

Predicting invasion winners and losers under climate change

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Invasive plant species are human-introduced, nonnative, and damaging. They can restructure natural habitats, change community composition, disrupt food webs, and degrade ecosystem services. Global climatic changes are often thought to exacerbate invasions (1), but no consensus exists over the generality of this phenomenon (2). As a consequence, anticipating areas of high invasion risk or decreased impact in the future is still uncertain. By combining experimental biogeography with demographic models, Merow et al. (3) develop climate driven process-based models to predict population growth or decline under current and future climate scenarios for two established and damaging invasive plant species in New England, United States. They find that one invasive species will likely perform better, whereas the other will do worse in areas that are currently occupied.

Forecasting the distribution and performance of invasive species under a changing climate comes with particular challenges. Invasive species have not had time to colonize all favorable habitats available in the nonnative range. This nonequilibrium situation is problematic for correlative species distribution models, which may then use incomplete occurrences in the nonnative range as inputs for predicting suitable climatic conditions. However, predictions can be improved by using occurrence data from the native range (4). A more concerning challenge is that invasives may be able to establish in environmental conditions the species has not encountered in the native range (4–7), even if those conditions occur but are unoccupied in the native range (6). Niche shifts of invaders can have consequences for population biology; the observed climatic niche shift for the invader *Centaurea stoebe* (7) in the United States was associated with differences in population performance, even in a common environment (8). Although working with invasive species is a challenge, it is equally an opportunity to develop models for other nonequilibrium systems, which will increasingly become the norm due to climate change.

Invaders can be exposed to never-before-experienced conditions in mesocosm experiments, but real-world complexity demands field-based approaches (9). The recent availability of databases of plant and animal

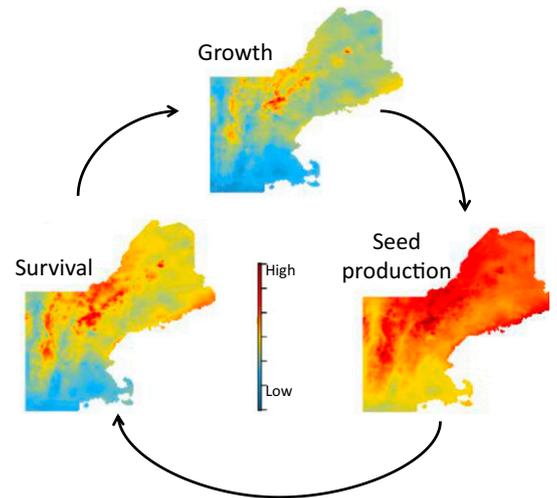


Fig. 1. Spatially explicit models of demographic rates of survival, growth, and seed production for an invasive plant species, *Alliaria petiolata*, reproduced from Merow et al. (3). The influence of environmental drivers varies with the vital rate modeled, which can decouple the effect of the environment on integrated population performance.

matrix population models, parameterized from field data, enables the analysis of geographical, environmental, and phylogenetic signal in population performance data (10). However, similar to problems with species distribution models, such correlative approaches in population biology lack the mechanism needed to reliably project population performance under new conditions. Mechanistic approaches require large-scale field experimentation across multiple species, a task often beyond the resources of a typical ecology research grant, but team-based distributed networks have made progress in extending the scale of ecological experiments (11). Experiments in artificial multispecies systems that are both invaded and subject to climatic perturbations are emerging (12), but to generalize responses and tease out differences that have significant negative impacts, we need to take small-scale mesocosm experimentation to larger biogeographic scales across tens to hundreds of species.

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Merow et al. (3) used an experimental biogeography approach and transplanted populations to 21 locations across occupied and currently unoccupied areas of the nonnative range of an herb and a shrub species. Transplant experiments are not new in plant ecology (13) and experimental demography (where vital rates are recorded under different environmental, treatment, or management conditions) also has a long history, albeit at local to regional scales (14). A recent shift from local to global-scale ecology and from pattern description to process-based biogeographic modeling has led to the merging of fields normally applied at different scales, such as the combination of biogeography and experimental demography (15). In Merow et al. (3), environmentally driven models of the population-vital rates of survival, growth, and reproduction are parameterized by measuring performance of individual plants transplanted across the current range and into areas where these plants do not currently naturally occur (3). The vital rate models generated using this experimental approach were combined within an Integral Projection Model (16) to project population growth rate. Not only does this approach enable the prediction of population growth rate from the experimental locations, but the vital rates can be predicted for any location where the environmental drivers can be obtained (Fig. 1). Based on the results of the experiment, population growth rates can be predicted for areas where the invader has not yet reached and for new climatic conditions.

Despite considerable progress for individual species such as those in Merow et al. (3), predicting the fate of populations in new areas or under new climate conditions remains very challenging on the large scale needed to make land management and conservation decisions (17). A major cause for this is the lack of large-scale, spatially and temporally replicated biological datasets for most species. Correlative species distribution models (18) based on the most readily available source of ecological data, species occurrences, have been used widely to project distributions under future climate scenarios. However, predicting population-level responses to a changing climate is more complex than relying on correlative models of climatic drivers of occupancy alone. These

models have undergone a series of extensions and improvements to incorporate dispersal (19) and population dynamics (20). However, evidence to date (3, 21) suggests that the probability of occurrence may be decoupled from population growth rates. This may happen because limits imposed by climate on vital rates may not immediately integrate through to overall population performance (22). Although this realization opens up a fascinating avenue for further research, it remains untested beyond a restricted set of species and life forms. A direct consequence is that the use of correlative species distribution models to predict integrated measures of population performance may not be possible. To move forward with large-scale multispecies predictions of population performance in new environmental conditions, we need to gain a better understanding of both how probability of occurrence is related to underlying vital rates and how vital rates combine through the life history to determine population persistence or extinction patterns (Fig. 1). Correlations between probability of occupancy from occurrence data and population performance may be mediated through vital rates. As demonstrated by Merow et al. (3), key climatic drivers can have opposite effects on different vital rates and populations can buffer environmental differences across large spatial scales through these vital rate trade-offs.

Management strategies for damaging nonnative plants must consider effects of future climate changes on local populations. Why manage a currently damaging population that will decline anyway as climate changes? Where do we put in place preemptive management strategies for high-impact invaders likely to expand into newly suitable areas? How do we mitigate legacy impacts of invaders that decline? These questions are critical for guiding cost-effective (23) management strategies for invasive species, but without clear mechanistic forecasts of population dynamics under predicted climate changes they have not been adequately tackled. We run the risk of wasting management resources on sink populations and failing to manage leading-edge populations that will be sources for further invasion.

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