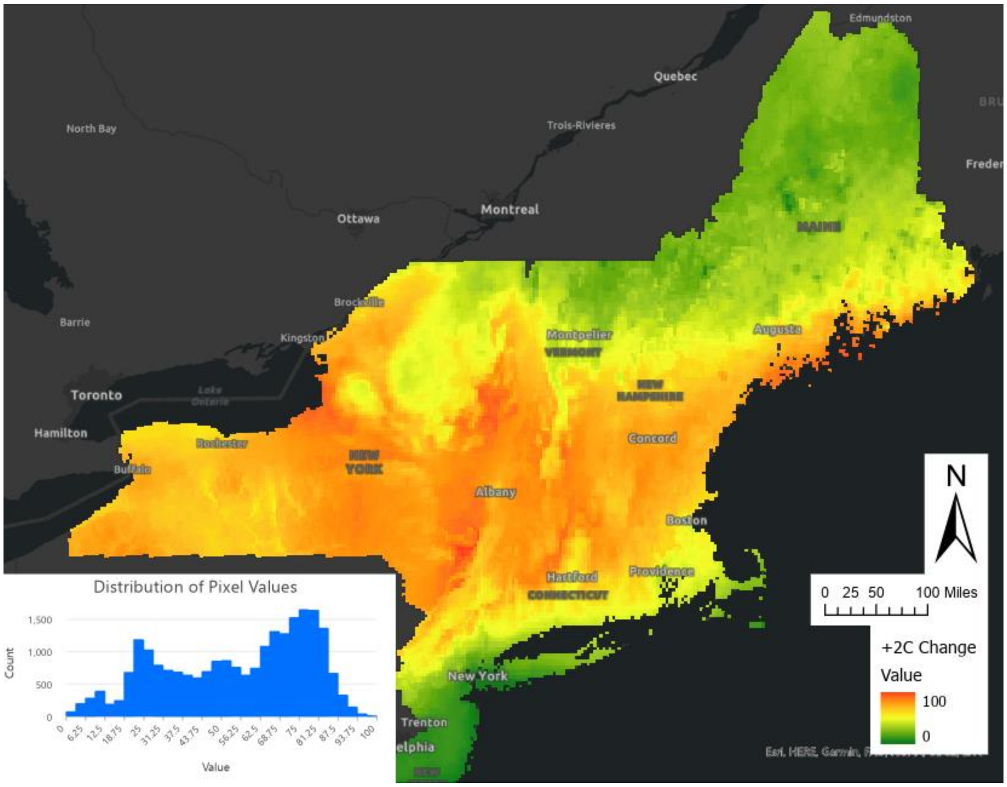


FIGURE 6: TWO DEGREE CELSIUS WARMING SCENARIO FOR CLIMATE DEVIATION. AREAS WITH MORE RED ARE PROJECTED TO UNDERGO MORE CHANGE, WHEREAS GREENER AREAS ARE EXPECTED TO REMAIN RELATIVELY STABLE

AGGREGATE CLIMATE EXPOSURE MODELS – SPECIES LEVEL

For each species, the sum of the normalized species abundance, disturbance frequency, projected change in suitable habitat and climate variability was used to calculate an aggregate climate exposure value with a possible range between -100 and 400. This additive model was repeated for low and high climate scenarios, for three disturbance scenarios (no disturbance, all disturbance, climate related disturbance only). Low emission scenarios were defined using the TerraClimate +2 degrees Celsius model and the Climate Tree Atlas RCP 4.5 models, while high emission scenarios were estimated using the TerraClimate +4 degrees Celsius and Climate Change Tree Atlas RCP 8.5. Symbology was rescaled to reflect the minimum of -100 (minimum climate exposure) and a maximum of 400 (maximum climate exposure), with a constant linear stretch between all maps. As a final step, models were masked by the 2019 NLCD Land Cover raster values to exclude non-forestland from final map products.

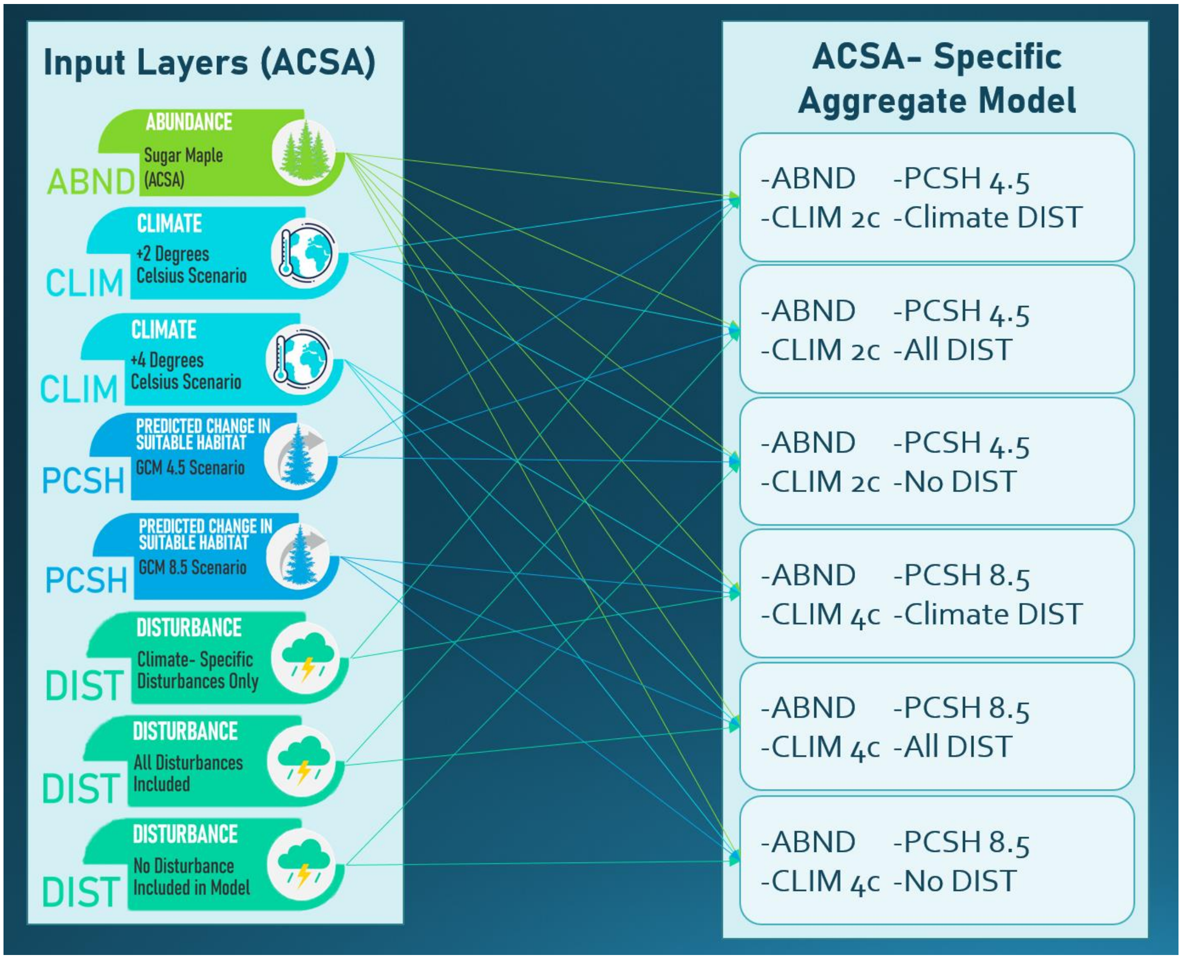
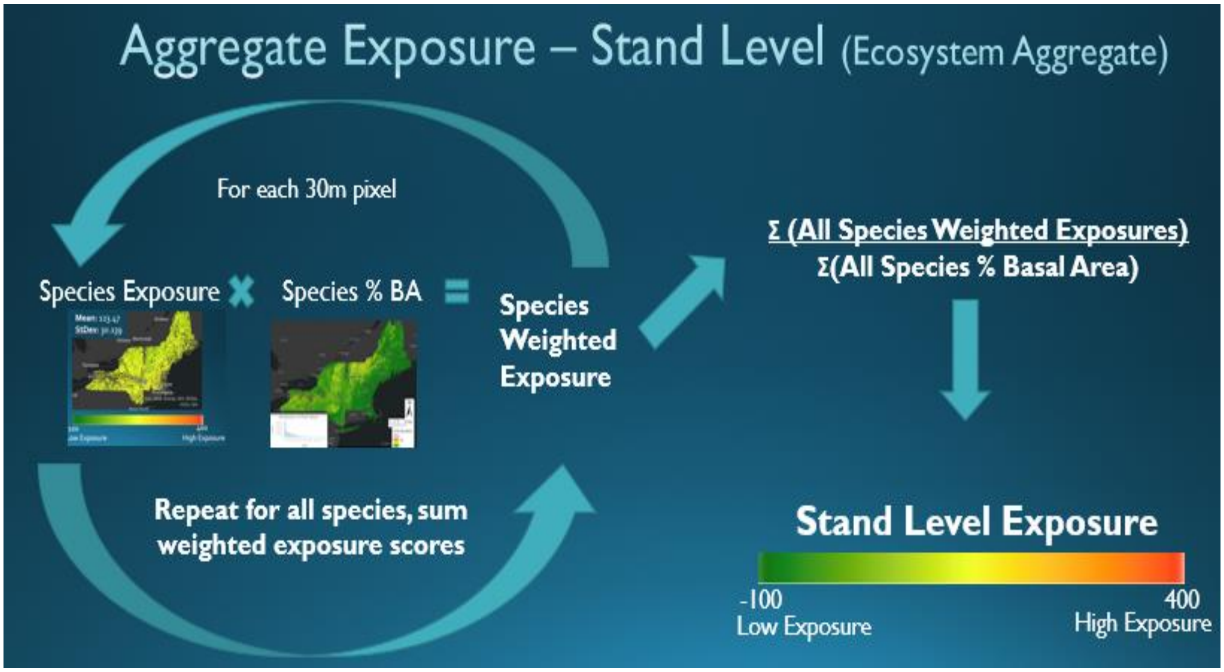


FIGURE 7: COMBINATION OF INPUT LAYERS TO YIELD SIX SUGAR MAPLE (ACSA) AGGREGATE MODELS USING SUGAR MAPLE AS AN EXAMPLE.

ALL-SPECIES, COMMUNITY-LEVEL EXPOSURE MODEL

In addition to the species-specific maps, community-level aggregates were developed to reflect overall climate exposure at the stand level for each of the six climate-disturbance scenarios. Community exposure was calculated as an average of the species-level climate exposure values, weighted by the percent basal area of all species present in any given pixel. The result is an average exposure for all species present in any given pixel with a possible range between -100 (minimum exposure) to 400 (maximum exposure). This yielded an additional six scenarios of community-level exposure maps.



Aggregate Exposure – Stand Level (Ecosystem Aggregate)

For each 30m pixel

Species Exposure × Species % BA = **Species Weighted Exposure**

Repeat for all species, sum weighted exposure scores

$\frac{\Sigma \text{(All Species Weighted Exposures)}}{\Sigma \text{(All Species \% Basal Area)}}$

Stand Level Exposure

FIGURE 8: THE PROCESS OF GENERATING THE COMMUNITY-LEVEL EXPOSURE FOR EACH OF SIX SCENARIOS

FINAL MAPPING PRODUCTS

Final outputs are reflected in Table 2 and are downloadable from the project's FEMC website. An interactive discovery and visualization tool has also been produced for viewing the maps without downloading the underlying raster data.

DATA SUMMARY

To better understand the output climate exposure products, we analyzed spatial patterns in the output layers and how the distribution of the data varied across the 14 target species and their 6 climate-disturbance scenarios.

SPECIES VARIATION

At a species level, one can utilize these mapping products to address several questions: 1. How climate exposure differs across species and 2. How climate exposure differs between low and high emissions scenarios. Using average exposure values for the full region, this aggregate climate exposure model indicates that both the overall level of exposure, as well as the direction that exposure changes between low and high emissions scenarios may be important.

For example, some species (e.g. white oak (QUAL), chestnut oak (QUPR), and black birch (BELE) are located in areas with relatively high overall climate exposure, but actually see their exposure scores decrease under the high emission scenario. This is primarily driven by projected increases in relative importance values for these species as climate continues to warm and climate deviation changes in shoulder seasons. In this case, exposure to changing climate conditions may actually benefit the species across the region.

Conversely, other species have relatively low climate exposure across the region under low emissions scenarios but show significant increases in exposure under the high emissions scenario. Red spruce (PIRU), balsam fir (ABBA), and paper birch (BEPA) are slated to have the highest increases in exposure, though most species experienced some form of increased exposure with higher emissions. The mentioned species may experience higher vulnerability to the changes in climate they are projected to be exposed to.

Several tree species show very little difference between low and high emission exposure models. This includes red oak (QURU), red maple (ACRU), eastern hemlock (TSCA), white pine (PIST) and sugar maple (ACSA). There are three possible hypotheses for this pattern: 1. These species are predominantly located in ecoregions where climate exposure is relatively low, or 2. These species are relatively insensitive to the types of changes expected between the low and high emission scenarios in our focal region, or 3. These species are already at the peak of their tolerable exposure at the low emission scenario. For these highly exposed species, the increase in exposure from low to high emission scenarios does not impact exposure that is already maximized. These regional patterns warrant further investigation to understand the drivers and variable impacts under low and high emission scenarios.

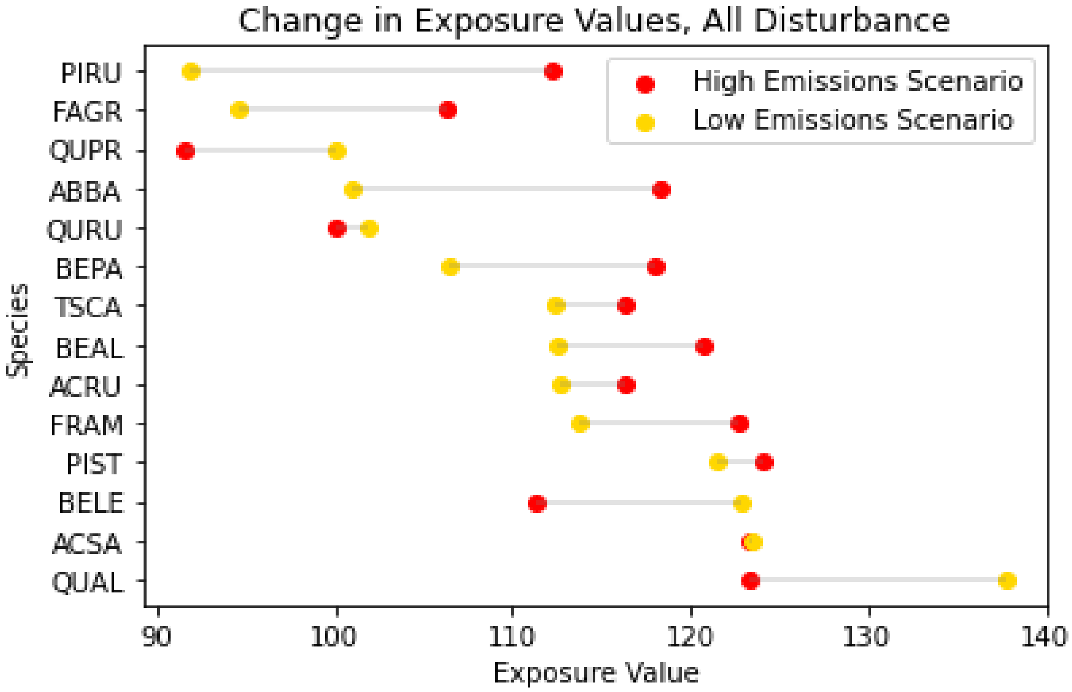


FIGURE 9: VARIATIONS IN EXPOSURE VALUE BY SPECIES

COMMUNITY- LEVEL EXPOSURE MAPS

In addition to exposure trends being viewed at a species level, the data were viewed at a regional scale using data from community-level exposure layers. Analyzing how exposure differs across ecoregions (**Error! Reference source not found.**) and how this exposure changes under low and high emission scenarios can inform how climate exposure may impact varying forest types differentially across the region. Two of the nine major ecoregions in the Northeast are projected to see increased climate exposure between low and high emission scenarios (Acadian Plains and Hills and Northeastern Highlands). The Northeastern Highlands (**Error! Reference source not found.**) represent the Northeast's mountainous regions, which are dominated by spruce-fir and northern hardwoods systems, which are projected to experience increased climate exposure under higher emission scenarios (Figure 9). Though at first glance Figure 10 may suggest an overall decrease in exposure regionally, the majority of land area (67%) is contained within these two ecoregions expected to increase in exposure.

The remaining seven ecoregions dominate the southern portion of the study area, representing about 30% of the regions forested lands. In these regions, climate exposure is projected to decrease under higher emission scenarios. This is likely a function of the local dominance of species (white oak, chestnut oak, and black birch) projected to benefit from a warming climate.

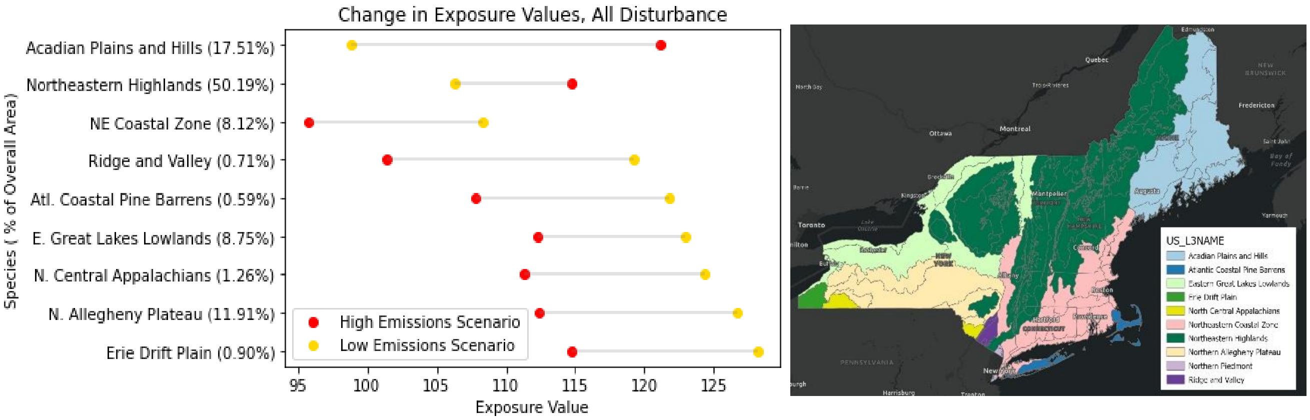


FIGURE 10: REGIONAL VARIATIONS IN EXPOSURE. THE PERCENTAGE OF TOTAL CALCULATED AREA FOR EACH ECOREGION IS INCLUDED AFTER THE LABEL ON THE X AXIS.

THE NORTHEASTERN CLIMATE CHANGE EXPOSURE MAPPING WEB TOOL

DESCRIPTION

The Northeastern Climate Change Exposure Mapping Tool can assist in answering a range of questions regarding how major tree species and the whole region are projected to respond to the effects of increased temperatures and emissions. Such data can be utilized for adaptive forest management and planting efforts, among other means.

The tool is an ArcGIS Online-leveraged GIS hub utilizing raster-based tile maps that display the calculations created during this effort.

For each species, six mapped scenarios are included representing combinations of emissions and disturbance layers. In addition to this, six additional maps representing a weighted average of all species in the study broken out by each scenario are included to help illustrate exposure at the stand level. Access to the input layers used in the production of the species aggregates is also provided. Maps can be viewed via the online GIS hub, and/or geospatial data can be downloaded at the attached link.

DIRECTIONS

The tool is relatively straight forward to use but for the user's convenience, guidance on how to properly use all aspects of this tool can be viewed in this video tutorial.

CONCLUSION

The NEFCCEM effort set out to quantify climate exposure throughout the region, projecting which regions are likely to be vulnerable or resilient to the effects of climate change. Areas of higher exposure are projected to be more vulnerable in the face of climate change. These areas should be considered for the implementation of adaptive management efforts to increase the forest's capacity to withstand change. Conversely, areas of lower exposure are projected to be more resilient to climate change and should be less prioritized for adaptive management efforts. The findings of this effort should be used to guide the implementation of adaptive silvicultural techniques based on projected exposure to changing climate conditions.

At an ecosystem level, mountainous regions and southeastern Maine are broadly projected to increase in exposure with higher emissions and are areas of relatively high exposure in the region throughout all scenarios. The Hudson valley, eastern Massachusetts and northern Maine are projected to have lower exposure given both increased emissions scenarios. At a species level, species such red spruce and balsam fir are projected to increase in exposure with higher emissions. Species such as northern red oak, white oak, and black birch are projected to decrease in exposure with higher emissions. Species such as sugar maple and eastern white pine are projected to maintain similar exposure levels throughout both emissions scenarios.

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APPENDIX

1. COMMUNITY- LEVEL EXPOSURE MAPS FOR ALL SCENARIOS

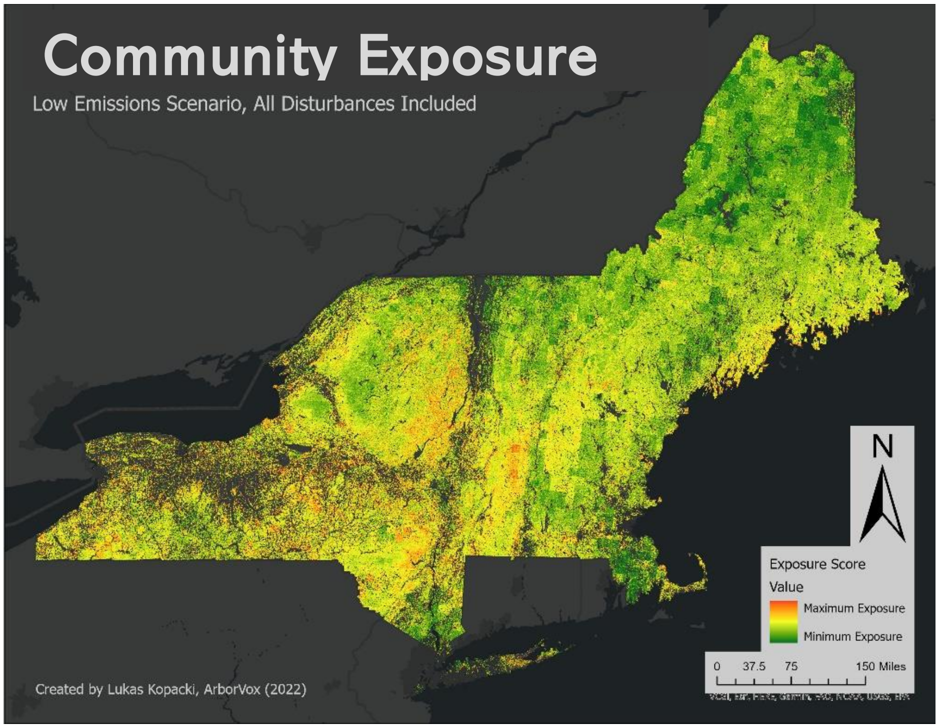

FIGURE 11: COMMUNITY- LEVEL EXPOSURE LOW EMISSIONS (2C CLIM AND RCP 4.5 PCSH), ALL DISTURBANCE SCENARIO.

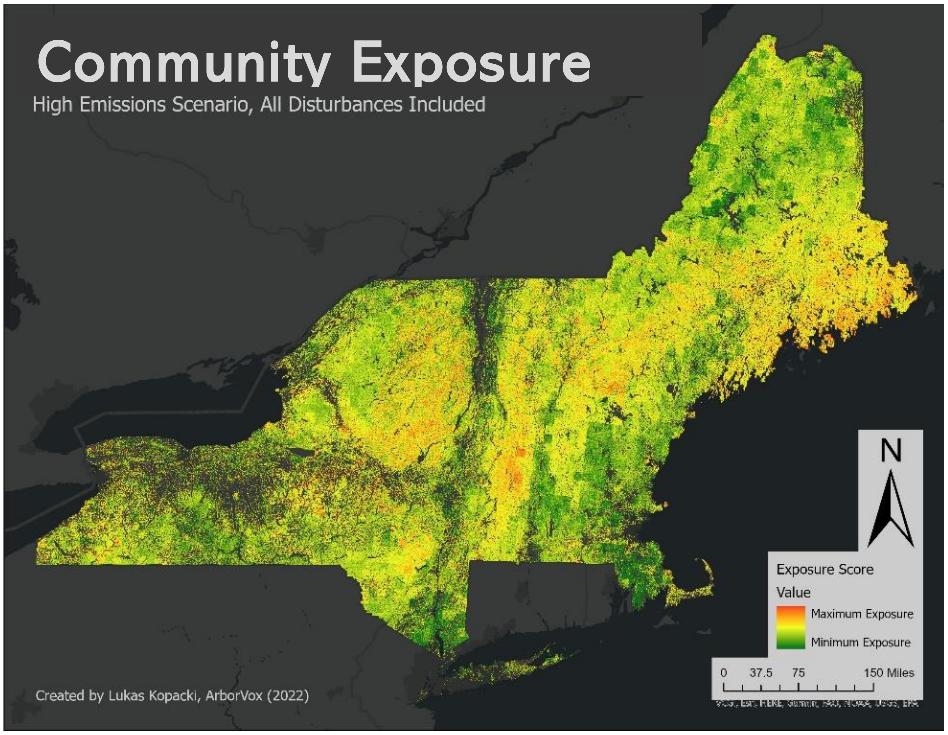

FIGURE 12: COMMUNITY- LEVEL EXPOSURE HIGH EMISSIONS (4C CLIM AND RCP 8.5 PCSH), ALL DISTURBANCE SCENARIO.

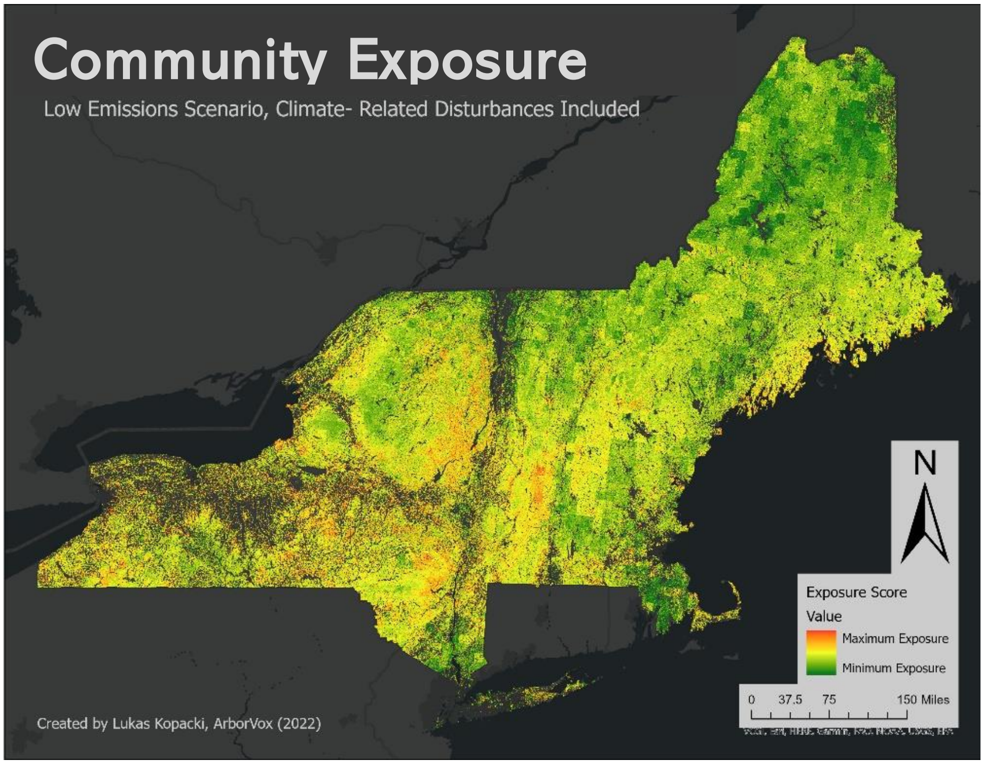

FIGURE 13: COMMUNITY- LEVEL EXPOSURE LOW EMISSIONS (2C CLIM AND RCP 4.5 PCSH), CLIMATE- RELATED DISTURBANCE SCENARIO

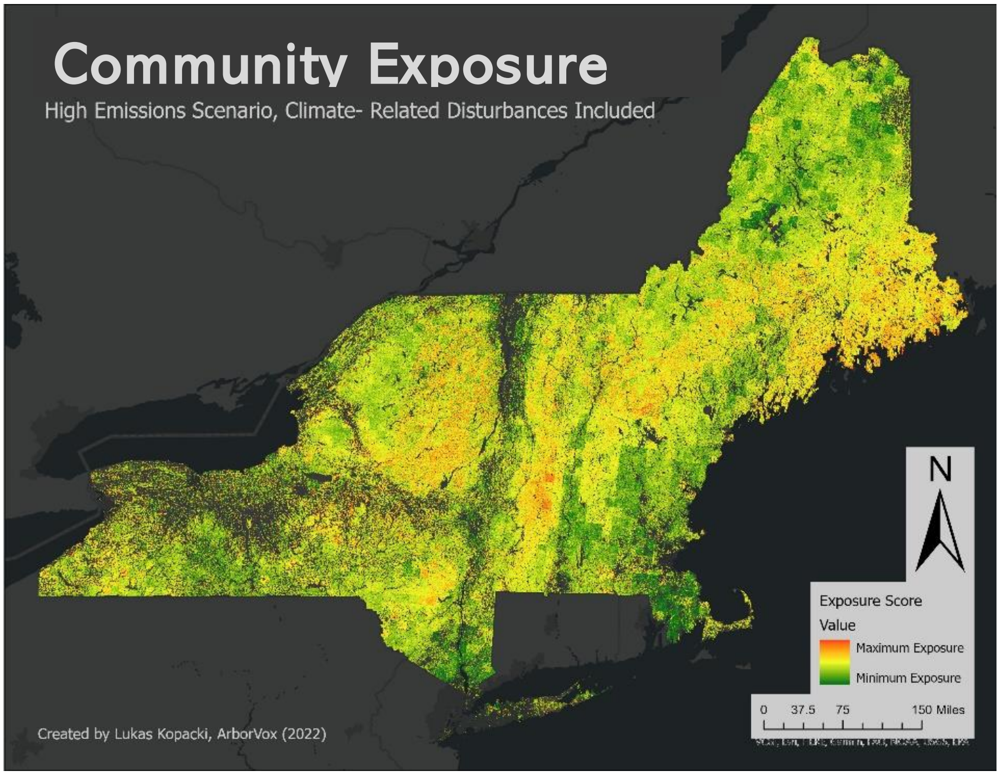

FIGURE 14: COMMUNITY- LEVEL EXPOSURE HIGH EMISSIONS (4C CLIM AND RCP 8.5 PCSH), CLIMATE- RELATED DISTURBANCE SCENARIO.

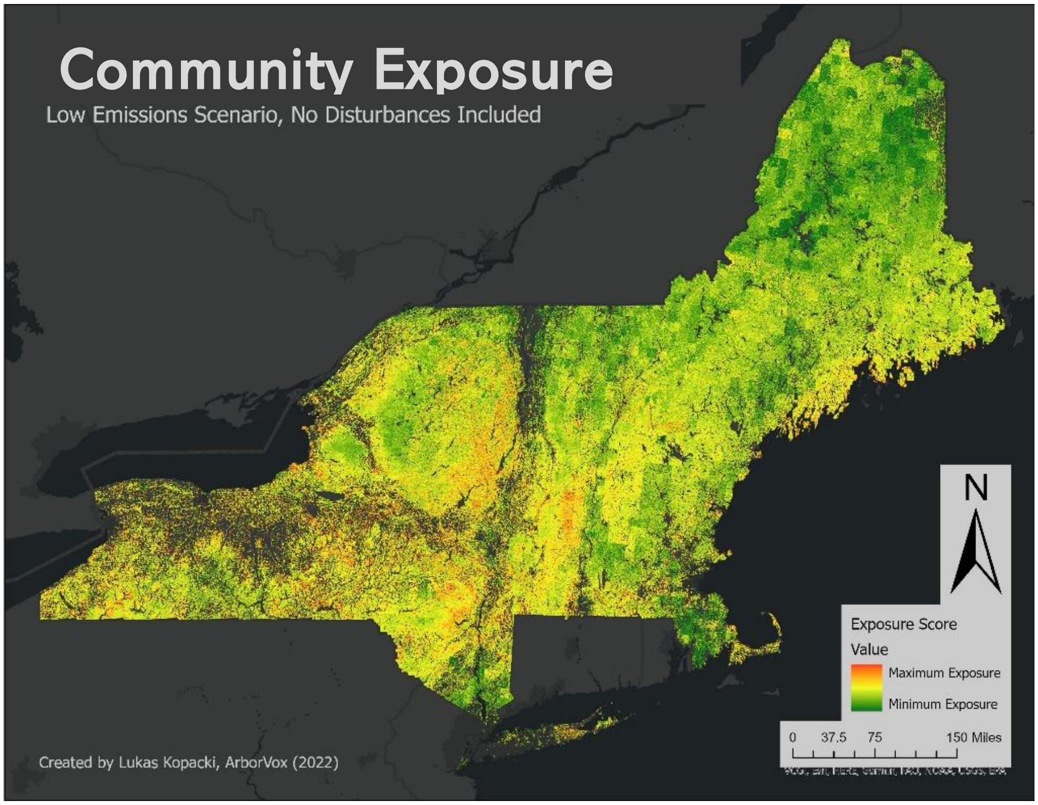

FIGURE 15: COMMUNITY- LEVEL EXPOSURE LOW EMISSIONS (2C CLIM AND RCP 4.5 DIST), NO DISTURBANCE SCENARIO.

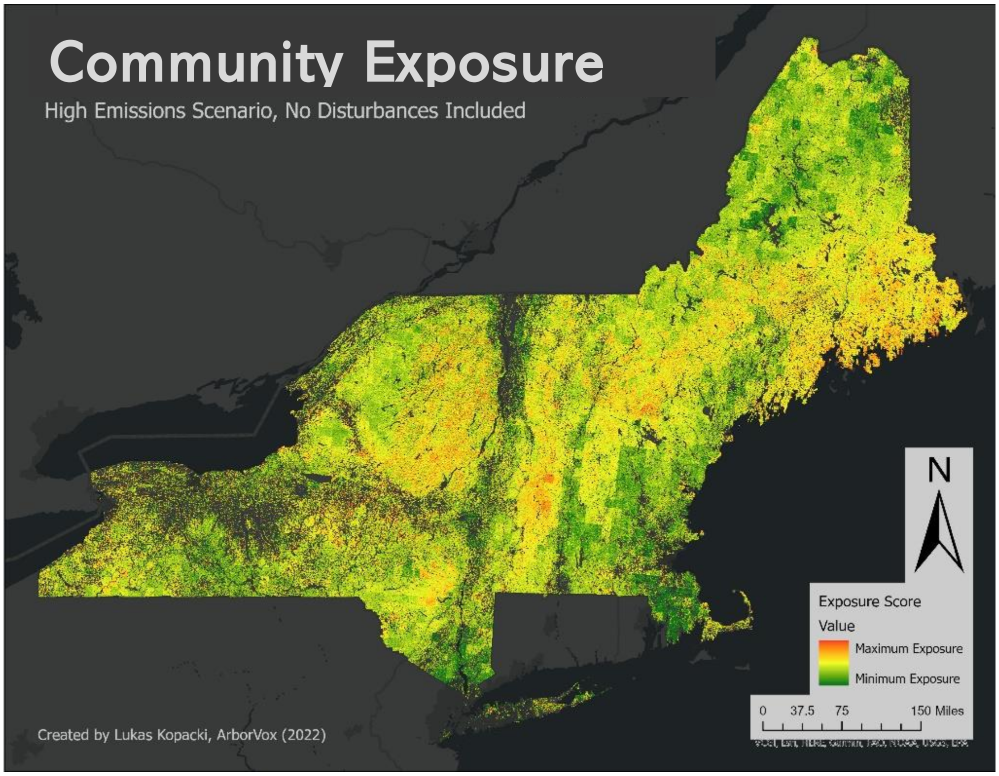

FIGURE 16: COMMUNITY- LEVEL EXPOSURE HIGH EMISSIONS (4C CLIM AND RCP 8.5 DIST), NO DISTURBANCE SCENARIO