Predicting Plant Invasion with Modeling

By Scott Steinmaus

How do we know whether a non-native plant is likely to invade a particular area? Can we tell when an invasive has stopped spreading—or where it will someday stop — based on geographic factors? Such questions intrigue researcher Scott Steinmaus of Cal Poly San Luis Obispo. Here he describes tools he is developing tools to find answers.

As a graduate student, I learned to question assumptions. Michael Barbour taught us to challenge the assumption that we could ever really know the "native" condition of California. Marcel Rejmánek taught me to ask, "Is your invasives problem truly growing over time, or does it just look that way because you are doing a better job of measuring it?" These questions underlie my development of models for evaluating the potential for plant invasions.

Prediction is key

Few would disagree with the philosophy that "prevention is the best cure." Predicting where a plant species might become invasive is a key component of prevention programs.

One technique for making predictions uses empirical models that are based on observations without necessarily understanding the mechanism. These predictions are usually accurate only under a narrow range of conditions within which the observations were made.

A more robust technique for making predictions uses a mechanistic understanding of how and why invasion is successful for a given species. Biological characteristics alone are often not enough to predict invasion in a particular location because they do not consider the other two components to a successful invasion: site characteristics and the form of disturbance. This is where models become useful.

We look at three components of invasion:

(1) species characteristics—biological factors make a species invasive, consider native weaknesses as well;

(2) site characteristics—ecotones, complexity, isolation, and environmental factors; and

(3) disturbance—any diversion from the native condition that facilitates invasion.

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Species characteristics

Biological characteristics of an exotic species have been used to predict invasiveness. Two systems of criteria appear least prone to error: Reichard's risk assessment system for woody plants in North America, and the Australian weed risk assessment system for all plants (White and Schwartz 1998). The two systems use essentially the same criteria:

(1) a history of invasive behavior elsewhere;

(2) closeness of biological relationship to another species that is invasive;

(3) climatic/ecological similarityof introduction area to original home range;

(4) aggressive traits such as allelopathic chemical release or extremely competitive;

(5) biological attributes such as vegetative reproduction, vine-like growth habit, short juvenile period, habitat generalist, easy germination/establishment patterns.

Site characteristics

Cronk and Fuller (1995) provide general hypotheses that explain common plant invasions. These may be used to develop characteristics of sites that lend themselves to invasion. Susceptibility can be based on:
(1) an absence of predators;
(2) poorly adapted natives with low reproductive vigor;
(3) low biodiversity on site; and
(4) empty ecological niches.

Disturbance

Some invasives are aggressive enough to establish an infestation in an intact native habitat. Most, however, are opportunistic and favor the opening afforded by some type of anthropogenic disturbance. These can be:

(1) chemical changes such as fertilizer, sewage, and nitrogen deposition;

(2) physical disturbance such as erosion, bare ground, roads and construction;

(3) biological disturbance such as removal of niche plants; and

(4) hydrologic disturbance such as irrigation and groundwater pumping.

The modeler's job

Explaining and predicting invasion is a multidimensional process involving many variables. In developing a model it is important to identify, quantify, and incorporate the most significant mechanistic variables. Including too many variables can lead to unreliable predictions because of problems associated with error propagation and dependencies among the variables. Thus, the modeler's job is to find the optimal set of variables that give the most useful predictions.

Discriminant analysis is one statistical method that we can use to classify a species as invasive or noninvasive based on its characteristics. For example, working with *Pinus* species, Rejmánek (1995) determined which biological characteristics contributed most significantly to a discriminant function and thus were the best predictors for invasive behavior in pines:

(1) small mean seed size with a short chilling requirement;

(2) minium juvenile period;

(3) short interval between production of large seed crops; and

(4) maximum opportunity for dispersal by vertebrates.

Similar lists of most significant characteristics can be developed for other species.

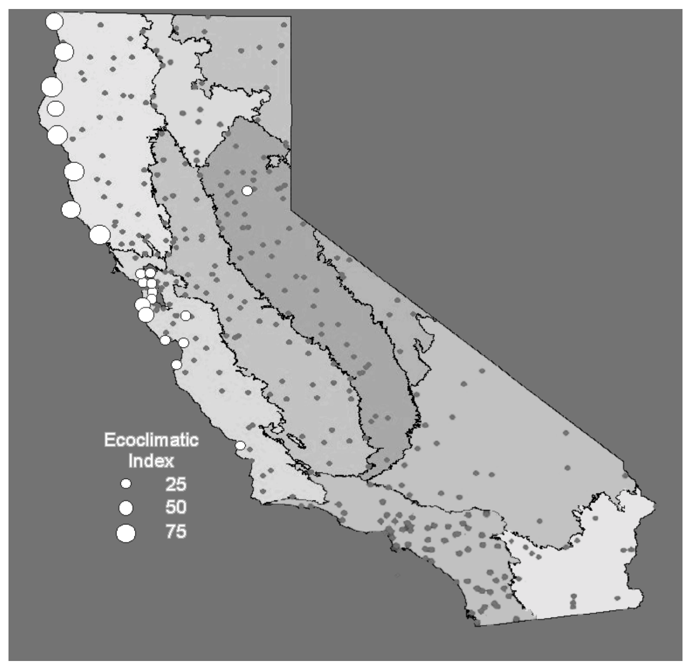

Figure 1. Ecoclimatic Index for gorse suitability in California. Higher values of EI indicate higher suitability. Dots represent sites tested in the model (sites are determined by presence of a local weather station).

Buckaroo Bonzai tackles gorse

My graduate students have taken to calling our approach to model development the "Buckaroo Bonzai" method because we incorporate combinations of eclectic elements, depending on what is most useful. We use biology of the invasive species, a climatic matching model, and ordination methods to incorporate environmental characteristics of currently infested sites.

Our overall goal is to design a system with sufficient flexibility that one can assess the risk of invasion for any weed in any location in California. To start, though, we needed one good question to test such a system. We decided to analyze the likelihood that gorse (*Ulex europaea* L.) would be an aggressive invader in San Luis Obispo County. The county's WMA was trying to decide whether to plan for an imminent invasion from Monterey County to the north, and we thought maybe we could help.

Climate modeling

Many factors can potentially explain a successful plant invasion, but if the climate at a given location is not conducive for growth then it is highly unlikely that a successful invasion will ever occur. So climate is the primary characteristic we use in assessing a site's vulnerability to invasion by a particular plant.

Our literature searches provided us with the native and current invasive distribution range for gorse. Gorse is native to Europe, centering on Ireland,

and has been invasive in cool, moist areas including tropical latitudes at high elevations (New Zealand, southeast Australia, Hawaii, Yucatan highlands, as well as the Pacific coast of the US).

For the initial stage of our model development, we focused on the distribution of the species in its native region. We assume that the species has had every opportunity to establish throughout the entire native region, so sites where the species does not grow provide as much information as those sites where it does. From distribution maps of gorse and close relatives in its native Ireland, we deduced gorse's constraints and preferences for temperature and moisture.

In order to assess the suitability of the San Luis Obispo climate for gorse we utilized CLIMEX, software that uses weather station data (Sutherst *et al* 1999). Only 14 of the CLIMEX database's 2,400 weather stations worldwide were in California, so we acquired additional data from a NOAA database that has 321 stations in the state.

CLIMEX computes an Ecoclimatic Index (EI) for the modeled species with values between zero (no survival) and 100 (highly suitable climate). The EI is the combination of a Growth Index (GI) and a Stress Index (SI). The GI incorporates climatic preferences for a species and determines the abundance of a species for a particular location. The SI incorporates climatic constraints that describe the conditions a species cannot tolerate and determines a species' distribution. The predictive model includes parameters such as the temperature above which development occurs for gorse (i.e. its "base temperature"). Similarly, thresholds and rates were estimated for moisture levels based on gorse's native distribution. (Nonlinear responses to temperature and moisture can be incorporated with interactions amongst the variables. Values for these parameters can be determined experimentally in controlled atmosphere chambers, extracted from the literature, or inferred from native distribution.)

With climate and other factors all figured together, our model gives a clear prediction that gorse should have only marginal success south of Monterey County (Figure 1). With this evidence we recommended that a relatively low priority be given to gorse management in San Luis Obispo except for cooler, wetter microclimates in the coastal valleys. This guidance will help the WMA plan its approach to gorse.

Other environmental variables

Canonical correspondence analysis (CCA) is a dimension-reducing ordination method used to determine the environmental variables that best explain a species' distribution (Ter Braak 1987). This method is insensitive to many of the violations required by general linear models (such as ANOVA and multiple regression), and is not hampered by high correlations among species or environmental variables. If CCA finds that moisture and temperature are the most significant factors in explaining species distribution, then CLIMEX may be the only model you need for predictions.

We gathered information for several gorse-infested sites along the coast, using GPS coordinates to take information such as soil type, elevation and aspect from existing GIS layers. Running a CCA on these sites, we deduced that gorse prefers, in order of significance: highly disturbed sites (burn or grazed); north facing slopes; moderate cover (using leaf area index in m^2 leaf/ m^2 ground); moderate riparian charater; low pH soils; and high sand content soils. The CCA tells us that gorse is associated with broom, and avoids pine species. (We did not include climate in this particular CCA because we were attempting to decide which additional environmental variables to measure for an extensive sampling session in the future.)

Cape ivy prediction

We also used CLIMEX to predict cape ivy invasivity throughout California. Our original model required that we account for the higher water availability that exists in riparian environments where Cape ivy typically grows. We did this by artificially increasing moisture levels in the NOAA and CLIMEX databases, which uses only precipitation for moisture. Once we parameterized a model that predicted growth in the locations where it grows in its native South African habitat we applied the model to California.

With this model, we found suitable

Figure 2. Ecoclimatic Index for Cape ivy suitability.

climates all along the California coast just as Mona Robison has found with her field surveys and distribution mapping (Figure 2). We also predicted that a few cape ivy populations could succeed in the Central Valley. Infestions in these locations have just recently been found and reported on Mona's distribution map. These findings speak well for the accuracy of our work.

Assessing biocontrols

We can also use CLIMEX to assess the suitability of an infested location for a biocontrol agent. Insect biological control agents are at a higher trophic level (i.e. primary consumer) than the pest (i.e. primary producer). Therefore, they are typically more sensitive to the climatic nuances of a new habitat than the plant pest is. Predicting the suitability of a climate for a biocontrol agent could make lab and field efforts to assess suitability more efficient.

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A tool in development

The models described here are intended to aid human intuition, not to replace it. They should be used as tools, and considered as a project in process—always open to improvement. A model is only as good as its assumptions and input data, and is only an approximation to reality.

We are currently compiling a larger weather database with data from vineyard and farm weather stations, and incorporating other variables into CLIMEX and CCA. We are also introducing stochastic elements into these climatic models, since to date they are based solely on annual averages, and we all know there is no such thing as an "average year" in California's climate. As we learn how to better apply such sophisticated computer tools, we can begin to develop a better sense for the larger patterns of non-native species invasions.

References

Cronk, Q.C.B., and J.L. Fuller. 1995. *Plant Invaders: the Threat to Natural Ecosystems*. Chapman and Hall. NY.

Sutherst, R.W., G.F. Maywald, T. Yonow, and P.M. Stevens. 1999. CLIMEX. *Predicting the Effects of Climate on Plants and Animals*. Version 1.1 CSIRO Publishing. Victoria, Australia.

Rejmanek, M. 1995. What makes a species invasive? In *Plant Invasions—General Aspects and Special Problems*. P. Pyšek, K. Prach, M. Rejmánek, and M. Wade (eds.). SPB Academic Publishing. Amsterdam, The Netherlands. pp 3-13.

Ter Braak, C.J.F. 1987. The analysis of vegetation-environment relationships by canonical correspondence analysis. *Advances in Vegetation Science* 8:69-77.

White, P.S., and A.E. Schwarz. 1998. Where do we go from here? The challenges of risk assessment for invasive plants. *Weed Technol.* 12(4):744-751.

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