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Braidwood, David W.; Taggart, Mark A.; Smith, Melanie; Andersen, Roxane

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Translocations, conservation and climate change – use of restoration sites as protoreffuges and protoreffugia

Running head: Aiding conservation with protoreffuges and protoreffugia

Authors, emails and addresses:

David W. Braidwood¹, Mark A. Taggart¹, Melanie Smith², Roxane Andersen¹

¹ Environmental Research Institute, University of the Highlands and Islands, Castle Street, Thurso, Scotland

² Inverness College, University of the Highlands and Islands, Inverness Campus, Inverness, Scotland

david.braidwood@uhi.ac.uk *Corresponding author

mark.taggart@uhi.ac.uk

melanie.smith.ic@uhi.ac.uk

roxane.andersen@uhi.ac.uk

Author contributions: DB, RA, MT conceived and expanded ideas; DB created figures and maps, wrote text; RA, MT, MS reviewed and edited text; DB final edit of manuscript

Abstract

High levels of human activity have affected the quality and usability of the natural landscape, leading to habitat degradation, loss of connectivity between sites and reduced chances of long-term survival for individual species. In line with conservation policy, ecological
restoration practitioners try to improve degraded sites by means of re-establishing species lost from these sites, thereby returning ecological functionality and maintaining biological diversity. It may appear difficult to integrate the long-term potential impacts of climate change within restoration strategies. However, more refined climate projections and species distribution models provide us with better understanding of likely scenarios, enabling us to consider future proofing as an integral part of the design of restoration sites, aiding plant conservation. We believe that it is possible to go one-step further with a closer integration of restoration and conservation objectives. We introduce the novel concepts of ‘protorefuges’ and ‘protorefugia’ – restoration sites that threatened species can be translocated to, where the restoration design can be specifically adapted to help reduce the decline of threatened species at the leading and trailing edges (respectively) of bioclimatic envelope shifts. This is particularly relevant for nuclear decommissioning sites, which may be free from human activity for decades to centuries.

**Keywords:** Plant conservation; restoration; conservation policy; nuclear decommissioning; brownfield sites.

**Conceptual implications:**

- A rapidly changing climate is causing distribution shifts in plant species. Although beneficial to some species it is detrimental to many, especially those in decline or scarce.

- Species conservation could be delivered more effectively by integrating longer-term planning and considering climate change effects in the restoration design for industrial sites.
• Restoration sites could be used for conservation by becoming “protorefuges”, i.e. providing habitat space for translocated threatened species ahead of the climate’s leading edge. Sites that are projected to maintain a stable suite of climatic variables in the medium to long term, could become “protorefugia” for species losing bioclimatic space.

• Integrating restoration and conservation in this way will benefit all sides through cost savings on projects.

Introduction

Humanity currently faces the prospect of a sixth mass extinction event (Thomas et al. 2004), the first that could be avoided, and the first that ‘bears our name’ (Pievani 2014). Globally, data have been analysed and targets produced to provide an overarching plan within which biodiversity targets can be set to try to help prevent a catastrophe. The Aichi biodiversity targets, set out in 2010 at the 10th Conference of the Parties (COP) in Nagoya, provide an internationally acceptable framework within which actions are expected to be taken to preserve biodiversity and ensure continued functioning of ecosystems and delivery of the associated services they provide to society.

From Aichi’s twenty targets, set within five strategic goals, targets 5, 10 and 12 state that, respectively, ‘fragmentation and degradation [of natural habitats] is significantly reduced’, ‘by 2020 multiple anthropogenic pressures [...] on vulnerable ecosystems [...] are minimized, so as to maintain their integrity and functioning’ and ‘by 2020 the extinction of known threatened species has been prevented and their conservation status, particularly of those most in decline, has been improved and sustained’ (CBD Secretariat 2010). The Achi targets provide the global framework within which regional targets can be set, and policy agreed. As
size of area within any region being considered for conservation diminishes, the legislation tends to reflect national and then local habitats’ and species’ requirements. A prevailing constraint to implementation of local and regional policy is often financial, and despite the willingness of many, it remains difficult for NGOs, scientists and practitioners to implement the necessary actions in terms of restoration and conservation, especially in the current context of global climate change (Dawson et al. 2011).

We discuss below some of the problems facing plant conservation, and argue that improved strategies in restoration ecology could help to overcome the challenges posed in terms of achieving biodiversity targets and halting species loss. We propose a new concept of “proto-refugia” and “proto-refuges” that integrates conservation of threatened species with restoration, particularly in industrial sites.

**Impacts of climate change**

Despite efforts put in place to prevent it, a rise in average global temperature of over 2°C above pre-industrial levels, as a consequence of anthropogenic activity, is highly likely (Jordan et al. 2013), with upper limits projected to be as high as 6°C by the end of the 21st Century (Pachauri & Reisinger 2007). With climate changing faster than would be expected naturally and the rate of warming increasing in the long-term, anthropogenic influences are significantly contributing to continued biodiversity losses. Changes in climate can directly lead to alterations in species distributions, expanding range if the change is beneficial to ecological need, contracting it where change is detrimental, or shifting latitudes polewards. Rapid range expansion can lead to the natural creation of hybrid or novel ecosystems, while range contraction can force species into refugial space, where this is available, or lead to species extirpation. This is particularly true for plant species that, for the most part, are only able to
shift location once in a generation (e.g. seed or spore dispersal), but are otherwise sessile. To assist with species survival we therefore need to be able to predict and understand the likely limits of distribution and limiting factors for individual taxa (Pearson & Dawson 2003).

**Refugia and refuges—definitions and scope**

The terms ‘refugia’ and ‘refuges’ have been much used in recent years, with crossovers between terms occurring (Keppel & Wardell-Johnson 2012) – pertinent definitions for these, as well as other associated terms, are given (Table 1). As climate oscillates from warmer interglacial periods to the glacial maxima, refugia change, as do the species within them. Refugia can be hotspots for diversity, hosting a combination of species previously found there, alongside species pushed to the limit of their range by other events. However, refugia seldom act as hotspots for evolutionary change (Petit et al. 2003). Large areas across which climate and habitat are suitable may be termed macrorefugia (Leal 2001) while smaller areas are referred to as microrefugia (Rull 2009). The species residing in these refugial types are determined by prior species distributions and overall ecological traits (Bhagwat and Willis 2008). The identification, and appropriate management of refugia holds promise, if selected effectively, in helping combat species loss as a result of climate change (Keppel et al. 2015).

Within Europe, during the last glacial maximum (LGM), there were refugia across southern Europe for temperate plant species, whose distributions have since re-spread northwards during the interglacial period. Many of the native species in the British Isles, for example, would have arrived prior to the flooding of Doggerland, the land bridge that connected Britain with mainland Europe, some 8200 years ago (Weninger et al. 2008); although some species would have been able to disperse over long distances (Darwin 1859) and may have arrived naturally since then. The short time over which the southern front of the LGM ice sheet
retreated, combined with the disappearance of Doggerland, largely accounts for the relative paucity of today’s British flora (Lusby & Wright 1996). Following the British Isles’ disconnection with other European landmasses and a rapidly warming climate, arctic/alpine species there had increasingly finite options for further (northward or altitudinal) dispersal and distribution. Refuges would have provided safety for a short time, maybe few generations, until remaining suitable climate space was finally lost. The very north of Scotland, and the high plateaus of Britain (including the Cairngorms), thus became refugia for such species (Stewart et al. 2010). The polar and altitudinal spread of more temperate species would have been assisted by some longer distance dispersal into their expanding range. This space would have supported the first few individuals of these temperate species to arrive from the wider population, until their abundance increased, and they became part of the established vegetation matrix.

These refugia sit within the bioclimatic envelope required by a species in order for it to survive, however, this does not account for the full distribution of a species (Braidwood & Ellis 2012). Factors including soil type, habitat niche, local micro-climate and competition (Luoto et al. 2007) will also continue to limit species survival in new locations. Shifts in bioclimatic envelopes will likely result in one of three options for plants: i) failure to adapt and loss from the location in which they presently exist; ii) ability to survive where they are as a result of plasticity, or, through genetic adaptation to the new climate regime; iii) dispersal at a rate that allows continued survival in a new location (Dawson et al. 2011) (Figure 1). Identification of suitable locations (e.g. through climate modelling or transplant studies) within which plant species will survive in the future is now recognised as beneficial to long-term plant survival (Keppel et al. 2012).
Linking restoration and conservation

The potential shrinking of refugia for plant species, in association with a warming climate, means that human intervention may be required if we desire to conserve species and minimise wider species/biodiversity loss. Wiens and Hobbs (2015) have discussed how the disciplines of conservation biology and restoration ecology differ and yet complement one another as climate changes, and, that better integration between these disciplines may be necessary as the predictability of a particular species’ ability to survive in a location becomes less certain. One purpose of conservation is to prevent further degradation of ecosystems, aiming to maintain their functionality within a broad range of historical natural conditions, even though this is likely to be outside their once ‘pristine’ condition. Restoration, meanwhile, is likely to start with an already heavily degraded ecosystem - the aim being to bring it back to a state where it bears some resemblance to historical conditions. Climate change will likely create as yet unseen ecosystems and species assemblages, with matrices of species growing alongside each other for the first time on record. How restorations should progress in light of predicted climate change, and how historic, hybrid and novel ecosystems could (or should) be developed, remains an often debated issue (e.g. Perring et al. 2015). Ultimately, restoration can create both hybrid and novel ecosystems that, while restoring degraded areas, could also provide habitats that specifically conserve climate vulnerable species, as well as future-proof ecosystem functions. Diverse communities, with a diverse genetic mix within species, are desirable to build in resilience and enable systems to persist into new states.

Building resilience to threats through translocation has long been accepted as a method to help conserve species - providing them with the space and habitat required to survive (Richardson et al. 2009; Ferrarini et al. 2016). This may be of significant long-term benefit, as long as best practice is applied and associated dangers of translocations are minimized by
following appropriate codes (e.g. ‘Best practice guidelines for conservation translocations in Scotland’ (National Species Reintroduction Forum 2014) and ‘Guidelines for translocation of plant species at risk in British Columbia’ (Maslovat 2009). Translocations are most often used for threatened species, but are more recently being specifically aimed to conserve species sensitive to projected anthropogenic climate change scenarios (Vitt et al. 2010). Botanic gardens, best known for their ex-situ conservation, will likely become more involved with restoration through in-situ conservation projects such as these (Miller et al. 2016). Such translocations, occurring outside of a species historic distribution, have been known as ‘conservation introductions’, ‘assisted colonisations’ (Chauvenet et al. 2013) and ‘assisted migrations’ (McLachlan et al. 2007).

A high proportion of plant species, 58 ± 2.6% (median ± SD), have been projected to lose suitable climate conditions within European protected areas by 2080 (Araújo et al. 2011). These areas were often set up specifically to preserve just a single ‘at risk’ species (which, in future climate scenarios, may be placed at even greater risk). In the past, a lack of sufficient knowledge regarding the impacts of future climate change means that species are now being lost from areas designed to protect them. As a result, translocations of these species to new areas where the climate is likely to be suitable are therefore becoming necessarily more frequent to aid conservation (Baron et al. 2008). Appropriate site selection also remains problematic when there may be little knowledge regarding the potential impact of an introduction (Thomas 2011), or, of how a individuals of a particular provenance will interact with the population at the translocation site (Bucharova 2016). Better and more frequent use of species distribution models (SDMs) (also called ecological niche models (ENMs) when planning conservation projects/preservation areas, and in particular, when planning translocations, could improve success in terms of long term species survival and conservation
(Guisan et al. 2013). Bio-informatic database availability, holding significant volumes of previously hard to find information, can help facilitate data access for such models (Jetz et al. 2012). Further assistance toward this can come from the knowledge held in botanic gardens, where expertise can help direct species choices, often a complex decision (Heywood 2015).

**Protorefuges, protorefugia and restoration goals**

Here, we suggest that the translocation of species could/should be more closely and routinely integrated within the early stages of restoration and reclamation project design. This type of “future proofing” would not only improve the likelihood that ecosystem function would be maintained long term, it may also offer enhanced potential for conservation by targeting (in particular) endangered species for translocation. In other words, such restoration sites would effectively act as man-made micro-refuges and microrefugia before a shift in the bioclimatic envelope occurred, forcing them from their present day locations. For sites where translocations such as these are made, we propose the terms “protorefuge” and “protorefugium” respectively (Table 1, Figure 2). In practice, this “future proofing” could be aligned with the IPCC aims of limiting temperature increases to 2°C by 2100, and could take advantage of industrial sites that will need reclamation or restoration.

Most species for which a translocation is considered will be of conservation concern (i.e., Near Threatened or worse according to the IUCN Red List of species), or known to be in decline. It is then mandatory, desirable, or both, to assist with their conservation (IUCN Global Species Programme 2015). Species being pushed out of habitable space (i.e., at the trailing edge of a climate shift), and those moving into that space (i.e., at the leading edge of the climate shift) need to be considered. Many species at the leading edge of their bioclimatic envelope are steadily expanding their range as long as there is a large enough population present.
Translocation of threatened species into protorefuges (as part of restoration) would allow them to establish a foothold ahead of the *en masse* movement of competitors. It would also facilitate the provision of a mix of genetic material – strengthening a species’ chance of survival as the bulk of its population occupies the region in which the protorefuge sits. Sites could further act as protorefugia by providing space for cold-adapted species, provided that those sites are projected to become refugia in the future (Figure 2).

More tightly combining conservation within restoration will allow the limited resources for such work to go further, providing joint benefits to both researchers and practitioners. Restoration sites may at times also hold a number of aces over ‘natural’ (e.g. existing conservation areas) refugial translocation sites. For example, options for soil amendments (or other habitat management options) to benefit translocated species may be available; and, there is likely to be far less opposition to ‘new’ species being introduced into an industrial restoration site than there is in a presumed ‘natural’ area. Translocations to restoration sites for conservation can improve restoration outcomes such as functional integrity (Hobbs & Norton 1996) increasing economic feasibility, both of which are desirable. However, wider social (stakeholder) acceptance remains unclear, and would need to be investigated further.

**Site availability**

Globally there are numerous sites in need of restoration or remediation, many of which will have good potential to act as protorefuges or protorefugia. Brownfield sites (sites that have had previous development on them) within urban areas, quarries and other mineral extraction sites (both in agricultural and natural landscapes), completed landfill sites and other industrial sites (urban or otherwise) such as power plants (including both fossil fuel and nuclear plants) could provide desired space. Sites closer to built-up areas are more likely to
be developed (industrial or housing), and in the short to medium-term are suited to act as protorefuges. Sites that will act as long term protorefugia are harder to identify due to the uncertainty in long term climate projections (Pachauri & Meyer 2014), though better modelling capabilities in the future will help overcome some of these difficulties.

As an example, many of the nuclear power plants constructed in the mid to late twentieth Century are now coming to the end of their productive lives. Across Europe, there are 78 reactors at 38 sites already closed or in SAFSTOR (an intermediate ‘safe storage’ decommissioning state), with a further 126 reactors at 52 sites scheduled to be closed by 2025 (World Nuclear Association 2015) (Figure 3). These are of particular interest because in most cases they will be restricted in terms of post-decommissioning human activities on site – probably for decades and possibly for centuries, ensuring minimal disturbance. Where sites can be considered safe for plants, animals and humans, this lack of further human disturbance will provide the longevity required for the stabilisation of translocated plant populations, while minimising external stressors, enhancing their viability as some of the most suitable protorefuge sites.

Potential restoration/remediation sites will range in size from less than an acre (where single buildings are demolished), to hundreds of acres where power plants and mineral extraction sites are restored. Brownfield sites are currently underutilised for development, while each year upwards of 1000 km² of greenfield sites (previously undeveloped areas, usually amenity or agricultural land) across Europe are threatened by development (Science for Environment Policy 2013). The expedient use of brownfield sites would put them to good use for conservation purposes, and preserve more natural habitats. There may not be ‘corridor’ connectivity between such sites, but, they could act as ‘stepping stones’ or ‘islands’ - in other
words, they could provide new, albeit disconnected, spaces for species to colonize. The combined use of these sites could create a set of widespread and diffuse niche habitats. This is not to suggest that this alone is sufficient to conserve species, and further efforts must still remain in place to protect areas of good quality habitat (Hodgson et al. 2009) from which the larger population may disperse. Wind and animal dispersed seed or spores would eventually reach restoration sites unassisted, and invertebrates, particularly flying species, will also reach them. However, certain plant species are less likely to reach these spaces without assistance and would benefit the most from assisted migration: for instance species with large seeds, or rarer species, such as those classified as near threatened, vulnerable or endangered, which have smaller populations, hence depleted genetic pools (Loss et al. 2010).

Before considering using restoration sites for conservation in the aforementioned way, thought needs to be given to the best seed provenance for restoration projects (in light of a changing climate). This may include using different sub-populations as a source of propagules/seed for a given restoration project to maximise genetic diversity (Hufford & Mazer 2003). As we do not yet have full knowledge regarding all species plasticity, competitive interactions, limits of biotic and abiotic needs, etc., it has been suggested that the best source of seed for restoration is that sourced as locally as possible (Bucharova 2016). This may be possible for restoration towards a historic state that is already represented by the local reference flora, but will not be possible for distant translocations aimed at creating future proofed and long-term ecologically functional ecosystems. Relying solely on species with local provenance may unintentionally lead to a genetic dead end for some if they are unable to adapt to the new climate scenario in which they exist (Harris et al. 2006), though understanding the potential consequences of admixture between the local and translocated populations, e.g. outbreeding depression, needs to be accounted for (Hufford & Mazer 2003).
Shifting species beyond their range limits to test limiting factors on their distribution has been tried (e.g. Marsico & Hellmann 2009; Stevens & Emery 2015), with both these experiments finding that species distribution was dispersal limited. Finally, with respect to this, we would concur with Bucharova (2016) that we do indeed need to experimentally test species we are aiming to conserve in their potential new locations, ideally using large scale field trials where possible.

Conclusion

Increased provision of space for threatened species, through a better use of restoration projects on industrial sites undergoing decommissioning to suit species needs will be of benefit for their conservation. Although we accept that this is not a simple process (Anderson 2013), more and more studies use climate projections to forecast the likely climate that will occur at a given restoration site. Combining these projections with species distribution models (Franklin et al. 2013) should form part of the design of sites that have a strong potential to become protorefuges or protorefugia (Fig. 4). Assuming the rate of climate change continues at its current pace (or faster), such sites could be protorefuges, providing space for species with an expanding range in the short to medium term. If the rate of climate change reduces in the future, it will become easier to match species to sites that will act as refugia, allowing for the creation of protorefugia through translocations. By ameliorating restorations to suit the requirements of particular threatened species, conservation and biodiversity can be boosted, and the outcome of restoration projects enhanced. At the outset, there will be the need to create greater acceptance among stakeholders that restoring a functional ecosystem may not always mean that the site will return to its pristine or historic state. It does mean, however, that within protorefuges and protorefugia, species composition
will be engineered to facilitate the long term ecological functionality of such sites, while simultaneously benefitting conservation and going some way towards reaching globally desirable biodiversity targets.

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Table 1. Definitions of key concepts relevant to both species conservation and restoration ecology. Novel terms ‘protorefuge’ and ‘protorefugium’ are defined.

<table>
<thead>
<tr>
<th>Concept</th>
<th>Definition</th>
<th>Reference</th>
</tr>
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<tbody>
<tr>
<td>Historic ecosystem</td>
<td>Ecosystem present prior to 'disruption' (human intervention); ecosystem present prior to European discovery (new world)</td>
<td>(Jackson &amp; Hobbs 2009)</td>
</tr>
<tr>
<td>Hybrid ecosystem</td>
<td>Historic characteristics remain, composition or function now outside of former natural variability - caused by limited changes in biotic and/or abiotic conditions</td>
<td>(Hobbs et al. 2009)</td>
</tr>
<tr>
<td>Novel or 'no-analog' ecosystem</td>
<td>Species composition/function completely transformed from historic system - caused by significant changes in biotic and/or abiotic conditions</td>
<td>(Hobbs et al. 2009)</td>
</tr>
<tr>
<td>Refugium</td>
<td>Areas where extensive changes, most typically as a result of changing climate, have not occurred, and are isolated from the surrounding landscape, e.g. mountain summit. Often applied when range contracts, as do reductions in a species abundance</td>
<td>(Allaby 1994)</td>
</tr>
<tr>
<td>Macrorefugium</td>
<td>Large areas with continuous populations of refugial species</td>
<td>(Leal 2001)</td>
</tr>
<tr>
<td>Temperate refugium</td>
<td>Areas closer to the equator where temperate species are pushed during glacials</td>
<td>(Stewart et al. 2010)</td>
</tr>
<tr>
<td>Inter-glacial refugium</td>
<td>Areas closer to the poles where cold-adapted species are pushed during inter-glacials</td>
<td>(Stewart et al. 2010)</td>
</tr>
<tr>
<td>Microrefugium</td>
<td>A small area with local favourable environmental features, in which small populations can survive outside their main distribution area, protected from the unfavourable regional environmental conditions. These can be natural, in-situ isolates that may be ‘distal or remote’, i.e., few at a large distance from macrorefugium, 'diffuse or widespread', occurring frequently throughout inhospitable areas, or 'proximal or ecotonal', with isolates close to the edge of macrorefugia</td>
<td>(Rull 2009)</td>
</tr>
<tr>
<td>Ex-situ microrefugium</td>
<td>E.g., botanical gardens, seed banks</td>
<td>(Rull 2009)</td>
</tr>
<tr>
<td>Protorefugium</td>
<td>Suitable sites where species are translocated to, which will preserve species with a contracting range, that will become a microrefugium or part of a macrorefugium. By definition, protorefugia are hybrid or novel assemblages of species.</td>
<td>This essay</td>
</tr>
<tr>
<td>Refuge</td>
<td>A 'microhabitat providing spatial and/or temporal protection from disturbances or advantages in biotic interactions'. Often over a single or few generations, e.g. edible plants growing amongst spiny plants to protect from herbivory</td>
<td>(Keppel et al. 2012)</td>
</tr>
<tr>
<td>Protorefuge</td>
<td>Suitable sites, outside of a species geographic range, where species are translocated to, which will act as a refuge, becoming integrated into the larger habitable space for a species at the leading edge of climate change, i.e., with an expanding range. By definition, protorefuges are hybrid or novel assemblages of species.</td>
<td>This essay</td>
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</tbody>
</table>
Figure 1. Theoretical changes in plant species assemblages because of climate change. Large circles show present, changing and future climate space/bioclimatic envelope. Small circles show species of different origin with different abilities to adapt. Arrows pointing to grey circle indicate natural dispersal, arrows pointing to open (white) circles indicate translocation. Adapted from (Harris et al. 2006).

Figure 2. Schematic showing changes in occupation of space over time. On the left temperate species are confined to glacial macrorefugia in the main, with a small amount of space available to them in microrefugia. As the ice caps have retreated more space has become available to the temperate species, and former glacial refugia (i) are now enveloped by wider habitable space. Inter-glacial microrefugia (ii) remain for the cold-adapted species, e.g., mountain tops. Increasing rates of climate change (present day) make adaptations to the new climate harder. Translocations (from source sites) to protorefuges (iii) and protorefugia (iv), e.g. restoration sites, provide space for both temperate species “in advance” as future habitable space grows, and for cold-adapted species to survive in space projected to become macrorefugia or microrefugia. Further warming will continue to reduce the amount of space available for cold-adapted species, forcing them into limited refugial space. Dates given for induced increase in warming (1850) and reduced rate of warming (2100) are best projections based on current knowledge and accuracy of hindcasts/forecasts.

Figure 3. Map of Europe showing the locations of nuclear power plants and the status of their reactors. These reactors are closed or in SAFSTOR, are scheduled to shut down by 2025, or are scheduled to shut down after 2025. These sites have the potential to become protorefuges or protorefugia for threatened species. Map produced in ESRI ArcMap™ 10.0, Redlands, CA.
Figure 4. Conceptual model for assessing suitability of species to be integrated into the novel species pool, and to remain in the restored species pool. Evaluating the limitations of the species from reference sites, and those threatened by climate, will allow for the right selection of species to be made which will not outcompete/be outcompeted by other species.

Figure 1
HABITABLE SPACE FOR COLD ADAPTED SPECIES

Protorefugia for translocated species (long term space)

Protorefuge for translocated species (short term space)

Translocation source sites

(i)

Glacial microrefugia

(ii)

Translocation source sites

(iii)

Inter-glacial microrefugia

(iv)

Inter-glacial macrorefugia

HABITABLE SPACE FOR TEMPERATE SPECIES

Retreat of ice caps

Anthropogenically induced increase in rate of warming ca. 1850

Present day

Reduced rate of anthropogenic warming (by 2100)

Time

Figure 2
Regional species pool from target habitat

Local reference species pool

Evaluation of environmental constraints

Target species pool

Evaluation of dispersal constraints

Threatened species

Climate projections

Species vulnerable to climate change

Translocation to proto-refugia/proto refuges

Novel species pool

Active restoration

Internal dynamics

Restored species pool

Figure 4