Climate Modeling of Southern Pine Beetle Habitat Dynamics

A Machine Learning Approach to Quantify Biodiversity Risk

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Abstract

- Loblolly Pine (*Pinus taeda*) is a highly beneficial species with a variety of economic and climatic benefits, including timber production, carbon sequestration, climate regulation, and support for biodiversity. Sustainable management practices are essential to ensure the continued provision of these benefits while addressing challenges such as pests, diseases, and the potential impacts of climate change.
- Climate change is reshaping forest ecosystems, influencing the growth potential of tree species and altering the dynamics of associated insect pests. This study will employ machine learning statistical modeling and climate scenario analysis to investigate the potential impacts of climate change on habitats of the Southern Pine Beetle (*Dendroctonus frontalis*), one of the most destructive pests of Loblolly Pines in the southern United States.
- Species Distribution Modeling is a common tool in habitat analysis that employs machine learning to estimate the probability distribution that is closest to uniform (maximum entropy) based on a species' known occurrences and environmental variables such as can be extracted from historical climate datasets or future projections from Global Climate Model (GCM) datasets. Using species distribution modeling and environmental fields representing a future climate scenario, we modeled the relationships between climate change and habitat expansion/contraction of the Southern Pine Beetle. In doing so, we sought to understand the implications for timber production, carbon sequestration, and sustainable forest ecosystem management of Loblolly Pine in the United States and southeastern Canada.

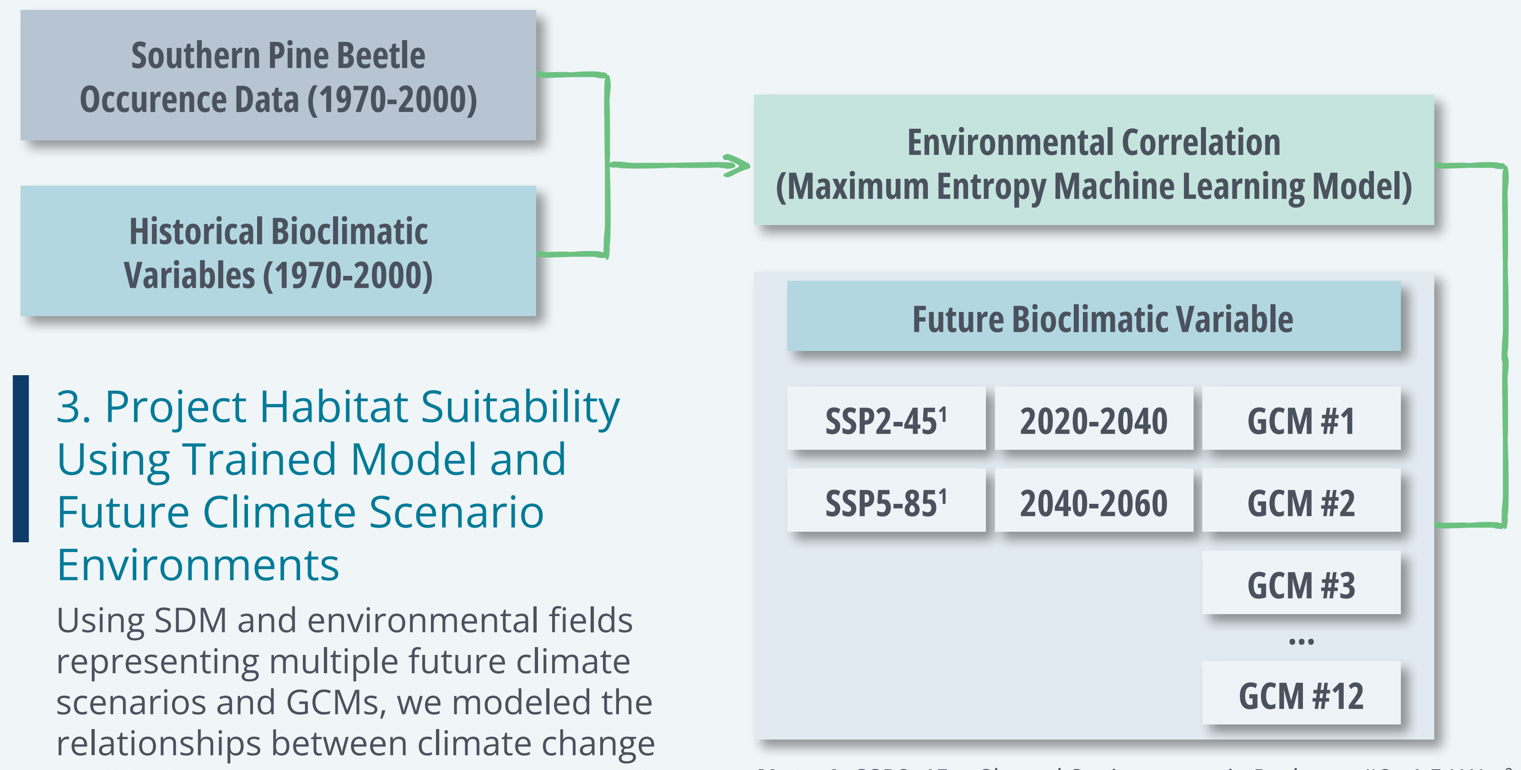
Simplified Methodology

1. Historical Data Inputs

Historical bioclimatic raster data was utilized with concurrent beetle occurrence data. Bioclimatic raster data was chosen to have similar horizontal resolution as county-level species occurrence data *(REF 1).*

2. Train Model on Historical Bioclimatic Data

Species Distribution Modeling (SDM) is a common tool that employs machine learning to estimate the probability distribution that is closest to uniform (maximum entropy) based on a species' known occurrences and bioclimatic variables *(REF 2).*



3. Project Habitat Suitability Using Trained Model and Future Climate Scenario Environments

Using SDM and environmental fields representing multiple future climate scenarios and GCMs, we modeled the relationships between climate change and habitat expansion/contraction of the Southern Pine Beetle.

Note 1: SSP2-45 = Shared Socioeconomic Pathway #2; 4.5 W/m² net radiative balance by 2100. SSP5-85 = Shared Socioeconomic Pathway #5; 8.5 W/m2 net radiative balance by 2100.

Discussion

MODEL VERSUS OBSERVATION

The historical (1970-2000) extent of observed occurrences of the Southern Pine beetle (SPB) is plotted as pink hatching in the Results panels to the right. In panel (a), colored shading represents the modeled habitat suitability resultant from training the Maximum Entropy model using the concurrent (1970-2000) historical bioclimatic variables (Results panel b). Those variables with a substantial AUC ("area under the curve" – the curve being the Receiver Operating Characteristic curve; an AUC of more than 0.9 is typically considered an excellent performance threshold for a model) include precipitation in the driest quarter and month, annual precipitation, precipitation in the coldest quarter, and mean temperature of the coldest quarter. These key bioclimatic predictors are in line with previous research on the climatic window associated with the beetle's known geographic range *(REF 3)*. Based on the AUC statistics and the expected variables identified by the model, the suitability map is considered representative and a valuable predictor of the beetle's habitat (Results panel a).

MODEL PROJECTIONS UNDER TWO CLIMATE SCENARIOS

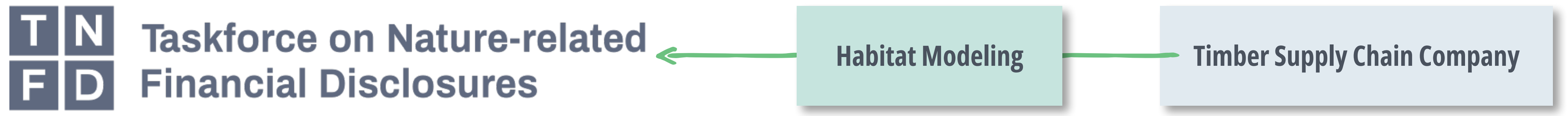
When future climate conditions are considered, the beetle's favorable (> 0.50) habitat is modeled to expand northward under both scenarios and future timeframes considered (SSP2-45, a "middle of the road" emissions scenario, and SSP5-85, a "high" emissions scenario), likely related to an increase in the mean temperature (Results panels c-f). Under the SSP2-45 scenario, the beetle's highly favorable (> 0.75) habitat generally increases in the east by 2060, especially over the Appalachian and Blue Ridge Mountains and eastward (Results panel d). Habitats to the west in eastern Texas and southern Louisiana are modeled to become less suitable for the beetle, although remaining marginally favorable. Under the more extreme SSP2-85 scenario, this decrease in habitat suitability is markedly enhanced by 2060 (results panel f), with highly favorable conditions being limited to generally the mid-Atlantic coastal states. Conditions in the southeast US remain marginally favorable for the beetle, but climatic conditions likely associated with precipitation and temperature changes during the driest and coldest months presumably act to restrict highly favorable conditions in that region.

IMPLICATIONS FOR NORTHERN PINES

With a projected expansion of the beetle's favorable climatic habitat northward, especially in the next 15 to 30 years, forest management and risk mitigation practices could focus on monitoring investments in asset forests in northern New England and New York State where historical conditions have been less favorable for the SPB and observed occurrences fewer. Forest assets in the southeast US will likely continue to face persistent threat from the beetle, albeit under extreme climate conditions, presuming changes to temperature (potential increase in extreme hot days and heat wave lengths could limit beetle movements and population growth) and precipitation dynamics, some regions may require less focus and investment for beetle mitigation, given the existing programs in place to combat the beetle now.

APPLICABILTY TO TNFD BIODIVERSITY RISK ANALYSIS

TNFD stands for the Task Force on Nature-related Financial Disclosures. It's a global initiative similar to the Task Force on Climate-related Financial Disclosures (TCFD) but focuses on the risks and opportunities related to nature and biodiversity *(REF 4)*. The TNFD aims to develop a framework for companies and financial institutions to assess, manage, and report on their nature-related risks and dependencies, similar to how the TCFD framework addresses climate-related risks. The goal is to encourage more transparent and consistent reporting on nature-related risks and opportunities, thereby integrating biodiversity considerations into financial decision-making processes.

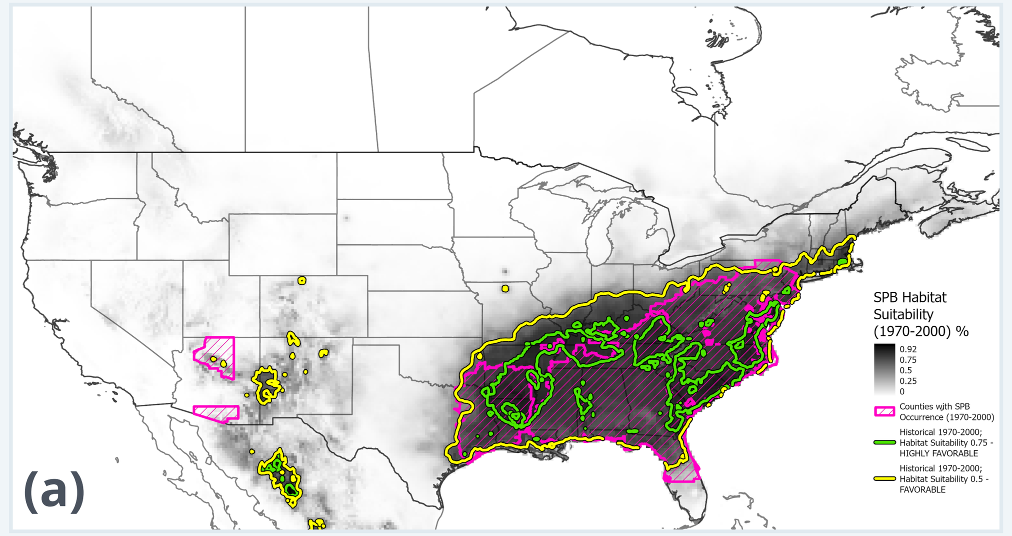


The modeling performed here can be leveraged in a TNFD analysis to assess and quantify the potential impacts of biodiversity loss and habitat degradation on an organization, particularly with respect companies dependent on timber supply chains throughout the eastern US and southeastern Canada. Here's three ways how:

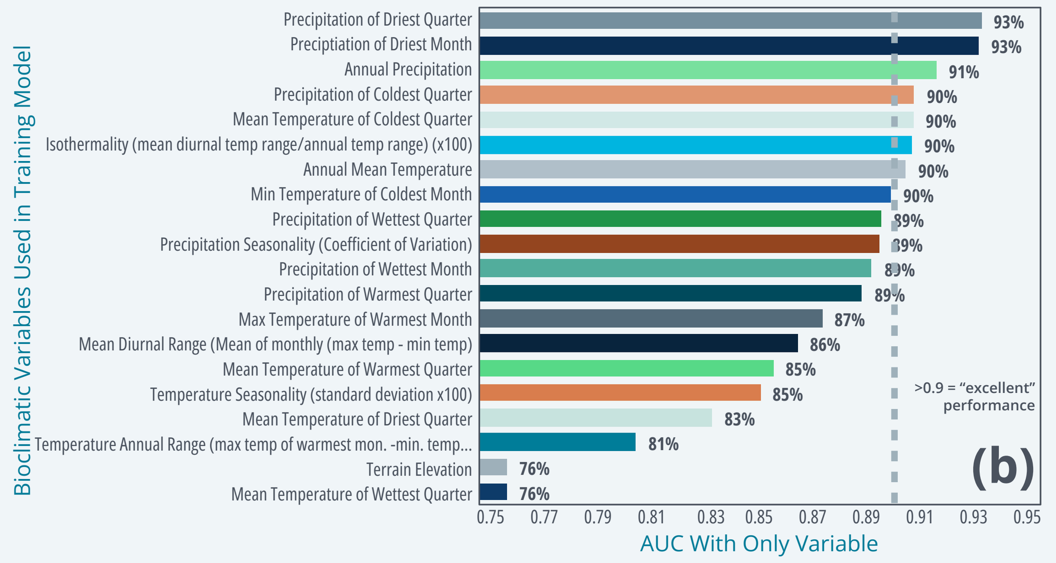
1. *Assessment of Biodiversity Loss Risk: This modeling has identified areas where timber could be affected by habitat loss or degradation due to climate change-enhanced infestations of the Southern Pine Beetle. By mapping species habitat suitability, an organization can understand the extent to which climate would impact biomes critical to their business continuity and supply chain.*
2. *Scenario Planning: The scenarios applied here allow an organization to explore different scenarios of climate change and their potential effects on species habitat suitability. This allows the organization to understand how different future trajectories related to energy and biodiversity policy initiatives and GHG mitigation may affect their operations and investments.*
3. *Strategic Decision Support: This type of modeling can provide decision support for an organization seeking to mitigate biodiversity risks. By identifying areas of high biodiversity value or areas at risk of habitat loss, the organization can develop strategies to enhance their resilience to future environmental changes.*

Results

Modeled Historical Habitat Suitability

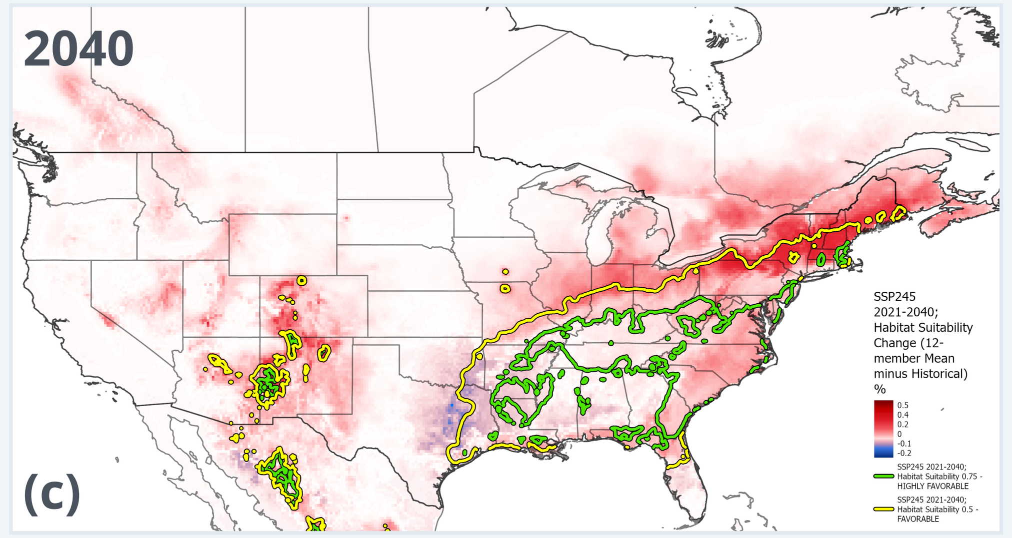


Independent AUCs of Bioclimatic Variables Used to Train Model

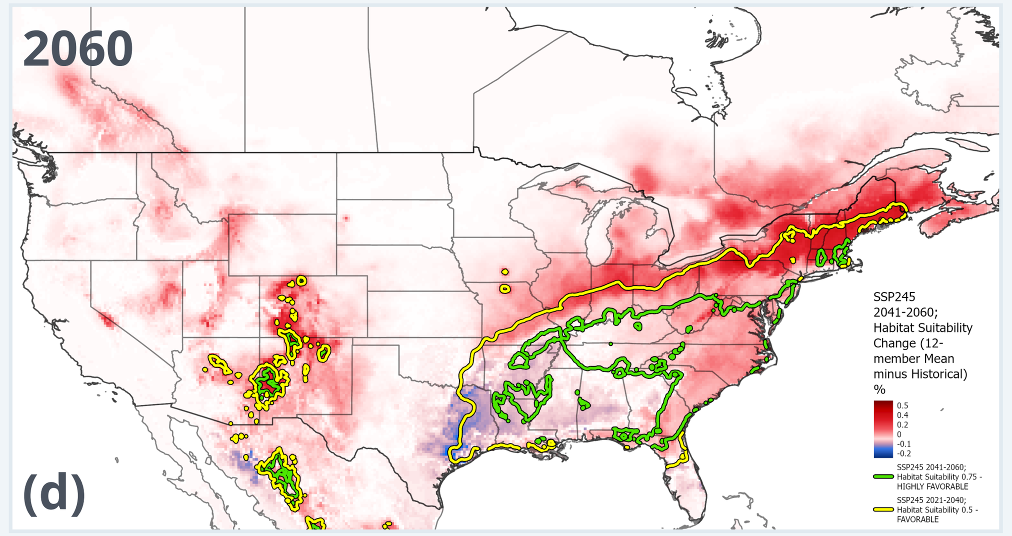


Change in Habitat Suitability from Historical

SSP2-45

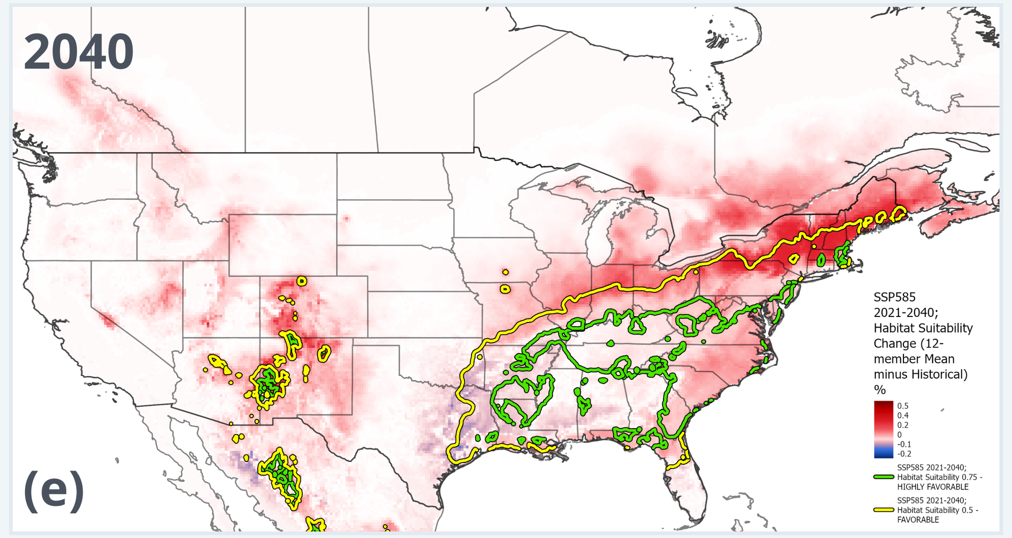


Change in Habitat Suitability from Historical

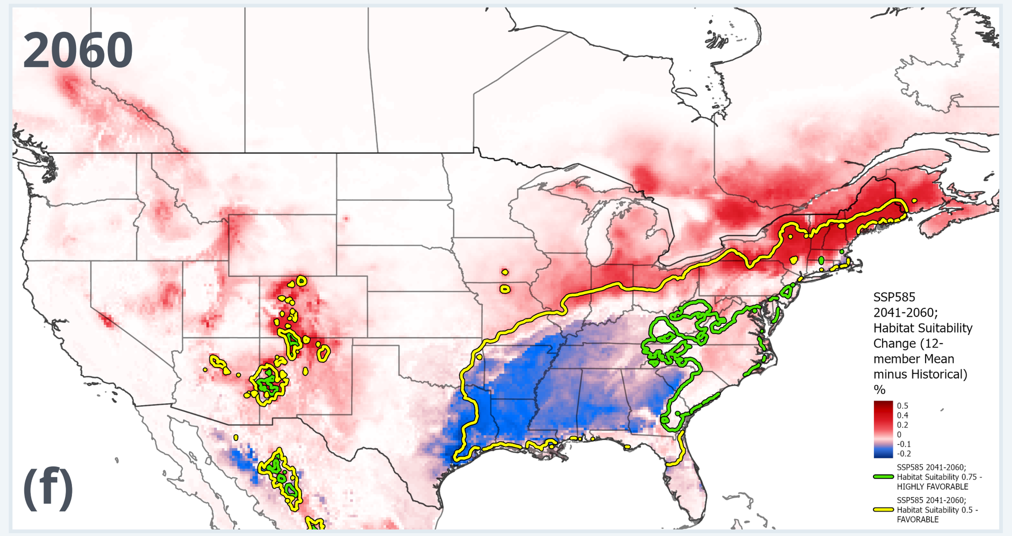


Change in Habitat Suitability from Historical

SSP5-85



Change in Habitat Suitability from Historical



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