Assisted migration: Introduction to a multifaceted concept

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ABSTRACT

The idea that humans can assist nature by purposely moving species to suitable habitats to fill the gap between their migration capability and the expected rate of climate change is being increasingly contemplated and debated as an adaptive management option. The interest in assisted migration, both in the scientific community and society at large, is growing rapidly and is starting to be translated into action in Canada. However, the concept is in its infancy; clear terminology has not yet been established and assisted migration still encompasses a broad range of practices. This introductory paper for the special issue of *The Forestry Chronicle* on the subject of assisted migration describes increasing interest in the subject and its complexity. It also provides an overview of the potential scale of assisted migration, proposes a terminology, and briefly introduces the following papers. Overall, the five papers aim to present a comprehensive state of the scientific and operational knowledge and the debate on assisted migration in the context of Canada's forests.

Key words: assisted migration, Canada's forests, climate change, forest management, adaptation, species migration

RÉSUMÉ

L'idée que les humains peuvent aider la nature en déplaçant volontairement des espèces vers les habitats qui leur conviennent dans le but de réduire l'écart entre leur capacité de migration et la vitesse des changements climatiques est de plus en plus prise en considération et débattue comme option d'aménagement forestier adaptatif. L'intérêt pour la migration assistée, tant dans la communauté scientifique que dans le public en général, augmente rapidement et a commencé à se traduire en action concrètes à travers le Canada. Cependant, le concept de migration assistée est nouveau, la terminologie qui lui est associée n'a toujours pas été arrêtée et le terme migration assistée désigne une grande diversité de pratiques. Cet article d'introduction au présent numéro spécial de *The Forestry Chronicle* sur le sujet de la migration assistée décrit l'accroissement de l'intérêt pour cette pratique ainsi que sa complexité. De plus, il présente un survol de la diversité d'échelle d'application potentielle de la migration assistée, propose une terminologie et introduit les autres articles. Dans son ensemble, ce numéro spécial a pour but de présenter une couverture exhaustive du sujet en proposant l'état des connaissances scientifiques et opérationnelles, ainsi que l'état du débat sur la migration assistée dans le contexte des forêts du Canada.

Mots clés : migration assistée, forêt du Canada, changements climatiques, aménagement forestier, adaptation, migration des espèces

The Context

Changes in climate have accompanied the development of life on earth, but the rate of current climatic changes is unprecedented and projected to increase (IPCC 2007). General Circulation Models (GCMs) predict that an average temperature increase in North America could be between 2°C and 5°C (IPCC 2007). Warming is especially pronounced at northern latitudes, where increases up to 10°C in winter temperatures are projected by 2100 (IPCC 2007). The impacts of the changing climate are already being observed in Canada's forests, and are evidenced by the increase in the frequency and severity of natural disturbances such as wildfires, pest outbreaks and droughts (Lempriѐre *et al.* 2008, Williamson *et al.* 2009, Michaelian *et al.* 2011). Observations of more subtle impacts such as changes in the phenology (Arft *et al.* 1999, Menzel and Fabian 1999, Ahas *et al.* 2002, Parmesan and Yohe 2003, Walker *et al.* 2006) and the ranges of species (Gamache and Payette 2005, Caccianiga and Payette 2006, Hickling *et al.* 2006, Parmesan 2007, Beckage *et al.* 2008, Lenoir *et al.* 2008) are also accumulating and can be attributed to climate change with increasing confidence (Parmesan 2006, Rosenzweig *et al.* 2008).

Even though species are migrating toward higher latitudes and altitudes to follow their climatic niche in space, the rate of climate change is estimated to generally exceed the potential migration speed of species (Malcolm *et al.* 2002, Jump and Peñuelas 2005, Aitken *et al.* 2008). The immobility of individual plants makes them especially vulnerable to climate maladaptation, and this is often more pronounced for tree species because their long generation time may limit rapid adaptation (Vitt *et al.* 2010). Based on atmosphere–ocean GCMs, McKenney *et al.* (2007) estimated that climatic envelopes for major North American tree species could shift 330 to 700 km northward over the next half-century (6600 to 14 000 metres per year). Rates of northward tree migration after the last glacial maximum in Europe and North America, estimated from fossil pollen data, range between 100 and 2000 metres per year (Davis 1981, Huntley and Birks 1983, Pakeman 2001). In the eastern United States, the migration potential of five tree species, persimmon (*Diospyros virgini-*

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ana L.), sweetgum (*Liquidambar styraciflua* L.), sourwood (*Oxydendrum arboreum* [L.] DC.), loblolly pine (*Pinus taeda* L.) and southern red oak (*Quercus falcata* Michx.), is predicted by models not to exceed 100 to 200 metres per year (Iverson *et al.* 2004). Other factors add challenge to migration. Landscape fragmentation presents significant, and in some cases insurmountable, barriers to northward migration (Fazey and Fischer 2009, Vitt *et al.* 2010). Competition with existing vegetation for light, nutrients and space can limit the establishment of seedlings in a new environment; intact ecosystems are often resistant to introduced plant species, and are less likely to readily support self-sustaining populations of new species (Hunter 2007).

As the climate changes too rapidly to stay in equilibrium with the rates of species migration, some tree species may become maladapted to their environment (Huntley 1991). Differences in adaptation capacity and physiological tolerance are expected to lead to species-specific responses to climate change. Some species may benefit from new growing conditions while others, being physiologically weakened, may become more prone to insect outbreaks and diseases (Bhatti *et al.* 2003). Although environmental changes may have a more detrimental effect on species with a narrow fundamental niche, generalists may also become maladapted to new climate conditions. Tree ring studies indicate that at elevational tree line in Yukon (D'Arrigo *et al.* 2004) and in warmer zones in Alaska (Barber *et al.* 2000, Beck *et al.* 2011), average temperatures over the growing season have already shifted beyond the physiological tolerance of white spruce (*Picea glauca* [Moench] Voss), leading to growth decline. A study by van Mantgem *et al.* (2009) indicates that the increase in tree mortality rates in the western United States from 1955 to 2007 could be attributed to regional warming, and more specifically to an increase in drought stress and/or the enhanced growth and reproduction of insects and pathogens. Species that are unable to adapt quickly enough may eventually become extirpated and in some cases extinct (Huntley 1991, Weber and Flannigan 1997, IPCC 2007). Thomas *et al.* (2004) used projections of maximum expected climate warming to conclude that globally the estimated percentage of species "committed to extinction" by 2050 will be 21% to 32% for species with unlimited dispersal and 38% to 52% for those with no dispersal capabilities. Although recent studies have indicated more conservative estimates of extinction risk for some populations (He and Hubbell 2011, Morin *et al.* 2008), climate change will undoubtedly accelerate the rate of species loss (Sahney and Benton 2008, Rockström *et al.* 2009).

The idea that humans can assist nature to help fill the gap between species capability to migrate and the rate of change in climatic conditions by assisting their migration to suitable climate habitat is being increasingly contemplated and debated as an adaptive management option. In 2008, the Canadian Council of Forest Ministers (CCFM) identified climate change as one of the two national priorities for Canada's forest sector (CCFM 2008) and stated that "the impacts of a changing climate have to be considered in every aspect of managing Canada's forests". Since then, a federal/provincial/territorial task force has undertaken a variety of analyses and syntheses to inform sustainable forest management decision-making. The CCFM report *Vulnerability of Canada's tree species to climate change and management options for adaptation: An overview for policy makers and practitioners* (Johnston *et al.* 2009) reviews the implications of climate change for the management of tree species in Canada and provides a range of options for adaptation. This portfolio included "ensuring all disturbed or harvested forests are promptly reforested with species and seed sources that are adapted to predicted future climates (i.e., using assisted migration)".

Over 93% of Canada's forested land is publicly owned (Crown forest land), of which the majority (77%) falls under provincial or territorial jurisdiction (Natural Resources Canada 2011). The provinces and territories have legislative authority over conservation and management of forest resources on provincial and territorial Crown lands, with companies having access to these lands through legal agreement. Interest in assisted migration of tree species is generally growing across the country, and is starting to be translated into preliminary actions in a few jurisdictions. Although there is considerable debate and uncertainty regarding the widespread implementation of assisted migration for species conservation, the practices being implemented within the forestry community are at the low-risk end of the spectrum (Kreyling *et al.* 2011)—the movement of populations within a species range (termed "assisted population migration") or the movement of species just outside their range ("assisted range expansion"). An overview of the state of the implementation of assisted migration in Canada is provided by Pedlar *et al.* (2011) in this issue.

An Emerging and Rapidly Evolving Concept

Deliberate movement of species outside their natural range is an established practice in human culture and history, with long traditions in both agriculture and horticulture. However, the concept of moving species with the explicit intent to accommodate climatic changes is in its infancy; clear terminology has not yet been established and assisted migration still encompasses a broad range of practices (Seddon 2010). Three terms are used, somewhat interchangeably, in the scientific literature: assisted migration (the primary term in 51% of the documents examined), assisted colonization (41%) and managed relocation (9%).

Interest in assisted migration, in the scientific and forest management communities as well as society at large, is growing rapidly, as shown by the increasing number of published documents covering the subject matter. To measure and depict this interest, an examination of research and media literature was conducted in January 2011. Peer-reviewed research publications on assisted migration were quantified by searching "assisted migration", "assisted colonization" and "managed relocation" in SciVerse Scopus (2004–2010), which is a comprehensive abstract and citation database. This search yielded over 100 articles, of which only 47 addressed the movement of species in response to the threat of climate change (Fig. 1). Assisted migration peer-reviewed literature has increased rapidly since 2007, with a peak in 2009 largely caused by the number of published letters responding to the strong statements against assisted migration made by Ricciardi and Simberloff (2009) in *Assisted colonization is not a viable conservation strategy*.

News media reports (from established news sources such as newspapers, magazines and newswires) were found using Factiva (2010), searching the same three assisted migration terms. Of the hundreds of documents found, 203 addressed the movement of species, of which 124 directly referenced climate change. “Assisted migration” remained the most common term, with 82% of the 124 climate change media documents containing this term. Media coverage of assisted migration closely followed the temporal pattern of scientific publications (Fig. 1), with a steep increase in the number of documents starting in 2007, once again, followed by a peak in 2009.

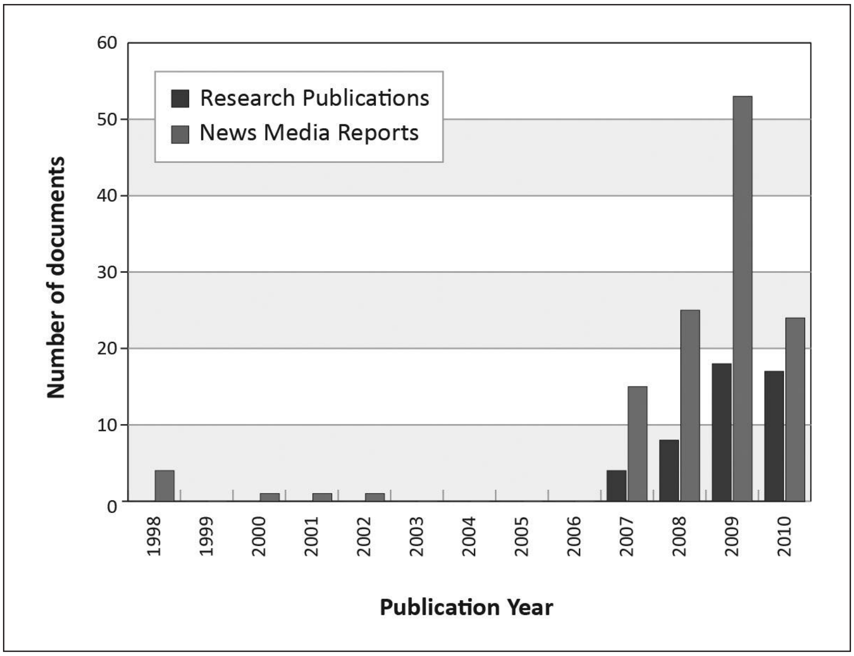

Fig. 1. Volume of assisted migration resource literature and media reports as of January 2011.

Table 1. Definition of the concept of assisted migration from the scientific literature

Term	Definition
Assisted migration	Human-aided translocation of species to areas where climate is projected to become suitable to reduce the risk of extinction due to climate change. (Mueller and Hellmann 2008)
	The purposeful movement of species to facilitate or mimic natural range expansion as a direct management response to climate change. (Vitt *et al.* 2010)
Assisted colonization	The translocation of species to favourable habitat beyond their native range to protect them from human-induced threats such as climate change. (Ricciardi and Simberloff 2009)
	Translocation of a species beyond its natural range to protect it from human-induced threats. (Seddon 2010)
Managed relocation	An intervention technique aimed at reducing negative effects of climate change on defined biological units such as populations, species or ecosystems. It involves the intentional movement of biological units from current areas of occupancy to locations where the probability of future persistence is predicted to be higher. The underlying motivation is to reduce the threat of diminished ecosystem services or extinction from climate change. (Richardson *et al.* 2009)
	A conservation strategy involving the translocation of species to novel ecosystems in anticipation of range shifts forced by climate change. (Minteer and Collins 2010)

The Many Definitions and the Scale of Assisted Migration

Despite the growing body of literature addressing the issue, assisted migration still does not have an established definition; instead, it has multiple interpretations and therefore can be applied to a broad range of practices. In Table 1, definitions are provided from scientific publications, demonstrating that despite the use of different terms to describe assisted migration, the concepts are complementary and overlap substantially. The term “assisted migration” is the most commonly used term, and it combines the concepts of “assisted” (human intervention) with “migration” (movement of biological units). Attempts to clarify the terminology have been made in recent years. Seddon (2010) proposes a “standard framework and terminology for discussing translocation option” and ranks conservation translocation practices along a gradient based on the reliance on documented historical distribution, ranging from species reintroduction to assisted colonization (his synonym for assisted migration), and then one step further to community construction (introduction of novel species assemblages). In Canada, Sally Aitken (in Johnston *et al.* 2010) also proposed an alternative terminology based on the potential risk of the translocation, from “assisted population expansion” (low risk) to “translocation of exotics” (high risk), with “assisted range expansion” posing moderate risks. The following discussion provides an overview of the potential scale of assisted migration, including the terminology that has been introduced to differentiate between assisted migration practices. Our proposed terminology, developed following a review of the literature, and selected for its effective communication, is outlined in Table 2.

What is moved?

In general, assisted migration refers to the movement of species. However, the movement of genetic populations within a species range has also been advocated as an adaptation measure under climate change (Jump and Peñuelas 2005, Aitken *et al.* 2008, Seddon 2010, Kreyling *et al.* 2011). This practice is most easily described as “assisted population migration” but has been described as “reenforcement” (Seddon 2010) and “assisted population expansion” (Johnston *et al.* 2010). At the opposite end of the spectrum, assisted migration can apply to the movement of

Table 2. Proposed terminology for assisted migration modes

Term	Definition
Assisted migration	The human-assisted movement of species in response to climate change.
Assisted population migration	The human-assisted movement of populations (genotypes) within a species-established range in response to climate change.
Assisted range expansion	The human-assisted movement of species to areas just outside their established range in response to climate change, facilitating or mimicking natural range expansion.
Assisted long-distance migration	The human-assisted movement of species to areas far outside their established range (beyond areas accessible via natural dispersal) in response to climate change.

species assemblages to protect mutualisms or trophic associations (McLachlan *et al.* 2007), termed "community construction" by Seddon (2010).

Why is it moved?

The discussion of assisted migration of plant and animal species in the scientific literature centres on conservation goals. A flagship example is the proposed assisted migration of the bay checkerspot butterfly (*Euphydryas editha bayensis* Sternitzky, 1937), threatened by climate change and habitat destruction in the San Francisco Bay Area, California (Marris 2008). Another example is the actual translocation of *Torreya taxifolia* Arn., a threatened tree species, with a small endemic range in northern Florida (Richardson *et al.* 2009). For conservation of species via assisted migration to be effective, climate change must be the primary cause of extinction risk (Hunter 2007, McLachlan *et al.* 2007, Huang 2008, Vitt *et al.* 2009); however, to attribute the cause of a particular species decline to climate change requires in-depth knowledge of the biology and environment of the species of interest (Hoegh-Guldberg *et al.* 2008, Vitt *et al.* 2010). This kind of detailed information on population dynamics, reproductive biology and migration rates is not always available for common or economically valuable plant species (Vitt *et al.* 2010), with even less information available for the rare or uncommon species most likely to need assisted migration for conservation (Huang 2008). In Canada, the only widespread or formerly widespread endemic tree species assigned a conservation status by the Committee on the Status of Endangered Wildlife in Canada are butternut (*Juglans cinerea* L.), endangered due to the impact and potential impact of the fungal disease butternut canker (*Sirococcus clavigignenti-juglandacearum* V.M.G. Nair, Kostichka & Kuntz) and American chestnut (*Castanea dentata* [Marsh.] Borkh.), endangered as a result of the introduction of chestnut blight fungus (*Cryphonectria parasitica* [Murr.] Barr).

Even though the scientific literature generally focuses on conservation goals, assisted migration in agricultural and silvicultural systems is primarily implemented to maintain health and productivity, which bear significant economic and social implications (Minteer and Collins 2010, Mueller and Hellmann 2008, Vitt *et al.* 2010). Commercial nurseries in Europe already promote ornamental plantings an average 1000 km north of a species northern range limit (Mueller and Hellmann 2008). Assisted migration in Canada's forestry context is principally motivated by the optimization of health and productivity of commercial tree species. In 2010, the forestry industry contributed over $19 billion to Canada's gross domestic product and employed over 200 000 Canadians (Natural Resources Canada 2010). Growth and productivity of Canadian tree species are often temperature-limited and are predicted to increase under a changing climate where moisture and nutrients are not limiting. Provenance experiments with balsam fir (*Abies balsamea* [L.] Mill.), larch (*Larix* spp.) and white spruce showed significant growth enhancements when planted in regions with warmer average temperatures (Andalo *et al.* 2005, Beaulieu and Rainville 2005), although jack pine (*Pinus banksiana* Lamb.) experienced small growth reductions (Carter 1996, Savva *et al.* 2007). Therefore, there is an economic interest to take advantage of a potential gain in productivity via changes in seed transfer zones for commercially valuable species.

Where is it moved?

The risk of unintended consequences associated with assisted migration is generally considered to increase with migration distance (Mueller and Hellmann 2008, Vitt *et al.* 2010). The practice of moving populations to facilitate or mimic natural range expansion in response to changing climatic conditions, termed "assisted range expansion" (Johnston *et al.* 2010), is unlikely to carry the same risk as assisted long-distance relocation (Vitt *et al.* 2010; Winder *et al.* 2011, this issue). The most attractive sites for assisted migration are those that are within the historical range of the candidate species (Hunter 2007). However, historical species ranges, as well as the outcomes of any species introduction, even those that take place just beyond a species range limit, are hard to determine accurately (Hunter 2007). In Canada, current assisted migration initiatives are focused on moving populations within the species range, and extending the range by a few hundred metres in altitude or a few hundred kilometres in latitude.

How is it moved?

The potential success and the risks of assisted migration depend somewhat on the method used to introduce the candidate species or populations to a new site. Assisted migration can follow the same procedures as those used in traditional regeneration practices, including various methods of planting and direct seeding. Planting is done with bare-root seedlings, containerized seedlings or cuttings; direct seeding is done by aircraft, machine or hand, and includes such methods as broadcast and precision seeding (Hayes 2001). Assisted migration can also include less intensive but strategic planting of individuals, which, once established, become a nucleus for seed dispersal and/or vegetative regeneration (e.g., suckering, sprouting and layering). In Canada, in 2009, almost 400 000 ha of land (1/1000 of overall land with tree cover) was regenerated by tree planting, and over 20 000 ha by direct seeding (National Forestry Database 2011). Given the overall scale of regeneration practices, even full implementation of assisted migration is unlikely to affect a large portion of Canada's forest resources in the near future.

Risks of Doing vs. Not Doing Assisted Migration

The precautionary principle advises that action must be taken when there is a danger of irrevocable harm, even in cases where there is considerable uncertainty. Assisted migration offers a potential option to alleviate the risks climate change poses to biodiversity and tree health and productivity. However, the risks of implementing such a strategy must be balanced against those associated with not doing it. As clearly summarized by Mueller and Hellmann (2008): "Risk exists on all sides of the AM [assisted migration] debate—risk of inaction, risk of unsuccessful action, and risk of being too successful (i.e., creating novel invasive species)."

Aubin *et al.* (2011, this issue) describe how different forms of assisted migration can be motivated by different objectives and how positions are influenced by fundamental perspectives on nature; for example, our position on whether to deliberately manage natural systems or allow them to adapt on their own. Their analysis shows that the debate centres on risks and benefits for which assessment is impeded by numerous uncertainties. They propose to move toward a clearer identification of values and motivations to advance and nuance the assisted migration debate.

An area of significant uncertainty is the determination of fundamental life history traits that make species more likely to benefit from assisted migration (Vitt *et al.* 2010). Species with low dispersal abilities and limited bioclimatic envelopes are considered the most vulnerable to the combined effects of climate change and habitat fragmentation (Hunter 2007, McLachlan *et al.* 2007). Recent research suggests that the potential of evolutionary adaptation for numerous taxa may in fact be more prominent and rapid than expected under current scientific paradigms (Hoffmann and Sgrò 2011). This has been exemplified not only by the species that have invaded new habitats but also the native species responding to these invasions (Carroll 2008, Whitney and Gabler 2008, Hoffmann and Sgrò 2011). Although the innate capabilities allowing species to adapt to various conditions are ultimately determined by genetics, environmental conditions may play a more crucial role in gene expression than was previously believed by modulating gene expression without changing the DNA sequence. By influencing primary phenotypic diversity, these effects, also known as epigenetic effects, may thus have a major impact on evolutionary history, resulting in different environmental adaptations for even closely related species (Paun *et al.* 2010). In some cases, these adaptations may be beneficial to species in changing climatic conditions. The potential ability of species to adapt in place through epigenetic effects or natural selection is a strong argument against aggressive implementation of assisted migration, despite the rapid rate of climate change.

Vulnerability assessment tools can help identify which species or ecosystems are projected to be impacted by climate change and also contribute to a better understanding of the potential risks. These tools support decision-making related to forest management adaptation strategies by helping to evaluate and prioritize actions such as assisted migration. Beardmore *et al.* (2011, this issue) present an overview of existing tools for climate change vulnerability assessments at the species level, and provide examples of their application. Knowledge of species ecology is an integral part of the development of vulnerability assessment tools to support decision-making, with improvements in ecological knowledge directly enhancing these tools.

A key uncertainty in assisted migration is the unknown risk of the impact of species introductions on recipient ecosystems (Sandler 2010). Invasion biology is still an emerging science, and it is extremely difficult to predict which species are likely to become invasive when introduced into novel habitats (Davidson and Simkanin 2008, Mueller and Hellmann 2008, Ricciardi and Simberloff 2009). Sax *et al.* (2009) argue that competition from introduced species is unlikely to cause extinction of native species; however, extinction is not the only indicator of ecosystem damage. Introduced species can potentially alter key ecological processes such as nutrient cycling, hydrology, reproduction (e.g., pollination, seed dispersal) and disturbance (Ricciardi and Simberloff 2009). They can also carry diseases and parasites into recipient ecosystems, and present challenges to native species through increased competition for resources (Hoegh-Guldberg *et al.* 2008, Ricciardi and Simberloff 2009). Hybridization of introduced species with closely related native species can alter the genetic structure and breeding system of local populations, and may thus result in the dominance of a smaller number of genotypes (Hoegh-Guldberg *et al.* 2008, Ricciardi and Simberloff 2009, Vitt *et al.* 2010). Invasion risk in tree species is discussed in greater detail by Winder *et al.* (2011, this issue) in their analysis of the ecological implications that need to be incorporated into assisted migration decision-making. Also, Pedlar *et al.* (2011, this issue) provide an extensive description of the implementation requirements for assisted migration as well as a review of the existing information, tools and infrastructure that can support assisted migration, from planning to moving to post-establishment maintenance and evaluation. Pedlar *et al.* (2011) also present a high-level cost assessment of implementing different scenarios of assisted migration, and conclude with the identification of priorities and options for next steps, including key information gaps and technical and infrastructure requirements.

Any decision on assisted migration needs to be informed and supported by sound science. Also, there is a need for a policy framework to guide assisted migration (McLachlan *et al.* 2007, Mueller and Hellmann 2008). Currently, private citizens are allowed to move species without governmental permission (McLachlan *et al.* 2007), as shown by migration of the endangered species *T. taxifolia* Arn. in Florida by a self-organized group, the Torreya Guardians[2], without a permit (Schwartz *et al.* 2009).

Assisted migration represents an illustrative example of adaptation and is often perceived as an empowering means for humans to help threatened natural systems cope with climate change. Despite the apparent simplicity of assisted migration as a feasible option for adaptation to climate change, it is not a panacea: it is still the subject of numerous uncertainties, questions and debates. The knowledge gaps associated with assisted migration decision-making are an important barrier to its successful implementation. However, insufficient knowledge represents only one issue in the broad spectrum of policy, ethical, operational and scientific challenges posed by assisted migration. Assisted migration is mul-

[2]www.torreyaguardians.org

tifaceted. It poses new and complex questions. It requires new knowledge to be generated, and management practices, paradigms and policies to be revisited, and it questions our fundamental values concerning the relationship of humans with nature. Because of the interest in assisted migration as a potential adaptation option and because of the complexity of the issue, the need to develop a comprehensive review of assisted migration as a forest management option to adapt to climate change in Canada is addressed in this special issue of *The Forestry Chronicle*.

Assisted migration is an emerging concept with many unknowns. To move forward on this issue requires the best scientific and technical knowledge available, an informed and open discussion among all potentially affected parties and a framework for the decision-making process. The goal of this special issue is to present a comprehensive yet accessible review of the state of the scientific and operational knowledge and the debate on assisted migration. To facilitate the reading of our series, a glossary of technical terms that re-occur throughout the articles is included in the present special issue for easy reference to their definitions. The authors hope that these five papers will contribute to inform future decisions related to assisted migration in Canada's forests.

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