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Original Manuscript

One option, two countries, several strategies: subjacent mechanisms of assisted migration implementation in Canada and France

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Abstract

Climate change obliges societies to develop adaptive strategies in order to maintain sustainable management of resources and landscapes. However, the development and implementation of these strategies require dialogue between researchers and policy-makers about what they understand for adaptation. This dialogue can be hindered by language differences, the hidden agendas, and conflicting concerns of those involved. In this research study, we explored the mechanisms that underlie the implementation process of assisted migration (AM), an adaptation strategy that aims to limit the impact of climate change. We conducted a comparative analysis of 80 semistructured interviews with actors in the forestry sectors in Canada and France. In Canada, our results show a division between the provinces strategies, causing a debate about AM because researchers are wary of the geoengineering and economic arguments that frame AM in areas where the effects of climate change remain unclear. In contrast, we found that the observation of climate impacts is a strong trigger for the application of AM despite an awareness of its associated risks. In France, we explained the absence of AM implementation by a lack of information flow between research and foresters regarding the concept of AM, a cultural attachment of French foresters to their forest landscapes and that climate change effects are not clear yet. Clarity on what implies a true ecological engineering approach in ecological restoration can help maintaining adaptive actions like AM within the general scope of ecosystem management and minimize simplistic applications of adaptation strategies because of climate change.

Key words: adaptation strategies, assisted migration, climate change, ecological engineering, geoengineering, implementation barriers, proactive restoration

Implications for Practice

- Adaptation is an ambiguous concept with two different approaches, geoengineering and ecological engineering.
- Defining assisted migration (AM) as a totally new concept hampers its implementation.
- In Canada, AM raises debate because of a lack of distinction between the economic and conservation goals of AM.
- In France, despite AM being accepted by forest actors, the desire to preserve forest legacy blocks the application of AM.
- The observation of climate change impacts and the local forest culture seems to be the subjacent mechanisms of the AM implementation.

Introduction

Climate change poses very real challenges to policy-makers and managers. These challenges are difficult to assess and predict, but they include the implementation of strategies to maintain ecosystem services. Faced with the environmental impacts of climate change, societies have two main strategies: mitigation and adaptation. Mitigation (essentially reducing CO₂ emissions) is a generally accepted concept that is both understandable and has clear guidelines for application. Mitigation is limited only by the success and scope of international negotiations and agreements that are often blocked by arguments regarding the uncertainty of climate change outcomes (Barrett & Dannenberg 2012). On the other hand, adaptation is a more national or local strategy whose methods of application are rather less clear. In contrast to mitigation, strategies for adaptation to climate change depend not only on human choice but also on ecosystem functioning, that is, the implementation of a relevant adaptation strategy must benefit both the well-being of and resource provision for humans, as well as the preservation of biodiversity and ecosystems. Compliance with this compromise almost always requires dialogue between policy-makers, scientific actors, and managers. Such dialogues are often complex and entail discrepancies between the concepts, language, and agendas of each actor.

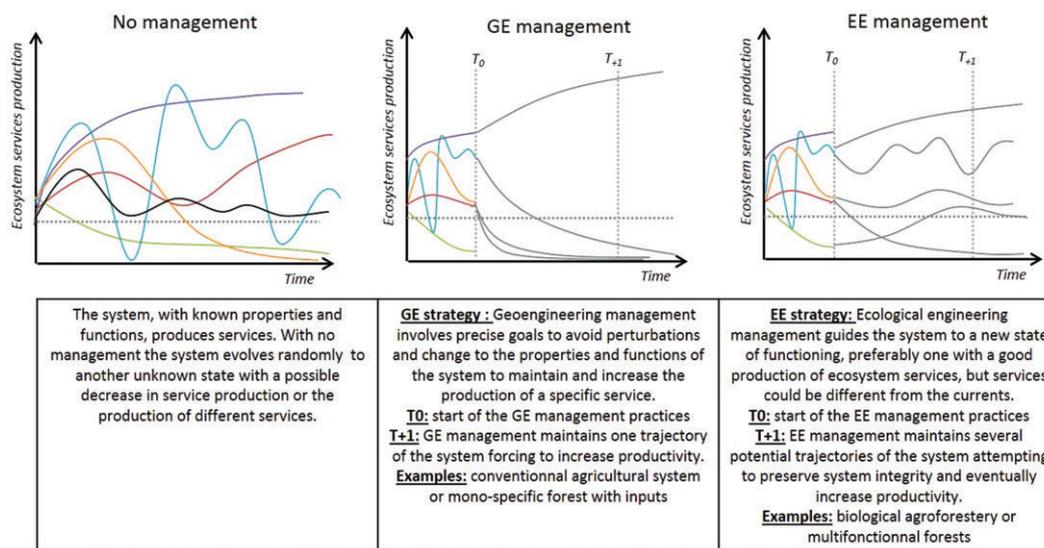


Figure 1. Theoretical graphic representation of the effects of the no-management, geoengineering (GE), and ecological engineering (EE) management approaches to a system.

Even when stakeholders share the same goals, they diverge frequently on how to approach an adaptation strategy. Originally, in biological sciences, the term adaptation referred to Darwin's evolutionary theory of the nineteenth century, and could be used as either a verb ("to adapt") or as a noun. The verb describes the *process* of how natural selection preserves characteristics that permit organisms to survive and evolve in a given environment but with no precise ultimate goal. The noun refers to the *result* of the process as a particular organ or physiology has changed in response to environmental selection. However, in a climate change context, the concept of adaptation has evolved to place more emphasis on the ultimate goal of the process. In the report of working group II of IPCC (2007), adaptation is referred to as an "adjustment in natural or human systems in response to actual or expected climatic stimuli or their effect, which moderates harm or exploits

beneficial opportunities.” Hence, in the public sphere, adaptation is commonly used to refer to a strategy that involves detailed processes and specific expected goals and is designed to cope with change and manage potential risks. Nevertheless, the strategy remains vague about what “adjustment” or “response” is required from society. Today, strategies to limit risks and cope with change in social-ecological systems fit into the development of “adaptive strategies,” which could be described in two main ways, geoengineering (GE) and ecological engineering (EE) approaches. Adaptation strategy in this context should not be equated to adaptive management as the first refers to a set of objectives to cope with perturbation and the second with how any management decision should be monitored, evaluated, and reformulated periodically.

In the face of climate change, political actors are more likely to understand adaptation strategies in terms of the GE approach. The GE approach considers the strategy process to involve the accommodation of perturbations through a process of blocking or avoiding the impact of the perturbation (Keith 2000) (Fig. 1, center panel). The GE approach differs from traditional engineering because it addresses the threat to the global climate and develops strategies to cope with climate change. The most famous example is the deployment of aerosols of SO₂ into the atmosphere to limit solar radiation. With this type of adaptation approach, managers want to keep the existing functioning of the productive system from the impacts of climate perturbation, supposedly without changing the intrinsic system characteristics or functioning of the system. This type of strategy generates a rapid response of the system, but it implies regular interventions to maintain the sustainability of the system. Obviously, there is an uncertainty on the intervention and its consequences on the system evolution, and on the success of the management action.

At the same time, most researchers in the biological sciences think of the EE approach when invoking adaptation strategies. The EE approach considers adaptation as an intrinsic change of the system, that is, a perturbation such as climate change is accepted as a new element of the environmental condition. In this type of adaptive approach, the system has to change its characteristics, functioning, and thinking, perhaps in an unexpected manner, in order to remain sustainable (Mitsch 2012) (Fig. 1, right panel). It consists to maintain a

process rather than a state and requires, in theory, one intervention at the beginning of the management. Moreover, one of the key characteristics of the EE approach is that the final system could be radically different from the previous system and there is a big time offset between the intervention and the adaptation of the system. Once again, there is uncertainty with this adaptation strategy concerning the success of the management action, and the rebalancing of the system after the intervention. This contrasts with the GE approach in which the goal is to maintain the same system. In both the GE and EE approaches, adaptation strategies require a dialogue between scientists and policy-makers to make the best choice for ecosystems and societies. This means that barriers to implementation can arise during discussions between stakeholders as a result of differing views of adaptation.

In recent years, a new adaptation strategy of assisted migration (AM) has been developed in order to limit the impact of climate change on biodiversity. AM is frequently defined as the human voluntary movement of individuals or populations from a site where they are threatened by climate change to another site where they are not currently present but where we suppose they could survive under future climate predictions. However, in an ecosystem restoration context, AM has also been defined as the integration in a target ecosystem of individuals or populations supposed more robust face to changing conditions in order to reinforce the local ecosystem (Kreyling et al. 2011; Sansilvestri et al. 2015a).

The proposition of AM has not been greeted with unanimous enthusiasm in the scientific community. Between 2005 and 2011, AM caused a fierce debate about the associated risks, with conservatives concerned about the biologic and genetic risks of AM opposing interventionists who wanted to act proactively against the climate threat (McLachlan et al. 2007; Neff & Larson 2014). Many researchers have attempted to use scientific arguments to settle the debate but with little success, in part because of the ethical, political, ecological, and economic issues (Schwartz et al. 2012) that complicate decision-making processes regarding the artificial movement of individuals or species in the face of climate change.

The view of AM as a completely new management practice mainly for species conservation has inscribed it de facto as a forceful manipulation of nature and made it

more likely to be embraced by those with political agendas that entail a need to show results in combating the effects of climate change. However, AM is not in fact a new concept. Gardeners and foresters have been moving plants and trees for millennia (Pardé 1924) without causing much debate. The novelty of the proposition is only in the use of intentional movement as an adaptation strategy in a climate change context. Most definitions and applications of AM are at the scale of species, which means that they take a GE approach to AM that involves the movement of threatened species from one unsuitable site to another in order to recreate the same system without changing the practices used to manage that system. Even if the GE approach supposes a robustness of the intrinsic functioning of the system, there is always a risk to change the target ecosystem with the movement of species. Yet, as Seddon (2010) has proposed, AM can also be applied from an EE perspective at the scale of community, which implies a holistic and adaptive approach. In this case, AM could be thought as a restoration practice for communities impacted by climate change. This type of management represents a proactive restoration with the aim to build new ecological communities that create new suitable habitats for future environmental conditions with a concomitant change in management practices (Fig. 1, right panel) (Sansilvestri et al. 2015b). Hence, the shift from a GE to an EE approach implies an extension of AM to the natural communities and landscape management, rather than a sole focus on species or population management. Today, AM is mainly envisaged as a type of management for forest ecosystems on a species-by-species scale, but it could take different forms in the future according to the scientific view, political and social considerations.

Considering the slow migration rate of trees, forest ecosystems represent a good candidate for AM. However, forest characteristics also exacerbate the complexity involved in the implementation of climate adaptive strategies. With very large temporal scales in their development, there are crucial issues in the sustainable management of forests in the uncertain context of climate change. The selection and planting of trees must be suitable not only for today and the next 30 years, but must also remain appropriate for the following 60 or 100 years and beyond. A key challenge in restoration of forests and forestry is therefore to maintain the evolutionary potential of tree species and/or populations (Williams & Dumroese 2013) while maintaining productivity.

In this article, we offer an analysis of data collected from semistructured interviews with

French and Canadian forest actors who have considered, or who are actively involved in, the implementation processes of AM in forest ecosystems. These two countries represent good candidates for the application of AM programs because of their steep climatic gradients, their potential vulnerability to climate change, and the important position of the forestry sector within the two countries as a whole. The goal of this analysis is to determine the factors that influence decision-making in relation to the implementation of a complex adaptation strategy such as AM, and the potential barriers to its implementation. Our specific questions are (1) what are the subjacent mechanisms in Canada and France that facilitate or constrain AM implementation processes? And (2) what are the lessons that can be learnt from Canadian and French examples of the implementation of AM in forest ecosystems?

Methods

Our study was conducted in Canada and France. For the Canada, interviews were conducted during the spring of 2014 in four provinces: Quebec, Ontario, New Brunswick, and British Columbia (Fig. 2B). These provinces were chosen because they currently have AM programs. In Québec, Ontario, and New Brunswick, programs are, for the time being, experimental. In British Columbia, programs include species conservation, experimental research, and official large-scale initiatives. In France, interviews were conducted between August 2014 and February 2015 in five French forest regions: one mountain Alpine forest, one Mediterranean forest, two temperate forests, and one Atlantic forest (Fig. 2A). These regions were chosen in view of their ecological, economic, and climatic vulnerabilities, which mean that AM could be a relevant management option in these areas. Here, we present a comparative analysis of AM in France and Canada on the basis of semistructured interviews that form part of another study on forest social-ecological vulnerability, which we discuss in details elsewhere. In total, 80 semistructured interviews were performed in the four provinces of Canada and in the five regions of France. In Canada and France, interviewees were researchers, institutional officers of the respective national forest offices, members of the forest/natural resources ministry, technical field managers, and industry people. Three types of interviews were designed, one for the private forest owner, one for the forest policy-makers, and one for the forest members company.

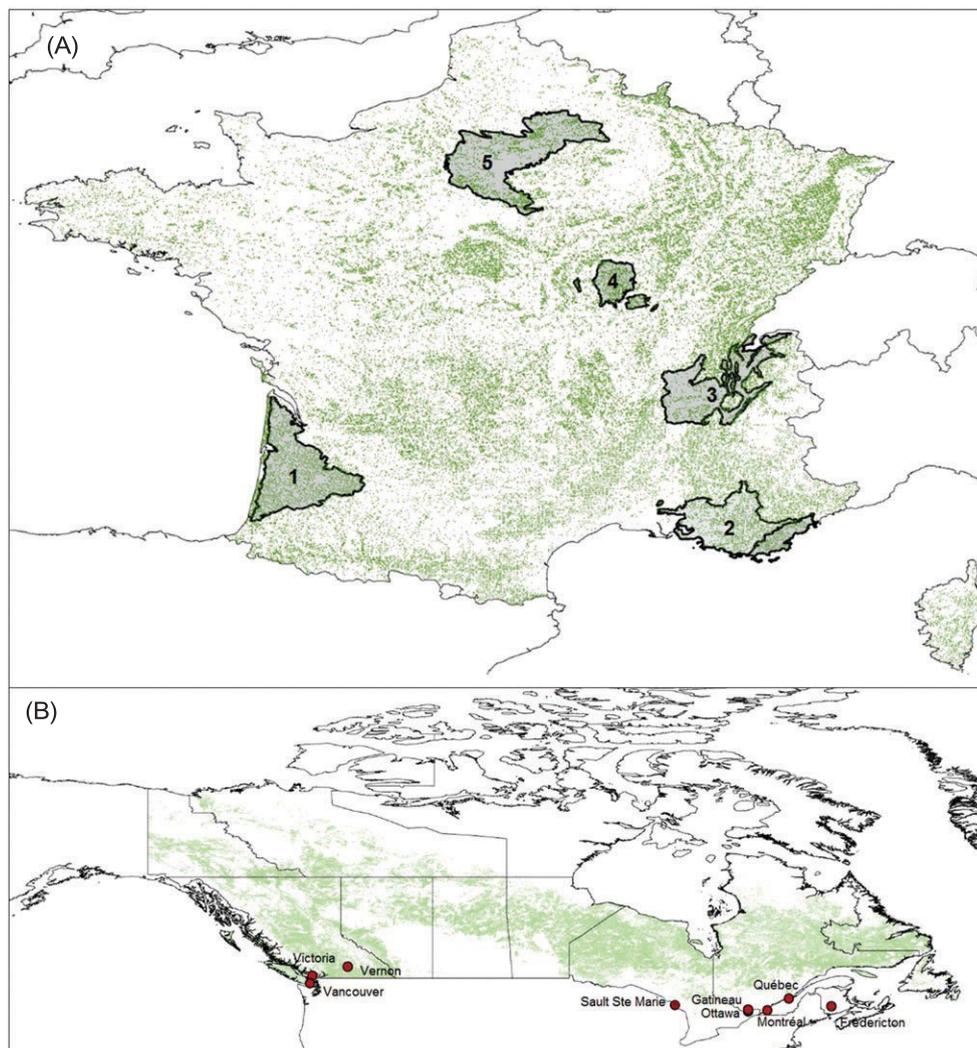


Figure 2. (A) Map of France with the location of the five selected forest regions 1: Atlantic region; 2: Mediterranean region; 3: Alpine region; 4 and 5: Temperate regions; (B) Map of Canada with the different sites visited.

The semistructured interviews are characterized by the absence of proposed answers, the interviewees are free in their answers, and the text is analyzed using as much as possible the interviewees' point of view. The lists of questions are available by request to the first author.

Results

In this section, we proceed to a comparative analysis between Canada and France, and we attempt to understand why it seems to be easier to move trees in Canada than in France (Fig. 3).

AM in Canada: Contrasting Visions Across Provinces

Even though AM programs have already been implemented in Canada, there are opposing views and complex debates separating the reactive eastern provinces (Quebec, Ontario, and New Brunswick) “*AM is an interesting idea but there are still too many uncertainties*” (Forest researcher 1, Ontario); and the proactive province of British Columbia (BC) “*AM represents a good tool to diminish the stress caused by pests, insects, and climate*” (Forest genetic institute member 1, BC).

For the eastern provinces, the biggest barrier to AM is the differences between the approaches of scientists and decision-makers. The former take an ecosystem approach to AM, akin to the EE approach, whereas the latter take a species-centered economic approach (assimilated to GE approach). For many actors, AM is seen as a lure of the attractive to governments as a way to avoid the implementation of mitigation policies. “*AM was proposed as THE solution to maintain good healthy forests in the face of climate change, but in reality*

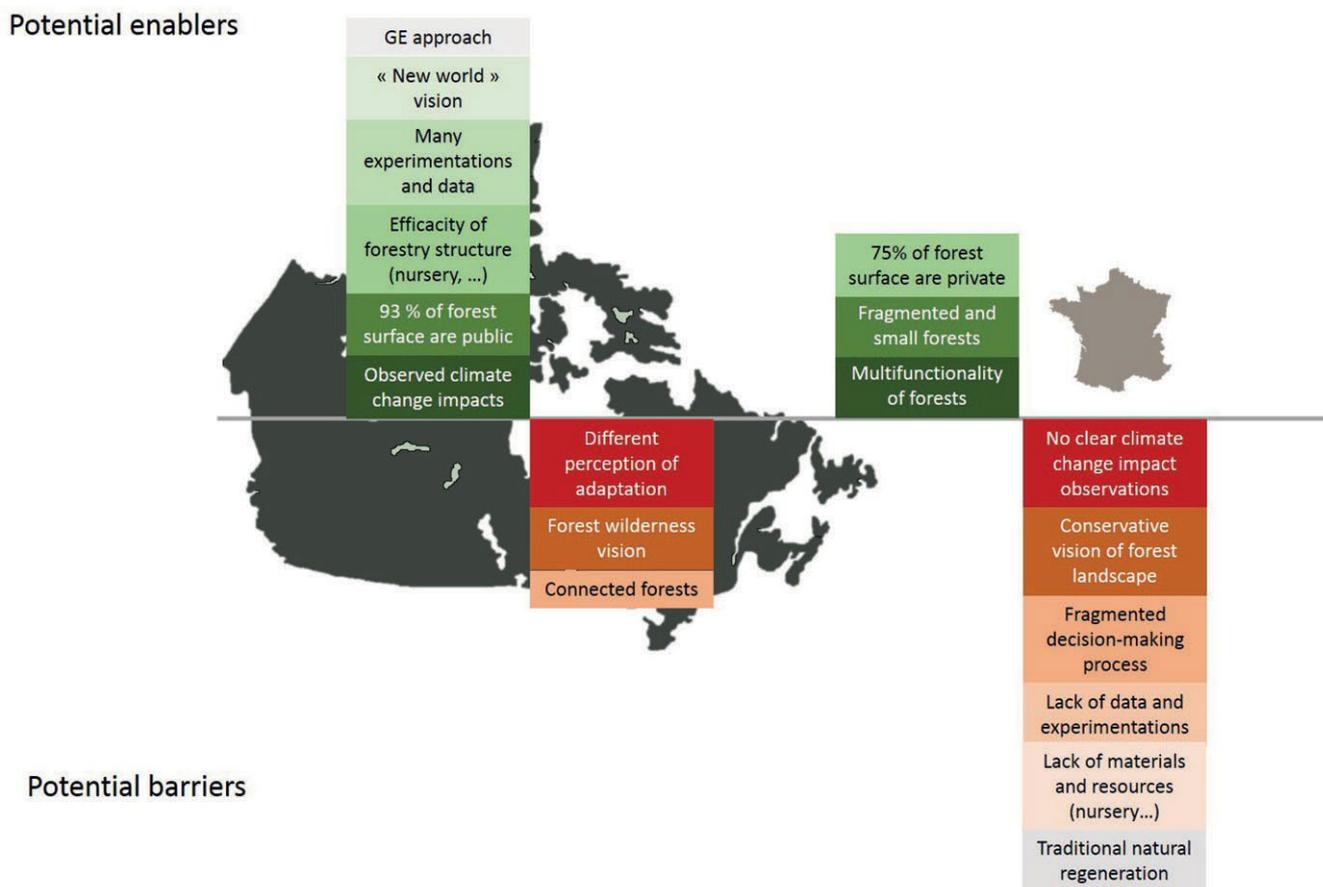


Figure 3. Graphical representation of subjacent mechanisms of assisted migration implementation for Canada and France. In green, the potential enablers of assisted migration implementation. In red, the potential barriers of assisted migration implementation. More the color is dark more the mechanism has an important role in the process.

AM is mainly developed to maintain and increase the productivity of forests” (Forest researcher 2, Ontario)/“AM is a tool, is not the only tool that exists but it is the only tool that politicians want to use. Government uses smoke and mirror with AM implementation to avoid involvement in a mitigation strategy” (Forest researcher 3, Ontario). The Natural Resources Ministry funds a large spectrum of research on AM to develop knowledge (<http://www.nrcan.gc.ca/forests/climate-change/13121>) at the provincial level. Currently in the eastern provinces, AM programs are experimental or in the initial stages of conception; researchers use provenance tests and forest data (Table 1) to review seed guidelines for

forest management within the provinces. For example, the Ontario Forest Research Institute supervised a project to assess AM as a climate change adaptation (Eskelin et al. 2011). AM programs exist mainly for tree species with economic value. Yet, as Hewitt et al. (2011) have pointed out, AM programs conducted for economic rather than for conservation benefits represent a barrier to the social acceptance of AM. Hence, scientists in these provinces feel cheated by government policies and forestry management choices, and believe that economic issues are considered more important than ecological issues. Researchers interpret government actions as “green-washing.” *“Today, lobbyists divert government and research money from mitigating the impact of climate change to a focus on adaptation in order to maintain business as usual and bet on adaptation like geo-engineering”* (Forest researcher 2, Ontario)/ *“AM is not helpful, except for some endangered species. For the rest it is just an economic issue”* (Forest researcher 4, New Brunswick). Within the multiple definitions, the species-focused definition of AM allows decision-makers to interpret the adaptive action of AM only from a GE approach. In addition to the debate about the risks of AM, we witnessed specific discussions inside the Canadian scientific community about its definition. Many papers have been published that describe differing types of AM (Seddon 2010; Ste-marie et al. 2011; Aitken & Whitlock 2013), and discuss whether the movement of a species should be *beyond* the existing distribution, *inside* the existing distribution, or *at the limit* of the existing distribution of the concerned species (Table 1). Yet, all of these definitions focus on species or populations as the unit that is moved during AM, suggesting that the existing system can be maintained but moved to limit the impact of climate change and supporting the “business as usual” view of decisions-makers regarding forest management. Sadly, no definition conceptualizes AM at the scale of community or ecosystem management (but see Pedlar et al. 2012; Sansilvestri et al. 2015a, 2015b). This limits the possibility of the evolution of a more ecosystem-centered approach to AM, which in our opinion is a better approach in a climate change context to restore and reinforce the integrity and the functioning of ecosystems for current and supposed impacts implementation of AM.

Table 1. Differences between Canada and France with regard to the concept and implementation of AM

| | <i>Canada</i> | <i>France</i> |
|--|---|---|
| Forest property | Stated owned, given by concession to companies | Private ownership mostly (75%), but the state exploits forests as well |
| Forest goals | Either production or conservation | Multidimensional objectives including management of heritage sites |
| Extant AM debate | Yes | No |
| Widespread definition | The movement of species or populations with some debate about whether movement takes place within or outside of the current range of the species | The movement of species or populations beyond the existing range of species |
| Knowledge of the AM concept | Well known to all forest actors | Known to scientific and policy forest actors but unknown to forest managers and owners in the field |
| Type of species considered | Local and in some extreme cases nonlocal species but from the same continent | Nonlocal species (same continent) but also exotic species |
| Implemented in official programs | Changes in regulations for <i>Western larch pine</i> plantation in British Columbia | No |
| Policy development | Advanced thinking in Ontario and Québec concerning changes in seed provenance regulations | Some hesitancy about seed provenance recommendations |
| Experimental programs (nonexhaustive list) | Yes. Optisource (Québec, Beaulieu 2010); SeedWhere (Ontario, McKenney et al. 1999); the <i>eastern white pine</i> study (New Brunswick, Major 2012) AMAT Trial (British Columbia (O'Neill et al. 2008); <i>Whitebark pine</i> case (British Columbia, McLane & Aitken (2012)) | Unofficial and in early stages, anecdotal |
| Main policy goal | Contradictory issues in Quebec, Ontario, and New Brunswick. Productivity and conservation issues in British Columbia | Mainly to maintain forest productivity and genetic conservation |

In BC, like in most Canadian provinces, there is recognition of the risks of AM, and there are some actors who are against it. However, despite this, the BC forest administration has implemented a new seed regulation for one species, the Western larch pine, which makes changes to the regulations governing altitude planting (O'Neill et al. 2008; Klenk & Larson 2015; Natural Resources Canada, <http://www.nrcan.gc.ca/forests/climate-change/adaptation/13121>). With this modification, the Western larch pine can now be planted 100 m higher in altitude to compensate for observed climate change impacts and preserve productivity. Because of the importance of the forestry sector in BC, AM management has been accepted rapidly as a means to maintain both wood productivity and the integrity of forest ecosystems, and for genetic conservation (Table 1) “*AM is a good tool for resilience and to respond to a threat like climate change where we do not know the exact nature of change*” (Provincial forest officer 2, BC). In recent years, the provincial natural resources ministry and the Forest Genetic Council of BC have funded many research

programs (Table 1) to develop knowledge about genetic issues and wood productivity “*We need more knowledge of species and ecological indicators, AM outside of ecological range needs a genetic assessment. It is a tool to develop*” (Forest researcher 5, BC).

Currently, AM policy in BC is proactive and involves the implementation of large experiments and new regulations. These initiatives are implemented by decision-makers despite the existence of some debate. Because the discourse surrounding them is characterized by strong arguments about forest management, they succeed to go through the conservatory debate (Klenk & Larson 2015). The proactive policies of BC can be explained by three suppositions. First, BC is characterized by a steep and complex climatic gradient, which makes this province a good, and perhaps involuntary, candidate for AM. This complex climatic gradient allows the presence of many specialist tree species within specific distribution areas. Moreover, a report by Hamman and Wang (2006) demonstrated that big changes in BC ecosystem climates are expected, which represented an additional argument to consider AM as an interesting option to maintain the integrity and productivity of forests. Second, BC has already been affected by climate change, with waves of mortality caused by epidemics of the “mountain pine beetle” and large fires caused by heat and drought. Government scientists and decision-makers used these events as an opportunity to garner support for proactive management. To avoid a sharp politic or scientific u-turn, the new regulations have been implemented as a “range expansion” of the species and not as an introduction: “*People think that AM means that we lose the*

*existing distribution of species with a shift of distribution, but in reality, it is an expansion of species distribution” (Provincial forest officer 1, BC). Third, BC benefits from a very organized and efficient forest management structure with a Tree Seed Center that centralizes all the tree seeds in BC, and a Seed Planning Registry for the selection of seed lot. Hence, each year BC has the capacity to plant more than 250 million tree seeds for future harvesting, which facilitates the application of AM programs. Furthermore, there is a developed and supported genetic conservation policy within the Forest Genetic Council. For researchers, the recent move toward AM in BC represents a “transition from tree improvement to genetic management” (Forest researcher 6, BC). However, even though AM seems to be more accepted in BC, its application is still at the scale of species (for conservation e.g. *Whitebark pine*, and for productivity e.g. Assisted Migration Adaptation Trial or *western larch pine*). This raises the question of whether this discourse will lead to the implementation of more extensive and far-reaching AM programs, such as the introduction of exotic species and larger scales of operation in BC or in other provinces, or form the basis for a future EE approach to AM.*

For the time being in Canada, we could observe that policy-makers have appropriated a concept of AM that is constrained to the movement of a particular species. This situation could be explained, *inter alia*, by the existing administration of forest landscapes, which separates forests by their functions. In Canada, forests are either a conservation area (national parks) or a productive area (forest with exploitation license). This means that the potential of AM management practices to increase the adaptive capacity of forests is not a high priority, and AM is instead used for the strict management of one species, for either economic or conservation purposes.

AM in France: Some Hesitancy and Big Forest Legacy

Historically, forests and forestry have been very important in France, with its influential forest culture and a long tradition of *savoir-faire*. We selected five forest regions with economic, historical, social, climatic, and ecological issues, which suggest that AM could be a management option for these regions. This allowed us to analyze possible implementation processes of AM in France (see Fig. 2).

With a steep climate gradient from Mediterranean to Alpine areas including the Atlantic climate, French forest researchers and ministry members recognize that France represents a good candidate for AM programs (*Forest officer 1, French forest ministry*). However, there are currently no official AM programs in France, even at the experimental level (Table 1). Contrary to Canada, the proposition of AM in France has not created a debate “*The idea of species movement is accepted but we are still thinking about it*” (*Forest researcher 1, Forest National Office*). Scientists in France, as in Canada, have raised the question of the risks involved in AM and the uncertainty of climate change outcomes (Benito-Garzón et al. 2013), but they will consider implementing AM in future forest management if adequate evidence of the benefits exists (Benito-Garzón & Fernández-Manjarrés 2015). In general, forest researchers and the forest ministry are publicly in agreement in forums and workshops about the development of new forest regulations; AM has always been considered as an interesting option for both parties. This consensus can be explained by the historic profile of forest management and the relationship between forest and foresters in France.

French foresters (in both public and private forests) probably identify more with their forests than Canadian foresters, and in consequence feel these forests as their own living spaces. This may be because French forests are mainly small and accessible. On the contrary, the Canadian unexploited forests, with their large and wild characteristics, create a “wilderness” vision of forests even if the forestry practices are harder than in France. Moreover, today there are few natural or primary forests in France; forests have been highly managed either in the past or presently and their characteristics are now the result of earlier human management choices. For instance, since the seventeenth century, French forests have mainly been managed in order to produce wood for economic and military interests (Polge 1990). Hence, the economic importance of forests is largely accepted in France “*The management of forest is an act of optimization, we are very proud of our tree production*” (*Forest manager 2, French temperate region*). The biodiversity aspect came later, at the end of the twentieth century with the “green” movement. This movement initiated a multidimensional vision of forest management in France, which means that economic, social, and biodiversity aspects must be taken into account in management

choices, at least at the level of regulation even if not in the minds of all stakeholders. This multidimensional vision potentially helps to avoid a narrow focus on the AM of species only, as is the case in Canada. Hence, we could assume that in France AM could be applied at the scale of the ecosystem in line with the EE approach.

Despite this consensus and willingness to apply AM in managed forests, there are currently no AM programs in the field, not even for single tree species. This could be explained by three assertions. First, AM is regularly discussed and proposed in ministry and research meetings. Yet, managers and owners in the field are not usually aware of this type of management. The impact of climate change has not yet been considered widely in forest management in France. *“Even if we’ve talked about climate change for a long time, for the moment, we do not observe climatic impacts in our forests. So it is not tomorrow that we will begin to act”* (Forest private owner 1, French Atlantic region). The extent of this gap in knowledge between institutions and managers may derive from the fragmentation and breakdown of French forest governance. The long history of mainly private ownership of forest in France has generated an accumulation of stakeholders who interact at different levels of forest management. These complex frameworks of actors make the transmission of information between stakeholders difficult. Forest owners do not know who to talk to and forest operators are too busy with industrial competition to take on the role of providing a bridge for information *“We hear lot of things; we do not know whom to believe”* (Forest private owner 20, French Mediterranean region). At present, French forest

Table 2. Forest characteristics and main barriers to tree species change in different regions of France.

| <i>Region</i> | <i>Species</i> | <i>Climate Vulnerability</i> | <i>Barriers to Species Change</i> |
|--|--|---|---|
| Atlantic region: South West of France | Maritime pine (<i>Pinus pinaster</i>) | Storms, droughts, and pests | Emotional and cultural attachment. Strong industrial attachment |
| Temperate region: East of France | Douglas fir (<i>Pseudotsuga menziessi</i>) | Not yet, but models suggest high risk because of heat | Industrial development |
| Temperate region: North East of France | Common beech (<i>Fagus sylvatica</i>) | Droughts | Strong emotional attachment |
| Mediterranean region: South East of France | Atlantic cedar (<i>Cedrus atlantica</i>) | Droughts | Cultural attachment and landscape conservation |

governance is undergoing reform as a result of changes to the recommendations on provenance made to managers and forest owners. However, rather than using this reform to implement a new strategy or new recommendations for AM, the ministry remains cautious probably because they fear the failure of AM. For the moment, the committee in charge of changing the 5-year report of recommendations on the provenance of tree seeds (two forest officers from the forest ministry, two forest engineers from the Environmental and Agronomic Research and Technological Institute, four forest researchers from different research laboratories, one forest PhD student, one forest industrialist, and one forest manager from a private forest management institute) have limited their output to recommending the use of seeds from the southern adjacent area of the previously recommended area and only for a few species (Sansilvestri R, 2014, Université Paris-Sud, Paris, personal observation). In practice, there is a real will to change the regulations on provenance but the committee has few resources for the implementation of these new regulations. Moreover, they are afraid of a possible backlash against them by forest actors (Sansilvestri R, 2014, personal observation) if AM involves relocations that are too far removed from the present locale of forests. *“Regarding the question of whether to act or not, people are torn. Hence, we remain cautious about recommendations”* (Forest officer 2, French forest ministry). So, unlike Canada, the barrier to AM implementation does not come from a divergence in opinion about forest management between researchers and ministry officers, but from extreme caution due the potential of AM to create thousands of disconnected private forest owners.

Second, the history of forest management creates a strong forest culture and a conservative vision of forest landscapes. Managers are rather conservative concerning landscape management and the choice of tree species. Surprisingly, many species in France have been imported (e.g. *Pseudotsuga menziessi*, *Picea sitchensis*, *Acacia* ...), but many managers and forest owners now consider them to be “native” because they have naturalized over the course of the last century or two. Climate change in France is exacerbating the marginal condition of some species and is highlighting the negative management choices of the past: *“[Climate change] reveals our past mistakes”* (Forest manager 2, French

temperate region/Forest manager 11, French Mediterranean region). This is the case for *Abies alba* in the low Alps or *Fagus sylvatica* marginal populations in Eastern France (Frascaria-Lacoste N, 2015, AgroParisTech, Paris, personal observation) for instance. Despite these early warnings of climate change effects, foresters are not willing to change species because of emotional or economical attachments (see Table 2), but also because of an interest in keeping the current landscape features of their forests.

Contrary to the intensive use of seeds in Canada, particularly in BC, the species composition of forests in France is controlled mainly through selection during the natural regeneration of trees. French foresters have a rather technical vision of forest management. Hence, even though there is a possibility of natural reorganization of forests through natural regeneration, the proposition to artificially change the distribution of species through AM is very difficult to implement in the field: *“The social acceptance of new forest landscapes is the main barrier to adaptation policies”* (Forest manager 9, French temperate region).

Lastly, French forest research currently involves few experimental programs and the collection of data from provenance tests is not on the level and to the extent that would be required to make decisions for climate change adaptation. All researchers agree that there is a need to increase knowledge about the ecological characteristics of tree species, genetic issues, and provenance tests: *“There are few resources allocated to forest research, so there is a big lack of knowledge, especially for species distributions”* (Forest Researcher 2, French Mediterranean region). This problem of lack of resources is clearly understood by forest managers: *“There is no budget. We see the research institutions coming with research programs but after a few years everything is abandoned. There is lots of data there if we bothered to collect it”* (Forest Manager 8, French temperate region)/ *“We need resources to implement experiments in the field to show concrete results to foresters”* (Forest Manager 10, French Alpine region). For example, it can be noted that there are no provenance tests being set up between France and other countries further south such as Spain, Italy, Morocco, or Tunisia, which could anticipate the effects of a potentially warmer climate in the south of France in future. France remains a little reticent about

experimental programs compared with Canada or even other European countries. This can be explained by fragmented forest management in France and lower investment in any kind of forest research that does not focus on genetics and genomics.

Discussion

Adaptation and AM are complex concepts that need to be precise and context-specific. In this article, we have examined the impact of the ambiguous definition of AM, caused by the differences between GE and EE approaches to AM. The GE approach is often better understood and more accepted by decision-makers because it allows the development of specific tools with precise goals, such as the movement of a specific tree species from one area to another to maintain its productivity, as we saw in Canada. Moreover, the GE approach is more accepted because in theory, it does supposedly not change the system intrinsically. But, the GE management, despite its simplicity, implies also risks and uncertainty concerning the success of the management and the reaction of the ecosystem to the intervention, as genetic pollution, biological invasion, or unforeseen effects on ecosystem functioning. An AM application with GE approach, that is, maintaining a productive tree species with a simple relocation, promotes the risk of ecosystem collapse because of the focus on only one dimension of the system. On the contrary, the EE approach to AM is more daunting because of the uncertainty caused by changes to the system and because it is difficult for nonscientists to understand its application in the field. The EE approach to AM involves allowing the system to change freely according to its own dynamics. Again, there is a risk of failure and uncertainty on the ecosystem evolution. However, this ecosystem approach allowing biological mechanisms to compensate each other, diminish the risk of collapse with the possibility of a natural evolution of the system. The desire for complete control of the forest system could explain the slow implementation of AM in France, despite the fact that a multidimensional vision of the forest exists there. Moreover, French foresters are afraid to lose the control on forests. To promote the evolution of forest management in a climate change context, it is very important for researchers to advance complex notions case-by-case to avoid misunderstandings occurring in dialogues between scientists and decision-makers. For France and Canada, definitions should include precise goals, risks, issues, and

guidelines.

We believe that it is essential to take an ecosystem vision to define AM with an EE application. This approach could allow a less controlled vision of ecosystems which is important in an uncertainty context like climate change to let the possibility of both management and ecosystems to evolve. The application of AM in a mono-directional manner appears easier technically and economically than a more ecosystem-centered approach, but there is a substantial risk during manipulations of ecosystems of a consequent loss of biodiversity and function diversity. The EE version of AM is very recent, so its conception and implementation will take many years. Meanwhile, foresters should move beyond a technical approach to forestry and consider managed forests as living systems with their own independent evolution. In other words, we must support ecosystems rather than try to dominate them.

The comparative analysis between France and Canada demonstrates that the introduction of new species to forests is a social barrier to the implementation of AM in both continents, but not for the same reasons. The differentiation between productive and protected forests limits the likelihood of AM being approached from an EE perspective in Canada. In a protected forest, it is difficult to implement AM programs beyond those that aim to protect and conserve specific endangered trees (e.g. *Whitebark pine*), which means that the application of AM is reduced to the monitoring of one species. In a productive forest, management is influenced by what could be called a “new world” culture involving a vision of limitless and controllable resources, which facilitates the implementation of AM programs only for economic goals with a “hard” GE approach. In all cases, forest management is limited to the strict management of one species, for the fulfillment of either economical or conservation goals. This limits the potential of AM to increase the adaptive capacity of forests. In France, foresters (in both public and private forests) are attached to the forest landscape and wish to conserve the forest legacy even if it includes non-native naturalized species, while in Canada most foresters wish to conserve the wilderness of the forest. A new integrated version of forest management that would include both French and Canadian visions could introduce more flexibility to managed forests and provide more space for wilderness as in Canada, as well as meeting explicit economical goals, as in France.

In sum, this comparative analysis highlights that evidence of the impact of climate change on trees is a powerful trigger for the implementation of AM programs in forest management, and we are certain that this will be the case when other cases with endangered species or ecosystems appear. Perhaps, if the resource in question is private that do not necessarily accept a top down approach, like foresters in France, adaptation strategies can undergo a long scrutiny that may highlight their advantages and disadvantages before they are implemented. Only time will tell if when climate change effects become more apparent in France, AM would be applied at the ecosystem level respecting local biodiversity, or if productivity approaches will dominate.

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