Designing Sustainable Landscapes: Climate Stress Metric

A project of the University of Massachusetts Landscape Ecology Lab

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- North Atlantic Landscape Conservation Cooperative (US Fish and Wildlife Service, Northeast Region)
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General description

Climate is a major factor in determining ecosystem distribution, composition, structure and function. Therefore, with climate change it is reasonable to anticipate heterogeneous climate stress across the landscape in response to heterogeneous shifts in climate normals (Iverson et al. 2014). The ***climate stress*** metric assesses the estimated climate stress that may be exerted on a focal cell in 2080 based on departure from the current climate niche breadth of the corresponding ecosystem. Essentially, this metric measures the magnitude of climate change stress at the focal cell based on the current climate niche of the corresponding ecosystem and the predicted change in climate (i.e., how much is the climate of the focal cell moving away from the current climate niche of the corresponding ecosystem) between 2010-2080 based on the average of two climate change scenarios (see below) (**Fig. 1**). Cells where the predicted climate suitability in the future decreases (i.e., climate is becoming less suitable for that ecosystem) are considered stressed, and the stress increases as the predicted climate becomes less suitable based on the ecosystem's current climate niche model. Conversely, cells where the predicted climate suitability in the future increases (i.e., climate is improving for that ecosystem) are considered unstressed and assigned a value of zero.

The climate stress metric is an element of the ecological integrity analysis of the Designing Sustainable Landscapes (DSL) project (see technical document on integrity, McGarigal et al 2017). Consisting of a composite of 21 stressor and resiliency metrics, the index of ecological integrity (IEI) assesses the relative intactness and resiliency to environmental change of ecological systems throughout the northeast. As a stressor metric, climate stress values range from 0 (no effect from climate stress) to a theoretical maximum of 1 (severe effect; although in real landscapes, the metric never reaches 1). Note that the climate stress metric is computed separately for each ecosystem because each ecosystem has its own estimated climate niche (see below). This contrasts with all other stressor metrics, which are computed independently of ecosystem.

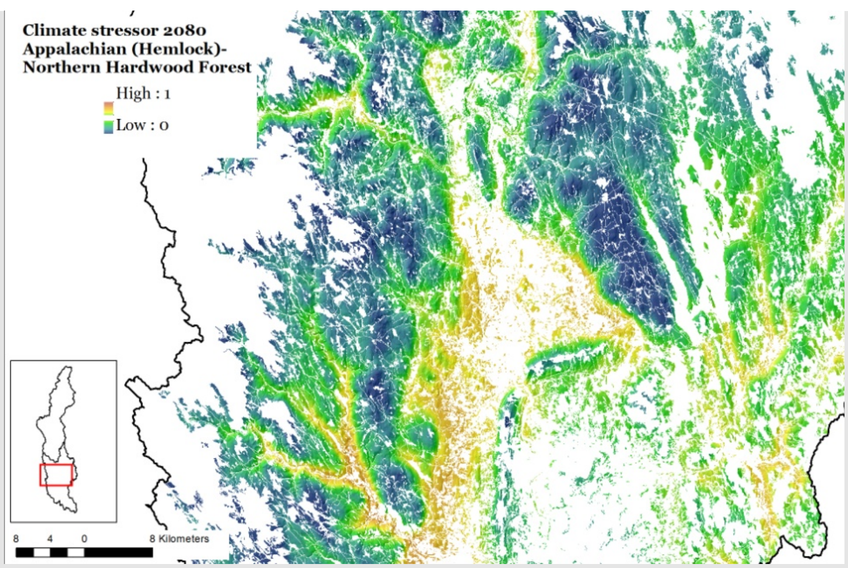

Figure 1. Example of *climate stress* metric in 2080 for the Appalachian (Hemlock)-Northern Hardwood Forest ecosystem for a portion of the lower Connecticut River watershed. Values for this ecosystem range from near 0 (neutral or improving climate) to near 1 (maximum loss of climate suitability) over the full extent of the Northeast region.

Use and interpretation of this layer

This metric relies of several assumptions which affect it use and interpretation:

- This metric relies heavily on the accurate mapping of ecosystems (see DSLland document, McGarigal et al 2017). The current (2010) climate niche is modeled separately for each ecosystem (see below) based on its mapped current distribution. Thus, any errors in the mapping of an ecosystem will affect its estimated climate niche.
- This metric assumes that the current distribution of an ecosystem is limited by climate such that we can model its relative probability of occurrence based on a suite of climate variables (see below). This metric ignores other biophysical variables that may be influencing the current distribution of an ecosystem.
- Because climate niche models are developed and applied separately for each ecosystem, it is best to consider climate stress separately for each ecosystem. Abrupt changes in the absolute value of the climate stress metric between adjacent cells is likely to be due to changes in the underlying mapped ecological system; it does not reflect an abrupt change in the absolute climate stress. Consequently, it is best to use an ecological system mask when viewing the results (e.g., **Fig. 1**).
- This layer reveals the magnitude of climate change stress; that is, it reveals places where the climate is predicted to worsen for the corresponding ecosystem between 2010-2080. It does not reveal places where climate suitability is likely to be improving for a particular system.
- The climate stress metric was not computed for several ecosystems that range well beyond the southern edge of the Northeast region (see below) to avoid building climate niche models on a small portion of the ecosystem's range.
- While the climate stress metric has a variety of potential uses, perhaps its most suitable application is as a component of IEI and the assessment of ecological integrity, which can facilitate efforts of organizations seeking to conserve biodiversity to identify and prioritize places of high ecological value for conservation action (e.g., land protection).

Derivation of this layer

Briefly, the derivation of the climate stress metric consisted of the following major steps:

1. *Training data*.—We sampled "present" and "pseudo-absent" locations by sampling the following six 2010 climate variable grids at up to 10k random points within each ecosystem group (**Appendix**), excluding open water and developed land cover classes (see technical document on climate, McGarigal et al 2017, for details):

   1) Average annual precipitation (precip)

   2) Growing season precipitation (precipgs)

   3) Average annual temperature (temp)

4) Average minimum winter temperature (tmin)
5) Average maximum summer temperature (tmax)
6) Growing degree days (gdd)

We sampled an equal number of pseudo-absent points by subsampling all of the random locations across ecological groups such that the sample equaled that of the present group. Thus, if 10k samples were not available the present group (due to the limited extent of the ecosystem group), the pseudo-absent sample matched the sample size of the present group.

2. *2010 climate niche model*.—We built a logistic regression model for each ecosystem group that did not have its southern boundary within the 13 northeastern states. We decided to exclude the climate stress metric for ecosystem groups that occurred on and extended beyond the southern edge of the region to avoid building models on a small portion of the system's range. We used an all subsets regression framework that considered, but did not force, quadratic terms for each of the six climate predictors. We included hump-shaped or negative quadratic responses because they represent an important theoretical relationship between ecosystem distributions and climate. However, we did not consider u-shaped or positive quadratic terms because there is no precedence for ecosystems responding to climate in this manner and we were concerned with extrapolation issues. We retained only the top model based on AICc if the percentage of deviance explained (D^2) was ≥0.28. Based on this criterion, we excluded six models. Finally, we applied the final models to derive a single predicted surface.
3. *2080 climate niche*.—We applied the 2010 climate niche model to the 2080 climate predictions averaged for the Representative Concentration Pathways (RCP) 4.5 and 8.5 scenarios (see technical document on climate, McGarigal et al 2017, for details). Thus, we applied the model fit to the 2010 climate predictors (i.e., the current climate niche model) but with the predicted 2080 climate variables.
4. *Climate stress metric*.—Finally, the metric is calculated as $(p - f)/p$, where p is the 2010 climate suitability surface and f is the 2080 climate suitability surface averaged across RCPs. Because this is viewed as a stressor metric, any final values that are negative (improving conditions) were set to zero. All cells without a corresponding climate niche model (e.g., southern ecosystems) were assigned a nodata value.

GIS metadata

This data product is distributed as a geotiff raster (30 m cells). Cell values range from 0 (neutral or improving climate) to a theoretical maximum of 1 for a cell with an optimal climate in 2010 that has a near zero probability of suitable climate in 2080.

Literature Cited

Iverson LR, Prasad AM, Matthews SN, and Peters MP. 2014. Climate as an agent of change in forest landscapes. In: Azevedo JC et al., eds. Forest landscapes and global change: challenges for research and management. New York: Springer: 29-50.

McGarigal K, Compton BW, Plunkett EB, DeLuca WV, and Grand J. 2017. Designing sustainable landscapes products, including technical documentation and data products. https://scholarworks.umass.edu/designing_sustainable_landscapes/

Appendix

Ecosystems, and their associated ecological formations, for purposes of modeling climate suitability, in addition to the top logistic regression model for predicting the distribution of the ecosystem in 2010. Included for the top model are the beta regression coefficients for the corresponding predictors and the model percentage of deviance explained (D^2). Note, p-values associated with the test of significance against the null model are not reported here, but all were all <0.01. The climate.stress.models.csv file is included separately in the zip file.