Integrated Bioclimatic-Dynamic Modeling of Climate Change Impacts on Agricultural and Invasive Plant Distributions in the United States

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Biological invasions of nonindigenous plants and pests are serious threats to U.S. natural and managed ecosystems, causing more than $120 billion per year of major environmental damages and losses. In agriculture alone, $27 billion per year is estimated for the crop production lost from alien invasive weeds and herbicide application expense. It is well established that climate is the dominant determinant of the geographic distribution of plant species, native or alien. This distribution is confined by the prevailing bioclimatic limits in the regional resources of light, heat, water, and nutrients. Given the rapid growth in worldwide trade or globalization, long-range transport of non-native plant species across national boundaries becomes increasingly important, exacerbating U.S. invasive species problems. Although humans facilitate the initial establishment, the invasion, spread, and subsequent distribution of nonindigenous species may be controlled largely by local environmental factors. Recent climate change, such as general warming, earlier spring, longer growing season, decreasing winter frost period, and altered hydrologic cycle has already caused unequivocal shifts in the distributions and abundances of species, and even pushed certain native species to extinction.

The objective of this study is to quantify and understand the impacts and uncertainties of regional climate changes from the present to 2050 on the U.S. agricultural and invasive plant species distributions, emphasizing crop production, and to account for both adaptation of alternative crops and invasion of non-native species to enable decision makers to design effective management and control strategies for a sustainable future agroecosystem. The original contribution of this research will derive from the application of a state-of-the-art bioclimatic-dynamic ensemble forecast system that integrates a species environmental matching or niche modeling component (SEM) with a high-resolution dynamic regional climate-ecosystem predictive component (CEP) over North America. Both components incorporate multiple alternative models representing the likely range of climate sensitivity and ecological response under the conceivable anthropogenic emissions scenarios to rigorously assess the resulting uncertainty to improve risk analysis. This study will account for both adaptation of alternative crops and invasion of non-native species in response to projected climate changes. Historical simulations of the observed climate and crop production first will be conducted using the CEP to provide the best proxy of the actual soil and bioclimatic conditions fundamental to the plant survival and reproduction. This module can generate a high-resolution (10-30 km in this study), physically consistent and most complete list of climate variables.

The high-resolution CEP-integrated bioclimatic predictors, including total plant productivity as input, will be used to establish the SEM functional relationships of species distributions with these environmental envelopes. The optimized ensemble of multiple CEP and SEM component models driven by four combinations of regional climate models/global climate models (RCM/GCMs) and emissions scenarios will be used to represent the most plausible range and uncertainty of future projections of U.S. agricultural and invasive plant species distributions in the 2050s. The coupled CEP will be used to study climate-crop interactions, focusing on how they affect U.S. agricultural productivity at the present and in the future. The representative GCM projected and RCM downscaled climate changes will be used in this study. The recent RCM incorporates the most comprehensive surface boundary conditions and advanced physics schemes that improve surface-atmosphere and convection-cloud-radiation interactions. More importantly, it has been coupled with comprehensive crop growth models to realistically simulate U.S. crop yields. The coupled RCM-crop modeling system will serve as the key CEP to predict the climate and crop production conditions needed for the development and application of the ensemble SEM system. These conditions will be used as input to develop a robust SEM to best capture the observed agricultural and invasive plant species distribution. Future projections for the potential niche distributions of alternative crops adaptable to the likely range of climate changes in the 2050s will subsequently be made using the CEP. These CEP simulations of the future soil and bioclimatic conditions will be integrated by the SEM to project the geographic distribution and abundance of U.S. agricultural weeds and invasive plant species in the 2050s.

Through the proposed application of this unique ensemble forecast system, the investigators will make major contributions to the key goal of the U.S. Department of Agriculture Cooperative State Research, Education, and Extension Service (USDA CSREES) to enhance protection and safety of the Nation's agriculture and food supply. The advanced state of the system components will result in a more in-depth understanding of complex interactions among regional climate and land use, focusing on agricultural crop production and invasive plant species across a full range of spatial and temporal scales. The investigators expect to model the risks associated with several high-profile, costly agricultural weeds in the United States. By using a conceivable range of climate scenarios, we will evaluate, with a credible estimate of associated uncertainties, how these weeds may change in future distribution across a wide suite of crop types and environmental envelopes. This will lead to better targeting of harmful invasive species in response to climate change. It is expected that that the results will greatly surpass the capability of existing studies for climate change impacts on future U.S. agricultural productivity.