A Framework for Debate of Assisted Migration in an Era of Climate Change

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Introduction

The Torreya Guardians are trying to save the Florida torreya (*Torreya taxifolia* Arn.) from extinction (Barlow & Martin 2004). Fewer than 1000 individuals of this coniferous tree remain within its native distribution, a 35-km stretch of the Apalachicola River, and these trees are not reproducing (Schwartz et al. 2000). Even if the Florida torreya was not declining toward extinction, the species would be at risk from climate change. Warming is projected to either significantly reduce or eliminate suitable habitat for most narrowly endemic taxa (Thomas et al. 2004; Hannah et al. 2005; Peterson et al. 2006), forcing species to colonize new terrain to survive.

The focus of the Torreya Guardians is an "assisted migration" program that would introduce seedlings to forests across the Southern Appalachians and Cumberland Plateau (http://www.TorreyaGuardians.org). Their intent is to avert extinction by deliberately expanding the range of this endangered plant over 500 km northward. Because planting endangered plants in new environments is relatively simple as long as seeds are legally acquired and planted with landowner permission, the Torreya Guardians believe their efforts are justified. Introducing this species to regions where it has not existed for 65 million years is "[e]asy, legal, and cheap" (Barlow & Martin 2004).

If circumventing climate-driven extinction is a conservation priority, then assisted migration must be considered a management option. Compelling evidence suggests that climate change will be a significant driver of extinction (McCarthy et al. 2001; McLaughlin et al. 2002; Root et al. 2003; Thomas et al. 2004). Researchers typically conclude that mitigating climate change and providing reserve networks that foster connectivity and movement should be a priority (e.g., Hannah et al. 2002). Ecologists must recognize, however, that even optimistic estimates of natural movement may be insufficient for species to keep pace with climate change.

Assisted migration is a contentious issue that places different conservation objectives at odds with one another. This element of debate, together with the growing risk of biodiversity loss under climate change, means that now is the time for the conservation community to consider assisted migration. Our intent here is to highlight the problem caused by a lack of a scientifically based policy on assisted migration, suggest a spectrum of policy options, and outline a framework for moving toward a consensus on this emerging conservation dilemma.

Current Policies Relevant to Assisted Migration

Land management agencies, in particular, must confront the issue of assisted migration in terms of their own management and their regulation of others' management efforts. Natural resource agencies are tasked with two mandates: preserving biodiversity and managing species of concern. Preserving biological diversity may include species diversity, habitat integrity, a historical construct of community structure, ecosystem function, or, more likely, a combination of these objectives (Grumbine 1994). As stewards of publicly owned land, agencies develop plans to accomplish these goals, and typically they lack a policy about new species that might be introduced for conservation purposes.

Government agencies also play a role in regulation of the intentional movement of species. In the United States federal and state natural resource agencies are the arbiters of the management and movement of species (Czech & Krausman 2001). In practice private citizens have broad latitude with respect to species movement

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and are not obligated to seek governmental permission to release most legally acquired nonvertebrate species. Although individuals do not own wild animals that occur on their property, states typically only regulate the capture, movement, and release of a few species.

Most states have rules that restrict the release of pest species into novel environments, although both content and jurisdiction vary (ELI 2002). Rules regarding noxious pest invasions, however, are typically limited to a subset of species whose movements are associated with outdoor recreation (e.g., zebra mussels on boats) or that threaten agriculture.

The relative ease with which species may be legally moved around poses a problem. Historically, there has been little accountability for unwanted plant and animal invasions, even when this adversely affects a land owner's property value. Thus, most natural resource agencies lack policies that address the legal introduction by a private citizen of a globally threatened species into a new environment and the species' spread to adjoining areas.

A Framework for Debating Assisted Migration

The prominence of assisted migration under climate change will depend on a broad spectrum of ethical and scientific beliefs (Fig. 1). The three axes in Fig. 1 emphasize how policy choices may be shaped by uncertainty in basic ecological understanding of the risks and benefits of assisted migration.

Ecologists likely vary in their perception of the risks associated with imposing or rejecting a policy of assisted migration. Conservation biologists studying rare endemics may be more willing to embrace assisted migration than ecologists studying invasive species, for example. In either case opinions about the appropriate scope and magnitude of assisted migration will also depend on confidence in our understanding of ecological dynamics (third axis in Fig. 1).

We identify three positions that illustrate the choices to be made in formulating policy on this issue (Fig. 1). These positions characterize perspectives that we have heard in discussions with ecologists on this topic. We neither advocate nor reject particular positions, and all three positions are consistent with a strong desire to reduce anthropogenic warming and create a network of reserves that maximizes connectivity and movement potential. However, there are important conflicts between these perspectives.

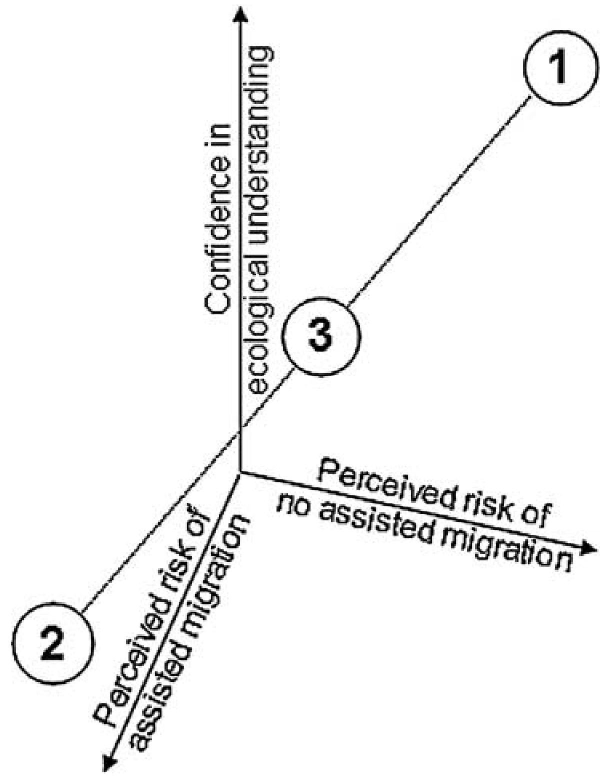

Figure 1. A representation of ecological perceptions and information that might frame a policy of assisted migration. Positions on assisted migration (1–3) are located within a conceptual space and more fully explained in text.

Three Policy Options

Position 1: Aggressive Assisted Migration

Proponents of position 1 are primarily motivated by the imminent threat of extinction, although they may also view species translocation as a way of addressing broader human-caused disequilibria with nature (Martin 2005). This policy may represent the best option to minimize species loss under devastating and rapid human-caused climate change, but it places existing communities under a high risk of disruption (Fig. 1).

A strong advocate of assisted migration is convinced that climate constrains the distribution of most taxa, projections of habitat shifts associated with future climate change are accurate, and dispersal limitation warrants human assistance. An advocate of this position may also argue that time is short and the opportunity to develop specific predictions and models for all the species that require assistance is lacking. Management strategies consistent with position 1 include extensive translocation of species well beyond their native ranges and restoration-style establishment programs. The strongest advocates for position 1 would apply the principle broadly to many species. One would still expect that the major constraint on projects would be permissions and notification. Under any sort of assisted migration program, we believe it is ethically mandatory that the parties proposing to move species not only seek legal authority to collect individuals and deposit them in new habitats, but also must notify all parties that may be affected. Legal mechanisms will need to be established to protect assisted-migration agents from litigation and to compensate recipient regions for damages.

Proponents of position 1 may require predictive habitat models to guide release of organisms, but they may also simply opt to endorse broad movement, allowing ecosystems to sort themselves out. Proponents that would use habitat models would typically have high confidence in the outcome of these predictive models and would argue that they can be generated quickly and easily for many taxa and tested with field trials. In Fig. 1 this position is high on the axis of both perceived risk of inaction and high on the axis of ecological confidence.

Position 2: Avoidance of Assisted Migration

Those who adhere to position 2 emphasize awareness of the unintended consequences of well-intentioned human interference. They recognize the enormous uncertainty in ecological understanding of what controls the distribution and abundance of species (Fig. 1), noting that great effort has been spent studying invasive species and yet which species will become pests cannot be predicted. Even with hindsight, it is difficult to say why some species become pests and others do not. Furthermore, the lag between introduction and population explosion in exotic invaders can be decades long, suggesting that efforts to monitor translocated species for negative ecological consequences is impractical.

Proponents of position 2 also stress the difficulties and problems of predicting target regions for assisted migration: lack of data for modeling climatic envelopes of most species; the obvious violation made by envelope models in their assumption of uniform climatic tolerances across a species' range; the problem of how to include biotic interactions in determining the influence of climate on species; and sizeable uncertainty in climatic predictions themselves (Guisan & Thuiller 2005).

Rejecting assisted migration will greatly increase the threat of climate-driven extinction. Policy consistent with position 2 must therefore place extensive emphasis on facilitating natural population spread. Scientific and conservation efforts to preserve isolated populations (Schwartz et al. 2002) and to design landscapes that facilitate spread (Pearson & Dawson 2005) are consistent with position 2. Opponents of assisted migration can take some comfort in knowing that existing species have accommodated rapid climate change in the past (Pitelka et al. 1997; Kullman 1998), but they must also accept the likelihood that restricting population spread to natural mechanisms may result in the extinction of species that might otherwise have survived.

Position 3: Constrained Assisted Migration

This position represents an attempt to balance the benefits and risks associated with assisted migration (Fig. 1). The hallmark of this position is the expectation that assisted migration is necessary to preserve biodiversity despite recognized risks. Risks can be minimized through careful restrictions on actions, planning, monitoring, and adaptive management. This position may range broadly between positions 1 and 2 (Fig. 1). Uncertainty as to the impacts of introducing species to novel environments and uncertainty in model predictions of the need to move organisms will demand constraints on assisted migration. Thus, proposals for assisted migration may require evidence of imminent threat, a quantitative model of predicted outcome of assisted migration, and an assisted migration management plan. Such a migration plan would be informed by scientific information on the topics described below, perhaps vetted by a board of experts charged with implementing the precautionary principle while allowing the establishment of pilot projects and easing policy restrictions when advances in research suggest it worthwhile.

There are obvious costs to constraining assisted migration projects. For example, assisted migration proposals would require substantial data and thus could only be implemented for a few species of highest concern. In addition, supportive evidence may be disputed, which could result in costly delays in assisted migration actions.

Reaching a Policy Decision

It is important for academics, advocates, and managers to discuss the role that assisted migration should play in the conservation of species. For example, a liberal policy of assisted migration, as described in position 1, may be irreversible, so we advocate a broad and open discussion before such actions are taken. Legitimate philosophical and scientific differences between positions may be difficult to reconcile. However, our shared concern about the biological consequences of climate change provides important common ground.

The only policy options we categorically reject are the two that are currently being implemented. Maverick, unsupervised translocation efforts run the risk of undermining current conservation work and do not reflect a consensus among interested parties. We more strongly reject the far more ubiquitous "business as usual" scenario that is the current de facto policy. Data and models suggest that extinctions are likely to be numerous and imminent given the range shifts and contractions currently underway. Even a policy rejecting assisted migration will have to offer alternative approaches to prevent species extinction.

A Research Agenda for Informing Assisted Migration Policy

Basic ecological research will play a role in resolving the issues raised by assisted migration. Here, we briefly outline five areas in which new information would help collapse the vertical axis in Fig. 1, resulting in better-informed policy: estimation and monitoring of species distributions, biogeographic modeling, community interactions, long-distance dispersal (LDD), and genetic diversity.

Estimation and Monitoring of Species Distributions

We lack basic information about the current distribution of most species even in some developed nations (NAS 1993). Previous efforts to inventory the distribution and abundance of species in the United States, such as the National Biological Survey (NAS) failed under political pressure. There are no current efforts to implement programs monitoring species response to global change at a national scale, although the proposed U.S. National Ecological Observation Network (NEON) might provide a framework to address this lack of basic distributional data (www.neoninc.org). In Europe successful long-term monitoring programs show that it is possible to monitor range shifts across a wide spectrum of species (Thomas et al 2004; Parmesan & Yohe 2003). These programs do not require advanced technology, but they do require commitment and political will.

Biogeographic Modeling

Several researchers have developed future scenarios for species distributions under climate change and believe that the models behave well for broadly distributed species (Iverson et al. 1999; Berry et al. 2002; Matthews et al. 2004). Others are working to improve modeling methods and assess the accuracy of biogeographic range modeling (Gelfand et al. 2005; Guisan & Thuiller 2005; Elith et al. 2006; Wright et al. 2006). Narrowly distributed and infrequent species may be particularly difficult to model accurately (Stockwell & Peterson 2002). Schwartz et al. (2006*b*), for example, showed that model fit for trees and birds declines with small range size, and climatic parameters become less important explanatory variables. The extinction risk of narrowly distributed species, although constrained by some climatic tolerance limits, might not generally be well predicted under the assumption that their current distribution is constrained climatically. Biogeographic habitat models that predict range shifts with warming (e.g., Thomas et al. 2004) must assume such a constraint, and would result in an overemphasis on species risk and movement potential.

Community Interactions

The expectation that species will shift their distributions under global warming assumes that climate is the primary constraint on habitat occupancy. This limiting role of climate has been documented in some systems (e.g., Root 2003) but is largely unknown in others. Other interactions, including competition, trophic associations, and mutualisms also can be important in determining the range limits of species (e.g., Case et al. 2005). In these taxa, range shifts may not take place unless obligatory food resources or mutualists occur in (or move to) the region of desired expansion. Thus, paired or multispecies assisted migration may be necessary to enable range shifts in some species. Examples include specialized herbivores that require a particular species or genus of food plant (e.g., Hellmann 2002) and tree species that require mychorrhizal innocula for germination and growth (e.g., Schwartz et al. 2006*a*).

To quantify the extent to which species interactions might limit the success of assisted migration, researchers could categorize the number of taxa with a range boundary that is shared with another, limiting species. For example, one could tally the proportion of herbivorous species that are range limited by host-plant availability. Research also is needed to determine when facultative interactions will limit the success of an introduced population and to reveal potential, novel interactions (e.g., predatory or competitive) that might limit the success of introduction. Such limiting interactions might be revealed in field trials. Studies of geographic variation in species interactions across ranges may suggest source populations for range expansion that are most likely to establish in a novel—or slightly different—community of interacting species.

Assisted species also will affect their introduced region through species interactions. These novel interactions might be revealed in field trials. Particular attention should be paid to potential trophic cascades or indirect effects that the introduced species might cause as well as time lags in the appearance of those effects.

Long-Distance Dispersal

Long-distance dispersal is one of the key processes in range dynamics, particularly in fragmented habitats that often are characteristic of the edge of a species' range. However, LDD is one of the most difficult aspects of population biology to characterize and small errors in the estimation of LDD could result in significant over or underestimation of natural changes in range (Clark et al. 2003; Trakhtenbrot et al. 2005). Improved LDD estimates are essential for two reasons. First, they are needed to predict which species do and which do not require an assisted migration intervention. Second, information on potential or historical LDD may be desirable even if a species is unlikely to disperse into areas made available by climate change. For example, consider a species capable of dispersal but facing an impermeable matrix on its poleward range edge. An assisted migration program for this species might attempt to simulate (as closely as possible) its "natural" potential for dispersal if such dispersal could occur.

Novel technology would help tremendously in the estimation of LDD. Small-sized and low-cost transmitters that could be placed on many individual organisms or seeds would help refine the dispersal curve, at least by increasing the number of recorded long-distance events for key species. Again, NEON could fund or inspire such technological development because it is targeted at emerging problems in global change ecology.

Genetic Diversity

Increasing evidence suggests that intraspecific genetic variation is frequently adaptive (Etterson 2004). This puts an additional onus on programs of assisted migration to choose source populations wisely. For instance, northern populations in many north temperate species may be preadapted for colonization ability because they contain the genotypes that were successful during population expansion after the last ice age (Cwynar & MacDonald 1987; Thomas et al. 2001; Hill et al. 2004). Such populations might contain the most suitable genotypes to introduce north of a species' current range limits. Furthermore, individuals from the periphery of the range would likely be the most common colonists under natural spread. On the other hand, one might wish to draw from populations near the equatorial periphery because genotypes in these populations may be most threatened by climate change (Hampe & Petit 2005).

The growth of phylogeographic research is making decisions about source populations for introduction easier by characterizing intraspecific genetic structure and providing insight into the historical processes that generated it. Nevertheless, understanding the adaptive significance of this structure for species faced with changing climates is impossible without large-scale common-garden and transplant experiments (Davis & Shaw 2001; Hellmann et al., unpublished data). These experiments are time consuming and expensive, but they will be critical for building an effective assisted-migration program.

Preparing for an Uncertain Future

Under a best-case scenario, scientific insight into these topics will sharpen our ability to identify appropriate targets for assisted migration and to implement introductions in a way that minimizes collateral ecological damage. Nevertheless, scientific breakthroughs alone will not make these policy decisions easy.

First, the idiosyncrasy of species biology precludes the development of well-supported assisted-migration plans for each of the many species likely to be threatened by changing climate. Consequently, managers will be forced to generalize expected range shifts based on broad classes of life-history characteristics. A similar approach has only had limited success in identifying likely invasive species (Williamson 1999; Kolar & Lodge 2001). We expect that future "assisted-migration biologists" will find themselves in a similar position to today's invasive species biologists: looking for useful generalizations in theory and struggling with unforeseen idiosyncrasies in practice.

More fundamentally, inherent stochasticity in processes such as LDD and species interactions means that collecting more ecological information will not necessarily improve our ability to make predictions (Clark et al. 2003). Scientists typically like to provide information that resolves questions. Forecasting the risks and benefits of assisted migration will instead require scientists to specify uncertainty about unresolved questions (Clark et al. 2001). If this uncertainty is large, policies will have to incorporate adaptive flexibility.

Conclusion

Regardless of forthcoming scientific progress, the magnitude of impending climate-driven extinctions requires immediate action. Delays in policy formulation and implementation will make the situation even more urgent. We advocate developing management strategies with the flexibility to respond to emerging insights from basic and applied research, but we cannot wait for better data. To an uncomfortable extent this war will have to be fought with "the army we have, not the army we want."

The current literature shows that data collected for other purposes often provide useful guidance for thinking about assisted migration. Nevertheless, research specifically focused on assisted migration will be needed before science can answer questions fundamental to informed policies of assisted migration: Is there a demographic threshold that should trigger the implementation of assisted migration? What suite of species should be prioritized as candidates for translocation? How should populations be introduced to minimize adverse ecological effects?

Questions such as these should be formulated and addressed by a broad group of scientists, managers, and policy makers. A consensus that identifies the risks and opportunities of alternative approaches to assisted migration and suggests ecologically sound best-management strategies would be a significant step toward developing a coherent policy on this issue. The alternative strategy of waiting to see what happens is an abdication of our values and responsibilities.

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Literature Cited

Barlow, C., and P. S. Martin. 2004. Bring *Torreya taxifolia* north—now. Wild Earth Winter/Spring: 52–56.

Berry, P. M., T. P. Dawson, P. A. Harrison, and R. G. Pearson. 2002. Modelling potential impacts of climate change on the bioclimatic envelope of species in Britain and Ireland. Global Ecology and Biogeography **11:**453–462.

Case, T. J., R. D. Holt, M. A. McPeek, and T. H. Keitt. 2005. The community context of species' borders: ecological and evolutionary perspectives. Oikos **108:**28–46.

Clark, J. S., et al. 2001. Ecological forecasts: an emerging imperative. Science **293:**657–660.

Clark, J. S., M. Lewis, J. S. McLachlan, and J. HilleRisLambers. 2003. Estimating population spread: what can we forecast and how well? Ecology **84:**1979–1988.

Cwynar, L. C., and G. M. Macdonald. 1987. Geographical variation of lodgepole pine in relation to population history. The American Naturalist **129:**463–469.

Czech, B., and P. R. Krausman 2001. The endangered species act: history, conservation biology, and public policy. Johns Hopkins University Press, Baltimore, Maryland.

Davis, M. B., and R. G. Shaw. 2001. Range shifts and adaptive responses to Quaternary climate change. Science **292:**673–679.

ELI (Environmental Law Institute). 2002. Halting the invasion: state tools for invasive species management. ELI, Washington, D.C.

Elith, J., et al. 2006. Novel methods improve prediction of species' distributions from occurrence data. Ecography **29:**129–151.

Etterson, J. R. 2004. Evolutionary potential of *Chamaecrista fasciculata* in relation to climate change. II. Genetic architecture of three populations reciprocally planted along an environmental gradient in the great plains. Evolution **58:**1459–1471.

Gelfand, A. E., A. M. Schmidt, S. Wu, J. A. Silander, A. Latimer, and A. G. Rebelo. 2005. Modelling species diversity through species level hierarchical modelling. Journal of the Royal Statistical Society Series C- Applied Statistics. **54:**1–20.

Grumbine, R. E. 1994. What is ecosystem management? Conservation Biology **8:**27–38.

Guisan, A., and W. Thuiller. 2005. Predicting species distribution: offering more than simple habitat models. Ecology Letters **8:**993–1009.

Hampe, A. and R. J. Petit. 2005. Conserving biodiversity under climate change: the rear edge matters. Ecology Letters **8:**461–467.

Hannah, L., G. F. Midgley, T. Lovejoy, W. J. Bond, M. Bush, J. C. Lovett, D. Scott, and F. I. Woodward. 2002. Conservation of biodiversity in a changing climate. Conservation Biology **16:**264–268.

Hannah, L., G. Midgley, G. Hughes, and B. Bomhard. 2005. The view from the cape. Extinction risk, protected areas, and climate change. Bioscience **55:**231–242.

Hellmann, J. J. 2002. The effect of an environmental change on mobile butterfly larvae and the nutritional quality of their hosts. Journal of Animal Ecology **70**: 925–936.

Iverson, L. R., A. M. Prasad, B. J. Hale, and E. K. Sutherland. 1999. Atlas of current and potential future distributions of common trees of the eastern United States. U.S. Department of Agriculture, Forest Service, Radnor, Pennsylvania.

Kolar, C. S., and D. M. Lodge. 2001. Progress in invasion biology: predicting invaders. Trends in Ecology & Evolution **16:**199–204.

Kullman, L. 1998. Non-analogous tree flora in the Scandes Mountains, Sweden, during the early Holocene—macrofossil evidence of rapid geographic spread and response to palaeoclimate. Boreas **27:**153–161.

McCarthy, J. J., O. F. Canziani, N. A. Leary, D. J. Dokken, and K. S. White, editors. 2001. Climate change 2001: impacts, adaptation and vulnerability. Intergovernmental panel on climate change, working group II. Cambridge University Press, Cambridge, United Kingdom.

McLaughlin, J. F., J. J. Hellmann, C. L. Boggs, and P. R. Ehrlich. 2002. Climate change hastens population extinctions. Proceedings of the National Academy of Sciences of the United States of America **99:**6070–6074.

Martin, P. S. 2005. Twilight of the mammoths: ice age extinctions and the rewilding of America. University of California Press, Berkeley, California.

Matthews, S. N., R. J. O'Connor, L. R. Iverson, and A. M. Prasad. 2004 Atlas of climate change effects in 150 bird species of the eastern United States. Northeastern Research Station, U.S. Department of Agriculture Forest Service, Radnor, Pennsylvania.

NAS (National Academy of Sciences). 1993. A biological survey for the nation. National Academy Press, Washington, D.C.

Parmesan, C., and G. Yohe. 2003. A globally coherent fingerprint of climate change impacts across natural systems. Nature **421:**37–42.

Peterson, A. T., V. Sanchez-Cordero, E. Martinez-Meyer, and A. G. Navarro-Siguenza. 2006. Tracking population extirpations via melding ecological niche modeling with land-cover information. Ecological Modelling **195:**229–236.

Pitelka, L. F., et al. 1997. Plant migration and climate change. American Scientist **85:**464–473.

Root, T. L., J. T. Price, K. R. Hall, S. H. Schneider, C. Rosenzweig, and J. A. Pounds. 2003. Fingerprints of global warming on wild animals and plants. Nature **421:**57–60.

Schwartz, M. W., J. D. Hoeksema, C. A. Gehring, N. C. Johnson, J. N. Klironomos, L. K. Abbott, and A. Pringle. 2006*a*. The promise and the potential consequences of the global transport of mycorrhizal fungal inoculum. Ecology Letters **9:**501–515.

Schwartz, M. W., L. R. Iverson, A. M. Prasad, S. N. Matthews, and R. J. O'Connor. 2006*b*. Predicting extinctions as a result of climate change. Ecology **87:**1611–1615.

Schwartz, M. W., N. L. Jurjavcic, and J. M. O'Brien. 2002. Conservation's disenfranchised urban poor. BioScience **52:**601–606.

Thomas, C. D., et al. 2004. Extinction risk from climate change. Nature **427:**145–148.

Trakhtenbrot, A., R. Nathan, G. Perry, and D. M. Richardson. 2005. The importance of long-distance dispersal in biodiversity conservation. Diversity and Distributions **11:**173–181.

Williamson, M. 1999. Invasions. Ecography **22**: 5–12.

Wright, J. W., K. F. Davies, J. A. Lau, A. C. McCall, and J. K. McKay. 2006. Experimental verification of ecological niche modeling in a heterogeneous environment. Ecology **87**: 2433–2439.