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RESEARCH ARTICLE

Redefining climate change maladaptation using a values-based approach in forests

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Abstract

1. Climate change adaptation can have unexpected and detrimental effects, typically conceptualized as maladaptation and narrowly defined in relation to climatic hazards and climate vulnerability. We revisit this narrow framing of maladaptation using a deliberative risk analysis method in 16 focus groups across British Columbia, Canada, where forests are crucial to social, economic and environmental well-being.
2. By analysing emergent logics of support and opposition around genomics-based assisted migration as an adaptation strategy in forests, we identify four sources of potential maladaptation in this context: technical failure, opportunity cost, path dependence and the too-narrow framing of adaptation.
3. Combined, these suggest that maladaptation is also too narrowly conceptualized, reflecting an obsolete definition of adaptation as rational adjustment to climatic hazards. Rather than being a failure of adaptation, per se, we argue that maladaptation comprises climate-adaptive policies or actions that, in a broader frame, threaten the very values that decision-makers ostensibly seek to protect and enhance.

KEYWORDS

British Columbia, climate change adaptation, forests, genomics-based assisted migration, judgement and decision-making, maladaptation, risk analysis, stakeholders

1 | INTRODUCTION

Climate change adaptation comprises actions intended to lessen the social, economic and environmental harms caused by changes in climate, or take advantage of potentially beneficial changes (Noble et al., 2014). Maladaptation, as a potential consequence, comprises nominally climate-adaptive actions that have perverse or unintended effects at odds with broader climate-related policy goals (Barnett & O'Neill, 2010; Juhola et al., 2016; Magnan et al., 2016; Noble et al., 2014), and is distinct from ecological or evolutionary concepts of maladaptation at the species level. Actions may be maladaptive, for instance, because they increase climate vulnerability in unanticipated ways, redistribute damages inequitably or exacerbate climate change. Magnan et al. (2016) detail four cases of adaptation gone wrong including, for instance, a project to increase the climate resilience of transportation infrastructure in south-west Bangladesh that has the unintended consequence of further encouraging habitation of climatically vulnerable areas.

Conceptual frameworks for understanding maladaptation are thought to help decision-makers identify and avoid it by providing

them with tools to assess the risk that adaptive actions will produce negative outcomes. Magnan et al. (2016) argue that practitioners have not paid enough attention to potential maladaptation risks, in part because these frameworks are not necessarily designed to be anticipatory. Barnett and O'Neill (2010) created perhaps the most influential maladaptation framework, conceiving of five types, where climate-adaptive actions may (a) increase greenhouse gas emissions; (b) create a disproportionate burden on vulnerable groups; (c) incur high opportunity costs; (d) reduce the incentive to adapt; or (e) create path dependence. The IPCC AR5 more narrowly defined maladaptation in relation to outcomes for climate vulnerability (Noble et al., 2014). More recently, Juhola et al. (2016) proposed a typology of maladaptation with three categories (rebounding vulnerability, shifting vulnerability and more broadly eroding sustainable development), while Magnan et al. (2016) highlighted the need to proactively assess the risks of maladaptation in four dimensions (process, multiple drivers, temporal scales and spatial scales). Though these maladaptation frameworks differ in detail, all of the authors agree that it remains under-conceptualized, that there is too little empirical evidence in the literature to understand it properly and that climate-sensitive decision-makers need to be more proactive in avoiding it.

Publicly owned forests provide a useful context in which to explore maladaptation risks. They are complex social-ecological systems with some measure of public accountability in their governance, multiple stressors and numerous, often conflicting, climate and non-climate objectives. As global carbon sinks, forests are essential to the mitigation of climate change, but its impacts already threaten their health and productivity (Fettig et al., 2013; Seidl et al., 2017). Changes in forest governance can enable new practices that will help forests adapt to shifting climate envelopes (Hagerman & Pelai, 2018). In the Canadian province of British Columbia (BC), forests are crucial to social, economic and environmental well-being. Scientists at the University of British Columbia (UBC) and policymakers in the provincial government have therefore proposed to help BC's forests adapt to climate change using genomics-based assisted migration (AM)—planting seedlings that have been selected, on the basis of their genomic information, to match expected future climates (Aitken & Whitlock, 2013; Aubin et al., 2016). The provincial government has already authorized forestry companies to begin using climate-based criteria for seed selection by combining climate models with data from traditional provenance trials (FLNRORD, 2018). The ongoing technical research on tree genomes and forest pathology is currently focussed on four species of commercial value: lodgepole pine, Douglas-fir, Western larch and jack pine. If successful, the genomics technology currently under development would allow for faster and more precise identification of specific seeds with characteristics that are well matched to the expected future climates in specific locations.

Genomics-based AM is a technologically driven policy change, from geographically based reforestation to climate-based seed transfer (e.g. FLNRORD, 2018), steeped in the kinds of ethical and scientific uncertainties that often motivate 'upstream' public and stakeholder engagement (Aubin et al., 2011; Findlater et al., 2020; Tindall et al., 2010). AM is expected to lessen the harms of climate change impacts (Gray & Hamann, 2011; Williams & Dumroese, 2013), but taking such action in a complex social-ecological system may also generate unanticipated knock-on effects through technical, ecological and socio-political linkages. In the context of AM, the potential for maladaptation has typically been conceptualized in terms of technical failure (Hewitt et al., 2011)—that is, the risk that some error in the process of seedling selection (likely in genomics or climate models) will result in the failure of those trees to thrive in future climates or compromise the broader health of the ecosystem into which they are introduced. However, a variety of less direct forms of maladaptation have been hypothesized or observed in other contexts, with Magnan et al. (2016) arguing that the range of potential maladaptation risks therefore needs to be evaluated 'ex ante'.

Here, we identify and characterize the maladaptation risks potentially created by the implementation of genomics-based AM as a means of climate change adaptation. We evaluate maladaptation using a broad frame defined by the stakeholders themselves, which helps to illuminate a fuller range of important objectives and possible outcomes than would be revealed by the narrower frameworks advocated in the literature. We analyse data from 16 deliberative focus groups in which stakeholders were facilitated in systematically exploring their shared forest values and the risks that threaten them, and the risks, benefits and uncertainties of genomics-based AM. To identify and characterize maladaptation risks, we ask two questions of the focus group data: (a) What logics do people use to motivate and contextualize their arguments about the risks and benefits of adaptation through AM? (b) How well do they align with current conceptualizations of maladaptation, and what new forms do they imply?

2 | METHODS

To examine the logics of support and opposition to genomics-based AM proposals for BC's forests, we conducted 16 deliberative focus groups in which, guided by an expert facilitator, participants discussed, negotiated and co-constructed answers to key questions. This systematic and deliberative approach more broadly assesses prospective maladaptation risks than the above frameworks or any other study known to us. In analysing these logics, we make no effort to assess their relative importance or to evaluate their merits, and we certainly make no overarching judgement about the appropriateness of AM as a climate-adaptive policy in BC's forests. The sample of participants was neither random nor representative, so any such generalizations would be misleading. However, these represent the range of logics of support and opposition expressed by these stakeholders, providing insight into the potential environmental and socio-political implications of this policy change in BC and broadening our conceptual understanding of maladaptation. The study design was approved by the Behavioural Research Ethics Board of the University of British Columbia (H17-00565), and all participants agreed to participate through a process of informed consent.

Each session was composed of members from one of four stakeholder groups: forestry professionals (e.g. foresters and forest

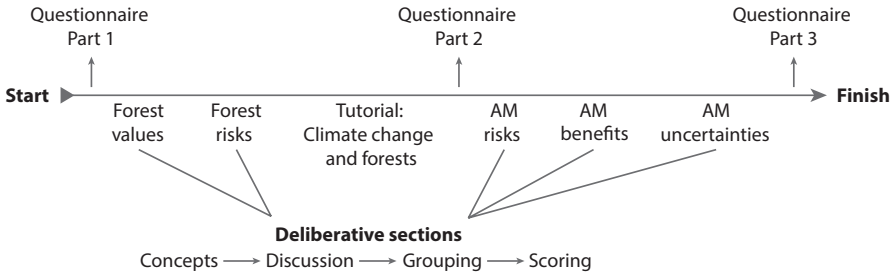

FIGURE 1 Focus group structure. Each session had the same structure, with five deliberative sections in which participants were asked to contribute concepts, explain and discuss them, organize them into related groups and score the groups for their relative importance. After the first two deliberative sections, the facilitator gave a short tutorial on climate change in BC's forests. Each participant also filled out a three-part questionnaire to evaluate changes in opinion after deliberation

biologists), environmental NGOs, municipal and district governments, and local business communities (e.g. owners, managers, employees of local Chambers of Commerce). Four focus group sessions (one for each stakeholder group) were held in each of four cities (Campbell River, Cranbrook, Kamloops, Prince George) selected to cover diverse ecological zones, expected climate change impacts, population sizes and the level of forest dependence in the local economy. Participants were recruited using advertisements forwarded to members of professional organizations through their email listservs (e.g. the Association of BC Forest Professionals, local Chambers of Commerce), snowball sampling and direct recruitment using professional contact information made publicly available by potential participants. There were 104 participants, ranging in age from 23 to 83 years with an average of 53. Overall, 73% identified as male, 24% as female and 2% as non-binary. Each session took about 3 hours to complete, and was audio-recorded and transcribed. The participant codes included in the results were randomly assigned and do not correspond to participants' initials. The sample is biased towards participants interested in learning about or discussing climate change and new forest management practices, since these topics were mentioned in the recruitment materials. Although an effort was made to schedule sessions at times that were convenient to those who expressed interest in participating, the sample is also biased towards individuals who had the flexibility to attend a 3-hr workshop.

Qualitative and deliberative methods are valuable in exploring the range of possible risks and benefits created by changes in public policy, especially in the context of recent science governance paradigms that prioritize constructive and engaged social science approaches to understand public and stakeholder opinion (Macnaghten & Chilvers, 2015). Emerging technologies, in particular, are often steeped in ethical and scientific uncertainties well-suited to stakeholder engagement early in the research and development process (i.e. 'upstream') to ensure responsible innovation by accounting for the diversity of values and preferences within and between groups, and the potential for changes in opinion (Findlater et al., 2020). Qualitative methods that allow for open-ended responses provide participants the freedom to elaborate nuanced logics in articulating their judgements, producing richer data and revealing relationships that may be invisible when using quantitative methods alone (Findlater et al., 2018). Deliberative focus groups, in particular, motivate participants to rationalize, contextualize and negotiate their positions in relation to their own knowledge, values and preferences, as well those of others in the group (Gregory & Dieckmann, 2019; Macnaghten, 2017). In contrast, more constrained methods, like surveys or questionnaires, have been shown to encourage superficial judgements that may prove unstable under scrutiny and over time (Satterfield et al., 2013). In Findlater et al. (2020), for instance, we found that the preferences expressed by respondents to a public survey on genomics-based AM were particularly unstable in response to simple messages about AM's potential implementation and impacts, like those that they might see in traditional and social media.

The focus group protocol used deliberative risk analysis to understand the logics underlying stakeholder perceptions of genomics-based AM as an adaptation in BC's forests. This method was adapted from Findlater et al. (2019), where it was used with individual participants to understand climate change as one risk among many in commercial farming. The focus groups all had the same structure, illustrated in Figure 1, and were all facilitated by the same individual (Findlater). In each of five deliberative sections, participants were first asked to brainstorm concepts individually (on yellow sticky-notes), contributing them to the group, and then to cooperatively cluster them with related concepts and discuss their importance, their causes and their effects. In the first two sections, each group established a shared set of (a) forest values and (b) possible risks to those values. The facilitator then gave a short tutorial on climate change in BC's forests, as well as six reforestation strategies (including genomics-based AM within and outside of the species' historic natural range) that might be used to help adapt forests to climate change. Following the tutorial, participants were asked to identify (c) potential risks from the implementation of AM as a climate change adaptation, (d) further benefits that AM might provide beyond adaptation and (e) key uncertainties underlying these risks and benefits. Additionally, each participant completed a three-part questionnaire individually, with one section at the beginning of the session, one following the tutorial and one at the end of the session. The tutorial information and questionnaire may be found in the Supporting Information.

The 16 focus groups generated four kinds of data: the transcripts of the group discussions, the answers to the three-part questionnaire (including demographics and levels of support before and

after deliberation), the elicited concepts (values, risks, benefits, uncertainties) and the individual scoring of the clustered concepts on their importance. The latter three datasets are analysed separately, and we here focus on the underlying logics that participants articulated in rationalizing their support and opposition in deliberation with others. The transcripts were first coded (in NVivo) for expressions of support and opposition regarding genomics-based AM as an adaptation in BC's forests, which were then coded into emergent categories representing distinct articulations of the underlying logics that participants used to rationalize their positions. We describe these distinct logics in the results section, with explanatory quotes, and then interpret them in the discussion section through a maladaptation lens. This qualitative analysis of the deliberative processes captured in the focus group transcripts is complementary to the mixed-methods analysis of the explicitly elicited risks, benefits and uncertainties described in Findlater et al. (forthcoming). It also extends, deepens and explains survey-based quantitative relationships described in Peterson St-Laurent et al. (2018), Peterson St-Laurent et al. (2019) and Findlater et al. (2020).

Given the legal and cultural importance of First Nations to the governance of land and natural resources in BC, the most notable limitation of this study is the absence of focussed Indigenous engagement. Although Indigenous members of the relevant stakeholder groups were welcome to participate, the recruitment methods did not specifically seek Indigenous representation in these sessions. Instead, the initial study design included focus groups with representatives from BC's First Nations to be analysed alongside the other focus group data. However, during pre-engagement with two First Nations, we determined that such an approach would be misleading and potentially harmful since each nation provides a microcosm of the diversity of perspectives represented across all of the stakeholder groups (including forestry professionals, environmental NGOs, local government representatives and business owners). As expressed to us during pre-engagement, First Nations do not therefore understand themselves to be a stakeholder group, but rather nations comprised of individuals and groups with varied interests, values and priorities with a diversity equivalent to that of the broader Canadian public. In the context of this project, appropriate Indigenous engagement would foreseeably require engagement with Indigenous stakeholder groups equivalent to those in the broader population. A better approach might be to conduct a parallel Indigenous research project co-developed with the First Nations in proximity to the four cities selected above as focus group sites. However, the current funding (through a Genome Canada grant that included both genomics and social science research) did not allow for either of these approaches in this iteration of the project.

3 | RESULTS: LOGICS OF SUPPORT AND OPPOSITION

The analysis revealed five distinct logics that participants articulated in rationalizing their statements supporting or opposing genomics-based AM as an adaptation strategy in BC's forests. Some logics were more prominent in certain groups—for instance, forestry groups tended to dwell more on scientific uncertainty than did other stakeholder groups. However, all logics were present in all groups, perhaps reflective of broad agreement on shared forest values. See Table 1 for quotes from members of each stakeholder group, illustrating each of these logics of support and opposition.

3.1 | Scientific (un)certainty

Reasoning: *The tree selection and climate models are deeply uncertain and the ecological dynamics are unpredictable. Do we have enough information to act?*

As might be expected, scientific uncertainty leading to technical failure was the most prominent theme across all groups, and typical of how AM risks are conceived in the literature. This reasoning suggests that AM interventions may be ineffective or harmful, with selected trees failing to thrive in future climates. Many specific factors were identified as potentially contributing to technical failure, but can broadly be captured in two categories: (a) the genomics technology may fail to reliably predict the future success of individual seedlings in specific climates and/or (b) climate models may fail to accurately predict future climates in specific locations.

Participants predicted that such failures would result in the impaired health and productivity of individual trees, as well as forests more broadly; increase their vulnerability to pests, diseases and other disturbances; have knock-on ecological effects through complex interconnections with other plants and wildlife; and lead to social and economic losses. In particular, three important intersecting factors were identified as contributing to these outcomes: (a) the narrow framing of climate risks as long-term changes in mean temperature or precipitation; (b) rising ecological risks the further that seedlings are moved; and (c) ecosystem complexity leading to unexpected or unknowable effects.

3.2 | (Dis)trust in decision-making

Reasoning: *Current policies and practices are flawed. Can we trust the same decision-making processes to generate successful climate-adaptive policies?*

Another prominent theme was distrust in the policymaking and decision-making processes on which AM's successful design and implementation depend. The provincial government and forest industry are perceived to make consequential choices that are shaped primarily by political and economic forces rather than by broader societal values on one hand and forest-related sciences on the other. Across all groups, there was widespread agreement that government and corporate decision-making processes are inadequate, though there was disagreement about the nature and implications of that inadequacy. Participants in forestry groups were more likely to suggest that government was not supportive enough of the commercial

TABLE 1 Quotes illustrating the five logics of support and opposition. The selected quotes elaborate, in participants' own words, the reasoning that that is synthesized in each section of the results

	Scientific (un)certainty	(Dis)trust in decision-making	(Over)confidence	(Lost) opportunity	Responsibility and resignation
Forestry	'Maladaptation of the tree…. It might not be resilient to droughts or other stressors that would make it more susceptible to disease'	'What's going on with the spruce harvesting right now is just disgusting, basically. … There is no consideration whatsoever for ecosystem and other values'	'Are we going to be able to learn? … We need to have some kind of active monitoring…. Otherwise, when something goes wrong, we won't even know it went wrong. How do we get better when we have no information?'	'Every tree has a dollar sign, and that's the biggest problem. I'm not trying to go against the industry. But the perception should be balanced. … It's not working. … How people are treating the existing forests is very mind-boggling'	'The status quo is going to end in a bad way if you don't do something…. It's hard to predict. It's complicated…. Things would change. There would be winners and losers…. Maybe we'd learn to live with armadillos'
Government	'We're all focusing on trees. You can't have a forest without trees, but forests are made up of thousands of organisms; they all fit together. We're dealing with one of them, and climate change is going to impact all the rest'	'That's as cynical as I am to the forest industry, that's where we're at right now with the decision-making…. It's based on a bureaucrat someplace… and they don't really give a damn to be really honest'	'The whole terminology of managing the forest, I kind of disagree with. We're manipulating it, we're messing with it. But that's hubris to think we can understand it well enough to manage it'	'I see current forest practices now that aren't proper…. Banking on something like [AM], even on the small scale, is just going to add to it. We need to correct the problems we have before we create new ones'	'We need to start to accept… that things are changing. And we need to be smart about how we will deal with that, and not stick our heads in the sand and hope that all this isn't going to be as bad as we think…. We created the situation'
eNGO	'Things at the edge of their natural range are often easier to stress…. If we push too far… we're planting a forest that's less productive than potentially what should or could be there'	'I don't trust professional management of forests…. They're all about turning the forest into a commodity. That's the bottom line. And I don't believe that forests are a commodity'	'Humans are fallible…. Any tinkering with what's going on, it's possible to over-manage these places into the ground. Humans make mistakes all the time'	'I really think this is a great opportunity, to really have to engage meaningfully the public and industry. These decisions are going to be far-reaching, particularly given the challenges of climate change'	'This is a human-altered landscape, whether it's on just a logging level or … climate change. We created it. … Now what responsibility do we have? And can we do it with the best evidence?'
Business	'You gotta plant for the future, obviously, but if your climate predictions are wrong … 30 or 40 years down the road we could have plantations where trees don't grow. … Now we have nothing to harvest'	'A lot of our policies are based on what the politicians think will buy them votes as opposed to listening to the science'	'We're human and we get it wrong'	'I'm supportive of [AM] because I see it as being forward-thinking and taking into consideration factors like climate change…. This feels more progressive'	'Sometimes even your… native plants are more at risk because they're not a very diversified population. The climate changes have already had a huge impact on forests in that area'

forestry sector, while participants in eNGO groups were more likely to suggest the opposite.

Forestry participants were also sceptical of the government's ability to commit to long-term forest policies (because of short political cycles and changes in the governing party), sufficient funding for AM research and risk-sharing with the industry. When participants did not raise 'decision-making' as an explicit concern, it emerged in other ways. For instance, participants in all groups were critical of past and present forestry practices. Wildfire was frequently raised as an example where past forest management practices have increased present-day risks. Many participants were also sceptical that government and industry would act in the public's best interest, and were wary of decision-making processes that they perceived to favour the short-term economic interests of the forest industry above all else. Such distrust even led a few participants to question the validity of the underlying AM and climate sciences.

More broadly, participants questioned the legitimacy of authority, access to information and engagement processes that include or exclude particular voices, with some suggesting that community and First Nations involvement are vital to produce effective forestry policies. Overall, these various forms of distrust made participants wary that the decision-making processes that led to these past mistakes are the same that have generated the proposed AM policies.

3.3 | (Over)confidence

Reasoning: *Humans are fallible. Do we risk acting too confidently with too little information?*

There was widespread concern that forests are complex ecosystems that are poorly understood, that decision-makers might underestimate the scientific uncertainty, and that AM might be implemented too quickly and with insufficient monitoring. Decision-makers may not recognize that they are missing key information, or that the information they do have is imperfect. Forestry participants, in particular, were concerned about the sufficiency of ongoing research and monitoring to detect and adjust for unexpected effects. Several participants argued for a broader recognition of human fallibility. Others advocated humility in attempting to manage complex natural systems that might be better left alone. More cynically, a few participants emphasized the need to account for intentional mismanagement. Overall, there was broad agreement that changes in policy must leave room for error.

3.4 | (Lost) opportunity

Reasoning: *Climate change requires that we reconsider how we manage forests. Can we transcend the status quo instead of reinforcing it?*

As noted above, participants across all groups expressed dissatisfaction with past and present forest governance, arguing for the need to change land use and forestry practices. Some suggested that discussions around AM may provide an opportunity to reassess forest management more broadly (e.g. making decisions more inclusive and transparent, managing for non-timber values, increasing species diversity, protecting old growth forests, eliminating herbicides, using controlled burning to reduce fire intensity, etc.), while others thought that AM's implementation would reinforce the *status quo* because it is limited to commercially important species. AM, as a major change in policy, therefore represents an opportunity to enact broader beneficial changes in forest governance and management. This opportunity exists, in particular, because climate change (and AM as an adaptation to it) requires that policymakers think longer term.

Decision-makers should therefore think broadly about long-term goals for the management of BC's forests. Too narrow a focus will unduly limit the options. Many participants, for instance, argued that forests should be managed for a broader set of values. The choices that are made now will have long-lasting effects, limiting future options. If these choices about reforestation strategy are made without exploring broader questions of forest governance, we may end up with a forest that is mismatched with our future needs. Regardless of the climate-adaptive decision at present, decision-makers will need to revisit their management goals in the future because ecological, social and economic factors are dynamic. Forest-dependent communities have always had to be adaptable, and forest policy should be too.

3.5 | Responsibility and resignation

Reasoning: *Humans have already altered forest ecosystems through direct management and climate change. It is therefore our responsibility to help forests adapt, even if that involves some risk.*

Participants broadly agreed that business-as-usual is simply not an option because of the damage that climate change will cause to forest ecosystems. Inaction is therefore unacceptable, even though the outcome of AM is uncertain and the details of its implementation need scrutiny. There was widespread perception that forests have long been shaped by human actions, and have recently been put at risk through mismanagement and climate change. These forests are not 'natural'; they have already been modified. Because the problem is human-made, humans must also take responsibility for fixing it.

There was unanimous agreement that implementing AM will create risks, but most participants were still generally supportive. Most participants expressed belief that, given the likely impacts of climate change, AM would help to maintain or improve forest health (by conserving ecosystem structure and function) and the productivity of the forest industry (by protecting the timber supply), help to protect local communities (through conservation of economic and non-economic forest values) and contribute to climate change mitigation (through carbon sequestration). AM may even lead to other co-benefits beyond climate adaptation, like economic diversification in forest-dependent communities. However, no participant expressed unqualified support for AM, or advocated its implementation irrespective of climate change. Participants therefore generally agreed that we must act, but with caution, appropriate monitoring and quick action should things go wrong.

4 | DISCUSSION

4.1 | Potential maladaptation risks

These five emergent logics of support and opposition suggest that while stakeholders are concerned about the potential for technical maladaptation in forests (i.e. the failure of selected trees to survive and thrive), they also have important concerns that represent non-technical forms of maladaptation. Here, we interpret these logics of support and opposition through a maladaptation lens (Figure 2): What forms of maladaptation do they imply, and how well do these align with current conceptualizations of maladaptation in the literature? We identify four forms of maladaptation that we elaborate below: technical failure, opportunity cost, path dependence, and too-narrow framing. These forms are context specific, and there will certainly be additional forms in other contexts. Overall, we find that common frameworks of maladaptation are too constrained to adequately capture the diverse ways in which adaptation actions can undermine the very social, economic and environmental values that they seek to protect and enhance. We suggest broadening the concept of maladaptation and rethinking its analysis from a values-based perspective.

4.1.1 | Technical failure

Despite the best efforts of governments, scientists and forestry companies working together, AM may be unsuccessful. There are numerous climatic uncertainties and ecological unknowns that make it difficult to predict the long-term performance of specific seedlings planted in specific locations. Many of these uncertainties and unknowns are intractable because the global climate system and local ecologies are too complex to adequately understand and model.

This form of maladaptation, at the intersection of scientific uncertainty and overconfidence, is relatively straightforward. *Our present actions may not have the benefit that we expect and may actually cause more harm than the business-as-usual scenario* (i.e. leaving forests to adapt by themselves). This is how the AM literature, and the broader literature on climate change adaptation in forests, typically conceptualizes maladaptation—as the failure of the adaptive action

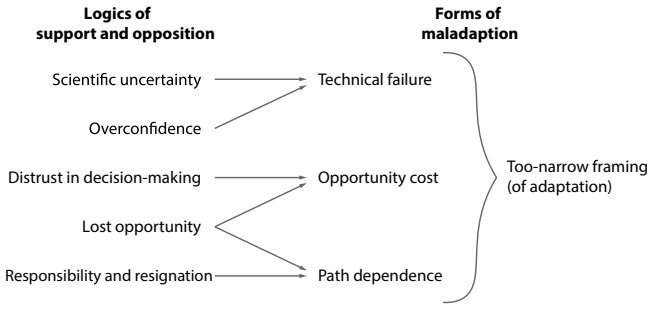

FIGURE 2 Forms of maladaptation that are implied by participants' emergent logics of support and opposition for genomics-based AM, as elaborated in the text below

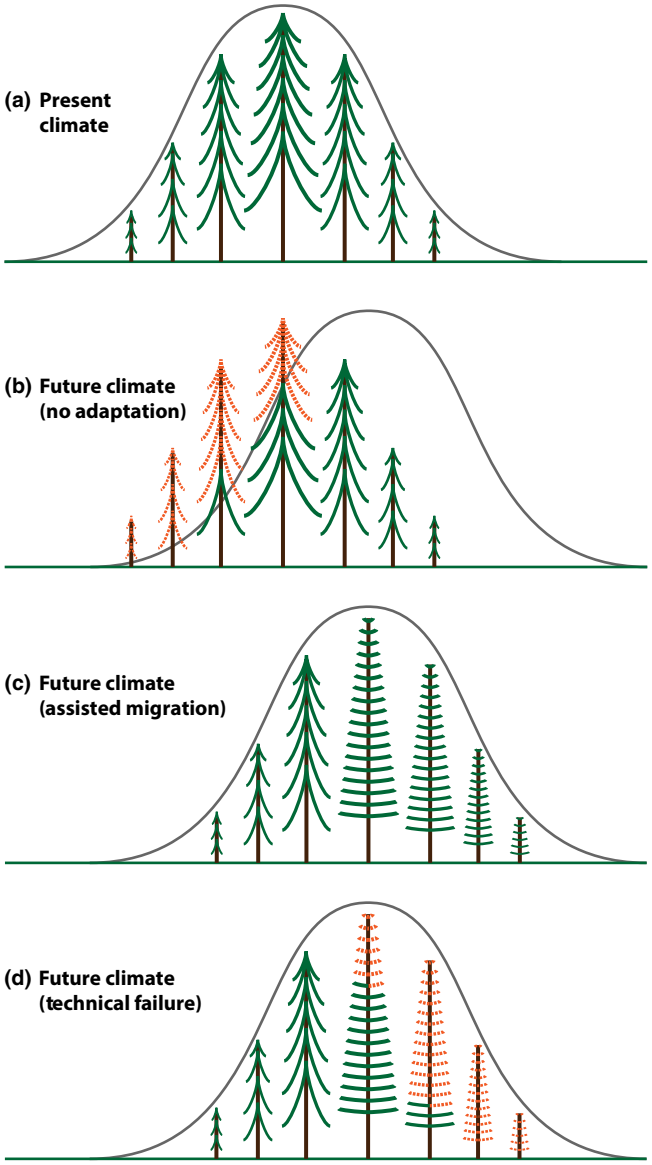

FIGURE 3 Forest health implications of technical failure. Forests are understood to be well-matched to the historical climates in which they evolved (a), but are becoming increasingly mismatched with their local climates. Because trees migrate very slowly, forests will become less healthy and less productive as their local climates change (b). AM can help to better match the trees that are planted now to their expected future climates (c), but scientific uncertainty (genomic, climatic, ecological) combined with overconfidence may lead to the failure of the selected trees (d). Healthy and productive trees are shown in green, while unhealthy and unproductive trees are shown in orange

to result in healthy and productive forests in the future because of scientific uncertainty (Figure 3).

4.1.2 | Opportunity cost

Climate change is a disruptor; AM is a consequential response to that disruption, which will change the composition, structure, function

and benefits of the forests on which communities across BC depend. Such moments of disruption provide opportunities to reconsider past actions and ways of thinking—like broader approaches to forest governance and forest management—to evaluate performance, re-prioritize long-term objectives and plan thoughtfully for the future. AM, as currently framed in relation to four commercially important tree species, represents a reinvestment in the *status quo*—the management of BC's public forests for the benefit of a commercial forest industry geared to the production of logs and fibre; AM policy is therefore a specific choice to protect the commercial forestry model that prioritizes timber supply above other forest values. However, the widespread and cascading impacts created by climate change provide the opportunity to consider alternative models that may be more beneficial from social, environmental and even economic perspectives.

Barnett and O'Neill (2010) recognized opportunity cost as a form of maladaptation, but they defined it as choosing a costlier option when other less costly options exist (in terms of economic, social and environmental costs). Here, the themes of distrust and lost opportunity intersect to return 'opportunity cost' to its broader definition: *by choosing a particular option, we forego the potential benefits of other actions*. Actions that perpetuate or strengthen *status quo* forest governance without a broader re-examination of the model of commercial forestry in BC may reinforce undesirable, inefficient or inequitable characteristics and forego the potential benefits of unconsidered alternatives, including diversifying the values for which forests are managed (Figure 4). Adaptation could conceivably include other changes in forest management, not just changes in tree selection, making it difficult to judge the acceptability of AM in isolation. Participants across all stakeholder groups were critical of *status quo* decision-making processes and forest management for a variety of reasons, not least because it focusses on limited species representing a narrow set of forest values. The foregone benefits are therefore of two kinds: (a) process-related benefits created by re-evaluating the priorities of forest governance and (b) outcome-related benefits created by enhancing non-timber forest values.

4.1.3 | Path dependence

Pursuing an AM strategy based on costly technical investments in adaptation knowledge for only four species of current commercial interest reinforces the future dependence of the forestry sector on those species. This will limit policymakers' ability to change governance priorities in the future because there will be little knowledge of how to help other tree species adapt. It will then be harder to respond to future changes in markets (for forest products) and societies (in prioritizing non-timber forest values). Investments in genomics-based AM for these tree species, determined to be most commercially valuable at present, therefore create path dependence in forest management broadly and climate-adaptive forest management in particular, that will make forest governance less adaptable in future.

This conceptualization of maladaptation, at the intersection of resignation and lost opportunity, is again the broadening of a classic: *by reinforcing the status quo, we limit our future adaptability*. Barnett and O'Neill (2010) conceived of path dependence as an important maladaptation; if our present adaptive actions lock us into particular pathways, we will be less adaptable in future and less able to respond to unexpected climatic, economic, environmental and social changes (Figure 5). However, their conceptualization was specific to costly and long-lasting physical infrastructure. Here, it is rather embodied in costly investments in scientific knowledge that reinforce present-day institutions and decision-making processes, making

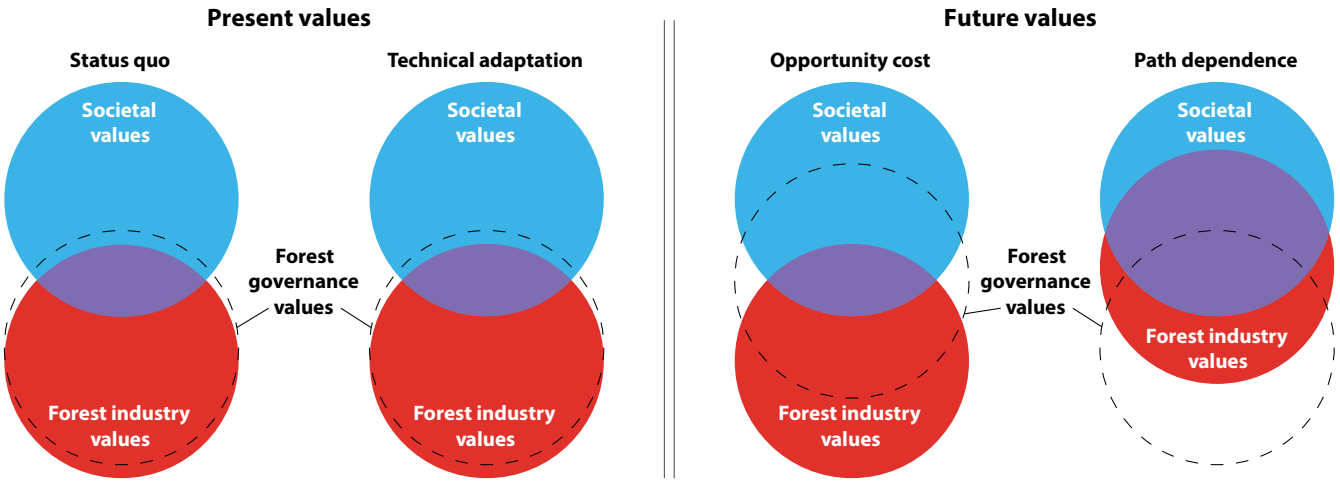

FIGURE 4 Opportunity cost and path dependence as related to forest governance values. Technical adaptation (using genomics-based AM on four commercially valuable species) protects the values for which forests are presently governed, which are perceived to closely align with the priorities of the forest industry. However, there may be an opportunity cost to that decision: technical adaptation foregoes the potential societal benefits of broadening the values for which forests are presently governed. This investment in technical knowledge in support of the *status quo* also creates path dependence that may limit future adaptability by making it difficult or costly to change forest governance priorities as societal and forest industry values shift

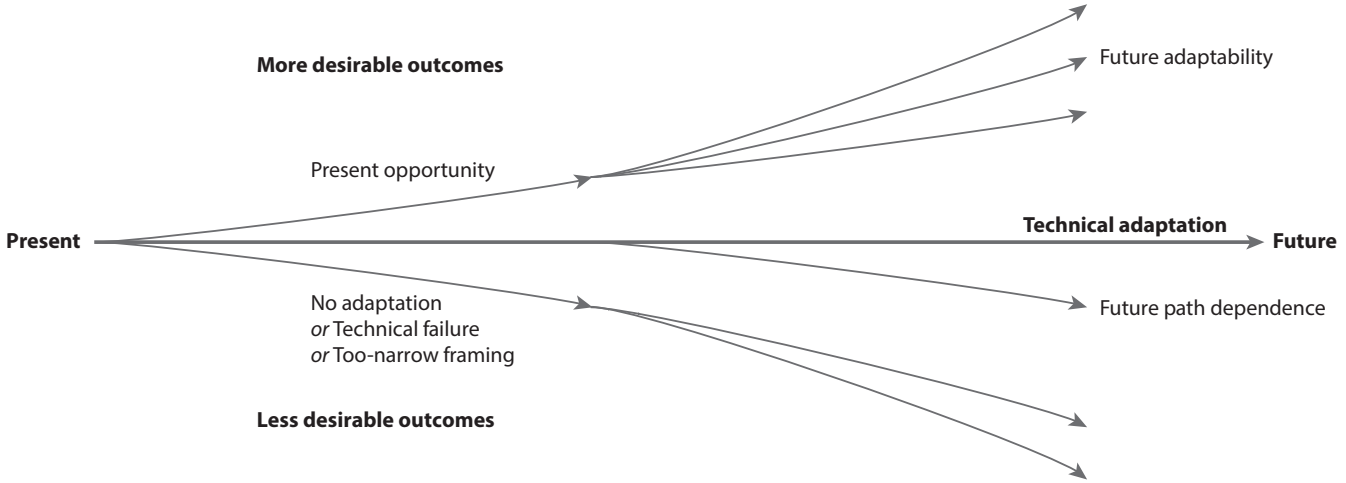

FIGURE 5 Conceptual representation of adaptation and maladaptation pathways. The middle pathway represents successful technical adaptation, which would protect the forest values for which forests are presently managed. The upper pathways symbolize present and future opportunities that may yield more desirable outcomes than technical adaptation alone (e.g. reimagining forest governance for a broader set of values; ensuring the adaptability of governance, scientific, social and economic processes in anticipation of unpredictable future challenges), while the lower pathways symbolize present and future obstacles that may yield less desirable outcomes (e.g. no adaptation, technical failure, path dependence and too-narrow-framing)

forest governance less adaptable to future economic, environmental and social changes. The particular structure of those institutions and decision-making processes, which have now prioritized genomics-based AM, themselves represent a form of path dependence created by decades of cooperation between government and industry. This has, in turn, sowed broader distrust of forest governance as demonstrated in Peterson St-Laurent et al. (2019). In this context, path dependence and opportunity cost are related. By reinvesting in the *status quo*, we forego the potential benefits that might be created by overcoming historical path dependence in how forests are presently governed and managed. The same choice increases future path dependence along that historical trajectory.

4.1.4 | Too-narrow framing of adaptation

Adaptation is not an objective unto itself; the meaningful goals of adaptation are to protect and enhance important forest values, like the economic benefits of the forest industry or the aesthetic, recreational and spiritual benefits of forests. *When adaptation is framed as a response to climate change alone*—and in helping trees, rather than forests, adapt—*decision-makers may lose sight of more fundamental goals*. The most impactful actions towards these objectives may have little to do with climate, and may be restricted or eliminated by the 'adaptation'.

This form of maladaptation, spanning all of the reported logics, signals the danger of too narrowly framing adaptation (and maladaptation as its inverse), and echoes earlier warnings against treating adaptation as a distinct and rational adjustment to climate hazards (Bassett & Fogelman, 2013). As a systemic, long-term and highly uncertain stressor, climate change reveals and exacerbates existing weaknesses in forest governance and management, broadly. The literature tends to conceive of maladaptation in reference to climate impacts alone: exacerbating climate change, redistributing climate impacts inequitably and reducing long-term climate adaptability. However, adaptation is a means by which to protect and enhance more fundamental values (e.g. food, water, shelter, energy, safety, community, livelihoods), and the concept of maladaptation should therefore account for these goals.

4.2 | Rethinking maladaptation

Three key papers anchor the current conceptualization of maladaptation (Barnett & O'Neill, 2010; Juhola et al., 2016; Magnan et al., 2016). Though Magnan et al. (2016) briefly discuss four specific cases, these foundational papers are largely based on broad overviews of the literature; none systematically explore the breadth of potential forms of maladaptation using an empirical approach. In these common frameworks, maladaptation is caused by decision-makers too narrowly framing the adaptation problem—drawing temporal, spatial or system boundaries around a climate-adaptive decision that externalize key processes and outcomes. Magnan et al. (2016), for instance, describe a case in which a homeowners' association in Cape Town, South Africa, installed sandbags to reduce coastal erosion, leading to the loss of the very kinds of coastal values that they were meant to protect (beach access, recreational value, tourism, tourism-derived revenue, property values), and impacting a much longer stretch of coastline than was considered in planning the project. The authors suggest that this demonstrates a failure to account for spatial and temporal impacts of the adaptive action. They suggest the need to consider non-climate outcomes, but do not include it in their formal definition of maladaptation: 'Only an initiative that would negatively affect exposure and/or the sensitivity of

ecosystems and/or society *to climate-related stressors* should be considered maladaptive to climate change' (emphasis added). Notably, Juhola et al. (2016) argue that past definitions of maladaptation were too broad to be analytically useful, and that researchers must narrow the analytical frame to make the concept of maladaptation more tractable.

In contrast, our deliberative approach to risk analysis was broad, empirical and stakeholder led. In our focus group sessions, the participants themselves identified important forest values and pre-existing forest risks prior to any specific discussion of climate change. The most widely shared forest values, further analysed in Findlater et al. (forthcoming), included ecosystem health and resilience; wildlife, habitat and biodiversity; clean air and water; carbon sequestration; jobs, forest products and other economic benefits; and recreation and spiritual well-being. Although all of these are threatened to some degree by climate change, carbon sequestration was the only elicited forest value directly related to it. Within this context and without any preconception of what might constitute maladaptation, we asked participants to discuss the potential risks created or made worse by adaptation. We then interpreted their deliberations through a maladaptation lens to develop a grounded understanding of maladaptation risks in this context.

We identify specific logics of support and opposition that represent risks of maladaptation through technical failure, opportunity costs, path dependence and the too-narrow framing of adaptation. Opportunity costs, path dependence and too-narrow framing are all perceived to be maladaptive because they limit policymakers' ability to account for a broader set of values and public policy goals, or to respond to future market and societal changes. Barnett and O'Neill (2010) conceived of maladaptive opportunity cost mainly with regard to less costly adaptation options, and maladaptive path dependence mainly in the context of costly, long-term and heavily engineered infrastructure. However, our results suggest that when more broadly defined, opportunity cost and path dependence may be even more important.

These findings show that stakeholder engagement is a powerful method by which to improve the analysis of maladaptation risks; Aminpour et al. (2020) argue that because stakeholders have such diverse sources and kinds of knowledge, they may collectively understand complex social-ecological systems better than scientists alone. Engagement should not be approached as an exercise in unilateral risk communication or an effort to overcome stakeholder resistance, where the primacy of natural science is unchallenged. Such tendencies have led, for example, to the continued failure of climate science institutions to provide user-driven climate services to inform adaptation and other climate-sensitive decisions (Findlater et al., 2021). Engagement should rather be approached as an integral step in making good climate-adaptive decisions within social-ecological systems that provide diverse values. While public and stakeholder engagement can achieve normative, substantive and instrumental goals (Fiorino, 1990; Pidgeon et al., 2017), including the strengthening of legitimacy and public trust (Stehr, 2015), here it enables us to better understand the broader implications of what may first appear to be a constrained policy choice.

We find that narrow conceptualizations of maladaptation prevent its systematic analysis because they artificially limit the processes and outcomes that are considered relevant. These findings resonate with Bassett and Fogelman's (2013) persuasive argument against conceptualizing adaptation itself as a distinct process involving a rational adjustment to climate hazards. Such framing isolates climate concerns from other decisions, which can lead to their neglect by climate-sensitive decision-makers (Findlater et al., 2018, 2019). There is therefore widespread agreement that adaptation needs to be 'mainstreamed' because the decision-making objectives of individuals, groups and societies are multifaceted and climate is a pervasive factor (Porter et al., 2014). Maladaptation itself is often a product of the too-narrow framing of adaptation; in turn, its narrow framing as envisioned by Barnett and O'Neill (2010), Noble et al. (2014), Juhola et al. (2016) and Magnan et al. (2016) limits our understanding of the ways in which climate-adaptive actions can undermine broader social, economic and environmental goals. Climate adaptations that are undertaken without consideration of these broader concerns risk creating longer-term maladaptation at odds with the win–win, flexible, robust and mainstreamed decision-making approaches advocated in the adaptation literature.

5 | CONCLUSIONS

These results illustrate how adaptation in complex socio-technical-environmental systems must be broadly construed by climate-adaptive decision-makers to adequately understand, identify and avoid maladaptation risks. Climate change is a global phenomenon, defined by intractable uncertainty, whose impacts are filtered through innumerably diverse and challenging socio-political, economic, ecological and climatic contexts. The stress that it exerts on these systems reveals and amplifies existing weaknesses in governance, inequalities of wealth and opportunity, socio-political disagreements and scientific uncertainties. As a systemic and often politicized stressor, climate change therefore provides a natural focal point for broader pre-existing concerns.

Maladaptation itself has been too narrowly framed, reflecting the obsolete idea of adaptation as 'rational adjustment to climatic hazards'. We have shown that potential modes of maladaptation are richer and more nuanced than presently conceptualized, intersecting with other risks arising from simultaneous socio-political and technical processes. Rather than being a failure of adaptation, per se, *maladaptation is a failure of climate-adaptive decision-making to account for all of the relevant factors—across spatial scales, temporal scales and interconnected systems—that contribute to the intended socioeconomic and environmental outcomes*. Maladaptation therefore comprises climate-adaptive policies or actions that, in a broader frame, threaten the very values that decision-makers ostensibly seek to protect and enhance.

This suggests the need for a values-based approach to both adaptation and maladaptation in keeping with recent movement towards more inclusive and dynamic concepts like transformative resilience. Rather than protecting *status quo* priorities and processes by default, we should take the opportunity afforded by this moment of disruption to reconsider the values for which we manage complex social-ecological systems. We may then see climate change adaptation as an instrument rather than a goal unto itself and maladaptation not as adaptation 'gone wrong' but as a misapplication of that instrument towards too narrow a goal.

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CONFLICT OF INTEREST

Nothing to declare.

AUTHORS' CONTRIBUTIONS

K.F. designed the study, conducted the focus groups, analysed the data and drafted the paper; K.F., S.H. and R.K. conceptualized the study, and reviewed and revised the paper; V.G. analysed the data; S.H. and R.K. conceptualized and supervised the overarching project and acquired the funding.

DATA AVAILABILITY STATEMENT

The interview data that support the findings of this study are not publicly available because they contain information that would compromise the research participants' confidentiality and undermine the process of informed consent.

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