Forest Ecology and Management 470–471 (2020) 118214

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Ecological issues related to second-growth boreal forest management in eastern Quebec, Canada: Expert perspectives from a Delphi process

Kaysandra Waldron[a,*], Nelson Thiffault[b], Frédéric Bujold[c], Jean-Claude Ruel[d], Jean-Martin Lussier[b], Dominique Boucher[a]

[a] Natural Resources Canada, Canadian Forest Service, Laurentian Forestry Centre, 1055 rue du P.E.P.S., P.O. Box 10380, Stn. Sainte-Foy, Québec, QC G1V 4C7, Canada
[b] Natural Resources Canada, Canadian Forest Service, Canadian Wood Fibre Centre, 1055 rue du P.E.P.S., P.O. Box 10380, Stn. Sainte-Foy, Québec, QC G1V 4C7, Canada
[c] Ministère des Forêts, de la Faune et des Parcs du Québec, Direction des relations avec les nations autochtones et Direction générale des mandats stratégiques, 5700 4e avenue Ouest, Québec, QC G1H 6R1, Canada
[d] Centre d'étude de la forêt, Département des sciences du bois et de la forêt, Université Laval, 2405 de la Terrasse, Québec, QC G1V 0A6, Canada

ARTICLE INFO

Keywords:
Delphi method
Old-growth forests
Forest fragmentation
Stand structure
Woodland caribou habitat

ABSTRACT

The Eastern boreal forests of Quebec, Canada, have been extensively harvested over the past decades. Second-growth stands originating from sites harvested between 1920 and 1950 will soon reach the stage allowing for a second harvest. In order to guide the decision-makers responsible for ecosystem-based management of these forests, their specific management issues must be identified, based on the best knowledge available. In this context, we used the Delphi method and asked experts to identify and prioritize the main ecological issues related to the management of second-growth forests. Fourteen experts participated in at least one round of the process, out of an initial population of 30 known experts. After three rounds of questions, experts identified the maintenance of old-growth forests as the most important issue related to second-growth forest management in this region. The protection of woodland caribou and its habitat, and land fragmentation by forest roads were the second and third most important issues identified by the Delphi survey participants. These issues are not unique to second-growth forests, but should be given priority in considering management strategies associated with second-growth stands.

1. Introduction

Boreal forest management impacts ecosystems at both the landscape and stand levels, such as by increasing fragmentation, homogenizing structural attributes and modifying stand composition and age distribution (see Venier et al., 2014 for a review). These consequences of management may affect boreal forest resilience and biodiversity, and tend to be more pronounced in forests with a long fire return interval and, thus, a high proportion of old-growth stands (Boucher et al., 2015; Cyr et al., 2009). To minimize the gaps between managed and natural stands, ecosystem-based management has been implemented in many jurisdictions (Perera et al., 2004). This paradigm aims at protecting biodiversity and ecosystem services, while preserving the economic benefits of wood supply (Gauthier et al., 2009). Using a coarse-filter approach, ecosystem-based management leverages knowledge of natural disturbance dynamics and ecosystem processes to maintain managed stands within their natural range of variability (Gauthier et al., 2009; Kuuluvainen and Grenfell, 2012). Alternative silvicultural treatments to traditional clearcutting, such as tree retention, partial cutting or longer rotations, are thus used to ensure ecosystem resilience and maintain the production of goods and services (Bauhus et al., 2009; Lindenmayer et al., 2012; Puettmann et al., 2015). However, long-term impacts of these practices on boreal ecosystems remain unknown (Bose et al., 2013).

Second-growth boreal stands, which are stands that have already been harvested, differ from natural-origin stands in many ways. For example, second-growth stands have less coarse woody debris (Siitonen et al., 2000; Thompson and Curran, 1995) than do natural forests. Differences in age class distribution at the regional scale, as well as in stand compositions, are also observed. For example, stands harvested between 1920 and 1950 differ significantly from fire-origin stands in the eastern boreal forest of Quebec, Canada. One of the main differences is an over-representation of balsam fir (*Abies balsamea* (L.) Mill) in second-growth stands in comparison to fire-origin stands, at both the

* Corresponding author.
E-mail address: kaysandra.waldron@canada.ca (K. Waldron).

https://doi.org/10.1016/j.foreco.2020.118214
Received 22 November 2019; Received in revised form 28 April 2020; Accepted 2 May 2020
Available online 21 May 2020
0378-1127/

stand and landscape levels (Bouchard and Pothier, 2011; Boucher et al., 2015). In addition to its ecological impacts, such a shift in composition has economic consequences, as black spruce (*Picea mariana* (Mill) BSP) is the most desirable commercial species in this area due to its superior wood mechanical properties (Giroud et al., 2017; Lessard et al., 2014). Also, higher balsam fir density in the landscape increases vulnerability to spruce budworm (*Choristoneura fumiferana* Clem. - SBW) infestations (Blais, 1983). At the landscape level, forest management can cause a further inversion of the age class distribution compared to the one resulting from natural disturbance dynamics (Venier et al., 2014). In Canada's eastern boreal forest, areas with a higher proportion of managed stands have significantly younger stands than unmanaged areas (Bouchard and Pothier, 2011; Boucher et al., 2015).

The boreal forest of eastern Canada has been extensively managed for decades. A large proportion of second-growth stands in this region will soon reach rotation age. Ecosystem-based forest management strategies need to consider these stands. Certain silvicultural treatments may need to be performed to reduce their structural and compositional differences with stands originating from natural disturbances in order to address ecological issues. However, ecological issues specific to second-growth forests have yet to be identified and documented.

For ecosystem-based forest management, the Province of Quebec opted for an issues-and-solution approach, where ecosystem management issues specific to the forest management unit or district are identified and specific solutions are designed in terms of policies, acceptable practices and management targets. However, boreal forests are complex systems with important differences between regions, and empirical datasets can be long and expensive to obtain. In this context, using expert knowledge is a good way to get or consolidate information in a relatively short term (Kangas and Kangas 2005, Martin et al. 2012, Drescher et al. 2013). The use of expert knowledge has increased in ecological sciences over the last few years (Drescher et al., 2013). The contribution of experts can be qualitative, quantitative or both (Drescher et al., 2013; Tapio et al., 2011).

In this context, we aimed to (a) compile a list of confirmed or perceived ecological issues related to management of the second-growth boreal forests of eastern Canada, and (b) to rank the issues so that we could identify priorities for the ecosystem-based management of this forest type.

As the literature is scarce for many of the potential issues related to second-growth forests, we used the Delphi method to gather expert knowledge on the topic (Linstone and Turoff, 2002). The Delphi method has proven its higher efficiency when the experts are geographically dispersed and/ or when the small number of experts is overwhelmed by the demands of conducting specific assessments for multiple forest management units, as shown by Waldron et al. (2016). While this paper focuses on assessing the Delphi methodology, we present the results from the expert panel's consultations, in the hope of providing guidance to forest managers and decision makers in minimizing critical ecological gaps between managed and unmanaged forests.

2. Methods

2.1. Study area

Our study area is located in Canada's eastern boreal forest, in the North Shore region of Quebec (Fig. 1). The main surface deposit is glacial till and the topography is irregular, with some high elevation sites as well as deep valleys. From 1981 to 2010, mean annual precipitation was 920.6 mm/year (including 258 mm in the form of snowfall), ranging from an average of 53.2 mm in March to an average of 96.4 mm in October (Godbout meteorological station; 49.32 °N, 67.62 °W). Mean annual temperature was 2.1 °C, ranging from −13.9 °C in January to 16.2 °C in July (Government of Canada, 2019). The study area encompasses two bioclimatic subdomains: the eastern black spruce-moss bioclimatic subdomain in the north, and the eastern balsam fir-white birch (*Betula papyrifera* March.) bioclimatic subdomain in the south (Saucier et al., 2009). Most of the study area was located in the fir-white birch bioclimatic subdomain. Therefore, no distinction has been made between bioclimatic subdomains for this study. The main tree species in this region are black spruce and balsam fir, with a proportion of white spruce (*Picea glauca* (Moench) Voss), white birch, trembling aspen (*Populus tremuloides* Michx.) and jack pine (*Pinus banksiana* Lamb). The fire cycle averages 300 years or more (Bouchard et al., 2008), and insect outbreaks and windthrow are the main natural disturbances (Bouchard and Pothier, 2010; De Grandpré et al., 2009; Waldron et al., 2013). As the longevity of the main tree species is shorter than the fire cycle, more than 70% of the primary forest stands have an irregular size distribution (Boucher et al., 2003).

Clearcutting operations in the North Shore regions started in the 1920s, close to the St. Lawrence River, and progressed northward. Second-growth forests, i.e., forests that were harvested between 1930 and 1950, cover about 700 km^2 of the study area (Fig. 1). Harvests supplied sawmills and pulp and paper mills, mostly with black spruce. Mechanization started in the 1960s, with motor-manual felling and cable skidders. Fully mechanized operations were common by the 1980s.

2.2. General approach to issue identification

In a way to choose the best method of experts' consultation, a focus group was held in 2014, with five scientists having a good experience in the expert consultation processes. Scientists had to list the main methods of experts' consultation and highlighted advantages and disadvantages of these methods. The focus group results make us chose the Delphi method in a way to answer our study objectives. See Waldron et al. (2016) for more details about the theoretical framework behind our method selection and the appreciation of the process by the participants.

The Delphi technique is mainly used for complex problems when empirical data are lacking, but it can also be a complementary source of information when empirical data are sparse (Hess and King, 2002; Linstone and Turoff, 2002; Masse et al., 2014; Mukherjee et al., 2015). The Delphi technique is a confidential and iterative method of expert consultation, based on enquiry, having the advantage of allowing participants to express their opinions without fear of judgment. It enables participants to answer questions without having to attend meetings in person or by teleconference, and at a time when they are available. This approach is advantageous in a context where experts are highly solicited and/or hard to get together for face-to-face meetings because of distance and budgetary constraints. Specifically, the Delphi technique consists in answering a few rounds of questions. Depending in the accessibility of Internet infrastructure, it could be by mail but most of the time questions are now send and answer by email (Donohoe and Needham 2009). The first round typically includes broad questions and is similar to a brainstorming exercise. The succeeding rounds become more precise and seek to confirm some aspects highlighted in the previous rounds. We used the "ranking-type" variant of the Delphi method, which consists in ranking issues to establish priorities (Okoli and Pawlowski, 2004; Schmidt, 1997).

In March 2014, we sent an email to 30 experts at governmental institutions, non-governmental organizations, and colleges and universities, asking them to participate in our study. These experts were selected based on their area of expertise, including wildlife ecology, soil science, forest management, silviculture, plant ecology, natural disturbances, climate change and forest dynamics. These 30 experts were selected with the snowball technique, i.e. we first chose three experts, and they were asked to suggest three to five experts. This process was repeat until no new experts were suggested (Waldron et al. 2016). All of the invited experts were known to be familiar with forest management in the North Shore area of Quebec, which is a particular ecosystem of the Canadian eastern boreal forest (Saucier et al., 2009). Twenty-one

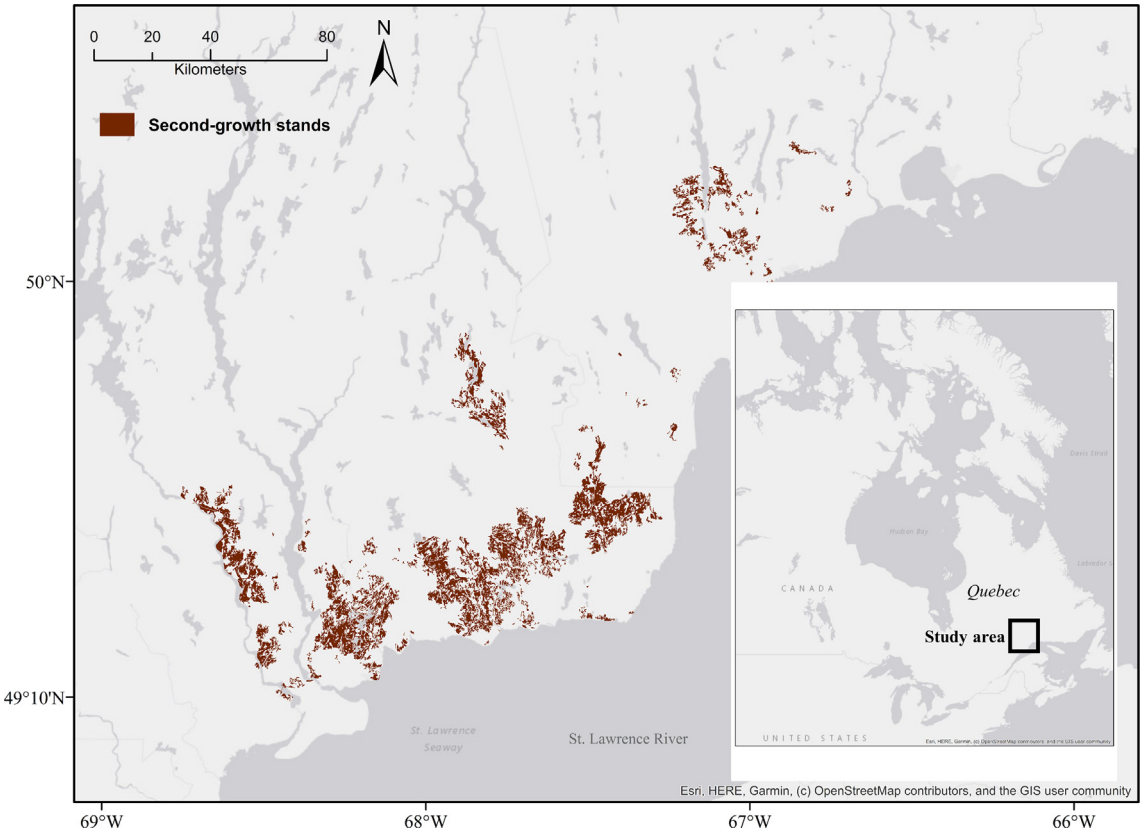

Fig. 1. Study area. The dark polygons are the second-growth stands harvested between 1920 and 1950.

people agreed to participate in our study.

Our Delphi approach consisted in three rounds of questions that participants were asked to answer in their own time, but within three weeks. Before starting the Delphi survey, we validated our questionnaire with experts who were not participating in the study, to ensure that the questions were clear and to validate the time required for responding to them. The complete questionnaires are presented by Waldron et al. (2016). The first round of questions was sent to the 21 experts on April 1, 2014, and 13 experts responded. The goal of this round was to review an exhaustive list of potential issues from the expert panel, without ranking them. Our message included the definition of an issue (a problem, element or feature that could lead to a management objective) to make sure that the participants understood what was expected of them. In this first round, we sent a list of 38 ecological issues that may be associated with management of second-growth stands of the eastern boreal forest. This list was adapted from a previous study that had focused on primary forests from the same region (Bujold, 2010, unpublished data). Experts were asked to analyze the list and to add, drop or merge issues. They also had the option of commenting on or justifying their choices. In order to stimulate brainstorming, experts also had the options of evaluating the scale of application of each issue (site, stand, landscape) and categorizing issues as being documented or anticipated. Three reminders were sent by email for each round.

We sent our second round of questions on June 9, 2014. Eleven experts from the initial group of 21 experts participated in our survey. The second round was focused on sorting out the relevant issues from the list, as determined by the vote of the experts. Based on the results of the first round, we sent a list of issues that were considered relevant by at least one participant and asked whether each issue should be kept or discarded. Participants choose here as many issues as they considered as relevant. Again, participants had the option of commenting on their choice. Based on the response from the second round, the revised list of issues was filtered again to retain only items considered worth keeping by the majority (more than 50%) of the participants.

Finally, on July 14, 2014, the third and last round of questions was sent to the same 21 participants as in the first round. This time, the goal was to rank the potential issues according to their importance and priority. 11 participants responded, but the participants were not exactly the same as in the previous round. Using the filtered list of issues resulting from the second round, each participant was asked to select seven issues that he/she considered the most important and to rank them from 1 to 7, 7 representing the highest priority and 1, the lowest priority. Participants had to choose their top seven issues, since it represented 25% of the number of issues listed after the second round. Indeed, it would have been a hard exercise to rank 29 issues. A value of 0 was attributed to the issues not selected among the top seven. After each round, we sent the participants a report with the results from the previous round.

2.3. Data analysis

To determine if the participants' affiliation influenced how they classified issues as anticipated or documented during all rounds, we used a chi-square test with a significance threshold of $P \leq 0.05$, with the R software version 3.6.0 (R Core Team, 2019). Differences in scores between the experts based on their affiliation were also tested by applying a chi-square test on the Score x Affiliation frequency table, for each of the issues.

For the third round, which aimed to prioritize the issues, we used a weighted score approach inspired by the Borda scoring method (Emerson, 2013). Issues that were selected by the majority of participants (i.e. more than 50% so at least 6 participants) in the second round were kept in the third round. The score for each issue was calculated as the sum of the individual scores, multiplied by the occurrence of individual scores that differed from 0 for the issue. This approach favours

issues for which there was a consensus among the experts, giving a lower score to issues that were not included in the short list of seven important items chosen by the participants. The weighted score could range from 0, if all 11 participants ranked a given issue at 0, to 847 if all participants ranked a given issue at 7 (Comité scientifique sur les enjeux de biodiversité, 2010). We used boxplots to examine the score distribution of the 10 issues with the highest weighted score.

3. Results

In total, 14 participants responded to at least one of the three rounds of questions. Eight participants answered all rounds. The number of participants was the highest for the first round, and then decreased but remained stable between rounds two and three. However, the eleven participants in the second round were not entirely the same as those who participated in the last round. The participation pattern showed that only one participant answered the first round of questions and subsequently withdrew from the process. This suggests that the selected experts were interested in the process, even if some chose to answer only two out of the three rounds of questions. All of the last-round participants had participated in at least one of the previous rounds, showing a continued interest in the study and stability, i.e. a small attrition rate (Donohoe and Needham 2009) (Table 1).

Not all participants classified all the issues as being documented or anticipated; participants seemed to classify only the issues that were important for them. There seemed to be a relationship between the classification of issues as documented or anticipated and the affiliation of participants, but the chi-square test was not significant ($\chi^2 = 5.86$, $P = 0.054$, Table 2). Participants affiliated with academia tended to consider a higher proportion of issues to be documented rather than anticipated. On the other hand, participants from the provincial government considered that more issues were anticipated rather than documented (Table 2).

The first round was mainly brainstorming, resulting in 40 issues that at least one participant indicated as relevant. Among these 40 issues, 30 came from the initial list and eight were added. The last two issues encompassed six issues from the original list that experts wanted to merge into two issues.

During the second round, participants had to decide, for each of these 40 issues, whether they should be kept or removed from the list (see Appendix A). From this stage, the majority of participants, i.e. more than 50% identified, a filtered list of 29 issues to be kept. Only one issue was chosen by a consensus of all the participants: “Protection of woodland caribou (*Rangifer tarandus caribou*) and its habitat”. Five of the 40 issues achieved a near-consensus, with only one participant disagreeing on their relevance (“Protection of endangered species (other than caribou)”, “Old-growth forest rarefaction”, “Simplification and normalization of landscape age structure”, “Territory fragmentation by forest roads”, “Stand internal structure simplification”) (Appendix A).

From the third and last round on prioritization of the issues, the highest weighted score (> 400) was reached for two issues, i.e., “old-growth forest rarefaction” (score of 570) and “protection of woodland caribou and its habitat” (score of 423) (Table 3). For these two issues, only one participant and two participants, respectively, assigned a zero value as the priority score, and six participants assigned a score equal to or higher than 5. Participants who classified issues as anticipated or documented all considered that they were documented (Table 3). The four issues with the highest weighted score represented 74% of the total weighted score for the whole list of 29 issues. The weighted score was zero for six issues, indicating a consensus on their ranking (Table 3).

Only three issues were assigned a value different from zero by the majority of participants, i.e., by six or more participants (Fig. 2). The issues of “old-growth forest rarefaction” and “protection of woodland caribou and its habitat” had the highest median scores (respectively 6 and 5), the lowest variance in participant answers, and a distribution skewed towards high scores (Fig. 2). The third-place issue was “territory fragmentation by forest roads” (median = 3), with a more variable and symmetrical distribution of scores.

Chi-square tests on the distribution of issues scores by affiliation group did not show significant differences of scoring between the groups for all issues. Table 4 shows the chi-square tests for the 10 issues with the highest score (Table 4).

Table 1
Participants in the Delphi study, their affiliation and rounds answered.

Expert’s ID	Affiliation	Round 1	Round 2	Round 3
1	Provincial government	x	x	x
2	Provincial government	x		x
3	Academia	x	x	
4	Federal government	x		x
5	Federal government	x	x	
6	Provincial government	x	x	x
7	Federal government	x		
8	Academia	x	x	x
9	Provincial government	x	x	x
10	Academia	x	x	x
11	Provincial government	x	x	x
12	Federal government	x	x	x
13	Provincial government	x	x	x
14	Academia		x	x
Total number of participants:		13	11	11

4. Discussion

In boreal forests of eastern Canada where extensive forest harvesting has occurred over the past decades, second-growth stands represent a large proportion of the territory. Second-growth stands differ from stands originating from natural disturbances in their age and species distribution, among other attributes (Boucher et al., 2015). There is, however, little literature on issues associated with management of second-growth forests. We therefore used a Delphi approach to gather expert knowledge on the topic.

Participants tended to consider documented issues as more important than anticipated issues. Indeed, among the ten most important ecological issues related to the management of second-growth boreal forests, eight was considered as documented by the participants. Experts also highlighted the lack of knowledge and gaps in the literature gaps for some anticipated issues, which will help to identify some future research needs.

4.1. Most important issues

Our results show that, in the context of the boreal forest of eastern Quebec, Canada, issues related to caribou, as well as the issues of forest age and complexity, are considered by the experts to be the most important.

4.1.1. Old-growth forest rarefaction

The ecological issues classified as the most important pertained to the rarefaction of old-growth forests. This issue encompasses other issues, and was referred to many times in the boreal forest literature as one of the most important aspects to consider for boreal forest management and resilience, particularly in a context of climate change (Bergeron et al., 2017; Kuuluvainen and Gauthier, 2018).

The proportion of old-growth stands in Canada’s eastern boreal forest has declined where forest management has occurred (Bouchard and Pothier, 2011; Boucher et al., 2015; Cyr et al., 2009). However, two participants mentioned that second-growth forest management should be considered as a way to recreate some old-growth characteristics, for example, by using uneven-aged practices such as partial cutting, tree retention or longer rotations (see Bauhus et al. (2009) for more

Table 2
Number of issues classified as anticipated or documented in relation to the affiliation group of the participants, and chi-square test results between the number of times all issues were classified as documented and anticipated, and the participant's affiliation.

Issue classification	Participant's affiliation	Number of times that a participant classified an issue as anticipated or documented	Chi-square test
Anticipated	Federal government	7	$\chi^2 = 5.86$, df = 2, $P = 0.054$
	Provincial government	5	
	Academia	4	
Documented	Federal government	9	
	Provincial government	2	
	Academia	15	

Table 3
Final list of issues and prioritization. Each participant gave a score from 1 to 7, with 7 assigned to the most important issues for them, and put a zero elsewhere. The weighted score is the score sum for the issue multiplied by the number of times that the score differed from 0. Participants had the option of classifying each issue as documented (D) or anticipated (A). When both letters are present for an issue, there was no consensus among participants regarding the classification.

Rank	Second-growth forest management ecological issues	Number of times that the given score was not 0	Weighted scores	D or A
1	Old-growth forest rarefaction	10	570	D
2	Protection of woodland caribou and its habitat	9	423	D
3	Territory fragmentation by forest roads	7	224	D
4	Conservation of the quality of aquatic habitats	5	115	D
5	Residual forest connectivity	5	70	D
6	Biological legacies lost	4	68	D
7	Vulnerability to spruce budworm (SBW)	4	60	A, D
8	Stands internal structure simplification	4	56	D
9	Time between two cuts (rotation)	3	48	A
10	Forest matrix inversion	2	26	D
11	Protection of endangered species (other than caribou)	2	20	A
12	Dead wood rarefaction	2	20	D
13	Balsam fir augmentation in black spruce stands	3	18	A, D
14	Broadleaved species augmentation	3	18	A, D
15	Second-growth forest quality for organisms associated to old-growth forests	2	18	D
17	Headwater lakes protection	2	10	A, D
18	Simplification and normalization of landscape age structure	2	10	D
19	Preventive harvesting or salvage logging due to SBW	2	6	A
20	Ericaceous species encroachment	1	4	A, D
21	Minimization of forest soil disturbances	2	4	D
22	White spruce rarefaction	1	2	A, D
23	Soil and water conservation	1	1	–
24	Impacts of permanent anthropic disturbances on regeneration	1	1	D
25	Mixed stands conversion	0	0	A
26	Regeneration after a clearcut with protection of soil and regeneration	0	0	A
27	Productive areas lost because of anthropic disturbances	0	0	A, D
28	Soil fertility diminution because of biomass exportation	0	0	A
29	Contribution to the ecological cycles	0	0	–
30	Maintaining stands in the margins of their geographical distribution	0	0	–

examples). Indeed, these silvicultural treatments could help to increase the structural complexity of second-growth boreal forests (Bauhus et al., 2009; Kuuluvainen et al., 2015). For instance, mixed second-growth forests dominated by balsam fir managed with partial cutting and affected only by partial disturbances share structural characteristics with old natural mixed balsam fir forests (Tremblay et al., 2007). As one participant observed, *"There are too many species associated with this issue for it not to be considered."* Indeed, old-growth boreal forests are associated, among other things, with saproxylic beetle species (Janssen et al., 2011), bird species including black-backed woodpeckers (*Picoides arcticus*), martens (*Martes americana*) and red-backed voles (*Myodes gapperi* Vigors) (see Venier et al. (2014) for a review of species associated with different age classes).

4.1.2. Protection of woodland caribou and its habitat

One of the species associated with mature and old-growth resinous forests that has received a lot of attention in recent years is the woodland caribou, which is a threatened species in Canada (COSEWIC, 2019). Participants in our Delphi study identified caribou habitat protection as the second most important issue associated with second-growth forest management. Even if most of the participants considered this issue as being documented, one participant pointed out that there is a lack of literature on this subject and called for the precautionary principle to be applied for this endangered species: *"Caribou habitat selection in second-growth forests is not well known and, as a result, this issue should be maintained following the precautionary principle."*

Forest management (logging and dense road networks) affects caribou behaviour and habitat use (Beauchesne et al., 2013; Courtois et al., 2007; Fortin et al., 2008). Forest management can also influence caribou predation. Indeed, young stands are conducive to the growth of berry-producing shrub species and, consequently, also favour black bears (*Ursus americanus*) (Brodeur et al., 2008). Bears are predators of caribou, particularly calves (Pinard et al., 2012). Road networks also increase the risk of predation by wolves (*Canis lupus*) (Courbin et al., 2009; Whittington et al., 2011). Most of the second-growth forests considered in this study are located in a region covered by a government recovery plan for caribou. The study area is characterized by many anthropic disturbances, a dense road network and recreational use of the forest. Thus, increasing or maintaining caribou populations might prove to be difficult (Équipe de rétablissement du Caribou Forestier, 2013). In Quebec, caribou conservation is also a significant issue at a landscape scale. Favouring population recovery of this species requires maintaining adequate habitats within managed areas and planning disturbances following ecosystem-based principles (Équipe de

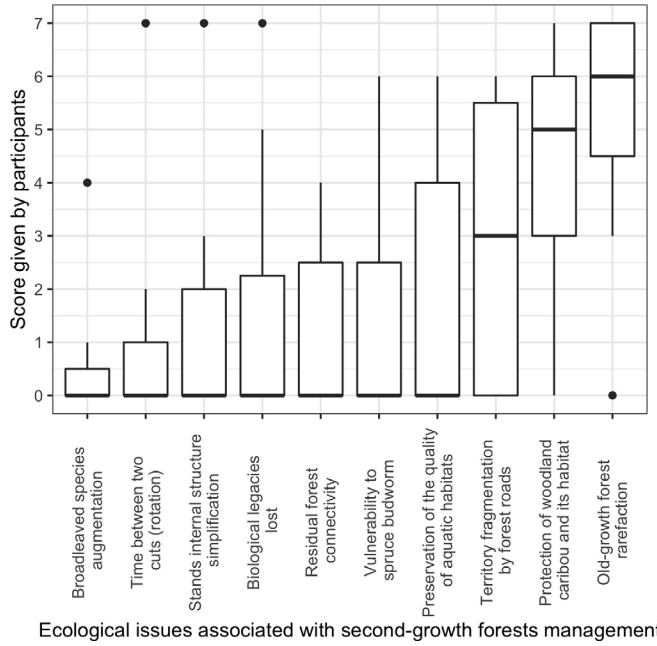

Fig. 2. Boxplots of the score given by individual participants for the 10 issues having the highest weighted score. Each participant gave a score from 1 to 7, with 7 assigned to the most important issues for them, and put a zero elsewhere.

Table 4
Chi-square tests ($\chi 2$), degree of freedom (df) and the significance value (significance threshold of $P \leq 0.05$) on individual scores among the different participant's affiliations, for the 10 issues with the highest weighted scores.

Issue	χ^2	df	*P*
1- Old-growth forest rarefaction	9.63	10	0.474
2- Protection of woodland caribou and its habitat	8.25	8	0.41
3- Territory fragmentation by forest roads	10.36	10	0.41
4- Preservation of the quality of aquatic habitats	3.36	6	0.76
5- Residual forest connectivity	8.35	8	0.4
6- Biological legacies lost	14.14	8	0.08
7- Vulnerability to spruce budworm (SBW)	8.90	6	0.18
8- Stands internal structure simplification	5.76	6	0.45
9- Time between two cuts (rotation)	6.65	4	0.16
10- Forest matrix inversion	5.70	4	0.22

rétablissement du Caribou forestier, 2013). Empirical knowledge is lacking regarding caribou response to alternative silvicultural practices that differ from the conventional clearcutting approach Indeed, as was noted by one participant, *"It is not excluded that forest management of second-growth forests could help to create good potential habitats for caribou."*

Three participants highlighted that caribou is an umbrella species, and that its habitat protection will positively impact other species, including the barrow's goldeneye (*Bucephala islandica*). Habitat conservation thus appears to be important not only for caribou, but also for other species.

4.1.3. Landscape fragmentation by forest roads

Landscape fragmentation by forest roads was the third most important issue identified by the Delphi participants; this aspect affects boreal forest ecosystems in many ways. For example, road networks impact caribou (Courbin et al., 2009; Fortin et al., 2008) and wolves (Lesmerises et al., 2012) in terms of their behaviours, and also affect aquatic habitats and watershed patterns (Gunn and Sein, 2000; Kreutzweiser et al., 2015; Tinker et al., 1998). In the words of one participant, *"[…] road impacts are long-lasting in harvested sectors and their management (closure, replanting) is an important element of ecosystem restoration."* Road network and infrastructure planning should be included in management strategies as a way to maintain biodiversity and the integrity of aquatic ecosystems (Lindenmayer et al., 2006).

4.2. Other issues

Two issues, i.e., preservation of the quality of aquatic habitats and vulnerability to SBW, raised many comments from participants, even though these issues were not selected as the most important ones.

4.2.1. Preservation of the quality of aquatic habitats

Forest management can affect the quality of aquatic habitats mainly because of the changes in nutrient cycles caused by harvesting and the construction of forest roads (and culverts) (Kreutzweiser et al., 2015). One participant who advocated for keeping this issue referred to its potential long-term impact: *"The obsolescence of roads and stream crossings in second-growth forests will require maintenance over time to preserve water quality and fish movement."*

Indeed, if road and stream crossing maintenance is deficient, negative effects can be measured many years after the initial road construction (Gunn and Sein, 2000). In boreal forests, the negative impact of roads on aquatic habitats and organisms could be minimized with improved construction methods, strategic siting, and proper culvert installation (Kreutzweiser et al., 2015). Harvesting techniques such as partial cutting and tree retention could also reduce the negative impacts on watersheds (Prepas et al., 2003). However, many unknowns remain; most studies measuring the impacts of forest management on aquatic organism behaviour and habitat quality are small-scale and focused on specific aquatic ecosystems (Kreutzweiser et al., 2015).

4.2.2. Vulnerability to spruce budworm

In eastern boreal forests of Canada, forest management results in a higher proportion of balsam fir in managed landscapes than the proportion that occurs following a natural disturbance regime (Boucher et al., 2015; Fourrier et al., 2013). The high proportion of fir in stands and at the landscape level increases forest vulnerability to SBW outbreaks (Blais, 1983; Morin, 1994); balsam fir is more likely to be affected by this insect than are other tree species (Nealis and Régnière, 2004). One participant mentioned that this issue is particularly important, all the more if it means more salvage logging, thereby questioning the potential impact of salvage operations on forest homogenization at the landscape level. Another participant commented as follows: *"An increase in the areas affected by SBW as well as more severe outbreaks […] could have an impact on wood supply and on biodiversity."* Indeed, when salvage logging follows an insect outbreak, this creates two successive disturbances. The cumulative effect of these disturbances may affect ecosystem resilience (De Grandpré et al., 2018), as well as species richness and community composition (Thorn et al., 2018). From a wood supply perspective, balsam fir is less desirable than black spruce because of its inferior wood mechanical properties (Giroud et al., 2017; Lessard et al., 2014).

4.3. Limitations of the study

Expert solicitation methods are often described as subjective and biased (Martin et al., 2012). However, all methods are subject to subjectivity and biases if they are incorrectly used or if the number of experts is small. When expert knowledge is used in a rigorous way, it helps to elucidate complex problems or issues, which are often found in ecology or forest management. We have taken many precautions to minimize bias and pitfalls in our study design and methodology. For example, we conducted pretests before sending the surveys to the participants in order to make sure that the questions were unambiguous and that the time required to answer them was not too long (Drescher et al., 2013; Linstone and Turoff, 2002). Even if all the participants needed to have a good knowledge of the study area, they were

heterogeneous in their affiliation and specialities (Belton et al., 2019; Rowe and Wright, 2001). In addition, the inclusion of all the comments in the reports was a way to avoid providing only the interpretation of the answers by the survey facilitator. This is also a good way to allow participants to change their opinion between two rounds if they agreed with a vision that someone presented. Indeed, the performance of expert judgment methods is enhanced when participants have the opportunity to examine other participants' answers (Burgman et al., 2011). In spite of these efforts, our study still has limitations.

Delphi studies are traditionally associated with the notion of consensus among participants (Linstone and Turoff, 2002). This notion has, however, been called into question in recent years. Indeed, there is no unanimous agreement regarding the level of consensus that must be obtained, the consensus definition, and the relevance of using the consensus criterion under all circumstances (Hasson et al., 2000; Mukherjee et al., 2015; Powell, 2003; von der Gracht, 2012). Participant answers can be stable even if opinions diverge (Belton et al., 2019). Also, answers can be divergent and heterogeneous, but still provide useful knowledge (Belton et al., 2019), such as indicating topics for which more empirical research is needed (Mukherjee et al., 2015). In many instances, the number of rounds required for a Delphi study is determined by budget or time constraints, and not because a consensus is reached (von der Gracht, 2012). This was the case in our study: we decided to end the process after the third round as we anticipated a significant reduction in participation rates (as in Mukherjee et al., 2015). Generally, three rounds are usually needed to reach stability in responses (Belton et al., 2019; Day and Bobeva, 2005; Rowe and Wright 2001). However, as participants were limited to a selection of seven issues in the third and last round and had no limit in the second round, it was not possible to achieve perfect stability in the results, i.e. to have the exact same choice of issues at both rounds. In spite of that, our results showed a certain degree of stability, since the variability levels between both rounds was weak. Indeed, the three issues with a weighted score considerably higher than the others were chosen by 10 or 11 participants in the second round and, for nine of the 10 issues with the highest weighted score, two participants or fewer suggested removing them. We also analyzed the possible bias caused by unbalanced representation between affiliation groups. In our study, experts from the provincial government were over-represented (n = 6) in relation to experts from academia (n = 3) and the federal government (n = 2). This likely did not bias the overall score statistics, since no significant differences were found between affiliation groups with regard to scoring the issues.

5. Conclusion

Many of the issues chosen by participants are not exclusive to second-growth forests management and could be applied to the management of natural-origin stands. Most of them are also interrelated or interdependent. Our results will help forest managers to make informed decisions for the management of second-growth forests. However, these issues are ecosystem-dependant and the same process in another boreal region may lead to a different list.

Our results highlight the importance of considering woodland caribou and its habitat, as well as landscape fragmentation and old-growth forest rarefaction, in the management of second-growth boreal forests of eastern Canada. Even if these issues are not unique to second-growth forests, experts considered that they should be given priority in planning for second-growth forests management. Thus, our results confirmed their importance for the sustainable management of the eastern boreal forest.

The method used for participant selection did not include the participation of citizens and their local knowledge, such as that of First Nations. Moreover, our iterative Delphi approach entails the danger of the so-called "anchoring", where the design of questions might have unintentionally solicit biased answers. Although the Delphi method may not be the best approach for all categories of stakeholders and have some drawbacks, it can be used as a starting point for disentangling the main issues related to complex environmental problems, including studies focusing on issues other than those related to forest management for wood supply.

CRediT authorship contribution statement

Kaysandra Waldron: Conceptualization, Formal analysis, Writing original draft, Writing review and editing. **Nelson Thiffault:** Conceptualization, Methodology, Writing original draft, Writing review and editing. **Frédéric Bujold:** Conceptualization, Writing review and editing. **Jean-Claude Ruel:** Conceptualization, Funding acquisition, Writing original draft, Writing review and editing. **Jean-Martin Lussier:** Conceptualization, Methodology, Funding acquisition, Writing original draft, Writing review and editing. **Dominique Boucher:** Writing original draft, Writing review and editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

This study was funded by FRQNT (Fond de recherche du Québec – Nature et technologies). We would like to thank Dr. Solange Nadeau, who provided useful comments on a previous version of the manuscript. We also thank the experts who agreed to participate in the Delphi process.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.foreco.2020.118214.

References

Bauhus, J., Puettmann, K., Messier, C., 2009. Silviculture for old-growth attributes. For. Ecol. Manage. 258, 525–537. https://doi.org/10.1016/j.foreco.2009.01.053.

Beauchesne, D., Jaeger, J.A.G., St-Laurent, M.H., 2013. Disentangling woodland caribou movements in response to clearcuts and roads across temporal scales. PLoS ONE 8. https://doi.org/10.1371/journal.pone.0077514.

Belton, I., MacDonald, A., Wright, G., Hamlin, I., 2019. Improving the practical application of the Delphi method in group-based judgment: a six-step prescription for a well-founded and defensible process. Technol. Forecast. Soc. 147, 72–82. https://doi.org/10.1016/j.techfore.2019.07.002.

Bergeron, Y., Irulappa Pillai Vijayakumar, D.B., Ouzennou, H., Raulier, F., Leduc, A., Gauthier, S., 2017. Projections of future forest age class structure under the influence of fire and harvesting: implications for forest management in the boreal forest of eastern Canada. Forestry 90, 485–495. doi: 10.1093/forestry/cpx022.

Blais, J.R., 1983. Trends in the frequency, extent, and severity of spruce budworm outbreaks in eastern Canada. Can. J. For. Res. 13, 539–547. https://doi.org/10.1139/x83-079.

Bose, A.K., Harvey, B.D., Brais, S., Beaudet, M., Leduc, A., 2013. Constraints to partial cutting in the boreal forest of Canada in the context of natural disturbance-based management: a review. Forestry 87, 11–28. https://doi.org/10.1093/forestry/cpt047.

Bouchard, M., Pothier, D., 2011. Long-term influence of fire and harvesting on boreal forest age structure and forest composition in eastern Québec. For. Ecol. Manage. 261, 811–820. https://doi.org/10.1016/j.foreco.2010.11.020.

Bouchard, M., Pothier, D., 2010. Spatiotemporal variability in tree and stand mortality caused by spruce budworm outbreaks in eastern Quebec. Can. J. For. Res. 40, 86–94. https://doi.org/10.1139/X09-178.

Bouchard, M., Pothier, D., Gauthier, S., 2008. Fire return intervals and tree species succession in the North Shore region of eastern Quebec. Can. J. For. Res. 38, 1621–1633. https://doi.org/10.1139/X07-201.

Boucher, D., De Grandpré, L., Gauthier, S., 2003. Développement d'un outil de classification de la structure des peuplements et comparaison de deux territoires de la pessière à mousses du Québec. Forest. Chron. 79, 318–328. https://doi.org/10.5558/tfc79318-2.

Boucher, D., De Grandpré, L., Kneeshaw, D., St-Onge, B., Ruel, J.-C., Waldron, K., Lussier,

J.-M., 2015. Effects of 80 years of forest management on landscape structure and pattern in the eastern Canadian boreal forest. Landscape Ecol. 30, 1913–1929. https://doi.org/10.1007/s10980-015-0220-6.
Brodeur, V., Ouellet, J.-P., Courtois, R., Fortin, D., 2008. Habitat selection by black bears in an intensively logged boreal forest. Can. J. Zool. 86, 1307–1316. https://doi.org/10.1139/Z08-118.
Burgman, M.A., McBride, M., Ashton, R., Speirs-Bridge, A., Flander, L., Wintle, B., Fidler, F., Rumpff, L., Twardy, C., 2011. Expert status and performance. PloS one 6. https://doi.org/10.1371/journal.pone.0022998.
Comité scientifique sur les enjeux de biodiversité, 2010. Enjeux de biodiversité de l'aménagement écosystémique dans la réserve faunique des Laurentides. Québec, Canada.
COSEWIC, 2019. Committee on the Status of Endangered Wildlife in Canada. http://www.cosewic.ca/index.php/en-ca/ (accessed August 2019).
Courbin, N., Fortin, D., Dussault, C., Courtois, R., 2009. Landscape management for woodland caribou: the protection of forest blocks influences wolf-caribou co-occurrence. Landscape Ecol. 24, 1375–1388. https://doi.org/10.1007/s10980-009-9389-x.
Courtois, R., Ouellet, J.-P., Breton, L., Gingras, A., Dussault, C., 2007. Effects of forest disturbance on density, space use, and mortality of woodland caribou. Ecoscience 14, 491–498.
Cyr, D., Gauthier, S., Bergeron, Y., Carcaillet, C., 2009. Forest management is driving the eastern North American boreal forest outside its natural range of variability. Front. Ecol. Environ. 7, 519–524. https://doi.org/10.1890/080088.
Day, J., Bobeva, M., 2005. A generic toolkit for the successful management of Delphi studies. EJBRM 3, 103–116.
De Grandpré, L., Gauthier, S., Allain, C., Cyr, D., Périgon, S., Pham, A.T., Boucher, D., Morissette, J., Reyes, G., Aakala, T., Kuuluvainen, T., 2009. Towards an ecosystem approach to managing the boreal forest in the north shore region: disturbance regime and natural forest dynamics. In: Gauthier, S., Vaillancourt, M.-A., Leduc, A., De Grandpré, L., Kneeshaw, D., Morin, H., Drapeau, P., Bergeron, Y. (Eds.), Ecosystem management in the boreal forest. Les Presses de l'Univeristé du Québec, pp. 229–256.
De Grandpré, L., Waldron, K., Bouchard, M., Gauthier, S., Beaudet, M., Ruel, J.-C., Hébert, C., Kneeshaw, D., 2018. Incorporating insect and wind disturbances in a natural disturbance-based management framework for the boreal forest. Forests 9, 471. https://doi.org/10.3390/f9080471.
Donohoe, H.M., Needham, R.D., 2009. Moving best practice forward: Delphi characteristics, advantages, potential problems, and solutions. Int. J. Tourism Res. 11, 415–437. https://doi.org/10.1002/jtr.709.
Drescher, M., Perera, A.H., Johnson, C.J., Buse, L.J., Drew, C.A., Burgman, M.A., 2013. Toward rigorous use of expert knowledge in ecological research. Ecosphere 4, 83. https://doi.org/10.1890/ES12-00415.1.
Emerson, P., 2013. The original Borda count and partial voting. Soc. Choice Welfare 40, 353–358. https://doi.org/10.1007/s00355-011-0603-9.
Équipe de rétablissement du Caribou Forestier, 2013. Plan de rétablissement du caribou forestier (Rangifer tarandus) au Québec- 2013–2023, produit pour le compte du ministère du Développement durable, de l'Environnement, de la Faune et des Parcs du Québec, Faune Québec.
Fortin, D., Courtois, R., Etcheverry, P., Dussault, C., Gingras, A., 2008. Winter selection of landscapes by woodland caribou: behavioural response to geographical gradients in habitat attributes. J. Appl. Ecol. 45, 1392–1400. https://doi.org/10.1111/j.1365-2664.2008.01542.x.
Fourrier, A., Pothier, D., Bouchard, M., 2013. A comparative study of long-term stand growth in eastern Canadian boreal forest: fire versus clear-cut. For. Ecol. Manage. 310, 10–18. https://doi.org/10.1016/j.foreco.2013.08.011.
Gauthier, S., Vaillancourt, M.-A., Kneeshaw, D., Drapeau, P., De Grandpré, L., Claveau, Y., Paré, D., 2009. Forest ecosystem management, origins and foundations. In: Gauthier, S., Vaillancourt, M.-A., Leduc, A., De Grandpré, L., Kneeshaw, D., Morin, H., Drapeau, P., Bergeron, Y. (Eds.), Ecosystem Management in the Boreal Forest. Les Presses de l'Université du Québec, Québec, Canada, pp. 13–37.
Giroud, G., Bégin, J., Defo, M., Ung, C.H., 2017. Regional variation in wood density and modulus of elasticity of Quebec's main boreal tree species. For. Ecol. Manage. 400, 289–299. https://doi.org/10.1016/j.foreco.2017.06.019.
Government of Canada, 2019. Canadian climate normals 1981-2010 station data. http://climate.weather.gc.ca/climate_normals/results_1981_2010_e.html?searchType=stnProv&lstProvince=QC&txtCentralLatMin=0&txtCentralLatSec=0&txtCentralLongMin=0&txtCentralLongSec=0&stnID=5686&dispBack=0 (accessed September 2019).
Gunn, J., Sein, R., 2000. Effects of forestry roads on reproductive habitat and exploitation of lake trout (*Salvelinus namaycush*) in three experimentale lakes. Can. J. Fish. Aquat. Sci. 57, 97–104. https://doi.org/10.1139/f00-129.
Hasson, F., Keeney, S., McKenna, H., 2000. Research guidelines for the Delphi survey technique. J. Adv. Nurs. 32, 1008–1015. https://doi.org/10.1046/j.1365-2648.2000.t01-1-01567.x.
Hess, G.R., King, T.J., 2002. Planning open spaces for wildlife. I. Selecting focal species using a Delphi survey approach. Landscape Urban Plan. 58, 25–40. https://doi.org/10.1016/S0169-2046(01)00230-4.
Janssen, P., Hébert, C., Fortin, D., 2011. Biodiversity conservation in old-growth boreal forest: black spruce and balsam fir snags harbour distinct assemblages of saproxylic beetles. Biodivers. Conserv. 20, 2917–2932. https://doi.org/10.1007/s10531-011-0127-8.
Kangas, J., Kangas, A., 2005. Multiple criteria decision support in forest management—the approach, methods applied, and experiences gained. For. Ecol. Manage. 207, 133–143. https://doi.org/10.1016/j.foreco.2004.10.023.
Kreutzweiser, D.P., Beall, F.D., Webster, K., Thompson, D., Creed, I., 2015. Impacts and prognosis of natural resource development on water and wetlands in Canada's boreal zone. Environ. Rev. 23, 78–131. https://doi.org/10.1139/er-2013-0044.
Kuuluvainen, T., Bergeron, Y., Coates, K.D., Seymour, R.S., 2015. Restoration and ecosystem-based management in the circumboreal forest: background, challenges, and opportunities. In: Stanturf, J.A. (Ed.), Restoration of Boreal and Temperate Forests, second ed. CRC Press, pp. 251–270.
Kuuluvainen, T., Gauthier, S., 2018. Young and old forest in the boreal: critical stages of ecosystem dynamics and management under global change. For. Ecosyst. 5, 26. https://doi.org/10.1186/s40663-018-0142-2.
Kuuluvainen, T., Grenfell, R., 2012. Natural disturbance emulation in boreal forest ecosystem management - theories, strategies, and a comparison with conventional even-aged management. Can. J. For. Res. 42, 1185–1203. https://doi.org/10.1139/X2012-064.
Lesmerises, F., Dussault, C., St-Laurent, M.-H., 2012. Wolf habitat selection is shaped by human activities in a highly managed boreal forest. For. Ecol. Manage. 276, 125–131. https://doi.org/10.1016/j.foreco.2012.03.025.
Lessard, E., Fournier, R.A., Luther, J.E., Mazerolle, M.J., van Lier, O.R., 2014. Modeling wood fiber attributes using forest inventory and environmental data for Newfoundland's boreal forest. For. Ecol. Manage. 313, 307–318. https://doi.org/10.1016/j.foreco.2013.10.030.
Lindenmayer, D.B., Franklin, J.F., Fischer, J., et al., 2006. General management principales and a checklist of strategies to guide forest biodiversity conservation. Biol. Conser. 433–445. https://doi.org/10.1016/j.biocon.2006.02.019.
Lindenmayer, D.B., Franklin, J.F., Lõhmus, A., Baker, S.C., Bauhus, J., Beese, W., Brodie, A., Kiehl, B., Kouki, J., Martinez Pastur, G., Messier, C., Neyland, M., Palik, B., Sverdrup-Thygeson, A., Volney, J., Wayne, A., Gustafsson, L., 2012. A major shift to the retention approach for forestry can help resolve some global forest sustainability issues. Conser. Lett. 5, 421–431. https://doi.org/10.1111/j.1755-263X.2012.00257.x.
Linstone, H.A., Turoff, M., 2002. The Delphi method. Techniques and application. Addison-Wesley Pub Co.
Martin, T.G., Burgman, M.a, Fidler, F., Kuhnert, P.M., Low-Choy, S., McBride, M., Mengersen, K., 2012. Eliciting expert knowledge in conservation science. Conserv. Biol. 26, 29–38. doi: 10.1111/j.1523-1739.2011.01806.x.
Masse, S., Marchand, P.P., Bernier-Cardou, M., 2014. Forecasting the deployment of short-rotation intensive culture of willow or hybrid poplar: insights from a Delphi study. Can. J. For. Res. 44, 422–431. https://doi.org/10.1139/cjfr-2013-0364.
Morin, H., 1994. Dynamics of balsam fir forests in relation to spruce budworm outbreaks in the boreal Zone of Quebec. Can. J. For. Res. 24, 730–741. https://doi.org/10.1139/x94-097.
Mukherjee, N., Hugé, J., Sutherland, W.J., McNeill, J., Van Opstal, M., Dahdouh-Guebas, F., Koedam, N., 2015. The Delphi technique in ecology and biological conservation: applications and guidelines. Methods Ecol. Evol. 6, 1097–1109. https://doi.org/10.1111/2041-210X.12387.
Nealis, V.G., Régnière, J., 2004. Insect-host relationships influencing disturbance by the spruce budworm in a boreal mixedwood forest. Can. J. For. Res. 34, 1870–1882. https://doi.org/10.1139/X04-061.
Okoli, C., Pawlowski, S.D., 2004. The Delphi method as a research tool: an example, design considerations and applications. Inform. Manage. 42, 15–29. https://doi.org/10.1016/j.im.2003.11.002.
Perera, A.H., Buse, L.J., Weber, M.G., 2004. Emulating Natural Forest Landscape Disturbances: Concepts and Applications. Columbia University Press, New York, NY.
Pinard, V., Dussault, C., Ouellet, J.-P., Fortin, D., Courtois, R., 2012. Calving rate, calf survival rate, and habitat selection of forest-dwelling caribou in a highly managed landscape. J. Wildl. Manage. 76, 189–199. https://doi.org/10.1002/jwmg.217.
Powell, C., 2003. The Delphi technique: myths and realities. J. Adv. Nurs. 41, 376–382. https://doi.org/10.1046/j.1365-2648.2003.02537.x.
Prepas, E.E., Pinel-Alloul, B., Steedman, R.J., Planas, D., Charette, T., 2003. Impacts of forest disturbance on boreal surface waters in Canada. In: Burton, P.J., Messier, C., Smith, D.W., Adamowicz, W.L. (Eds.), Towards Sustainable Management of the Boreal Forest. NRC Research Press, Ottawa, ON, pp. 369–393.
Puettmann, K.J., Wilson, S.M., Baker, S.C., Donoso, P.J., Drössler, L., Amente, G., Harvey, B.D., Knoke, T., Lu, Y., Nocentini, S., Putz, F.E., Yoshida, T., Bauhus, J., 2015. Silvicultural alternatives to conventional even-aged forest management – what limits global adoption? For. Ecosyst. 2. https://doi.org/10.1186/s40663-015-0031-x.
R Core Team, 2019. R: A language and environment for statistical computing.
Rowe, G., Wright, G., 2001. Expert opinions in forecasting: the role of the Delphi technique. In: Armstrong, J.S. (Ed.), Principles of Forecasting. A handbook for researchers and practitioners. Springer Science+Business Media, New York, pp. 125–144.
Saucier, J.-P., Robitaille, A., Grondin, P., 2009. Cadre bioclimatique du Québec. In: Doucet, R., Côté, M. (Eds.), Manuel de foresterie, second ed. Ordre des ingénieurs forestiers du Québec, Québec, QC, Canada, pp. 186–205.
Schmidt, R.C., 1997. Managing Delphi surveys using nonparametric statistical techniques. Decision Sci. 28, 763–774. https://doi.org/10.1111/j.1540-5915.1997.tb01330.x.
Siitonen, J., Martikainen, P., Punttila, P., Rauh, J., 2000. Coarse woody debris and stand characteristics in mature managed and old-growth boreal mesic forests in southern Finland. For. Ecol. Manage. 128, 211–225. https://doi.org/10.1016/S0378-1127(99)00148-6.
Tapio, P., Paloniemi, R., Varho, V., Vinnari, M., 2011. The unholy marriage? Integrating qualitative and quantitative information in Delphi processes. Technol. Forecast. Soc. 78, 1616–1628. https://doi.org/10.1016/j.techfore.2011.03.016.
Thompson, I.D., Curran, W.J., 1995. Habitat suitability for marten of second-growth balsam fir forests in Newfoundland. Can. J. Zool. 73, 2059–2064. https://doi.org/10.1139/z95-242.
Thorn, S., Bässler, C., Brandl, R., Burton, P.J., Cahall, R., Campbell, J.L., Castro, J., Choi, C.-Y., Cobb, T., Donato, D.C., Durska, E., Fontaine, J.B., Gauthier, S., Hebert, C., Hothorn, T., Hutto, R.L., Lee, E.-J., Leverkus, A.B., Lindenmayer, D.B., Obrist, M.K., Rost, J., Seibold, S., Seidl, R., Thom, D., Waldron, K., Wermelinger, B., Winter, M.-B.,

Zmihorski, M., Müller, J., 2018. Impacts of salvage logging on biodiversity: A meta-analysis. J. Appl. Ecol. 55, 279–289. https://doi.org/10.1111/1365-2664.12945.

Tinker, D.B., Resor, C.A.C., Beauvais, G.P., Kipfmueller, K.F., Fernandes, C.I., Baker, W.L., 1998. Watershed analysis of forest fragmentation by clearcuts and roads in a Wyoming forest. Landscape Ecol. 13, 149–165. https://doi.org/10.1023/A:1007919023983.

Tremblay, J.A., Bélanger, L., Desponts, M., Brunet, G., 2007. La restauration passive des sapinières mixtes de seconde venue: une alternative pour la conservation des sapinières mixtes anciennes. Can. J. For. Res. 37, 825–839. https://doi.org/10.1139/X06-263.

Venier, L.A., Thompson, I.D., Fleming, R., Malcolm, J., Aubin, I., Trofymow, J.A., Langor, D., Sturrock, R., Patry, C., Outerbridge, R.O., Holmes, S.B., Haeussler, S., De Grandpré, L., Chen, H.Y.H., Bayne, E., Arsenault, A., Brandt, J.P., 2014. Effects of natural resource development on the terrestrial biodiversity of Canadian boreal forests. Environ. Rev. 22, 457–490. https://doi.org/10.1139/er-2013-0075.

von der Gracht, H.A., 2012. Consensus measurement in Delphi studies. Review and implications for future quality assurance. Technol. Forecast. Soc. 79, 1525–1536. https://doi.org/10.1016/j.techfore.2012.04.013.

Waldron, K., Lussier, J., Thiffault, N., Bujold, F., Ruel, J., 2016. The Delphi method as an alternative to standard committee meetings to identify ecological issues for forest ecosystem-based management: a case study. Forest. Chron. 92, 453–464. https://doi.org/10.5558/tfc2016-081.

Waldron, K., Ruel, J.-C., Gauthier, S., 2013. The effects of site characteristics on the landscape-level windthrow regime in the North Shore region of Quebec, Canada. Forestry 86, 159–171. https://doi.org/10.1093/forestry/cps061.

Whittington, J., Hebblewhite, M., Decesare, N.J., Neufeld, L., Bradley, M., Wilmshurst, J., Musiani, M., 2011. Caribou encounters with wolves increase near roads and trails: a time-to-event approach. J. Appl. Ecol. 48, 1535–1542. https://doi.org/10.1111/j.1365-2664.2011.02043.x.