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Assisted colonization as a climate change adaptation tool

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Abstract Assisted colonization is a form of conservation translocation which introduces species at risk from extinction to new habitats, beyond their current range, in anticipation of more suitable conditions. Identifying which species, communities and ecosystems may benefit most from assisted colonization in coming decades is a key goal for conservation. Climate change is expected to lead to the loss or movement of suitable habitat for a range of species and anticipating which can be effectively conserved through assisted colonization is critical. Here, we identify a series of scenarios that may predispose terrestrial species to the need for assisted colonization in order to reduce extinction risk resulting from anthropogenic climate change and assemble a list of traits commonly associated with at-risk species. These traits may help to provide broad-scale guidance on how to select species to target for assisted colonization as a conservation management response to climate change. We also identify six key themes associated with successful conservation translocations including recipient site selection and preparation, a clear understanding of species biology and ecology, and taking lessons from invasive species research.

Key words: biodiversity conservation, climate change, managed relocation, species trait, translocation.

INTRODUCTION

The pace and severity of current changes in the climate system threaten the ongoing existence of a large number of species across the globe (Thuiller *et al.* 2005a; Parmesan 2006; Carpenter *et al.* 2008). Climate is a key determinant of species distribution, and many species have adapted to use climate signals to cue phenological events, such as bud-burst in plants or overwintering in insects (Parmesan 2006). However, there is clear evidence that both mean and extreme climate conditions are changing rapidly (IPCC 2013) and that this is already having important ecological consequences for many species (Rosenzweig *et al.* 2008; Chen *et al.* 2011). For example, combined land and sea-surface temperatures have warmed by an average of 0.85°C (0.65–1.06°C) in the period 1880–2012 and it is likely that the incidence of heat waves has increased in some regions (IPCC 2013). Changes in climate have put many species at an increased risk of extinction as the optimal conditions for their growth and reproduction shift in the landscape. Identifying which species are most at-risk under future climate scenarios and implementing conservation actions that will reduce extinction risk is a key goal for scientists, and the policy-makers who rely on their expert advice and opinion.

In this review, we focus on one strategy – assisted colonization – for conserving species acutely at-risk from anthropogenic climate change. We define assisted colonization in relation to climate change and identify scenarios that may prompt the implementation of this conservation practice to protect species into the future. A list of traits commonly associated with species in need of assisted colonization is compiled from the literature and we illustrate how these traits may help to provide broad-scale guidance on how to select species to target. We also identify six themes commonly associated with successful conservation translocations and review their application in practice.

WHAT IS ASSISTED COLONIZATION?

Assisted colonization is a type of conservation translocation; a form of introduction, where organisms are intentionally moved outside their indigenous range to avoid extinction of populations of the focal species (IUCN/SSC 2013). The movement of organisms beyond their indigenous range is also commonly referred to as 'managed relocation', 'assisted migration' and 'benign introduction' (Richardson *et al.* 2009; Seddon 2010; Lunt *et al.* 2013).

Anthropogenically induced climate change is predicted to prompt changes in the distribution, phenology and abundance of species. At-risk species may adapt *in situ* without migration (via adaptive genetic

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variation or phenotypic plasticity) or migrate to regions with more suitable climatic conditions for growth, reproduction and survival (Hughes 2000). Species that cannot adapt *in situ* or migrate are candidates for assisted colonization. Proponents of assisted colonization argue that a decision not to assist species threatened by climate change by deliberately extending their current range dooms candidate species to extinction (McLachlan *et al.* 2007; Hoegh-Guldberg *et al.* 2008; Thomas 2011).

WHEN IS ASSISTED COLONIZATION MOST LIKELY TO BE NEEDED?

Scenarios under which individual species, species assemblages or entire communities may benefit from assisted colonization in response to climate change include:

1. *Loss of suitable climatic habitat within the current range.* In some circumstances levels of change may fall outside the natural climatic variability experienced by some species under both current conditions and through evolutionary time. There is evidence that some organisms are already shifting their ranges to track optimal conditions for growth and reproduction under the relatively modest levels of climate warming already experienced globally (Parmesan & Yohe 2003; Rosenzweig *et al.* 2008; Chen *et al.* 2011). The response of species is likely to be highly idiosyncratic, leading to the potential for substantial reassembly of the composition of communities, with flow-on effects to ecological interactions and ecosystem services (Gilman *et al.* 2010; Lavergne *et al.* 2010; Urban *et al.* 2012). Assisted colonization may be the only option available for organisms that cannot keep pace with species with which they have co-evolved and upon which they are dependent. In addition, some species may be constrained by anthropogenic or geophysical migration barriers, such as mountain ranges or water bodies, or equally by areas devoid of suitable habitat due to land clearance that effectively block their migration to more suitable locations under future climate change. These species may require some form of assisted colonization to overcome dispersal barriers.
2. *The emergence of novel or non-analogue climates.* Projections for the emergence of novel climatic environments both globally and within Australia in a relatively short space of time (between 2050 and 2100) indicate that whole assemblages of species may be under threat and may need assistance (Williams *et al.* 2007; Dunlop *et al.* 2012; Mora *et al.* 2013). The large scale of these projections may make it difficult to prioritize species for assisted colonization. However, pre-emptive feasibility studies could help identify potential candidates or flag the need for multi-species translocations.
3. *The changing nature of restoration priorities.* Many habitats are now anthropogenically modified and are typically characterized by the presence of invasive species, alterations to and disruption of disturbance regimes and changes to soil, hydrological and other conditions, altering both biotic and abiotic interactions (Fischer & Lindenmayer 2007). In addition, these modified habitats generally preclude effective species migration and gene flow by fragmenting populations among a matrix of land-uses (Cushman *et al.* 2006). As a result of extensive alterations to natural systems, managing for conservation to historically referenced conditions may no longer be achievable or desirable (Harris *et al.* 2006; Thomas 2011; Shackelford *et al.* 2013). Returning species to suboptimal conditions may only subject them to multiple stresses and they may have a higher chance of persistence elsewhere, in a climate-ready location.
4. *Exposure to pre-existing stressors.* Vulnerability of species to climate change will also be exacerbated by interactions with pre-existing stressors. These stressors may include native vegetation clearance, habitat fragmentation, altered land use practices or disturbance regimes, or interactions (such as competition, predation and disease) with other biota, including introduced weeds, pests and pathogens (Lindenmayer *et al.* 2010). In addition, stochastic events may also increase vulnerability to climate change by reducing the size of individual populations or the breakdown of metapopulation dynamics (McDonald-Madden *et al.* 2011; IUCN/SSC 2013).
5. *Replacement of the loss of an ecological function/service.* Assisted colonization can allow for the replacement of species that have been lost from an ecosystem (and the corresponding loss of the role that species performs) and can thereby restore a similar ecological service and/or fill existing gaps in biological function (Hewitt *et al.* 2011; Lunt *et al.* 2013). Augmenting species in this way may also be beneficial where biotic interactions have changed as a result of the loss of species.

While climate change is a global phenomenon and the emergence of novel environments is predicted to be relatively common (Williams *et al.* 2007; Dunlop *et al.* 2012), projected changes will vary spatially and seasonally, and influence vulnerability of individual species accordingly. Position in the landscape will influence exposure to environmental changes such as temperature extremes, precipitation increases or decreases, changes in stream flow (floods

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and intermittent drying), changing fire regimes, frost exposure and reductions in snow cover and sea level rise (inundation and salinity). Homogeneous landscapes, particularly areas with low-relief topography, are projected to be particularly vulnerable to climate change impacts due to a reduced number of topographically determined microrefugia in which organisms can persist (Dobrowski 2011).

HOW CAN CANDIDATE SPECIES FOR ASSISTED COLONIZATION BE IDENTIFIED?

Determining candidate species for assisted colonization is multifaceted and should be approached using diverse viewpoints across relevant disciplines (Rout *et al.* 2013). The capacity for an organism or population to adapt to climate change depends on both biotic factors (such as adaptive genetic variation, capacity for phenotypic plasticity, inherent rates of evolution, the expression of functional traits), and on abiotic factors (such as the availability and connectedness of suitable habitat, climate or soil conditions) (Hughes 2000; Parmesan 2006). Assisted colonization is likely to be most needed for species which exhibit a combination of traits that limit their ability to disperse or to adapt to changing climate and the associated habitat change. An individual species vulnerability to climate change will depend on its sensitivity (the potential to persist *in situ*), exposure (the degree to which the physical environment will change) and adaptive capacity (persistence due to its ability to cope with microevolutionary change or dispersal) (Dawson *et al.* 2011; Foden *et al.* 2013). It is important to recognize that individual species are likely to respond to changing climates at different rates, leading to changes in the composition of current communities or assemblages (Ackerly 2003; Gallagher *et al.* 2012; Urban *et al.* 2012). The potential for reassembly of communities poses a set of distinct management challenges, which includes the need to identify and clearly define the role that multi-species translocations may play in attempts to retain current function into the future.

Traits associated with candidate species for assisted colonization

Being able to anticipate which species are most likely to benefit (in conservation terms) from assisted colonization is critical to avoid failure and wasted investment. Species with the traits listed below have been identified in previous studies as the most likely to be affected by rapid climate change (note that several of the traits listed are interconnected and should not be viewed in isolation):

1. Species with *small effective population sizes* (less than a thousand breeding individuals) are likely to have *reduced genetic diversity*, a heightened risk of inbreeding depression and an increased vulnerability to demographic and environmental stochasticity, all factors that increase the risk of extinction (Hoffmann & Sgrò 2011). The effects of inbreeding depression are deleterious for reproduction and survival regardless of climate change (Frankham *et al.* 2010). However, the process of rapid climate change is thought to exacerbate the rate of reduction in genetic diversity and temperature stress has been demonstrated to heighten inbreeding depression in some species (Armbruster & Reed 2005). Inbreeding depression also reduces the capacity for species to evolve and therefore adapt to changing conditions (Frankham *et al.* 2010).
2. Species with *long generation times* have slow replacement rates, fewer chances for genetic recombination and reduced opportunity to increase evolutionary responses to climate change than species which reproduce more frequently (Buckley & Kingsolver 2012; Renton *et al.* 2012).
3. It is generally expected that adaptation to climate change may be more difficult for species with *narrow distributions* (narrow endemics) than those with broader habitat tolerances. Species with restricted ranges or limited distribution may not have sufficient genetic diversity to cope with changes affecting phenological events, thermal responses and/or resilience to stressful climatic conditions (Hoffmann & Sgrò 2011). Species with narrow ranges and small effective populations are more likely to have low genetic diversity and therefore reduced adaptive capacity (Pauls *et al.* 2013). However, widespread species should not be overlooked as candidates for assisted colonization because (i) migration barriers (geophysical or anthropogenic) may prevent migration; (ii) connectivity to new areas may not be feasible; (iii) disruption to disturbance/obligate relationships may preclude persistence or natural colonization to new areas; (iv) differential rates of dispersal/migration and adaptation capacity may occur among the leading, central and lagging populations of widespread species (Zakharov & Hellmann 2008; Mellick *et al.* 2012).
4. *Specialist* species (those with a narrow range of climatic conditions, habitat or diet) are predicted to be more sensitive to climate change than generalists (Thuiller *et al.* 2005b; Buckley & Kingsolver 2012). Specialists can include those species that are depended on or have a *mutualistic relationship* with another organism. Under climate change, the alteration to distribution, phenological events and/or abundance of one species may

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negatively affect the other and trophic interactions may be disrupted (Bernazzani *et al.* 2012). Specific mutualistic relationships between plants and mycorrhizae may also become decoupled.

5. *Higher trophic level* species will be disproportionately affected if their host or prey species shifts distribution under climate change, particularly if the interaction represents a highly specialized relationship (Thackeray *et al.* 2010).
6. The ability of different plant species to take advantage of elevated levels of atmospheric CO_2 differs according to their *photosynthetic pathway* (Ehleringer *et al.* 1997). Generally, C_3 plants (usually woody species) are able to take advantage of higher concentrations of atmospheric CO_2 relative to C_4 plants (often grasses). Incursions into grasslands and grassy woodlands by C_3 plants are therefore expected (Bond & Midgley 2000; Hovenden & Williams 2010). However, increased growth rates vary considerably within taxa and depend on interactions with nutrients, temperature and rainfall (Huxman *et al.* 2004; Harper *et al.* 2005). Increasing CO_2 will also reduce leaf nitrogen content and increase secondary metabolites, altering plant herbivore relationships and nutrient cycling processes (Veteli *et al.* 2002; De Graaff *et al.* 2006).
7. Species close to their *physiological limits* are at risk from climate change. There is evidence that fauna is at risk from thermal stress affecting rates of locomotion and feeding, reducing food availability and changing biotic interactions (Buckley & Kingsolver 2012; Cahill *et al.* 2013). The relative importance of physiological tolerance to high temperature stress may develop over time as temperatures and extreme weather events increase in frequency and magnitude (Cahill *et al.* 2013). For example, death from over-heating (hyperthermia) in flying foxes in NSW was observed during an extreme temperature event in 2002 (Welbergen *et al.* 2008).
8. Bergmann's rule states that there is a trend for mean *body size* in endotherms to decrease with decreasing latitude (interpreted as body size decreases with increasing temperature) (Bergmann 1847). However, it has been demonstrated that the magnitude and direction of size response varies between endotherms and may depend on the nature of the change in temperatures, water stress and extreme events (Gardner *et al.* 2011). McCauley and Mabry (2011) argue that organisms with larger body size are more likely to be long-distance dispersers and successful colonizers. These traits may render large body mass species less vulnerable to climate change and smaller body mass species more likely to suffer adverse *in situ* impacts.
9. Species *lacking dispersal capability* will have limited capacity for shifting their range in response to a rapidly changing climate. For sessile organisms like plants, species with seeds that lack adaptations for dispersal, such as aerodynamic appendages (pappus, coma, wings) for wind dispersal or fleshy fruits to attract dispersal mutualists such as birds or bats (Leishman *et al.* 2000) may be disadvantaged. Dispersal-limitation can arise in species that have been exposed to stable conditions over long periods. This can lead to: (i) a lack of genes to code for new functions, such as a change in thermal tolerance; (ii) DNA decay in genes that are functionally important; and/or (iii) low levels of genetic variation (Hoffmann & Sgrò 2011).

Candidate species for assisted colonization may have a combination of the above described traits, be involved in several biotic interactions, suffer from multiple anthropogenic stressors and may respond using numerous modes. For example, large-bodied taxa that are ecological specialists at higher trophic levels with long generation times, poor dispersal ability, low or delayed reproductive output occupying small geographic ranges, may be particularly at risk (Dawson *et al.* 2011).

WHEN DOES ASSISTED COLONIZATION HAVE THE MOST LIKELIHOOD OF SUCCESS?

Evaluating the success of past translocation projects provides insight into how to improve the likelihood of an assisted colonization being successful. Unfortunately, there are relatively few well-documented examples of successful translocation projects where self-sustaining populations have been formed. The IUCN states that 'the pivotal criteria for justifying any conservation translocation will be situation-and species-specific' (IUCN/SSC 2013). However, six key and inter-related themes repeatedly appear in the literature with general suggestions or recommendations for successful assisted colonizations.

1. *Recipient site selection and preparation:* The characteristics of the sites that receive species (recipient sites) will have a major influence on the success or otherwise of assisted colonizations (Vallee *et al.* 2004). One purpose of assisted colonization is to move species to areas with suitable future climate and hence reduce the extinction threat. In general, translocations and ecological restorations are more likely to fail where there is a large difference in the biogeographic regions between the source and the recipient populations (Dalrymple & Broome 2010; Thomas 2011; Harris *et al.* 2013). The introduction of organisms

into sites free from predators, pests and/or pathogens may increase the chance of translocation success. In a review of Australian vertebrate translocations, predation was cited as the key reason for the project failure for mammals and birds and a significant issue for reptiles and amphibians (Short 2009). Furthermore, sites free of key threatening processes yielded greater translocation success than sites that were less secure (Short 2009). Site selection should also consider the availability of co-dependent organisms, and the adequacy of site size and tenure (Bennett *et al.* 2013). Preferably, sites will be located inside the protected area network, such as national parks and reserves; however, suitable habitat may often lie outside these places. In addition, a recent survey of practitioners and researchers identified full approval from all stakeholders at source and recipient sites as the most important factor affecting the success of assisted colonization (Hancock & Gallagher 2014).

2. *The use of predictive models:* Climate models (e.g. global circulation models or global climate models (GCMs)) are used to predict the future climate of both source and recipient sites. The current generation of climate models reproduce observed continental-scale surface temperature patterns and trends over many decades with a high-level of confidence (IPCC 2013). While there is high confidence in models of climate at the global scale, predictions from regional climate models are essential for finer-scale identification of at-risk species or communities and recipient sites for assisted colonization projects.

Species distribution models (SDMs), are used to predict the distribution of suitable habitats for species, under both current and future climate scenarios. Also termed ecological niche, environmental niche, habitat suitability and bioclimatic envelope models (Pearson & Dawson 2003), SDMs employ either a correlative or mechanistic approach. Correlative models combine species occurrence records with gridded environmental data (e.g. climate, soils) to project the location of suitable habitat for individual species, or suites of species (Guisan & Thuiller 2005). By contrast, mechanistic SDMs project species ranges by incorporating information on physiologically limiting mechanisms which govern tolerance to conditions with environmental data (Pearson & Dawson 2003). Correlative models are more commonly employed due to the availability of occurrence records, climate data and free-software, whereas detailed biological data needed for mechanistic models is often unavailable. The utility of models for identifying candidate species or recipient sites is substantially improved when a combination of tools and parameters are used (Pearson & Dawson 2003; Angert *et al.* 2011). For instance, extending the type of parameters used to calibrate SDMs beyond climate variables to include such factors as topography, soil conditions, dispersal distances, evolutionary change, biological traits and biological interactions will fine-tune predictions.

Population viability analyses (PVAs) model the effects of different life history, environmental and threat factors (deterministic and stochastic) on the population size and extinction risk of populations or species (Frankham *et al.* 2014). Historically, PVAs have been used to predict reproductive and survival parameters for threatened species. PVAs would arguably be of benefit in assessing potential assisted colonization projects, for both the source and recipient populations. Information on reproduction, mortality rates, population size, carrying capacity, frequency and effects of threats and genetic information (susceptibility to inbreeding depression and gene flow) are required for analysis (Frankham *et al.* 2010).

3. *Ensuring adequate levels of genetic diversity:* The presence of genetic diversity is an important factor in the success of any conservation translocation. Genetic considerations in successful translocations include the avoidance of inbreeding and outbreeding depression, a loss of genetic diversity due to founder effects or genetic drift and the ability to maintain appropriate breeding systems (Menges 2008; Weeks *et al.* 2011). Genetic diversity can be divided into two categories: neutral and adaptive. Neutral genetic diversity reflects population dynamics and evolutionary forces such as genetic drift, mutation and migration and is not under natural selection (Sgrò *et al.* 2011). Adaptive genetic diversity is under natural selection and gives rise to the ability to adapt to new environments (Sgrò *et al.* 2011). It is therefore important that translocations that introduce populations outside of its known historical range (assisted colonizations) have adequate levels of both types of genetic diversity to enable adaptive capacity. Estimates of both types of genetic diversity may be difficult to attain. Commonly proposed strategies to retain maximum genetic diversity are to source the genetic material to be transplanted from multiple sources (Frankham *et al.* 2010) and from provenances that match likely future climate at the recipient site to increase adaptability (Sgrò *et al.* 2011). In the context of assisted colonization, it is important to identify the financial and ecological trade-offs between moving unthreatened extant populations, currently with substantial adaptive capacity, and prioritizing threatened species with reduced genetic diversity, but with a high need for translocation due to other stressors.
4. *Species information:* Biological information is lacking for many species to enable confident predictions of successful assisted colonizations

(Hancock & Gallagher 2014). All translocations are undoubtedly more successful where there is knowledge of climatic/trophic breadth and niche, expected successional trajectories, disturbance regimes required for reproduction, breeding systems, ideal habitat preferences, mutualisms, and the physiological constraints on growth and survival. However, the time taken to acquire knowledge before acting needs to be balanced against the potential consequences of failing to act soon enough. The risk of proceeding without specific biological information needs to be carefully evaluated on a case by case basis to ensure factors that can influence translocation success are adequately understood.

5. *Learning from invasive species research:* Opponents of the use of assisted colonization as a climate change adaptation strategy typically draw examples from the lessons learnt from invasive species research. Parallels have been drawn between species moved beyond their natural range for assisted colonization purposes and the negative impacts of invasive species on recipient communities, such as reduced native plant recruitment through impacts on colonization-extinction dynamics (Yurkonis & Meiners 2004); the disruption of key ecological interactions (i.e. plant–animal mutualisms) (Traveset & Richardson 2006); or the unintentional introduction of novel pathogens or pests to ecosystems (Ricciardi & Simberloff 2009). Therefore, the need to move species beyond their range to secure viable populations under climate change needs to be weighed against the potential non-target effects on communities at recipient sites (Mueller & Hellmann 2008). In many cases, translocations may resemble a form of controlled and predictable 'invasion' of a novel species into a recipient ecosystem. However, while the risk of invasiveness and flow on effects from assisted colonization are valid, it is important to note that candidate species often possess biological traits incompatible with the tendency to become invasive (e.g. poor dispersal, long generation times, low fecundity).
6. *Adaptive management:* Due to the nascent nature of assisted colonization, it follows that management will need to be structured and adaptive. The outcomes of monitoring and evaluation need to drive management actions. Actions should also be based on the best available knowledge and any uncertainties should be acknowledged (Chauvenet *et al.* 2013). Theoretical guidelines, risk management tools and decision frameworks have previously been developed to assist all aspects of decision making surrounding assisted colonization (see Appendix S1 in Supporting Information).

RISKS INVOLVED IN IMPLEMENTING ASSISTED COLONIZATION

Both advocates and critics of assisted colonization recognize the significant operational obstacles to implementing assisted colonization as a conservation action. These obstacles include, but are not limited to financial costs of design, implementation and ongoing monitoring; coordination across political boundaries or jurisdictions; failure of species to colonize, despite a well-designed program; difficulty identifying suitable recipient sites due to habitat loss or a paucity of suitable land tenures, as well as the uncertainty inherent in identifying areas projected to contain suitable climatic habitat in coming decades.

If assisted colonization is being considered, consideration must be given to minimizing the risks and consequences of failure. These consequences may include the loss of valuable individuals and their genetic material, loss of the (sometimes large) investment made in the attempt, and a cumulative decline in capacity to risk further assisted colonization attempts. Risks, and practical strategies to minimize or remedy them, need to be addressed in the preparatory phase and knowledge gaps filled to the best extent possible. Failures may occur due to biological factors such as inappropriate genetic mixing of populations leading to inbreeding depression, genetic swamping or hybridization; introduction to recipient sites with unsuitable edaphic or climatic conditions; or a lack of co-evolved mutualists, such as pollinators, leading to reproductive failure (Moir *et al.* 2012). In addition to these biological factors, a failure to implement long-term stewardship of, and resources to, assisted colonizations may result in a lack of monitoring, or the control of threats such as weed invasion or feral animals.

Strategies for minimizing risks associated with assisted colonization may include completion of comprehensive pre-translocation assessments for each species, the use of the principles of adaptive management to tailor the design, implementation and ongoing monitoring of projects, and/or the use of existing frameworks (see Appendix S1 in Supporting Information) and guidelines to inform specific aspects of assisted colonization.

Assisted colonization as a conservation strategy also has ethical, social, cultural, economic and political implications (Byrne *et al.* 2011). Programs and projects require a clear set of goals and objectives and procedures as the implementation of assisted colonizations has the potential to create tension among stakeholders with competing interests (Schwartz *et al.* 2012). While assisted colonization projects remain at a relatively low scale and/or frequency and at an experimental level (e.g. Liu *et al.* 2012; van der Veken *et al.* 2012), tensions and conflicting goals may be resolvable on a case by case basis. A requirement for a formal translocation proposal

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for each project, coupled with a pro-forma for such proposals that requires that scientific, socio-ethical and consultation factors all be addressed, would help to ensure consistency to the degree possible and anticipate, prevent or minimize conflicts.

CONCLUSIONS

It is increasingly likely that assisted colonization will become a more accepted conservation action in coming decades as the need to protect species affected by changing climate regimes continues to rise. While this review highlights a series of scenarios in which assisted colonization may be an appropriate conservation action, and identifies which traits and actions can potentially increase the success of this type of project, many uncertainties remain. For instance, while distribution models can provide an overview of the threat imposed by changing climate to some species and help to locate potential recipient sites for assisted colonization, securing long-term tenure for projects that require lands that fall outside the current protected area network may be problematic (Lunt *et al*. 2013). Much uncertainty also exists around the practical implementation of assisted colonization and there is evidence that it is viewed poorly as conservation strategy among translocation practitioners (Hancock & Gallagher 2014). In addition, reporting of the factors that drive the success, or failure, of translocation projects more widely is lacking, reducing the ability for past ventures to inform the implementation of new assisted colonization projects (Vallee *et al*. 2004).

Despite the uncertainties and risks associated with assisted colonization, this practice may be the only option for many species faced with extinction as a result of climate change. For this reason, it is imperative that researchers, policy-makers and practitioners work collaboratively to ensure this conservation strategy delivers results for those species they seek to protect.

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SUPPORTING INFORMATION

Additional Supporting Information may be found in the online version of this article at the publisher's web-site:

Appendix S1. Existing frameworks for assessing candidate species and situations for assisted colonization.

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