AN OVERVIEW OF SOME CONCEPTS, POTENTIALS, ISSUES, AND REALITIES OF ASSISTED MIGRATION FOR CLIMATE CHANGE ADAPTATION IN FORESTS

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INTRODUCTION

The climate has always been changing, but the rapid rate of climate change, as projected by the IPCC (2007) will likely place unique stresses on plant communities. In addition, anthropogenic barriers (e.g., fragmented land use) present a significant modern constraint that will limit the ability of species migration in responses to a changing climate. As such, managers are faced with four options that lay along a continuum when managing species in the face of climate change: (1) They can do nothing, and therefore allow existing landscapes to change without active intervention, accepting unknown or risky outcomes; (2) They can rely on passive resource management strategies to allow accommodation, such as linking existing preserves with corridors; (3) They can actively manage landscapes to preserve them as they are, thus create refuges. Such habitat management would include actions like preventing invasions, installing irrigation, and regulating biotic interactions; or (4) They can actively manage landscapes to convert them into something deemed more compatible with projected climatic conditions. This last example of management would include assisted migration. The specific risks and benefits of each of these actions will depend upon the magnitude of climate pressure, the context of the ecosystem and its landscape, and the goals of human decisions.

This paper describes some options on how to decide among the above choices, introduces assisted migration, and describes the possible ramifications associated with it. We then present one research approach to assist in locating and evaluating potential applications of assisted migration.

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DEFINITIONS

Assisted migration has been used synonymously in the literature with several terms, with slightly nuanced differences. We present here the definitions as published by a consortium of investigators on the topic (Schwartz et al. 2012):

- Translocation: Any intentional movement of a species from one location to another. (e.g., reintroducing wolves to Yellowstone National Park).
- Assisted Migration (AM): Introducing a species into a new location by bringing propagules or individuals and releasing them. (e.g., the movement of the tree *Torreya taxifolia* to North Carolina from its native range in Florida).
- Assisted Colonization: Assisted migration where the introduction is managed to ensure successful establishment. (e.g., translocated *Torreya* populations are carefully monitored and managed).
- Managed Relocation: The intentional act of moving species, populations, or genotypes to a location outside a target's known historical distribution for the purpose of maintaining biological diversity or ecosystem functioning as an adaptation strategy for climate change (e.g., introducing a butterfly into new habitat when current locations are likely to become unsuitable with climate change).

We also acknowledge two more terms, introduced by Pedlar et al. (2012) and revisited in the Johnson et al. paper of this volume, which add clarity to the discussion by making an important distinction:

a. Species Rescue Assisted Migration: a means to rescue species threatened by climate change.
b. Forestry Assisted Migration: aims to ensure that forests (often plantations) of widespread (often commercially valuable) tree species are established using seed sources that will be climatically adapted for the duration of the rotation. To be consistent with Johnson et al. (this volume), we will broaden this term to include using assisted migration to maintain ecosystem services, hereafter termed "Ecosystem Services AM".

THE DEBATE

The use of assisted migration has elicited controversy within conservation circles because balancing extinction risk against the potential negative impacts of managed relocation requires choosing between comparably unfortunate risks (Hoegh-Guldberg et al. 2008; Richardson et al. 2009; Schwartz et al. 2012). Opponents are concerned mostly because the placement of species outside their range may disturb native species and ecosystems when these ‘‘climate refugees’’ establish themselves in new environments; they cite many cases where intentional relocations resulted in a myriad of environmental issues (Davidson and Simkanin 2008; Ricciardi and Simberloff 2009; Seddon et al. 2009), like runaway invasions, that surface only after it is too late to turn back. Proponents point out that assisted migration is a key option to be available in the face of unprecedented global change (Sax et al. 2009; Schwartz et al. 2009; Minteer and Collins 2010; Vitt et al. 2010). Concerns about species extinction, population extirpation, the loss of genetic diversity, and the maintenance of particular ecosystem services are paramount. For some species, conventional conservation strategies will not provide sufficient protection from future environmental change, and pressure to actively do something is likely to increase as the consequences of climate change become more apparent. Several groups have put together frameworks to evaluate risks and benefits related to assisted migration such that decision makers have solid approaches to use (Hoegh-Guldberg et al. 2008; Richardson et al. 2009; Seddon 2010; Lawler and Olden 2011; Schwartz et al. 2012).

The issue also provokes a number of legal issues that result from these unprecedented times of climate change. Camacho (2010) identified several key points that will be germane to the forest debate including a lack of clear jurisdiction precedence without regulatory mandates, especially for non-governmental assisted migration initiatives (e.g., in the Torreya example, a small group of individuals [the Torreya Guardians] moved the species). Another key topic raised by Camacho (2010) is the new paradigm that climate change brings to bear that natural systems can be dynamic (with climate change accelerating this notion) and traditional natural resource management must have the legal flexibility to respond. We must also recognize that contemporary natural resource law’s fidelity to historic baselines, protecting preexisting biota, and shielding nature from human activity is increasingly untenable, particularly in light of climate change. More broadly, assisted migration illustrates how the natural resource organizations, laws and policies must be changed to better reflect a dynamic, globalized world with potential for major disruptions.

Finally, the choices we make come down to ethics. Do we prioritize to protect endangered species likely to lose habitat under climate change or do we focus on conserving native biota in situ? Do we manage ecological systems actively or leave nature wild and uncontrolled? Do we manage resources to promote their fitness under future conditions or work to preserve resources, as they exist today?

VALUE OF DISTINGUISHING ECOSYSTEM SERVICE AM FROM SPECIES RESCUE AM

One way to parse the debate is to subdivide assisted migration into Species Rescue AM and Ecosystem Services AM. As the names imply, the former is moving species to rescue them from extinction in the face of climate change, and this is the source of most of the uncertainty and controversy. The latter refers more to a traditional forestry approach aimed at maintaining high levels of productivity and diversity in widespread, commercially, socially, culturally, or ecologically valuable tree species (Gray et al. 2011; Kreyling et al. 2011). With Ecosystem Services AM, maintaining forest productivity and ecosystem services are the most obvious desired outcomes.

Given the broad distribution of most tree species, and the relatively short distances proposed for tree seed migration, Ecosystem Services AM typically involves transfers within or just beyond current range limits to locations where a population’s bioclimatic envelope is expected to reside within the lifetime of the planted population (Gray et al. 2011). Additionally, the introduction of genotypes to climatically appropriate locations may also contribute to overall forest health by establishing vigorous plantations across the landscape that are less susceptible to forest pests and diseases (Wu et al. 2005). If realized, such an outcome would help ensure the continued flow of ecosystem services provided by forests, such as wildlife habitat, erosion prevention, carbon uptake, and many others (Kreyling et al. 2011). Thus, this form of assisted migration is much less controversial than the 'rescue' approach for species of special conservation concern. It is thus a viable tool at this time for adaptation to climate change in the forestry arena.

Pedlar et al. (2012) make the distinction between forms of AM based on intended outcomes, target species, movement logistics, potential risks, science-based feasibility, scope, cost, and practice. Ecosystem Services AM thus has several traits enabling the justification for AM, provided certain precautions are undertaken. When the discussion concerns trees, especially trees that are not necessarily rare or endangered, as is *Torreya taxifolia* (Schwartz 2005), it is often the case that planting trees in places where they previously did not occur has been done for centuries. The authors believe that, if practiced cautiously, and with the focus on moving species within or slightly beyond their current broadly-defined range margins to encourage 'filling in' of rarer occurrences, Ecosystem Services AM does hold promise as a relatively low risk climate change adaptation tool.

HOW MIGHT WE DECIDE WHETHER TO IMPLEMENT ASSISTED MIGRATION?

Land managers, through public participation, already are deciding among the four choices presented in the introductory paragraph. Such decisions will likely become more frequent and more involved as the rate of climate changes increases. Thus it is important to establish a set of approaches to choose from, and to include the choice of implementing assisted migration in some cases. Key to any approach is the following three elements:

1. Model potential outcomes in advance. We present an example below.

2. Evaluate the ecological impacts on both the target species and the recipient ecosystem, as well as the economic and social values influenced by management actions. This is accomplished through expert panels, modeling, experiments, and common sense evaluation.

3. Use a decision framework so that AM is only used with eyes wide open and often the last resort.

The authors endorse the decision framework presented by the Managed Relocation Working Group and published in Schwartz et al. (2012) and reiterated here without modification. They propose a set of key questions among four general themes that are central to creating a cohesive, broad-based general framework for decision making relative to proposed assisted migration actions. People are to answer each question as best possible and then weight them to arrive at a decision. Note that the economic and political considerations may override or modify many of the ethical and ecological questions in some situations.

Ethical Questions

1. What are the goals of conservation, and why do we value those goals?
2. Which conservation goals take ethical precedence over others and why?
3. What is the ethical responsibility of humans to protect biodiversity (genotypic, population, species, ecosystem)?
4. Is there an ethical responsibility to refrain from activities that may cause irreversible impacts, even if restraint increases the risk of negative outcomes?
5. How does society make decisions in consideration of divergent ethical perspectives?

Legal and Policy Questions

6. Do existing laws and policies enable appropriate managed relocation actions?
7. Do existing laws and policies inhibit inappropriate managed relocation actions?
8. Do the existing implementation policies of environmental laws provide the guidance for resource managers to fulfill their obligations for climate change adaptation?
9. What is the process for managers, stakeholders, and scientists to work collaboratively to make managed relocation decisions?
10. Who pays for managed relocation, including the studies needed to support an action, monitoring, and the outcomes of the management action?

Ecological Questions

11. To what extent do local adaptation, altered biotic interactions, no-analog climate space, and the persistence of suitable microhabitats within largely unsuitable landscapes mitigates the extinction risk (and managed relocation need) of species listed as vulnerable?
12. What evidence suggests that species are absent from climatically suitable locations because of dispersal limitations that could be addressed by managed relocation?
13. What are the limits of less dramatic alternatives to managed relocation, such as increasing habitat connectivity?
14. How well can we predict when management must address interacting suites of species rather than single species?
15. How well can we predict when relocated species will negatively affect host system species or ecosystem functioning (e.g., nutrient flux through food webs, or movement of individuals)?
16. How well can we predict the likelihood of a species' successful long-term establishment in light of a changing climate?

Integrated Questions

17. What are the priority taxa, ecosystem functions, and human benefits for which we would consider invoking managed relocation?
18. What evidence of threat (extinction risk, loss of function, loss of benefit to people) triggers the decision process?
19. What is adequate evidence that alternatives to managed relocation are unavailable and that the probability that managed relocation will succeed is adequate?
20. What constitutes an acceptable risk of harm and what are adequate assurances for the protection of recipient ecosystems?
21. Who is empowered to conduct managed relocation, and what is their responsibility in the event that the consequences are not those predicted?

AN EXAMPLE OF ASSISTING TREE SPECIES MIGRATION FOR FOREST ADAPTATION

Northern Wisconsin has served as a pilot landscape for a substantial amount of research on climate change and forest ecosystems as part of the Climate Change Response Framework (www.climateframework.org). Northern Wisconsin forests have been the focus of a comprehensive climate change vulnerability assessment (Swanston et al. 2011), a large integrated effort to foster scientists - manager interaction (Brandt et al. 2012), and the development of an adaptation framework (Swanston and Janowiak 2012), all of which are intended to assist the region with forest management under climate change. The threats and vulnerabilities for many species and forest types have been changing in this area; many of these changes are directly or indirectly tied to the changes underway with climate, which is projected to change even more. For example by 2100, May–September (growing season) temperatures in this region are projected to increase substantially, leading to a wide-ranging set of impacts on forest ecosystems (Swanston et al. 2011). From this base of previous work in northern Wisconsin, we here initiate an effort to assess the feasibility and prioritization of assisted migration within this broader context.

We have evaluated 134 tree species for their current and future importance in the eastern United States, using our DISTRIB (Tree Atlas) modeling approach (Iverson et al. 2008; Prasad et al. 2009; Iverson et al. 2012). Briefly, in this approach, we model suitable habitat, as defined by those climatic, edaphic, and physiognomic conditions suitable for a particular species to occur. Using Random Forest modeling, 38 predictors (including 7 climate, 5 elevation, 9 soil class, 12 soil property, and 5 land use and fragmentation variables) are statistically correlated to species abundance derived from inventory data. The metric used for quantifying suitable habitat is summed importance values (IV) for any particular region of the eastern U.S. Thus, the area and the abundance of the species are accounted for, both now and potentially in the future. Our online website, www.nrs.fs.fed.us/atlas, provides a plethora of data for each of the 134 tree species as well as 147 bird species in the eastern U.S.

As part of the vulnerability assessment in northern Wisconsin (Swanston et al. 2011), 73 species were evaluated as being present currently or having suitable habitat in the future. The current range of one species, black oak (*Quercus velutina*), lies almost entirely to the south of this area, such that the species is almost exclusively located along the southern edge of vulnerability assessment region of northern Wisconsin.

As such, it is our candidate species to assess the feasibility for this species to move into the region, and we ask these two questions:

1. How might black oak move through a fragmented forest in northern Wisconsin under projected climate change?
2. How might this movement be augmented via assisted migration?

The migration potential for any species is related to both its source strength and sink strength. By source strength, we mean the propagule pressure - how many 'darts' can be sent out in front of the current boundary? This is related to the abundance of the species near its range boundary, and the distance the species must move to its new colonization site. Sink strength, on the other hand, is related to how receptive the new sites will be to the 'darts'. This is related to the future suitable habitat, as determined by amount of climate change, edaphic conditions, and fragmentation status. As we define it, a suitable sink must also be currently forested, so that a future suitable location for a colonizing tree must now have trees. As we model how black oak might move through the fragmented landscape in Wisconsin, the following steps are necessary.

1. Model Potential Changes in Suitable Habitat for Black Oak Under Two Scenarios of Climate Change

This initial modeling step provides the sink strength for the model. In the future, will the habitat be suitable for black oak? We assessed future habitat using the DISTRIB model for two scenarios of future climate – the Parallel Climate Model, B1 scenario (PCMlo - mild scenario (Washington et al. 2000)) and the Hadley CM3 model, A1fi scenario (Hadhi - harsh scenario (Pope 2000)). PCMlo is a mild warming scenario, while the Hadley A1fi is a much warmer scenario for Wisconsin. By assessing the range we can capture the bounds of modeled projected change; however, our planet is currently tracking and even possibly exceeding the warmest scenario (Canadell et al. 2007). The results show a substantial northward movement of suitable habitat into northern Wisconsin, especially under the Hadley scenario (Figure 1.) For the Hadley case, there appears to be little ecological restriction for black oak suitable habitat in northern Wisconsin, but can it get there? To help answer this question, we need the additional steps (below) to prepare data and then use another model, SHIFT, which models migration potential over 100 years.

2. Create Defensible Range Boundary

Since the early 1970s, the standard bearer of range boundaries for tree species were the maps developed by E.L. Little (1971,1977), which are available online (through our group and the USGS) and are remarkable for their ability to portray the overall range extent for so many tree species across North America. However, in the 40+ years since Little was collecting data for these maps, there have been more sources of geographic distribution (most notably the impact of the US Forest Service Forest Inventory and Analysis (FIA) sampling (Miles et al. 2001), plus there may have been some actual distributional changes. The Little maps also tend to identify the absolute boundaries of the species (see boundary vs. abundance on Figure 1), whereas in some cases, we prefer a 'core boundary' to migrate from. Thus, we used a number of GIS tools in conjunction with FIA data and DISTRIB model outputs for current distribution to generate a 'Generalized Species Boundary' (Figure 2).

3. Map the Fragmented Forest

For modeling migration, we also needed a method to map the fragmented nature of the forest into which black oak must migrate. For this, we used the 2006 National Land Cover Data (Xian et al. 2009) and extracted the forest classes to create a forest-nonforest map at a resolution of 30 m. The 30-m cells were aggregated to 1 km, and if at least 10 percent of the cells were forest, the 1-km cell was deemed 'forested' for being able to accept propagules during migration. We then used the software 'GUIDOS' to determine 'core' from 'edge' forest (Vogt et al. 2007). This process produced a map showing the fragmented nature of the forests of the Wisconsin region (Figure 3).

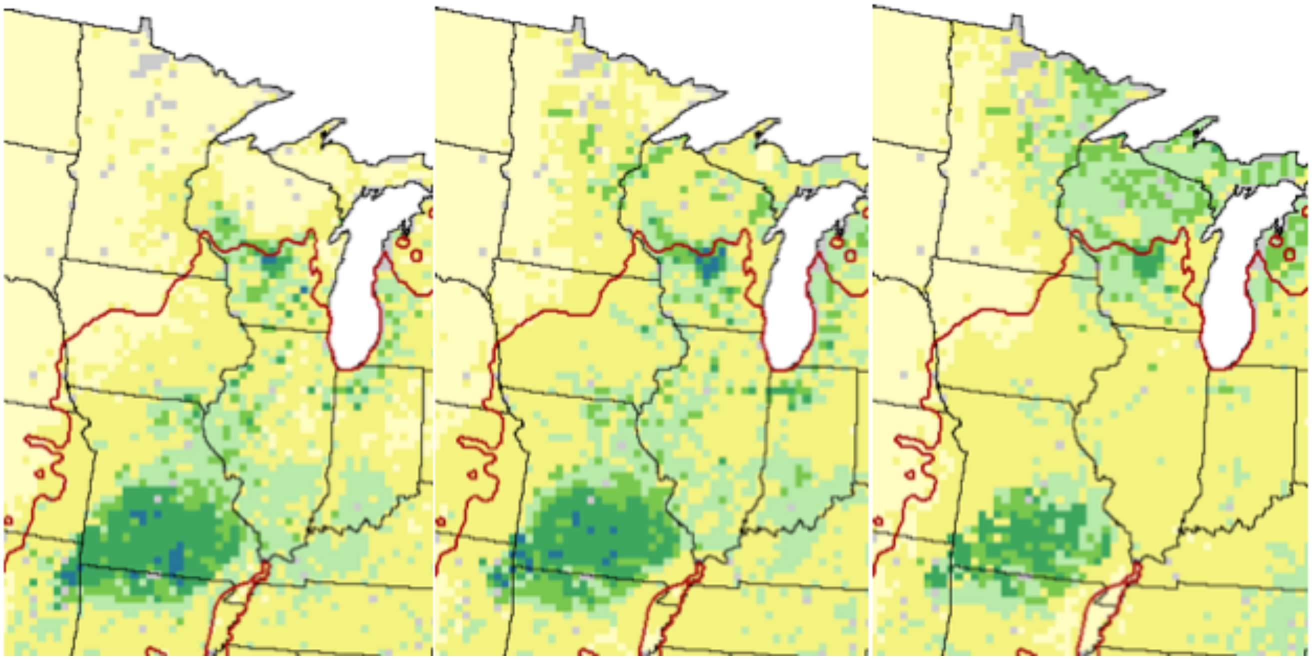
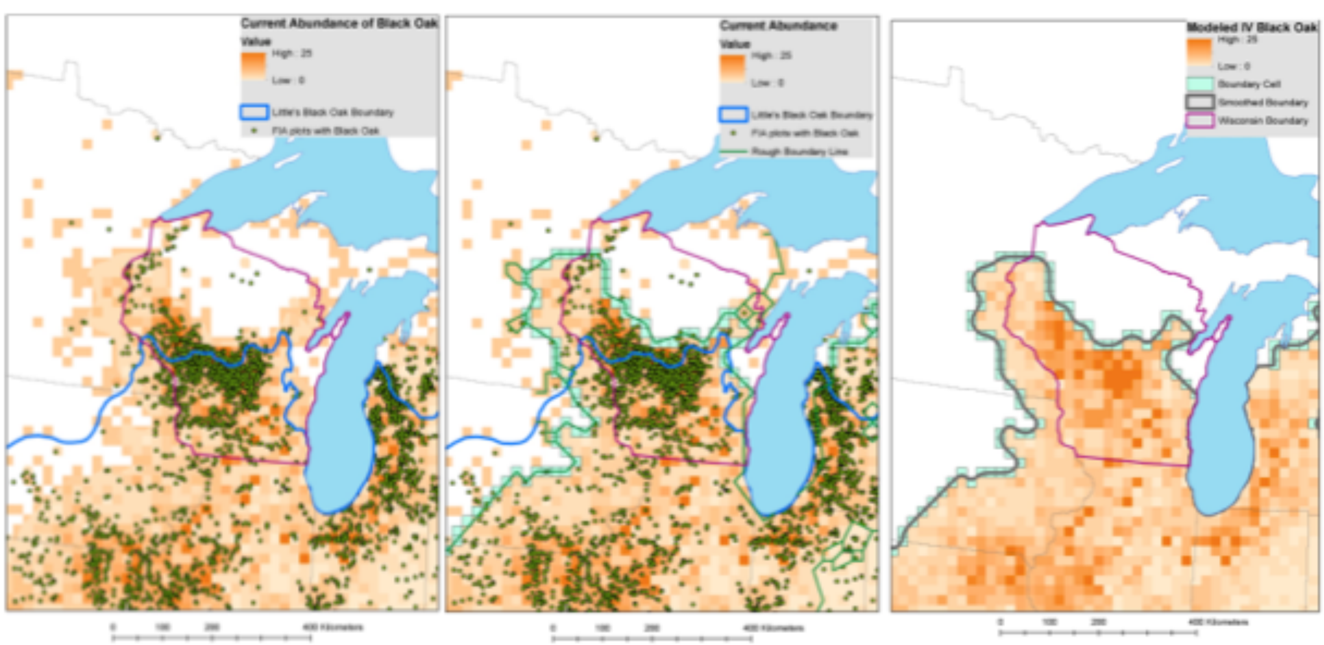


Figure 1. Current modeled importance of black oak (left) and projected change in suitable habitat under two scenarios of climate change: PCMlo (mild scenario; center) and Hadhi (harsh scenario; right). The brown line indicates the species range boundary for black oak according to Little (1971).



(A) (B) (C)

Figure 2. The basis and method to create a Generalized Core Boundary for black oak. **A)** Little's boundary does not adequately capture the current distribution of black oak as the current FIA plots show presence north of Little's boundary (blue line); **B)** an algorithm by S. Matthews identifies 'edge' pixels (in light blue) and rough boundary line (in green) based on the modeled current distribution, upon which some manual adjustments are made if needed to generalize the boundary further; **C)** the trimmed and smoothed boundary then is created to use in the SHIFT modeling.

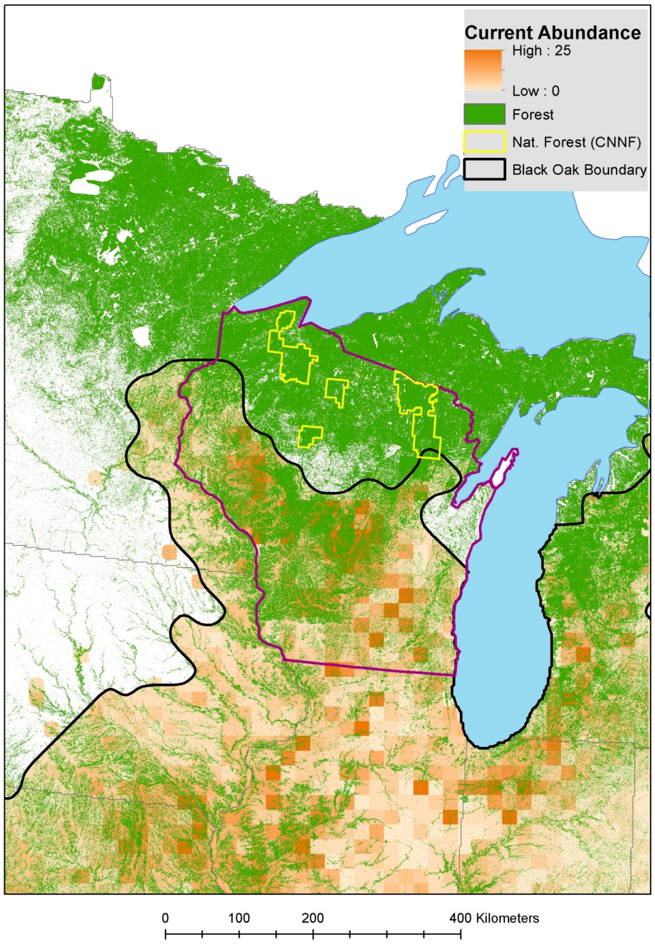


Figure 3. The Generalized Species Boundary line for black oak, with estimates of black oak abundance inside the boundary (current species range) and forest cover inside and outside the boundary. Yellow lines show the boundaries of the Chequamegon-Nicolet National Forest.

4. Model 100-Year Migration

Next was to run the SHIFT model, which uses simulation to estimate future colonization potential for black oak beyond the current range boundary over a 100-year period. The model is explained in previous publications (Iverson et al. 2004a, Iverson et al. 2004b) and fully developed in Prasad et al. (2013), but suffice it to say that it uses the source strength (black oak's abundance and distance from boundary edge) with sink strength (percent forest in the 1-km cell) to migration propagules. The rate of migration was calibrated to approximate 50 km/century, which is on the high end of migration rates estimated via paleoecologic data from the Holocene (Davis 1981). The output is the probability of a 1-km cell getting colonized in 100 years, over 2-4 generations depending on the species. To constrain the SHIFT migration output with future suitable habitat as derived in step 1, the two model outputs were then combined to produce maps of probability of colonization where habitat will be suitable in 100 years under the 2 scenarios of climate change (Figure 4). This provides an estimate of potential migration success without human mediated assisted migration. To see the potential for that, we need to select appropriate locations for assisted migration to occur and rerun the SHIFT model.

5. Select and Add Locations for Assisted Migration

Selecting suitable locations for assisted migration is nontrivial, because one needs to prioritize and optimize over a number of criteria. For this example, we visually (via GIS) selected nine locations to assist (shown as red dots on Figure 5), based on:

1. Suitable habitat in future. The selected locations must contain suitable habitat in the future, preferably under both scenarios of climate change. This information is available from DISTRIB output (Figure 1).

2. Generally larger patches of forest. The larger patches of forest could be expected to more readily create a viable reservoir from the plantings, and thereby generate future expansion out from the assist. This information comes from the forest habitat map (Figure 3).

3. Promoting growth on/near the National Forest lands. Since the Chequamegon-Nicolet National Forest occupies some of the key forestland north of the current boundary of black oak (boundaries visible on Figure 3), and has substantial suitable habitat in the future, we modeled the creation of 'stepping stones' towards and within the National Forest boundaries as one example of targeted translocation efforts.

The selection of locations could be aided to a large degree by further GIS analysis, and that is our intention in later efforts. Fore example, the GUIDOS software (Vogt 2007) and others can help derive patches that are best connected to each other. GIS will be used to quanitify the before and after assisted migration results. We present here only the visual results for example.

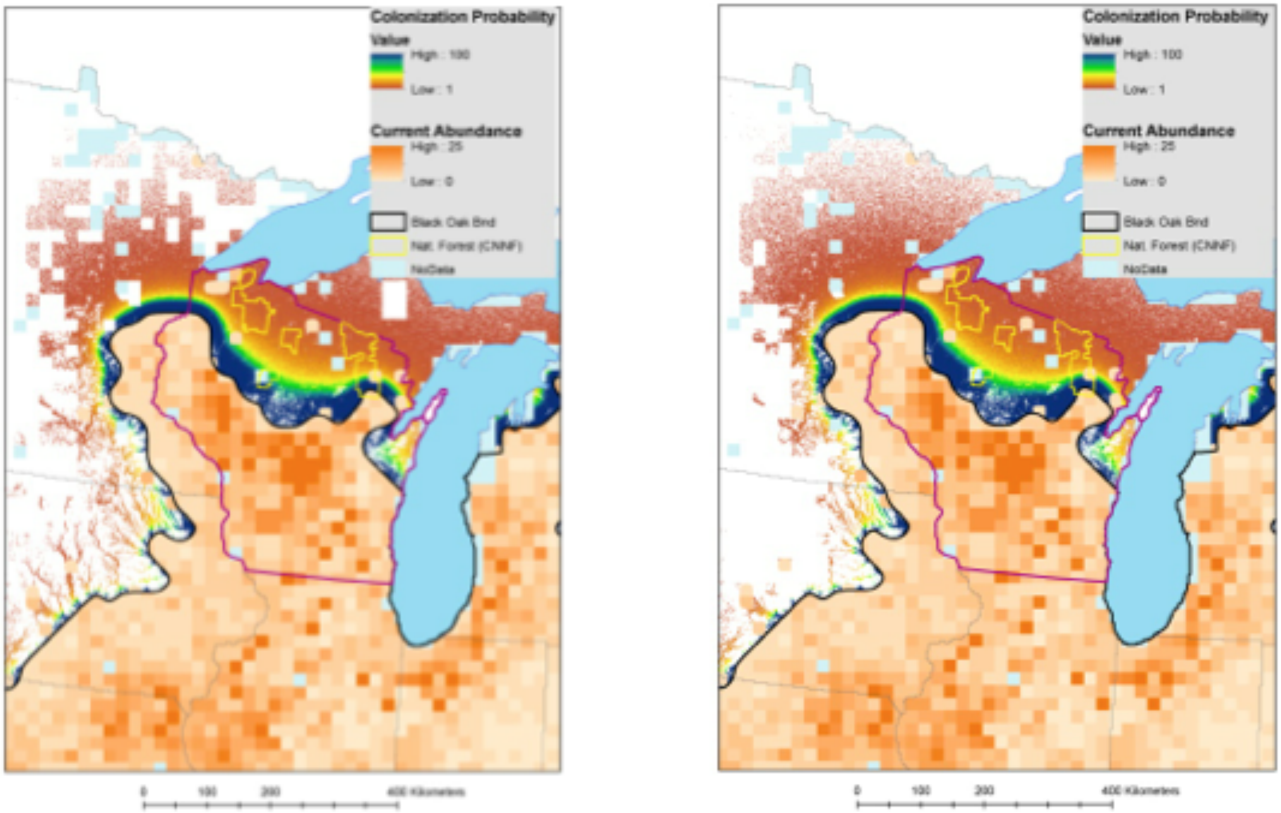


Figure 4. Probability of colonization over 100 years (at a rate of ~50 km/century) as overlaid on suitable habitat for 2100 with PCMlo (mild scenario; left) and Hadhi (harsh scenario; right). Also shown is modeled current abundance inside the black oak generalized boundary, with some peach-colored cells outside the current boundary being outlier cells with black oak currently present according to inventory data. If white, PCM or HAD do not project suitable habitat for black oak in 2100; no data cells refer to insufficient data for DISTRIB modeling.

6. Rerun SHIFT to Evaluate Potential Future Expansion After Assisting Migration

Following placement of the nine cells to accommodate the assisted migration, which assumes a low level of planting was accomplished throughout the 1-km cell, SHIFT was rerun with future habitat importance from DISTRIB providing the initial abundance, and to simulate 100 years of migration from the range boundary (which included some outliers present in the Little maps), and the new locations where assisted migration occurred (Figure 5). This map, when compared with the original SHIFT output, shows the distinct migration out from the outlying cells (where black oak was already present according to forest inventory data) but also a general rise in probability away from the current boundary because of the extra 'darts' generated by the outlying locations. Presumably, over time the outlying locations would amalgamate into regions of black oak presence.

In sum, the black oak presented is one example which provides an explorative, modeling framework for assessing and demonstrating the overall complexity of assisted migration approaches. Further research is needed to refine these methods and make them accessible to managers looking to plan or evaluate the potential to use assisted migration. Of course, additional research is also needed to better understand the genetics of any species under study for an assisted migration program, and the role of potential pests and pathogens in such a venture.

CONCLUSIONS

1. Considering Assisted Migration as a management option has merits, potential, and perhaps necessity, but care is advised!
2. Ecosystem Services (Forestry) AM has been underway for centuries, and carries fewer risks than Species Rescue AM; this distinction is useful.
3. Modeling experiments can aid in understanding how AM may work in the landscape.

4. However, a major research challenge remains to create distribution models that are relevant to, and sufficiently informative and scaled for, management decisions regarding translocations.

5. Included in this challenge is to better understand the role of pests and pathogens in the bigger AM picture, and thus it is vitally important for the forest disease and insect pest community to be engaged!

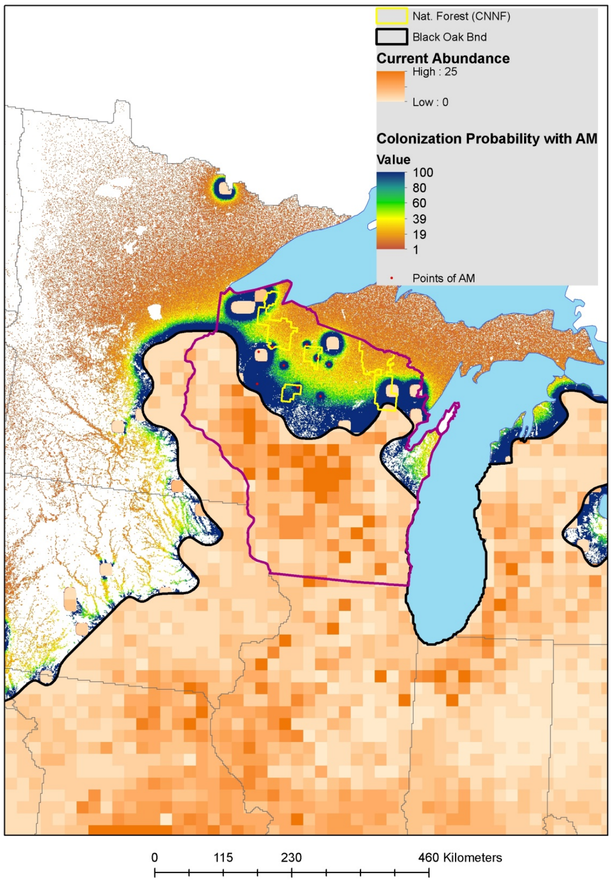


Figure 5. Probability of black oak colonization in 2100 following assisted migration of nine locations. Also included is the migration around current outliers.

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