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ABSTRACT

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This paper analyzes a novel conservation strategy: assisted migration (AM). AM is the practice of moving a highly vulnerable (i.e., endangered) species impacted by climate change and other exacerbating factors (e.g., land use), out of its historic range to a recipient site. Ideally, this site would be one where the species would have migrated, were there no barriers to dispersal or anthropogenic stressors. The paper is concerned with the readiness of the conservation community—particularly land managers—to implement a decision-making framework for AM. As such, the author reviews existing frameworks, both conceptual and statistical, and presents a step-by-step qualitative framework of her own that encompasses the ecological, legal, social and ethical dimensions of the AM strategy. The framework acknowledges that AM will likely occur in concert with other interventions of varying intensity (e.g., maintenance of habitat quality, restoration, and genetic rescue). The author acknowledges the limits of species distribution models (SDMs), a key tool to assess species vulnerability, which is the prerequisite of candidacy for AM. The author concludes that ecological theory—particularly concepts such as ‘adaptive capacity’ and the ‘evolutionary niche’—must better inform the design of models. An overview of modelling pitfalls, including the coarseness of climate data, data surveyed at differing resolutions or scales, gaps in data, the robustness of varying weighting and sampling techniques, and the need for development of community assemblage forecasts reveals the amount of work to be done, in terms of making confident assessments at finer scales into the future for this conservation strategy, which will likely be more prevalent with time. Finally, the author uses the holistic decision-making framework to assess two vulnerable species: the American pika and the whitebark pine. These case studies provide insights into the orientations of research and management communities to AM currently, and reveals the interplay of values that influence how we prioritize the survival of species, which can often be surrogates for the protection of a host of other species and environments.

Developing a Decision-Making Framework for Assisted Migration: Applying this to the American Pika and Whitebark Pine

The debate on Assisted Migration (AM) has grown since 2007, and has led to numerous papers on the ethical and scientific dimensions of the conservation strategy, as well as studies of legal ramifications, ecological case studies, and public interface. Now that much deliberation on the ethical and scientific merits has come to the fore, there have been calls on the one hand to act, and on the other to conduct careful experiments in anticipation of AM projects.

AM, also known as assisted colonization, managed relocation, or species translocation is the strategy of manually moving species of concern or endangered species whose ecosystems are impacted by climate change, so that they can no longer thrive in their native habitat--and to move these species to a new location. The practice has been criticized for its potential hubris, the potential to spread invasive weeds and pathogens, the potential for domination over the new ecosystem or invasion, and/or failure to establish, which would entail fruitless economic costs. Advocates argue that without AM, species will indeed go extinct and that AM, with careful planning and monitoring, is the best option, as novel ecosystems emerge that are inhospitable to certain species and as the climate indeed continues to warm, quite possibly by 6.4°C by the year 2100; studies employing comprehensive lists of feedback factors predict temperature increases of up to 8°C (Park and Talbot 2012). Even so, some scientists, land managers, and biologists take a tempered approach in recommending AM as a last resort strategy, and one that must be developed in tandem with mitigation.

To be sure, there must be a public and democratic process of governance connected with management that deals with the cultural, social and ethical values of communities, and weighs the risks with information-gathering by scientists (Camacho 2010). There may be differing receptivity between receiving and sending communities of the species at hand, and various legal frameworks that differ between federal management agencies and state law regarding invasives and the handling of endangered species.

In this paper, I propose a decision-making framework for assessing proposals for assisted migration that incorporates scientific/ecological, legal/policy, social value, and ethical considerations. There are a handful of decision-making frameworks that have already been proposed (Hoegh-Guldberg et al. 2008; Schwartz et al. 2012; Richardson et al. 2009; Hällfors et al. 2018; Rout et al. 2013; McDonald-

Madden et al. 2011). I briefly review the key features and assess the strengths and weaknesses of each model in light of the important scientific, legal, social and ethical questions that need to be addressed in any proposal for AM, noting where there are gaps. I then address these gaps in developing a framework that uses a guided decision-making process about AM proposals following four consecutive steps: scientific, legal, social, and ethical considerations. The framework I propose is informed by the earlier frameworks; the goal of this project is to lead to more sophisticated and thorough models that help with the evaluation of the appropriateness of moving a species from its source population and environment to a recipient ecosystem.

The first part of the paper is a literature review with several sections regarding the statistical and ecological facets of AM and their integrative uncertainties. I then examine the progress and limitations in using models, namely species distribution models (i.e., ecological niche models or bioclimatic envelopes) to inform conservation strategies, specifically when it comes to assessing species vulnerability into the future, especially with respect to climate change. This is an important step because the assessment of candidate species is dependent upon the veracity of scientific conclusions, which most often are based on statistical and other models. Before moving on to a discussion of the institutional use of statistical models (or rather lack thereof), I discuss the intersection between the evolution of various ecological aspects—genetics, evolution, the niche concept—to show how these discourses are nascently impacting the development of statistical models. I then give some attention to the fact that model-makers/ecologists and decision-makers are not yet conversing in a formal, systematic, and iterative manner to improve scientific assessments of species vulnerability, and therefore candidacy for strategies such as AM. Given the available models and assessment framework, however, I transition to evaluating the ways in which scientists', managers', and the public's emerging values are informing the science and viability of AM.

In the second part of the paper, I provide an overview of the decision-making guides and frameworks available to us thus far, from a simple linear decision tree to complex multivariate statistical modelling. I then present my own framework as a flow chart of questions to guide the deliberative process for any proposal for AM. I explain how to use the framework, and provide more detailed explanations of what each series of questions and accompanying considerations entails in practice, with separate charts for the Scientific/ecological, Legal/policy, Social, and Ethical dimensions. Each step for each of these

aspects of AM culminates with a comprehensive list of the key questions that need to be asked in the four areas to identify what is needed to develop a comprehensive AM proposal. In the literature review, I provide a summary list of these questions, and the key concepts and tools they entail, as decision-makers evaluate an AM proposal.

In the final part of this paper, I use the proposed framework to assess two case studies of AM with regards to the situation of two species, one animal and one plant. These are the American pika, a less mobile mammal inhabiting montane rocky areas of the western United States, and the movement of whitebark pine farther north.

Forecasted Extinction Rates

One of the main reasons conservationists are proposing assisted migration is because of the greatly accelerated forecasted extinction rates of species. Climate change is causing a decrease in genetic diversity of populations because of positive selection of extreme alleles and rapid migration, which could also affect ecosystem functioning and resilience (Bellard et al. 2012). Further, the response of some species may indirectly affect the species that depend on them. The web of interactions at various trophic levels are compromised, and an ensemble of strategies should be promoted by conservation organizations and institutions, which must change their goals from ones designed to address the preservation of “natural” and static systems, to an integrated and adaptive approach.

The most recent strategy being considered is assisted migration (AM). AM is the practice of moving endangered and less mobile species from their indigenous range to areas where they would be predicted to move as the climate changes, if there were no anthropogenic barriers (e.g., cities, roads, and farmland) or lack of time (Hällfors et al., 2018). There are a handful of decision-making frameworks published in the literature to assess proposals for AM.

AM proves to be an important strategy to consider for biodiversity protection in a time of rapid climate change. A report assessed extinction risks for 2050 by sampling regions that cover some 20% of the Earth’s terrestrial surface and encompass 1,103 animals and plants (Thomas et al. 2004). Fifteen to 37% of species studied are predicted to be extinct by 2050 and one species is already extinct.

For climate projections of mid-range atmospheric change, estimates are 15–20% extinctions with dispersal and 26–37% without dispersal. Estimates for minimum expected climate change are 9–13%

extinction with dispersal and 22–31% without dispersal. For projections of maximum expected climate change, the authors estimated 21–32% with dispersal and 38-52% with no dispersal (Thomas et al. 2004).

Many of the most severe impacts of climate-change are likely to stem from interactions between threats or factors not taken into account in the authors' calculations. The ability of species to migrate to suitable areas will be hampered by habitat loss and fragmentation, as well as their ability to persist with atmospheric changes in the midst of new diseases and invasive species (Thomas et al. 2004, Wilson et al. 2009; Kolar and Lodge 2001).

Because of this, AM has become relevant to conservation strategies, but scientists and managers are ill equipped to know its precise consequences, in terms of disrupting the ecosystem resilience of the recipient and source ecosystem. Information on future community assemblages is also lacking. Particularly difficult to surmise is the kind and impact of human influences, especially with land use.

Critics of AM point to its potential hubris, the potential for maladaptation of species, the potential to spread an invasive species or weeds, the potential for domination over the new ecosystem or trophic cascading, and/or failure to establish, which would entail fruitless economic costs (Ricciardi and Simberloff 2009; Elliot, 2007; Katz, 1997; Sandler, 2012) . However, advocates argue that without AM, species will indeed go extinct and that AM, with careful planning and monitoring, is the best option, as novel ecosystems emerge that are inhospitable to certain species and as the climate continues to warm, quite possibly by 6.4°C by the year 2100 (Park and Talbot 2012). Again, studies employing comprehensive lists of feedback factors predict temperature increases of up to 8°C. Even if we reduced greenhouse gas (GHG) emissions to a safe level, which is a critical effort to strengthen, GHGs already emitted since the industrial revolution have given us no choice but to accept a temperature rise of a degree or more (Christensen et al. 2007). Several studies also report a breadth of responses from an array of species to changing climate, (e.g., latitudinal and altitudinal distribution range shifts, reduced survival or reproduction, and increased extinction risks) (Thomas et al. 2004).

Assessing Species Vulnerability

Statistics and SDMs

A critical consideration about the potential success of AM proposals is assessing the vulnerability of the target species. Conservation strategies have attempted to glean reliable and appropriate data from species distribution models (SDM), also known as ecological niche models (ENM) and bioclimatic envelopes. Ideally, these models are spatially explicit, project threats, and reveal populations most likely to act as strongholds for species. Of course, no model or even mix of models/statistical tests is enough to eliminate uncertainty, (i.e., from multicollinearity, incompatible resolutions, overfitted models, or gaps in data). Given these shortcomings, it is important to understand the different levels of predictive capacity, probability, or causation that modelling can display.

Environmental predictors exert direct or indirect effects on species along a gradient (Austin 1998, Etterson 2004). These are optimally chosen to reflect three main types of influences on the species (Huston 2002):

1. Limiting factors/regulators, or factors controlling species ecophysiology (temperature, water, soil compositions)
2. Disturbances, meaning all sorts of perturbations affecting environmental systems, regardless of whether they are naturally or humanly induced, and
3. Resources, or all compounds that can be assimilated by organisms, (e.g., energy and water)

These influences and relationships can cause different spatial patterns at different scales, likely in a hierarchy (Pearson et al. 2004): A gradual distribution observed over a large extent and at coarse resolution is likely to be controlled by climate factors, whereas patchy distribution over a smaller area at fine resolution is more likely to be driven by microtopographic variation or habitat fragmentation (Scott et al. 2002). The environmental data related to these three types of influence on species distribution are best manipulated in GIS (Huston 2002).

SDMs focus on occupancy data, when other landscape metrics take habitat heterogeneity or configuration into account, and include temporal explicitness. These latter aspects might be needed to predict population stability; this also accounts for additional variance in extinction risk (Oliver et al. 2012).

While SDMs are useful for resolving practical questions, they are also relevant to the ecological and evolutionary theories underlying them. Ecological theory often has been ignored, weakening the statistical approach (Guisan & Thuiller 2005).

The Evolving Niche Concept and Assumed Equilibrium in SDM Models

As we bring up the importance of underlying theory and projections of models, we turn to a discussion of how models develop and progress, by integrating the accompanying evolution of ecological theory, which is so important to AM strategy. Currently, updates in some SDM models are accounting for competition and dispersal mechanisms, but still SDM models usually fail to integrate genetic, evolutionary, and “evolutionary niche concepts”, as well as their interactions with the former aspects of ecology. Many scholars do not ask key questions about the nature of equilibrium in a model and how long, after a period of environmental change—perhaps drastic—equilibrium will be reached again (Guisan and Thuiller 2005).

SDMs tend to rely on two niche concepts as defined by Joseph Grinnell or Evelyn Hutchinson, and sometimes by the impact of the species on the environment as defined by Charles Elton, Robert MacArthur or Richard Levins. Pulliam (2000) distinguishes Grinnell’s view of species as occupying all of their suitable habitats (the fundamental niche) and Hutchinson’s view of species as being excluded from part of their fundamental niche by biotic interactions, resulting in the realized niche actually observed in nature.

The niche is a useful reflexive paradigm, independent of its implications for interspecific interactions and community organization. It is a conceptual tool for understanding range limits and represents the potential environments an organism faces as an abstract space, with axes corresponding to environmental factors that affect its performance. The niche is a mapping of population dynamics onto this space (Holt 2009).

The demographic perspective on the niche was later expressed as a growth parameter: birth rate minus death rate assessed at a low density, as a function of a vector of environmental states $r(x)=b-d$. Although community ecologists recognize that scientists must also consider the impact of species on their environments, this comprehensive niche concept has yet to influence SDMs (Holt 2009).

However, it will be helpful if ecological niche models can guide site selection for valuable experimental analyses of range limits and field experiments to boost confidence in the models, drawing attention to important variables in the process (Holt 2009).

Even still, SDMs do not illustrate Hutchinson's realized niche. While biotic interactions and limiting resources are accounted for, dispersal, density, competition, and evolutionary effects have not been integrated with classical niche theory

Dispersal, for example, can create source-sink dynamics in which immigration maintains species in habitats outside of their optimal niches. On the other hand, dispersal limitations can prevent species from occupying suitable but isolated habitats (Svenning and Skov 2004). Because of feedbacks, the domain where a niche can be established versus where a species can actually persist can be very different. Moreover, the genetic benefits or costs of these changes are not accounted for, where evolution plays a part at spatio-temporal scales over which a population within a geographic range might be attuned to a specific environment while a neighboring population is attuned to another. Significantly, SDMs based on the entire geographic ranges of species may very well over or underestimate the niche that pertains to local populations (Holt 2009).

Theory favors niche conservatism over niche evolution, with or without genetic variation and with respect to adaptation. Even with high genetic variation, and pulsed dispersal, adaptive colonization is unlikely and a species would be more likely to be overwhelmed by demographic factors.

This shows the importance of refugia and metapopulation dynamics (e.g., sinks), as a means of genetic variation from the source. At times, this leads to niche evolution and other times maladaptation (Holt 2009).

Details of genetic architecture matter most here. Clearly, the subtle and not so subtle qualities of ecology, patterns of dispersal, and population connectivity are not just perturbations of species distribution from the "inherent mapping of niches onto distribution, but are subtly woven into the fabric of the niche itself"' (Holt 2009, p. 19664):

Scale

As decisions are made about AM strategy, one must consider the scale at which these strategies are delineated, and be wary of their reliance on a model at an inappropriate scale—that is, the resolution and the extent of the study area (Guisan and Thuiller 2005). Mismatch can occur between the resolution at which species data were sampled and the one at which environmental predictors are available.

With General Circulation Models (GCM) in SDMs, in particular, projections are coarser than those of the species and environmental data used to set parameters for the SDM. Regional Climate Models and fine scale GCM will help, but future climate surfaces are also limited by resolution of current climate affected by noise from the statistical calculations of GCM data (Hewitson 2003). Fine-scaled climate data sets are available, but these products too are limited by the regularity of climate station data and interpolation techniques used to create continuous surfaces (Guisan and Thuiller 2005).

Competition between species can only be detected at certain resolutions that capture those interactions where species vie for the same resources. For less mobile organisms, it will not be conclusive that a combination of suitable conditions occurs within the same graphic cell; instead, these must overlay at least at one specific location within the cell. For other species, (i.e., mobile animals), spatial matching of resources within the cell may not be necessary.

Clearly, selection of resolution and extent is a critical step in SDM building. The integration of these factors in a multiscale hierarchical modelling framework (Pearson et al. 2004) may solve the problem partially (Wiens and Graham 2005) by associating scale domains to eco-predictors having the most control over species distributions (Mackey and Lindenmayer 2001).

Sometimes creating complementary models for each type of niche space or for types of individuals (e.g., young, juvenile, and adult, or male and female) is also possible. Due to this neighborhood influence, released matching does not necessarily pose a problem, but for very mobile species, true absences in occupancy might be hard to capture. The latter is a concern, so that usually specific presence-only models are fitted or pseudo-absences are generated (Mackey and Lindenmayer 2001).

Model Fitting

Since the number of parameters for interactive effects increases greatly with the number of predictor variables (Rushton et al. 2004), a combination of statistical approaches can be used to find the key interactions (e.g., a generalized boosting model (Friedman et al. 2000).

Spatially, the independence of observation is a basis for applying these methods. Yet, dependence in terms of biology, including dispersal, demography, and behavior, is definitely observed in ecological data. Solutions to this problem include: correcting the number of degrees of freedom used in model inference tests, adding a spatial autocorrelation (SAC) (Lichstein et al. 2002); or (re)sampling plots at sufficient spatial distance to avoid autocorrelation (Guisan and Thuiller 2005). This grapples with variance partitioning. Geostatistics is less involved with process, resulting in more easily performed broad-scale predictions in modelling, so that ecologists may also want to take care to incorporate dispersal and more nuanced population data.

Evaluating the Models

A model's functionality must be evaluated for its full-proofing (e.g., algorithms), assessed for its usefulness in providing information of high value and confidence, and for the likelihood that those correlations and conclusions drawn are based on sound data interactions, which neither replicate, omit, or provide erroneous interactions among variables. If they address question(s) at a scale and intensity that is appropriate, and if they can explain the level of variance, they are robust (Mac Nally 2002). Problems may arise also in the opposite case, when a model is overfitted. There is no absolute definition of robustness, so that evaluation must be discussed in relation to the model's purpose (Fielding 2002). A model based on climatic predictors, for example, might have a low goodness-of-fit, yet it could explain all the climate-related variance for a target species. That is, the model is sufficient to assess the broader worldwide impact of climate change on species distribution, even if it is cannot provide definitive answers to conservation management questions at a local scale. A range of metrics are used to compare predictions with observations, whether based on a test data set or resampled observations from the training set.

Usually environmental and algorithmic errors are only considered. However, two major questions arise when considering biological errors (Pulliam 2000; Huston 2002): why and how often are species observed in unsuitable habitats? And why and how often are species absent from suitable habitats? These can be termed omission and commission errors, which also imply costs for management strategies that overlook presence (e.g., the cost of omission errors for invasive species management) or can expect an underestimation (e.g., omission errors in areas defined by source-sink dynamics).

Connecting SDMs to a Decision-Making on AM

For species that have some time, a major flaw in conservation data-gathering, modelling, planning, and decision-making is that scientists and managers/decision-makers do not engage in a formal process of exchange, in terms of what managers' needs are, and the most effective way to address these needs through data-gathering and modelling. This exchange, ideally an iterative process, would inform controversial decisions about AM, and would improve conservation strategy and ecological theory overall. A more systematic process of learning and implementation might better answer questions such as whether specialist species have lower dispersal and colonization capabilities than generalist species or, in the context of climate change, whether species will be able to adapt and/or migrate fast enough to track changes (Guisan et al. 2013).

Gauging the Adaptive Capacity of Species-

Whether to employ AM is closely related to whether a species exhibits adaptation at a fast enough pace, whether the type of adaptation a species exhibits is intrinsic or extrinsic, and finally whether that adaptation is most suited to their currently changing environment or whether they are maladapting to the point of needing AM. Gauging a species' vulnerability to climate change depends not only on the species' exposure and sensitivity, but also their adaptability to stressors. As Beever et al. (2015) explain:

> "Exposure denotes the magnitude of exogenous disturbance likely to be experienced, whereas sensitivity refers to how dependent or tightly linked a species is to current conditions. In contrast, AC [adaptive capacity] is the capacity of a species to persist under new conditions by acclimating, redistributing locally, migrating regionally, evolving, or a combination of these. AC encompasses and reflects genetic diversity, dispersal ability, and phenotypic plasticity, among other factors" (Beever et al. 2015 p. 5-6)

Borrowing from Hutchinson's conception of a fundamental and realized niche, in the context of climate change, the adaptive capacity of a species can similarly be viewed in terms of both a fundamental (intrinsic) and a realized (extrinsically constrained) state (Holt 2009). But adaptive capacity has largely been omitted from studies. Among a recent review of 403 climate-related vulnerability assessments for

U.S. ecological resources, exposure was assessed as part of the vulnerability in 87.9% of the assessments. Sensitivity was evaluated in 68.5%. However, adaptive capacity was evaluated in only 33.1% of projects and only when the other two measures were included (Thompson et al. 2015).

As Beever et al. (2015) attests, greater clarity on the conceptual basis for adapted capacity is likely to increase its incorporation into vulnerability assessments and species models that include consideration of ecosystem and climate-change effects, and improve conservation management planning, decisions, and outcomes. The diagram below shows the framework for adaptive capacity (Beever et al. 2015, p.8**):**

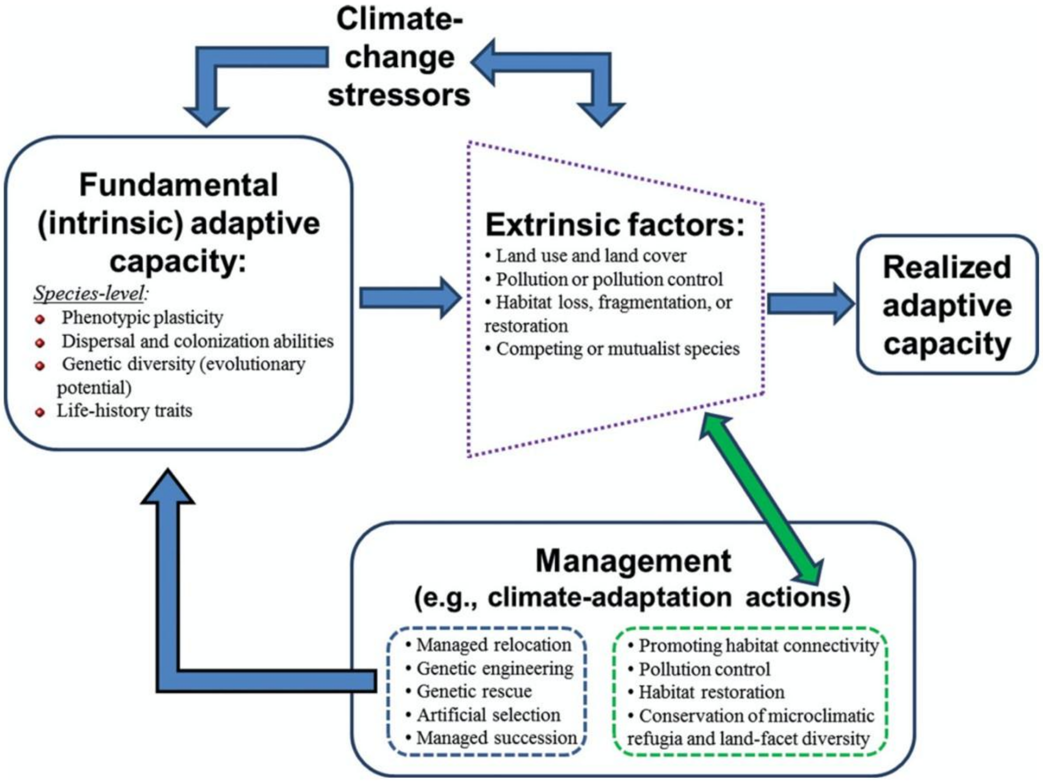


Figure 1 A new heuristic conceptualization of adaptive capacity (AC): Conceptual model of fundamental (intrinsic) and realized (extrinsically constrained)

Without Adaptive Capacity: Near-Term Vulnerability Indices for Species Candidacy

Without a proper assessment of adaptive capacity and its integration into assessment models, exposure and sensitivity are the main guides in assessing a species' candidacy in the near-term for AM.

Near-term vulnerability assessments to climate change can be categorized into two broad groups. First, there are examinations of spatially explicit shifts in the geographical range of species with changing climate, based on empirical evidence from the paleoecological record of past changes in response to Holocene climate cycles (Guralnick 2007) or twentieth century observations of shifts in species (Rosenzweig et al. 2008). Forecasts of range can also be used (i.e., SDMs) using correlative (Thuiller et al. 2005; Pearson et al. 2006; Lawler 2009) or mechanistic relationships between species and their environments (Kearney and Porter 2009).

The second approach employs evaluative frameworks that generate relative indices of climate change vulnerability. These indices can integrate information about species' exposure and sensitivity (morphology, physiology, life history, dispersal and behavior, all of which govern response to abiotic habitat conditions) to climate change based on observation, field experiments and the results of SDMs.

Some considerations to take into account in vulnerability indices is that a species may be inherently sensitive to changes in climate but not be exposed to such changes, or exposed to climate change but not sensitive. Also, paleological reconstructions often overestimate migration rates, and studies have documented more complicated responses to climate change, involving differing controls over upper and lower range limits, as well as other factors, largely land use and anthropogenic stressors (Rowe et al. 2009, Aitken et al. 2008). However, in response to limits on time, data availability and computational capacity for modeling, conservation organizations and management agencies have begun designing evaluative indices for species candidacy.

These include NatureServe's Climate Change Vulnerability Index (CCVI) (NatureServe 2014; Young et al. 2009); a vulnerability index developed by the Rocky Mountain Research Station of the United States Forest Service (USFS- RMRS) (Bagne et al. 2011) to assess vertebrates; and a framework developed for the Environmental Protection Agency's National Center for Environmental Assessment (EPA-NCEA) to evaluate threatened and endangered species (US Environmental Protection Agency 2009).

Without Adaptive Capacity: A Long-Term Vulnerability Indice

In the long-term, a vulnerability indice that could thoroughly assess a species' candidacy for AM is available. Conventional risk frameworks are not suitable to judge novel dynamics over long time scales in which species will continue to respond to climate change (Fischlin et al. 2007). Thomas et al. (2011) develop a framework to evaluate species' responses to climate change.

The assessment framework has six stages, each of which contains steps A through D. Stages I and II assess species' declines within their recent historical ranges (e.g. their distributions in the 1970s); and Stages III and IV consider increases outside the species' recent historical ranges (including areas of recent colonization and potential new areas where species may become established in future).

Within each stage, Step A assesses distribution or abundance changes, Step B assesses links with climate, Step C addresses disturbances or worsening factors (e.g., including small population), and Step D assesses the stage based on rate of change with a confidence level assigned. Finally, Stage VI assigns species an overall risk category based on the balance of threats vs. benefits.

Assisted Migration's Role in Conservation Strategy

As prescribed in "Assisted Migration: Part of an Integrated Conservation Strategy" (Vitt et al. 2009), the authors recommend as the first course of action enhancing traditional conservation strategies to improve the rate of species survival. In many habitats that have become fragmented owing to human activity, assistance in the form of short distance jump dispersal or corridor creation might become necessary to ensure species survival. These types of dispersal pathway are less likely to result in enemy release and biological invasion than are long distance and mass dispersal.

Some scholars who hope that species can follow a more natural migration pattern call for the removal of barriers to dispersal and colonization, with data from Lawson et al. (2012) corroborating this. However, enhancing population survival can help to facilitate range expansions too. Populations at range edges are highly vulnerable, and survival can be improved locally (e.g., by. enlarging patch size and increasing habitat quality) or by improving connectivity to other landscapes.

Parmesan and Yoh (2003) analyzed data for over 1,700 species and showed that 83% have recently shifted their ranges, mostly in the poleward or upward direction predicted by climate change models. However, poleward range shifts in specialist, low dispersal species tend to be associated with the evolution of increased dispersal abilities (Simmons and Thompson 2004**)** or with the ability to use more widespread habitats (Thompson et al. 2001). This suggests that at least in the short-term, poleward range shifts are more common than local adaptation that would enable populations to stay in their native ranges (Wiens and Graham 2005). The remaining 17% of species analyzed that have not shown predicted range shifts might be limited by their dispersal abilities, leaving them to extinctions as their habitats become increasingly small and fragmented (Parmesan and Yohe 2003).

Gene flow may be especially important for adaptation to climate change, since many alleles required at a species' poleward edge might already exist at the equatorial edge. Sustained evolutionary response to climate change could depend on these alleles moving poleward in time. Movement across gradients and genetic backgrounds might be particularly difficult where population densities are low, or gradients locally steepened by anthropogenic habitat loss (Kirkapatrick and Barton 1997).

Whereas gene swamping could prevent local adaptation in adjacent populations, low migration and population extinction might prevent the spread and establishment of beneficial alleles at the scale of the metapopulation. Nevertheless, local adaptation could quickly alter these patterns of gene flow by altering the productivity of patches.

Detailed investigations of how local adaptation and gene flow interact at range margins are needed, and Bridle and Vines (2007) provide important questions to consider:

- Does migration from differentially adapted populations increase or decrease the potential for local adaptation? Is the answer the same when populations are considered at different spatial scales?
- Does genetic variation for adaptive traits generally increase or decrease towards range margins? Is genetic variation more abundant in contracting versus expanding species' edges? If so, does such variation make local adaptation more probable?
- Are range margins found where selective gradients are locally steep and/or populations are reduced in size? How often do interactions with other species determine parapatric range margins? Do the same ecological and genetic factors determine internal as well as external species' edges?

- Is the strength of the character displacement at parapatric margins or in hybrid zones negatively or positively correlated with levels of gene flow from nearby allopatric populations? Does this gene flow affect divergence in ecological and reproductive characters differently?
- Which invasive or expanding species have modified their climatic and ecological tolerances in new parts of their range? What ecological or life history characteristics do these species share?

Some scholars challenge the idea of prior adaptation to warmer climates, demanding that some species merit population-level study when forecasting the effects of climate change, as they respond in genetically based and distinct ways to changing conditions (O'Neil et al. 2014).

More tested but by no means standardized conservation strategies based on genetic or demographic rescue implicitly target adaptive population *states* whereas more novel conservation strategies utilizing transgenerational plasticity or evolutionary rescue implicitly target adaptive *processes* (Fraser et al. 2019). *Adaptive state* strategies optimize current population fitness, reducing phenotypic and genetic variance, so as to result in the reduced adaptability in changing or precarious environments. *Adaptive process* causes maladaptation at first with the genetic variance introduced, but increases the populations' adaptability over the long term.

Adaptive process coincides with the theory that increasing genetic diversity should benefit small populations (e.g., genetic rescue), but acknowledges the necessary outcome of some maladaptation at the level of a population. Here, we increase heritable trait variation at the expense of mean population fitness, with regards to the optimal phenotype: Hybridization between diverse source populations or related species is a good example of this effect, in which maladaptive traits and genetic variation lower mean population fitness in a generation but maintain higher average fitness ultimately due to genetic resiliency (Hamilton and Miller, 2016).

However, despite it novelty, AM is on the extreme end of conserving the adaptive state (Armstrong and Seddon, 2008). It entails moving organisms to an environment to which they are said to be adapted, and away from an environment that is not suitable anymore, due to climate change. Derry et al. (2019) therefore prescribes AM for assisting threatened, isolated endemics when insufficient genetic material is present for evolutionary adaptation (Thomas, et al. 2011).

While managers hesitate to use or even plan for AM, often because of the concern regarding invasion, Mueller and Hellman's (2008) study of databases encompassed found only 69 of 468 invasive species, or (14.7%), to be intracontinental in origin. Their study suggested that if AM projects are a success, "the introduced population will not be excessively damaging" (Mueller and Hellman 2008, p. 565). Climate change, however, will lead to the creation of new invasives without AM.

Reintroduction literature also has a role to play in informing AM practice. Past reintroductions have occurred in areas where there was no historic record of the species. Experience suggests that the risks of failing to establish a viable population under AM could be greater than the risk of unintentionally creating an invader, especially as many priority species would be slow-moving habitat specialists (Van Andel and Grootjans 2006). Regardless, each unsuccessful attempt requires extraction from an at-risk source population.

To prevent the latter issue, multiple translocations into the new environment could be employed to reintroduce genetic diversity within the population, especially if populations in the recipient ecosystem stay small. However, if maladaptation is density dependent and persists in a translocated population with too many individuals occupying the new environment, individual fitness will decrease because the environment's carrying capacity might be prohibitively low (Derry et al. 2019).

> "To help moderate the negative consequences of maladaptation, such as reduced productivity and increased mortality, it has been suggested that genotypes best suited to a predicted future climate be preferentially used in ecosystem restoration efforts--termed assisted migration" (Grady et al. 2011, p. 3724).

While genetic manipulation of forests, for example, is contentious, proponents of AM argue that without such tactics, many populations may face extirpation. Effective AM, as well as conventional restoration via reforestation, requires genetic constitutions adapted to a warmer climate (Aitken et al., 2008). A lack of adaptation in a changing environment, with limited phenotypes, can cause further problems, as well, so that conservation for adaptive process is also important (Derry et al. 2019). For a given environment, it is expected that there should be an optimal amount of variation around the fitness optimum that would facilitate future adaptation and yet not reduce mean fitness so much that the population cannot persist.

While studies on AM tend to concern themselves with determining what range of environmental conditions will advance individual survival (TaÏbi et al. 2016) and to a lesser degree, also concern themselves with the impact management has on the recipient community's genetic diversity after translocation (Wright et al. 2014, Komdeur et al. 1998), there do not seem to be studies concerned with determining the population variation needed to promote long-term persistence.

Increasingly provenance studies are being used to identify favorable genotypes for AM, as well as to analyze climate influence on evolutionary trajectories of a species by testing genetic factors related to local adaptation (Savolainen et al. 2007; Wang et al. 2010)

For example, to augment knowledge of plant adaptation to temperature, and identify genotypes for use in restoration and AM projects, Grady et al. (2011) conducted a common garden provenance trial testing for annual maximum temperature (MAMT) for three species: two trees, the Fremont cottonwood (*Populus fremontii*) and Gooding willow (*Salix gooddingii*), and one shrub, coyote willow (*Salix exigua*).

> "Several populations of each species were collected across a temperature gradient ranging in MAMT by approximately 6.5 °C, approximating the predicted increase in mean temperature in the southwestern United States over the next 80 years and were transplanted to a common garden near the warmest end of this temperature gradient and at the warm edge of these species' distribution. This novel experimental design allows characterization of the potential adaptive responses of multiple species to temperature, and hence, is an initial step to assess the need for assisted migration" (Grady et al. 2011, p. 2725).

Ecologists, Ethics, and Assisted Migration

A general reading of ecologists is that they agree that it is time to move forward with the development of AM, but they vary in their degree of confidence as to how and when AM should play out in tandem with a suite of conservation options.

Neff and Larson (2014) identified four types of scientists and managers, drawn from a pool of 50 scientists and managers with expertise in disciplines that had engaged in the AM debate. Twenty-four completed the study. They used a sophisticated survey to gauge respondents' attitudes toward AM using both scientific and values concepts. Specifically, they used the Q method, which uses an analysis that inductively elicits individuals' understanding of a topic in a way that allows their concerns to define the axes along which they are compared. In this way, they reveal insights typically inaccessible via survey research and have been frequently used to understand the dimensions of environmental debates, although the authors used a novel approach.

> "Q method can be used to simulate a dialogue between participants and their colleagues by exposing them to statements made by people like them, and allowing them to rank those statements and justify their rankings," (Neff and Larson 2014, p. 2).

From a broad list of statements, the authors used an inductive semi-structured approach to select 33 that covered the breadth of views. From there, the authors chose 50 science/manager participants. To provide a wide cross-section of scientific perspectives on AM, they recruited scientists from the top publishing researchers and five journals that focus on different scientific aspects of conservation: *Biological Invasions*, *Conservation Biology*, *Ecology*, *Global Change Biology*, and *Restoration Ecology*. The authors chose varimax rotation "because the purpose of the study was to identify the dominant mental frameworks within the participant community and thus [the authors] wanted the data to drive the analysis." (Neff and Larson 2014, p. 4)

The authors settled on 4 (unknown) factors that explained 54% of the variance, with the fourth helping to identify key issues amongst participants. They identified four designations of respondents as Ecological Interventionists, Native Technocrats, Intervention Technocrats or Reluctant Interventionists.

Ecological Interventionists accepted significant human management of "nature", believing that conventional conservation strategies are necessary for biodiversity, but not sufficient in an era of climate change. These respondents did not perceive AM to be a radical transformation of natural ecosystems, but rather a necessary response to anthropogenic climate change.

Nativist Technocrats agreed with the traditional conservation of habitats and species and rejected AM, with concerns not least being the introduction of diseases or invasive species. A Nativist respondent commented, “Do we keep moving species further and further poleward or uphill as the climate warms?” These respondents believed that AM was counteracting the importance of mitigation activities.

Interventionist Technocrats were open to AM, though they strongly disagreed with basing ecological practice on people’s preferences. A respondent noted that decisions should be made based on science. He also strongly felt that citizen groups with appropriate expertise should not be allowed to move species.

Finally the Reluctant Interventionists, who were far more cautious about implementing AM, expressed concerns about the potential negative implications of introduced species even as they were less pessimistic about maintaining viable populations of native species under future climate conditions. They were open to informed citizen groups taking part in implementation. One manager citied significant challenges in figuring out how to “balance the interests of different groups with that of the public and with future generations.” Reluctant Interventionists held more strongly than the others to considering public values in the process of AM decision-making.

All respondents agreed that AM can carry disease and genetic risks to recipient ecosystems. Further, they all were concerned about who should conduct AM activities, and more importantly the role of endangered species laws in species conservation. Other statements with high salience and standard deviations related to the appropriateness of using people’s preferences as a basis for ecological practice and policy. Respondents called for a framework for debate about subjective values relating to AM, which suggested contestation about whether values should play a role in decision-making and/or whether they should be openly debated, since they are non-technical in nature (Neff and Larson 2014).

But values are inescapable in ecology (Odenbaugh 2008). Bowler (1993) suggested that a “positivist” account of science accepts that claims about facts and values are conceptually distinct and that science is values-neutral (Odenbaugh 2008; Bowler 1993).

Given that ecological data are samples from populations under investigation, and given how difficult the data can be to collect, there is always uncertainty and error, making room for values, hopefully determined by both expertise and ethics. This means scientists are in the position of choosing which type of error to minimize, which involves the error we believe to be more important to avoid. In attempting to answer which hypothesis to reject, scientists are necessarily involving themselves in questions of value and ethics. Moreover, these questions of value will in part be ones of moral value (Odenbaugh 2008).

While judgments to decide whether AM is applicable are value-laden, the very concept of AM is ethically debated. Scientists, land managers, biologists, and environmental ethicists generally take a tempered approach, recommending AM as part of a portfolio of conservation strategies, and one that must be developed in tandem with mitigation and research to ensure the intergenerational bequeathing of ecological heritage (Albrecht et al. 2012).

Crucial to the debate is whether an AM project can transfer a species to a predicted range, and thus retain more value than the outcomes of “AM” elsewhere (Siipi and Ahteensuu, 2016). The goal for these scholars is to show how accepting the moral relevance of a species’ indigenous range helps to reconcile Sandler’s argument with earlier arguments about value loss in ecosystem restoration by Elliot and Katz (Elliot, 2007; Katz, 1997; Sandler, 2012). All three, (Sandler, Elliot and Katz), agree on value loss resulting from human involvement, but differ on what this value loss implies to conservation in cases where it is impossible to retain biological units in a human-independent state (Siipi and Ahteensuu, 2016). For example, Sandler argues that neither instrumental value, nor interest-based intrinsic value, valuer-dependent intrinsic value, or objective interest value are a basis for AM, as Elliot and Katz argue that the AM approach is a mere advancement of the project of human artifice, dominance and control. However, others contend that these philosophers do not take account of the human disturbance and anthropogenic factors that have led to broader complexities, such as climate change, and the need for practical interventions (Camacho 2010), as well as a need for more integrated conservation (e.g. landscape connectivity and genetic diversity) (Loss et al., 2011). The preservation of “pristine” landscapes and native biota are no longer practicable goals around which to orient the entirety of natural resource law and policy (Camacho, 2010).

As no policy yet exists to guide the implementation of AM, legal analysis of whether National Park Service lands, the National Wildlife Refuge System, Multiple Use Lands managed by the U.S. Forest Service (USFS) and the Bureau of Land Management (BLM), and the Acts that govern them, would be amenable to this strategy (Joly and Fuller, 2009). A preliminary analysis shows differing levels of openness that an interpretation of the law provides, along with the limitations and allowances afforded by the Endangered Species Act, laws governing invasive species, cross-border species transfers, and even the Convention on International Trade in Endangered Species.

> "Already the term 'neo-native' is coming into use to define a species that
> was not historically part of an ecosystem but, because of shifting climate patterns, may now be considered native. Such a new understanding will likely eventually result in new agency policies" (Joly and Fuller 2009, p.13).

Until then, existing legal structure and case law are the guides, and show that AM is a legal option on most federal lands under certain circumstances, with no outright prohibition. The NPS is most conservative and possibilities might arise under Federal Wildlife Services refuge lands, with greatest flexibility on military installations. Finally, all agencies appear to be able to use whatever legal flexibilities that exist to pursue species-specific goals, especially where they are threatened or endangered, or sometimes "experimental" (Joly and Fuller 2009).

A reorientation of all management agencies to ensure ecosystem health, a subjective label which may best described as resilience and function, is ultimately necessary to make lasting change in which AM is a viable strategy.

Public views of AM are also an important influence on the prospects of research and experiments to proceed, and the way AM is implemented. A total of 1,926 completed surveys between May 15 and May 30, 2017 revealed three main insights into the views of the public on AM adaptive strategies:

1. "The location of potential public controversy resides not with the potential implementation of AM strategies per se, but rather with AM strategies that involve movement of tree species beyond their native range" (St- Laurent et al., 2018, p. 585). Risks that matter are not specifically associated with application of genomics to reforestation, but rather with the transgression of native boundaries.
2. "Increasing public knowledge and science literacy would allow the public to understand the associated risks and benefits of different forest management options, thereby leading

to more informed opinions'" (St-Laurent et al. 2018, p. 585). The framing, description, and definition of AM influenced perceptions of it.

3. "...a relatively high proportion of respondents feel that AM outside of range either should not proceed until further research is conducted or should be avoided outright due to too many uncertainties" (St-Laurent et al. 2018, p. 585). This finding also points to the possibility of exploring the complexities and potential malleability of support or opposition, "and to foster informed dialogue on this issue" (St. Laurent et al. 2018, p. 585).

News reporting on AM mirrored the timing of scientific literature expounding on the potential of the strategy in 2007, with it being referred to as "assisted migration", "assisted colonization", or "managed relocation". A spike in literature in 2009, when Ricciardi and Simberloff (2009) published "Assisted colonization in not a viable conservation strategy" (Ste-Marie et al. 2011), led to more news reports. Two-hundred and three reported on the movement of species, 124 of which referenced climate change. "Assisted migration" was the most common phrase used: 82% of the 124 climate change media documents contained this term (Ste-Marie et al. 2011). Public exposure to news writing on AM will be increasingly important in informing public opinion. In the meantime, there is clearly more research that needs to be done to effectively determine on a case by case basis whether AM is appropriate, and how models forecasting future scenarios can integrate feedback loops with data more precisely for conservationists.

Conclusion:

In concluding this literature review, here is a summary list of the key concepts and tools essential to any AM proposal:

- **What is projected persistence of the population into 2050/2100?**
- **What factors play a role in either the persistence or demise of a vulnerable species? (i.e., intrinsic/extrinsic adaptive capacity, genetic fitness and diversity, competition, dispersal and migration ability, metapopulation dynamics, evolutionary niche/niche conservatism, ecosystem function, local to regional to global climate change, and topographical features/microclimate.**

- **What is the current legal/policy management orientation to this species' persistence at the population, range, species scale?**
- **What contribution does a species make to society? (i.e., high intrinsic value, historic value, social/cultural value, commercial/economic/tourism value, ecosystem function, research/instrumental/option value)**
- **What public education and survey efforts need to be made to gauge an informed local public opinion at the source and recipient sites?**
- **Do management agencies have the data, capacity, expertise, finances and infrastructure needed to carry out an AM project?**
- **Do management agencies have the capacity to monitor these strategies in the long-term to ensure establishment and prevent invasion/interruption of ecosystem dynamics?**

II. Developing an Assisted Migration Decision-Making Framework

A. Current Assisted Migration Decision-Making Frameworks

A democratic process evaluating how AM interacts with existing conservation strategy, such as restoration, preservation, novel ecosystems, and the need for mitigation, will be of immense importance. Undoubtedly, there will need to be more action, research, and consensus on an overall program for AM, which, despite hesitation from some, appears to be a likely strategy. The values informing our ethical response balanced with scientific risk will govern the methodology and policy programs that might ultimately come to fruition as the climate warms. Whether these programs effectively converse with other management strategies and align with a greater overall mitigation plan will be a critical piece in determining whether AM projects succeed in tandem with others. While AM presents intense manipulation, AM follows an anthropocentric disturbance of climate patterns, and must be informed by a holistic analysis of when and how it can be a prudent course of action.

The decision-making frameworks available to us include a straightforward linear decision tree of potential actions under a suite of possible future climate scenarios (Hoegh-Guldberg et al. 2008), a list of categorized questions pertaining to ethical, legal, policy, ecological, and integrated dimensions of AM

(Schwartz et al. 2012); a list of questions categorized for planning and implementation of AM (Chauvenet et al. 2012); a conceptual model concerned with the loss versus availability of suitable habitat (Hällfors et al. 2018); a heuristic tool applying a multivariate analysis that collapses 4 classes of ecological and social criteria into graphical 2-D space (Richardson et al. 2009); a rigorous mathematical/statistical formulation depicted by a more complex decision tree for assessing the species whose introduction would be of maximum to minimum benefit followed by a formula for cost effectiveness (which does not monetize species or ecosystems) (Rout et al. 2013); and a dynamic modeling of optimal timing of AM for species faced with climate change (McDonald-Madden et al. 2011) as presented.

1. The Hoegh-Guldberg et al. Model

Considering Hoegh-Guldberg et al. 2008's linear decision tree, as Richardson et al. (2009) reason, complex conservation decisions such as AM are poorly suited for resolution via simple decision-trees because a linear approach does not accommodate the multiple dimensions of decision-making. With just one route to a particular decision, it is difficult to evaluate the relative merits of competing conservation options in terms of the species' ecology, its legality, its social applicability, or its ethical merit. Likewise, it does not include a factoring of the competing social values at play, or the values informing ethics. The tree also presents AM as a last resort option, instead of a portfolio of options (Richardson et al. 2009).

However, the questions posed by Hoegh-Guldberg (2008), though a simple model, thoughtfully encompass considerations of a species' ability to migrate on its own, perhaps importantly to be preserved for later manual expansion/reintroduction, and the continued relevancy of improved traditional strategies such as connectivity. The tree also realizes some of the subtleties of engaging in intense conservation (e.g., nuanced translocation which may involve facilitating establishment as species arrive) and of course considering species vulnerability to begin with and the feasibility of engaging in action. This is a good starting point in thinking about AM.

Below is the framework (Hoegh-Guldberg 2008):

1 Is there a high risk of decline or extinction under climate change?

2 Are translocation and establishment of species technically possible?

3 Do benefits of translocation outweigh the biological and socioeconomic costs and constraints?

Go to options 2 and 3

1 Continue and improve conventional conservation approaches.

2 (i) Improve landscape connectivity in required direction of colonization, (ii) genetically enhance to improve climate robustness of populations within existing geographic range, and (iii) reduce local stressors on population.

3 Invoke ex situ conservation practices (e.g., store egg/sperm/seed).

4 Is it possible to create habitat (e.g., artificial reef, wetlands) at higher latitudes to accommodate "natural" movement?

Will the organisms arrive on their own to new habitat?

5 Wait and facilitate establishment (protect organisms as they arrive).

6 Undertake translocation (assisted migration).

2. The Schwartz et al. Model

This model poses questions in no necessary order of importance divided by ethical, legal, ecological, and integrated questions respectively regarding AM: See Box 1 below:

Box 1. A proposed set of key questions identified by the Managed Relocation Working Group that are central to creating a cohesive, broad-based general framework for decisionmaking relative to proposed managed relocation actions.

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

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

Ecological questions
To what extent do local adaptation, altered biotic interactions, no-analog climate space, and the persistence of suitable microhabitats within largely unsuitable landscapes mitigate the extinction risk (and managed relocation need) of species listed as *vulnerable*?
What evidence suggests that species are absent from climatically suitable locations because of dispersal limitations that could be addressed by managed relocation?
What are the limits of less dramatic alternatives to managed relocation, such as increasing habitat connectivity?
How well can we predict when management must address interacting suites of species rather than single species?
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)?
How well can we predict the likelihood of a species' successful long-term establishment in light of a changing climate?

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

These questions are thought-provoking and encompass nearly all considerations that stakeholders would need to account for in their decision-making. However, the questions posed are not structured enough to guide a decision-making process.

While these questions take vastly more into account and allow for a more nuanced thought-process than the preceding framework, it remains a preliminary process of reflection, rather than an articulated process of decision-making, and lacks direct considerations of adaptive capacity key to any framework.

3. The Chauvenet et al. Model

This model is not a framework as much as it is a tool-kit meant to contribute to planning and implementation of AM for a specific species, the Hihi of New Zealand. Planning and implementation is an aspect of the strategy which has not been fleshed out. Questions are more specific to AM, and so this tool-kit is helpful in noting what details will critically impact the success of a decision to move forward (e.g., number of individuals and sex ratio of species needed, scenario-building with SDMs' applications, and, significantly, adaptive management: See Table 2 below:

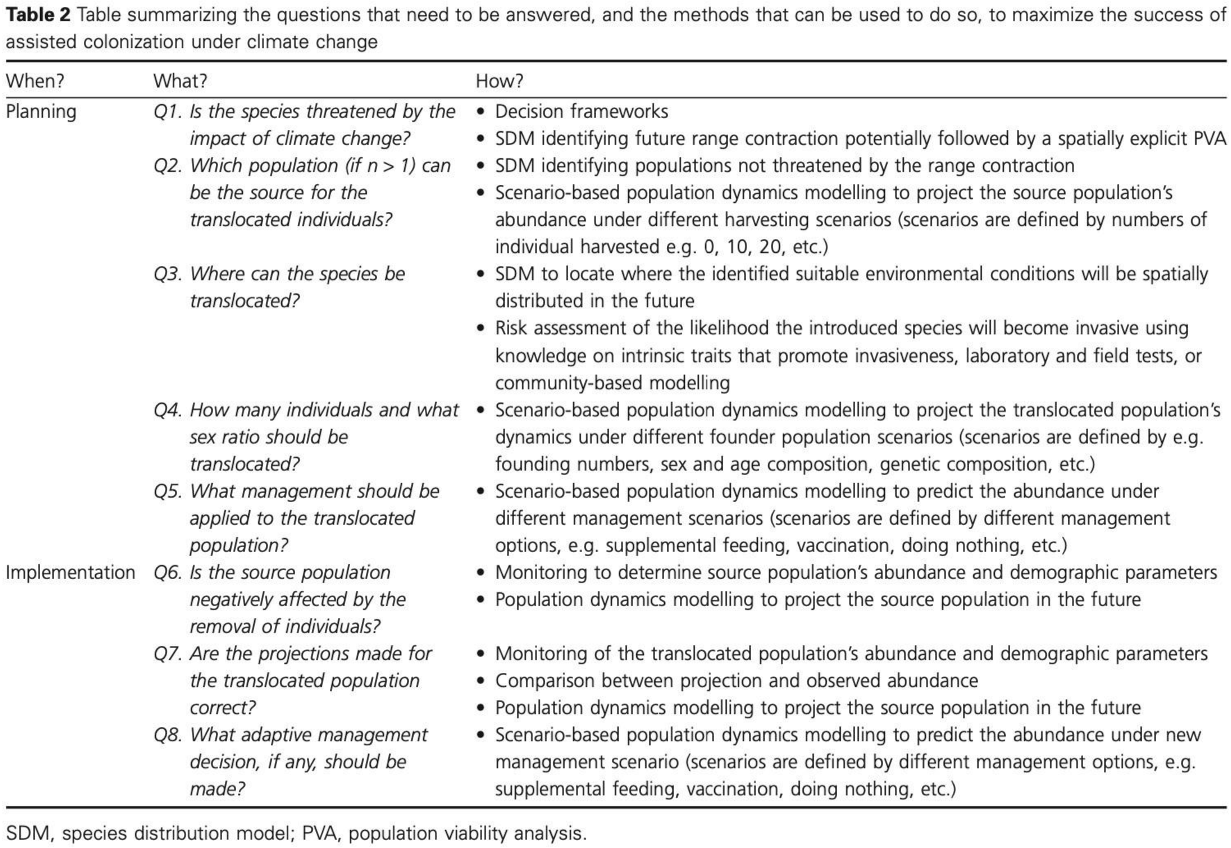


Table 2 Table summarizing the questions that need to be answered, and the methods that can be used to do so, to maximize the success of assisted colonization under climate change

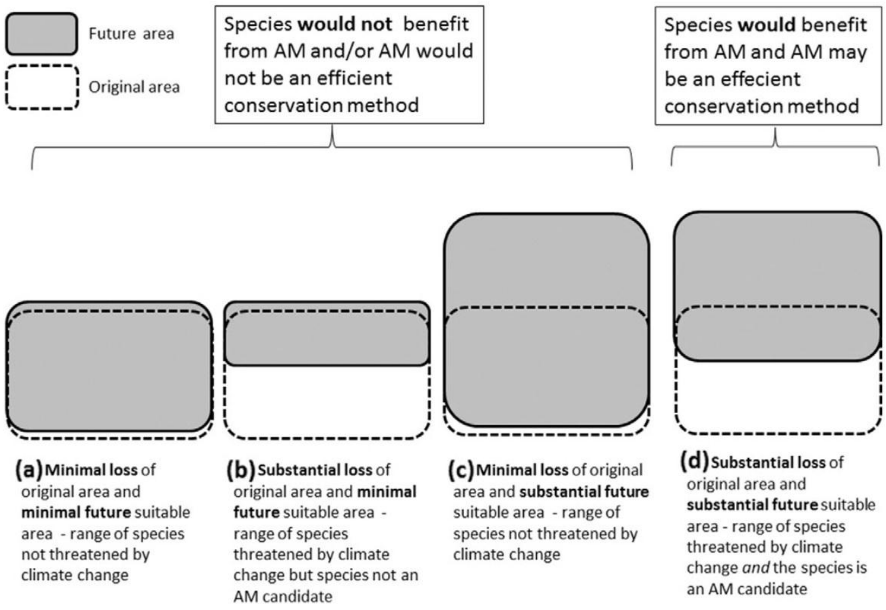
When?	What?	How?
Planning	*Q1. Is the species threatened by the impact of climate change?*	• Decision frameworks • SDM identifying future range contraction potentially followed by a spatially explicit PVA
	Q2. Which population (if n > 1) can be the source for the translocated individuals?	• SDM identifying populations not threatened by the range contraction • Scenario-based population dynamics modelling to project the source population's abundance under different harvesting scenarios (scenarios are defined by numbers of individual harvested e.g. 0, 10, 20, etc.)
	Q3. Where can the species be translocated?	• SDM to locate where the identified suitable environmental conditions will be spatially distributed in the future • Risk assessment of the likelihood the introduced species will become invasive using knowledge on intrinsic traits that promote invasiveness, laboratory and field tests, or community-based modelling
	Q4. How many individuals and what sex ratio should be translocated?	• Scenario-based population dynamics modelling to project the translocated population's dynamics under different founder population scenarios (scenarios are defined by e.g. founding numbers, sex and age composition, genetic composition, etc.)
	Q5. What management should be applied to the translocated population?	• Scenario-based population dynamics modelling to predict the abundance under different management scenarios (scenarios are defined by different management options, e.g. supplemental feeding, vaccination, doing nothing, etc.)
Implementation	*Q6. Is the source population negatively affected by the removal of individuals?*	• Monitoring to determine source population's abundance and demographic parameters • Population dynamics modelling to project the source population in the future
	Q7. Are the projections made for the translocated population correct?	• Monitoring of the translocated population's abundance and demographic parameters • Comparison between projection and observed abundance • Population dynamics modelling to project the source population in the future
	Q8. What adaptive management decision, if any, should be made?	• Scenario-based population dynamics modelling to predict the abundance under new management scenario (scenarios are defined by different management options, e.g. supplemental feeding, vaccination, doing nothing, etc.)

SDM, species distribution model; PVA, population viability analysis.

Although Chauvenet et al. (2012) do not present this as a decision-making framework, this writer believes their questions should be highlighted as a tool that would contribute to the planning process, after a decision to move forward with AM. It is also a good anticipatory list of questions to bear in mind even before an affirmative decision, as far as the ecological dimensions of decision-making go.

4. The Hällfors et al. Model

This model is useful to examine carefully what areas will be lost and what areas are logistically available and climatically suitable to species. Here is the conceptual framework offered:



The framework expresses the concept using linear statistical models that incorporate a species' ability to disperse, with terms for species' migration need and migration ability, both dependent on an equation expressing available area. This leads to a "parameter space plot" showing AM's feasibility exponentially with a simulation of climate:

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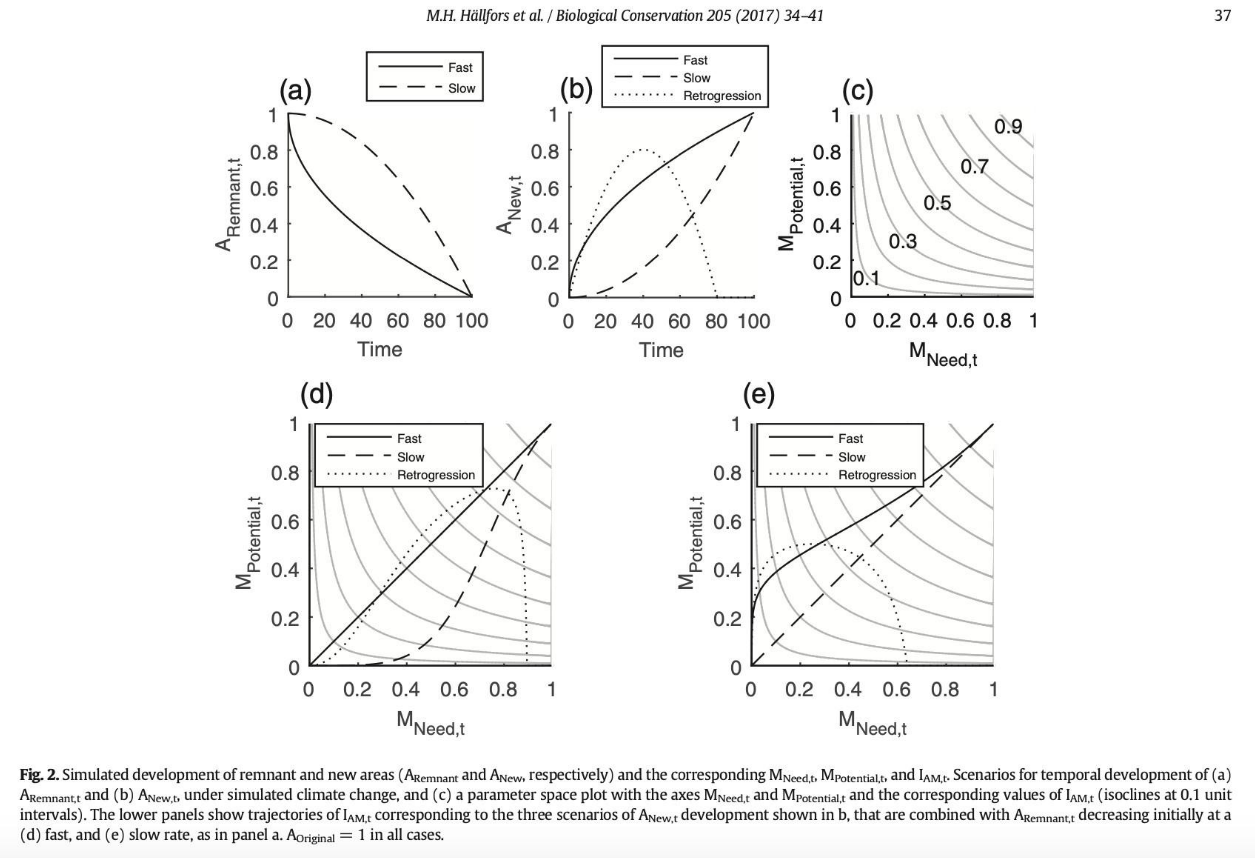


Fig. 2. Simulated development of remnant and new areas ($A_{Remnant}$ and A_{New}, respectively) and the corresponding $M_{Need,t}$, $M_{Potential,t}$, and $I_{AM,t}$. Scenarios for temporal development of (a) $A_{Remnant,t}$ and (b) $A_{New,t}$, under simulated climate change, and (c) a parameter space plot with the axes $M_{Need,t}$ and $M_{Potential,t}$ and the corresponding values of $I_{AM,t}$ (isoclines at 0.1 unit intervals). The lower panels show trajectories of $I_{AM,t}$ corresponding to the three scenarios of $A_{New,t}$ development shown in b, that are combined with $A_{Remnant,t}$ decreasing initially at a (d) fast, and (e) slow rate, as in panel a. $A_{Original} = 1$ in all cases.

The model can readily obtain data from SDMs, with likely data including species occurrences, climate variables, dispersal abilities, habitat requirements, habitat availability, and biotic interactions among species. The veracity of the Hällifors et al. model, while incredibly useful, is dependent on whether that data can fit into grid cells and the quality of the data. The model first graphs the remnant area, then the new area, each according to ‘slow’ and ‘fast’ rates of migration, and the latter with a regression. Then a migration graph would be created. Various scenarios would follow for migration when modelled with the integrated remnant/new graphs, likely showing isoclines that initially decrease for a vulnerable species while hopefully increasing in the long-run for an ideal candidate. These scenarios would, again, simulate a fast and slow rate, with a regression each.

While this model is a great conceptual and potentially applied tool, it remains to be seen how effectively it can incorporate data, specifically on genetic and adaptive capacities. The study is not descriptive of how data will relate, although this presumable malleability could be advantageous in terms of adapting the model to various contexts. However, the conceptual and statistical frameworks alone are not enough to make a decision, as they do not evaluate ethics or explicitly consider legality or economic cost.

5. The Richardson et al. Model

While Richardson's et al. (2009) model better integrates these concerns empirically/theoretically and allows for stakeholders to compare and contrast their interests preliminarily, the multivariate model is still highly subjective to the perceptions of stakeholders. The model considers species, or 'focal units', according to four general classes, 1) the impacts of conducting or not conducting AM on the species, 2) the impacts of AM activities on the recipient ecosystem, 3) the practical feasibility of conducting AM, and 4) the social acceptability of AM: See Table 1 below. The first two classes are considered to be in the domain of ecologists and managers, while the latter two are in the domain of stakeholders and political decision-makers. These four classes are determined by settling subjectively on a collection of attributes for grading each class, which entails subjectively ranking the attributes within each class, and assigning a qualitative or quantitative score to each class. See the Table below:

Table 1. Ecological and social considerations for evaluating individual cases of managed relocation (MR), wherein the goal is to prevent the loss of a species or population

Ecological criteria	Social criteria
Focal impact[*]	
Likelihood of outcome: Extinction Decline in geographic distribution Decline in abundance within geographic distribution Indirect effects of decline on community members and community composition	*Likelihood and consequence of outcome:* Cultural importance of the target and its community (e.g., is the target a flagship or iconic species? is the historic integrity of the community important?) Equity of the impact on particular groups of people Concerns about the harm to individual organisms subjected to MR Financial loss whether focal unit declines in abundance or goes extinct
Consequence of outcome: Uniqueness (phylogenetic, functional, etc.) Geographic distribution (common versus rare; small versus large range) The potential for reversibility (e.g., if no action were taken and the species went extinct in the wild, are there *ex situ* individuals available for population reestablishment)	
Collateral impact[†]	
Likelihood of outcome: Decline or extinction of native species in recipient region Decline or loss of ecological functions in recipient region	*Likelihood and consequence of outcome:* Cultural importance of the target and its community (e.g., is the target a flagship or iconic species? Is the historic integrity of the community important?) Equity of the impact on particular groups of people Concerns about the harm to individual organisms subjected to MR Financial loss whether focal unit declines in abundance or goes extinct
Consequence of outcome: Uniqueness of affected focal units Geographic distribution of affected focal units Effect on existing conservation efforts Degree to which effects are reversible (e.g., whether the focal unit could be easily controlled or managed once established in the recipient region)	
Feasibility[‡]	
Degree to which the target can be captured, propagated, transported, transplanted, monitored, or controlled Availability of appropriate sites for translocation Sustainability of MR in achieving conservation objectives (e.g., whether MR for a given focal unit would need to be performed iteratively to match changes in environmental conditions)	Economic cost Legal or regulatory obstacles (permits, etc.) that would hinder or restrict the capacity to conduct MR Regulations or laws that facilitate MR
Acceptability[§]	
N.A.	Willingness to accept potentially irreversible consequences (cultural, aesthetic, or economic) Willingness to support action Trust and acceptance of ecological information Aesthetic, cultural, and moral attitudes toward focal and collateral units Concern that a focal unit's protection will restrict land in the recipient region from being managed or developed Willingness to support new laws and policies that encourage or enable MR

This list is illustrative, not exhaustive, and will vary by case and stakeholder group. Additional criteria would be needed to consider MR if the goal was to replace a species complex or ecological function that had been lost from a system. In the case of focal and collateral impact, risk is measured by the likelihood of an outcome times the consequence of that outcome. N.A., not applicable.

[*] Impact on focal unit and its community from climate change and exacerbating effects of MR.

[†] Effect of focal unit in recipient region.

[‡] Constraints on or opportunities for MR.

[§] Societal willingness to pursue MR.

Collectively, the criteria-based classes are meant to reveal net benefits and risks of AM in a particular situation by the particular individual or group performing the exercise. Thus, while more integrative, this framework lies in more of an evaluative phase that, while statistical, does not heavily rely on method. While it could very well be used to make a decision, it is not the most rigorous or ideal way to do so. The ethical implications of the decision to employ AM are not clear enough, as social interests, and other dimensions—legal and economic in particular—are more implied and all are malleable in their weight. It is also unclear whether users would be able to interpret the output transparently.

6. The Rout et al. Model

A much more meticulous evaluation with data on the proportional impacts on the source and recipient locations that encompasses cost-effectiveness, without monetizing environmental elements and species, can implement weights for several factors (Rout et al. 2013). It is also depicted as a decision tree, albeit a much more involved and complex one. After a statistically measured assessment of vulnerability, according to empirical data assessments of species, there is an option to weight the value of each species:

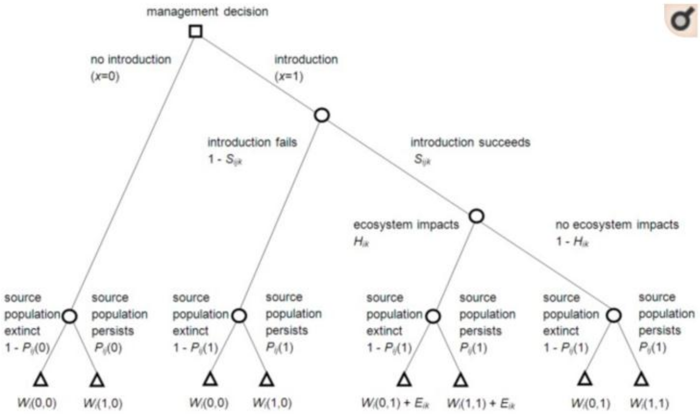
> “When evaluating options across multiple species, the benefit of introducing a species incorporates the relative value of that species compared with the other candidate species for introduction. This is expressed in the weight *W_i*. All species could be valued equally, or they could be weighted based on factors such as cultural significance, ecological function, economic importance, taxonomic distinctiveness, or a combination of several factors,” (Rout et al. 2013, p. 7):

$$
\begin{aligned}
B_{ijk} = {} & S_{ijk}(1-H_{ik})[(1-P_{ij}(1))W_i(0,1)+P_{ij}(1)W_i(1,1)] \\
& + S_{ijk}H_{ik}[(1-P_{ij}(1))(W_i(0,1)+E_{ik})+P_{ij}(1)(W_i(1,1)+E_{ik})] \\
& + (1-S_{ijk})[(1-P_{ij}(1))W_i(0,0)+P_{ij}(1)W_i(1,0)] \\
& - [(1-P_{ij}(0))W_i(0,0)+P_{ij}(0)W_i(1,0)].
\end{aligned}
$$

While the model seems to omit legal constraints, these could be integrated. Otherwise, the model avails itself to more formal decision-making, with conscientious assessments of ecological, cultural, and economic feasibility weightings that, together, could represent the ethical warrant of an AM decision. It is effective in allowing the selection of candidate species until budgetary constraints do not allow, and it is thorough in displaying mathematically the interactions between probability of success.[4]

The model incorporates and equally considers impacts on both the source population and the new population.

See their complex decision tree:



A decision tree describing the conservation introduction problem.

Squares represent decision nodes, circles are stochastic events, and triangles are outcomes. The expected value of each choice is calculated by multiplying down the branches of the tree to obtain the probability each outcome will occur, and summing across the possible outcomes under each choice. For example, if we choose not to introduce (x=0), there is a probability $1 - P_{ij}(0)$ that the source population will go extinct (outcome $W_i(0,0)$), and probability $P_{ij}(0)$ that the source population will persist (outcome $W_i(1,0)$). The expected value of choosing not to introduce is the sum of these two expected values, i.e. $(1 - P_{ij}(0))W_i(0,0) + P_{ij}(0)W_i(1,0)$.

The net expected benefit of introducing species i to location k using strategy j is the expected value of this introduction (x=1) minus the expected value of doing nothing (x=0), which can be derived mathematically from the decision tree.

This framework is descriptive enough to include presumably all aspects of AM, even legal and ethical. Although these are not descriptive by word, the model implicitly factors and weights all values, including social, cultural, economic, and potentially legal and certainly ecological ones.

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[4] "If introduction is chosen, it may or may not be successful. We assume the probability of success, S_{ijk}, depends on the species i, strategy j, and location k. If an introduced population is successfully established, there is a probability H_{ik} that it will have an undesirable impact on other species or on ecosystem function at location k. Let E_{ik} be the predicted impact (weighted by its relative importance compared to species persistence outcomes [which is mathematically explained later] should the introduced species i cause undesirable impacts at location k. We assume the species cannot colonize these locations without being introduced, although a probability of natural colonization can easily be incorporated" (Route et al. 2013, p. 4)

The model is targeted to a single decision-maker, such as a government agency or NGO, and it applies to any introduction strategy, not only AM, which might lead to other realistic strategies encompassing translocation within range or future ex situ establishment, making it a platform to inform various/integrated strategies.

> “This prioritization framework can also be used to compare introduction options with alternative plausible management actions for mitigating the effects of climate change, such as managing threats to the species within its current range, managing the species *ex situ*, or managing connectivity to facilitate natural colonization” (Rout et al. 2013, p. 8).

However, the planning, implementation, and monitoring aspects of AM are not explicitly included, although they could be informed by cost constraints.

Besides this, the main limitation is data. With regards to this, the authors make an important note:

> “Rather than being a barrier to rigorous decision-making, this lack of information should be seen as a motivator for using such a framework. By first implementing the framework with currently available information, the key parameters affecting a decision to introduce can be identified. Future research can then be directed towards estimating those parameters for which more information is needed to be able to make a good decision” (Rout et al. 2013, p. 9).

7. The McDonald-Madden Model

The employment of Rout et al.’s (2013) model could be coupled with McDonald-Madden’s et al. (2011) model, optimizing the timing of introduction (according to species needs) with projections of climate change: see Figure 2 below. McDonald-Madden et al. (2011) assume the probability of persistence in a monotonically increasing function of population size, with the explicit objective of increasing that size at some point in the future, defined as T. Other objectives, such as maximizing growth rate, are possible. The model does not assume to cover the legal, social, ethical, or even all ecological aspects of AM. As the authors relay, “the actions that the decision-maker needs to evaluate regarding managed relocation include whether and where to move individuals, which kinds of individual to move, how many to move, whether to move all at once or in staggered cohorts, what methods to use for release and whether a period of temporary captivity is required.” That is why this model, in tandem with the former would be an ideal pairing to make an informed decision.

It could be said that ethical implications are not adequately addressed in this model coupling, but given the thoroughness of its data infusion and considerations of all aspects of impact, as well as social cost to an extent should weighting be applied, this coupling of models could address many of the central issues for AM decision-making issues. See the figures below:

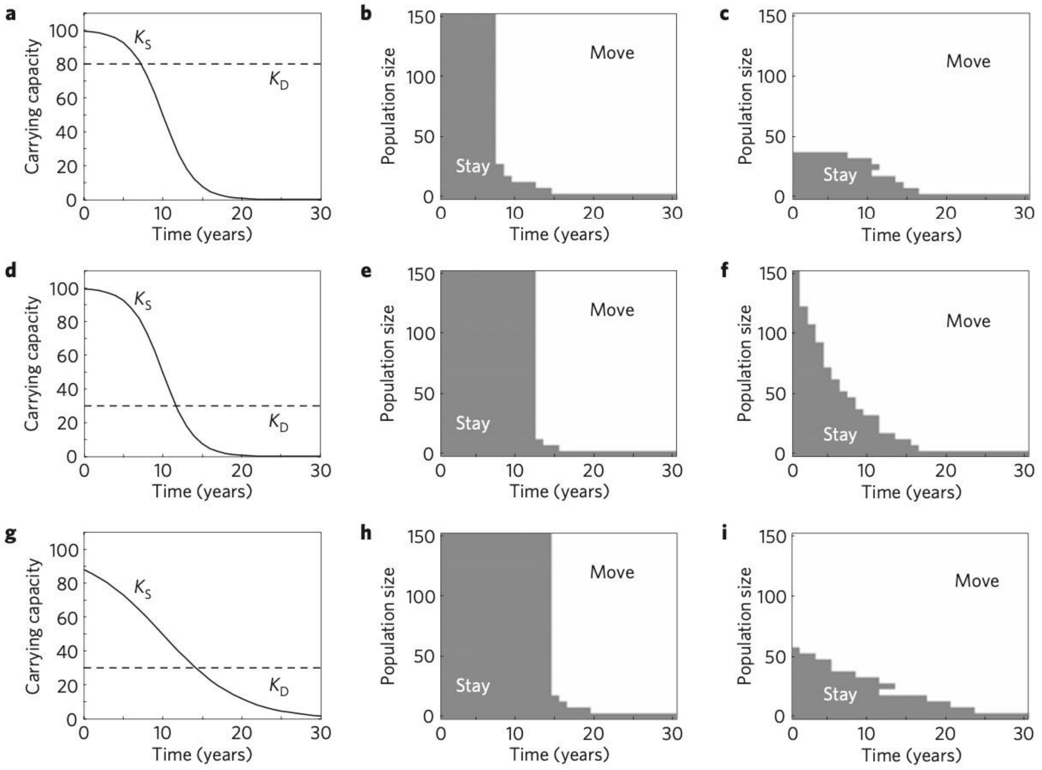


Figure 2 | Optimal timing of managed relocation, as a function of population size in the source, when the change in the carrying capacity under climate change is known. **a**,**d**,**g**, Known habitat carrying capacity over time in the source (K_S, solid line) and destination (K_D, dashed line), for three scenarios. **b**,**c**,**e**,**f**,**h**,**i**, Optimal state- and time-dependent decision strategy for the corresponding habitat scenario when the relocation survival rate is high ($\phi = 0.95$; **b**,**e**,**h**), and when the relocation survival rate is low ($\phi = 0.3$; **c**, **f**, **i**).

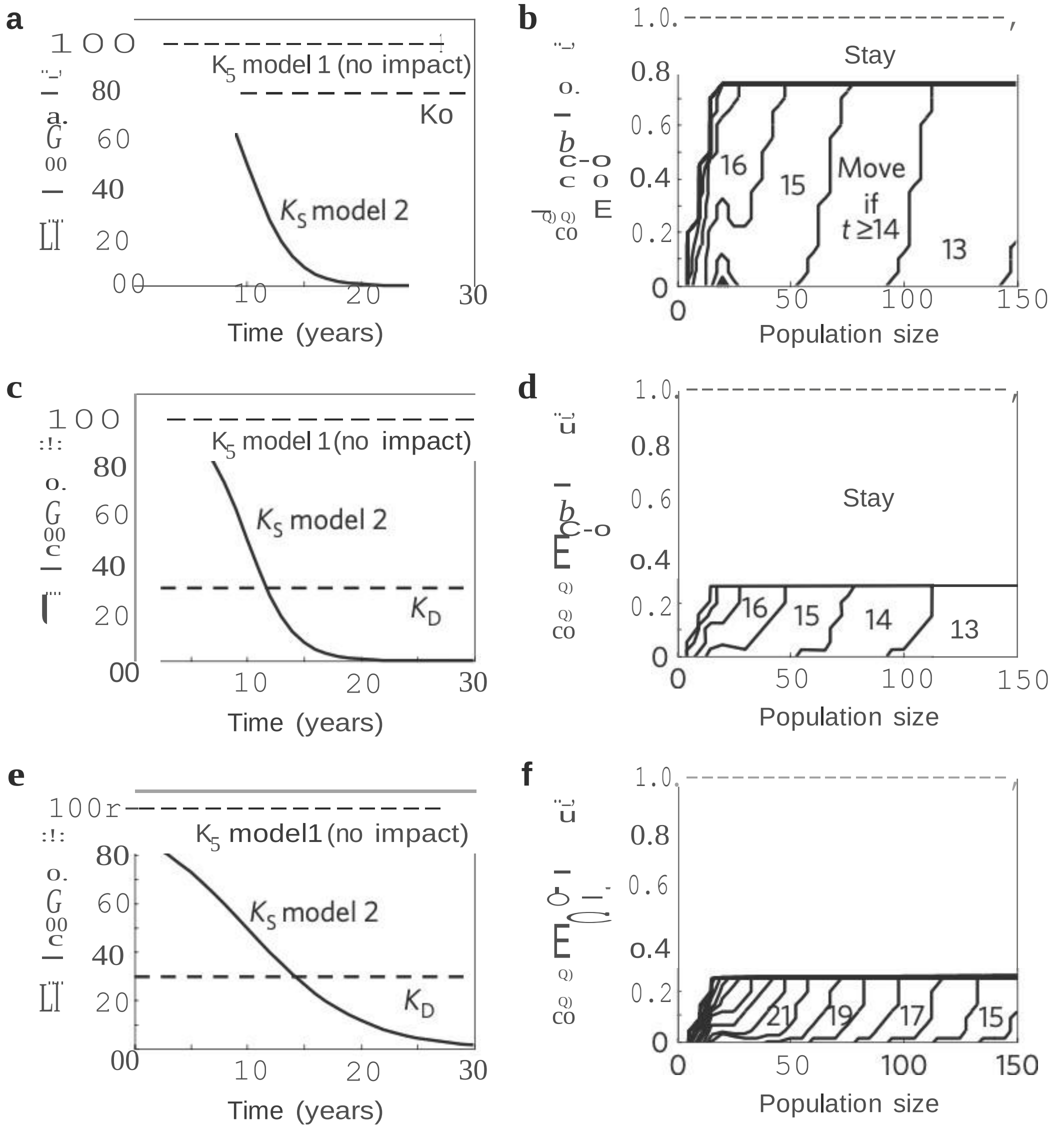


Figure 3 | Optimal timing of managed relocation in the face of uncertainty about the impact of climate change. a,c,e, For each scenario, there are two potential models for the carrying capacity in the source, one in which there is no impact of climate change (*Ks* modell), and one in which carrying capacity declines with time CKs model 2). The three scenarios of decline correspond to the scenarios in Fig. 2. **b,d,f,** Optimal state-, time-, and belief-dependent decision strategy for the corresponding habitat scenario, when the relocation success rate is low ($\phi = 0.3$).

Concluding Remarks

Hurdles remain for the implementation of climate-informed actions in natural resource management, particularly as they relate to the feasibility of AM. There are barriers posed by the legal and policy framework of environmental regulation, which currently fosters the preservation and restoration of ecological systems to twentieth century reference conditions, many of which are likely no longer supported by our rapidly changing climate (Craig 2010). More significantly, there is limited public acknowledgement of the ecological and socio-economic issues related to climate change, and thus, minimal public understanding and acceptance of adaptation efforts and the devotion of resources toward them. Federal-level acknowledgement of the need for climate adaptation strategies, starting with vulnerability assessments (Salazar 2009), requires further action in order to address the constraints on implementation imposed by current regulations, as well as by public support.

The Managed Relocation Working Group (MRWG), is an independent collection composed of over 30 scientists, scholars, and policymakers that met to discuss dimensions of managed relocation (Schwartz et al. 2012). Despite emphasis on US policies, agencies, and problems, issues of AM extend beyond national borders and involve nations with contrasting regulations, law-enforcing capacities, and economic needs. Schwartz et al. (2012) see the Convention on Biological Diversity, the Ramsar Convention on Wetlands, the Man and Biosphere Programme, and the United Nations Convention to Combat Desertification, as playing key roles in assisting different nations to build capacity and eventually coordinate actions. Within the U.S. the MRWG recommends that government agencies and NGO conservation organizations develop detailed policies on AM.

> “At the federal level, this effort could be led by groups structured like the Climate Change Adaptation Task Force (co-chaired by the White House Council on Environmental Quality, the Office of Science and Technology Policy, and the National Oceanic and Atmospheric Administration) or the National Fish, Wildlife, and Plants Climate Adaptation Strategy (co-chaired by the USFWS, the National Oceanic and Atmospheric Administration, and the New York Division of Fish, Wildlife, and Marine Resources; *www.wild lifeadaptationstrategy.gov*). State government fish and wildlife and resource-management agencies will also need to be fully engaged in this effort, because--other than actions involving endangered species--most regulation of the

Critical Questions	Hoegh-Guldberg Model	Hallifors Model	Schwartz Model	Chauvenet Model	Richardson Model	Rout Model	McDonald-Madden Model
1. What is the projected persistence of the population into 2050/2100? (species distributon model robustness/comprehensiveness, near and long-term vulnerability indices, records, and expert opinion)	X	X			X	X	
2. What factors play a role in either the persistence or demise of a vulnerable species? (i.e., intrinsic/extrinsic adaptive capacity, genetic fitness and diversity, competition, dispersal and migration ability, metapopulation dynamics, evolutionary niche/niche conservatism, ecosystem function, local to regional to global climate change, and topographical features/microclimate.	X (partially)	X (potentially)	X		X (potentially)	X	Climate projection
3. What is the current legal/policy management orientation to this species' persistence at the population, range, species scale?	X (potentially)		X		X	X	
4. What contribution does a species make to society?			X	X	X	X	

(i.e., high intrinsic value, historic value, social/cultural value, commercial/economic/tourism value, ecosystem function, research/instrumental/option value)							
5. What public education and survey efforts need to be made to gauge an informed local public opinion at the source and recipient sites?			X	X (potentially)	X (potentially)	X (potentially)	
6. Do management agencies have the data, capacity, expertise, finances and infrastructure needed to carry out an AM project?			X	X	X (potentially)	X	X (contributes to this understanding)
7. Do management agencies have the capacity to monitor these strategies in the long-term to ensure establishment and prevent invasion/interruption of ecosystem dynamics?				X	X (potentially)	X (potentially)	X (contributes to this understanding)

movement of plants and animals in the United States is under state jurisdiction" (Schwartz et al. 2012, p. 741).

AM has yet to formally integrate the ecological, legal, social and ethical dimensions necessary to coordinate governance, action, and research programs necessary to anticipate the needs of the future.

Below is a Table listing the frameworks evaluated thus far, with a summary judgment of the critical questions (first listed at the end of the literature review) which are or are not addressed.

Proposing a Decision-Making Framework for Assisted Migration

I now propose a new, holistic decision-making framework that incorporates scientific, legal, social and ethical considerations. The purpose of the framework is to gather and assess the critical information needed in each of these four areas to assess more comprehensively proposals for AM as a conservation strategy. I then apply it briefly to the case of the American pika and whitebark pine in the U.S. to test the applicability of the framework.

The Framework poses several questions in each of the four sections to be answered by those proposing Assisted Migration for a species, and for those evaluating AM proposals. By each question is a box of considerations to bear in mind in answering the questions. Depending on the answer to each, the decision-maker may backtrack or proceed to the next question and ultimately the next step. If the decision-maker is unable to answer a particular question, it may suggest a gap in the needed information and what further information is needed before proceeding with assessing the proposal. For this reason, at the end of each step, the decision-maker is asked to list the concluding critical questions, key tools and concepts that still need to be explored, perhaps through further research, data-gathering, consultation and analysis, for a management agency to feel confident in moving forward with a conservation strategy.

The framework begins with scientific/ecological considerations to assess the urgency of the threatened status of the species, and whether AM is required to address this. If the answer to questions 1B or 1C qualitatively leads the decision-maker to conclude that less intense and moderately intensive strategies alone may not be sufficient, then other conservation strategies should be considered. However, if the scientific consensus is that AM is needed to protect the species, then proceed in the framework. The next section considers legal/policy issues – even if there is scientific need for AM, is the proposal legally permissible in the proposed place and time? If not, consideration of the proposal should end here. If it is permissible, or the legality is ambiguous, proceed to examine important social considerations in the next section. Is there enough social value to invest the time and resources needed for the AM proposal to succeed? Asking the social questions then leads finally to assessing any remaining ethical considerations. Even if the proposal meets all the scientific, legal and social considerations, *should* this proposal proceed in this time and place?

STEP 1: SCIENTIFIC/ECOLOGICAL

[redacted]

1A Is the species vulnerable? ------

[redacted] t vulnerable to the effects of climate change?
es it lack adaptive capacity or dispersal ability?
er what space and time?
es it lack population viability?

Yes/No

1B Can vulnerability be ameliorated by less intense co[redacted]n actions (i.e., improve habitat quality, jump dispersal, corridor creation, etc.) -----

[redacted]

mbination of simpler management strategies?

1C Can vulnerability be ameliorated by mo[redacted]inte[redacted]on? (Connectivity, reserve networks, rehabilitation, restoration, management of [redacted]

here institutional capacity and coordination?
licies developed by land management agencies?
t financially feasible?
nitoring ability?

1D Can vulnerability be ameliorated b[redacted]ve a[redacted]M, reintroduction, genetic rescue, ex situ future introduction)

[redacted]

here institutional capacity and coordination?
t legal?
here infrastructure?
t financially feasible?
nitoring ability?

Evaluation: What[redacted]critical ques[redacted]s an[redacted]ts that need to be further discussed to move forward wit[redacted]osal?

STEP 2: LEGAL[redacted]CY

2. Is the propose[redacted]

[redacted]

Is there legislation / laws on AM in particular jurisdictions?
Legislation / laws on AM in particular landscapes?
Implications of court decisions on AM?

[redacted]

Evaluation: What are the critical questions, key tools and concepts that need to be further discussed to move forward with a proposal?

STEP 3: SOCIAL

3A How is the species valuable?

[redacted]

ction component?
es species contribute economically?

3B Does AM/the conservation strategy suite integrate with a [redacted] gional pl[redacted]

[redacted]

ticipating research needs?
ticipating capacity needs?
n modeller/Decision-maker
laboration

3C What are the opinions of community members in both th[redacted]an[redacted]t ecosystems about the proposal?

3D Is there societal consensus about the value of the propo[redacted]

Evaluation: What are the critical questions, key tools and co[redacted]at [redacted]e further discussed to move forward with a proposal?

STEP 4: ETHICAL

Should this A[redacted]

[redacted]

herence among preceding step values?
herence with theoretical interactions/practical applicati[redacted]her
ditional and emerging anthropogenically driven method[redacted]
odiversity value to ecosystem function given evolutiona[redacted]al
taining ecosystem services (i.e. instrumental value, opti[redacted]
insic value)?

Evaluati[redacted] are the critical questions, key tools and co[redacted]at [redacted]e further discussed to move fo[redacted]h a proposal?

SC[redacted]C

Proposals for AM depend largely on scientific assessments of the current or future threat to the viability of a species, particularly with the effects of climate change. In this step, I pose questions which cause the decision-maker to consider species vulnerability, the prerequisite to candidacy for AM. These questions approach vulnerability in diverse ways to blend various dimensions of ecological theory with climate change. (As with each step), I list considerations in the boxes in order of their importance, according to my judgment as informed by previous researchers. As we proceed, the steps concern themselves with the level of intensity of action that a vulnerable species would merit, while keeping in mind that a host of strategies might be appropriate. So this part of the framework implicitly acknowledges that there is a level of complexity to the aspect of conservation action coordination, which is important to AM, a strategy that may very well often be implemented conscientiously with other accompanying actions (e.g., within range translocation, habitat maintenance for certain populations, corridor creation for others, and genetic rescue elsewhere). This awareness of the distributional, behavioral, and adaptive complexities and diversity among members of the same species and range ground the first step of the framework.

LEGAL

This is perhaps the most precarious and gray area of the framework, as explicit laws on AM have yet to be developed. Currently state and federal laws mainly give AM its potential through the Endangered Species Act (ESA), which individualistically prefers the maintenance of a given species under threat, be it anthropogenic, ecological, or a combination of these. However, the ESA does also impose some barriers to doing so, namely the decision to assess species status independent of climate change forecasts. Federally, the ESA is governed by the United States Fish and Wildlife Service and the National Marine Fisheries Service. State laws vary regarding the movement of species. Currently individuals may move many species across state boundaries as was the case of the first reported AM by Torreya Guardians, a civil society group that successfully moved the endangered *Torreya taxifolia* from Florida to Tennessee, North Carolina, Georgia, Ohio, Michigan and New Hampshire in 2005 (Chapman 2019). However, scientists and many concerned citizens are understandably wary of public efforts to move species as an AM strategy.

In terms of management policy, legal scholars argue that the National Park Service (NPS) lands, the National Wildlife Refuge System, Multiple Use Lands managed by the U.S. Forest Service (USFS) and the Bureau of Land Management (BLM), and the Acts that govern them, would be amenable to this strategy (Joly and Fuller, 2009). However, NPS lands are least likely to implement an AM measure, and the National Wildlife Refuge System, the BLM, and particularly military installations provide language that is most amenable to AM, as they have specific clauses which prioritize experimental populations and the survivorship of species not historic to those lands. Conservation management and paradigms are most explicitly oriented to the protection of native species, and the preservation of historic landscapes, however subjective those designations are at times.

At the international level, the ESA interacts with The Convention on International Trade in Endangered Species of Wild Fauna and Flora. Congress historically stated that the ESA's role should be to guard against species extinction at all cost, although the ESA has potentially been considerably weakened. Limitations have been proposed that would limit the ability of regulators to take climate change into consideration when making listing assessments. Also, language prohibiting the consideration of economic factors when deciding whether a species should be listed are proposed to be removed, and the government would be given more discretion in deciding what is meant by "foreseeable future" (Friedman 2019). Representatives of the American Petroleum Institute claim that these changes remove duplicative regulation and overregulation of presumable economic development (Friedman 2019).

These factors suggest the need for developing policy conversations among managers, and lobbying for accompanying laws or stronger existing laws to preserve species, and their ecosystems, in an integrated way in order to have the needed guidance for assessing AM proposals. Thus far, no court decisions have been made regarding AM. To be sure, conservation decisions that consider the possibility for potential litigation when AM is involved should gather information to inform their conversations.

SOCIAL (VALUE)

This step considers the various social values that a species may pose, depending on the stakeholder or demographic of society. A species may be valuable for its overall contribution to biodiversity, which in itself leads to ecosystem services and contributes utilitarian as well as natural value to human and ecosystem livelihoods. However, some stakeholders may perceive these values in a differential way, with respect to their own development, charismatic, or cultural interests. The recipient/source social community may or may not value the introduction/maintenance of the species, or the source community may not want to give up individuals. This will impact whether AM is conducted at all, or in such a way as to maintain historical and new populations where possible.

As far as integrating with a local and regional plan (i.e., land use and state wildlife plans), it is important to have documentation of management issues and the science that informs the conservation strategy for the various climatic possibilities that could be in store in 2050 and possibly 2100. The integration of social values into these political plans for the immediate and far future should be made explicit, so that stakeholders can anticipate the benefits, resources and planning needed to potentially implement AM as part of an integrated conservation strategy that considers the timeframe and location of intense, moderate, and very intense intervention.

ETHICAL

In terms of ethics, it may seem odd to place this step at the very end of the framework. Yet ethical considerations are always context-specific, and without good scientific, legal and social information about a specific AM proposal, clear ethical deliberation is impossible. Premature discussion of ethical issues risks converting a discussion of ethics into an unlevel and uninformed playing field among stakeholders with varying interests that, though value-driven, may not be epistemically, cognitively, or morally informed. At this final step in the model, decision-makers and stakeholders will have gathered the necessary information and perspectives to inform their assessment of ethical points, especially as they relate to uncertainty. While the utilitarian and intrinsic values of a species are monumentally important interests to bear in mind, they are not the only ethical considerations. We live in a world that constantly unfolds within and between the natural and material. Therefore, ethics must be informed by a comprehensive list of considerations regarding the very nature of value. Every species is valuable, but its value is only realized in the context of well developed, informed, and integrative plans across ecosystems and its coherence with social, political, and legal thought.

III. Case Studies

A. AM for the American Pika

The American Pika:

Overview:

The American Pika (*Ochotona princeps*) is a habitat specialist ranging across cold rocky or mountainous areas through the western U.S (Wilkening et al. 2015). They are listed as a Species of Greatest Conservation Need in eight of the 10 states where they are located-- Wyoming, Colorado, Washington, Oregon, California, Nevada, Utah, and New Mexico. Montana and Idaho are the exception.

They pika are lagomorphs, with a narrow thermal tolerance and a resting body temperature of 40.6° C that is only a few degrees away from their upper lethal levels (43° C) (Wilkening et al. 2015; Smith et al. 2016; MacArthur and Wang 1973). They occupy areas with access to cooler microclimates (talus) for behavioral thermoregulation, and they do not hibernate (Wilkening et al. 2015). They are a sentinel species, meaning that they are a species whose ecological requirements allow scientists to detect hazards to a host of other species, including humans (Wilkening et al. 2015). Their distinct temperature sensitivity has led to research that uses the species' response to assess how "climate constrains species distribution" (Houston 2014; Mathewson et al. 2016, p. 1). Their responses are indicative of the response of endotherms.

Occupying mountainous ranges -- which are one of the most vulnerable environments globally to climate change (Markcrow 2017; Diaz et al. 2003) -- the pika are an ideal candidate for AM. They are also poor dispersers, as once a pika has established territory they are unlikely to move and, being habitat specialists, are less densely populated. Annual reproductive capacity is low, with 2 small litters per season, only one of which is successfully weaned each season (Smith et al. 2016). Offspring depend on their mother for care.The young are weaned after a month, and after three months reach adult size. After a year, they develop into breeding adult pikas (American Pika Foundation 2020). In growing seasons, the pika collect vegetation in haypiles stored in the cool talus they occupy for continued energy over the winter.

While some scientists point to the pika's adaptive capacity, particularly at Mono Craters in California, these areas observed keep an extremely low number of pikas, although they are genetically fit, and benefit from a subtending layer of permafrost, which besides keeping the pika cool in talus where microclimate dynamics produce ice to begin with, also can provide moisture to shrubs and herbaceous perennials (Smith et al. 2016). Density and fitness increase when vegetation is more abundant and made up of forbs, and pika are highly selective, but as global warming ensues and the makeup of haypiles created by pika are more dominantly composed of graminoids at Mono Craters, the pikas persist, again at low numbers. Over the past century, its range has risen 150 m as poor dispersers, whose migration is found to be 0.8 to 3.0 km maximum and under cool conditions (Burke 2018).

This might be an indication that the pika can naturally migrate as it needs, but it also anticipates that natural migration may very well not be enough for populations. This is an important caveat, as it points to the importance of context-specific analysis of the pika's needs, especially with regards to the level of adaptive capacity the pika exhibit (intrinsically and extrinsically) with time, fitness, and numbers within population, climate warming forecasts and disturbance events (Beever et al. 2015). Not only are pika populations isolated and discontinuous across the Great Basin region, but in the 20sth century already the region has warmed an average of 0.3 to 0.6°C, with an expected further rise of 2.5 to 4°C by 2100 (Rowe and Terry 2014), with 25 populations already extirpated across Nevada and southern Oregon (Burke 2018; Center for Biological Diversity 2020). Recent population losses have also been found in those areas, and in the Sierra Nevada range of California, leading to shifts north. Average elevations in the Great Basin have risen some 900 ft (275 m) in recent decades, with a loss of lower elevation sites. These extirpations have been correlated with climate change (Burke 2018). .

Dr. Eric Beever, who completed this study of the pika range encompassing the mid-1990's to 2017, has designed a geodatabase with Kyle Burke of the pika's presence and absence based on talus locations surveyed and not surveyed. His intent is to further understand climatic impacts in niche habitats that are especially susceptible to environmental change. The pika, being extremely sensitive to great shifts in climate, are an ideal indicator for the biodiverse species in these montane areas, as well as coastal zones. The pika are found at elevations from sea level to 3,000 m along the northern edge of their range, and to 2,500 m at upper elevations of the southern edge.

The needs of the American pika may be amenable to a combination of conservation strategies, including the maintenance of habitat quality and genetic rescue at edges and in metapopulations, as well as relocation within historic ranges, as well as out of range (Wilkening et al. 2015; Smith et al. 2016).
The American pika are found in Alaska, Montana, Wyoming, Colorado, Idaho, Washington, Oregon, California, Nevada, Utah, and New Mexico, and also western Canada, where the species' natural migration may be undermined by the collared pika (Ochtona collaris), which already occupies the refuges suitable to the American pika in Alaska, the Yukon, and northwestern British Columbia (American Pika Foundation 2020; Ray et al. 2012). The geodatabase that Dr. Beever created covers paleological presences of the species, as well as well as areas continuously extant for more than five years. The database allows for quick updates based on collected data using a data dictionary that aligns with GPS receivers (Burke 2018; Gonzalez-Tennant 2009). But the database must also be reconstructed for longer- term use allowing for the storage of collaborative data across management agencies, which are still transitioning their data collection to this approach (Burke 2018; Smith et al. 2016).

A range of strategies, including habitat improvement, corridor linkage, upward/elevation migration, artificial feeding of forbs, captive breeding and release to supplement populations are likely needed to preserve the species. With this background, we can now use my proposed framework to evaluate a hypothetical proposal for using AM for the American pika.

STEP 1: SCIENTIFIC/ECOLOGICAL

1A Is the species vulnerable?

[redacted]

e pika was denied an ESA listing in 2007 and 2010, due to the evaluation guidelines that do not prioritize the use of climate ange factors, and then to a deeming that pika populations will survive into 2050 and that losses will not be detrimental to the ecies, subspecies, or other species (U.S. Forest Service 2010).

t vulnerable to the effects of climate change?
s, it cannot withstand temperatures above 43°C, especially with exposure over time.

es it lack adaptive capacity or dispersal ability?
hile some scientists point to the pika's adaptive capacity, particularly at Mono Craters in California, these areas observed kee a v number of pikas, although they are genetically fit. Density and fitness increase when vegetation is more abundant and made of forbs, and pika are highly selective, but as global warming ensues and the makeup of haypiles created by pika are more minantly composed of graminoids, pikas persist, again at low numbers. Over the past century, its range has risen 150m (~.1 . The pika are poor dispersers.

er what space and time?
e pika have low heterozygosity across the range. Without genetic rescue and possibly translocation, within and outside of ge, the pika are expected to further decline, and become regionally extirpated, with probable extinction by the mid-21st ntury, especially with extreme related disturbance and climate events. Already the pika may be impacted by new climate ctors, including several novel and known diseases to the pika.

es it lack population viability?
terms of numbers, yes, but in terms of genetic fitness remaining pika are hnically preserved. In the Great Basin (primarily Nevada, much of Oregon and Utah, and parts of California, Idaho and Wyoming), the rate of site-wide extirpation of pikas from sites is even higher than what's cited in the 2016 publication of Erik Beever's. In that region, one site encompasses all of the talus within a 3-km radius. Among the sites in that region with historical record of pikas that still have pikas extant, 8 hours of surveys (starting once the surveyor is on the talus) produced 14. individuals detected per site. In that >100-million-acre region, Beever estimated that there are probably thousands to (at most) tens of thousands of individual pikas. In contrast, surveyors detected >350 pikas at 222 points across all talus patches in the Columbia River Gorge (primarily Oregon, Washington, and Vancouver areas)that were reachable by hiking trails and roads. In yet sharper contrast, in Grand Teton National Park (Wyoming), every talus patch we have surveyed is pika-occupied (Beever Personal Comm. 2020). According to the IUCN Red List, this species is of "Least Concern", and has no systematic surveying, tion recovery plan, or ex situ conservation plans; the IUCN acknowledges that the American pika have a decreasing pulation trend.

Yes/No

1B Can vulnerability be ameliorated by less intensive conservation actions (i.e., improve habitat quality, jump dispersal, corridor creation, etc.) -----

[redacted]

Besides habitat quality, less intense conservation alone will not save the species.

mbination of simpler management strategies?
mpler management strategies, even in combination, will not necessarily be sufficient to maintain pulations.

an vulnerability be ameliorated by moderately intensive action? (Connectivity, reserve networks, bilitation, restoration, management of novel ecosystem)

[redacted]

er measures.

there institutional capacity and coordination?
e genetic variability, by differentiation and local adaption, of different populations makes this species difficult to plan , and without an ESA or other listing, this species might not gather the attention it needs for formal coordination; and s coordination at only a moderately intensive level may not be enough to give rise to substantial populations.

licies developed by land management agencies?
Management agencies have pointed to certain data needs, including Inventory and mapping of American pika populations; monitoring population trends and status, coordinating and expanding knowledge of ecological climate - impact science, and integrating American pika research with studies on other alpine mammals, as well as developing and implementing adaptation plans (Hanley 2020; Smith 2013).

it financially feasible?
oderate intervention, in terms of restoration, might be a good strategy that will be more intense over time. The pika ve already increased their range by 150 m in elevation as poor dispersers, and a warming climate is the main stressor. hough the pika have shown an ability to tolerate that stressor at Mono Craters, their numbers are low and the rticular environment they experience with permafrost may or may not be the main contributing factor for their rsistence. Restoration without genetic rescue, which necessitates an evaluation of the persistence or lack thereof for a at other sites, might lead to inappropriate management overall. The pika—which are known to perish at nperatures exceeding 43° C, especially with time and a warming climate, call for a more comprehensive strategy in u and ex situ. Restoration alone may not warrant the funding needed, or may waste funding without an explicit nsideration for the likely need for a translocation.

1D Can vulnerability be ameliorated by very intensive action? (AM, reintroduction, genetic rescue, ex situ uture introduction)

[redacted]

he literature, there is some consensus among ecologists that AM is in order, but holars emphasize the mortality risks of taking and moving from various source pulations, and others stress the potential adaptive capacity of populations where they . Dr. Beever's geodatabase provides for the potential coordination at large, even as a populations might be assessed regionally for specific needs to maintain and give e to genetically fit populations. The most recent movement of the pika has resulted in aths after a day or two (Beever Personal Comm. 2020).

there institutional capacity and coordination?
ere is institutional capacity, but no coordination beyond research commissions, sentations at an annual conference, and attention from the American Pika undation, the National Wildlife Federation, the Center for Biological Diversity, tureWorks, and the California Department of Fish and Wildlife.

t legal?
always, there are open windows in management policy that could make AM possible, without an ESA listing in view, it is unlikely that this option will spur large-scale action ally, unless private individuals were to move the species, which is highly unlikely and ill vised.

there infrastructure?
rastructure has been detailed by Wilkening et al. (2015), in terms of wire mesh traps, dical evaluation of individuals, special transport, and a quarantined release site with xes or chambers underground, but this is not according to a formal plan.

t financially feasibile?
vould be cost intensive, though specifics haven't been forecasted. In terms of the long-m, planning for AM or translocations might make this cost worthwhile. However, Beever rsonal Comm. 2020) has said that AM is currently not a viable strategy.

nitoring ability?
nitoring could be relatively easy, with an initial monitoring of the quarantined site for weeks, followed by surveying twice per year in early and late summer, for two nsecutive summers, with original colonists located by ear tags for survivorship and ritory counts based on the number of hay piles to determine the success of juvenile ruitment.

E n: What are the critical questions, key tools and concepts that need to be further discussed to r ard with a proposal?

E d Burke's geodatabase should be adopted and contributed to by simple GPS population surveys i dardized system. Some questions that need further exploration are what the climate and a orecasts are for the pika at a population level? This might entail research on the genetic p type of adaptive capacity, fitness, and persistence of these populations. This might inform g scue. Further data on snowmelt is also needed, as well as topographic and microclimate i n that significantly attributes to the survival or demise of the pika, especially in southern regions. A analysis would help ascertain where AM might be applicable into the future. Also of interest is the i ural and protocols needed to ensure the survival and establishment of pika potentially in locations c historic range. Where this is deemed a possibility, managers will be equipped with more i n on the feasibility and cost-intensiveness of AM.

S LEGALITY/POLICY

2 roposed project legally permissible in the time and place proposed?

[redacted]

Is there legislation / laws on AM in particular jurisdictions?
Not currently.

Legislation/ laws on AM in particular landscapes?
Not currently.

Implications of court decisions on AM?
ESA denial may have backtracked the level of activity to address the predicament of the pika with research in a timely fashion. The court decision may have influenced the legality of AM, were management agencies to seriously consider AM. Orientation seems to have shifted to adaptive capacity and further study at the population level, with comparison (Beever et al. 2015).

Evaluation: What are the critical questions, key tools and concepts that need to be further discussed to move forward with a proposal?

More consultation is needed at regional scales to make appropriate context dependent decisions that might both be informed by the law and clarify its application.

STEP 3: SOCIAL

3A How is the species valuable?

[redacted]

[redacted] *s, the pika are a sentinel species.*

there a biodiversity/ecosystem function component?
e pika can be an indicator species for a host of other alpine species and is sensitive to climatic anges, especially in the near-term, that would help understand overall impacts on other mammals eever Personal Comm. 2020).

es species contribute economically?
.

oes AM/the conservation strategy suite integrate with a local/regional plan?

[redacted]

n for genetic rescue and translocations in/out of range are dependent on the available research that can sess how and for how long to sequence these different strategies according to the unique situations of pulations, some of which may be supported by restoration and genetic rescue alone, and some which require in situ translocation, and eventually ex situ establishment.

w? In 50 years?
overall plan, state by state, with multiple states collaborating is needed, and current plans may or might anticipate the level of need in 50 years' time to sustain substantial populations, despite Dr. Beever's database. Beever (Personal Comm 2020) has said that there is no overlap between populations.

ticipating research needs?
nagement agencies have anticipated research needs.

ticipating capacity needs?
nagement agencies have not collectively anticipated a plan for implementation at this point to finitively know the capacity needed in terms of surveying, employing simple conservation and moderate toration measures, with an eye on genetic rescue to bolster source populations, and based on an alysis of near term numbers and fitness. This informs the timing of longer-term strategies, including in and ex situ movement of species.

n modeler/Decision-maker collaboration
managers locally respond with simple measures to improve habitat quality, ecologists, NGOs, and ighboring jurisdictions/states should survey and assess the genetic/adaptive capacities of various pulations, so that managers will be better equipped to make informed decisions about the type and quence of conservation in store.

are the opinions of community members in both the source and recipient ecosystems about the ?

ost pika populations inhabit public lands, and opinions generally favor the survival of the species. here they overlap with cattle grazing landowners, there is some pushback (Palmer and Larson 12), as some scientists view cattle grazing as a more immediate threat (Smith 2020), while hers say its overall impact is minimal (Palmer and Larson 2012).

ere societal consensus about the value of the proposed AM?

enerally the public and social media at large favor this charismatic species. But across the ranks scientists and managers, there is a combination of reticence and readiness to move the pika. e costs and viability of doing so will be important to how conservation strategies unfold, if they .

on: What are the critical questions, key tools and concepts that need to be further discussed to rward with a proposal?

lic, in various regions/states, should be informed about the scientific, ecological, and social f this sentinel species in such a way that gives context to the species' particular vulnerabilities appropriate strategy as an isolated population, or (unlikely) through a strategy involving multiple ons. The public should be informed about the economic costs of these strategies, and surveyed ons about the acceptable level of losses, especially in southern regions.

STEP 4: ETHICAL

Should this AM proposal be implemented in this time and place, and if so, why?

[redacted] *some areas and moderate conservation in others, where it is important to bolster populations and derstand their connection and mismatch across the range (both as population pools and in terms of selection), translocation in situ might occur before AM.*

[redacted] **certainty and risk posed to species and people?**
as might very well carry several pathogens and diseases, which could impact recipient sites, but ely not people. Precautions can be taken to select healthy individuals from more robust populations; ere is concern that source populations may be pulled from too soon, to the detriment of an already indling species.

[redacted] **herence among preceding step values?**
ere is generally coherence among step values, were an ESA granted.

[redacted] **herence with theoretical interactions/practical applications of other traditional and emerging thropogenically driven methods?**
ere can be greater coherence among strategies employed, were there a clearer evaluation and mmary of pika populations across regions, as well as suitable relocation sites.

[redacted] **odiversity value to ecosystem function given evolutionary potential entailing ecosystem rvices (i.e. instrumental value, option value, intrinsic value)?**

e pika provide climate-indicator value, with evolutionary potential that does not exclude assistance.

[redacted] ation: What are the critical questions, key tools and concepts that need to be further discussed to forward with a proposal?

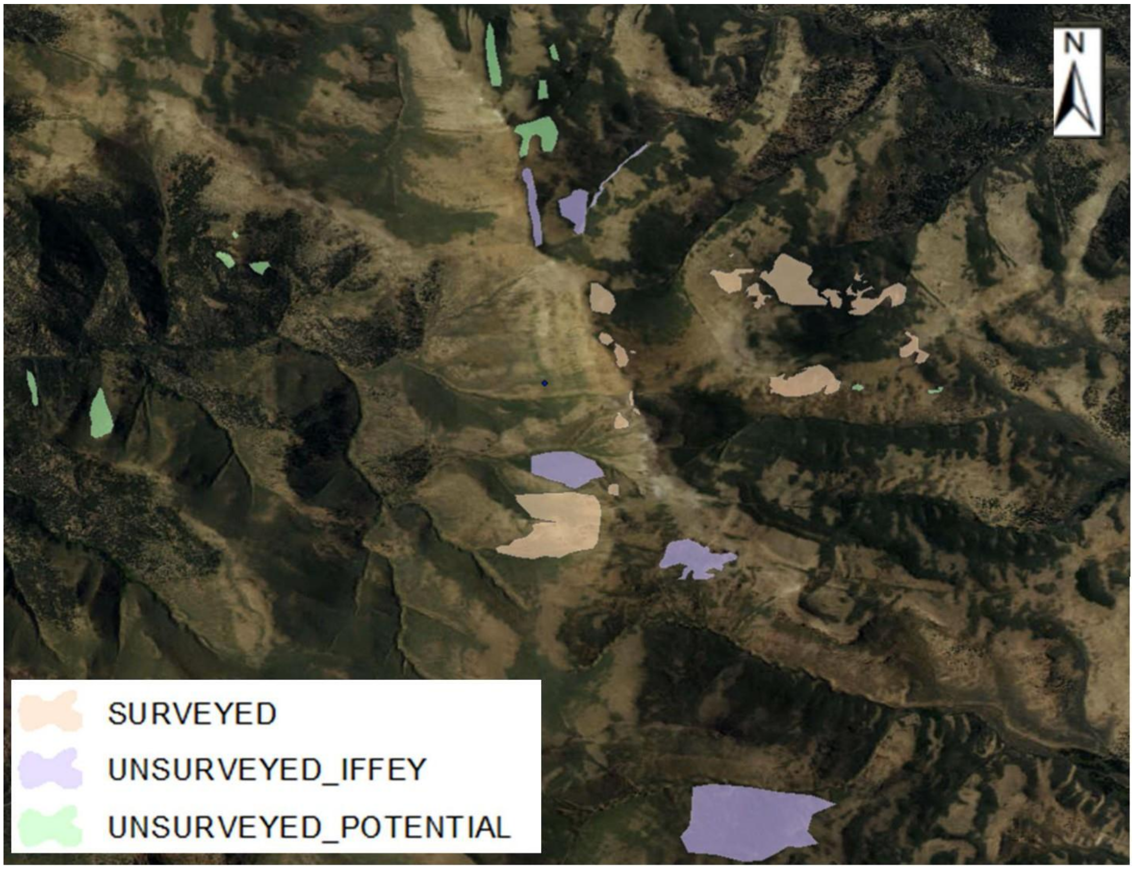
[redacted] is considerable uncertainty in terms of judging the persistence of the American pika population by ation, when regional details (e.g. population/genetic dynamics and adaptive capacity in light of local oader climate dynamics into the future) are not specifically detailed by SDMs or management ies. This is a key consideration when ethically approaching a decision to implement AM in the and draw from population sources that may or may not survive with dwindling numbers. The ses of a denial of the ESA listing might be challenged, were this research, data and consultation regional managers better accounted for.

[redacted] **ion:**

[redacted] Although the U.S. Forest Service finds, with the research of the IPCC and the National Oceanic mospheric Administration, that the native range of the pika is expected to increase in the summer ° by 2050, they denied the American pika an ESA listing once again in 2010. At that time, they [redacted] that the pika would survive across its range in the Northern Rockies, Southern Rockies, Coastal ain/Cascade, and Uinta Mountains, “where populations will not be adversely affected by climate change because the majority of pika populations occur at high elevations with correspondingly lower mean temperatures" (U.S. Forest Service 2010, p. 1).

The current isolation of multiple fragmented populations within each lineage may be similar to previous interglacial periods, resulting in similar genetic structures across high and low latitudes despite variation in climate. While this is informative, precaution should be taken by accounting for the general pattern of differentiation, which necessitates independent genetic management for at least each subspecies or mountain system (Wilkening et al. 2015). This requires better coordination among agencies and jurisdictions. This is also part of planning for a suite of conservation strategies that may or may not include AM for one region over another. But while the Forest Service and some scientists rest their hopes on the adaptive capacity of the pika, it may be that they only survive in small numbers in places like Mono Craters and the southern range in general, and it is doubtful that they will remain into the future without some intervention—even should subsurface temperatures (often not accounted for) be more important to the species' survival than surface temperatures (U.S. Forest Service 2010, p. 1). Until the identification of relevant loci and their quantitative connection to fitness and demography occurs more specifically it will be challenging to definitively predict a specific population's vulnerability to climate change. It is true that Dr. Beever's ongoing research and Burke's (2018) geodatabase conclusions at range scale are constructed in a meaningful way, but there is room for improvement by increasing temperature and humidity data records, the latter of which was assessed as the greatest predictor of survival, with the critical data from the iButton tool. Hardware to process these numerous records (e.g. by using Loggernet) would help, and so too would simpler survey designs based on Burke's (2018) study design.

While population specific studies are needed regionally, it is true that research through the 2000's shows increases in populations overall, even as surveys might not effectively account for pika presence. However, Beever (Personal Comm 2020) attests that overall there have been decreases across the range. Beever's at large overview of the pika is useful to the U.S. Geological Survey by providing answers to queries significant for the whole range (see queries below), and by giving an indication of the areas that have been surveyed, areas possible to survey, and areas with the greatest potential for survey. That is the critical connection to a prioritization of population study, which should entail more specific queries (Burke 2018, Table 2, p. 30).



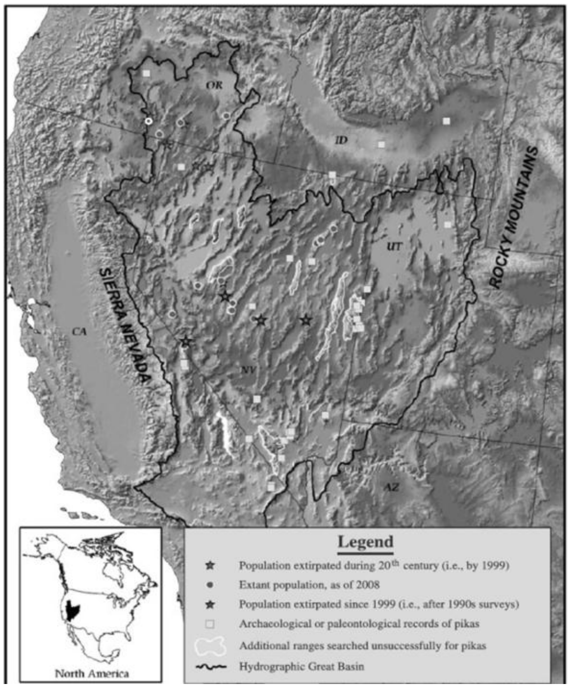
(Burke 2018, Figure 9, p. 29).

The Forest Service also found that the Great Basin population could be affected by climate change along with some lower elevation American pika populations outside of the Basin, where higher mean temperatures are predicted. Losses were deemed as “not causing any species, subspecies or distinct population segments of pika to become endangered in the foreseeable future,” or by 2050 (2010, p. 2).

While Burke’s (2018) geodatabase provides the impetus for an important bird’s eye view, the American pika, again, call for a dense genome-wide data set sampled from multiple populations across the range, so as to ascertain patterns of genetic distance, homozygosity and patterns of linkage disequilibrium among and within lineages that will build pedigrees of source populations and “determine whether the putative founders are close kin” (Wilkening et al. 2015, p. 229). Genotyping by sequencing coupled with high levels of multiplexing of individuals can lead to DNA libraries of population genomic data for the American pika, facilitating greater resolution of local genomic differentiation within isolated populations across the range (Parchman et al. 2012). These points indicate an understanding that the pika are very vulnerable, perhaps enough for a listing, because their genetic lineage, diversity, and fitness may or may not be enough as an isolated population, and losses may not be compensated for by far off populations who bear little resemblance. Therefore, this writer believes it is better for an ESA decision to be made with more knowledge of how exactly the American pika could survive into the future across the range.

Survival at large and adaptive behavior at regional scales would need to be incorporated into the planning process for AM, called genetic adaptation. This would be important when drawing from a source or many source populations. By considering the limits and extent of adaptation intrinsically and extrinsically over time at the mountain system or subspecies scale, managers could do a better job of coordinating and individualizing an overall strategy for the pika, that includes restoration and quite possibly AM in the future (Beever et al. 2015).

This writer expects that AM will have to be planned for now and translocation implemented in the near or farther-term future, based on the areas identified for restoration using Burke's (2018) geodatabase and considering the areas delineated for genetic rescue.



(Beever et al. 2011)

Adaptive capacity alone within range is definitely not a guarantee long-term, but slow migration rates and good behavioral plasticity to a cooler microclimate at higher elevations is. Recognizing and tracking adaptive capacity regionally will inform how populations should be managed in the near term, with an expectation that managers will have to intervene and assist populations in a way that facilitates a continuum of fitness, numbers, and environment. This could lead to appropriate, very intensive actions, regardless of the denied recognition of vulnerability through an ESA listing.

With respect to the importance of the development and limitations of the pika's adaptive capacity, this charismatic species is a useful indicator for climate impacts and their correlation with the survival of many other biodiverse species. The pika ought to survive substantially into the future, with an appropriate allotment of resources federally to direct and fuel regional management, whose context specific data will inform separate and at large management plans. It will, in turn be critical for future forecasts at the range scale. This is the uncertain and necessary range-to-region-to-population strategy that will have to safeguard the American pika.

B. AM for the Whitebark Pine

Overview:

Whitebark pine (*Pinus albicaulis*) is a keystone or 'foundation' species whose survival would provide for the persistence of hundreds of other species, chiefly among them the Clark's nutcracker species, as well as grizzly bears, black bears, and as a nurse tree for a host of other species (Palmer and Larson 2012; Smith et al. 2013). These species depend on the whitebark pine for its seeds, and the whitebark pine's survival, in terms of regeneration, depends on the Clark's nutcracker, which buries the pine's seeds some two to three centimeters underground. From here, under the right conditions, the seeds mature slowly. Whitebark pine sometimes require 30-60 years to begin producing cones, several decades more to produce significant seed crops, with roughly a 60-year generation time (Palmer and Larson 2012; COSEWIC 2010). It is also a habitat specialist, so that it is unlikely that the whitebark pine will move north beyond a few miles (Zimmer 2014). The keystone species—which further stabilizes soils, retains soil moisture, modifies soil temperatures, slows the progression of snowmelt and helps prevent flooding at lower elevations (Palmer and Larson 2012)—will likely suffer more as temperatures continue to warm. It is predicted that by 2100, 97% of the whitebark pine's natural range will disappear from the U.S. (McLane and Aitken 2012), where it is currently a candidate for an endangered species listing. In Canada, where a national endangered species listing was made in 2012, preceded by a listing under the Wildlife Act in Alberta and a listing of 'species of concern' by the British Columbia Conservation Data Center (Smith et al. 2012), the whitebark pine is expected to be extirpated in many local populations (COSEWIC 2010).

Already, whitebark pines are being decimated by white pine blister rust (WPBR) caused by the invasive fungus *Cronartium ribicola*, and it is also plagued by the mountain pine beetle (MPR, *Dendroctonus ponderosae*). Moreover, the synergistic effects with fire exclusion and, again, climate change are a reality (Smith et al. 2012). WPBR (*Cronartium ribicola*) reduces seed availability, by way of canopy kill and direct mortality; because the rust impacts the upper cone-bearing branches before the tree itself (McDonald and Hoff 2001), the loss of canopy translates to loss of seed production as well and therefore regeneration (Keane et al.1994). Seedlings can also be infected; once these develop cankers, known for their bright orange and yellow coloring (Smith et al. 2012), the majority die within three years

(Hoff and Hagle 1990). Although the MPR prefers the thicker phloem layer of larger diameter trees (>10-12 cm) that create better reproductive conditions (Cole and Amman 1980), even small trees are vulnerable to the beetles because of proximity to larger diameter stems in multistem clusters (Perkins and Roberts 2003). Both diseases were studied for their impacts on whitebark in 1996 (Kendall et al.), 2003, 2004 (Smith et al. 2013), and 2009 (Smith et al. 2013).

Already, some half of whitebark pine have died from the two diseases/synergistic impacts of decline. Agencies (i.e., the U.S. Forest Service and the National Wildlife Federation, with the help of the Whitebark Pine Ecosystem Foundation) drafted a plan in 2012 to restore the tree by rebuilding populations by planting seedlings and setting controlled fires (Zimmer 2014). Historically fires have been suppressed throughout the pine's habitat, giving an advantage to already dominant species such as subalpine fir and Engelmann spruce, whereas the whitebark pine are fire-tolerant.

Another strategy would be to fell competitor species within 10 km of whitebark pine seed sources, so that nutcrackers would be better attracted to cache there, further encouraging natural regeneration (Palmer and Larson 2012). However, if McLane and Aitken (2012) are correct, in 60-80 years when the trees would hopefully be in their reproductive prime, almost all of their climatic envelope in the U.S. would be lost. However, this same strategy could be employed in norther Canada, where temperatures would be more hospitable.

More recently, whitebark pine are exhibiting signs of resistance to rust and beetle infections, as well as warmer temperatures, and are being studied for selection, should AM be employed—allowing the species to move farther north (Palmer and Larson 2012).

Puzzlingly, ecologists note that nutcrackers have not moved the species north. It is surmised that the relatively high WPBR infections (49%) near the northern limit of the range has 'implications for natural migration latitudinally' (Smith et al. 2013). The northern edge produces less cones, and nutcrackers, which requires some 1000 cones/ha (McKinney et al. 2009), would be unlikely to cache there. Another likely answer, which scholars deem to be the straightforward one, is the absence of soil in this colder snowy region, where soil is unlikely to accumulate for millennia, if ever (Palmer and Larson 2012). This means that AM is perhaps not viable, unless there are resources to inoculate the site. Whitebark pine prefer siliceous soils as opposed to limestone soils in Canada, unless they are very moist, and nutcrackers prefer diverse microsites to cache 1 to 3 cm under substrate, including forest litter, mineral soil, gravel, or pumice (Keane et al. 2017).

For these reasons, many scholars consider AM to be a good idea, should it be feasible in terms of costs, which are not known for restoration or AM. Also there is always room for improvement of SDMs, which are challenged insofar as applying regional models at a local scale, where the microtopographical variability in montane habitats is less clear (Palmer and Larson 2012).

However, McLane and Aitken (2012) tested SDMs for their robustness, by experimentally determining whether the whitebark pine could survive beyond the current range. Collecting seeds from seven provenances, the authors' team planted these in eight locations, two within current range and six beyond, where it is predicted that the environment will be habitable for the tree under current and 2055 climatic conditions (Palmer and Larson 2012). Seeds were collected from the northwestern part of the range and were chosen intentionally from a wide geographic and climatic gradient to account for genetic differences. Half of viable seeds were treated. At all stages of the process, nonviable seeds were tallied (McLane and Aitken 2012).

Germination, survival, health (i.e. foliage and stem appearance), height and needle fascicle data were tracked over 2008-2010, with the first two factors considered as binary variables. Explanatory variables were four: cache microsite (vegetation heights, soil type, soil depth, slope, convexity), site climate (normal MAT and PAS, summer temperature, winter temperature, snowmelt date), provenance climate (normal MAT and PAS) and seed mass, and finally seed treatment. Survival was modeled separately for treated and untreated seeds in the 2010 dataset.

What is most significant is that all seedlings survived and grew in all 16 common gardens, showing that the whitebark pine, or at least resistant strains, might survive planted north, far outside its current range. The locations spanned some 10° latitude, from 600 km southeast to 800 km northwest of the current northern range margin (Palmer and Larson 2012; ibid). The study demonstrated that the failure of the species to move north is likely a matter of distribution, not survival (McLane and Aitken 2012). If calculated in terms of total original seeds, including those discarded, 8.1% of untreated and 11.7% of treated seeds survived.

> "Survival of untreated-seed seedlings was primarily negatively associated with colder winters, while survival of treated seed seedlings was primarily positively associated with seed mass and warmer summer, and negatively associated with later snowmelt dates" (McLane and Aitken 2012, p. 148).

Height, fascicles, and health were primarily positively associated with both provenance and site temperature, and negatively associated with later snowmelt. Microsite factors negligibly influenced these (McLane and Aitken 2012).

Among whitebark pine families, seed mass was highly variable and was the primary predictor of establishment potential. "Heavier seeds with better developed embryos developed into larger, healthier seedlings" (McLane and Aitken 2012, p. 148). While for most tree species seed mass decreases with latitude, whitebark pine is an exception (Moles and Westoby 2003), a sign of the coevolution of nutcrackers with the species: whitebark pine seeds must be larger to provide a net energetic gain for nutcrackers. Yet, the short growing seasons of the subalpine environments prevents full seed maturation prior to harvest. Where low seed masses and poorly developed embryos have been found, leading to low germination rates, ecologists believe that maternal effects caused by unusually extended snow cover during a summer of cone development are to blame, rather than genetic or normal-climate factors (McLane and Aitken 2012).

McLane and Aitken (2012) also believe that the species establishes even more successfully with landscape features such as trees, herbs, logs, rocks, and stumps that protect it from sun and wind (Mellmann-Brown 2002), an environment which was lacking in the systematic location of sites away from these features, "to minimize confounding effects" (McLane and Aitken 2012, p. 150).

This study did not go into quantitative-trait differences among populations because of the expense and difficulty of common garden experiments, although two such studies found seedlings from milder provenances grew faster and larger but had lower cold tolerance than those from harsher locations (Mahalovich et al. 2006, Bower et al. 2006). The data from McLane and Aitken's (2012) study partially confirmed these conclusions in their variable domain, as seed mass was only 3% correlated with provenance temperature. The authors further believe that genetic effects and genotype-by-environment interactions might increase with age, a factor that the authors will note in future site visits of the ongoing experiment.

Ecologists would have to anticipate how they would facilitate the movement of the Clark's nutcracker later, which could not take place until the whitebark pine reached reproductive maturity and produced sufficient feed crop, a delay of some 60 years posing one advantage of a warmer climate for the birds. It is possible that the Clark's nutcrackers would migrate by this time, but if not it is also possible to create stepping stones of suitable whitebark pine habitat to lead them on their way north (Palmer and Larson 2012).

Whitebark pine, with generations lasting 30-100 years, are highly unlikely to adapt to the estimated 3°-5° C mean annual temperature increases projected (Christensen et al. 2007). The species is likely to be outcompeted, even with migration at the margins that lack soil, by other faster-growing vegetation encroaching from lower elevations (McLane and Aitken, unpublished manuscript).

With this background, we can now use my proposed framework to evaluate a hypothetical proposal for using AM for whitebark pine.

STEP 1: SCIENTIFIC/ECOLOGICAL

1A Is the species vulnerable? ------

Yes/No

[redacted]

[redacted]

A in Canada.

it vulnerable to the effects of climate change?
s, with synergistic impacts from disease, as well.

es it lack adaptive capacity or dispersal ability?
as some drought-resistance and tolerance for the subalpine area and distribution beyond, and can
w in harsh environments.

ver what space and time?
e species has been vulnerable since 1910, when fire was suppressed, and its vulnerability is now
ent, with 97% of the population projected to decline by 2100 (McLane and Aitken 2012; Palmer and
rson 2012).

es it lack population viability?
s, many populations have already been extirpated in Canada and the U.S.

1B Can vulnerability be ameliorated by less intense conservation actions (i.e. improve habitat quality,
jump dispersal, [redacted]

e last conservation strategy spearheaded in the U.S. by Keane et al. (2012) to restore the itebark was reported a failure in the new Keane et al. (2017) strategy, which continues to employ toration, this time with an anticipated climatic responses at regional/landscape levels.

mbination of simpler management strategies?
intenance of habitat quality alone or with other strategies, such as fungicide and permethrin plications for rust and beetles respectively would not be sufficient to maintain species, due to cost d labor intensiveness.

1C Can vu y be ameliorated by moderately intensive action? (Connectivity, reserve networks,
[redacted]

e Keane et al. 2017 report reflects some consensus to stick to an augmented restoration plan, but no formal ns are definite and further research is needed to anticipate the predictions the authors report, as ecological nulations depart from management conclusions. While mention was made of drawbacks to restoring in range, nerally the authors outweighed these considerations with a bias against AM, which other ecologists believe is iable solution.

there institutional capacity and coordination?
ere is a level of coordination, as this new strategy was presented as a report responding across borders and s published by the USDA, the U.S. Forest Service, and the Rocky Mountain Research Center.

t financially feasible?
s unclear whether the restoration programs, in order to be successful—an outcome which is not defined— ve resources to indefinitely promote restoration at a large scale according to prioritized landscapes, because plan involves continual collecting of rust resistant seeds, the maintenance of orchards with the presumed lity to accelerate cone growth, and the likely failures that might not be mitigated by fire suppression or burns t interact with disease trajectories (perhaps sometimes for the good) or most importantly, the climate.

[redacted]

Can vu y be ameliorated by very intensive action? (AM, reintroduction, genetic rescue, ex situ
re intro

e most official report in the U.S. indicated that AM was not a good option, but this conclusion is mostly predicated on cost, well as the biased scenarios with climate under their response regime. Analysis was quick to frame AM implicitly as a istance method that might be effective in the short-term while returning to vulnerability as the climate warms. Other ologists actively promote AM and show that rust-resistant species can survive beyond range and will not migrate fast ough on their own to do so (McLane and Aitken 2012). A restoration only strategy seems to be approaching AM, with an phasis on genetic rescue or future introduction by way of continual collection and archival. This writer concludes that there apparently an informal consensus on the new restoration strategy, but it is doubtful that there is overall consensus among ologists or even managers.

there institutional capacity and coordination?
ere is capacity, with the 5 Needle Pine Group of the Crown Managers Partnership, and 90% of whitebark pine occurs on blic lands, so it is quite possible for there to be coordination (Palmer and Larson 2012).

it legal?
ould states and provinces coordinate across borders, the legality of an AM project should follow, especially with a potential A listing.

there infrastructure?
e main 'infrastructure' required is rust-resistant seedlings, which reportedly are not sufficient in number for AM (Keane et 2017) *.*

licies developed by land management agencies?
, though there is room for public agencies to apply AM with respect to vulnerability and even experimentation.

it financially feasible?
e high cost of AM, in terms of research and experimentation to test for survival under an AM plan, is noted by the new ategy report, although the costs of the new restoration strategy are not clearly assessed, and seem to occur indefinitely.

nitoring ability?
e level of implementation, planning, and improvised response treatments under the new restoration strategy, and the reased monitoring required make it likely that monitoring of an AM project would in comparison be relatively less intensive.

Evaluation: What are the critical questions, key tools and concepts that need to be further discussed to move forward with a proposal?

Some key questions to consider are perhaps the political and management orientations that will influence the discussion of high vulnerability for this species and its listing under the ESA in the U.S., as has been granted in Canada. Although media outlets make significant mention of AM as a likely strategy for conservation, management reports have relied heavily on restoration apparently in isolation of other strategies. SDMs/Simulations of various regions of whitebark pine responses to restoration management will have to be better reconciled with the latest report's qualitative judgment that the species will survive with their plan, due to apparently indefinite plantings of rust-resistant seeds; the species' ability to tolerate drought; and the short-term positive growth impacts of increased CO_2 levels, while competitor species migrate north to escape both drought and prescribed fires. Whether this truly leaves the whitebark pine as a "dominant" species is something to be better articulated, or reconsidered. Is there a better balance of a restoration strategy, which preserves the indigenous historical and recreational value of the whitebark pine in situ and further allows the keystone species to moderate flooding and soil composition as the climate warms, to extend this narrative and these values to recipient sites out of range in Canada? In short, are managers fairly considering the potential need for AM down the line, with restoration as well? And if managers are deeming that there are not yet enough rust-resistant seedlings available, what would be the material/infrastructural requirements necessary to carry out a potential project? Finally, if managers report that the mountain pine beetle is in fact the greater threat to the species, especially as the climate warms in subalpine areas as well where the chilling periods that would interrupt reproductive beetle cycles are no longer a factor in inhibiting the spread of disease, how is the current restoration strategy sufficient, especially as it assumes the weathering of blister rust, pine beetle, and synergistic climate impacts that have already been recognized as decimating a high percentage (over 65% in some regions) of the species, projected to be extirpated by 2100?

STEP 2: LEGALITY/POLICY

2. Is the p[redacted]

Is there legislation / laws on AM in particular jurisdictions?
No, not specifically.

Legislation/ laws on AM in particular landscapes?
No, not at the moment.

Implications of court decisions on AM?
No relevant court decisions to this point.

Evalu[redacted]hat are the critical questions, key tools and concepts that need to be further discussed to move[redacted] with a proposal?

What[redacted]litical and management orientations that will influence the discussion of high vulnerability for th[redacted]s and its listing under the ESA in the U.S., as has been granted in Canada? And are there mana[redacted]policies at the state and federal level which must be developed to better anticipate the logist[redacted] proposals and needs of this particular species, especially as it is an obligate species with the C[redacted]tcracker, and a keystone species for grizzly bears, black bears, and as a nurse tree for other[redacted]

STE[redacted]IAL

[redacted] *torically and culturally valued, especially by recreationists.*

[redacted] there a biodiversity/ecosystem function component?
[redacted]s, the tree is a keystone species and is important to and dependent [redacted]on on the Clark's nutcracker to regenerate.

[redacted]es species contribute economically?
[redacted], not in terms of commercial value.

3A H[redacted] species valuable?

3B D[redacted]he conservation strategy[redacted]egrate with a local/regional plan?

of these aspects are unclear, but in comparison to the restoration program, it could be and may be an important -hedging strategy. Much attention has been given to the species through media and environmental advocacy, so t AM has been introduced as a viable measure.

w? In 50 years

w and in 50 years.

ticipating research needs?

rther research quantifying genetic makeup of seeds is needed, also to identify responses to colder climates.

ticipating capacity needs?

s would entail transboundary coordination and coordination across states and provinces.

n modeler/Decision-maker collaboration

e USDA, Forest Service, Rocky Mountain Research Station, National Parks, and Natural Resources Canada ould converse with a greater portion of the ecological community to simulate the trajectories of an AM project in nada, especially using McLane and Aitken's (2012) study as a guide.

hat are the opinions of community members in both the source and recipient ecosystems about the proposal?

At the source, there is considerable value of the whitebark pine's survival. However, this support may be bound by the historical and cultural value of the species rooted in situ so that members of the local public have reached out to managers to point out omissions of trees where there is overall a dwindling number of whitebark pine. This is the only source opinion I gathered. In it, the individual in Washington also cited a paragraph from an indigenous court case against the federal Forest Service, in which the defendant noted that he would not indulge an exchange for money, but only land. The individual further corroborated his confidence in localized restoration plans with rust-resistant seeds.

there societal consensus about the value of the proposed AM?

There is a wide public/societal base of support for the whitebark pine's survival at large, with media making introducing AM as a viable strategy for the whitebark pine and other species into the future.

ation: What are the critical questions, key tools and concepts that need to be further discussed to forward with a proposal?

needs to be better consultation among management agencies in the West, and better formulation of propriate strategy across the range, to inform public outreach and education, while eliciting public ons, perhaps by region, through meetings and subsequent surveys. In this way, local and regional and roader public will be better attuned to both the in situ and ex situ values of different conservation gies, like restoration and AM.

4: ETHICAL

d this AM proposal be implemented in this time and place, and if so, why?

ere is great urgency, as the whitebark pine is attacked on all sides, by disease, climate warming, and vironmental factors such as competition, as well as low migration rates.

certainty and risk posed to species and people?

ere is reasonable uncertainty, but greater risk posed in an isolated and intensive restoration program. The lity of the species to survive has been tested and proven beyond historical range, while it is far from likely t nutcrackers will remain as a source of regeneration for weakened tree populations that ultimately sustain species. There is uncertainty in whether the nutcracker will have moved north by the time AM trees reach productive capacity. If they have not migrated, it would be wise to coordinate stepping stones.

herence among preceding step values?

I is not in total coherence with preceding step values, as it is unclear what the scientific community's overall sponse is to the movement of whitebark pine, even as a Canadian scientist carried out a successful AM periment with other scholars also coming to the conclusion that AM is a viable option. According to the four thors of the strategy report, restoration is best, however they show a reticence to employ AM, and qualify the ly severe impacts to the species that will occur with their restoration strategy alone. This might be in sponse to locally rooted values to maintain the population in situ, while the recipient communities (likely in nada) indicate an openness to AM. The public at large, without more indication of the possibilities of AM, is ly to simply support whatever conservation strategy is adopted, despite the underlying risk.

herence with theory and practicality of other traditional and emerging anthropogenically driven thods?

s, AM should be in concert with restoration, and shares the desire to promote resistant seed growth. Their meworks complement each other, as a way to prioritize populations across the country that are adapting so and move resistant seeds that are genetically fit and diverse from these populations to establish out of ge.

odiversity value to ecosystem function given evolutionary potential entailing ecosystem services . instrumental value, option value, intrinsic value)?

e whitebark pine is a keystone species, providing a higher protein source to nutcrackers (when in good alth and numbers), and they stabilize soils, retain soil moisture, modifiy soil temperatures, slow the gression of snowmelt and help prevent flooding at lower elevations. However it might lose those useful perties as other species migrate, when it could eventually provide a host of services for populations out of ge. Its evolutionary potential at the northern range is likely, given McLane and Aitken's study and further earch. But its adaptive capacity is limited in range, and its ability to be rejuvenated through toration/genetic rescue under an increasingly warm environment—is unlikely, as the nutcracker might very ll have moved on, necessitating a reliance on wind and pollinator cloud dispersal and further plantings. ese may result in a less genetically fit and diverse population, adding further costs and labor to the storation" program. The latest strategy, by ignoring the need to prepare an AM plan complementary to toration sites, condemns the overall range and justifies this with a claim that more seeds can always be nted in situ and expected to survive this time. This calls into question the purported economic motives hind the strategy, and relies too carelessly on the species' adaptive capacity. Furthermore, the whitebark e have social value as an iconic and aesthetic species enjoyed by recreationists that draws thousands of itors to national parks and public lands.

ation: What are the critical questions, key tools and concepts that need to be further discussed to forward with a proposal?

needs to be a better economic and ecological appraisal of what populations of whitebark pine will st, and under what ecological conditions, conservation treatments, and significantly, the forecasted ation of resources and time to a specific strategy. There needs to be better definition of the threshold ich scientists and managers decide a population or region is in need of a different strategy, and her the species/rust-resistant seed stock are sufficient to employ AM at an appropriate site.

Decision:

Despite the historic value of the whitebark pine's indigenous range, its cultural viability may not exist in the future under a restoration strategy that cannot adequately anticipate the local to global interaction of climate and extreme events, and also cannot claim to know the adaptive capacity of the whitebark pine.

Although ecologists do not exactly impose a duty to move the whitebark pine, they do recognize that there are several good reasons to do so. Infections of WPBR and MPR continue to cause alarm judging by the increase in mortality between 1996 and 2003-2004 (26% to 61%) and 65% in 2009 (Smith et al. 2013). Levels are higher in the Canadian Rockies than in the Greater Yellowstone Ecosystem (mean 20% infection, GYWPMWG 2010) and Washington (mean 22% infection and 31% mortality) (Rochefort 2008). The infection rates are highest in the southern Rockies (83% of trees), decreasing to a low in the northern region of Banff National Park (36%) and moderately rising in the northern end of the study area in Jasper National Park and McBride, British Columbia (49%) (Smith et al. 2013).

The adaptiveness that is assumed with extreme drought by the authors of the latest strategy is also predicated on the increase in CO_2 levels as a positive, with convoluted ecological logic casting doubt on higher elevations in terms of AM and promoting the incidental short-term aspects of growth and stability as a function of the whitebark pine's ability to retain water and energy, while fire and drought incite the movement of competitor species north. The whitebark pine would be "dominant", provided that there is low WPBR and MPR activity (Keane et al. 2017).

Finally, fires might wipe out rust-resistant trees, which are "the foundation of the restoration strategy" (Keane et al. 2017, p.35) in providing rust-resistant seeds and the potential for seed dispersal by nutcrackers. Were resistant trees to be killed, this would reduce opportunities to spread genes for rust. Whitebark pine's natural migration is boosted by the authors, when near the end of the report they return to the assessment that migration is slow and unlikely to keep pace with climate change.

Already there has been a large-scale decline of cones for nutcrackers. Therefore, it is evident that managers should proceed formally with plans for AM, as well as restoration in areas where whitebark pine populations are robust to disease, and not to expect that the already diminished species will recuperate through incidentally "positive" adaptations to various stressors. While finer scale research has not fully anticipated the genetic needs of the whitebark pine with respect to snowmelt, frost, and cover, and might take time to supply disease-resistant seeds, there is more uncertainty regarding the adaptive potential of whitebark pine, even perhaps with incessant restoration support, which has failed to maintain existing populations to date. The new strategy is too risky, even should historical values feel more rooted in indigenous range. While there is no direct commercial payback for the species, it is certainly valued in various ways—including holding snowpack for longer times that affect hydrological cycles, flooding and resilience to the effects of drought and rapid snowpack melt—but climate change is simply occurring too fast for the whitebark pine to naturally migrate or mitigate impacts. Without at least an intention to go forward with AM and restoration in concert, managers will not be equipped with the option past the near future. At some point, seeds will be tied to drought climates perhaps to its own detriment, which might wipe out the possibility to foster a species out of range and regenerate at substantial numbers. The capacity to plan and coordinate iteratively is there, regardless of AM's expense, which might be reasonable in retrospect should current restoration plans not save the species at large. A decision to move forward with AM and restoration where it is appropriate, is the truly moderate approach, and to write off AM when it is more helpful in the near term, might impact the whitebark pine's survival at large. AM can also account for the potential of a changing narrative, while restoration guards localized and historical values. The continued sole focus on restoration and genetic rescue might also prevent a much needed ESA listing, to more fully open up a legal and management orientation to AM's possibilities. The economic costs of indefinite ”restoration” are likely higher than AM, but coupled could better economically fuel research and action, and better inform how to prioritize conservation strategies with this species, according to improved modelling and communication with managers at various scales.

Conclusion:

In embarking on a study of assisted migration, this writer has found that there are important aspects of AM, especially ethically, that should be examined with care. While it is obvious that climate change is already having impacts on ecosystems, even creating novel ecosystems for which there is no specific reference, novel strategies like AM entail intense human manipulation and intervention. Without more clarity of the scientific viability of translocating a species out of range and its impact on both the source and recipient communities under various scenarios over time, this controversial conservation strategy risks poor implementation. It is an individualistic strategy, but can encompass overall ecosystem health by way of a species' contribution as a climate indicator and sentinel species (e.g., the American pika), a keystone species (e.g., whitebark pine), or other values (e.g., historical and cultural). As such, the integration of other moderate and less intense conservation strategies, namely restoration and maintenance of habitat quality, is key to preparing for AM's implementation. It will be important for land managers and ecologists to reorient their missions and research to the changing nature of conservation, which is currently devoted namely to the preservation of native and wild spaces, which are "untrammeled". Currently, the legislation that is most relevant to promoting AM is the Endangered Species Act. More coordination and experimentation/AM trials will give way to policy and laws that can explicitly account for the risks, logistics, and monitoring of AM projects. It will also allow managers to better anticipate the cost-intensiveness of AM, compared to or in conjunction with other strategies. As this process unfolds, decision-makers and ecologists will have to assess what frameworks are best to analyze the specific needs and context of a species at the landscape and regional scales. This writer hopes that the AM framework presented will inform that process. While the rigorous data needs of Rout's et al. (2013) statistical framework might seem prohibitive, it is an important model to take advantage of, as it accounts for both source and recipient ecosystems, and can incorporate nearly all the other dimensions of AM (i.e., legal and social) by using whatever data and expert opinions are available. Coupled with McDonald-Madden's (2011) model forecasting the optimal timing of AM in light of climate change, these frameworks allow for an effective assessment of whether to go forward with the strategy. However, the ethics of AM might be better captured by the qualitative framework I present. While the two models could be an effective analysis of AM's impacts, this writer's framework is a way to grapple with that analysis in a structured and holistic way. As managers and ecologists recognize the likelihood of AM in some cases, and likely more into the future as political, demographic, and climate changes unfold, in the near-term the conservation community is still hesitant to devote resources toward AM projects. The effects of climate change with ecosystem dynamics is still quite variable and unknown at finer scales, but for some species it is important to plan for that need, as in the case of the whitebark pine and the American pika. It will take a long time for those already highly vulnerable species to recover from disturbances. As our understanding of the appropriateness of AM develops, it will be important to educate and engage the public community about this approach.

In the meantime, this decision-making framework allows managers and other stakeholders, including the public at large, to participate in an articulated approach that gives insight into the ways in which law, policy and management must change, with respect to the development of novel ecosystems with climate change. The framework allows participants to assess all possibilities—from less to moderate to very intense conservation strategies, or an ensemble of these. By doing so, the framework tempers the application of intense novel approaches with a consideration of what other options are available, should assisted migration or some other intense strategy to save a species not be viable at the time, in terms of cost or current climate. It does not condemn or prescribe intense action. It contextualizes decisions at every step in terms of their logic, coherence, coordination, and practical application. Most importantly, it culminates with a much-needed consensus on the ethics of investing resources, time, and effort on preserving a species out of indigenous range. Although the decisions made in the two case studies for this paper indicated a preponderance to prescribe assisted migration with other strategies, namely restoration, the current gaps in research and uncertainty in terms of political climate and management capacity, is recognized by the framework. The framework provides an indication of which questions require more detail or insight, or anticipate new laws and structures of governance. The framework also shows with these two case studies, that while ecologists might be more inclined to a novel strategy such as assisted migration, the management community is much more cautious about the pacing of its shift to incorporate AM as part of its conservation strategies. The framework, by recognizing the limitations of current modelling and management functions, also challenges these limitations by simply posing more intense interventions as a viable solution. While doing so, the framework allows participants to notice the gaps in knowledge and perspective that would better inform an ethical judgment. For this reason, the Framework I present would be very useful to management agencies, even should they alter it for their specific purposes.

The framework I present is especially useful, as it avoids simplifying these various dimensions and the related questions to a Yes or No answer. The framework appreciates the ambiguity and dynamic nature of these various dimensions of AM, so that scientists, managers, stakeholders and the public, and decision-makers can engage in discussion with an awareness of the gaps in research, education and policy that are needed to give rise to an appropriate strategy, coherent with the values and ethical considerations of different communities, and society at large.

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