Predicting the Spread of Invasive Plants with Climate Change

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Introduction

Bull thistle (*Cirsium vulgare*) invading Tioga Pass. Photo by Bob Case.

The Sierra Nevada is likely to be heavily impacted by climate change. Invasive plants are predicted to spread into the region and to higher elevations. Land managers need to know where to focus their work to produce the most effective ecosystem restoration. Predictive models can help early detection by showing where invasive plants may spread and predicting the effects of changing conditions under global climate change. Such predictions are especially important in light of research showing that 66% of California's native plants could lose 80% of their range due to climate change (Loarie et al. 2008). Land managers can also use these data to justify projects to funding agencies.

In 2006-08, we examined 36 invasive plants statewide. We are currently studying 30 additional plants of concern in the Sierra region and improving the resolution of the results using new methods. This project will be completed in 2011.

Goals

1. Collect data on current distribution and population trends for a set of plant species of high priority for early detection.

2. Use predictive models to determine which areas of the Sierra are most suitable under current and future climate conditions.

3. Integrate data on current distribution and suitable habitat into risk maps using Geographic Information Systems (GIS).

4. Generate watch lists based on these maps to distribute to Weed Management Areas in the Sierra Nevada.

Data Collection

Occurrence: We trained the models with presence data from Calflora (www.calflora.org) and vouchered specimens from the Consortium of California Herbaria. We are adding additional data by contacting governments agencies, organizations, and individuals to better represent the plant habitat ranges. If you have data you are willing to share, please contact us!

Environment: We are using environmental layers from a free data product called BIOCLIM. This dataset contains parameters which are especially useful to describe the climatic conditions a plant needs to thrive. The variables are calculated from monthly maximum and minimum temperature, rainfall, solar radiation and pan evaporation from 1970-2000 within a 30 arc-second grid. For details see: http://fennerschool.anu.edu.au/publications/software/anuclim/doc/bioclim.html

Future Climate Change Conditions: BIOCLIM variables for future conditions are calculated from the outputs of major climate models, in our case Canadian Center for Climate Analysis and Modeling (CCCMA).

Methods

Maxent software developed by Phillip J. Stevens et al. at Princeton (Stevens et al. 2006) is freely available and frequently used to assess suitable habitat for plants and animals given specific environmental variables. The principle of the algorithm assumes that the distribution of a species will be random, or contain maximum entropy, unless conditions that encourage or discourage growth are in place.

Maxent requires only presence data in addition to environmental information. The software assumes pseudo-absence for areas with no presence. Environmental suitability is then mapped in the Maxent output in addition to the role, or percent contribution, each of the environmental variables played in the output. The resulting maps show the probability for that an occurrence in a raster cell is not random but an effect of the environmental conditions.

The results of this model fitting or training process can be used to estimate the future distribution under changing climate conditions.

However, habitat modeling does not work equally well for all species. Reliable results need a representative dataset (where all possible habitats are represented by data points), a state of relative equilibrium (the plant occurs in most of its possible habitats), and the adaptability of the species is restricted in a way that the environmental variables provide actual limits for further spread.

Since these conditions are not necessarily met for all invasive species, we developed a model evaluation tool with the goal to inform potential users of our results about the limitations of modeled suitability. We are currently experimenting with strategies to model the potential habitat of new invaders in California. One way is to use natural range training since equilibrium can be assumed in the native range.

Case Study #1 *Bromus japonicus* (Japanese brome)

Bromus japonicus (Japanese brome) is a cool season, annual grass common in Northern California. This grass out-competes native grasses in areas where grazing and fire have been reduced. Native to Europe, Japanese brome is now considered naturalized (in equilibrium) throughout the United States. It occurs on a wide variety of soils that include sand, silt, and clay, but thrives on fine-textured soils. Waste areas, disturbed sites, roadsides, pastures, rangelands, and wheat fields are areas where Japanese brome may establish. With climate change the available niche will increase further.

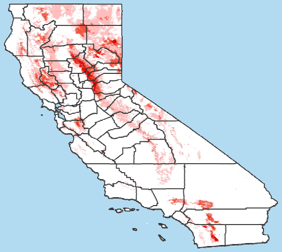
Photo Matt Lavin

Preliminary results

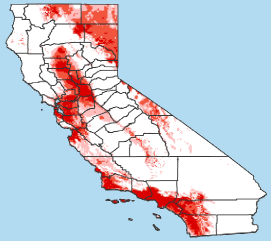
Annual precipitation, mean temperature of the wettest quarter, and precipitation of the driest quarter each played a large role (> 15% each) in the Maxent results. These percentages were determined by an estimate of relative contributions of the environmental variables to the Maxent model. We had 151 presence points for this species.

Our model shows that Japanese brome will spread with climate change, likely because of the more intense precipitation events.

Japanese brome currently



Japanese brome in 2080



Darker red shows areas with higher suitability.

Model evaluation

Data		Species			Model/Prediction			Overall score
point count	distribution	identification	adaptability	equilibrium	model statistics	clamping	expert evaluation	2.4
3	3	1	2	3	3	1	3	

Model Evaluation

To evaluate the accuracy and uncertainties of our Maxent models, we used the following criteria (scored from 1 to 3, poor to good for the model):

✧ Number of **data points** available

✧ **Distribution** of data points relative to known range

✧ Ease of accurate **identification** of species

✧ **Adaptability** of species to new environmental conditions

✧ Whether species is in **equilibrium** (i.e., no longer expanding, Stevens et al. 2006)

✧ **Model statistics** (Area Under the Curve (AUC) and significance) from Maxent

✧ Area where **clamping** is necessary in order to make a future prediction. Clamping deals with the fact that future climate might produce conditions that are not represented by the training data. In this case there are two options: One is to use the actual values as input for a prediction. Another option (clamping) replaces the actual value of an environmental variable with the closest value represented by the training data. If clamping in a big area is necessary, the future prediction will contain more uncertainties.

✧ **Expert evaluation:** We present our current suitability models to expert botanists and ask them how well our outputs represent their spatial and ecological knowledge about the plant. **Please let us know if you want to be part of this process!**

Case Study #2 *Isatis tinctoria* (Dyer's woad)

Isatis tinctoria (dyer's woad) is a winter biennial or short-lived annual herb/forb in the Brassicaceae family. Plants are highly competitive and often grow in dense colonies. Dyer's woad is native to central Asia and northern Russia. It was introduced to North America in the early 1900s as a contaminant in alfalfa seed. Plants occur in areas with poor, dry soils such as roadsides, rangelands, and open forests.

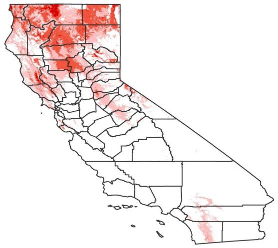
Photo Marla Knight

Preliminary results

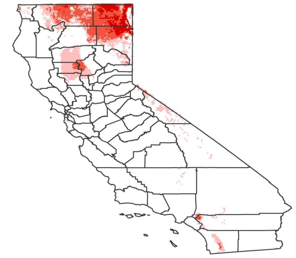
Annual precipitation and precipitation of the driest quarter each played a large role (> 25% each) in the Maxent results. We had 210 presence points for this species.

We suspect that the reason dyer's woad habitat does not expand in the future climate change scenario is because it requires dry soils and extreme precipitation events are likely to increase with climate change. Dyer's woad thrives in dry, rocky, or sandy soils, and our model shows that, with climate change, its habitat will likely decrease due to increased precipitation events.

Dyer's woad currently



Dyer's woad in 2080

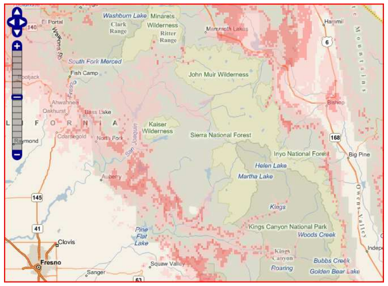


Darker red shows areas with higher suitability.

Model evaluation

Data		Species			Model/Prediction			Overall score
point count	distribution	identification	adaptability	equilibrium	model statistics	clamping	expert evaluation	2.6
3	2	3	2	2	3	3	3	

Management Implications



Current suitable habitat for Japanese brome shown on a finer scale on our web mapping tool (under development). Darker red shows areas with higher suitability.

This project will lead to long-term improvement in the effectiveness of Sierra agencies and organizations to address invasive plant detection and control. Land managers will be able to identify species that are good targets for early detection/rapid response. Identifying the "leading edge" of new invasions will encourage regional cooperation, leading to more effective use of time and funding. Applying for funding to eradicate such species will be backed by finer scale maps to help verify the need for support. Effective prevention, detection, and containment of invasive plant species in the region will decrease the stress that impedes range shifting of native species as our climate changes.

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Data provided by: Calflora, Participants of Consortium of California Herbaria

Literature Cited: Cal-IPC. 2006. California Invasive Plant Inventory, Publication 2006-02, Cal-IPC, Berkeley, CA; Loarie, S. R., B. E. Carter, K. Hayhoe, S. McMahon, R. Moe, C. A.Knight, D. D. Ackerly. 2008. Climate change and the future of California's endemic flora. PLOS One. 3(6): e2502. doi:10.1371/journal.pone.0002502; Stevens, P. 2006. Maximum entropy modeling of species geographic distributions. *Ecological Modelling*, 190:231-259, 2006.